Introduction to Digital Image Processing

— Image Color

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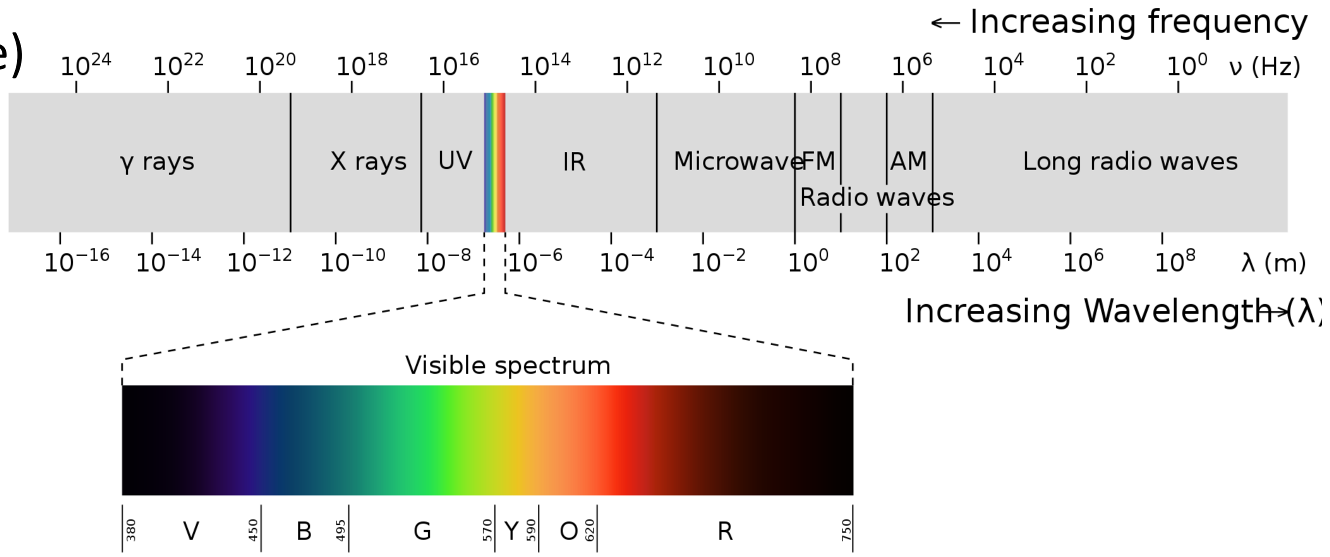
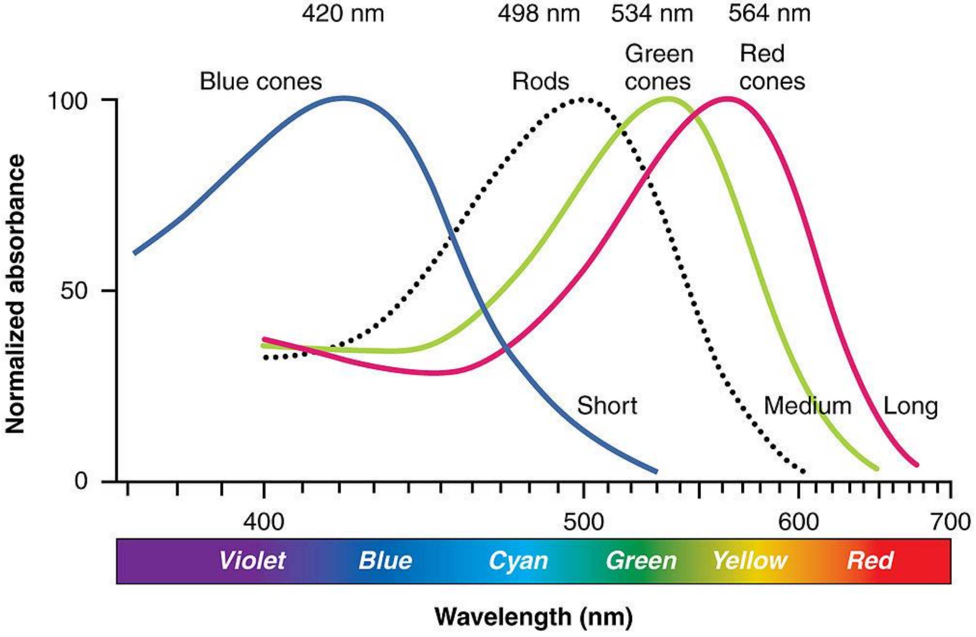
Light and Color

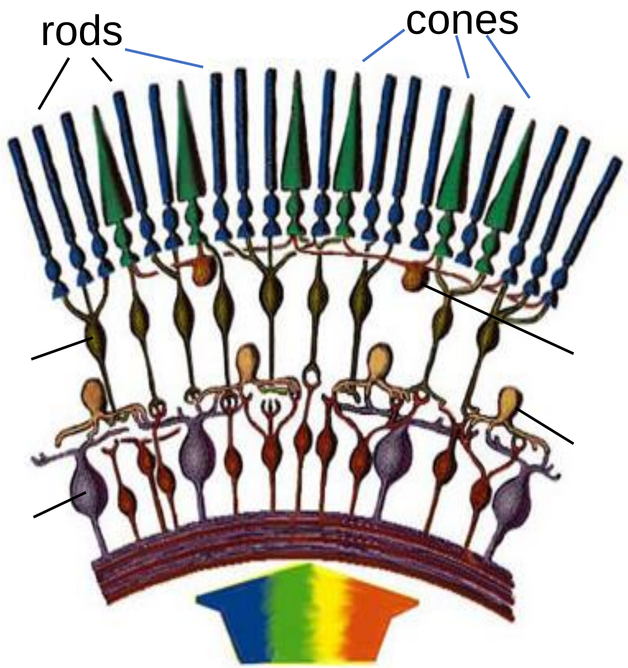
- **Light** is radiation in the electromagnetic spectrum
  - Visible light wavelength range is about **380nm - 700nm**
  - The wavelengths of the primary colors are *red:* 700 nm, *green:* 546.1 nm, and *blue:* 435.8 nm
  - The primary colors can be added to produce the secondary colors: *magenta* (R+B), *cyan* (G+B), and *yellow* (R+G)
- **Color** is a combination of illumination, reflectance, and interpretation
  - The spectral characteristics of the light source(s) (e.g., sunlight) illuminating the objects (relative spectral power distribution(s) SPD)
  - The spectral properties of objects (reflectance)
  - The spectral characteristics of the sensing devices (e.g., human eyes or digital cameras)
- Color can be described with the following components
  - **Hue**: dominant wavelength
  - **Saturation**: excitation purity
  - **Intensity**: amount of light

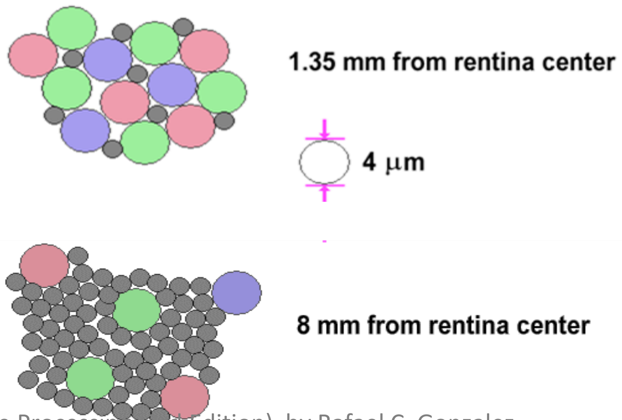


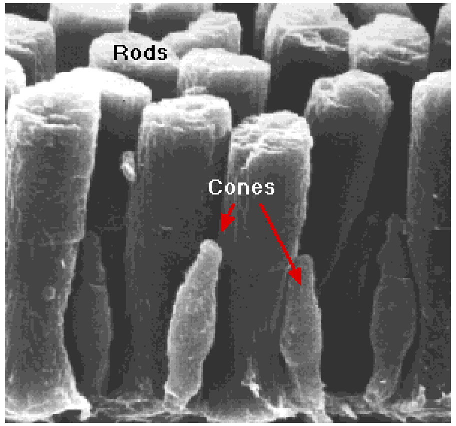
Human Vision

- Human eyes have two types of sensors:
  - Cones (~5 million in each eye)
    - Three different types of cones sensitive to color:
      - 420 nm (blue)
      - 534 nm (green-yellow)
      - 564 nm (red)
  - Rods (~120 million in each eye)
    - Sensitive to achromatic light
    - Give an overall picture of the FoV









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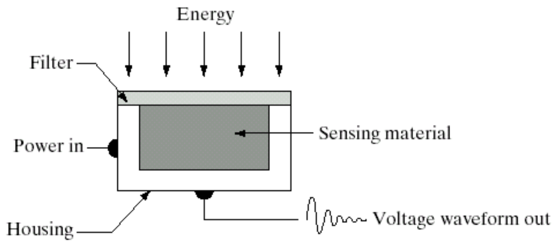
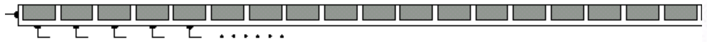
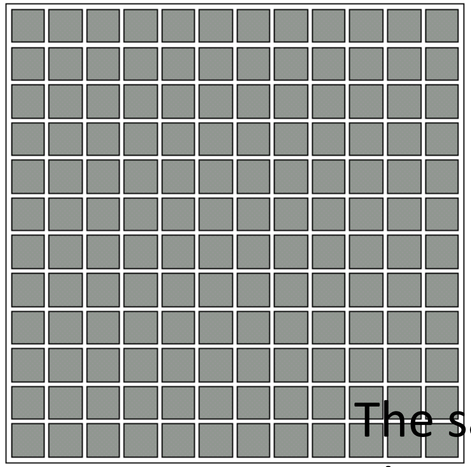
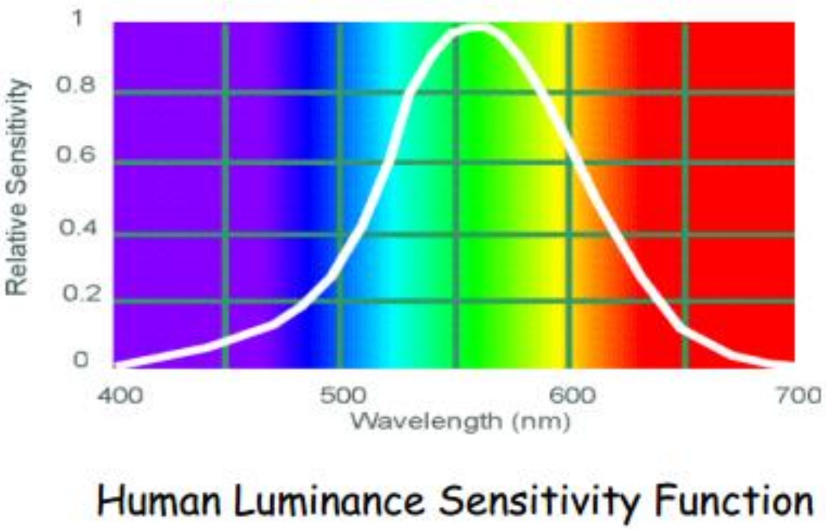
Digital Color Image Acquisition

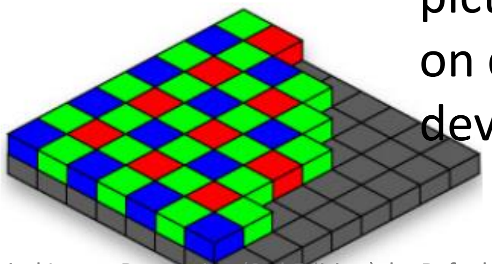




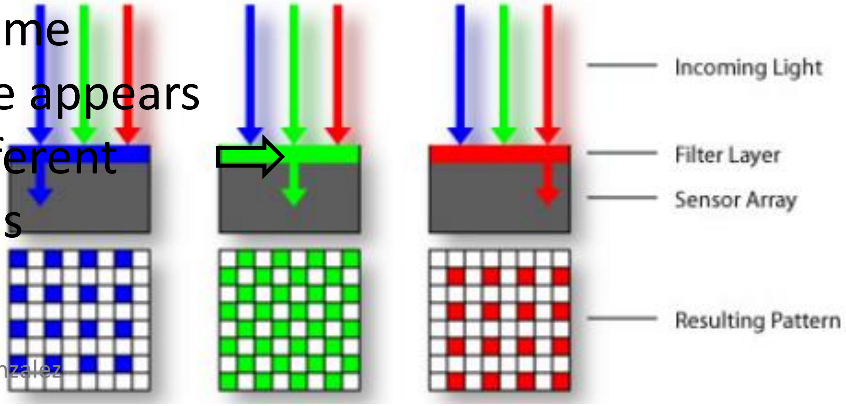


Why more green sensors?





The same picture appears on different devices



The same picture appears on different devices.

The mixture of RGB differs from one device to another

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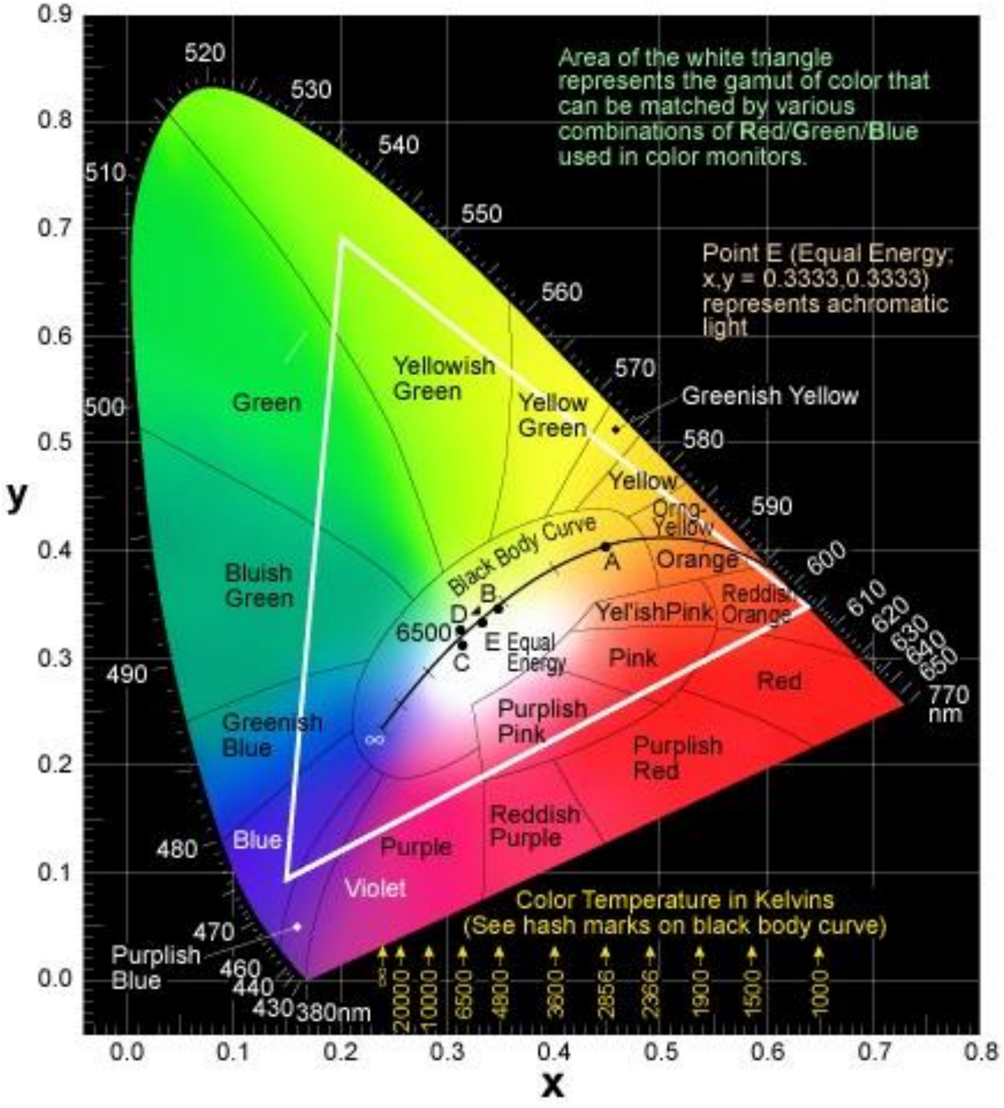
Chromaticity Diagram and CIE XYZ System

- In 1931, the *Commission Internationale de l'Eclairage* defined three primary colors: X, Y, and Z to form all visible colors.
  - The parameters are based on the spectral **power distribution of the light** emitted from a color object and are **factored by the sensitivity curves** measured for the human eye.
  - $x=X/(X+Y+Z)$, $y=Y/(X+Y+Z)$, $z=1-(X+Y)/(X+Y+Z)$
- The chromaticity diagram shows all the colors perceivable by human eyes.
  - All visible colors lie in the convex hull and pure (highly saturated) colors are at the boundary
  - White is (1/3,1/3,1/3)



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Color Model and Color space

- **Color model** is a mathematical model to specify colors with tuples of numbers
  - A color model provides a coordinate system and a subspace, where each color is represented by a single point
  - It specifies a color using a three-dimensional coordinate system
- **Color space** consists of a color model and a mapping function, i.e., a color model and gamut.
  - The gamut of a device is the portion of the color space that can be reproduced, which is often specified in the hue-saturation plane
- Most color models are linear transformations of the XYZ space.
- Hardware oriented:
  - RGB
  - CMY (CMYK)
  - YIQ (luminance, inphase, quadrature)
  - YUV (YCbCr)
- Image processing (or perception) oriented:
  - HSV (hue, saturation, value/intensity)

RGB and CMY (CMYK) Models

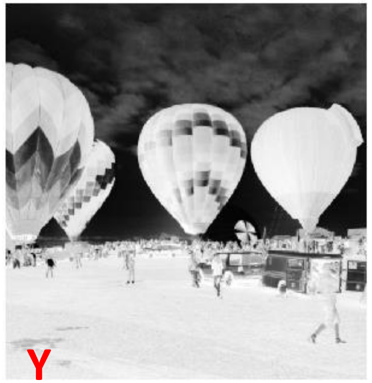
- Additive model for image displays
- An image consists of three bands, one for each primary color

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.9107 & -0.5326 & -0.2883 \\ -0.9843 & 1.9984 & -0.0283 \\ 0.0583 & -0.1185 & 0.8986 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.6067 & 0.1736 & 0.2001 \\ 0.2988 & 0.5868 & 0.1143 \\ 0.0000 & 0.0661 & 1.1149 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- CMY is a subtractive model to model absorption of light colors.
- K = min (C, M, Y)

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



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YIQ and YUV (YCbCr) Models

- YIQ is used by NTSC for TV broadcasting
  - Back compatible with B/W TV when only Y is used.
- Separates hue (I,Q) from luminance (Y).

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0.956 & 0.621 \\ 1 & -0.272 & -0.647 \\ 1 & -1.106 & 1.702 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

- YUV (a.k.a. YCbCr) is used by PAL TV standard and in video/image compression
  - Y is luminance as in YIQ. U and V are blue and red (Cb and Cr).

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.1473 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y \\ U \\ V \end{bmatrix}$$

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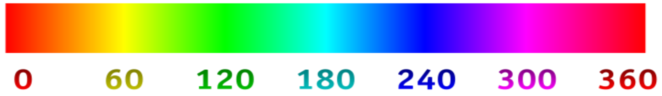
HSV Model

- Hue - The color we see



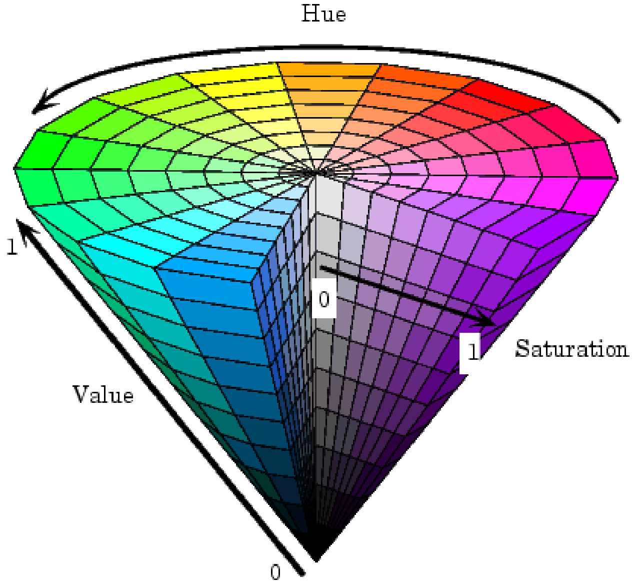
- Saturation - The amount by which the color has been diluted with white.
- Value (Brightness/Luminance) - The degree of brightness

$$I = \frac{(R+G+B)}{3}$$

$$S = 1 - \frac{\min(R,G,B)}{I}$$

$$H = \cos^{-1}\left\{\frac{1/2[(R-G)+(R-B)]}{\sqrt{[(R-G)^2+(R-B)(G-B)]}}\right\} \text{ if } B < G$$

$$H = 360 - \cos^{-1}\left\{\frac{1/2[(R-G)+(R-B)]}{\sqrt{[(R-G)^2+(R-B)(G-B)]}}\right\} \text{ if } B > G$$



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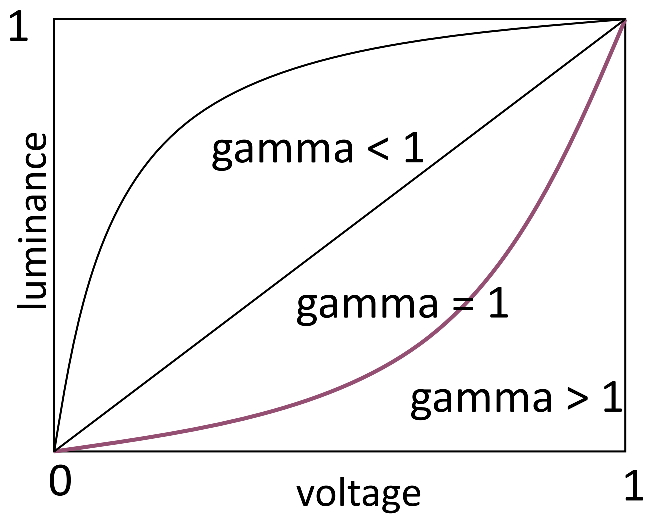
Color space Comparison

Color Space	Color Mixing	Parameters	Used for	Pros and cons
RGB	Additive	Red, Green, Blue	Display	Easy but wasting bandwidth
CMYK	Subtractive	Cyan, Magenta, Yellow, Black	Printer	Works in pigment mixing
YUV	additive	Y (luminance), U (blue chroma), V (red chroma)	Video encoding for PAL, SECAM	Bandwidth efficient
YIQ	additive	Y (luminance), I (rotated from U), Q (rotated from V)	Video encoding for NTSC	Bandwidth efficient
HSV	Additive	H (hue), S (Saturation), V (brightness)	Color image processing	Separate color from intensity and easy for use

Gamma

- **Gamma** is a non-linear operation to transform luminance.
- The amount of power (luminance) emitted is approximately proportional to the applied voltage (scaled to the range [0,1]) raised to constant power, a.k.a. *gamma* (γ).
  - $Luminance \approx Voltage^{\gamma}$
  - Typical CRTs have gamma values close to 2.5.
- A camera records the luminance (i.e., radiance) of an object.
  - If the recorded values are translated into a voltage signal and applied directly to a CRT, the reproduced image will have a distorted luminance.
  - A camera, therefore, applies a *gamma correction* transfer function.
- That is, it applies a $1/\gamma$ power function to the recorded RGB values:
  - $R' = R^{1/\gamma}$ (likewise for *G* and *B*)



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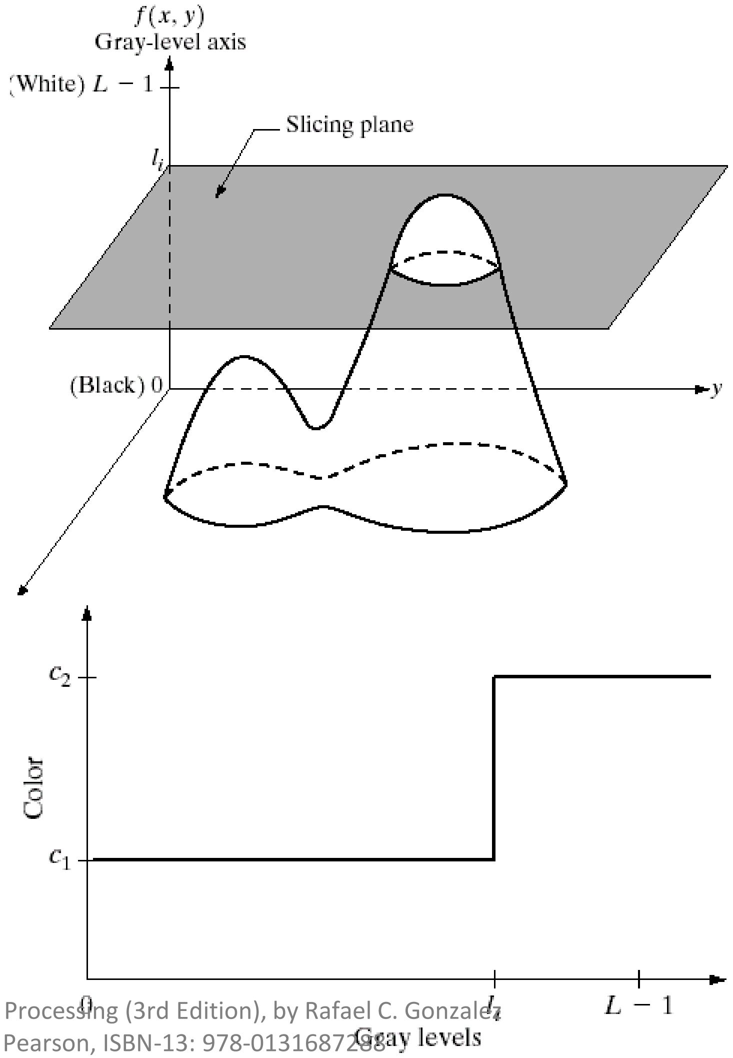
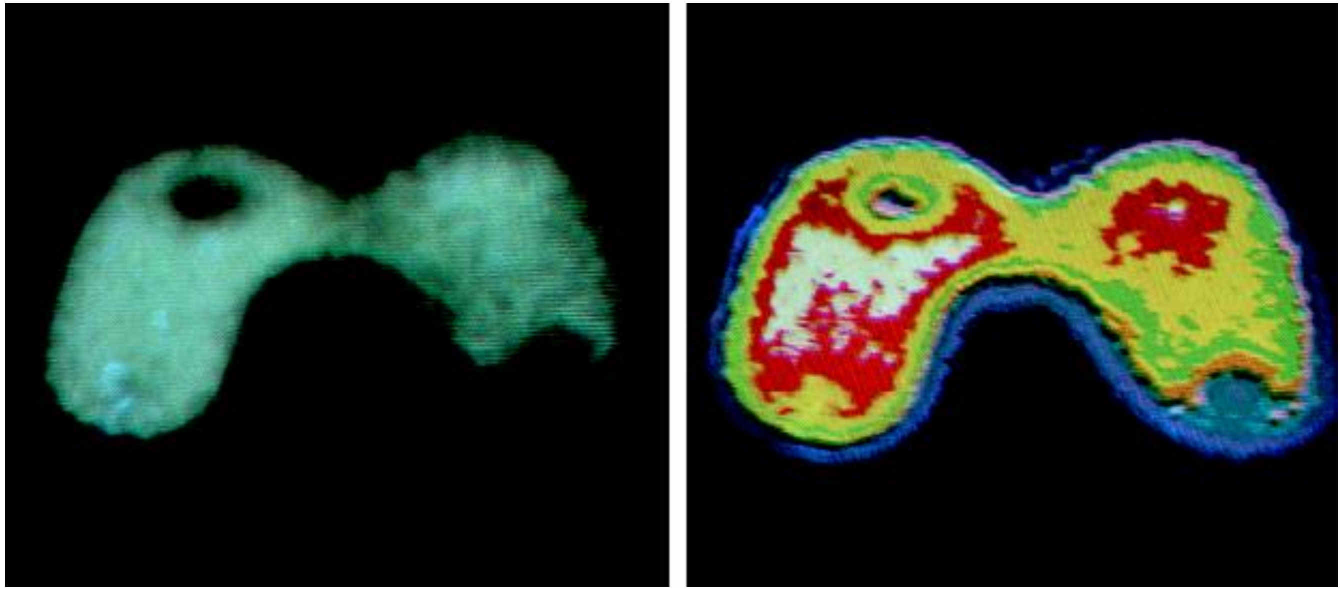
Pseudo Color





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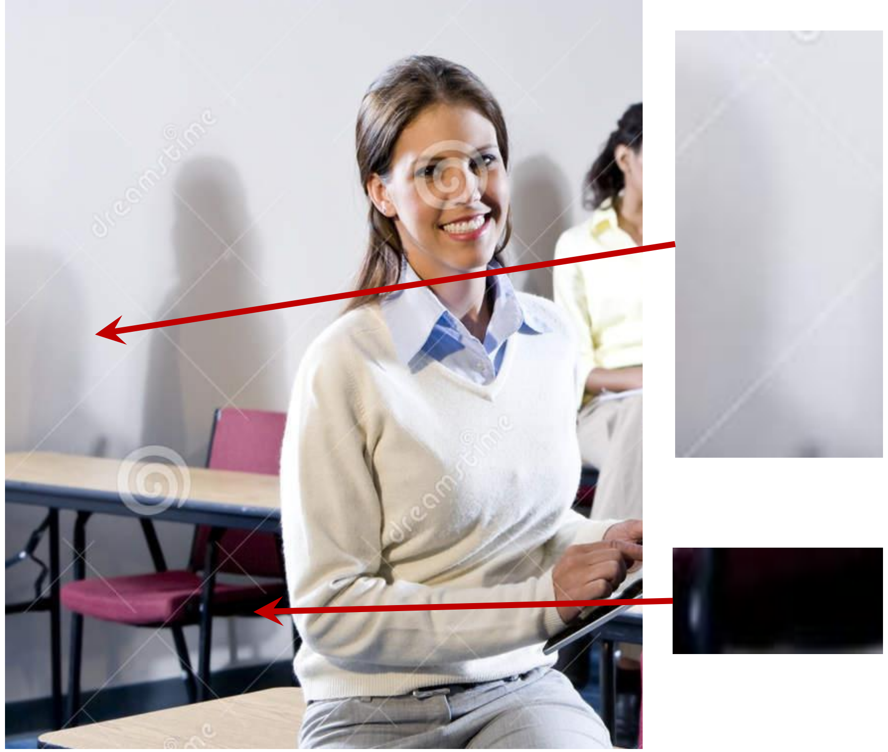
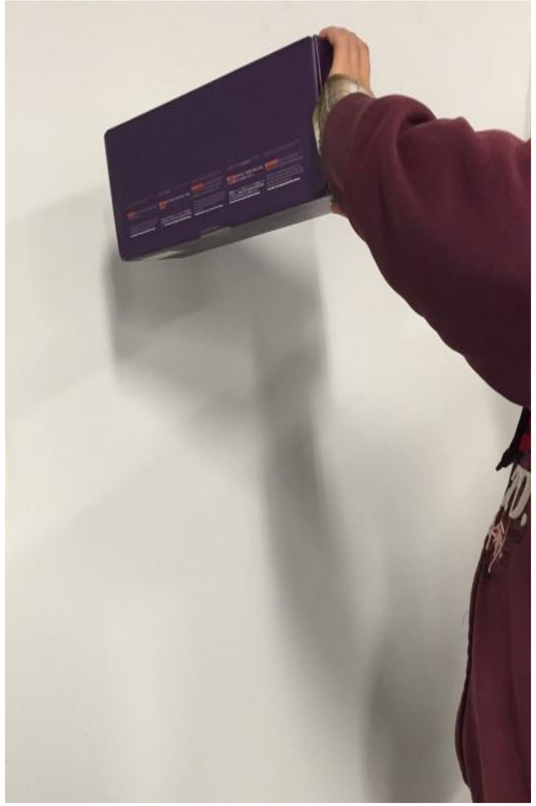
Shadow Detection — using Properties of Color

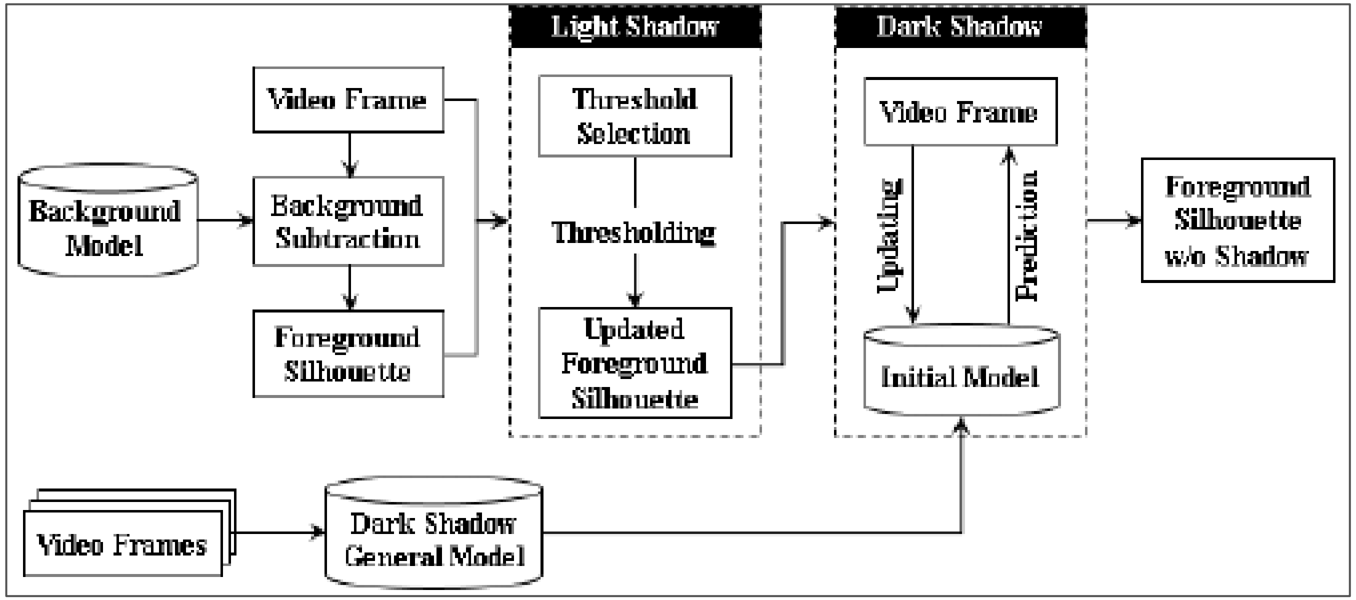


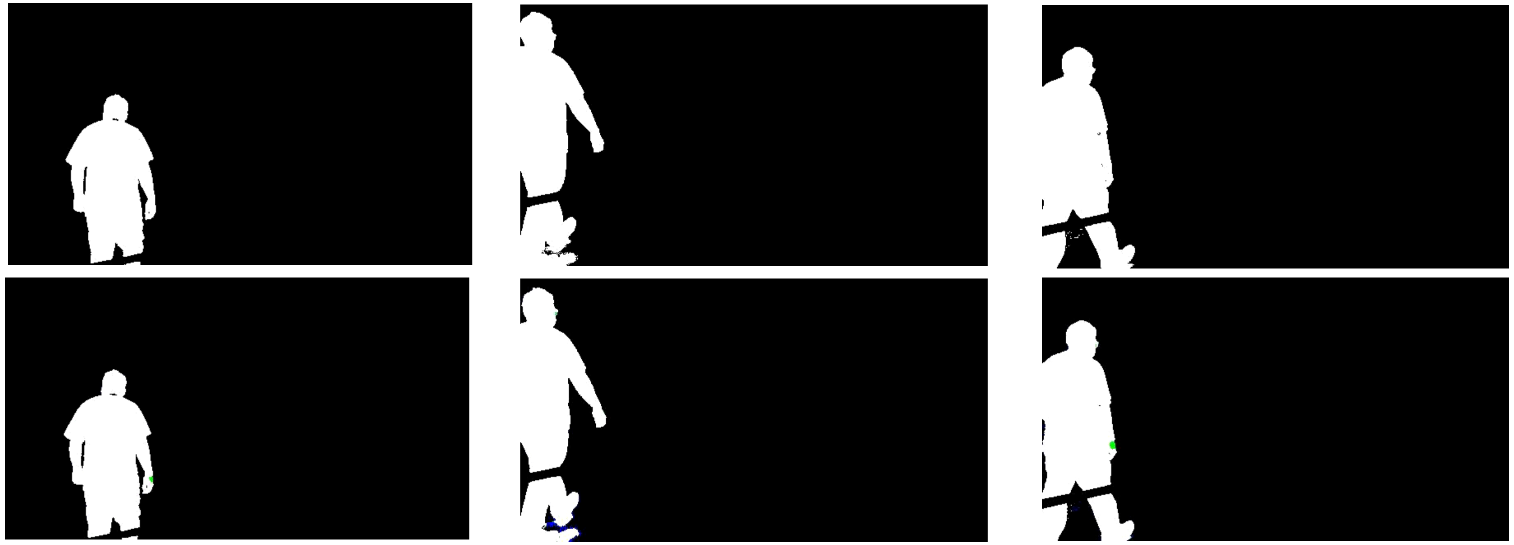


- **Light shadow** occurs when the object is at a distance to the background or there exists another light source that brightens the part of the shadow
  - Light shadows alter the background by slightly dimming its brightness
  - The hue of the affected pixels has little changes, and their intensity decreases proportionally to the lighting conditions
- **Dark shadow** occurs with (near) total obstruction of light

Dynamic Thresholding and Transfer Learning based Shadow Removal

- Method





X. Yuan, D. Li, D. Mohapatra, M. Elhoseny, *Automatic Removal of Complex Shadows from Indoor Videos using Transfer Learning and Dynamic Thresholding*, Computers and Electrical Engineering, 70, 813-825, August 2018