EE 4211 Computer vision

Lecture 1B

Semester A, 2020-2021

Outline

- Image acquisition
- Color model

Image Acquisition Process

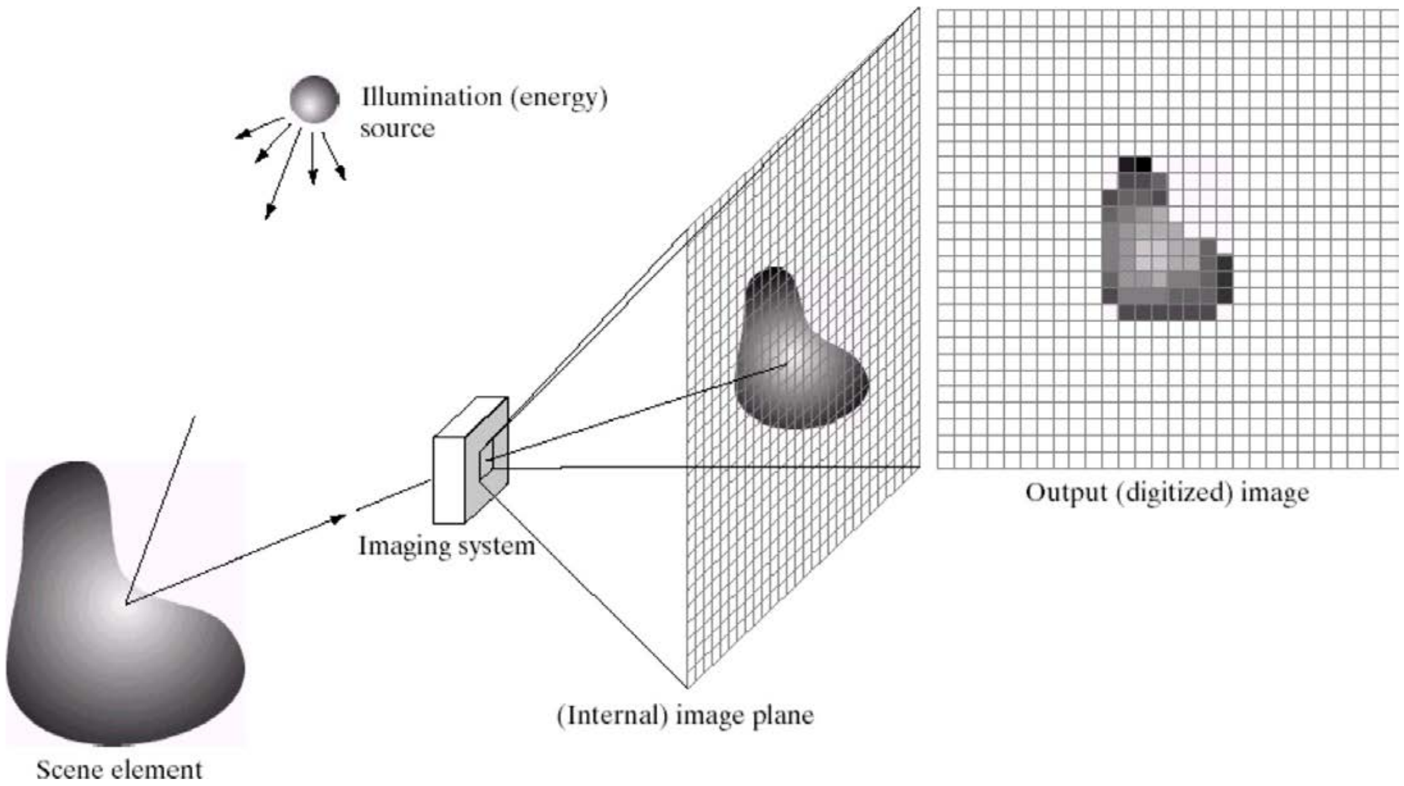
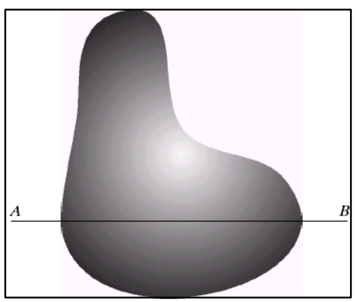


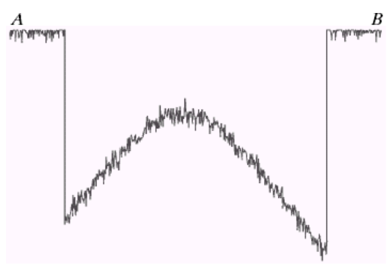
Image Sampling and Quantization

- A digital sensor can only measure a limited number of samples at a discrete set of energy levels
- Quantization is the process of converting a continuous analogue signal into a digital representation of this signal

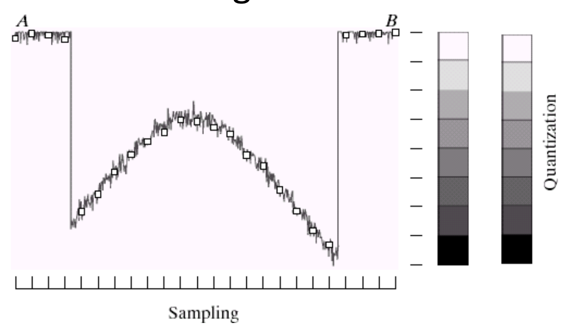
2D CT Signal



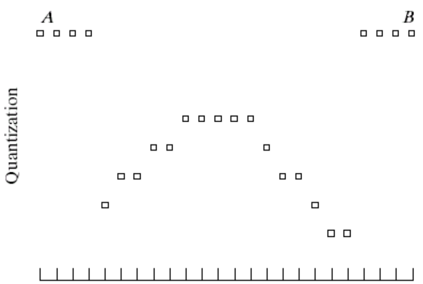
1D CT Signal



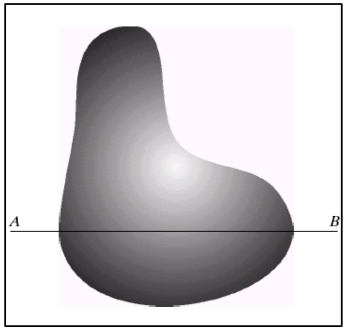
1D DT Signal

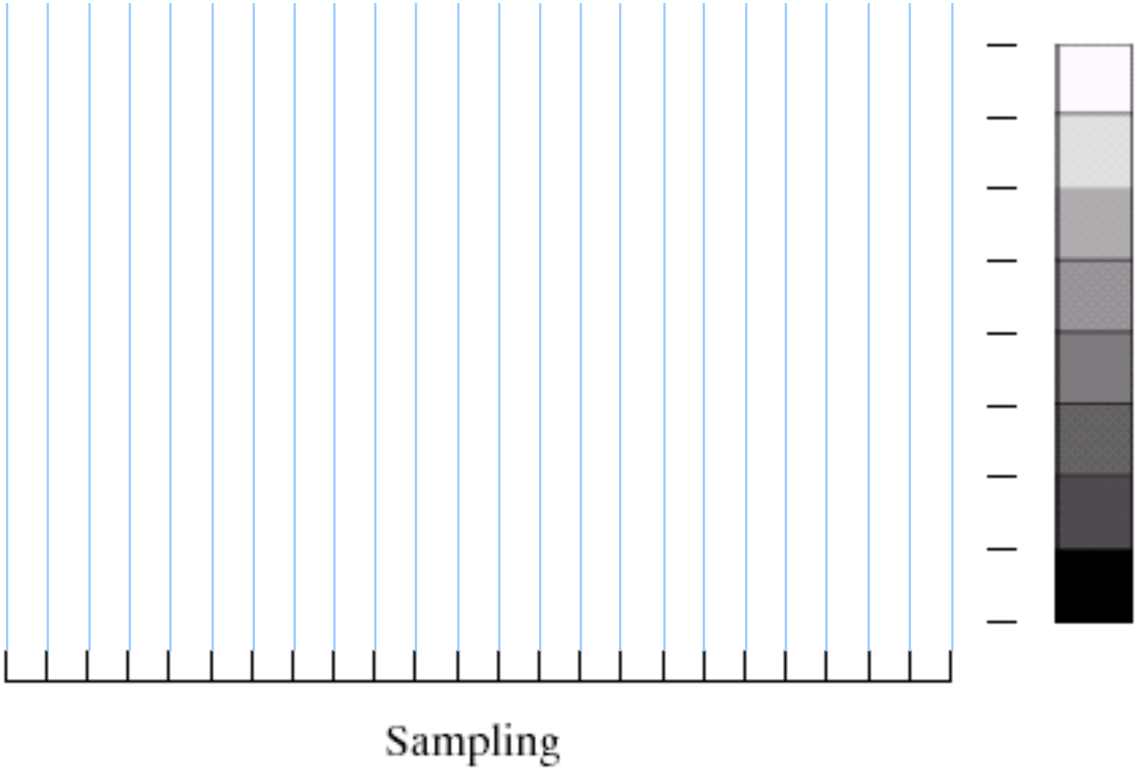


1D Digital Signal



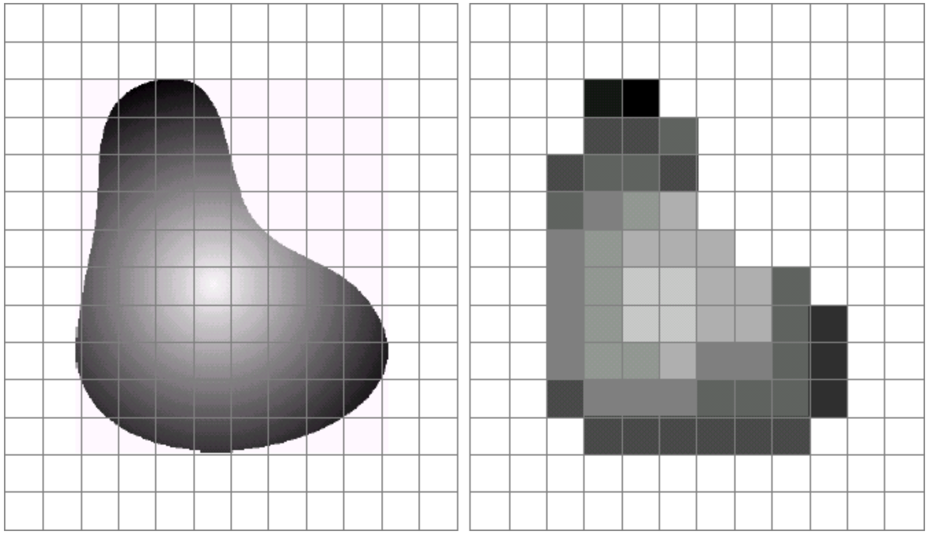
1-D Image Digitization Process





2-D Image Digitization Process

- Remember that a digital image is always only an approximation of a real world scene



What is a Pixel?

- Pixel = Picture Element
- The smallest discrete component of an image or picture on a screen is known as a pixel.
- The greater the number of pixels, the greater is the resolution.
- Each pixel is a sample of an original image, where more samples typically provide more-accurate representations of the original.

Amount of Image Data

- For an image with MxN :
  - Number of bits per pixel per channel: k bits
  - Number of gray levels per pixel per channel: $L = 2^k$ levels
  - Pixel value dynamic range: [0, L - 1]
  - Number of bits required to store a gray-scale image: MNk bits
  - Number of bytes per image: MNk/8 Bytes
  - Number of bytes with color image with RGB component: B = 3*MNk/8 Bytes

- For Example, a 8-bits 1920x1080 Full HD gray level image,
  - 1920 x 1080 x 8/8 = 2.0736 MB

Spatial and Intensity Resolution

Image Resolutions: Spatial and Gray-level

- Spatial Resolution:
  - Number of lines per millimeter, or Dot Per Inch (DPI).
  - Often say spatial resolution of MxN pixels.
  - The larger, the better.
  - Define how fine the sampling is.
- Gray-level Resolution:
  - Smallest discernible change in gray level.
  - Often say gray-level resolution of L.
  - 8 bits -> $2^8 - 1 = 255$

Spatial Resolution

- The spatial resolution of an image is determined by how sampling was carried out
- Image size M*N
- Spatial resolution simply refers to the smallest discernable detail in an image
  - Vision specialists will often talk about pixel size
  - Graphic designers will talk about dots per inch (DPI)

Spatial Resolution Examples

Spatial Resolution Examples

Intensity/Gray Level Resolution

- Intensity level resolution refers to the number of intensity levels used to represent the image
  - The more intensity levels used, the finer the level of detail discernable in an image
  - Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

$2^{\text{number of bits}}$

Intensity Level Resolution

256 grey levels (8 bits per pixel)

128 grey levels (7 bpp)

64 grey levels (6 bpp)

32 grey levels (5 bpp)

16 grey levels (4 bpp)

8 grey levels (3 bpp)

4 grey levels (2 bpp)

2 grey levels (1 bpp)

Resolution: How Much is Enough?

- The big question with resolution is always how much is enough?
- This all depends on what is in the image and what you would like to do with it
- Key questions include
  - Does the image look aesthetically pleasing?
  - Can you see what you need to see within the image?

Resolution Selection Example

- The picture on the right is fine for counting the number of cars, but not for reading the number plate

Intensity Level and Resolution Selection

Low Detail
(Face)

Medium Detail
(Cameraman)

High Detail
(Crowd)

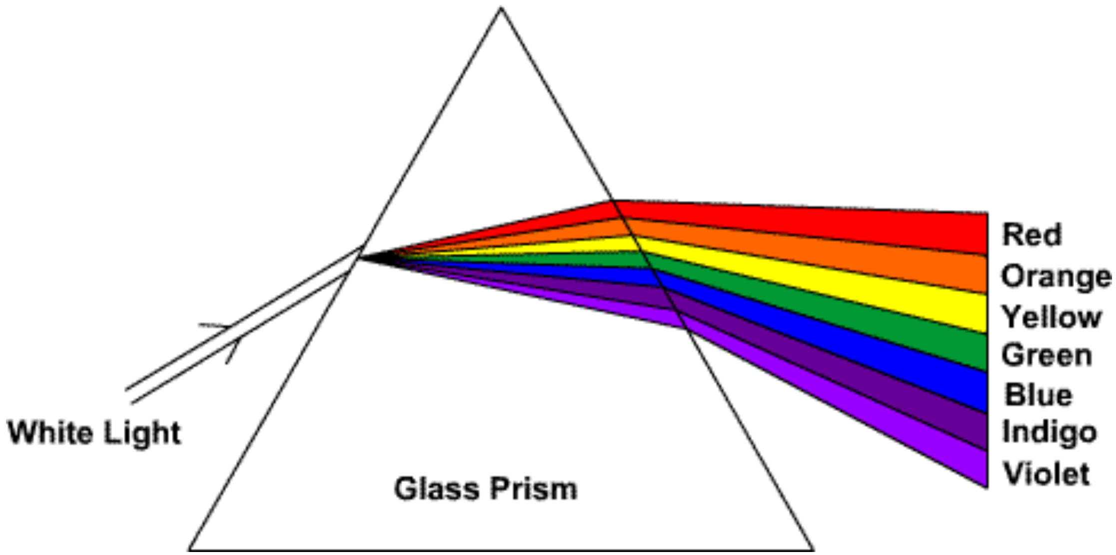
Outline

- Image acquisition
- Color model

Color

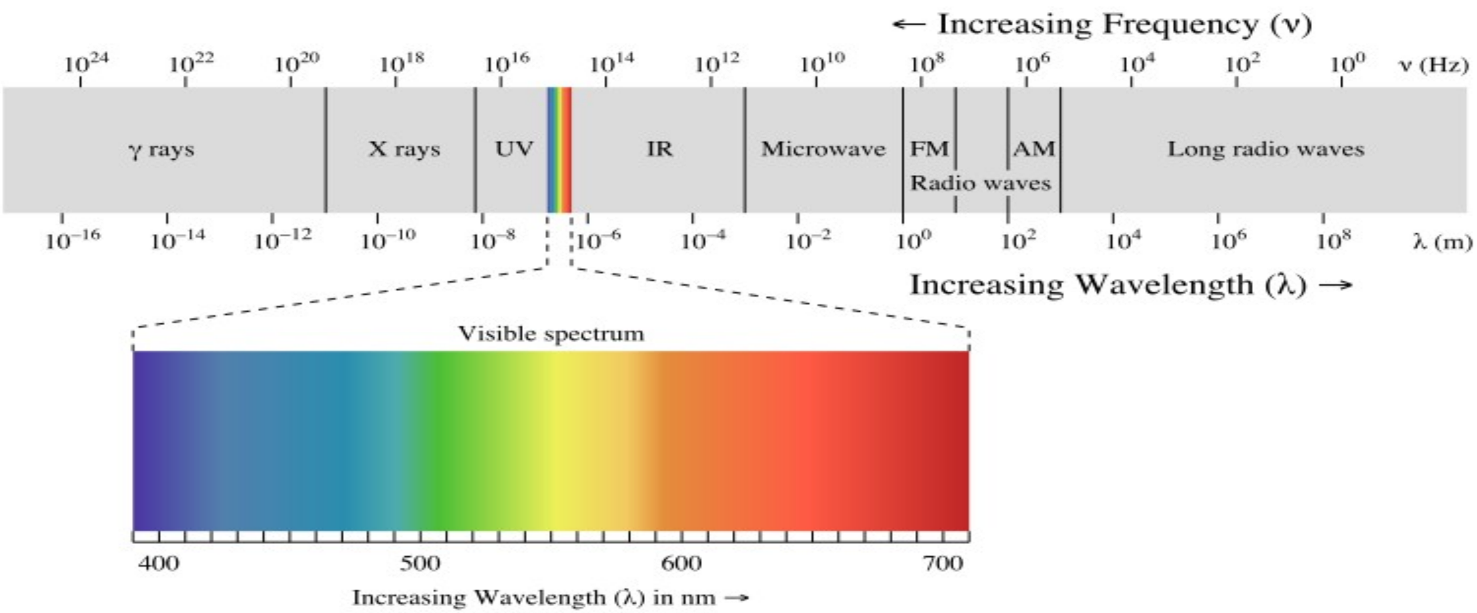
Color Fundamentals

- Color spectrum seen by passing white light through a prism.



The Electromagnetic Spectrum

- The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum



Color Model and Color Space

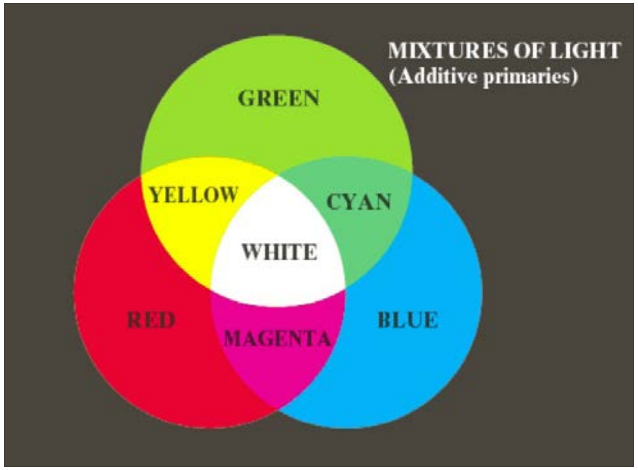
- Color Model
  - An abstract mathematical system to represent color
  - A 3 dimensional abstractions
  - Defines three primary colors along three dimensions
  - Is typically limited in the range of colors they can represent and hence often can't represent all colors in the visible spectrum

(色域)

- Gamut or Color Space
  - The range of colors that are covered by a color model.

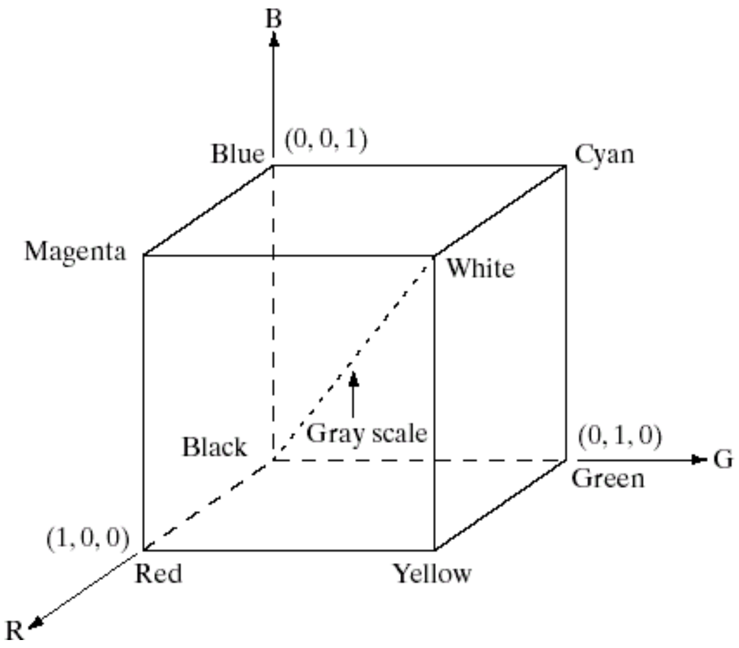
Additive Color Model

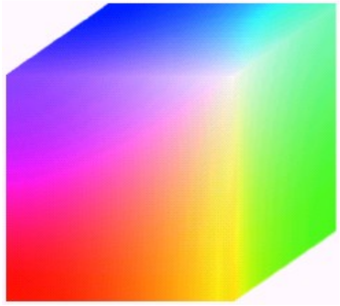
- Assumes that light is used to generate colors.
- Human perception is additive, since black is the absence of light and white represents all wavelengths of light.
- Devices: computer monitor, LCD screens, projectors
- RGB Color Model
  - Standard Primary Colors
  - Red
  - Green
  - Blue



RGB Color Model

- Color is defined by a 3-tuple that gives the amount of red, green and blue light in the color.
- R, G, B at 3 axis ranging in [0 1] each
- Gray scale along the diagonal
- If each component is quantized into 256 levels [0:255], the total number of different colors that can be produced is $(2^8)^3 = 2^{24} = 16{,}777{,}216$ colors.

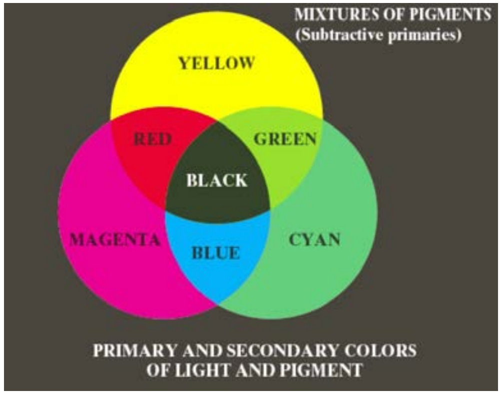




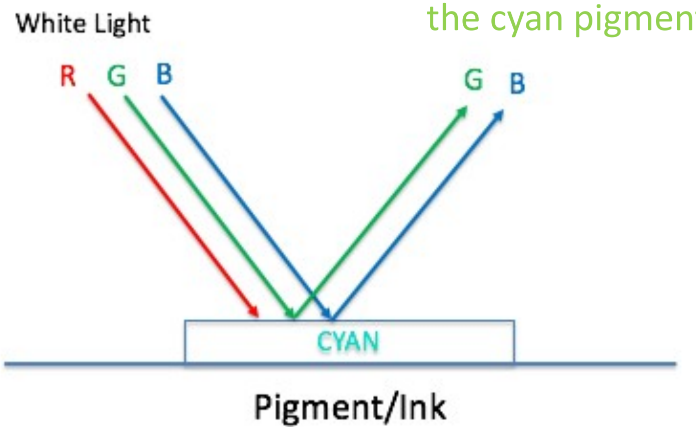
24-bit RGB color cube

Subtractive Color Model

- Assumes that pigment is used to generate colors
- White light is reflected off of an object which ‘absorbs’ or ‘subtracts’ certain wavelengths, the viewer sees the light that is not absorbed.
- The absence of pigment is “white” (blank piece of paper) while the presence of all types of pigment is “black”.
- Devices: painting, printers
- CYM Color Model
  - C - Cyan
  - Y - Yellow
  - M - Magenta

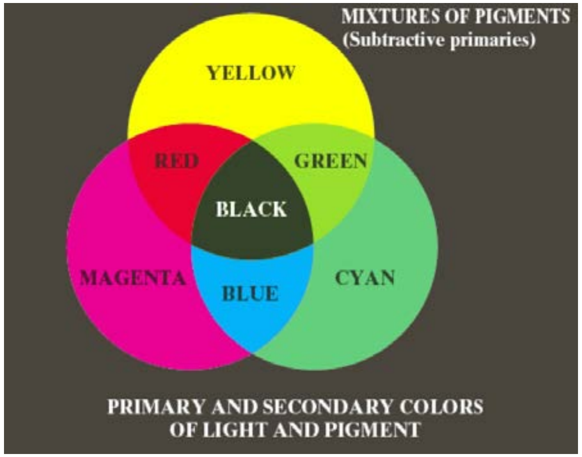


Red light is absorbed by the cyan pigment



CMY Color Model

- Color is defined by a 3-tuple that gives the amount of cyan, magenta and yellow light in the color.
  - Cyan is the first dimension
  - Magenta is the second dimension
  - Yellow is the third dimension
- The amount of each primary color is often given in normalized form as a value in the range 0 to 1
  - 0 means “none”
  - 1 means “maximum amount”
- Examples:
  - Cyan is then given as <1, 0, 0>
  - Magenta is given as <0, 1, 0>
  - Yellow is given as <0, 0, 1>



Conversion from RGB to CMY

- Given a color in normalized RGB space as <R,G,B>, the same color in CMY space is given as <C,M,Y> where

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

CMYK

- CMYK augments CMY by the addition of a black channel
  - CMY and CMYK are mathematically “equally expressive”
  - Color printers often use 4 or 5 colors

- Why CMYK?
  - Equal amounts of the pigment primaries, cyan, magenta, and yellow should produce black. In practice, combining these colors for printing produces a muddy-looking black.
  - To produce true black, the predominant color in printing, the fourth color, black, is added, giving rise to the CMYK color model.

Conversion from CMY to CMYK

- Given a color in normalized CMY space as <C’, M’, Y’>, the same color in CMYK space is given by

$$\langle C, M, Y, K\rangle = \begin{cases} \langle 0,0,0,1\rangle & \text{if } \min(C', M', Y') = 1, \\ \langle \frac{C'-K}{1-K}, \frac{M'-K}{1-K}, \frac{Y'-K}{1-K}, K\rangle & \text{otherwise where } K = \min(C', M', Y') \end{cases}$$

- K is a measure of the ‘blackness’ of the color and essentially serves as an offset after which the remaining amounts of cyan, magenta and yellow are ‘added’.

Color and Brightness

- Any color can be decomposed into
  - A brightness component. This corresponds to the ‘grayscale’ version of the color.
  - A color component. All other information is ‘color’ or ‘chroma’.
- In RGB and CMY space, the brightness and chroma are distributed over each of the three components.
- Other color models explicitly divide a color into one brightness dimension and two chroma dimensions.
  - HSV or HSB
  - YIQ
  - YCbCr
  - Others…

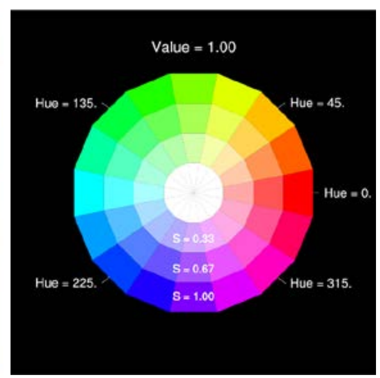
HSV Color Model

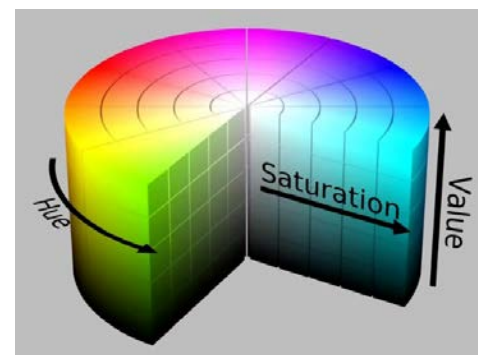
- HSV color model decomposes color according to perception rather than according to how it is physically sensed.
- Colors are distinguished from one another based on hue, saturation and brightness.
  - Hue: The dominant color.
  - Saturation: Purity or strength of the color.
  - Brightness/values: How much light there is.
  - Hue + Saturation define the chromaticity of a color.

HSV Color Model

- The HSV color space is a cylinder and hence HSV coordinates are given with cylindrical coordinates
  - hue=angle, saturation=radius, brightness=height
  - **Hue** is an angular measure [0-360] that is often normalized to be [0-1] where 1 correspond to 360 degrees.

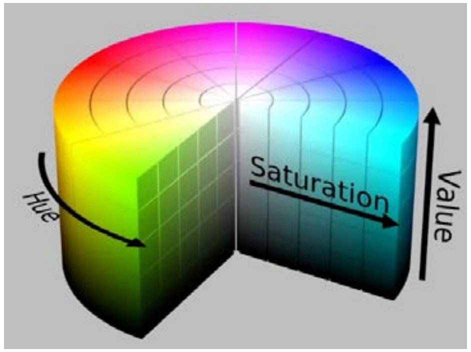
Angle	Color
0-60	Red
60-120	Yellow
120-180	Green
180-240	Cyan
240-300	Blue
300-360	Magenta

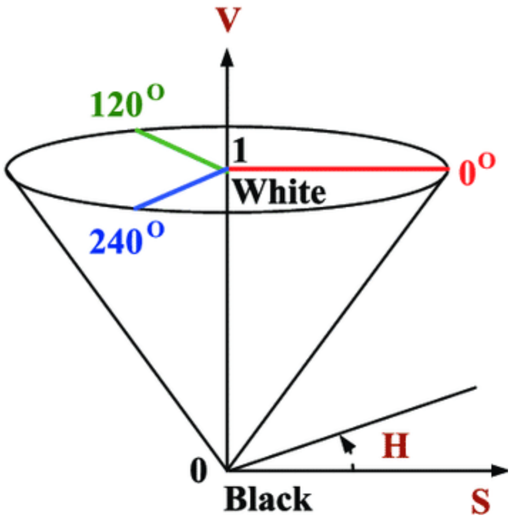




HSV Color Model

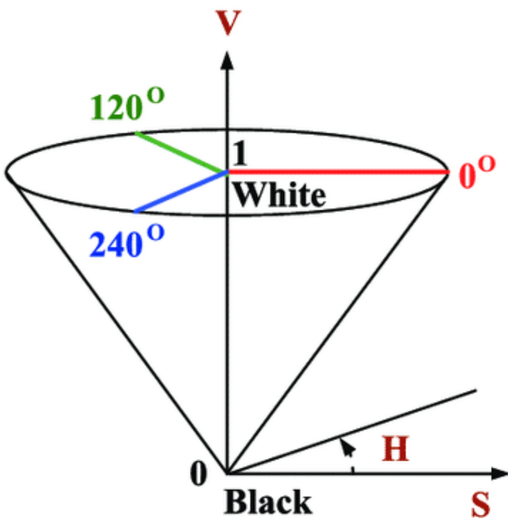
- The HSV color space is a cylinder and hence HSV coordinates are given with cylindrical coordinates
  - **Saturation** indicates the range of gray in color space.
  - For value 0, the color is grey while the value 1, the color is primary color
  - Fully saturated colors are the most vivid.
  - Fully de-saturated colors are grayscale (no color).





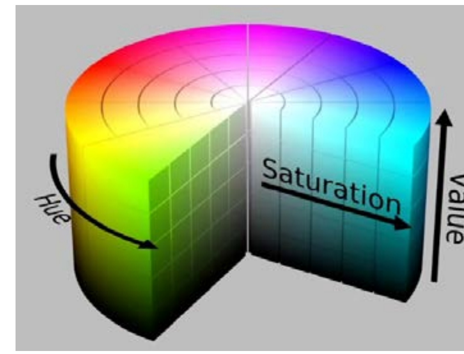
HSV Color Model

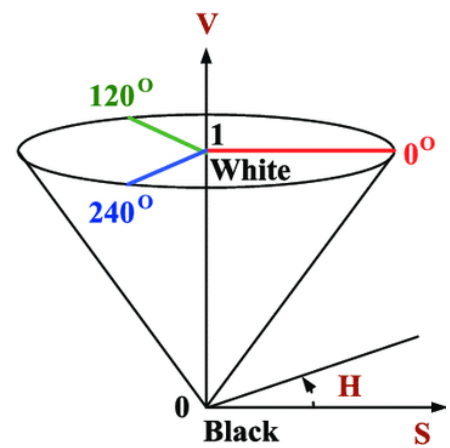
- The HSV color space is a cylinder and hence HSV coordinates are given with cylindrical coordinates
  - **Value** works in conjunction with saturation
  - Describes the brightness or intensity of the color from 0% to 100%
  - Value is 0, the color space will be totally black
  - With the increase in the value, the color space brightness up and shows various colors.



HSV Comments

- Notes on the HSV model
  - The center of the cylinder is the grayscale
  - Red is given as <0, 1, 1> while gray is given as <0, 0, 0.5>
  - HSV is computationally problematic since hue is cyclic. A hue value of 0 is equal to a hue value of 1.
  - HSV is useful since when filtering an image we often need to process only the brightness band.
  - Using HSV space we can process only brightness without altering the color.





RGB->HSV

- Transformations

$$V = \max = \max(R, G, B), \qquad \min = \min(R, G, B)$$

$$S = (\max - \min) / \max \qquad (\text{or } S = 0, \text{ if } V = 0)$$

$$H = 60 \times \begin{cases} 0 + (G - B) / (\max - \min), & \text{if } \max = R \\ 2 + (B - R) / (\max - \min), & \text{if } \max = G \\ 4 + (R - G) / (\max - \min), & \text{if } \max = B \end{cases}$$

$$H = H + 360, \text{ if } H < 0$$

- Matlab: rgb2hsv; hsv2rgb.

Color	Color name	Hex	(R,G,B)	(H,S,V)
	Black	#000000	(0,0,0)	(0°,0%,0%)
	White	#FFFFFF	(255,255,255)	(0°,0%,100%)
	Red	#FF0000	(255,0,0)	(0°,100%,100%)
	Lime	#00FF00	(0,255,0)	(120°,100%,100%)
	Blue	#0000FF	(0,0,255)	(240°,100%,100%)
	Yellow	#FFFF00	(255,255,0)	(60°,100%,100%)
	Cyan	#00FFFF	(0,255,255)	(180°,100%,100%)
	Magenta	#FF00FF	(255,0,255)	(300°,100%,100%)
	Silver	#C0C0C0	(192,192,192)	(0°,0%,75%)
	Gray	#808080	(128,128,128)	(0°,0%,50%)
	Maroon	#800000	(128,0,0)	(0°,100%,50%)
	Olive	#808000	(128,128,0)	(60°,100%,50%)
	Green	#008000	(0,128,0)	(120°,100%,50%)
	Purple	#800080	(128,0,128)	(300°,100%,50%)
	Teal	#008080	(0,128,128)	(180°,100%,50%)
	Navy	#000080	(0,0,128)	(240°,100%,50%)

YIQ Color Model

亮度

- Like HSV, YIQ separates color into luminance and color channels
  - Y: the luminance or grayscale component
  - I: the inphase component (amount of red-green)
  - Q: the quadrature (amount of blue-yellow)
- Used for TV broadcasts – backward compatible with monochrome TV standards
- Human visual system is more sensitive to changes in **intensity** than in **color** hence the bandwidth of YIQ is 4MHz in Y, 1.5 MHz in I, and 0.6 MHz in Q.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.321 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

YIQ Color Model

- Note that the Y value is given as the weighted sum of RGB values such that
  - about 60% of the brightness comes from green
  - about 30% of the brightness comes from red
  - about 10% of the brightness comes from blue
- This mirrors the human visual system since there are many more green cones than red and many more red cones than blue
- Also note that while Y is in [0, 1] the values of I and Q are NOT in [0,1]

YCbCr Color Model

- YCbCr is similar to YIQ : essentially a rotation around the Y axis
  - Y is luminance
  - Cb is a measure of ‘blueness’
  - Cr is a measure of ‘redness’
- Often called YUV
- Used in the JPEG file format and video systems

Conversion from RGB to YCbCr

- Given a color in normalized RGB space, the corresponding ***8-bit*** YCbCr color is given as <Y, Cb, Cr> where

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \begin{bmatrix} 65.481 & 128.553 & 24.966 \\ -37.797 & -74.203 & 112.000 \\ 112.000 & -93.786 & -18.214 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Note that Y is in [16, 235] while Cb and Cr are in [16, 240]. In practice, scaling is often used to convert into the full dynamic range of [0, 255].

Summarization

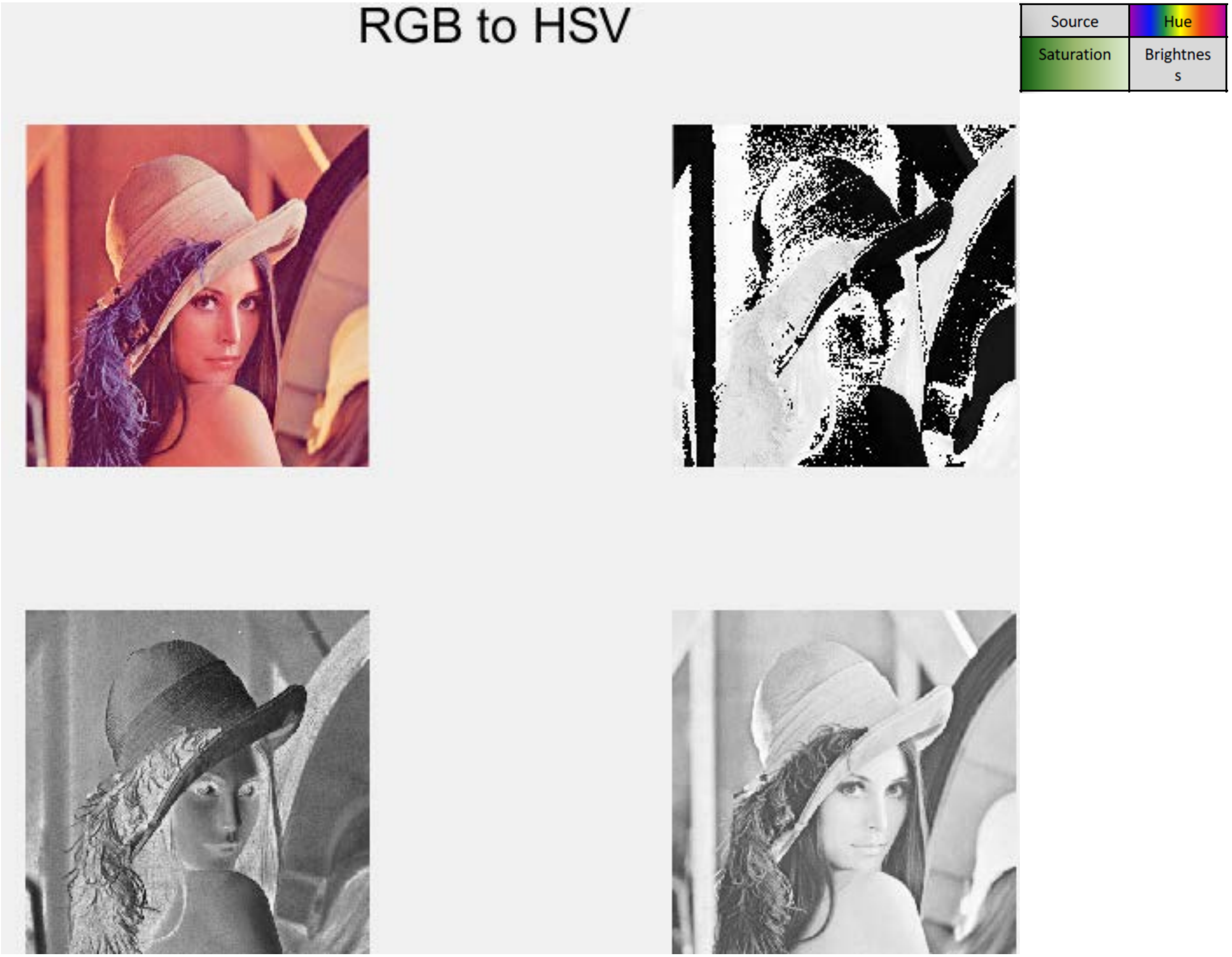
- Different color models: RGB,CMY(CMYK), HSV, YCbCr
- RGB color model: eye, monitor
- CMY (CMYK) color model: printing
- HSV/HSB: close to Human Visual Perception
- YCbCr are commonly used for image/video compressions

Example

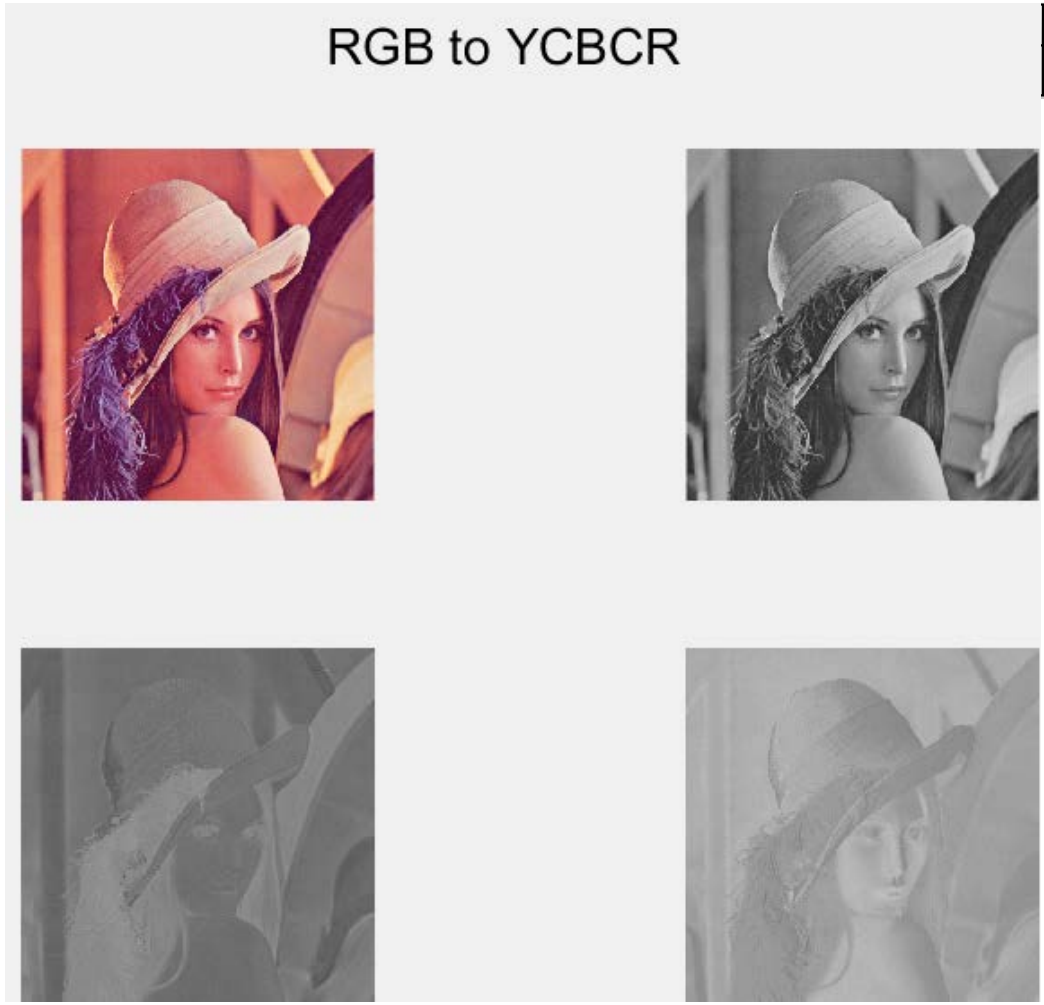
Example

Source	Cyan
Magenta	Yellow

Example



Example



Source	Y
Cb	Cr