Overview

- Images
  - What is an image?
  - How are images displayed?
- Color models
  - How do we perceive colors?
  - How can we describe and represent colors?

קורס גרפיקה ממוחשבת
סמסטר ב' 2009

Raster Graphics

חלק מהשקפים מעובדים משקפים של פרדו דוראנד, טומס פנקהאוסר ודניאל כהן-אור

What is an image?

- An image is a 2D rectilinear array of pixels

Continuous image   Digital Image

A pixel is a sample, not a little square!

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What is an image?

- An image is a 2D rectilinear array of pixels
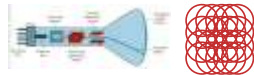

Continuous image   Digital Image

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Image display

- Re-create continuous function from samples
  - Example: cathode ray tube

Image is reconstructed by displaying pixels with a finite area (Gaussian)
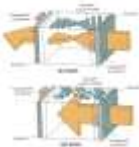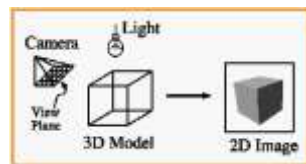

  - Example: LCD

Image Acquisition

- Pixels are samples from a continuous function
  - Photoreceptors in eye
  - CCD cells in digital camera
  - Rays in virtual camera

Camera Light
View Plane
3D Model → 2D Image

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Image Resolution

- Intensity resolution
  - Each pixel has only "Depth" bits for color/intensities
- Spatial resolution
  - Image has only "Width" x "Height" pixels
- Temporal resolution
 - Monitor refreshes images at only "Rate" Hz

Display	Width x Height	Depth	Rate
NTSC	640 x 480	8	30
Workstation	1280 x 1024	24	75
Film	3000 x 2000	12	24
Laser Printer	6600 x 5100	1	-
Portable devices (iPod)	320 x 200	24	~75

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Display Hardware

- Video display devices
  - Cathode Ray Tube (CRT)
  - Liquid Crystal Display (LCD)
  - Plasma panels
  - Thin-film electroluminescent displays
  - Light-emitting diodes (LED)
- Hard-copy devices
  - Ink-jet printer
  - Laser printer
  - Film recorder
  - Electrostatic printer
  - Pen plotter

Frame Buffer Refresh
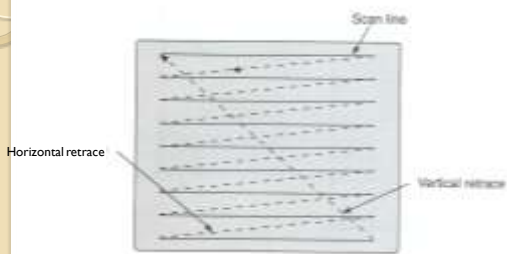
Refresh rate is usually 30-75Hz

Figure 1.3 from FvDFH
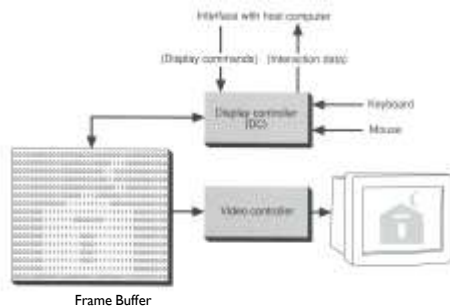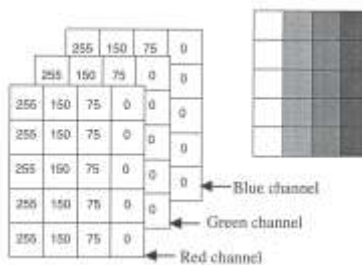
Frame Buffer

Frame Buffer
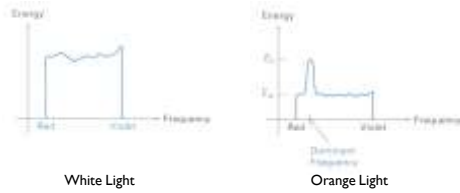
Figure 1.2 from FvDFH

Overview

- Images
  - What is an image?
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- Color models
  - How do we perceive colors?
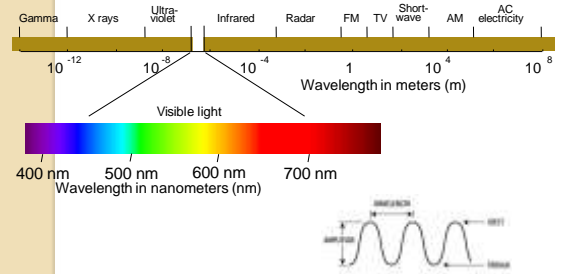 - How can we describe and represent colors?

Color Frame Buffer

Visible Light

- The color of light is characterized by …
  - Hue = dominant frequency (highest peak)
  - Saturation = excitation purity (ratio of highest to rest)
  - Lightness = luminance (area under curve)

White Light   Orange Light
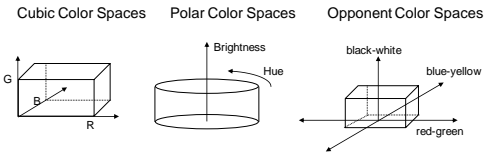
Figures 15.3-4 from H&B

Electromagnetic Spectrum

Gamma	X rays	Ultra-violet	Infrared	Radar	FM	TV	Short-wave	AM	AC electricity

10^{-12} 10^{-8} 10^{-4} 1 10^{4} 10^{8}

Wavelength in meters (m)

Visible light
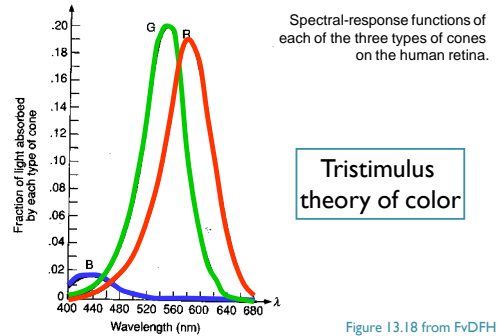
400 nm   500 nm   600 nm   700 nm

Wavelength in nanometers (nm)

3D Color Spaces

- Three types of cones suggests color is a 3D quantity. How to define 3D color space?

Cubic Color Spaces   Polar Color Spaces   Opponent Color Spaces

G

B

R

Brightness

Hue

black-white

blue-yellow

red-green

Color Perception

Spectral-response functions of each of the three types of cones on the human retina.

Fraction of light absorbed by each type of cone

.20 .18 .16 .14 .12 .10 .08 .06 .04 .02 0

400 440 480 520 560 600 640 680

Wavelength (nm)

λ

Tristimulus theory of color

Figure 13.18 from FvDFH

RGB Color Model

R	G	B	Color
0.0	0.0	0.0	Black
1.0	0.0	0.0	Red
0.0	1.0	0.0	Green
0.0	0.0	1.0	Blue
1.0	1.0	0.0	Yellow
1.0	0.0	1.0	Magenta
0.0	1.0	1.0	Cyan
1.0	1.0	1.0	White
0.5	0.0	0.0	
1.0	0.5	0.5	
1.0	0.5	0.0	
0.5	0.3	0.1	

Colors are additive

Plate II.3 from FvDFH

Color Models

- Linear (RGB, CMYK)
- Artistic View (Munsell, HSV, HLS)
- Standard (CIE-XYZ)
- Perceptual (Luv, Lab)
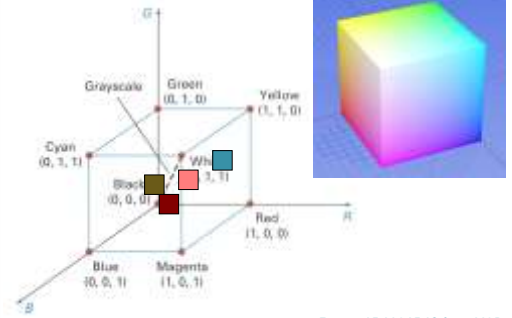- Opponent (YIQ, YUV) – used in TV

CIE 1931 Color Space

- CIE XYZ is based on experiments done by W. David Wright and John Guild in the 1920's
- It is based on direct measurements of human **visual perception**

Users could adjust brightness but not chromaticity
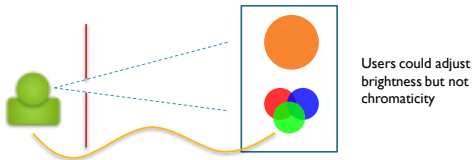
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RGB Color Cube
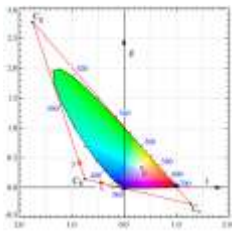

Figures 15.11&15.12 from H&B

CIE 1931 Color space

- We can parameterize chromaticity by defining: $r = \dfrac{R}{R+G+B}, g = \dfrac{G}{R+G+B}$

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CIE 1931 Color Space

- Experiments produced three functions: r(λ), g(λ), b(λ)
- Functions were normalized to have a constant area beneath them
- Therefore, RGB tristimulus values for a color I(λ) would be:

$$R = \int I(\lambda) r(\lambda)\, d\lambda$$
$$G = \int I(\lambda) g(\lambda)\, d\lambda$$
$$B = \int I(\lambda) b(\lambda)\, d\lambda$$

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XYZ Color Model (CIE)

Amounts of CIE primaries needed to display spectral colors

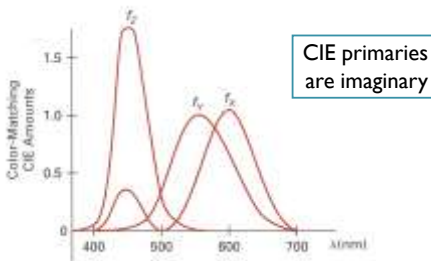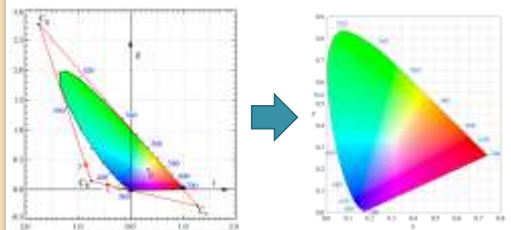CIE primaries are imaginary

Figure 15.6 from H&B

CIE-XYZ

- Transforming the triangle to (0,0),(0,1),(1,0) is a linear transformation

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RGB Color Gamut

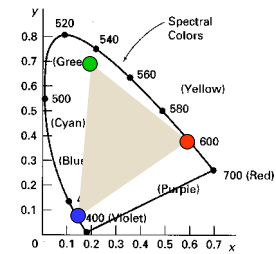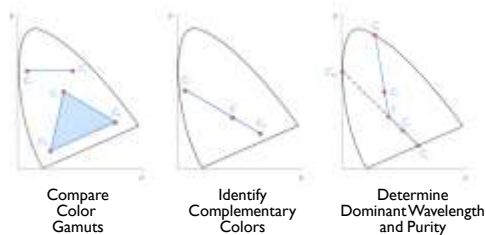Color gamut for a typical RGB computer monitor
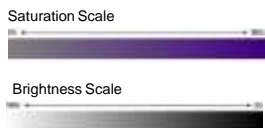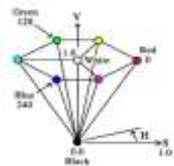

Figure 15.13 from H&B

CIE Chromaticity Diagram

Compare Color Gamuts

Identify Complementary Colors

Determine Dominant Wavelength and Purity

Figures 15.8-10 from H&B

HSV/HSB Color Model
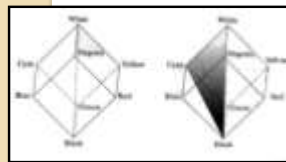
HSV = Hue Saturation Value
HSB = Hue Saturation Brightness

Saturation Scale

Brightness Scale

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HSV/HSB Color Model

- RGB is not suited to describing colors
- How do we describe colors?
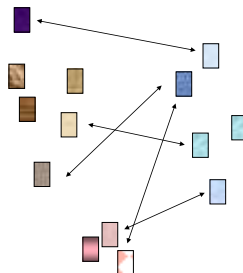 - Hue
  - Saturation
  - Brightness

?

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Summary

- Images
  - Pixels are samples
  - Frame buffers
  - Display hardware
  - Devices have limited resolution
- Color models
  - Tristimulus theory of color
  - CIE Chromacity diagram
  - Different color models for different devices, uses, etc.
  - Modern color models take into account better how we perceive colors and the differences between them

Distances between colors

- Distances are not linear in any color space.
- In perceptual color space distances are more suitable for our conception.
- Measuring color differences between pixels is more useful in perceptual color spaces.

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The End