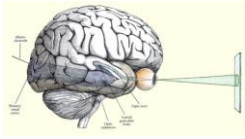
Overview

- 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

2008 סמסטר ב'

Raster Graphics

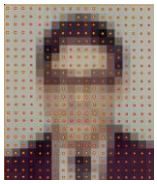


חלק מהשקפים מעובדים משקפים של פרדו דוראנד, טומס פנקהאוסר ודניאל כהן-אור

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!

What is an image?

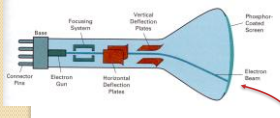
- An image is a 2D rectilinear array of pixels


Continuous image


Digital Image

Image display

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



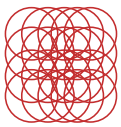
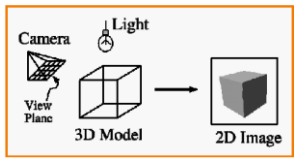


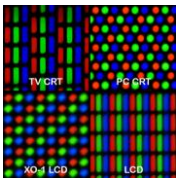
Image is reconstructed by displaying pixels with a finite area (Gaussian)

Image Acquisition

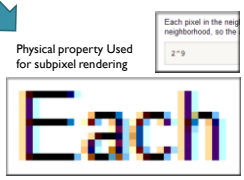
- Pixels are samples from a continuous function
  - Photoreceptors in eye
  - CCD cells in digital camera
  - Rays in virtual camera



Pixel geometry



Physical property Used for subpixel rendering



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Liquid Crystal Display (LCD)

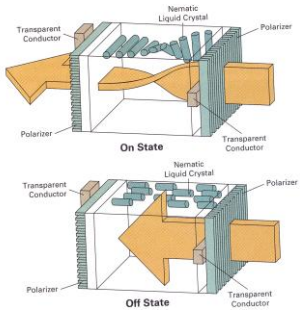

Figure 2.16 from H&B

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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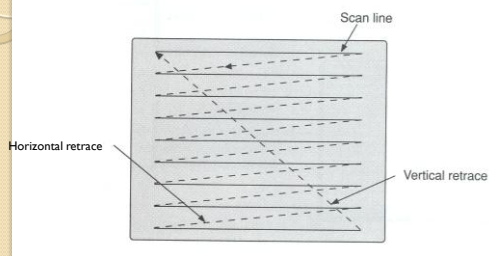
Display Hardware

- 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

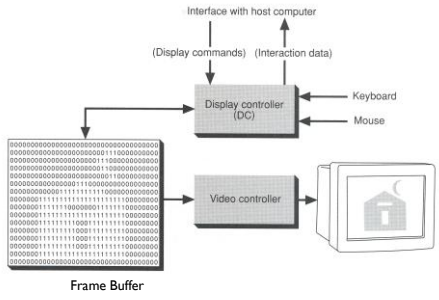


Figure 1.2 from FvDFH

Overview

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  - What is an image?
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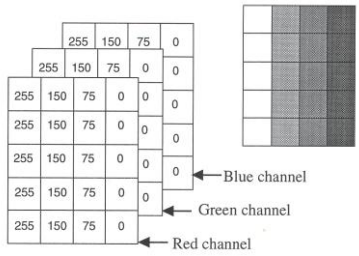
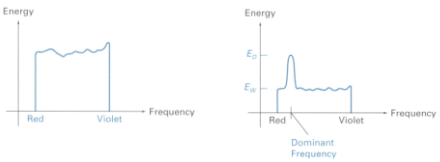
Color Frame Buffer



Visible Light

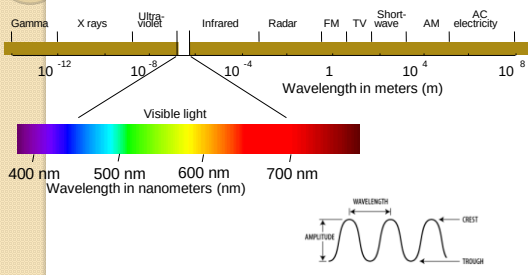
- The color of light is characterized by …
  - Hue = dominant frequency (highest peak)
  - Saturation = excitation purity (ratio of highest to rest)
  - Lightness = luminance (area under curve)



White Light Orange Light

Figures 15.3-4 from H&B

Electromagnetic Spectrum



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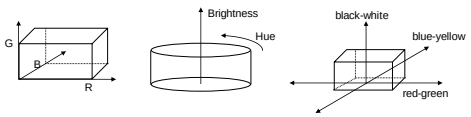
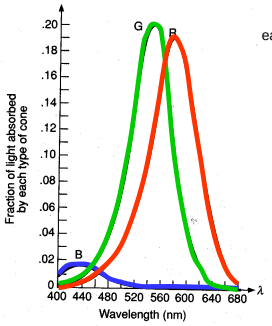
3D Color Spaces

- 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



Color Perception

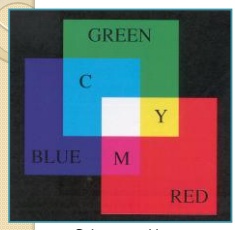


Spectral-response functions of each of the three types of cones on the human retina.

Tristimulus theory of color

Figure 13.18 from FvDFH

RGB Color Model



Colors are additive

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	

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

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22/5/2008

RASTER DISPLAY המשך

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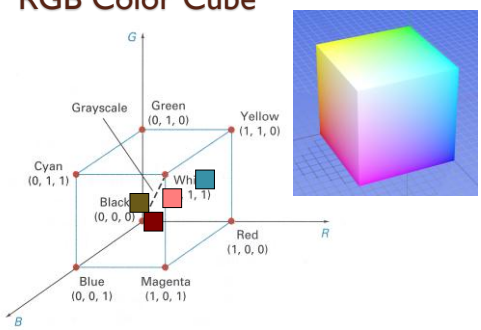
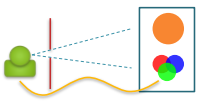
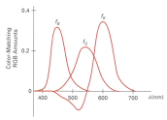
RGB Color Cube



Figures 15.11&15.12 from H&B

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:

$$R = \int_0^\infty I(\lambda)\,\bar{r}(\lambda)\,d\lambda$$
$$G = \int_0^\infty I(\lambda)\,\bar{g}(\lambda)\,d\lambda$$
$$B = \int_0^\infty I(\lambda)\,\bar{b}(\lambda)\,d\lambda$$

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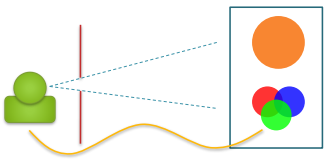
CIE 1931 Color Space

- CIE XYX 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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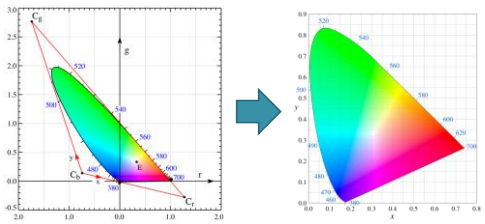
CIE-XYZ

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



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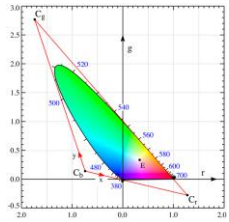
CIE 1931 Color space

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



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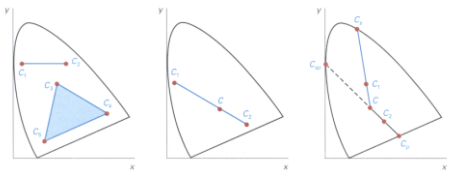
CIE Chromaticity Diagram



Compare Color Gamuts

Identify Complementary Colors

Determine Dominant Wavelength and Purity

Figures 15.8-10 from H&B

XYZ Color Model (CIE)

Amounts of CIE primaries needed to display spectral colors

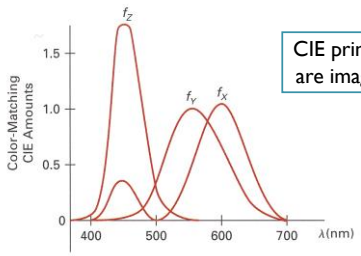
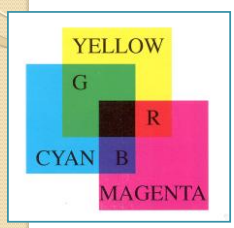


Figure 15.6 from H&B

CMY Color Model



Colors are subtractive

C	M	Y	Color
0.0	0.0	0.0	White
1.0	0.0	0.0	Cyan
0.0	1.0	0.0	Magenta
0.0	0.0	1.0	Yellow
1.0	1.0	0.0	Blue
1.0	0.0	1.0	Green
0.0	1.0	1.0	Red
1.0	1.0	1.0	Black
0.5	0.0	0.0	
1.0	0.5	0.5	
1.0	0.5	0.0	

Plate II.7 from FvDFH

RGB Color Gamut

Color gamut for a typical RGB computer monitor

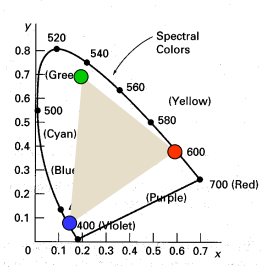
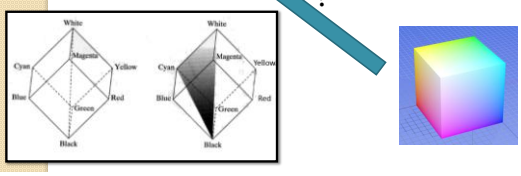


Figure 15.13 from H&B

HSV/HSB Color Model

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



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CMY Color Cube

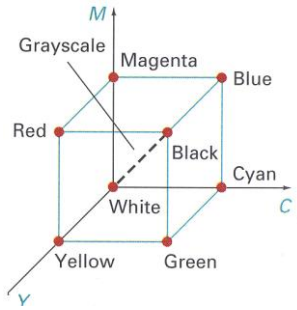
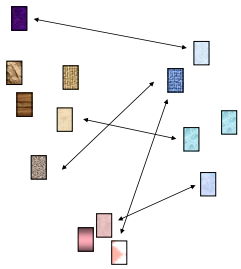


Figure 15.14 from H&B

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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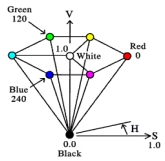
HSV/HSB Color Model

HSV = Hue Saturation Value
HSB = Hue Saturation Brightness



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The End

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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