Displays
Topics

Perception
- Spatial resolution
- Temporal resolution

Color calibration

Display technologies
Resolution

World is continuous, digital media is discrete ...

Three aspects:

- **Color and intensity resolution**
  - Physical limits: color “pigments”, 1-bit vs n-bit tones
  - Human limits: just-noticeable differences, trichromaticity

- **Spatial resolution (x, y)**
  - Physical limits: pixel size and display size
  - Human limits: photoreceptor density + optics

- **Temporal resolution (t)**
  - Physical limits: film transport, channel bandwidth
  - Human limits: neuronal response time
Contrast Sensitivity Function
Visual Acuity / Snellen Chart

20/20 vision = 1 arcmin

~1/16” at 20’

Monitor viewing range:

~1/100” at 3’
Spatial Resolution

Photoreceptor mosaic

- Foveal (1 deg.) vs. peripheral
- Photoreceptor density
  - Rods: 100 million total
  - Cones (3 subtypes L, M, S): 5 million total
    - 1 um (foveal), 10 um (periphery)
    - Foveal resolution: 10 arcmins (S), 0.5 arcmins (L, M)

Pupil of the eye is diffraction limited

- 4 mm pupil
- 6 um circle of confusion (bigger than a photoreceptor)
Common Image Resolutions

Television
- NTSC 720x480x8b  ¼ MB
- HDTV-1 1280x720x8b ~1 MB
- HDTV-2 1920x1080x8b ~2 MB

Computers
- VGA 640x480x24b ~3/4 MB
- XGA 1024x768x24b ~2.5 MB
- SXGA 1280x1024x24b ~4 MB
- UXGA 1600x1280x24b ~6 MB

Laserprinters (dpi = dots per inch)
- 300 dpi (8.5”x300)*(11”x300) 1.05 MB
- 1200 dpi (8.5”x1200)*(11”x1200) ~64 MB

Film (line pairs per mm, ASA 25 ~ 125 lpm)
- 35 mm (diagonal) 3000x2000x3x12b ~27 MB
## Display Resolution History

Rate of increase is low (1.1 compound overall)

<table>
<thead>
<tr>
<th>Date</th>
<th>Format and Technology</th>
<th>Bandwidth</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1024 x 768 x 60Hz, CRT</td>
<td>0.14 GB</td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>1280 x 1024 x 72Hz, CRT</td>
<td>0.29 GB</td>
<td>1.1</td>
</tr>
<tr>
<td>1996</td>
<td>1920 x 1080 x 72Hz, HD CRT</td>
<td>0.60 GB</td>
<td>1.1</td>
</tr>
<tr>
<td>2001</td>
<td>3840 x 2400 x 56Hz, active LCD</td>
<td>1.55 GB</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Slide from K. Akeley
IBM T221

Resolution: 3840 x 2400 (QXGA)
Size: 21.5” x 17.3” (204 dpi)
PowerWall

UC-Davis
PowerWall

Resolution: 3 \times 1280 \times 2 \times 1024 = 3040 \times 2048
Size: 18' \times 9' (18dpi)
VGA PDA

Resolution: 640 x 480 (VGA)
Size: 3.5” x 2.8” (182 dpi)
Temporal Resolution

Critical Flicker Fusion Rate
- High ambient light, large field of view: 80 Hz
- Low ambient light, 20-30 Hz

Frames per Second (FPS)
- Film (double framed) 24 FPS
- TV (interlaced) 30 FPS
- Computer (progressive) 60-75 FPS
Color Calibration

www.drycreekphoto.com/Learn/color_management.htm
Monitor Colors

Red Phosphor

Green Phosphor

Blue Phosphor

Monitor Phosphors

x  y
.635  .340
.305  .595
.155  .070

Resulting Spectra
Display Information

Dell 24” Flat Panel

![Image of Dell 24" Flat Panel Display Information]

- **Monitor**: Plug and Play Monitor
- **Media white point**: D65
- **Chromaticity coordinates**:
  - Red: x: 0.64, y: 0.33
  - Green: x: 0.3, y: 0.607
  - Blue: x: 0.149, y: 0.06
- **Target gamma**: 2.20
- **Profile name**: Plug and Play Monitor
- **Options**:
  - Install profile
  - Make default profile

[Buttons: Help, Cancel, Create]
Monitor Calibration

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>.640</td>
<td>.330</td>
</tr>
<tr>
<td>G</td>
<td>.300</td>
<td>.600</td>
</tr>
<tr>
<td>B</td>
<td>.150</td>
<td>.060</td>
</tr>
<tr>
<td>W</td>
<td>.313</td>
<td>.329</td>
</tr>
</tbody>
</table>
sRGB – Standard Color Primaries

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>.640</td>
<td>.330</td>
</tr>
<tr>
<td>G</td>
<td>.300</td>
<td>.600</td>
</tr>
<tr>
<td>B</td>
<td>.150</td>
<td>.060</td>
</tr>
<tr>
<td>W</td>
<td>.313</td>
<td>.329</td>
</tr>
</tbody>
</table>
Color Gamut

Gamut mapping: map colors from one color space to another.

Some colors may be outside the gamut; need to map to nearest color inside the target gamut.
Display Technologies
Cathode Ray Tube
Screen Mask

1 pixel
Phosphors

Delta Gun

Inline
Plasma
Liquid Crystal Displays
Liquid Crystal Displays

Diagram showing the components of a liquid crystal display, including a back light, polarizer, liquid crystal layer, molecular orientation layers, and transparent electrodes.
Dynamic Micro-Mirror Device (DMD)
Digital Light Processing (TI) - DLP
Virtual Retinal Display
OLED Keyboard

http://www.artlebedev.com/everything/optimus
Electronic Ink
Kindle 2
Things to Remember

Spatial and temporal resolutions
- Physical limits
- Psychophysical limits

Color gamuts

Emerging display technologies