Displays

Topics

Perception
- Spatial resolution
- Temporal resolution

Calibrating displays
Display technologies

CS148 Lecture 11
Pat Hanrahan, Winter 2007
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-noticable-differences, trichromaticity

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

- **Temporal resolution:** t
  - Physical limits: film transport, channel bandwidth
  - Human limits: neuronal response time
Contrast Sensitivity Function

Spatial Resolutions

Experiments
- Resolving power
  - Max equals 6-60 cycles per degree = 1-10 arcmins
- Hyperacuity
  - 5 arcsecs for very fine line position judgements!

Photoreceptor mosaic
- Foveal (1deg.) vs. peripheral
- Photoreceptor density
  - Rods: 100 million total
  - Cones: 3 subtypes (L,M,S), 5 million total
  - 1-10m diameter (fov.-per.),
    Fovea res: 10 arcmins (S), 0.5 arcmins (L,M) spacing
Image Resolutions in Practice

Television
- NTSC 640x480x8b  1/4 MB
- HDTV-1 1280x720x8b  ~1MB
- HDTV-2 1920x1080x8b  ~2MB

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

Laserprinters
- 300 dpi (8.5”x300)(11”x300)x1b  1.05 MB
- 2400 dpi (8.5”x2400)(11”x2400)x1b  ~64 MB

Film (line pairs/mm)
- 35mm (diagonal) slide (ASA25~125 lp/mm) = 3000
  3000 x 2000 x 3 x 12b  ~27 MB

"Moore’s Law" for Displays

Rate of increase is low (1.1 compound overall)
2001 resolution still true today

<table>
<thead>
<tr>
<th>Date</th>
<th>Format and Technology</th>
<th>Bandwidth</th>
<th>Rate</th>
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<tbody>
<tr>
<td>1980</td>
<td>1024 x 768 x 60Hz, CRT</td>
<td>0.14 GB</td>
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<tr>
<td>1988</td>
<td>1280 x 1024 x 72Hz, CRT</td>
<td>0.29 GB</td>
<td>1.1</td>
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<tr>
<td>1996</td>
<td>1920 x 1080 x 72Hz, HD CRT</td>
<td>0.60 GB</td>
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Estimates due to Kurt Akeley
IBM T221

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

PowerWall

UC-Davis PowerWall
PowerWall

Resolution: $3 \times 1280 \times 2 \times 1024 = 3840 \times 2048$
Size: 18' by 9' (18 dpi)

VGA PDA

Resolution: 640 x 480 (VGA)
Size: 3.5” x 2.6” (182 dpi)
Cathode Ray Tube

Temporal Resolution

Critical flicker fusion rate
- high ambient light, large field: 80 Hz
- low ambient light: 20-30 Hz

Frames per second (FPS)
- Film (double framed) 24 FPS
- TV (interlaced) 30 FPS × 1/4 = 8 MB/s
- Workstation (non-interlaced) 75 FPS × 5 = 375 MB/s

Interlaced (Progressive Scan)
Phosphors

Delta Gun

Inline

Screen Mask

http://www.aim-dtp.net/aim/calibration/crt_screen_visualized/screen.htm
Plasma

Color Calibration

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

Red Phosphor

Green Phosphor

Blue Phosphor

0.2 *

0.0 *

0.8 *

Monitor Phosphors

\[ \begin{align*}
\text{Red Phosphor} & : x = 0.635, y = 0.340 \\
\text{Green Phosphor} & : x = 0.305, y = 0.595 \\
\text{Blue Phosphor} & : x = 0.155, y = 0.070
\end{align*} \]

Resulting Spectra

Display Information

Dell 24” Flat Panel

Quick Monitor Profile reads from display
Monitor Calibration

**Monitor Phosphors**

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<tr>
<td>R</td>
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<td>G</td>
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<td>B</td>
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<td>.070</td>
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sRGB - Standard Primaries

**sRGB**

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Display Technologies

Liquid Crystal Displays
Liquid Crystal Displays

Micromirror (DMD/DLP)
Laser Projector

http://elm-chan.org/works/vlp/report_e.html

Virtual Retinal Display
OLED

http://science.howstuffworks.com/oled.htm

OLED Keyboard

http://www.artlebedev.com/everything/optimus/
Electronic Ink

Times Square