CS148: Introduction to Computer Graphics and Imaging

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

■ Spatial resolution (x, y)
  ■ Physical limits: pixel size and display size
  ■ Human limits: photoreceptor density

■ Temporal resolution (t)
  ■ Physical limits: film speed, channel bandwidth
  ■ Human limits: neuronal response time

Spatial Resolution
Contrast Sensitivity Function

Maximum sensitivity @ 4 cycles/degree

Human Contrast Sensitivity

Visible Stimuli

Maximum resolving @ 60 cycles/deg
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)
Display Resolution History

<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>
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</tbody>
</table>

Compound annual growth rate = 1.1
Rate of increase slow compared to CPU, disk, ...

Slide from K. Akeley

IBM T221

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

Resolution: 3 * 1280 x 2 * 1024 = 3040 x 2048
Size: 18' x 9' (18dpi)
iPhone 4 Retinal Display

OsiriX Radiological Viewer

Resolution: 960 x 640
Size: 3.5” diagonal (326 dpi)

Temporal Resolution
**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

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**Color Calibration**

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

Monitor Phosphors

\[
\begin{align*}
0.2 & \quad 0.635 & \quad 0.340 \\
0.0 & \quad 0.305 & \quad 0.595 \\
0.8 & \quad 0.155 & \quad 0.070
\end{align*}
\]

*Red Phosphor*

*Green Phosphor*

*Blue Phosphor*

Resulting Spectra

Display Information

Dell 24” Flat Panel

- Monitor: Plug and Play Monitor
- Chromaticity coordinates:
  - Red: \(x = 0.64\), \(y = 0.33\)
  - Green: \(x = 0.3\), \(y = 0.607\)
  - Blue: \(x = 0.149\), \(y = 0.06\)
- Media white point: \(0.65\)
- Target gamma: \(2.20\)
- Profile name: Plug and Play Monitor
- Options:
  - Install profile
  - Make default profile

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Monitor Calibration

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
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<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>
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</tbody>
</table>

Four Color Display

sRGB – Standard Color Primaries

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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
Phosphors

Delta Gun

Inline

Screen Mask

1 pixel

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Plasma

Dielectric layer
Display electrode
Visible light
Front glass plate
Pixel barrier
Surface discharge
UV
Phosphor
Rear glass plate

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Liquid Crystal Displays

Polarizer
Twisted Nematic Cell
Polarizer
Incident Light
Blocked Light
Electric Field

Polarizer
Twisted Nematic Cell
Polarizer
Incident Light
Transmitted Light

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Liquid Crystal Displays

Back Light

Polarizer

Molecular Orientation Layers

Glass

Liquid Crystal

Transparent Electrodes

Glass

Polarizer

LCD Displays

iPad  iPhone 1G  iPhone 3G  iPhone 4G

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### RGBW PenTile

[Image: PenTile RGBW and Traditional RGB Stripe diagrams.]

2 subpixels per pixel

3 subpixels per pixel

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### Dynamic Micro-Mirror Device (DMD)

[Image: Diagram of a micro-mirror device with labeled parts: Mirror -10 deg, Mirror +10 deg, Hinge, Yoke, Landing Tip, CMOS Substrate.]

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Digital Light Processing (TI) - DLP

3D TV - Field Sequential

Glasses for Viewing DLP 3-D HDTV

Double Frame Rate to 120 Hz
Alternate Left and Right Eyes
Electronic Ink (Reflective Display)

**Cross-Section of Electronic-Ink Microcapsules**

- Top Transparent Electrode
- Positively charged white pigment chips
- Clear Fluid
- Negatively charged black pigment chips
- Subcapsule addressing enables hi-resolution display capability
- Bottom Electrode

Light State: + +
Dark State: - -

*NOTE: Copyright E Ink Corporation, 2002. Image not drawn to scale - for illustration purposes only.*
Things to Remember

Spatial and temporal resolutions
  ■ Physical limits
  ■ Psychophysical limits
Color profiles and gamuts
Emerging display technologies