Displays

Topics

Spatial resolution
Temporal resolution
Tone mapping

Display technologies
Resolution

*World is continuous, digital media is discrete ...*

Three aspects:

- **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

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

Spatial Resolution
Contrast Sensitivity Function

Maximum sensitivity @ 4 cycles/degree

Human Contrast Sensitivity

Maximum resolving power @ 60 cycles/deg = 1 arcmin
Visual Acuity / Snellen Chart

20/20 vision = 1 arcmin

~1/16” at 20’

Monitor viewing range:

~1/100” at 3’

Photoreceptor Density in the Retina

Rods: 100 million total

Cones (3 subtypes L, M, S): 5 million total

- Fovea
  - Size of photoreceptors: ~1 um
  - Angular resolution:
    - S: 10 arcmins
    - L, M: 0.5 arcmins

- Periphery
  - 10 um
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>
</tr>
</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: $3 \times 1280 \times 2 \times 1024 = 3040 \times 2048$
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

Tone Reproduction
Real World = High Dynamic Range

The absolute amount of light of the marked pixels

Perception of Intensities

Sensation (S) vs. Intensity (I)

Stevens Power Law: \( S = I^p \)

<table>
<thead>
<tr>
<th>Sense</th>
<th>Exponent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightness</td>
<td>0.33</td>
</tr>
<tr>
<td>Smell</td>
<td>0.55</td>
</tr>
<tr>
<td>Loudness</td>
<td>0.60</td>
</tr>
<tr>
<td>Taste</td>
<td>0.80</td>
</tr>
<tr>
<td>Length</td>
<td>1.00</td>
</tr>
<tr>
<td>Heaviness</td>
<td>1.45</td>
</tr>
</tbody>
</table>

\[ B = I^{1/3} \]
Contrast = \text{Max/Min}

World:
- Possible: 100,000,000,000:1
- Typical: 100,000:1

People: 100:1

Adapt to the ambient light level

Estimating Gamma

CS148 Lecture 13
Pat Hanrahan, Fall 2010
Displays are Nonlinear

The amount of light (intensity) produced is a power function of the input value (voltage)

$I = g(V - V_b)\gamma$

Monitor: $\gamma = 2.5$

Monitor + Perception = Linear

Amazing coincidence!
Displays have Limited Dynamic Range

World:
- **Possible**: 100,000,000,000:1
- **Typical**: 100,000:1

People: 100:1

Media:
- **Printed page**: 10:1
- **Displays**: 80:1 (1000:1)
- **Typical viewing conditions**: 5:1

Correcting Exposure

Rancho de Taos, Taos, NM
Pat Hanrahan

Photoshop demonstration
Tone Mapping

Problem: Image has a higher dynamic range than the display (100,000:1 maps down to 20:1)

Solutions:
1. Linear map (min -> 0, max -> 255)
   - Bad: Independent of absolute brightness
2. Logarithmic map
   - Models camera exposure
   - Roughly maps into perceptual space

Tone Reproduction Algorithms

Linear map

Logarithmic map
Better Tone Reproduction Algorithms

Adaptive histogram  With glare, contrast, blur

Display Technologies
Cathode Ray Tube

Phosphors

Delta Gun

Inline
Screen Mask

Plasma
Liquid Crystal Displays

![Diagram of Liquid Crystal Display](image)

Liquid Crystal Displays

![Diagram of Liquid Crystal Display](image)
3D TV - LCD Shutter Glasses

Glasses for Viewing DLP® 3-D HDTV

http://www.reghardware.com

Double Frame Rate to 120 Hz
Alternate Left and Right Eyes

Responsive Workbench
LCD Displays

RGBW PenTile

2 subpixels per pixel

3 subpixels per pixel
Dynamic Micro-Mirror Device (DMD)

Digital Light Processing (TI) - DLP
eBooks

Kindle

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Electronic Ink (Reflective Display)

Cross-Section of Electronic-Ink Microcapsules

Top Transparent Electrode

Positively charged white pigment chips

Clear Fluid

Subcapsule addressing enables hi-resolution display capability

Negatively charged black pigment chips

Bottom Electrode

Light State

Dark State

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CS148 Lecture 11

Pat Hanrahan, Fall 2011
Things to Remember

Physics
- Limits of materials and fabrication

Perception
- Human limits: properties of the eye and brain

Spatial resolution
Temporal resolution
Tone reproduction