Exposure and Tone Reproduction

Topics

Perception of light intensities
Camera exposure
Exposure correction: levels and curves
Creating a high dynamic range (HDR) image
Displays and gamma
HDR tone reproduction
Perception

Real World = High Dynamic Range

The relative radiance values of the marked pixels, clockwise from lower left: 1.0, 46.2, 1907.1, 15116.0, 18.0
Perception of Intensities

1. 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 = \( I^{1/3} \)

Just-noticeable difference (JND)

Weber’s Law

\[ JND = \frac{\Delta I}{I} \approx 0.01 \]

For this reason, we sometimes say the eye’s Response is logarithmic (more accurately, obeys Steven’s Law)
Contrast

Contrast = Max / Min

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

2. People: 100:1

3. Media:
   Printed page: 10:1
   Displays: 80:1 (400:1)
   Typical viewing conditions: 5:1

Exposure
Relative Aperture or F-Stop

F-number and exposure:

\[ E = L \Omega = L \pi \left( \frac{r}{f} \right)^2 = L \frac{\pi}{4} \frac{1}{N^2} \]

F-stops: 1.4, 2, 2.8, 4.0, 5.6, 8, 11, 16, 22, 32, 45, 64

1 stop doubles exposure

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Camera Exposure

Exposure: \[ H = E \times T \]

Exposure overdetermined
- Aperture: f-stop - 1 stop doubles \( H \)
  - Decreases depth of field
- Shutter: Doubling the open time doubles \( H \)
  - Increases motion blur
Aperture vs Shutter

f/16  
1/8s

f/4  
1/125s

f/2  
1/500s

From London and Upton

Measured Response Curve
Correcting Exposure

Rancho de Taos, Taos, NM
Pat Hanrahan

Photoshop demonstration

Creating High Dynamic Range Images
Multiple Exposure : Bracketing

Sixteen photographs of the Stanford Memorial Church taken at 1-stop increments from 30s to 1/1000s.

From Debevec and Malik, High dynamic range photographs.
http://www.debevec.org/Research/HDR/

Algorithm

1. Estimate exposure for each image

$$\log E_i = R(V_i) - \log T_i$$

2. Merge results

$$\log E = \frac{\sum w(V_i) \log E_i}{\sum w(V_i)}$$
Single Floating Point HDR Image

Displays and Gamma
Estimating Gamma

\[ I = g(V - V_b)\gamma \]

Monitor: \( \gamma = 2.5 \)
Monitor + Perception = Linear

Amazing coincidence!

Perceptual vs. Intensity Space

Perceptual space
+ best set of values
  - Uniform perceptual steps
  - Most perceivable colors and intensities
+ optimal compression into “quanta”
  - Bits used most effectively
  - Less sensitivity to noise

Intensity space
+ easier to simulate physical effects
  - Mixing, blending, dithering, antialiasing, lighting, …
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)
   Independent of absolute brightness
2. Logarithmic map (model camera exposure)
   Photoshop demonstration
   Roughly maps into perceptual space
3. Fancy techniques!
   Preserve local contrast
   See Chapter 22, Shirley
Tone Reproduction

Linear map  Logarithmic map

Tone Reproduction Algorithms

Adaptive histogram  With glare, contrast, blur
BrightSide introduces the DR37-P, a spectacular breakthrough in display technology. The DR37-P uses an array of individually modulated LED backlights to provide 10 times the brightness and 100 times the contrast of existing televisions and computer monitors. BrightSide’s Extreme Dynamic Range display delivers more vibrant images and allows you to see your data in vivid detail.

- Extreme Dynamic Range
- Over 3000 cd/m² Brightness
- 0.015 cd/m² 2 Black Level
- Contrast Ratio > 200,000:1
- High Definition 1920x1080
- 37" Screen
- 16 bits per color
- IMLED – Individually Modulated Array of LED backlights

Brightside HDR Display

<table>
<thead>
<tr>
<th>HDR Image</th>
<th>LED array</th>
<th>LCD with correction</th>
<th>Output image</th>
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<tr>
<td><img src="image1.png" alt="HDR Image" /></td>
<td><img src="image2.png" alt="LED array" /></td>
<td><img src="image3.png" alt="LCD with correction" /></td>
<td><img src="image4.png" alt="Output image" /></td>
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Things to Remember

A real scene has a very large range of light energies
Max:min is the dynamic range
Perception of brightness is $S = \text{pow}(I, 1/3)$
Monitor gamma is approximately $I = \text{pow}(P, 2.2)$
Displays have a limited dynamic range
Cameras also have limited dynamic range
Cameras map light energy into exposure values
Can create HDR images using bracketing
Display HDR images using tone mapping