High Dynamic Range

Sean Arietta
Terminology
Terminology

- Radiance
Terminology

- Radiance
- Luminosity
Terminology

- Radiance
- Luminosity
- Brightness
Terminology

- Radiance
- Luminosity
- Brightness
- Irradiance
Terminology

- Radiance
- Luminosity
- Brightness
- Irradiance
- Exposure Time
Terminology

- Radiance
- Luminosity
- Brightness
- Irradiance
- Exposure Time
- Dynamic Range
Terminology

- **Radiance**: physical quantity describing the power of light in a given area
- Luminosity
- Brightness
- Irradiance
- Exposure Time
- Dynamic Range
Terminology

- **Radiance**: physical quantity describing the power of light in a given area
- **Luminosity**: the effect of radiance on our eyes or other light-measuring device (also referred to as intensity)
- **Brightness**
- **Irradiance**
- **Exposure Time**
- **Dynamic Range**
Terminology

- Radiance: physical quantity describing the power of light in a given area
- Luminosity: the effect of radiance on our eyes or other light-measuring device (also referred to as intensity)
- Brightness: the interpreted experience of luminosity
- Irradiance
- Exposure Time
- Dynamic Range
Terminology

- **Radiance**: physical quantity describing the power of light in a given area
- **Luminosity**: the effect of radiance on our eyes or other light-measuring device (also referred to as intensity)
- **Brightness**: the interpreted experience of luminosity
- **Irradiance**: the power of light “incident” on a given area
- **Exposure Time**
- **Dynamic Range**
Terminology

- **Radiance**: physical quantity describing the power of light in a given area
- **Luminosity**: the effect of radiance on our eyes or other light-measuring device (also referred to as intensity)
- **Brightness**: the interpreted experience of luminosity
- **Irradiance**: the power of light “incident” on a given area
- **Exposure Time**: the total amount of time light is measured for a given shot
- **Dynamic Range**
Terminology

- **Radiance**: physical quantity describing the power of light in a given area
- **Luminosity**: the effect of radiance on our eyes or other light-measuring device (also referred to as intensity)
- **Brightness**: the interpreted experience of luminosity
- **Irradiance**: the power of light “incident” on a given area
- **Exposure Time**: the total amount of time light is measured for a given shot
- **Dynamic Range**: the ratio of the most luminous part of an image to the least luminous part
Low-Dynamic Range

Blooming

Saturation

Photo Courtesy of ThunderChild5
LDR Effects

- Saturation >> Clamping
  - Light-Capturing Device
  - File Format
  - Display
- Bloom Effect
  - Bleeding
  - Headlights in Rain

Photo Courtesy of ThunderChild5
High Dynamic Range

- What is it?
  - Dynamic range
  - Extending the range

- Why is it useful?
  - Accuracy
  - Calibration

- How do we achieve it?
  - Algorithm [Debevec and Malik 1997]
  - Composition [Debevec and Malik 1997]
### Dynamic Ranges

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Eye (Instantaneous)</td>
<td>1,000:1^\text{O}</td>
</tr>
<tr>
<td>Human Eye (Overall)</td>
<td>1,000,000:1^\text{O}</td>
</tr>
<tr>
<td>Canon G1</td>
<td>495:1^*</td>
</tr>
<tr>
<td>Nikon Coolpix 990</td>
<td>446:1^*</td>
</tr>
<tr>
<td>Canon EOS-D30</td>
<td>488:1^*</td>
</tr>
<tr>
<td>Nikon D1</td>
<td>470:1^*</td>
</tr>
<tr>
<td>Conventional CRT</td>
<td>600:1^x</td>
</tr>
<tr>
<td>Conventional LCD</td>
<td>500:1^x</td>
</tr>
</tbody>
</table>

*Data Courtesy dpreview.com
\^\text{O}Data Courtesy Wikipedia
^*Data Courtesy Gabriel Torres (hardwaresecrets.com)
Non-Linear Response Curve

- Linear response curves (lenses)
  - No information lost
- Introducing: Non-Linearity
- Hardware is the problem
  - Impurities in detection
- HDR is the solution
  - Recovery is on its way
Finding the Curve

- What we know
  - Intensity values for a given pixel and a given exposure time ($Z_{ij}$)
  - Exposure time ($\Delta t_j$)

- What we want to know
  - Irradiance for a given pixel ($E_i$)
  - Non-linear response curve ($f(E_i \Delta t_j)$)

- How are they related
  - $Z_{ij} = f(E_i \Delta t_j)$
  - $f^{-1}(Z_{ij}) = E_i \Delta t_j$
Formula Nonsense

- Logarithmic Magic
  - \( f^{-1}(Z_{ij}) = E_i \Delta t_j \)
  - \( \ln\{f^{-1}(Z_{ij})\} = \ln\{E_i\} + \ln\{\Delta t_j\} \)
  - Let \( g = \ln\{f^{-1}\} \)
  - \( g(Z_{ij}) = \ln\{E_i\} + \ln\{\Delta t_j\} \)

- Least Squares Approximation
  \[
  O = \sum_{i=1}^{N} \sum_{j=1}^{P} \left[ g(Z_{ij}) - \ln E_i - \ln \Delta t_j \right]^2
  \]
  \[
  w(z) = \begin{cases} 
  z - Z_{\text{min}} & \text{for } z \leq \frac{1}{2}(Z_{\text{min}} + Z_{\text{max}}) \\
  Z_{\text{max}} - z & \text{for } z > \frac{1}{2}(Z_{\text{min}} + Z_{\text{max}}) 
  \end{cases}
  \]
  \[
  O = \sum_{i=1}^{N} \sum_{j=1}^{P} \left\{ w(Z_{ij})[g(Z_{ij}) - \ln E_i - \ln \Delta t_j] \right\}^2 + \lambda \sum_{z=Z_{\text{min}}+1}^{Z_{\text{max}}-1} \left[ w(Z_{ij}) g''(z) \right]^2
  \]

where \( N \) is the number of pixels, \( P \) is the number of photos.
Solving the Equations

- **System:**
  \[ O = \sum_{i=1}^{N} \sum_{j=1}^{O} \left\{ w(Z_y) [g(Z_y) - \ln E_i - \ln \Delta t_j] \right\}^2 + \lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} \left\{ w(Z_y) g''(z) \right\}^2 \]
  \[ g(Z_{mid}) = 0 \text{ where } Z_{mid} = y(Z_{min} + Z_{max}) \]

- **Method**
  - Minimize \( O \)
  - Solve \( Ax = b \)

- **Notes**
  - Reciprocity \( (E_i \alpha) \left( \frac{1}{\alpha} \Delta t_j \right) \)
  - Reciprocity breakdown (2 for 10sec – 1/10,000 sec)
Solve $Ax = b$

- $x = [g_1(x) \ g_2(x) \ ... \ \ln E_1 \ \ln E_2 \ ... \ \ln E_N \ -1]$
- $A = \begin{bmatrix}
1 & 0 & \ldots & -1 & 0 & \ldots & \ln t_1 \\
0 & 1 & \ldots & 0 & -1 & \ldots & \ln t_2 \\
\vdots & 0 & \ldots & \vdots & 0 & \ldots & \vdots \\
\vdots & \vdots & \ldots & \vdots & \vdots & \ldots & \vdots \\
0 & 0 & \ldots & 0 & 0 & \ldots & \ln t_{j_{\max}}
\end{bmatrix}$
- $b = [0]$ (in theory)
- $x = A^{-1}b$ if $A$ is invertible (which it is)
See It In Action

- Raw data from pictures
- Data normalized and smoothed

Photos Courtesy of Debevec/Malik
The Radiance Map: At Long Last

- A Bit More Math...
  - \( \ln E_i = g(Z_{ij}) - \ln \Delta t_j \)
  - \( \ln E_i = \frac{\sum_{j=1}^{P} w(Z_{ij})[g(Z_{ij}) - \ln \Delta t_j]}{\sum_{j=1}^{P} w(Z_{ij})} \)
<table>
<thead>
<tr>
<th>Relative Radiance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
</tr>
<tr>
<td>46.2</td>
</tr>
<tr>
<td>1907.1</td>
</tr>
<tr>
<td>15116.0</td>
</tr>
<tr>
<td>18.0</td>
</tr>
</tbody>
</table>
Look at the Pretty Colors

- RGB
  - Acquired independent
  - Applied independently

Photos Courtesy of Debevec/Malik
Conclusions

- DR of many devices is too low to capture the full radiance of a scene
- HDR is a method of recovering this radiance from multiple LDR images
- Once the HDR image has been recovered, we can get the true radiance of the scene in addition to the response curve of the given device
Pretty Pictures...

- To be provided courtesy Professor Lawrence

- Oh, and I stole most of the equations and explanations from Debevec and Malik