High Dynamic Range Imaging and Tone Mapping
Capturing, Representing, and Manipulating High Dynamic Range Imagery (HDRI)
Dynamic Range in the Real World

Office interior
Indirect light from window
1/60th sec shutter
f/5.6 aperture
0 ND filters
0dB gain

Sony VX2000 video camera
Dynamic Range in the Real World

Outside in the shade
1/1000th sec shutter
f/5.6 aperture
0 ND filters
0dB gain

16 times the light as inside
Dynamic Range in the Real World

Outside in the sun
1/1000th sec shutter
f/11 aperture
0 ND filters
0 dB gain

64 times the light as inside
Dynamic Range in the Real World

Straight at the sun
1/10,000th sec shutter
f/11 aperture
13 stops ND filters
0dB gain

5,000,000 times the light as inside
Dynamic Range in the Real World

Very dim room
1/4th sec shutter
f/1.6 aperture
0 stops ND filters
18dB gain

1/1500th the light than inside
Dynamic Range in the Real World

The real world is high dynamic range.
The Problem of Dynamic Range

• Dynamic Range: Range of brightness values measurable with a camera

<table>
<thead>
<tr>
<th>Luminance (log cd/m²)</th>
<th>-6</th>
<th>-4</th>
<th>-2</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>starlight</td>
<td>moonlight</td>
<td>indoor lighting</td>
<td>sunlight</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Range of Illumination</th>
<th>scotopic</th>
<th>mesopic</th>
<th>photopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual function</td>
<td>no color vision</td>
<td>poor acuity</td>
<td>good color vision</td>
</tr>
</tbody>
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(Hood 1986)

• Today’s Cameras: Limited Dynamic Range

- We need about 5-10 million values to store all brightnesses around us.
- But, typical 8-bit cameras provide only 256 values!!
High Dynamic Range Imaging

• Capture a lot of images with different exposure settings.

• Apply radiometric calibration to each camera.

• Combine the calibrated images (for example, using averaging weighted by exposures).

Images taken with a fish-eye lens of the sky show the wide range of brightnesses.
Relationship between Scene and Image Brightness

- Before light hits the image plane:

  Scene $\rightarrow$ Scene Radiance $L$ $\rightarrow$ Lens $\rightarrow$ Image Irradiance $E$

  Linear Mapping!

- After light hits the image plane:

  Image Irradiance $E$ $\rightarrow$ Camera Electronics $\rightarrow$ Measured Pixel Values, $I$

  Non-linear Mapping!

Can we go from measured pixel value, $I$, to scene radiance, $L$?
Radiometric Calibration

• Important preprocessing step for many vision and graphics algorithms such as photometric stereo, invariants, de-weathering, inverse rendering, image based rendering, etc.

\[ g^{-1} : I \rightarrow E \]

• Use a color chart with precisely known reflectances.

• Use more camera exposures to fill up the curve.

• Method assumes constant lighting on all patches and works best when source is far away (example sunlight).

• Unique inverse exists because \( g \) is monotonic and smooth for all cameras.
Ways to vary exposure

- Shutter Speed
- F/stop (aperture, iris)
- Neutral Density (ND) Filters
- Gain / ISO / Film Speed
RADIANCE Format

Greg Ward’s “Real Pixels” format

32 bits / pixel

Red | Green | Blue | Exponent
--- | --- | --- | ---
(145, 215, 87, 149) = (145, 215, 87) * 2^(149-128) = (1190000, 1760000, 713000)
(145, 215, 87, 103) = (145, 215, 87) * 2^(103-128) = (0.00000432, 0.00000641, 0.00000259)

8-bit Images (TIF, BMP, TGA, JPG, etc.)

- Useful for representing images to be output on a computer monitor or printer
- Less useful for representing images for film
- Inadequate for representing HDR images
- Usually nonlinearly encoded with a gamma curve, i.e.

  \[ \text{Amount of light} = (\text{pixel value})^{2.2} \]
High-Dynamic Range Photography

300,000 : 1

W/sr/m²

121.741
28.869
6.846
1.623
0.384
0.091
0.021
0.005
HDR Tone-mapping

Linear tone-mapping

Non-linear tone-mapping
Veiling Glare Simulation
Capturing Real-World Illumination
Mirrored Ball - Records light in all directions

Brightest regions are saturated

Intensity and color information lost

kitchen scene
HDR Image of a Mirrored Ball

Assembled from ten digital images,
$\Delta t = 1/4$ to $1/10000$ sec
Sources of Mirrored Balls

2-inch chrome balls < $20 ea.
King Bearing, Inc. / Applied Industrial Technologies
(many locations nationally, check www.bigbook.com)

6-12 inch large gazing balls
- Baker’s Lawn Ornaments
  570 Berlin Plank Road
  Somerset, PA 15501-2413
  814-445-7028
- www.amazon.com - $8
Types of Omnidirectional Images

Latitude/Longitude

Cube Map
Illuminating Objects using Measurements of Real Light

Environment assigned “glow” material property in Greg Larson’s RADIANCE system.

http://radsite.lbl.gov/radiance/

See also: Larson and Shakespeare, “Rendering with Radiance”, 1998
5. Illuminating Synthetic Objects with Real Light
Comparison: Radiance map versus single image
Making Rendering with Natural Light

SIGGRAPH 98 Electronic Theater
Light Probe Images

Eucalyptus Grove
UC Berkeley

Uffizi Gallery
Florence

St. Peter’s Basilica
Rome

Grace Cathedral
San Francisco

Light Probe Image Gallery:
www.debevec.org/Probes