High Dynamic Range Imaging and Tone Mapping

Paul Debevec’s SIGGRAPH Course

Dynamic Range in the Real World

Office interior

Indirect light from window

$1/60^{th}$ 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

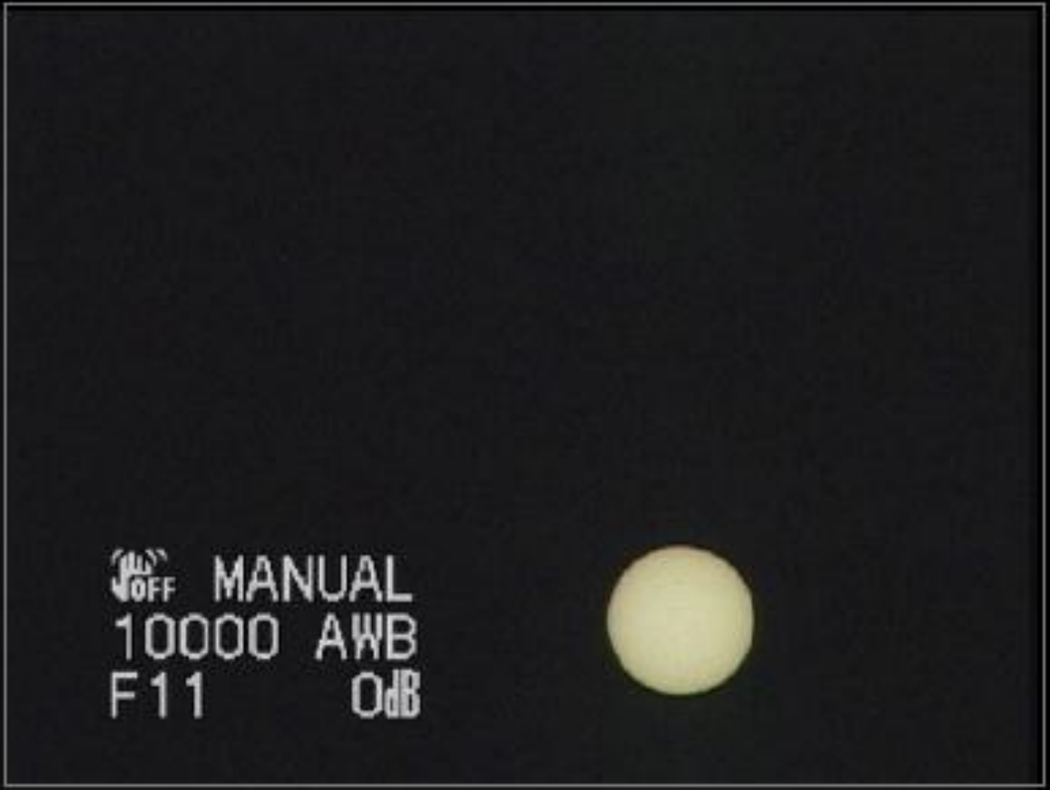
f/11 aperture

0 ND filters

0dB 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

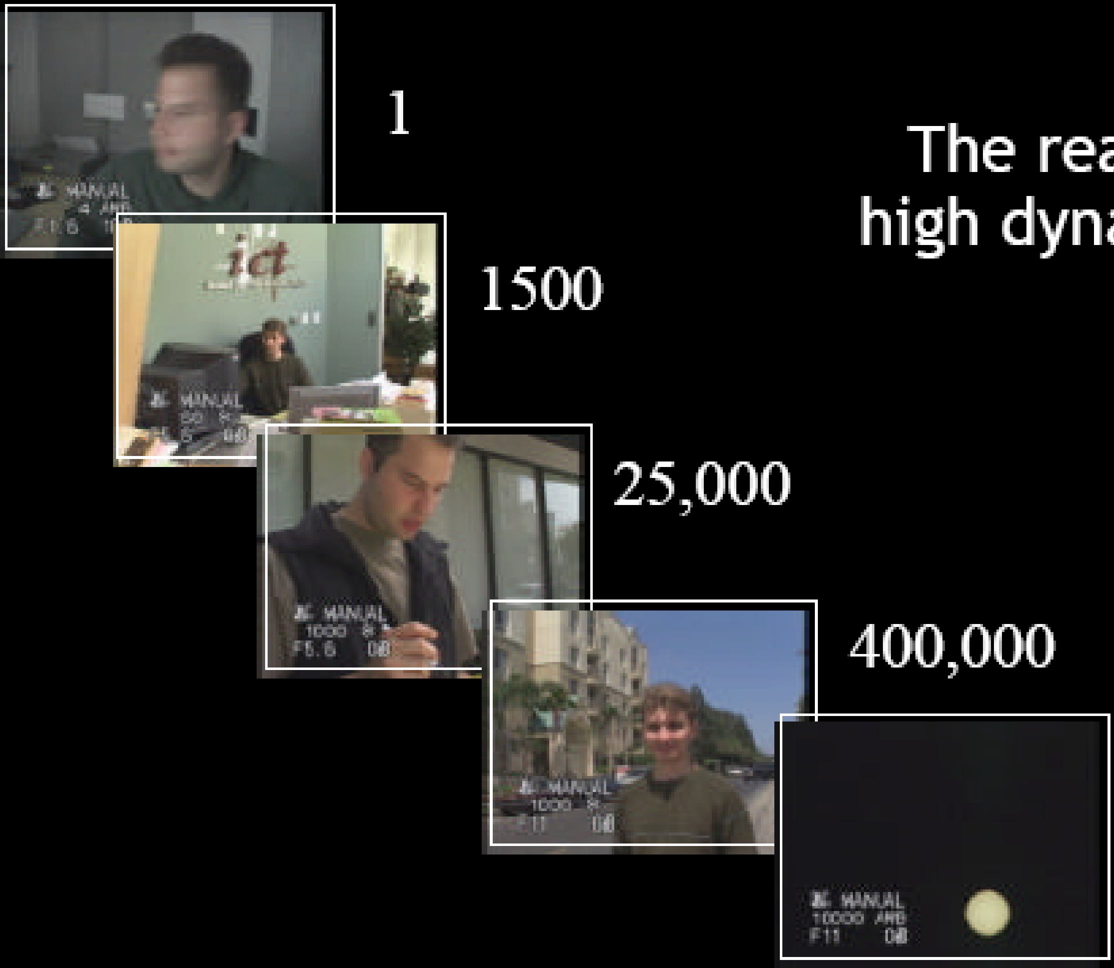
f/1.6 aperture

0 stops ND filters

18dB gain

1/1500th the light than inside

Dynamic Range in the Real World



1

1500

25,000

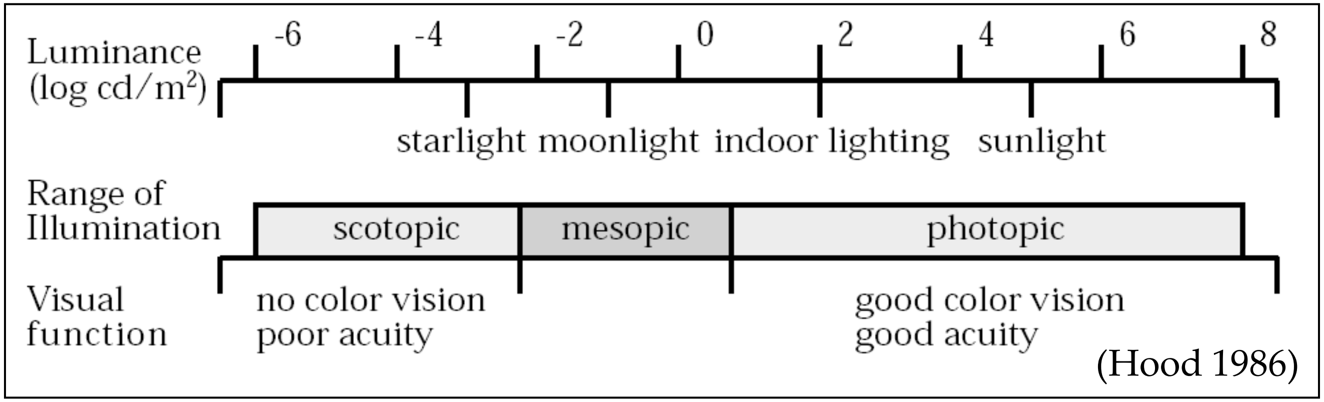
400,000

2,000,000,000

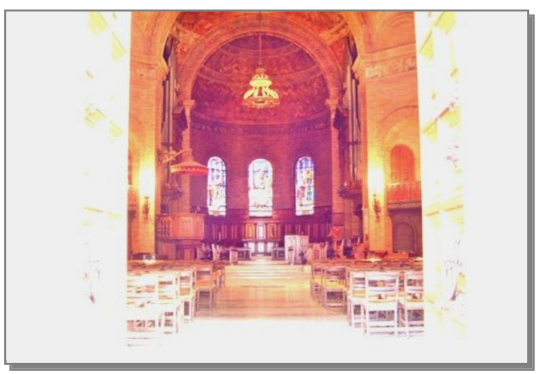
The real world is high dynamic range.

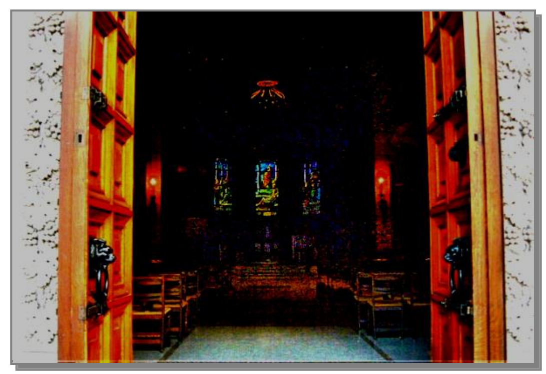
The Problem of Dynamic Range

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



- Today's Cameras: Limited Dynamic Range


High Exposure Image


Low Exposure Image

- 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).

(Mitsunaga)

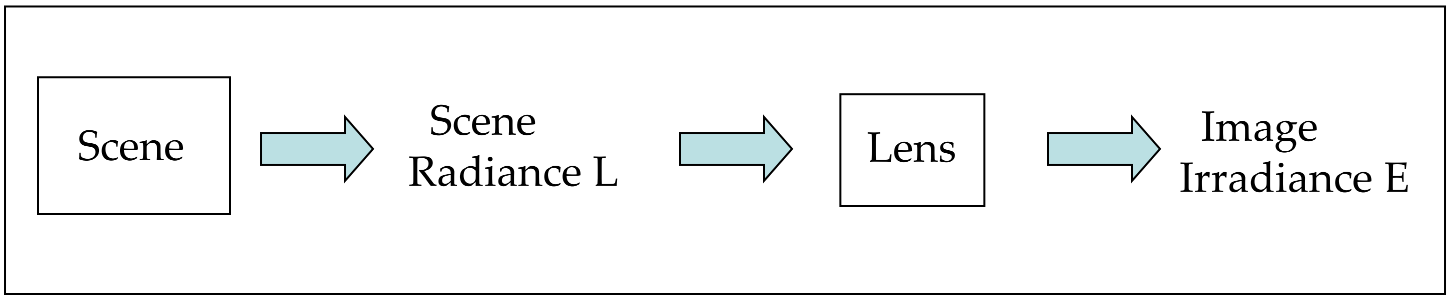
(Debevec)

f/4, 1s | f/4, $\frac{1}{4}$s | f/4, $\frac{1}{32}$s | f/16, $\frac{1}{16}$s | f/16, $\frac{1}{125}$s | f/16, $\frac{1}{1000}$s | f/16, $\frac{1}{8000}$s

Images taken with a fish-eye lens of the sky show the wide range of brightnesses.

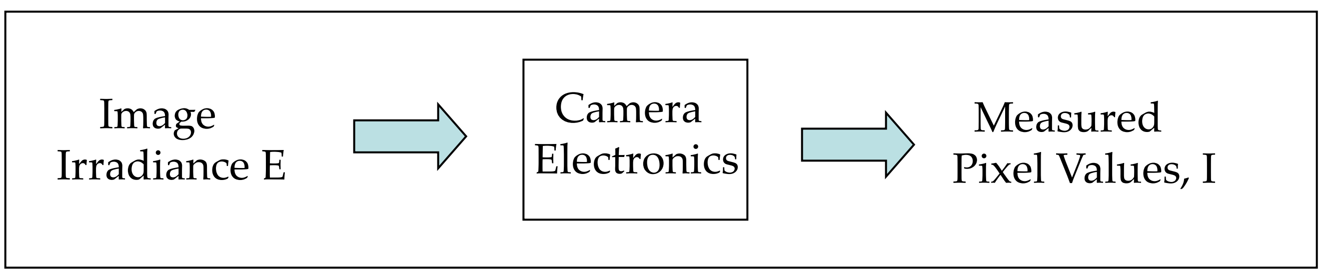
Relationship between Scene and Image Brightness

- Before light hits the image plane:



Linear Mapping!

- After light hits the image plane:



Non-linear Mapping!

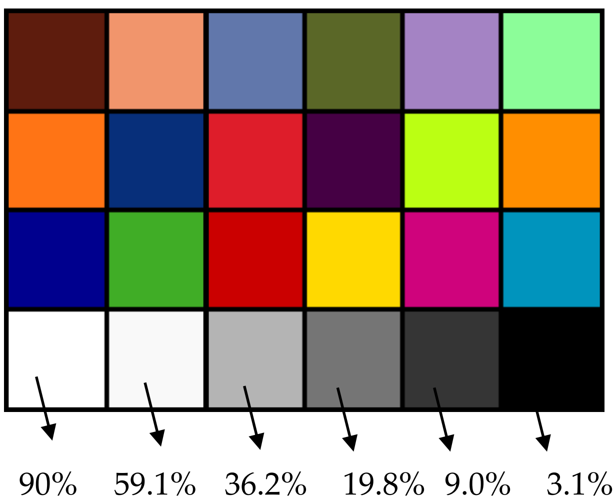
Can we go from measured pixel value, I, to scene radiance, L?

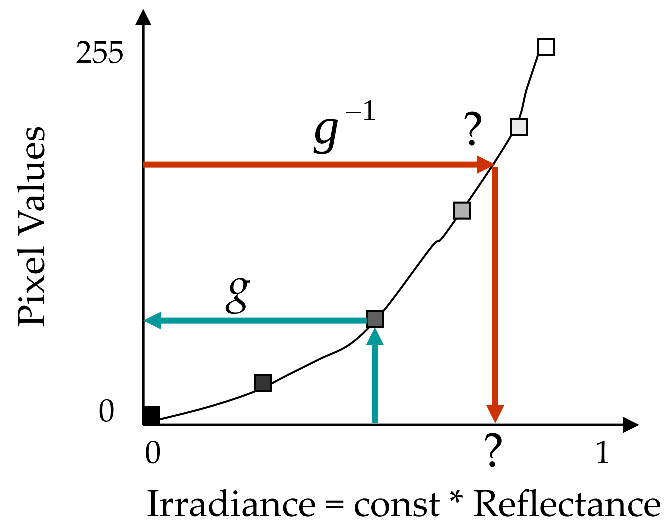
Radiometric Calibration

- 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) =

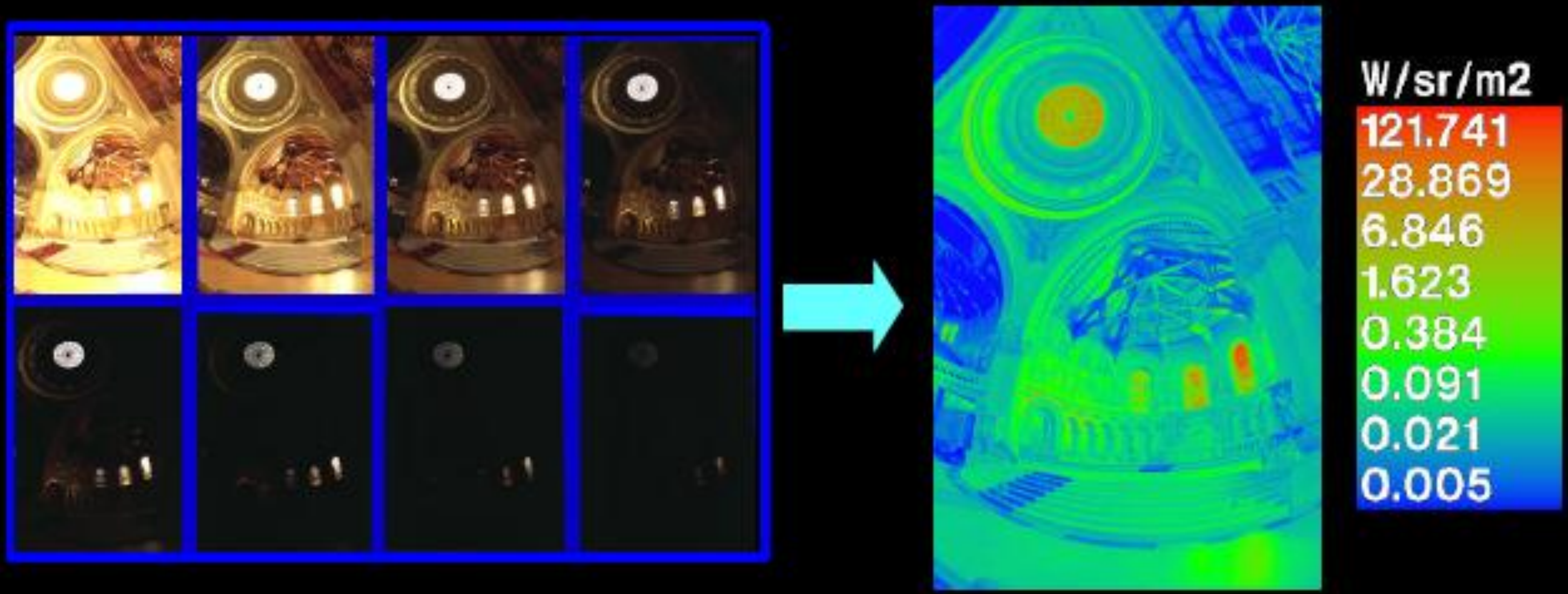
(0.00000432, 0.00000641, 0.00000259)

Ward, Greg. "Real Pixels," in Graphics Gems IV, edited by James Arvo, Academic Press, 1994

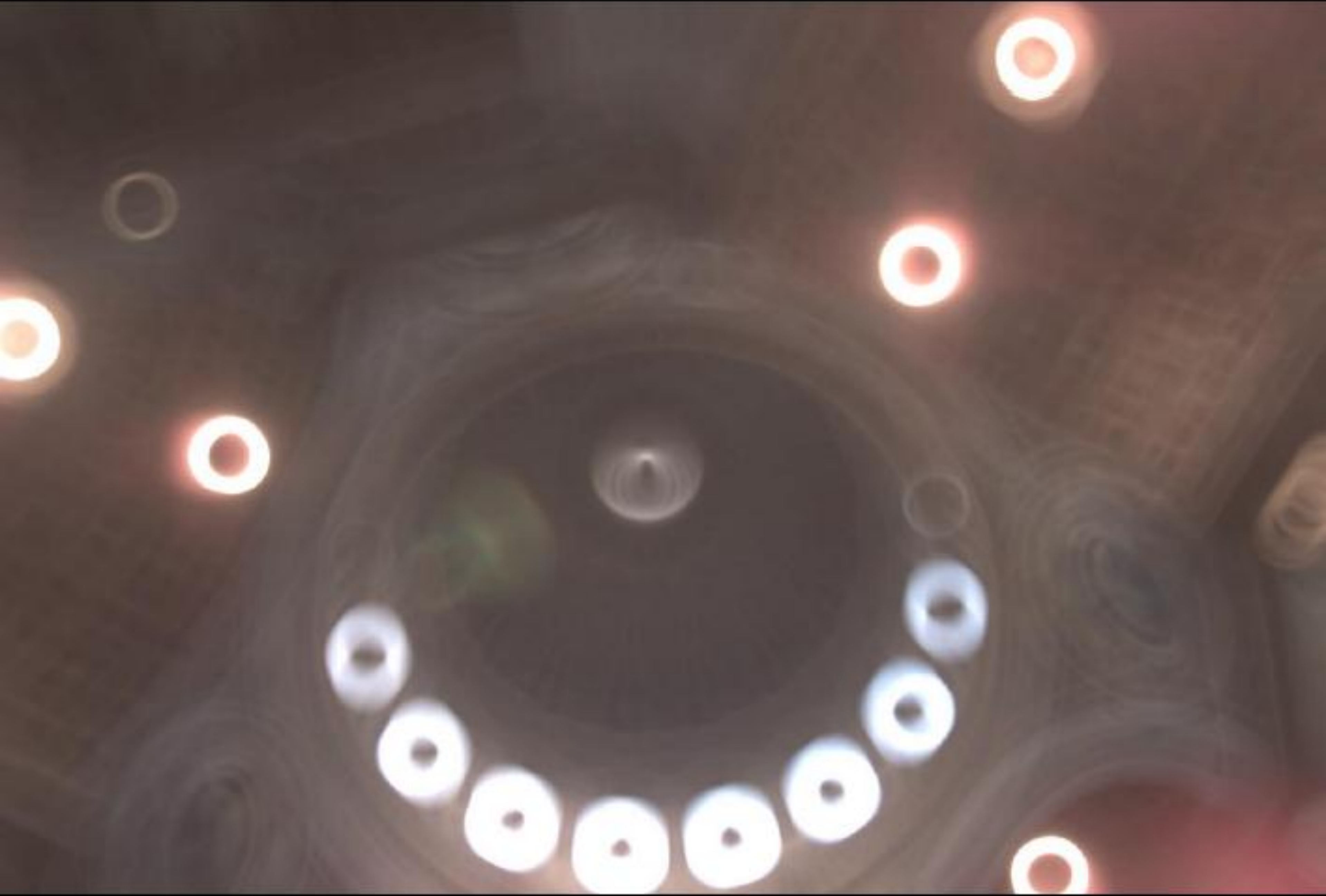
8-bit Images (TIF, BMP, TGA, JPG, etc.)

- 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.
- Amount of light = $(\text{pixel value})^{2.2}$

High-Dynamic Range Photography



300,000 : 1



[Greg Ward]

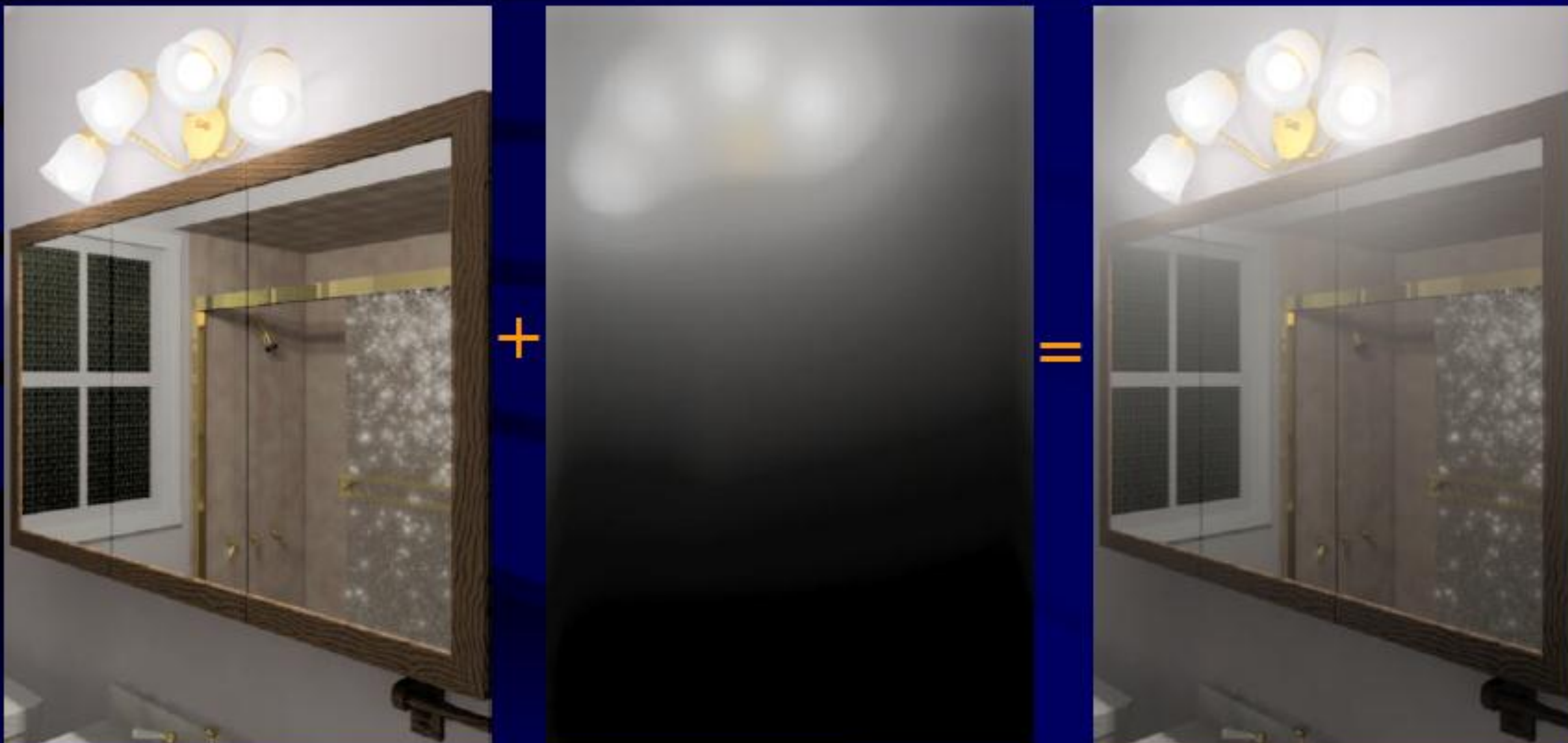
HDR Tone-mapping

Linear tone-mapping

Non-linear tone-mapping

[Greg Ward]

Veiling Glare Simulation



H D R S h o p

High Dynamic Range Image Processing and Manipulation

www.debevec.org/HDRShop

Introduction | Tutorials | Reference | Plugins | FAQ | Download/Licensing | WWW Links | Mailing List


Capturing Real-World
Illumination
SIGGRAPH

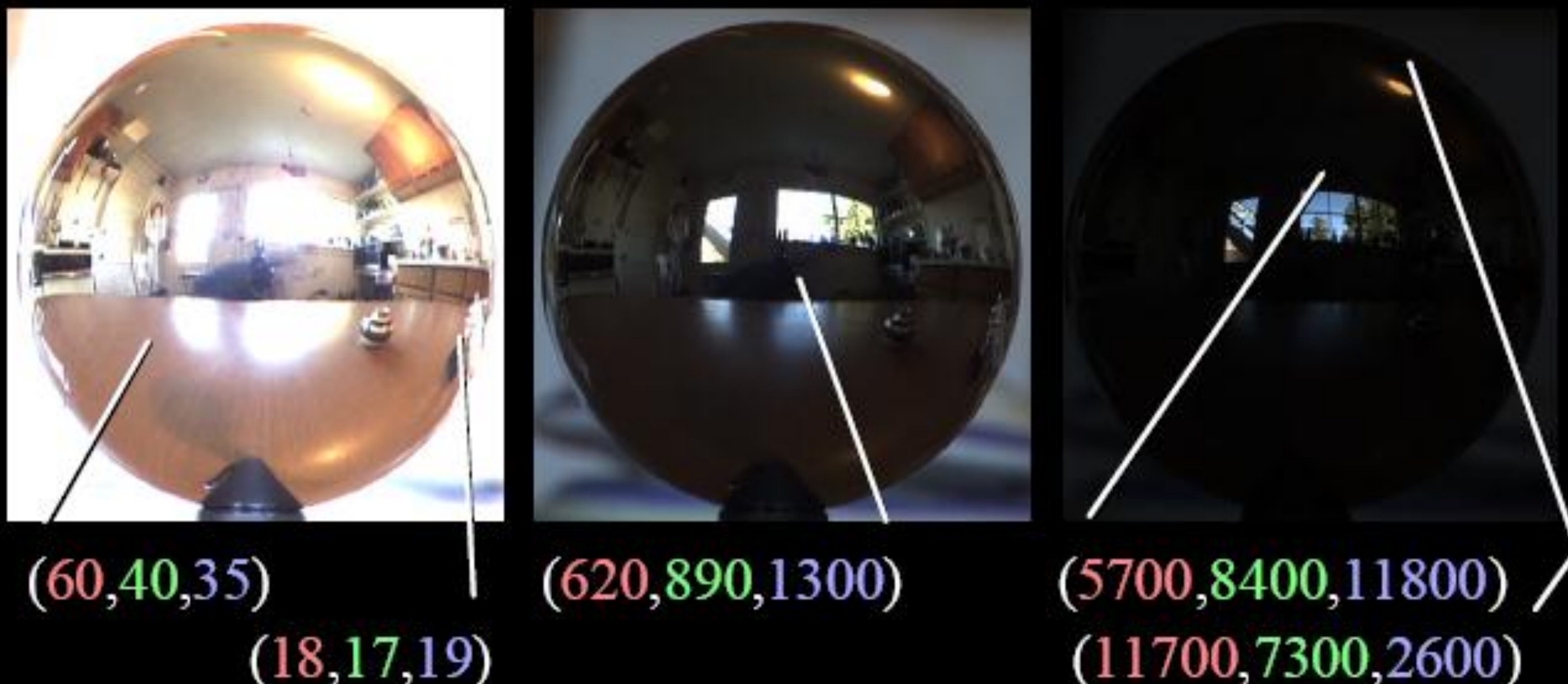
Mirrored Ball - Records light in all directions

Brightest regions are saturated

⬇

Intensity and color information lost

HDR Image of a Mirrored Ball



Assembled from ten digital images,

Δt = 1/4 to 1/10000 sec


Canon
Canon

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

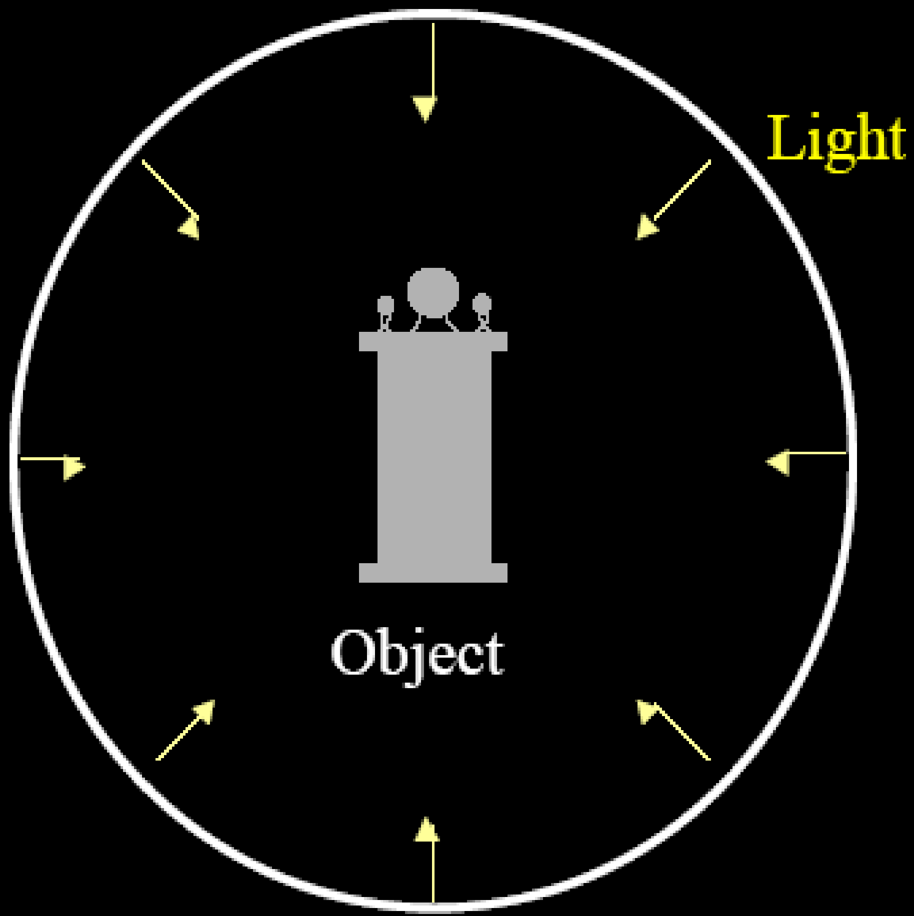
- Baker's Lawn Ornaments
  570 Berlin Plank Road
  Somerset, PA 15501-2413
  814-445-7028
- www.amazon.com - $8

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.

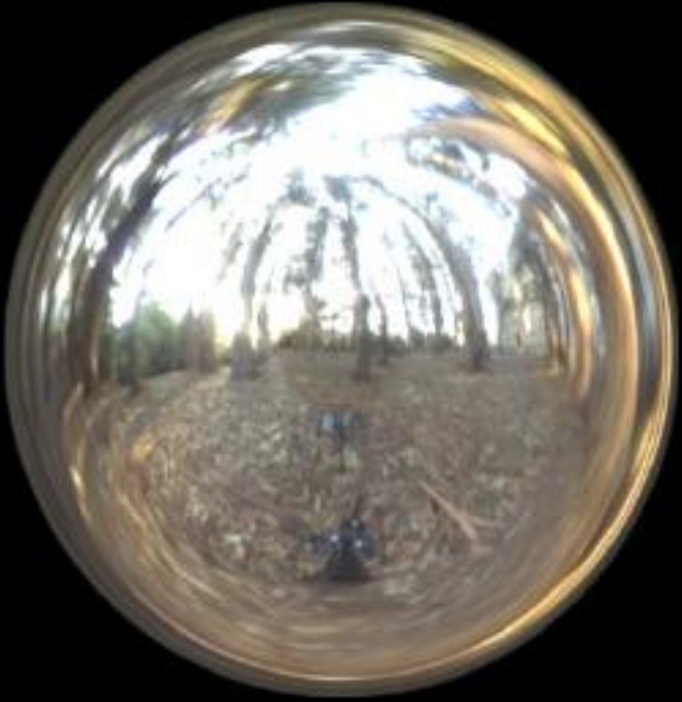
http://radsite.lbl.gov/radiance/

See also: Larson and Shakespeare, "Rendering with Radiance", 1998


5. Illuminating Synthetic
Objects with Real Light
SIGGRAPH

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