High Dynamic Range Imaging

COS 526, Fall 2012
With slides from Finkelstein, Debevec, Efros, Gunturk

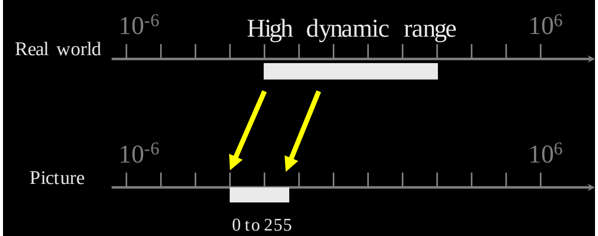
Dynamic Range

The real world is high dynamic range.

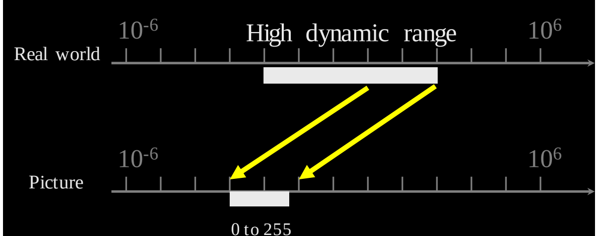
Problem

- Cameras cannot capture the full dynamic range of the world

Long Exposure

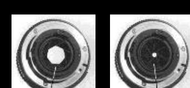


Short Exposure



Ways to Vary Exposure

- Shutter Speed (*)
- F/stop (aperture, iris)



- Neutral Density (ND) Filters

Varying Shutter Speed

Ranges: Canon D30: 30 to 1/4,000 sec.
Sony VX2000: ¼ to 1/10,000 sec.

Pros:

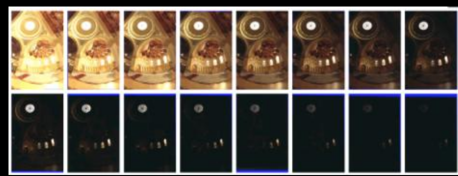
- Directly varies the exposure
- Usually accurate and repeatable

Issues:

- Noise in long exposures

Varying Shutter Speed

- Note: shutter times usually obey a power series
  - ¼, 1/8, 1/15, 1/30, 1/60, 1/125, 1/250, 1/500, 1/1000 sec
- Actually, each "stop" is usually a factor of 2:
  - ¼, 1/8, 1/16, 1/32, 1/64, 1/128, 1/256, 1/512, 1/1024 sec



Varying Shutter Speed

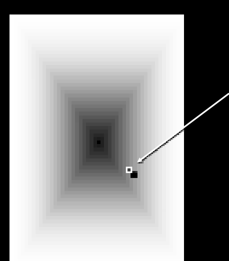
High Dynamic Range Imagin

- Infer radiance of scene from multiple images with varying exposure (photometric calibration)

General Approach

- Build model of imaging system
  (radiance → pixel values)
- Invert model
  (pixel values → radiance)

Imaging System?

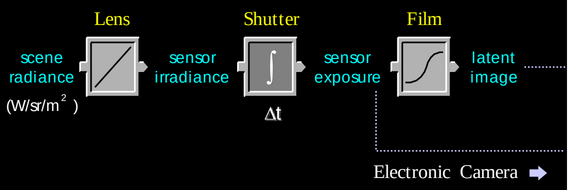


Image

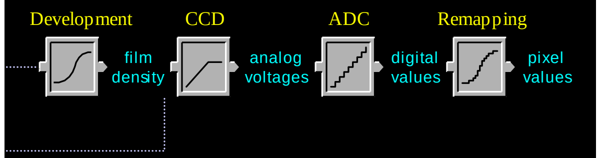
pixel (312, 284) = 42

What does 42 mean?

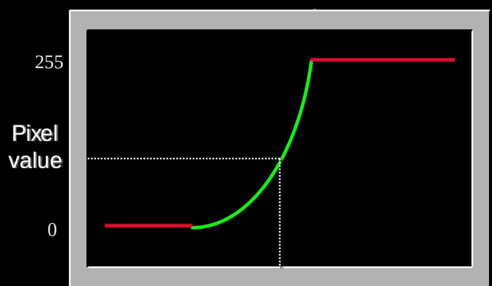
The Image Acquisition Pipeline



Recovering High Dynamic Range Radiance Maps from Photographs [Debevec97]



Imaging System Response Function

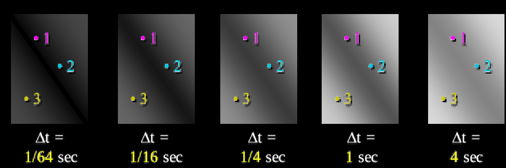


log Exposure = log (Radiance * Δt)

(CCD photon count)

Recovering the Response Curve

Image series

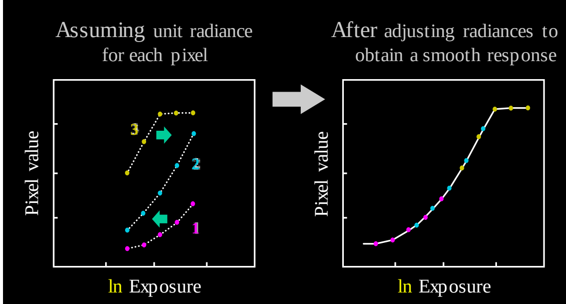


Pixel Value Z = f(Exposure)

Exposure = Radiance ´ Δt

log Exposure = log Radiance + log Δt

Recovering the Response Curve



Recovering the Response Curve

- Let $g(z)$ be the *discrete* inverse response function
- For each pixel site i in each image j, want:

$$\ln Radiance_i + \ln \Delta t_j = g(Z_{ij})$$

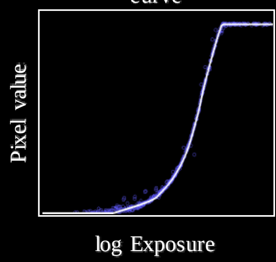
- Solve the overdetermined linear system:

$$\underbrace{\sum_{i=1}^{N}\sum_{j=1}^{P}\left[\ln Radiance_i + \ln \Delta t_j - g(Z_{ij})\right]^2}_{\text{fitting term}} + \underbrace{\lambda \sum_{z=Z_{min}}^{Z_{max}} g''(z)^2}_{\text{smoothness term}}$$

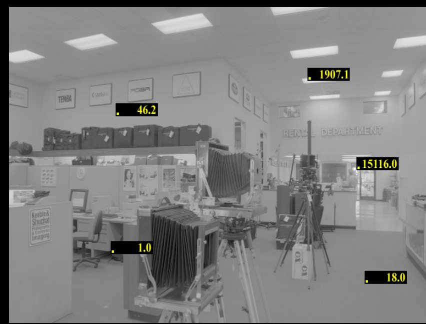
Results: Digital Camera

Kodak DCS460
1/30 to 30 sec

Recovered response curve

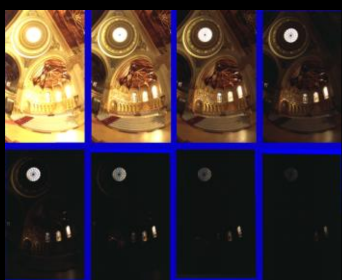


Reconstructed radiance map

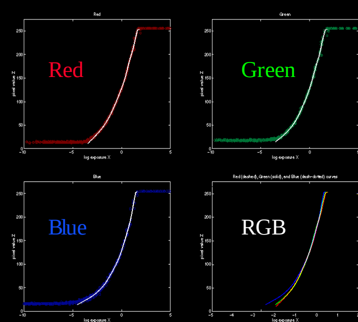


Results: Color Film

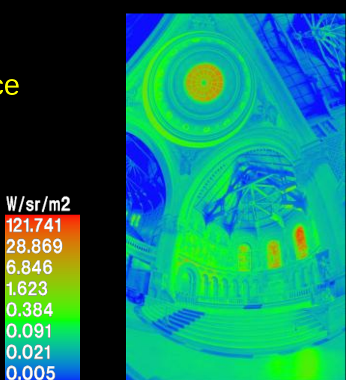
- Kodak Gold ASA 100, PhotoCD



Recovered Response Curves



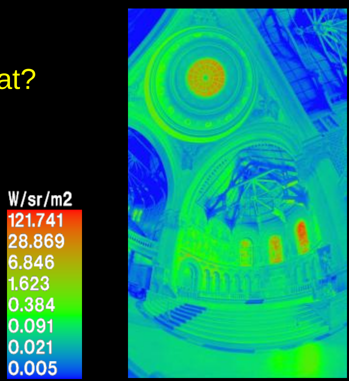
The Radiance Map



The Radiance Map

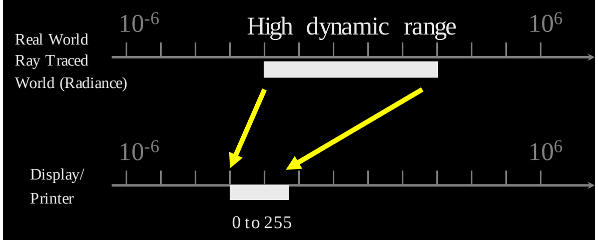
Linearly scaled to display device

Now What?



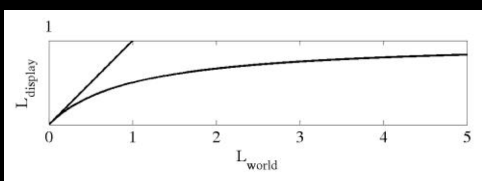
Tone Mapping

For displaying HDR images:

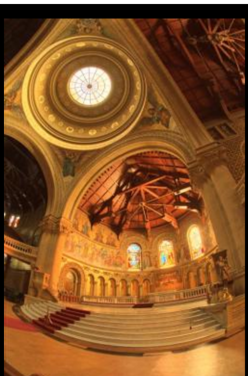


Reinhart et al

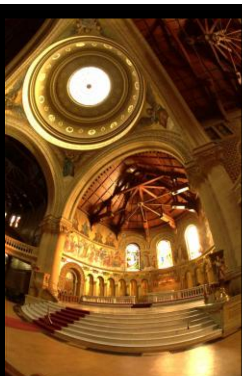
$$L_{display} = \frac{L_{world}}{1 + L_{world}}$$



Reinhart et al Results

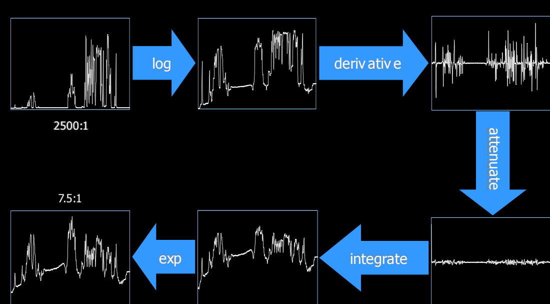


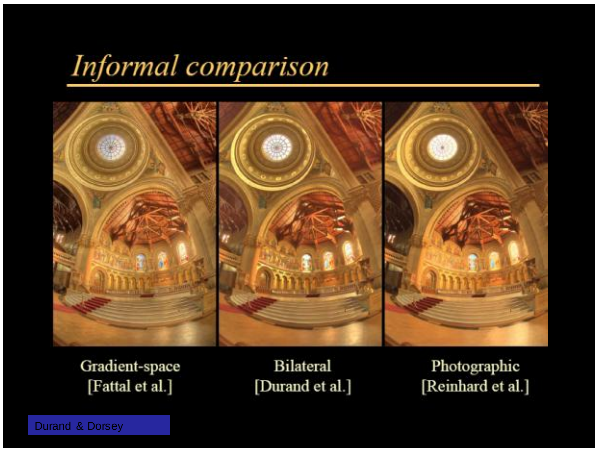
Reinhart Operator

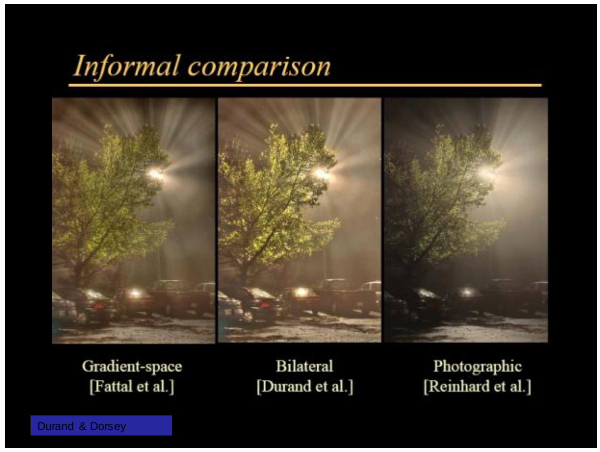


Darkest 0.1% scaled to display device

Fattal et al (in 1D)




Informal comparison
Gradient-space
[Fattal et al.]
Bilateral
[Durand et al.]
Photographic
[Reinhard et al.]
Durand & Dorsey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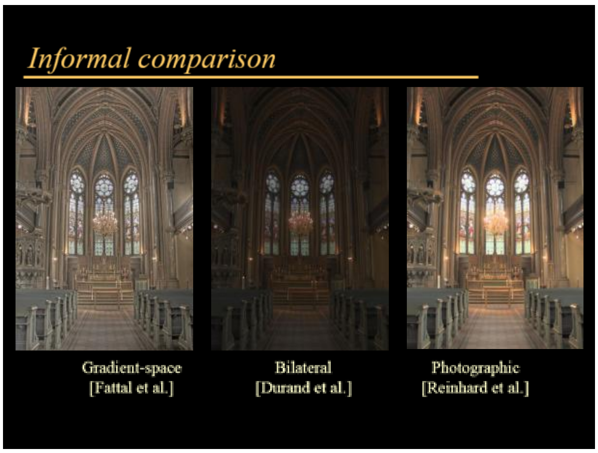
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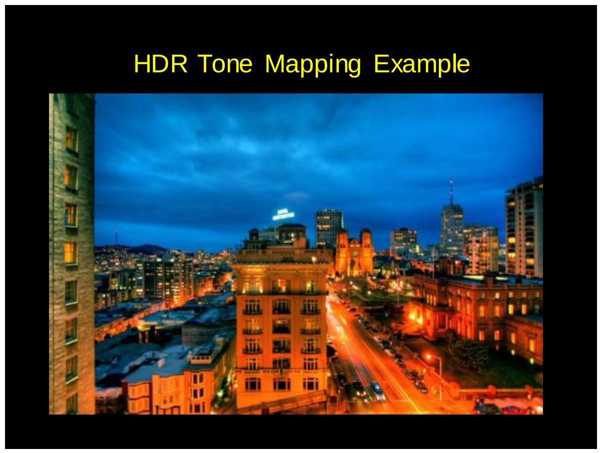
HDR Tone Mapping Example