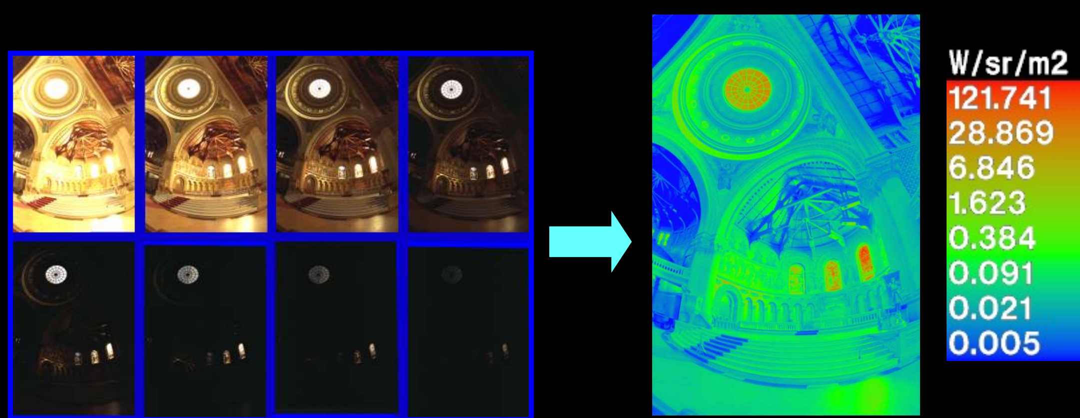
High Dynamic Range Imaging

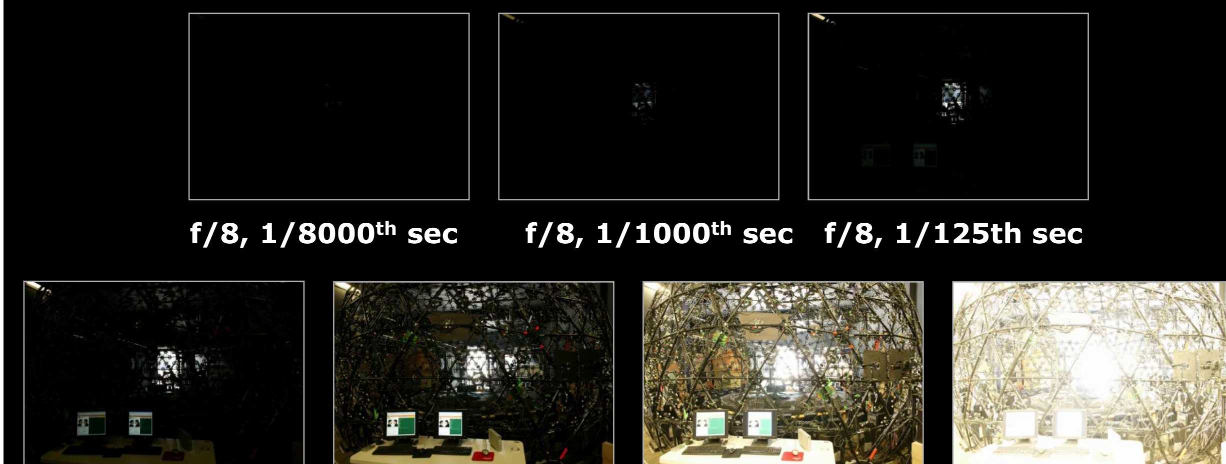


C0417 – Advanced Computer Graphics: Photographic Image Synthesis

Abhijeet Ghosh

Lecture 03, Jan. 18th 2019

High Dynamic Range Imaging



f/8, 1/8000th sec

f/8, 1/1000th sec

f/8, 1/125th sec

f/8, 1/15th sec

f/8, 1/2 sec

f/8, 4 sec

f/8, 30 sec

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HDR Imaging

- Exposure bracketing
  - 1 stop = 2X, 2 stops = 4X, 3 stops = 8X.
- Aperture settings
  - f/2.8, f/4, f/5.6, f/8, f/ 11, f/16, f/22

- ISO Gain
  - ISO 100 = 1X, 200 = 2X, 400 = 4X.
- Neutral Density Filter
  - 0.3 to 4.0 (log base 10 scale)

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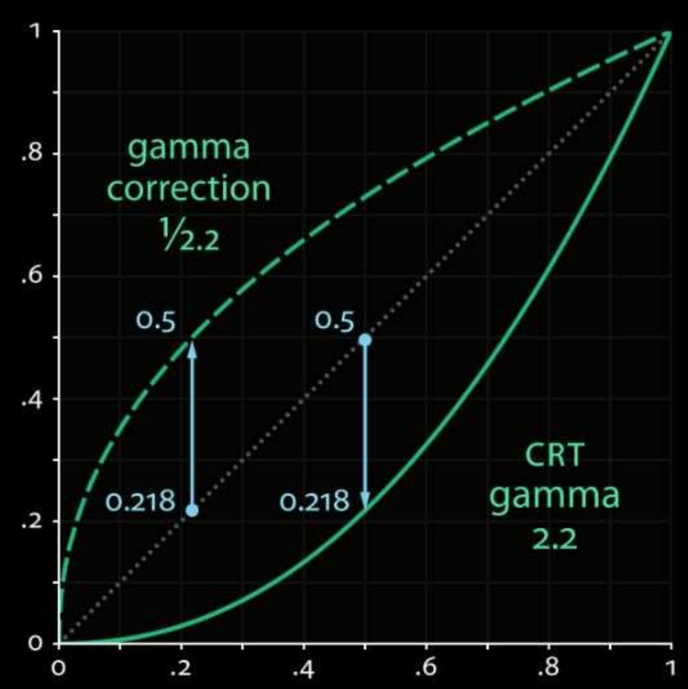
Gamma correction



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Gamma HDRshop demo

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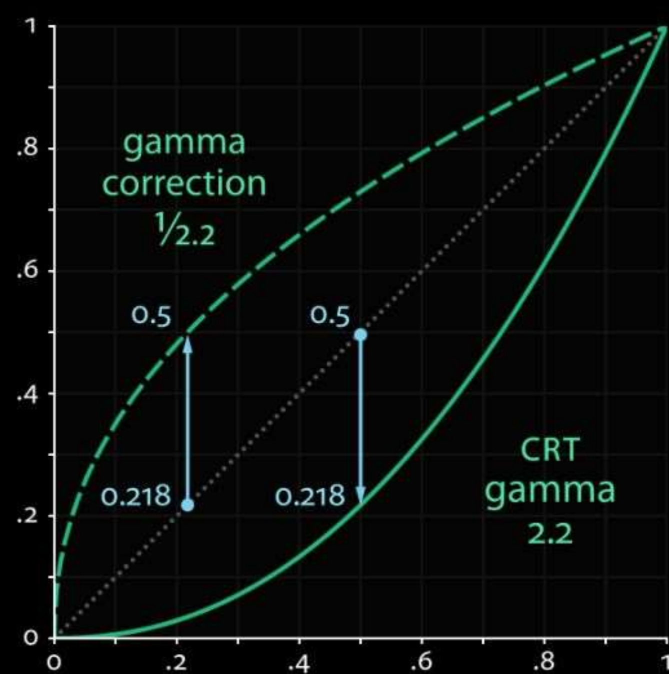
Gamma correction



Exponential and sigmoid curves also possible!

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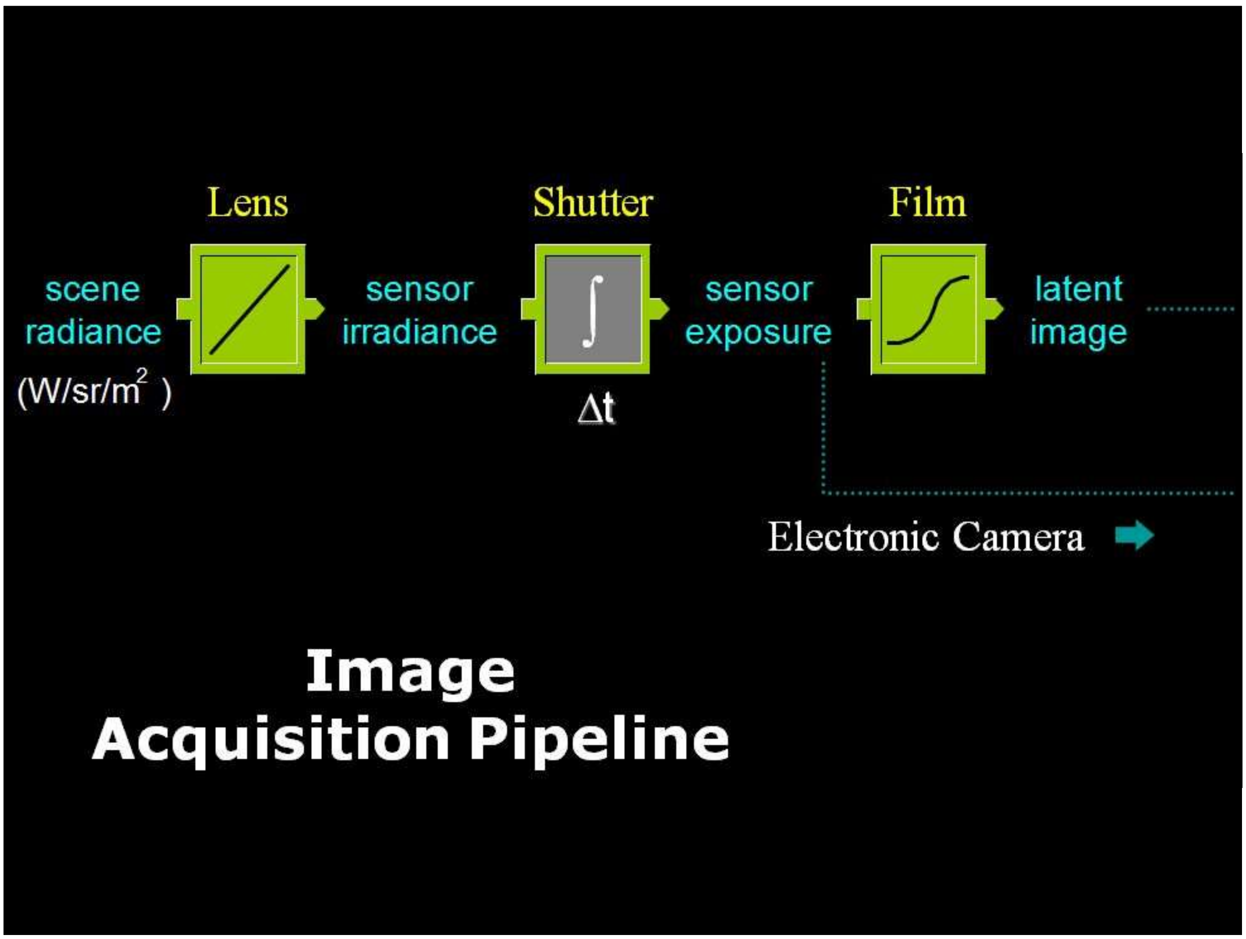
Lens
Shutter
Film
scene radiance
(W/sr/m2)
sensor irradiance
sensor exposure
latent image
Δt
Electronic Camera
Image
Acquisition Pipeline

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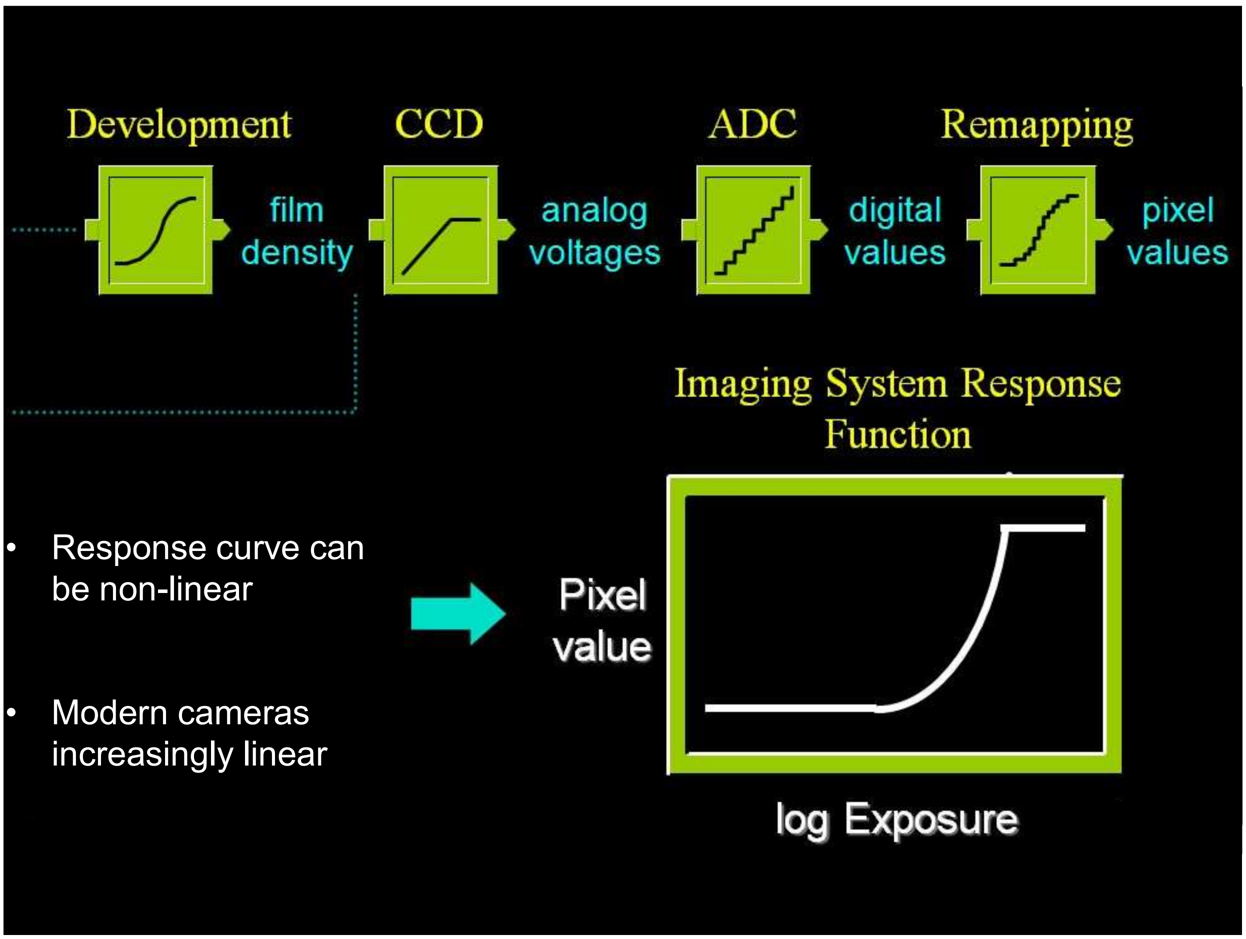

Development
CCD
ADC
Remapping
film density
analog voltages
digital values
pixel values
Imaging System Response Function
• Response curve can be non-linear
• Modern cameras increasingly linear
Pixel value
log Exposure

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Response Curve Recovery

Mann and Picard SPIE 95:

Track one pixel value across series and fit a gamma-like curve

Debevec and Malik SIGGRAPH 97:

Derive detailed curve from many pixels

$\Delta t =$	$\Delta t =$	$\Delta t =$	$\Delta t =$	$\Delta t =$
1/64 sec	1/16 sec	1/4 sec	1 sec	4 sec

$$\text{Exposure} = \text{Radiance} \times \Delta t$$

$$\log \text{Exposure} = \log \text{Radiance} + \log \Delta t$$

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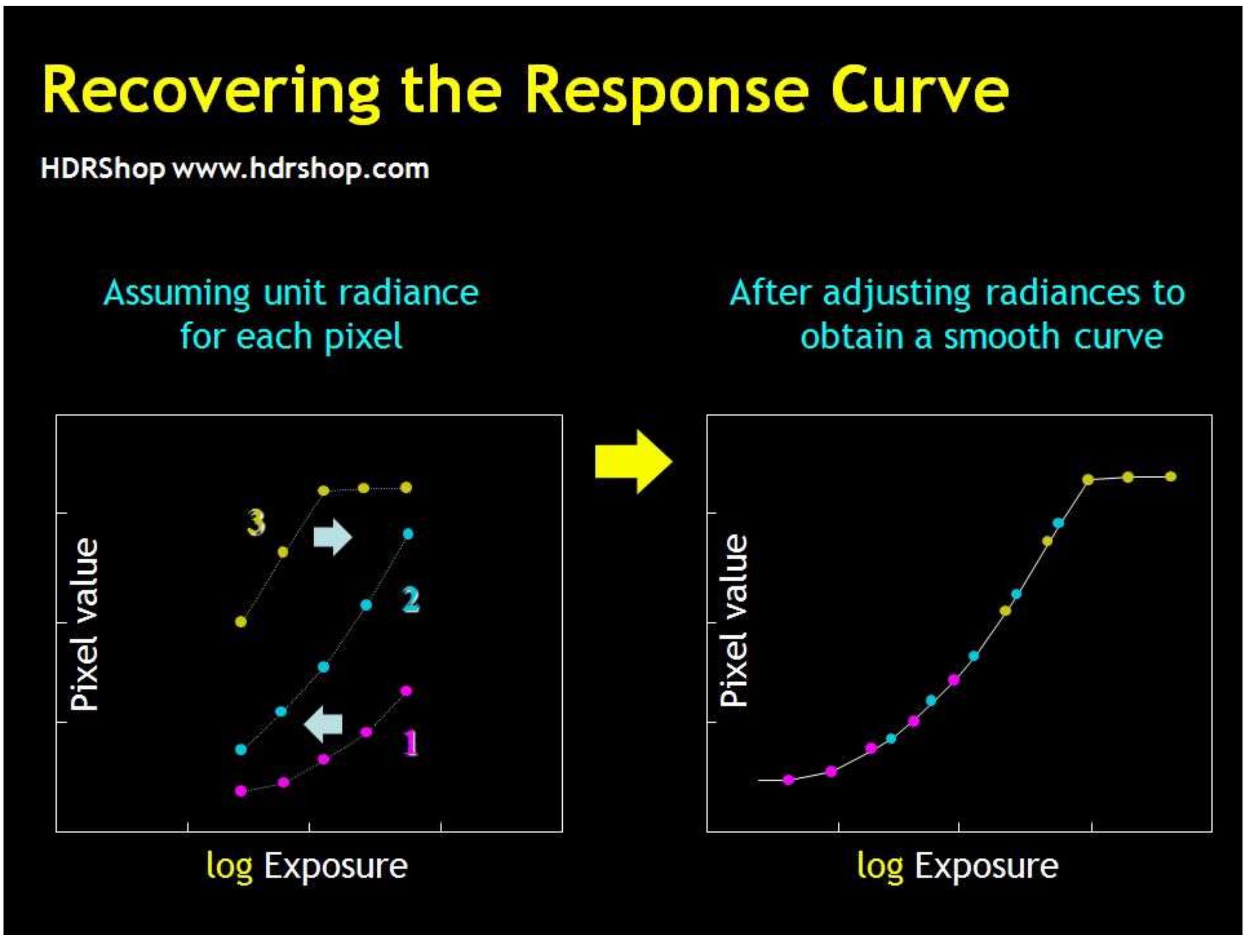
Recovering the Response Curve
HDRShop www.hdrshop.com
Assuming unit radiance for each pixel
After adjusting radiances to obtain a smooth curve
3
2
1
Pixel value
log Exposure
Pixel value
log Exposure

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Image formation model

$$\boxed{Z_{ij}} = \boxed{f}(\boxed{E_i \Delta t_j})$$

Camera pixels

Camera
response
(possibly nonlinear)

Irradiance × exposure

$$f^{-1}(Z_{ij}) = \boxed{E_i} \Delta t_j$$

Unknown

$$\ln f^{-1}(Z_{ij}) = \ln E_i + \ln \Delta t_j$$

[Debevec & Malik 97]

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Image formation model

$$\boxed{Z_{ij}} = \boxed{f}(\boxed{E_i \Delta t_j})$$

Camera pixels

Camera response (possibly nonlinear)

Irradiance × exposure

More details:

http://www.pauldebevec.com/Research/HDR/debevec-siggraph97.pdf

[Debevec & Malik 97]

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Linear response simplification

$$\boxed{Z_{ij}} = f(\boxed{E_i \Delta t_j})$$

Camera pixels

Irradiance × exposure

$$Z_{ij} = \boxed{E_i} \Delta t_j$$

Unknown

$$E_i = Z_{ij} / \Delta t_j$$

Note that each exposure provides *j = 1* to *N* different estimates of E_i.

Final step is to merge the multiple E_i estimates into one HDR value using weighted averaging.

Typically higher weights for values in the middle of [0 - 1] range than values at the ends of the range, i.e, hat function or a curve.

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HDR Imaging application – motion blur

Scene LDR simulation HDR simulation Real photograph

[Debevec & Malik 97]

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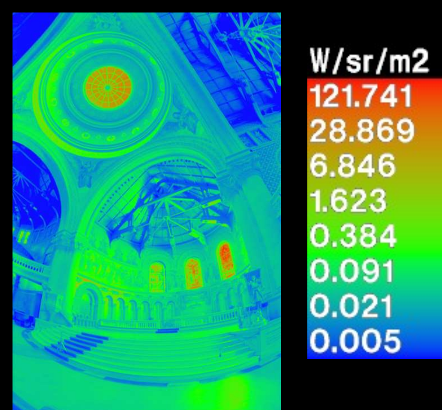
High-Dynamic Range Photography



300,000 : 1

Can assemble HDR images in:

Photoshop CS2
HDR Shop
Photosphere

PFSTools
...

Can save HDR images as:

OpenEXR (ILM) .exr
Radiance .hdr
LogLuv TIFF
Portable FloatMap .pfm

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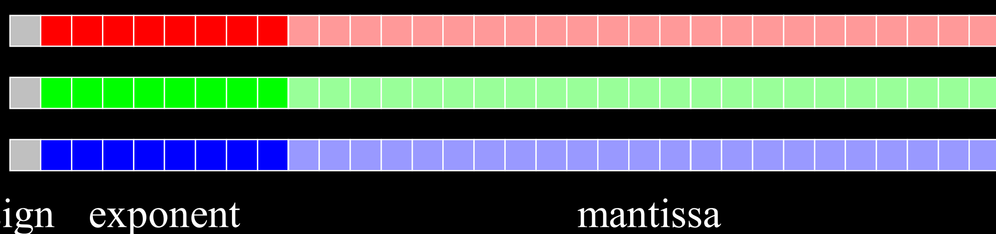
High Dynamic Range Image Formats

- **Portable FloatMap (.pfm)**
- **Greg Ward's RADIANCE format (.pic, .hdr)**
- **ILM's OpenEXR (.exr)**

Portable FloatMap

- 12 bytes per pixel, 4 for each channel



Text header similar to Jeff Poskanzer’s .ppm image format:

```
PF
768 512
1
<binary image data>
```

Floating Point TIFF similar

RADIANCE Format – Greg Ward

(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

ILM OpenEXR Format

- **Purpose:** HDR lighting and compositing
- 16-bit/primary floating point (sign-e5-m10)
- 9.6 orders of magnitude in 0.1% steps
- Wavelet compression of about 40%
- Negative colors and full gamut RGB
- Open Source I/O library released Fall 2002

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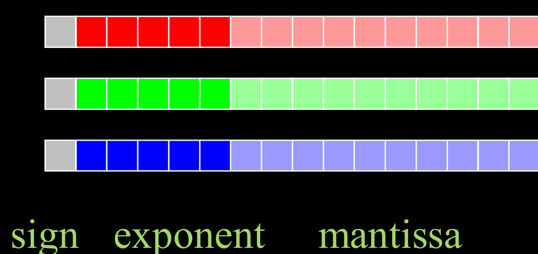
ILM's OpenEXR (.exr)

- 6 bytes per pixel, 2 for each channel, compressed



- Several lossless compression options, 2:1 typical
- Compatible with the “half” datatype in NVidia's Cg
- Supported natively on GeForce FX and Quadro FX
- Available at http://www.openexr.net/

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Tone mapping – automatic remapping

HDR radiance map

(floats)

LDR image

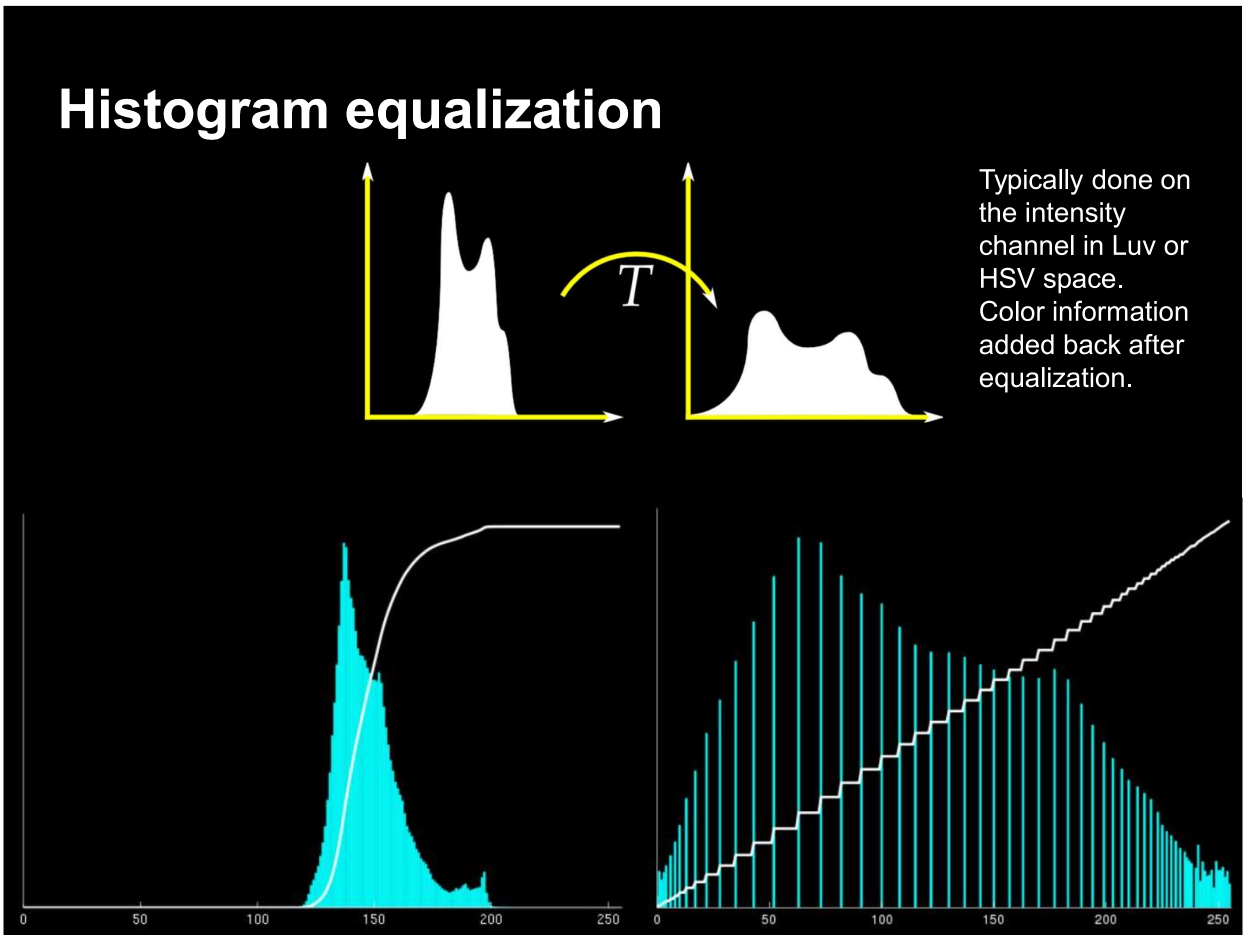
(8-bit,0-255)

entire range linearly compressed

LDR image

(8-bit,0-255)

with histogram equalization


Histogram equalization
T
Typically done on the intensity channel in Luv or HSV space. Color information added back after equalization.
0
50
100
150
200
250
0
50
100
150
200
250

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Global tone mapping – user driven

HDR radiance map

(floats)

LDR image

(8-bit,0-255)

Exposure bracketing

LDR image

(8-bit,0-255)

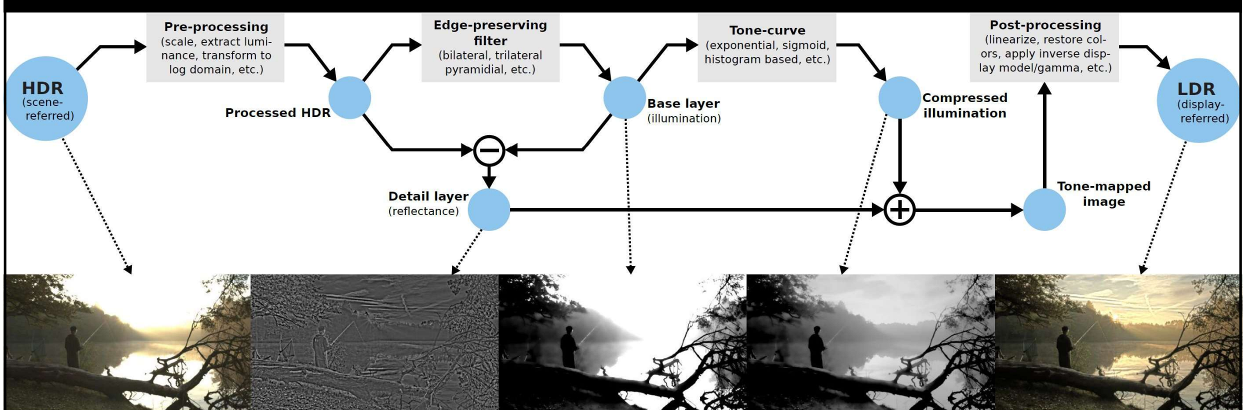
Exposure bracketing + gamma control

Global vs local tone mapping

- Global mapping – compress global dynamic range (scaling, gamma, sigmoid, histogram equilization, etc.)
  - Reduced local contrast, bad for Human visual perception ☹

- Local mapping – Edge or detail (local contrast) preservation
  - Mimic human visual system's perception
  - Secondary step along with some global mapping

Local tone mapping pipeline



[Eilertsen et al. 2017]

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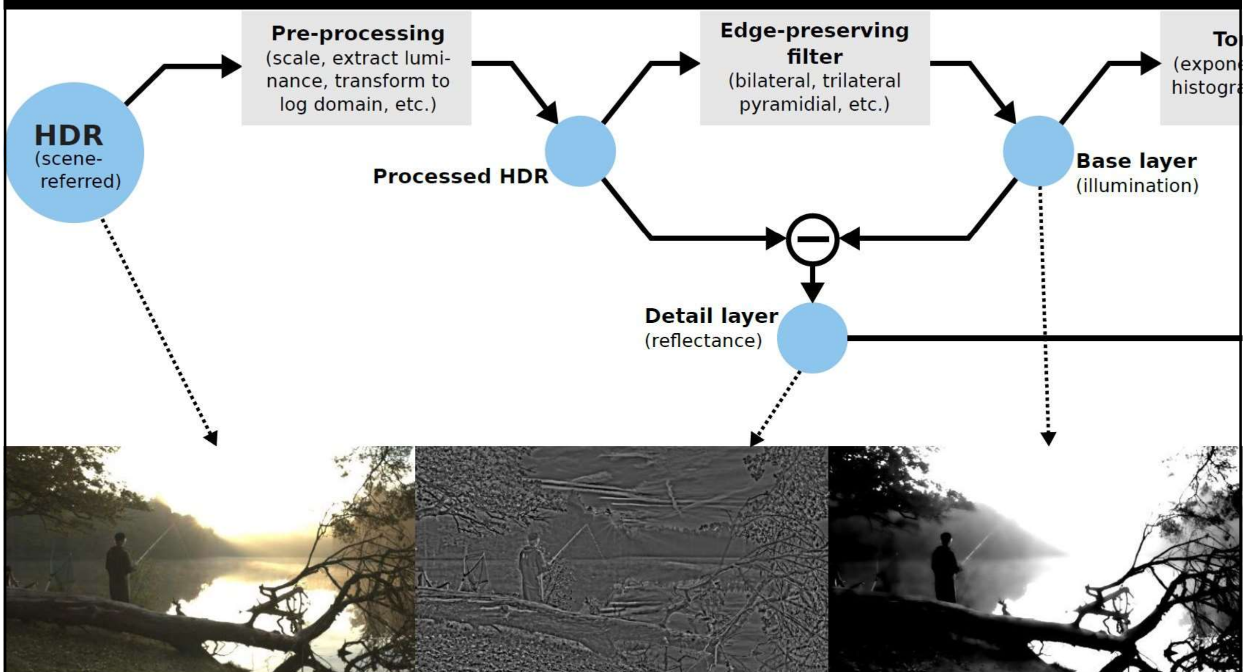
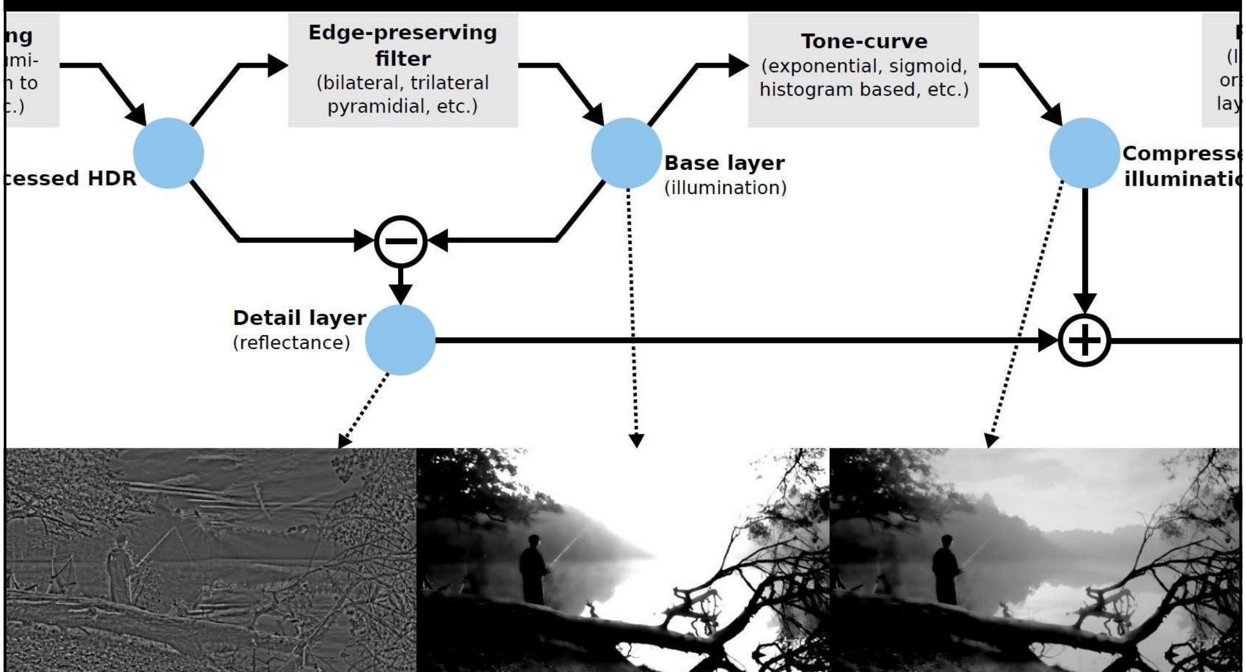
Local tone mapping pipeline



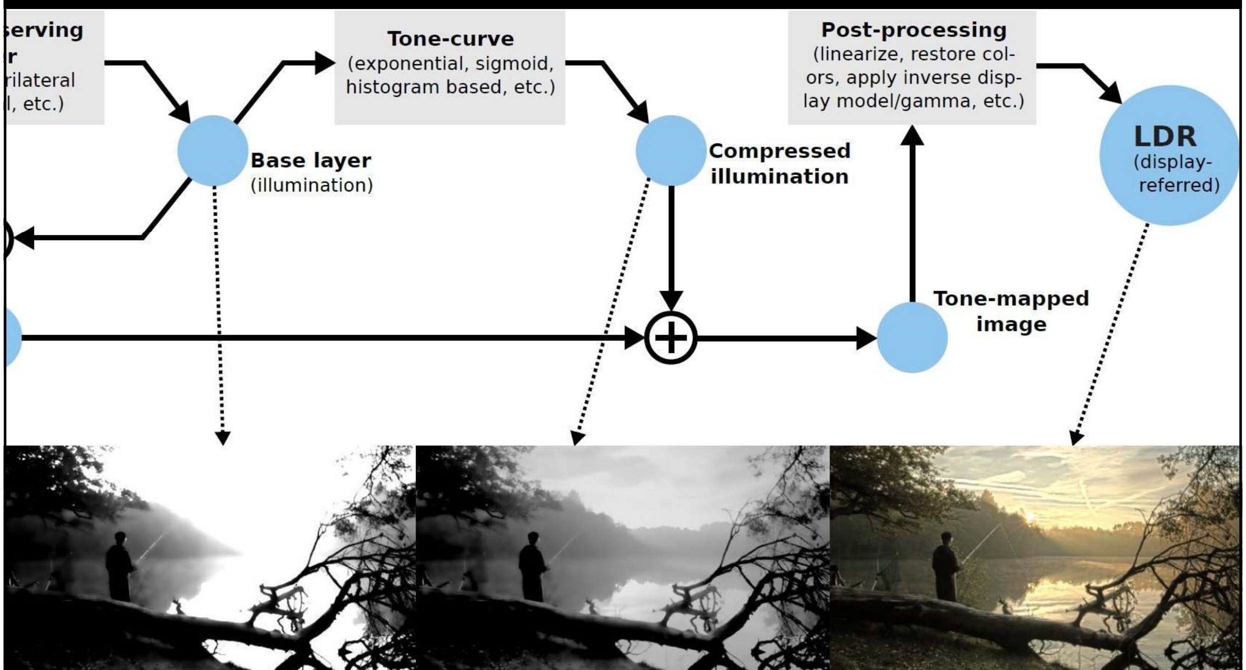
- Color is first removed, and then a base (luminance) layer is separated from the detail (reflectance) layer using an edge preserving filter.

Local tone mapping pipeline



- The dynamic range of base layer in compressed using a (global) curve.

Local tone mapping pipeline



- Compressed base layer is combined with detail layer and color to obtain the final tone mapped LDR!

Local tone mapping

- Tricky to get the local contrast preservation step correct
  - Halos and other artifacts such as image noise can arise if not done right!

- Various edge preserving filters considered
  - Bilateral
  - Filtering in the image gradient domain instead of image intensity