Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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High Dynamic Range Photography

* Importance and Characteristics of High Dynamic Range Images
* Merging Images to Create a High Dynamic Range Photograph

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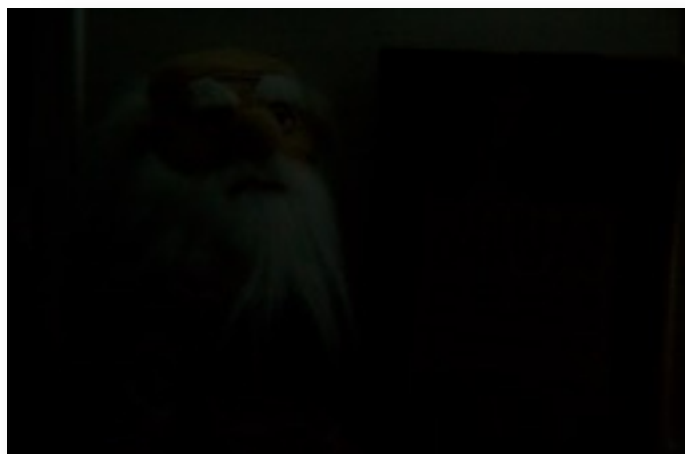
1. Dynamic Range
2. Digital cameras do not encode Dynamic Range very well
3. Image Acquisition Pipeline for Capturing Scene Radiance to Pixel Values
4. Linear and non-linear aspects inherent in the Image Acquisition Pipeline

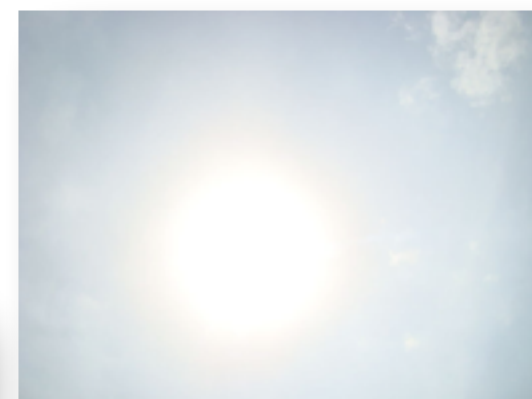
5. Camera Calibration
6. Pixel Values from different Exposure Images are used to render a Radiance Map of Scene
7. Tone Mapping

Dynamic Range in Real World

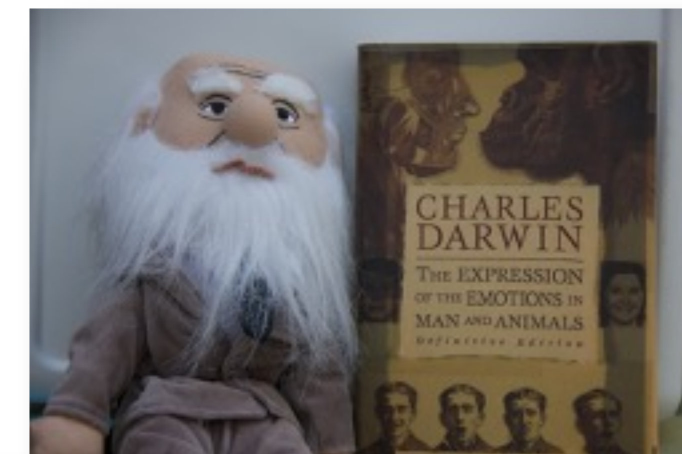
Inside, No Lights
Long Exposure

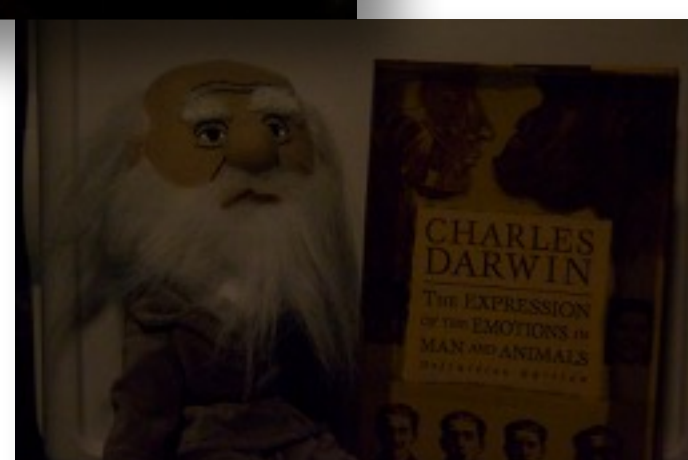


Into the Sun



Outside,
in the Sun





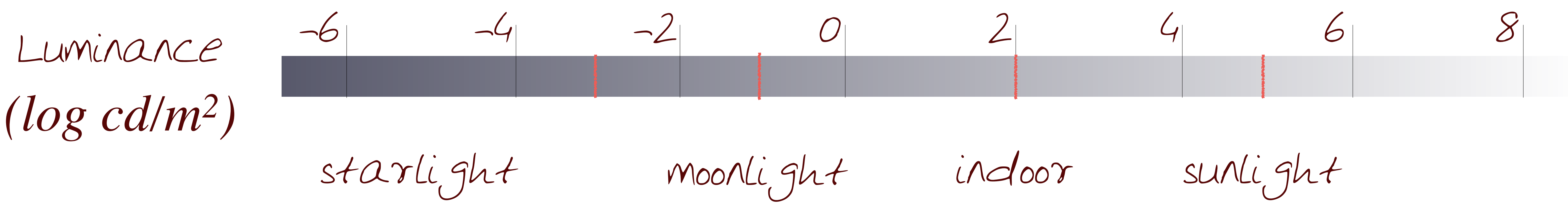
Inside,
Incandescent Light

Inside, Near Window
(Natural Light)

Outside,
Under Shade

Dynamic Range

Luminance: A photometric measure of the luminous intensity per unit area of light traveling in a given direction. Measured in candela per square meter (cd/m^2).



- Human Static Contrast Ratio: 100:1 (10^2:1) ➔ about 6.5 f-stops
- Human Dynamic Contrast Ratio: 1,000,000:1 (10^6:1) ➔ about 20 f-stops

Limited Dynamic Range of Current Cameras

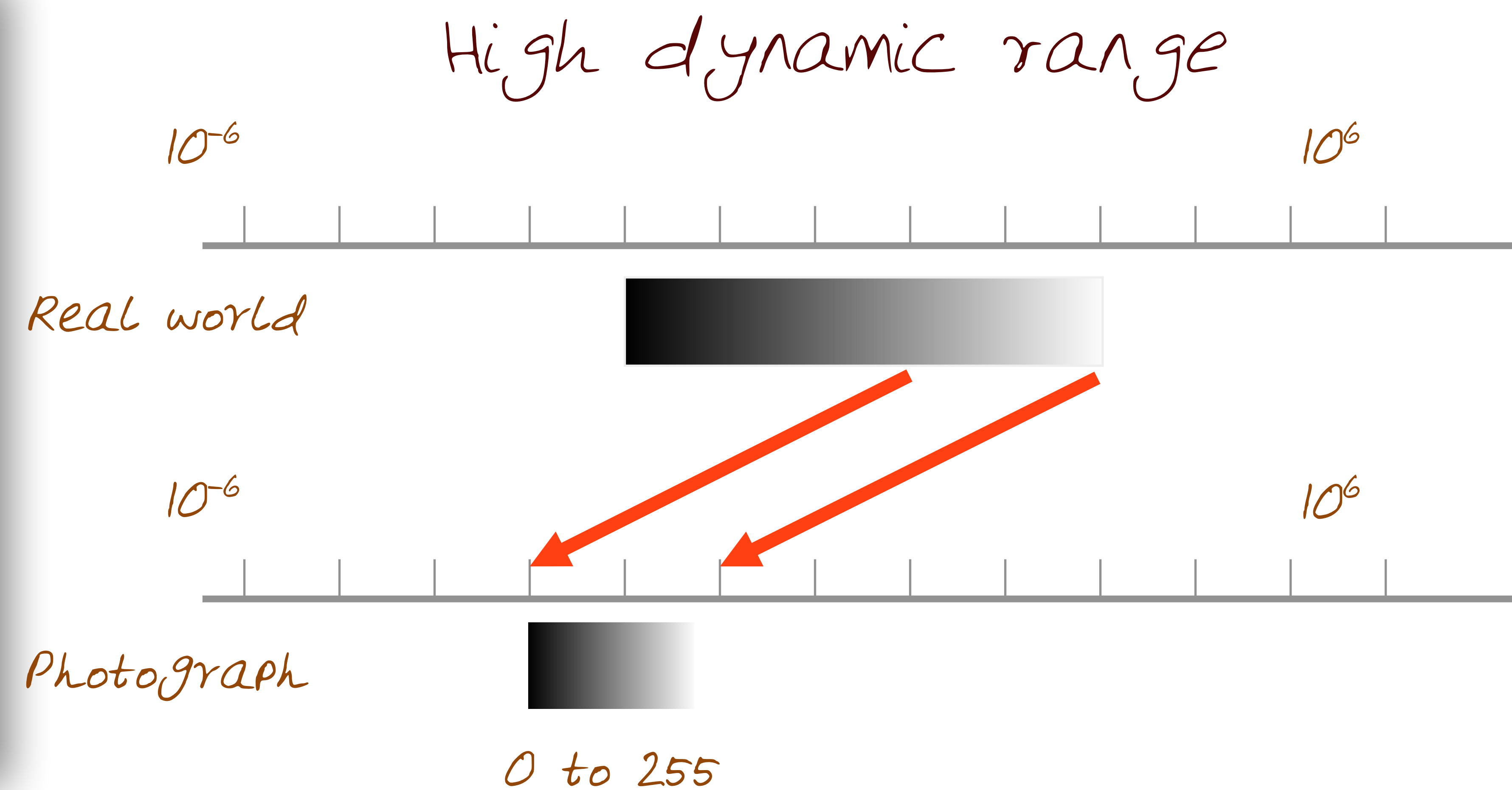
Short Exposure: Snow and Outside Visible

Long Exposure: Inside Visible

* Need about 5-10 million values to store all brightnesses around us
* 8-bit images provide only 256 values!!

Limited Dynamic Range of Current Cameras

Short Exposure: Snow and Outside Visible



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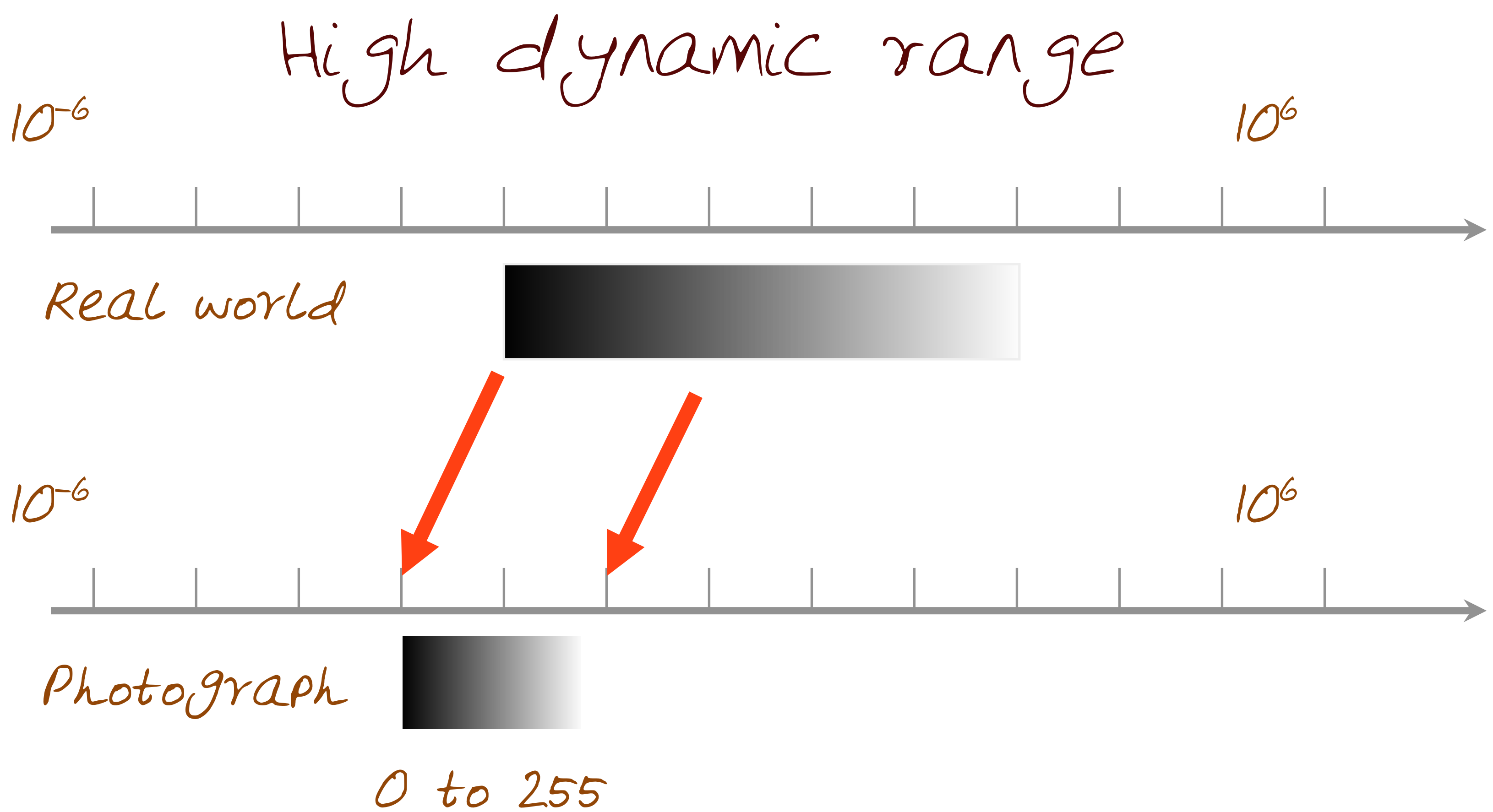
Limited Dynamic Range of Current Cameras



Long Exposure: Inside Visible

* Need about 5-10 million values to store all brightnesses around us.
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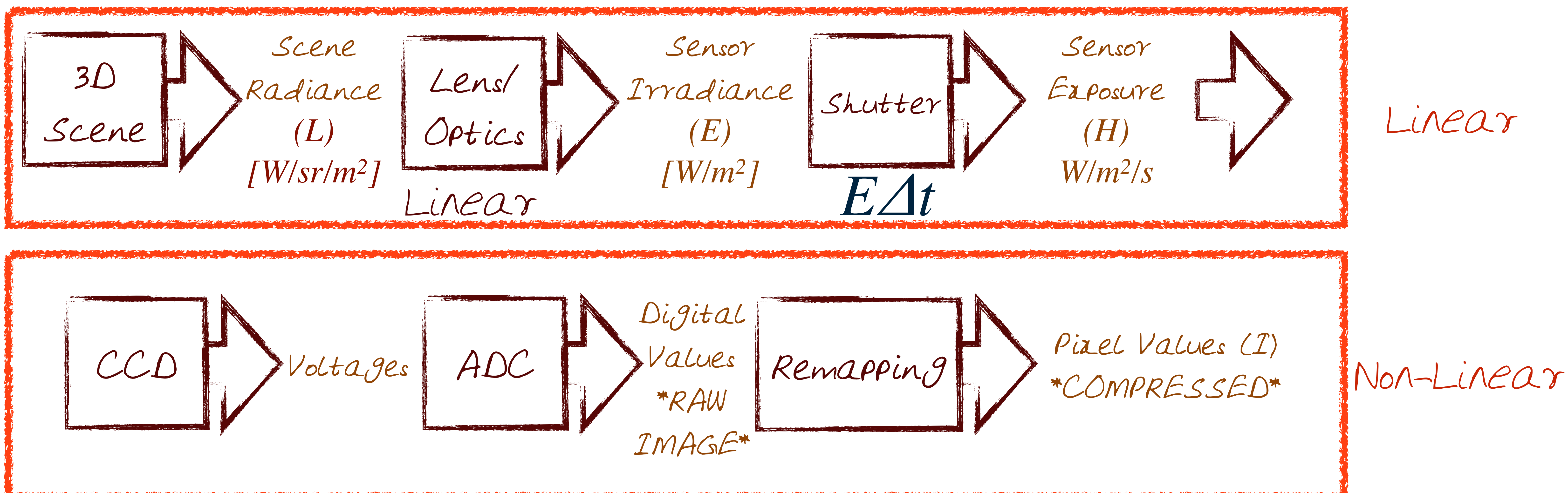
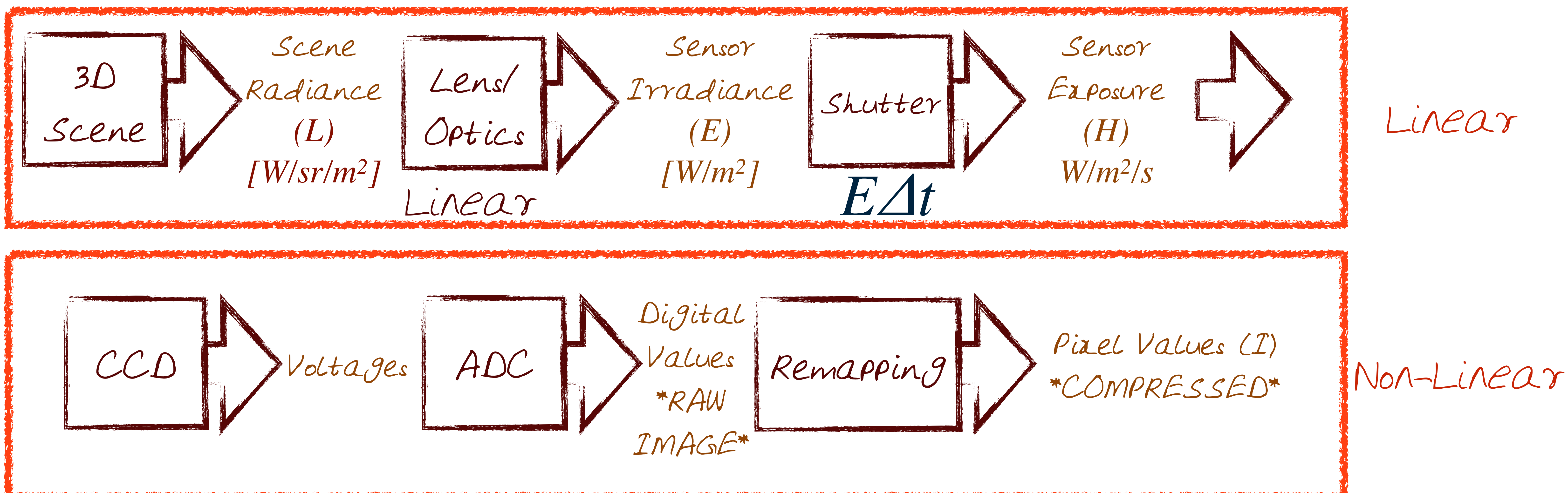
Relationship Between Image and Scene Brightness

The Image Acquisition Pipeline

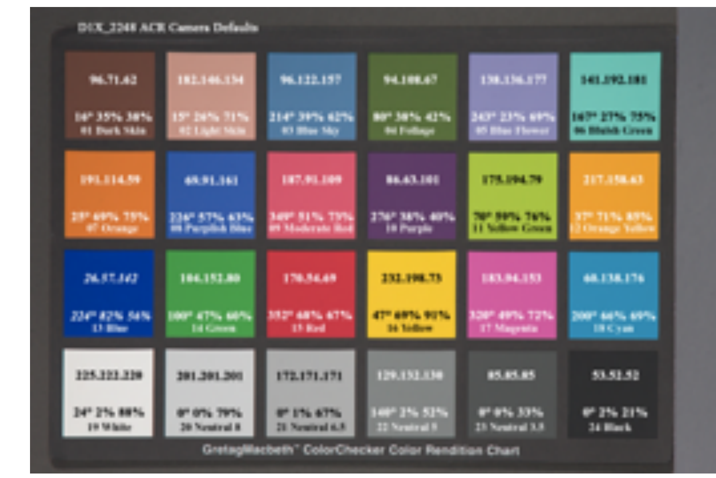


Relationship Between Image and Scene Brightness

$$g: L \rightarrow E \rightarrow H \rightarrow I \quad \Longleftrightarrow \quad g^{-1}: I \rightarrow E \rightarrow H \rightarrow L$$

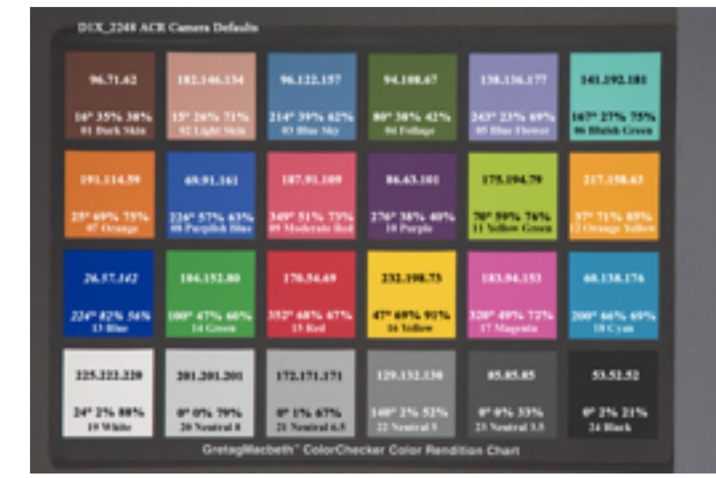


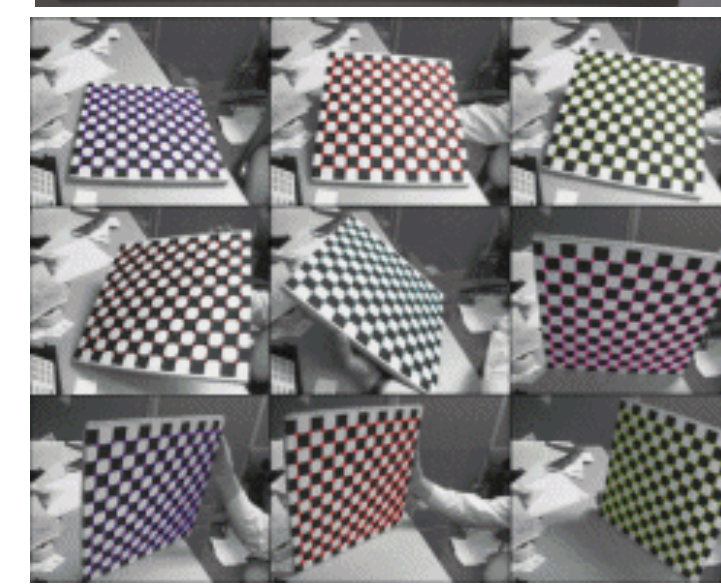
Camera Calibration

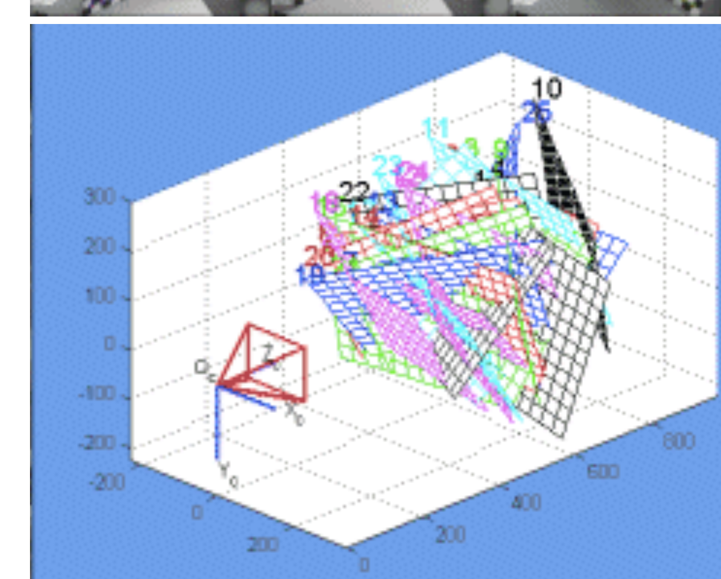


- Geometric
  - How pixel coordinates relate to directions in the world
- Radiometric / Photometric
  - How pixel values relate to radiance amounts in the world

Camera Calibration







- Geometric
  - How pixel coordinates relate to directions in ~~the world~~ other images
- Radiometric / Photometric
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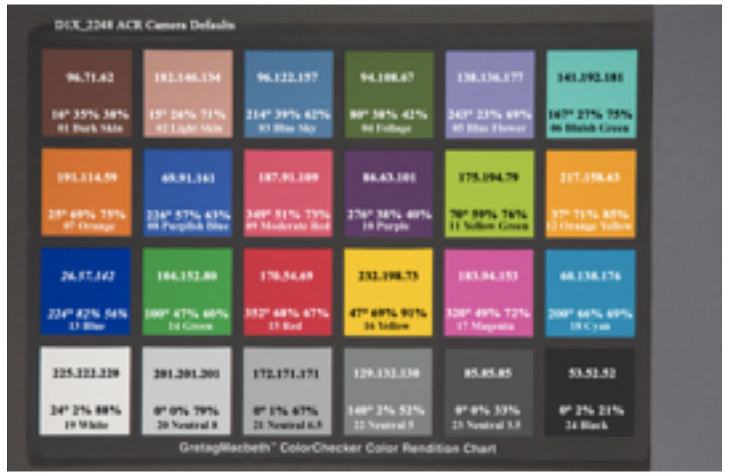
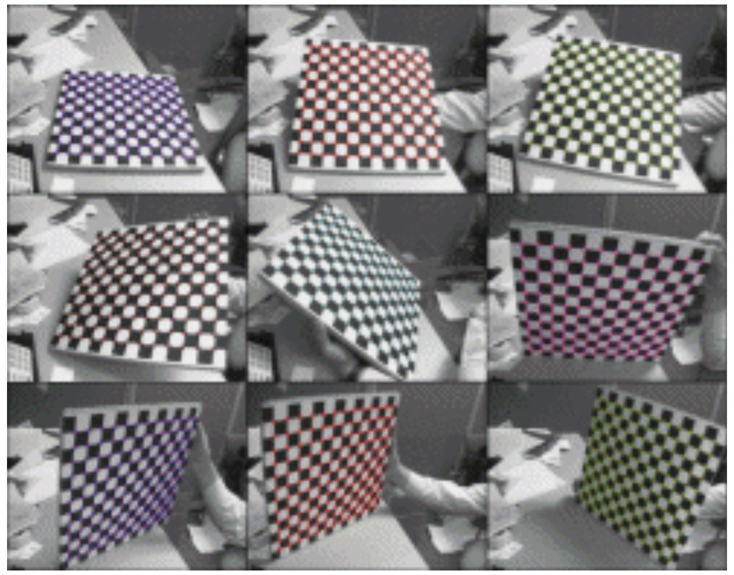
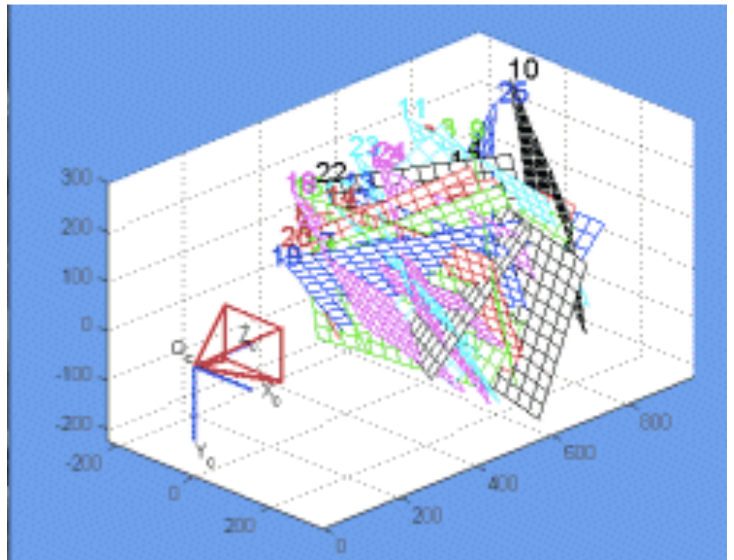
Camera Calibration



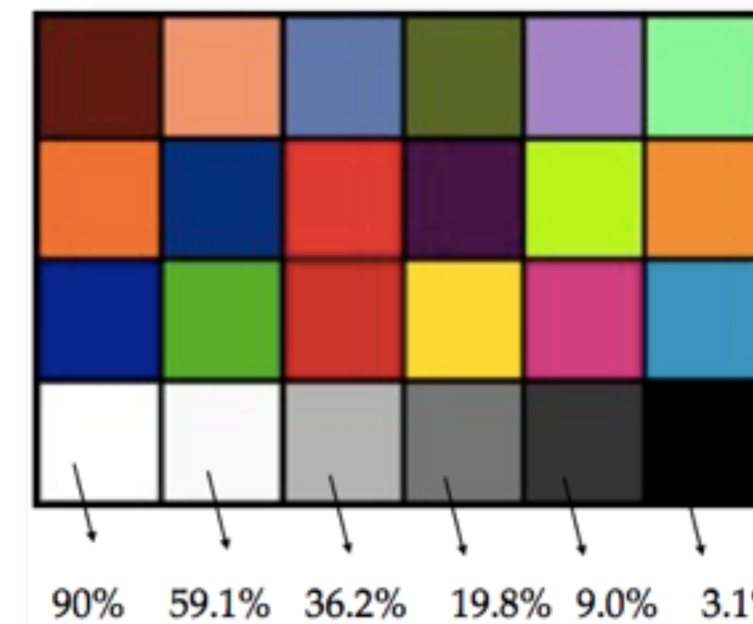




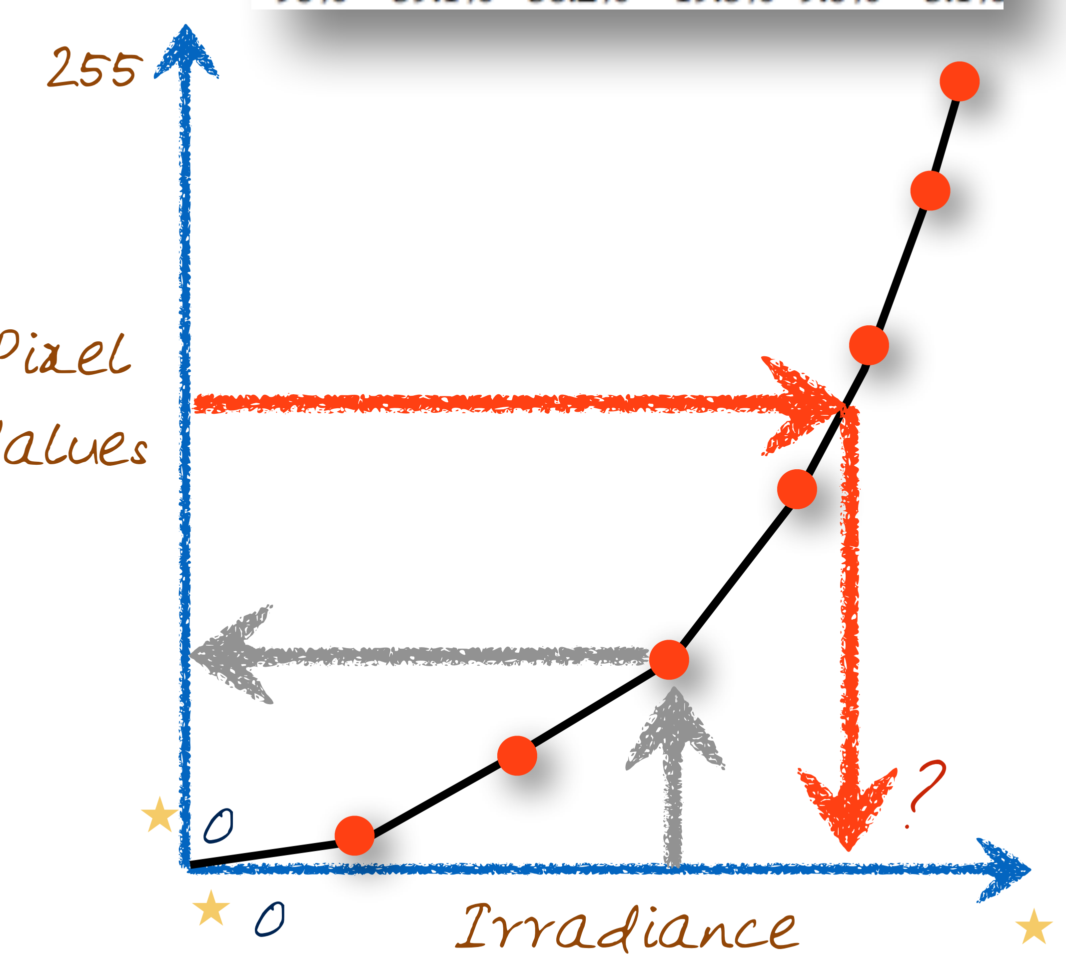
- Geometric
  - How pixel coordinates relate to directions in ~~the world~~ other images
- Radiometric / Photometric
  - How pixel values relate to radiance amounts in ~~the world~~ other images

Radiometric Calibration

$g: L \rightarrow E \rightarrow H \rightarrow I \Leftrightarrow g^{-1}: I \rightarrow E \rightarrow H \rightarrow L$



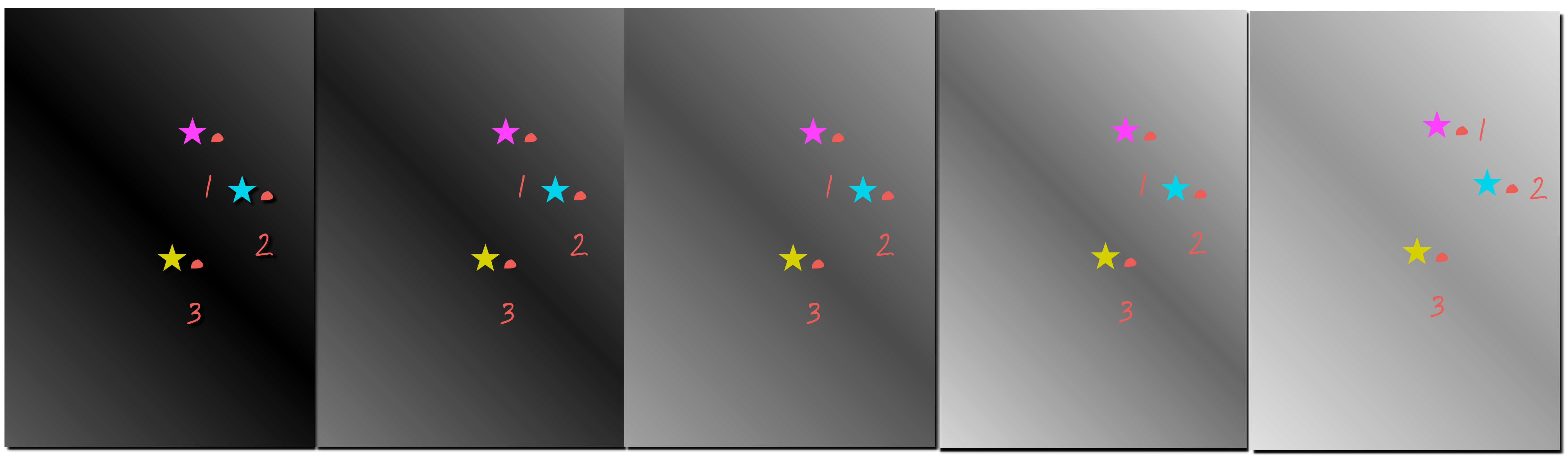
- A Color Chart with know reflectances
- Multiple camera exposures to fill up the curve
- Method assumes constant lighting on all patches and works best when source is far away (example sunlight)
- Unique inverse exists because g is monotonic and smooth for all cameras



(Grossberg and Nayar 2003)

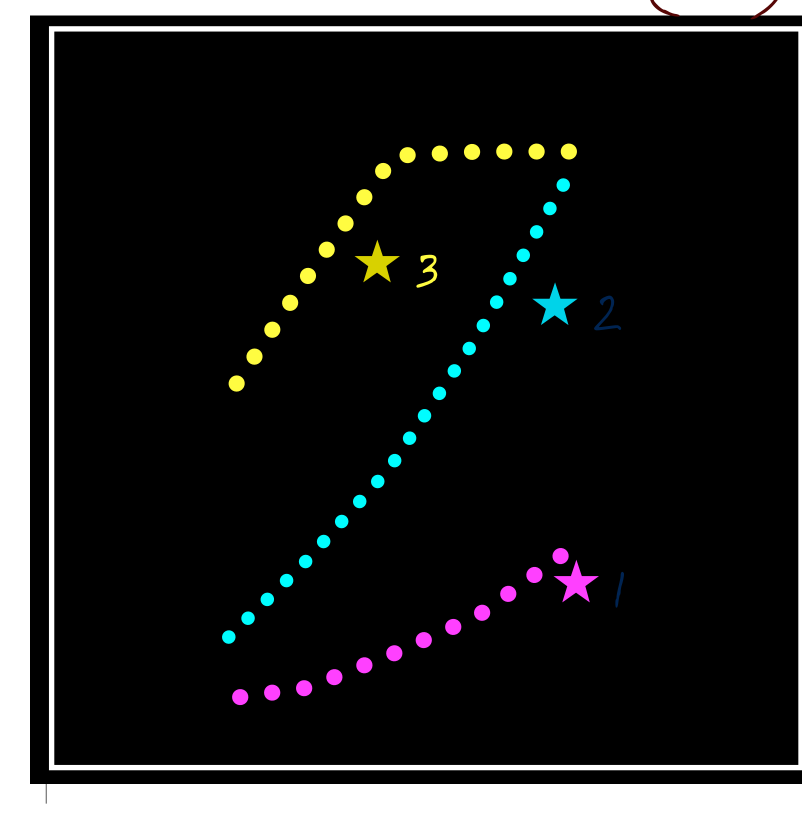
A Sequence of Images of Different Exposures

Series of Images



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

Pixel Values (I)



log Exposure (H)

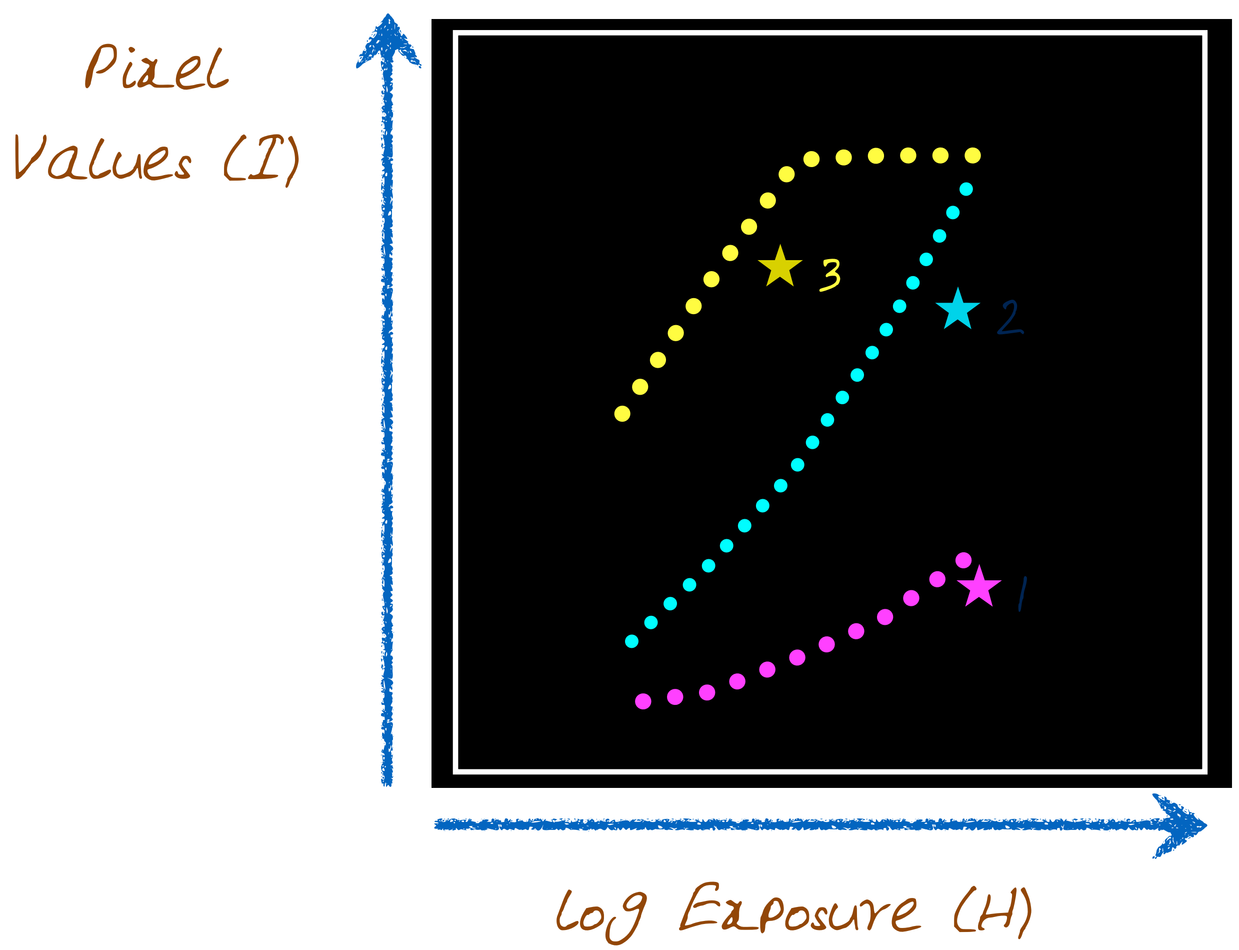
$$\text{Pixel Values (I)} = g(\text{Exposure})$$

$$\text{Exposure (H)} = \text{Irradiance (E)} * \Delta t$$

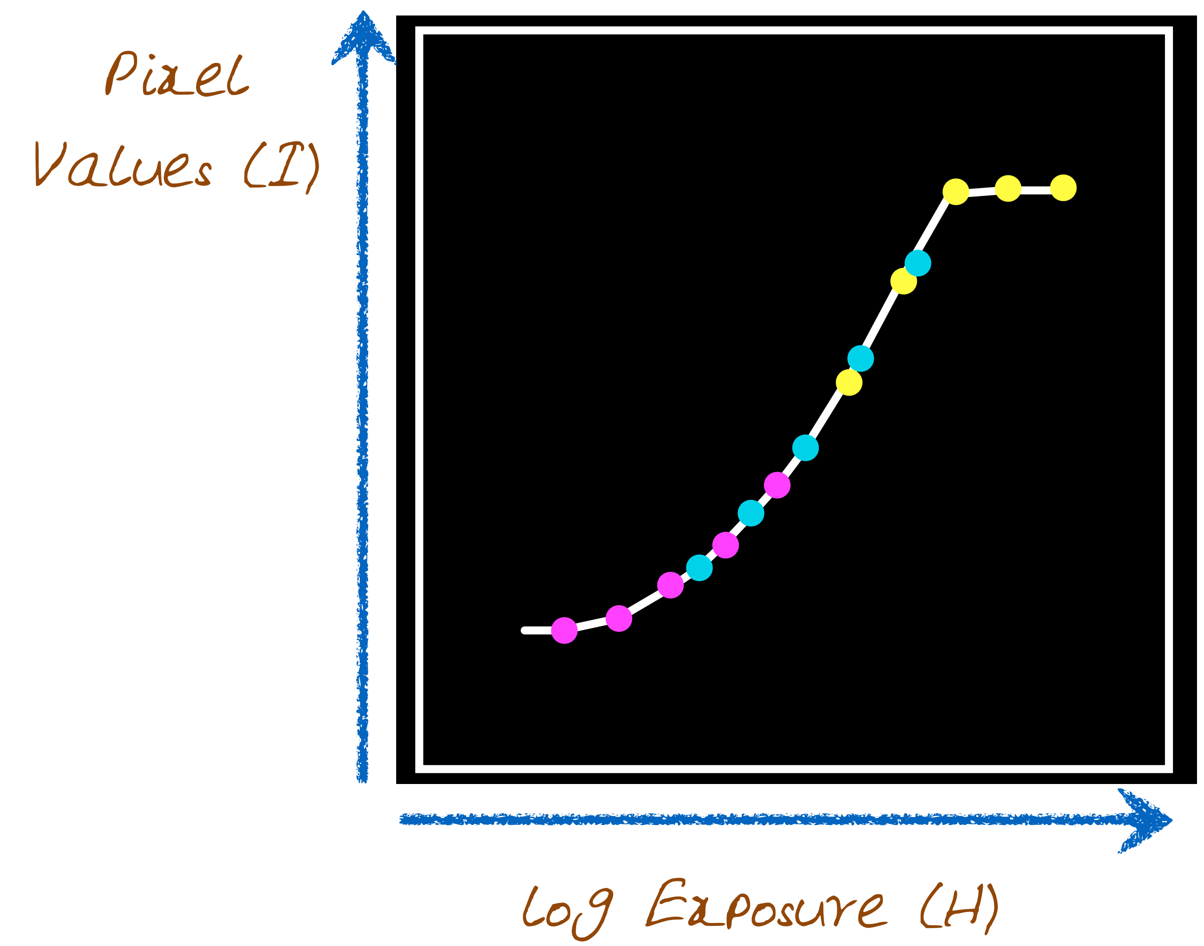
$$\log \text{Exposure (H)} = \log \text{Irradiance (E)} + \log \Delta t$$

Debevec and Malik 1997

Response Curves



Assuming unit radiance for each pixel



After adjusting radiances to obtain a smooth response curve

How to Compute

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

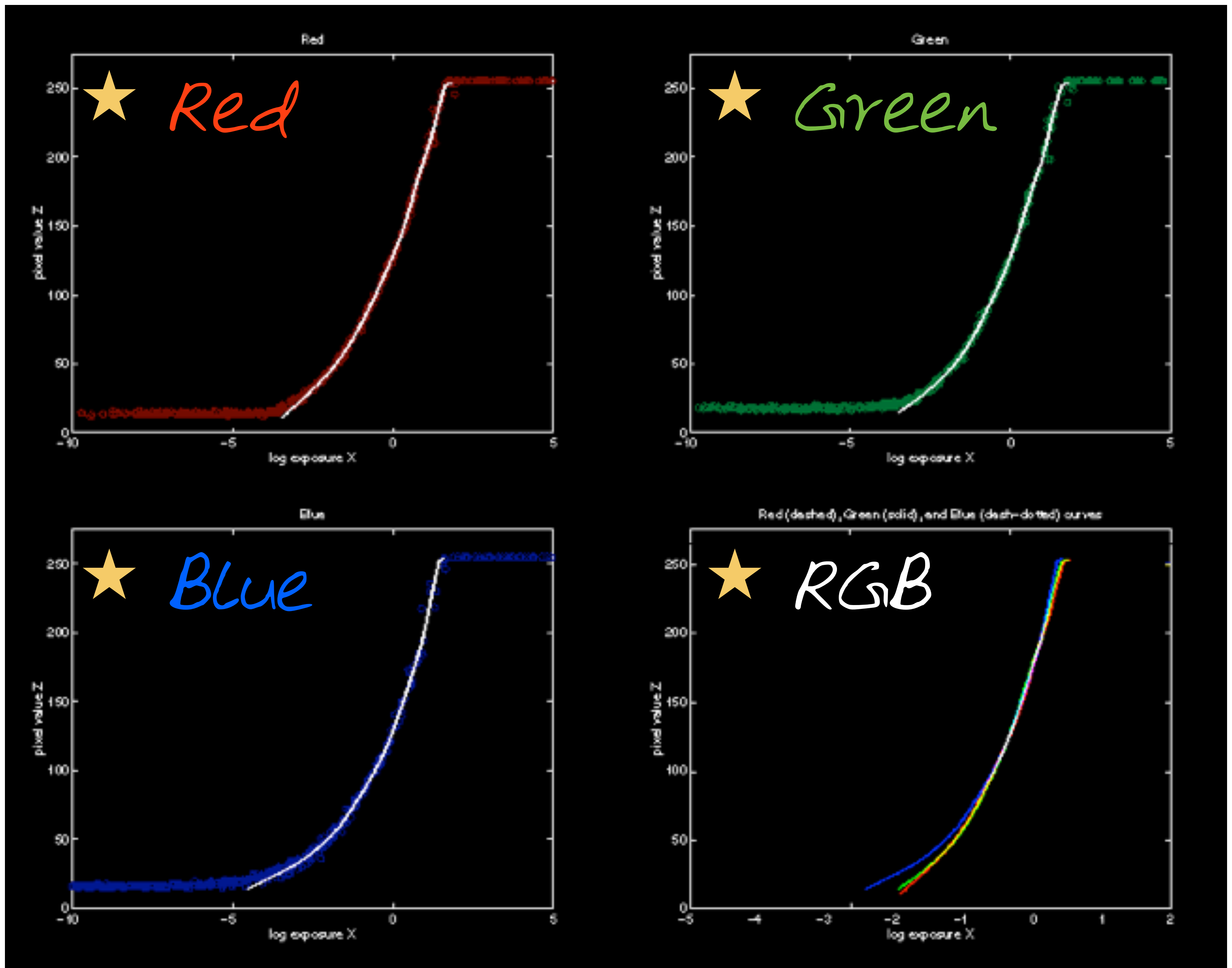
$$\ln(E_i) + \ln(\Delta t_j) = g(Z_{ij})$$

* Solve the overdetermined linear system for N pixels over P different exposure images:

$$\underbrace{\sum_{i=1}^{N}\sum_{i=1}^{P}\left[\ln(E_i) + \ln(\Delta t_j) - g(Z_{ij})\right]^2}_{\text{Fitting Term}} + \lambda \underbrace{\sum_{z=Z_{min}}^{Z_{max}} g''(z)^2}_{\text{Smoothness Term}}$$

See Debevec and Malik (1997) for more details

Response Curves



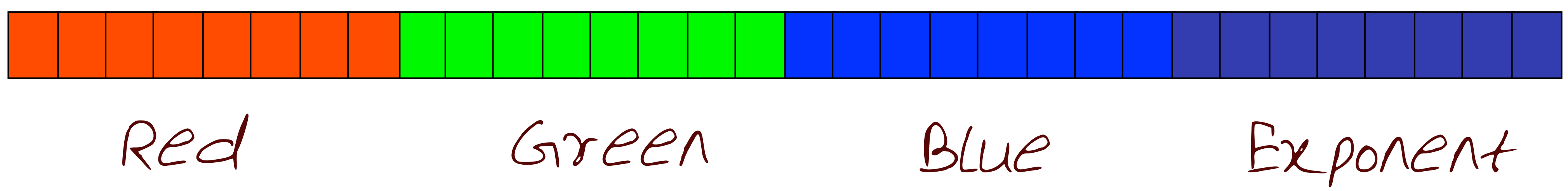
(Not actual curves for these images, used here just for demonstration)

Radiance Map

Need a New File Format

Radiance Format

32 bits / pixel



- ★ (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 (2001), There are many other formats too

Now to Display it!

Tone Mapping

* Map one set of colors to another
* Displaying on a medium that has limited dynamic range
    * Printers, monitors, and projectors all have a limited dynamic range
    * Inadequate to reproduce the full range of light intensities present in natural scenes

★ http://commons.wikimedia.org/wiki/File:Kanitz-Kyawsche_Gruft_in_Hainewalde_HDR.jpg

Tone Mapping

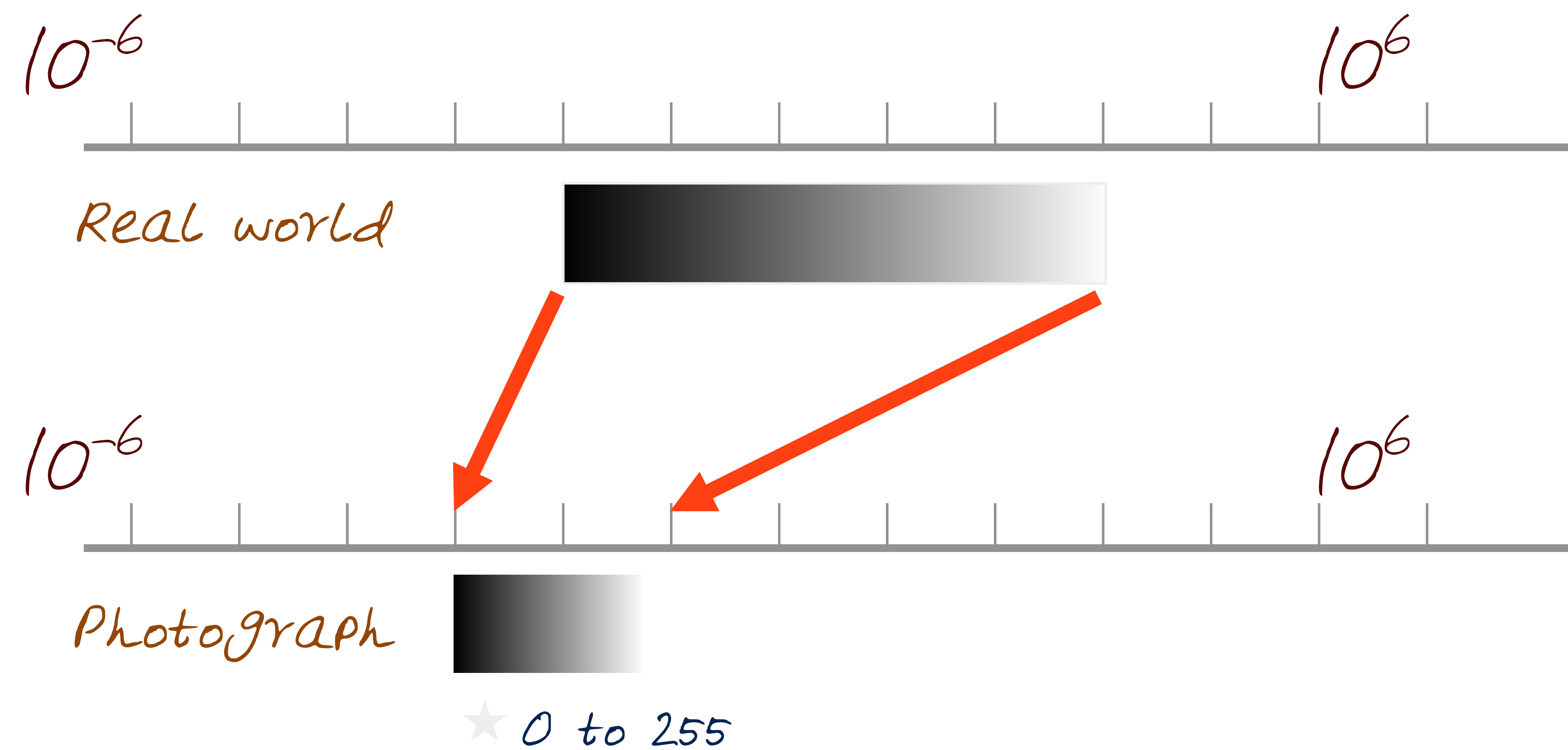
* Addresses the problem of
  * strong contrast reduction from the scene radiance to the displayable range
  * preservs the image details and color appearance
* Many well-known Algorithms exist for this
* See Banterle, et al. (2011), Reinhard et al. (2002) and Durand and Dorsey (2002)

* http://commonswikimedia.org/wiki/File:Kanitz-Kyawsche_Gruft_in_Hainewalde_HDR.jpg

Tone Mapping

http://en.wikipedia.org/wiki/File:Dundus_Square.jpg

High dynamic range



* Match limited contrast of the medium
* Preserve details
* Use filtering approaches to "compress" locally and globally

Summary

* Discussed issues of Dynamic Range
* Reviewed the Image Acquisition Pipeline for Capturing Scene Radiance to Pixel Values
* Discussed the linear and non-linear aspects of the Image Acquisition Pipeline for Capturing Scene Radiance to Pixel Values

Summary

* Introduced the need for Camera Calibration just from other images
* Presented the methods for going Pixel Values from different Exposure Images to render a Radiance Map of a Scene
* Introduced the concept of Tone Mapping

Further Information

* Grossberg and Nayar (2003), "Determining the Camera Response from Images: What is Knowable?," IEEE Transactions on Pattern Analysis and Machine Intelligence,
* Debevec and Malik (1997). "Recovering High Dynamic Range Radiance Maps from Photographs." In SIGGRAPH 1997
* Ward (2001), "High Dynamic Range Imaging," Proceedings of the Ninth Color Imaging Conference, November 2001.

Further Information

* Durand and Dorsey (2002), "Fast Bilateral Filtering for the Display of High-Dynamic-Range Images" In SIGGRAPH 2002.
* Reinhard, Stark, Shirley and Ferwerda (2002), "Photographic Tone Reproduction for Digital Images", In SIGGRAPH 2002.
* Banterle, Artusi, Debattista, and Chalmers (2011) Advanced High Dynamic Range Imaging CRC Press. (with Matlab Code)
* Many Software suites on the Internet.
* Also, look for "Exposure Fusion"

Credits

* Softwares used
  * Matlab by Mathwork's Inc.
* For more information, see
  * Richard Szeliski (2010) Computer Vision: Algorithms and Applications, Springer.
* Some concepts in slides motivated by similar slides by J. Hays.
* Photographs by Irfan Essa

Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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