

Computational Photography



Dr. Irfan Essa

Professor

School of Interactive Computing

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

High Dynamic Range Photography (Part 2 of 2)

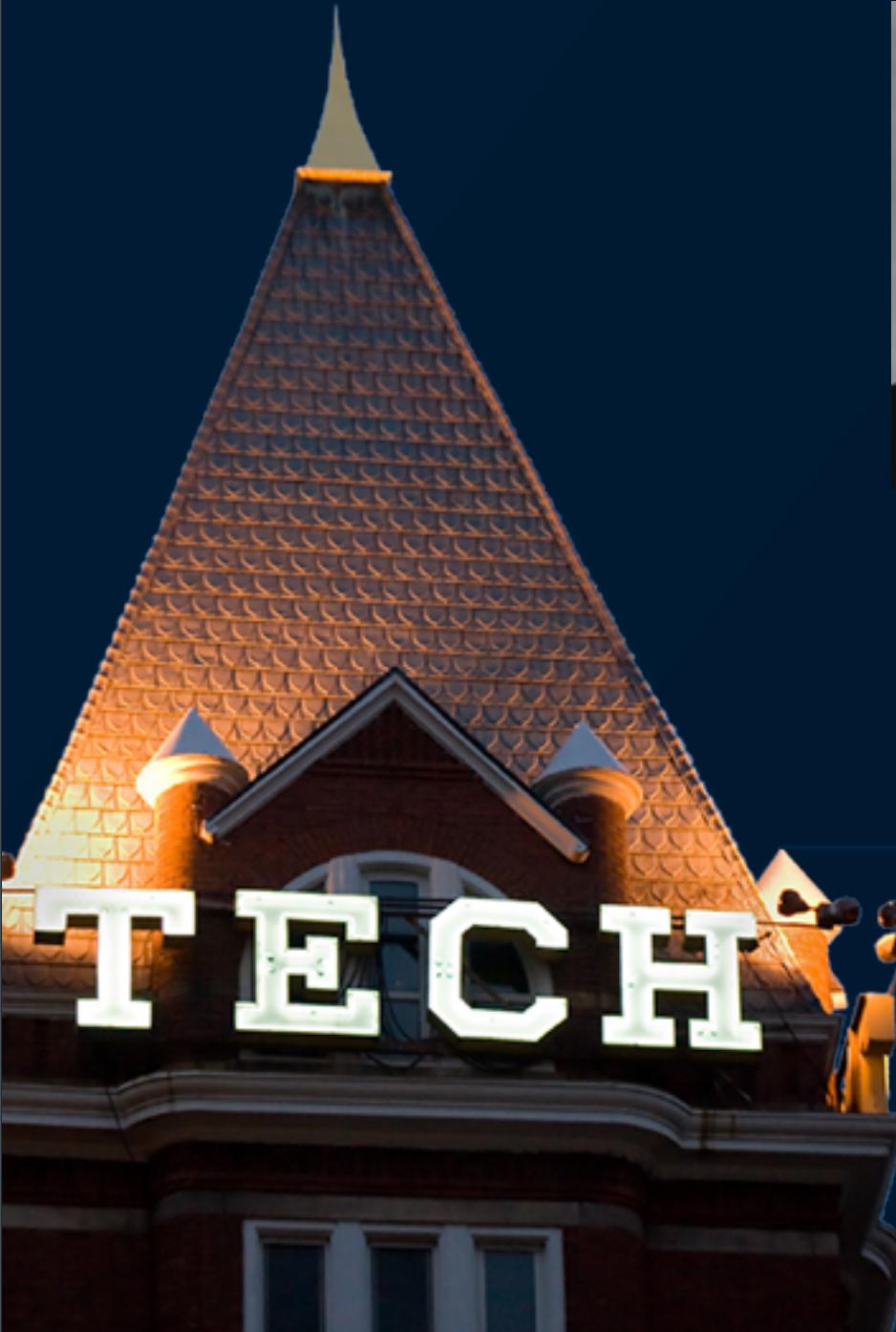


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Merging Images to Create a High Dynamic
Range Photograph



Lesson Objectives

- ★ Review in your own words the linear and non-linear aspect inherent in the Image Acquisition Pipeline for Capturing Scene Radiance to Pixels Values.
- ★ Identify one (1) reason for why Camera Calibration just from other images is needed.
- ★ Describe intuitively how Pixel Values from different Exposure Images are used to render a Radiance Map of Scene.
- ★ Describe mathematically how Pixel Values from different Exposure Images are used to render a Radiance Map of Scene.
- ★ Describe in your words the concept of Tone Mapping.
- ★ Identify one (1) reason for why Tone Mapping is important.



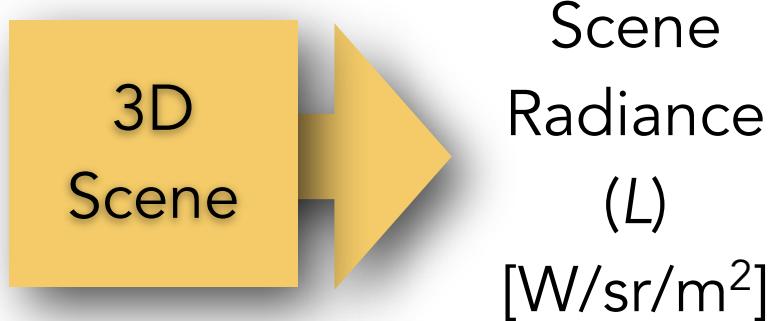
Relationship between Image and Scene Brightness

The Image Acquisition Pipeline

Relationship between Image and Scene Brightness

The Image Acquisition Pipeline

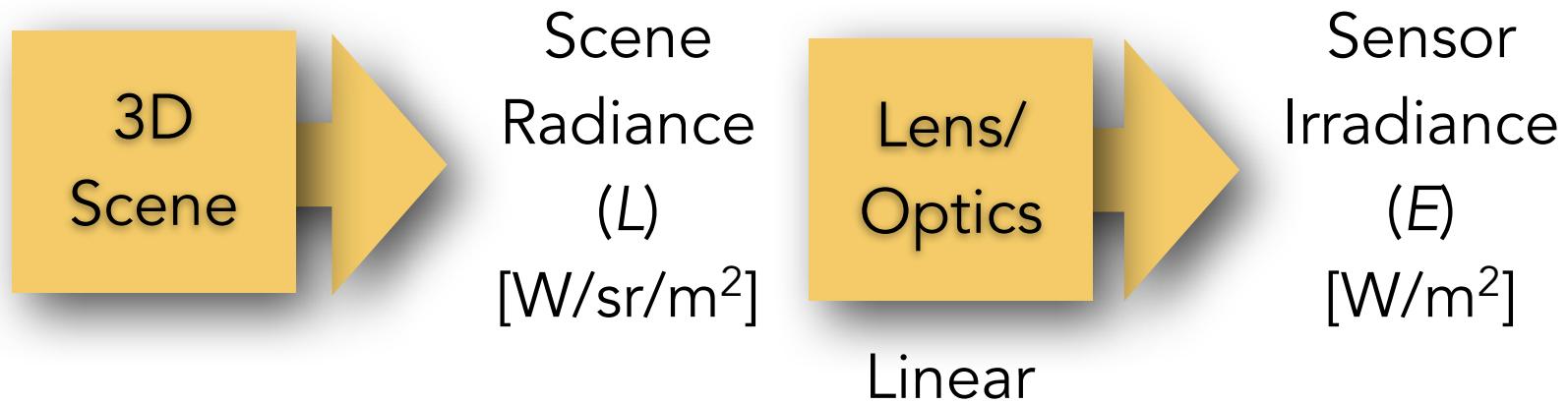
★ Scene Radiance



Relationship between Image and Scene Brightness

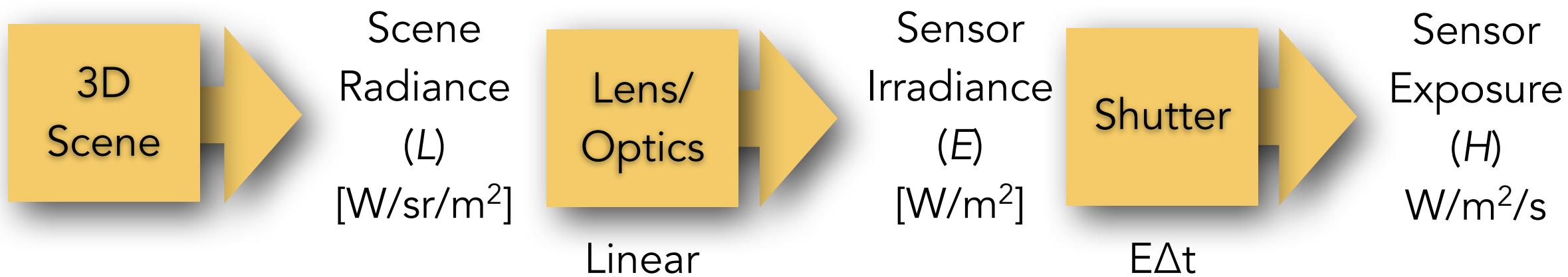
The Image Acquisition Pipeline

- ★ Scene Radiance
- ★ Sensor Irradiance



Relationship between Image and Scene Brightness

The Image Acquisition Pipeline

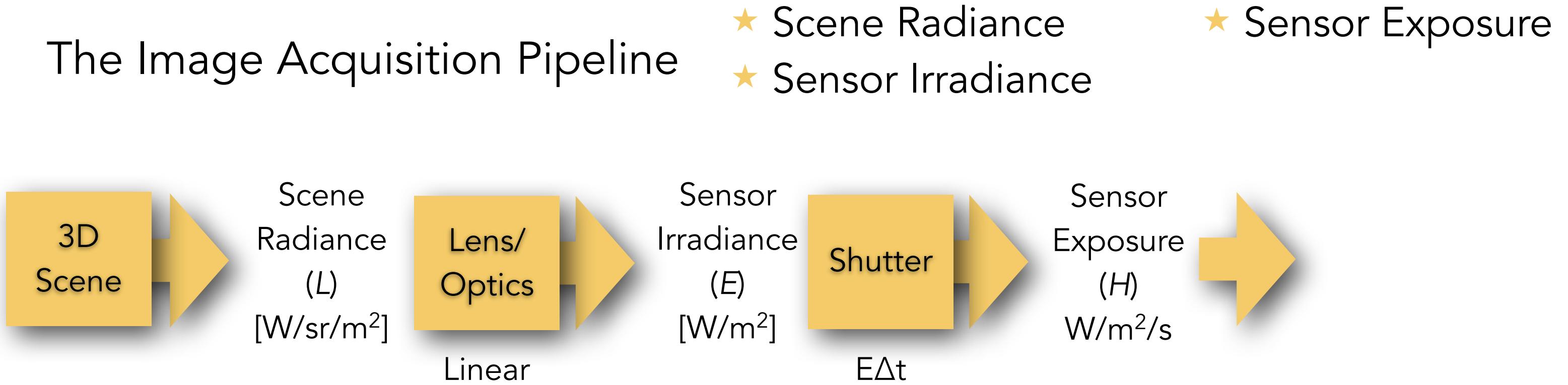


★ Scene Radiance
★ Sensor Irradiance

★ Sensor Exposure

Relationship between Image and Scene Brightness

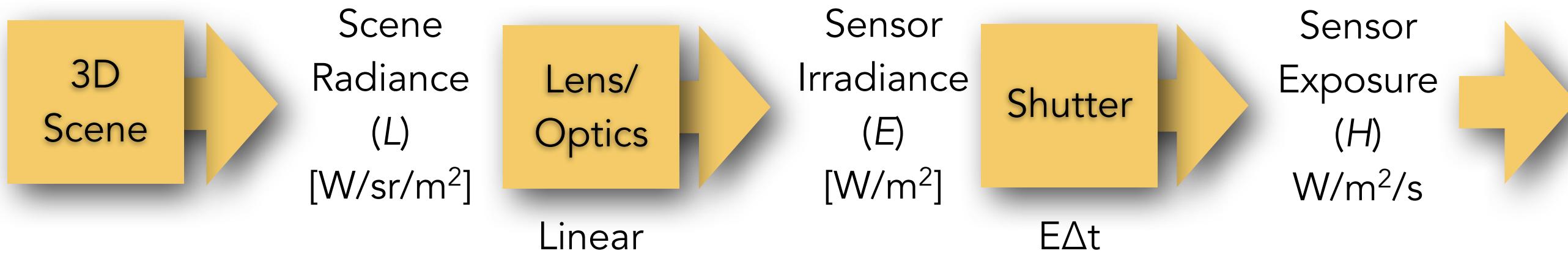
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Relationship between Image and Scene Brightness

The Image Acquisition Pipeline

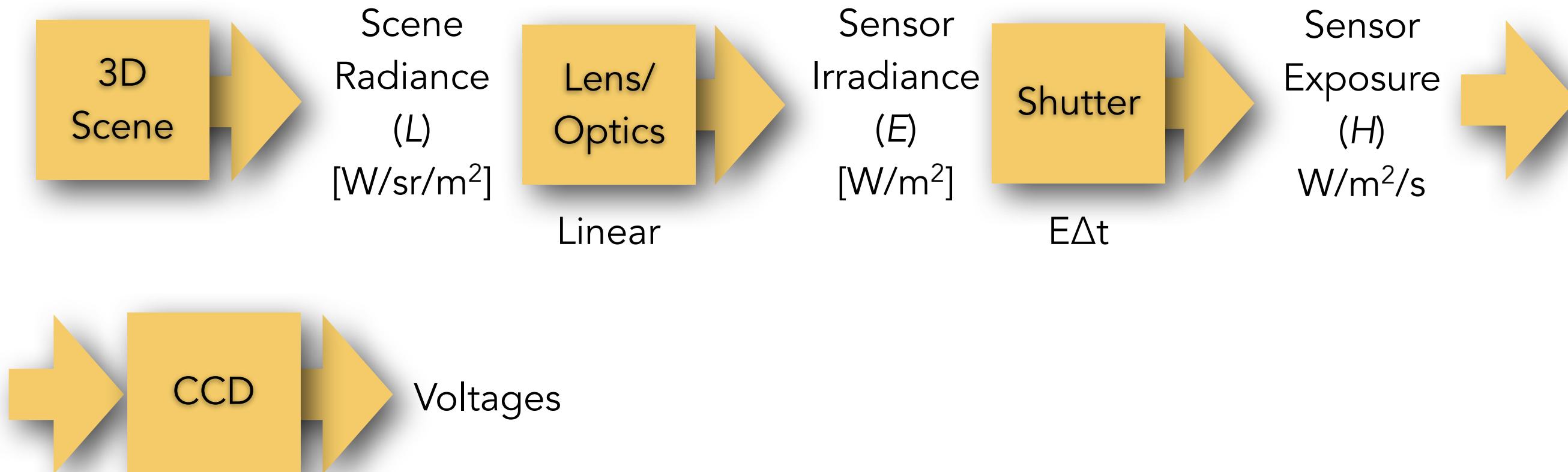
- ★ Scene Radiance
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- ★ Sensor Exposure



Relationship between Image and Scene Brightness

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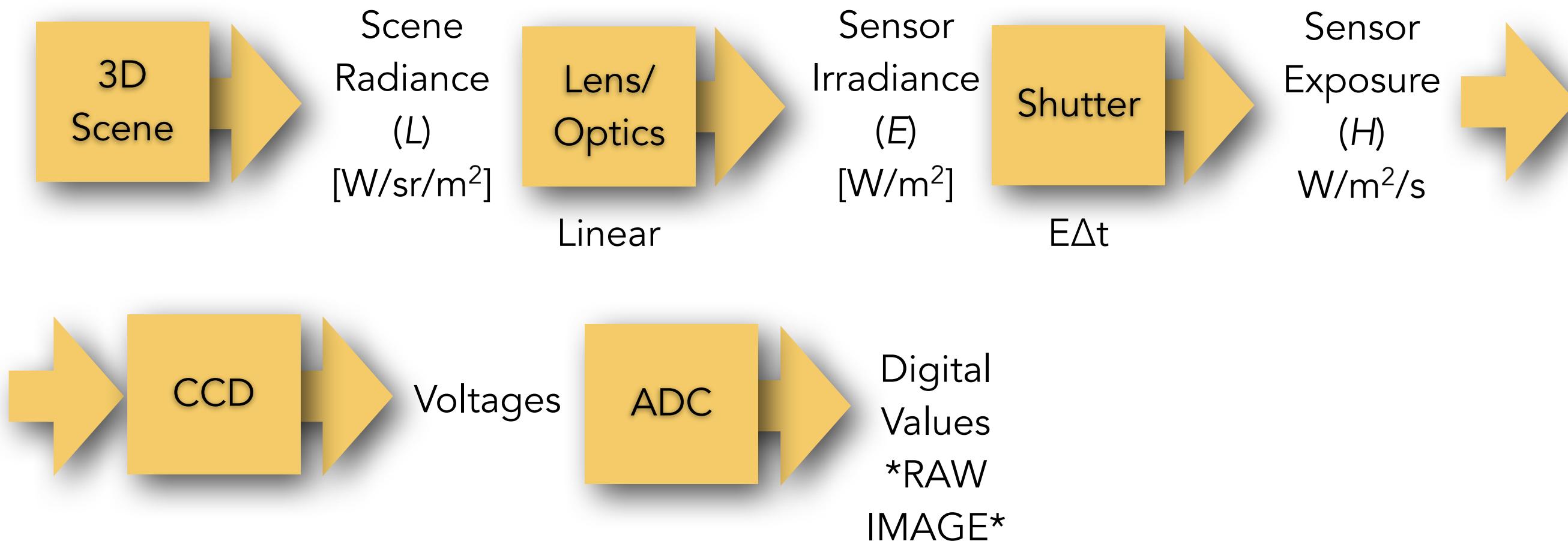
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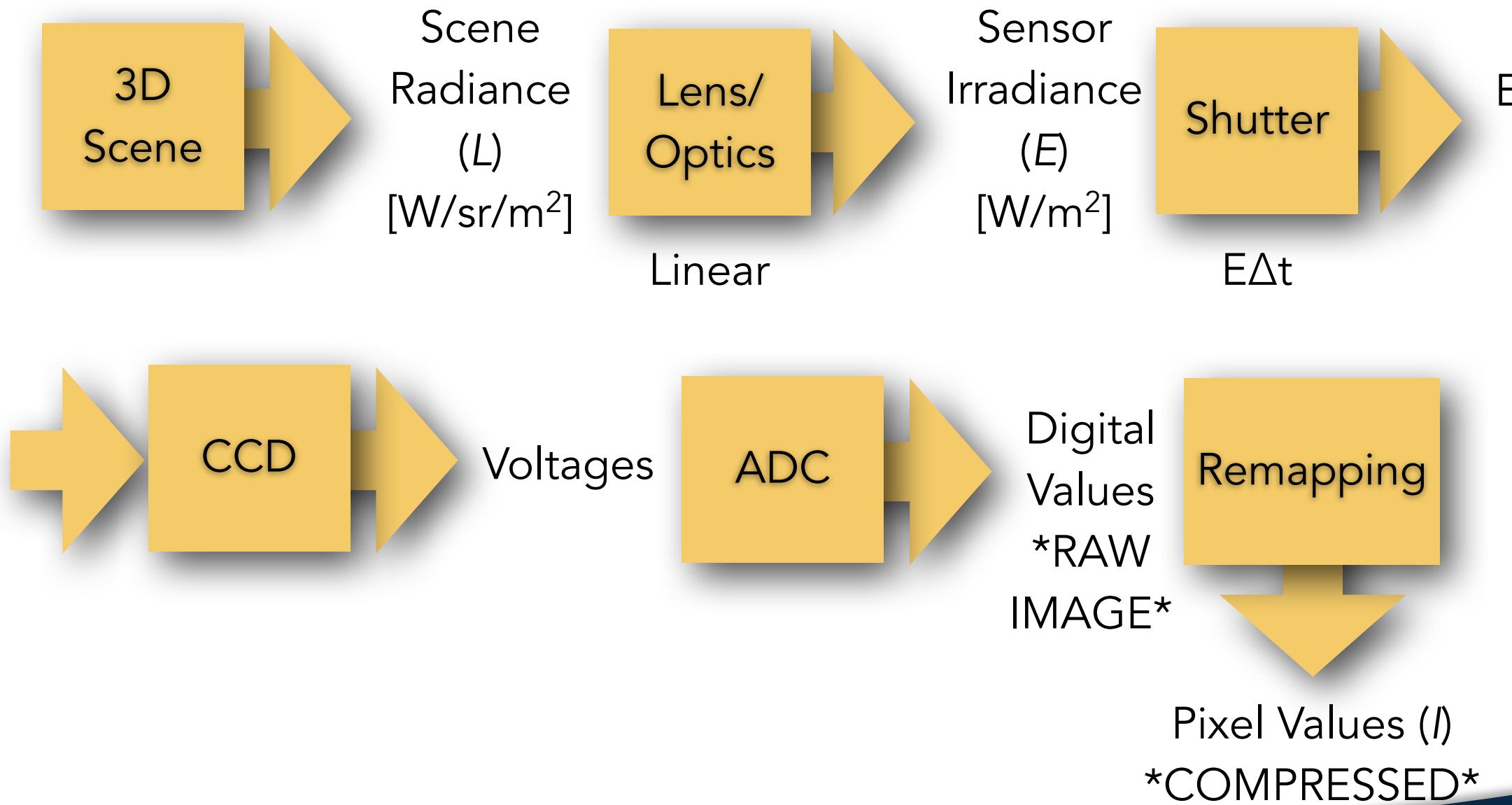
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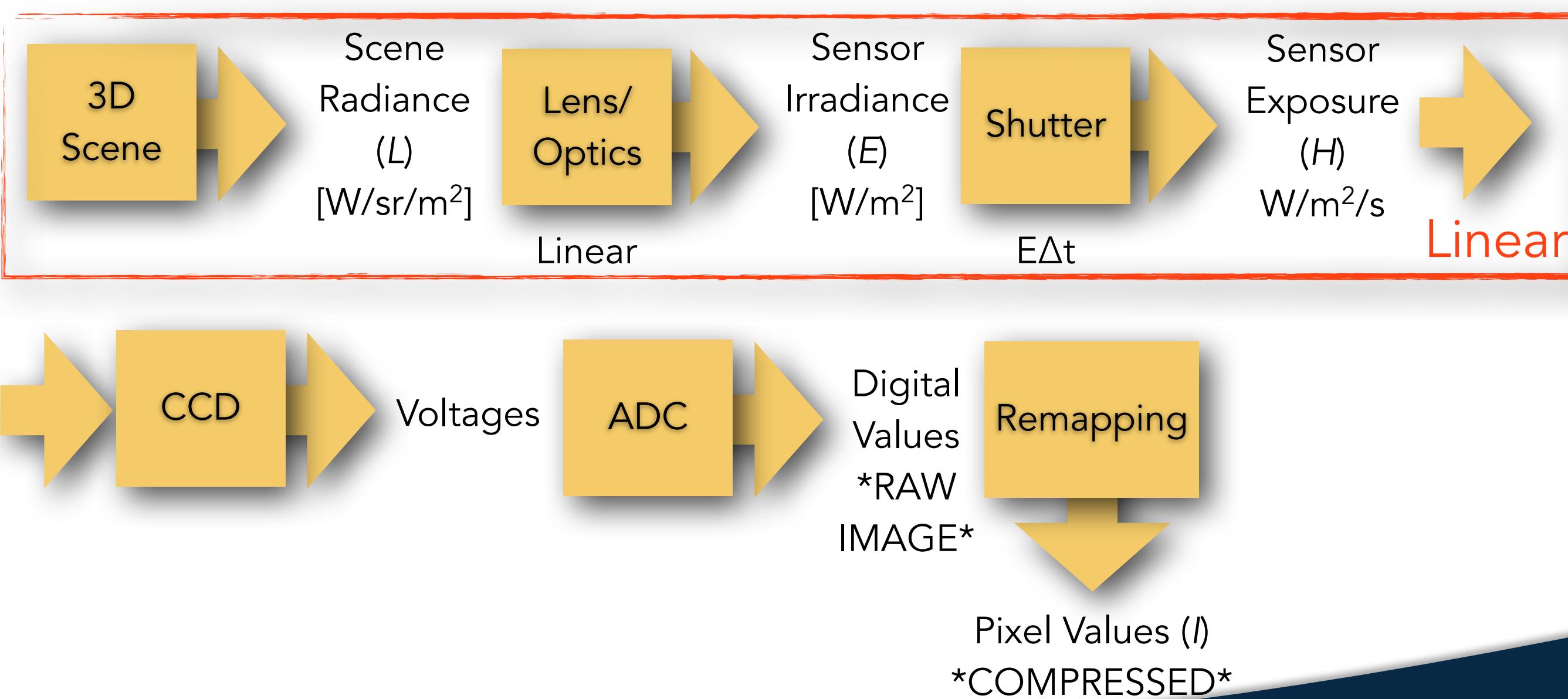
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- ★ Image Pixel Values



Relationship between Image and Scene Brightness

The Image Acquisition Pipeline

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 - ★ Sensor Exposure
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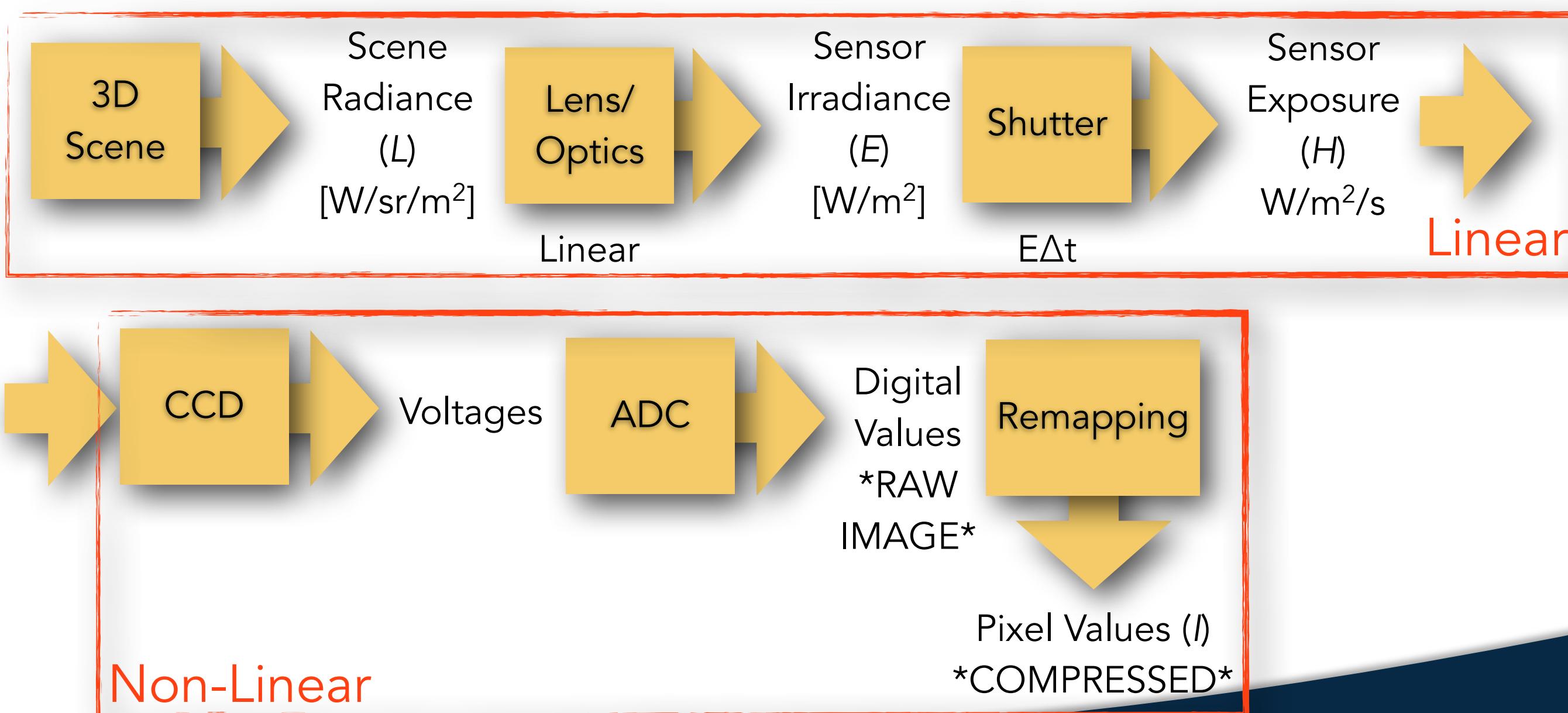


Relationship between Image and Scene Brightness

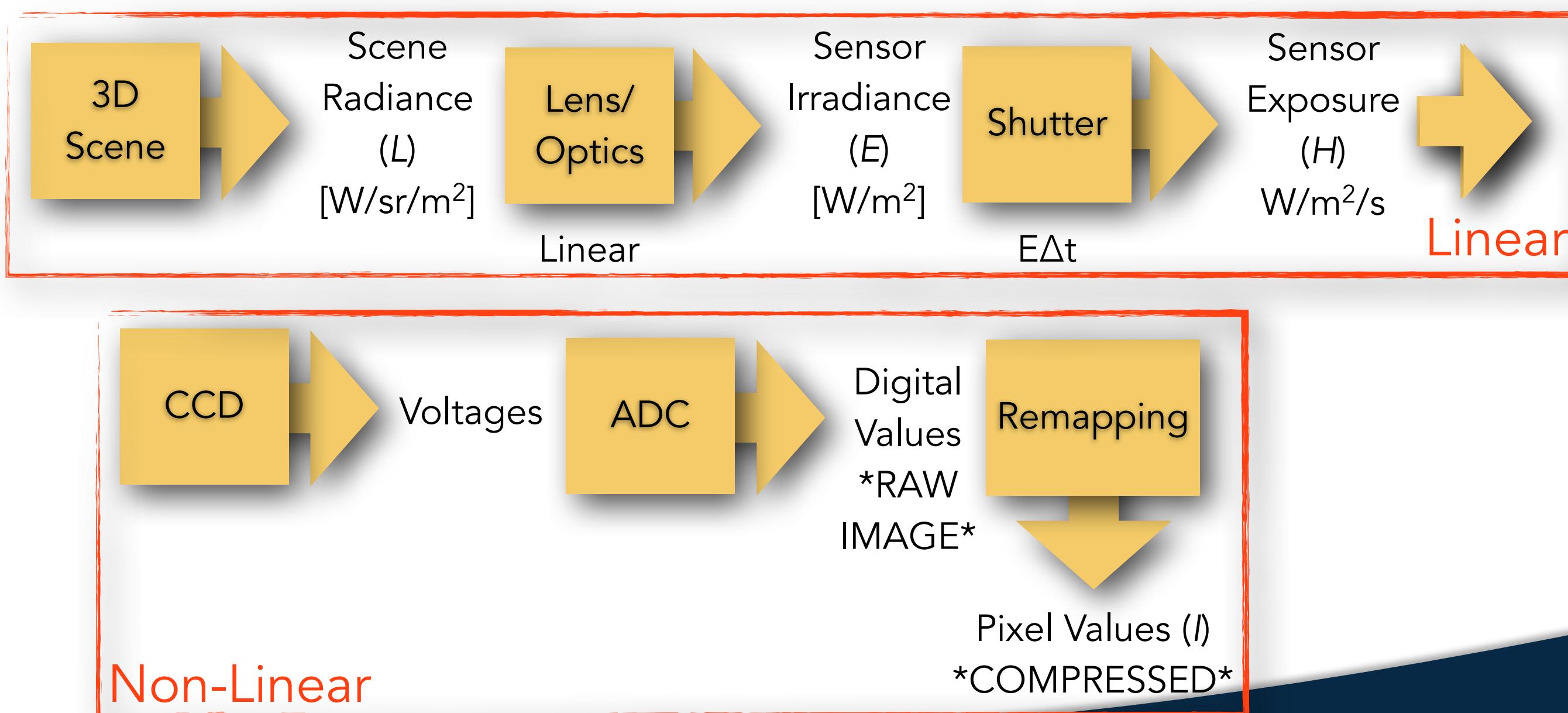
The Image Acquisition Pipeline

- ★ Scene Radiance
- ★ Sensor Irradiance

- ★ Sensor Exposure
- ★ Image Pixel Values

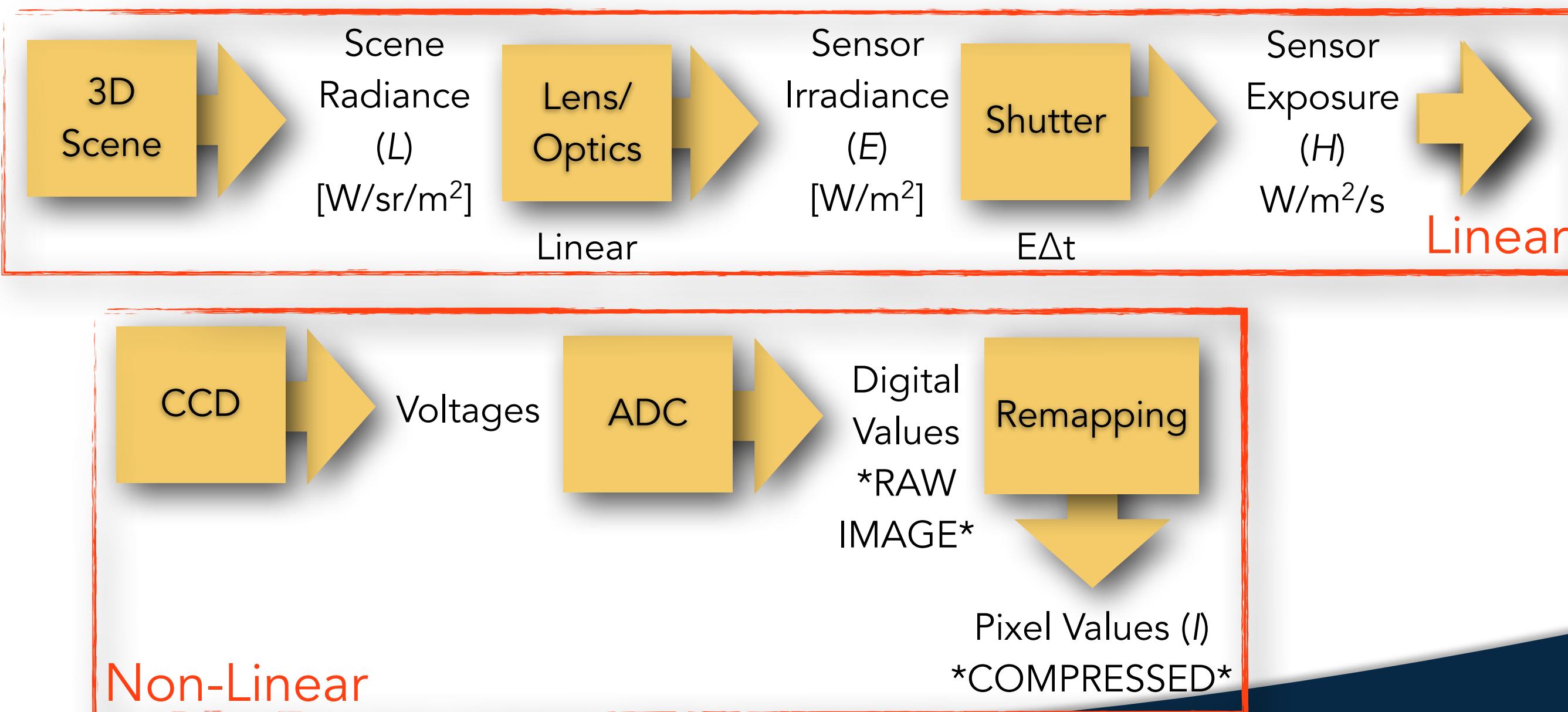


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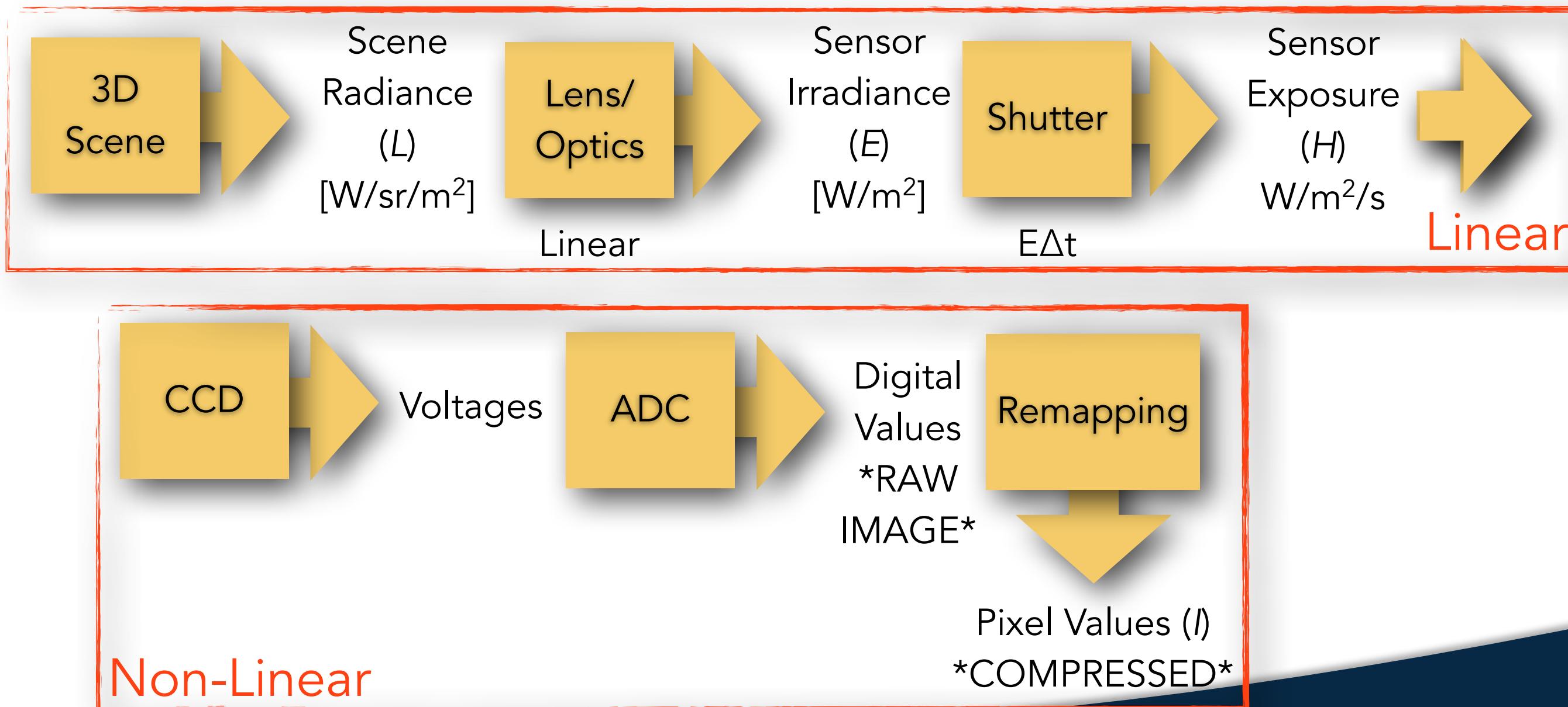
Relationship between Image and Scene Brightness

$$g: L \rightarrow E \rightarrow H \rightarrow I$$



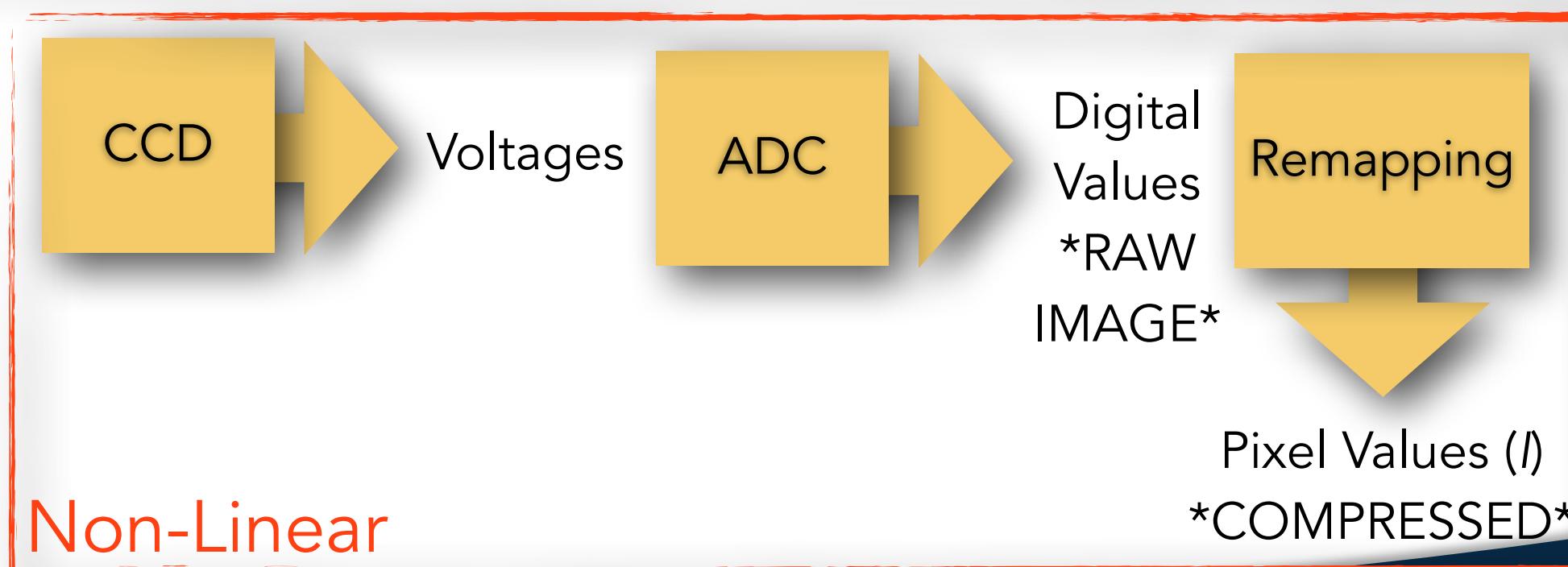
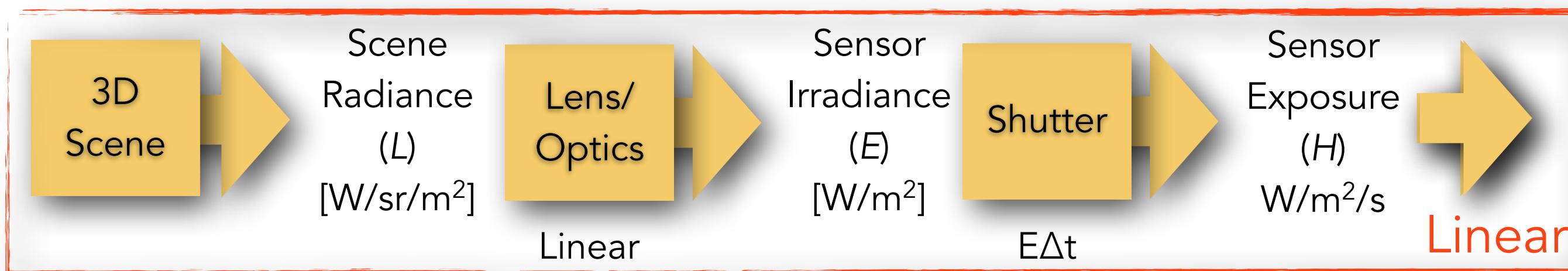
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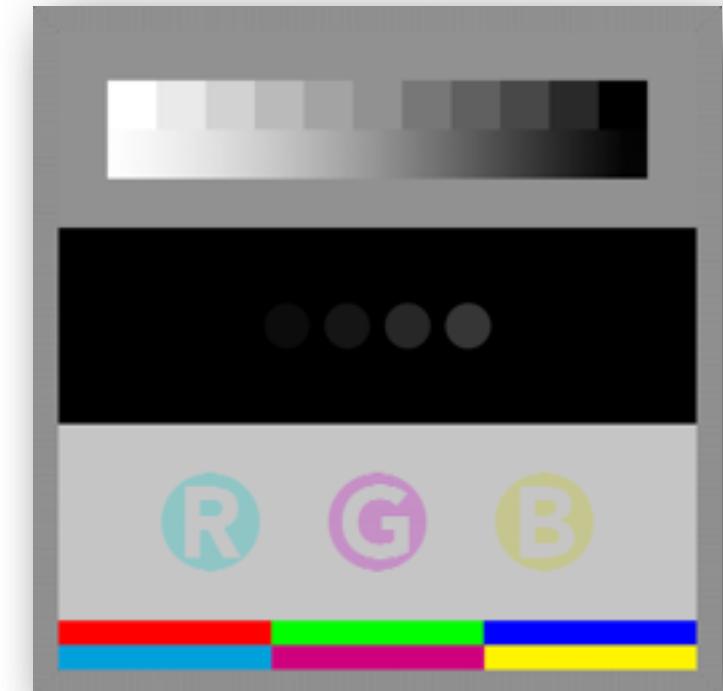


Relationship between Image and Scene Brightness

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



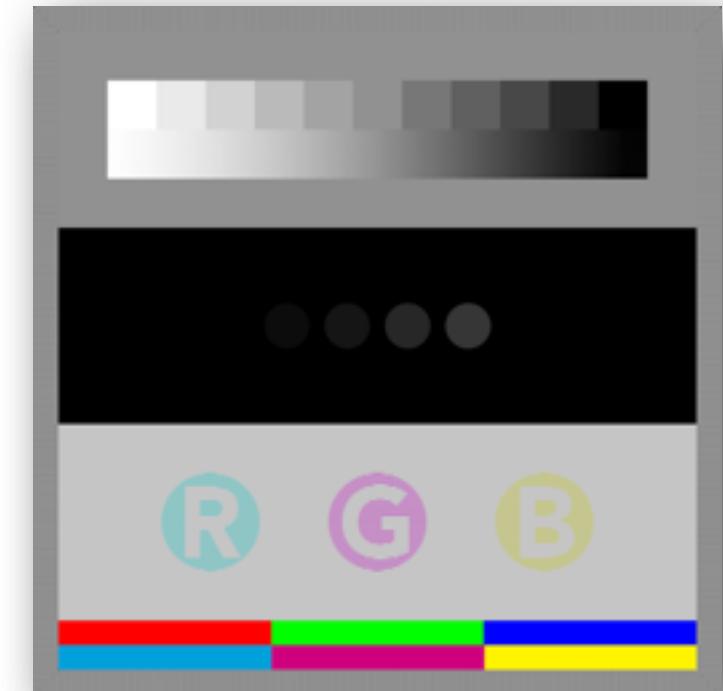
Camera Calibration



Camera Calibration

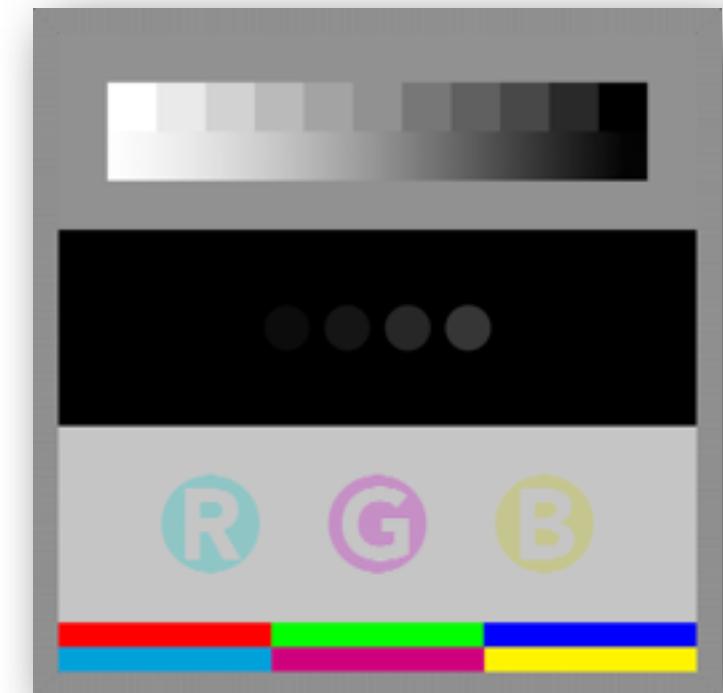
★ Geometric

- How pixel coordinates relate to directions in the world
-



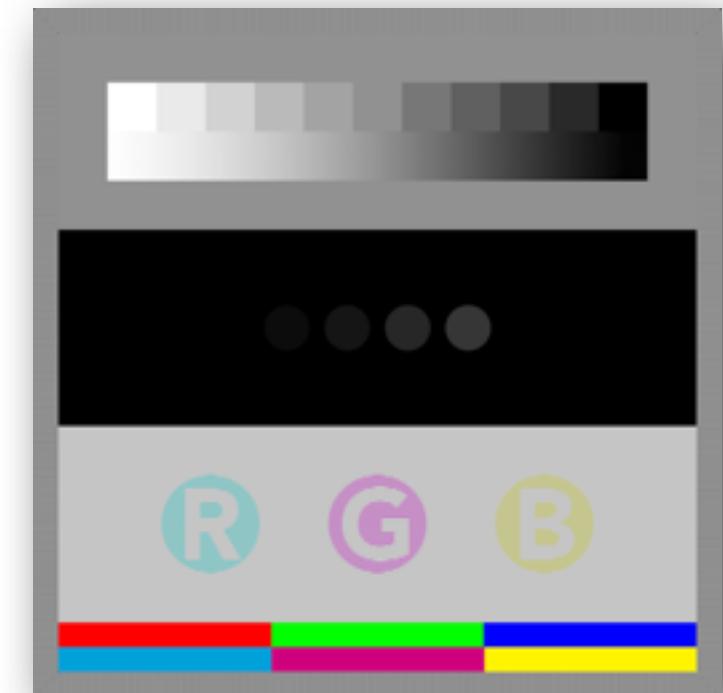
Camera Calibration

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



Camera Calibration

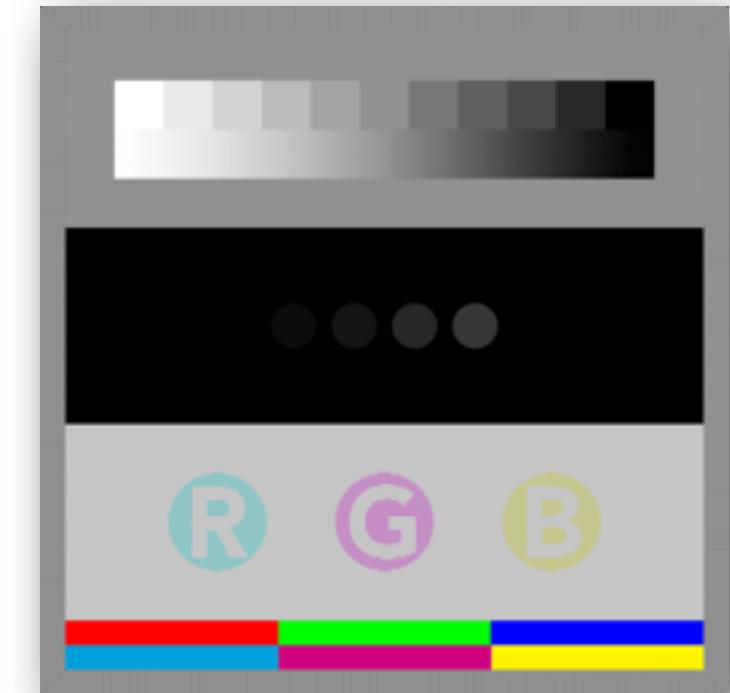
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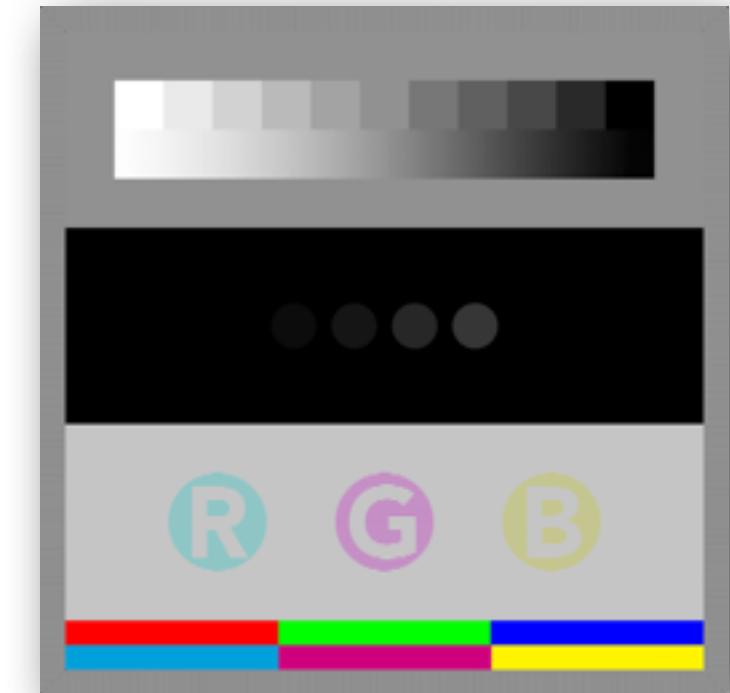
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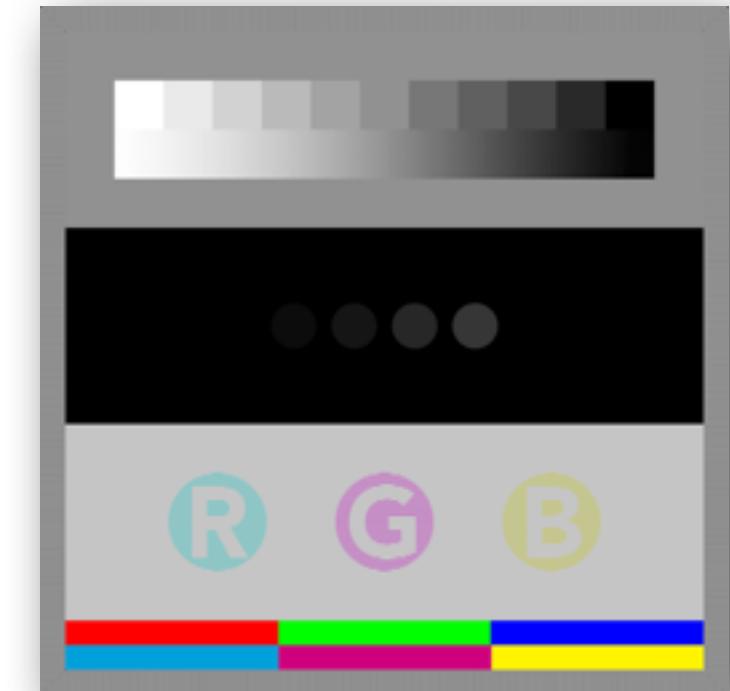
Camera Calibration

★ Geometric

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Radiometric Calibration

(Grossberg and Nayar 2003)

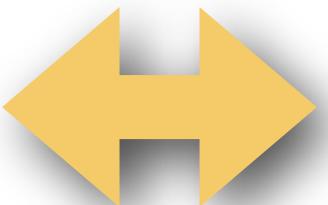
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$g: L \rightarrow E \rightarrow H \rightarrow I$

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

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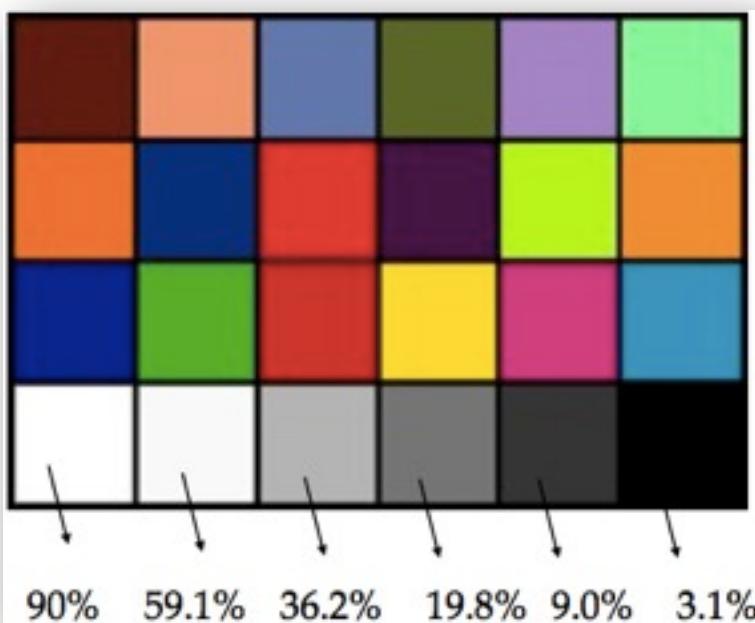
- ★ Use a Color Chart with precisely know reflectances

(Grossberg and Nayar 2003)

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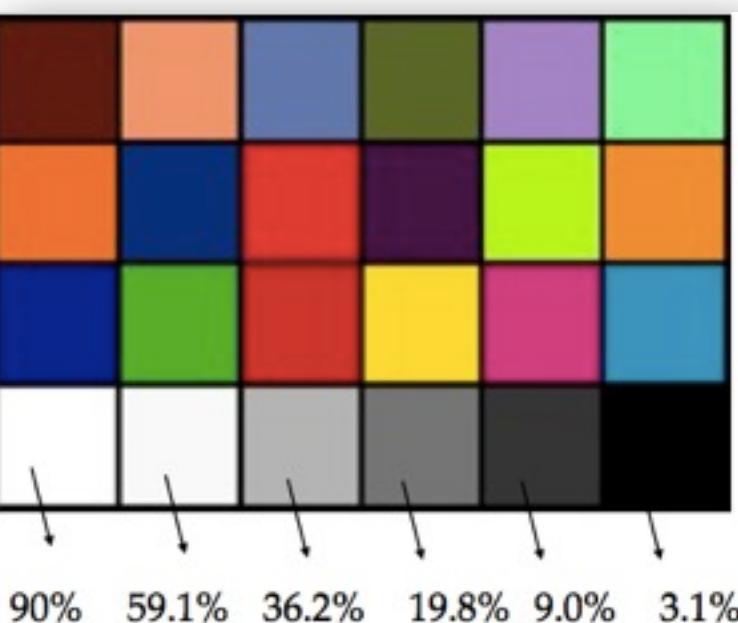
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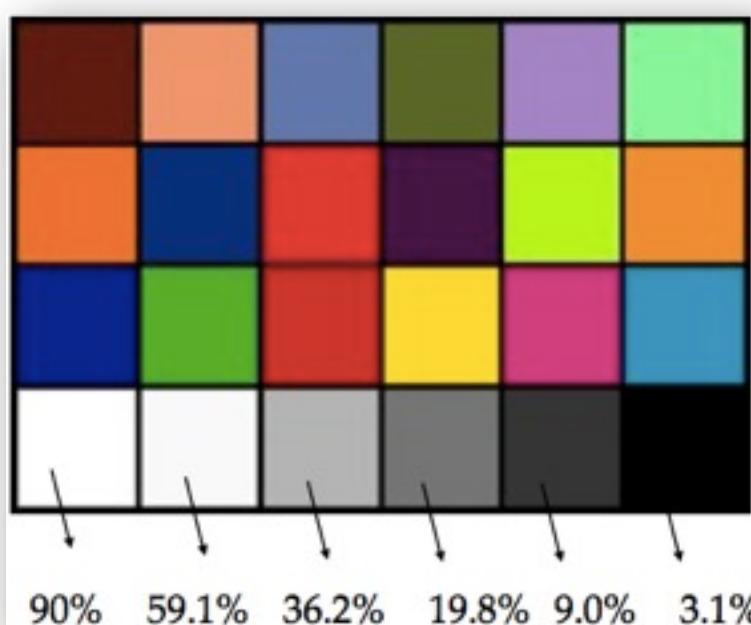


- ★ Use a Color Chart with precisely know reflectances
- ★ Multiple camera exposures to fill up the curve.

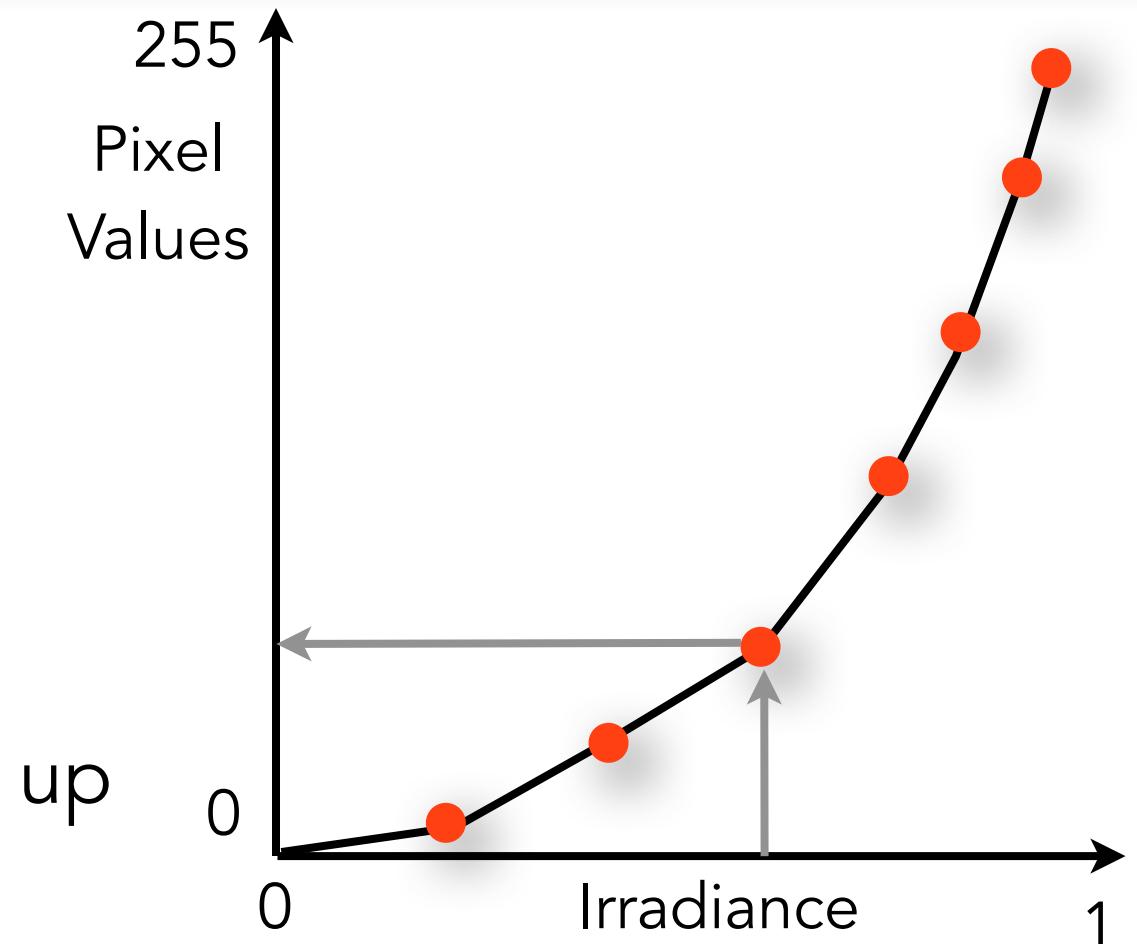
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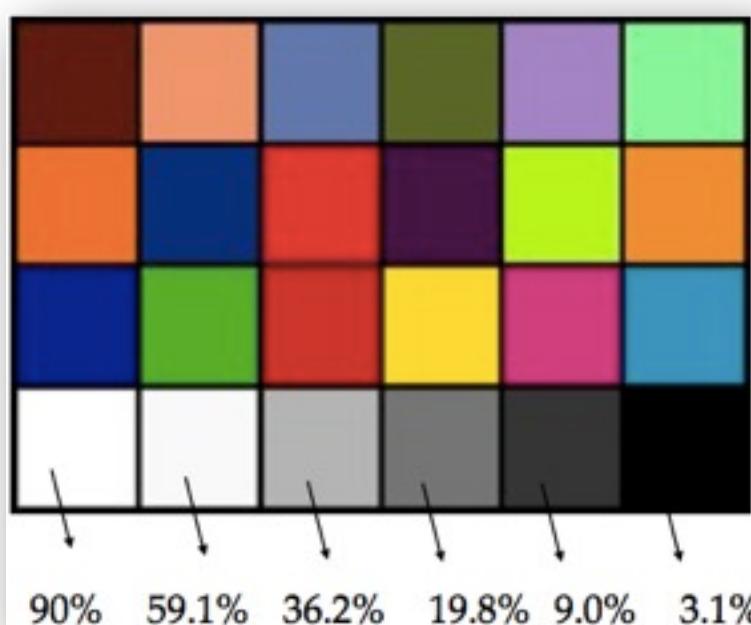
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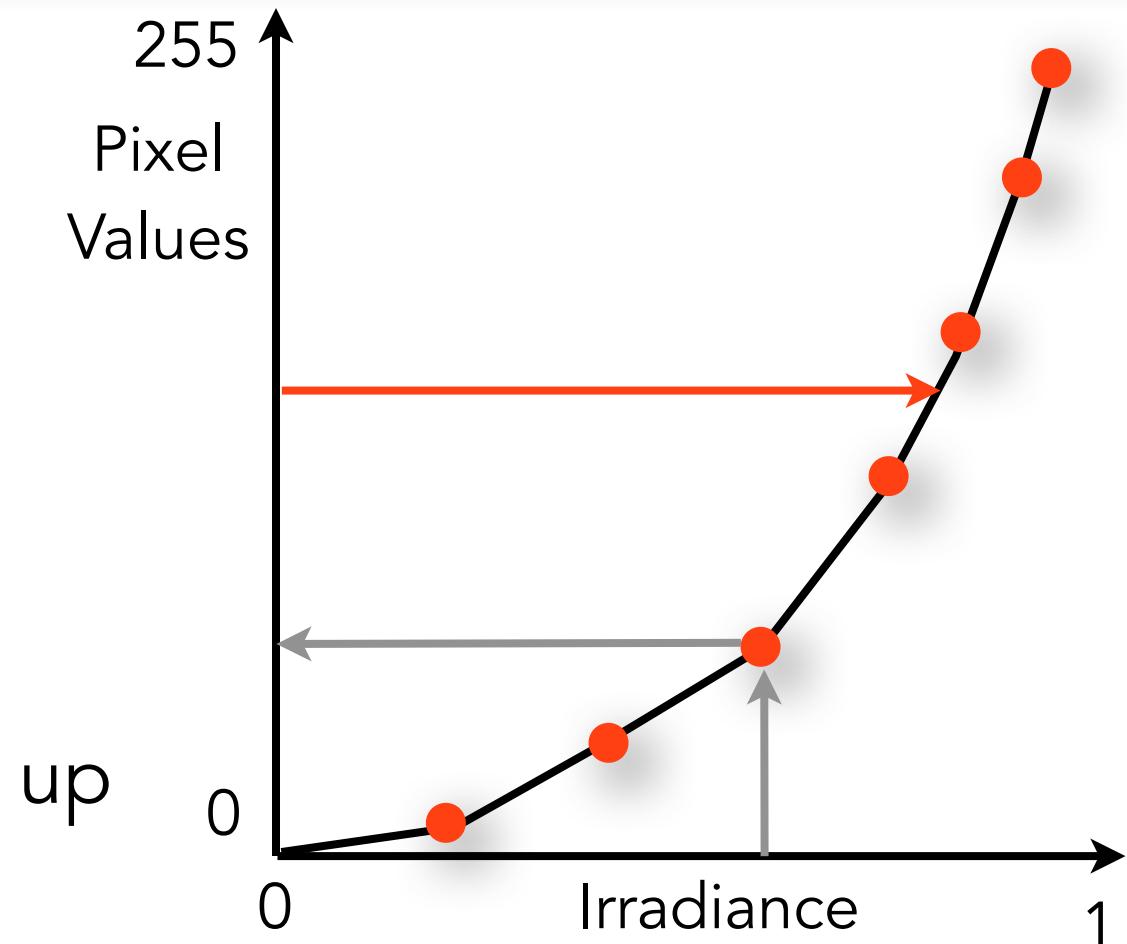
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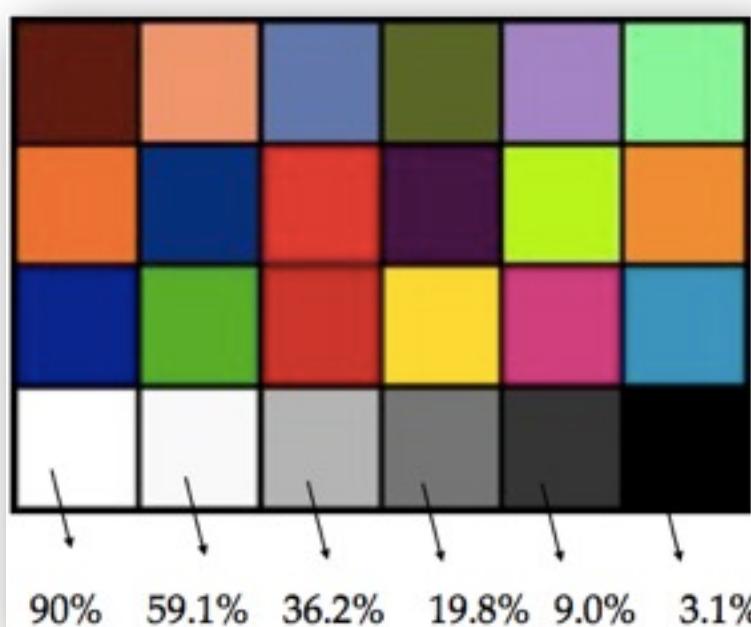
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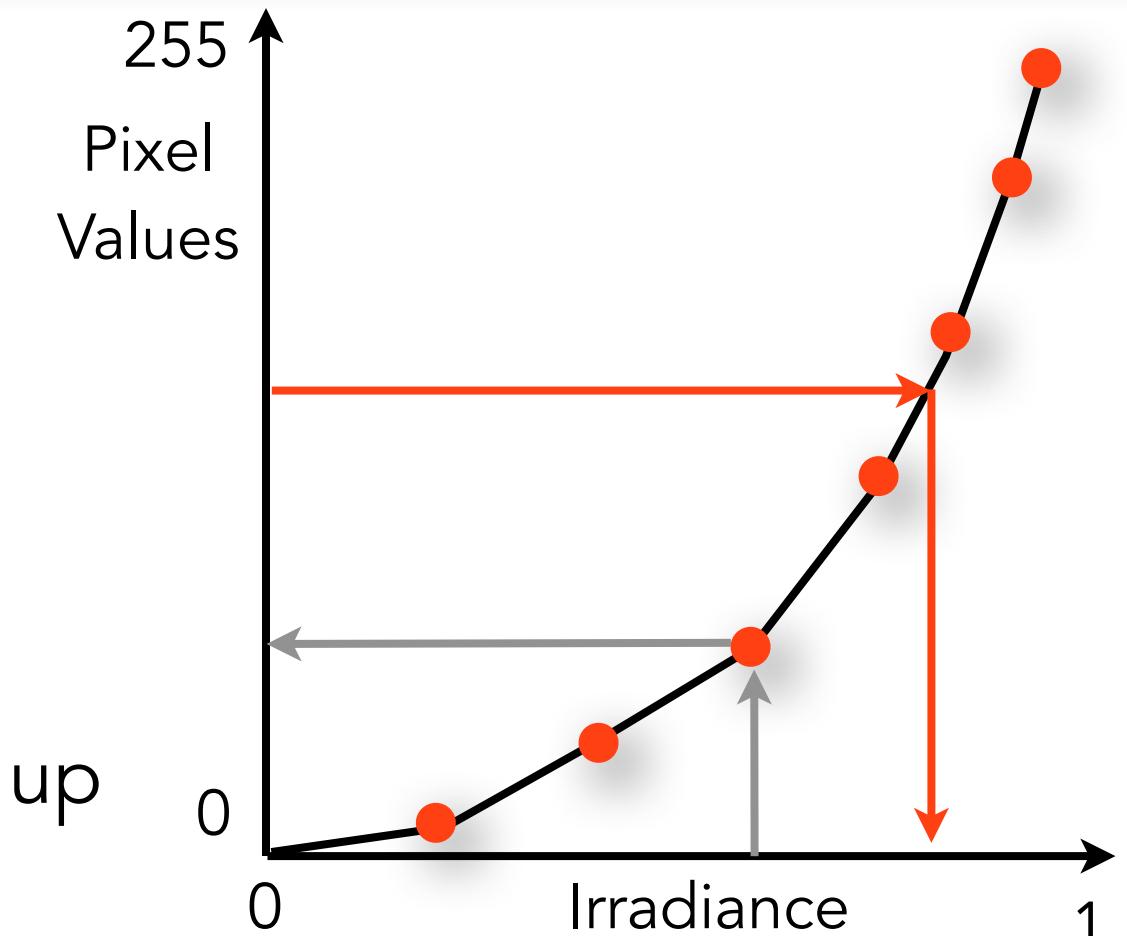
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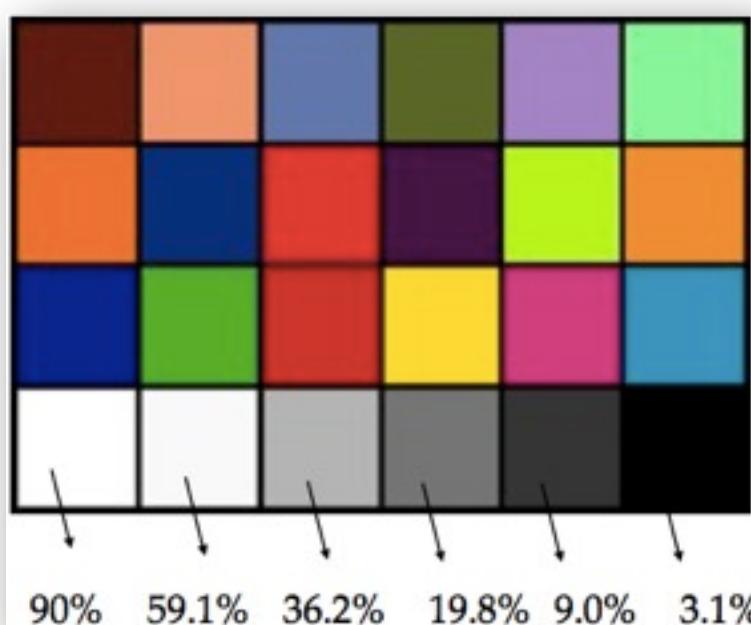
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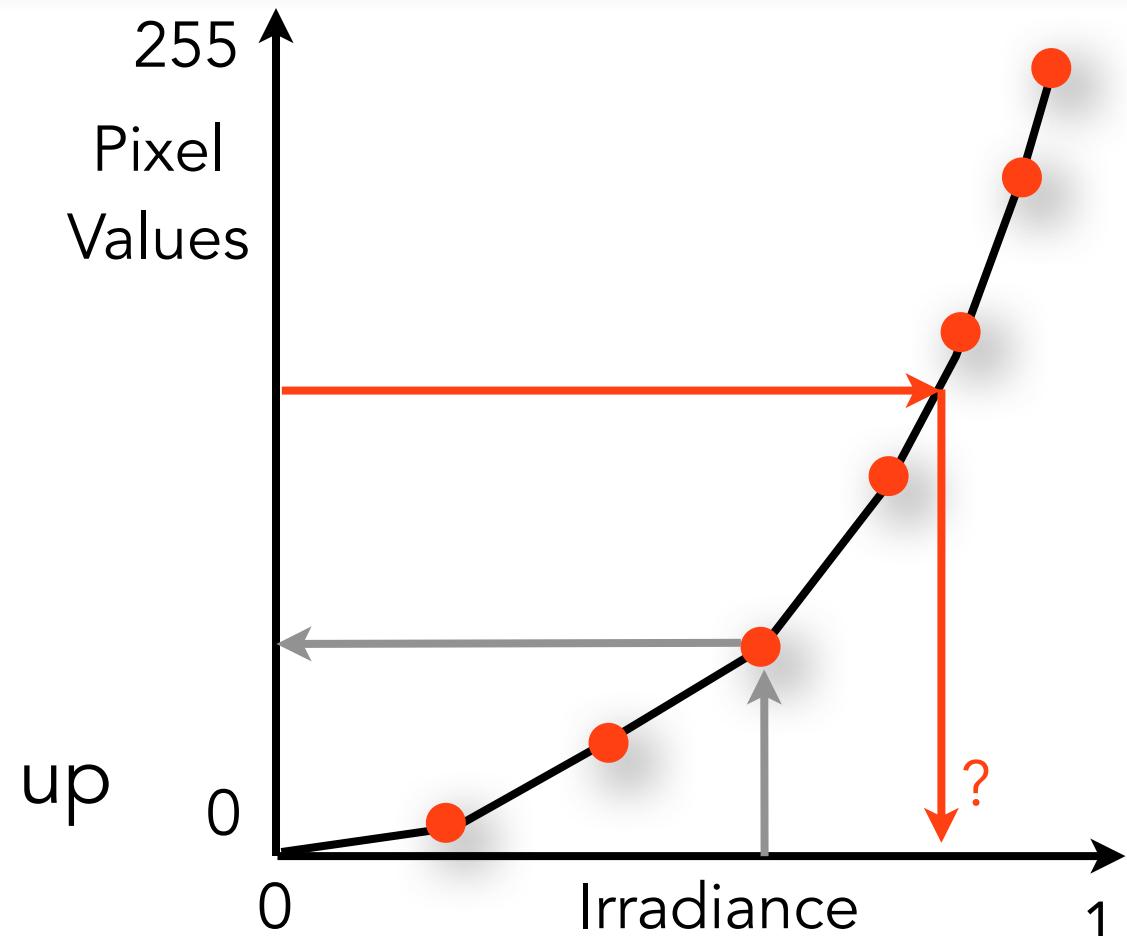
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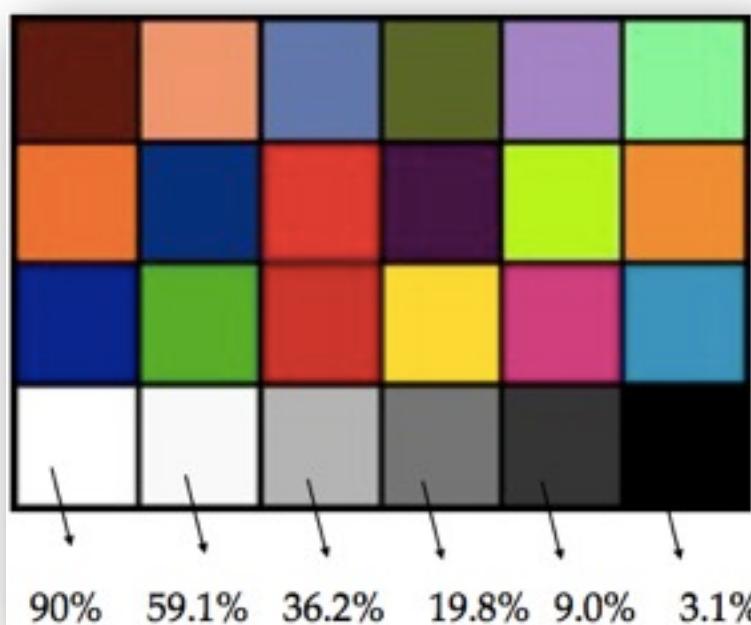
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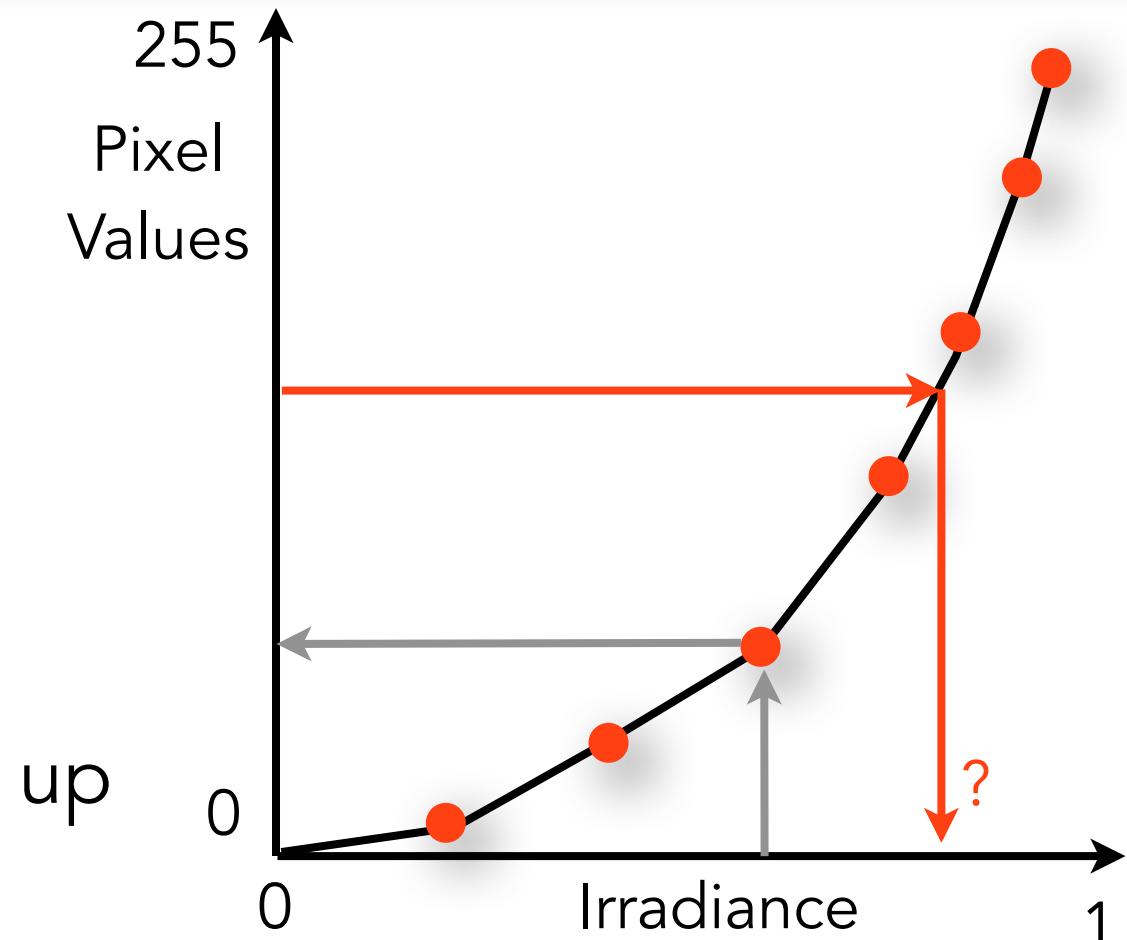
(Grossberg and Nayar 2003)

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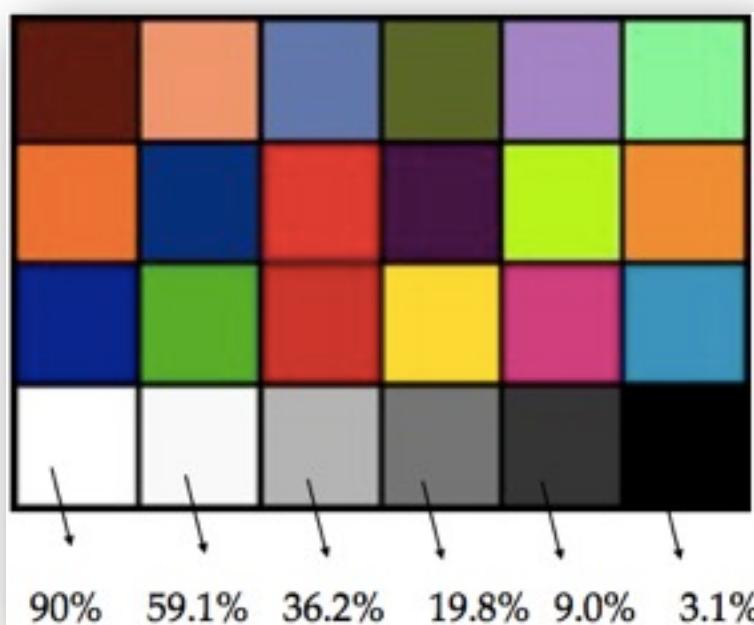
- ★ Use a Color Chart with precisely known reflectances
- ★ Multiple camera exposures to fill up the curve.
- ★ Method assumes constant lighting on all patches and works best when source is far away (example sunlight).



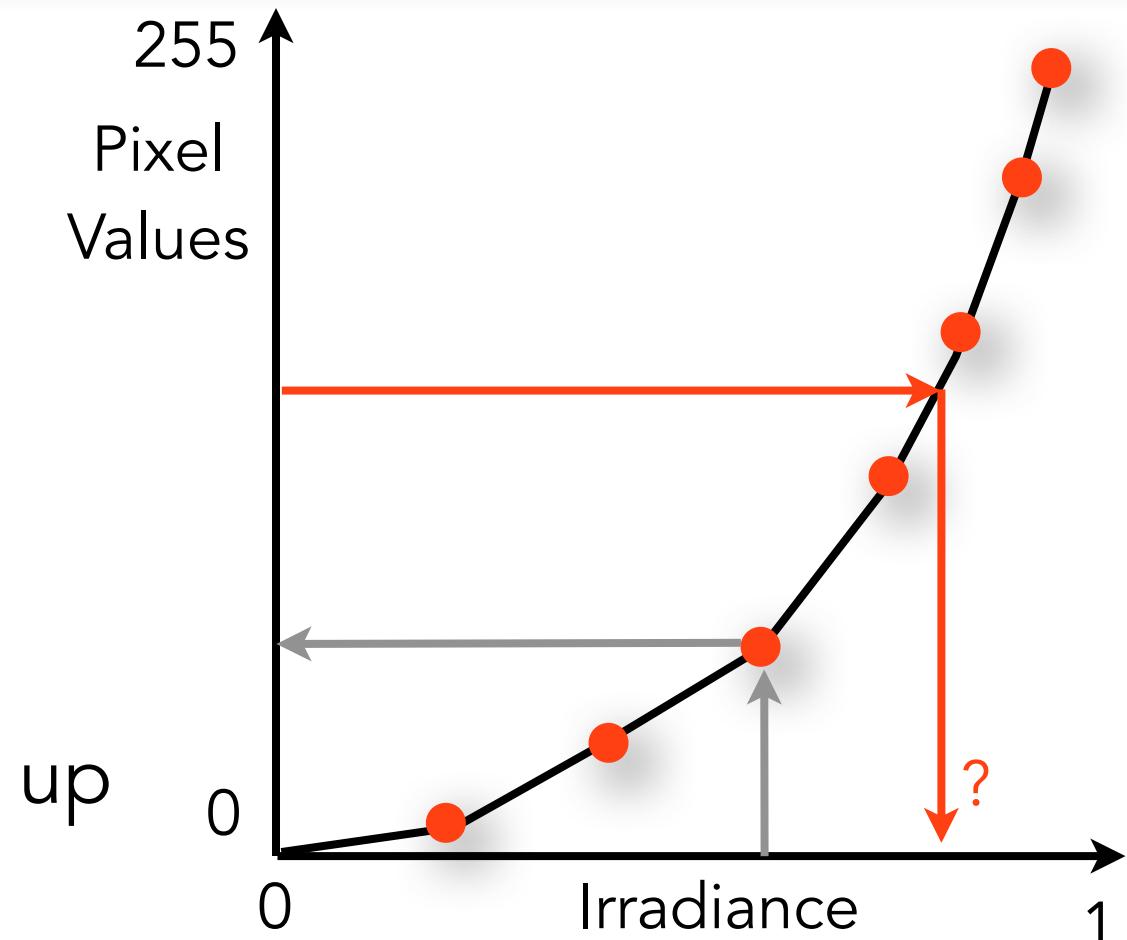
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Radiometric Calibration

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- ★ Use a Color Chart with precisely known 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

A

res



A

res



A

res









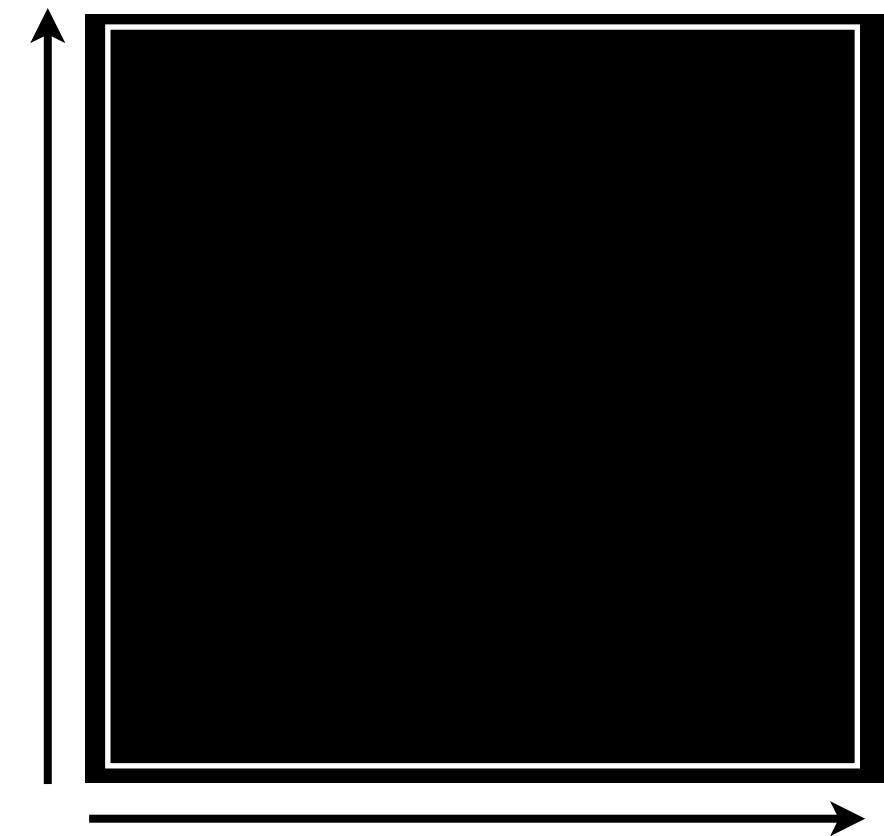
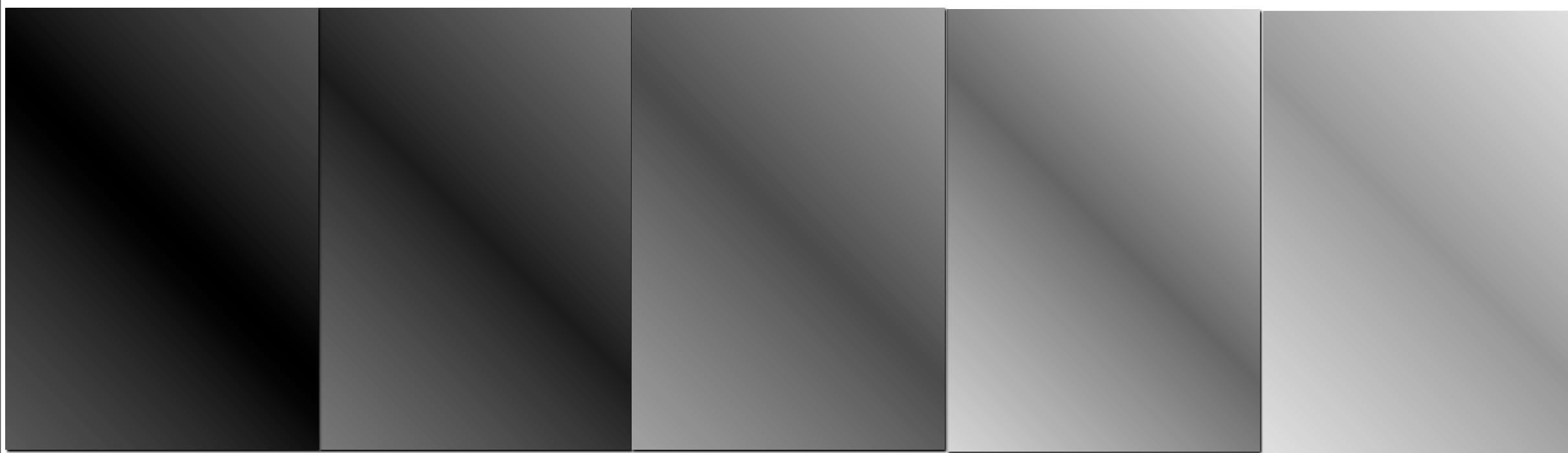


A Sequence of Images of different Exposures



Note: These images were all aligned. If not, we have to align them.

A Sequence of Images of different Exposures



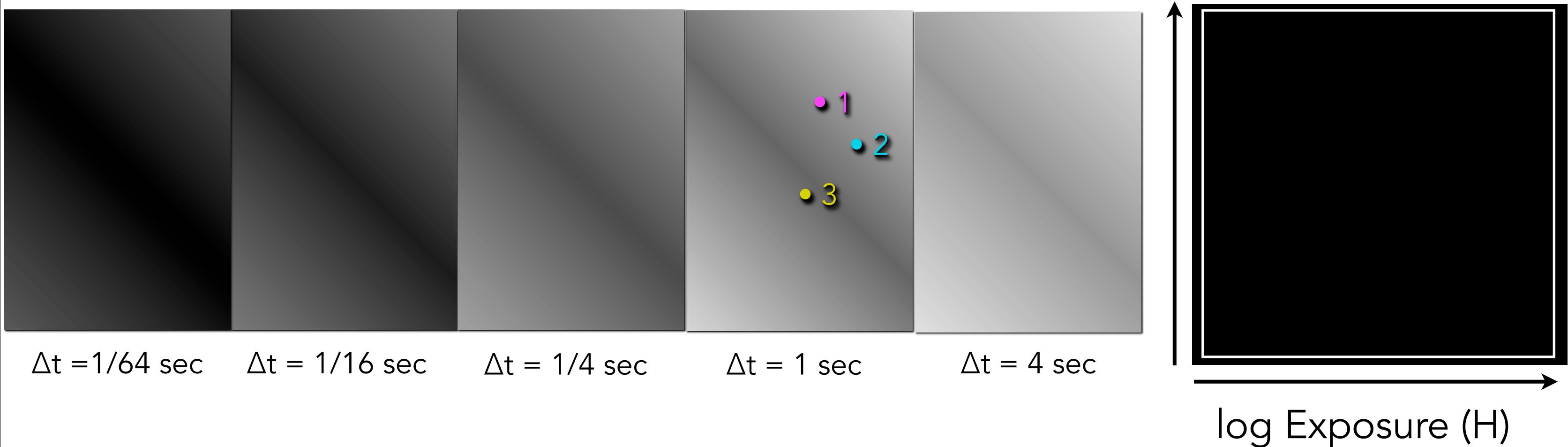
$$\text{Pixel Values } (I) = g(\text{Exposure})$$

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

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

Series of Images

Debevec and Malik 1997



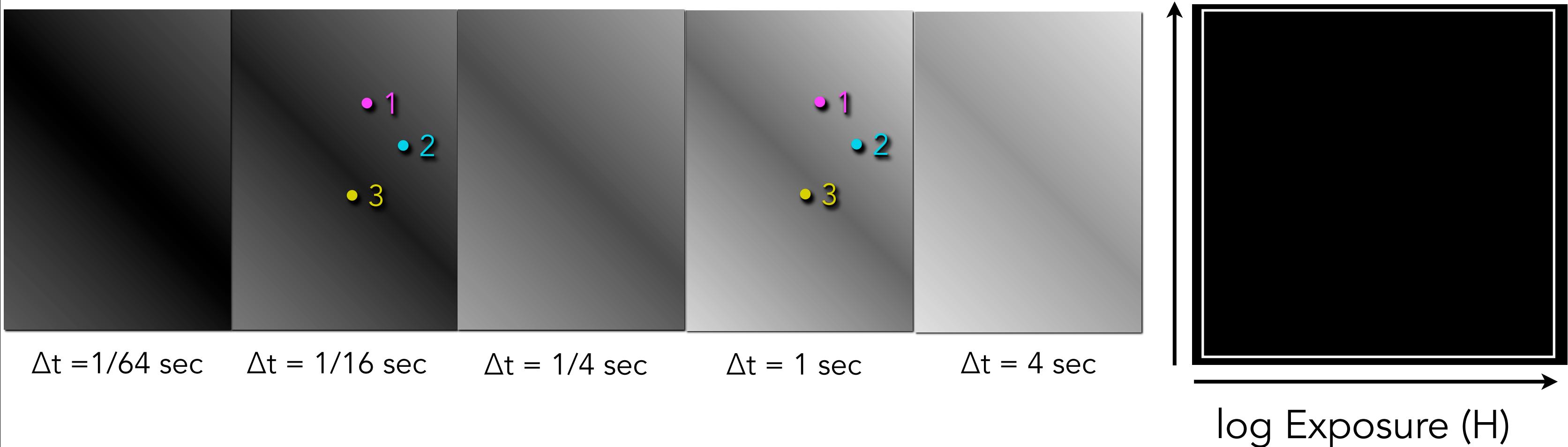
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Series of Images

Debevec and Malik 1997



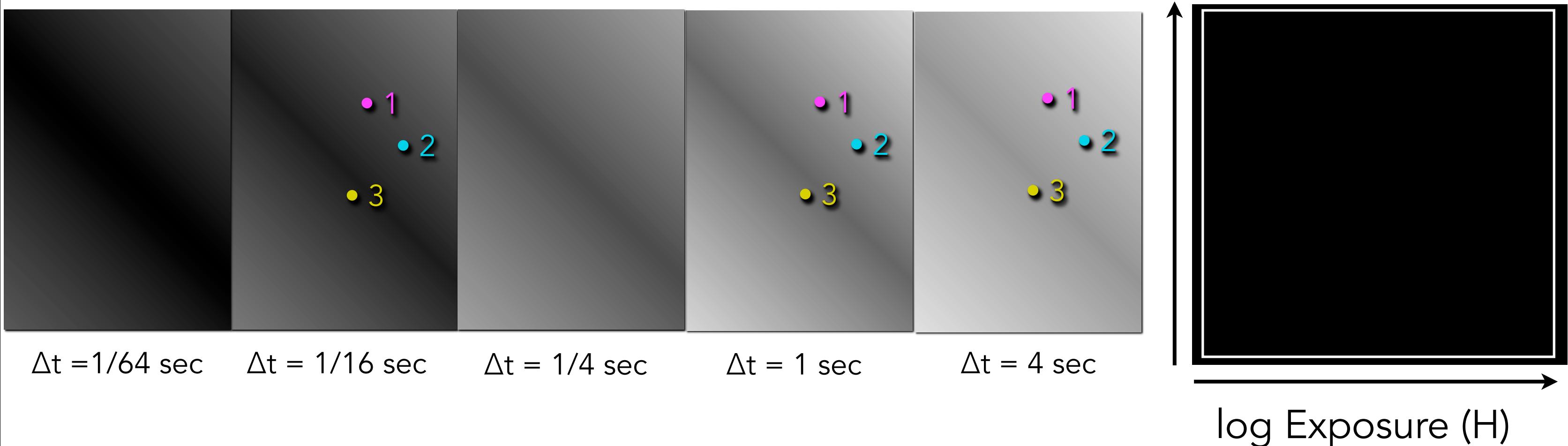
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Series of Images

Debevec and Malik 1997



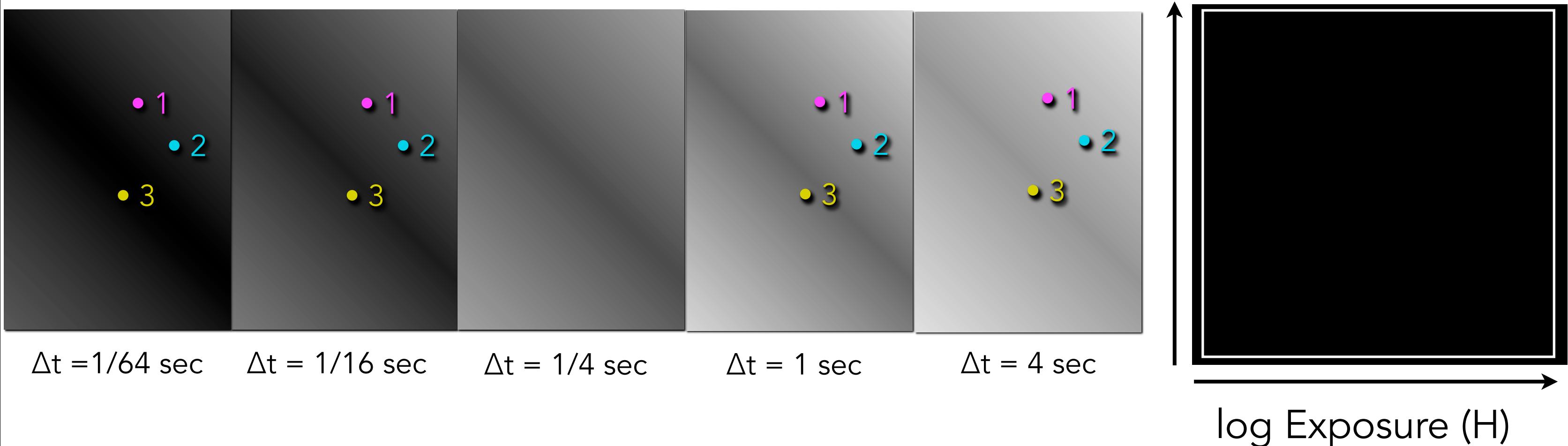
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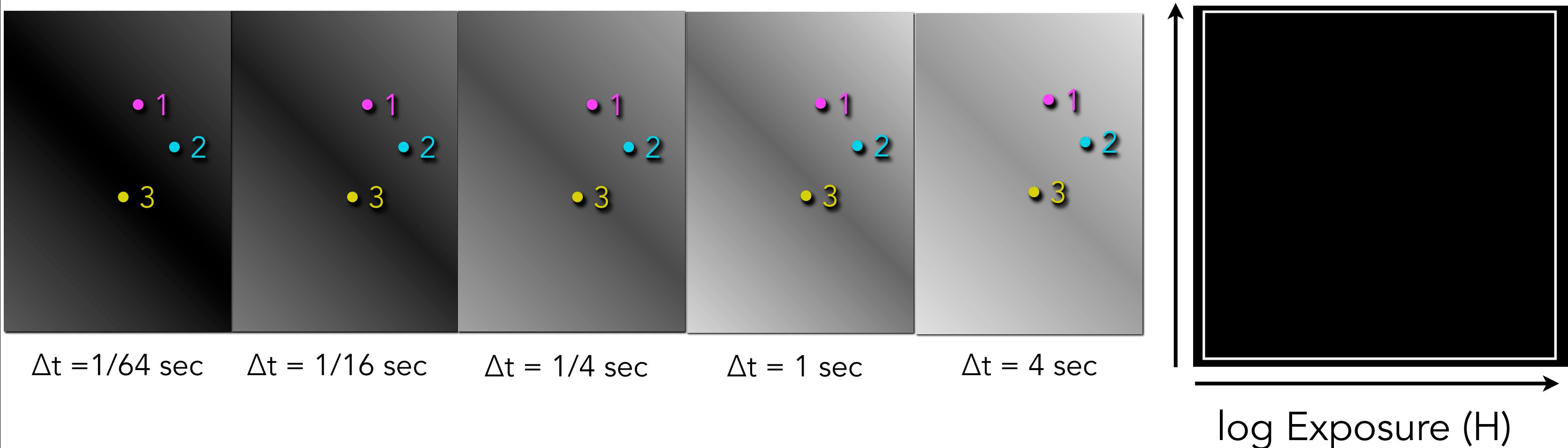
Series of Images

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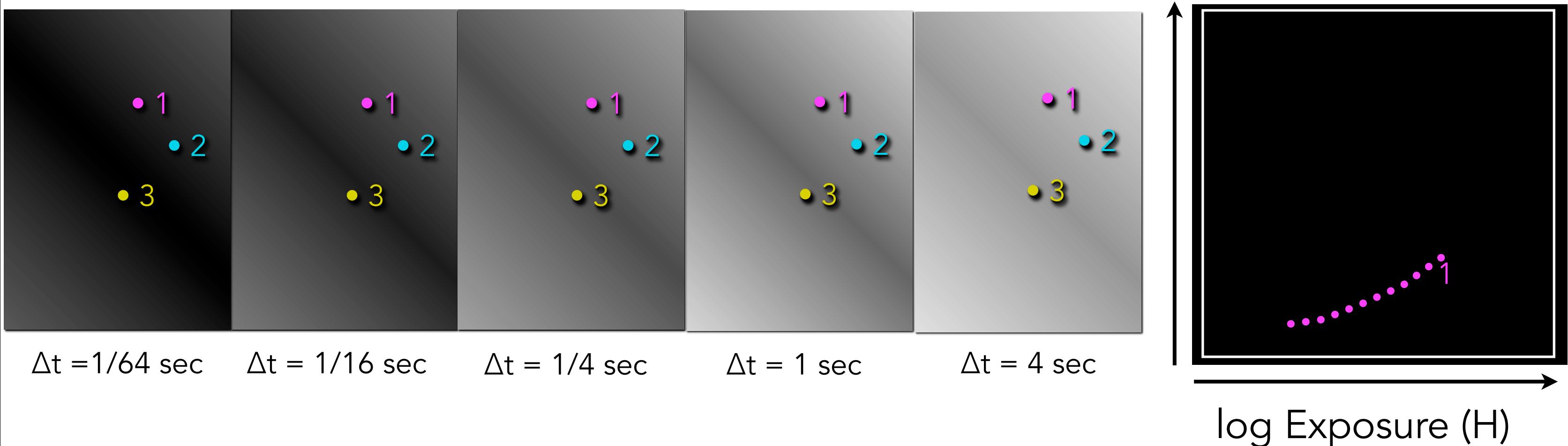
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Series of Images

Debevec and Malik 1997



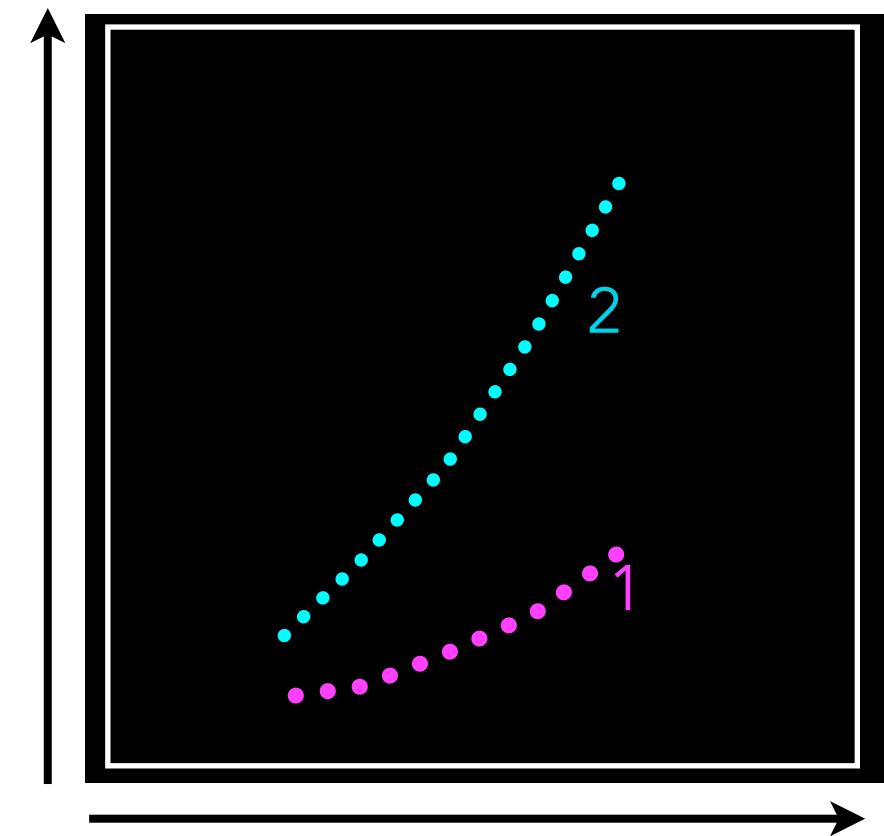
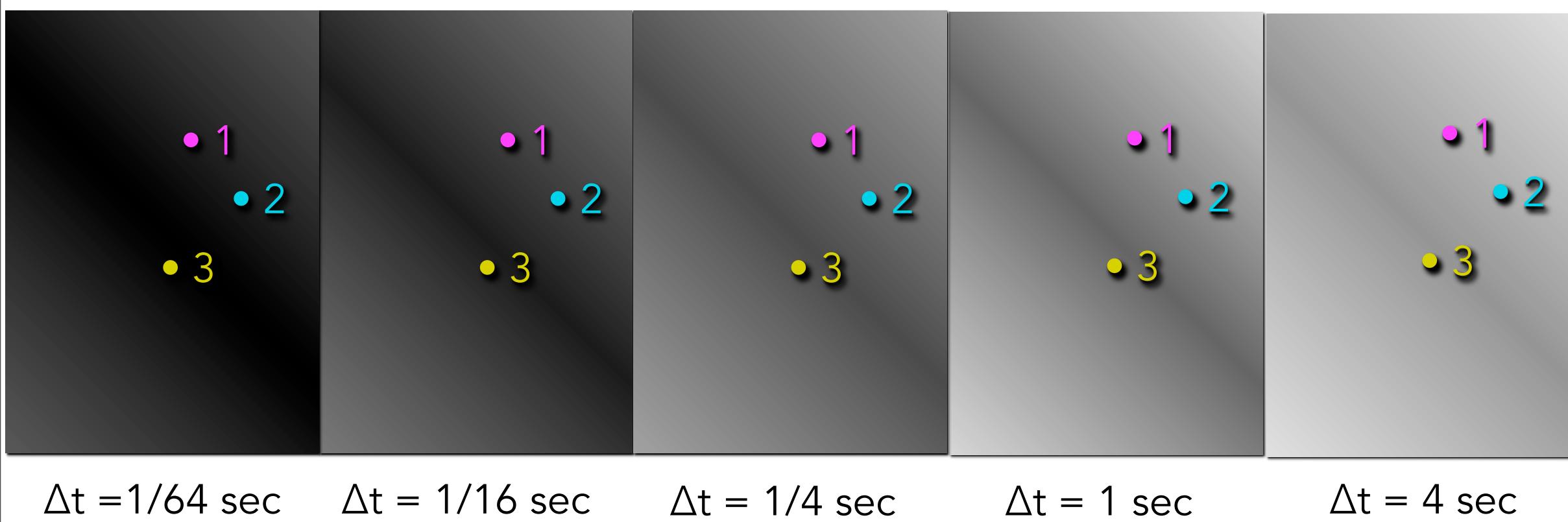
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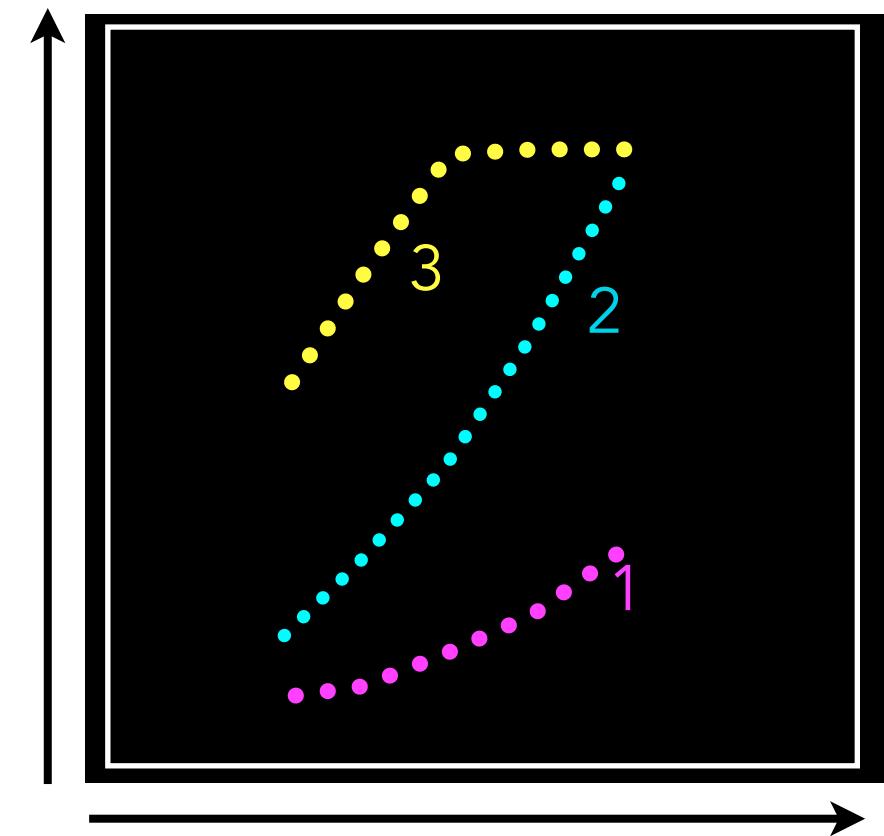
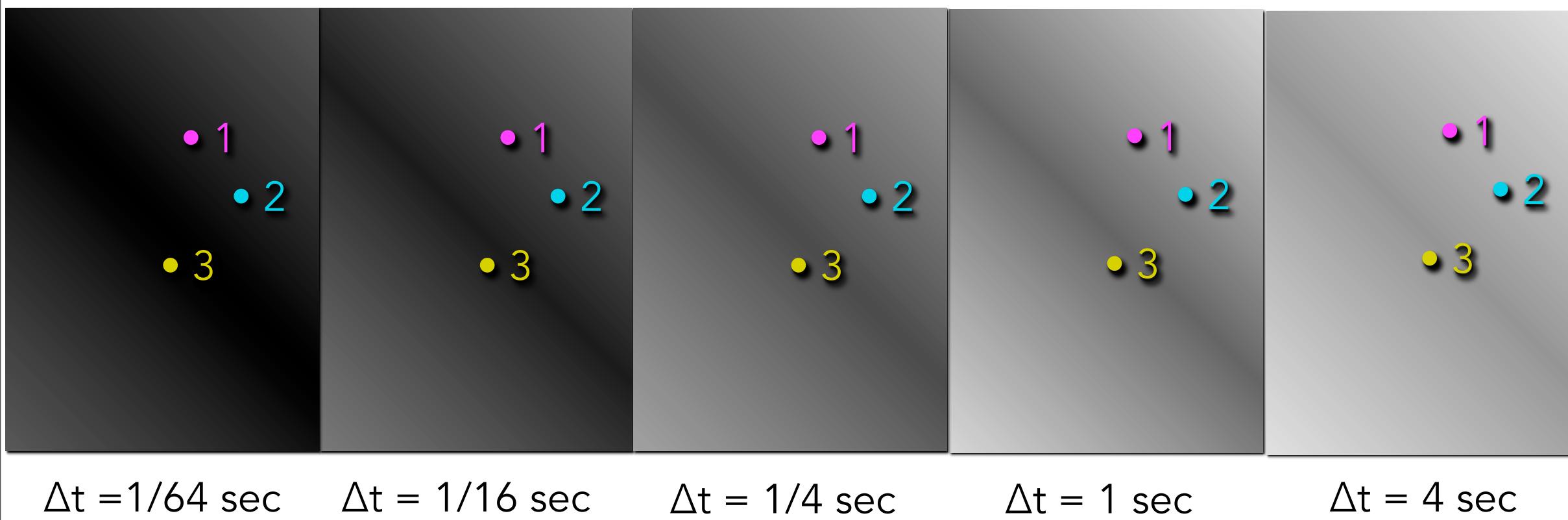
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Series of Images

Debevec and Malik 1997



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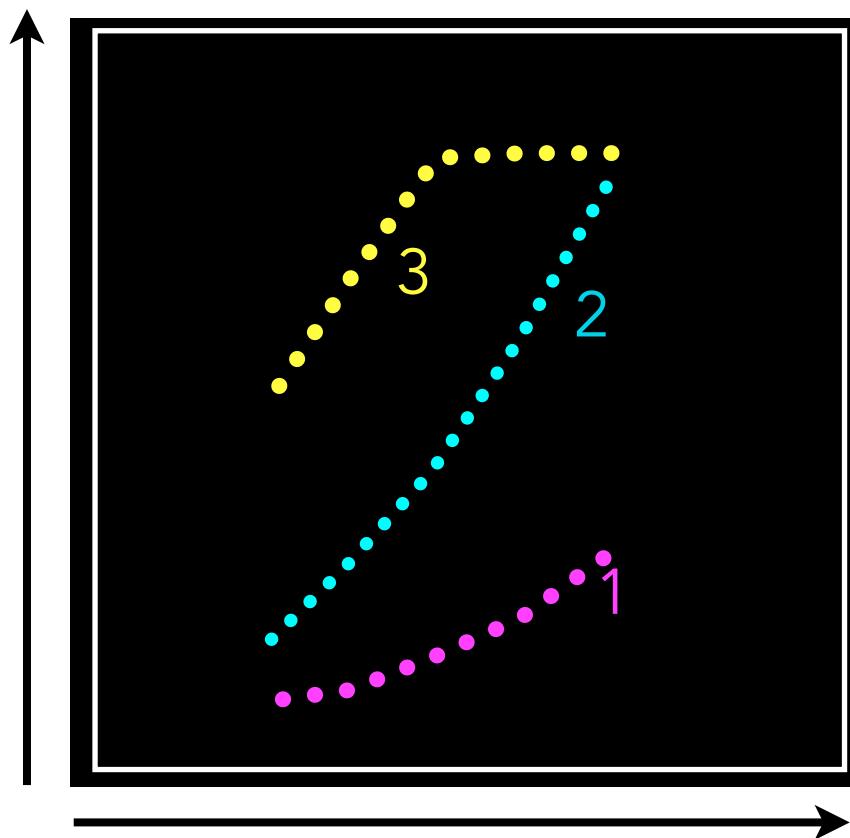
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Series of Images

Debevec and Malik 1997

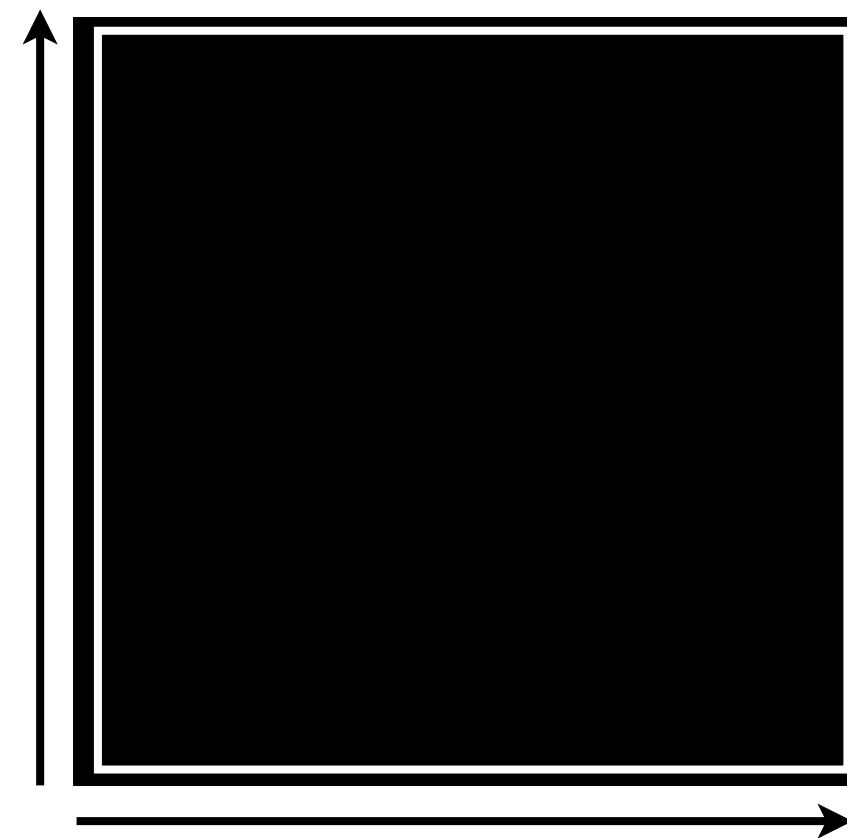
Pixel
Values (I)



log Exposure (H)

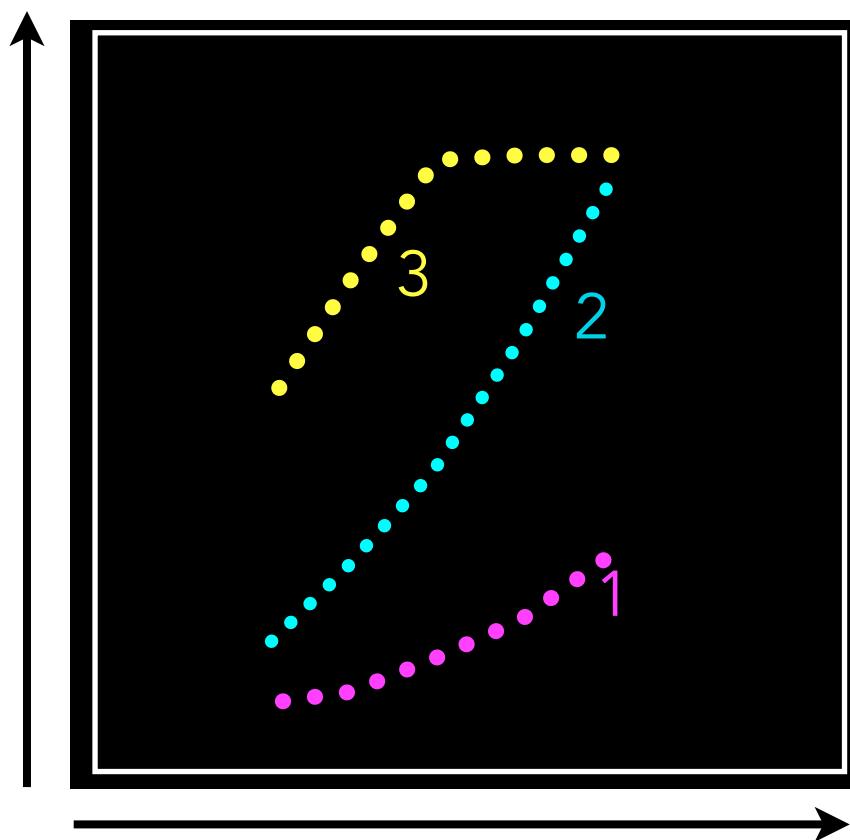
Assuming unit
radiance for each
pixel

Pixel
Values (I)



Response Curves

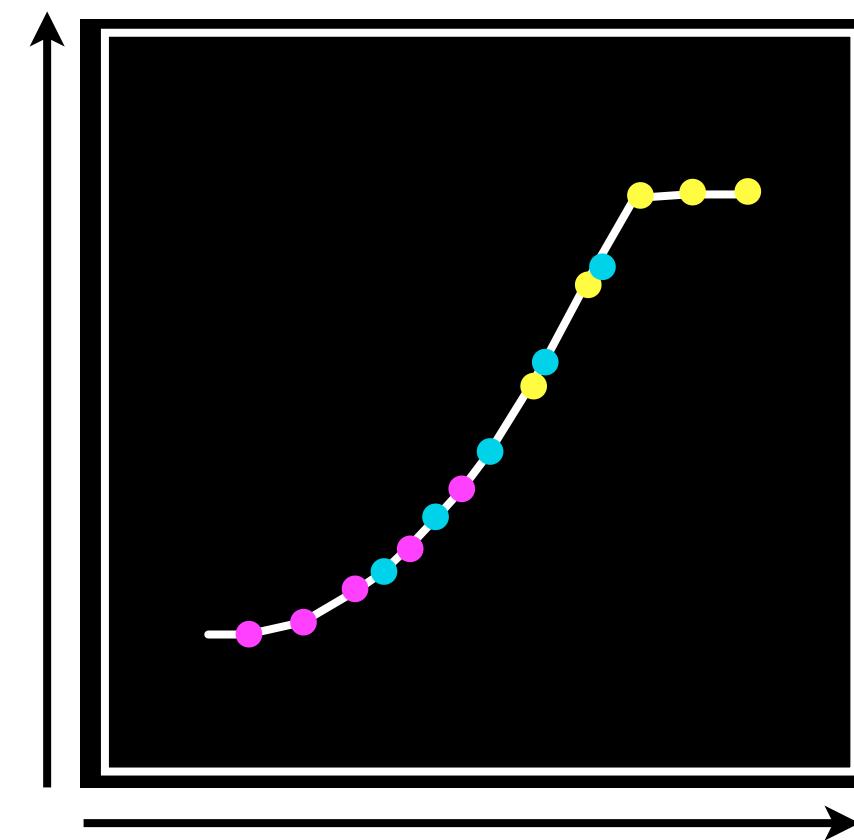
Pixel
Values (I)



log Exposure (H)

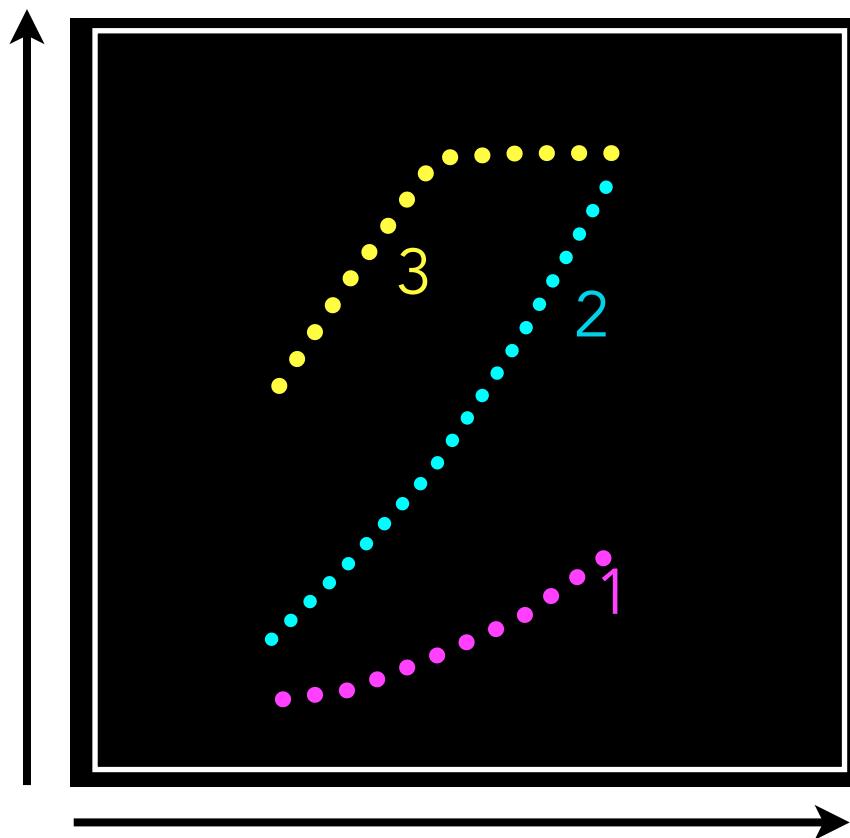
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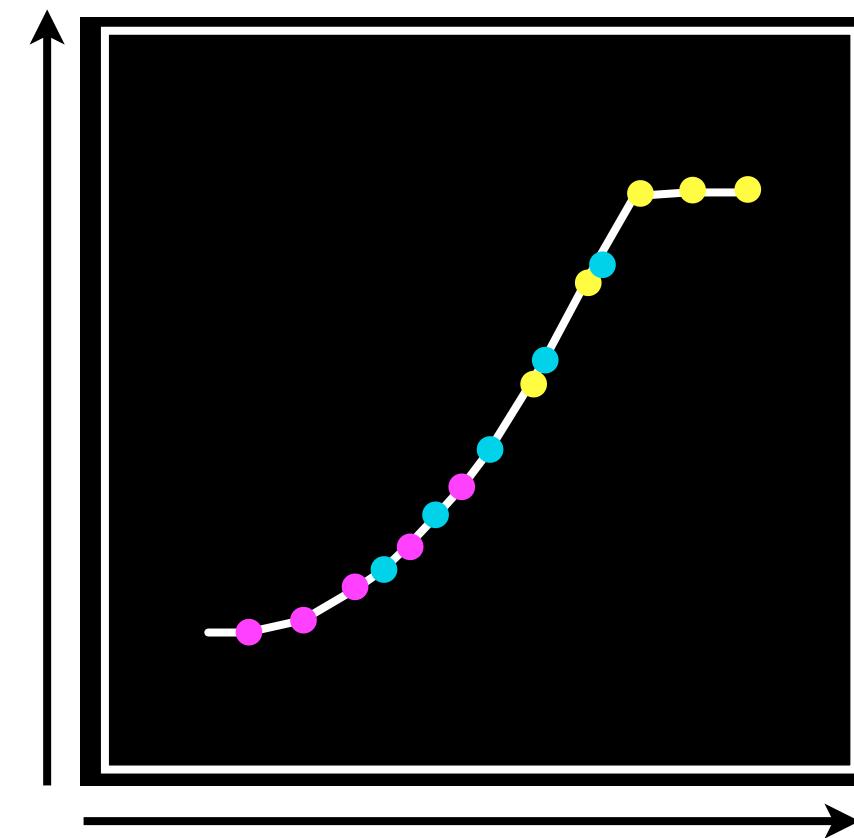
Response Curves

Pixel
Values (I)



Assuming unit
radiance for each
pixel

Pixel
Values (I)



After adjusting radiances
to obtain a smooth
response curve

Response Curves

How to Compute

See Debevec and Malik (1997) for more details

- ★ Let $g(z)$ be the discrete inverse response function

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

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

How to Compute

See Debevec and Malik (1997) for more details

- ★ 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:

$$\sum_{i=1}^N \sum_{j=1}^P [\ln(E_i) + \ln(\Delta t_j) - g(Z_{ij})]^2 + \lambda \sum_{z=Z_{min}}^{Z_{max}} g''(z)^2$$

How to Compute

See Debevec and Malik (1997) for more details

- ★ 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:

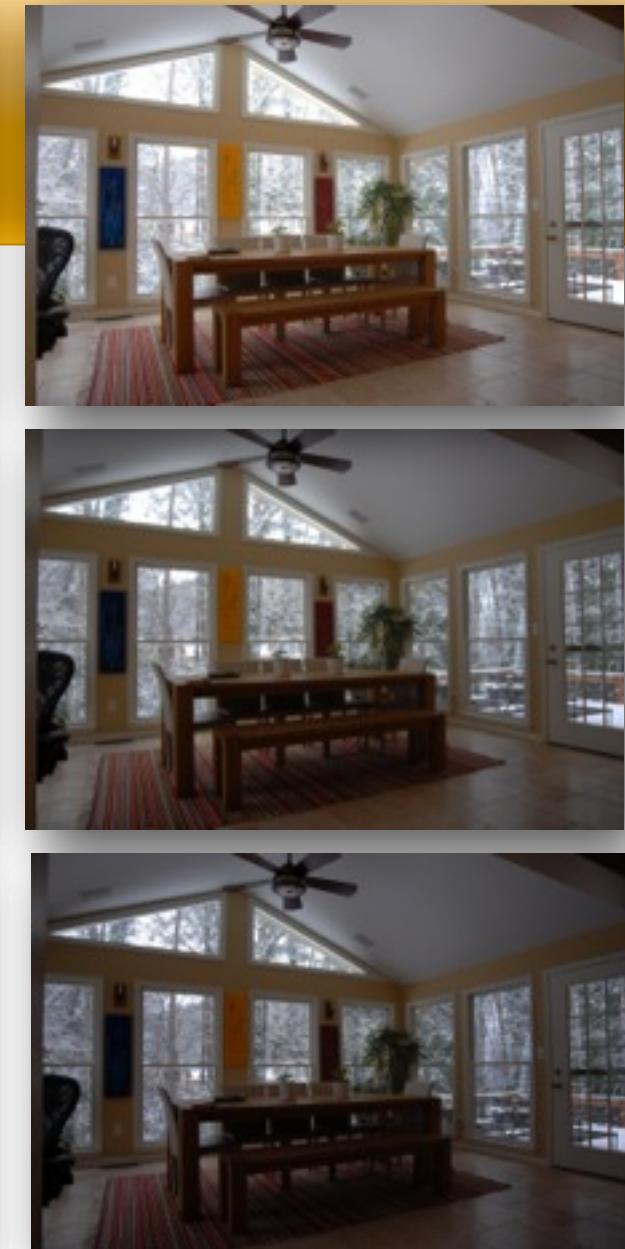
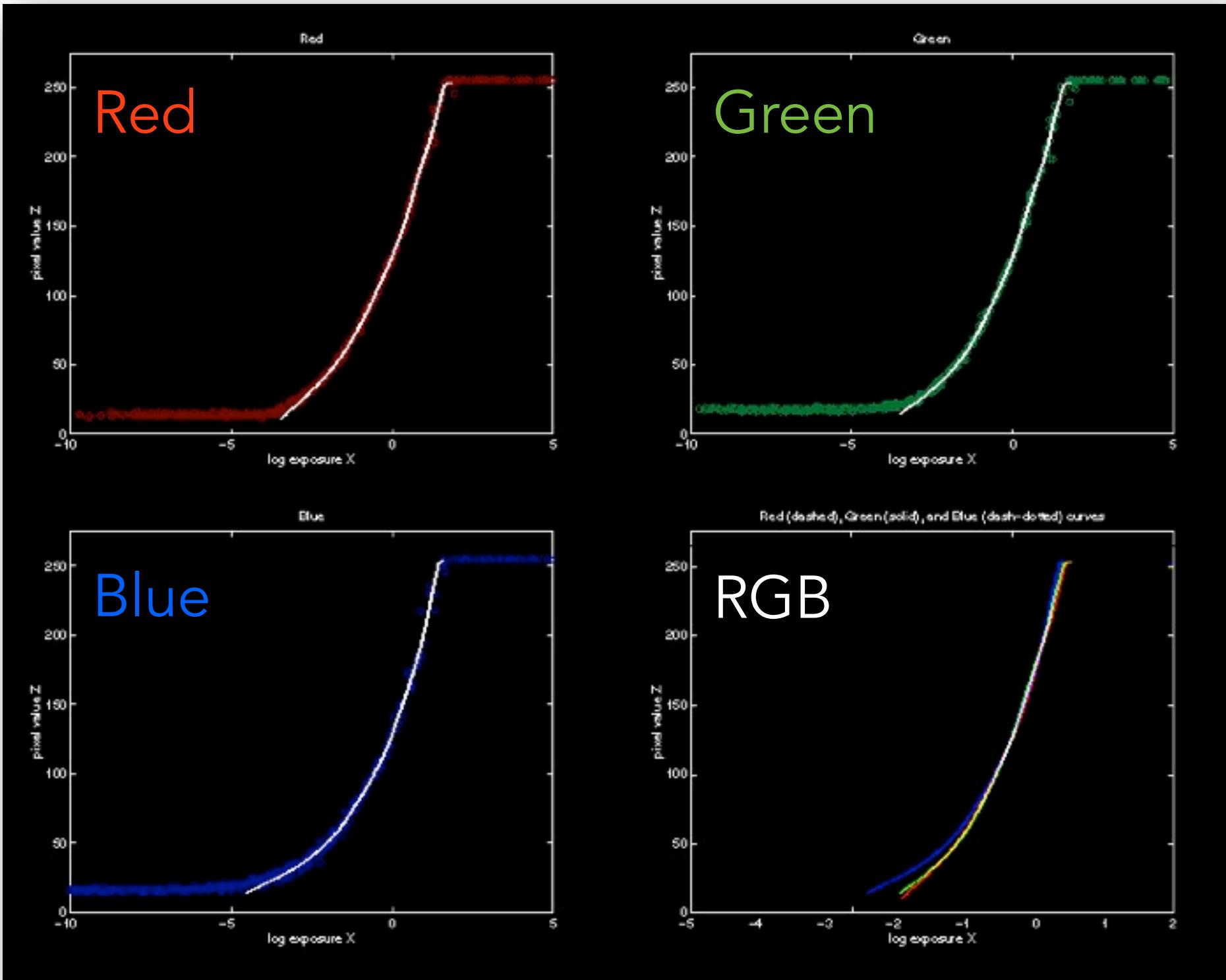
$$\sum_{i=1}^N \sum_{j=1}^P [\ln(E_i) + \ln(\Delta t_j) - g(Z_{ij})]^2 + \lambda \sum_{z=Z_{min}}^{Z_{max}} g''(z)^2$$

Fitting Term

Smoothness
Term

See Debevec and Malik (1997) for more details

How to Compute



Response Curves

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

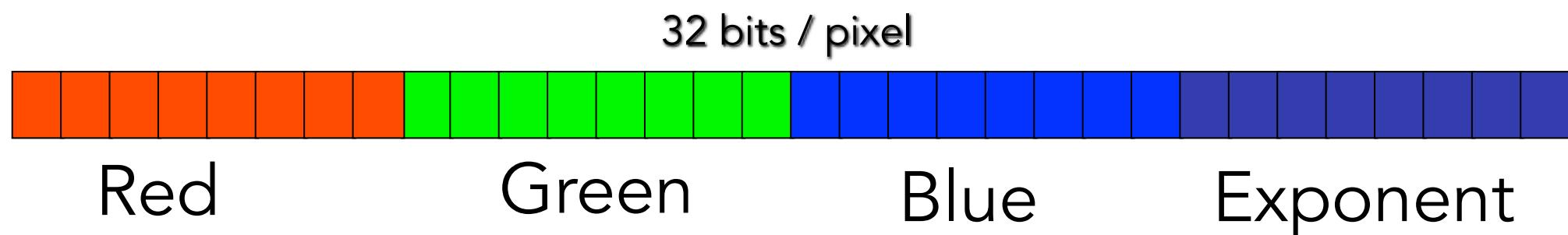
12,871.00



Radiance Map

0.6215

Radiance Format



Need a New
File Format

$$\begin{array}{l|l}
 \begin{array}{l}
 (145, 215, 87, 149) = \\
 (145, 215, 87) * 2^{(149-128)} = \\
 (\textcolor{red}{1190000}, \textcolor{green}{1760000}, \textcolor{blue}{713000})
 \end{array} & \begin{array}{l}
 (145, 215, 87, 103) = \\
 (145, 215, 87) * 2^{(103-128)} = \\
 (\textcolor{red}{0.00000432}, \textcolor{green}{0.00000641}, \textcolor{blue}{0.00000259})
 \end{array}
 \end{array}$$

Ward 2001

There are many other formats too.



Now to Display it!



Tone Mapping

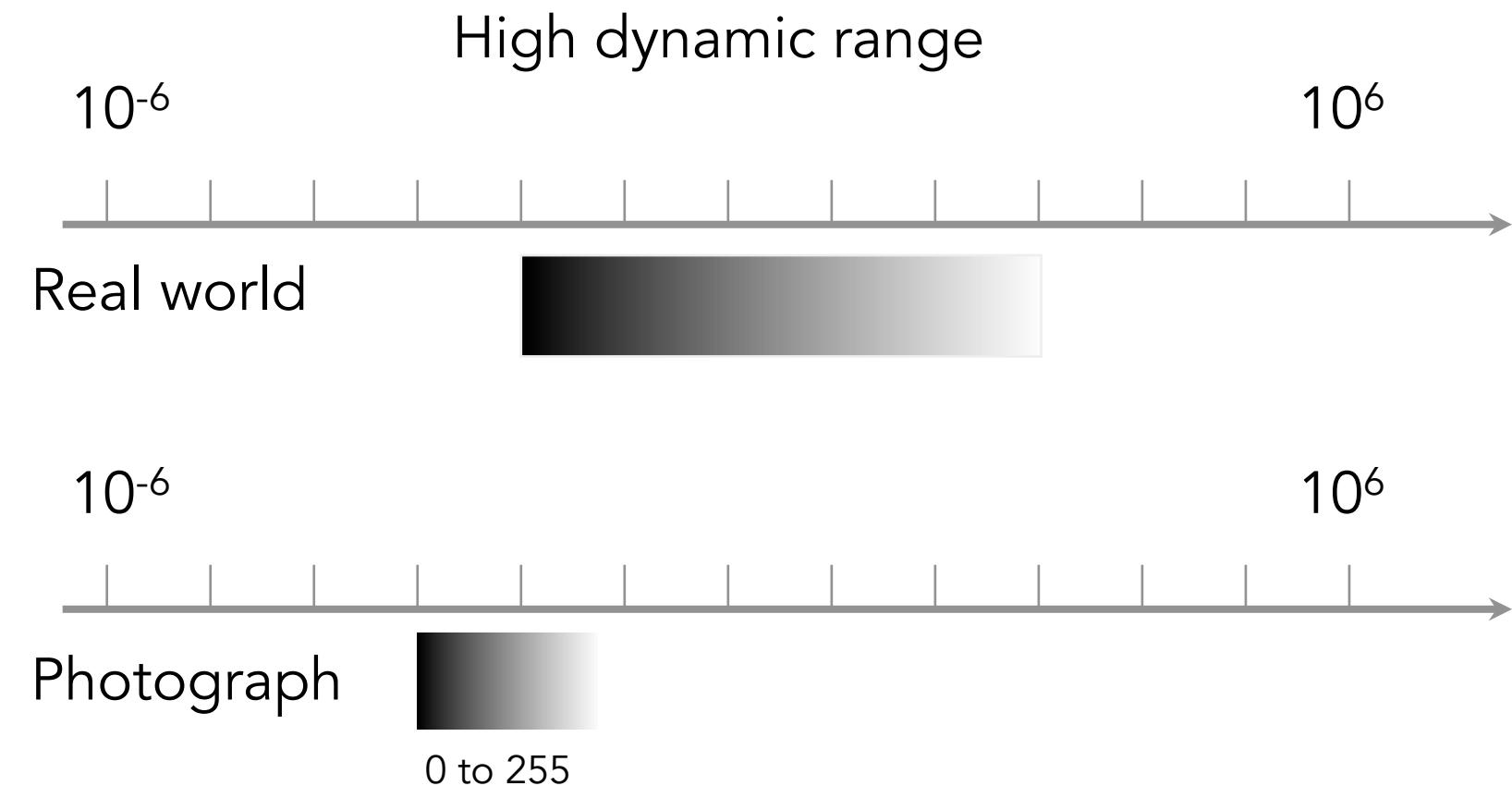
- ★ Map one set of colors to another in order to approximate the appearance of high dynamic range images
- ★ For displaying on a medium that has limited dynamic range.
 - Printers, monitors, and projectors all have a limited dynamic range that is inadequate to reproduce the full range of light intensities present in natural scenes.
- ★ Addresses the problem of strong contrast reduction from the scene radiance to the displayable range while preserving the image details and color appearance important to appreciate the original scene content.
- ★ Many well-known Algorithms exist for this.
- ★ See Banterle, et al. (2011), Reinhard et al. (2002) and Durand and Dorsey (2002)



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



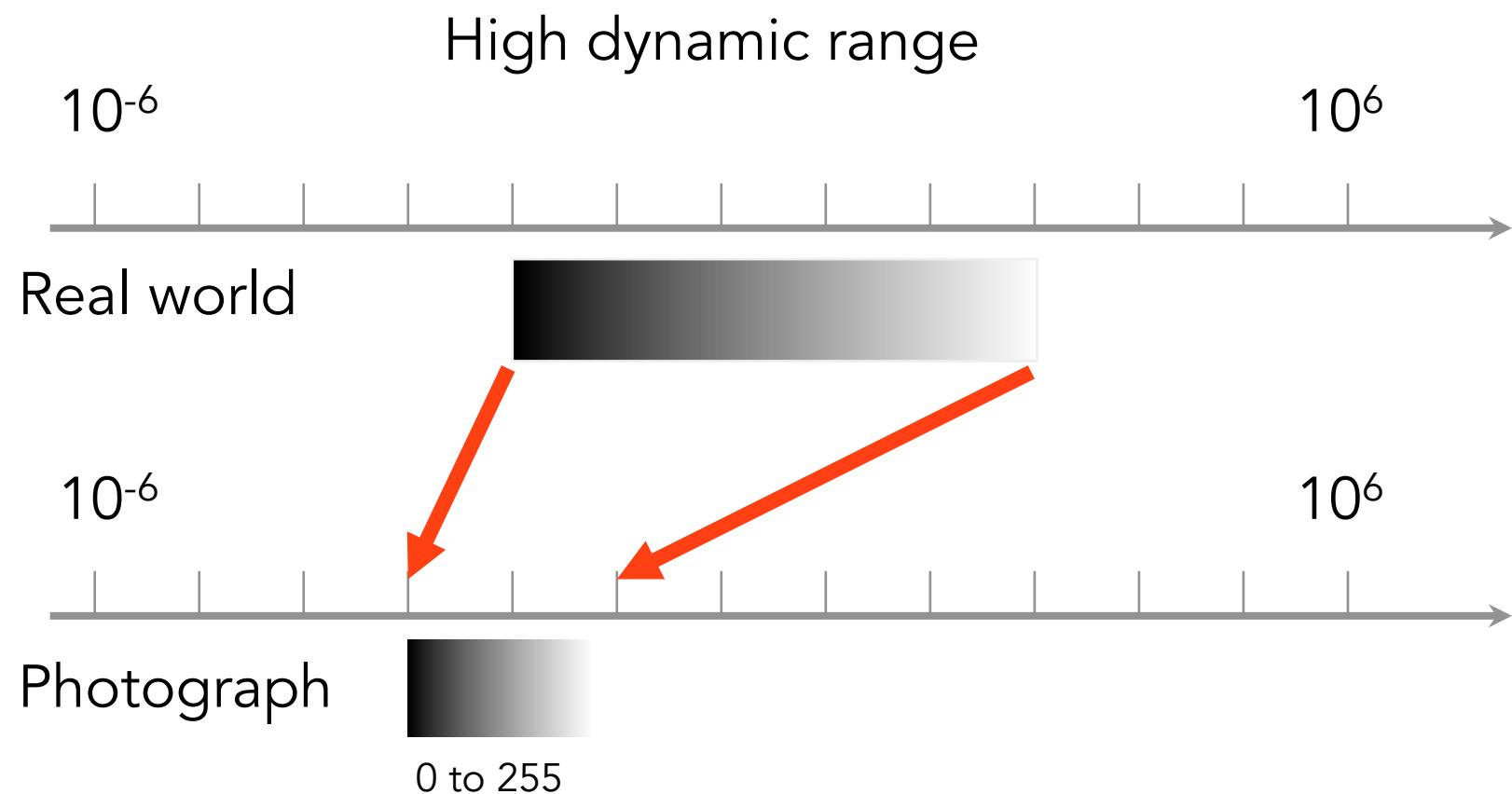
http://en.wikipedia.org/wiki/File:Dundas_Square.jpg



Tone Mapping



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

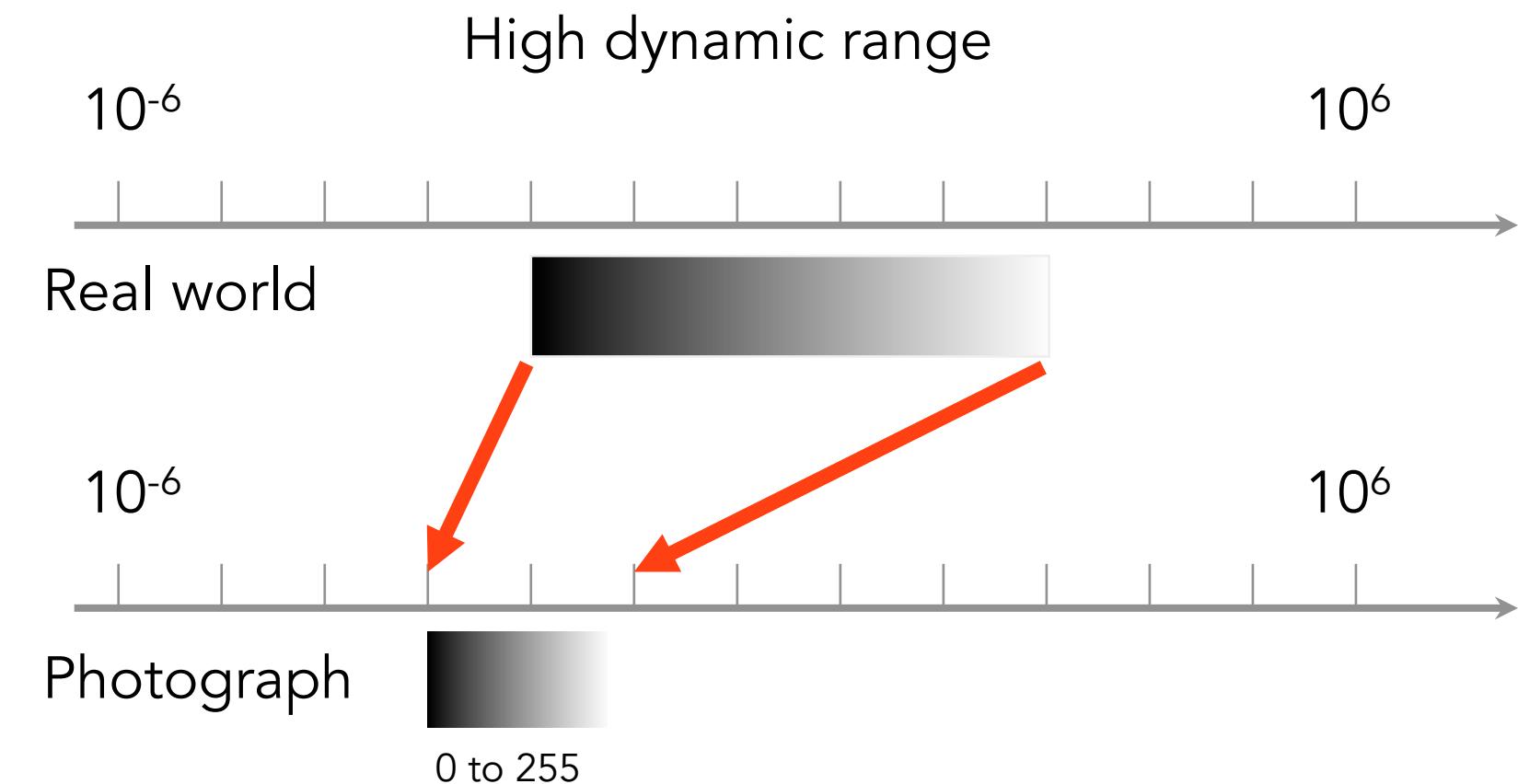


Tone Mapping



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

- ★ Match limited contrast of the medium

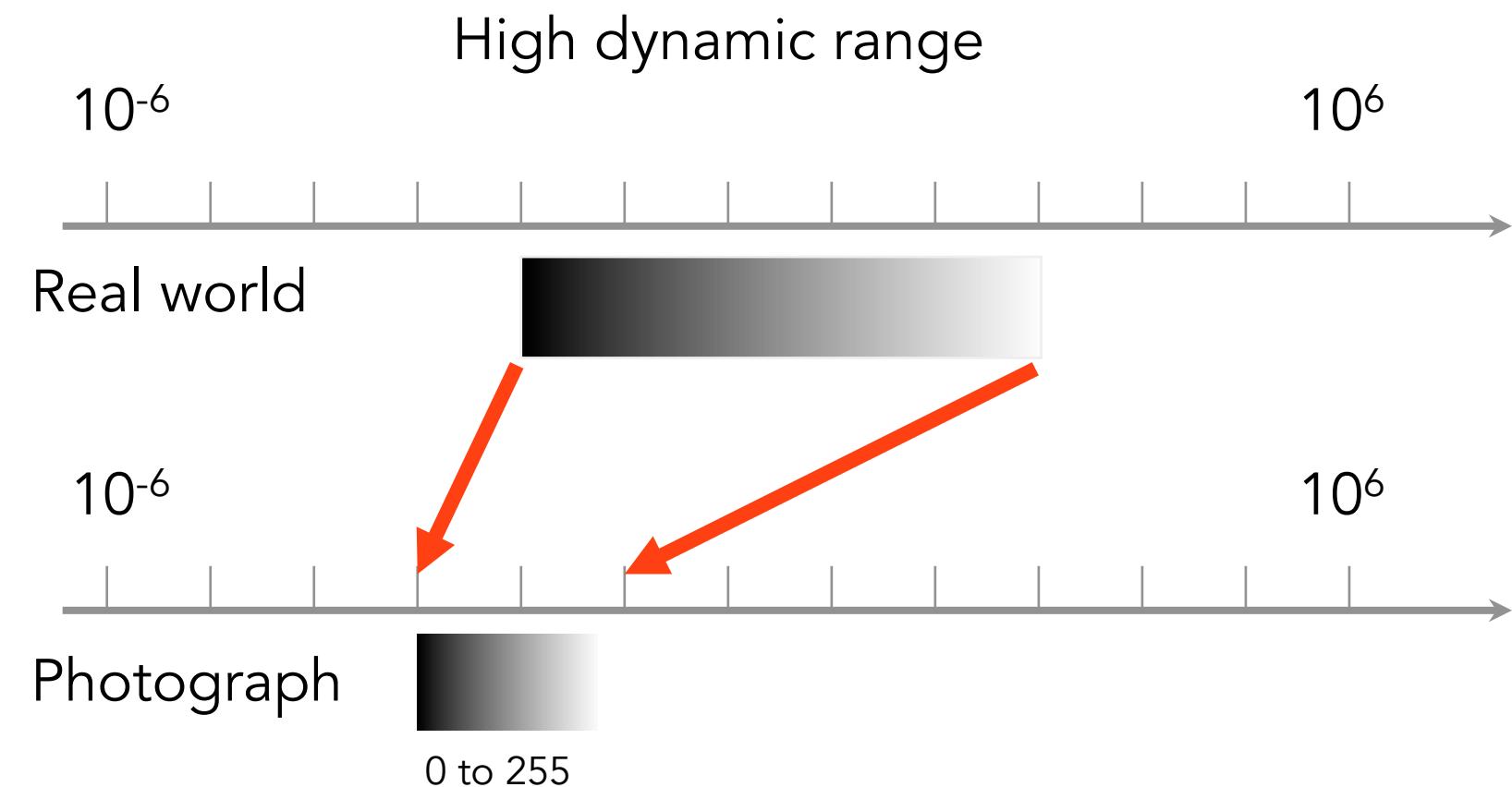


Tone Mapping



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

- ★ Match limited contrast of the medium
- ★ Preserve details



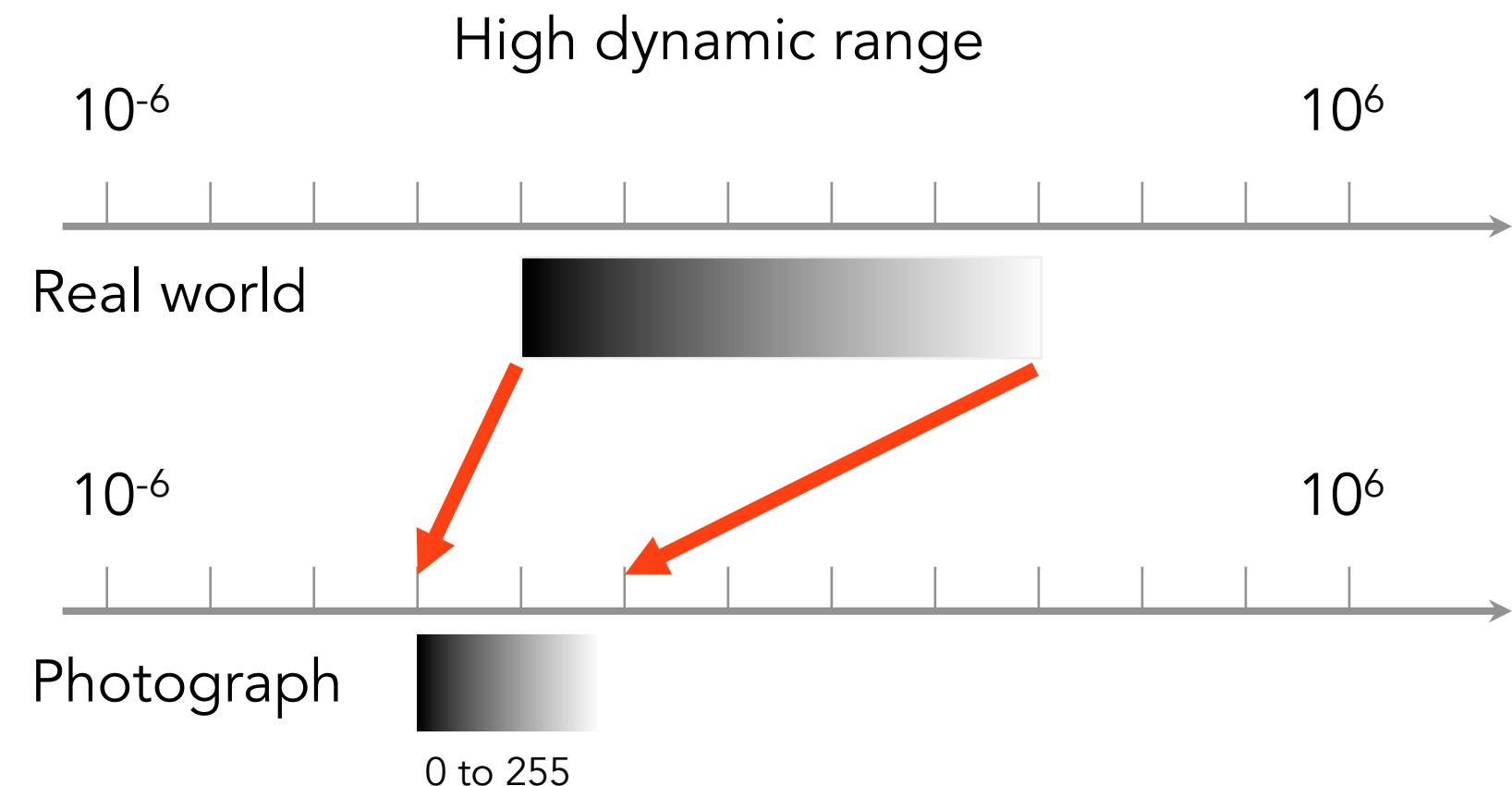
Tone Mapping



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

- ★ Match limited contrast of the medium
- ★ Preserve details
- ★ Use filtering approaches to “compress” locally and globally

Tone Mapping



Summary (of Part 1 and 2)

- ★ 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.
- ★ 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.



<https://commons.wikimedia.org>

Further Information

- ★ Grossberg and Nayar (2003), "Determining the Camera Response from Images: What is Knowable?," IEEE Transactions on Pattern Analysis and Machine Intelligence, [PDF]
- ★ Debevec and Malik (1997). "Recovering High Dynamic Range Radiance Maps from Photographs." In SIGGRAPH 1997 [PDF]
- ★ Ward (2001), "High Dynamic Range Imaging," Proceedings of the Ninth Color Imaging Conference, November 2001. [PDF]
- ★ Durand and Dorsey (2002), "Fast Bilateral Filtering for the Display of High-Dynamic-Range Images" In SIGGRAPH 2002. [PDF]
- ★ Reinhard, Stark, Shirley and Ferwerda (2002), "Photographic Tone Reproduction for Digital Images", In SIGGRAPH 2002. [Website]
- ★ 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"



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Next Class

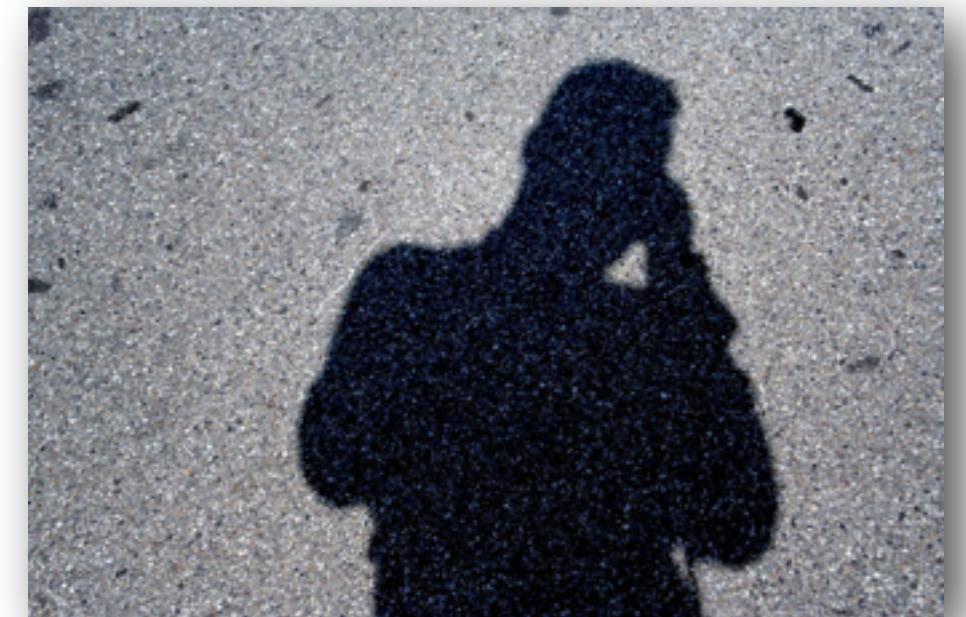
★ Introduction to Videos

- How can we do Computational Videography?



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.
- ★ Some images retrieved from
 - <http://commons.wikimedia.org/>.
 - List will be available on website.
 - Photographs by Irfan Essa



www.flickr.com/photos/neneonline/231886965/

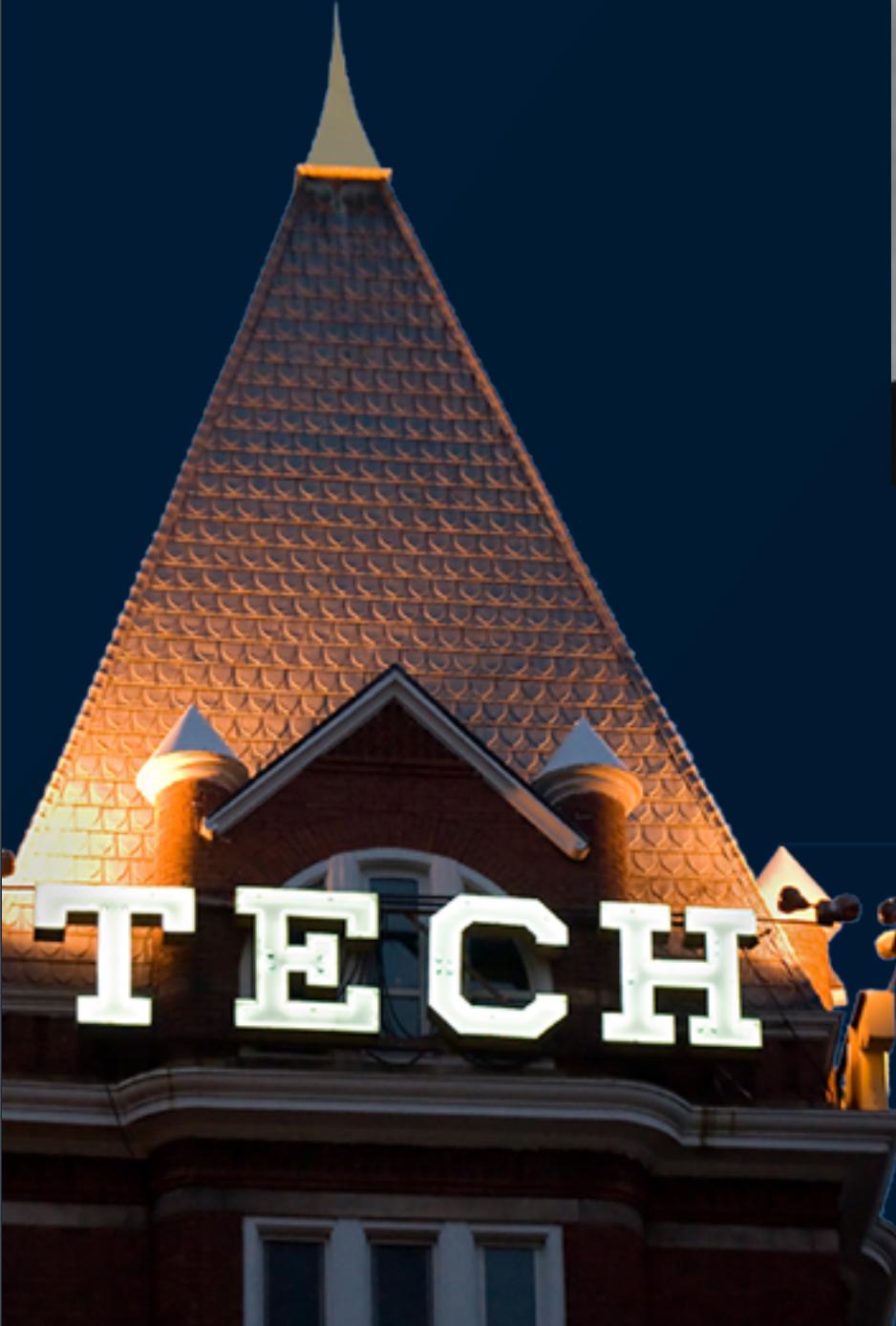
Computational Photography



Dr. Irfan Essa

Professor

School of Interactive Computing



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