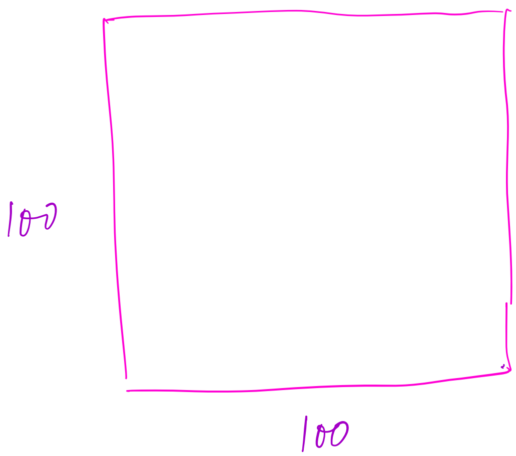
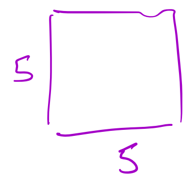
High Dynamic Range Photography

Computational Photography (CSCI 3240U)

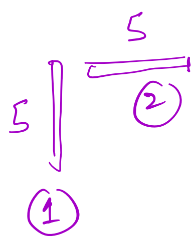
Faisal Z. Qureshi
http://vclab.science.ontariotechu.ca
OntarioTech UNIVERSITY





per pixel = 25 "*"
24 "+"

total = (10,000)(25 "*", 24 "+")



per pixel = 5 "*"
4 "+"

1 total = (10,000)(5 "*"
4 "+")

2 (10,000)(5 "*", 4 "+")

(10,000)(10 "*", 8 "+")

$$F = U \Sigma V^T$$

High Dynamic Range (HDR) Photography

- Human eyes have high visual range
  - It can differentiate and see structure between very bright and very dark regions in a scene
- An image is taken at a particular exposure setting, which determines whether it contains more visible structure in brighter or darker regions

Images taken at various exposure settings

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HDR techniques combine multiple images of the same scene to emulate the high visual range of human eyes

Images taken at various exposure settings

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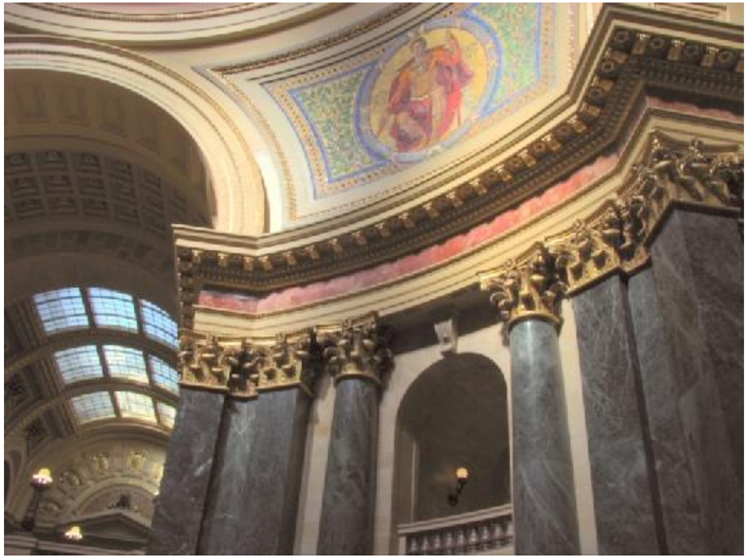
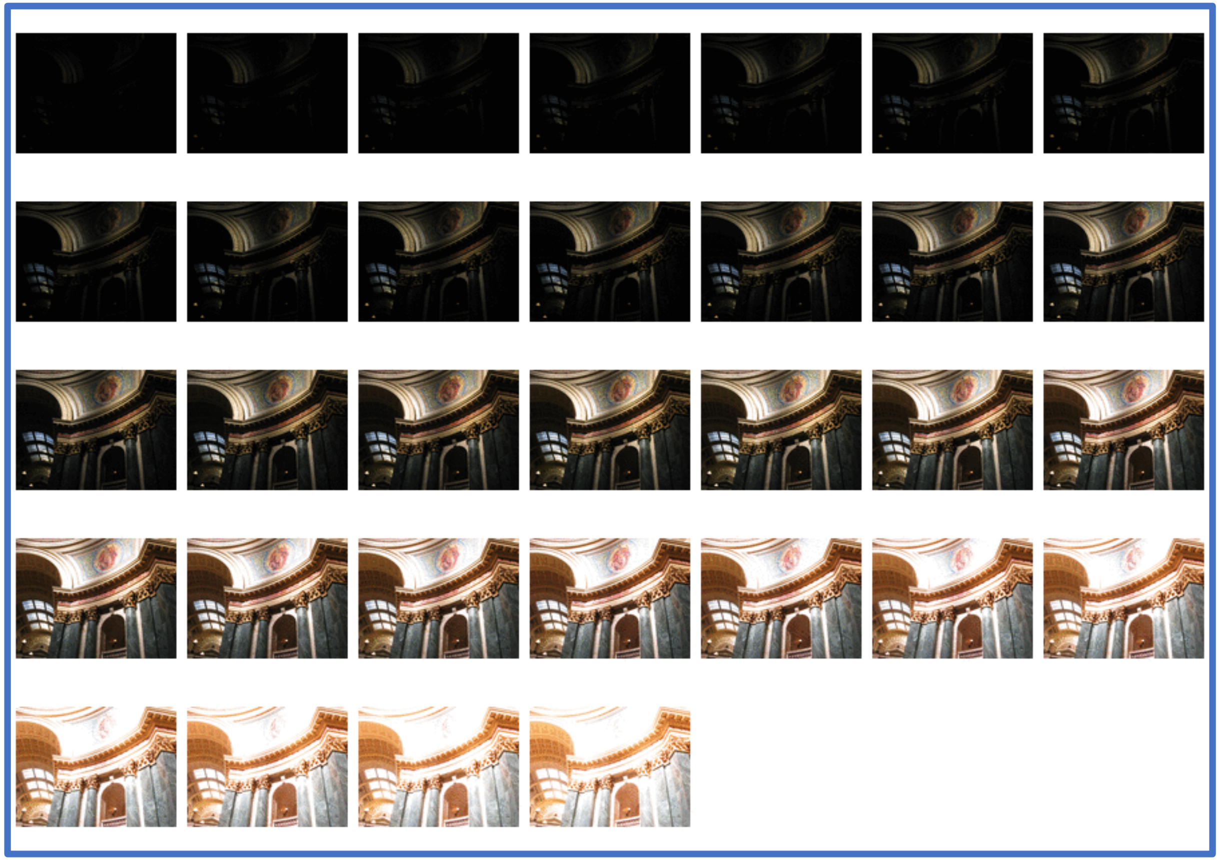
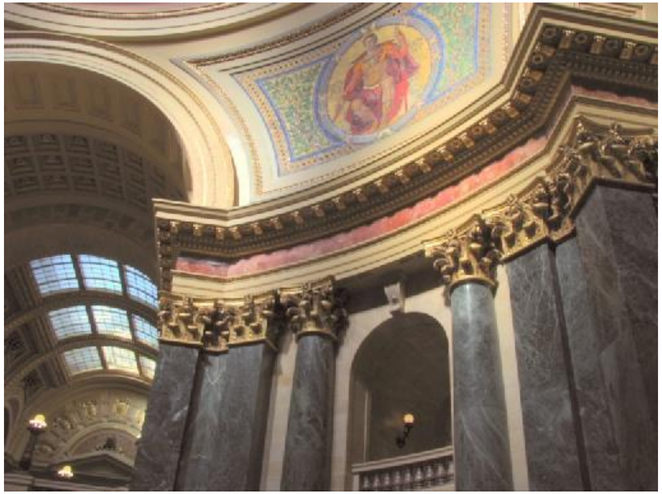


HDR image

High Dynamic Range (HDR) Photography



Images taken at various exposure settings



HDR image

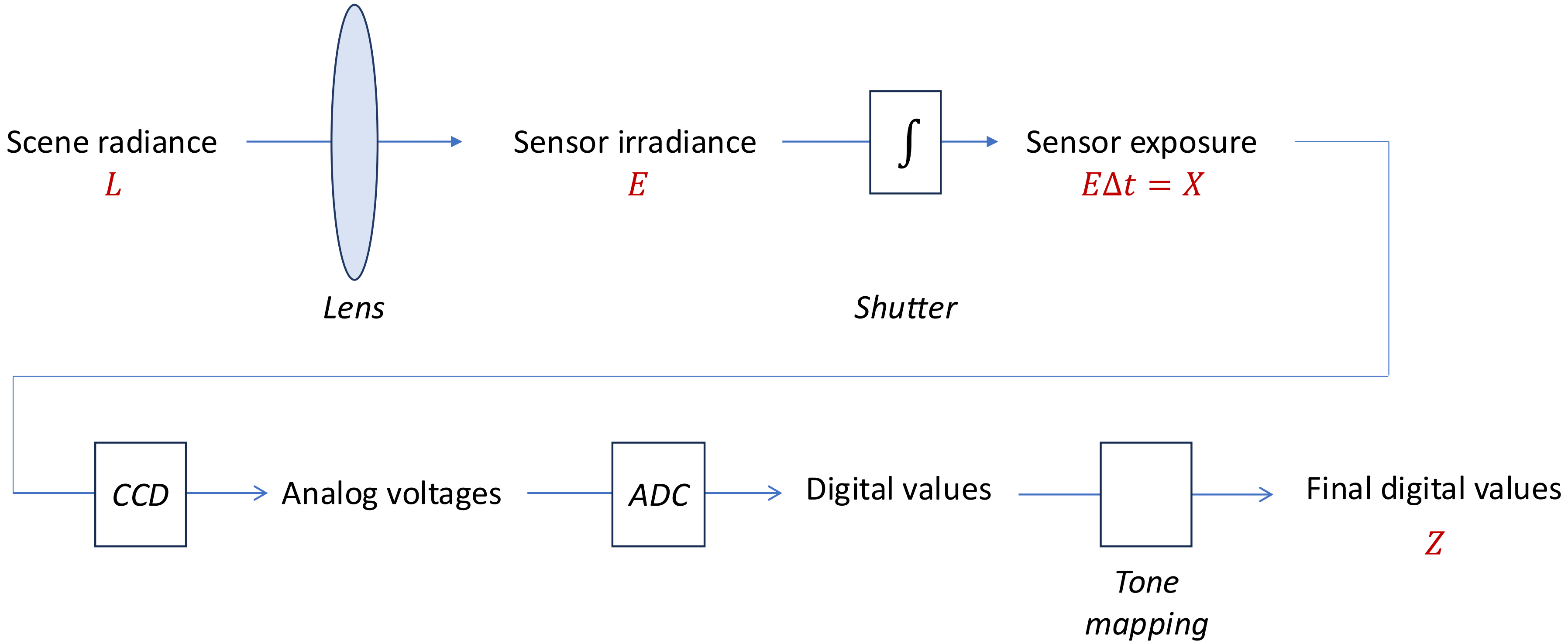
High Dynamic Range (HDR) Photography

- Collect images at different exposure settings
  - Align images if needed
- Estimate response curve
  - Set up the system of linear equations and solve for unknowns
- Use response curve to compute pixel irradiance values
- Perform tone mapping to construct the final HDR image that can displayed on a device with limited dynamic range

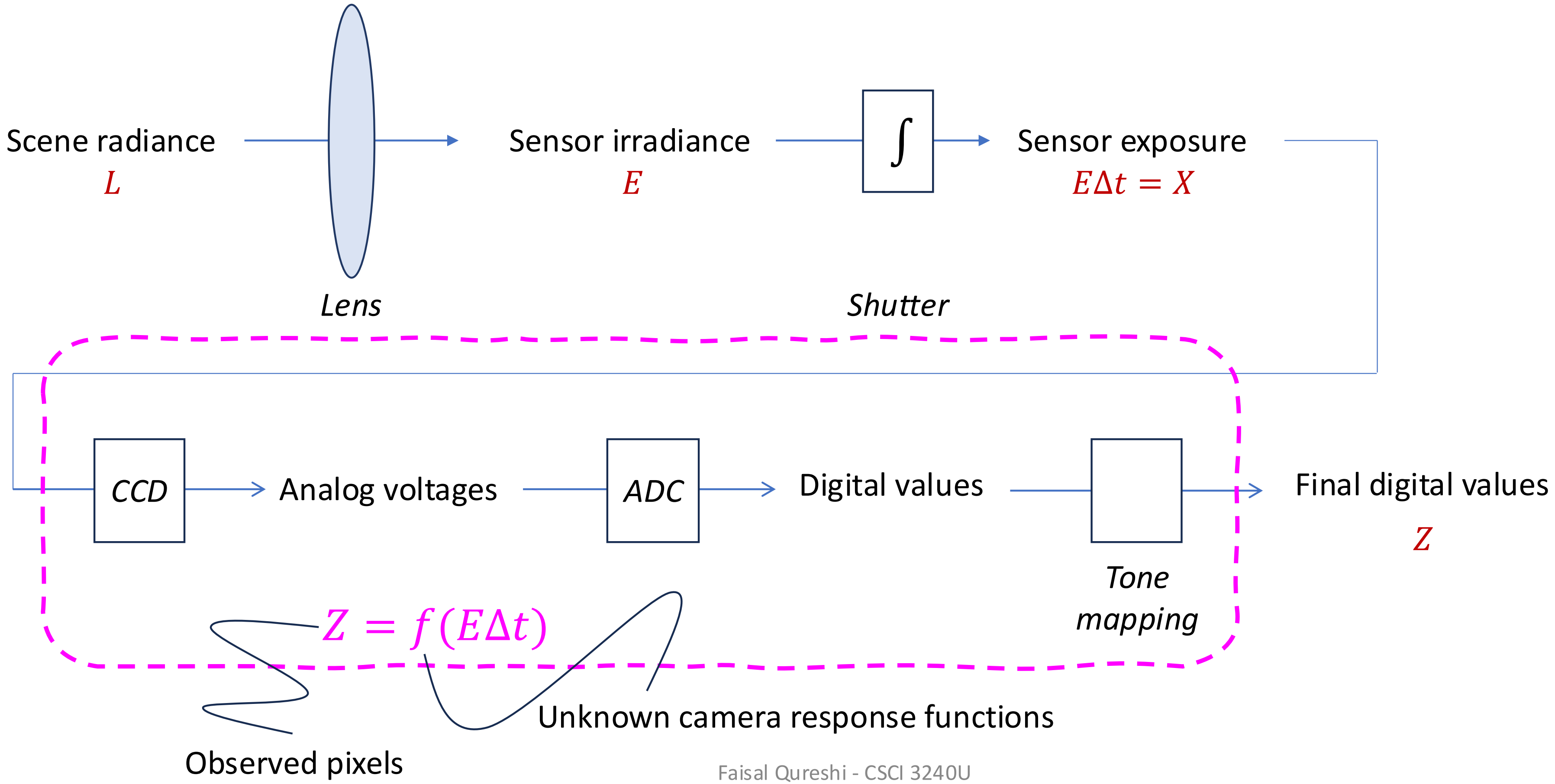
Reference

- https://pages.cs.wisc.edu/~csverma/CS766_09/HDRI/hdr

Digital Imaging Pipeline



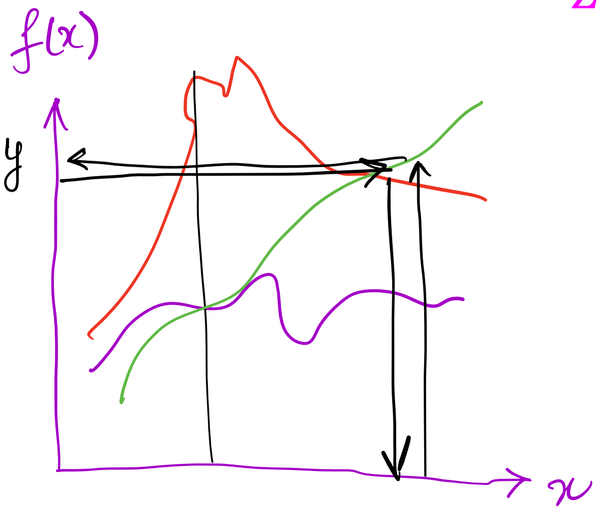
Digital Imaging Pipeline



Camera response function

- How to compute the camera response function f that maps sensor exposure $E\Delta t$ to pixel values Z as described by the following equation?

$$Z = f(E\Delta t)$$



How to compute camera response function?

Given

Pixel Values (8-bit, 255)

$$Z = f(E\Delta t)$$

Idea 1: Invert f and use log

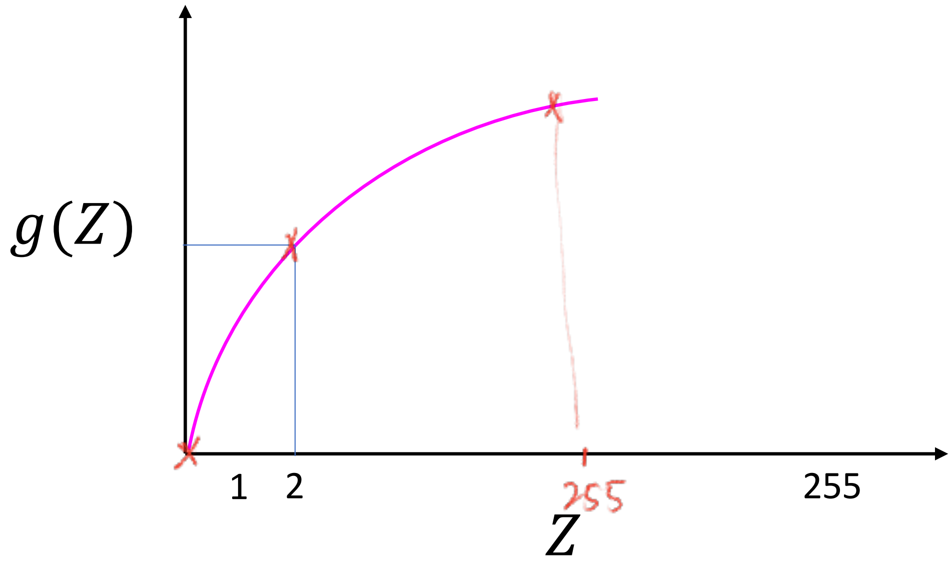
$$f^{-1}(Z) = E\Delta t$$

$$\log f^{-1}(Z) = \log E\Delta t$$

$$\boxed{\log f^{-1}(Z)} = \log E + \log \Delta t$$

$$g(Z) = \log E + \log \Delta t$$

Need to compute these values



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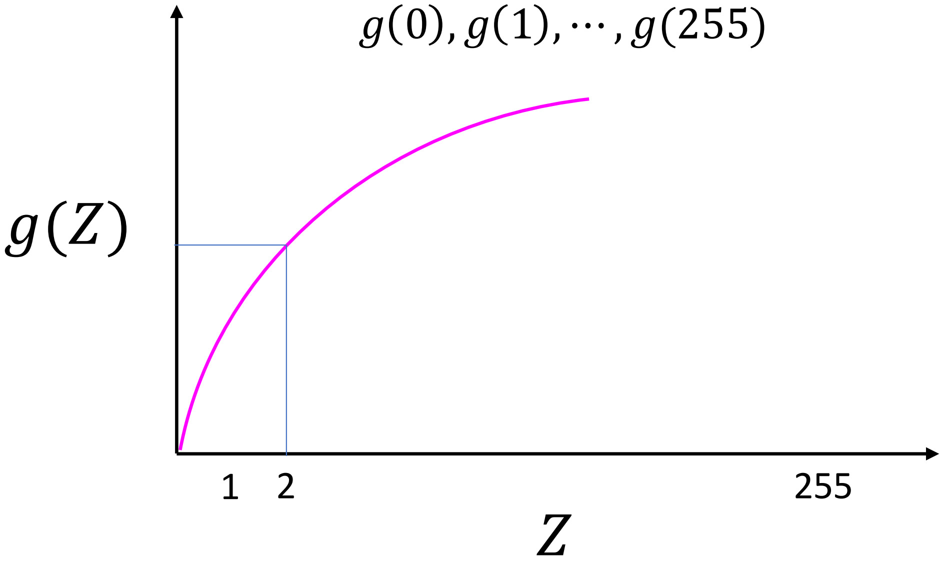
$$\underbrace{g(Z)}_{} = \log E + \log \Delta t$$

Need to compute these values

How many unknowns?

$g(0), g(1), \cdots, g(255)$



How do we estimate $g(0), g(1), \cdots, g(255)$?

Approach 1

- One pixel and many images
- Finally adjust Δt in range $[0, \infty]$
- Plot $\log \Delta t$ as a function of the pixel observed intensity

Q. What about $\log E$? We do not know it?

A. It doesn't matter, since it is a constant.

Too slow, requires us to take many many images

How do we estimate $g(0), g(1), \cdots, g(255)$?

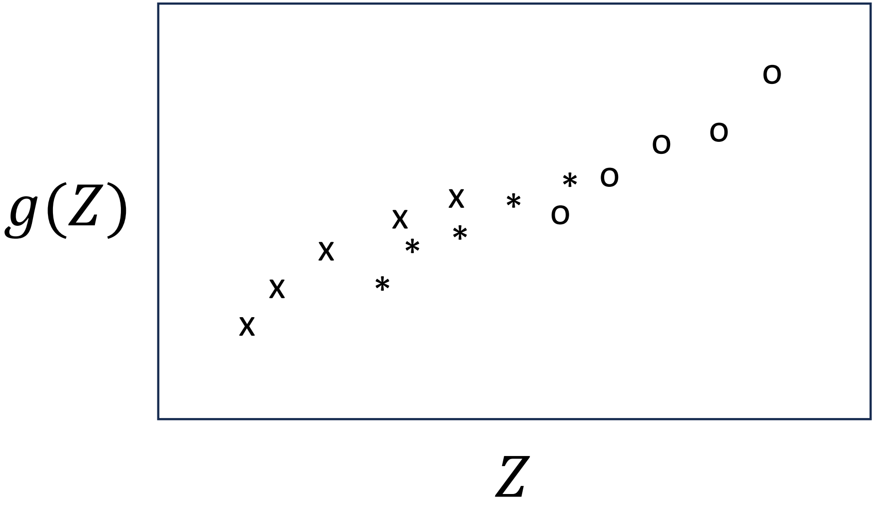
Approach 2

- A few pixels in a few images

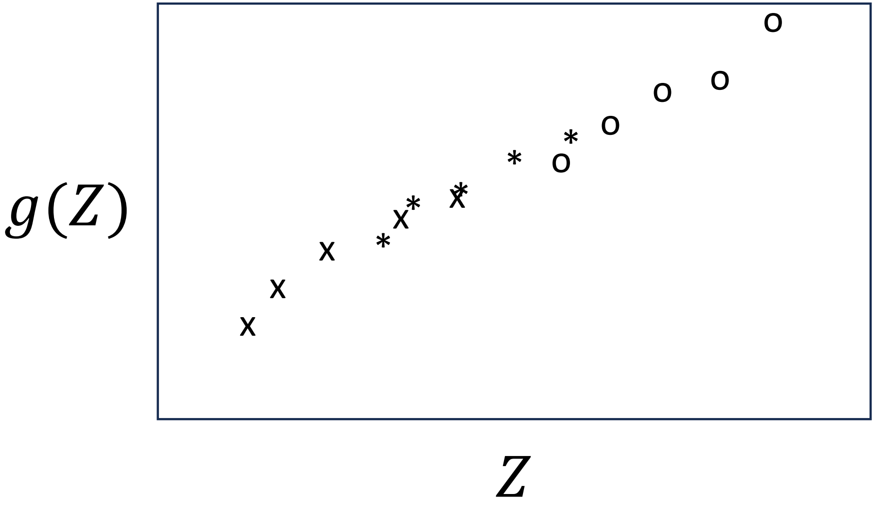
Approach 2 requires far less images than **Approach 1**

3 pixels and 5 images

Plot of $g(Z)$ from three pixels



Plot of normalized $g(Z)$ after determining pixel exposures



How do we estimate $g(0), g(1), \cdots, g(255)$?

- **Approach 2: N pixels in P images**

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

i^{th} pixel in j^{th} image

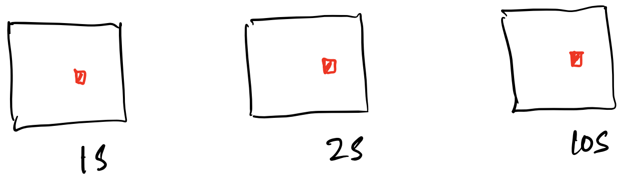
irradiance for i^{th}

exposure interval for j^{th} image

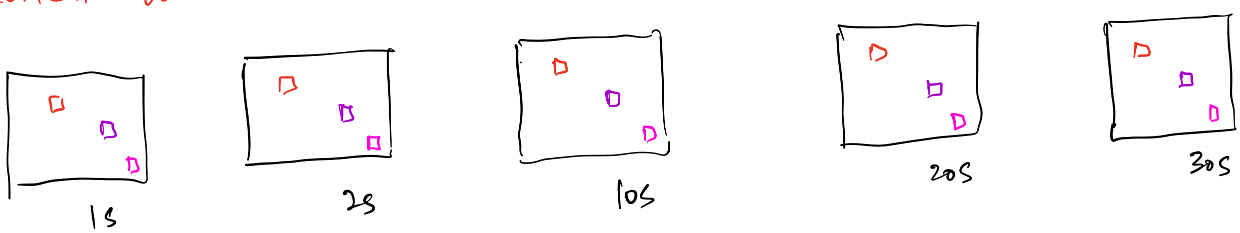
$$Z = f(E\Delta t) \longrightarrow \log f^{-1}(Z) = \log E + \log \Delta t$$

$$g(Z) = \log E + \log \Delta t.$$

APPROACH 1



APPROACH 2



→ $\log E_1$

→ $\log E_2$

→ $\log E_3$

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

UNKNOWNS:

$g(0), g(1), \ldots, g(255)$

$\log E_i$?

N images + P pixels

256 + P unknowns

$g(0)$ -- $g(255)$ $\log E_i$

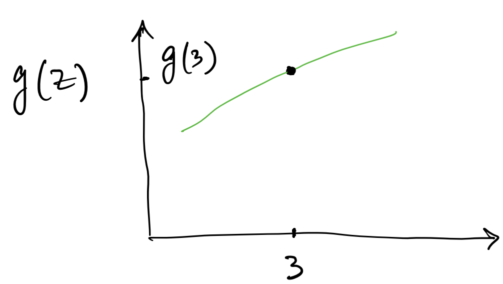
NP equations.

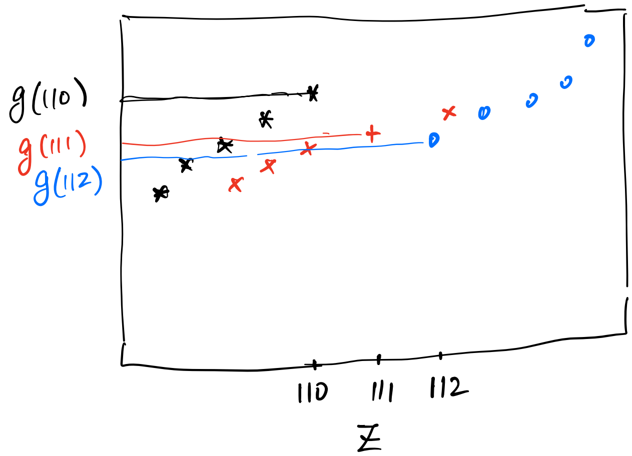
Example. 3 pixel, 5 images

equ. 15

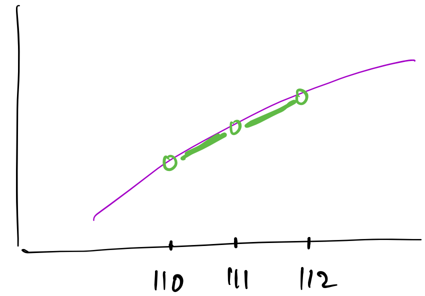
unknowns. 256+3

$g(0), \ldots g(255)$?





$$g(111) - g(110) = g(112) - g(111)$$



$$2g(111) - g(110) - g(112) = \emptyset$$

How many more equations? #254

$g(0)$ $g(1)$ $g(2)$ ... $g(110)$ $g(111)$ $g(112)$ ... $g(255)$

$$2g(1) - g(0) - g(2) = \emptyset \qquad 2g(111) - g(110) - g(112) = 0$$

N images, P pixels.

- 256 + P unknowns
- NP + 254 equations.

① $\underbrace{g(z_{ij})}_{g_{ij}} = \underbrace{\log t_i}_{e_i} + \underbrace{\log \Delta t_j}_{s_j}$

② $2g(z) - g(z-1) - g(z+1) = 0$

$$\boxed{\begin{aligned} g_{ij} &= e_i + s_j \\ 2g(z) - g(z-1) - g(z+1) &= 0 \end{aligned}}$$

Say pixel 99 in the 7^{th} image has intensity 128.

$$\Rightarrow Z_{\underset{(i)\ (j)}{99,7}} = 128$$

The associated eq. is: $g_{128} - e_{99} = s_7$

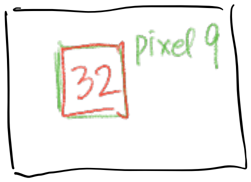


image 10

$$z_{9,10} = 32 \longrightarrow g_{32} - e_9 = s_{10}$$

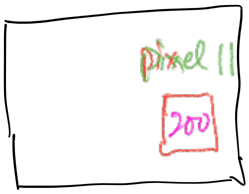


image 12

$$z_{11,12} = 200 \longrightarrow g_{200} - e_{11} = s_{12}$$