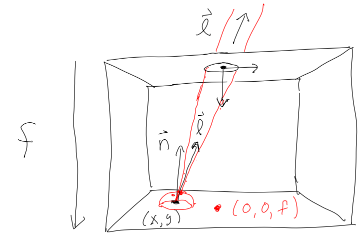
lecture 7

Camera response, color

Thin lens model (camera)



Let A be the aperture (lens diameter), so lens area is $\frac{\pi A^2}{4}$.

$$E(x,y) = L(\vec{\ell}) \left(\text{area of lens}\right) \frac{(\vec{n}\cdot\vec{\ell})^4}{f^2}$$

$$= L(\vec{\ell}) \frac{\pi}{4} \left(\frac{A}{f}\right)^2 (\vec{n}\cdot\vec{\ell})^4$$

Camera f-number (f-stop)

$$E(x,y) = L(\vec{\ell}) \frac{\pi}{4} \left(\frac{A}{f}\right)^2 (\vec{n}\cdot\vec{\ell})^4, \qquad N = \frac{f}{A}$$

$$\sim \left(\frac{1}{N}\right)^2$$

$$N = 1.4,\ 2,\ 2.8,\ 4,\ 5.6,\ 8,\ 11$$

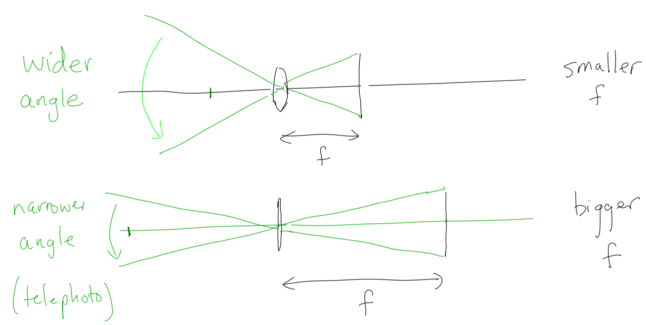
$$= \sqrt{2}, \sqrt{4}, \sqrt{8}, \sqrt{16}, \sqrt{32}, \sqrt{64}, \sqrt{128}$$

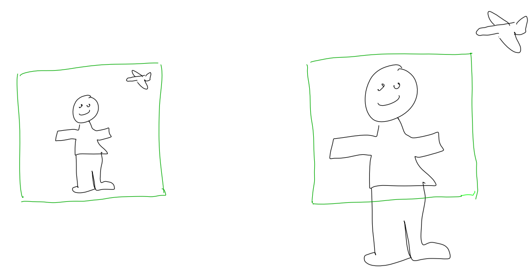
$$N = \frac{f}{A}$$

$\Rightarrow$ two ways to change N

Change f with A fixed

$$E(x,y) = L(\vec{\ell}) \frac{\pi}{4} \left(\frac{A}{f}\right)^2 (\vec{n}\cdot\vec{\ell})^4, \qquad N = \frac{f}{A}$$



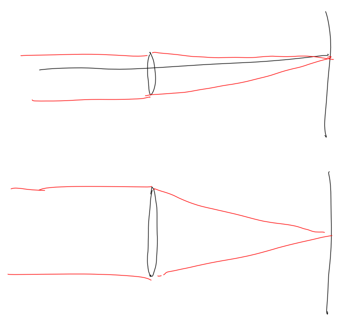


small f (wide angle)

large f (telephoto)

Same set of rays is spread out over larger sensor area $\Rightarrow$ darker

Change A with f fixed



Exposure

image irradiance	$E(x,y)$	$\frac{\text{light energy}}{\text{time} \times \text{area}}$
exposure time	t	
exposure	$E(x,y)\cdot t$	$\frac{\text{light energy}}{\text{unit area}}$

Shutter Speed $\left(\frac{1}{t}\right)$

Typical t

$$\ldots, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}, \frac{1}{32}, \frac{1}{64}, \frac{1}{128}, \frac{1}{256}, \frac{1}{512}, \ldots$$

Typical shutter speed $\frac{1}{t}$ (on camera dial)

$$\ldots, 2, 4, 8, 15, 30, 60, 125, 250, 500, \ldots$$

Exposure

$$E(x,y)\, t = L(\vec{\ell})\, \frac{\pi}{4} \left(\frac{A}{f}\right)^2 (\vec{n}\cdot\vec{\ell})^4 \cdot t$$

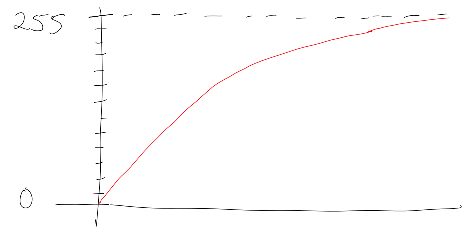
$\left(\frac{A}{f}\right)^2 \uparrow \frac{1}{N^2}$ $\qquad$ $t \uparrow \frac{1}{1/t}$

increase N (by decreasing A), decrease $\frac{1}{t}$ (increase t) $\Rightarrow$ $E(x,y)\cdot t$ fixed

increase N (by increasing f), decrease $\frac{1}{t}$ (increase t) $\Rightarrow$ EEK! size change (more complicated)

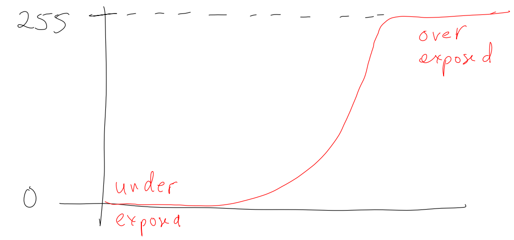
Camera Response (Tone Mapping)

$$T\big(E(x,y)\cdot t\big) \rightarrow \{0,1,\ldots,255\}$$

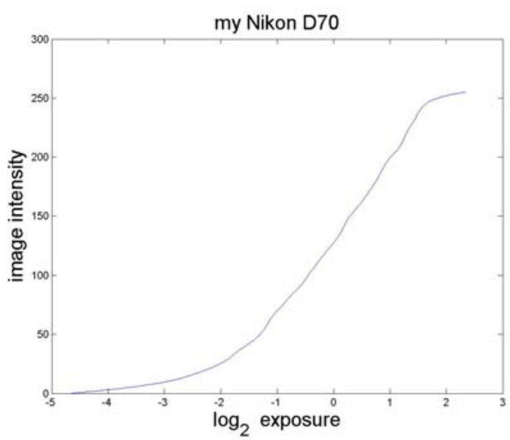


exposure, $E\cdot t$

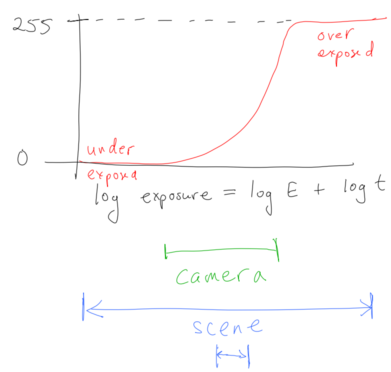
Camera Response



log exposure = log E + log t



Dynamic Range.



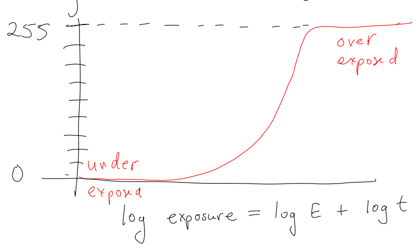
$\frac{1}{t} = 2000$

$\frac{1}{t} = 125$

$\frac{1}{t} = 8$

$\frac{1}{t} = \frac{1}{2}$

Dynamic Range.



High Dynamic Range Imaging

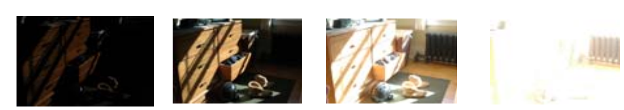
Given

- $T\big(E(x,y)\cdot t\big) \rightarrow \{0,1,\ldots,255\}$
- image intensities $I_t(x,y)$ for many shutter speeds $1/t$

Compute

$$E(x,y)\cdot t = T^{-1}\big(I_t(x,y)\big)$$

For each (x,y) use an image such that $0 \ll I(x,y) \ll 255$



log $E(x,y)$

Color

radiance $L(x, \vec{l}, \lambda)$

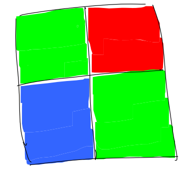
irradiance $E(x, \lambda)$

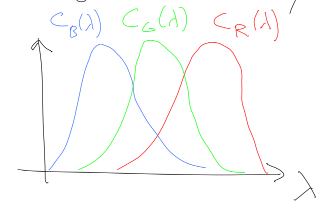
3D scene point

BRDF $\rho(x, l_{in}, l_{out}, \lambda)$

image irradiance $E(x, y, \lambda)$

Pixel (Bayer pattern)





$$E_{RGB}(x,y) = \int C_{RGB}(\lambda)\, E(x,y,\lambda)\, d\lambda$$

3 intensities per pixel