Lecture 21

photography

Wed. Nov. 18, 2020

Cameras

Digital SLR

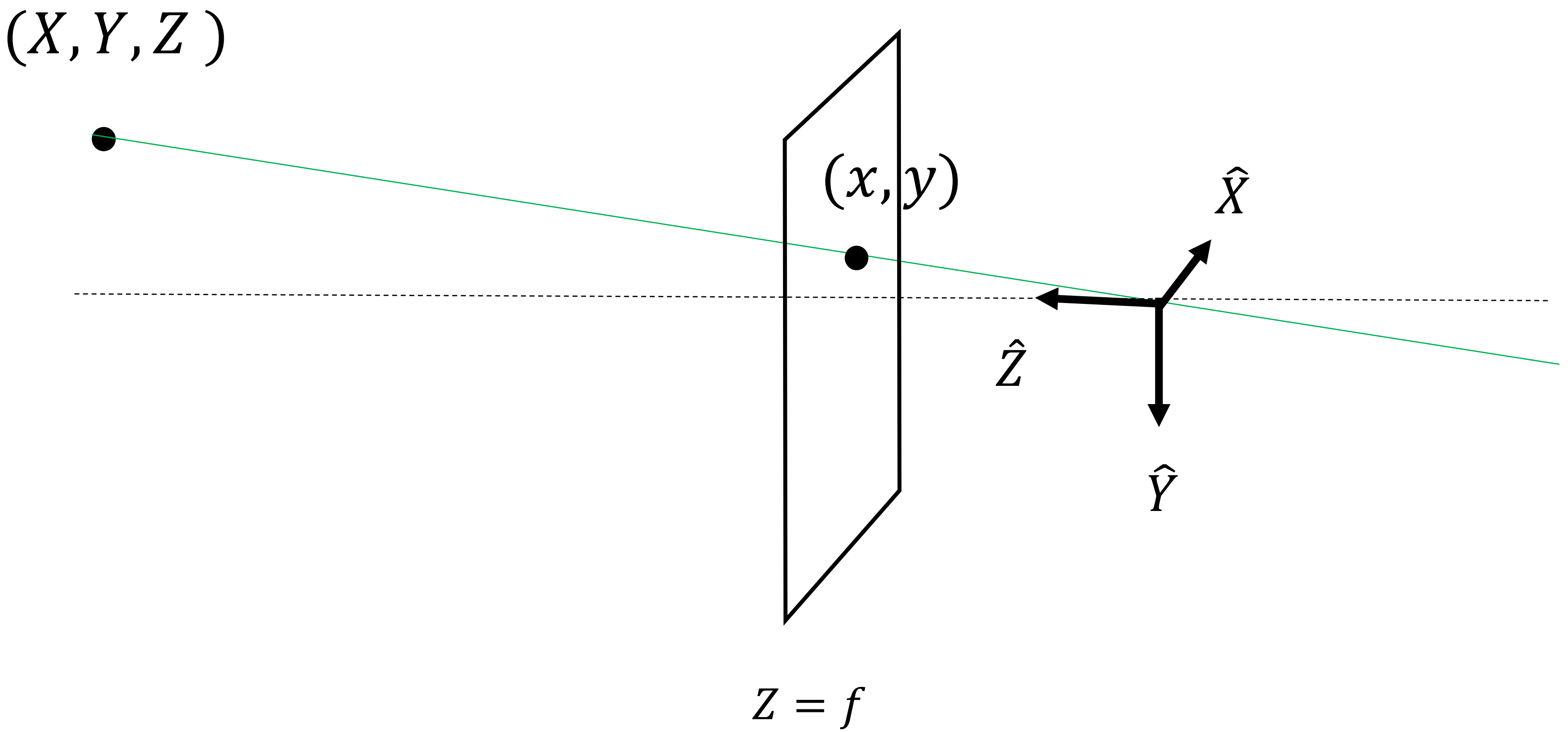
"point and shoot"

cell phone

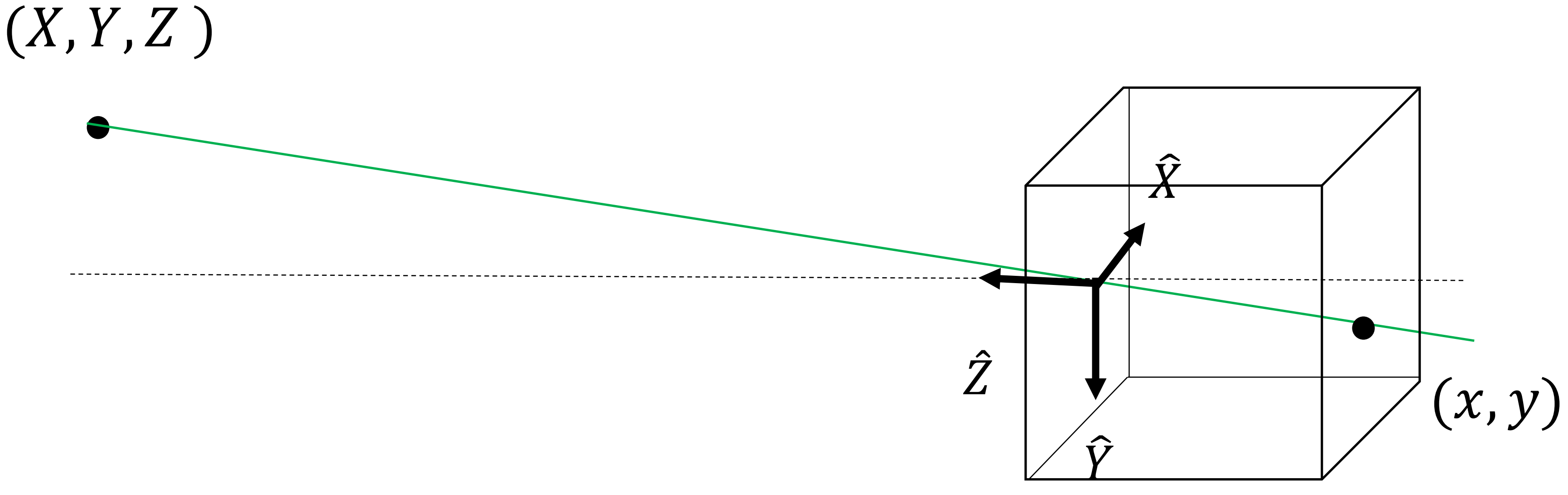
Overview of Today

- pinhole camera & field of view
- focal length & thin lens model
- defocus blur
- aperture
- field of view (revisited): wide angle vs. telephoto
- F-number
- exposure time
- gain ISO
- high dynamic range imaging & tone mapping
- motion blur

Projection Plane Model

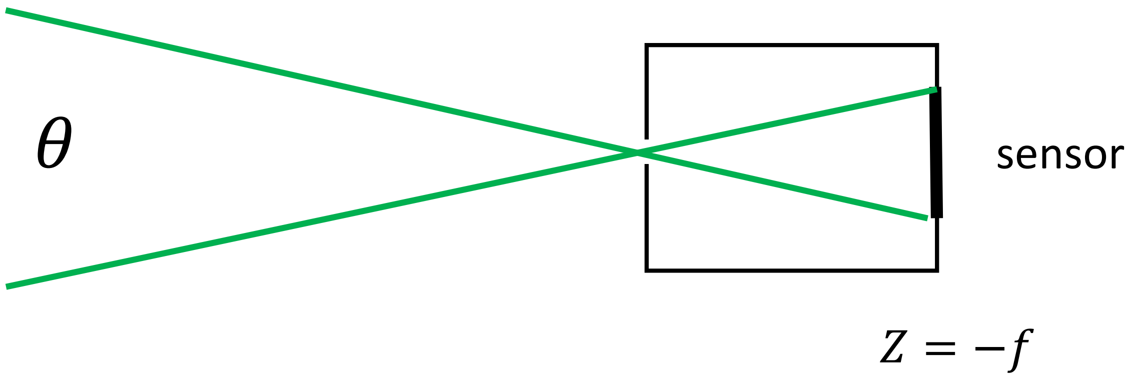


Pinhole Camera Model

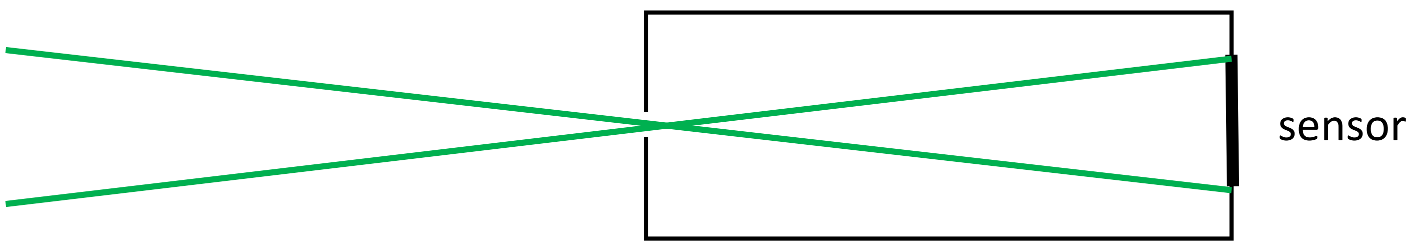


Projection plane
$Z = -f$

Field of view angle θ for pinhole camera



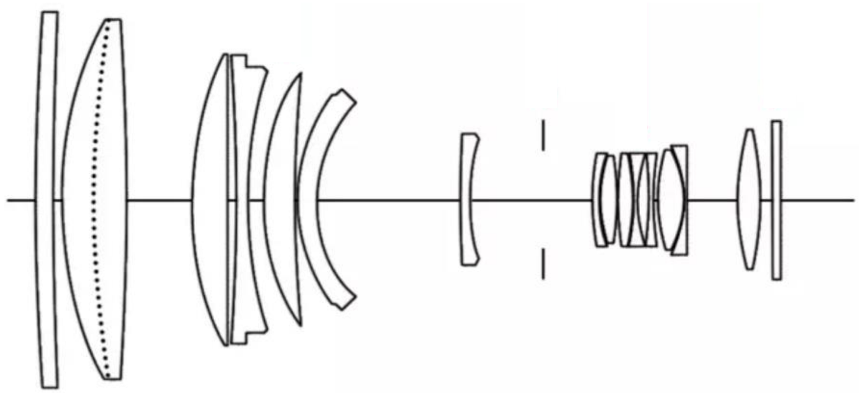
Moving the sensor away decreases the field of view angle



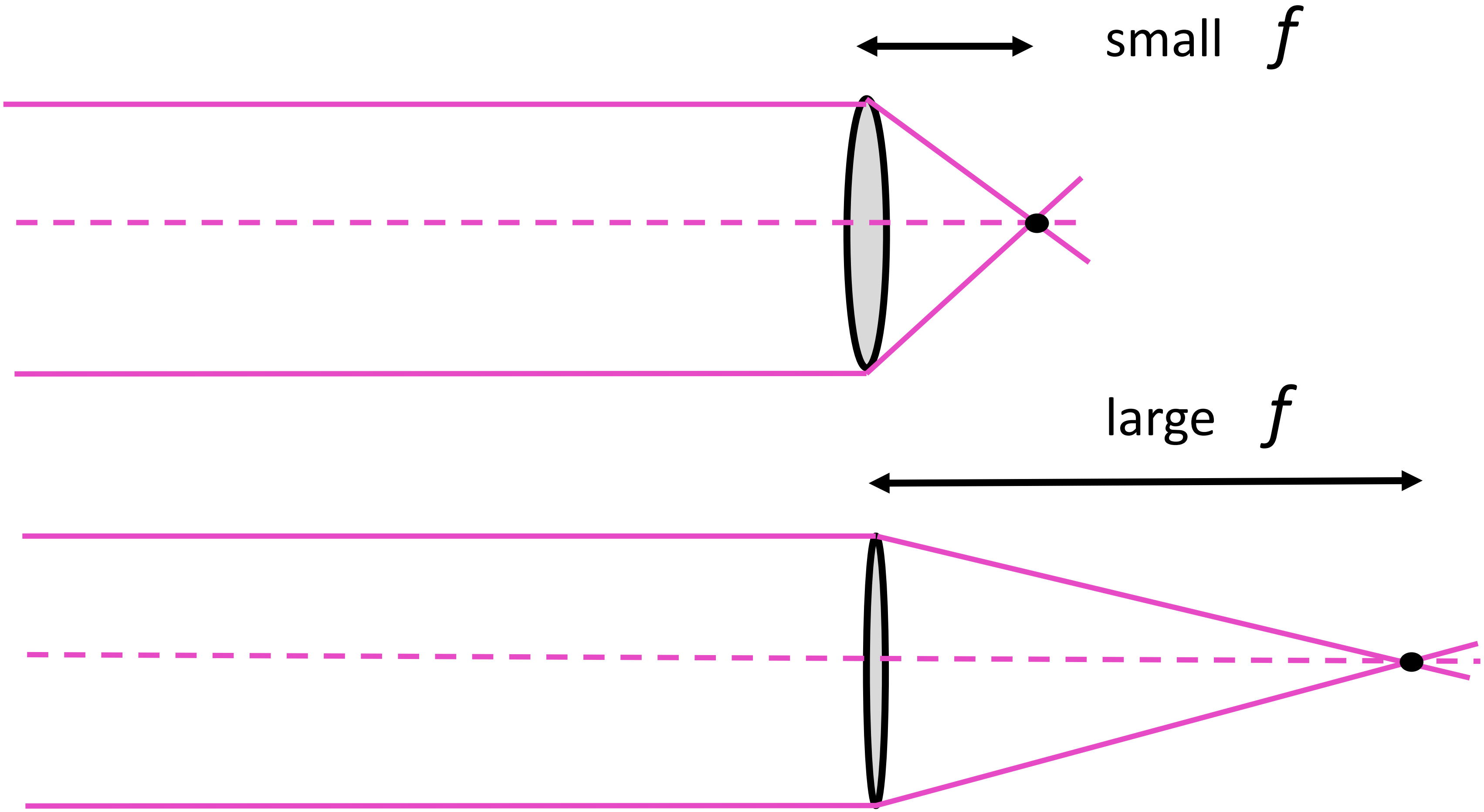
$$2 \tan\left(\frac{\theta}{2}\right) = \frac{sensor\ height\ or\ width}{f}.$$

Real Digital Camera (SLR)

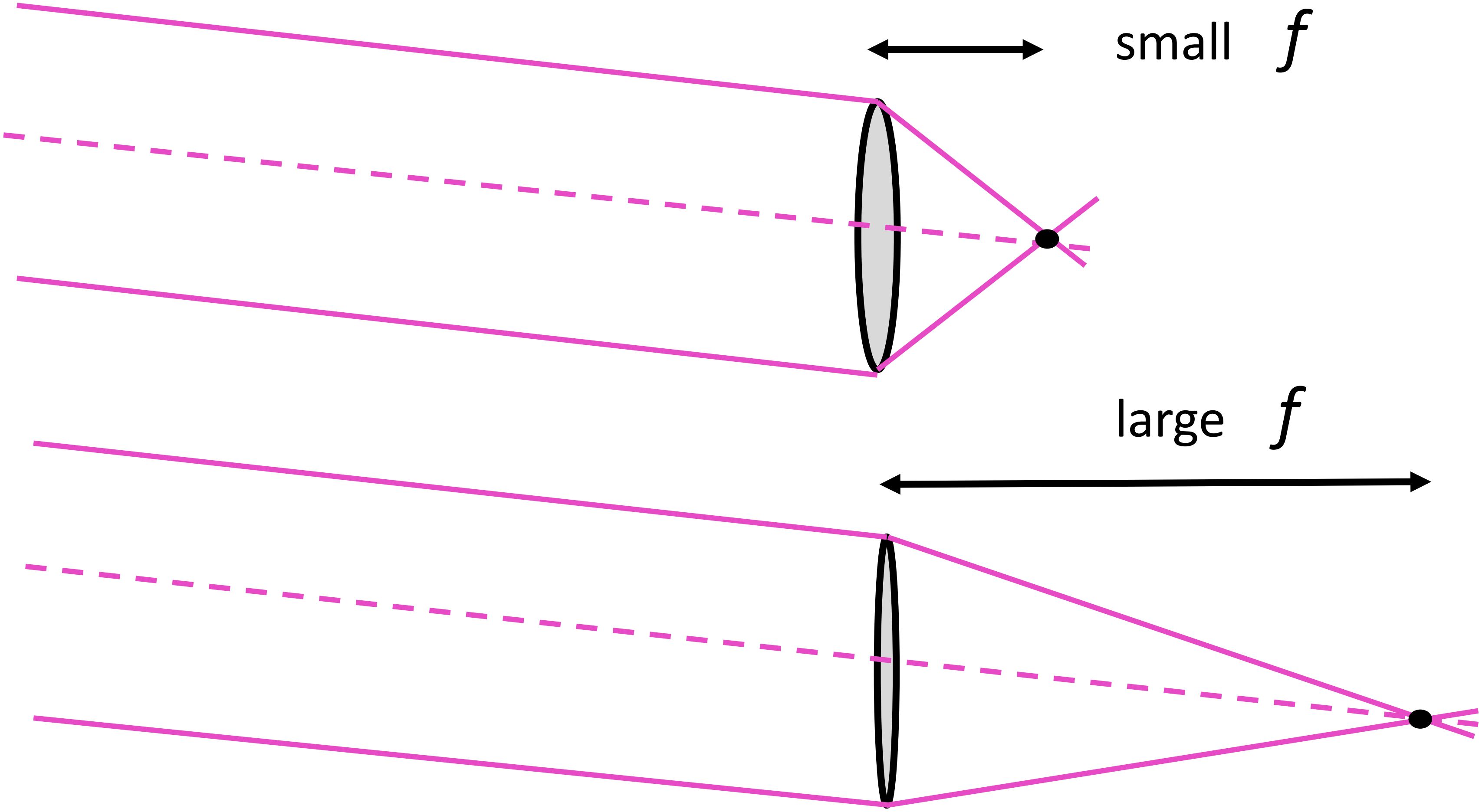
Camera lens



Thin lens: Focal length f



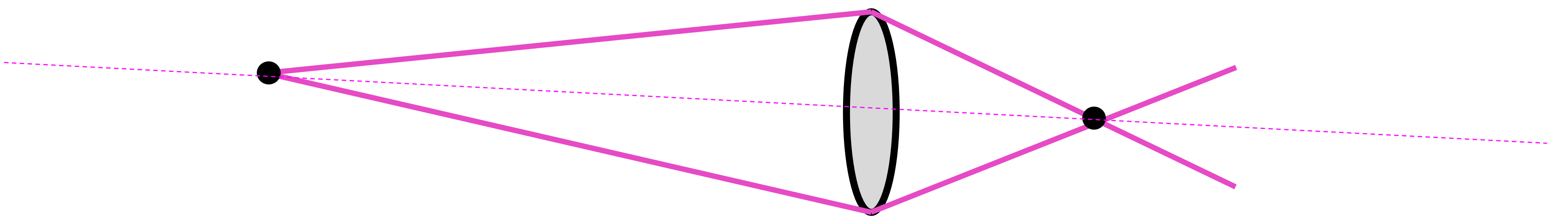
Thin lens: Focal length f



Thin lens model

One can show using simple geometric arguments (details omitted):

$$\frac{1}{\text{focal length of lens } f} = \frac{1}{\text{object distance}} + \frac{1}{\text{image distance}}$$



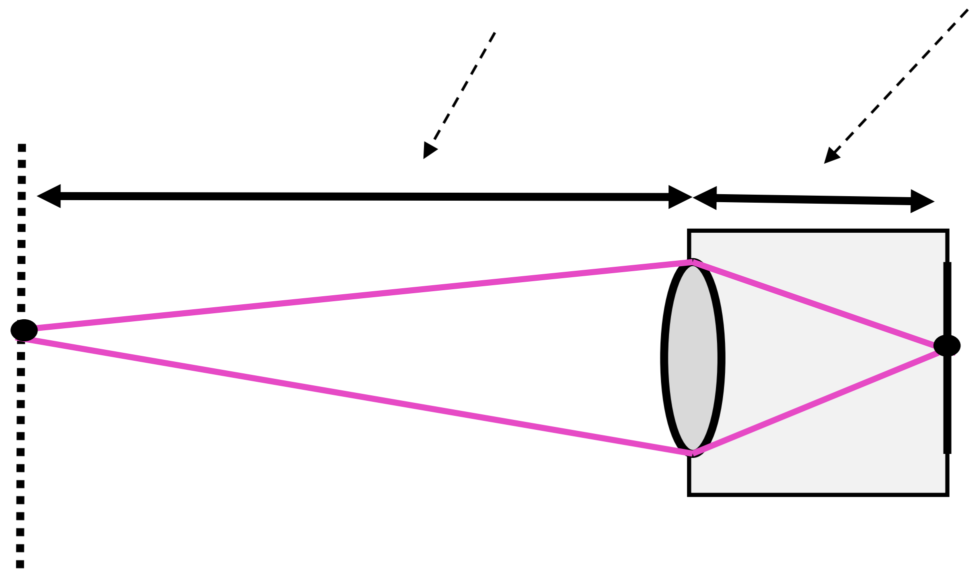
ASIDE: Such pairs of points are called "conjugate points".

Special case: object at infinity

$$\frac{1}{\text{focal length of lens}} = \cancel{\frac{1}{\text{object distance}}} + \frac{1}{\text{image distance}}$$

Which scene points are in focus?

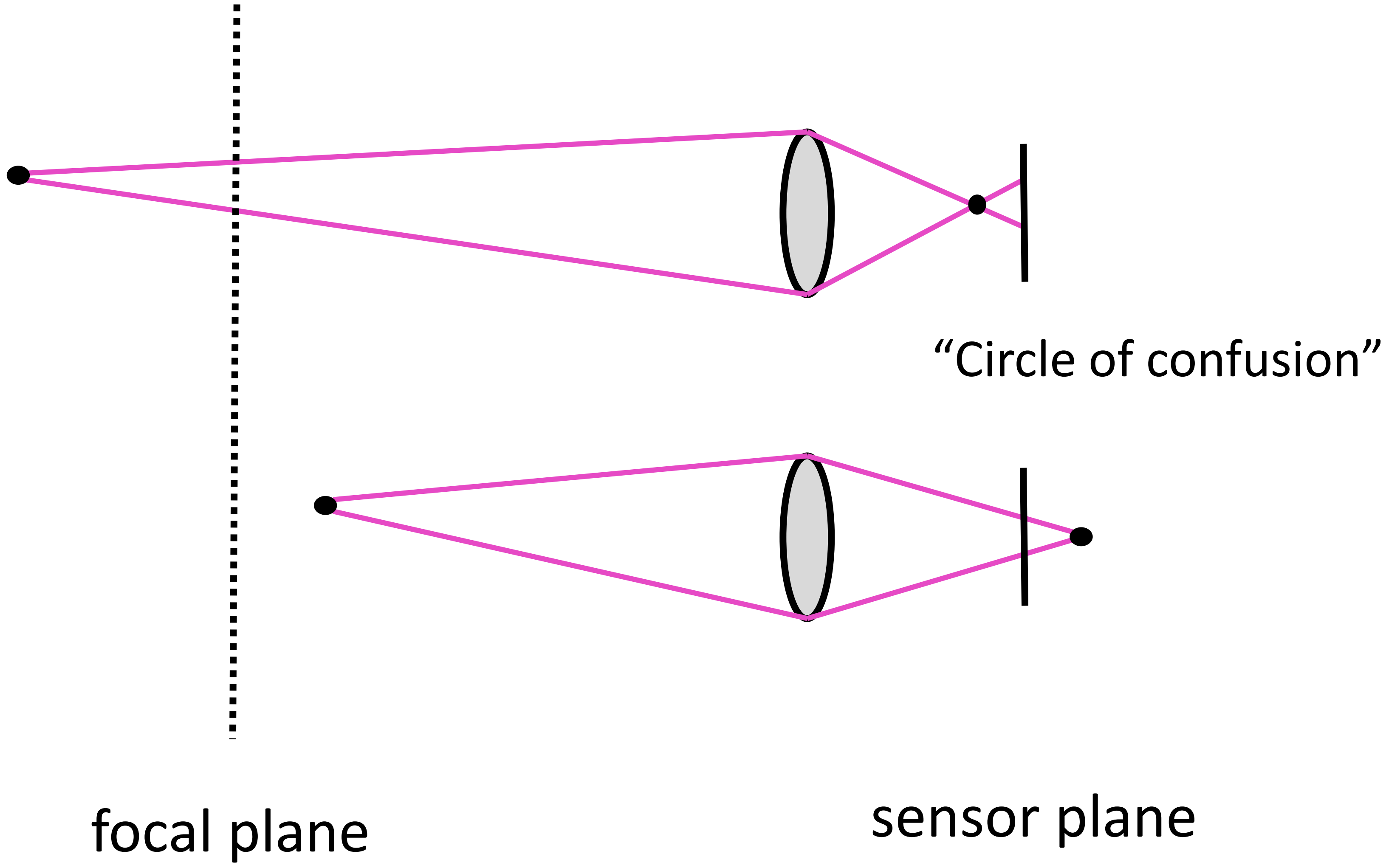
$$\frac{1}{\text{focal length of lens}} = \frac{1}{\text{focal plane distance}} + \frac{1}{\text{sensor distance}}$$



focal plane

sensor plane

Defocus Blur



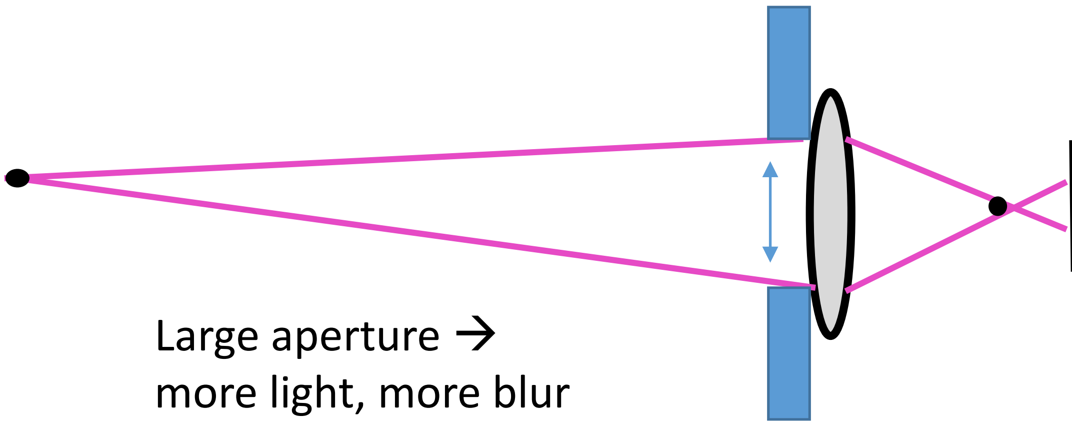
Blur and depth (more next lecture)

beyond
focal plane

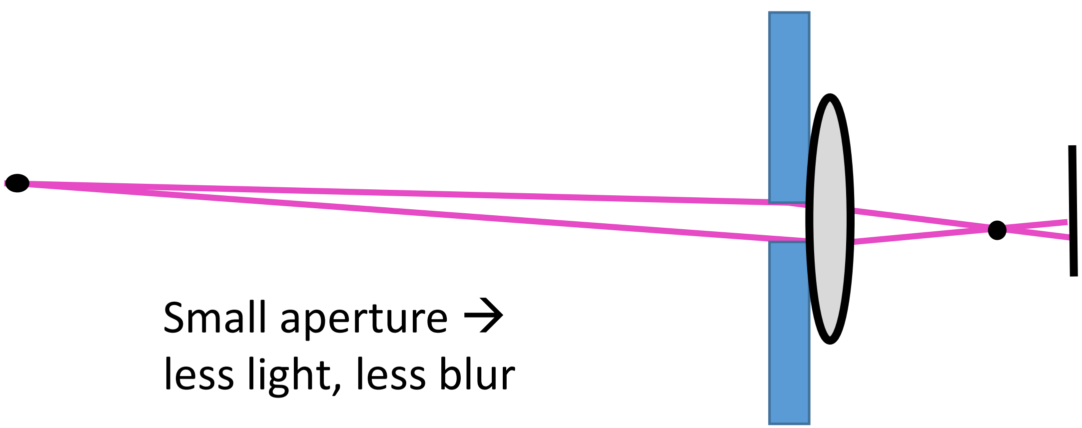
at focal plane

closer than
focal plane

Aperture

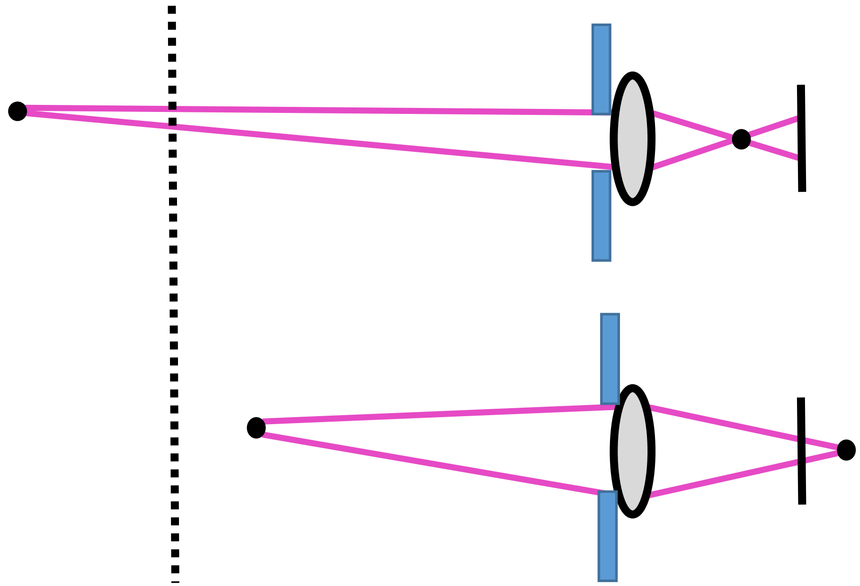


Large aperture →
more light, more blur



Small aperture →
less light, less blur

Defocus blur width

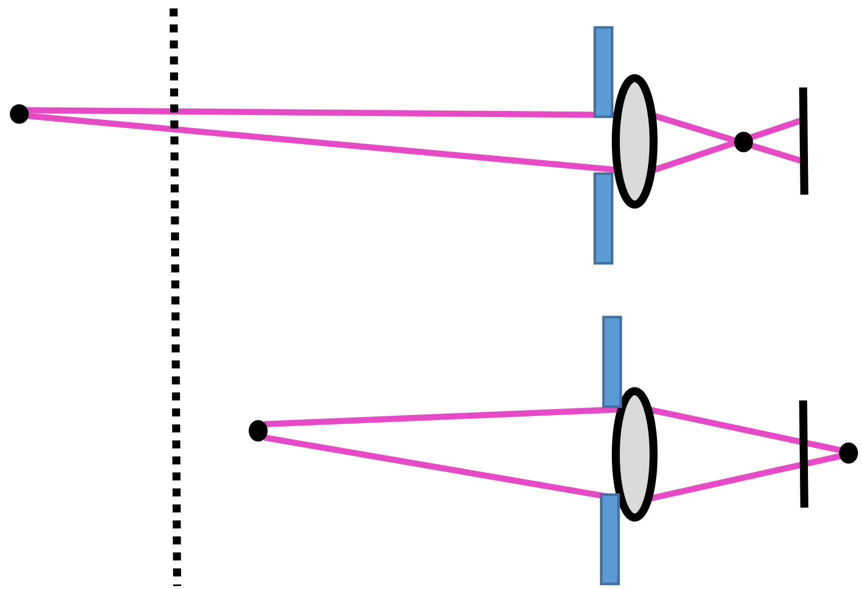


One can show:

$$\text{blur width} = \text{aperture} \left| \frac{1}{\text{focal plane distance}} - \frac{1}{\text{object distance}} \right|$$

Depth from defocus blur ?

(next lecture)



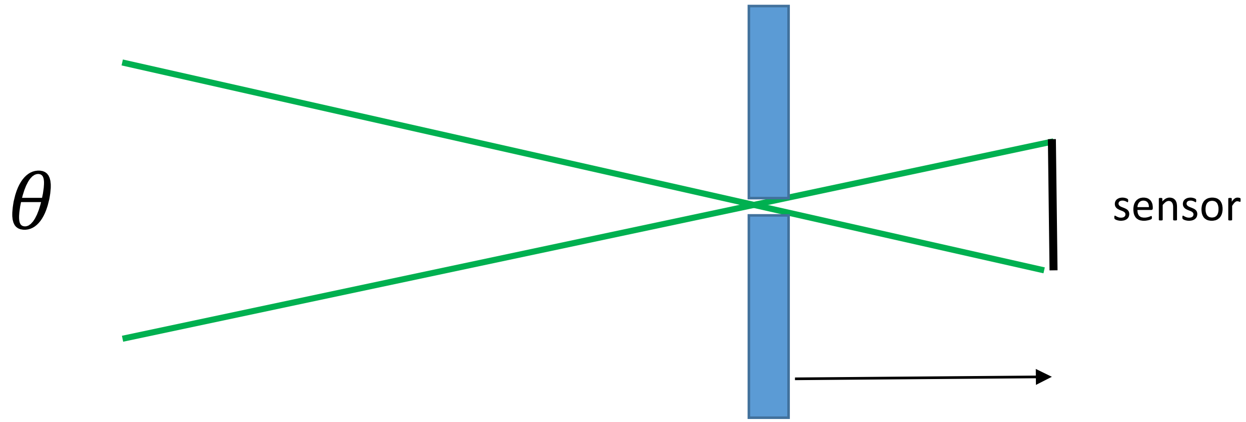
estimate — blur width; **known** — aperture, focal plane distance; **infer** — object distance

$$\text{blur width} = \text{aperture}\left|\frac{1}{\text{focal plane distance}} - \frac{1}{\text{object distance}}\right|$$

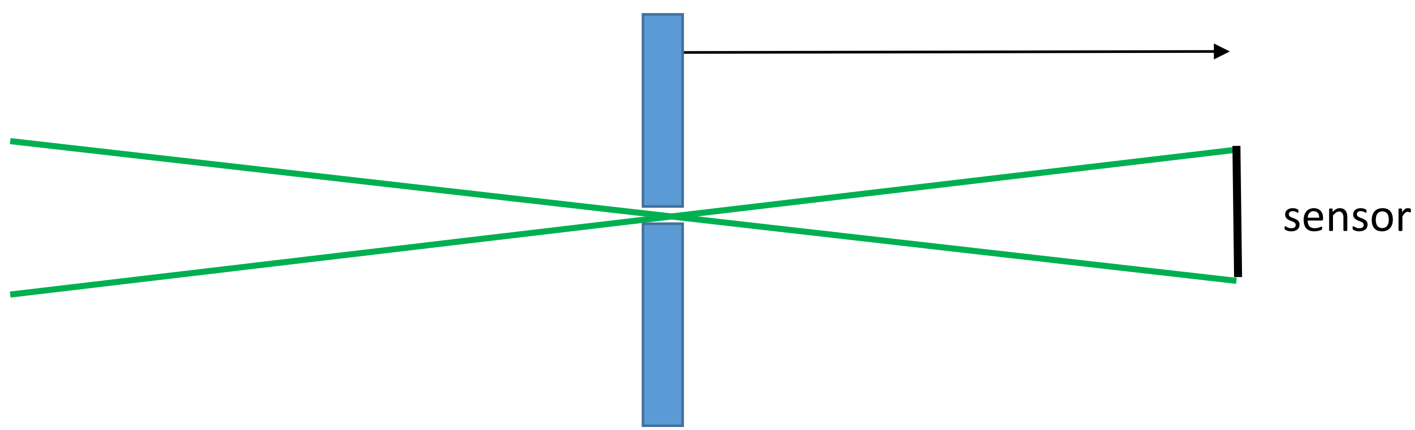
Back to pinhole model for a few concepts…

Recall: Field of view angle θ

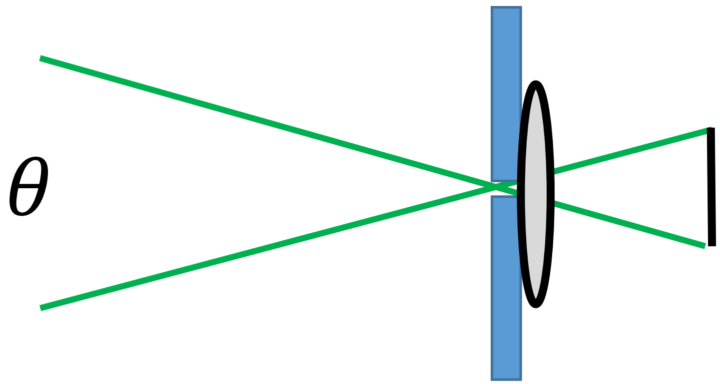
Assume small aperture: this approaches a pinhole

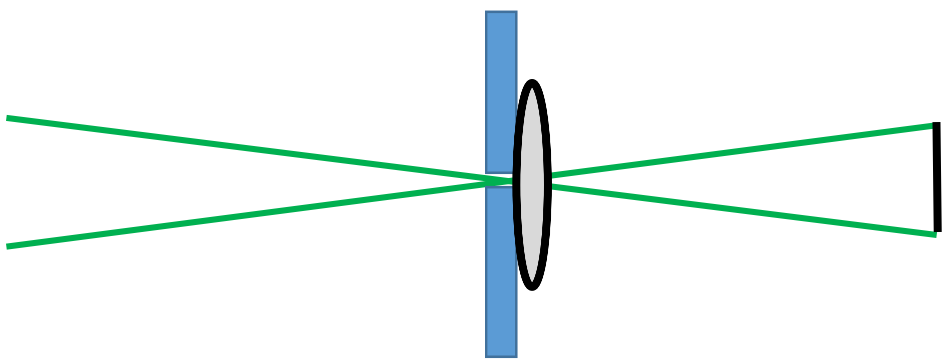


Moving the sensor away decreases the field of view angle



$$2\tan\left(\frac{\theta}{2}\right) \approx \frac{sensor\ height\ or\ width}{f}$$

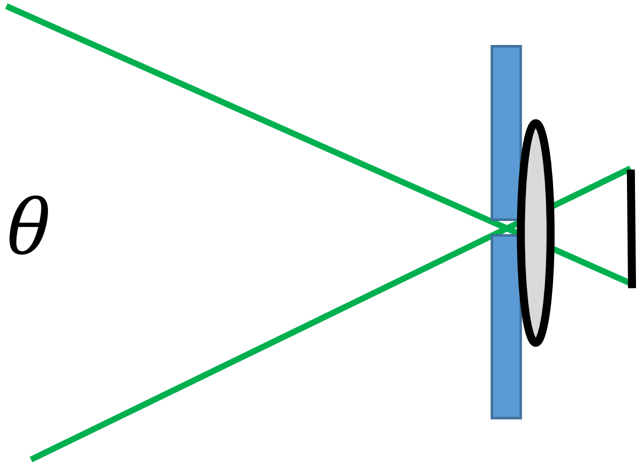


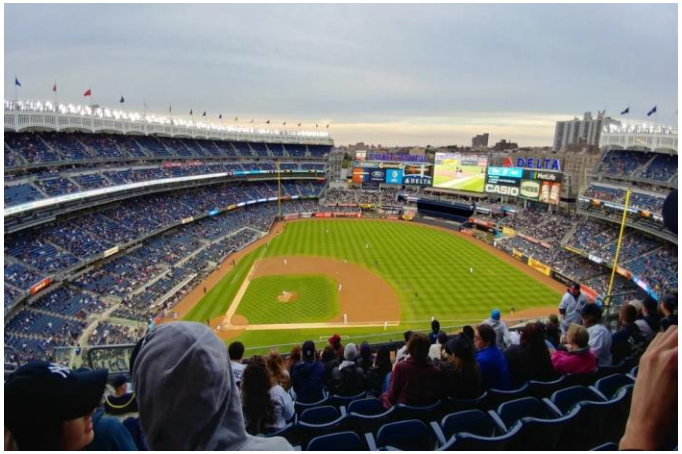


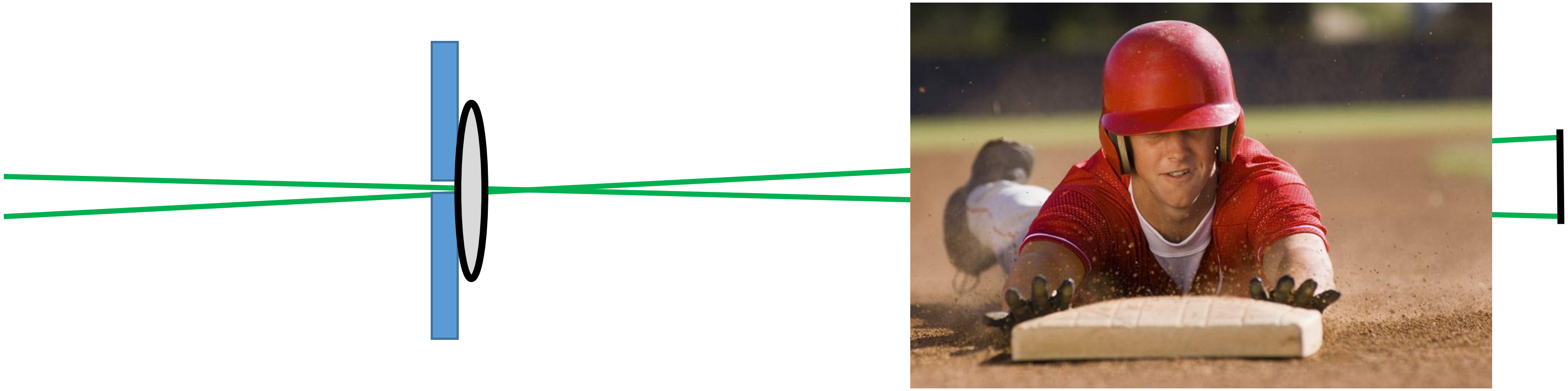
wide angle lens (small f)

telephoto lens (large f)

wide angle lens (small f)

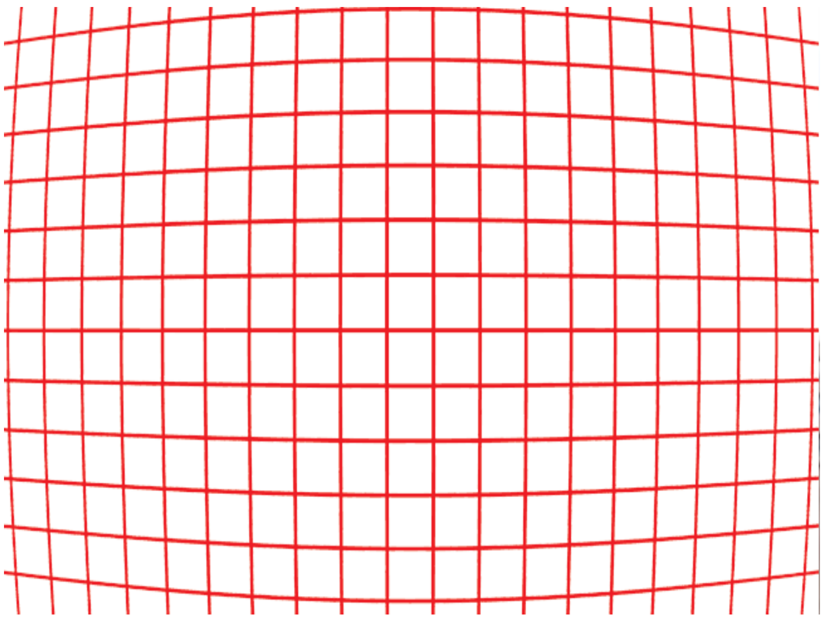






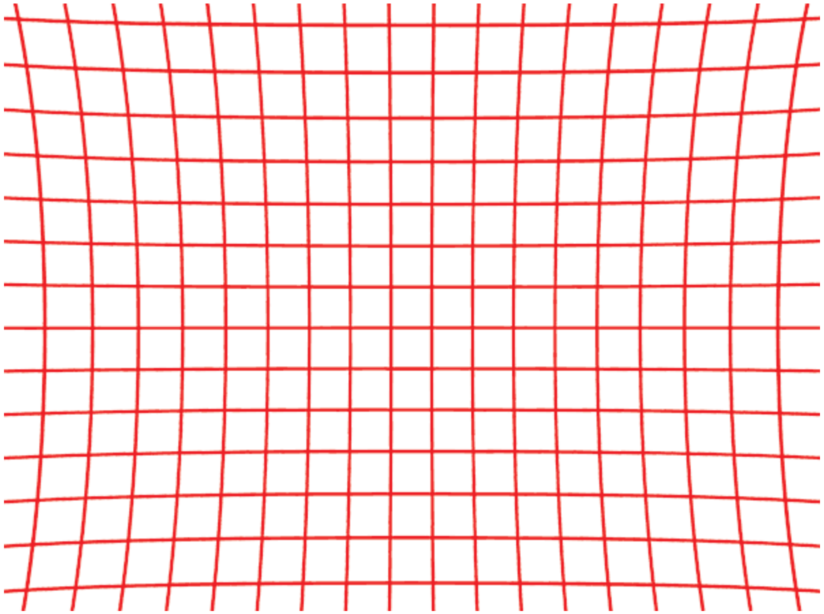
telephoto lens (large f)

ASIDE: Radial distortion



Barrel distortion

(more common with wide angle lenses)



Pincushion distortion

(more common with telephoto lenses)

Radial distortion example

Original image shot with
wide angle lens
(barrel distortion)

Corrected
(deform image by inverting
the modelled radial deformation
such as on previous slide left)

Image credit

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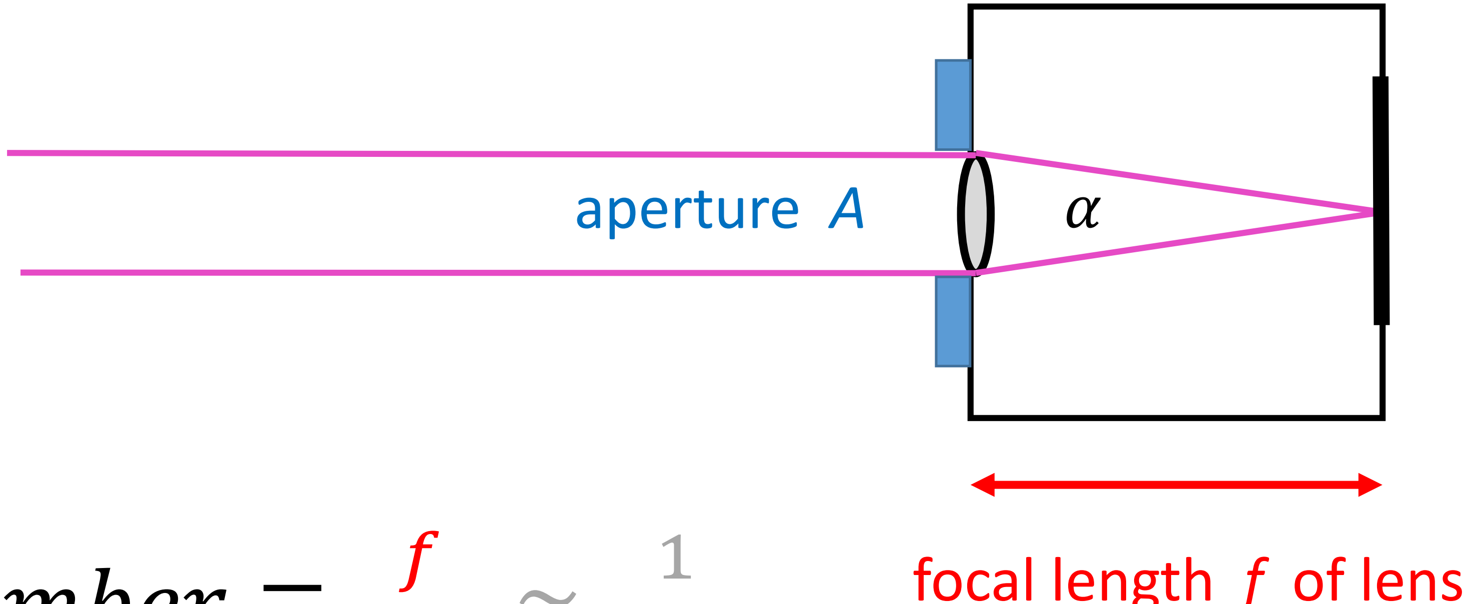
f-number

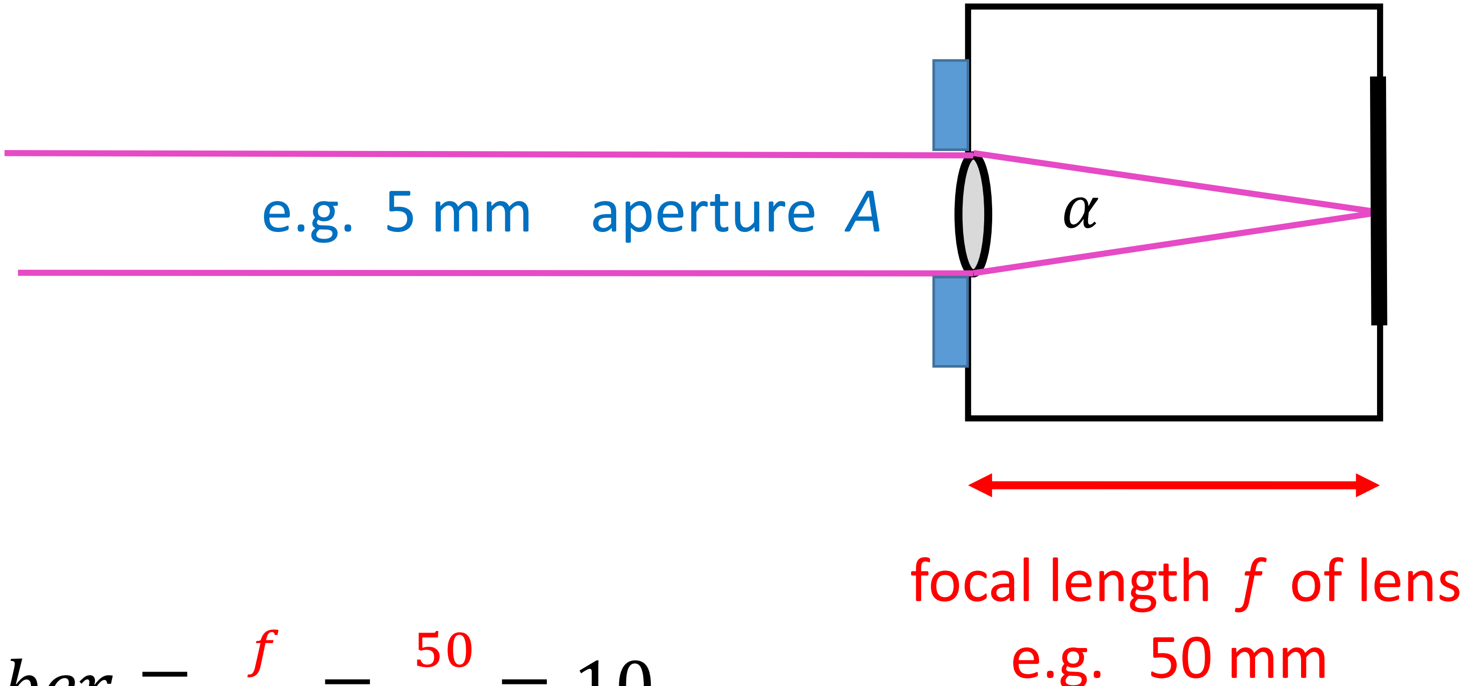


$$f\text{-}number \equiv \frac{f}{A} \approx \frac{1}{\alpha}$$

This illustration is for the case that the sensor plane distance equals the focal length of lens.

$$\alpha \approx 2\,tan\left(\frac{\alpha}{2}\right)$$

Example f-number



$$f\text{-}number \equiv \frac{f}{A} = \frac{50}{5} = 10$$

“f-numbers“ (1.8, 2.8, ….)

“f / #” notation means aperture, *i.e.* $\# \equiv \frac{f}{A}$

Exposure time

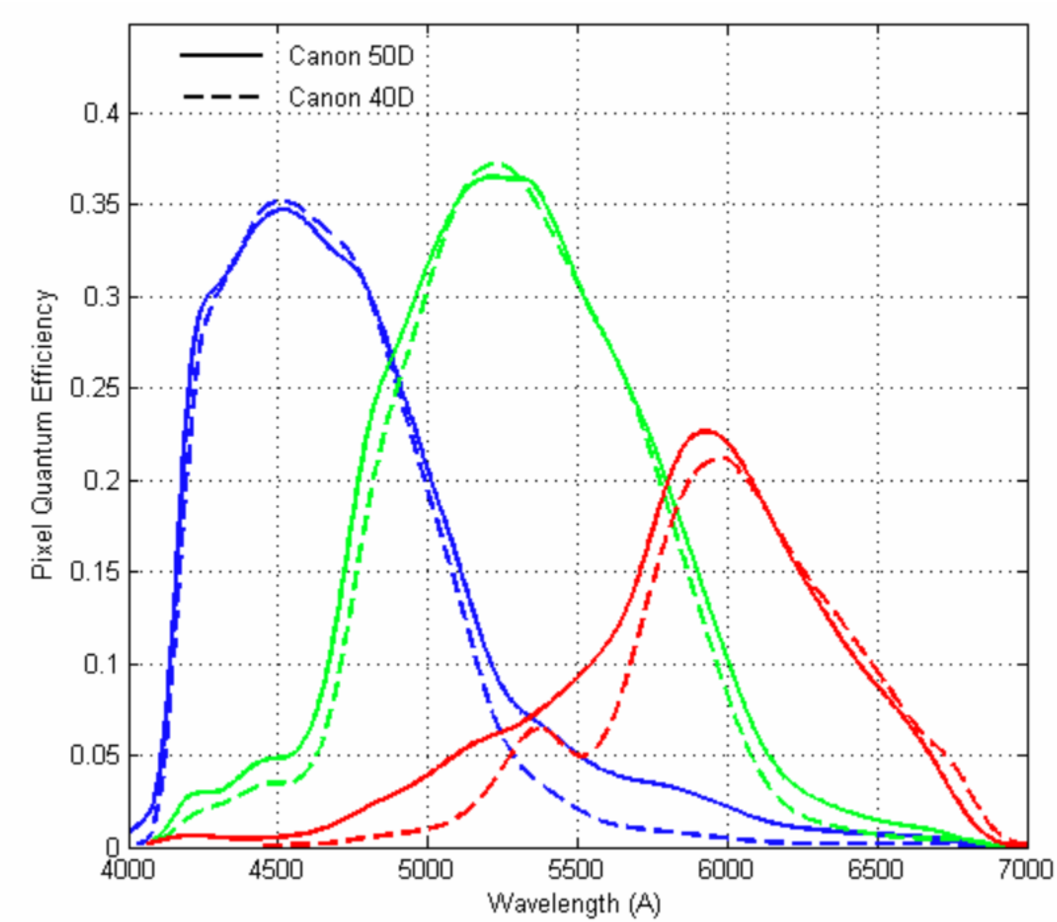
How long is the aperture (shutter) open?

The photographer can control this parameter

(also known as 'shutter speed') :

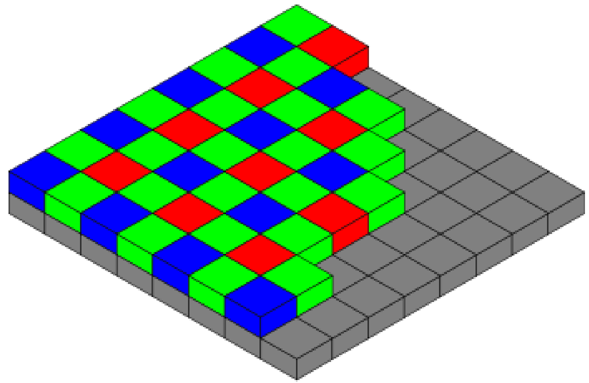
$\ldots,\ 8,\ 4,\ 2,\ 1,\ \frac{1}{2},\ \frac{1}{4},\ \frac{1}{8},\ \frac{1}{16},\ \ldots\ \frac{1}{256},\ \frac{1}{512},\ \ldots$ sec.

Recall lecture 2:
RGB spectral sensitivity e.g. for Canon camera(s)



http://astrosurf.com/buil/50d/test.htm

http://www.gujinwei.org/research/camspec/db.html



$$Exposure_{RGB}(x) = I_{RGB}(x) * \Delta t$$

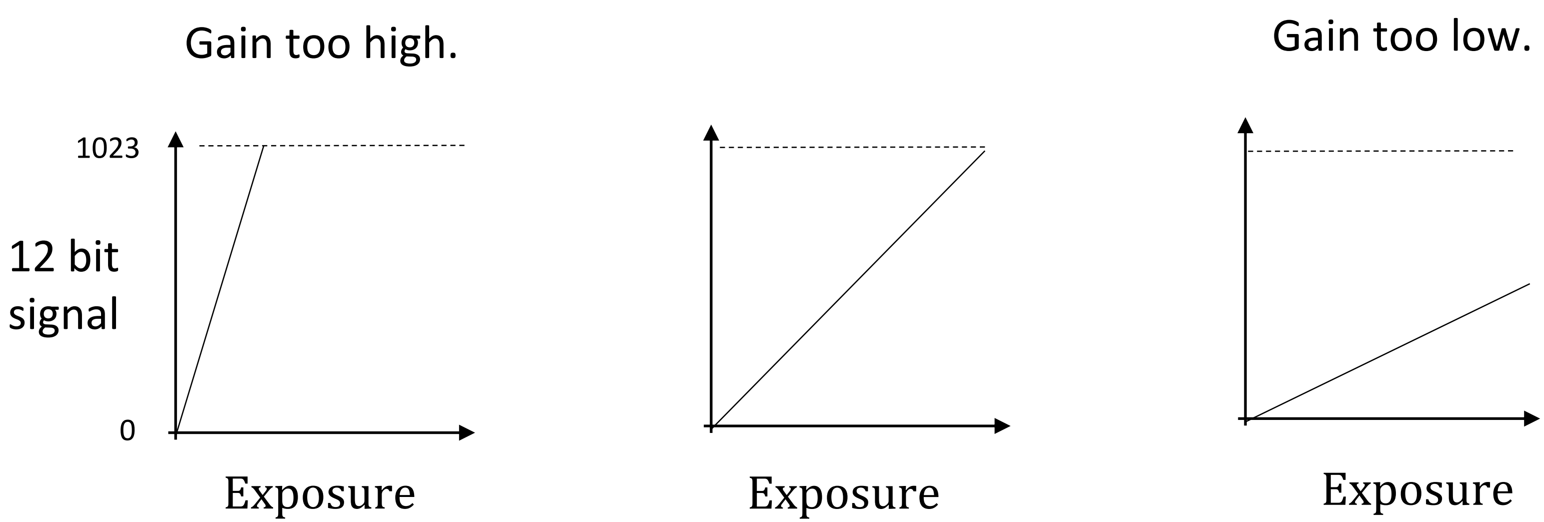
Exposure time

light intensity arriving at pixel
(RGB pixel exposure per unit time)

Gain ("ISO")

The signal that is to be encoded is the product of the exposure and a *gain*.

The photographer sets the gain by choosing a number mysteriously called the ISO.   Larger "ISO" means large gain.



No free lunch: high gain boosts both signal and noise.

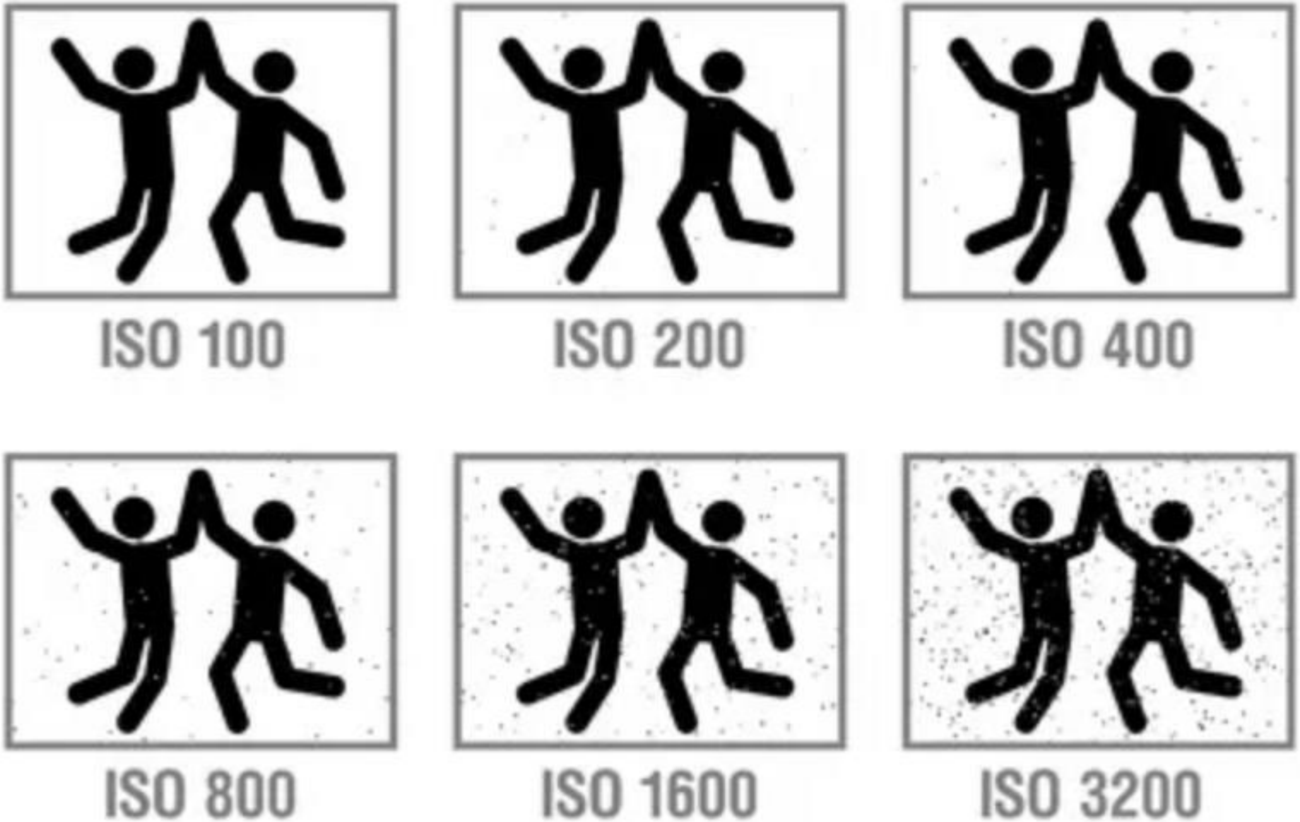


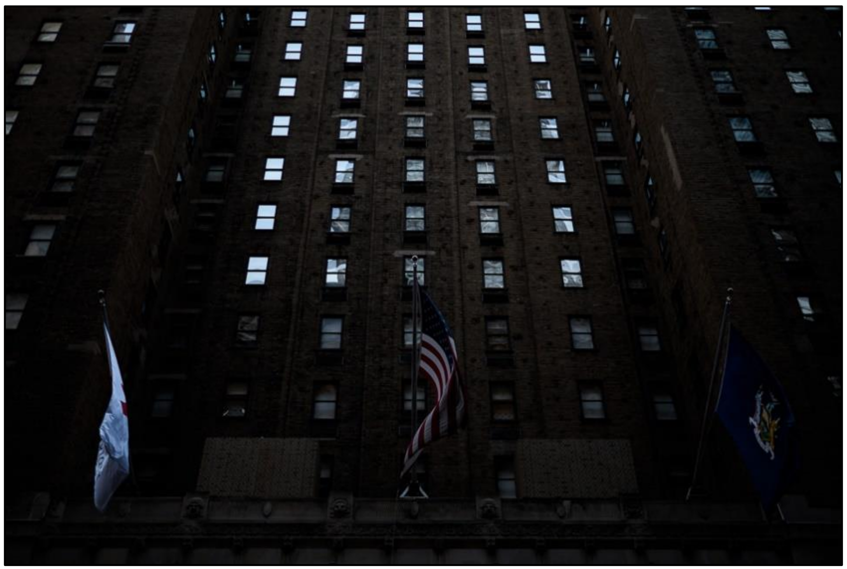
Image credit

Photographers can control a variety of camera settings:

- focal length of lens (field of view angle)
- f-number (together with focal length gives aperture)
- exposure time (shutter speed)
- ISO (gain)

Different combinations of settings can lead to the same exposure, and produce interesting effects.

Choosing the wrong f-number, shutter speed, or ISO.



Underexposed

Overexposed

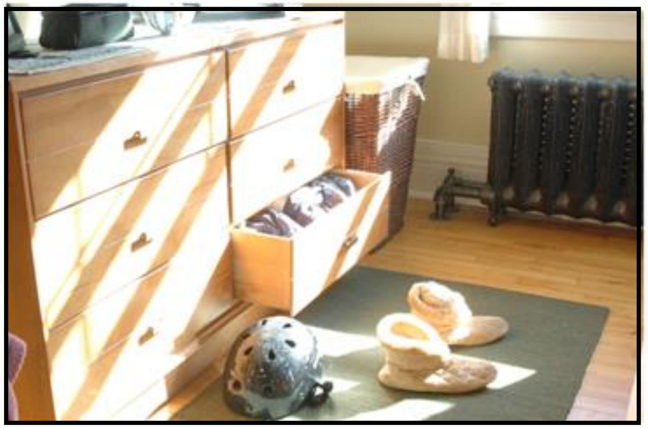
Image credit

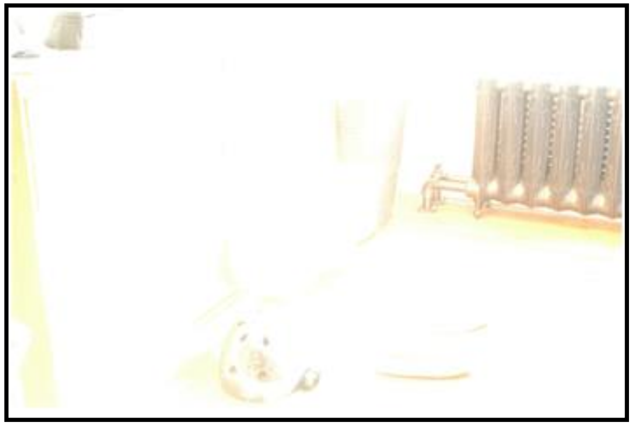
Exposure time and multiple exposures

$\frac{1}{2000}\ sec$

$\frac{1}{128}\ sec$

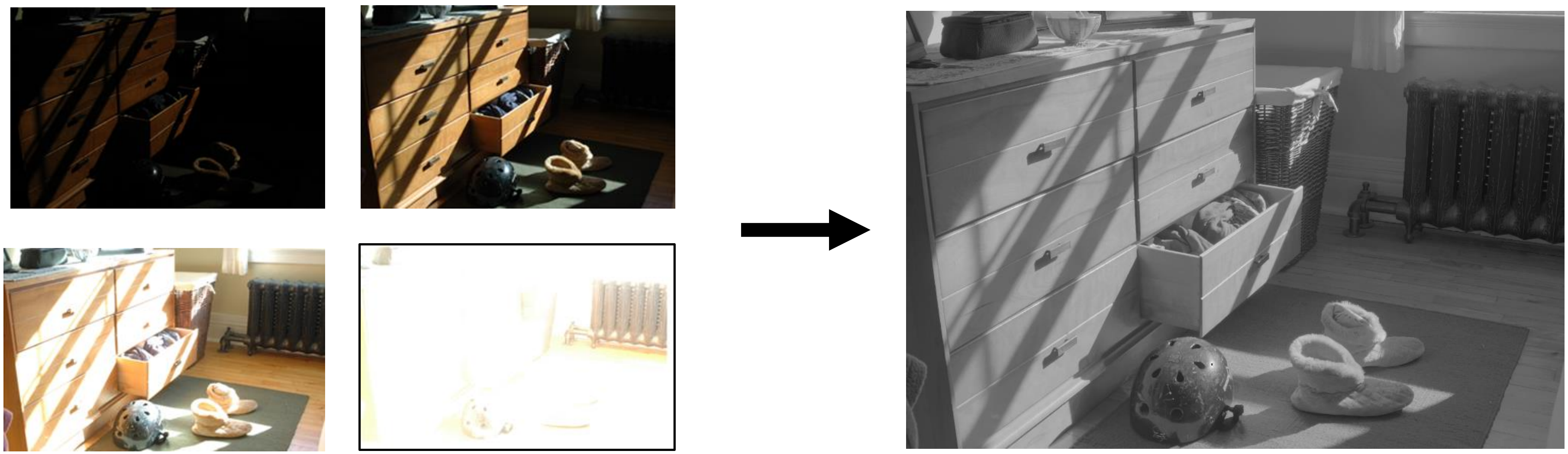
$\frac{1}{8}\ sec$





$2\ sec$

High dynamic range (HDR) imaging
+ tone mapping



There are various image processing tricks (detail omitted) for combining images of one scene with different exposure times to yield a single scene that shows details in all regions. (Only gray level shown in my example on the right.)

The intensities in this new image are not (linearly) proportional to the real scene light intensities!

HDR + tone mapping example 1

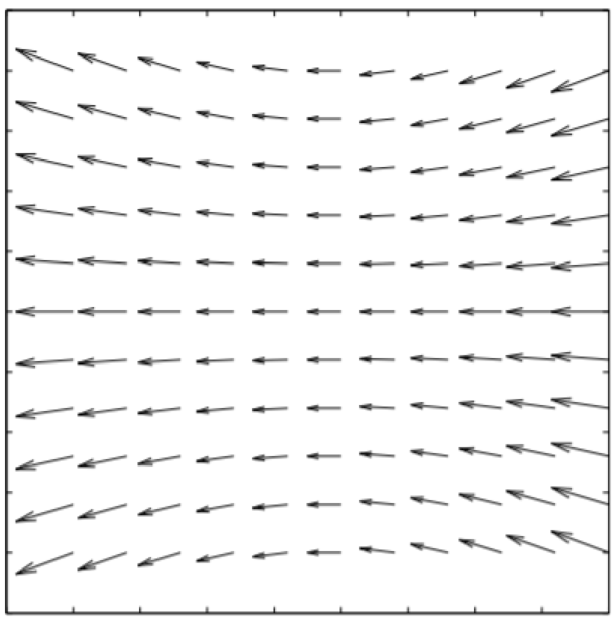
HDR + tone mapping example 2

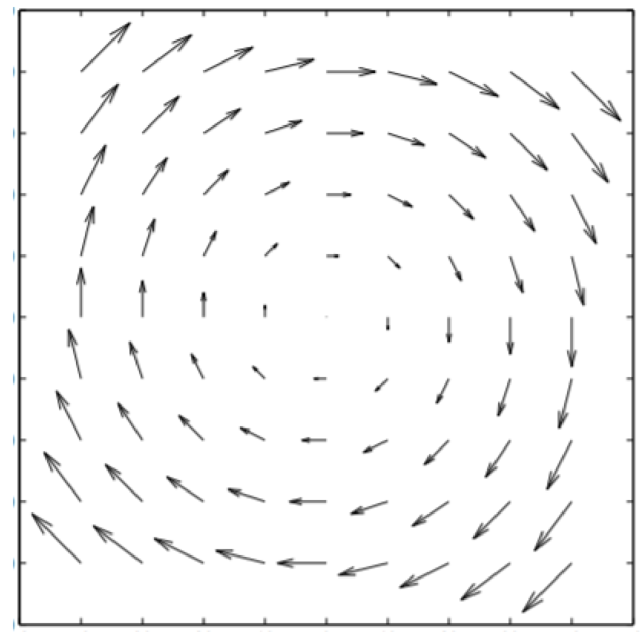
Motion blur

With a longer exposure time, moving objects are blurred.

Motion blur

With a longer exposure time, rotating the camera yields blur.





What is photographer doing here?

Why do we have more curved lines with this one ?

Exif

exchangeable image file format

- date and time information.
- camera settings (camera model, orientation, GPS position)
- aperture, shutter speed, focal length, metering mode, ISO
- thumbnail
- .....

These details are important for image forensics.

See interesting book: *Fake Photos* by Hany Farid.