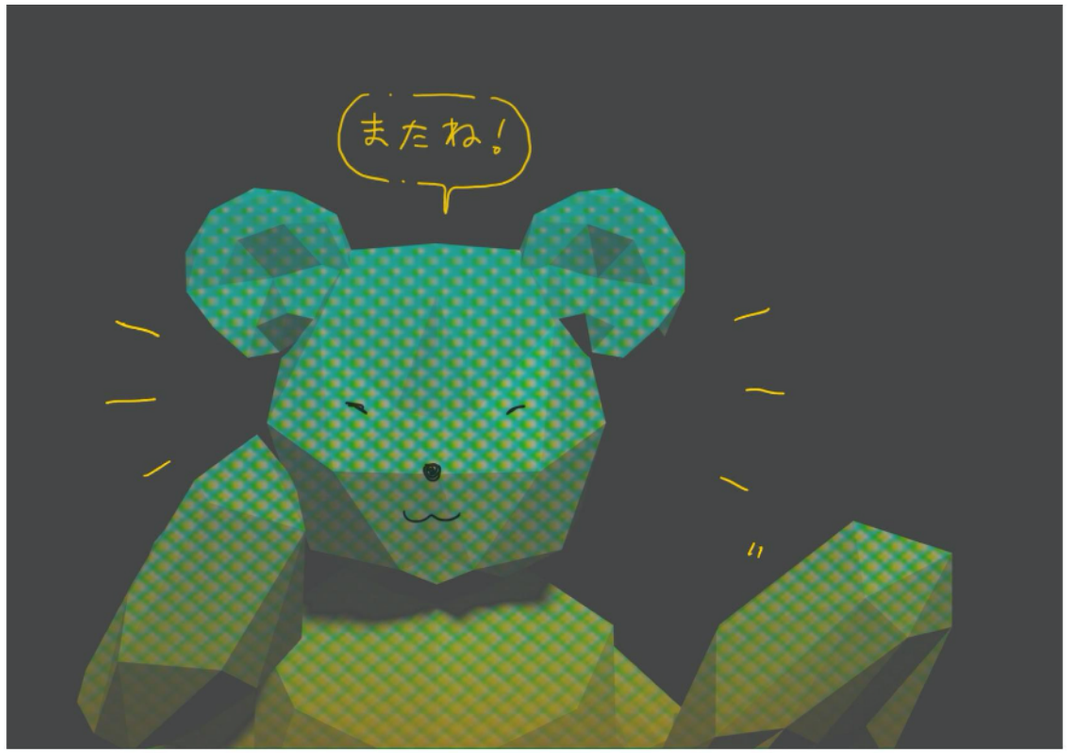
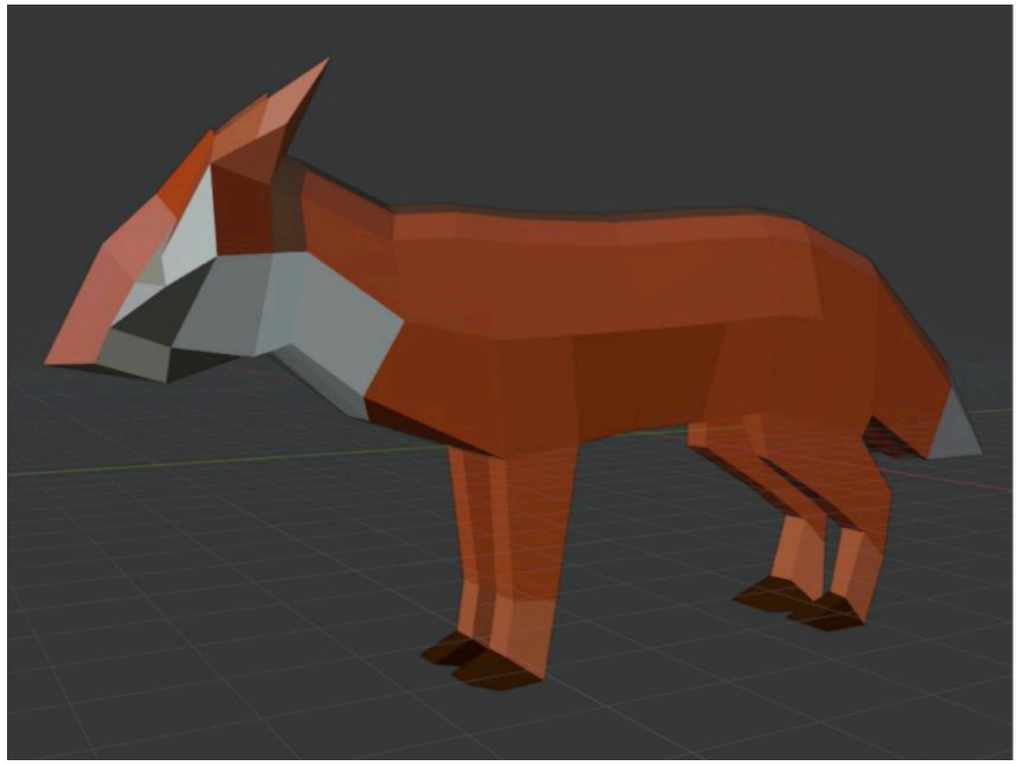
Cameras and Lenses

Computer Graphics and Imaging
UC Berkeley CS184
Summer 2020

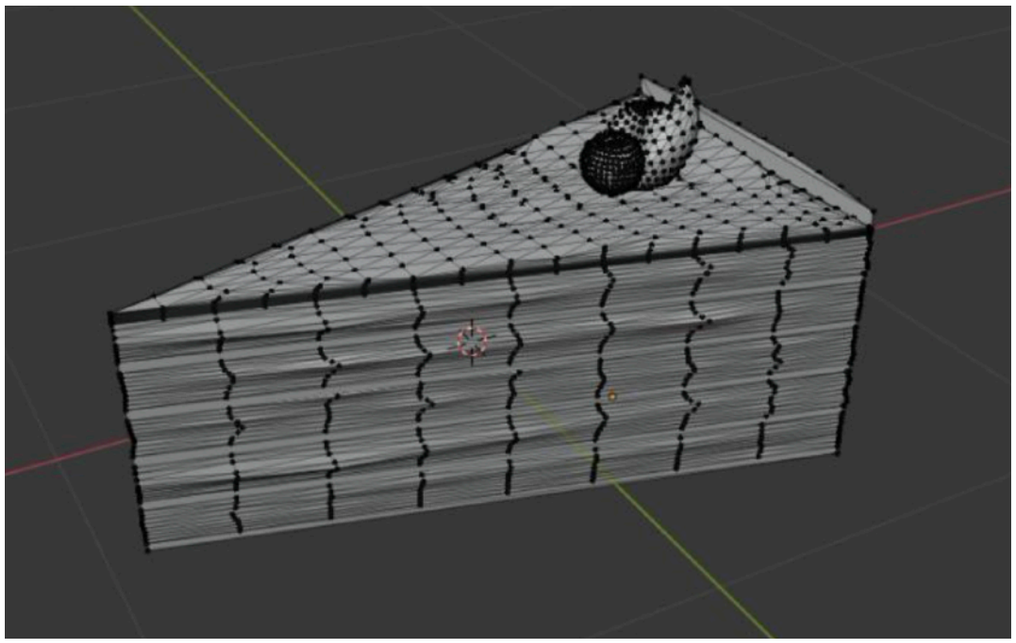
Mesh (Art)



Eunice Chan



Yifei Li



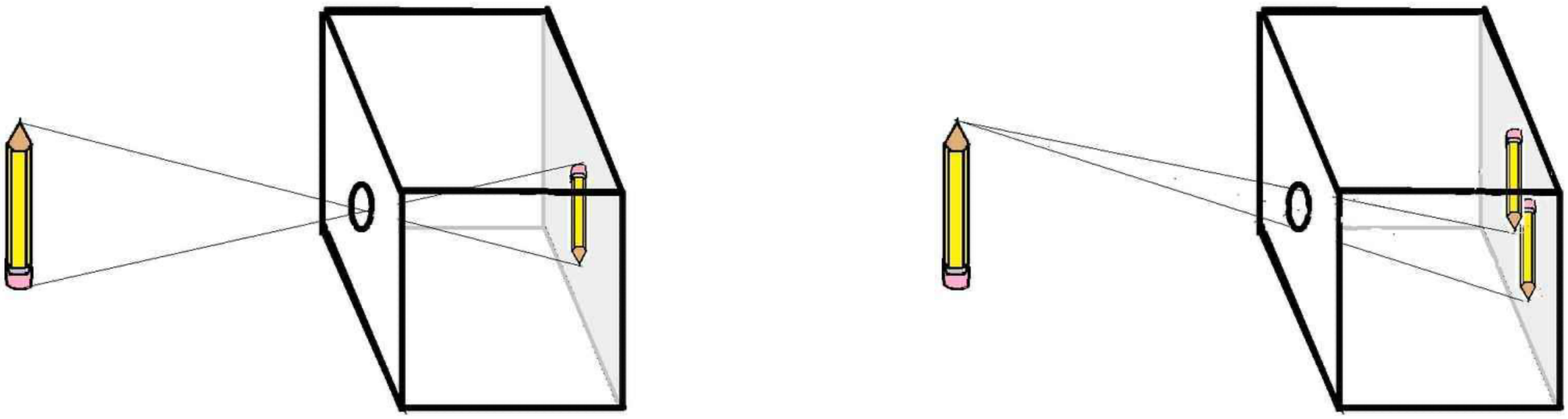
Apollo Thomopoulos

Agenda

- Cameras
  - Aperture, focal length, sensor, shutter, ISO
  - Field of view, depth of field
- Thin lens model
  - Ray Geometry
  - Circle of Confusion
  - Depth of field / depth of focus
- Lens Tracing
- Demo

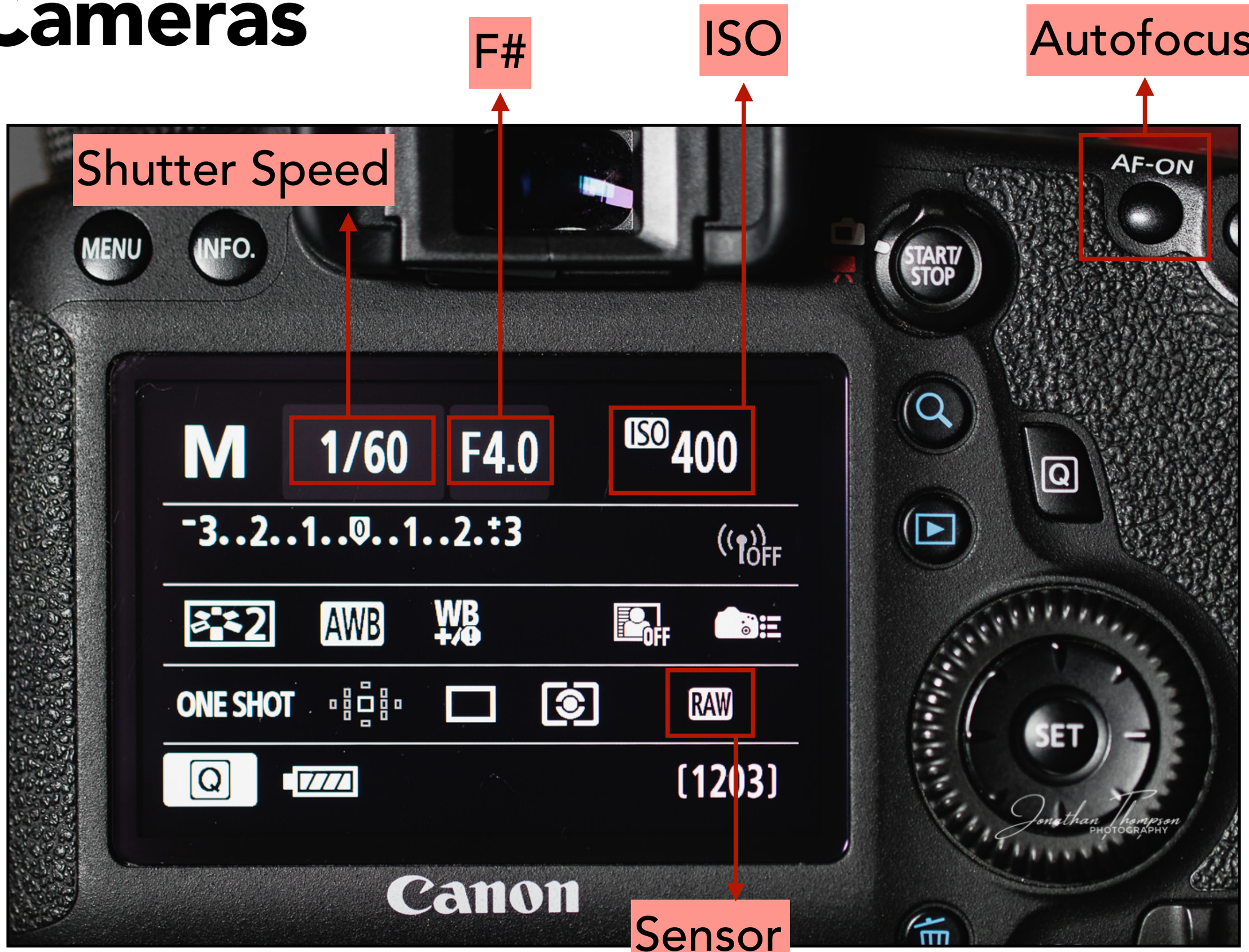
From Pinhole to Thin Lens

- What's the problem with pinhole model?



- What are introduced by a thin lens model?

Cameras


F#
ISO
Autofocus
Shutter Speed
AF-ON
MENU
INFO.
START/
STOP
M
1/60
F4.0
ISO 400
-3..2..1..0..1..2.+3
OFF
2
AWB
WB
+/0
OFF
ONE SHOT
RAW
Q
1203
SET
Canon
Jonathan Thompson
PHOTOGRAPHY
Sensor

Cameras

- Aperture
- Focal length

F#

- Sensor

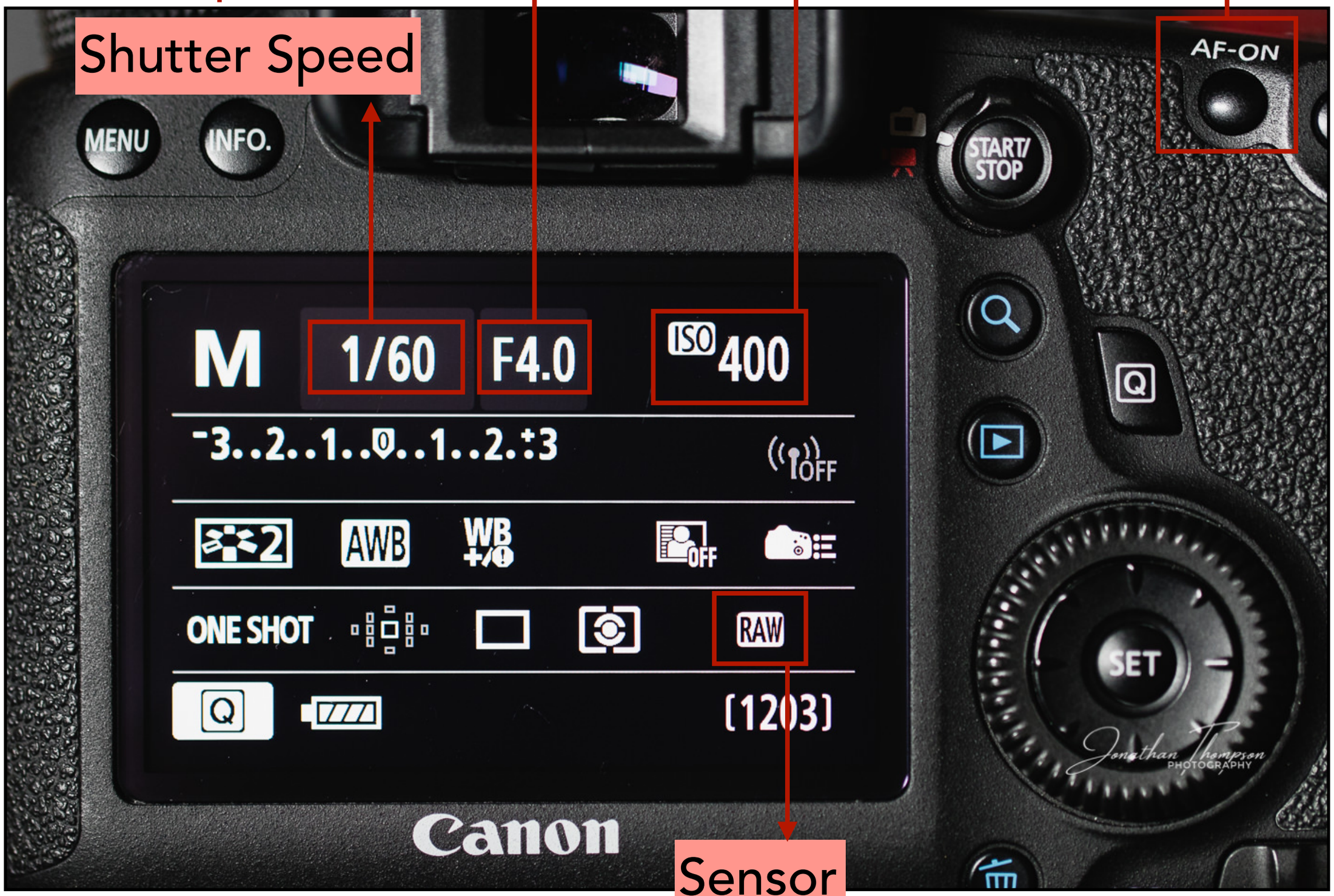
ISO

- Sensor
- Lens

Autofocus

- Aperture

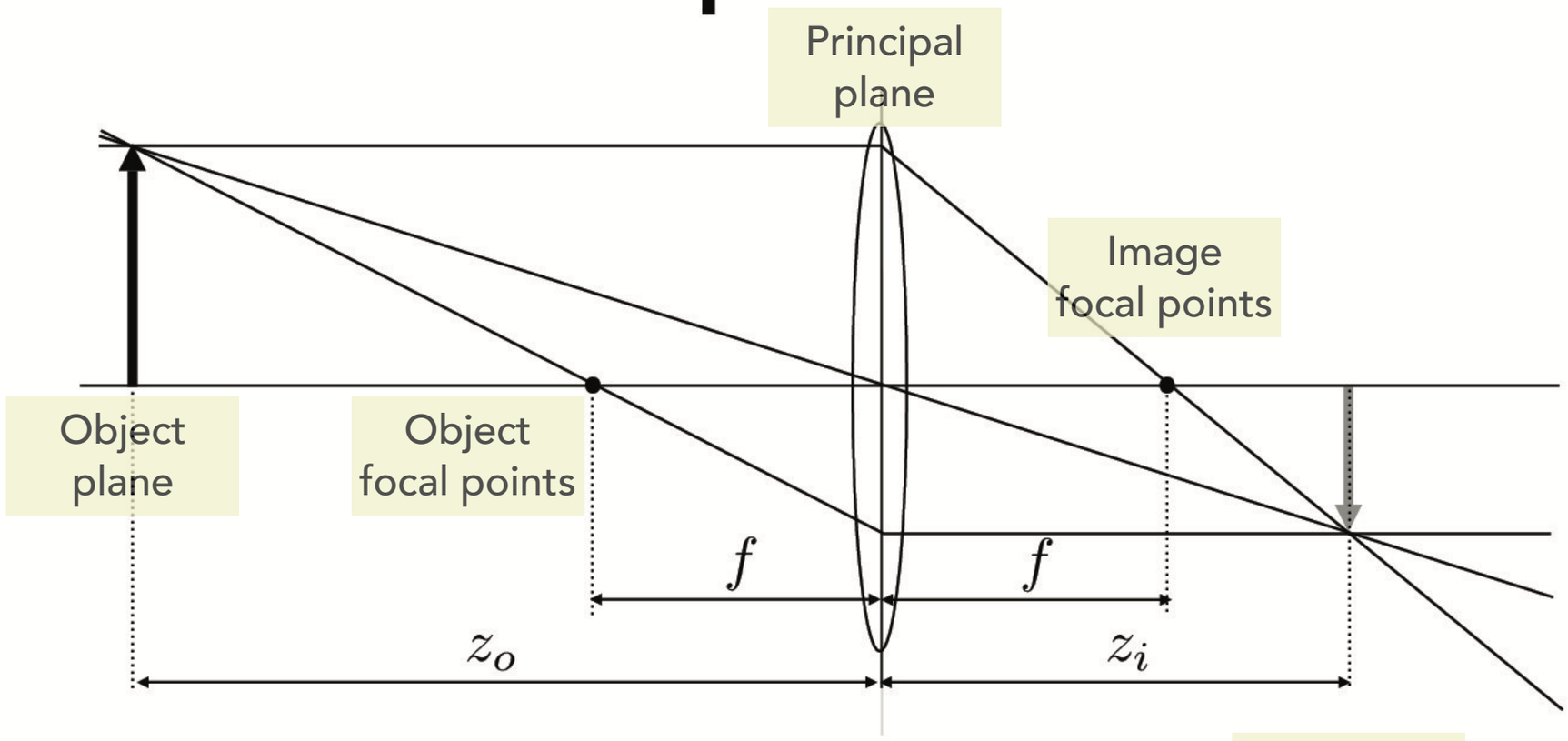
Shutter Speed



Sensor

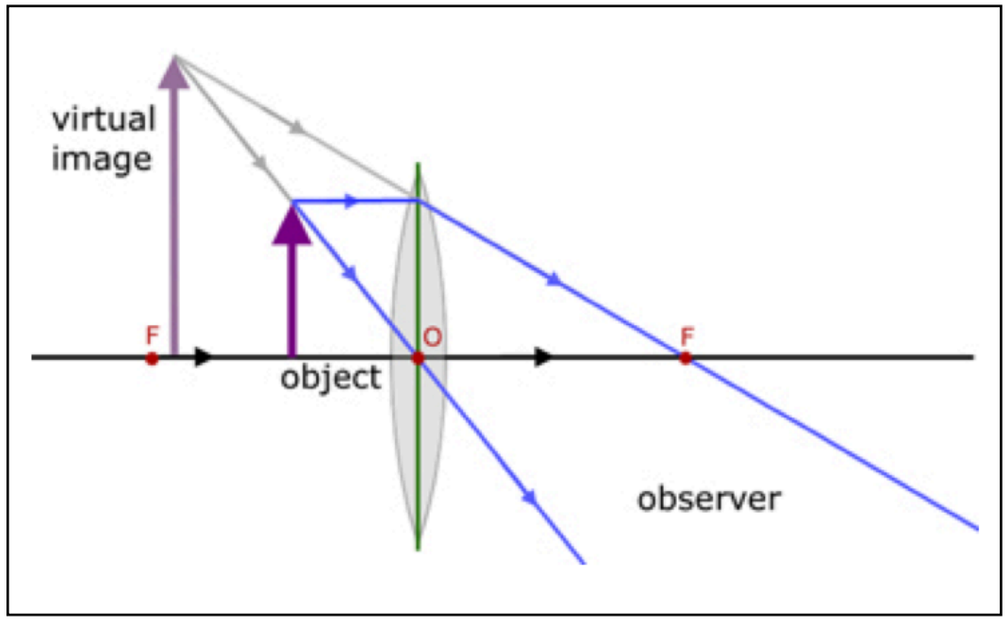
Thin Lens Model

The Thin Lens Equation

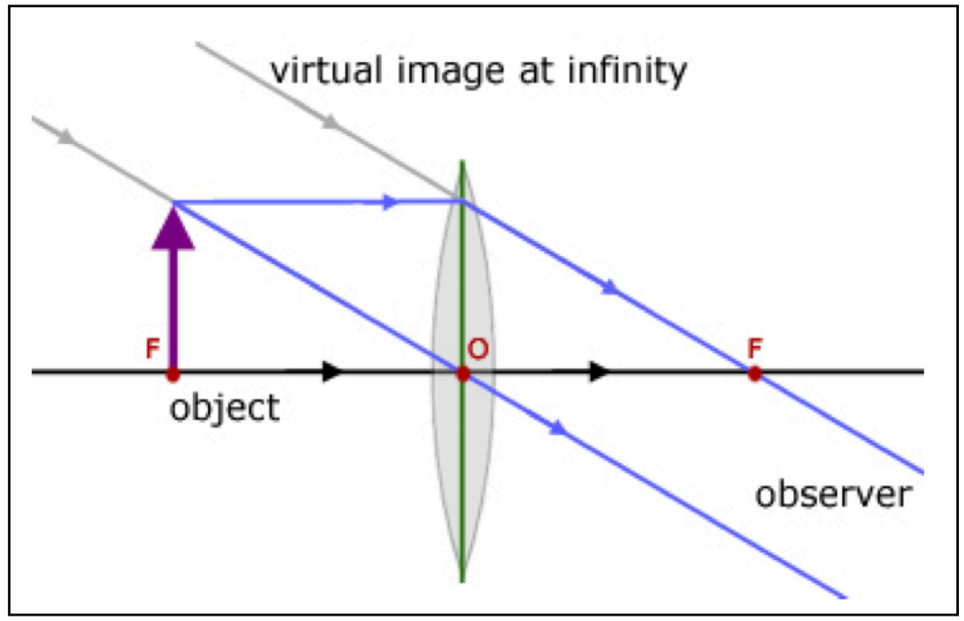


$$\frac{1}{f} = \frac{1}{z_i} + \frac{1}{z_o}$$

Thin Lens Model — different scenarios

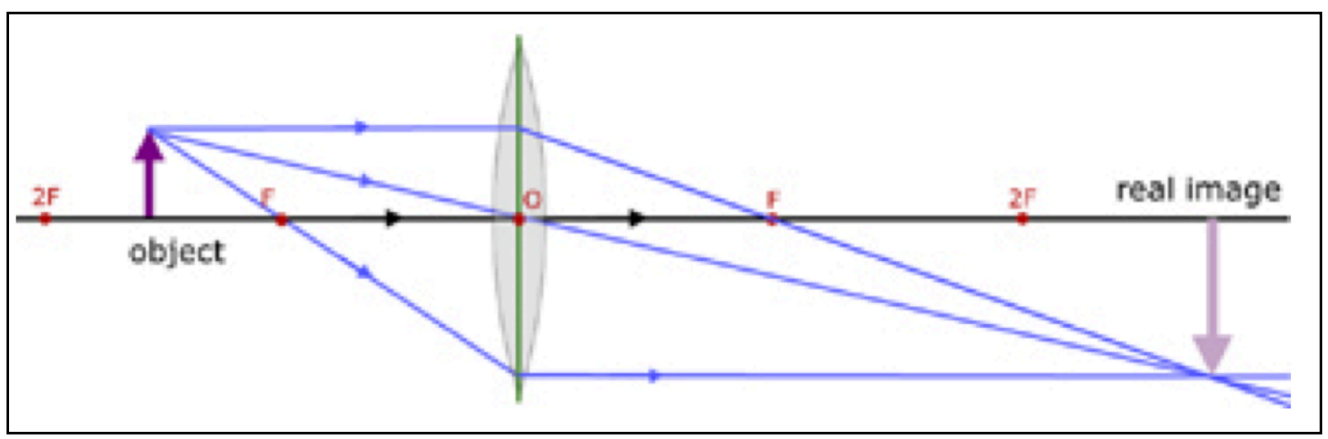


Object between F and the lens;
virtual, upright, magnified

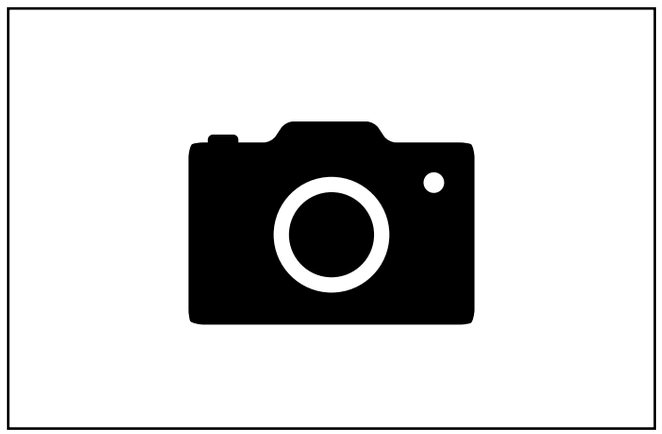


Object at F;

parallel rays, image at infinity = no image



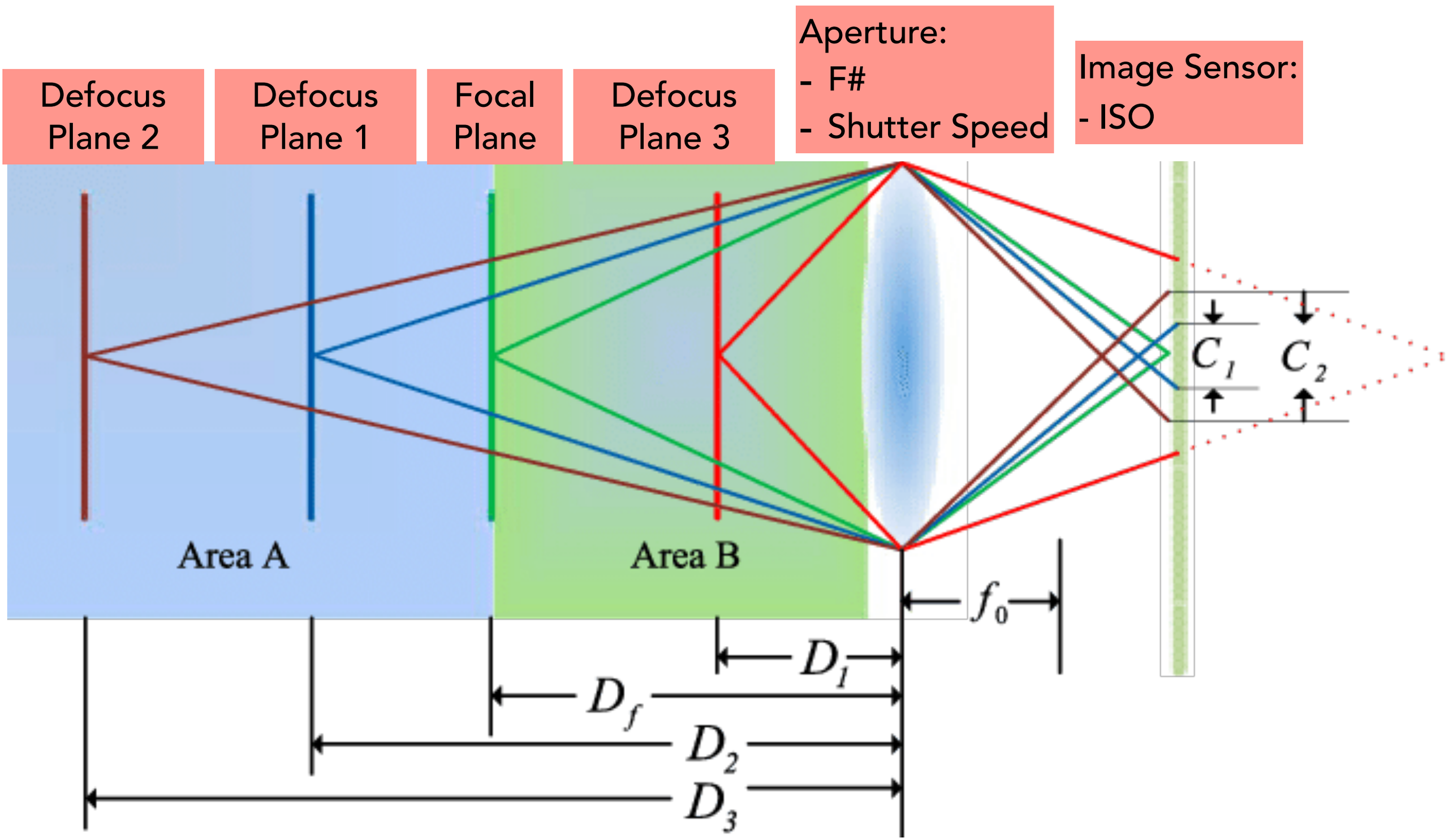
Object between F and 2F



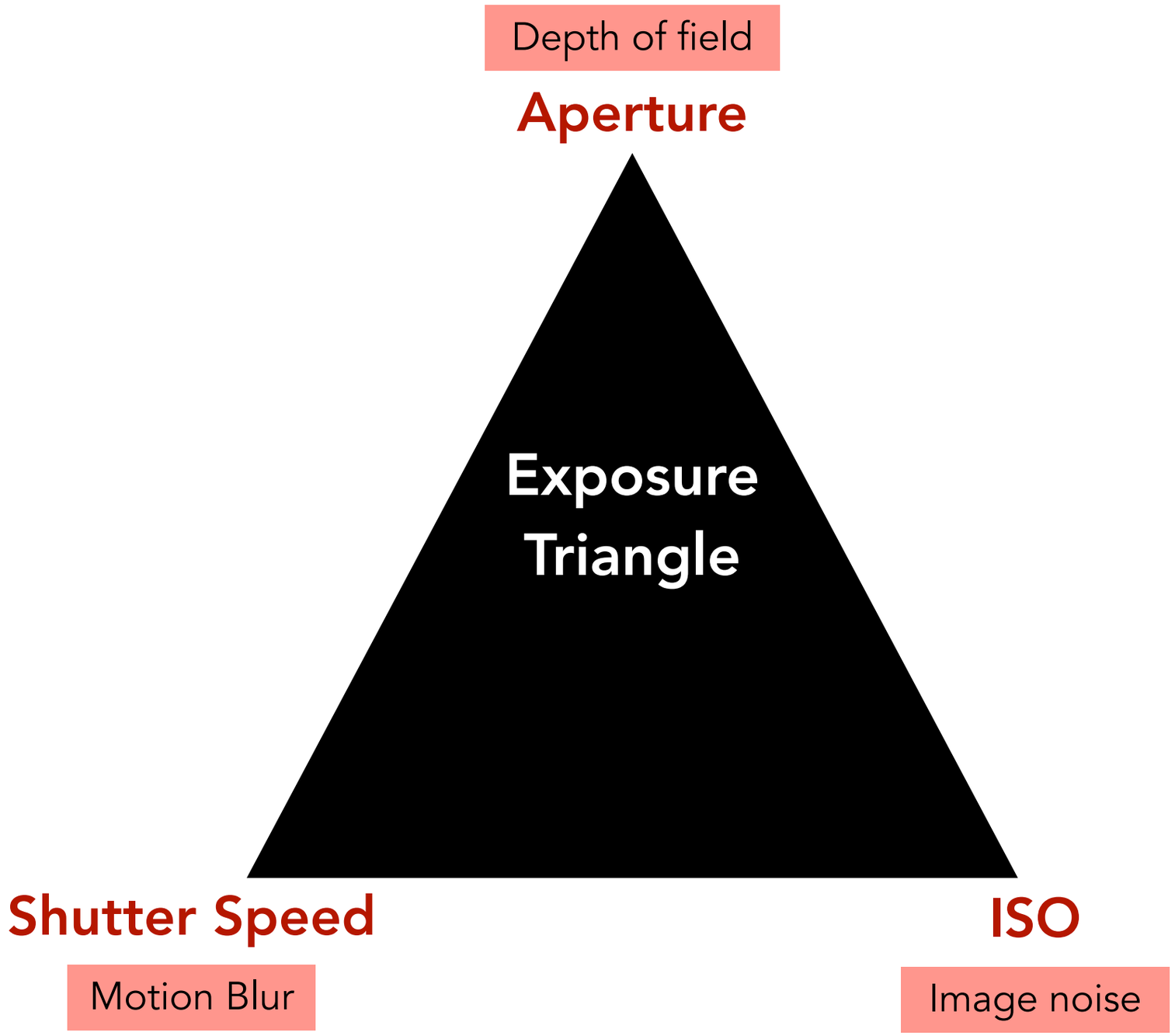
Distance to the object > 2F, usually ≫ F

Normal lens, wide-angle lens, telephoto lens.

Camera as a Thin Lens

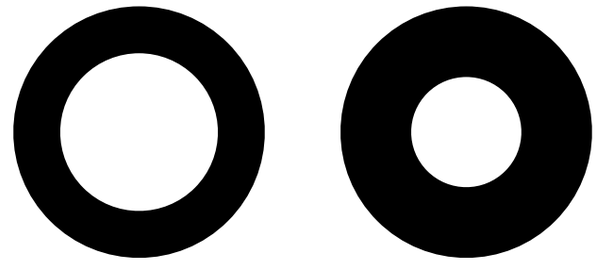


Camera Exposure



Camera Exposure

- How should I adjust the shutter speed?



F2 F4

- Does aperture change the field of view?

- To reduce shutter speed (e.g. moving object), you can ___ aperture or ___ ISO
  - What are the trade-offs?

Camera Exposure

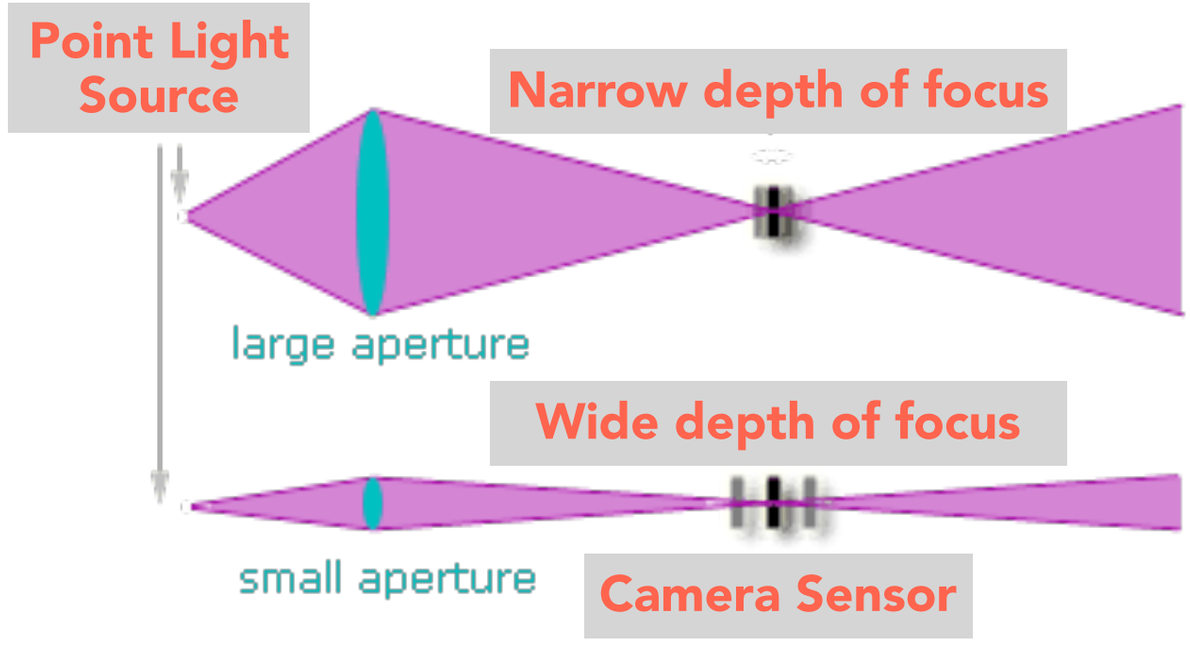
Stanley Kubrick, Barry Lyndon,
1975

Zeiss 50mm f/0.7

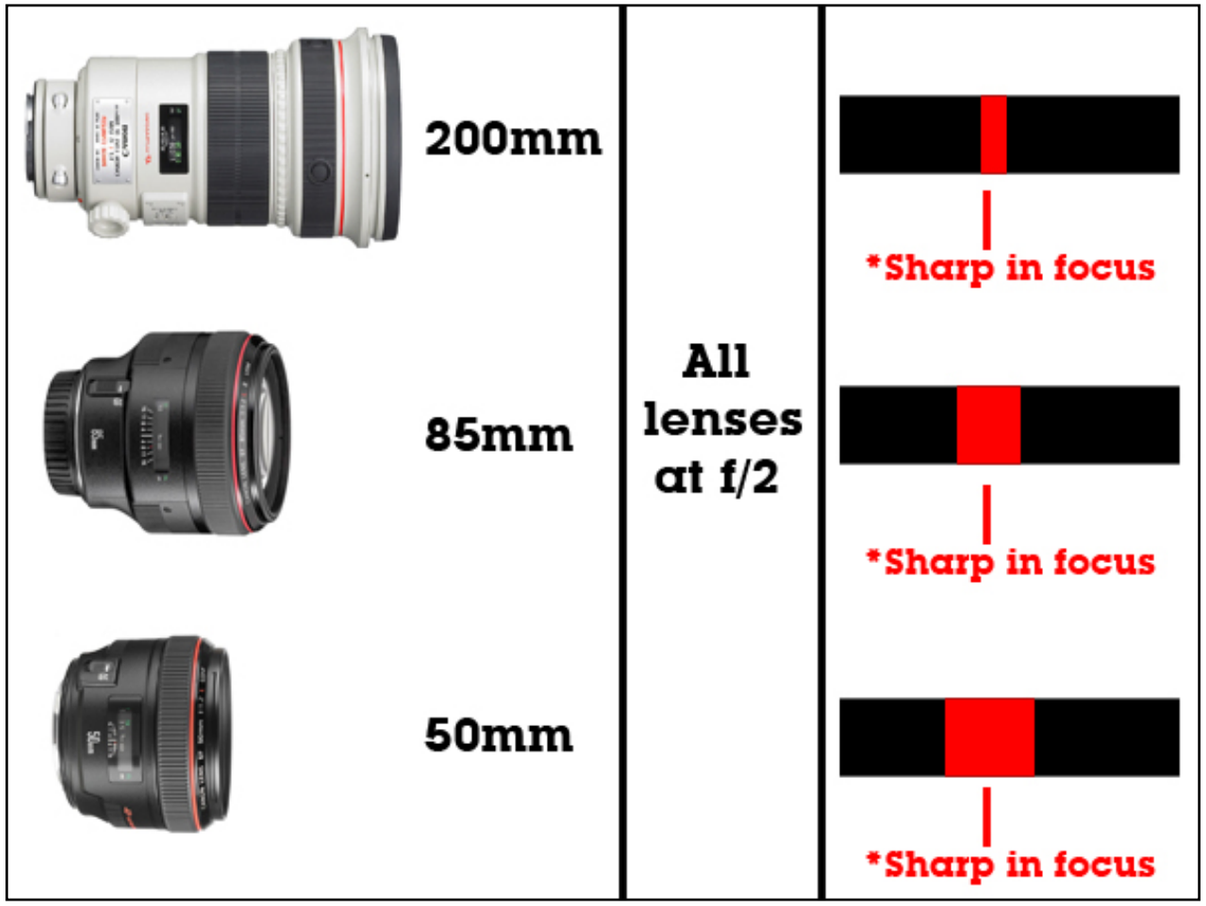
Depth of Field / Focus

- Aperture
- Focusing distance
  - Not focal length!

- Geometry



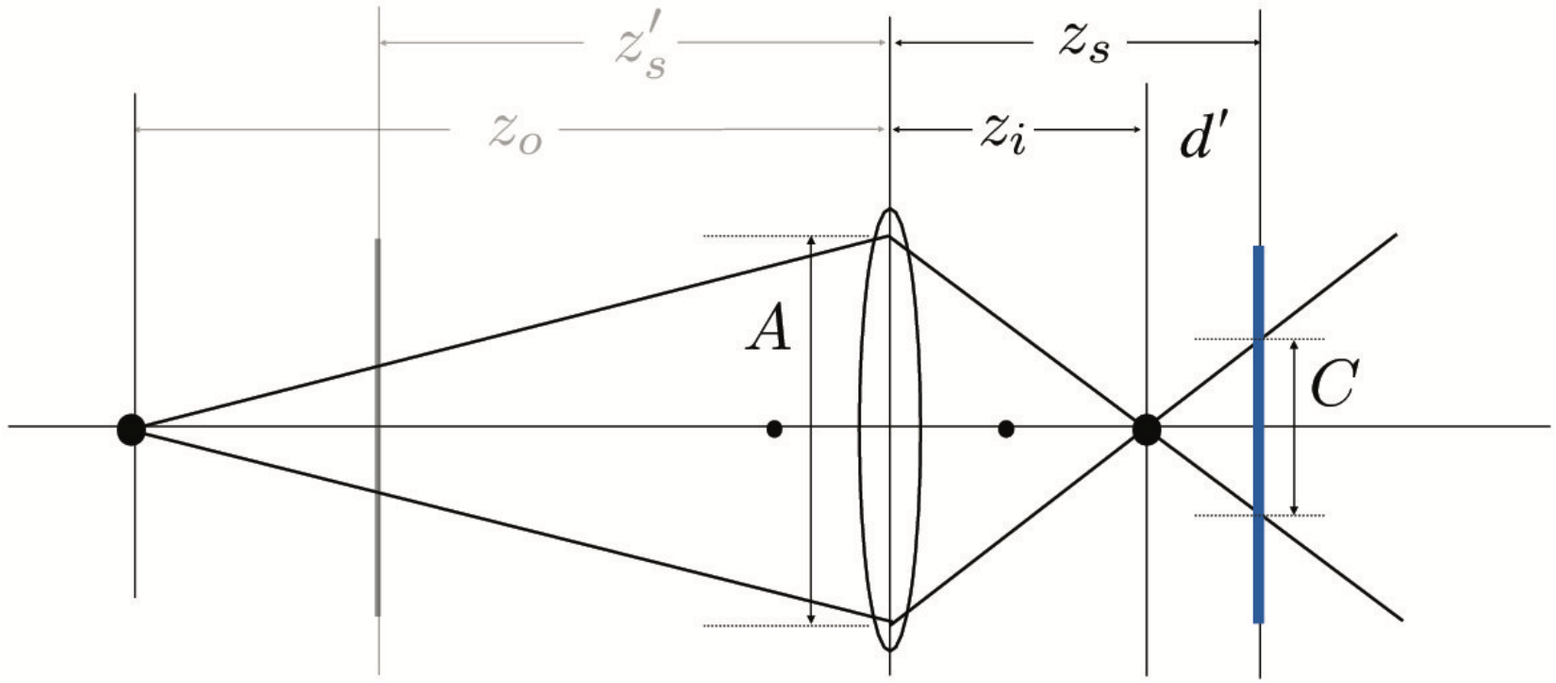
Depth of Field / Focus & Focal Length



- Focal length is technically not influencing DOF
  - The DOF effect is mainly due to magnification

Thin Lens Model — CoC

Computing Circle of Confusion Diameter (C)



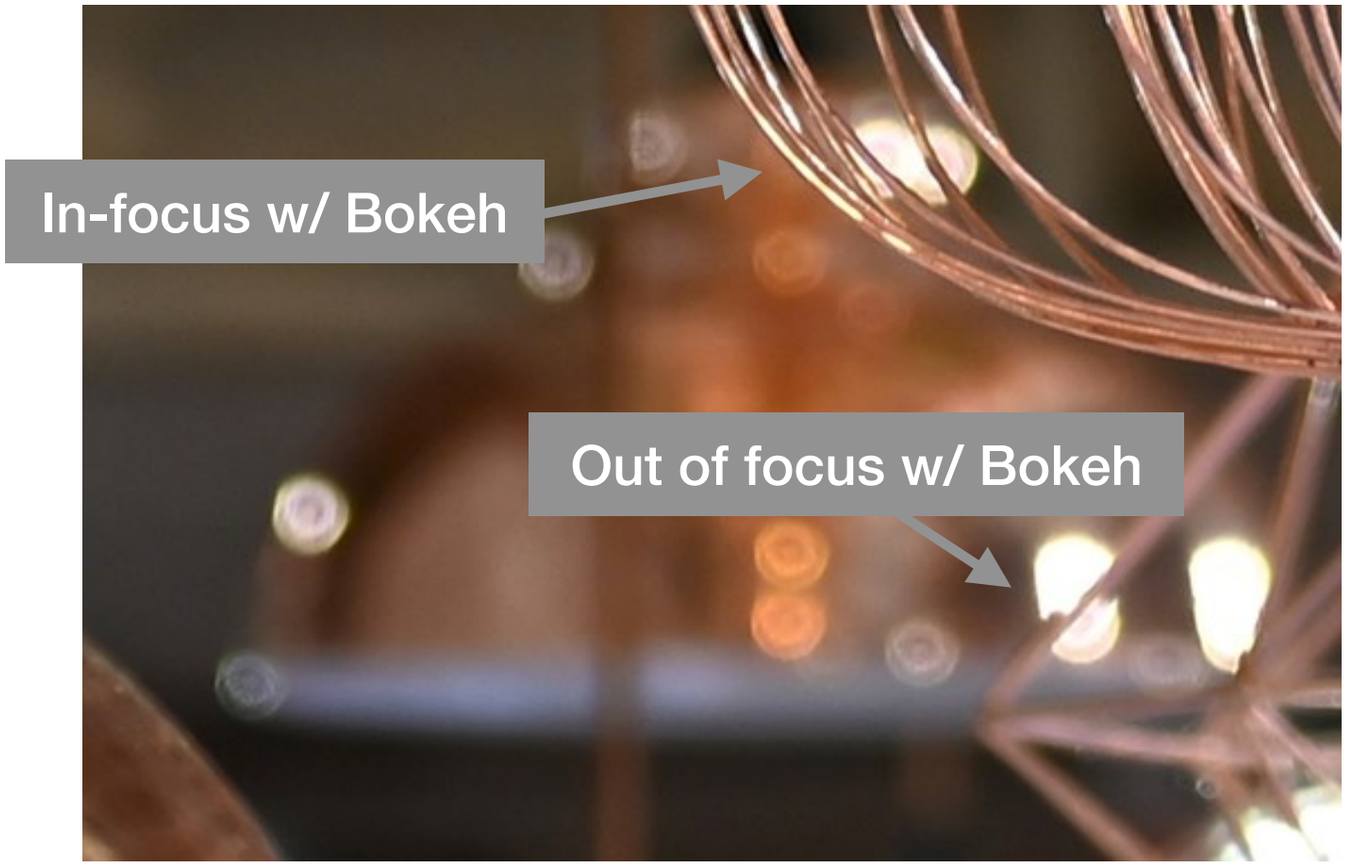
Circle of confusion is proportional to the size of the aperture

$$\frac{C}{A} = \frac{d'}{z_i} = \frac{|z_s - z_i|}{z_i}$$

Circle of Confusion

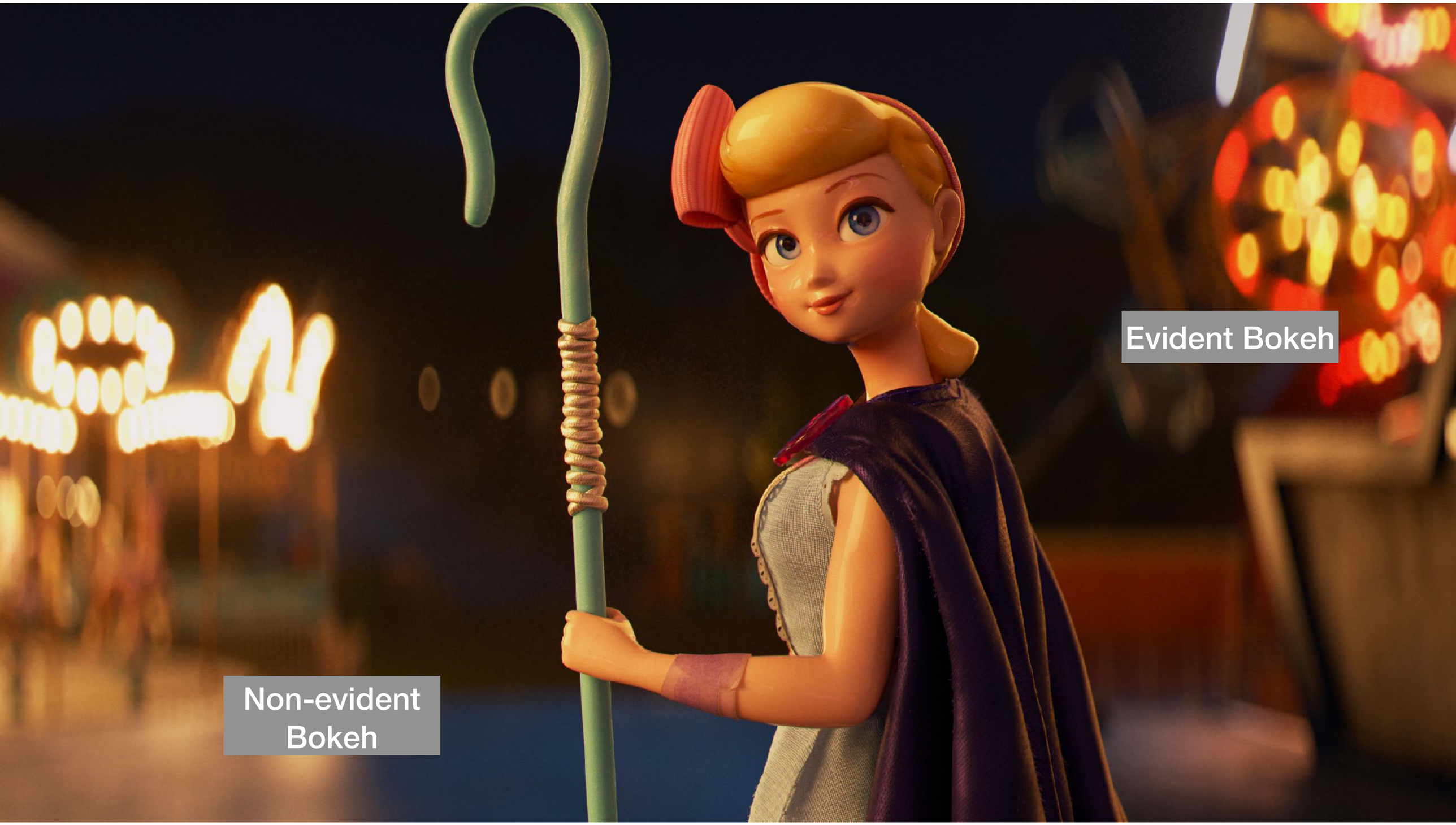
- Circle of Confusion
  - Describes the max DOF
  - Out-of-focus shape?

Regular lens Anamorphic lens



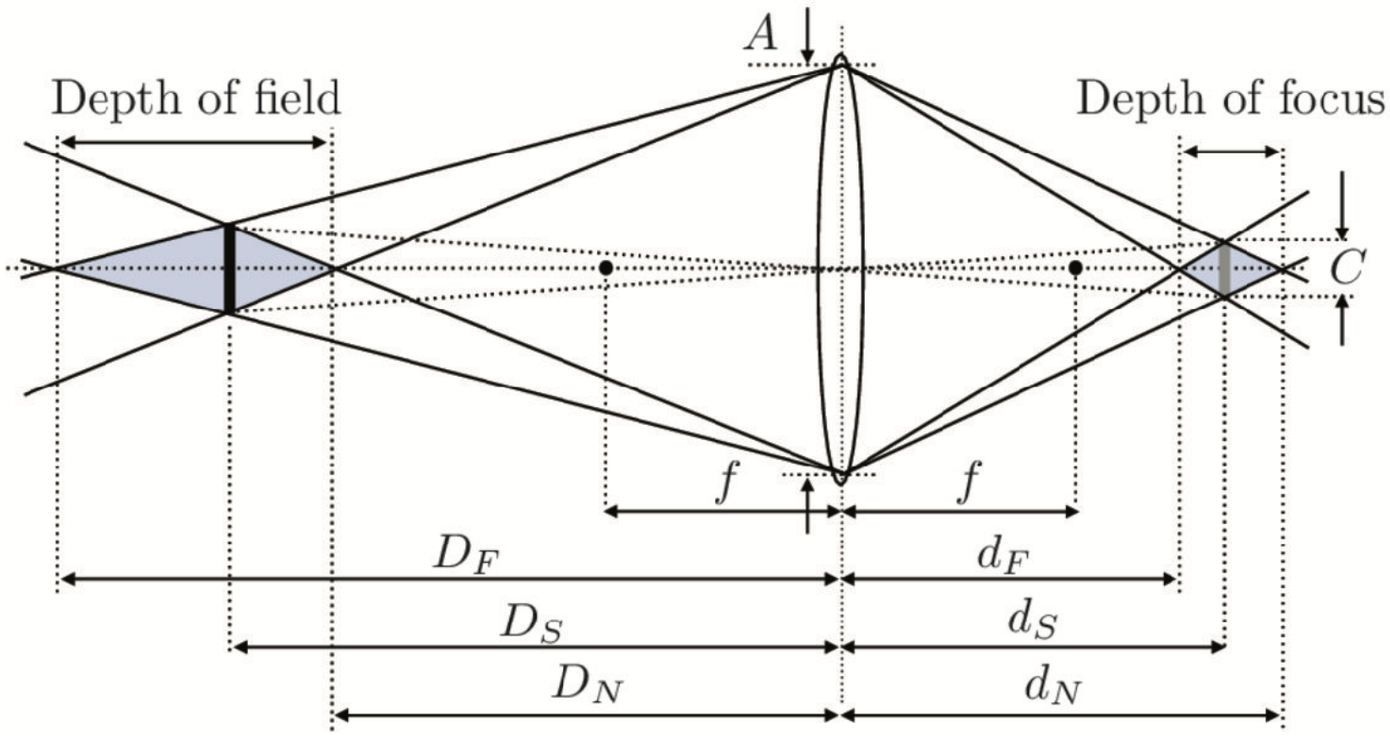
Geometry of Bokeh

Virtual Anamorphic Lens in Toy Story 4



Thin Lens Model — DoF

Depth of Field



$$\frac{d_N - d_S}{d_N} = \frac{C}{A}$$

$$\frac{d_S - d_F}{d_F} = \frac{C}{A}$$

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

$$\frac{1}{D_F} + \frac{1}{d_F} = \frac{1}{f}$$

$$\frac{1}{D_S} + \frac{1}{d_S} = \frac{1}{f}$$

$$\frac{1}{D_N} + \frac{1}{d_N} = \frac{1}{f}$$

$$\text{DOF} = D_F - D_N$$

$$D_F = \frac{D_S f^2}{f^2 - NC(D_S - f)} \qquad D_N = \frac{D_S f^2}{f^2 + NC(D_S - f)}$$

Thin Lens Model — DoF

$$DOF = \frac{2NCD_s^2 f^2}{f^4 - N^2C^2D_s^2}$$

- N F-number of lens
- C is Circle of Confusion (on image)
- D_s is distance to in-focus plane (in object space)
- f is focal length of lens
- $N^2C^2D_s^2$ can be ignored if CoC is small relative to Aperture

Thin Lens Model — DoF

$$DOF \approx \frac{2NCD_s^2}{f^2}$$

- Recall Dolly Zoom
  - If we zoom in (change f) and stand further away (change D_s) by the same factor
  - Then … ?

Thin Lens Model — DoF

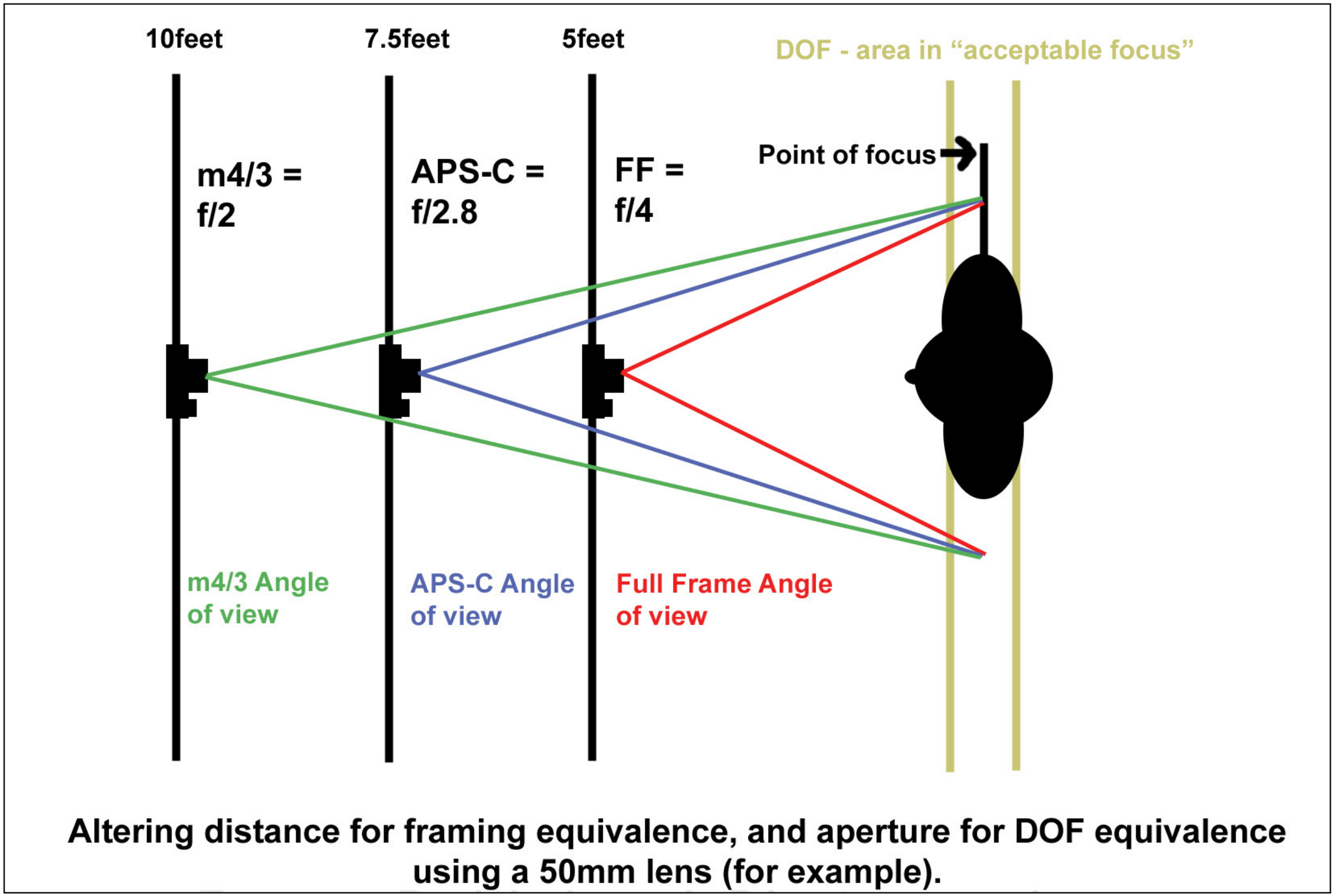
$$DOF \approx \frac{2NCD_s^2}{f^2}$$

50mm f/4.8

200mm f/4.8

(move back 4X)

Make the Objective Clear



Altering distance for framing equivalence, and aperture for DOF equivalence using a 50mm lens (for example).

Make the Objective Clear

- Which one longer focal length?
- Position from A + Lens from C?
- Position from C + Lens from A?

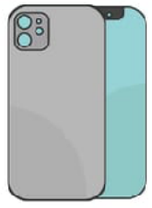
(a)

(b)

(c)

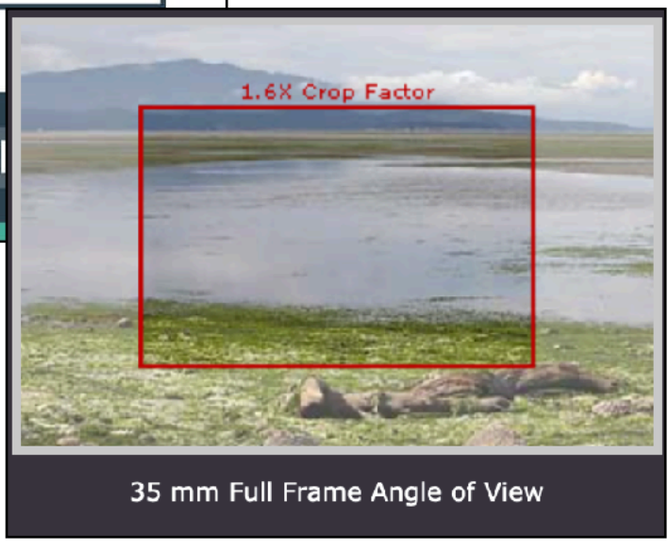
Sensor Size, Focal Length, FOV

CAMERA SENSOR SIZE COMPARISON CHART

	MEDIUM FORMAT	FULL-FRAME	APS-C	MICRO 4/3	1"	1/2.55"
PICTURE						
SENSOR SIZE	53.0 X 40.20 MM	35.00 X 24.00 MM	23.6 X 15.60 MM	17.00 X 13.00 MM	12.80 X 9.60 MM	6.17 X 4.55 MM
CROP FACTOR	0.64	1	1.52	2	2.7	5.62
CAMERA						

capturetheatlas.com

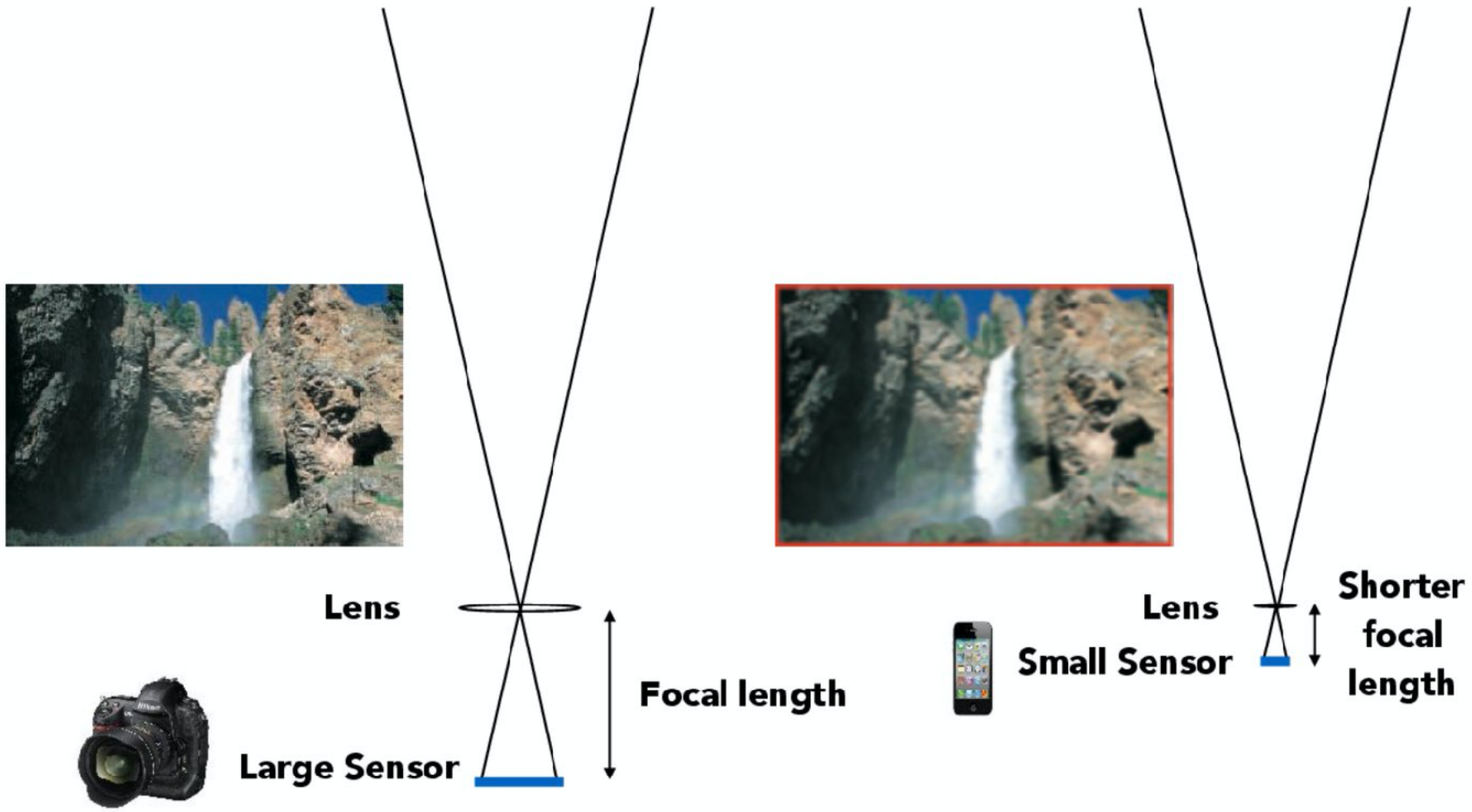
@Capturet



35 mm Full Frame Angle of View

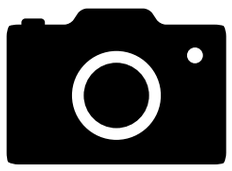
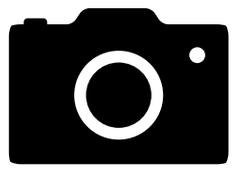
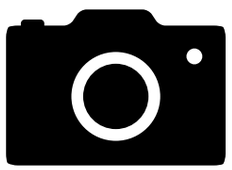
Sensor Size, Focal Length, FOV

Maintain FOV on Smaller Sensor?



To maintain FOV, decrease focal length of lens
in proportion to width/height of sensor

Sensor Size, Focal Length, FOV

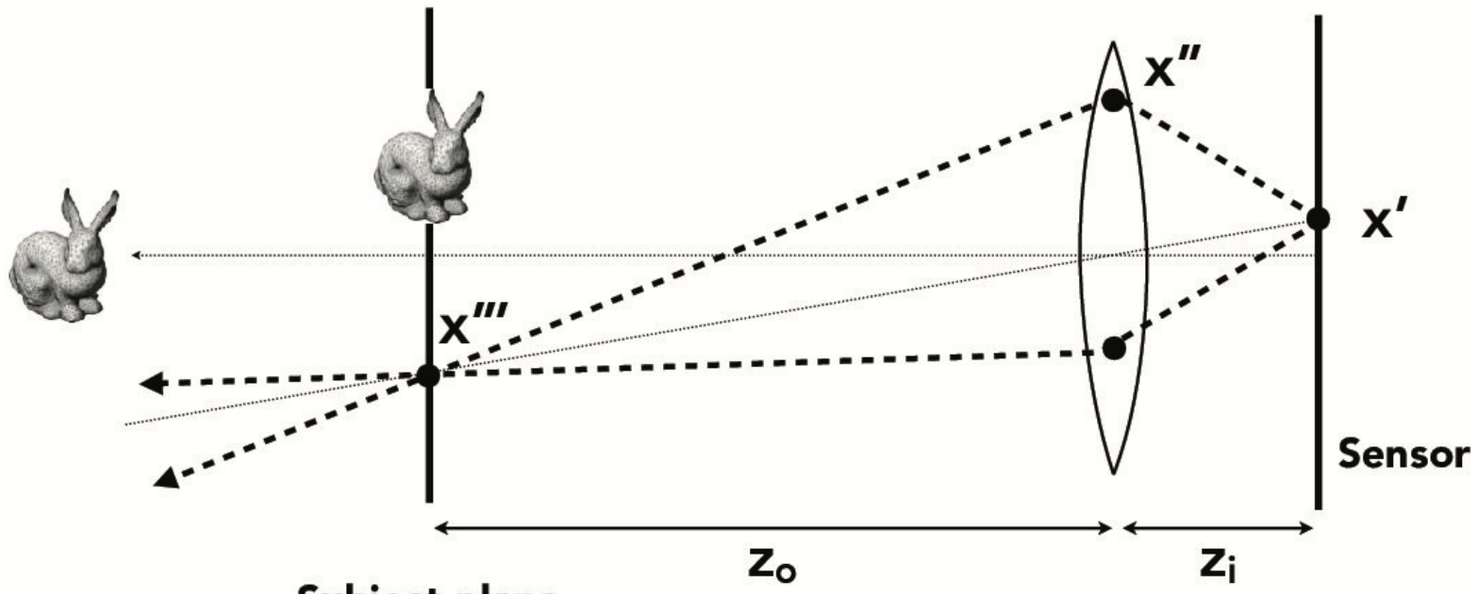
-  has a focal length, sensor width and height 4X of  both cameras have the same f#. The  has 4X as many pixels.
  - Each pixel in the  receives ? times more light
- iPhone X has a focal length of 4.25mm, which is a 26mm equivalent — 35mm equivalent focal length
  - Why 26mm?

Basic Lens and Depth of Field equations.

$$\frac{1}{s}+\frac{1}{d}=\frac{1}{f}$$	*f* = focal length— the lens's most important parameter. *s* = lens-to-object distance. *d* = lens-to-film plane distance. If object *s* is located an infinite distance from the lens (*s* >> *f*), the image is focused at a distance *f* from the lens, i.e., *d* = *f*.
$$N = \text{f-stop} = \text{f-number} = \frac{f}{a}$$	*a* = aperture diameter.
$$C_f = a\left\lvert\frac{(d_f - d)}{d_f}\right\rvert$$	Circle of confusion at the film plane (*d*) for object located at S_f (closer than *s*), which focuses on d_f. Derived from simple geometry using $1/s_f + 1/d_f = 1/f$.
$$C_r = a\left\lvert\frac{(d - d_r)}{d_r}\right\rvert$$	Circle of confusion at the film plane (d) for object located at S_r (behind s), which focuses on d_r. Derived from simple geometry using $1/s_r + 1/d_r = 1/f$.
$$M = \frac{d}{s} = \frac{f}{s-f}$$	Magnification
$$D_f = s - \frac{1}{\frac{1}{f} - \frac{1-\frac{C}{a}}{d}} = \frac{sCN(s-f)}{f^2 + CN(s-f)}$$	D_f (front depth of field limit relative to *s*) derived from (1) and (3) using $D_f = s - s_f$; N = f-stop = f/a **$s_f = s - D_f$; Lens to front DOF limit.**
$$D_f = \frac{1}{\frac{1}{f} - \frac{1+\frac{C}{a}}{d}} - s = \frac{sCN(s-f)}{f^2 - CN(s-f)}$$	D_r (rear depth of field limit relative to *s*) derived from (1) and (4) using $D_r = s_r - s$. D_r = infinity when demoninator $fa\text{-}c(s\text{-}f) <= 0$ ($f^2\text{-}CN(s\text{-}f) <= 0$). **$s_r = s + D_r$; Lens to rear DOF limit.**

Camera in Ray Tracing

Ray Tracing for Defocus Blur (Thin Lens)



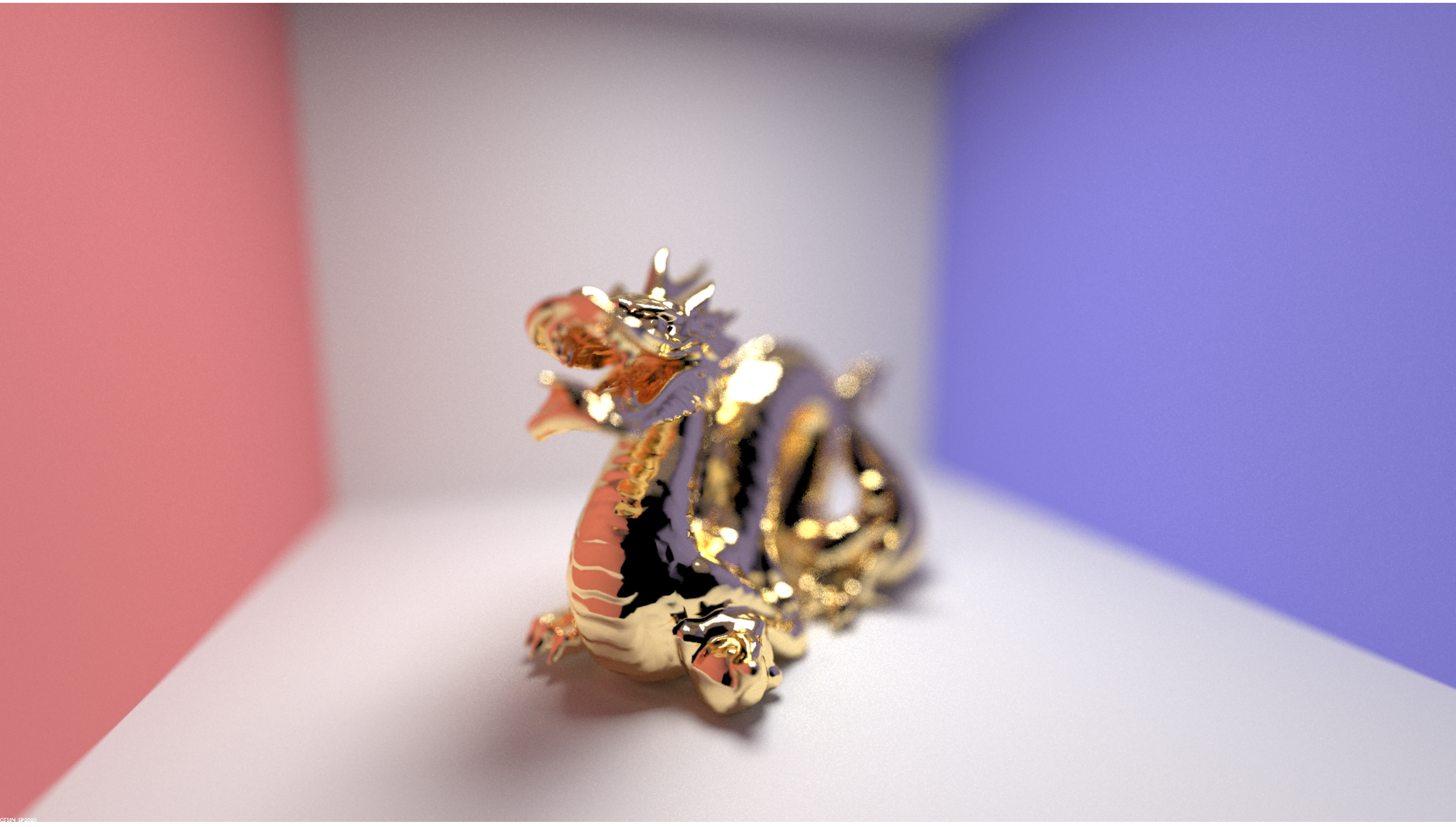
Setup:

- Choose sensor size, lens focal length and aperture size
- Choose depth of subject of interest z_o
  - Calculate corresponding depth of sensor z_i from thin lens equation (focusing)

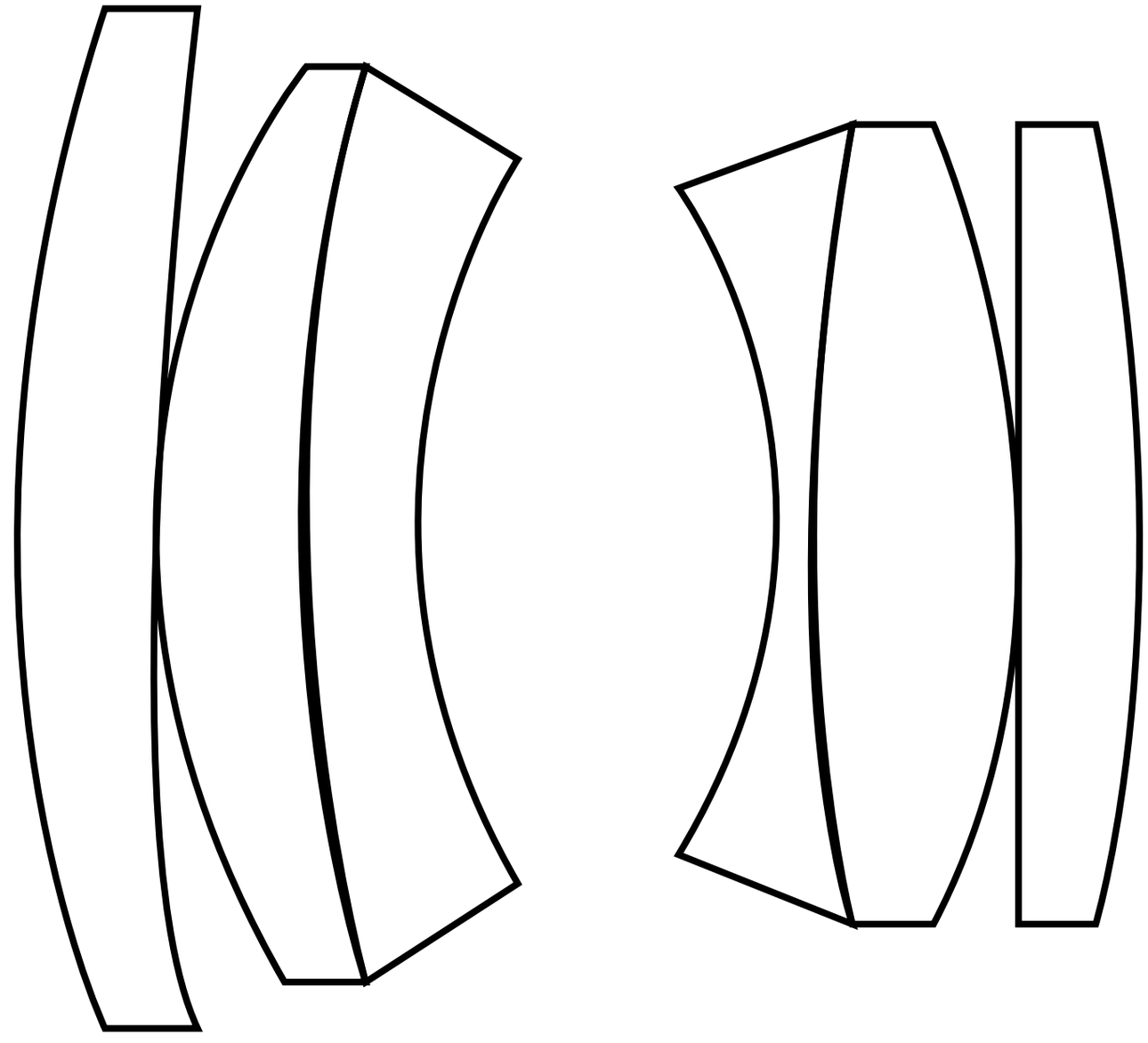
Camera in Ray Tracing

- Sampling from a thin lens
  - Lens is a ~disk shape
  - Recall uniform disk sampling

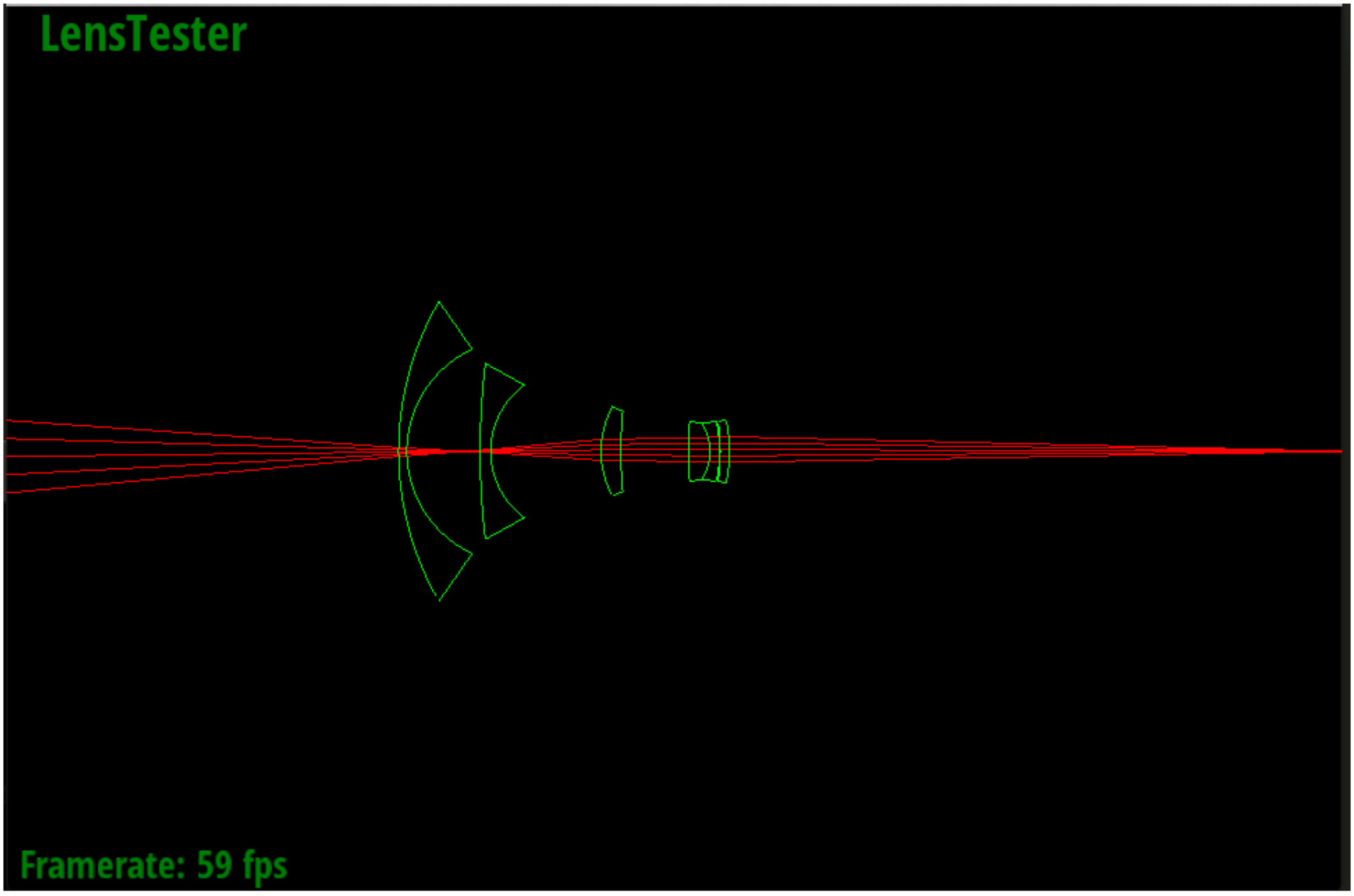
Your Proj 3-2



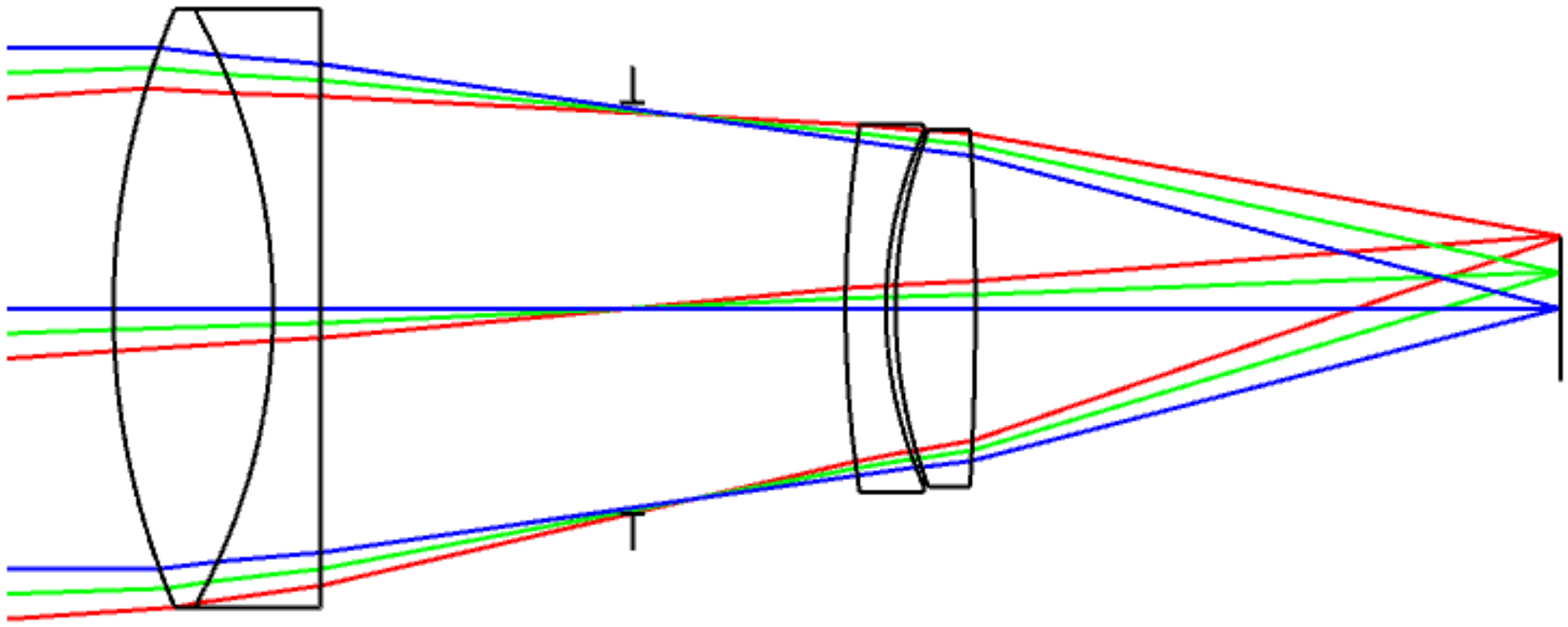
Demo Preview — Compound Lens

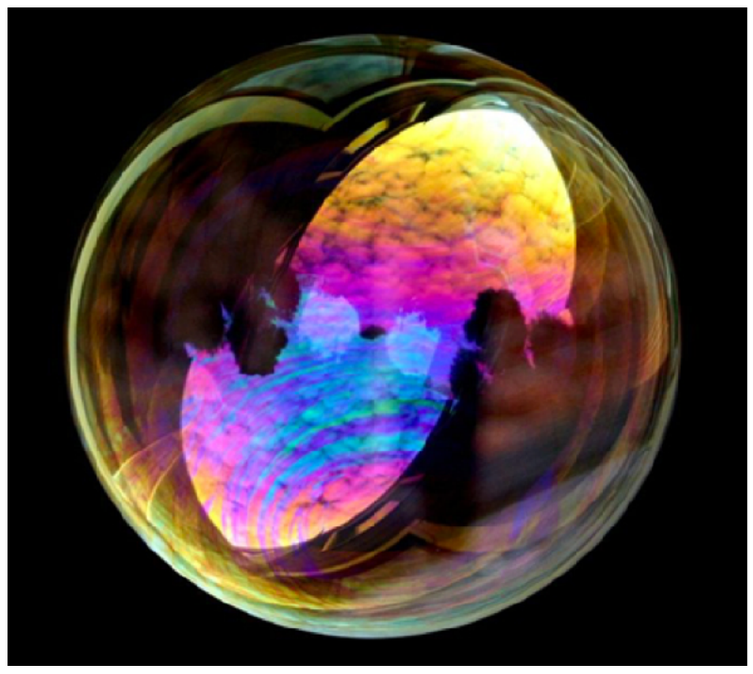


Demo Preview — Compound Lens



Demo Preview — Spectral Ray Tracer





Demo