

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.



Cameras, Optics, and Sensors



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Cameras: Lenses and Impact / Properties of
Focal Length on Photography

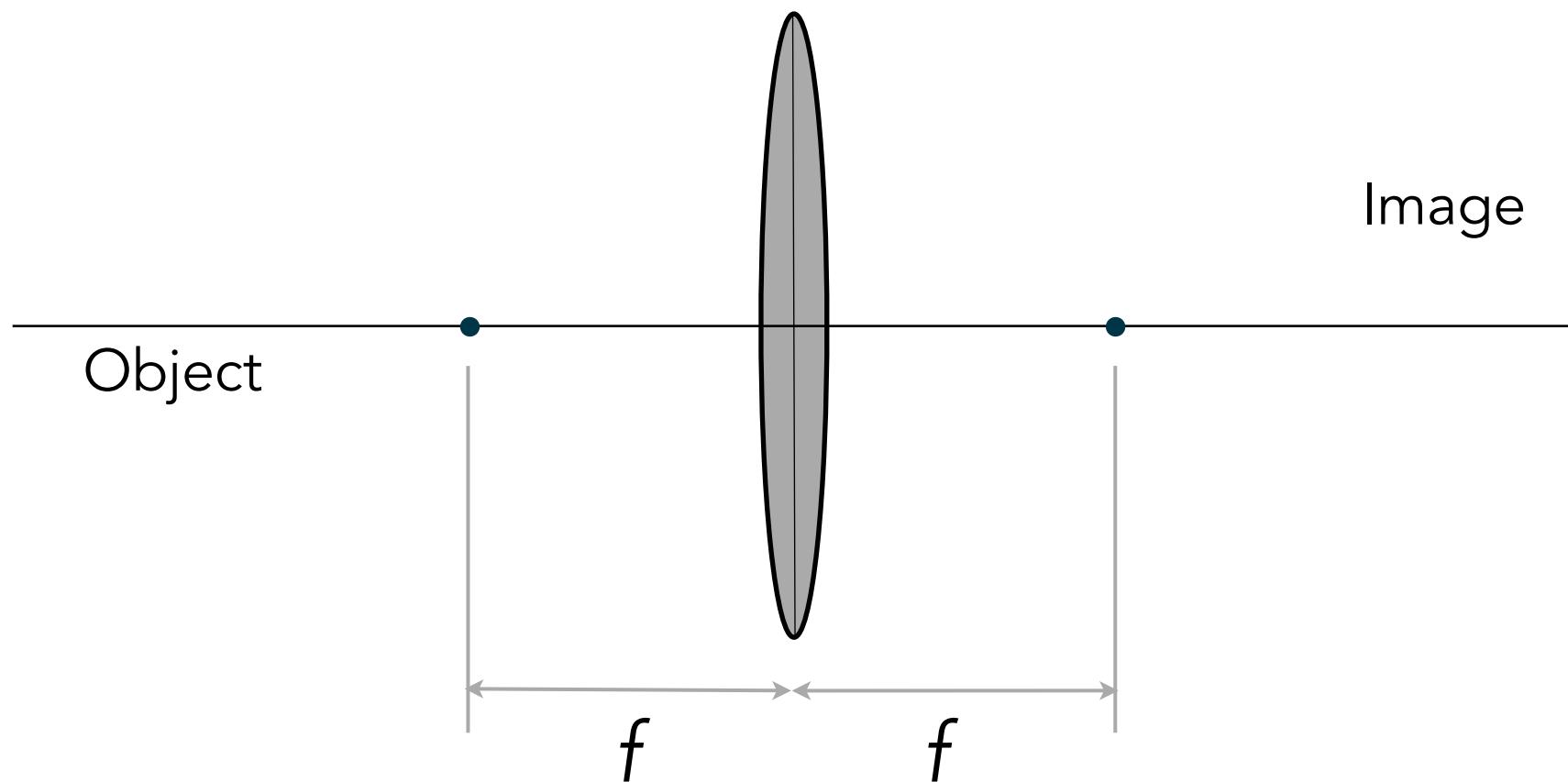
Lesson Objectives

- ★ Explain using your own words the importance of Focal Length in photography.
- ★ Describe in your own words the relationship between Focal and FOV.
- ★ Explain using your own words the impact of Sensor Size on photography.
- ★ Explain using your own words the impact of Focal Length on Image Formation/Capture.
- ★ Describe in your own words Perspective Projection with respect to Focal Length.

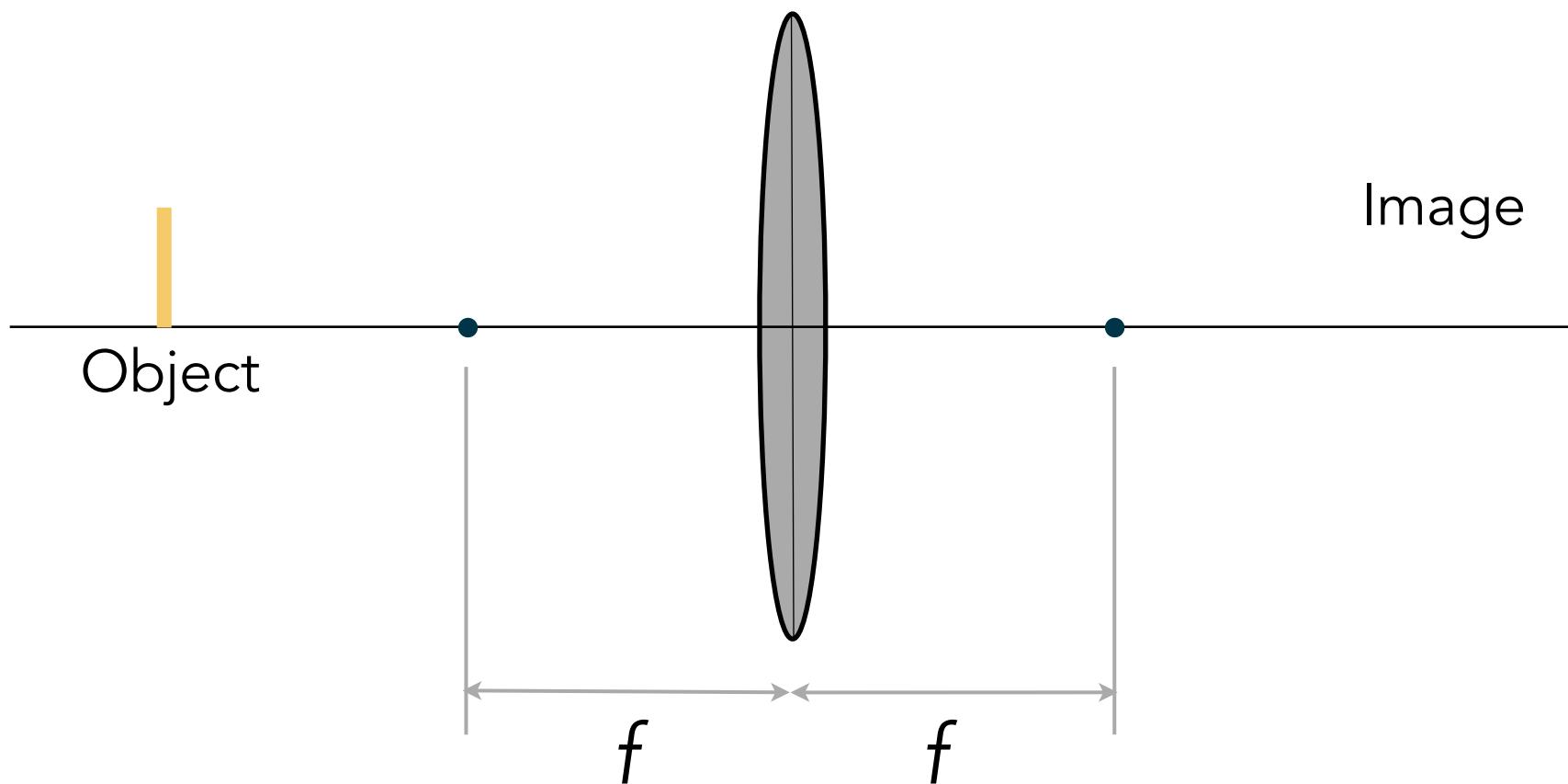


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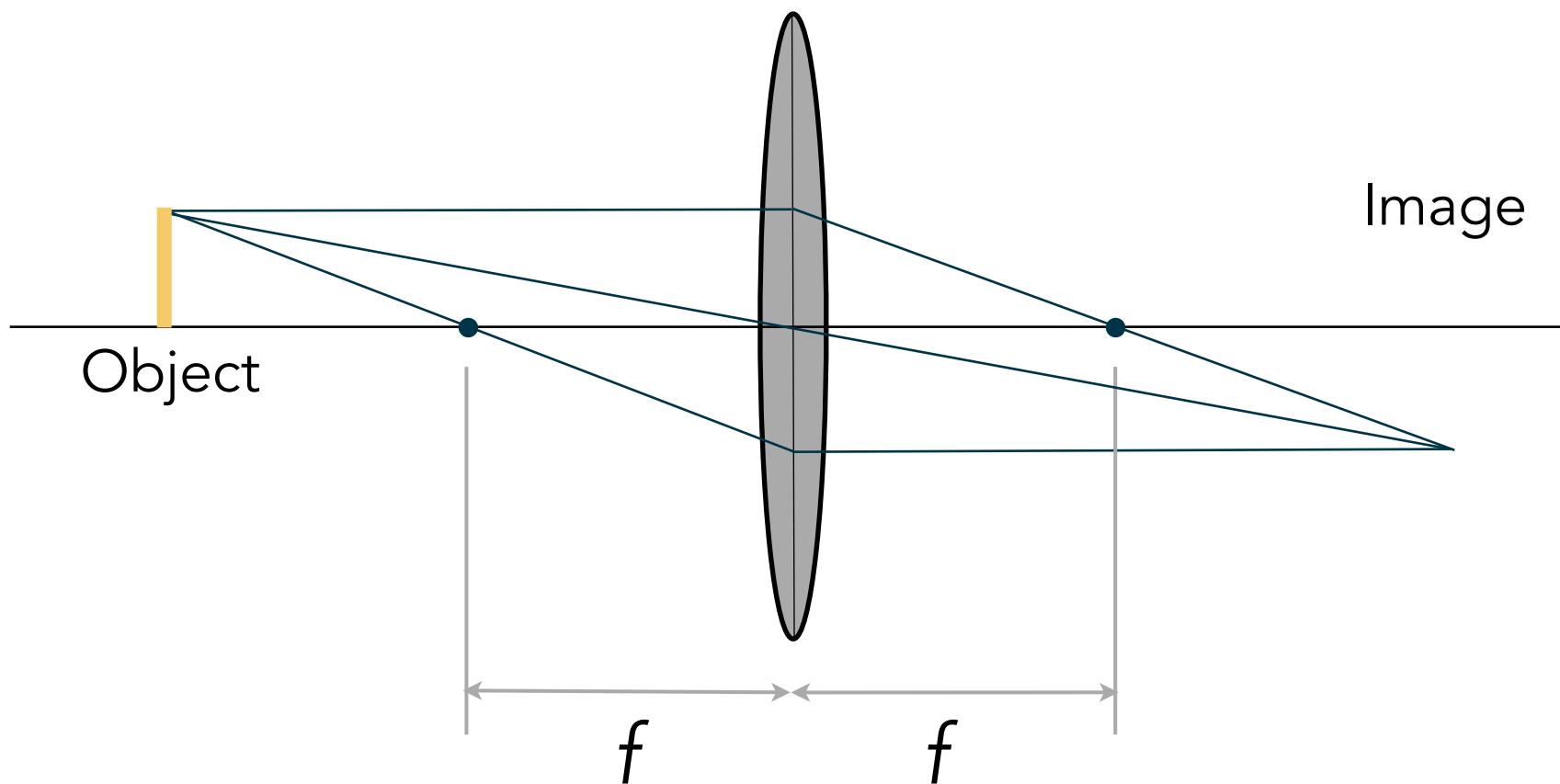
Review: Ray Tracing with Lenses



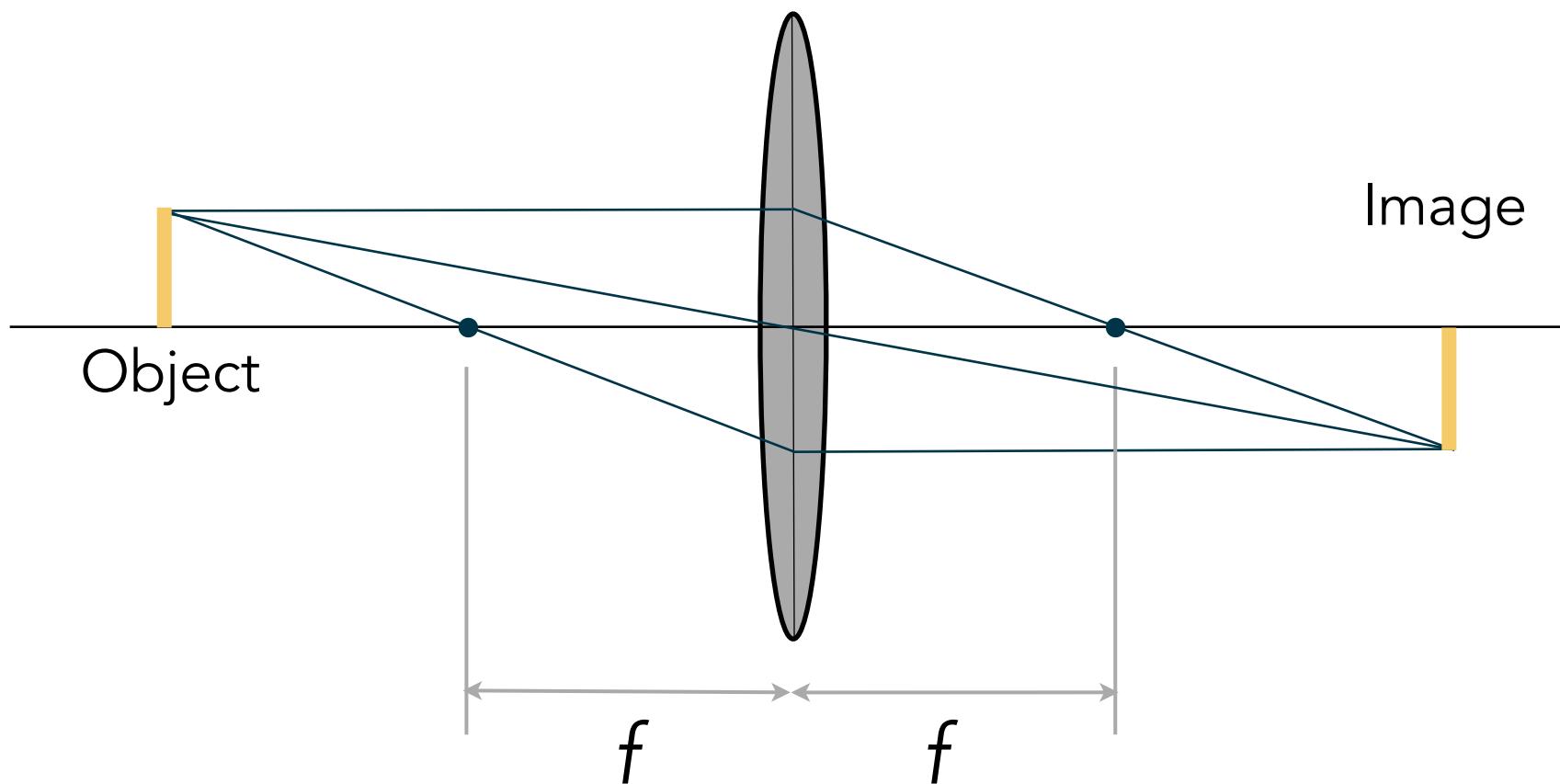
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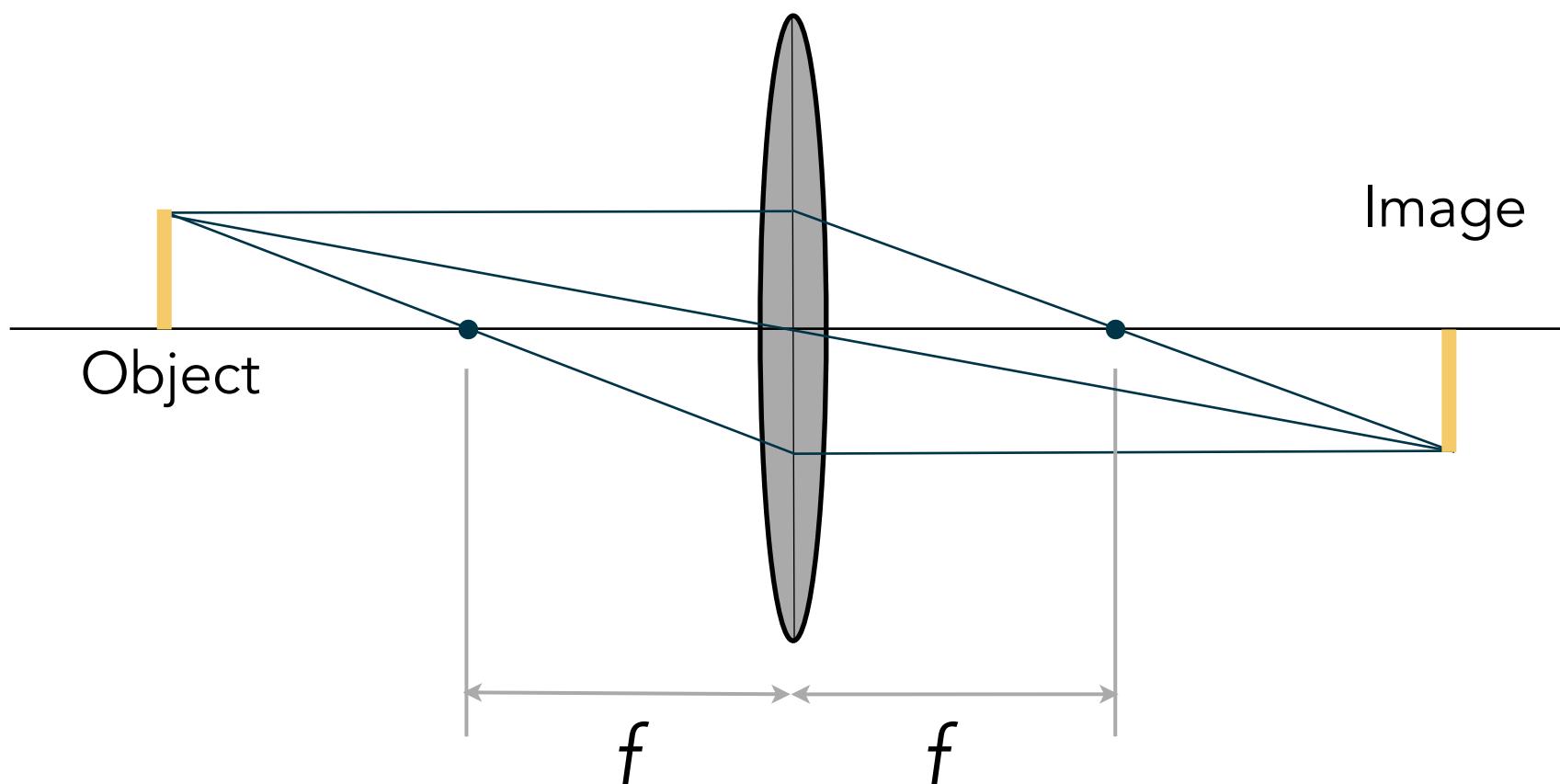
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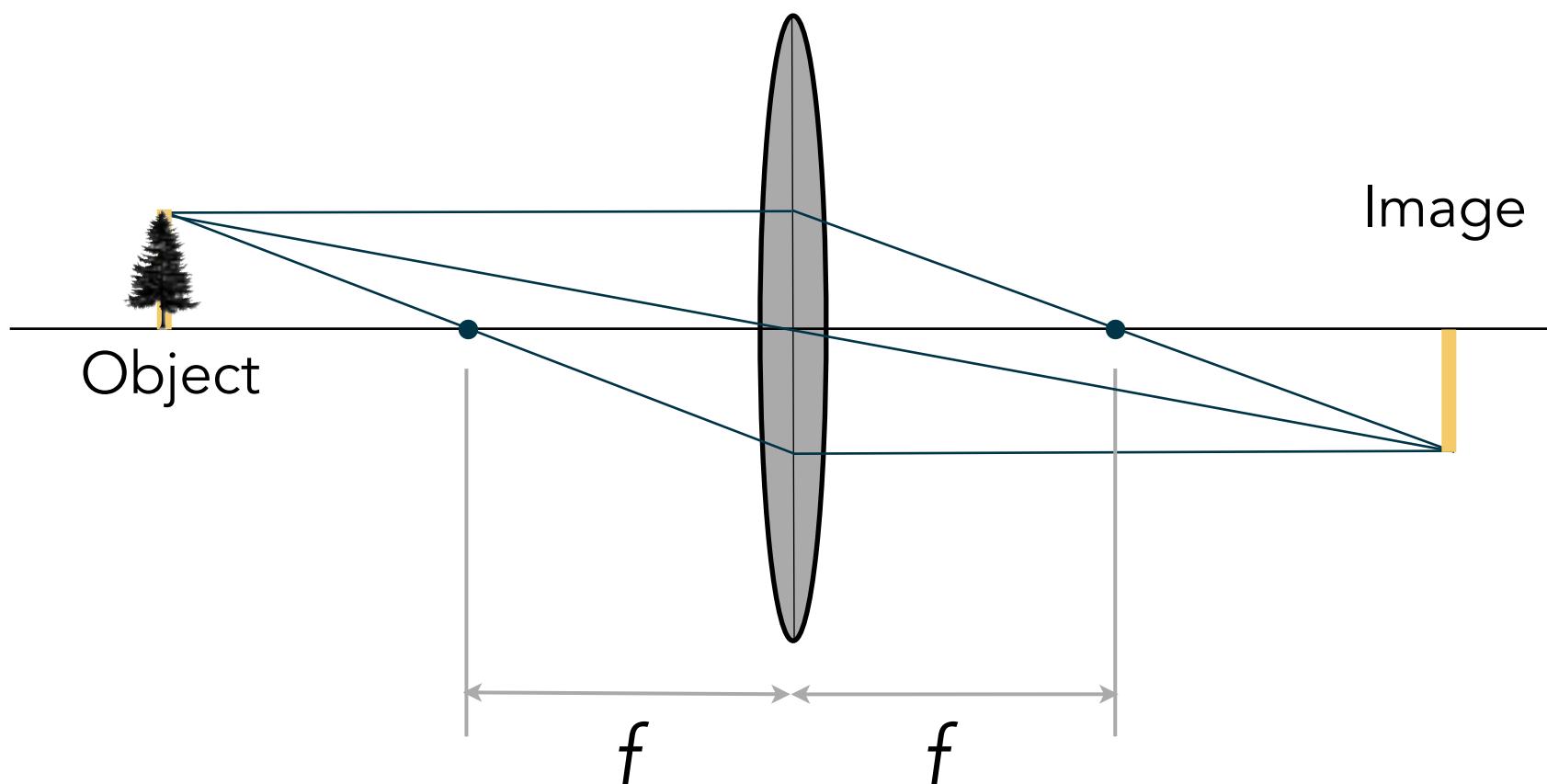


Review: Ray Tracing with Lenses



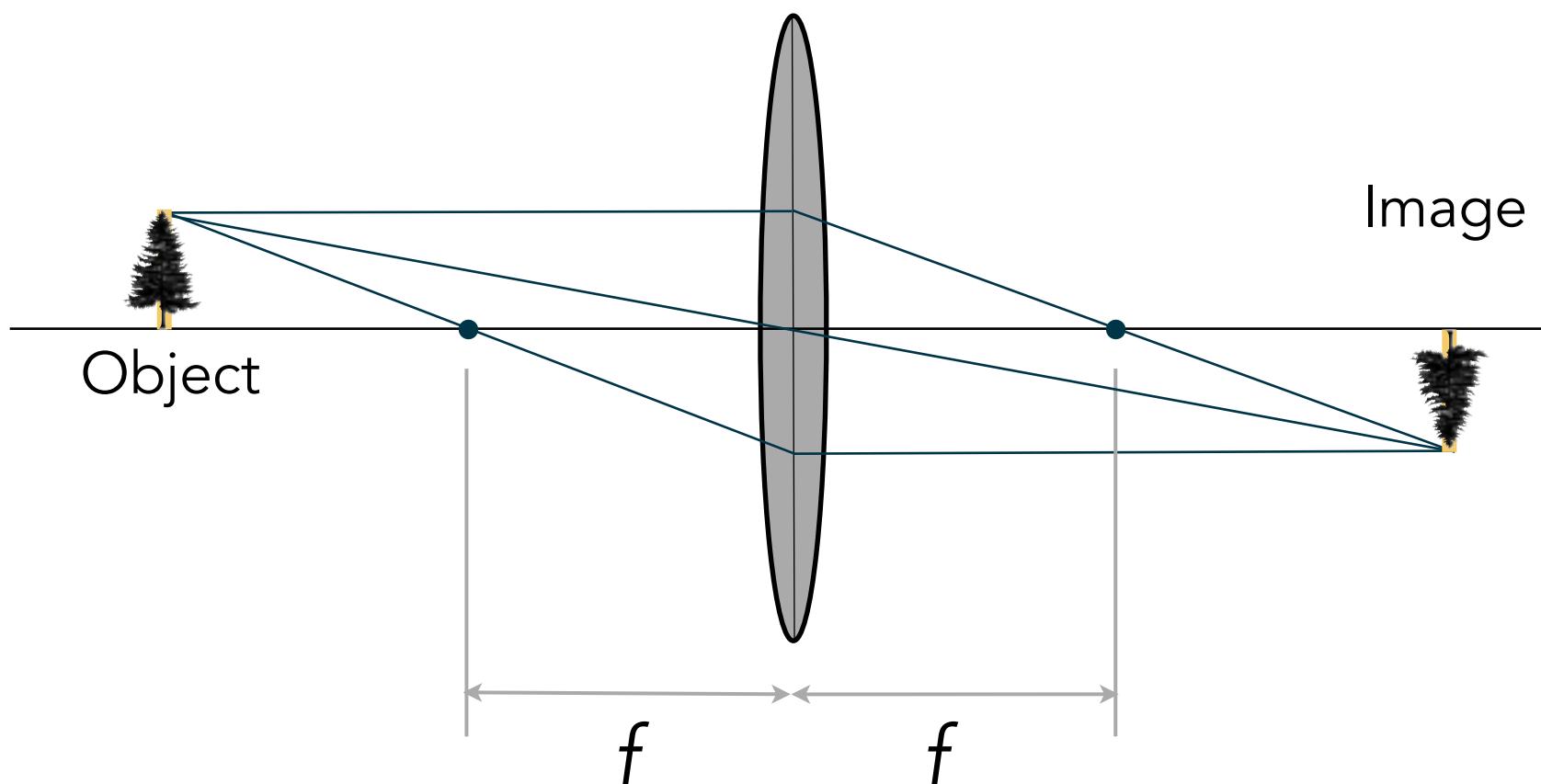
- ★ Rays from points on a plane parallel to the lens, focus on a plane parallel to the lens on the other side (and upside down).

Review: Ray Tracing with Lenses



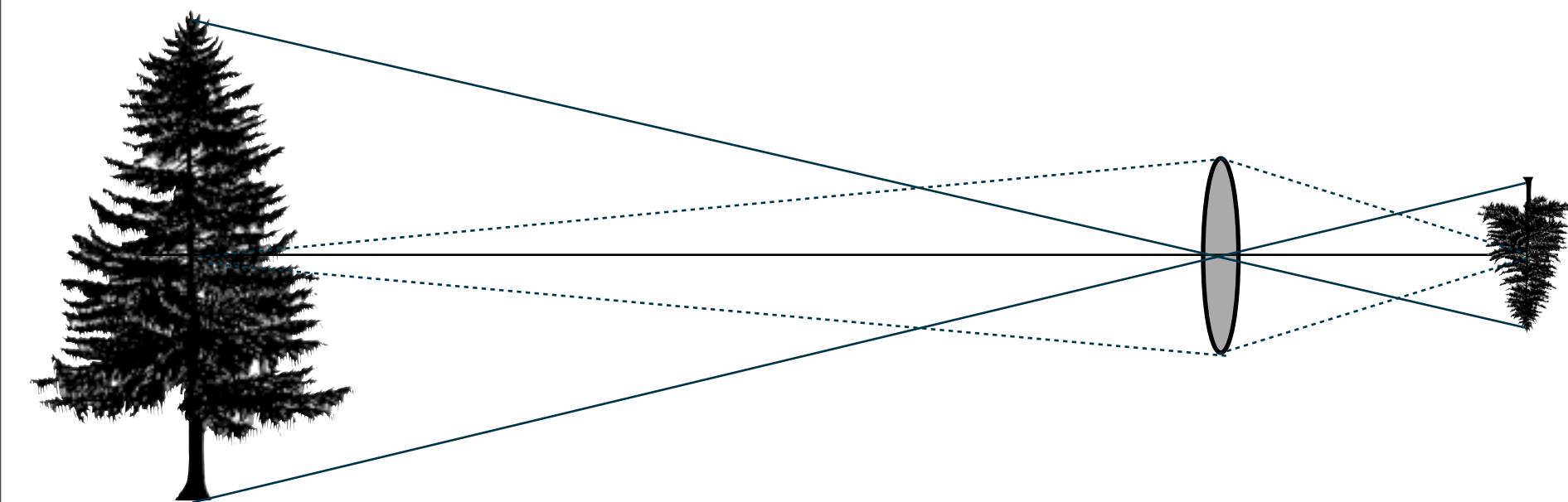
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Review: Ray Tracing with Lenses

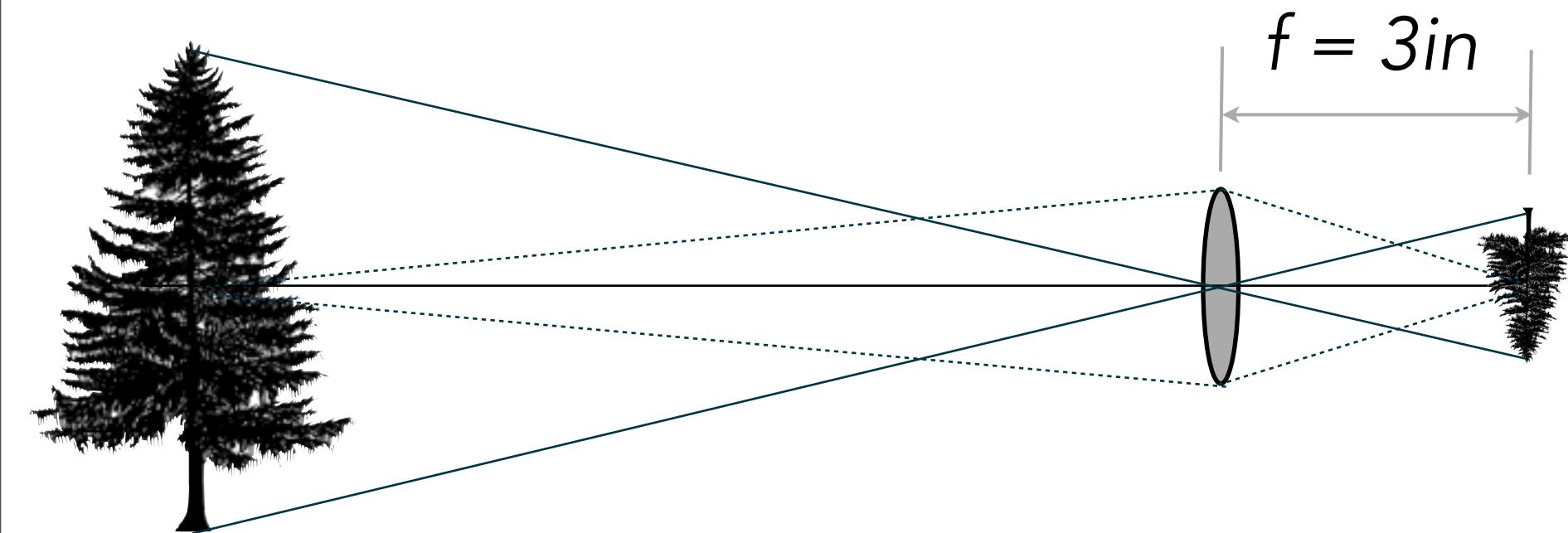


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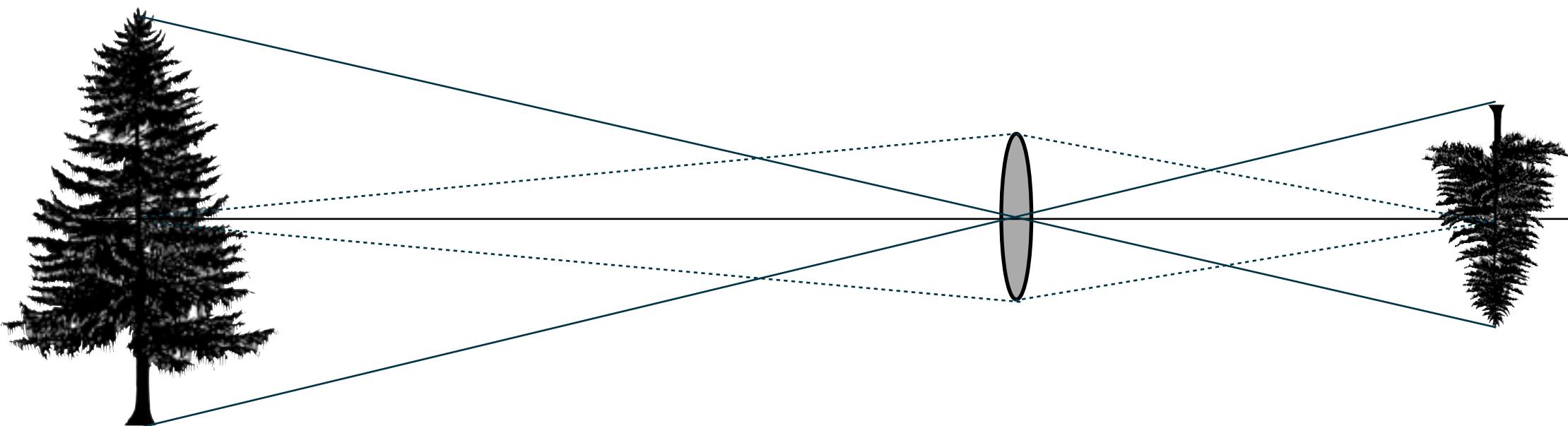
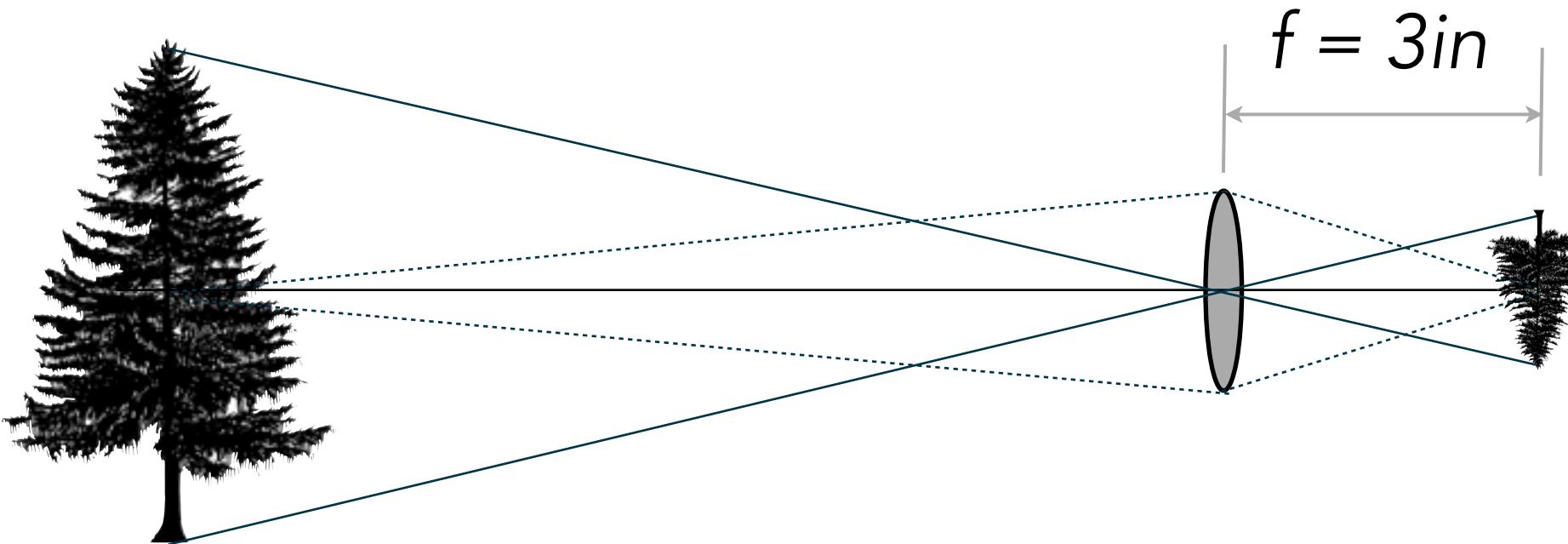
Changes in Focal Length



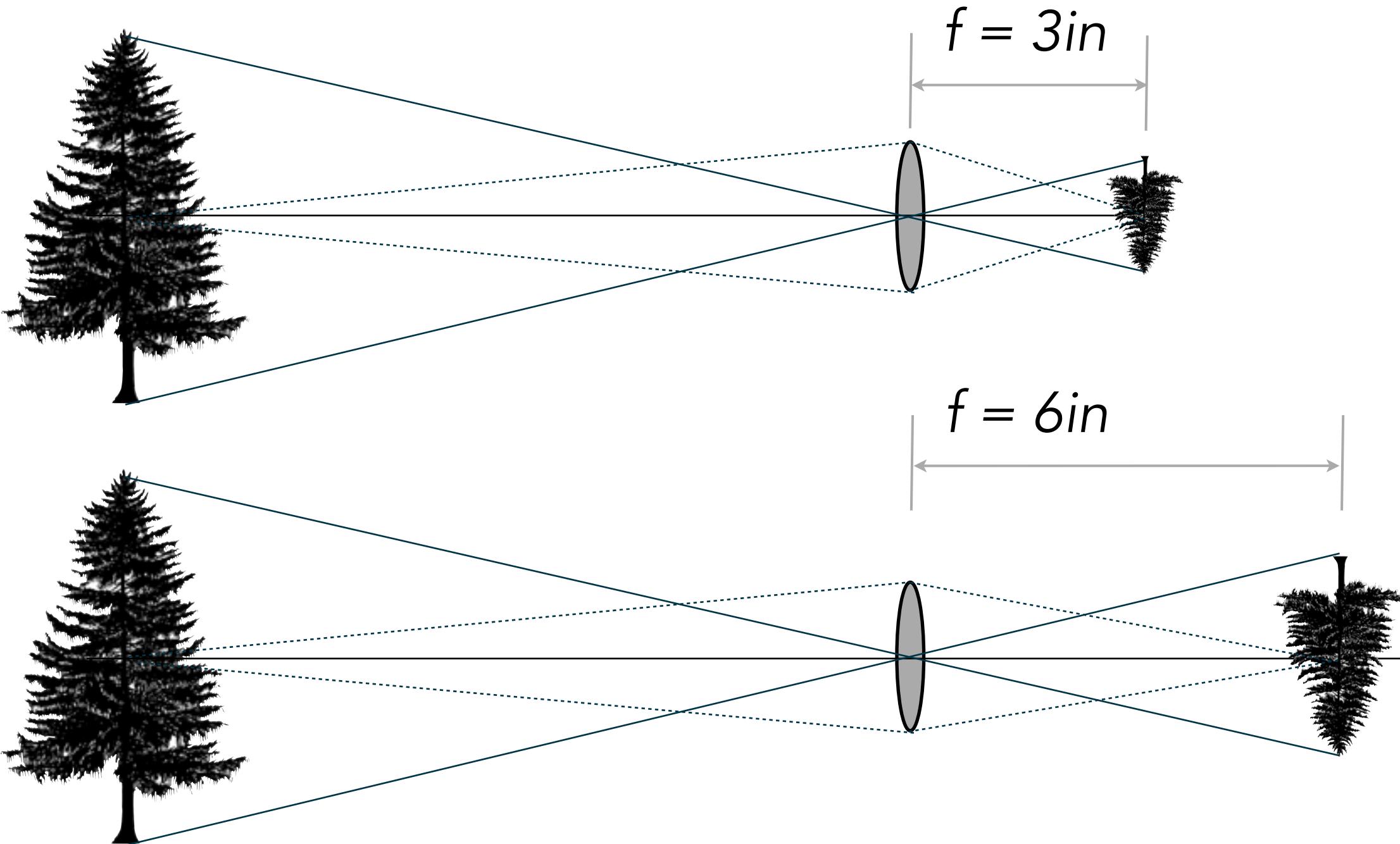
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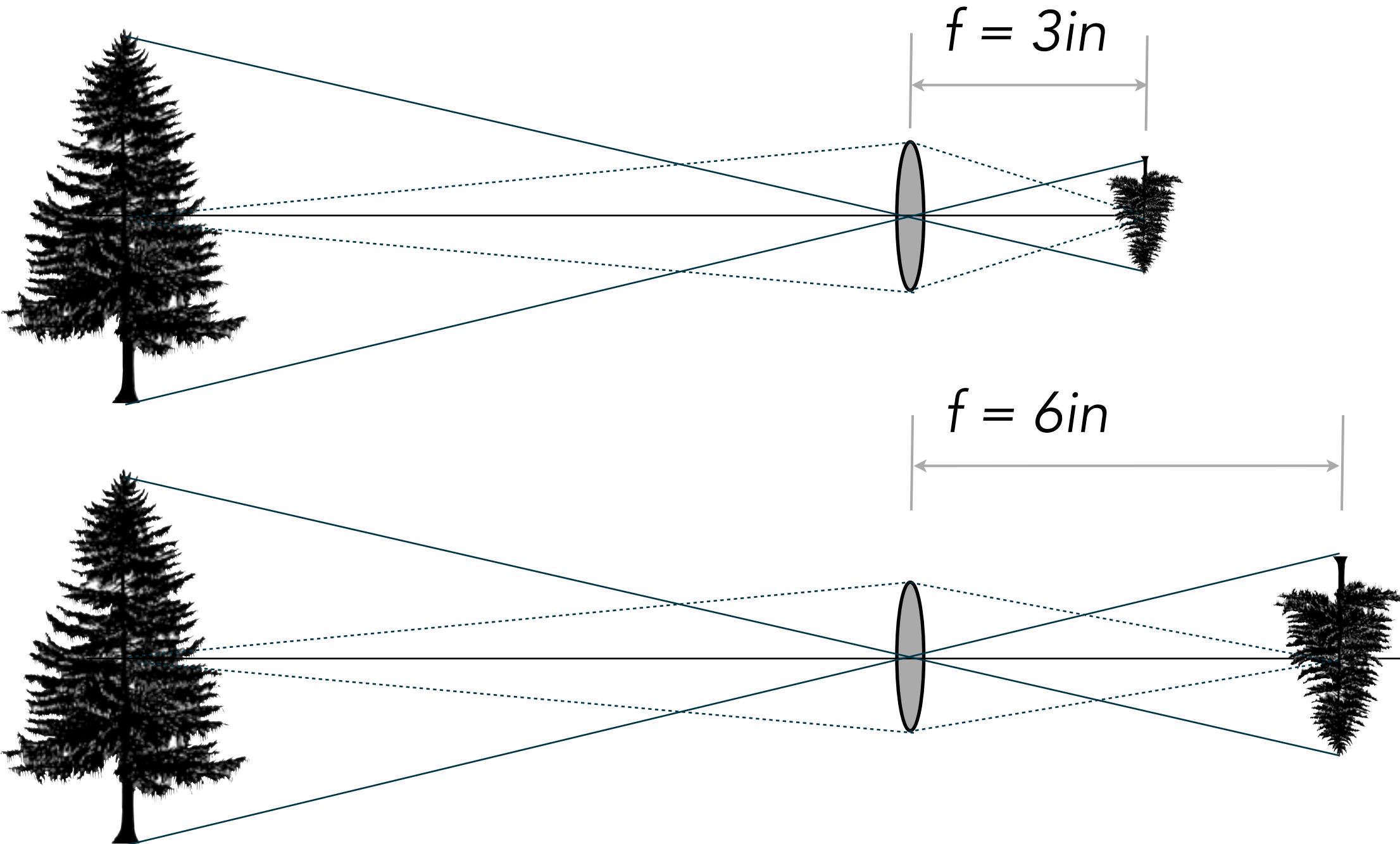


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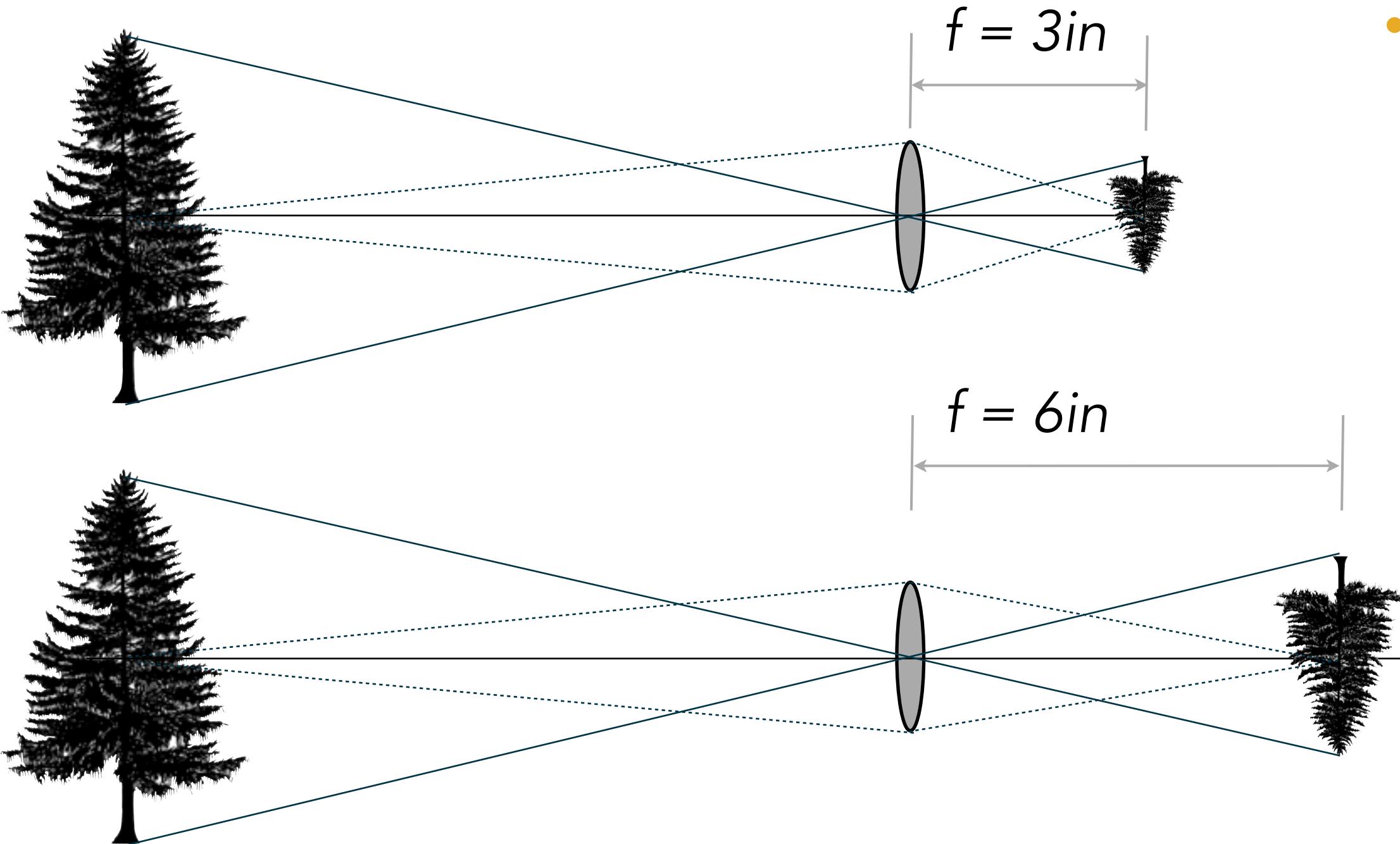
Changes in Focal Length

- ★ Lenses can have longer/shorter focal lengths.

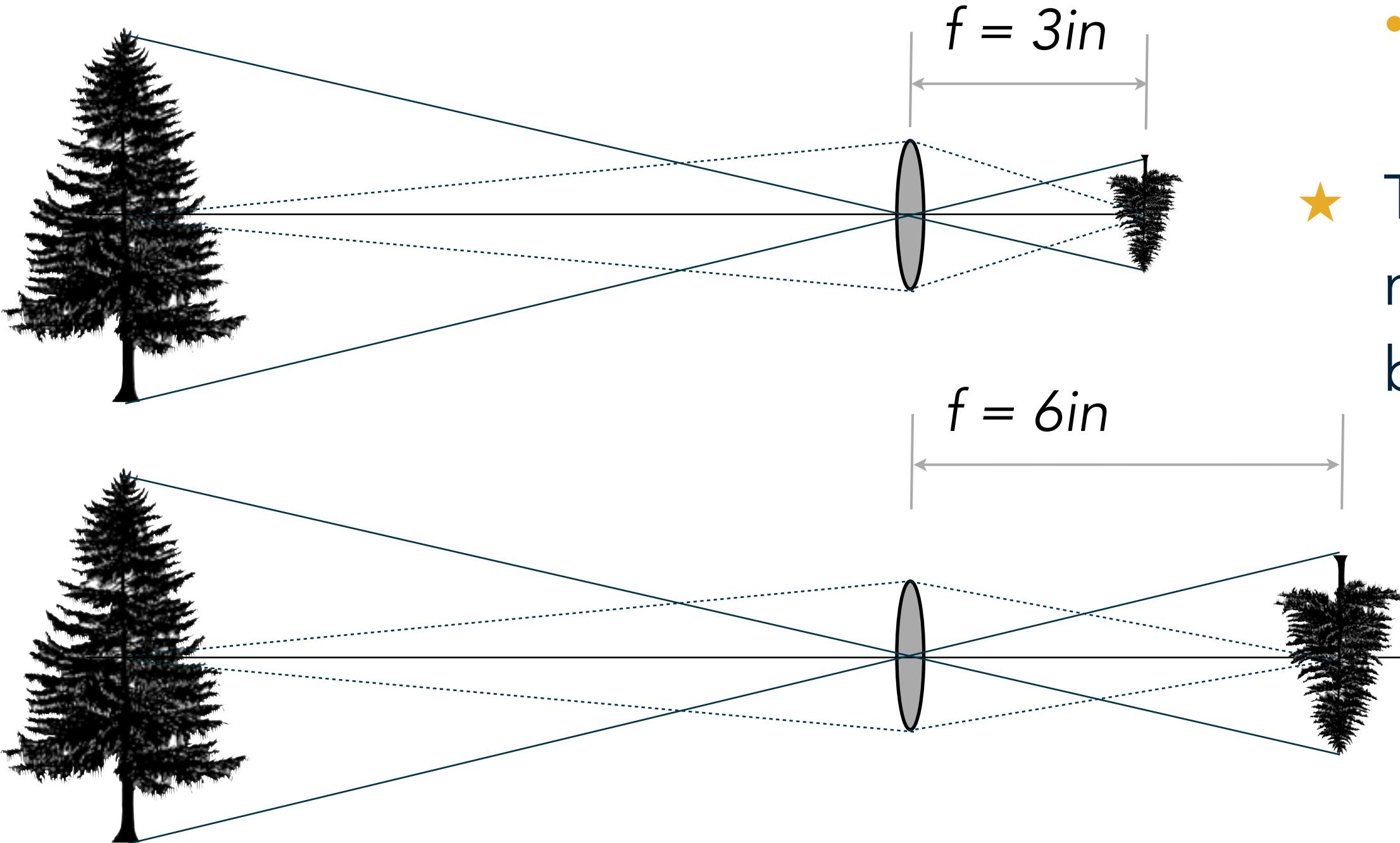


Changes in Focal Length

- ★ Lenses can have longer/shorter focal lengths.
 - Longer focal length implies “weaker” lens

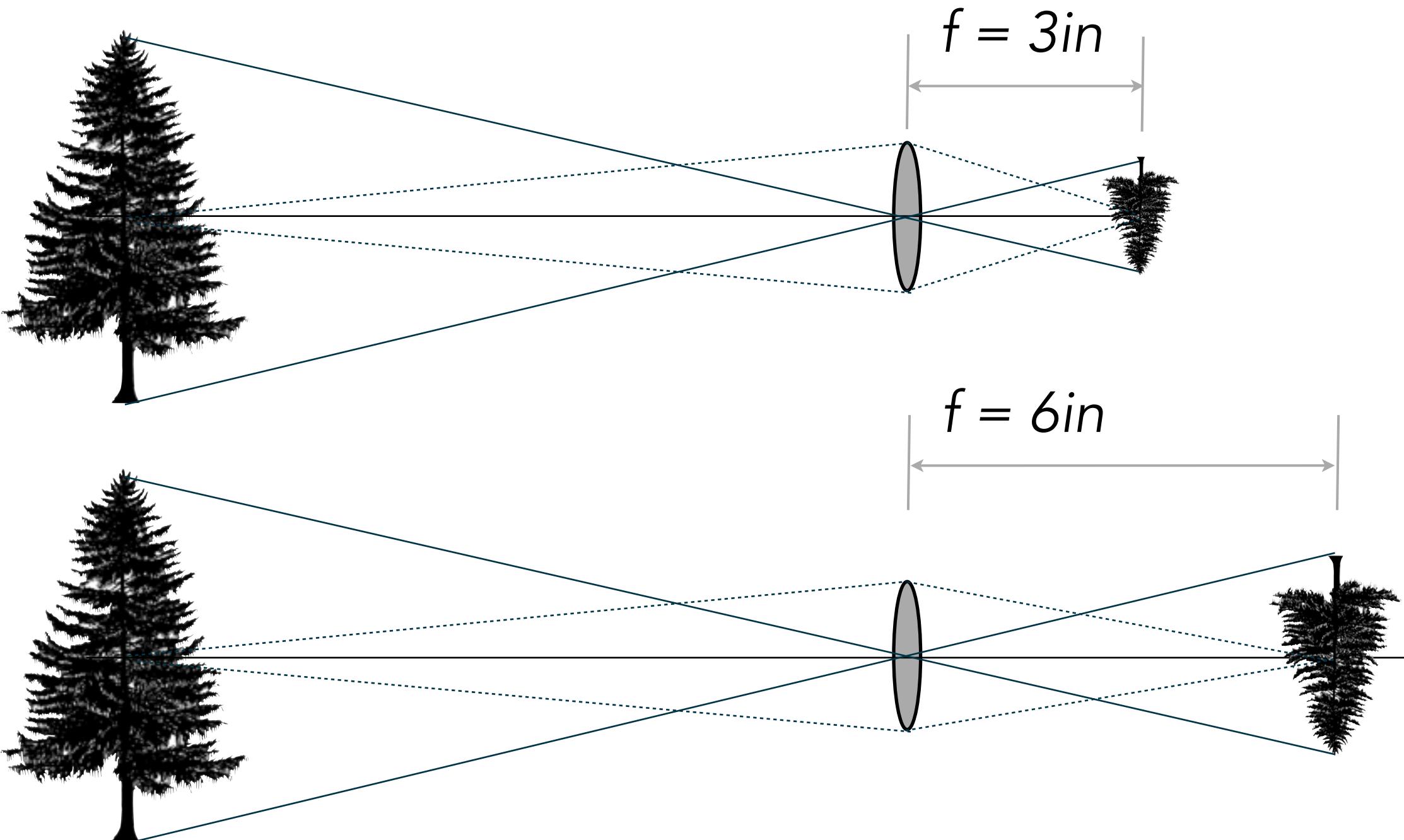


Changes in Focal Length



- ★ Lenses can have longer/shorter focal lengths.
 - Longer focal length implies “weaker” lens
- ★ To stay in focus for a lens, need to move sensor back (or forward)

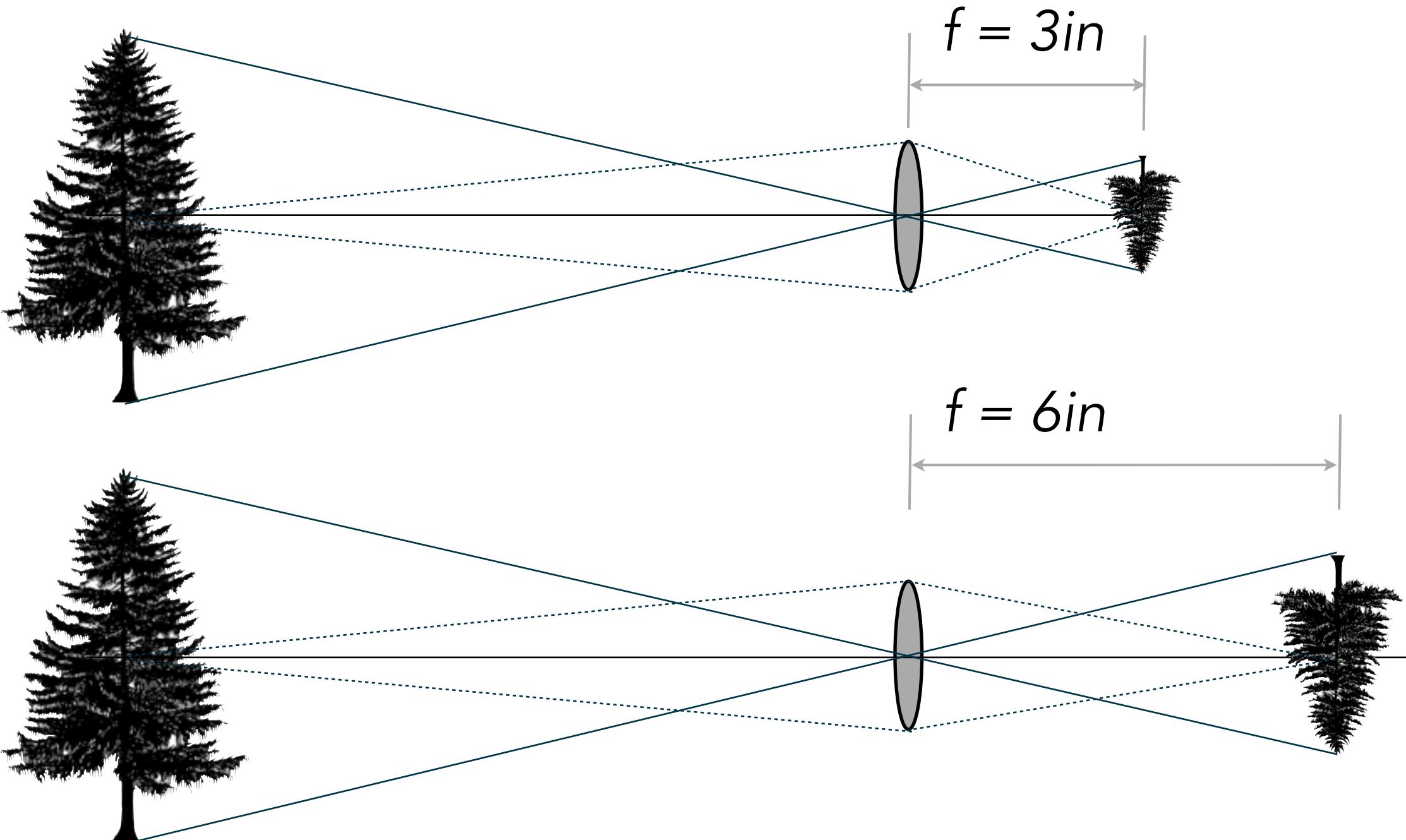
Field of View (FOV)



Slide adapted from Mark Levoy

Field of View (FOV)

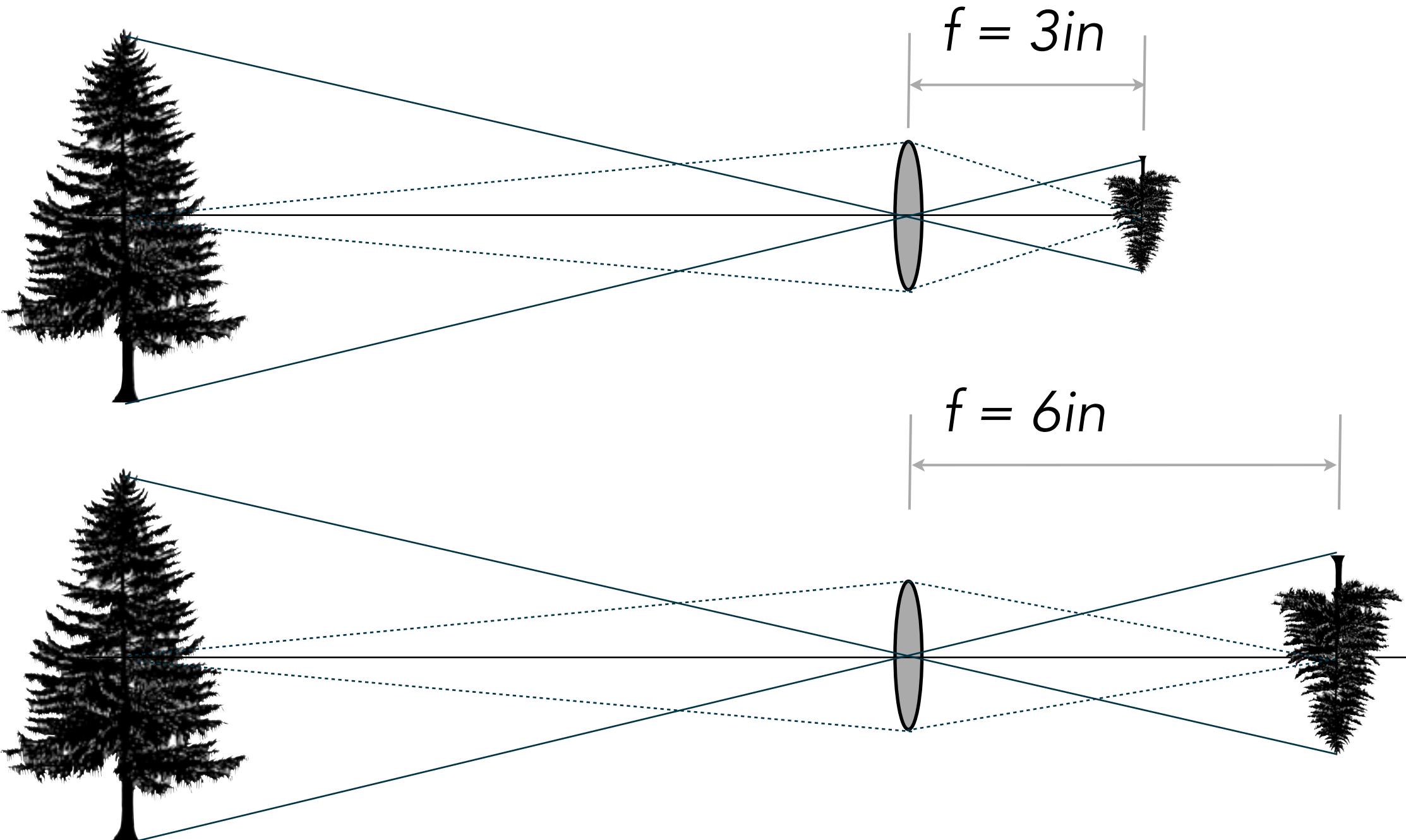
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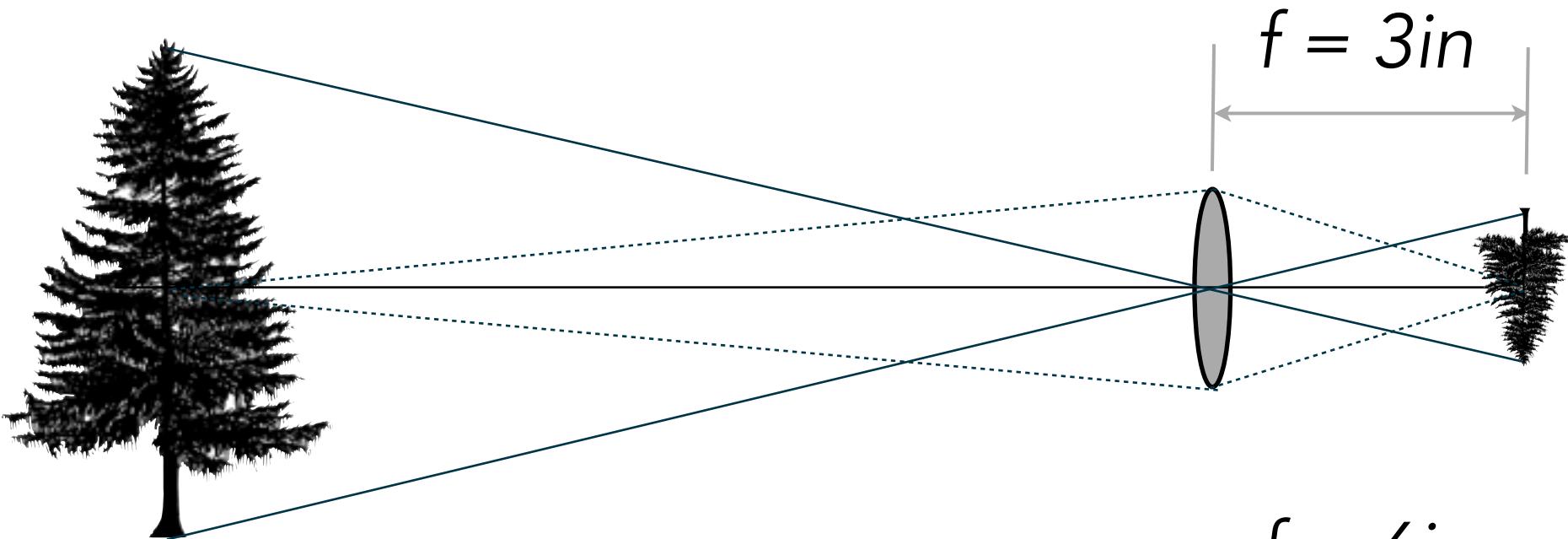
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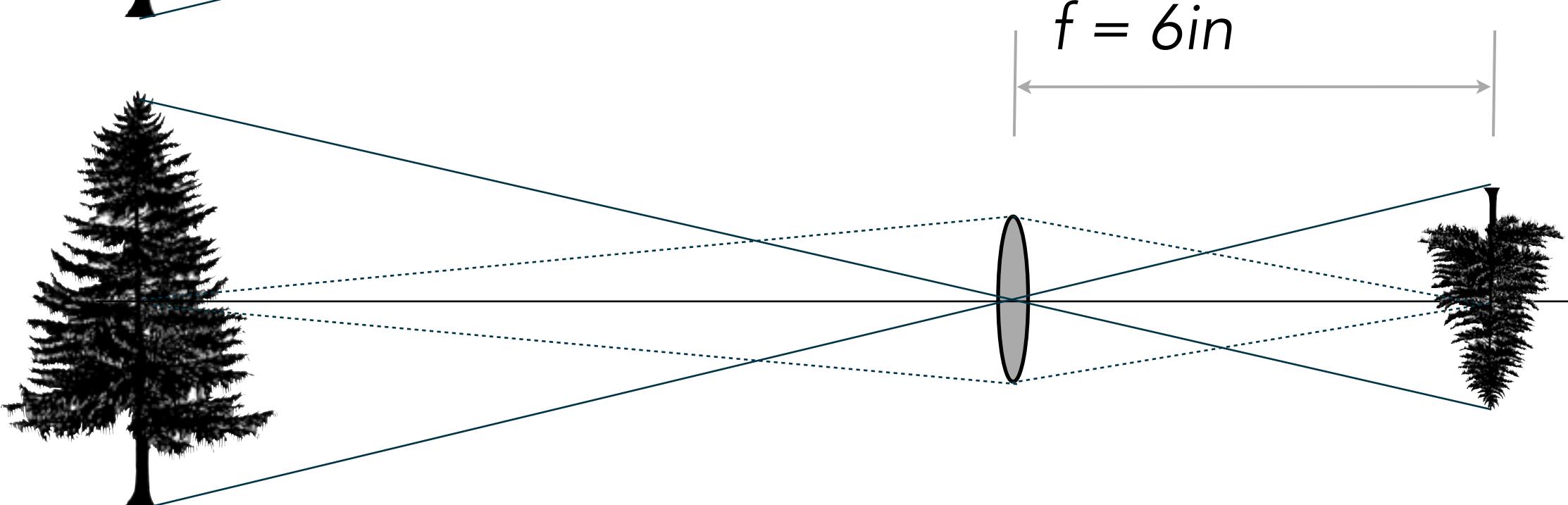
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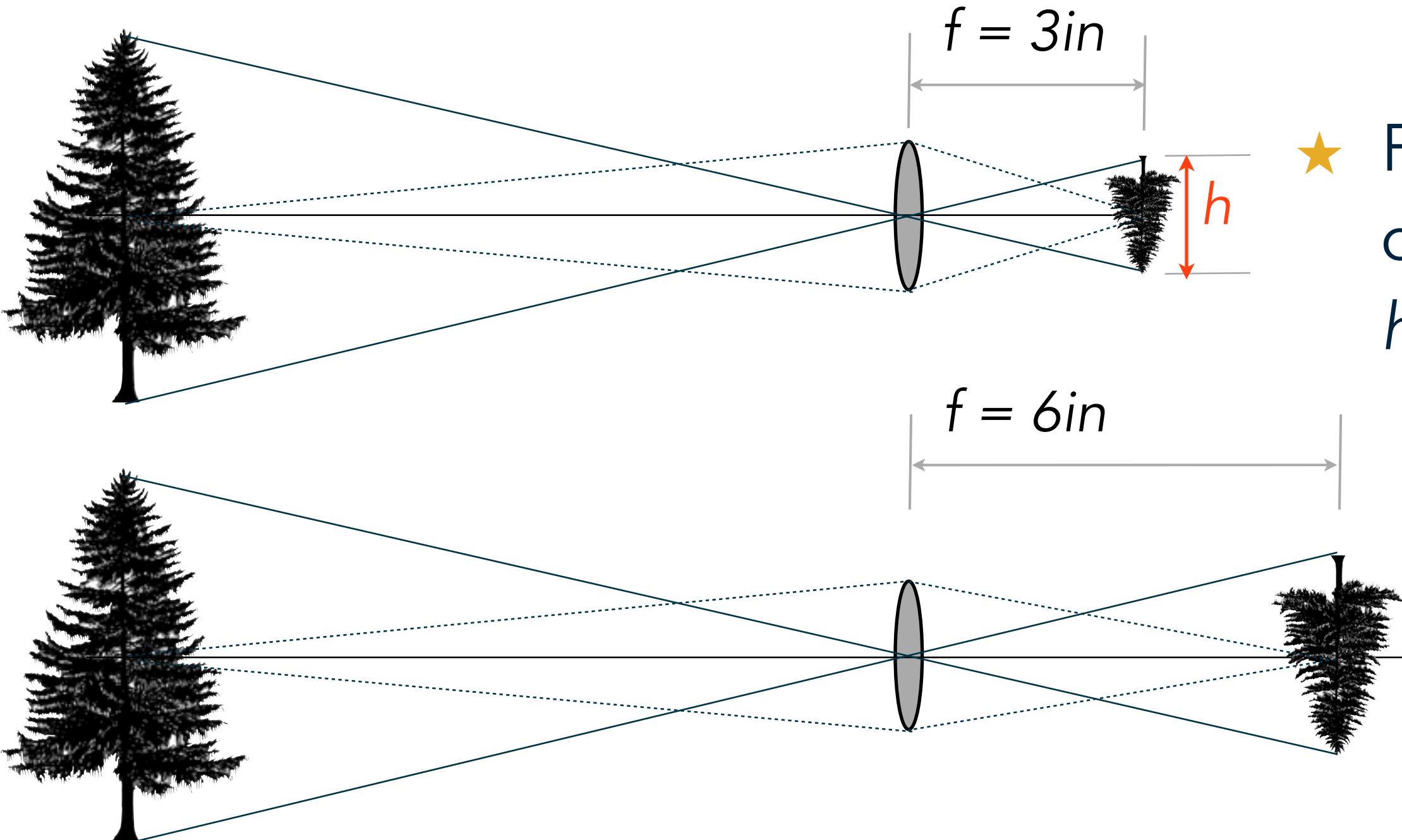
- ★ Field of View (FOV) depends on sensor size, h



Slide adapted from Mark Levoy

Field of View (FOV)

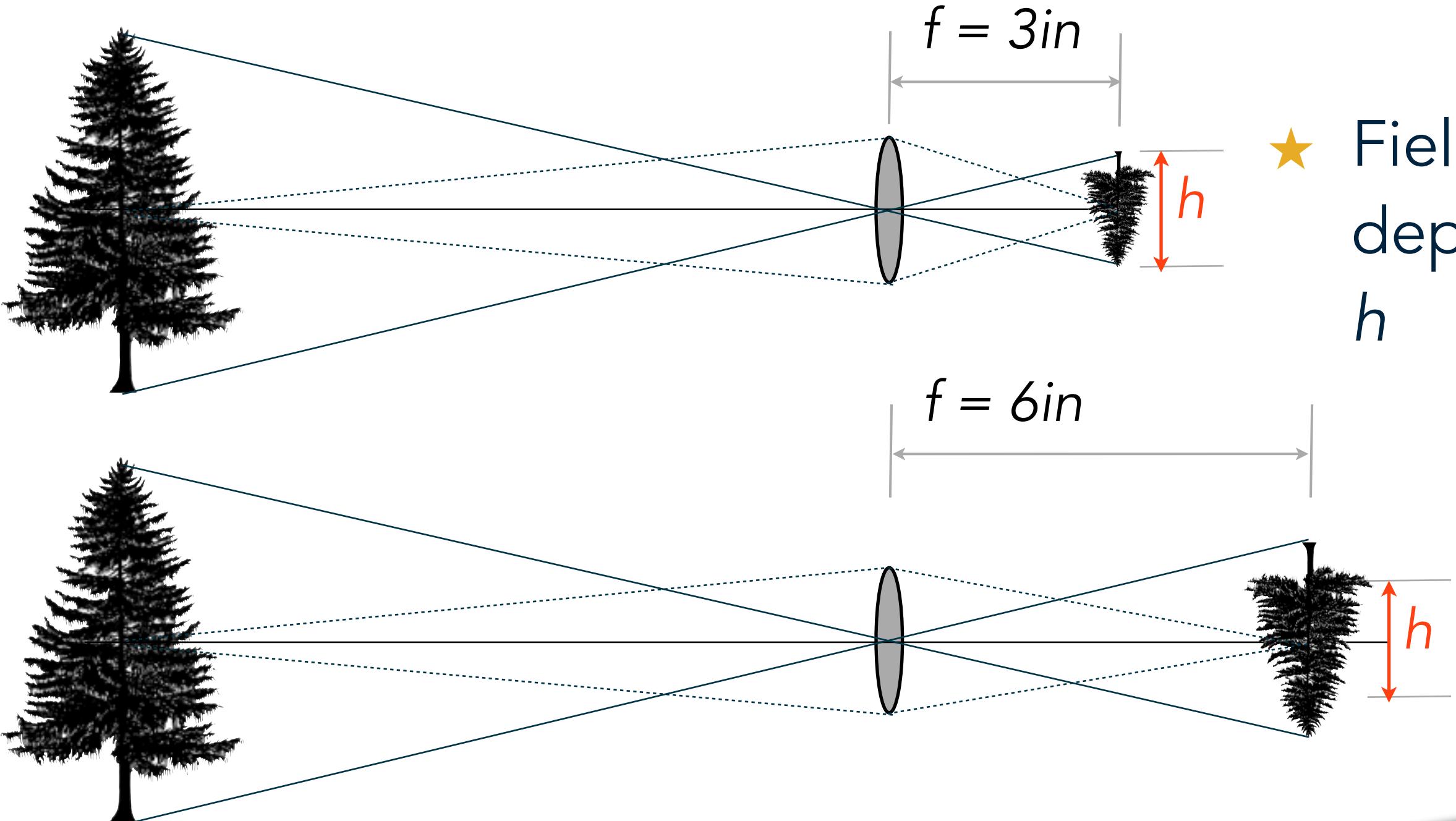
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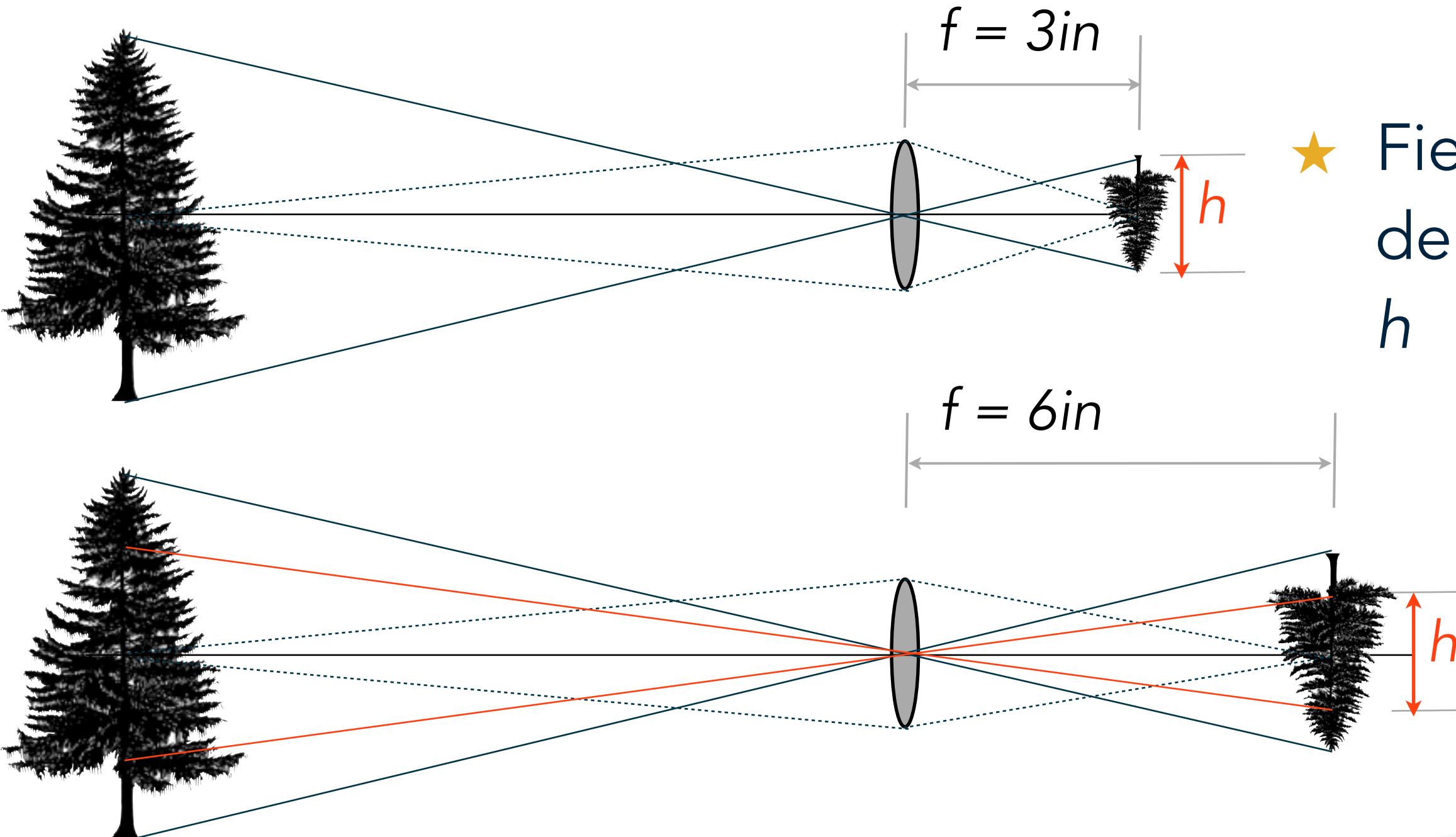
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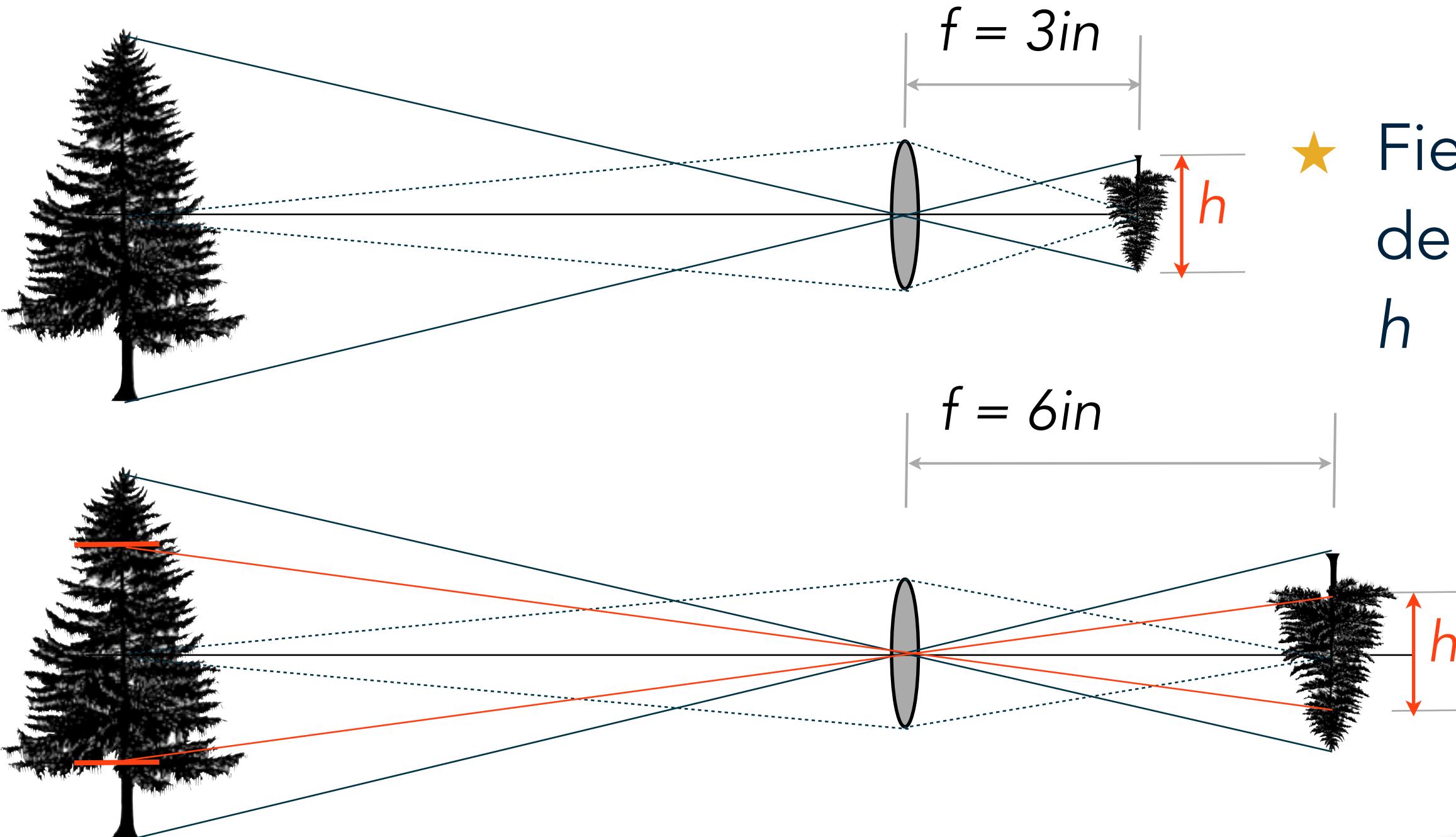
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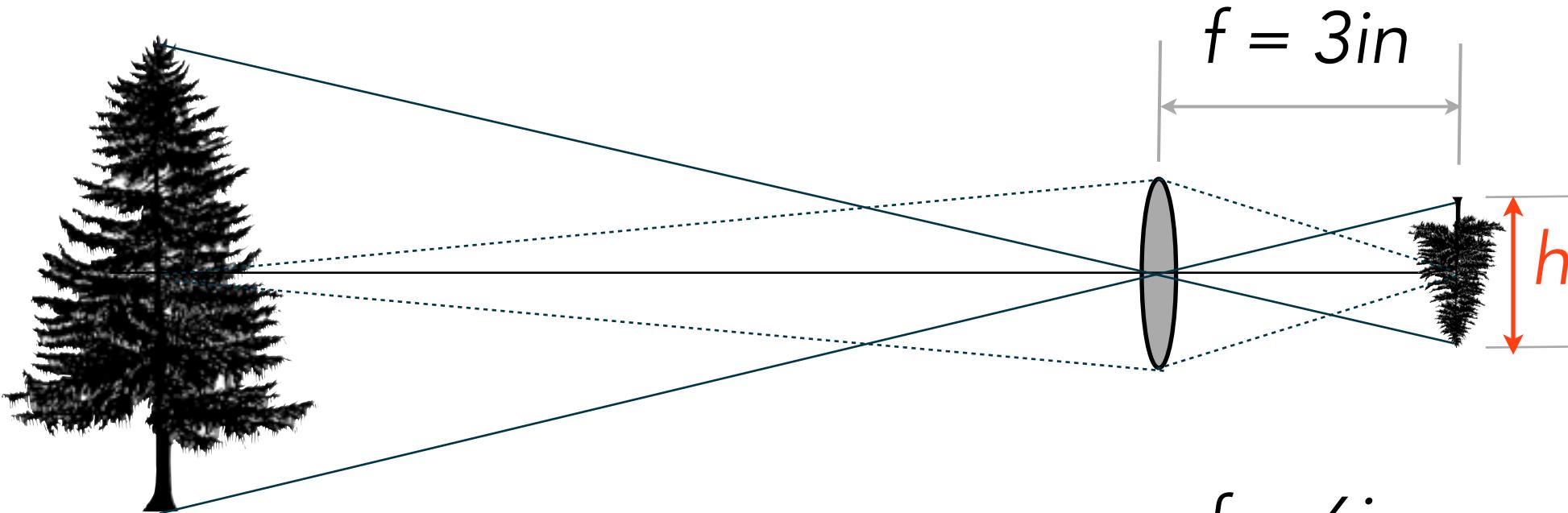
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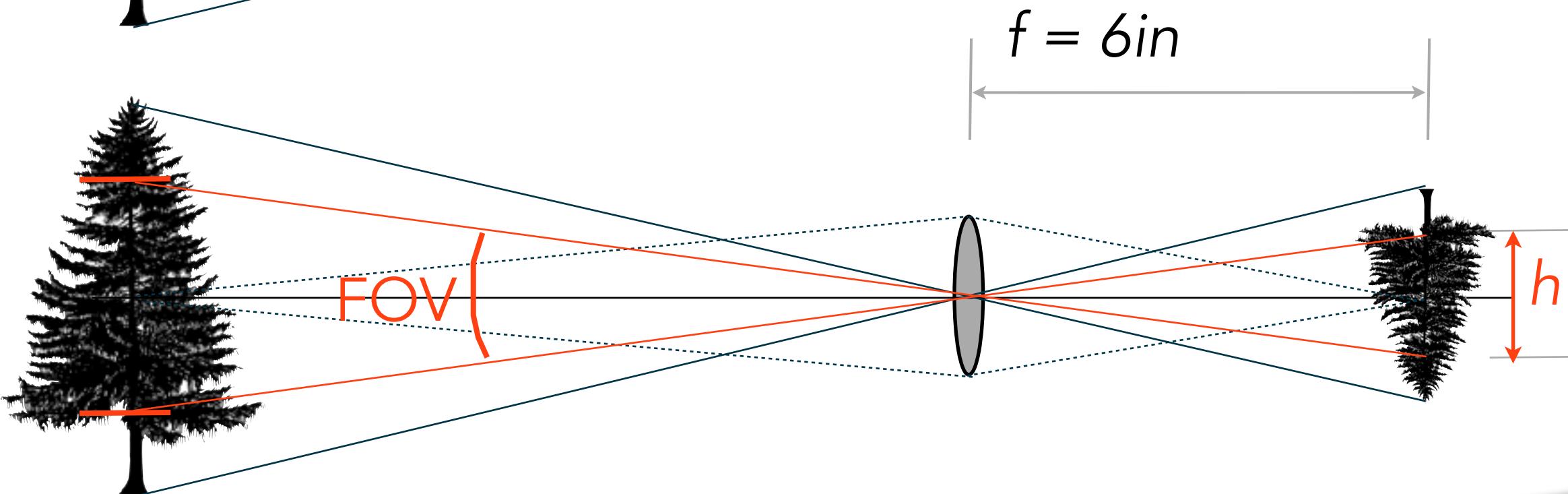
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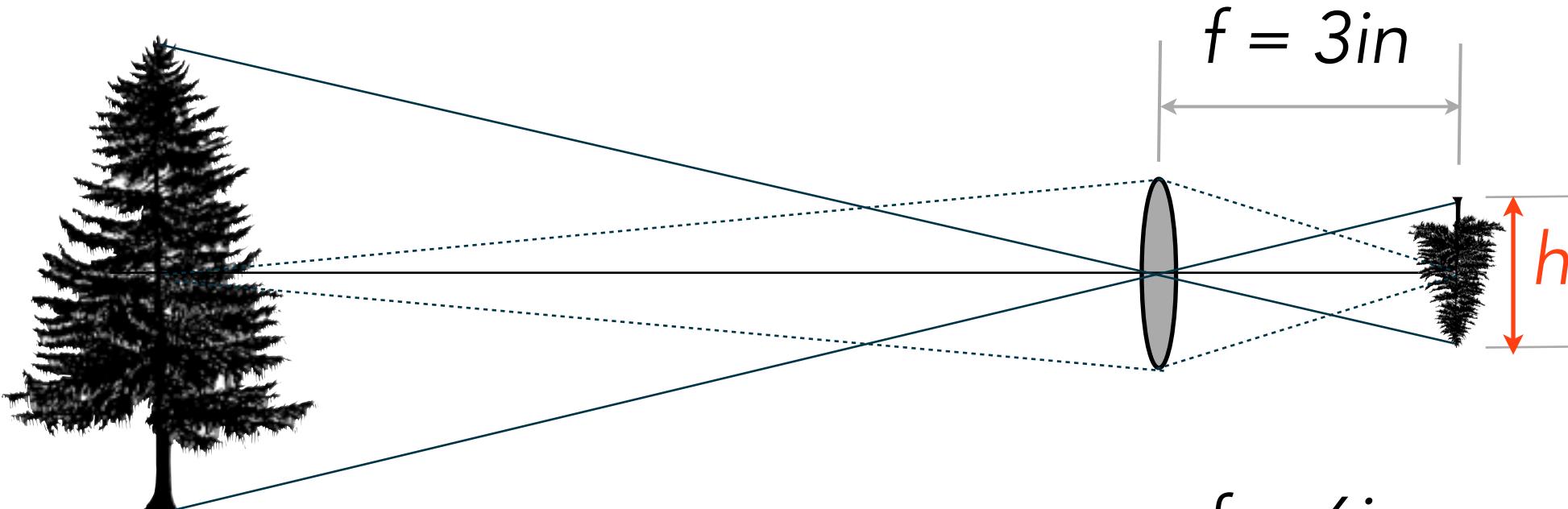
- ★ Field of View (FOV) depends on sensor size, h



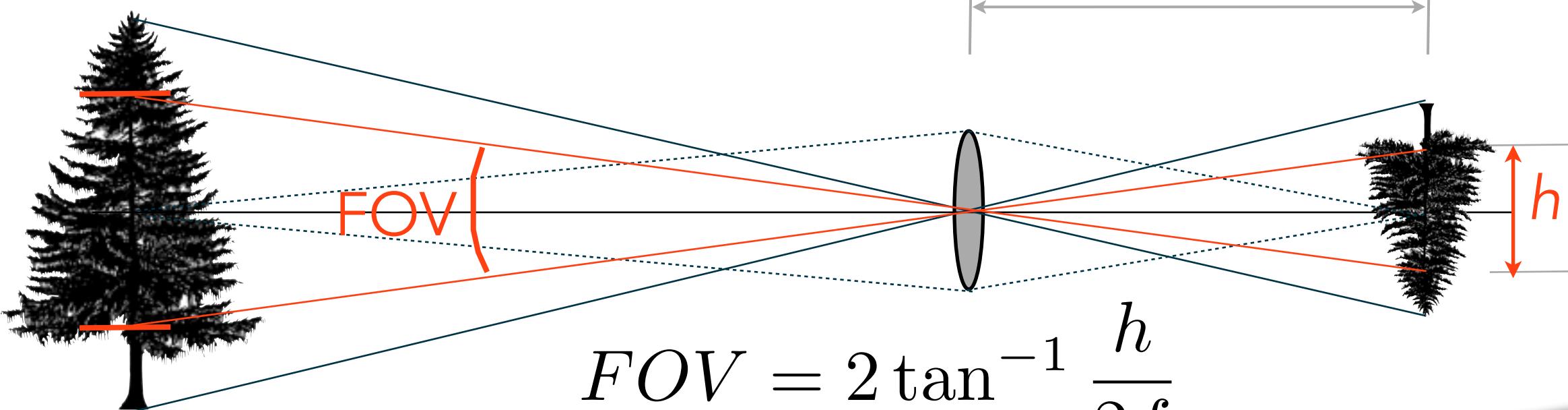
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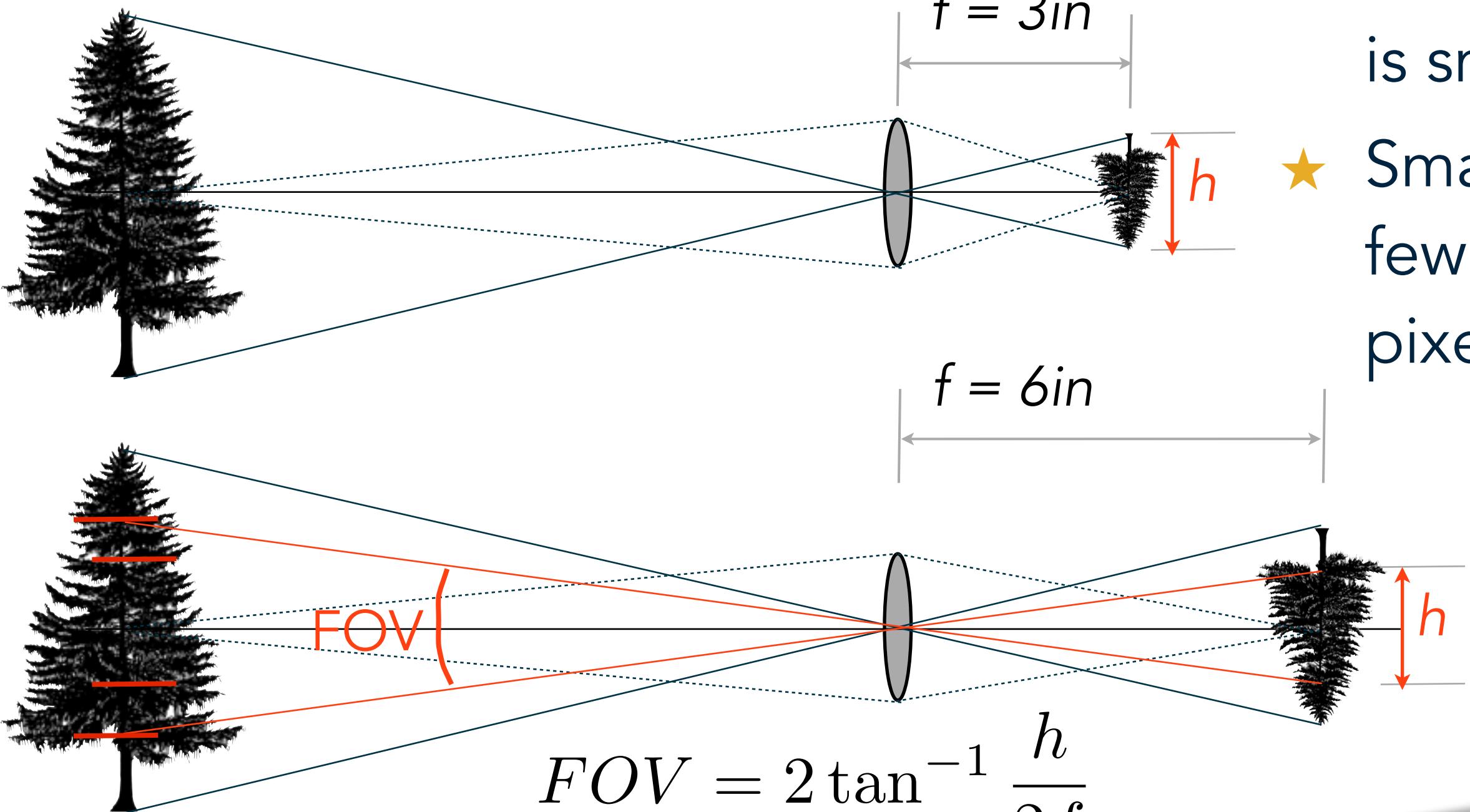
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$$FOV = 2 \tan^{-1} \frac{h}{2f}$$

Slide adapted from Mark Levoy

Field of View (FOV) & Sensor Size

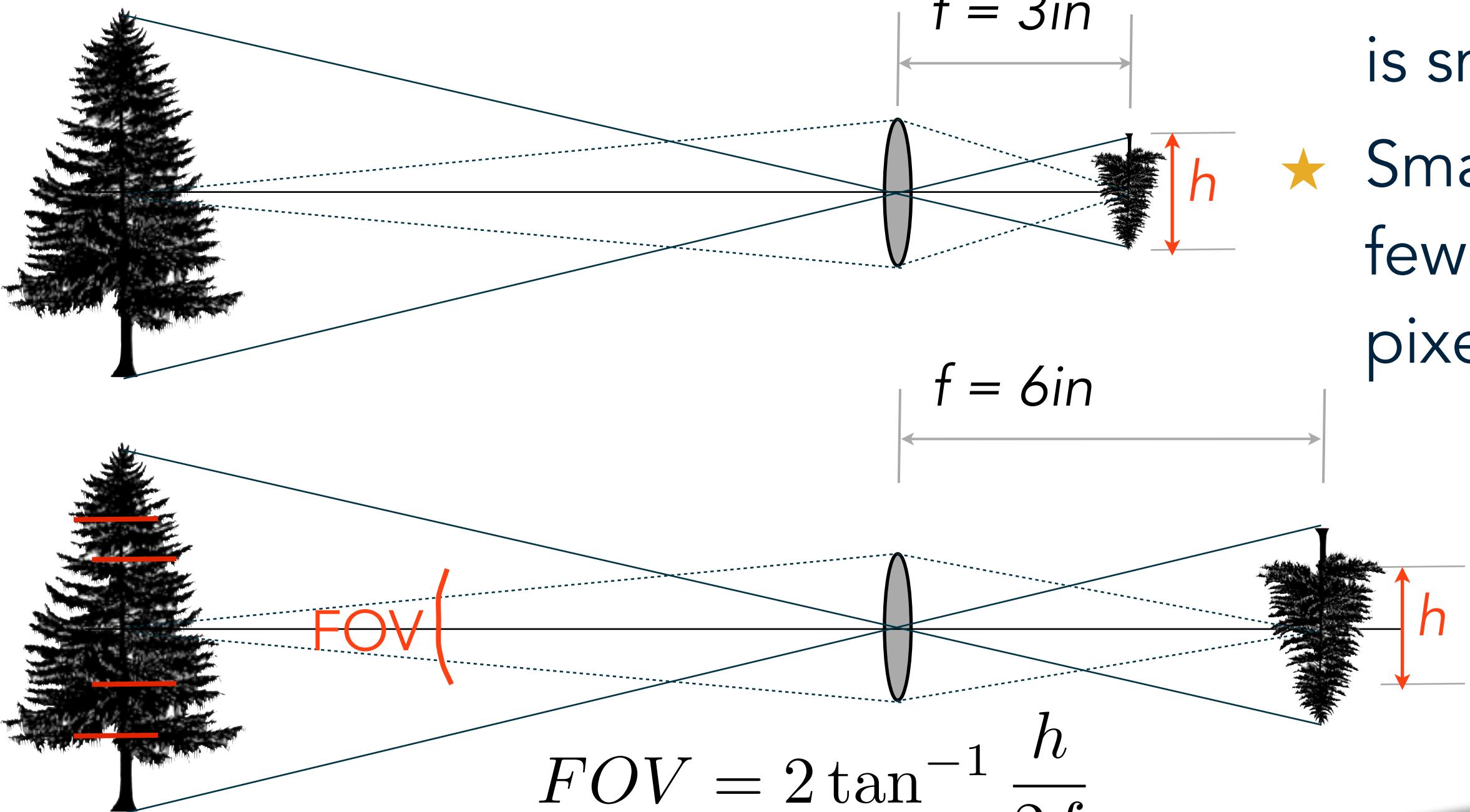


- ★ Sensor size small, FOV is small too
- ★ Smaller sensors have fewer pixels, or noisier pixels

$$FOV = 2 \tan^{-1} \frac{h}{2f}$$

Slide adapted from Mark Levoy

Field of View (FOV) & Sensor Size

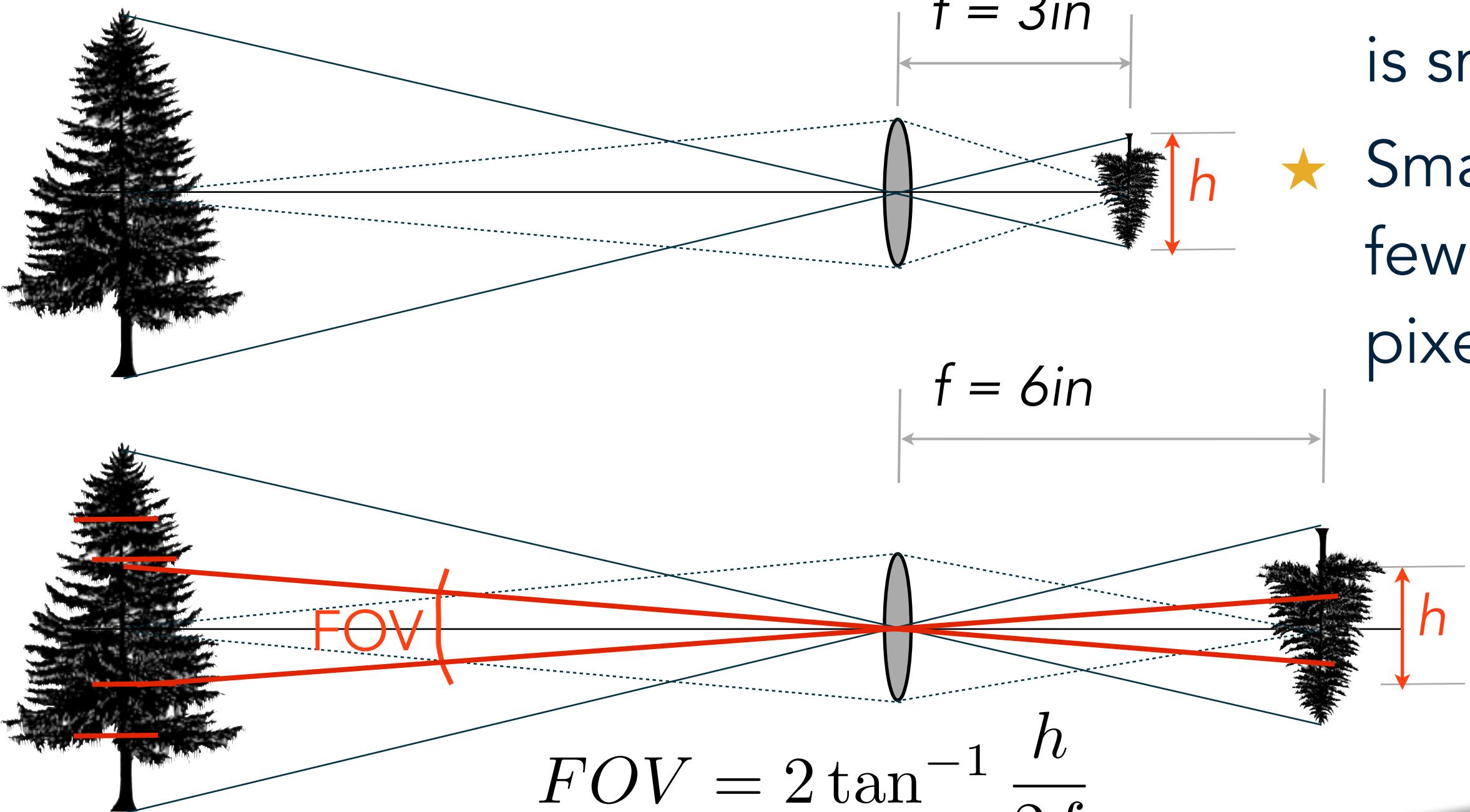


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Wide to Telezoom

Wide to Telezoom



24mm

Wide to Telezoom



24mm 50mm

Wide to Telezoom



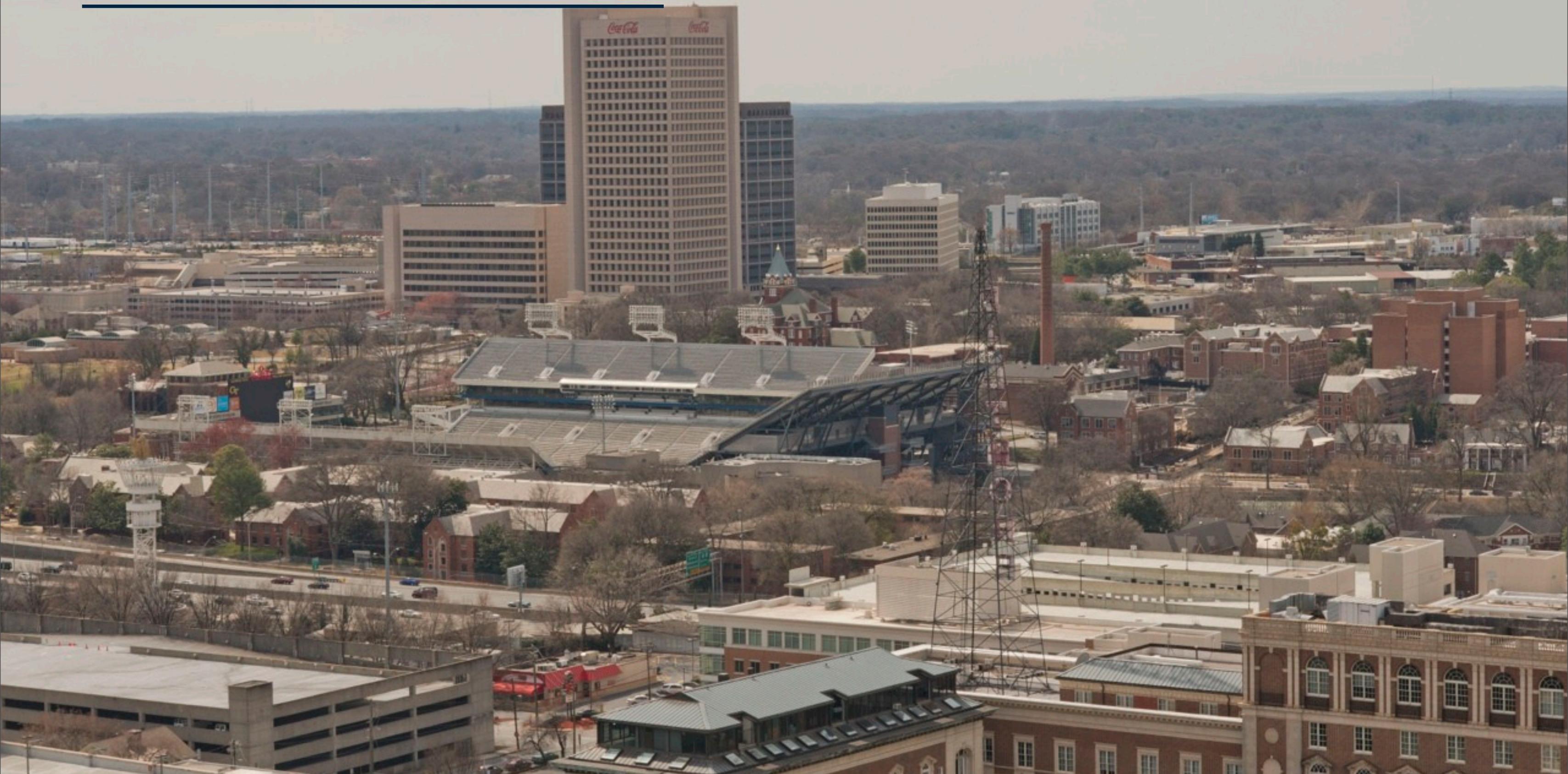
24mm 50mm 85mm

Wide to Telezoom



24mm 50mm 85mm 116mm

Wide to Telezoom



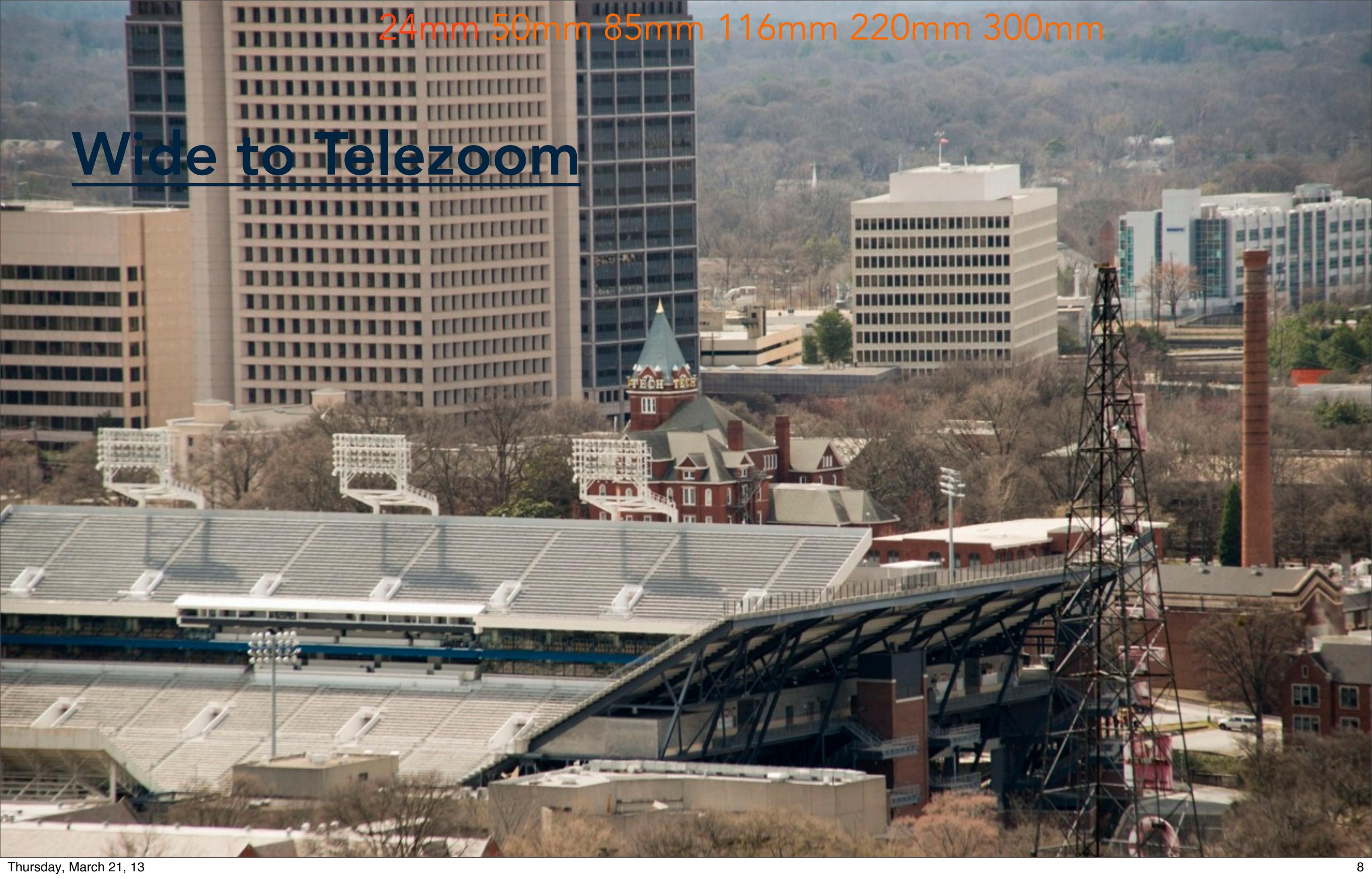
24mm 50mm 85mm 116mm 220mm

Wide to Telezoom

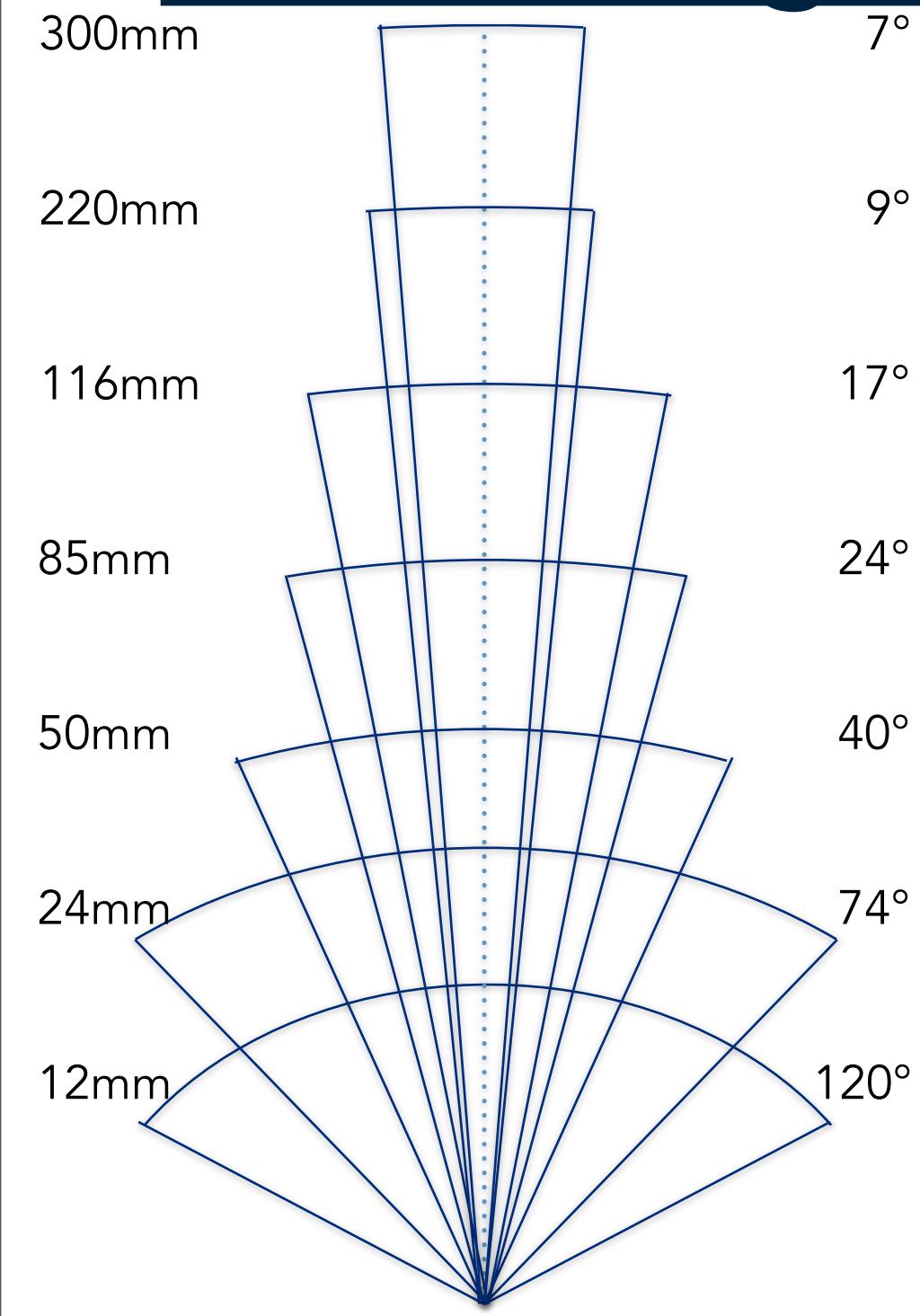


24mm 50mm 85mm 116mm 220mm 300mm

Wide to Telezoom



Focal Length and Field of View (FOV)



Photos by Henrik Christensen

FOV measured horizontally (x-direction) 35 mm full-frame camera 24x35mm

Focal Length and Field of View (FOV)

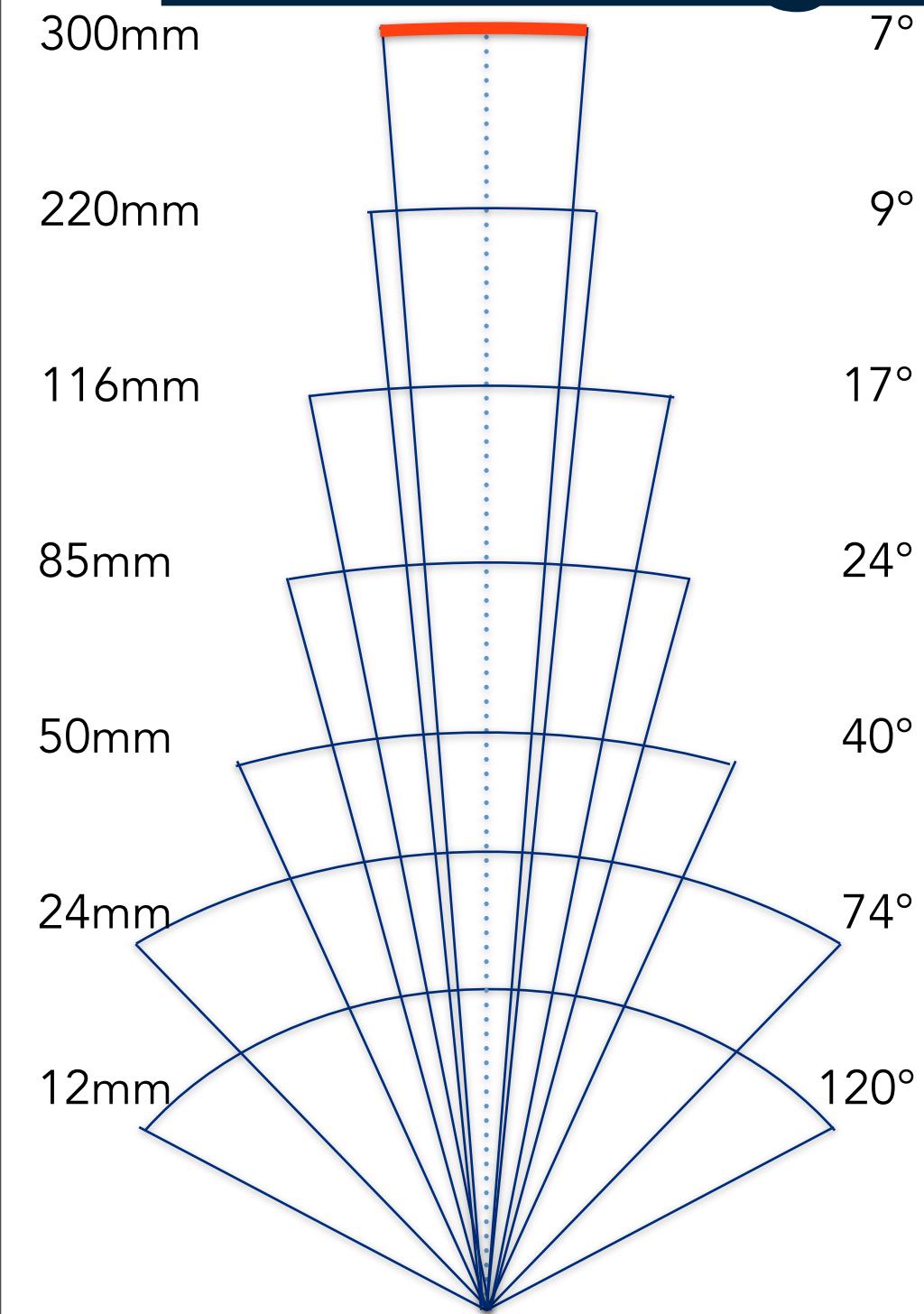


Photo by Michael Chastain

FOV measured horizontally (x-direction) 35 mm full-frame camera 24x35mm

Sensor Sizes

35mm X 24mm (Full Frame 1:1)

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28.7mm X 19.1 mm (1:1.26)

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17.3 mm X 13mm (1:2) micro 4/3

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17.3 mm X 13mm (1:2) micro 4/3

Sensor Sizes

"13mm X 17.3 mm (1:2) micro 4/3"
in original slides, SHOULD be
"17.3 mm X 13mm (1:2) micro 4/3"
CORRECTED HERE!

35mm X 24mm (Full Frame 1:1)

28.7mm X 19.1 mm (1:1.26)

23.7mm X 15.5 mm (1:1.5)

17.3 mm X 13mm (1:2) micro 4/3

8.8 X 6.6 mm
(1:2) micro 2/3

Sensor Sizes

"13mm X 17.3 mm (1:2) micro 4/3"
in original slides, SHOULD be
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CORRECTED HERE!

35mm X 24mm (Full Frame 1:1)

28.7mm X 19.1 mm (1:1.26)

23.7mm X 15.5 mm (1:1.5)

17.3 mm X 13mm (1:2) micro 4/3

8.8 X 6.6 mm
(1 7.25mm /3
X 5.33mm

Sensor Sizes

"13mm X 17.3 mm (1:2) micro 4/3"
in original slides, SHOULD be
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CORRECTED HERE!

35mm X 24mm (Full Frame 1:1)

28.7mm X 19.1 mm (1:1.26)

23.7mm X 15.5 mm (1:1.5)

17.3 mm X 13mm (1:2) micro 4/3

8.8 X 6.6 mm

(1 /3

4.54mm
X 3.52mm
(iPhone 5)

Sensor Sizes

"13mm X 17.3 mm (1:2) micro 4/3"
in original slides, SHOULD be
"17.3 mm X 13mm (1:2) micro 4/3"
CORRECTED HERE!

Focal Length vs. Viewpoint



Focal Length vs. Viewpoint



$f = 18\text{mm}$, 35mm sensor

Distance to 1st Subject = 0.5m

Distance to 2nd Subject = 2.0m

Focal Length vs. Viewpoint



$f = 18\text{mm}$, 35mm sensor
Distance to 1st Subject = 0.5m
Distance to 2nd Subject = 2.0m



$f = 180\text{mm}$, 35mm sensor
Distance to 1st Subject = 3.0m
Distance to 2nd Subject = 4.5m

Focal Length vs. Viewpoint



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- ★ Changing focal length allows us to move back, and still capture the scene

Focal Length vs. Viewpoint



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- ★ Changing viewpoint causes perspective changes

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Distance to 1st Subject = 3.0m
Distance to 2nd Subject = 4.5m

- ★ Changing focal length allows us to move back, and still capture the scene
- ★ Changing viewpoint causes perspective changes
- ★ See the “vertigo” effect from Hitchcock movies

Camera as a Window in a 3D World



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Geometry (Perspective)

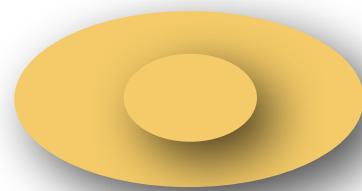


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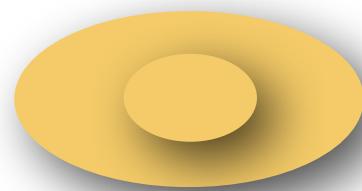
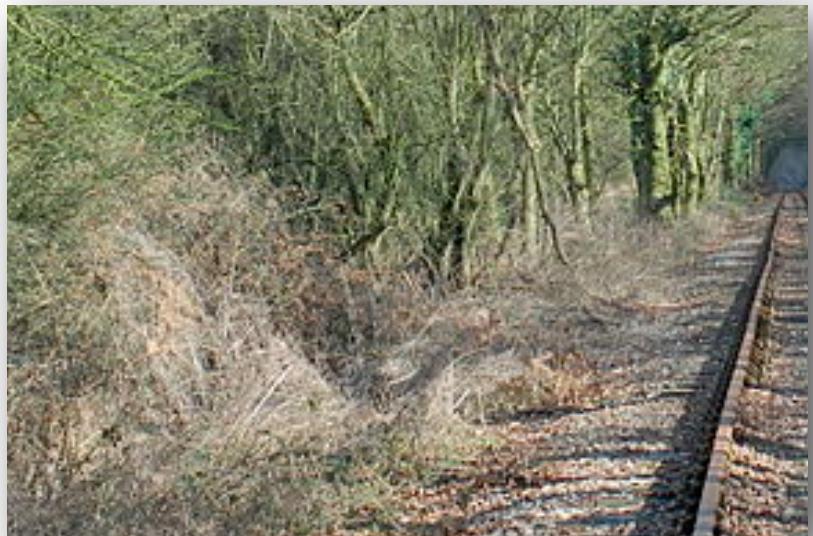


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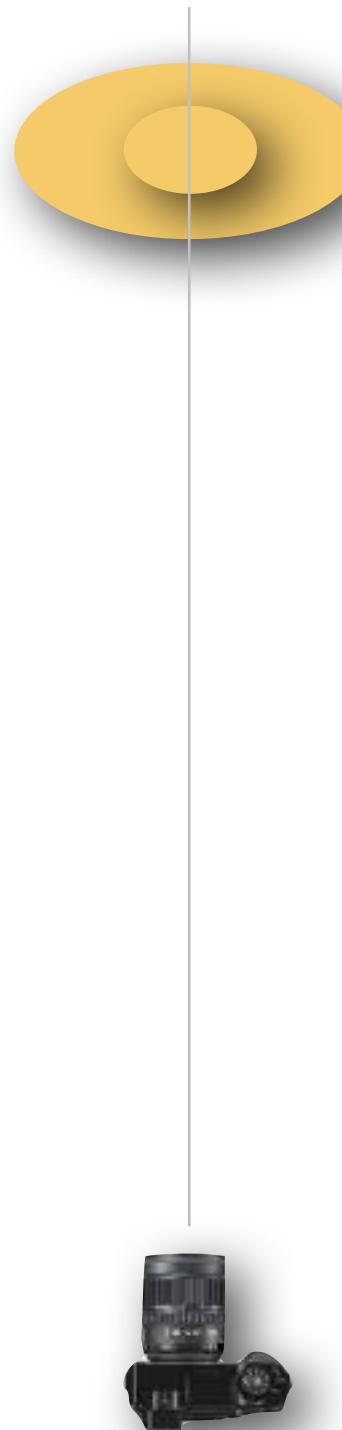


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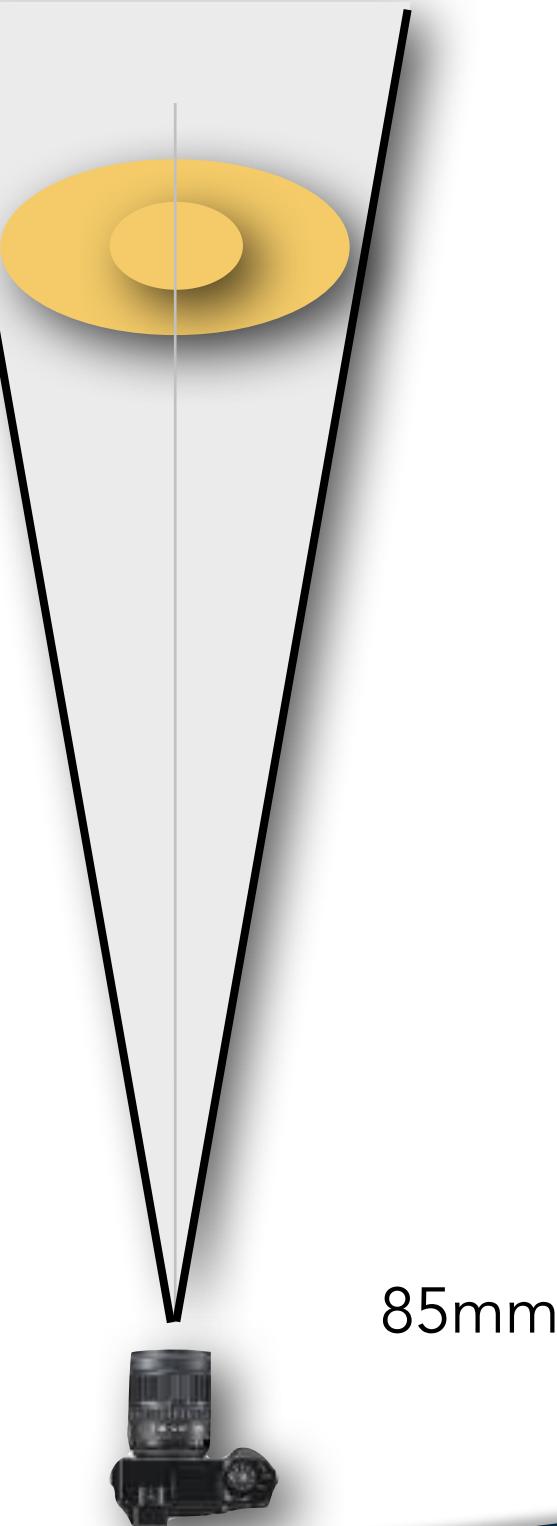


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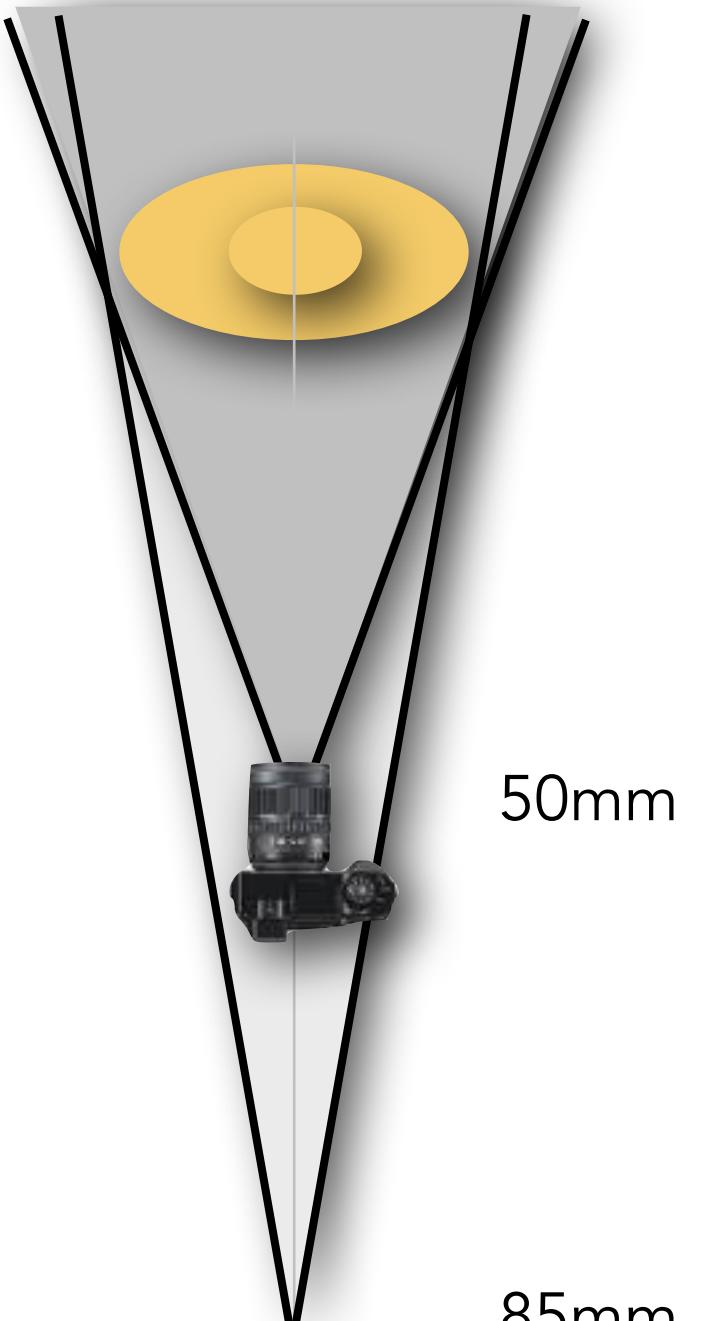


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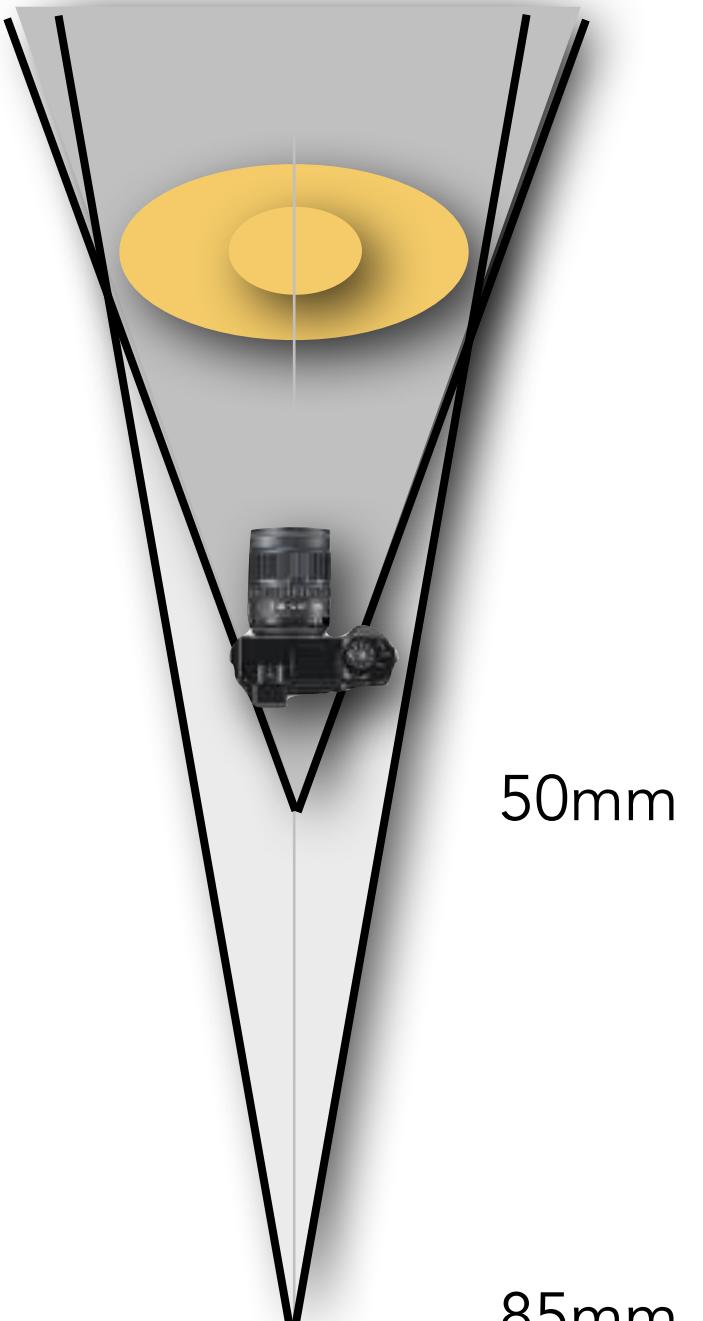
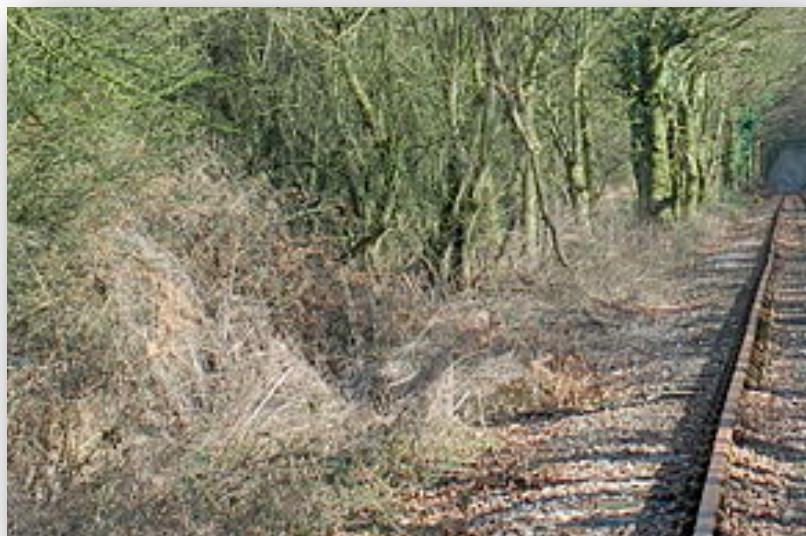


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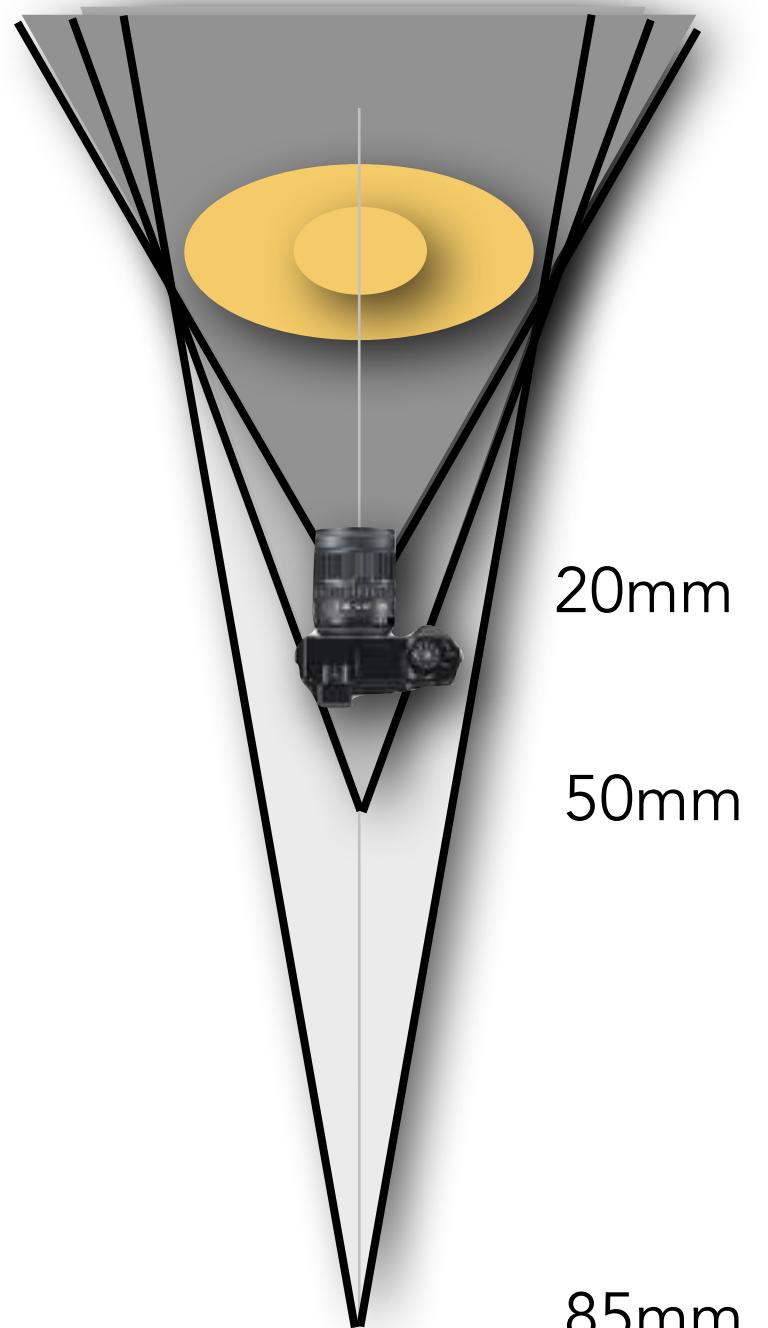
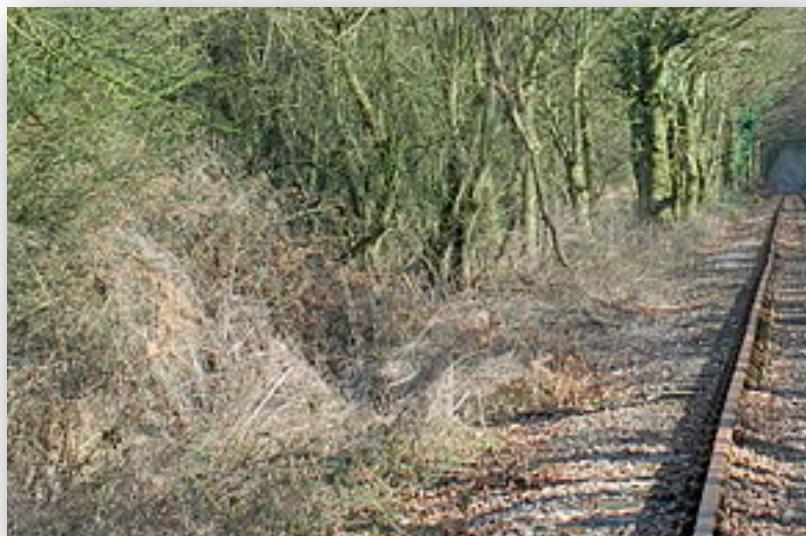


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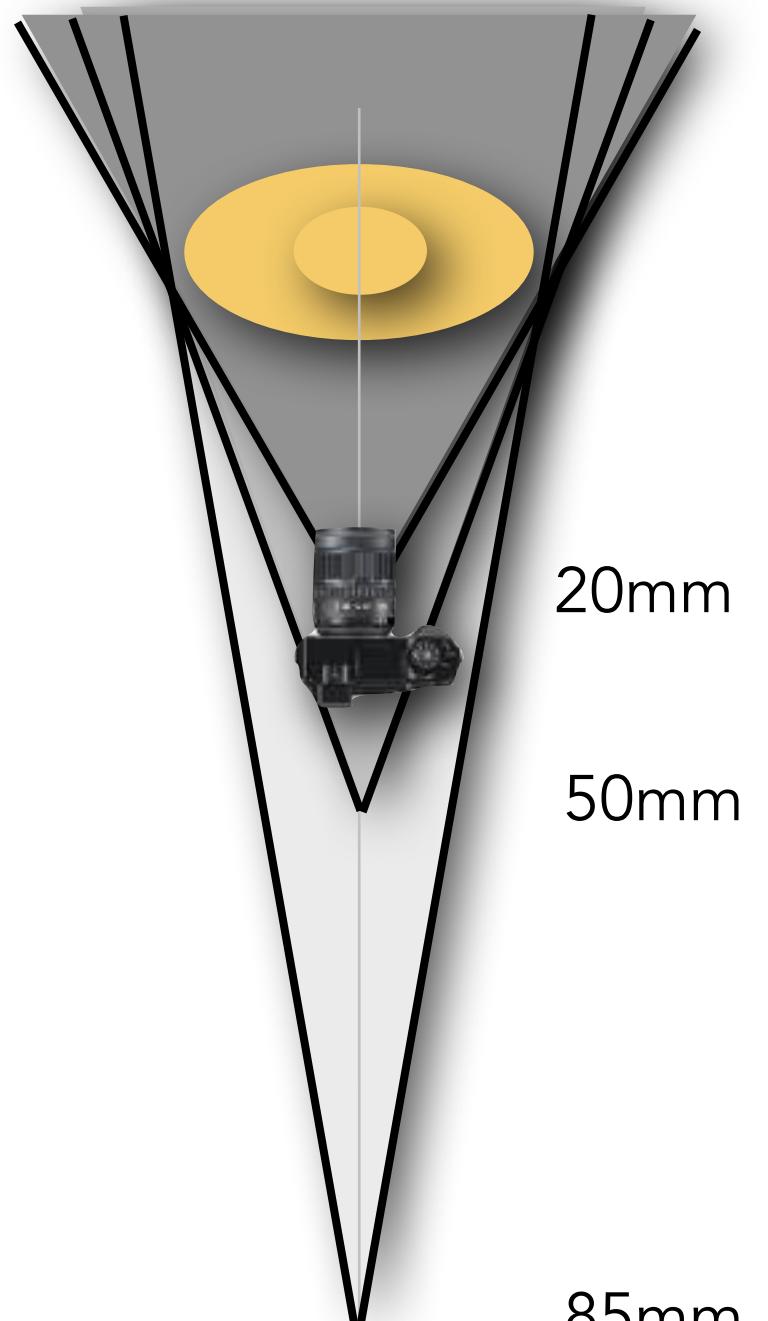


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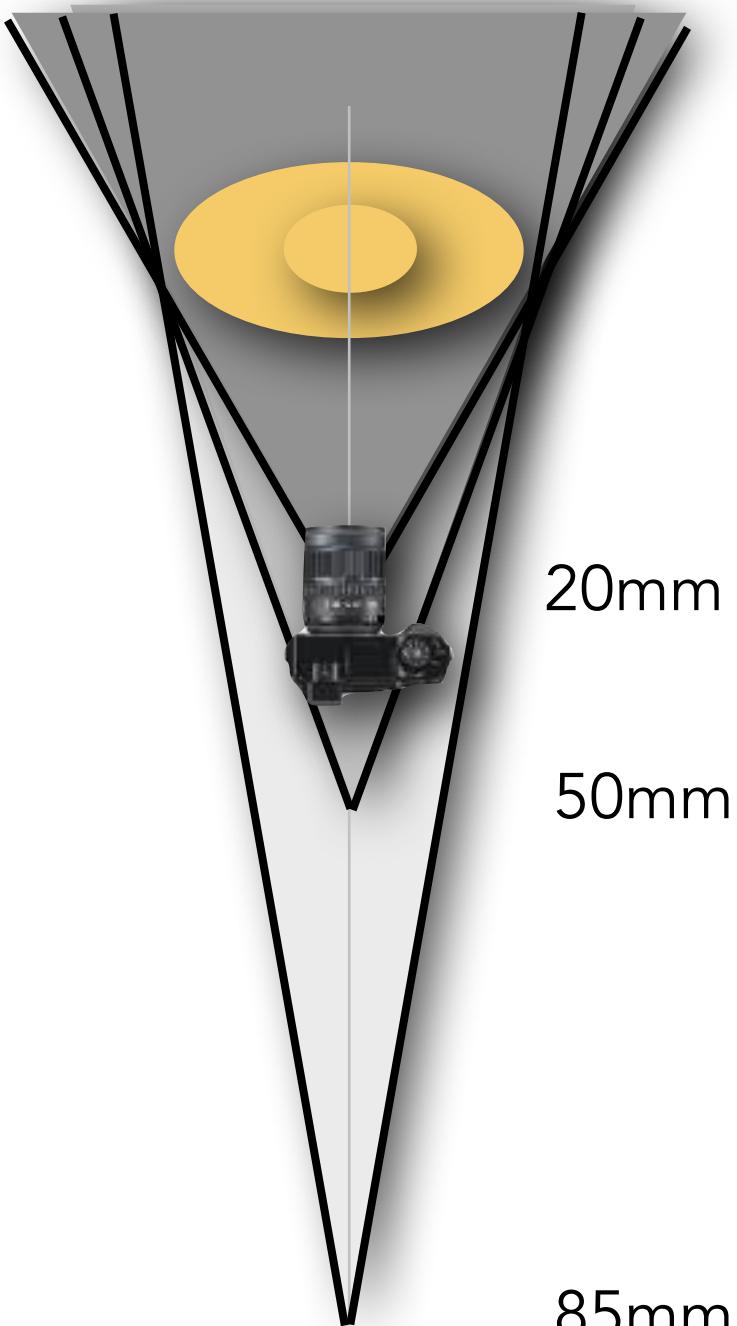


- ★ Images represent a view of the scene via a 2D array of pixels.

Camera as a Window in a 3D World

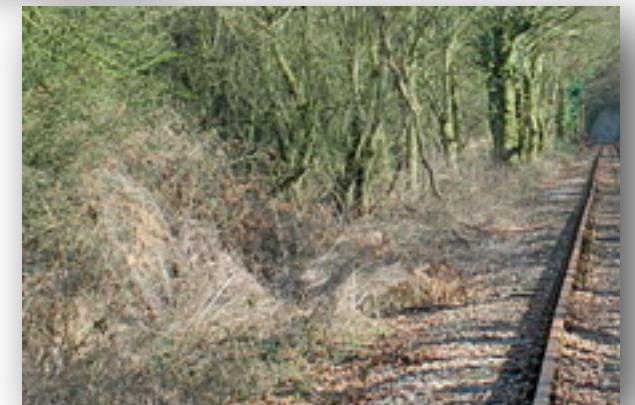


Geometry (Perspective)

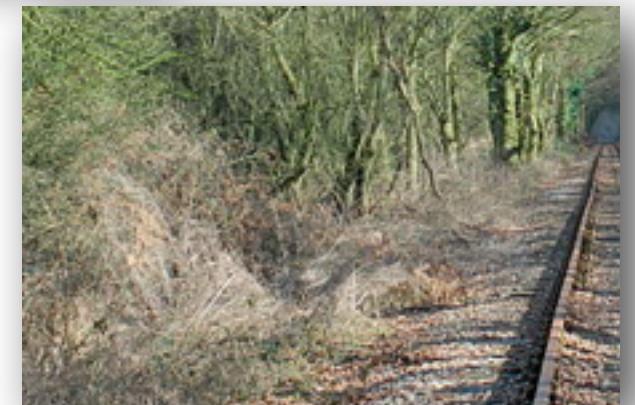
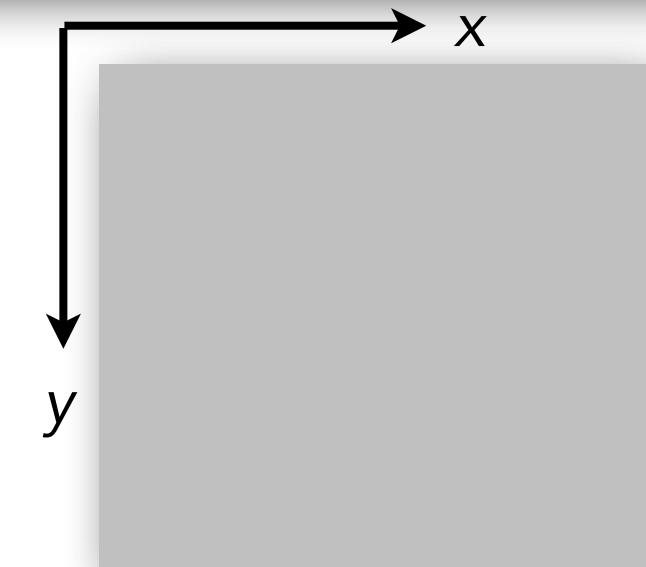


- ★ Images represent a view of the scene via a 2D array of pixels.
- ★ Rays are the fundamental primitives.

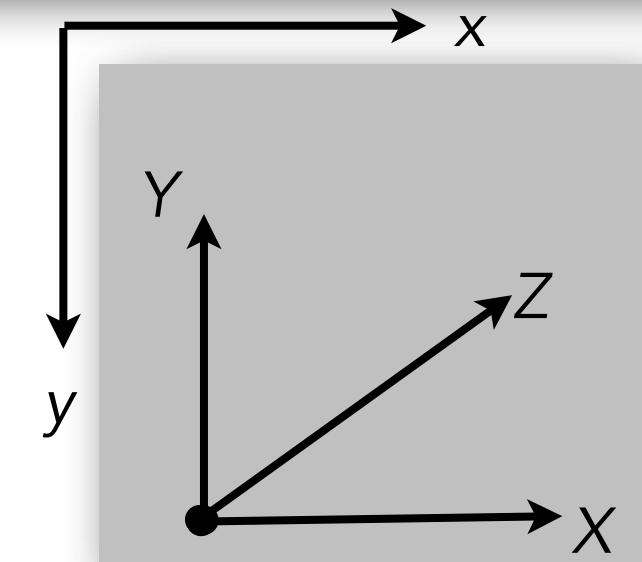
A Camera Model



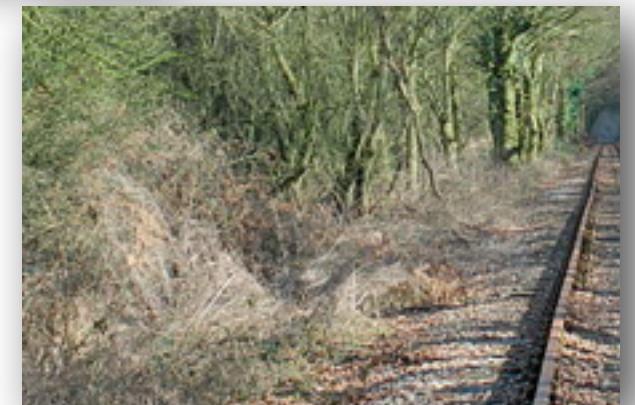
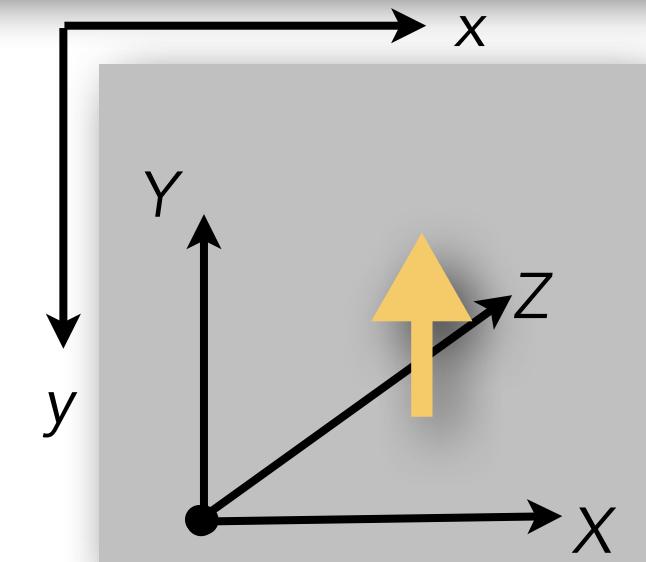
A Camera Model



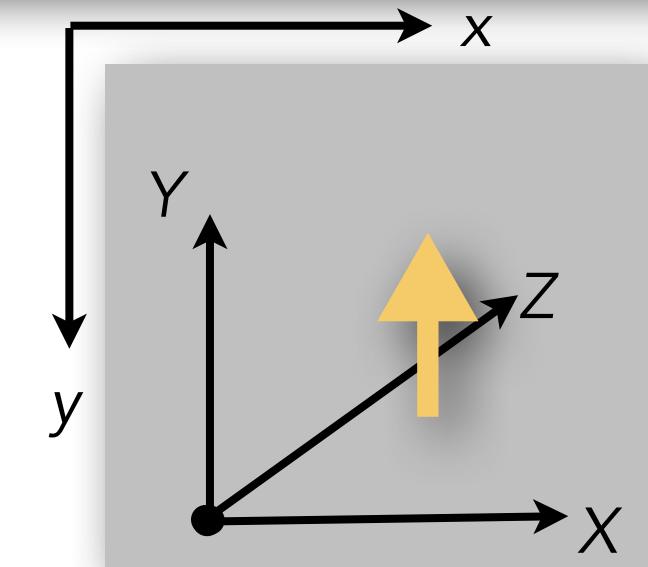
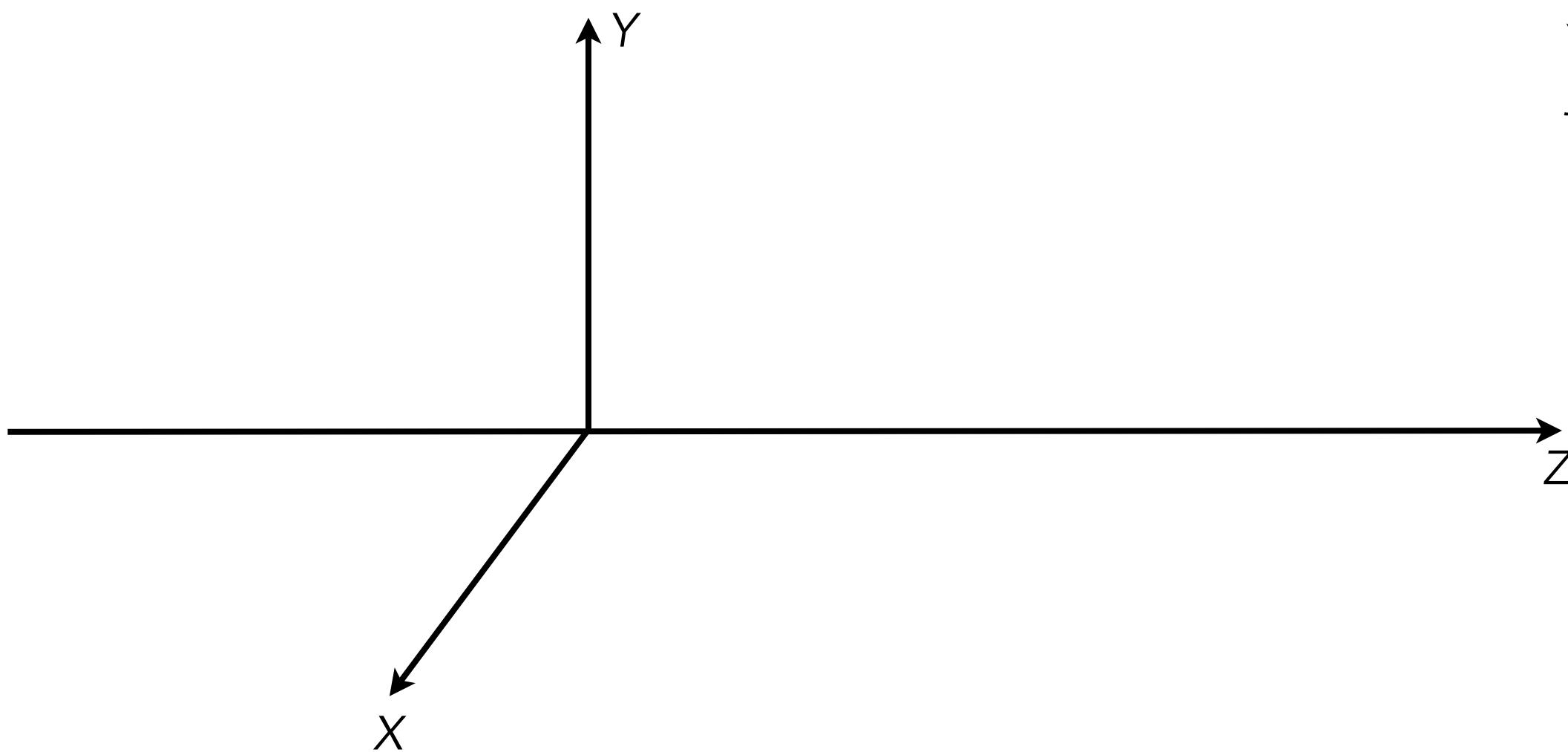
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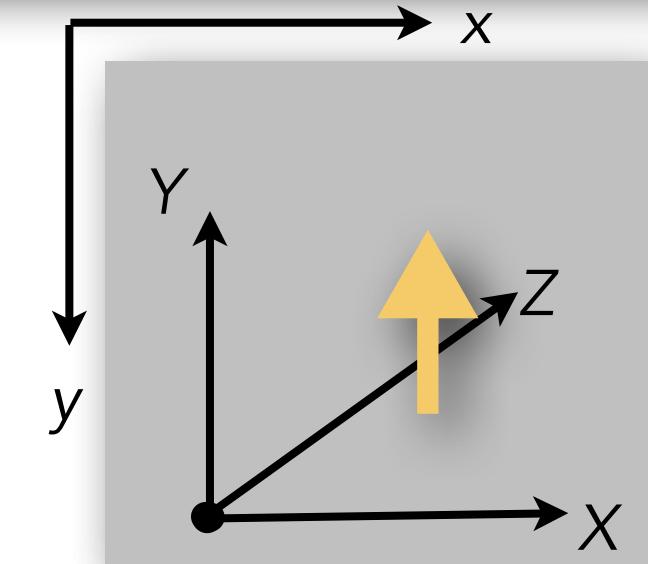
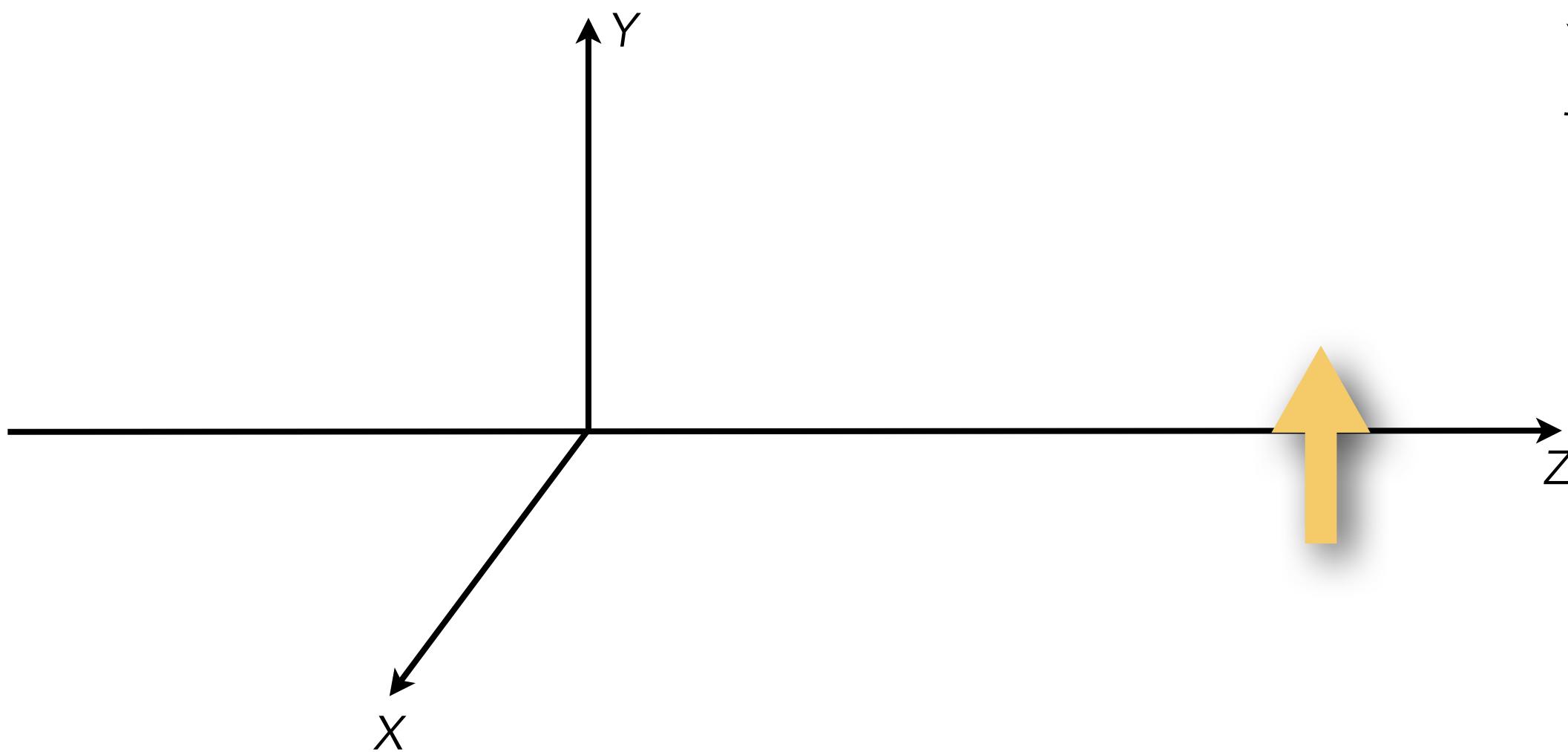
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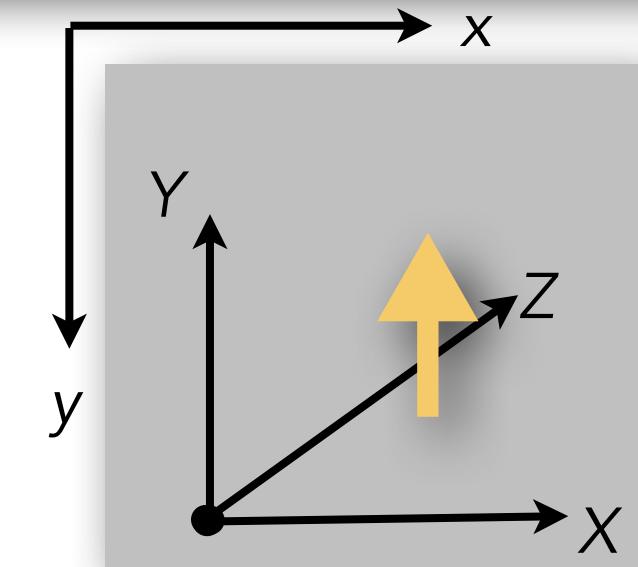
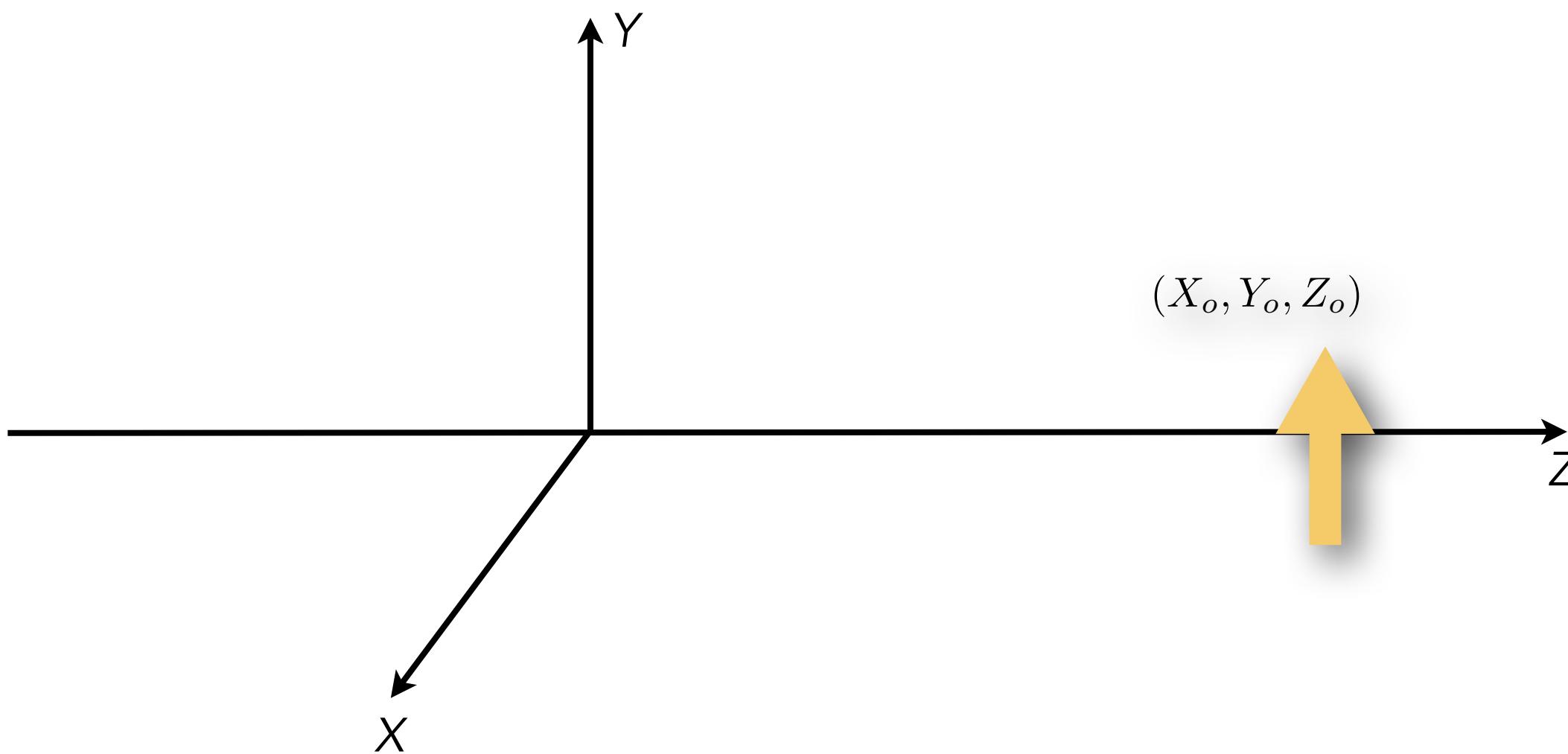
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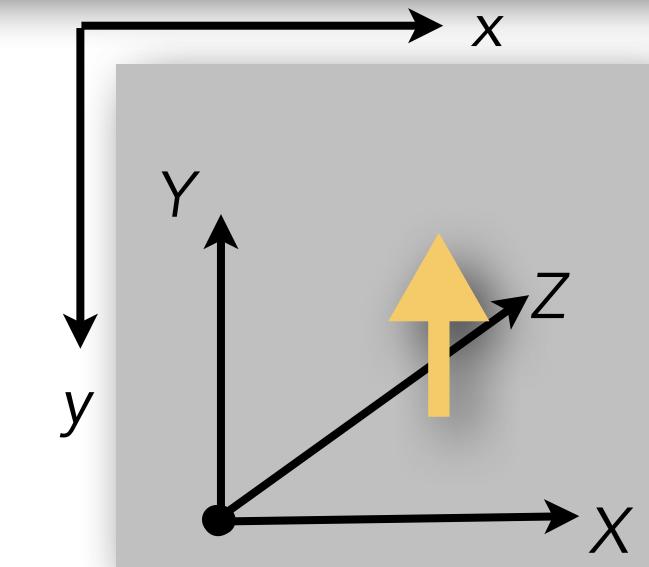
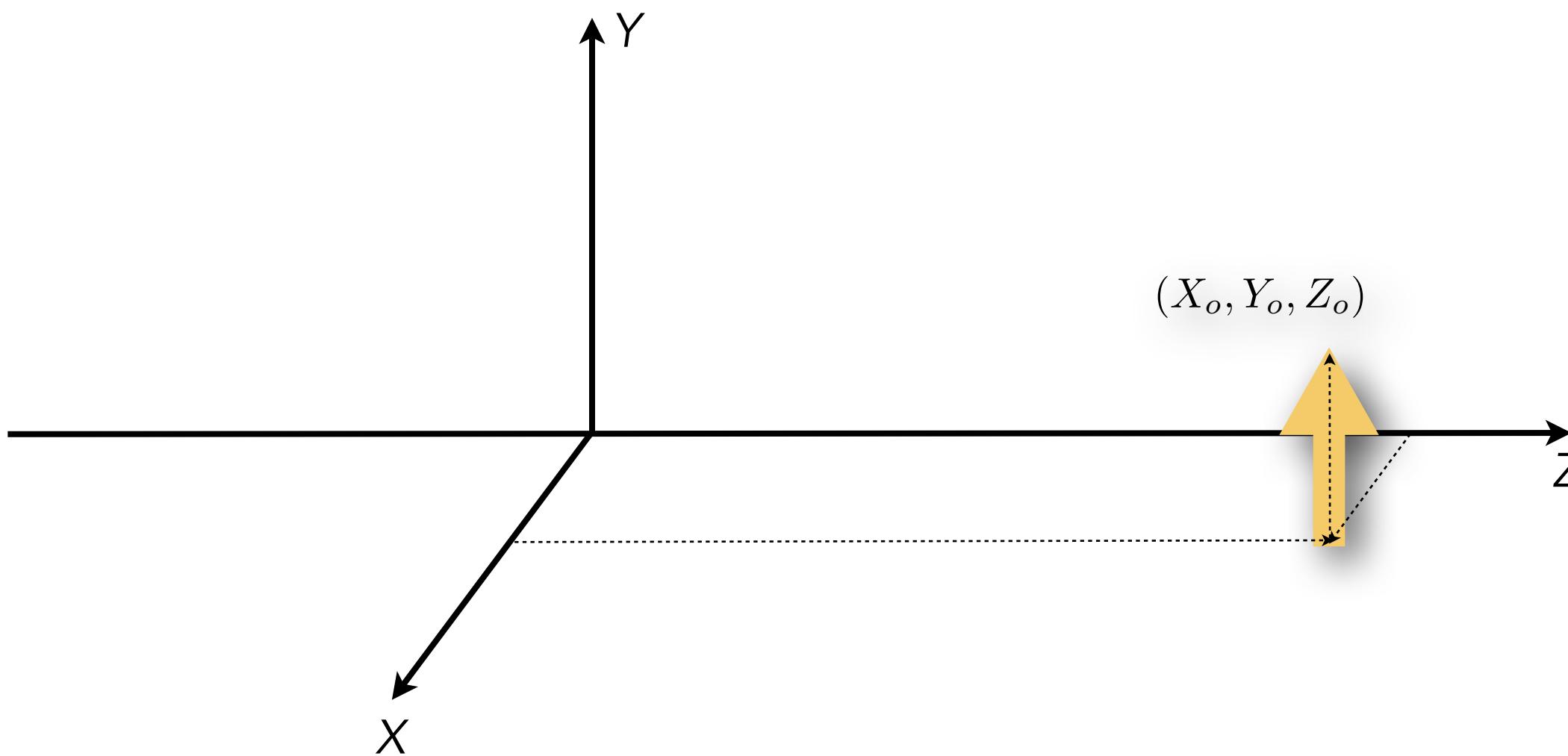
A Camera Model



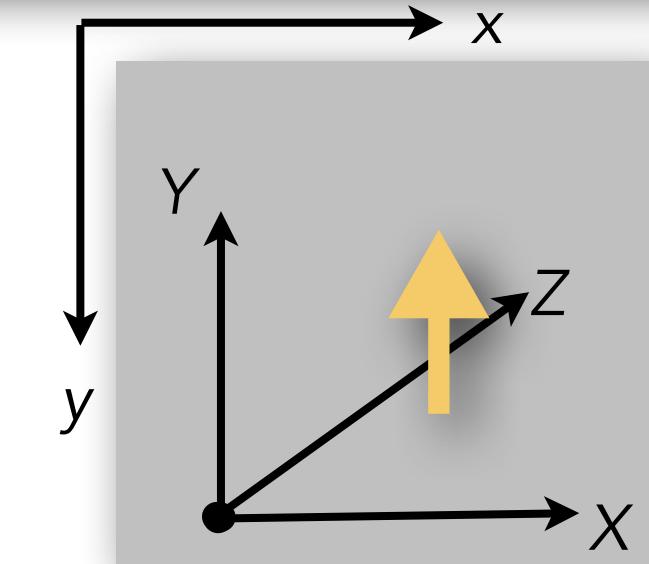
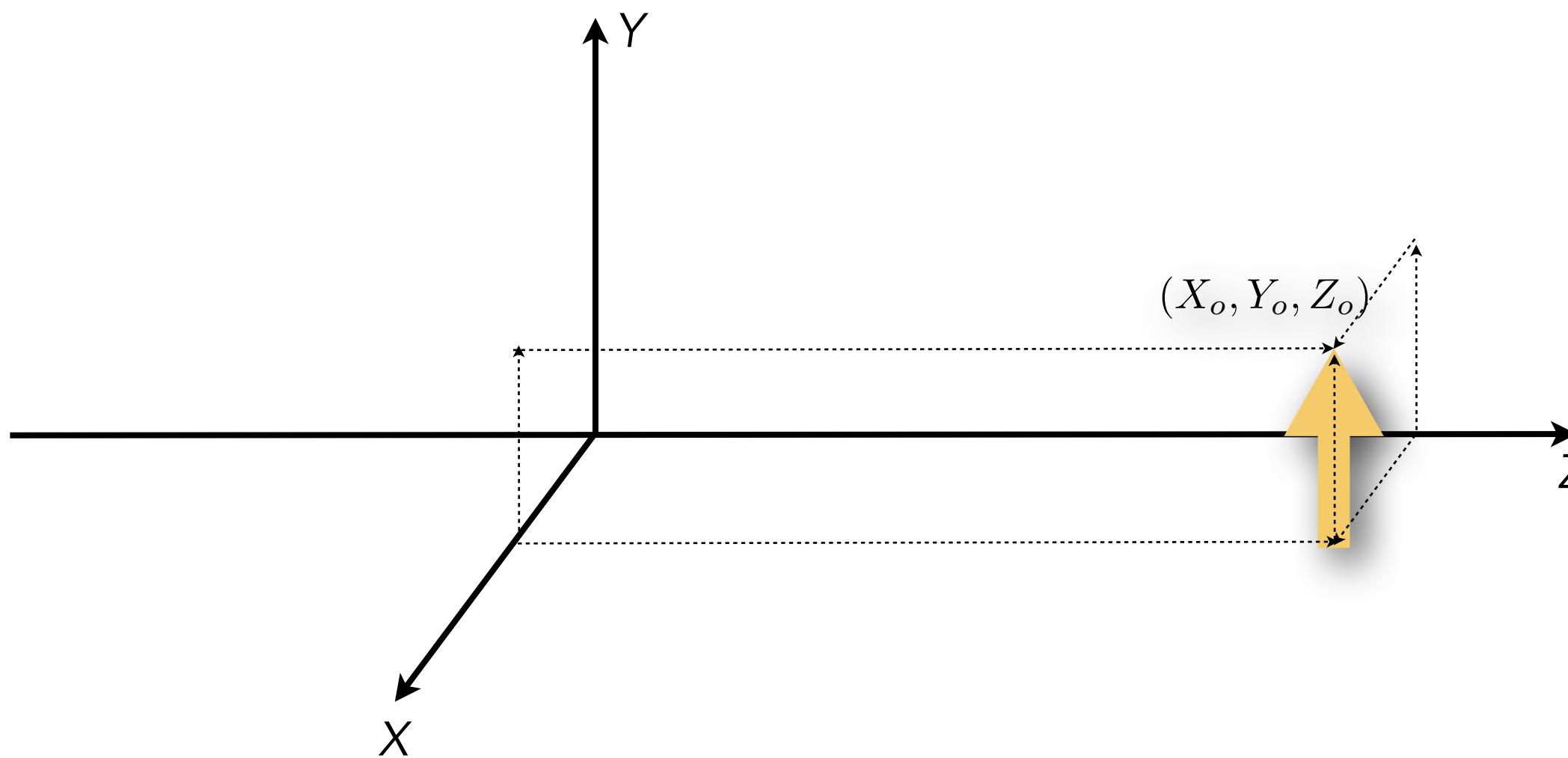
A Camera Model



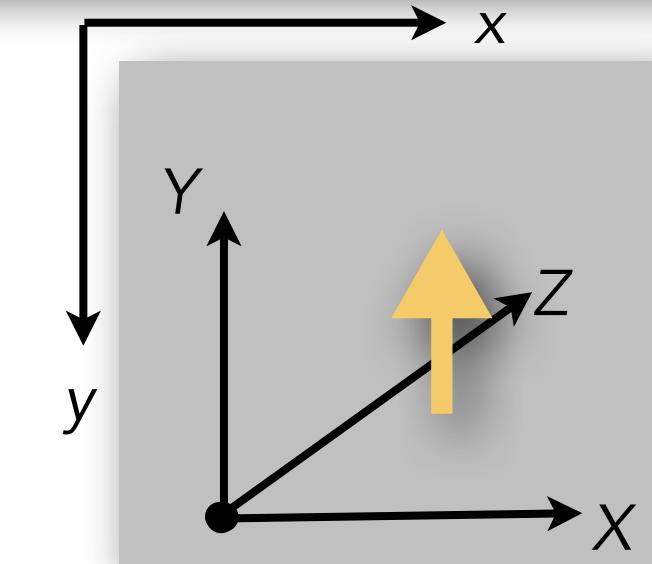
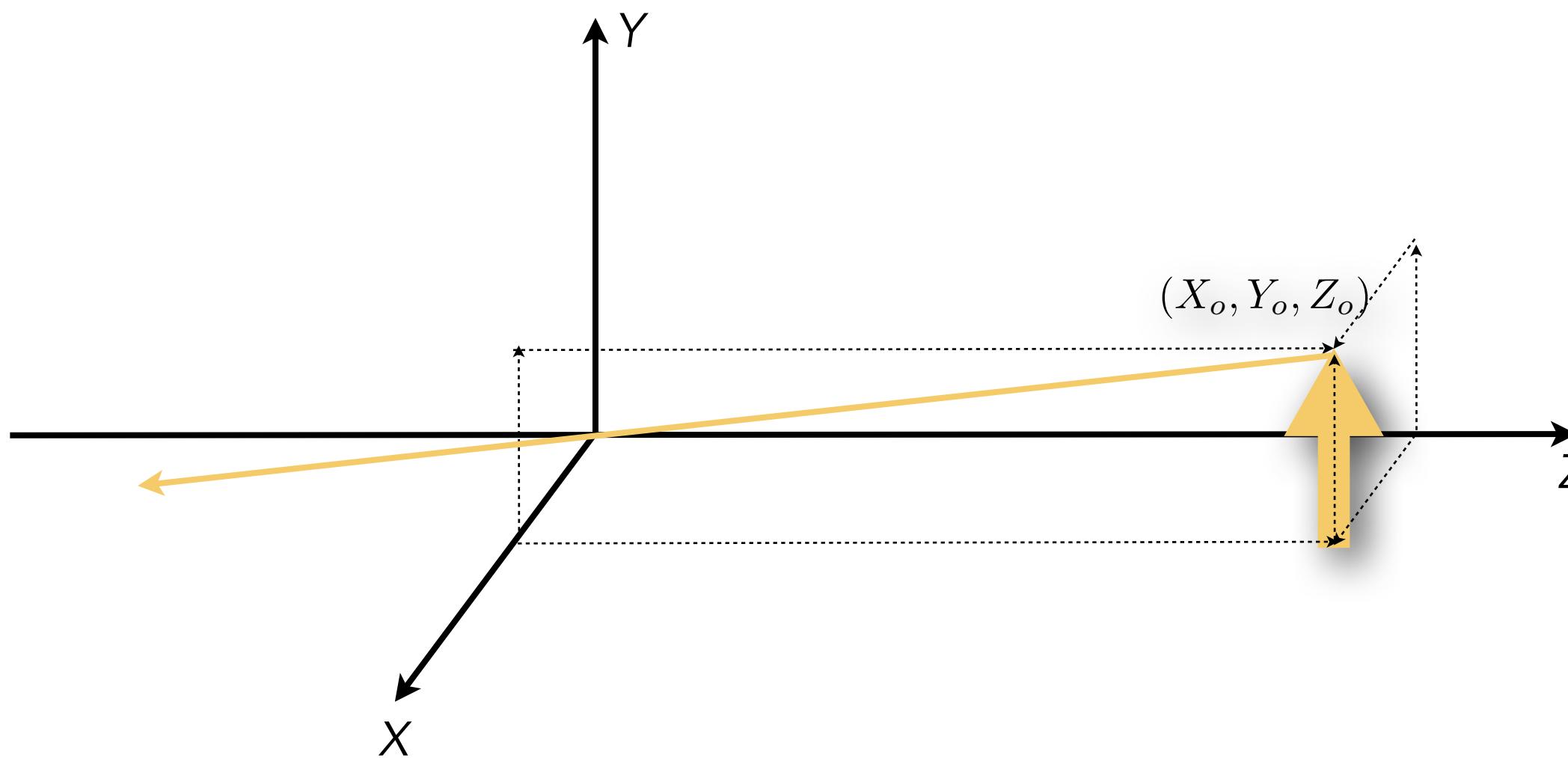
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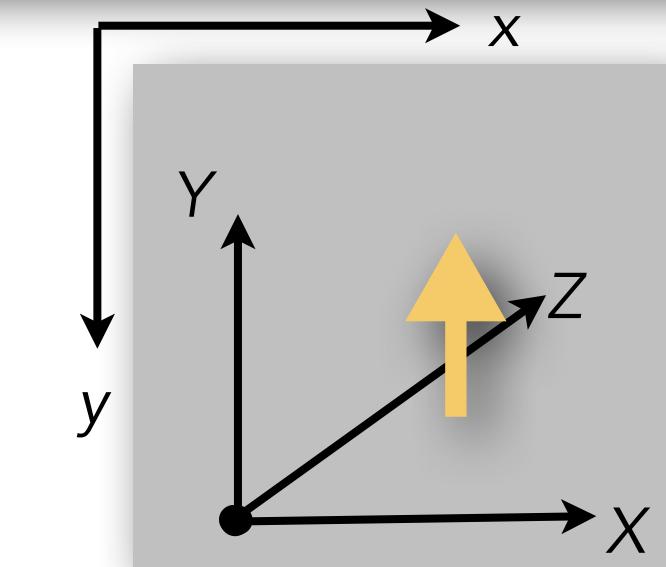
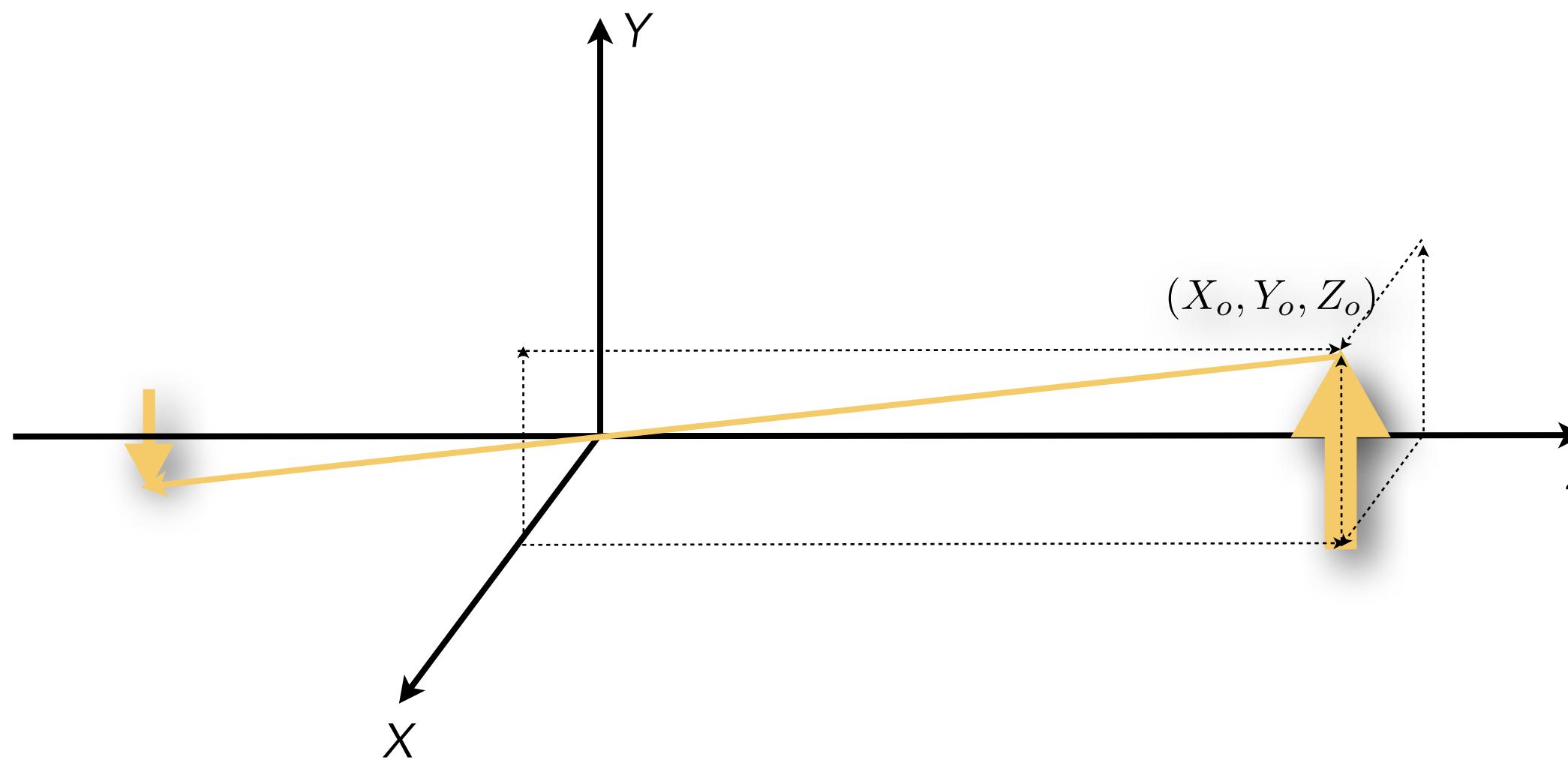
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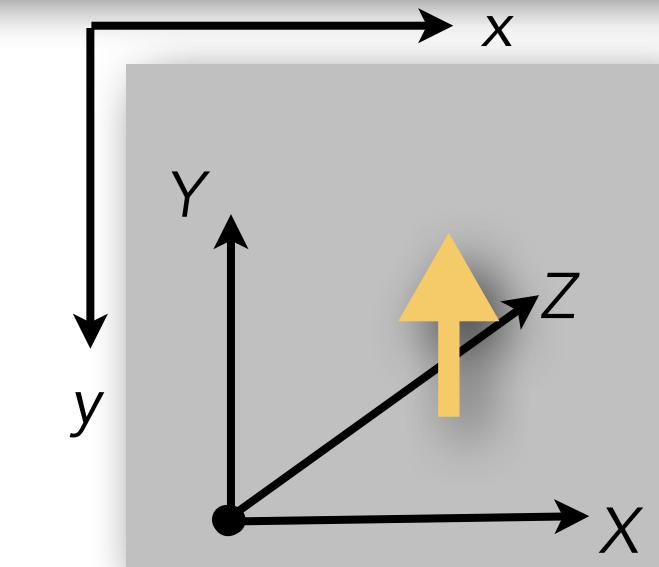
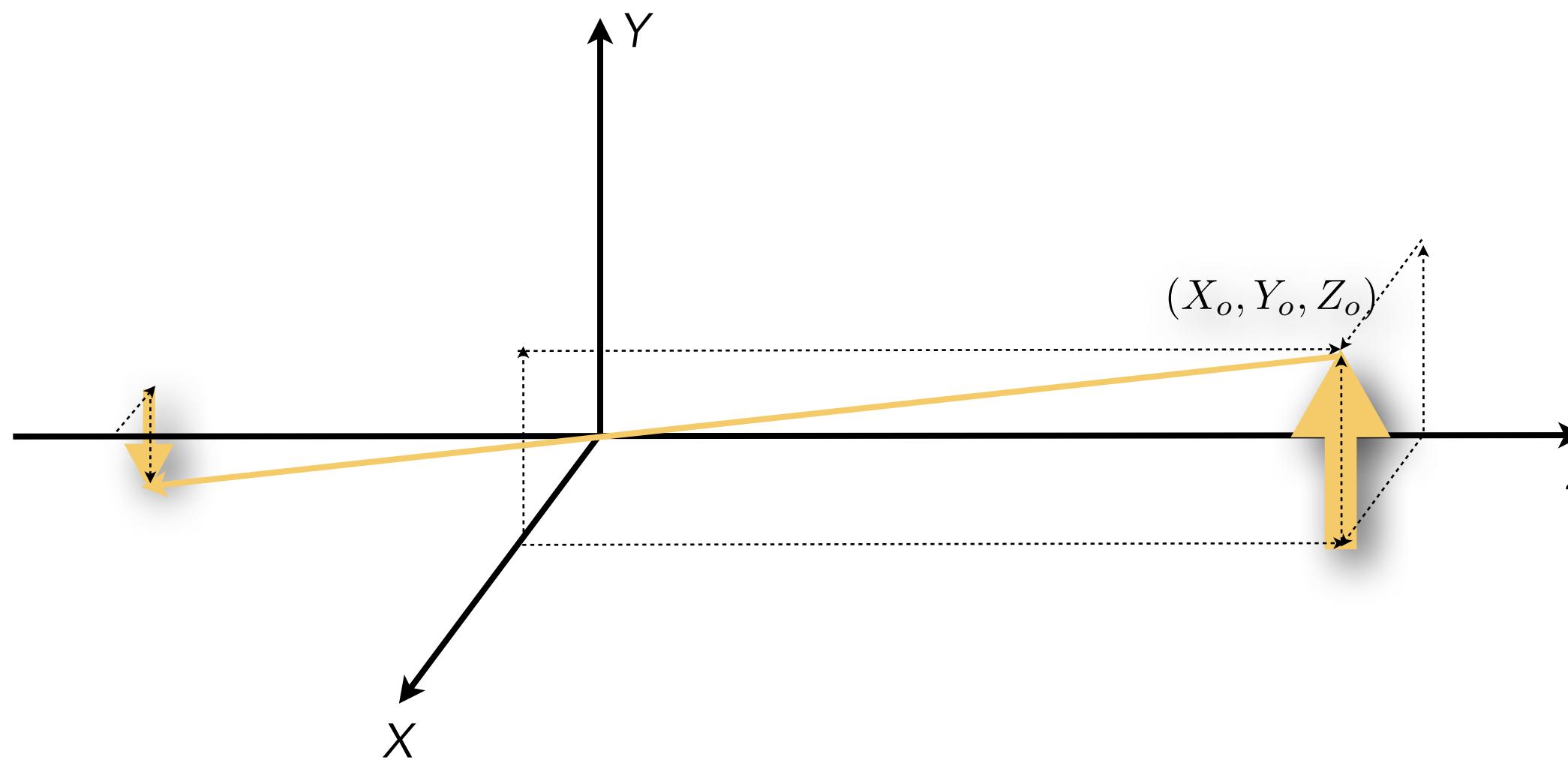
A Camera Model



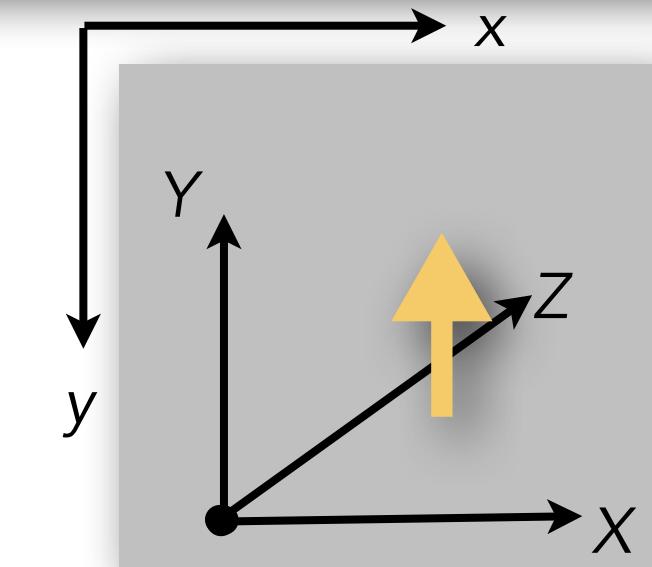
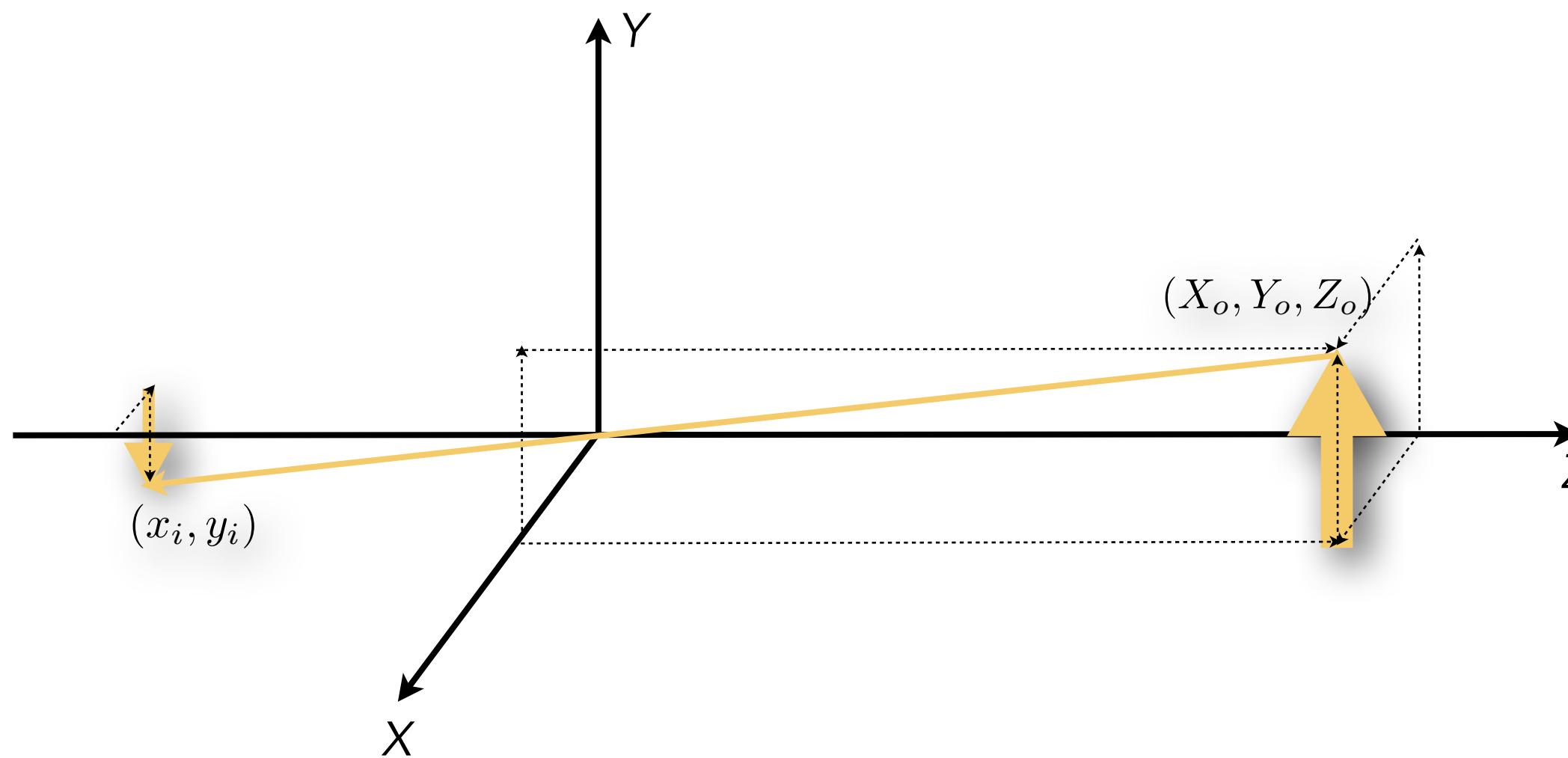
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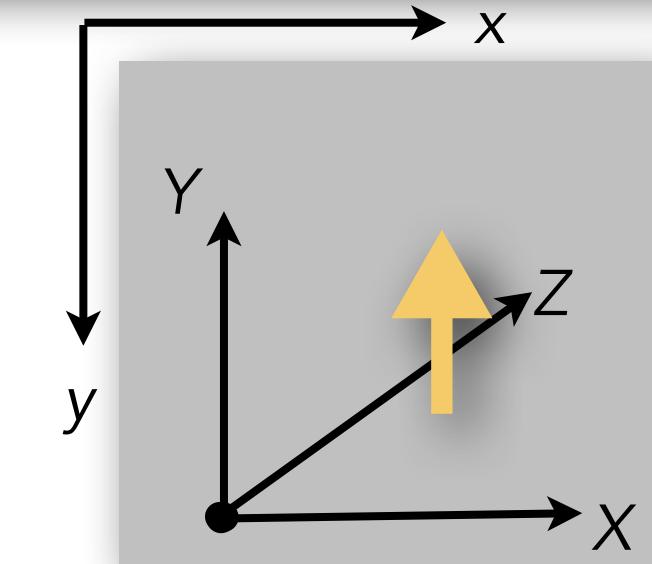
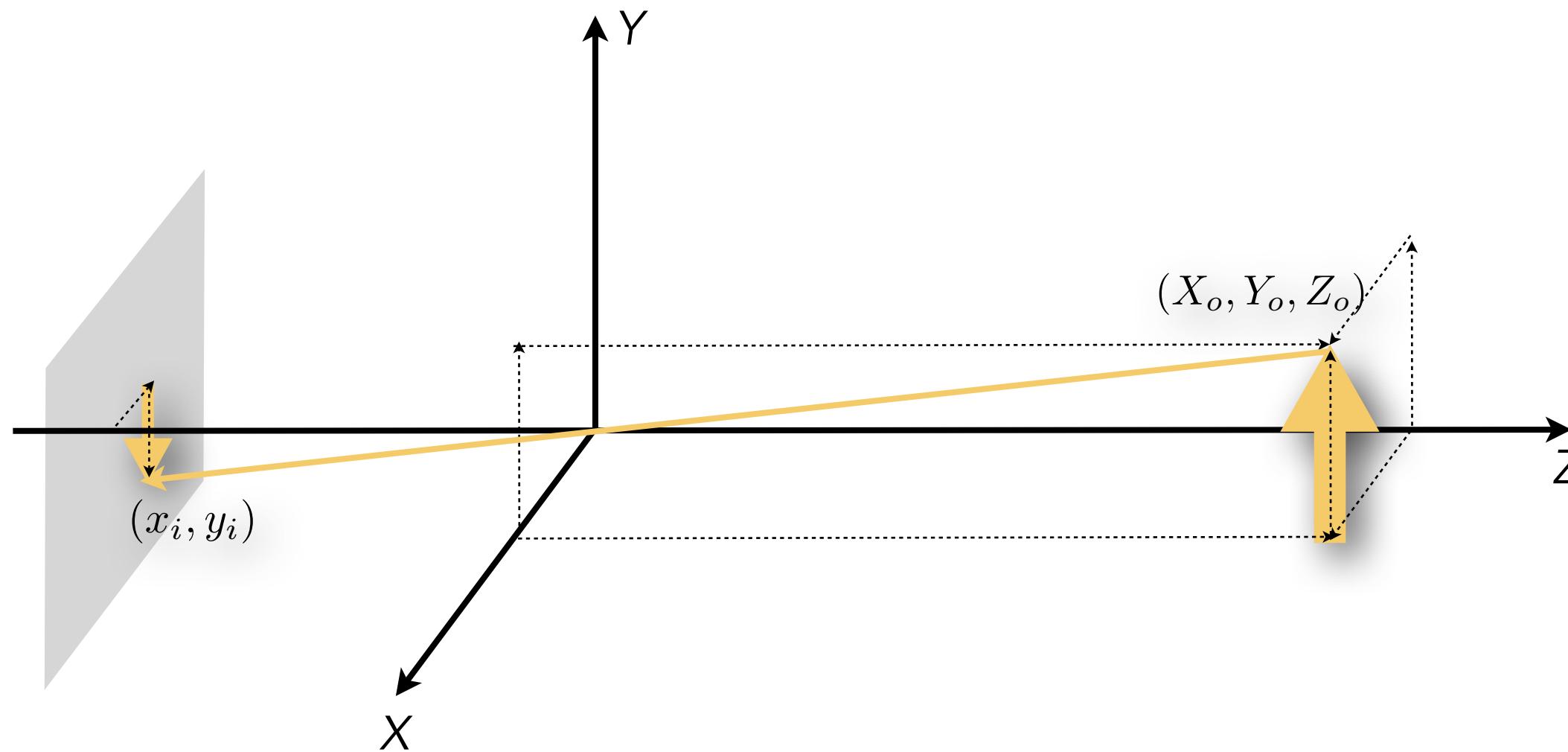
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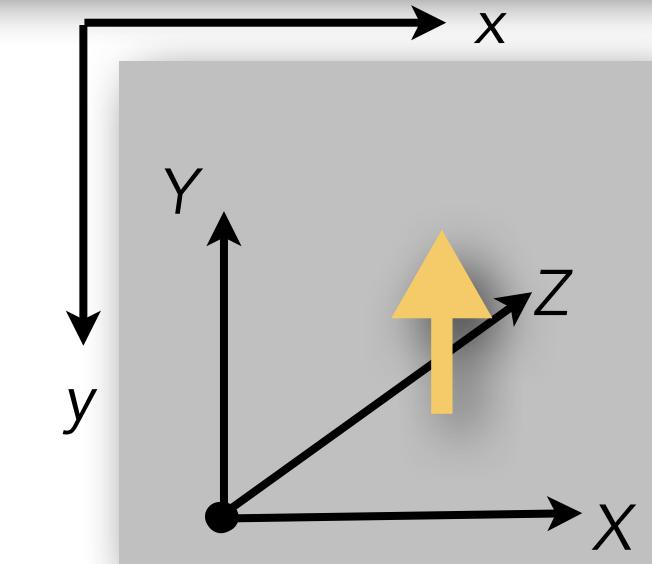
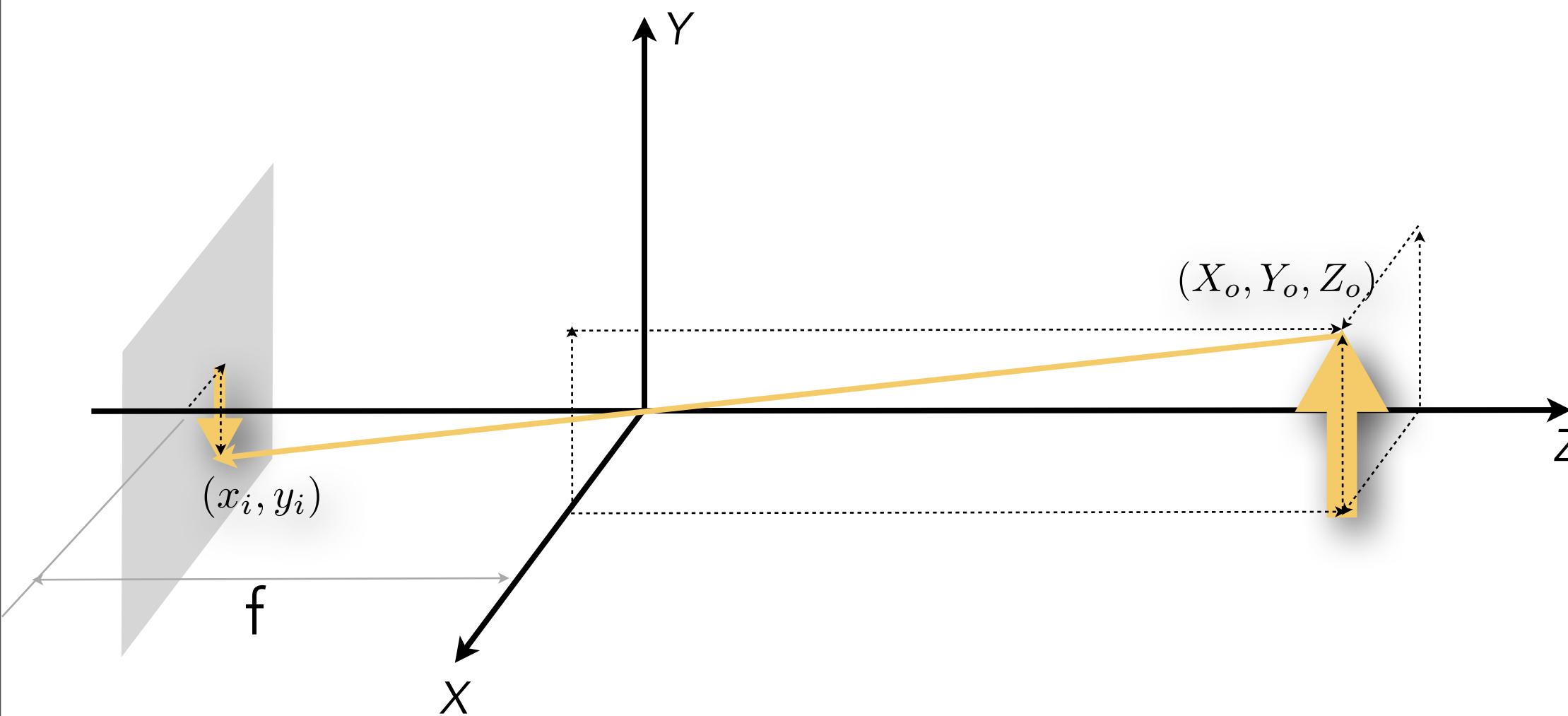
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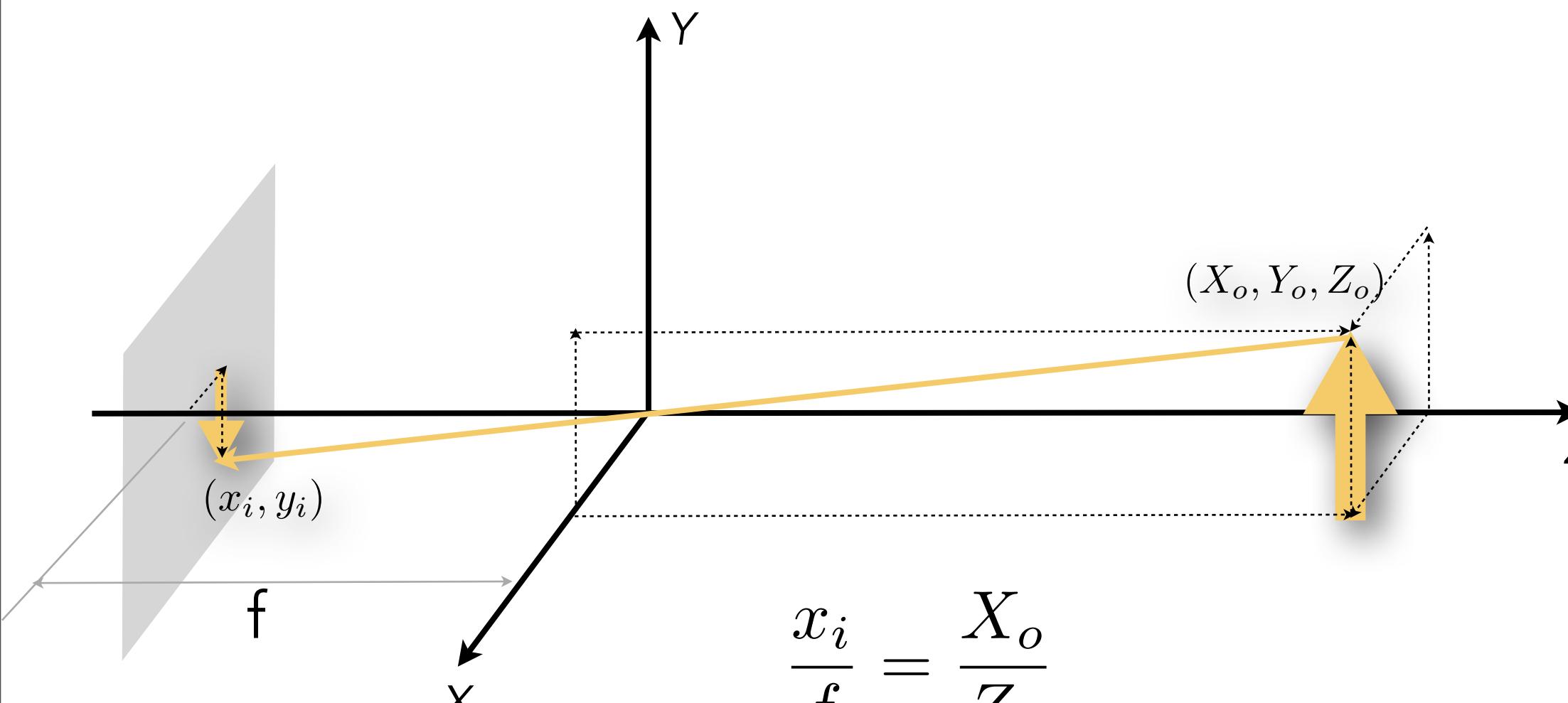
A Camera Model



A Camera Model



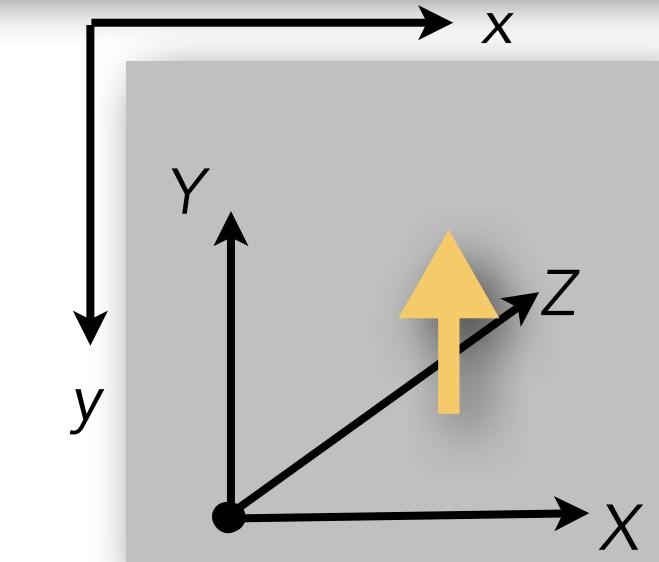
A Camera Model



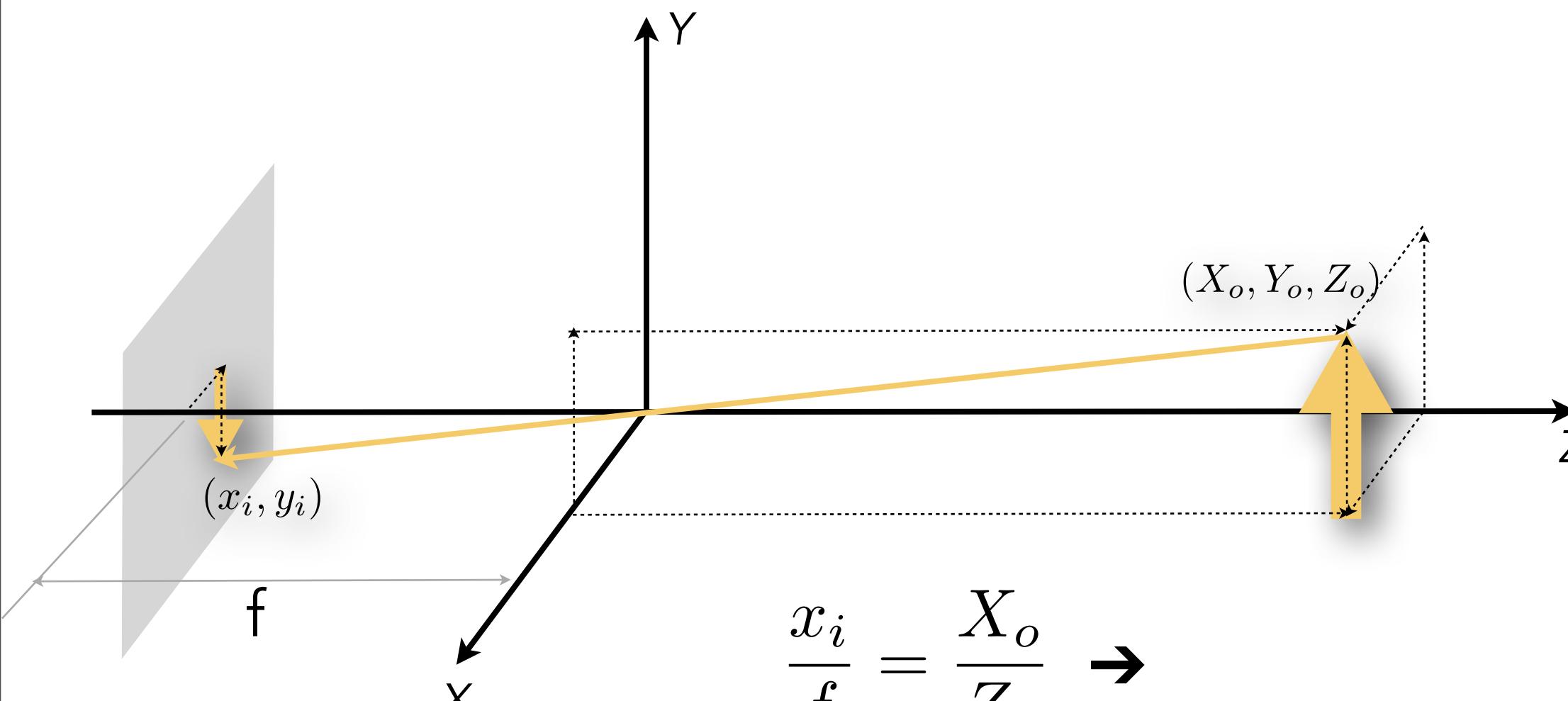
Using similar
triangles

$$\frac{x_i}{f} = \frac{X_o}{Z_o}$$

$$\frac{y_i}{f} = \frac{Y_o}{Z_o}$$



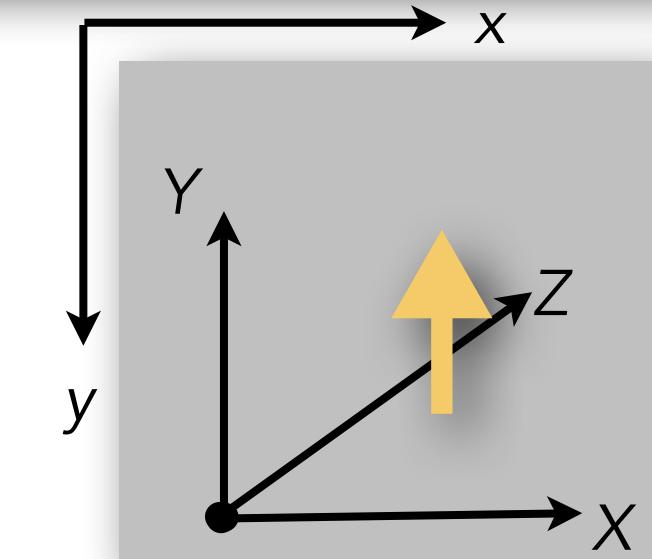
A Camera Model



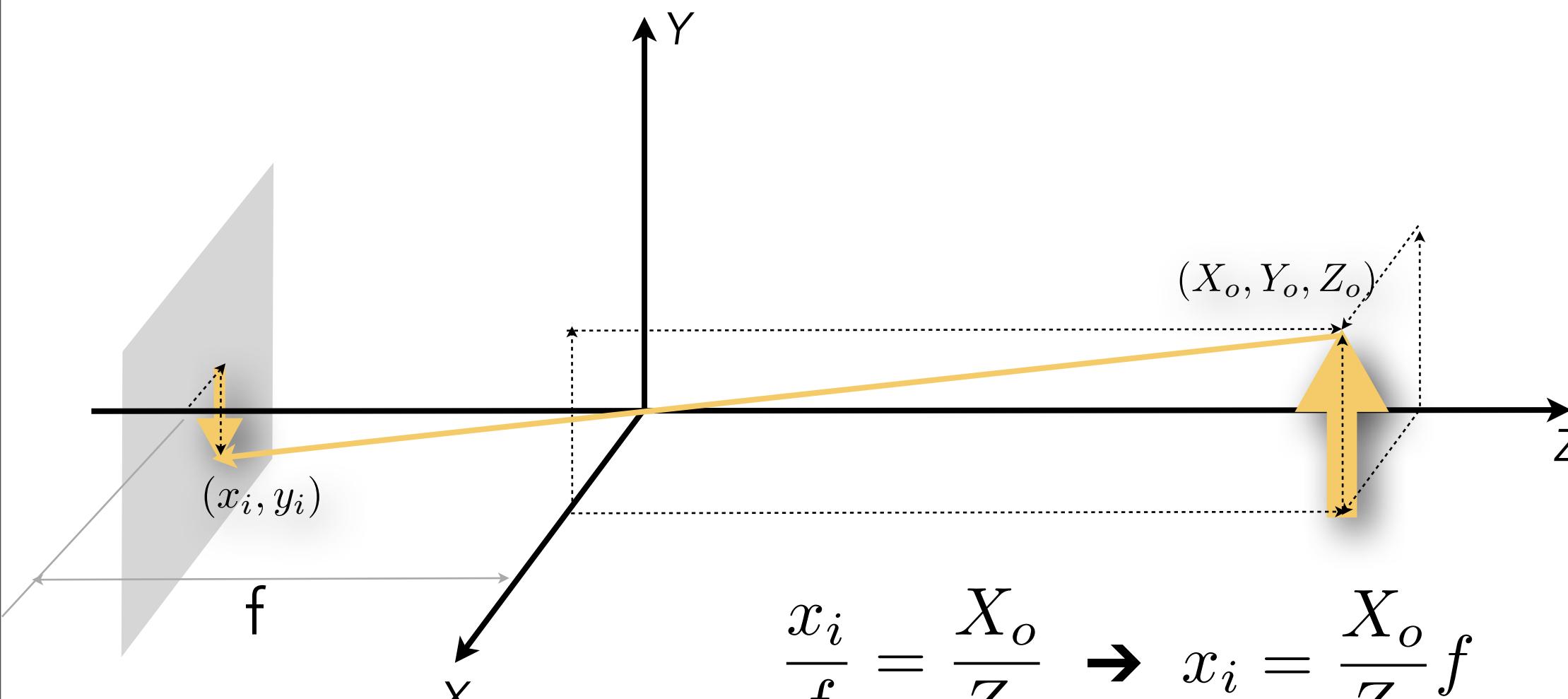
Using similar
triangles

$$\frac{x_i}{f} = \frac{X_o}{Z_o} \rightarrow$$

$$\frac{y_i}{f} = \frac{Y_o}{Z_o} \rightarrow$$



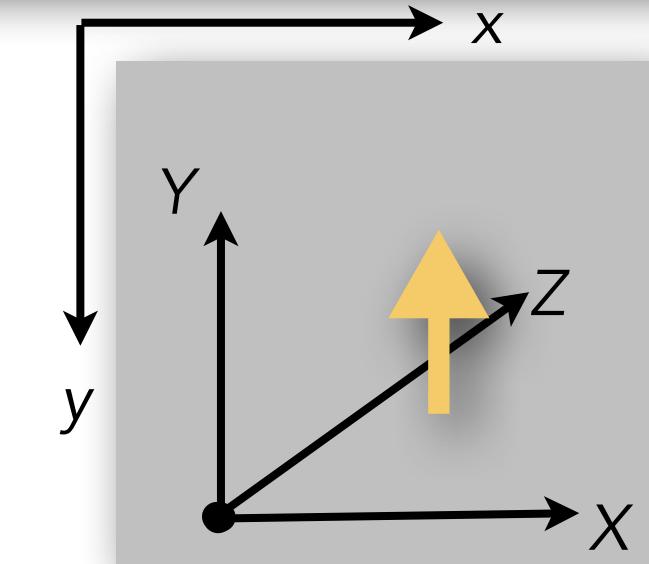
A Camera Model



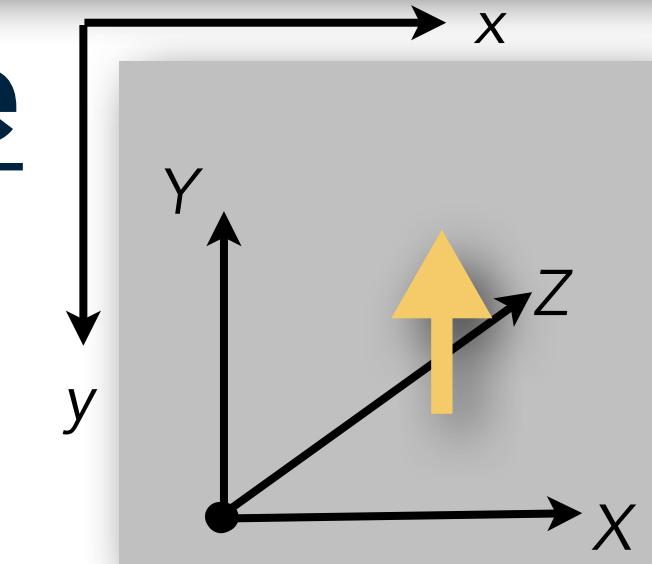
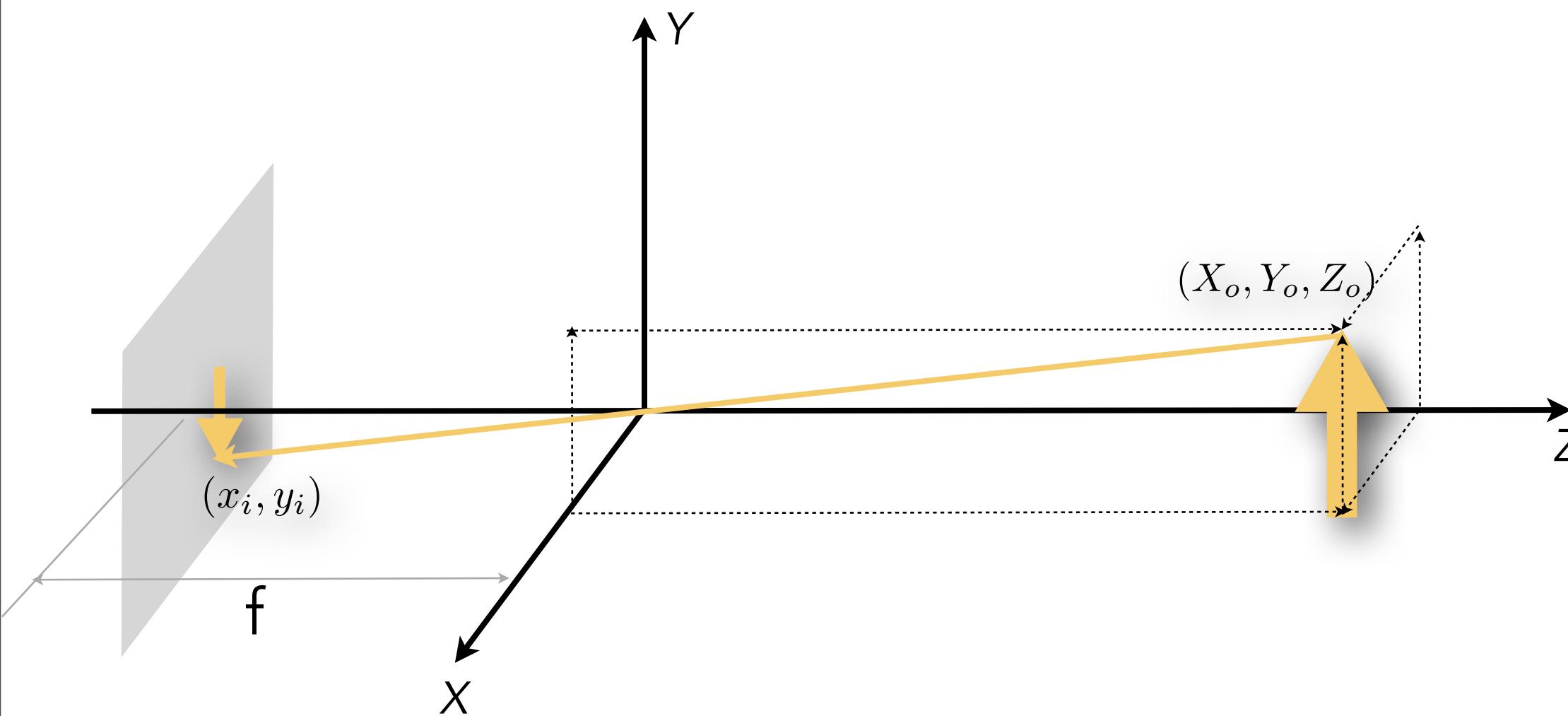
Using similar
triangles

$$\frac{x_i}{f} = \frac{X_o}{Z_o} \rightarrow x_i = \frac{X_o}{Z_o} f$$

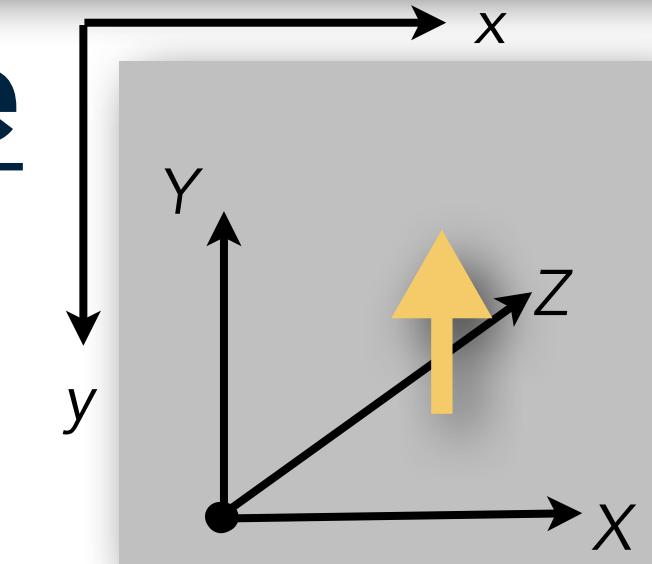
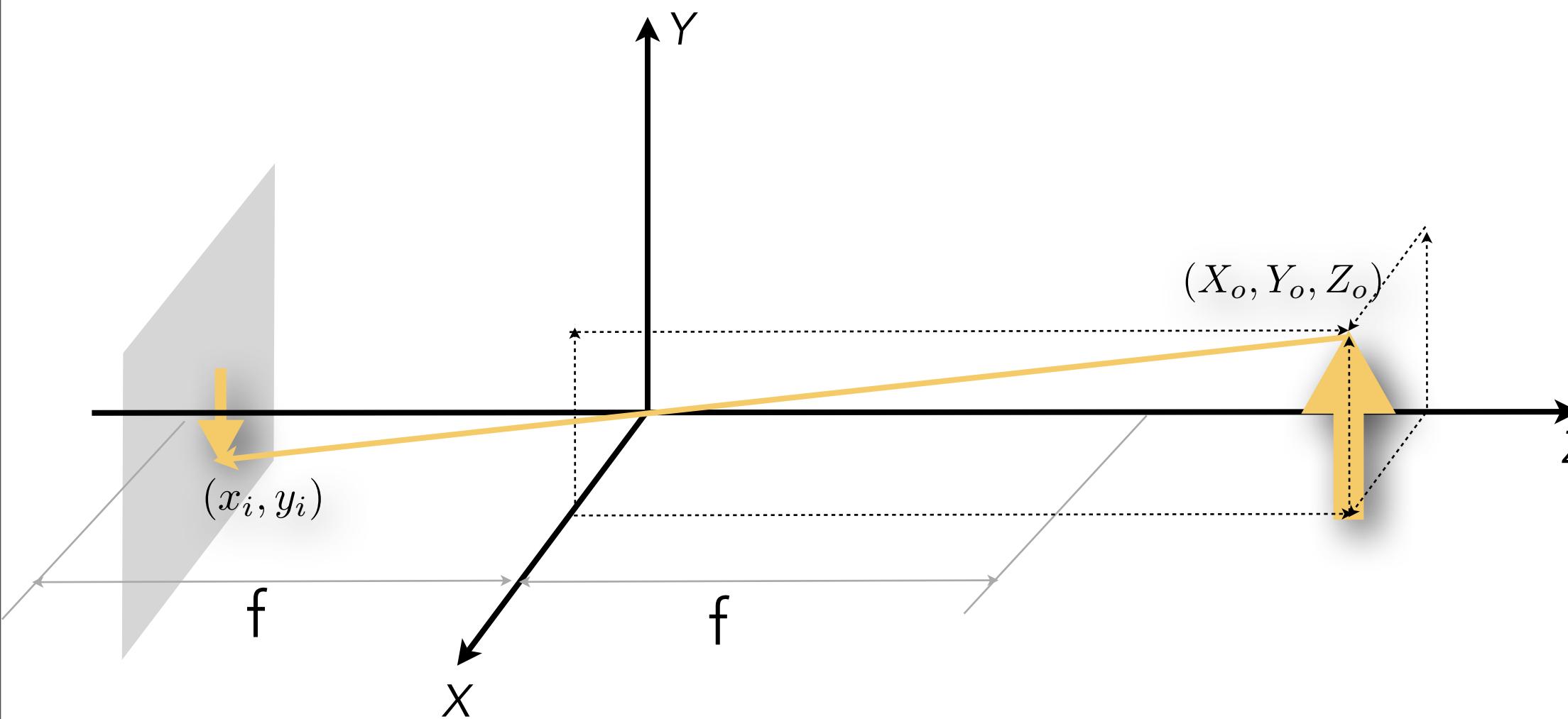
$$\frac{y_i}{f} = \frac{Y_o}{Z_o} \rightarrow y_i = \frac{Y_o}{Z_o} f$$



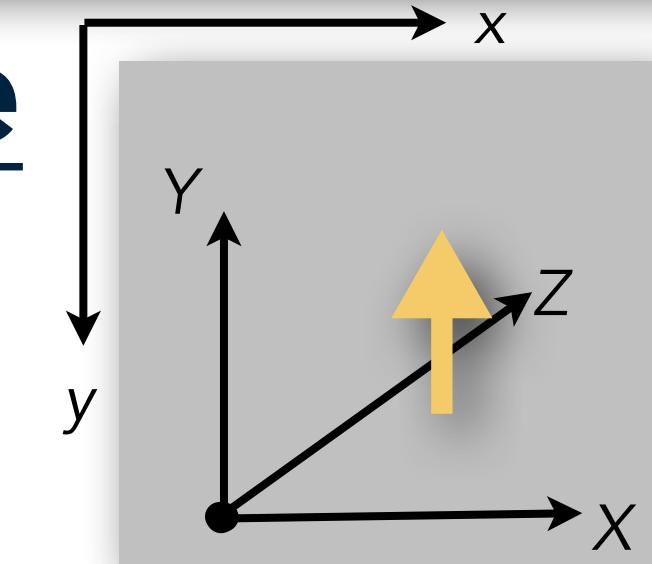
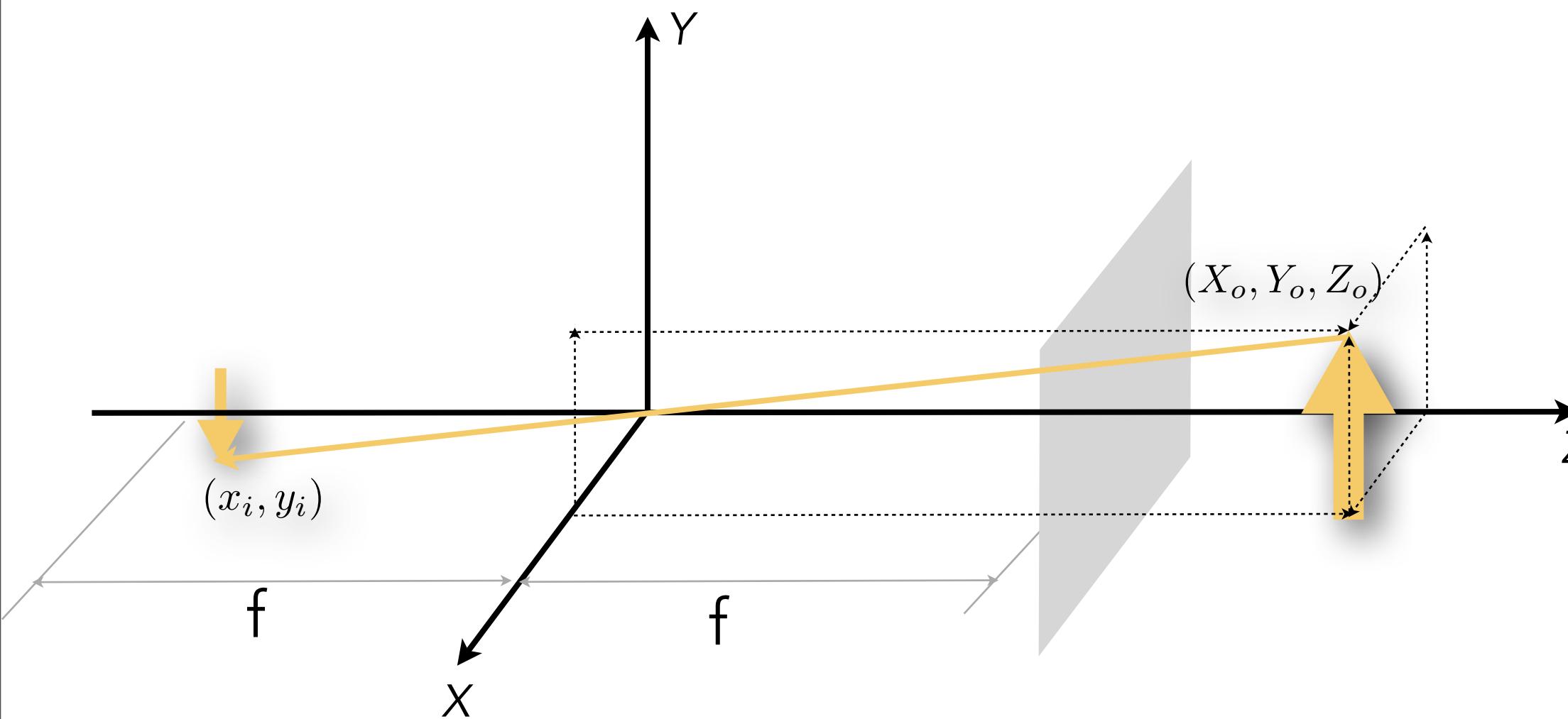
A Camera Model: Perspective



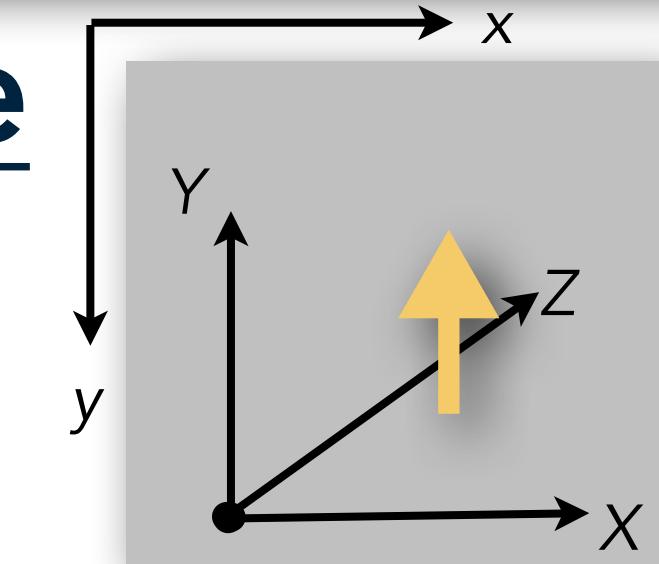
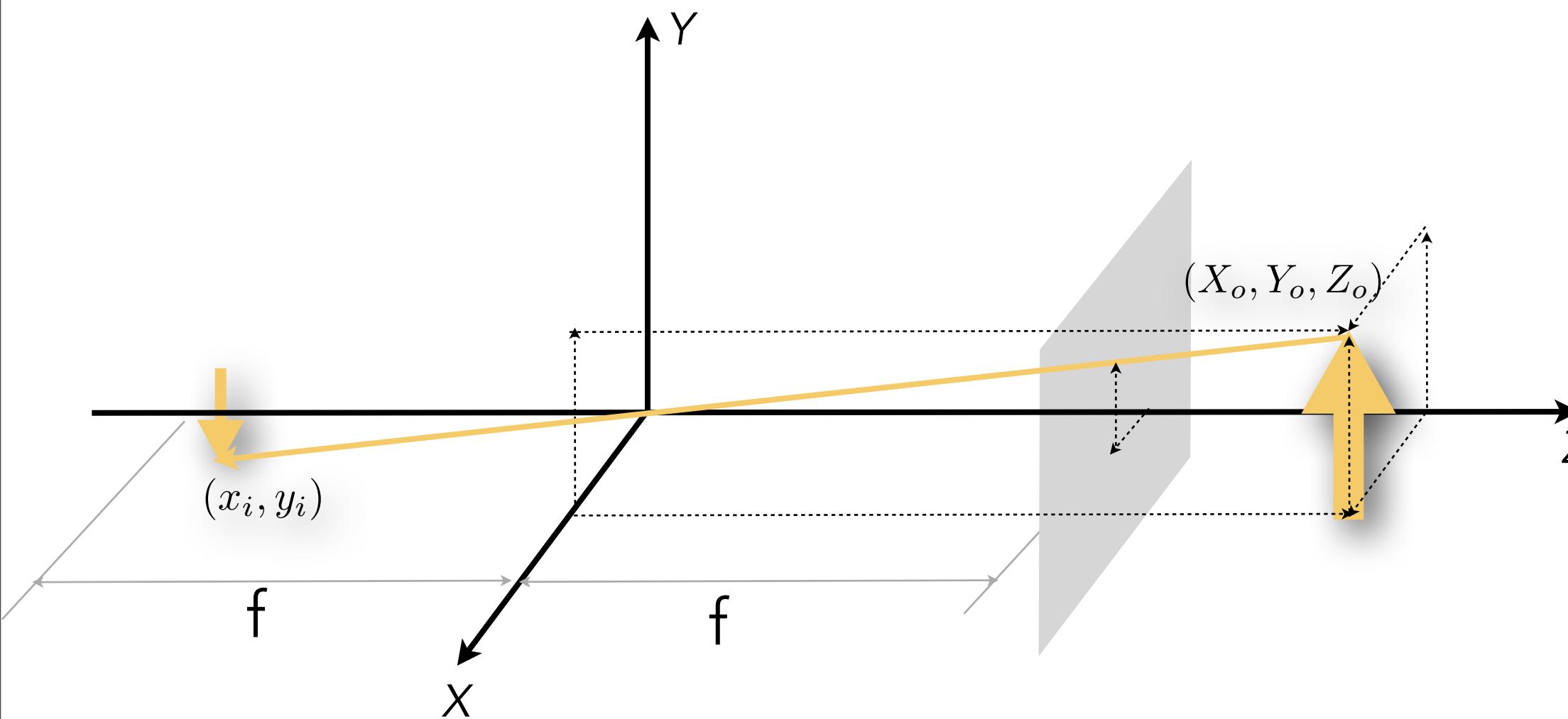
A Camera Model: Perspective



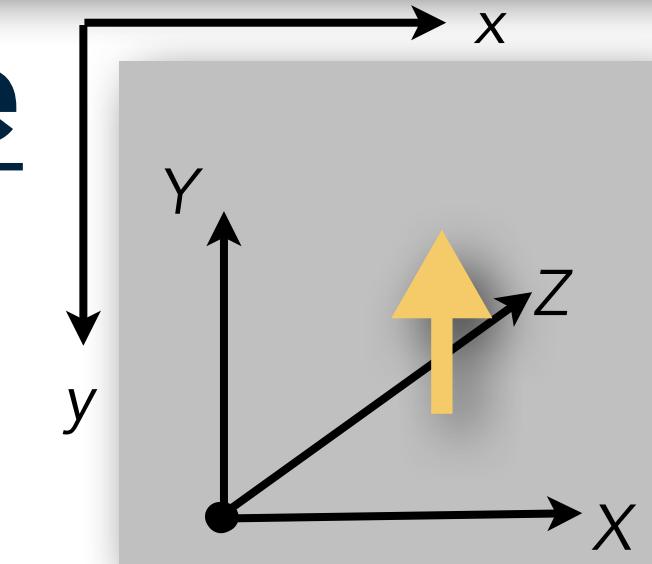
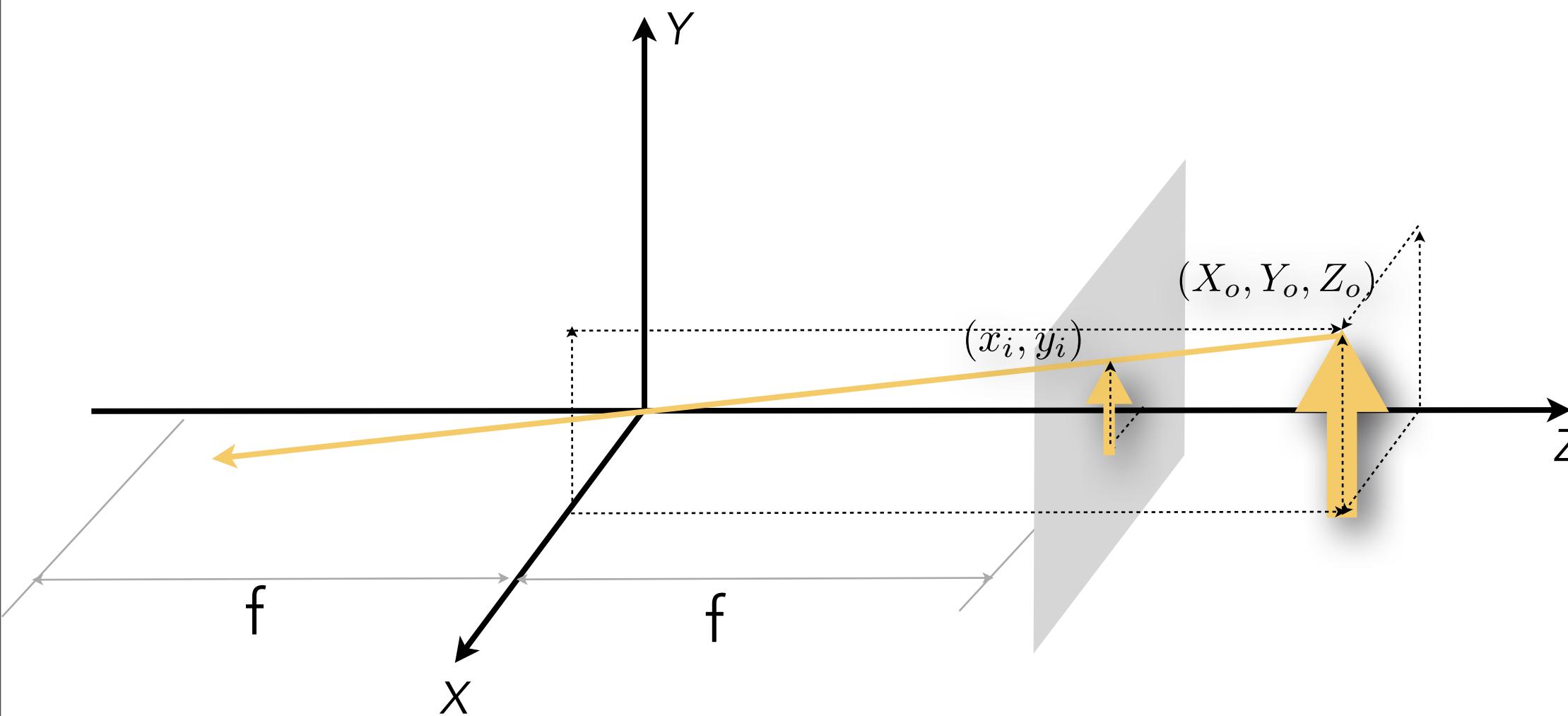
A Camera Model: Perspective



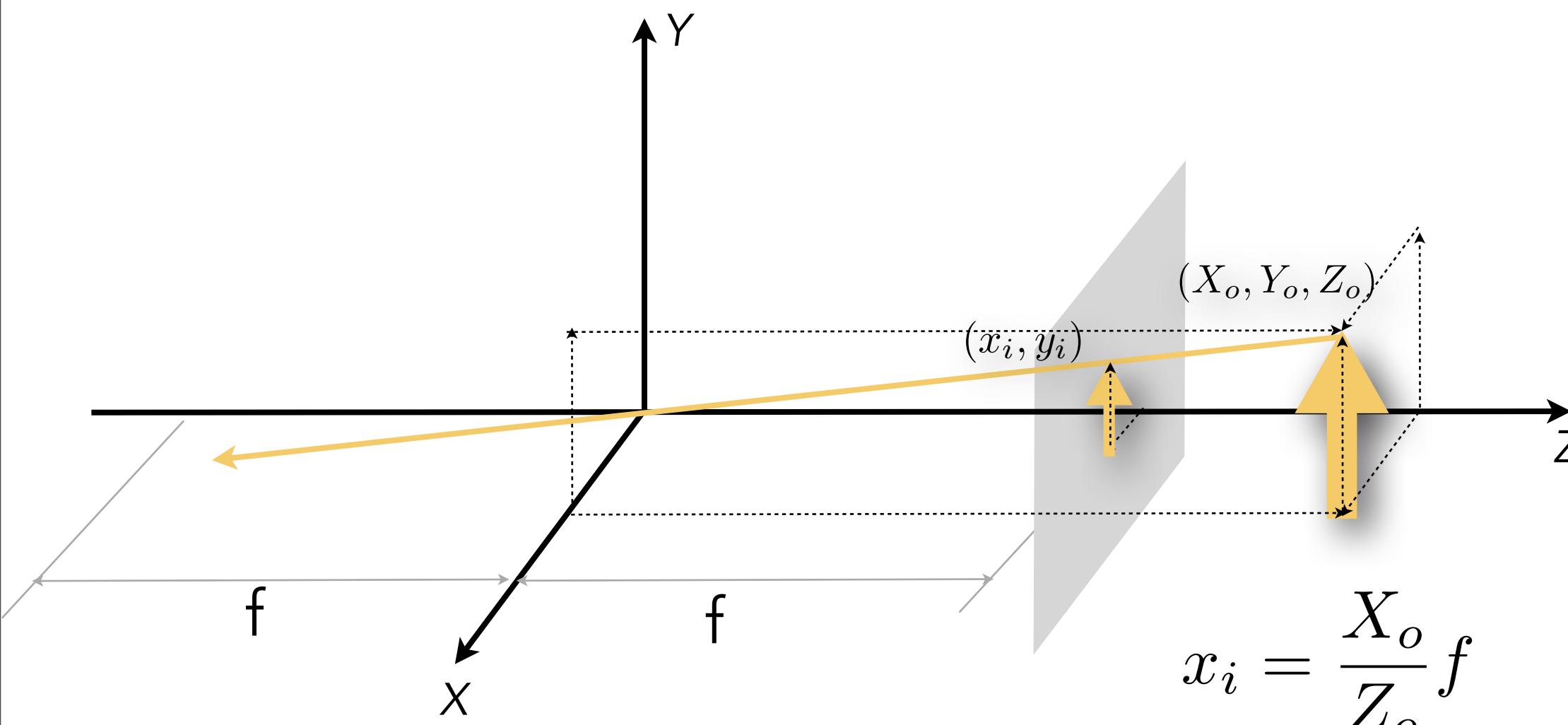
A Camera Model: Perspective



A Camera Model: Perspective

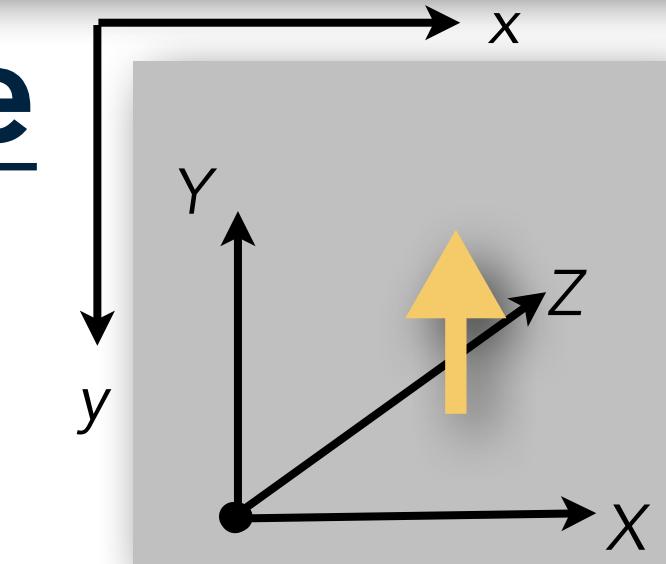


A Camera Model: Perspective



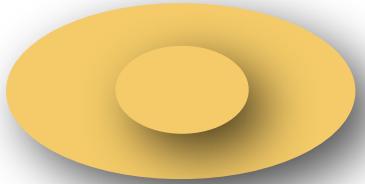
$$x_i = \frac{X_o}{Z_o} f$$

$$y_i = \frac{Y_o}{Z_o} f$$

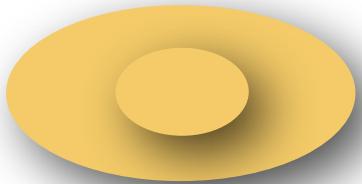


Focal Length for Portraits

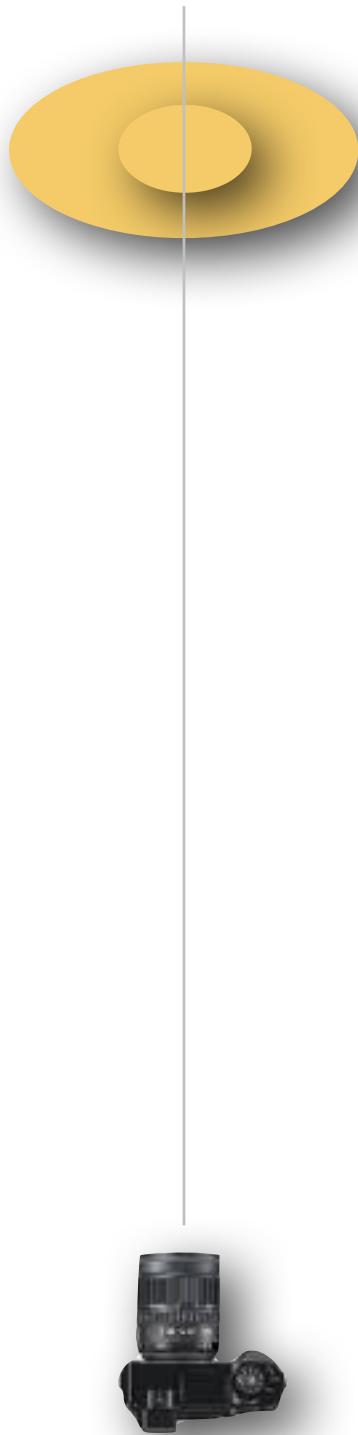
Focal Length for Portraits



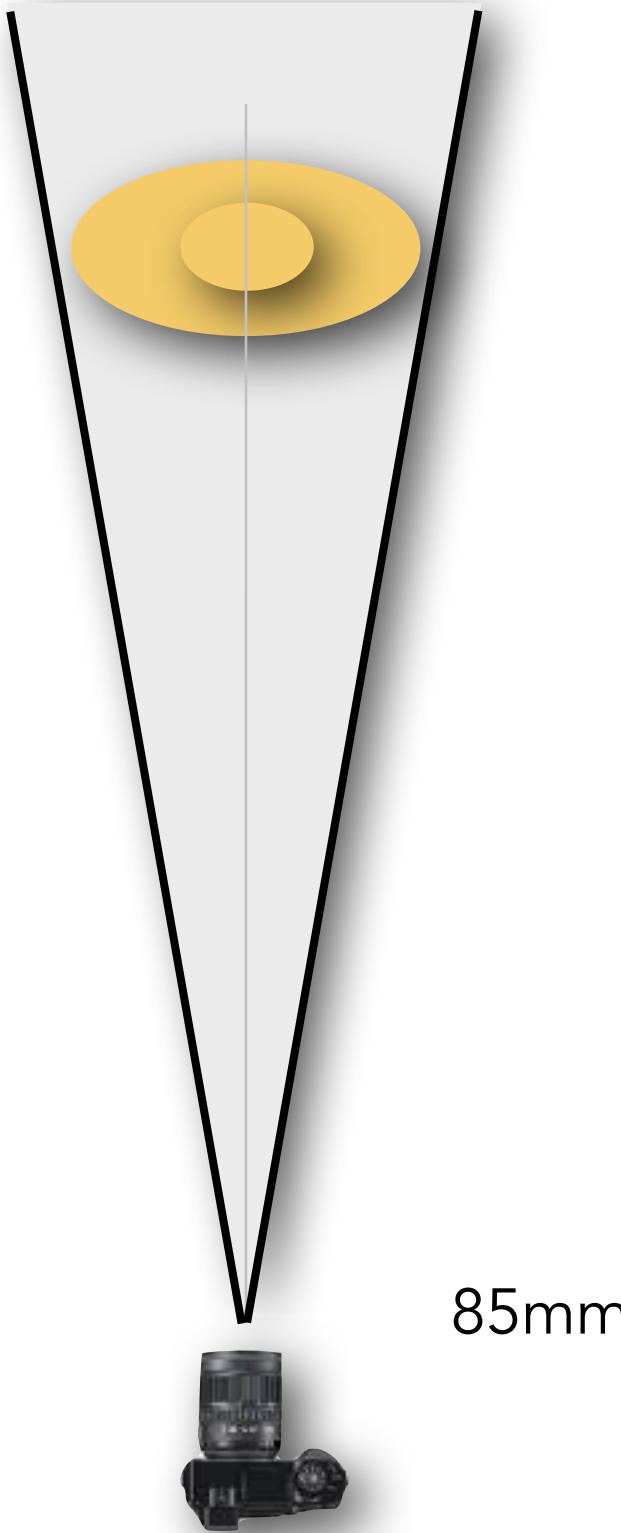
Focal Length for Portraits



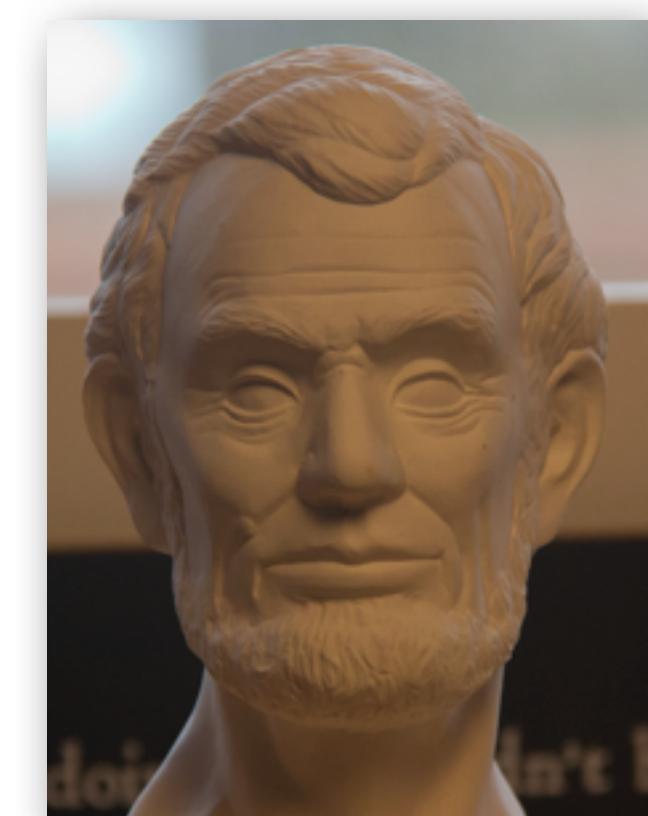
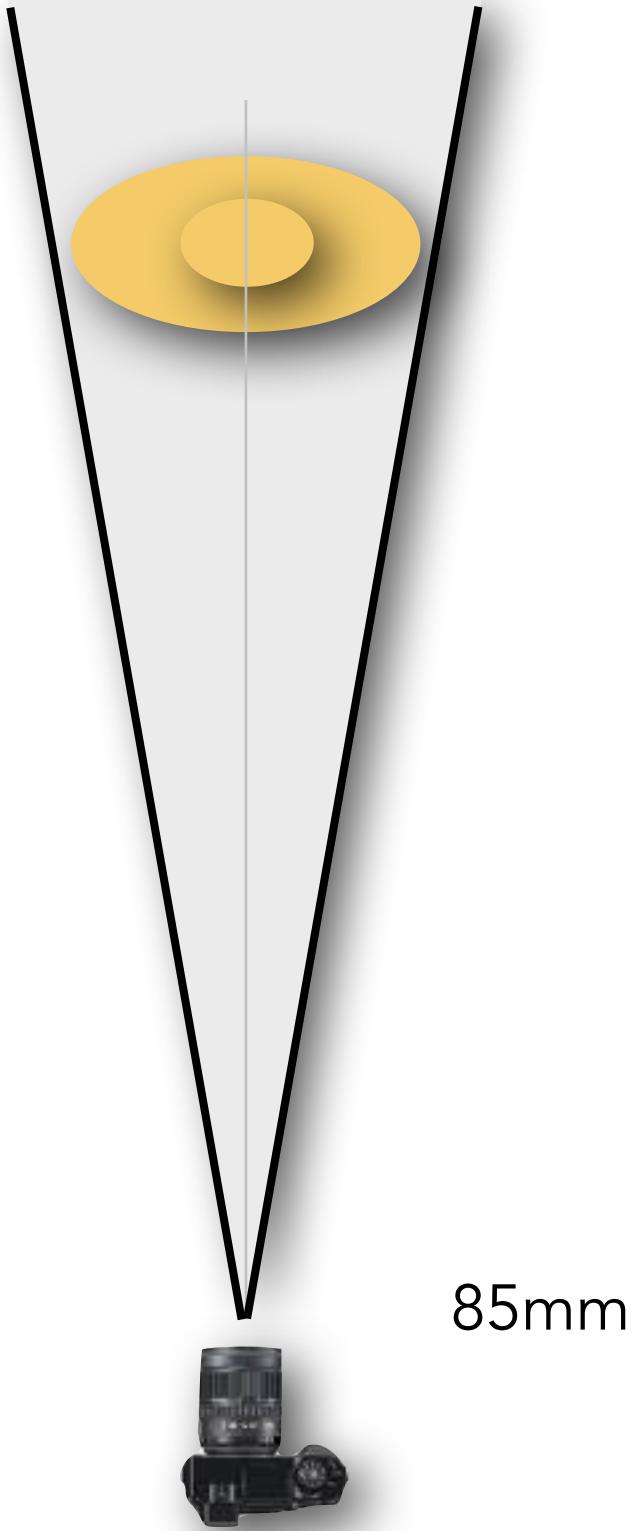
Focal Length for Portraits



Focal Length for Portraits

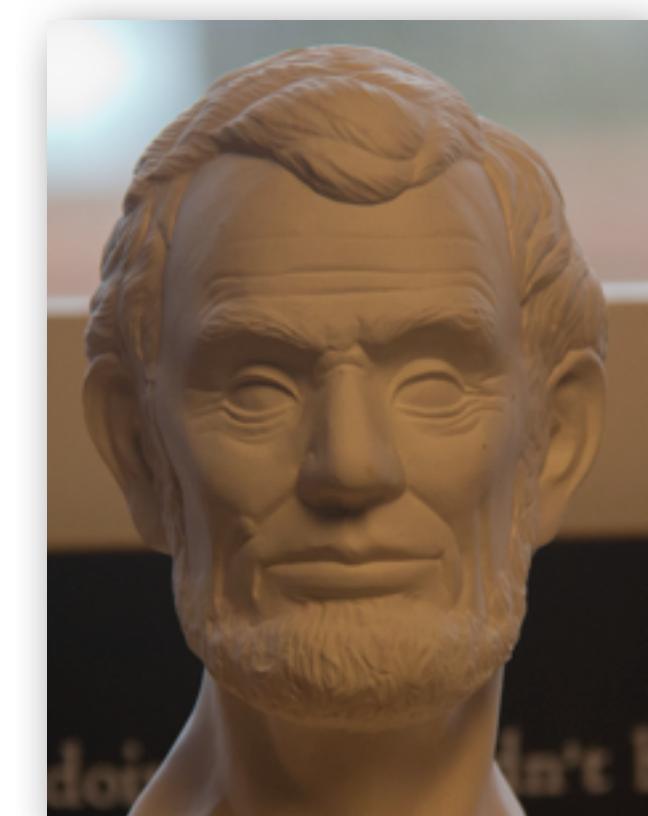


Focal Length for Portraits



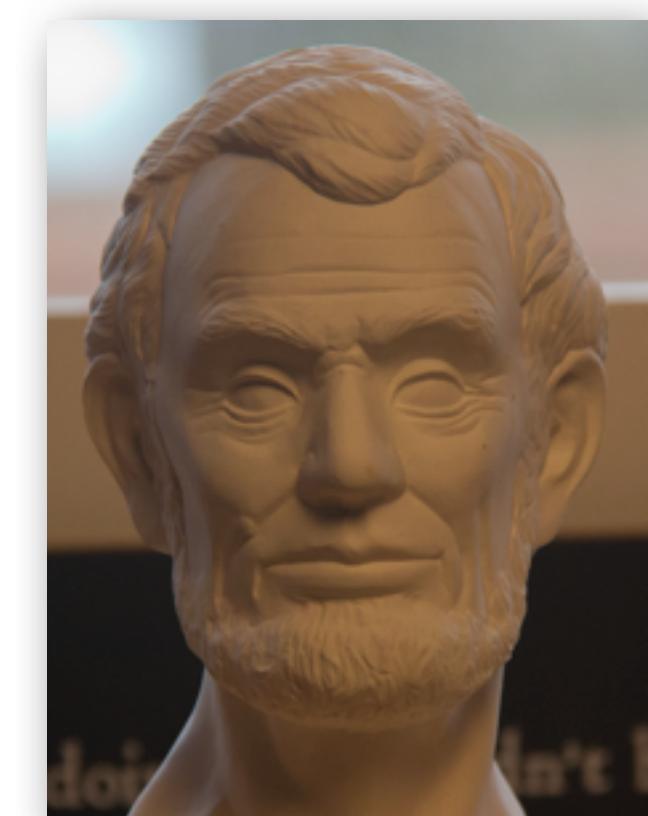
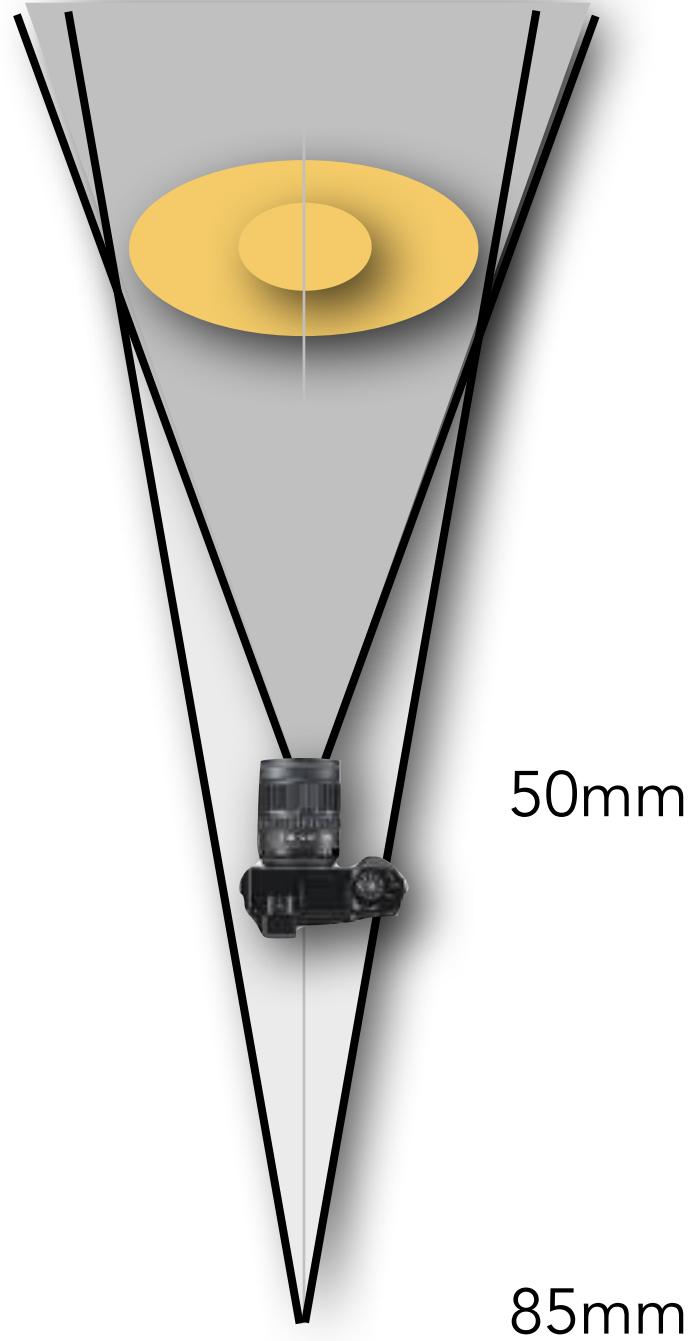
85
mm

Focal Length for Portraits

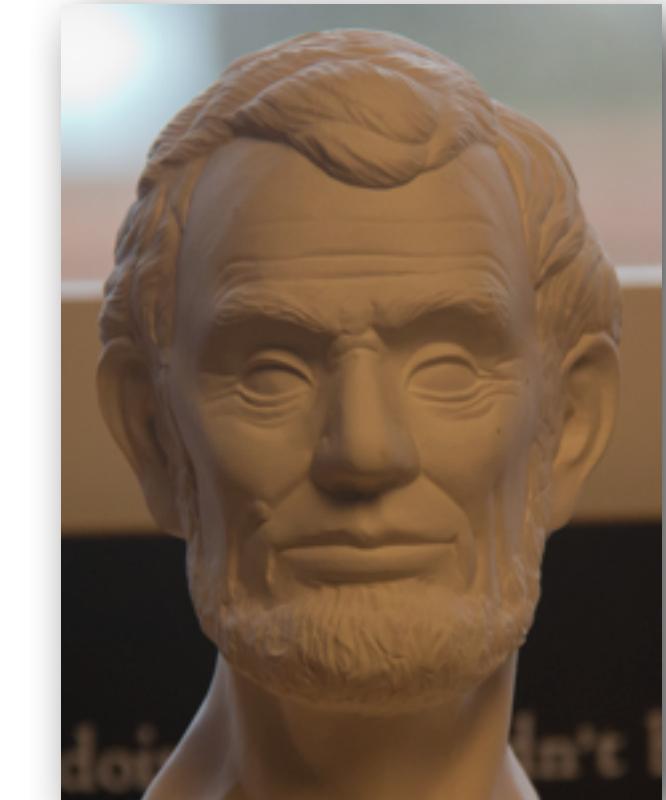
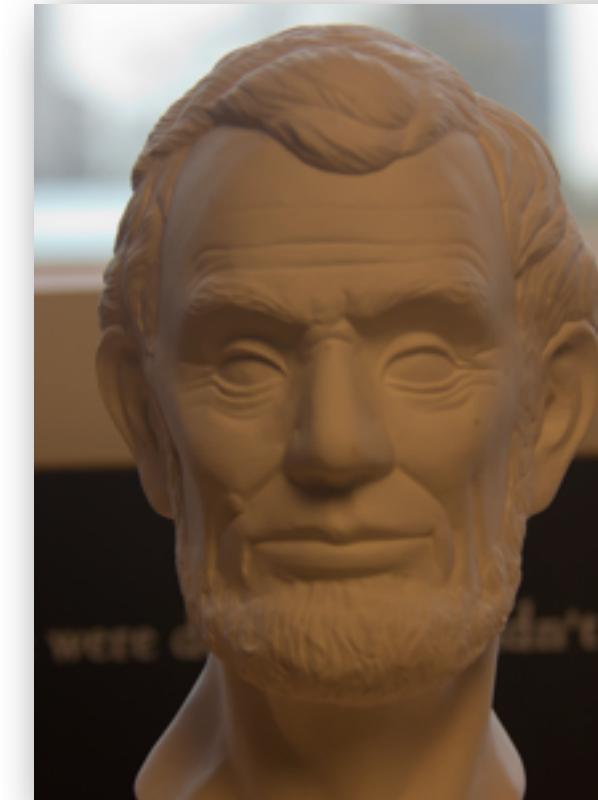
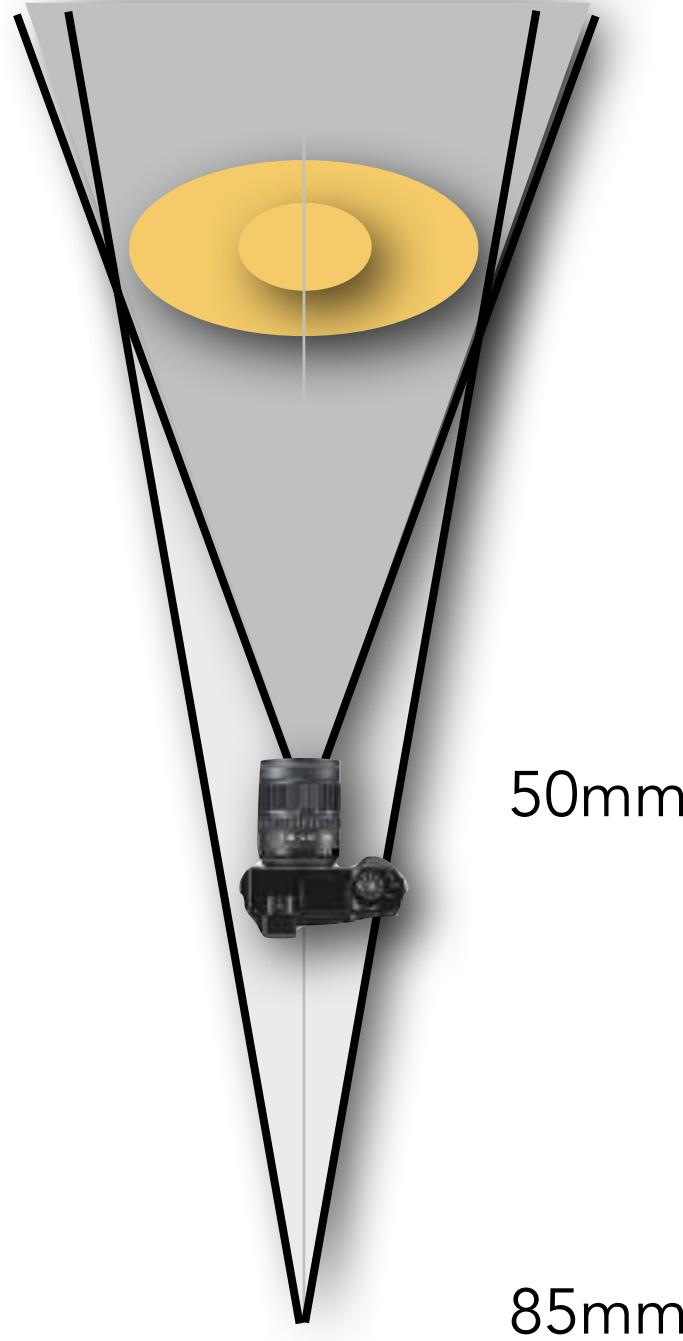


85
mm

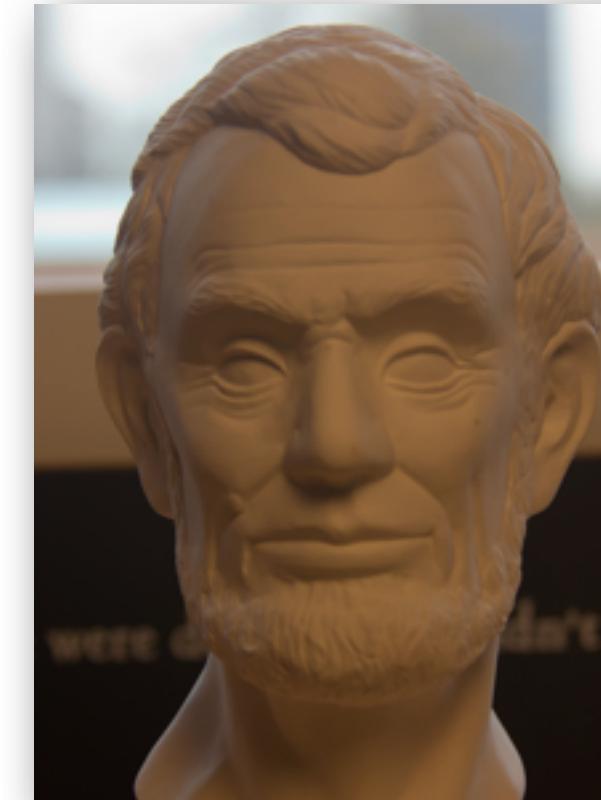
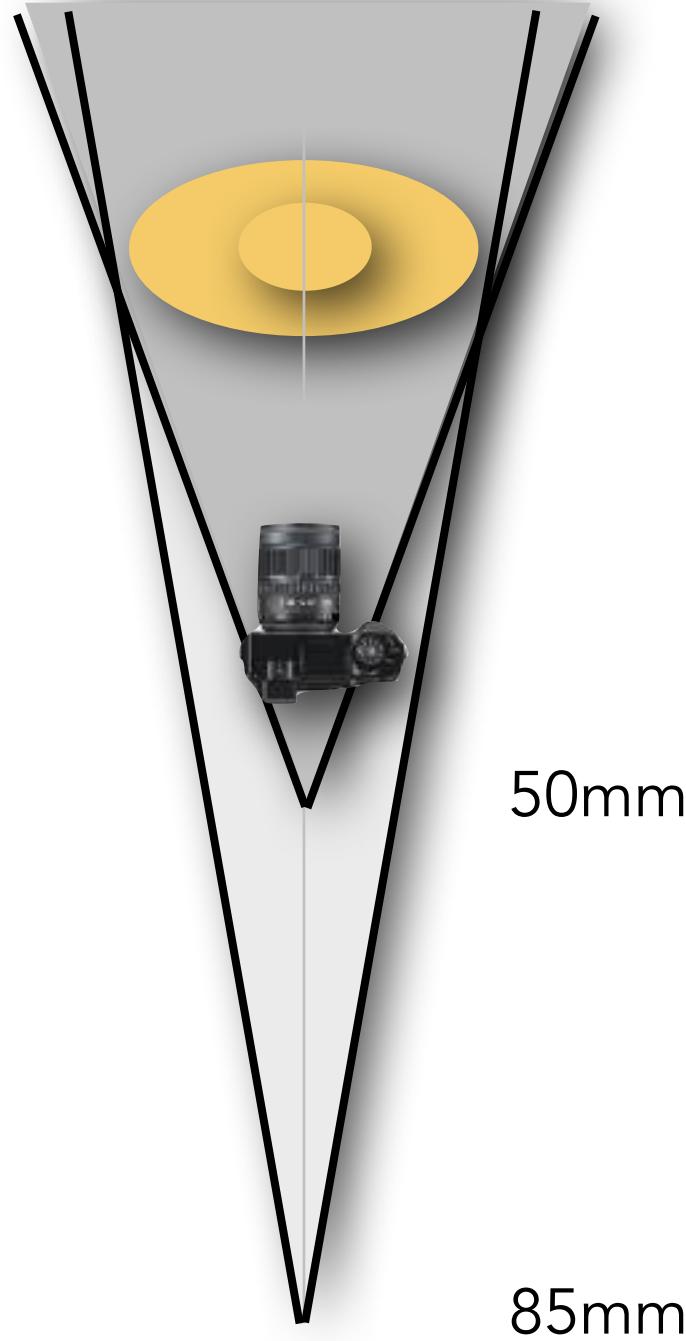
Focal Length for Portraits



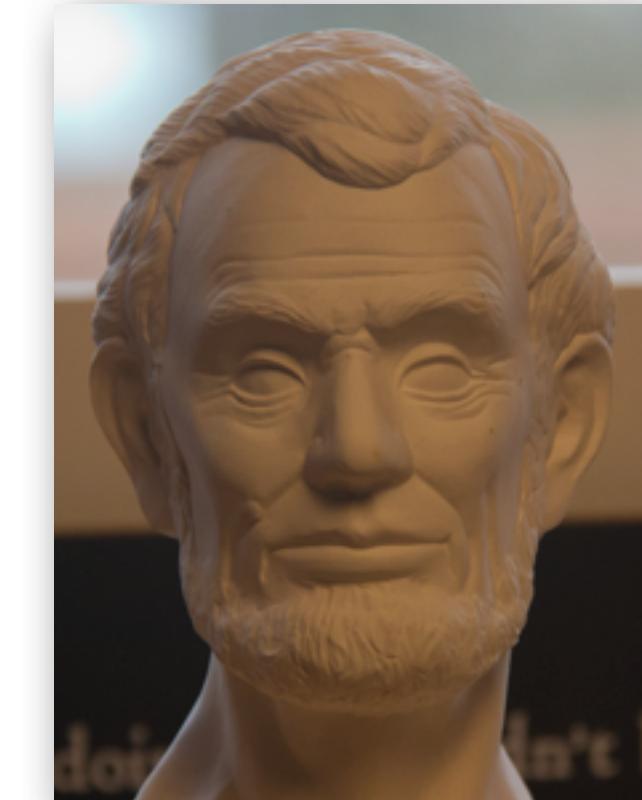
Focal Length for Portraits



Focal Length for Portraits

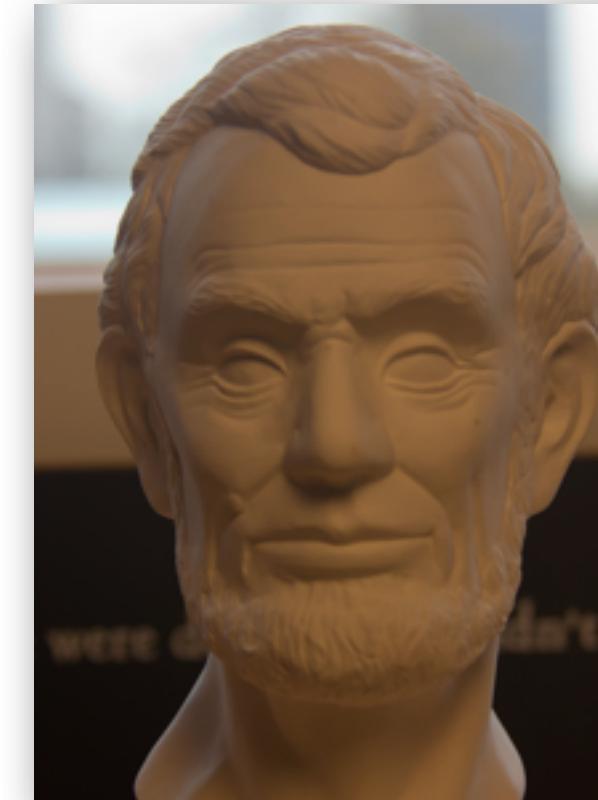
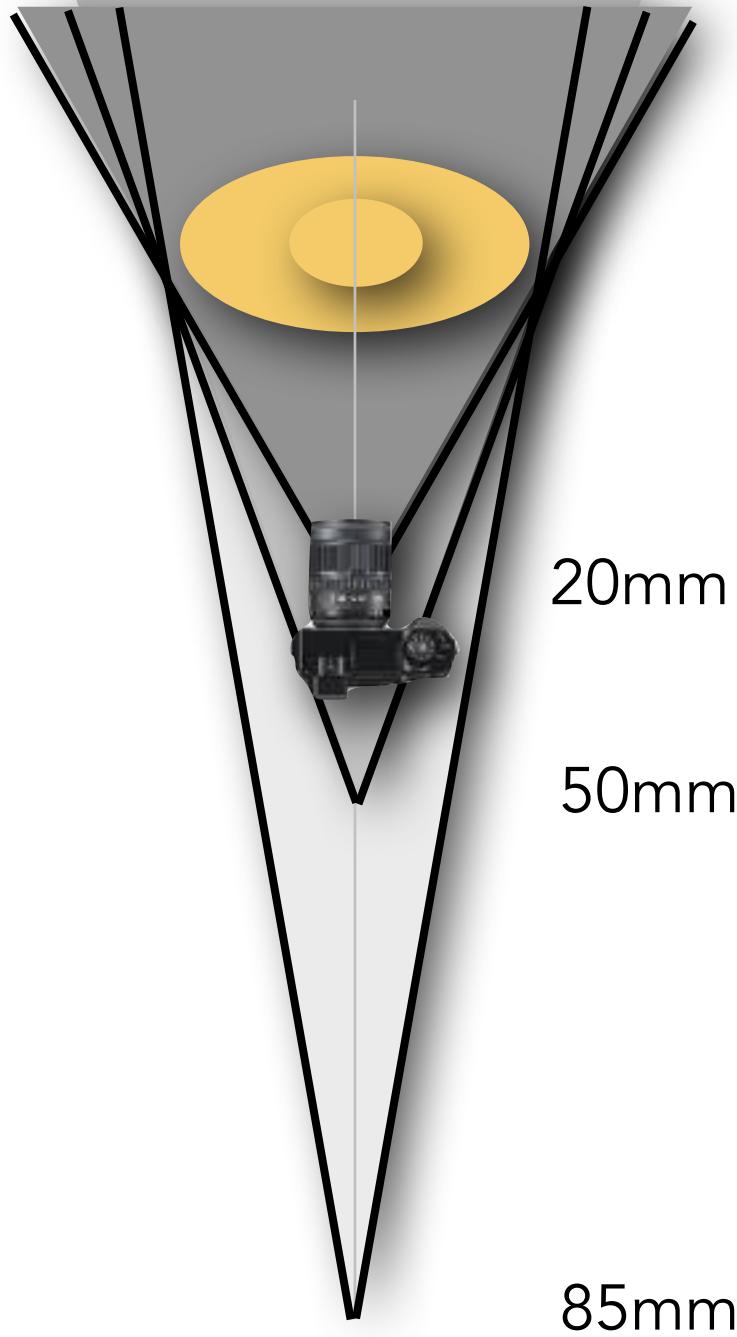


50
mm

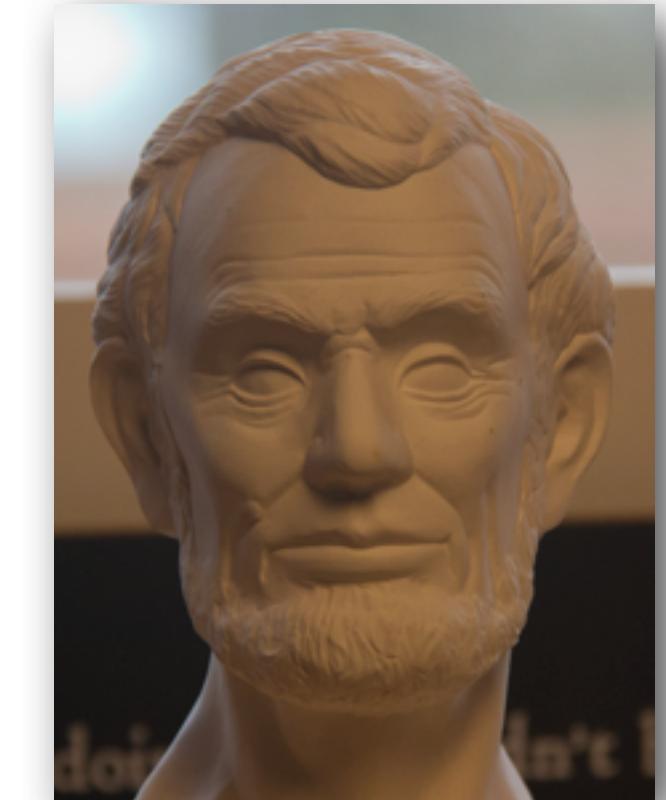


85
mm

Focal Length for Portraits

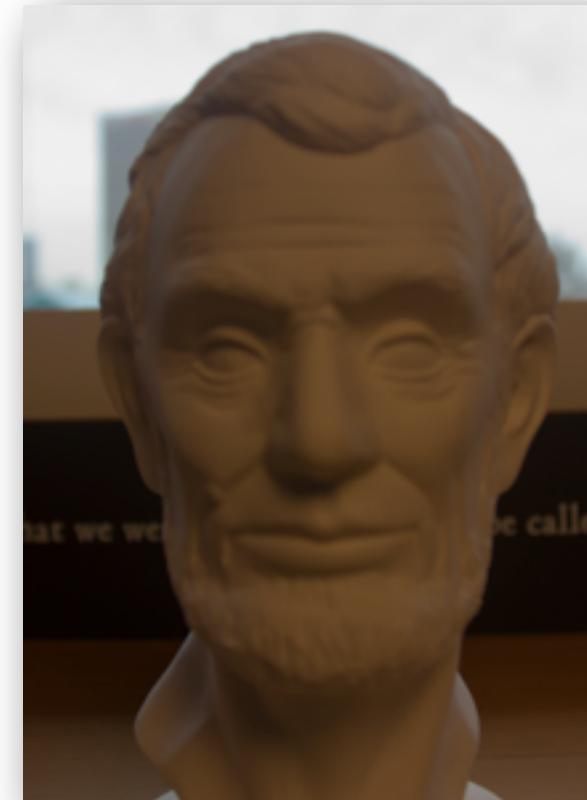
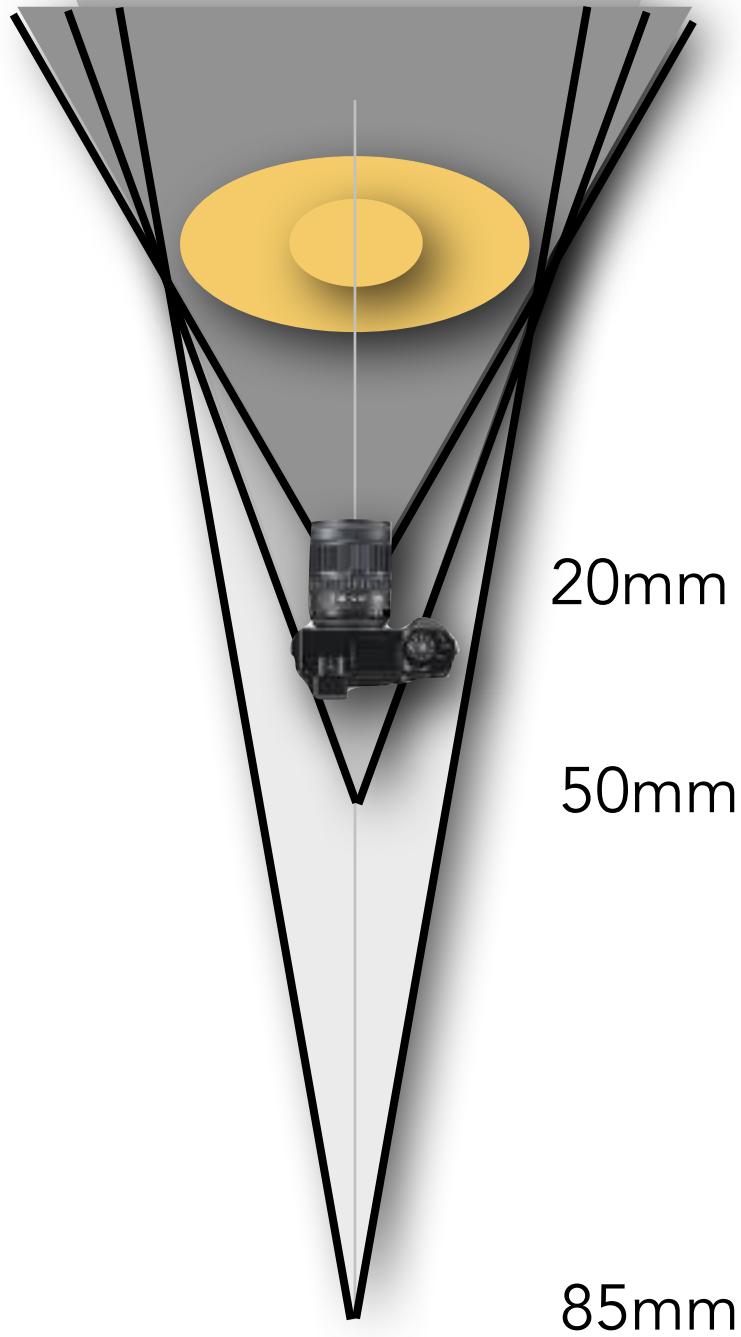


50
mm

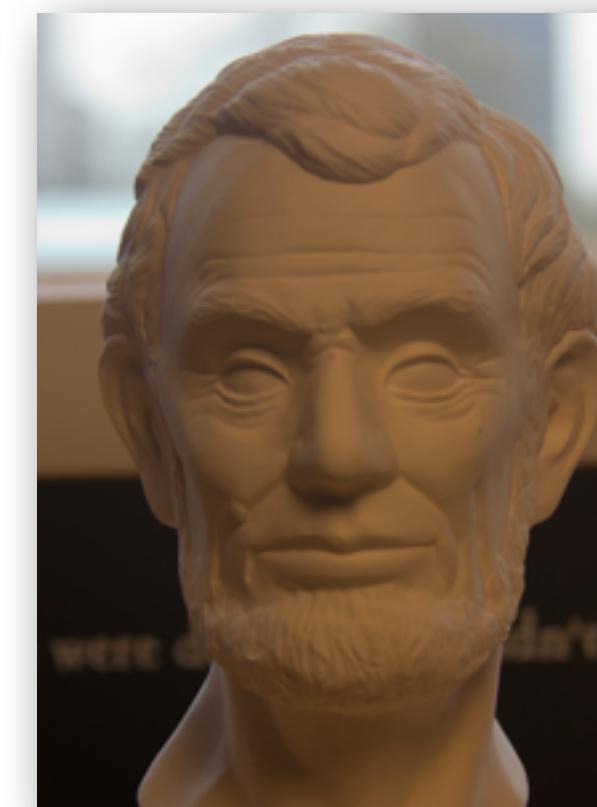


85
mm

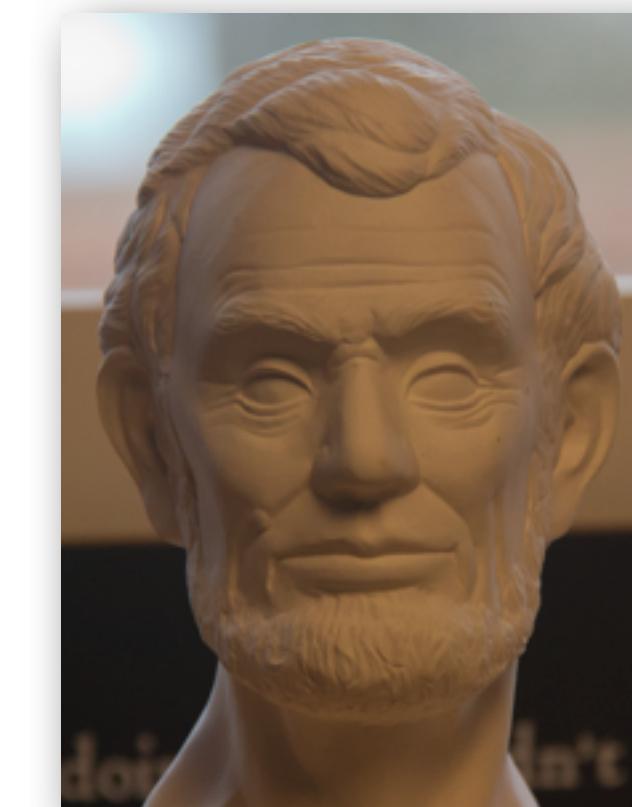
Focal Length for Portraits



20
mm

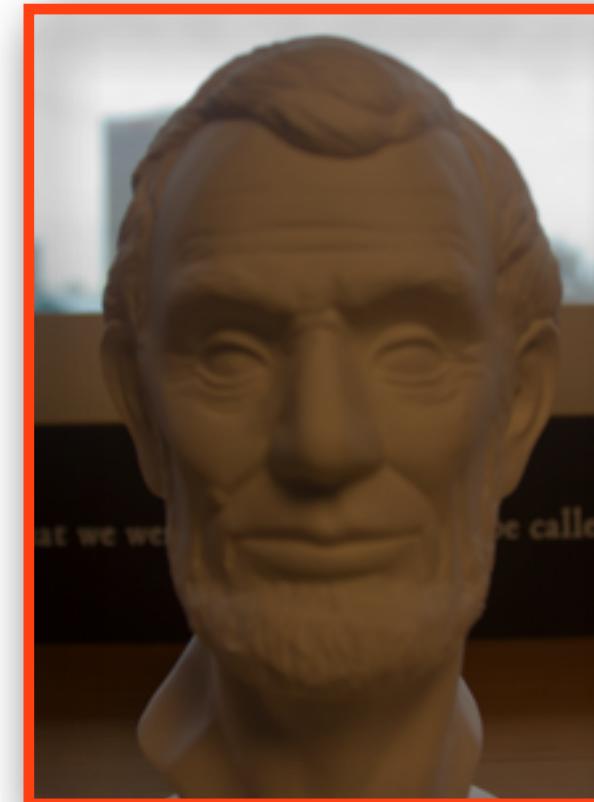
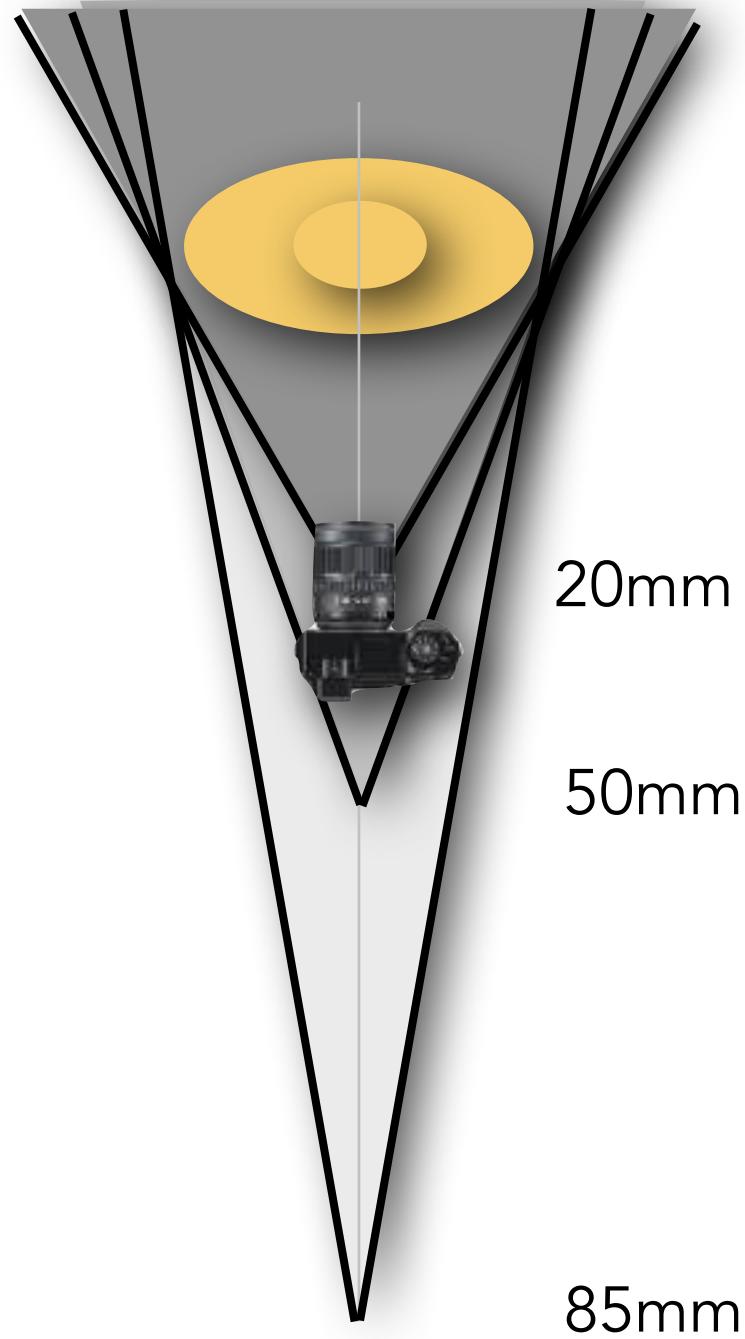


50
mm

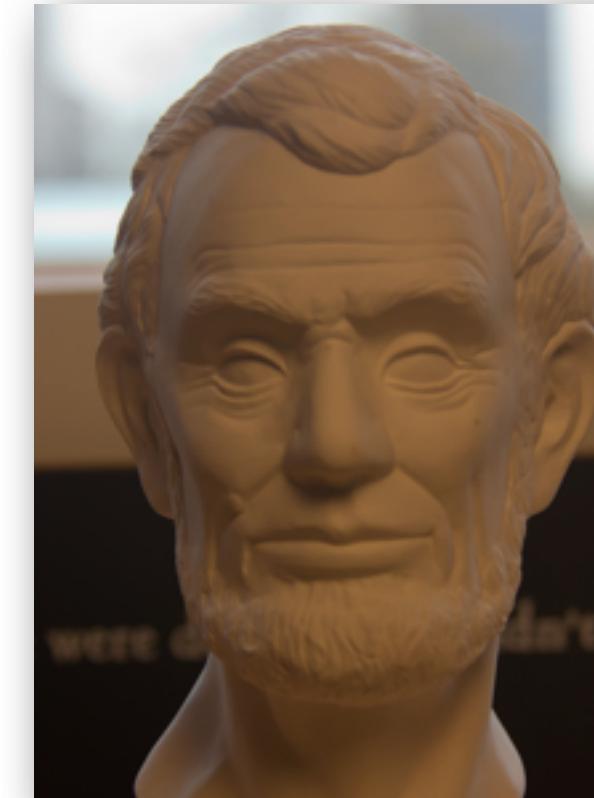


85
mm

Focal Length for Portraits



20
mm

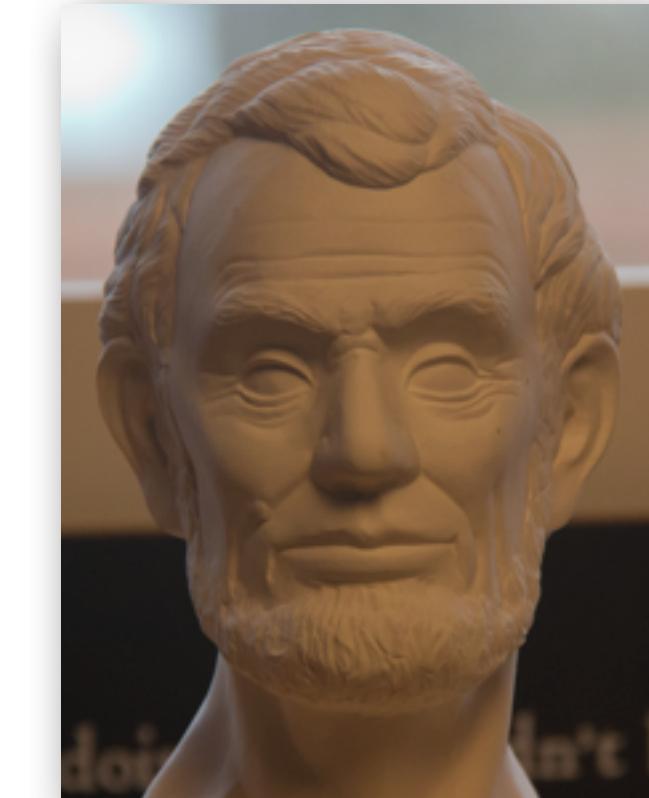
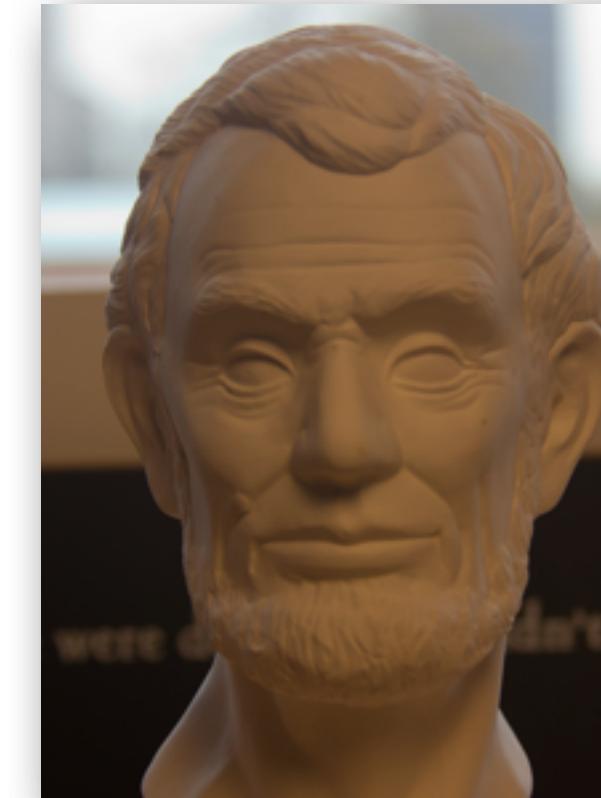
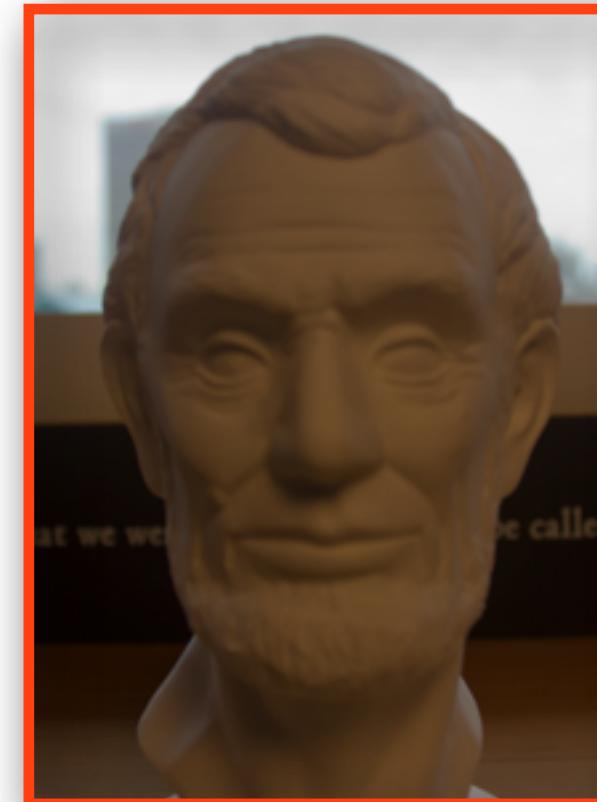
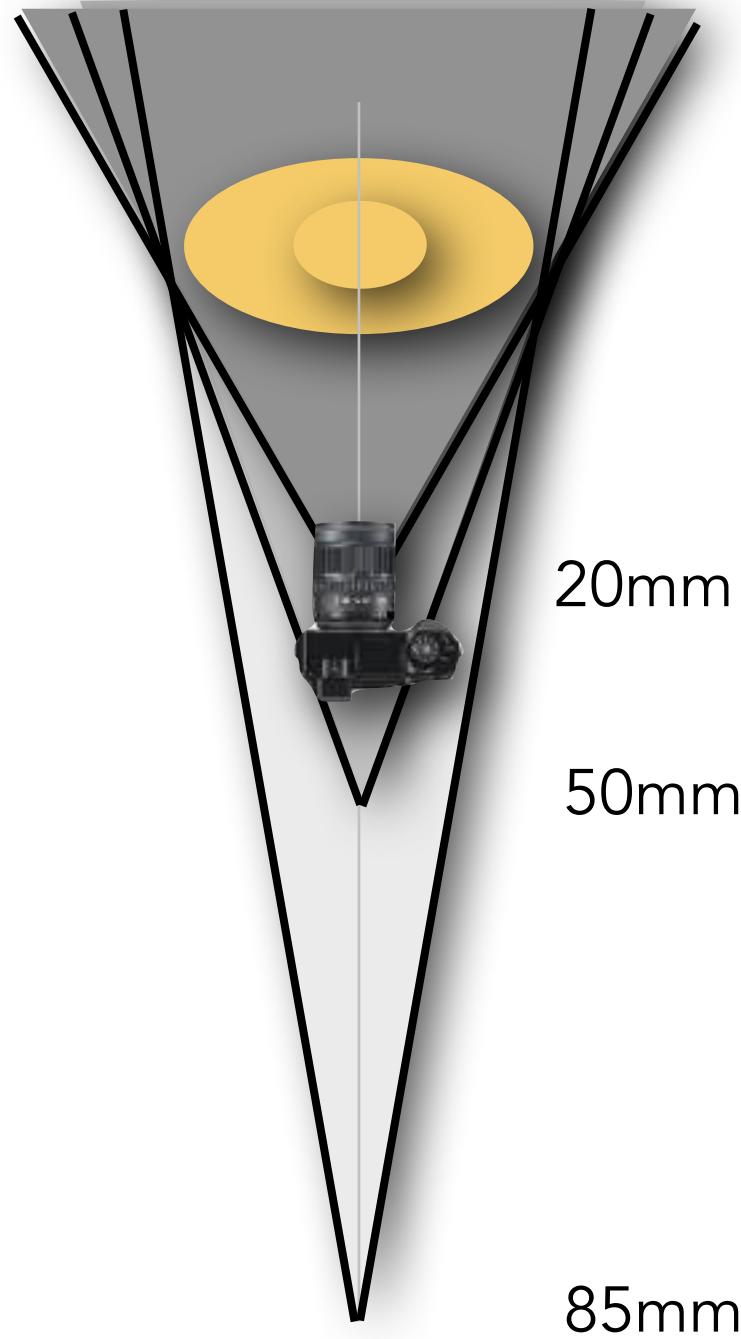


50
mm



85
mm

Focal Length for Portraits



Traditionally, 75-135mm focal length (I prefer 85mm) are used for Portraits

Summary

- ★ Brought together the concepts of Focal Length, FOV and Sensor Size
- ★ Discussed the impact of Focal Length on Image Formation/ Capture
- ★ Explained Perspective Projection for a camera with a Focal Length



Next Class

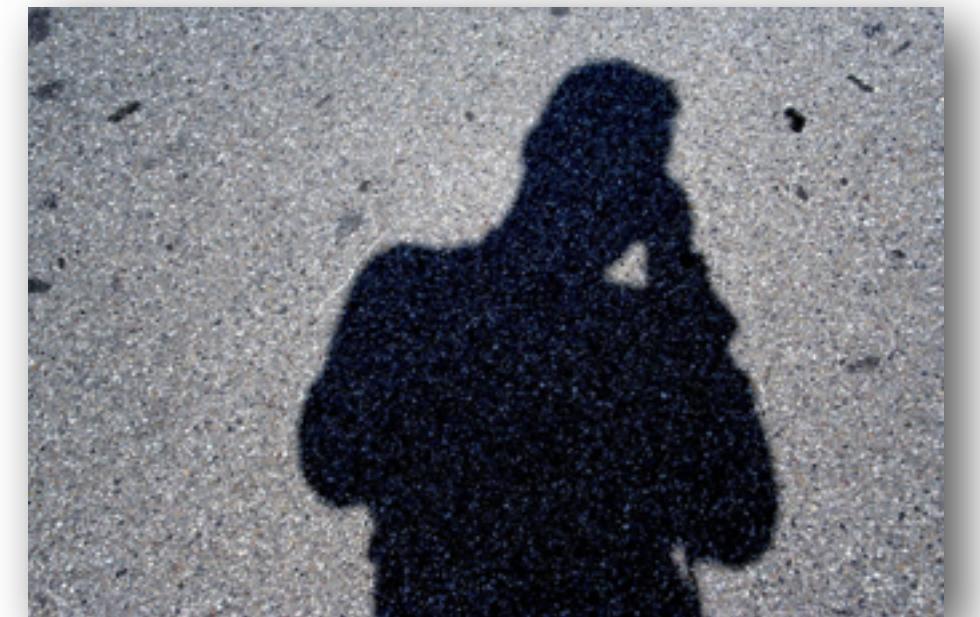
★ Camera

- Exposure Triangle
- Aperture
- Shutter Speed
- ISO



Credits

- ★ For more information, see
 - Hecht, E. (2002) *Optics*, 4th ed. Reading, MA: Addison-Wesley and
 - London, B., Stone, J., & Upton, J. (2011), *Photography*, 10th ed. Upper Saddle River, NJ: Prentice Hall.
- ★ Some images retrieved from
 - <http://commons.wikimedia.org/>.
 - List available on website.
- ★ Some Slides adapted from Mark Levoy.
- ★ Photos by Henrik Christensen and 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.