

Computational Photography



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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: Pinhole Camera and Optics



Lesson Objectives

- ★ Explain in your own words the practical aspects of how rays are converted to pixels.
- ★ Describe in your own words the concept of a camera without optics.
- ★ Recall at least two (2) advantages of adding a lens to the camera system.
- ★ Write the Lens Equation including the distance to the object, distance to the image, and focal length of a lens.

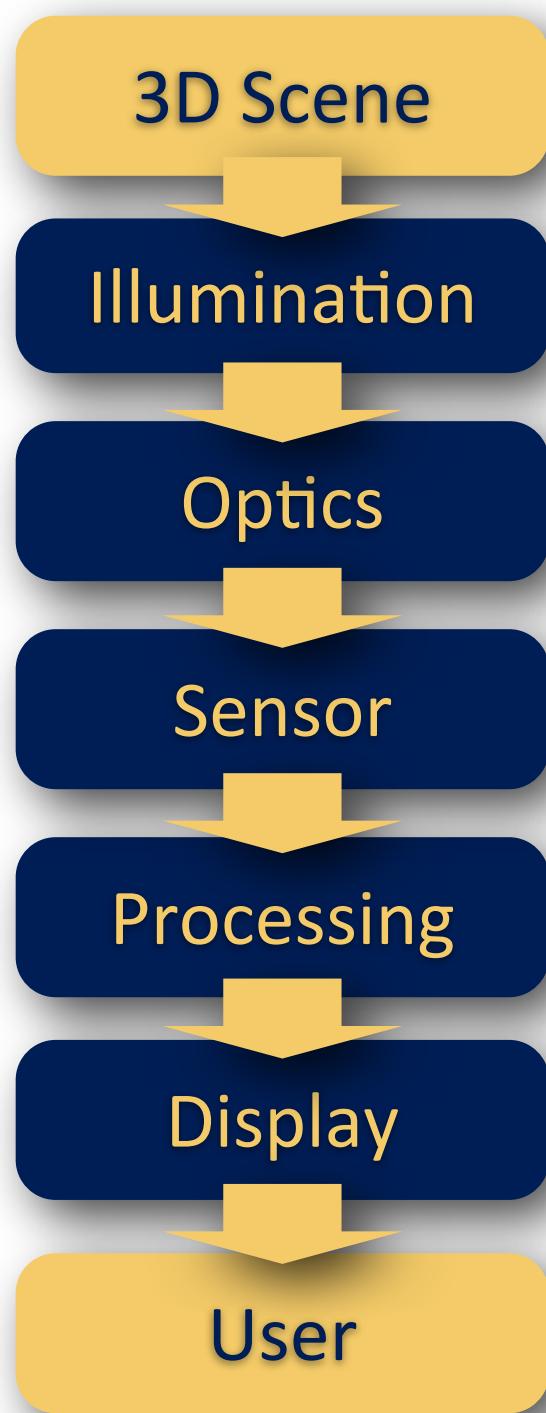




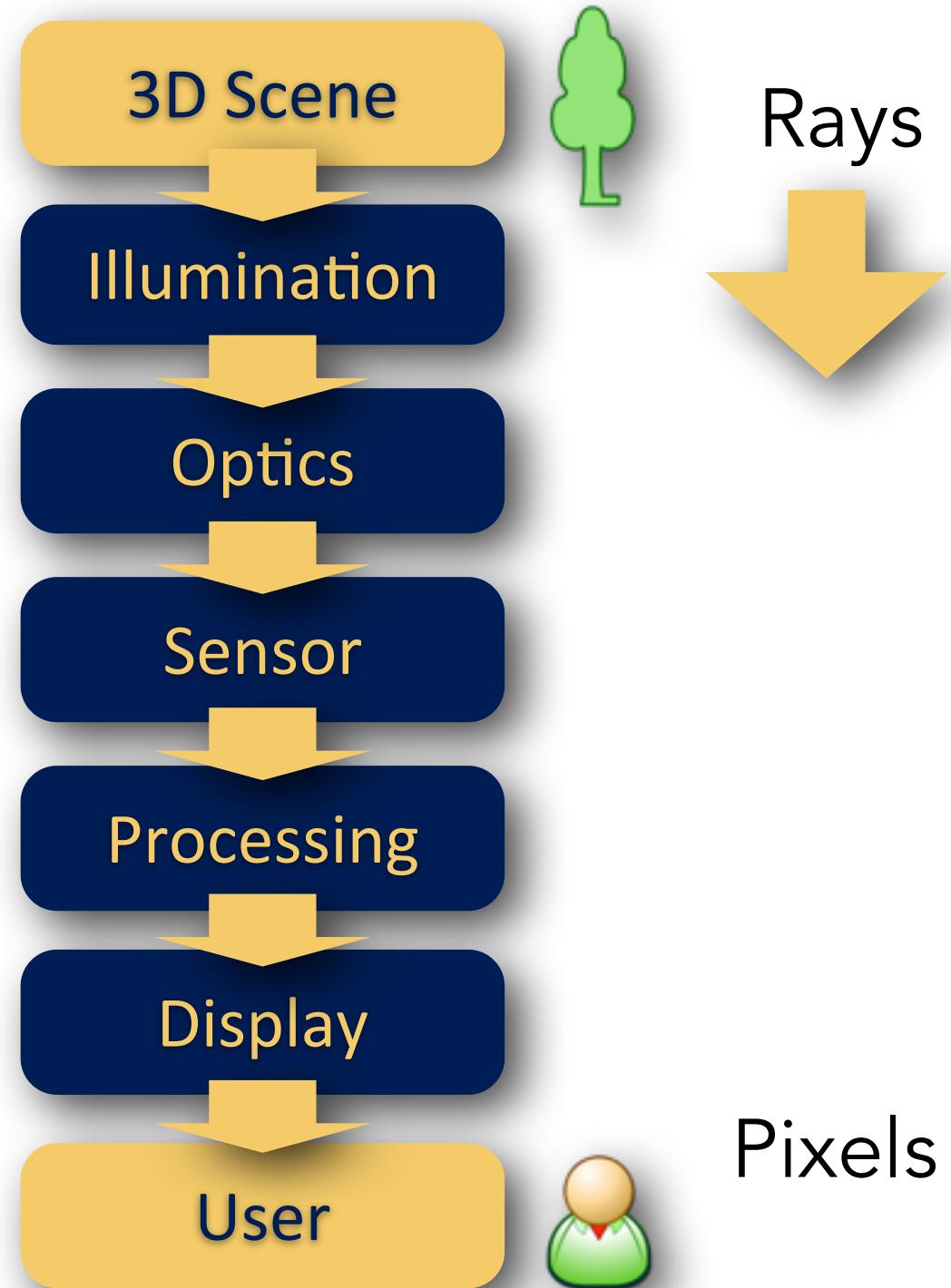
Review: Context of Computational Photography



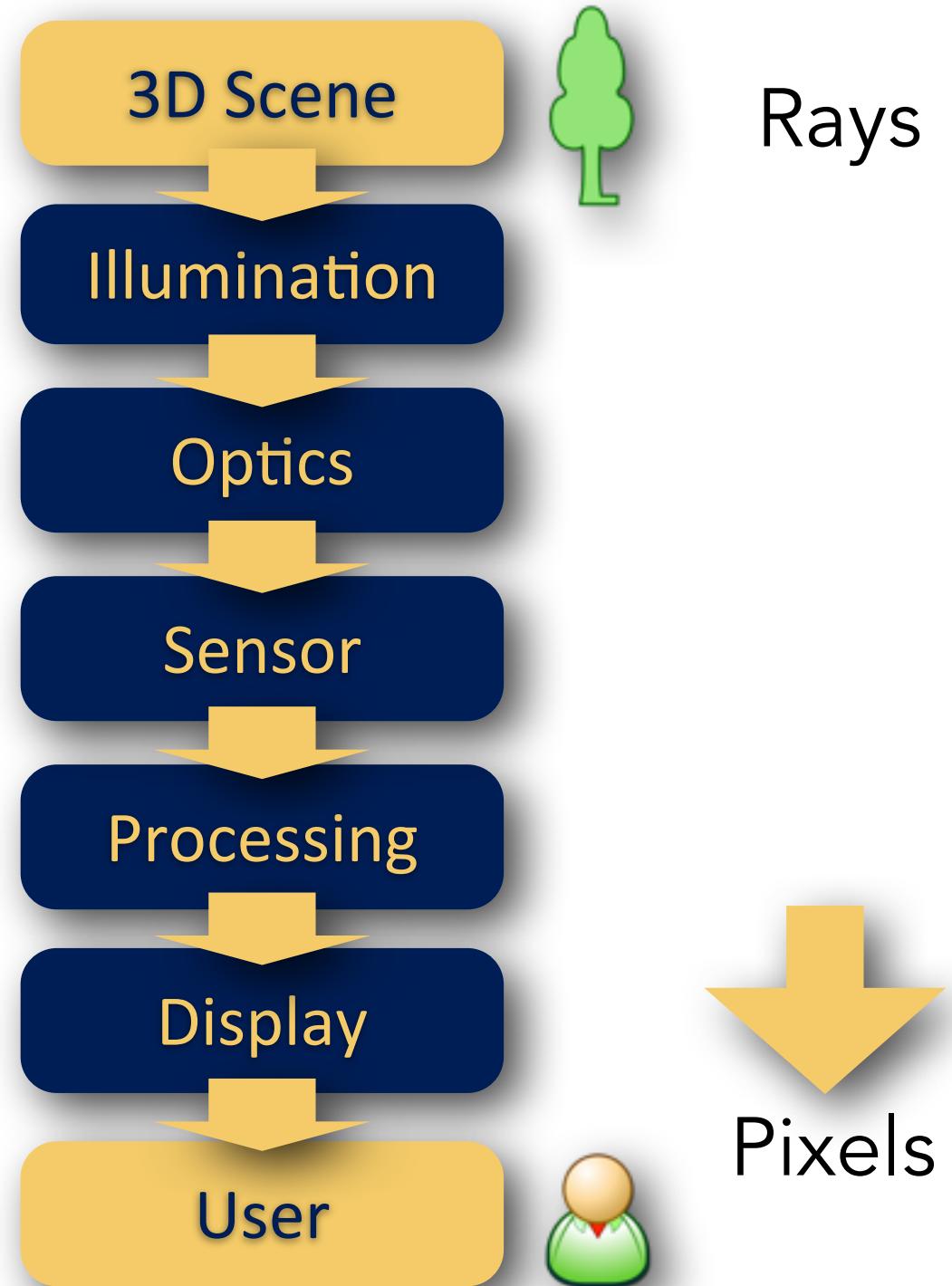
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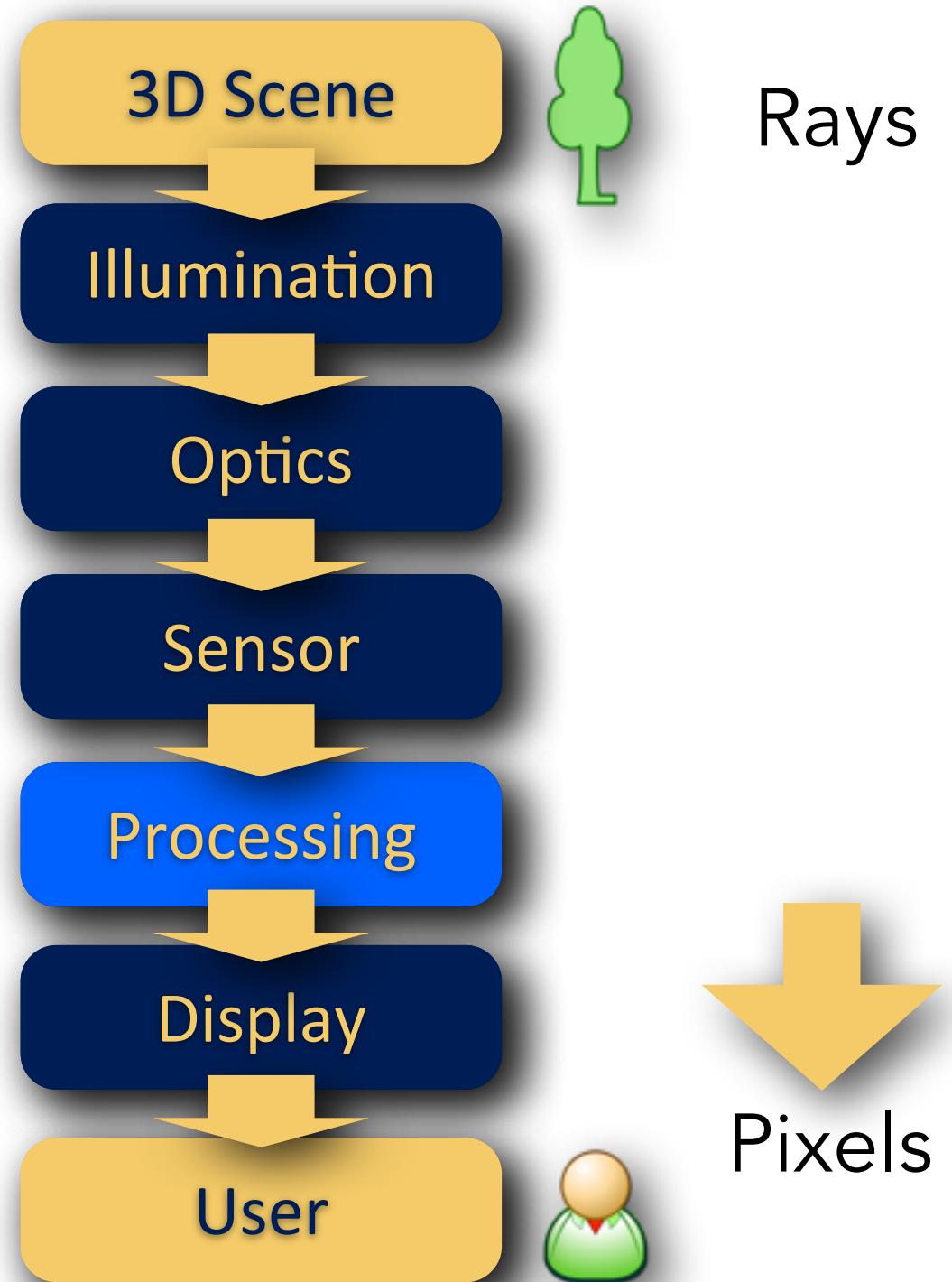
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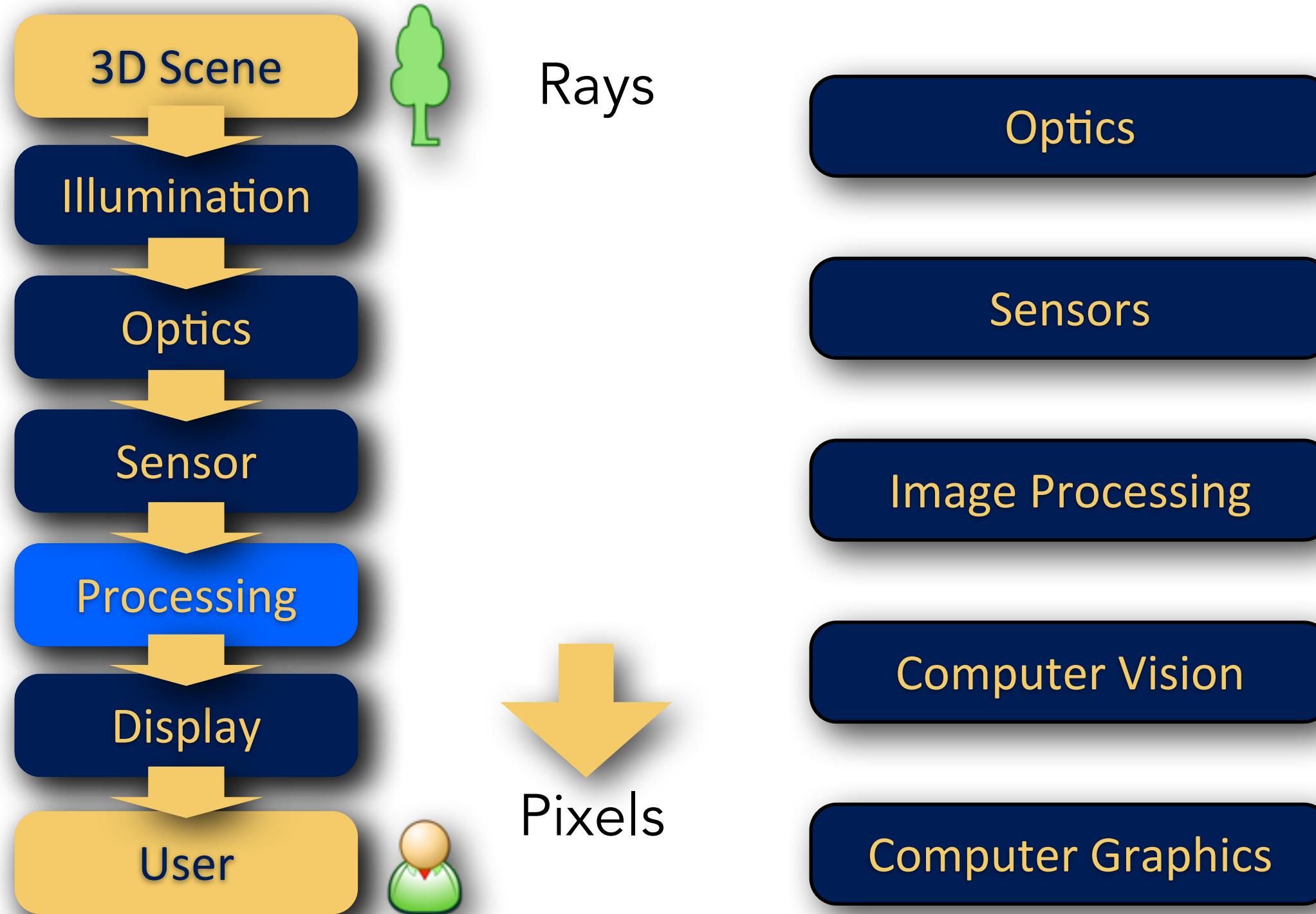
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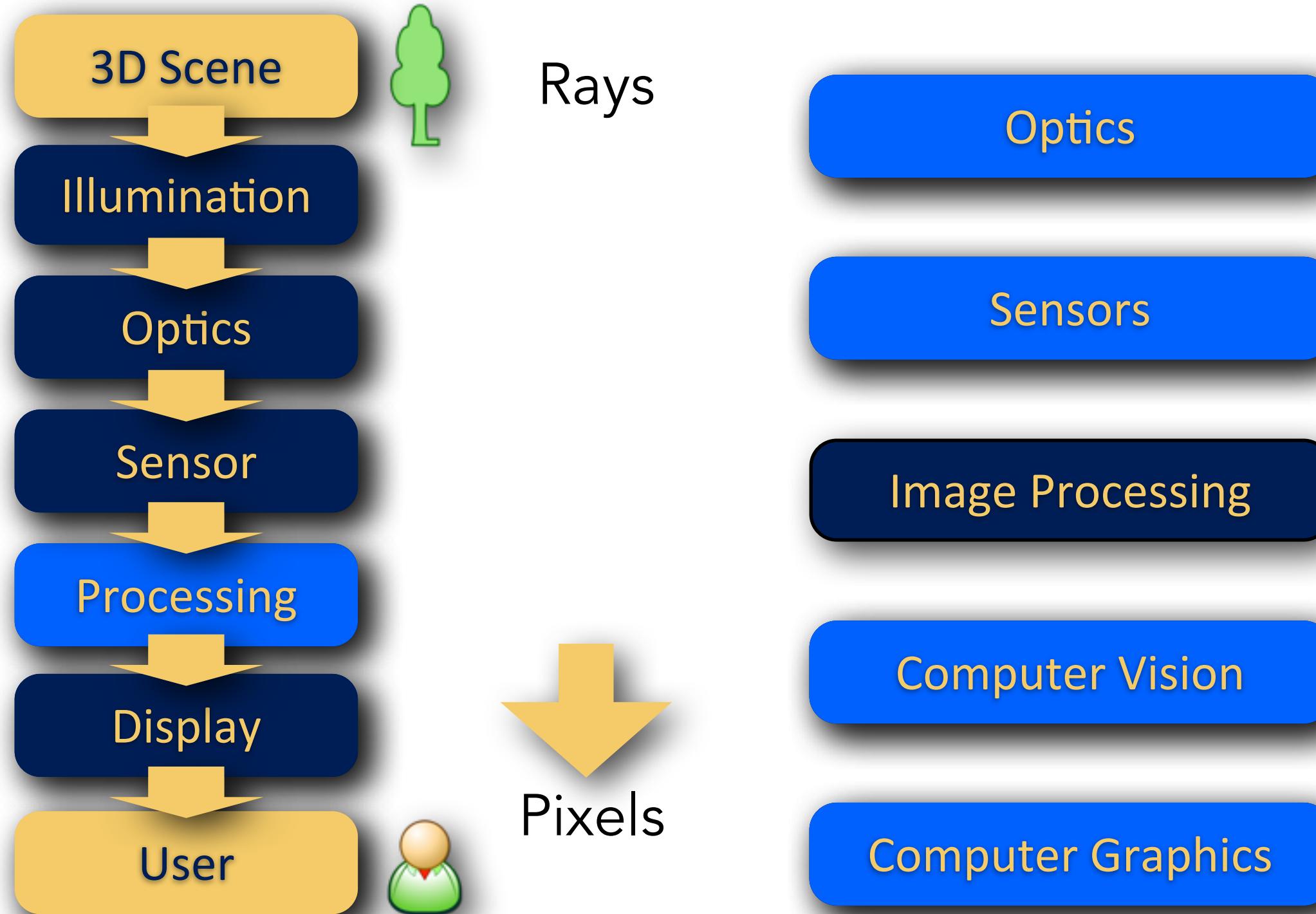
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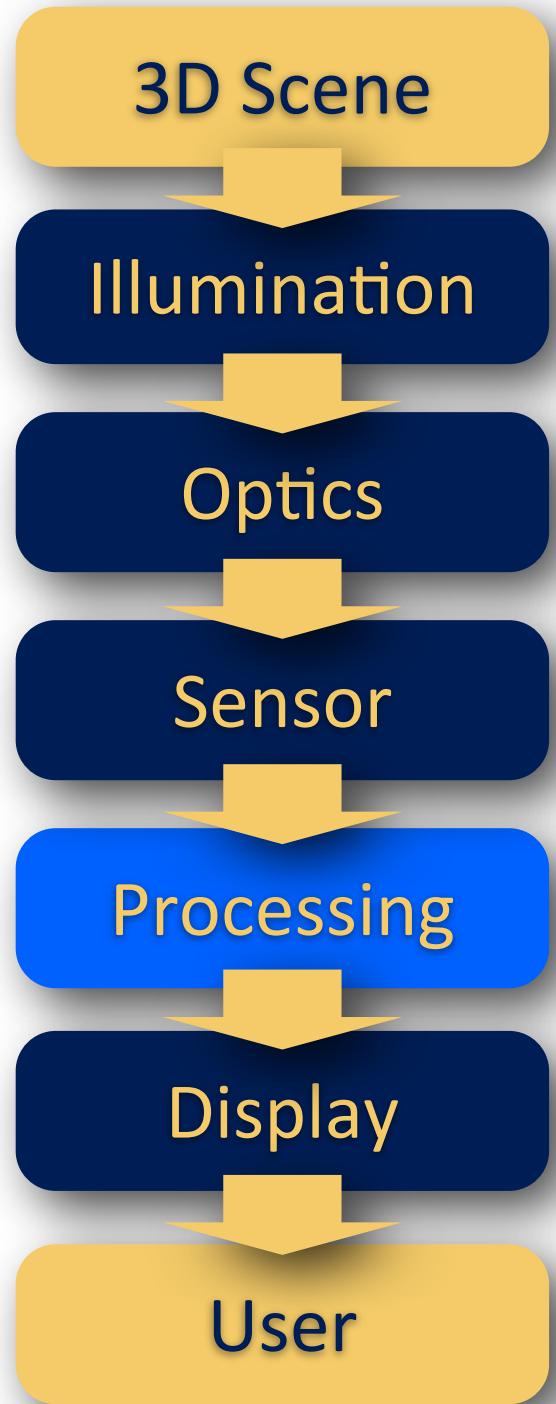
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Pixels vs. Rays

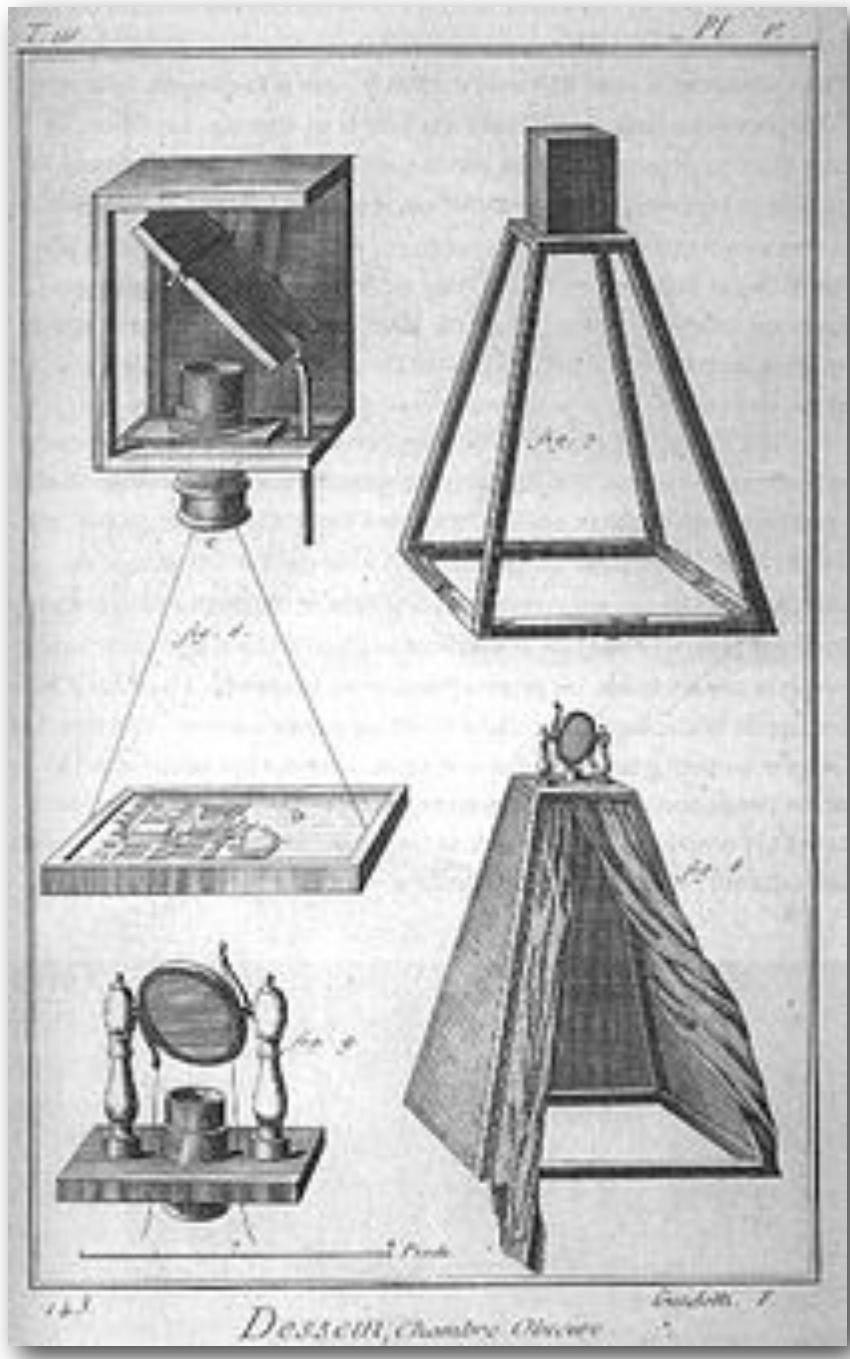


- Images represent a view of the scene via a 2D array of pixels.
- Rays are the fundamental primitives.
- Illumination (Light Rays) follows a path from the source to the scene.
- Computation adaptively controls the parameters of the optics, sensor and illumination.

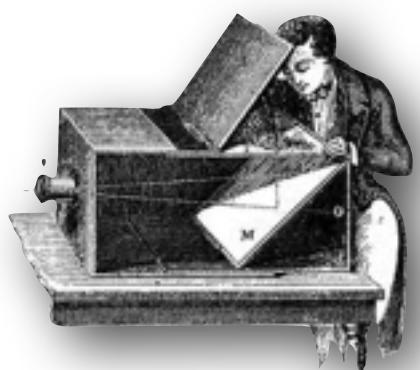
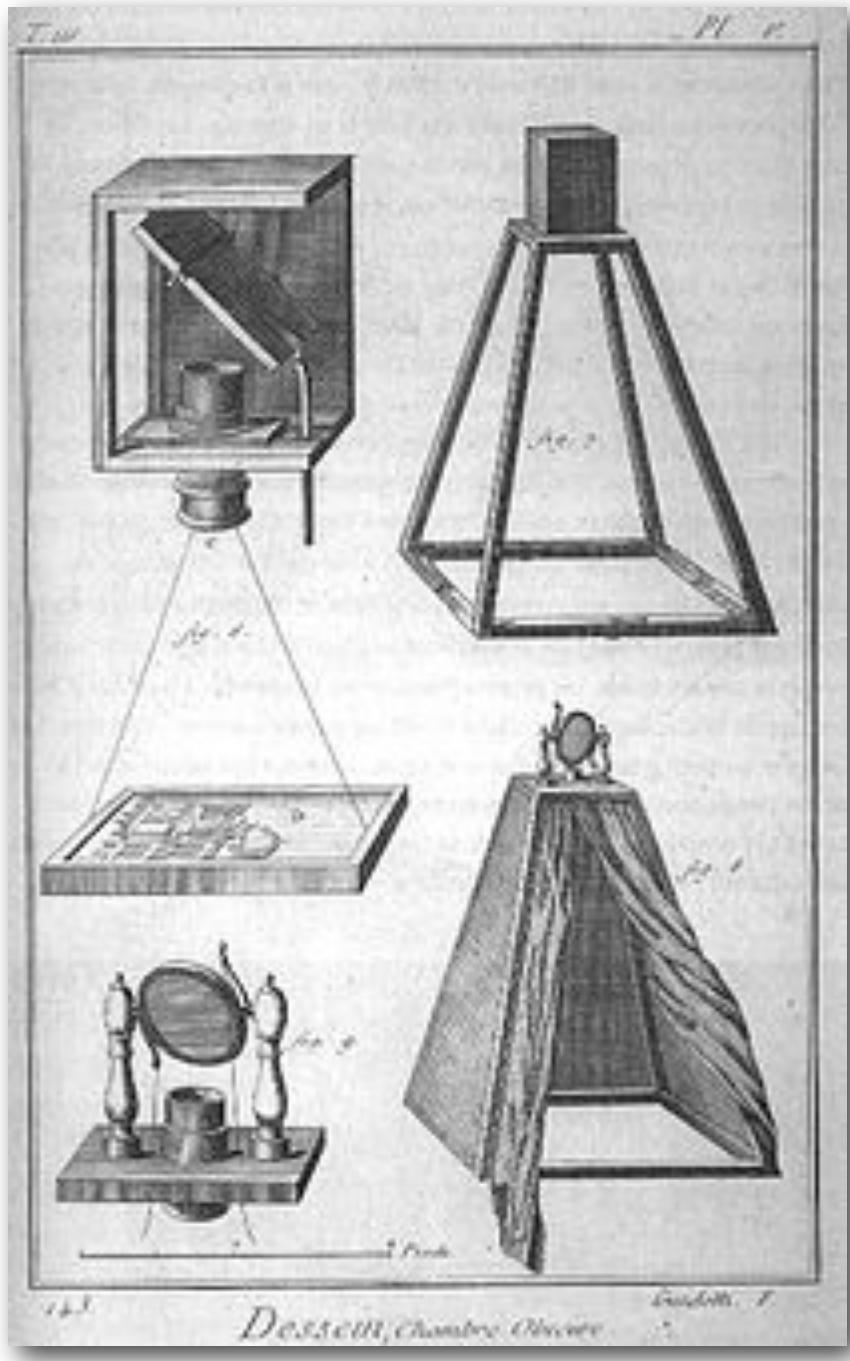


Cameras, Over the Years

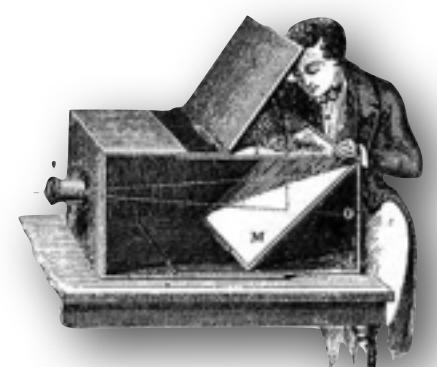
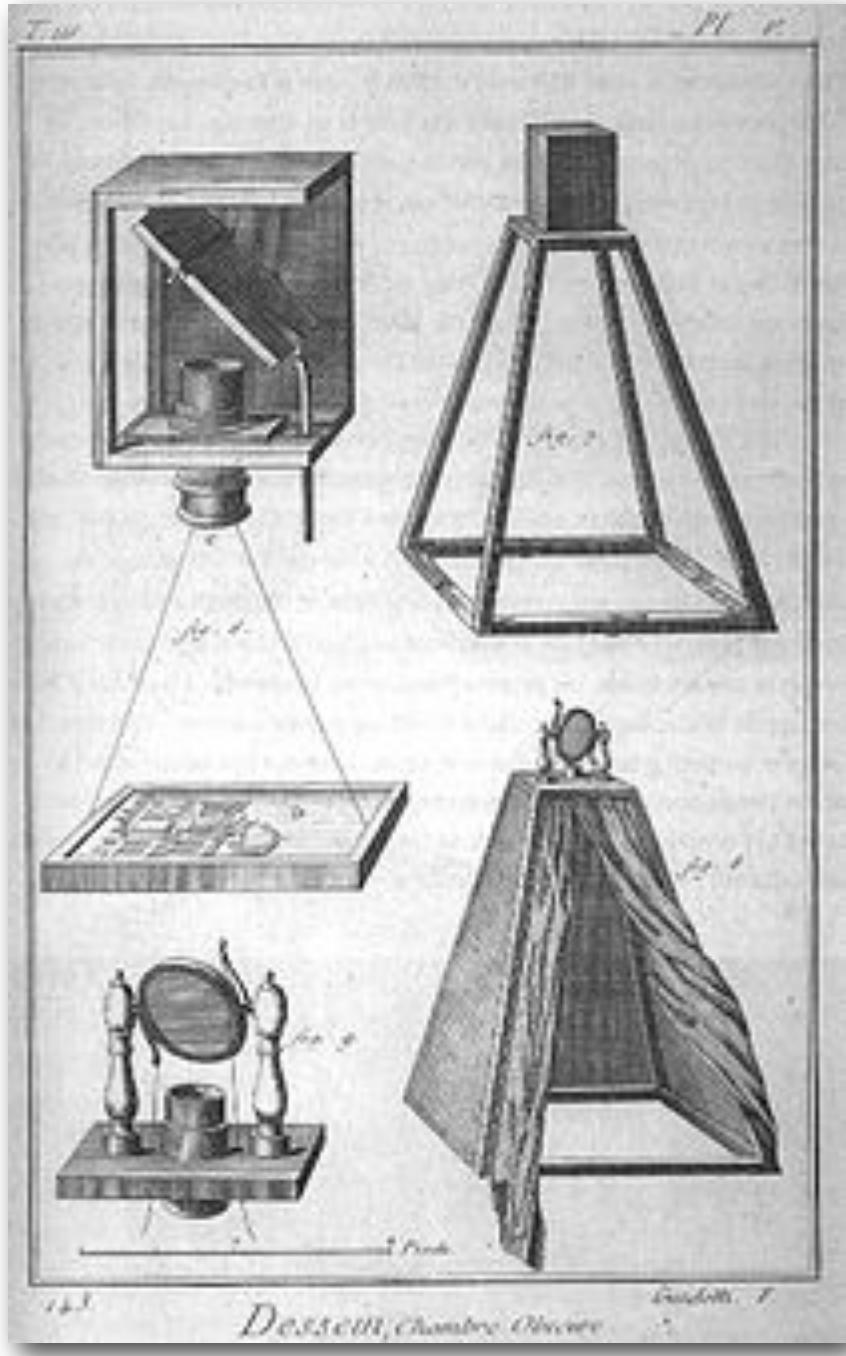
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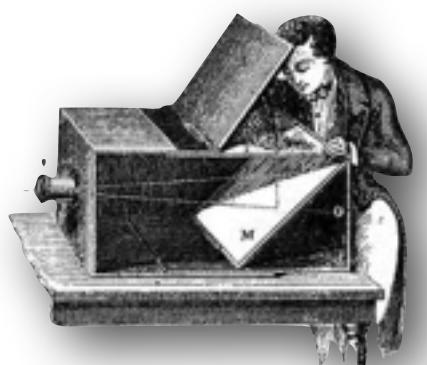
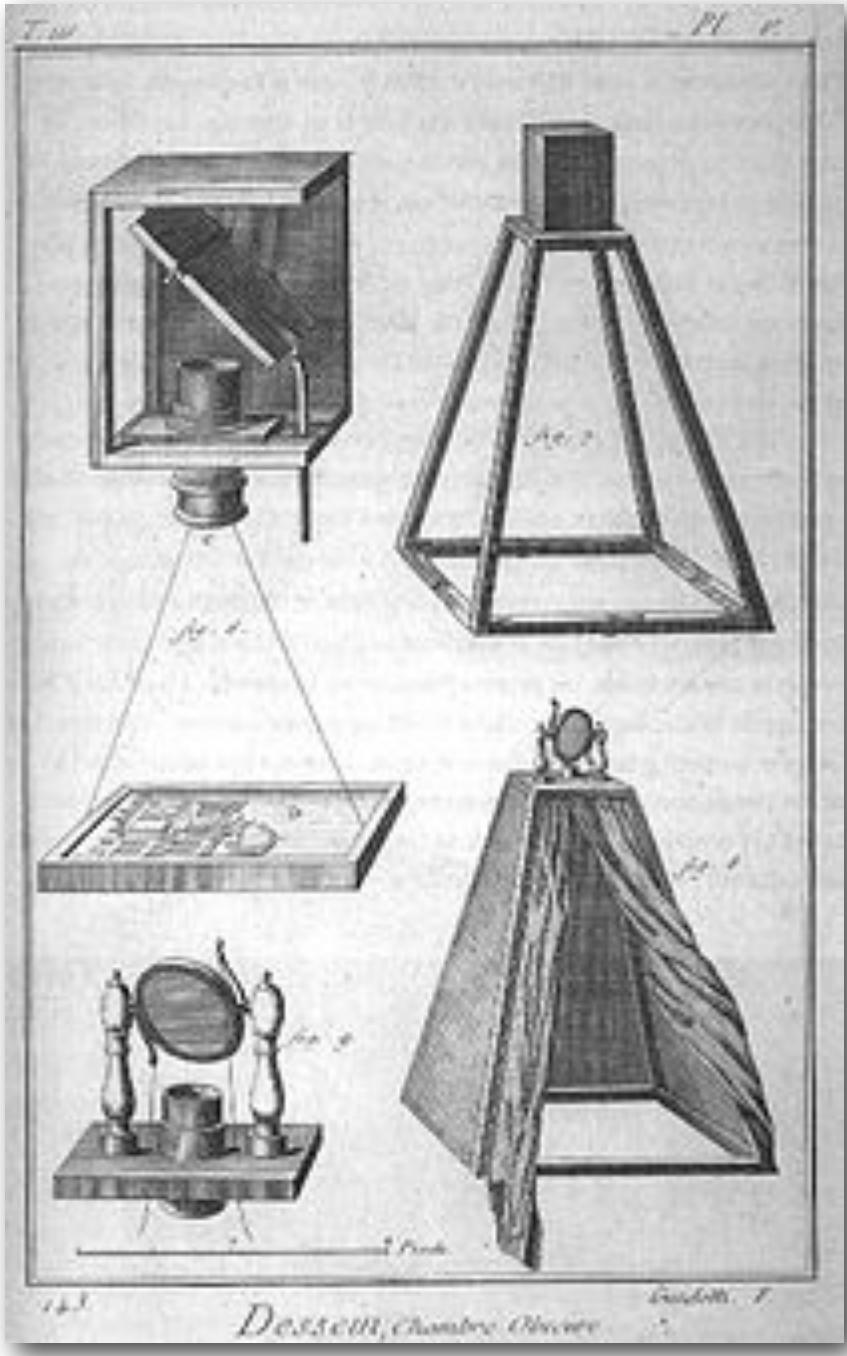
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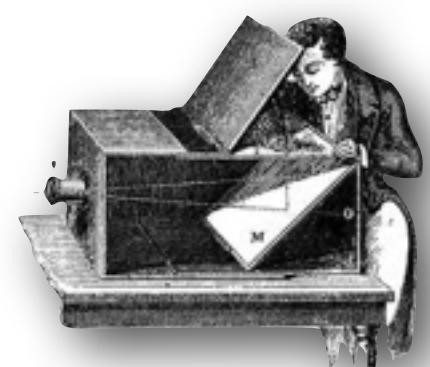
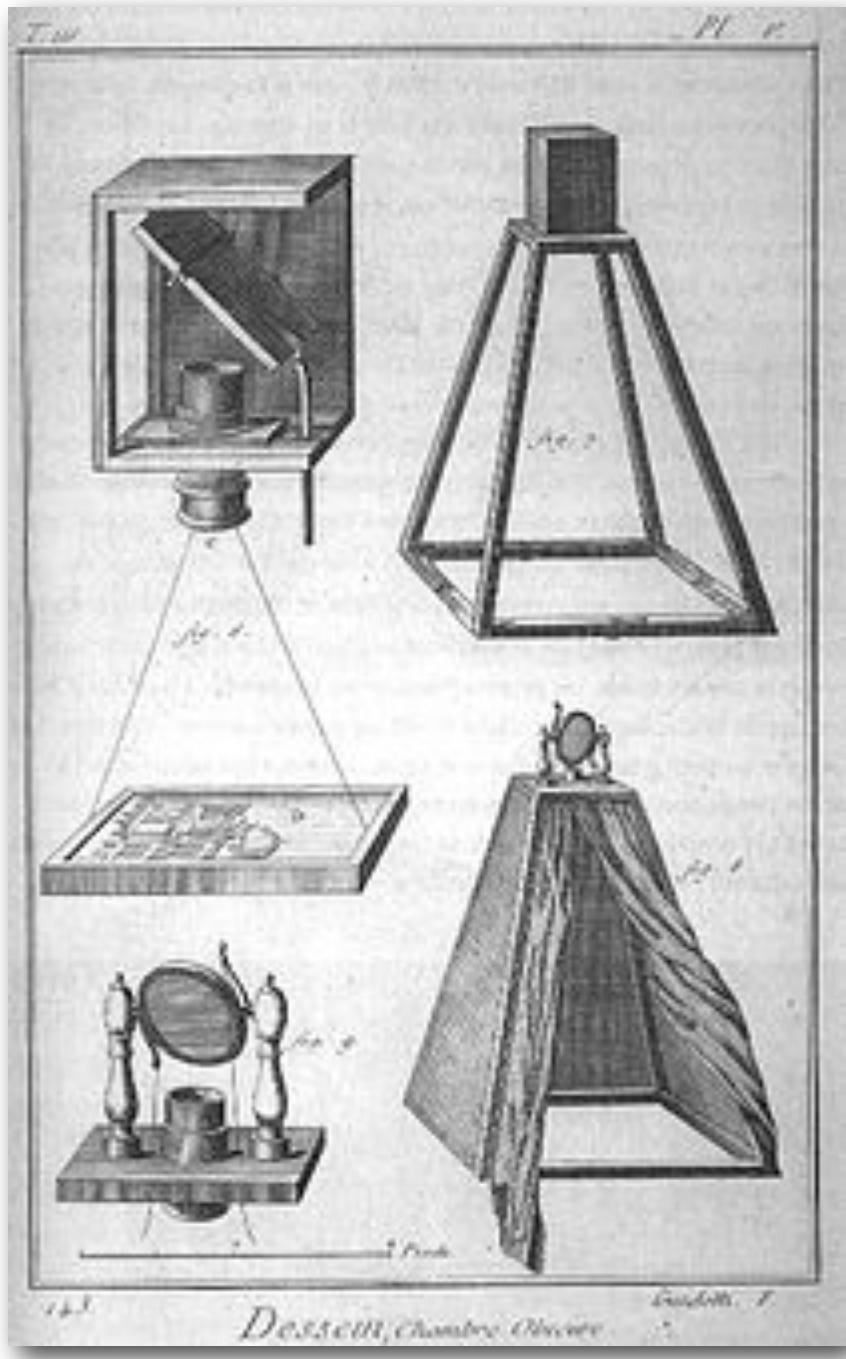
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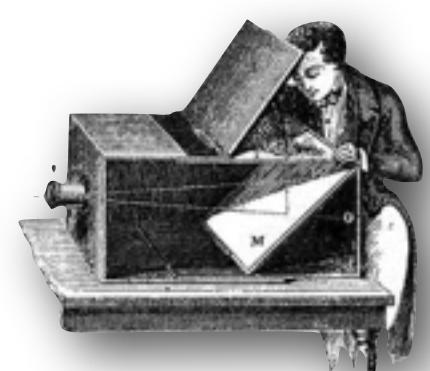
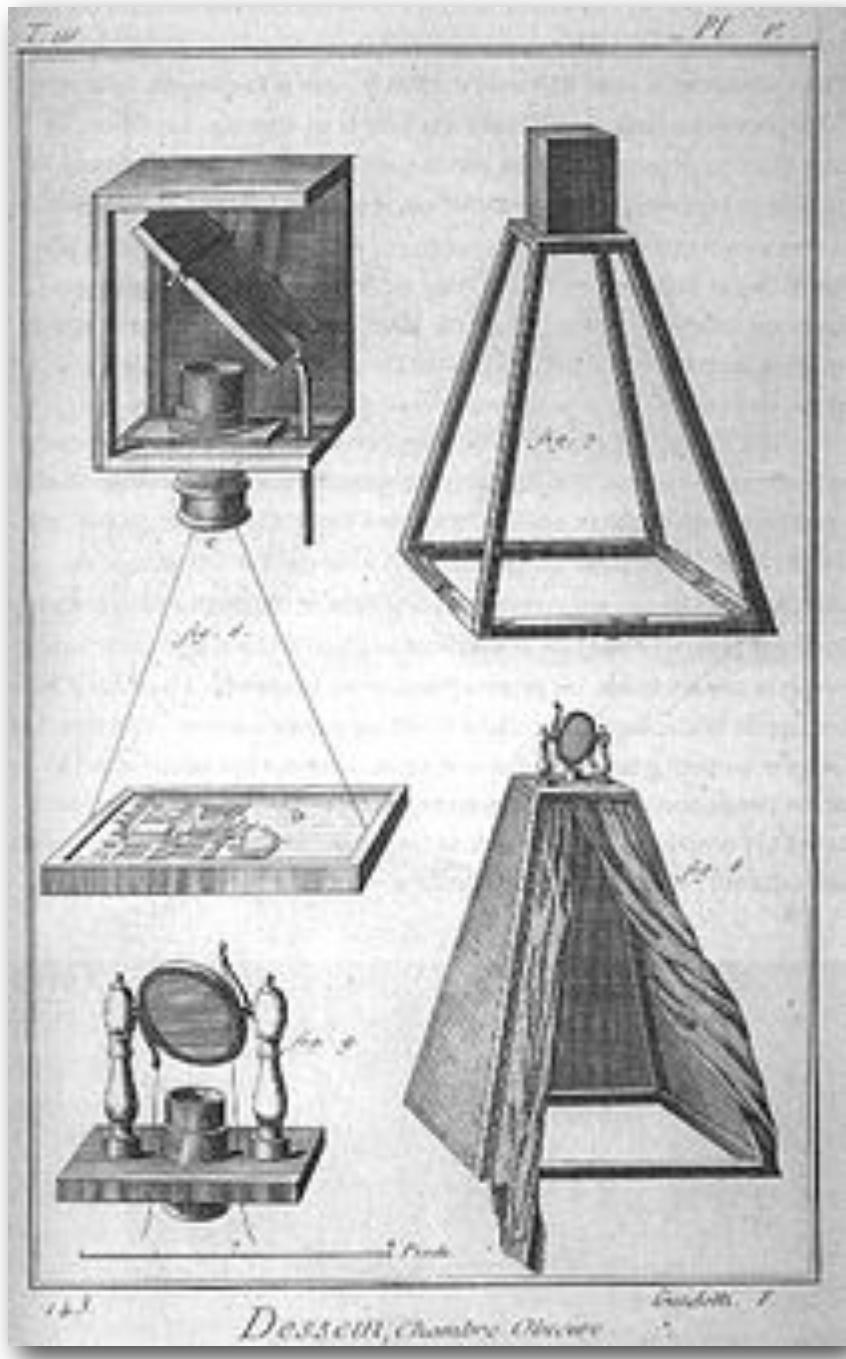
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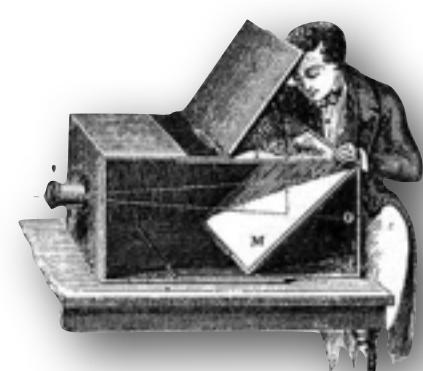
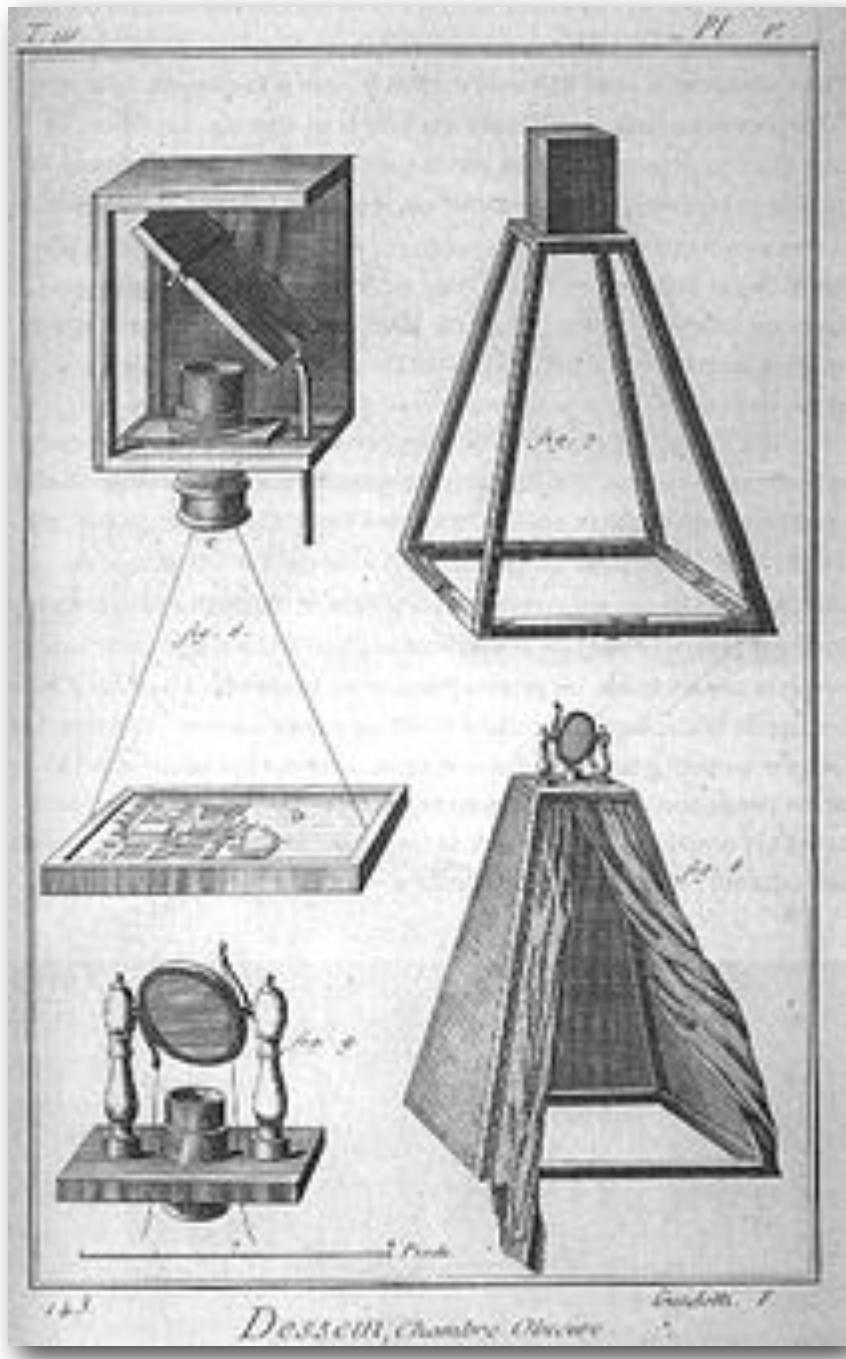
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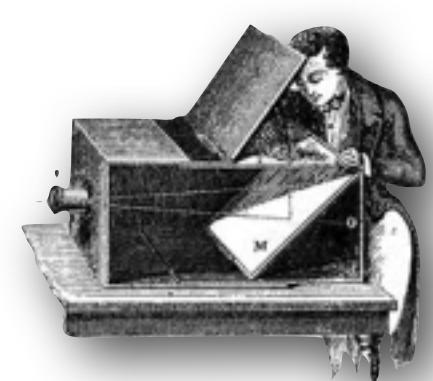
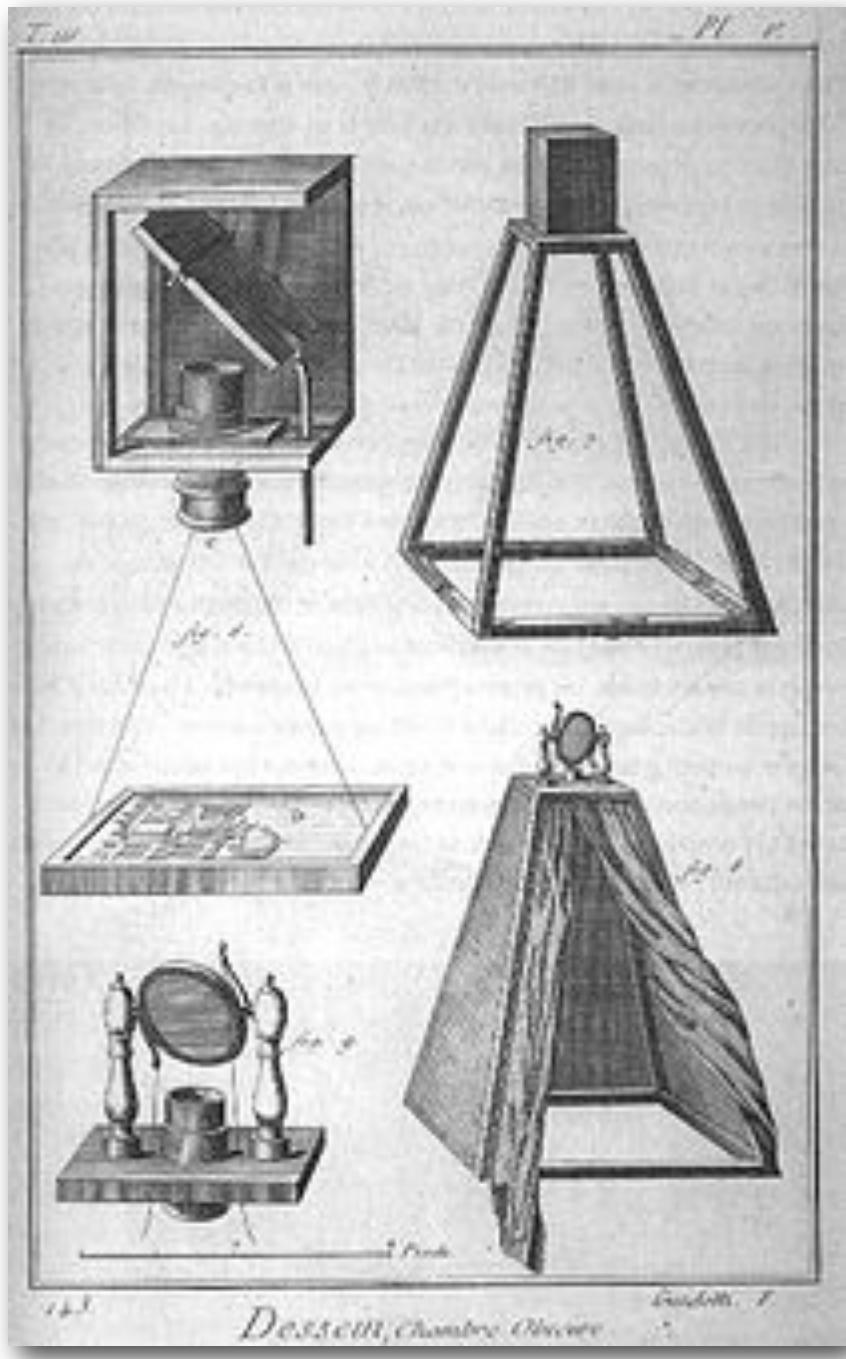
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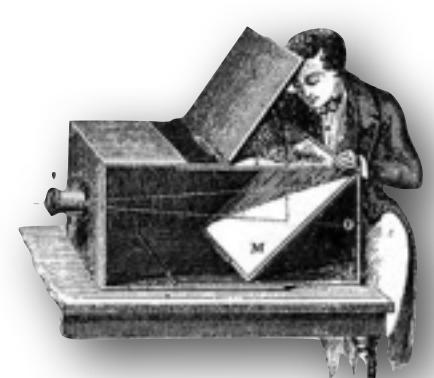
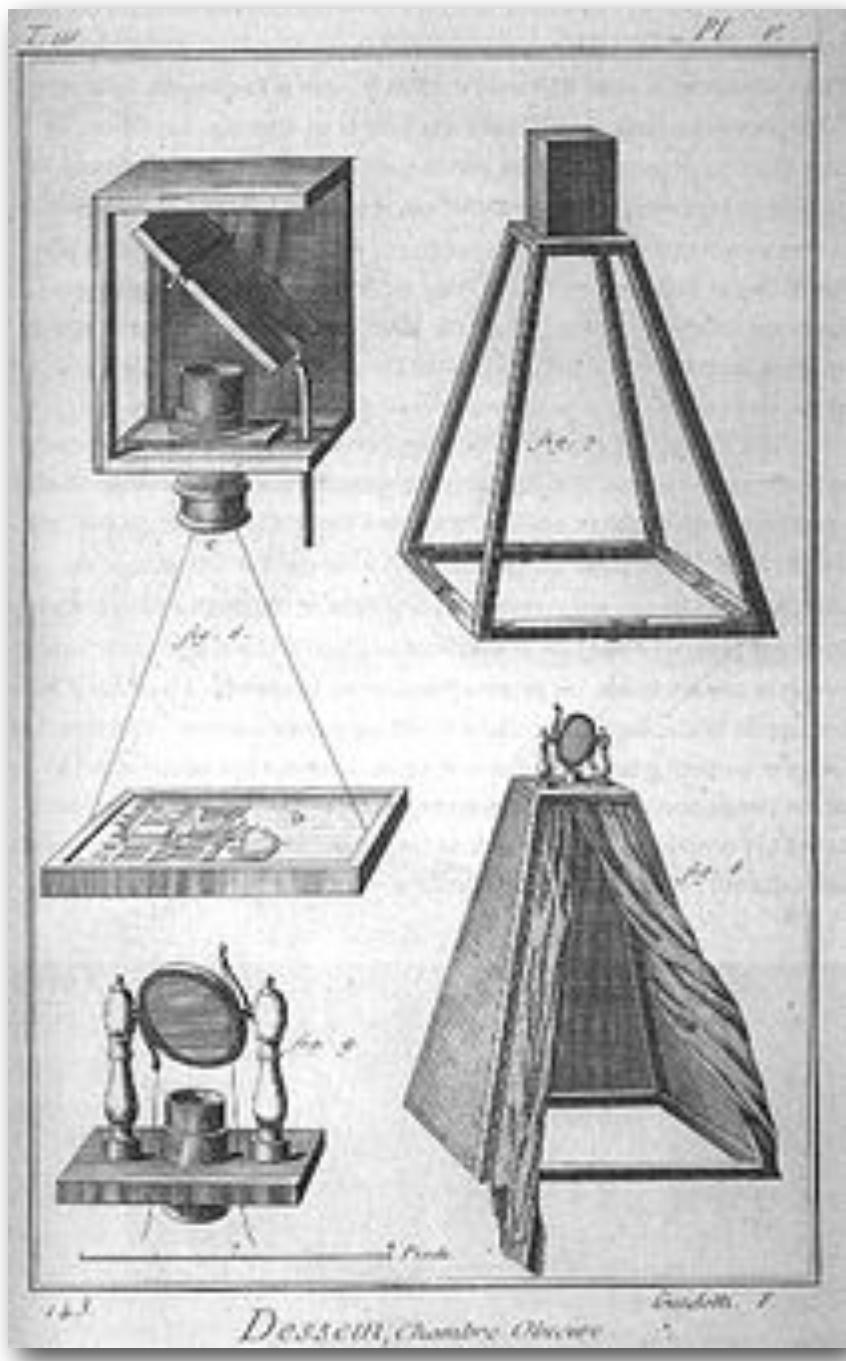
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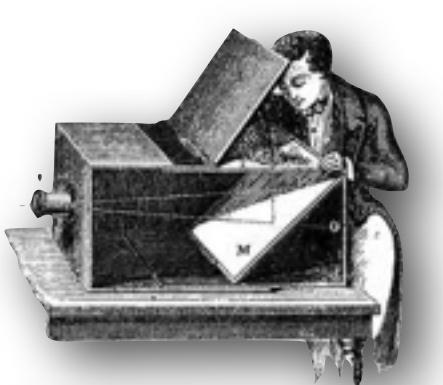
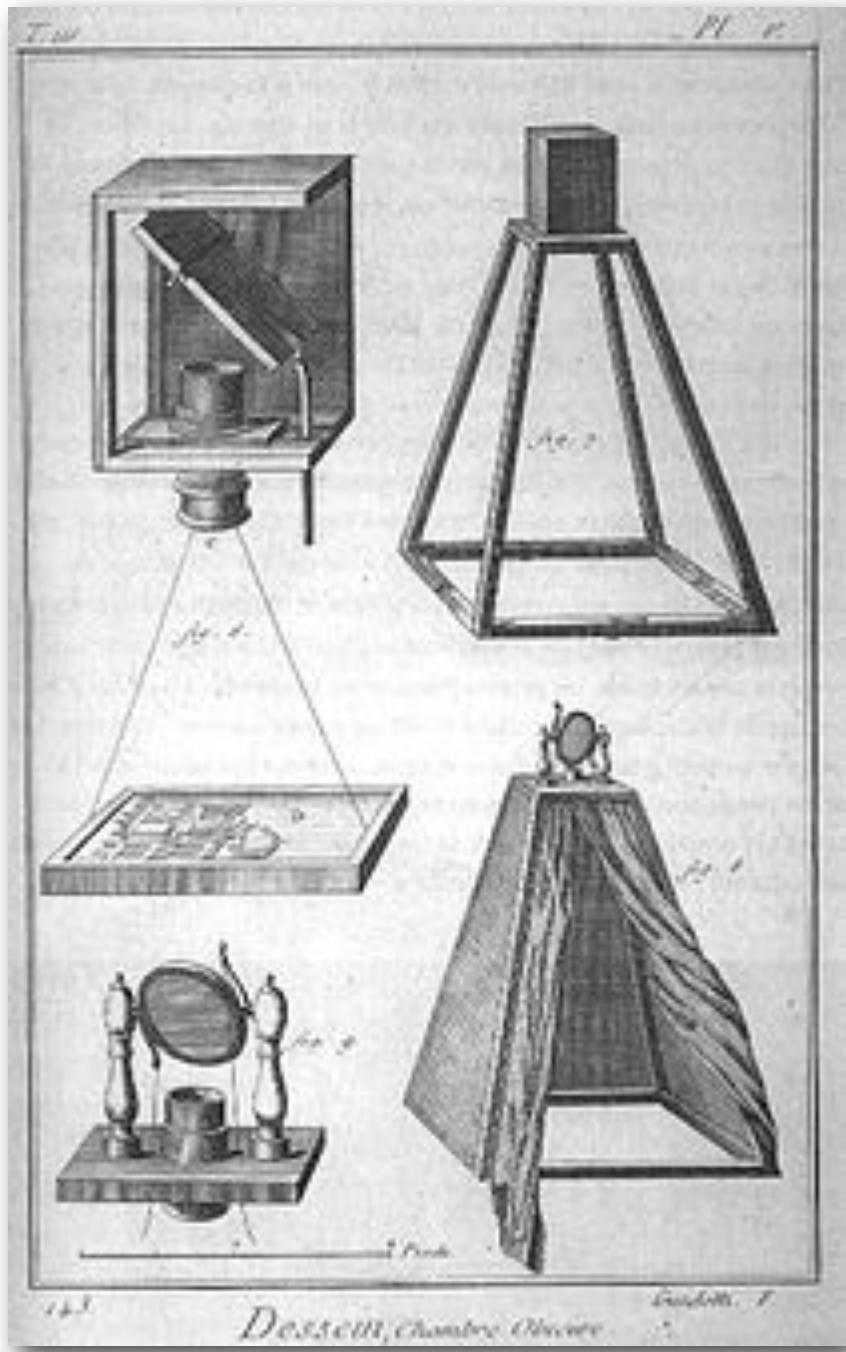
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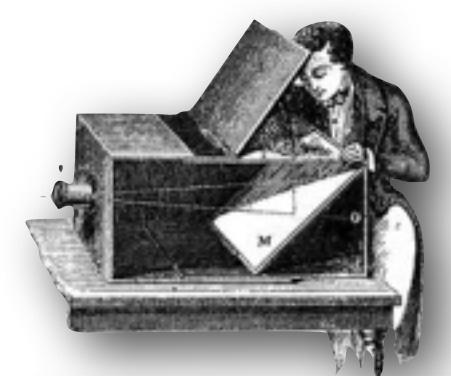
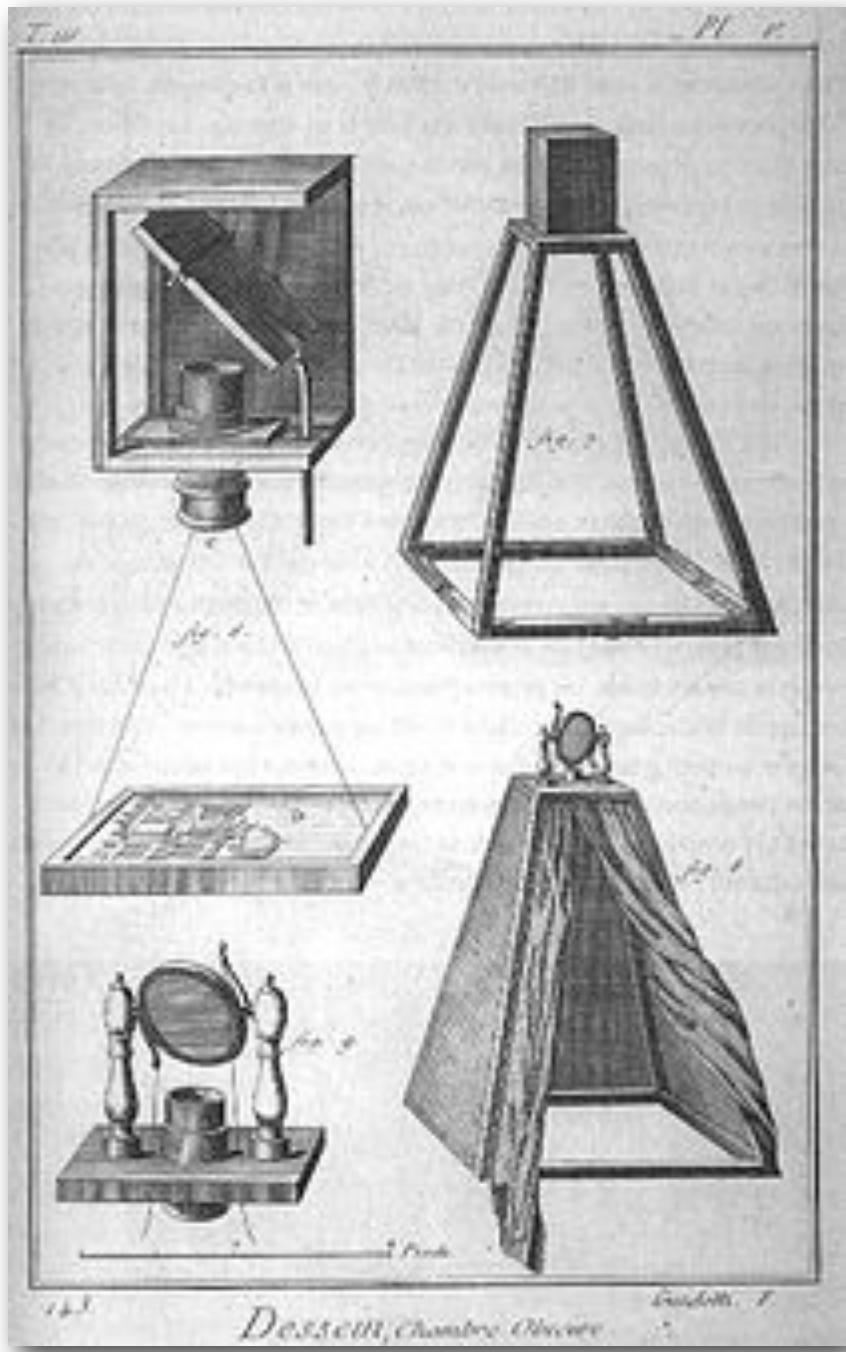
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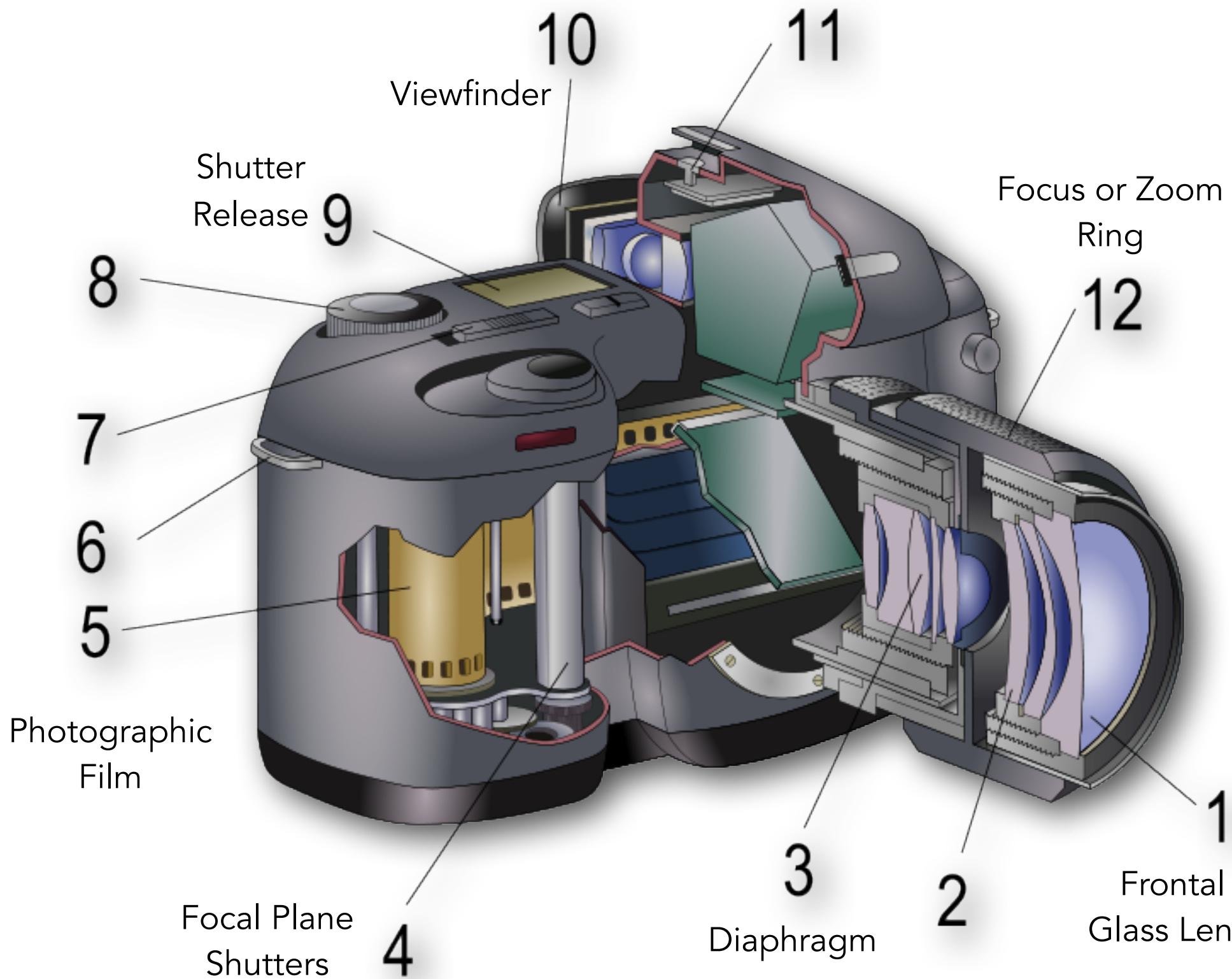


Cameras, Over the Years



Cameras, Over the Years





Camera Inside: From Rays to Pixels

From Rays to Pixels



Geometry (Perspective)

From Rays to Pixels



Geometry (Perspective)



Light Scattering

From Rays to Pixels



Geometry (Perspective)



Light Scattering



Optics / Lens

From Rays to Pixels



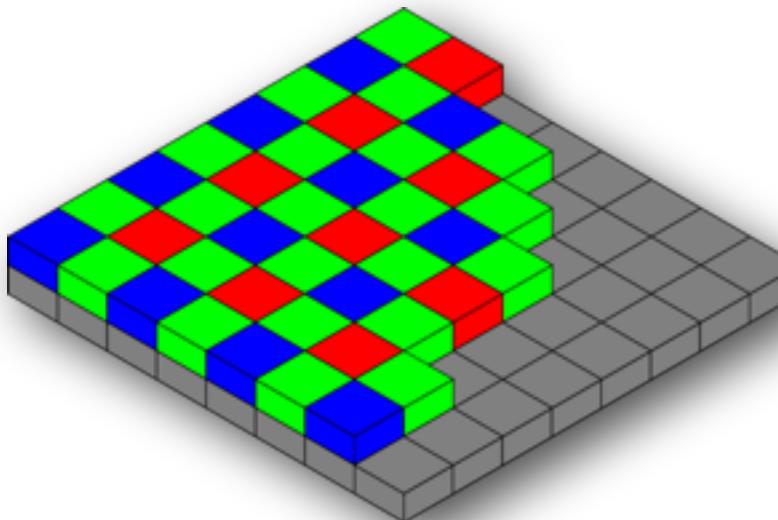
Geometry (Perspective)



Light Scattering



Optics / Lens

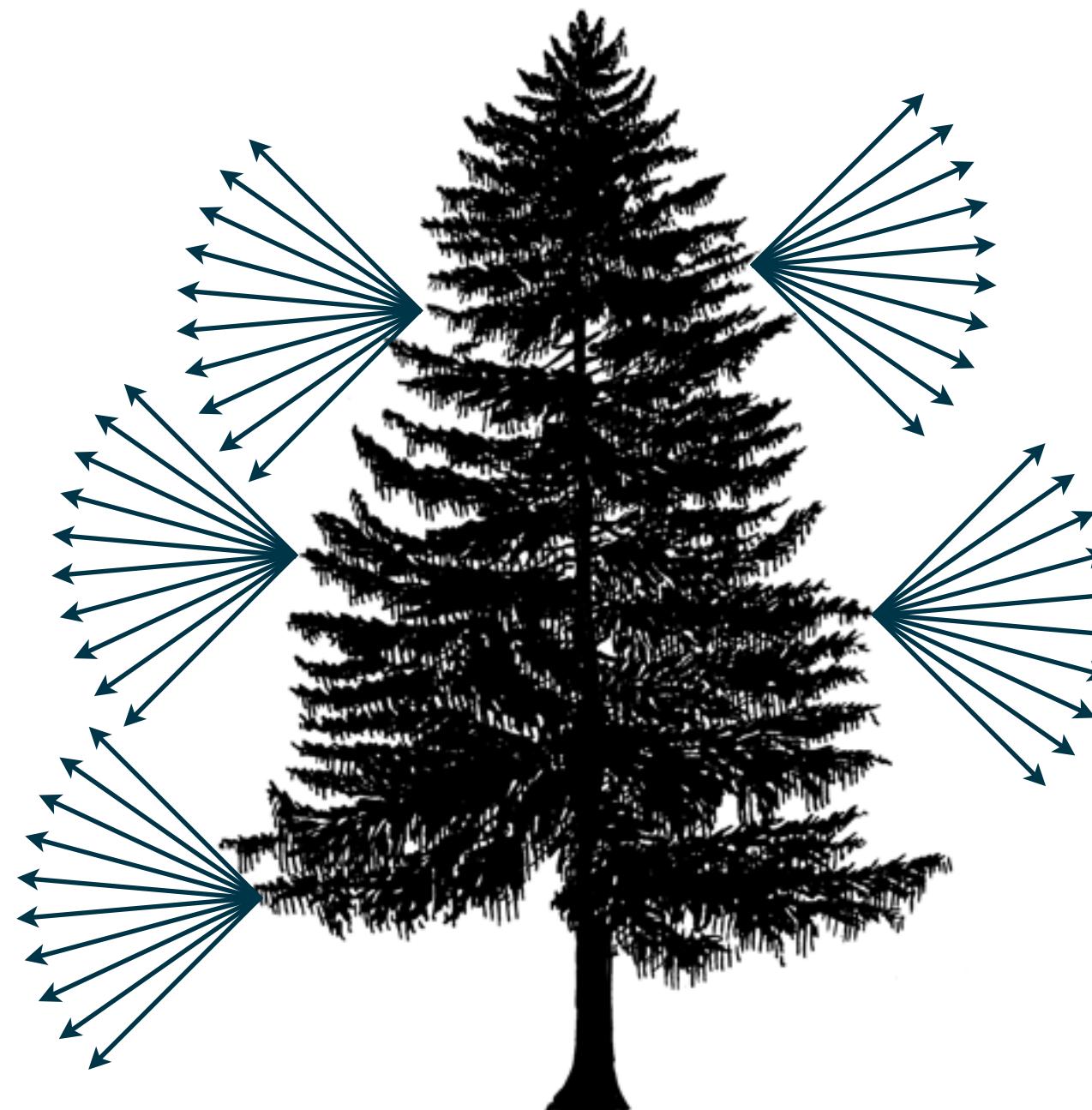


Sensor (Color/Filter)

From Rays to Pixels

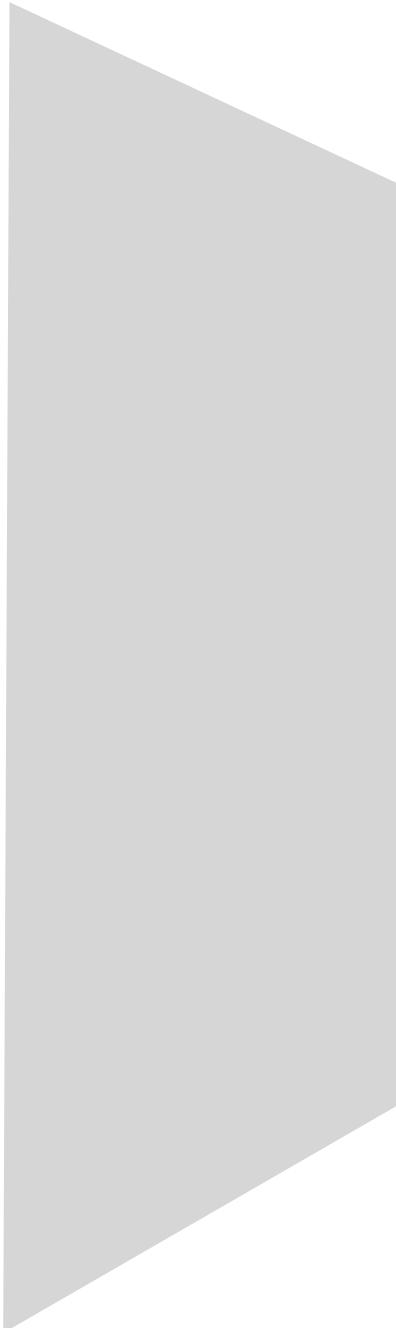


Cameras, without Optics



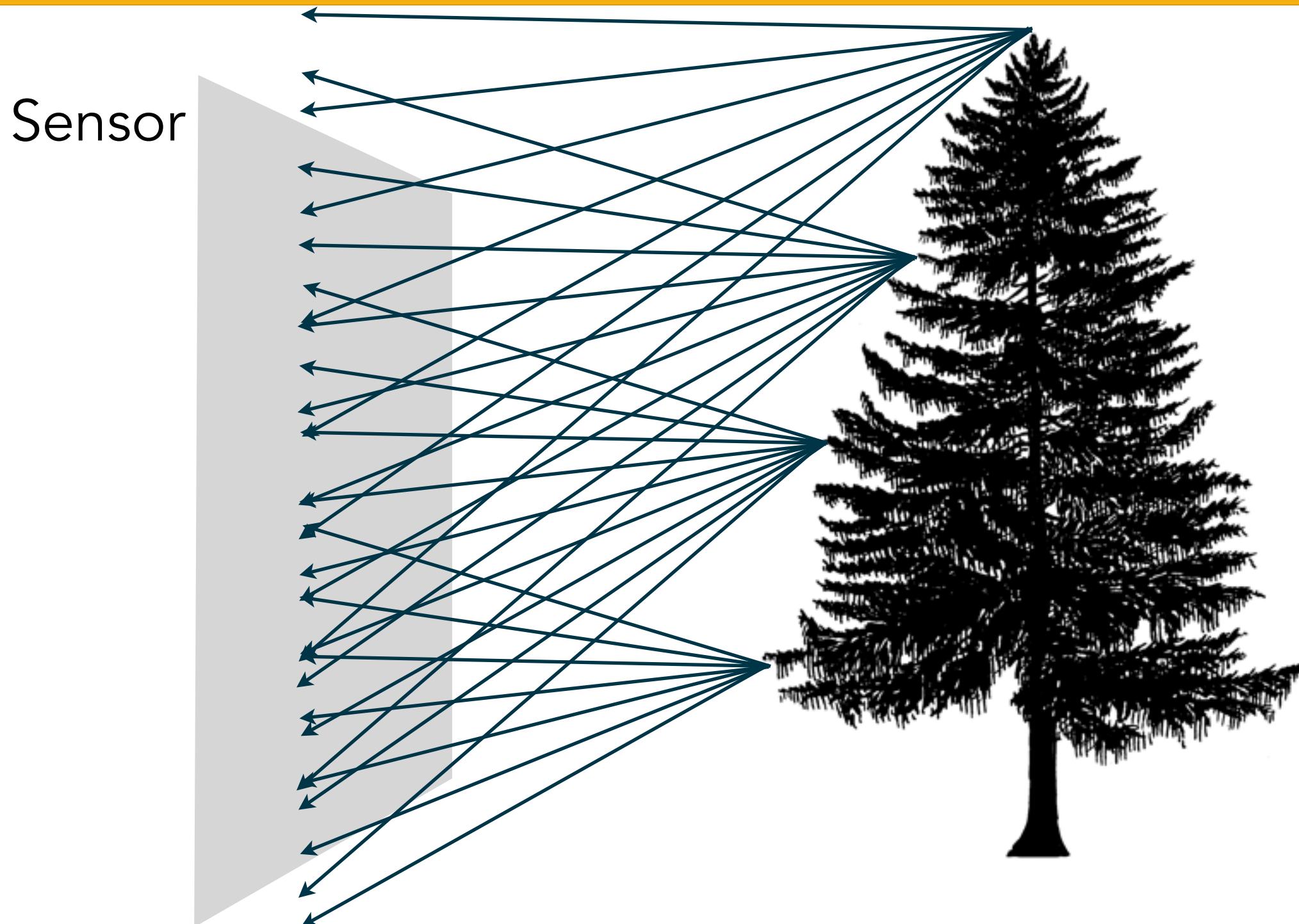
Cameras, without Optics

Sensor



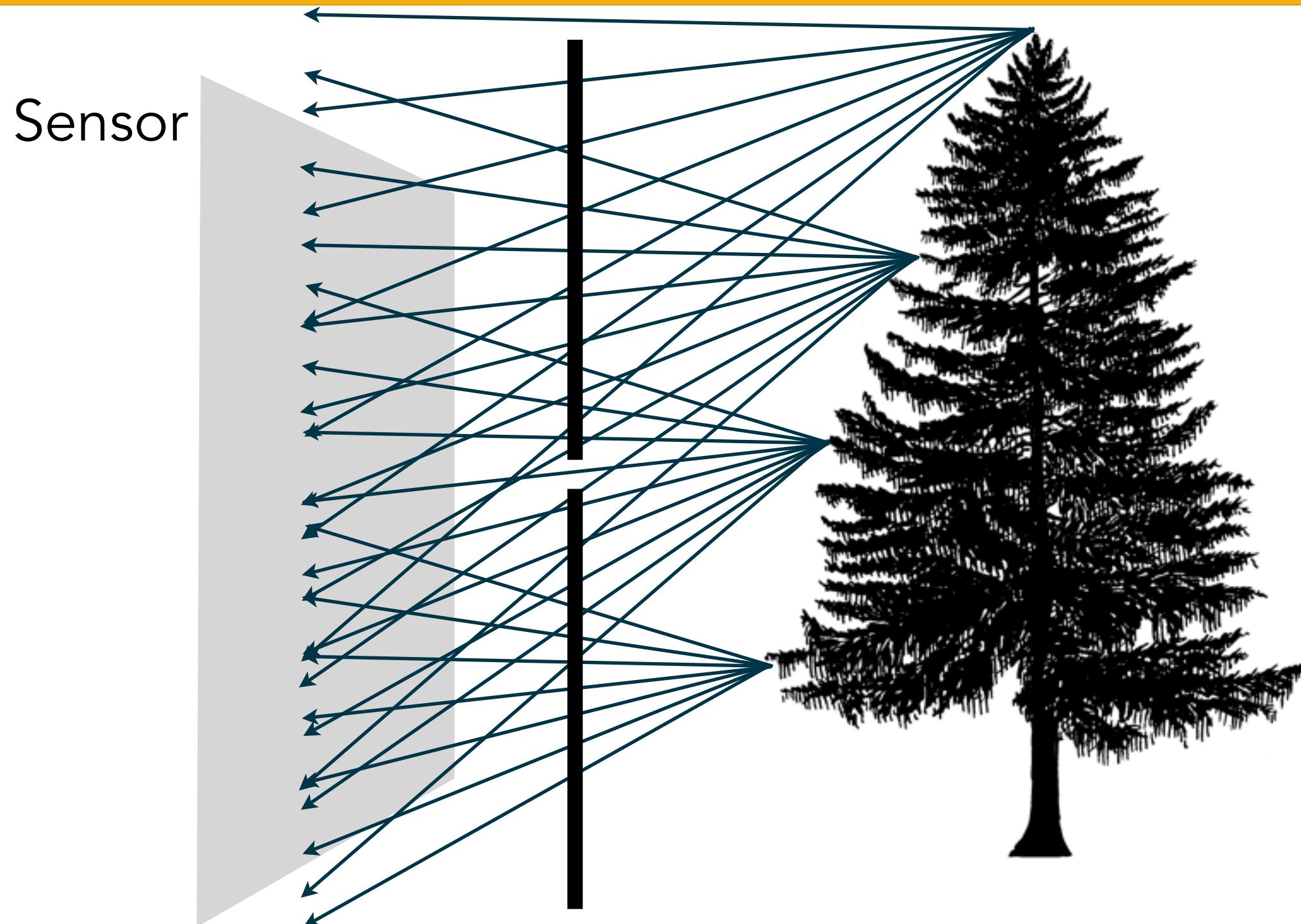
- ★ Each point on the “sensor” records the summation (integral) of all light from the scene (subject).

Cameras, without Optics



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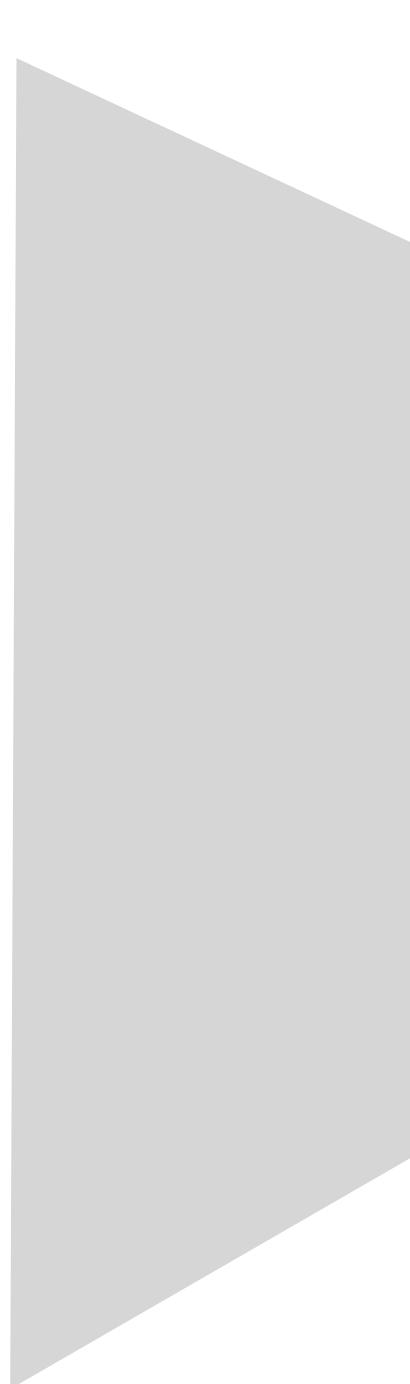
Cameras, without Optics



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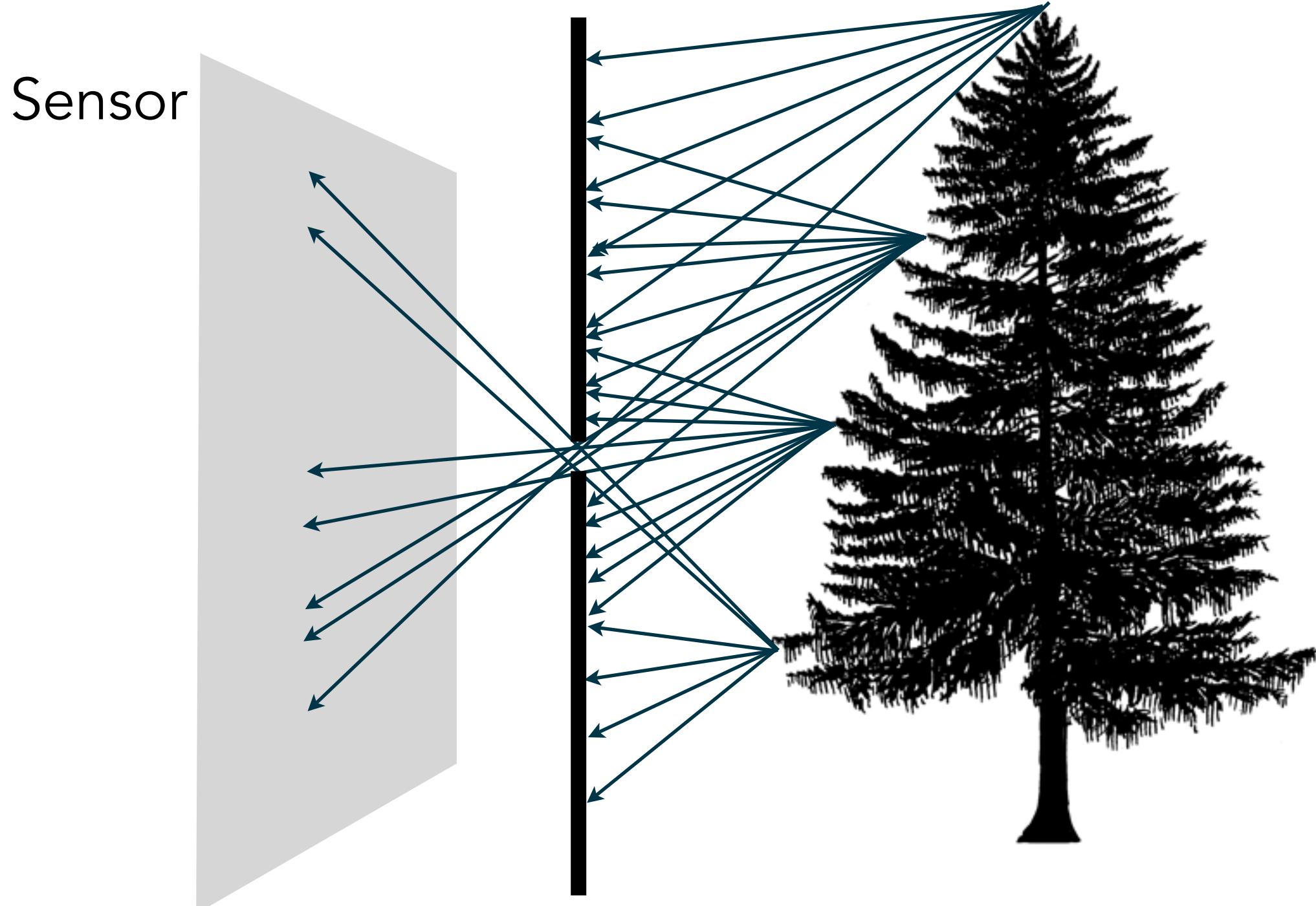
Cameras, without Optics

Sensor



Cameras, without Optics

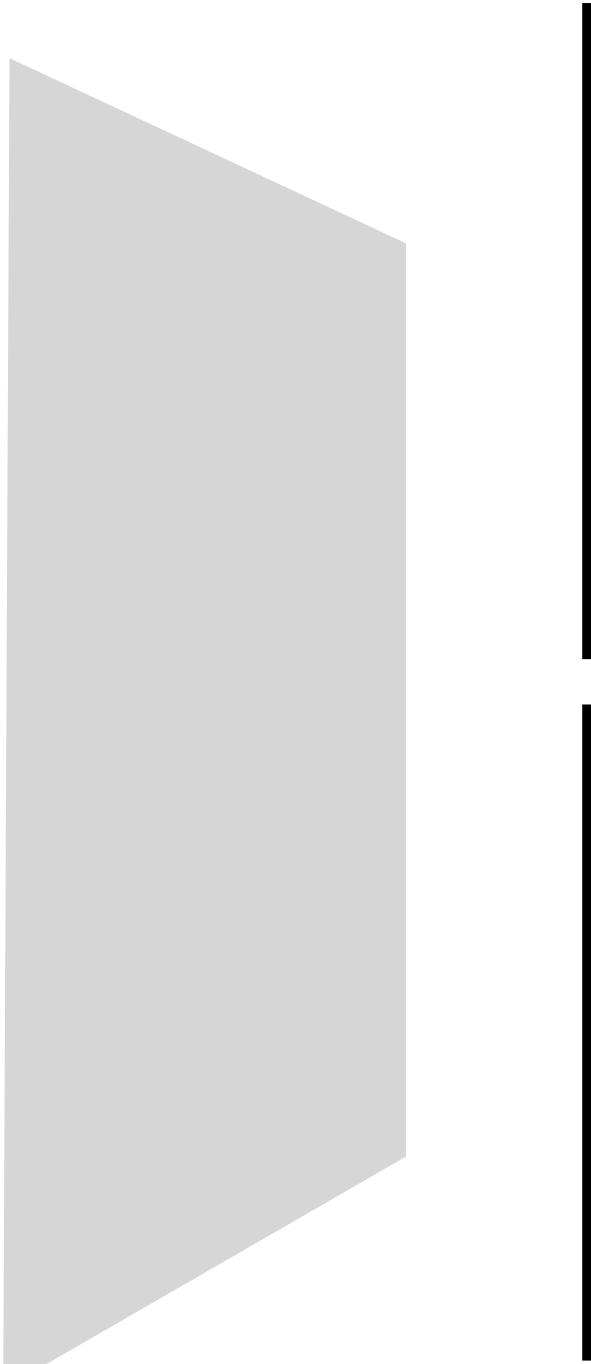
- ★ We add an “obstruction” in front of the sensor, then only a “bit” of the light gets to the sensor.



Cameras, without Optics

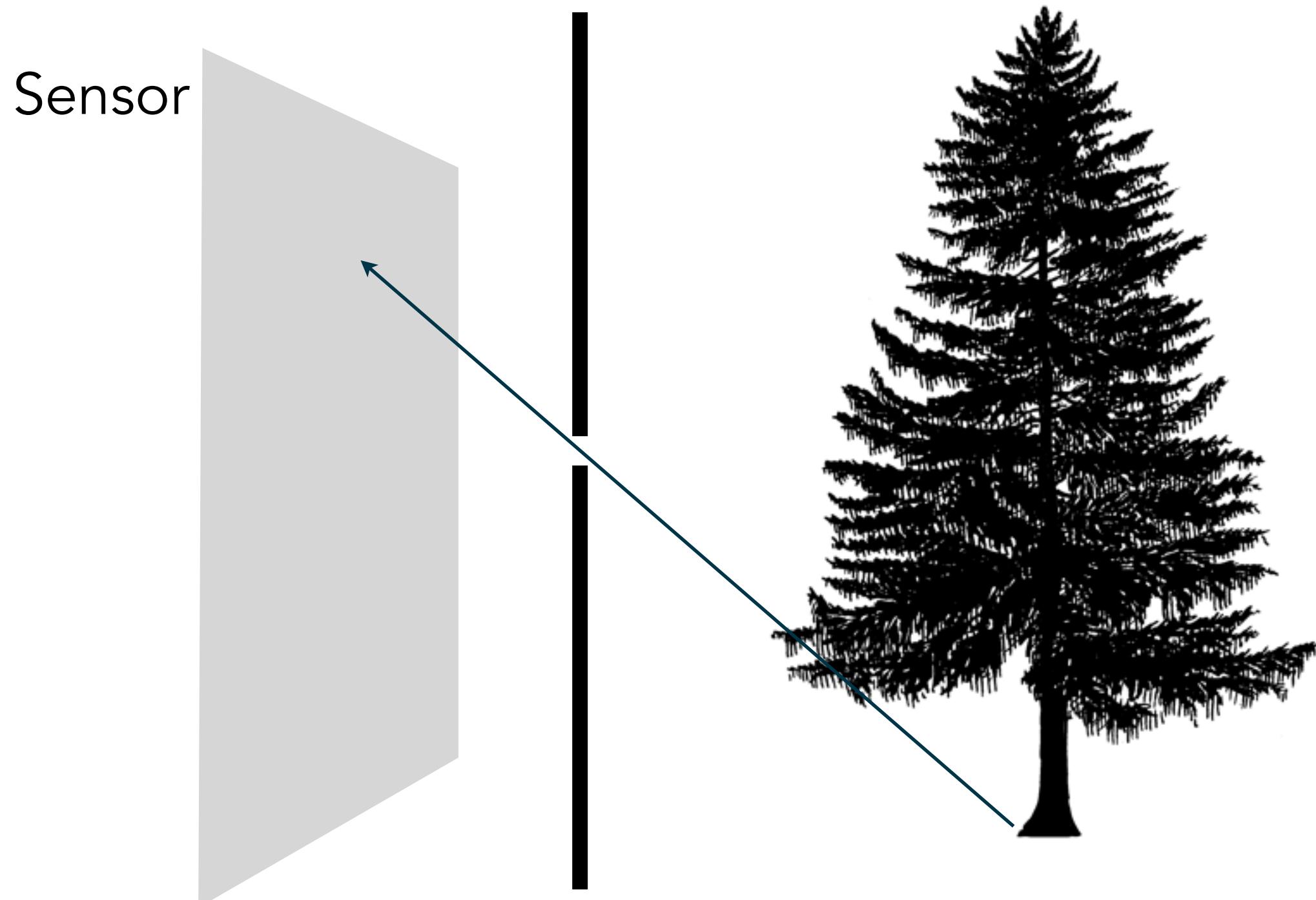
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Sensor



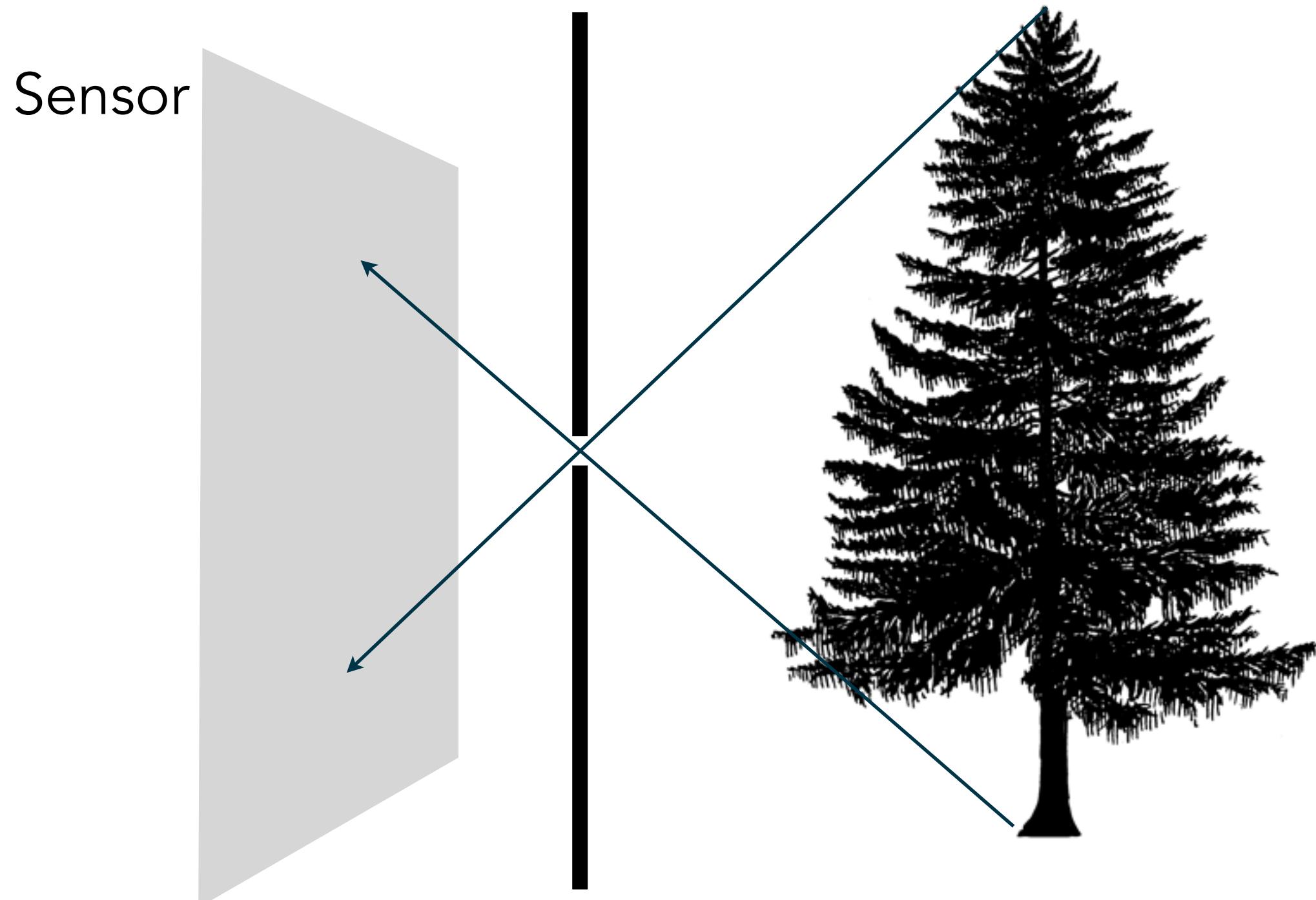
Cameras, without Optics

- ★ After the “obstruction” the subjects gets inverted on the sensor



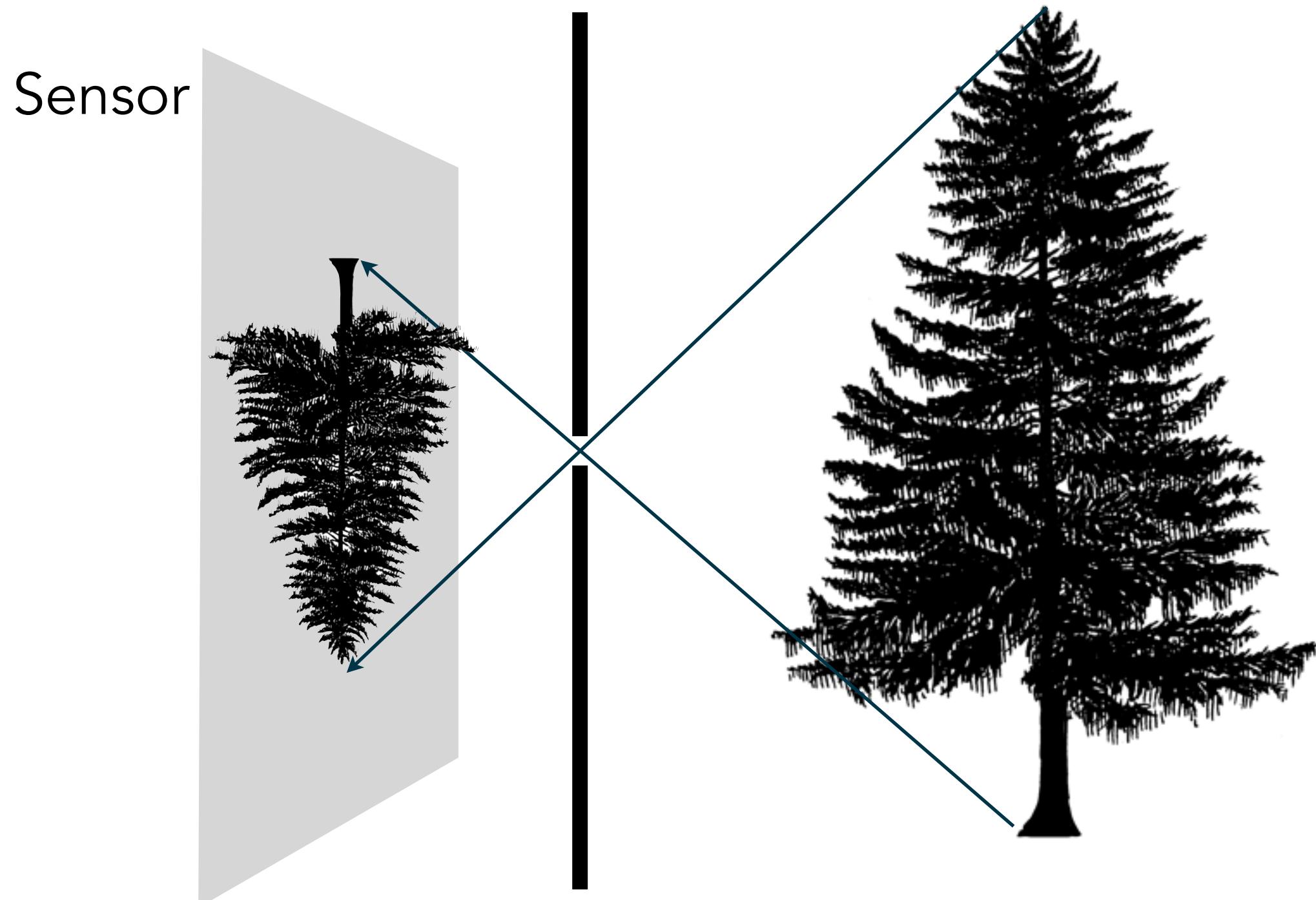
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Cameras, without Optics



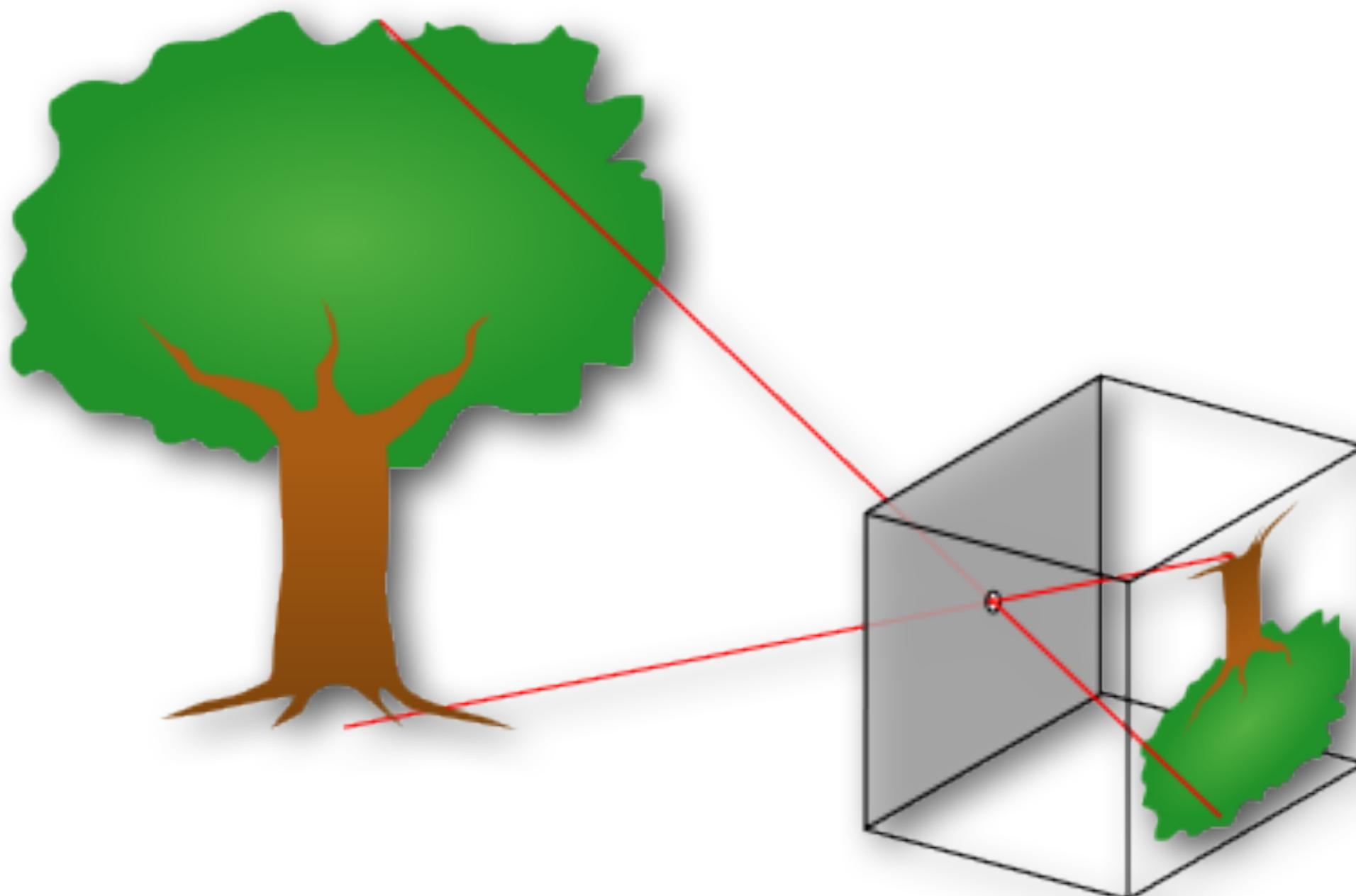
Cameras, without Optics

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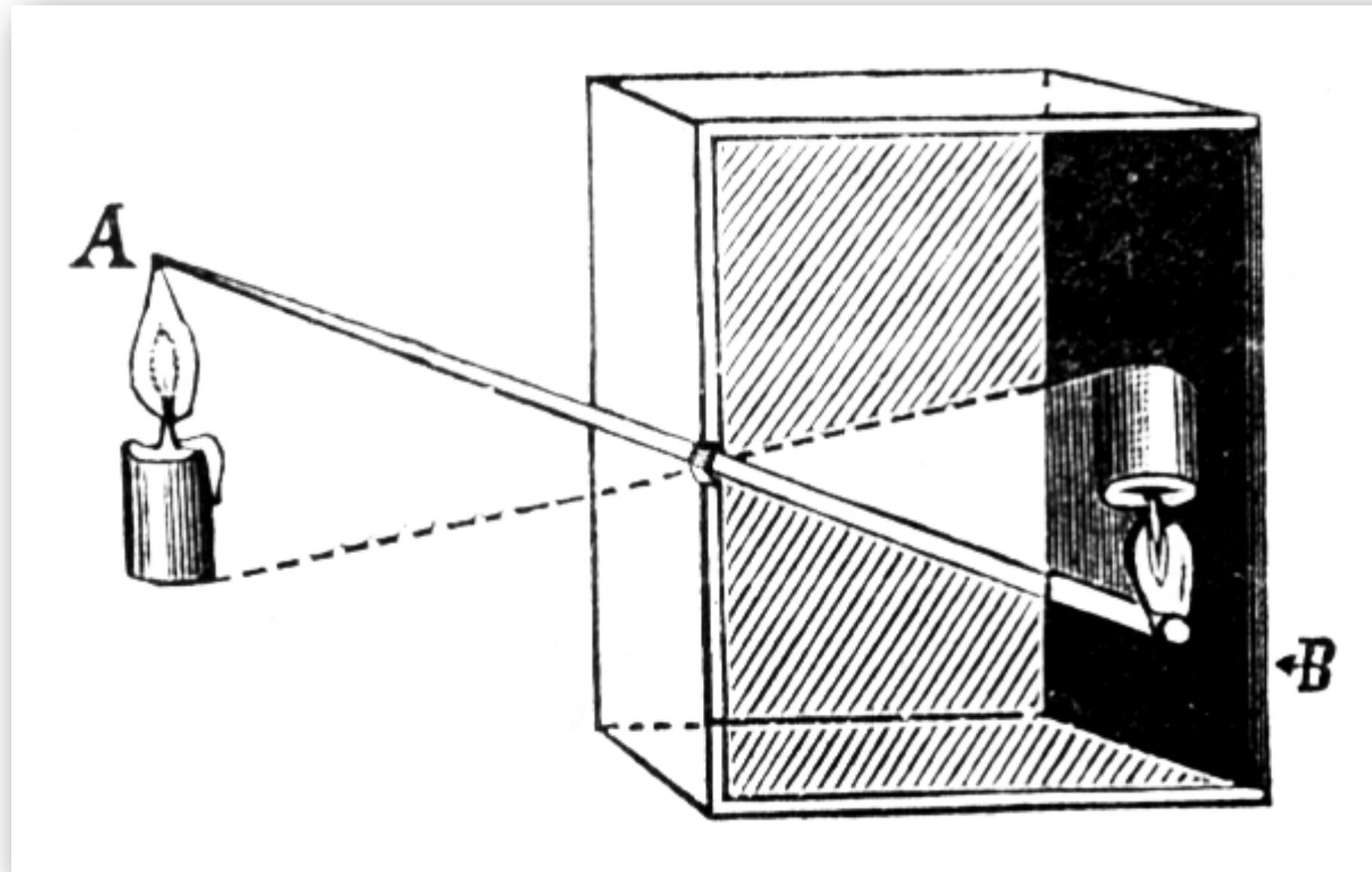


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Cameras, without Optics



Camera Obscura (Pinhole Camera)



Camera Obscura (Pinhole Camera)



Camera Obscura

Illustration of camera obscura from "Sketchbook on military art, including geometry, fortifications, artillery, mechanics, and pyrotechnics"



Pinhole Photograph

★ Theoretically

Byelorussky Station: commons.wikimedia.org/

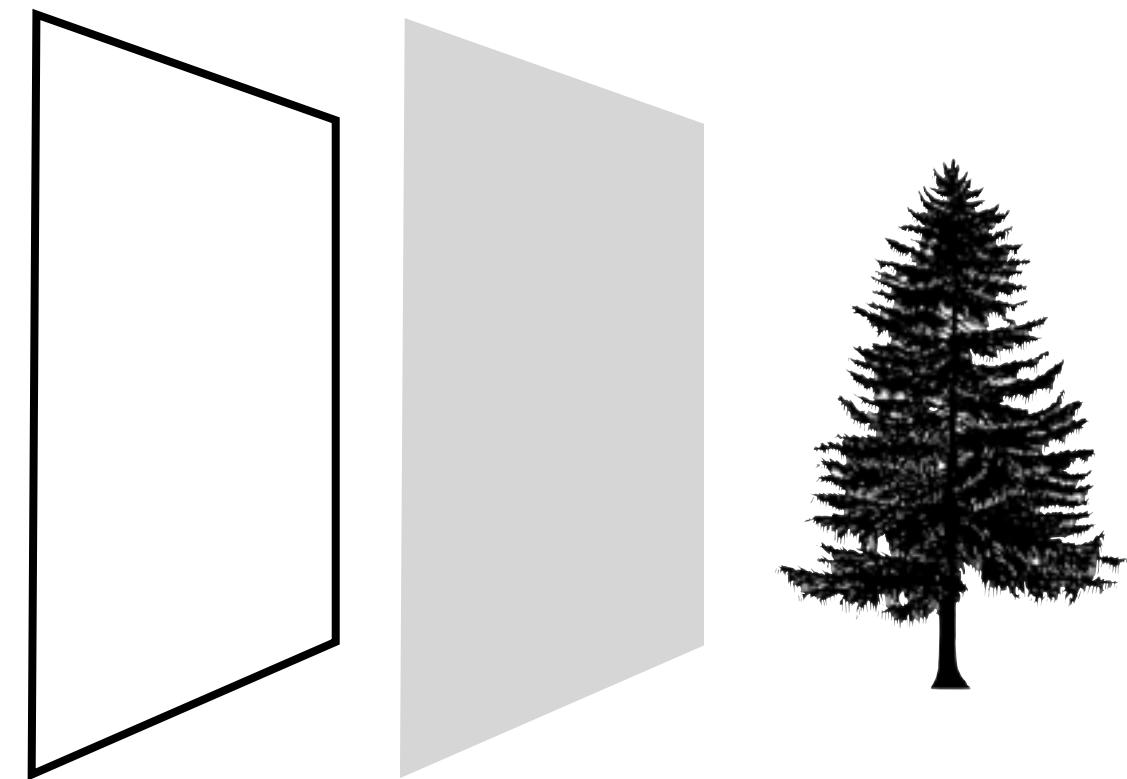
- No distortion: Straight Lines remain straight
- Infinite depth of field: Everything in focus (but there is optical blurring)

Slide adapted from Marc Levoy

Pinhole Size and Image Quality

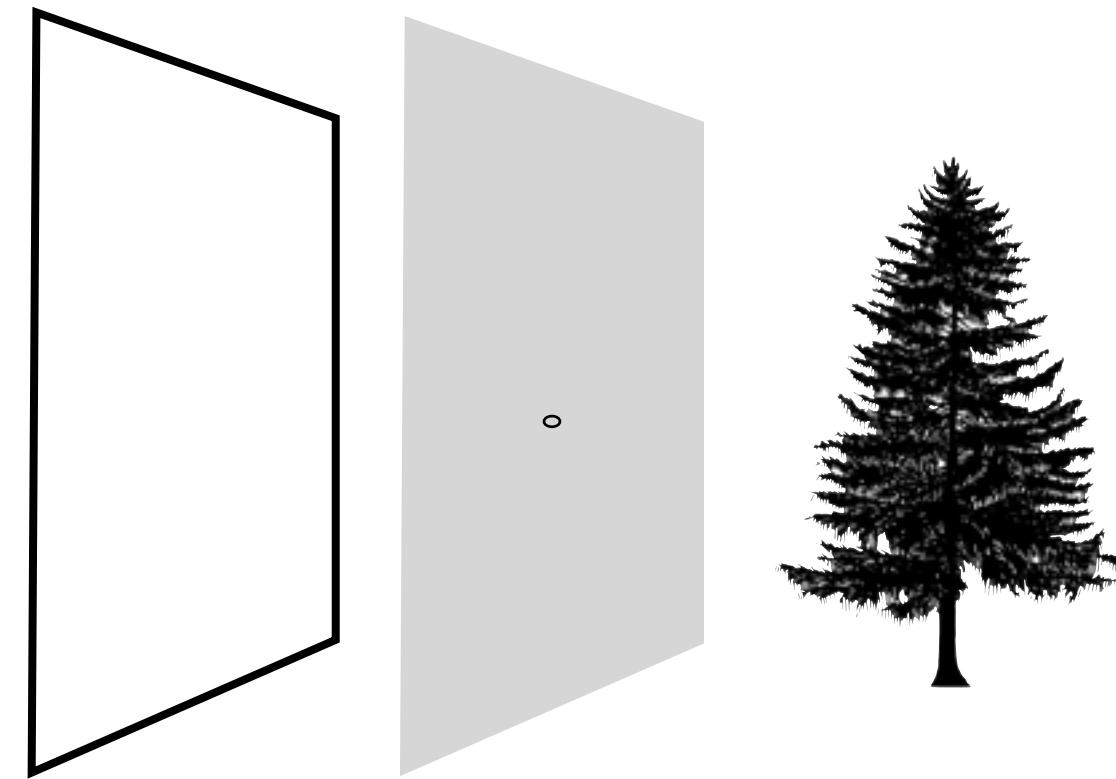
Pinhole Size and Image Quality

Pinhole Size = Aperture!



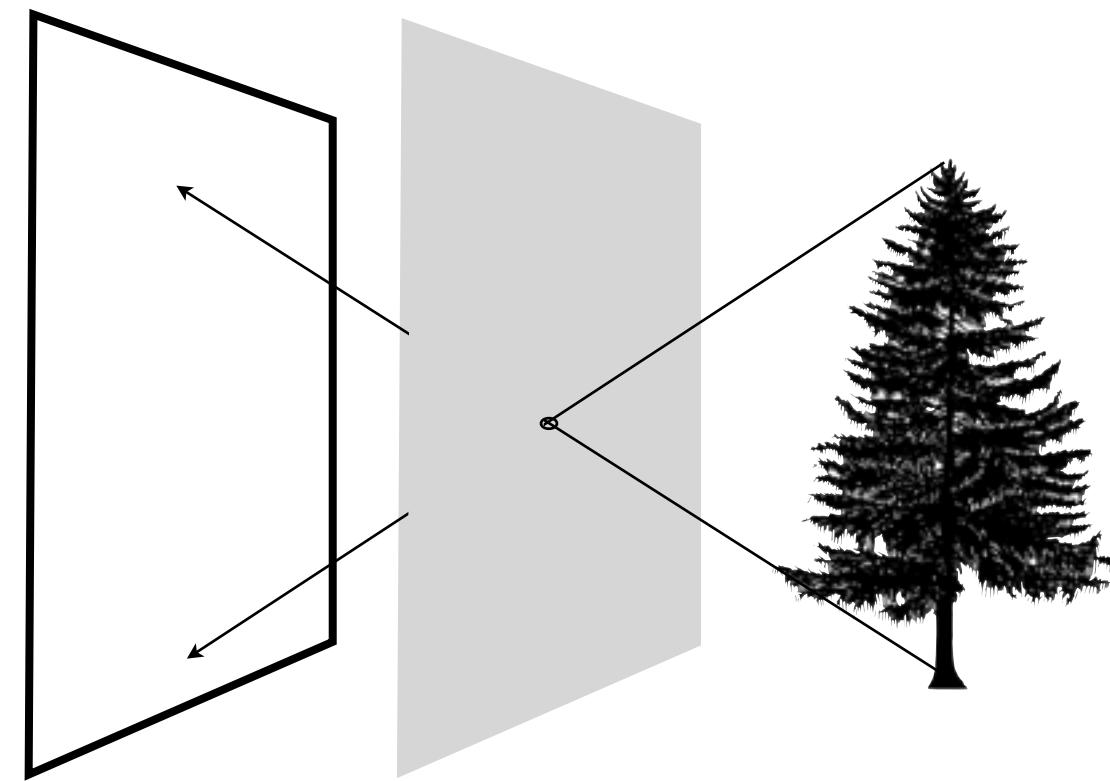
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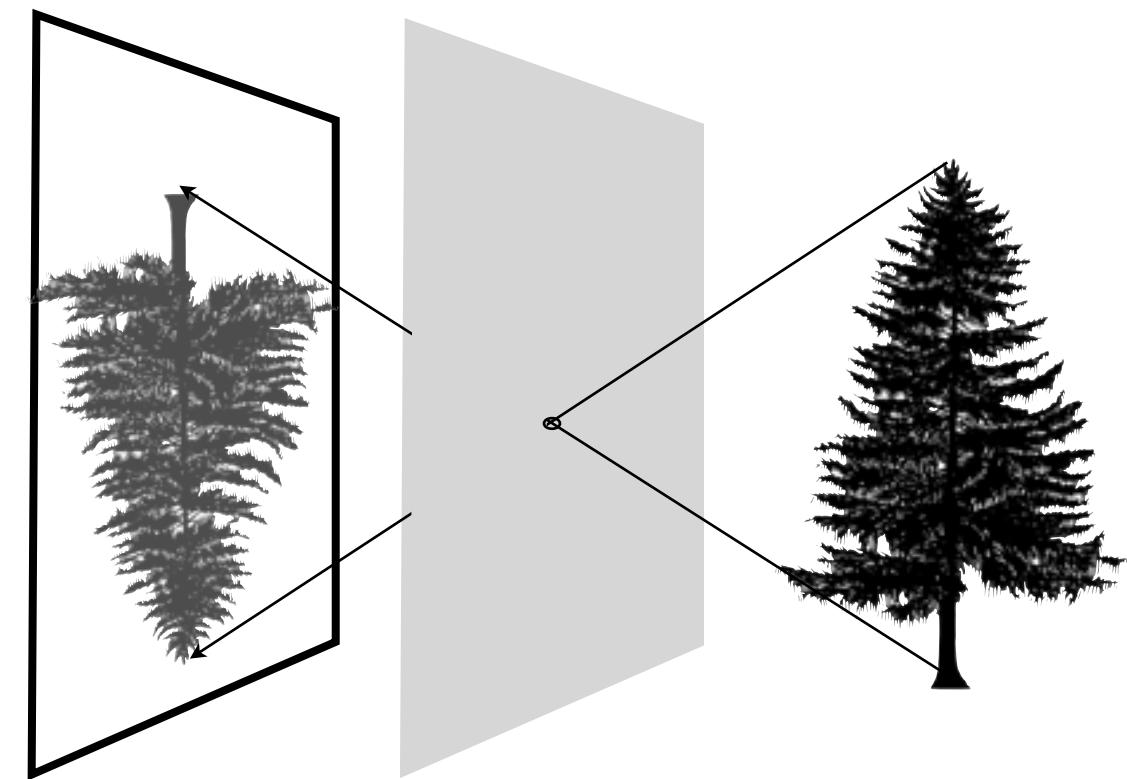
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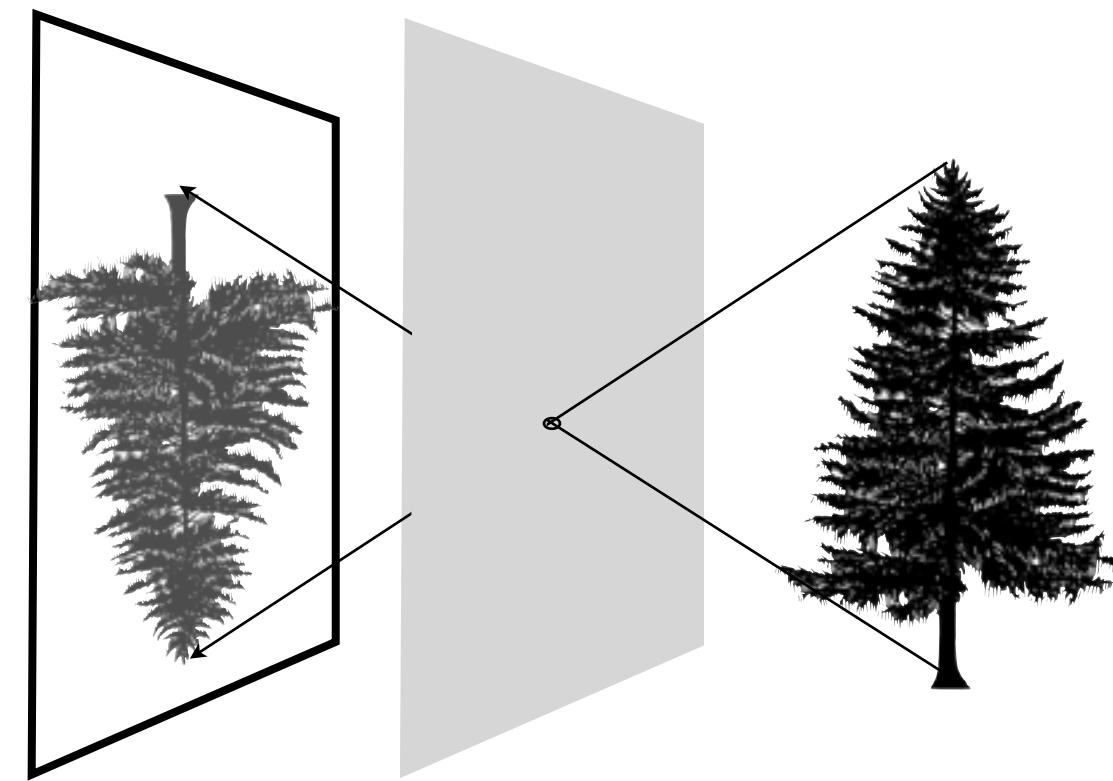
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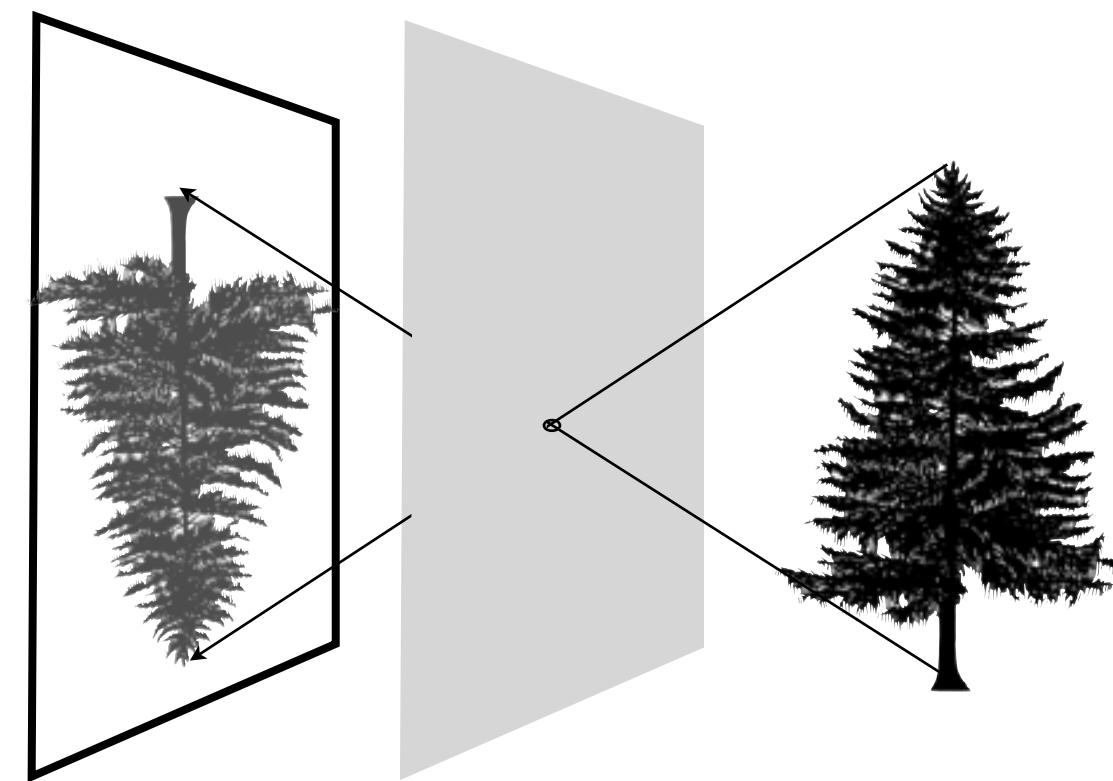
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Pinhole Size and Image Quality

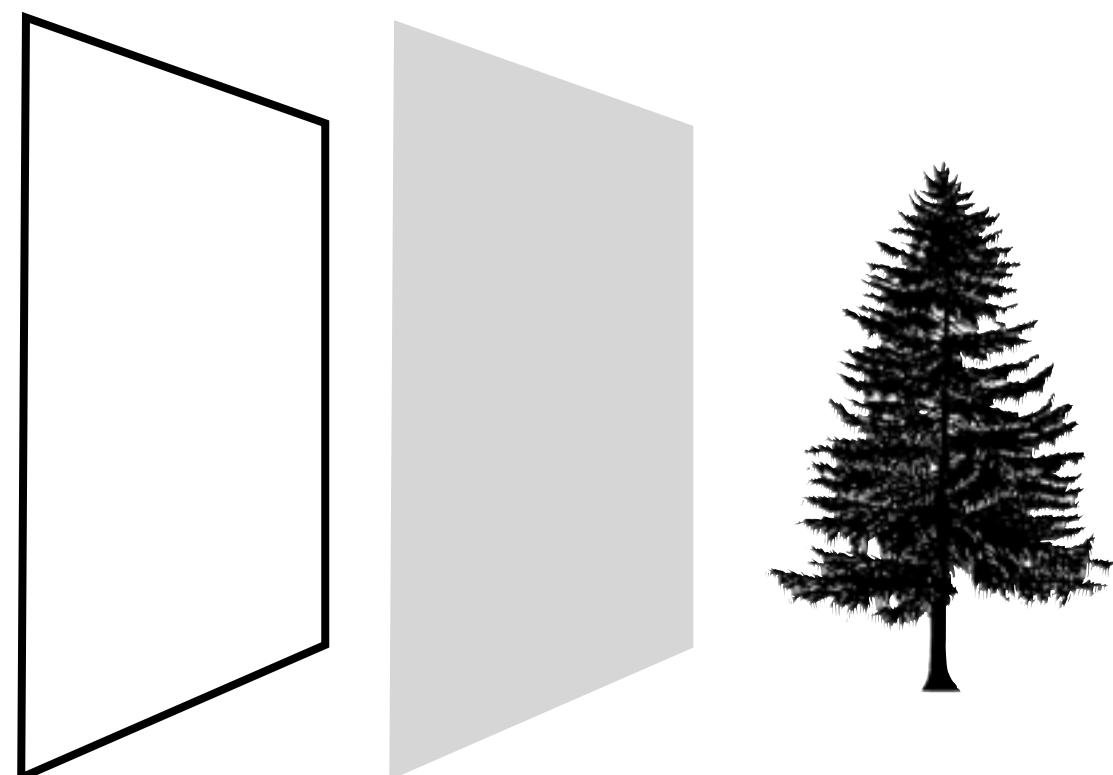
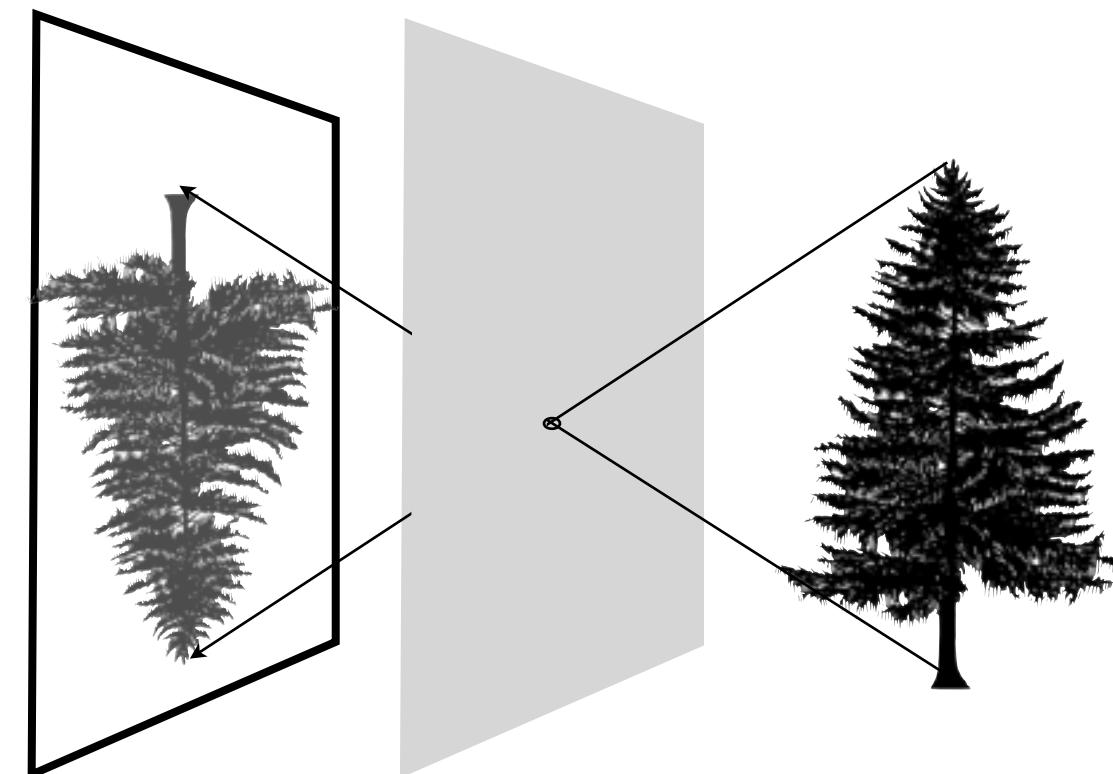
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Pinhole Size and Image Quality

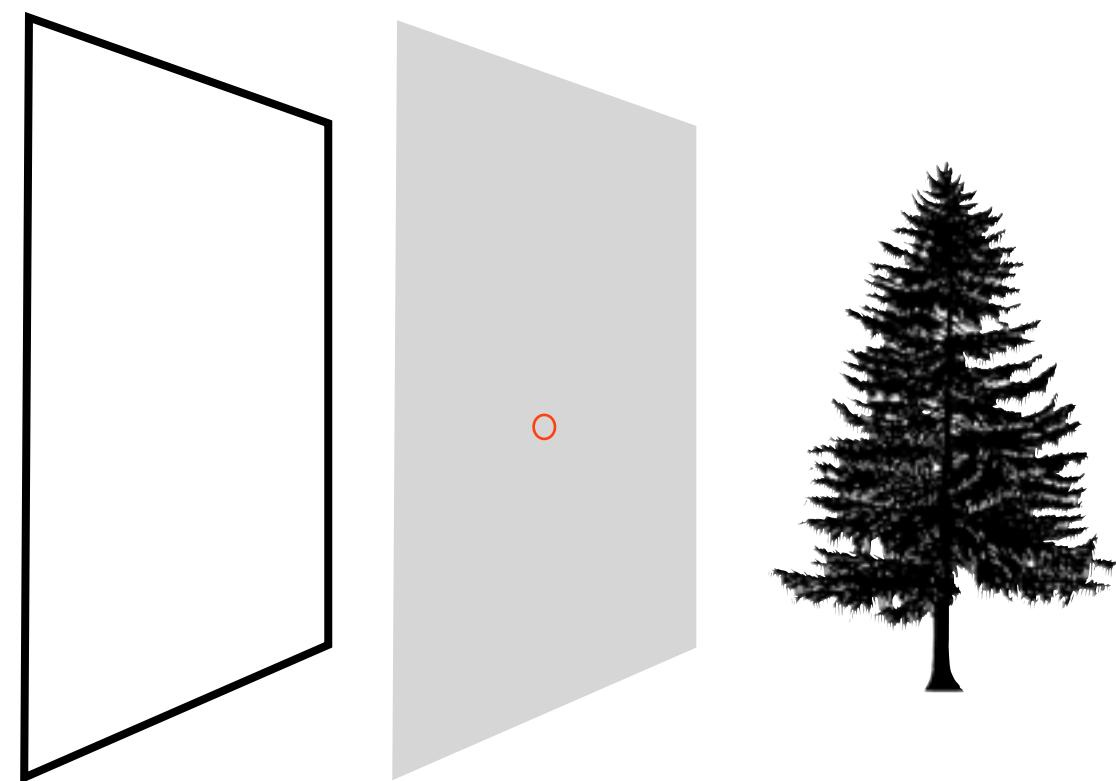
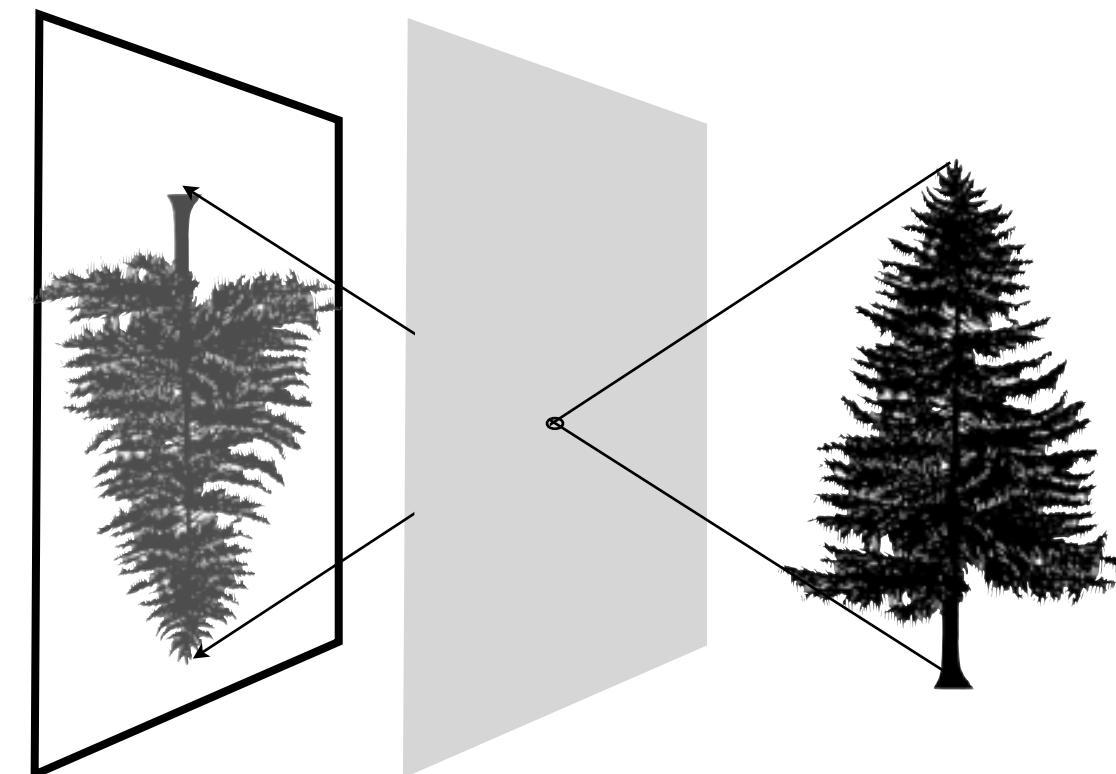
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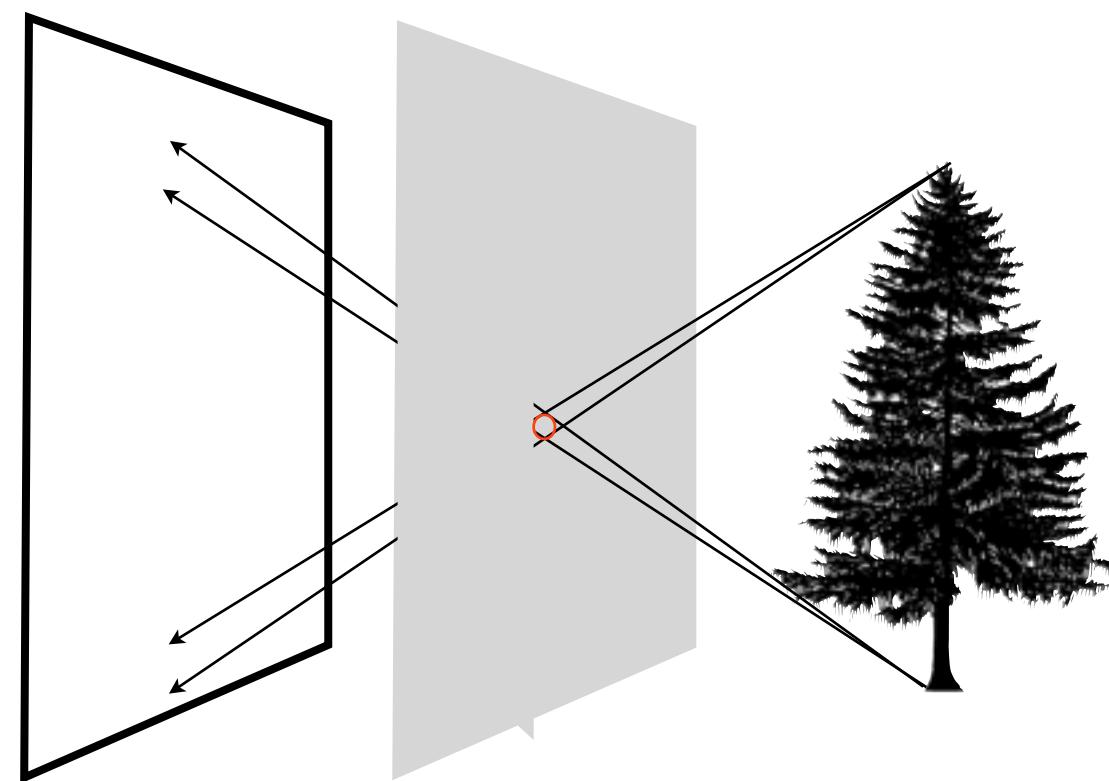
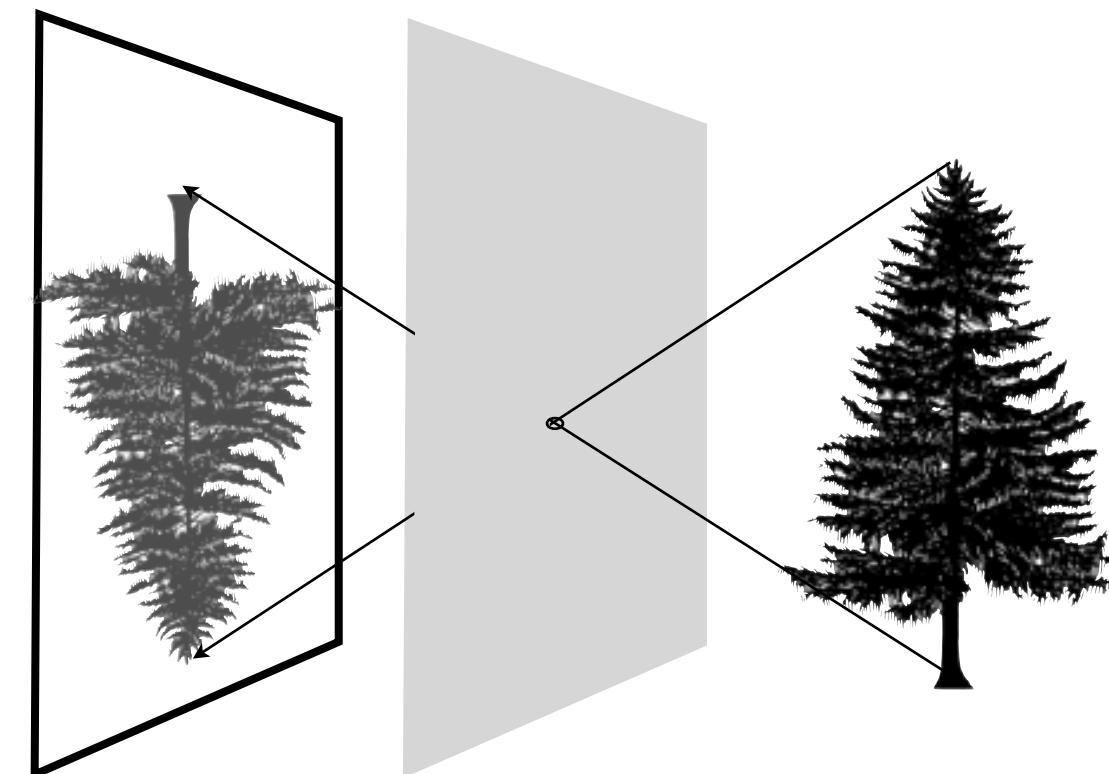
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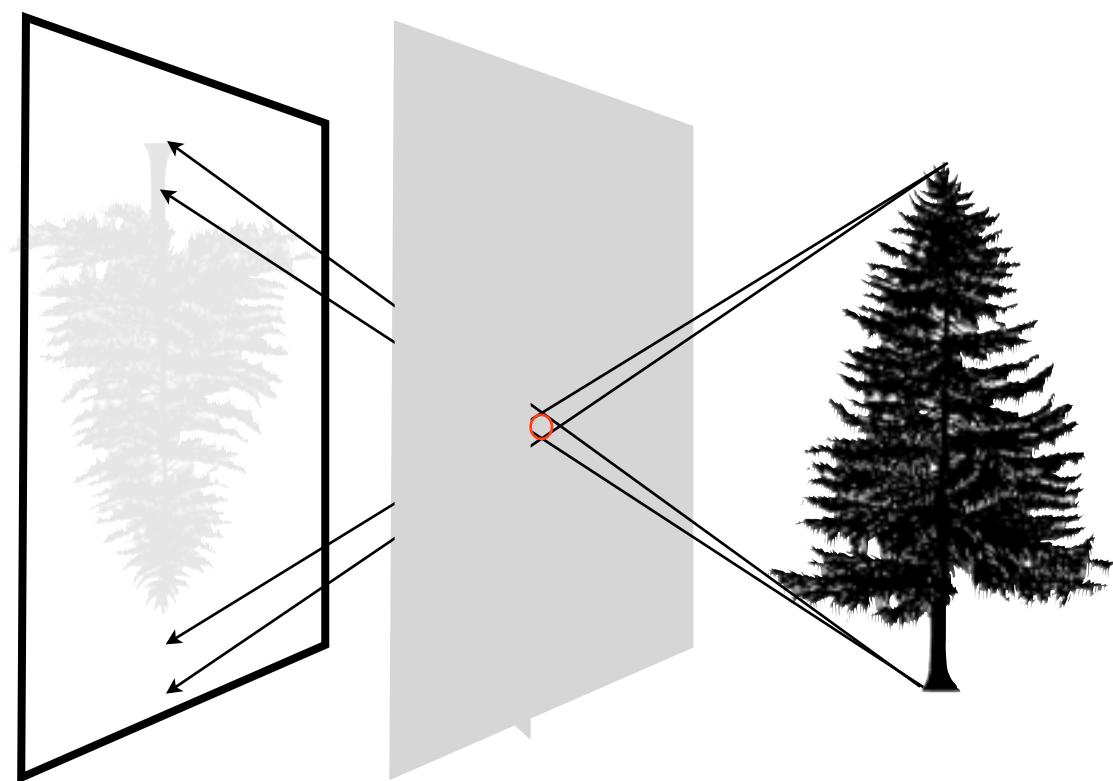
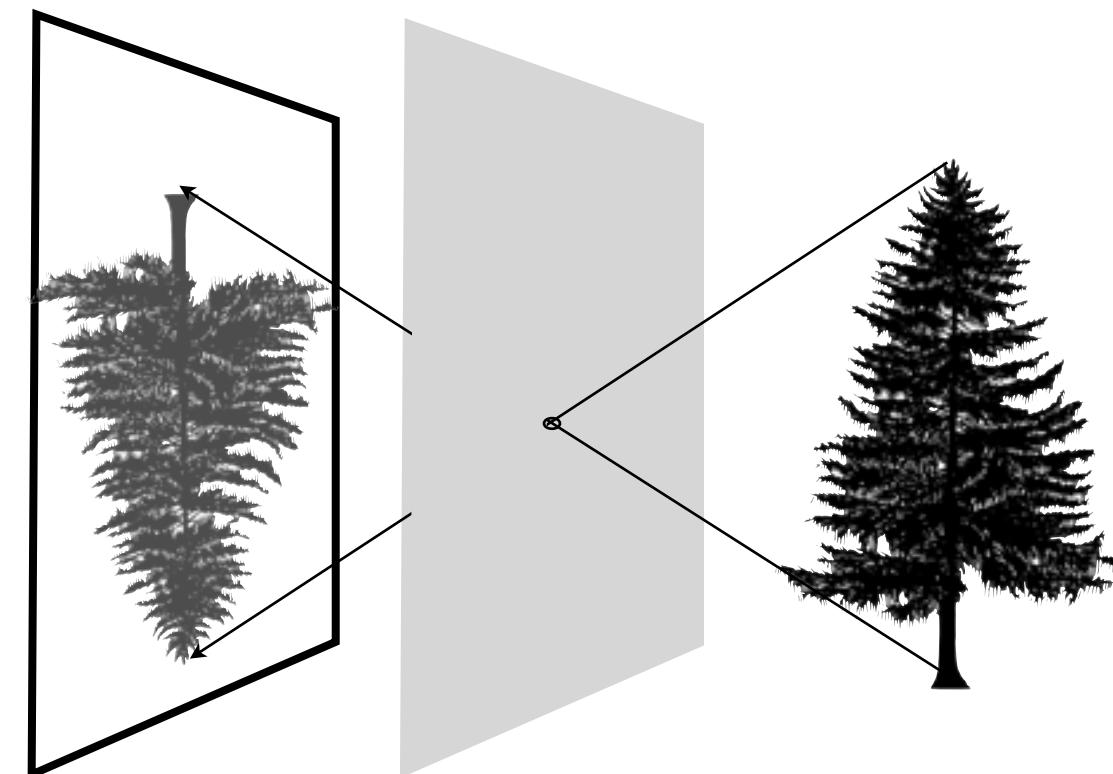
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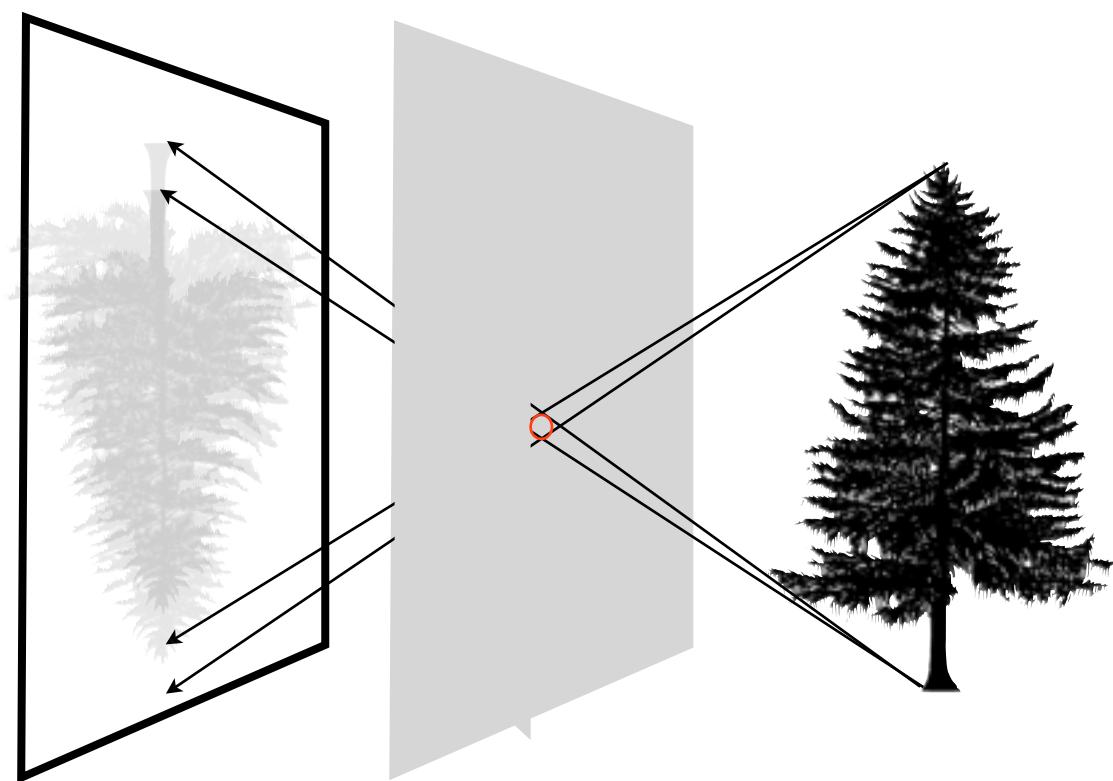
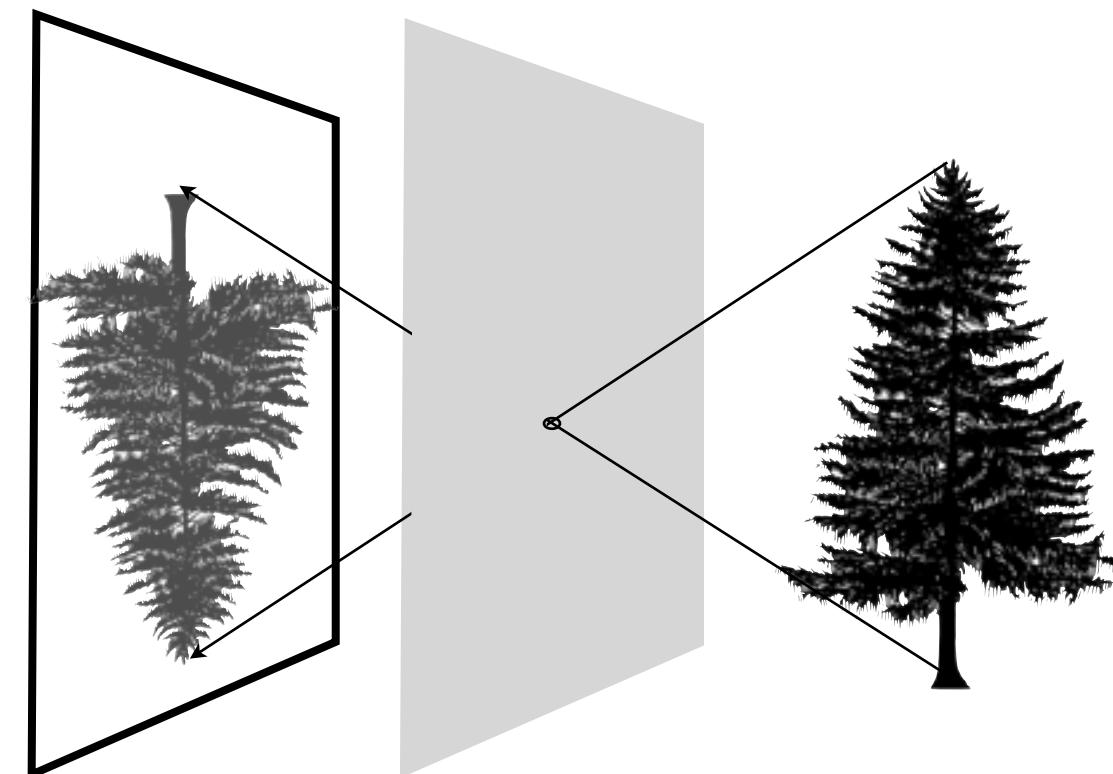
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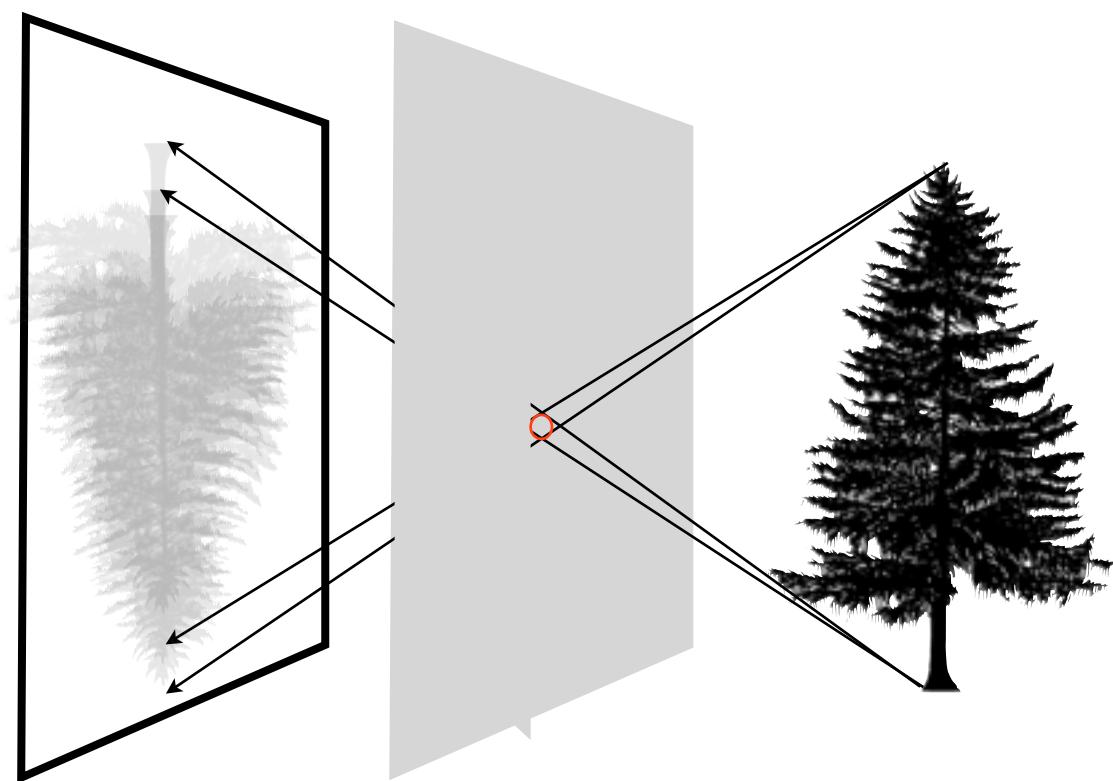
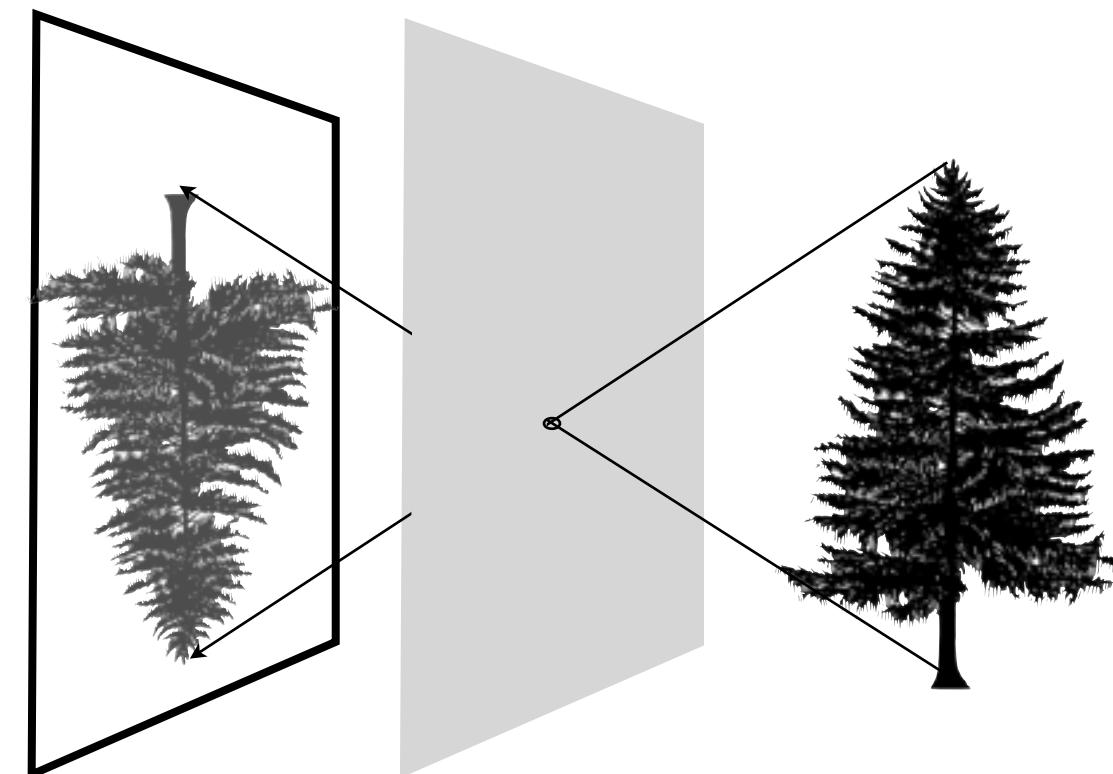
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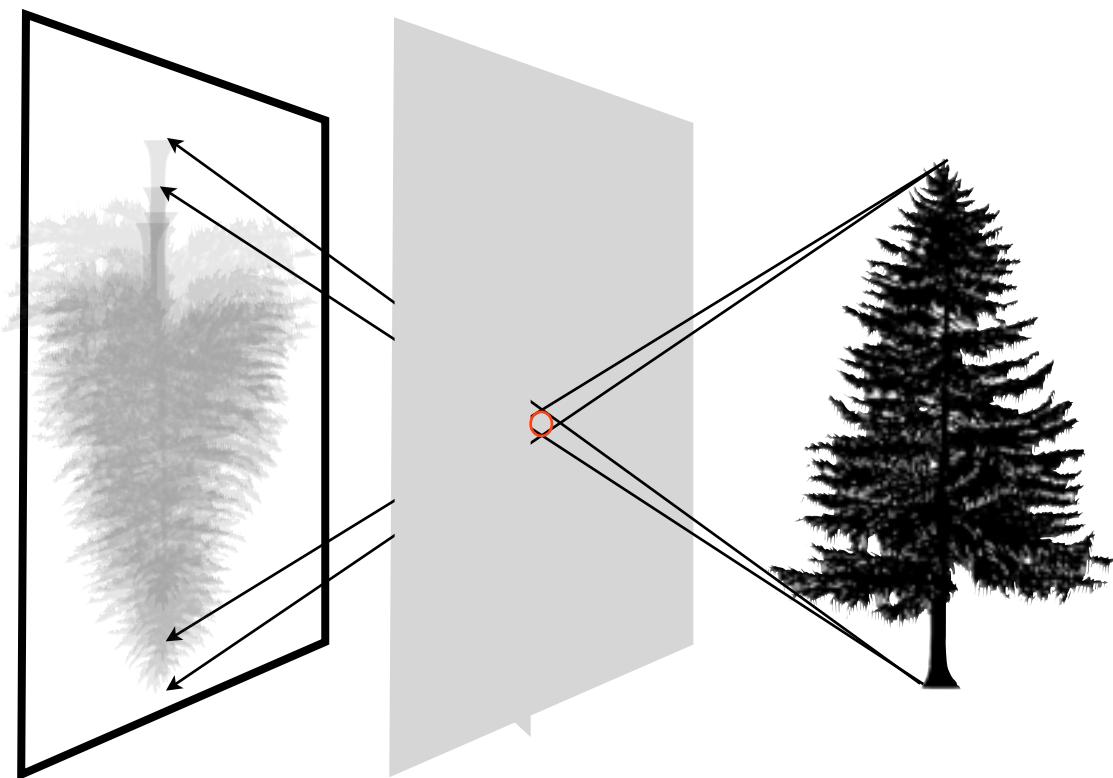
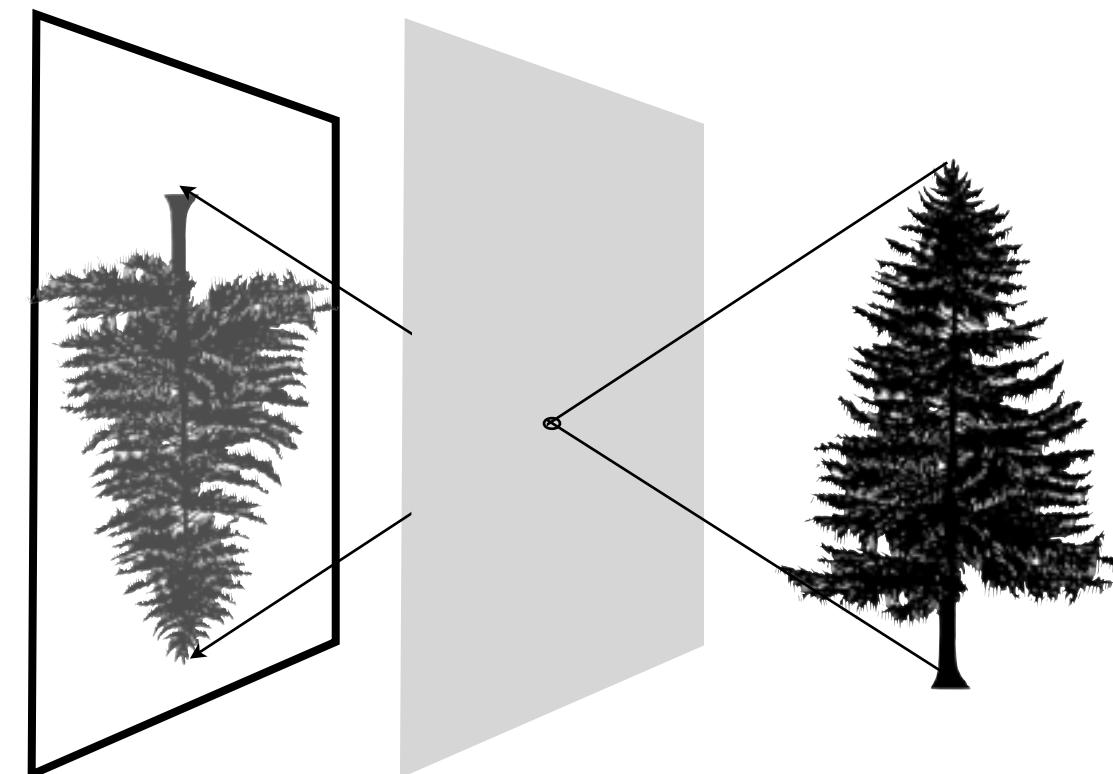
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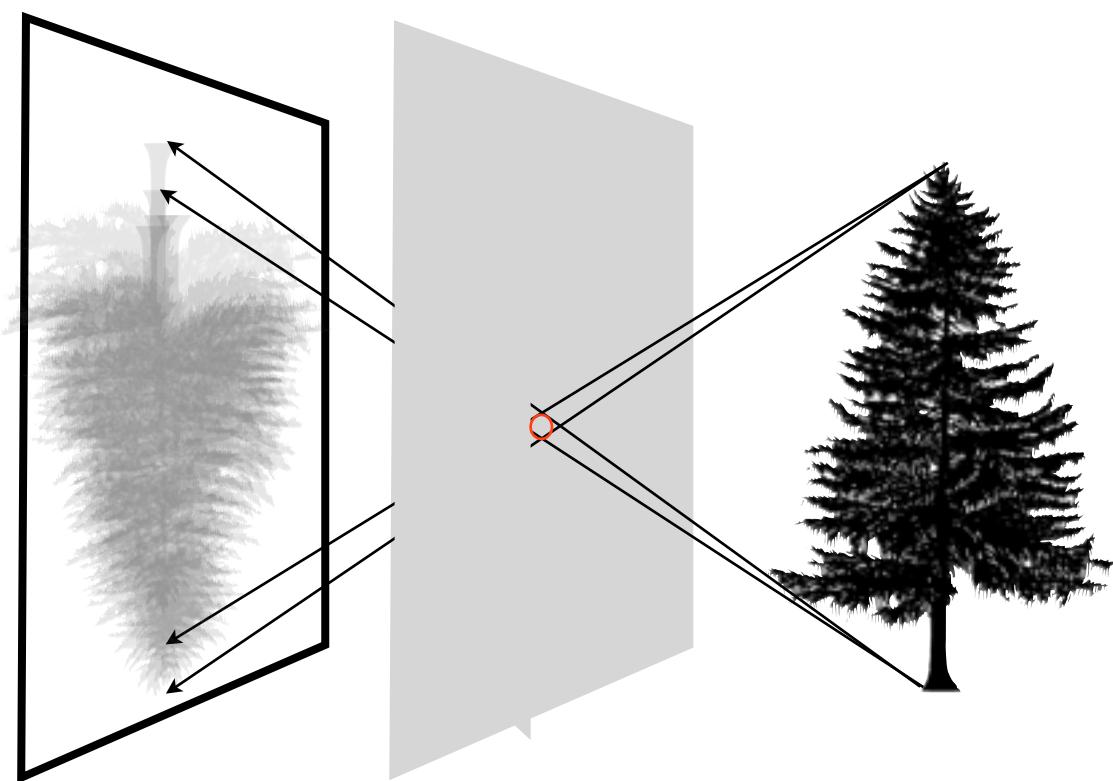
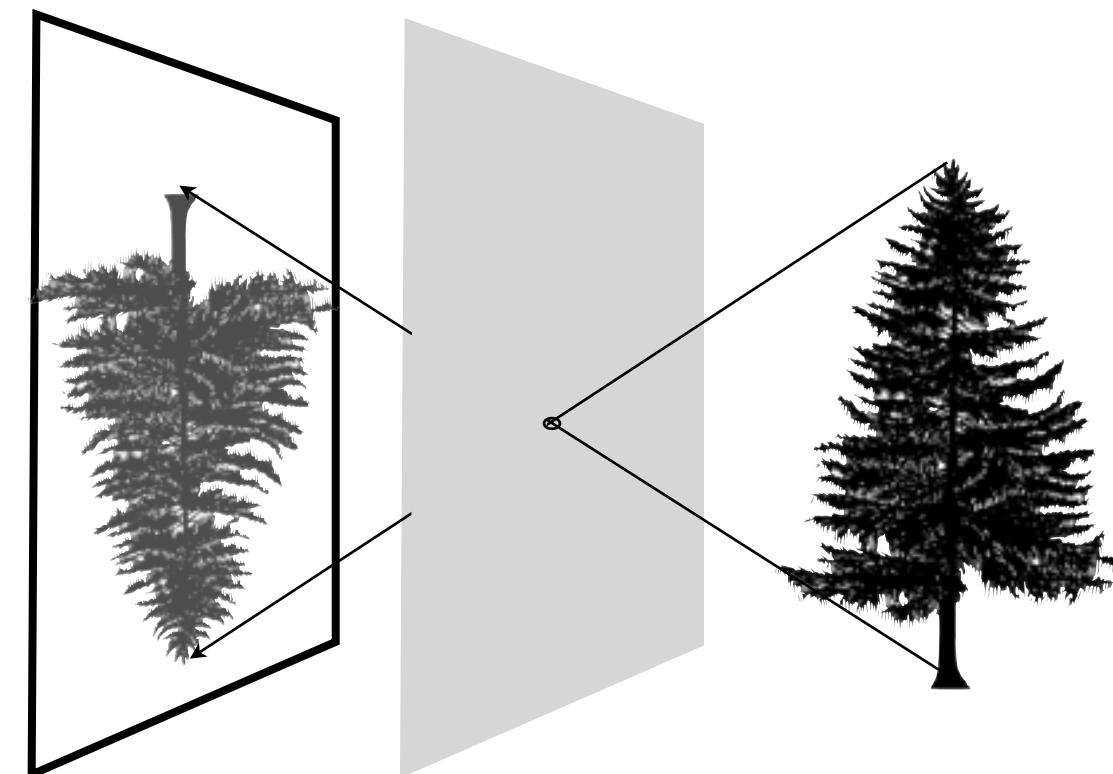
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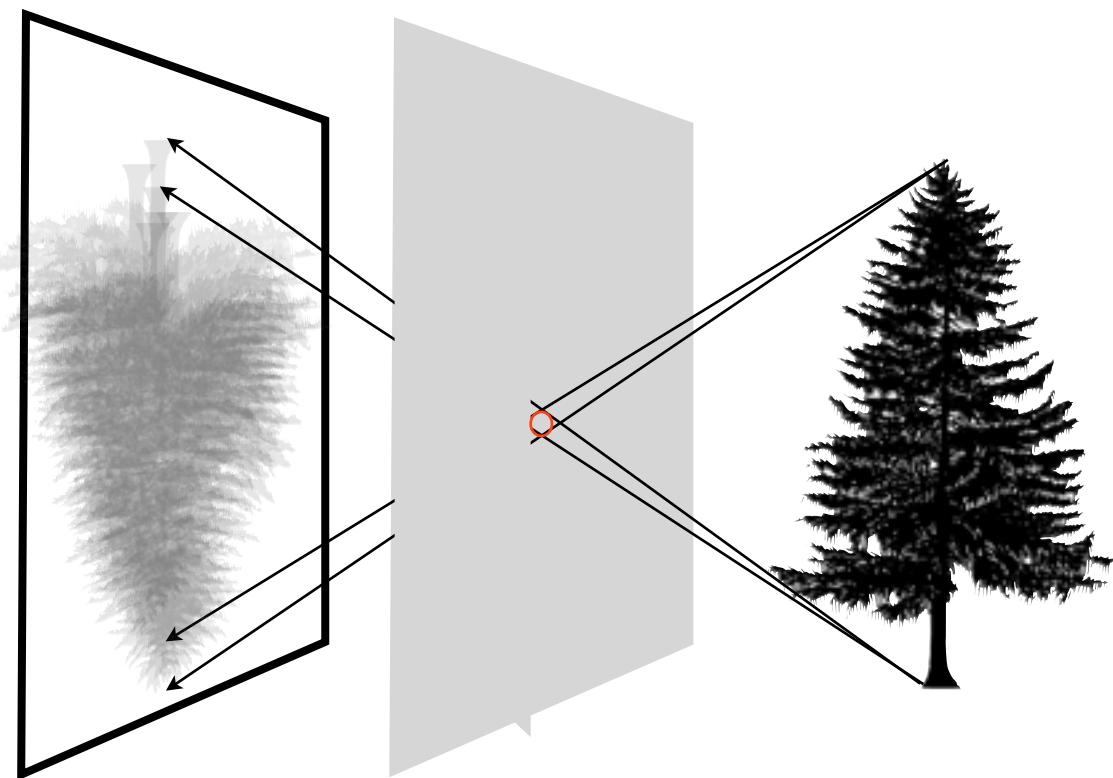
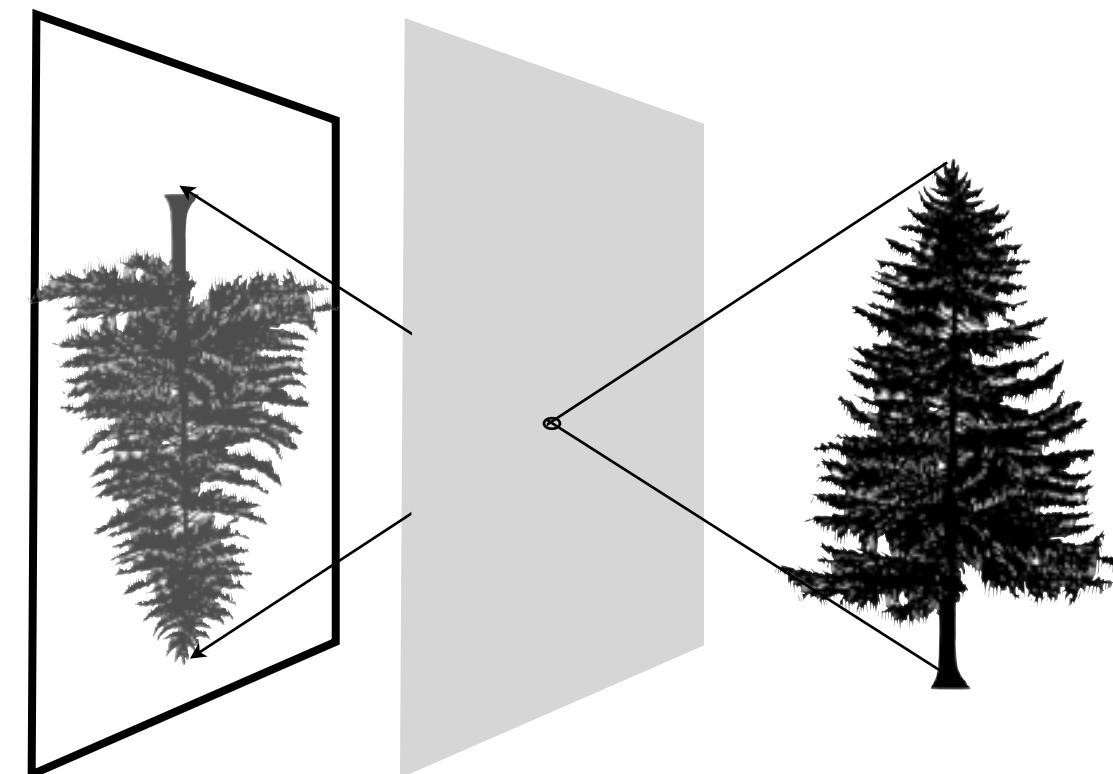
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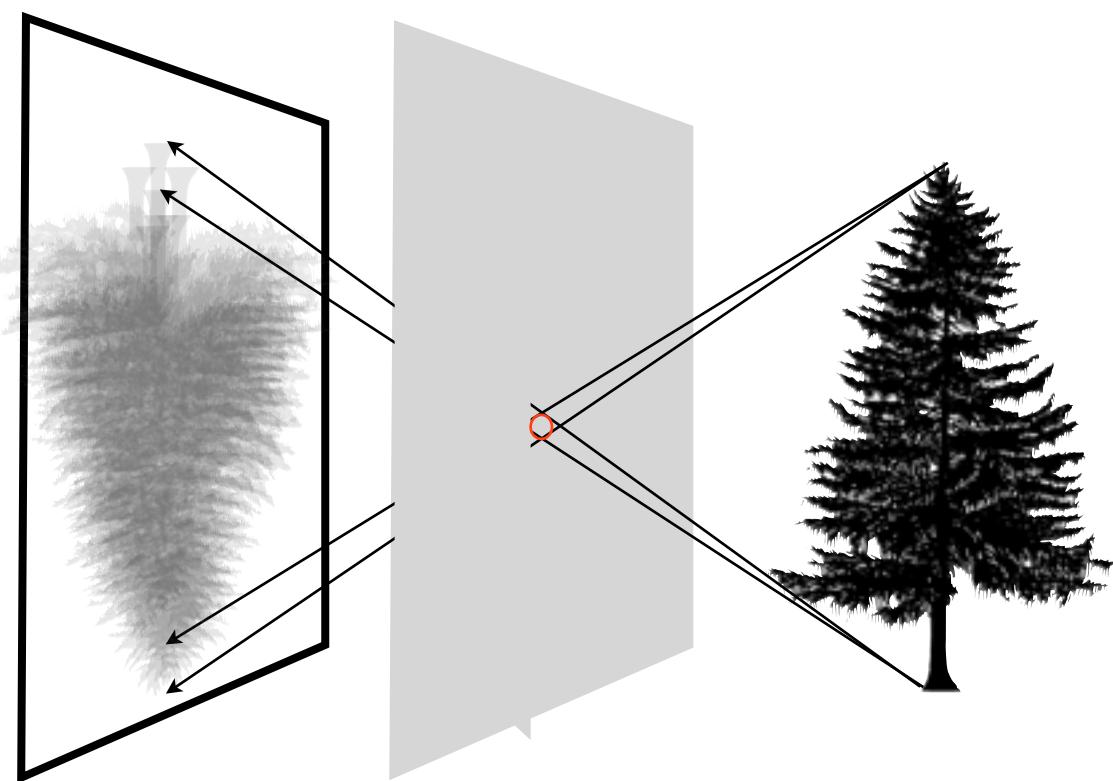
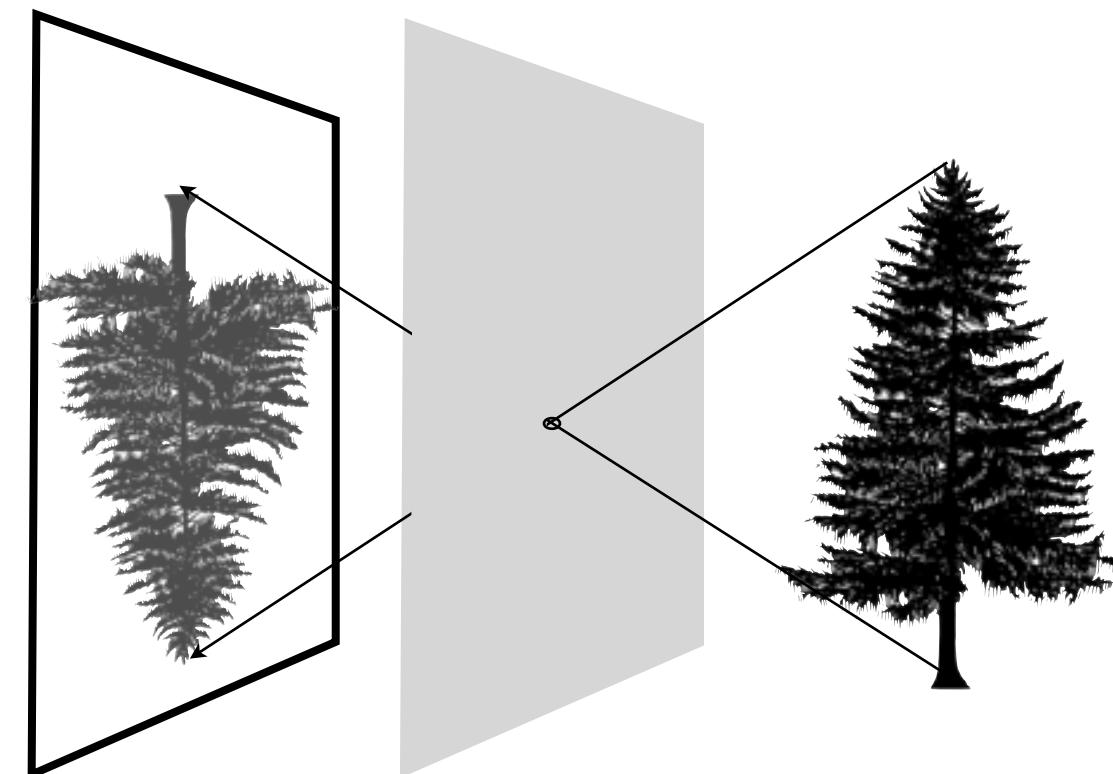
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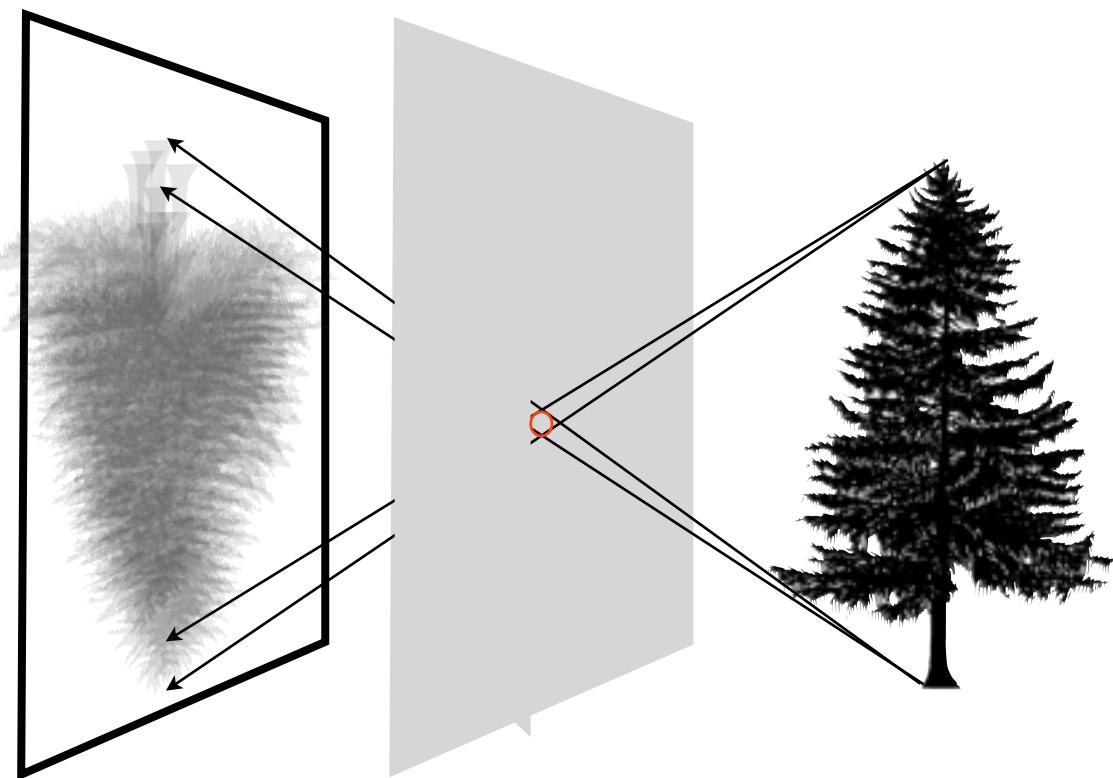
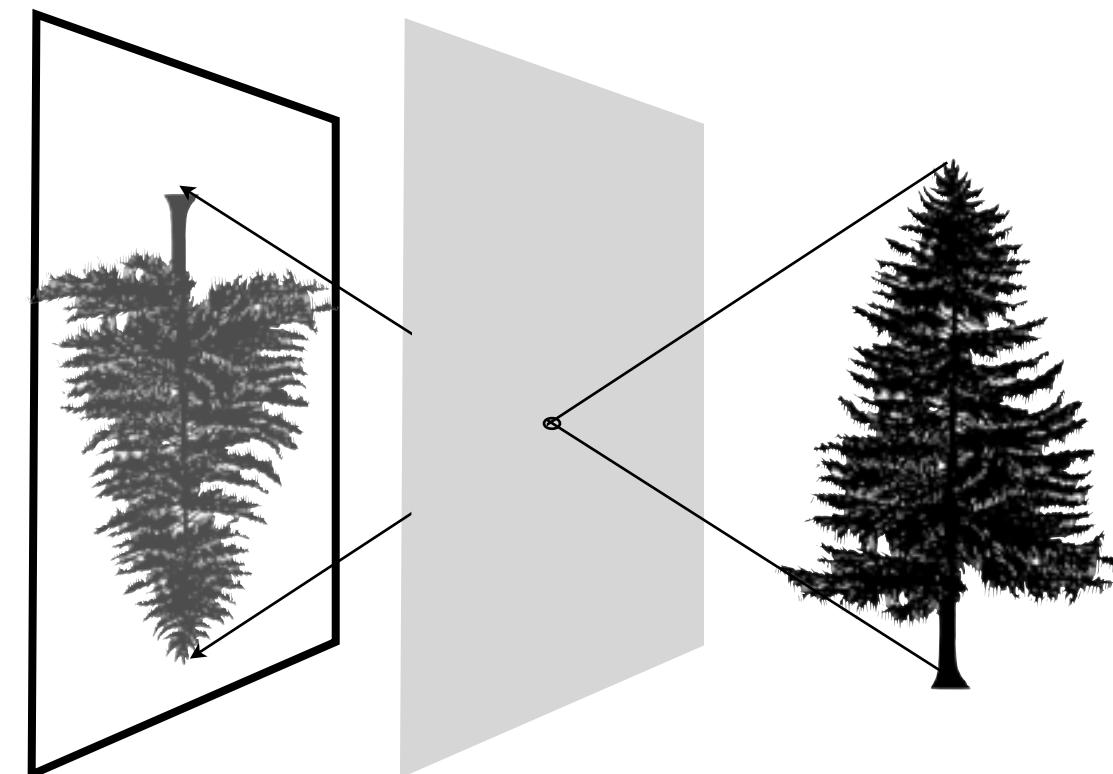
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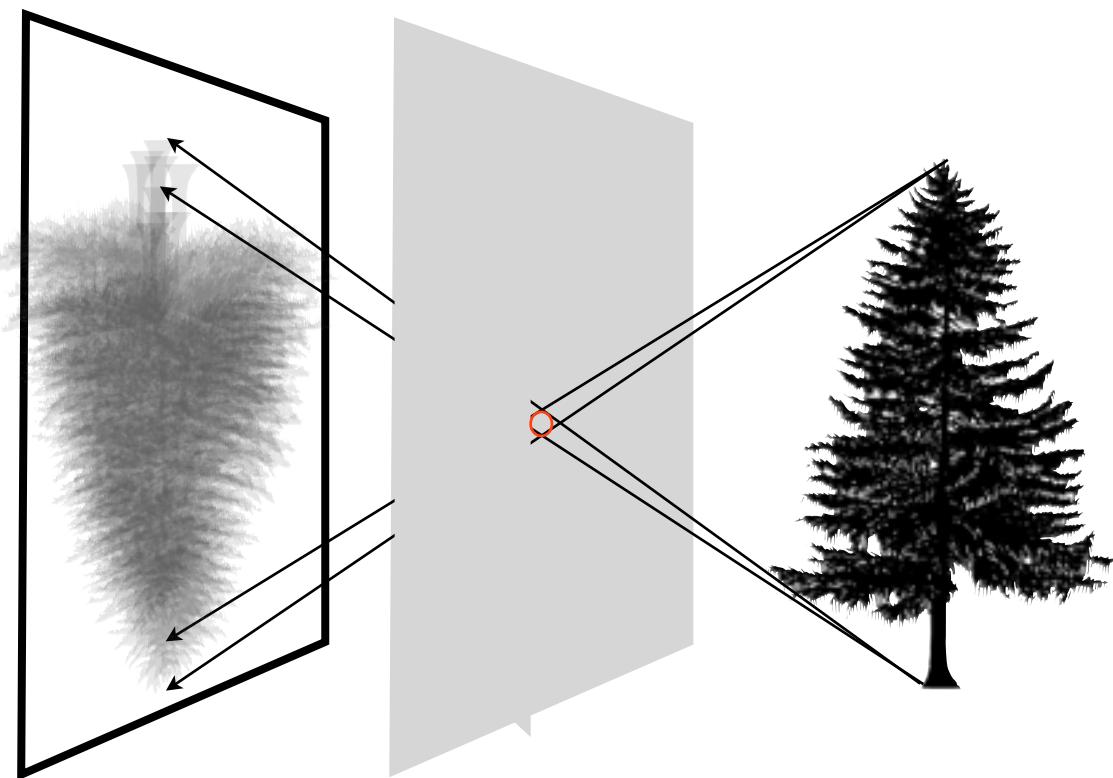
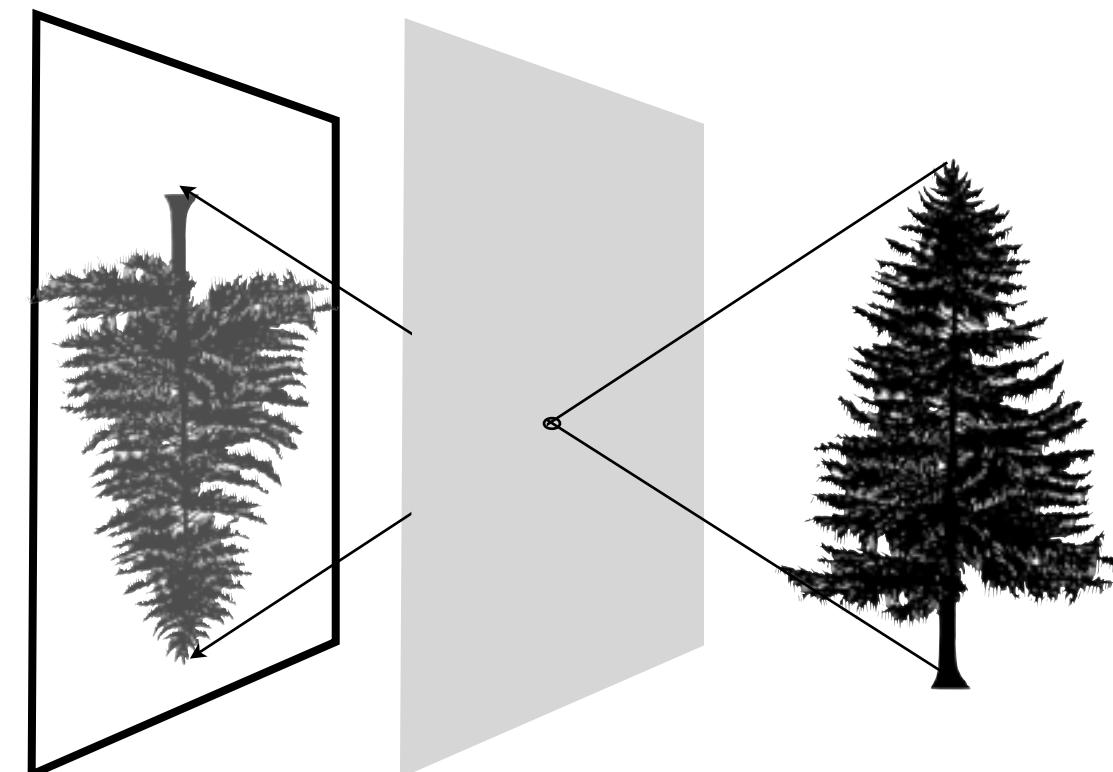
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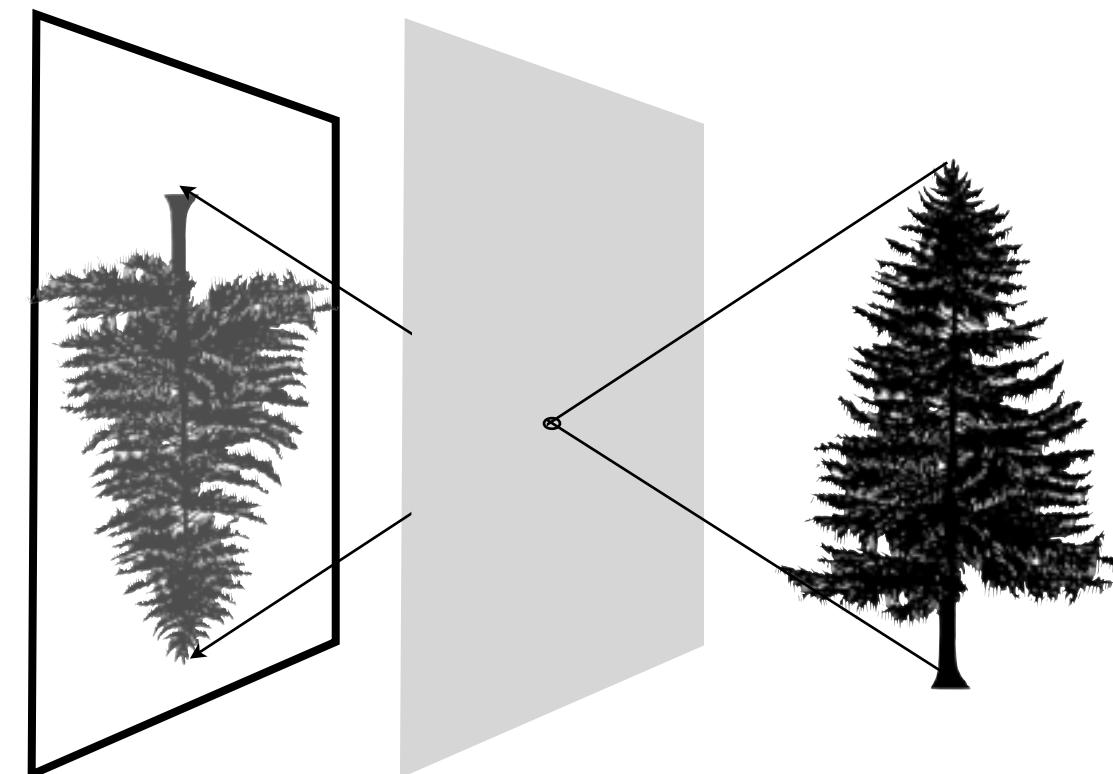
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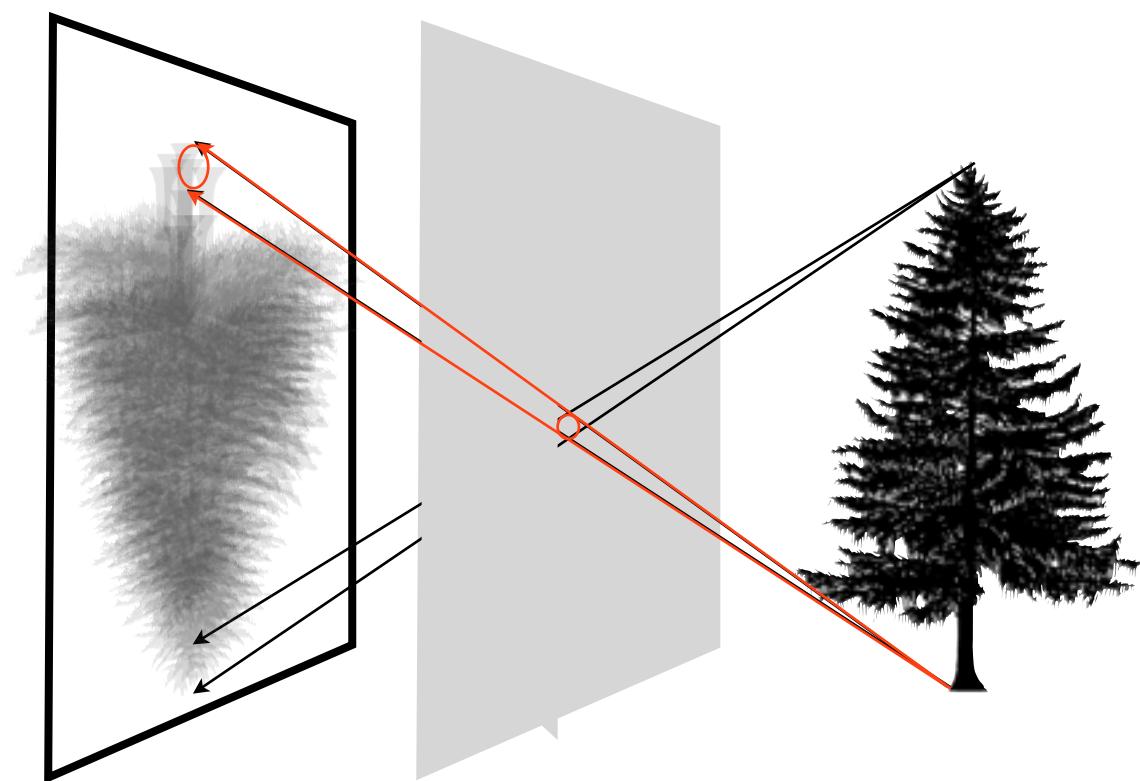
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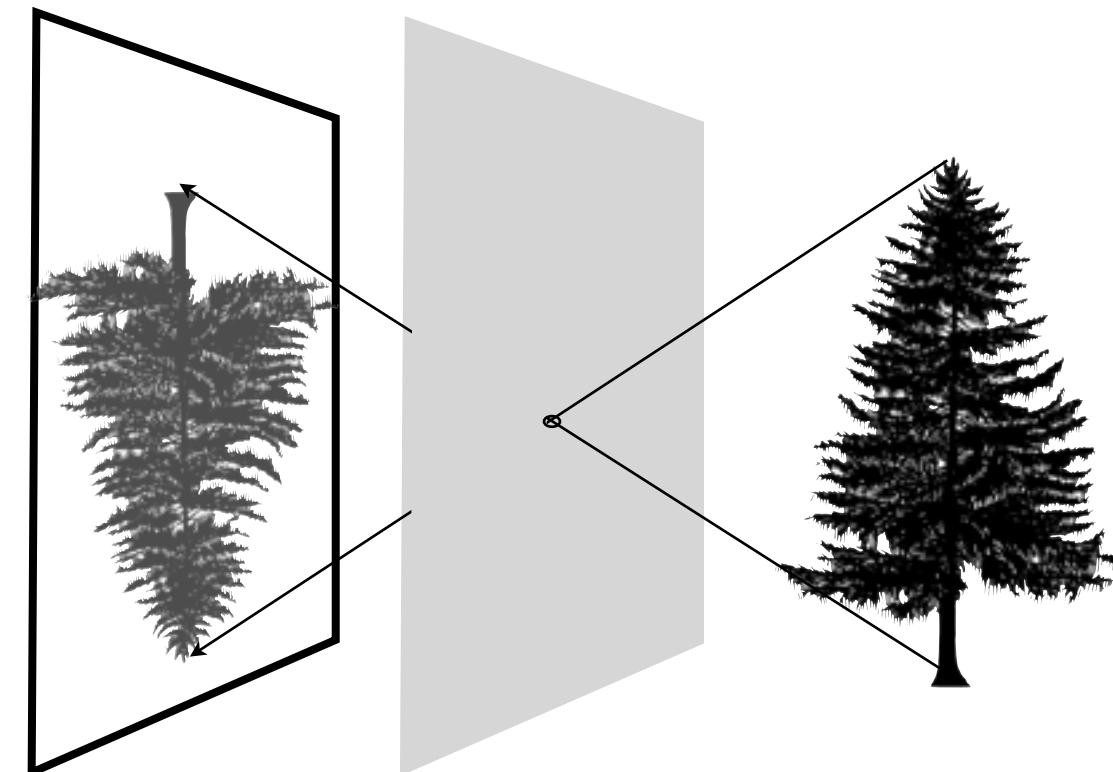
Pinhole Size = Aperture!



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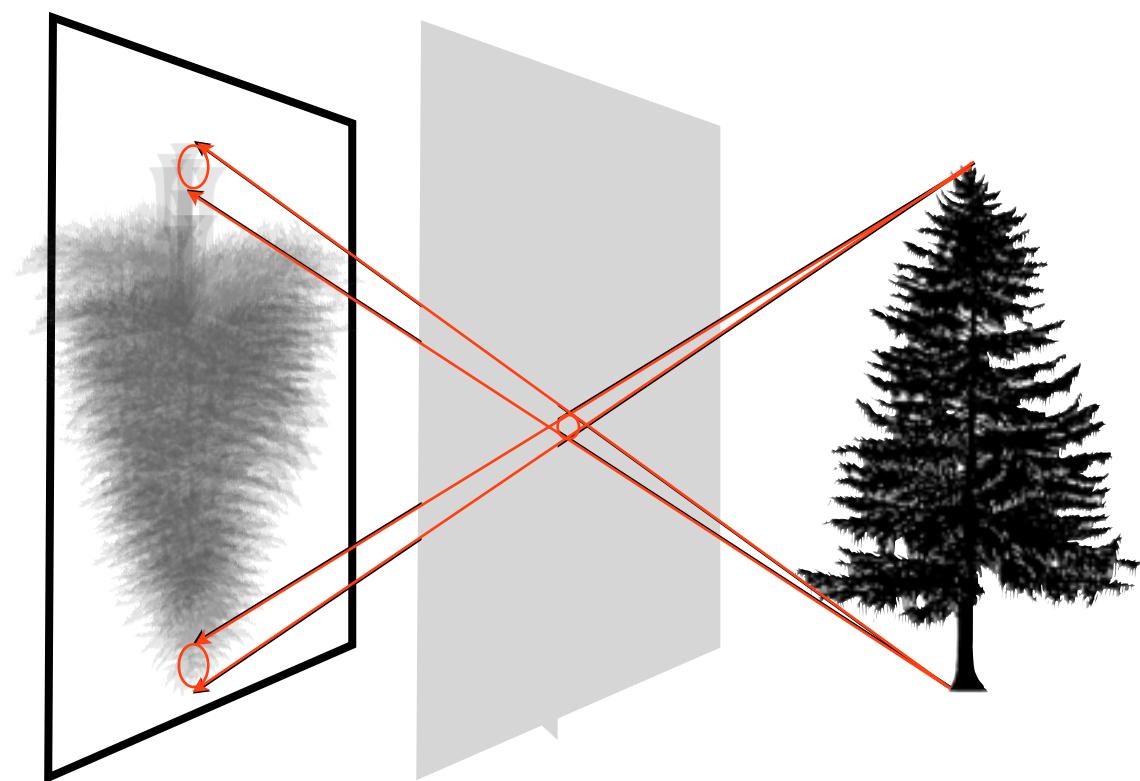
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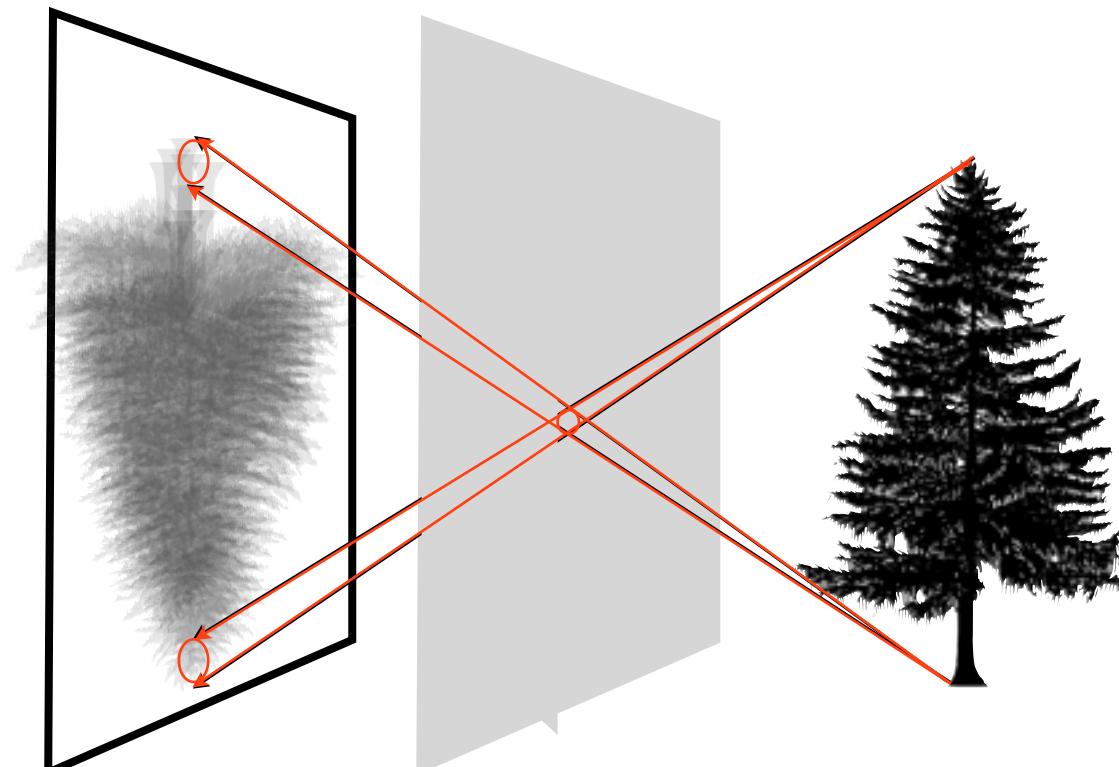
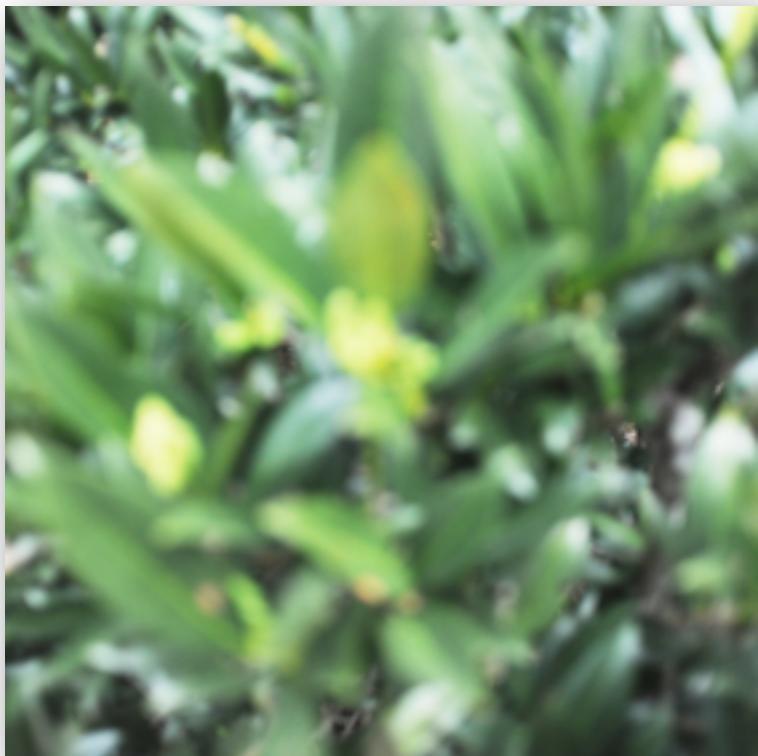
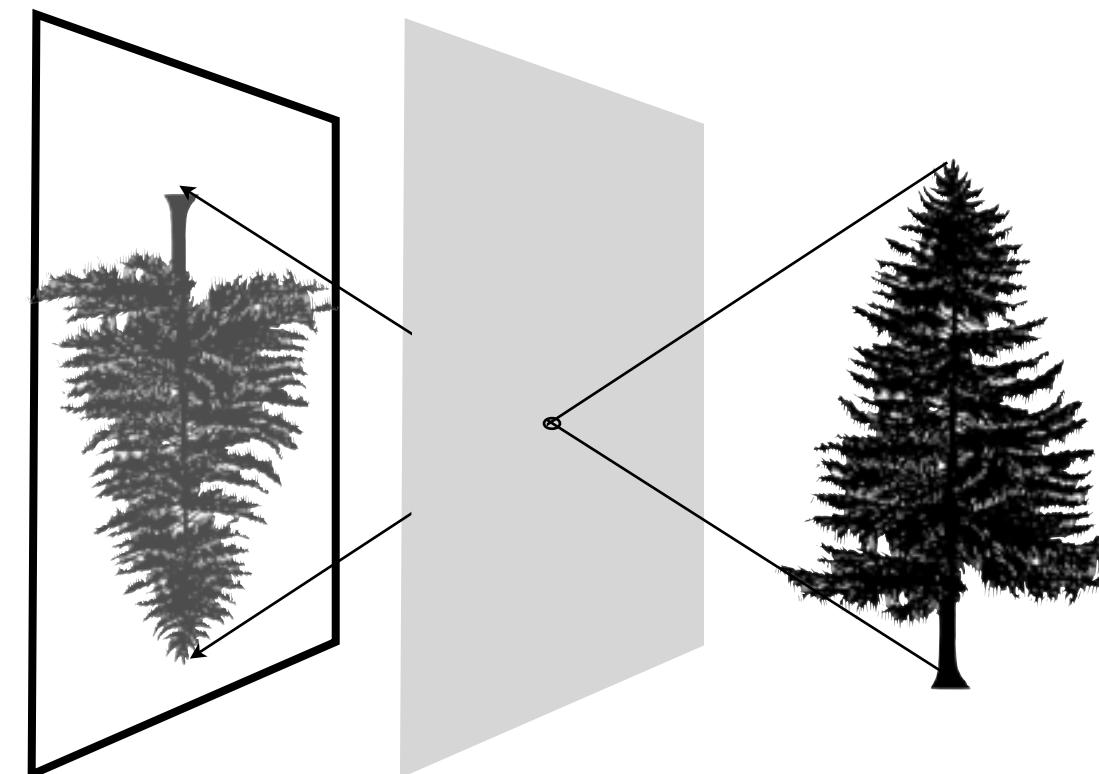




Pinhole Size and Image Quality

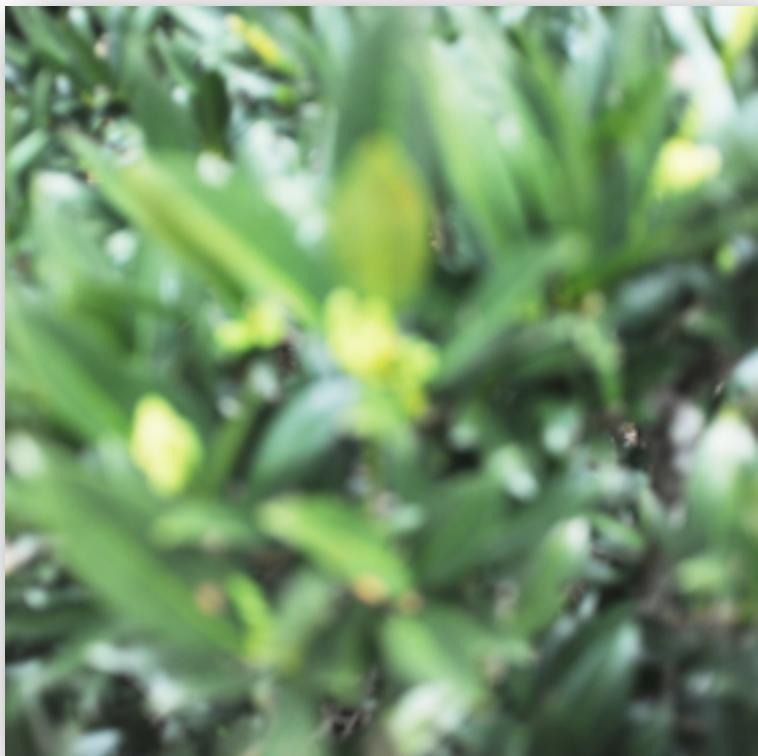
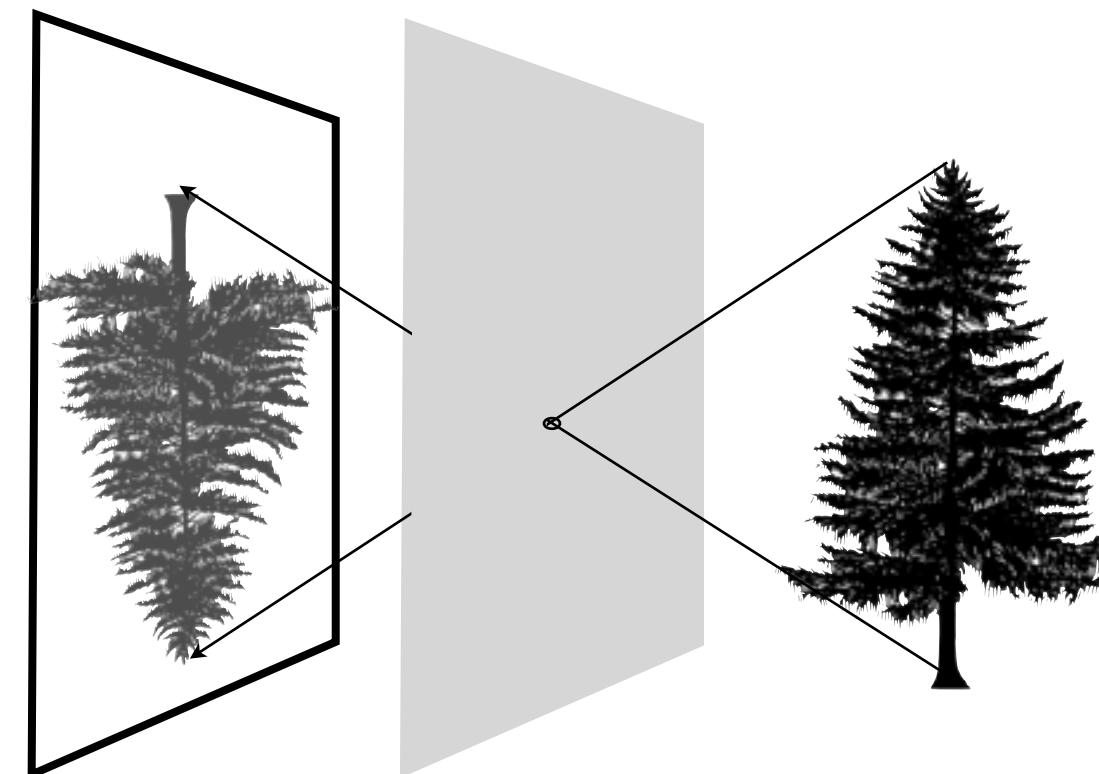
Pinhole Size = Aperture!



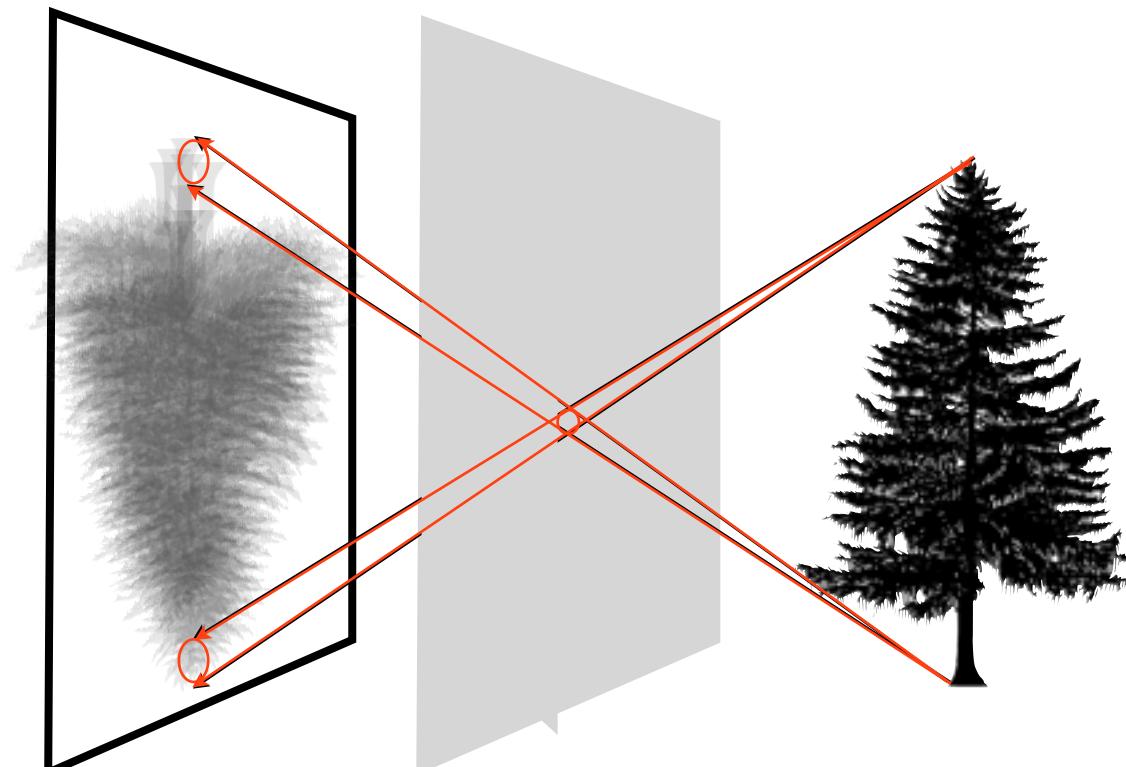


Pinhole Size and Image Quality

Pinhole Size = Aperture!

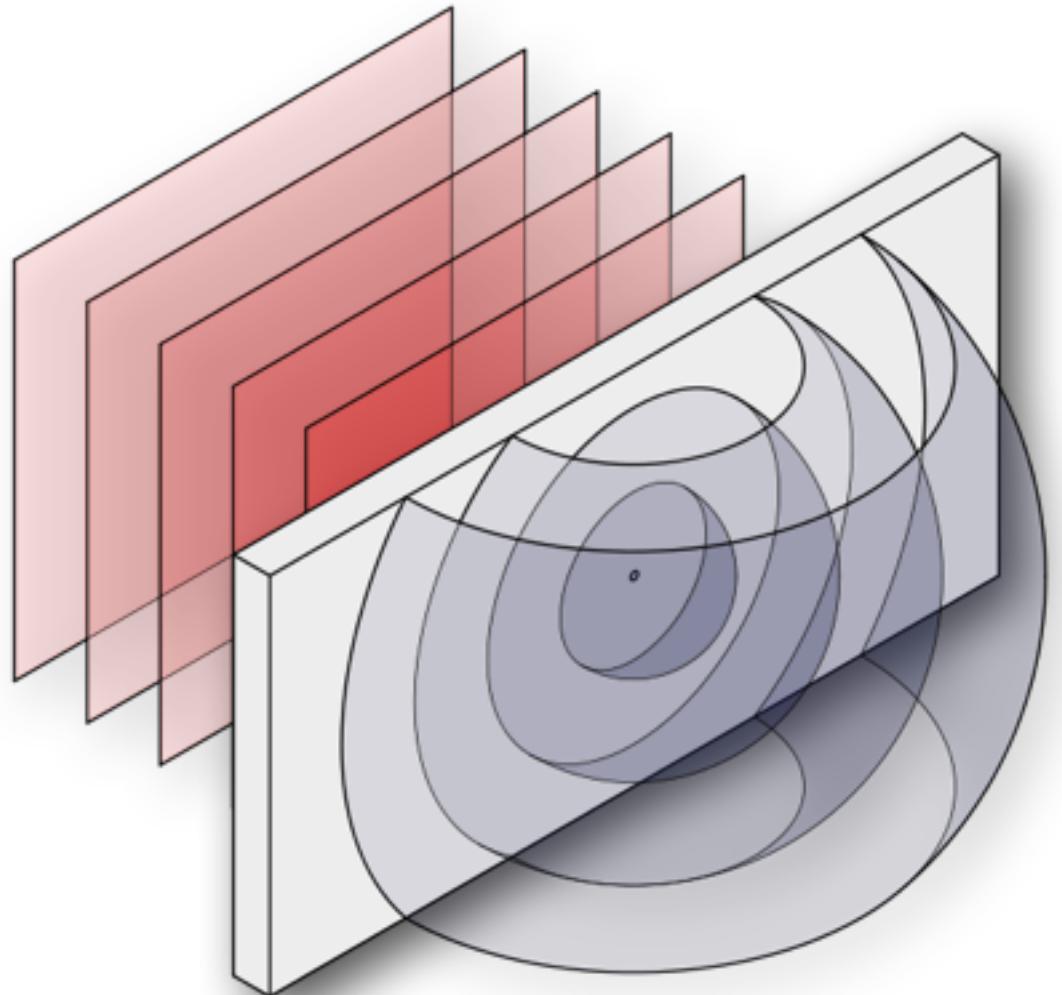


Pinhole "blur" simulated



Pinhole Size and Image Quality

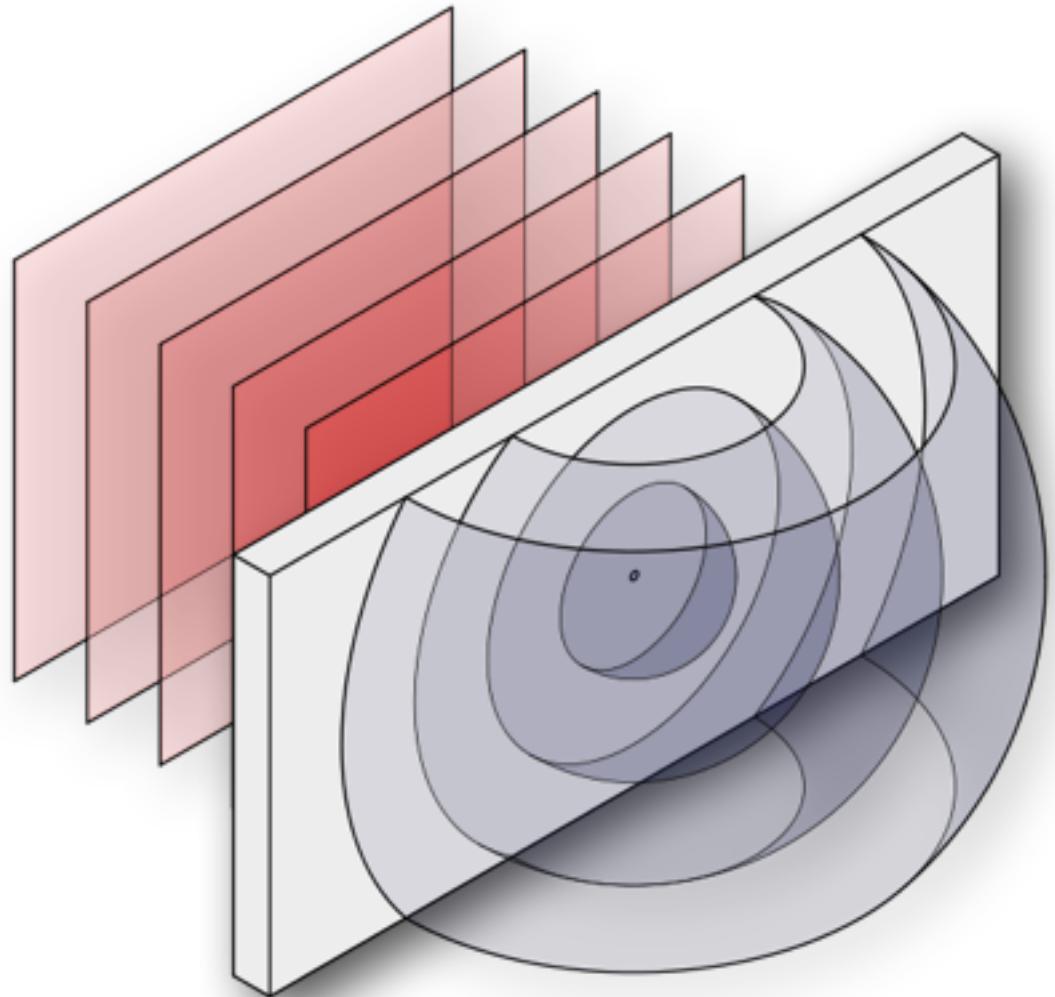
Pinhole Size = Aperture!



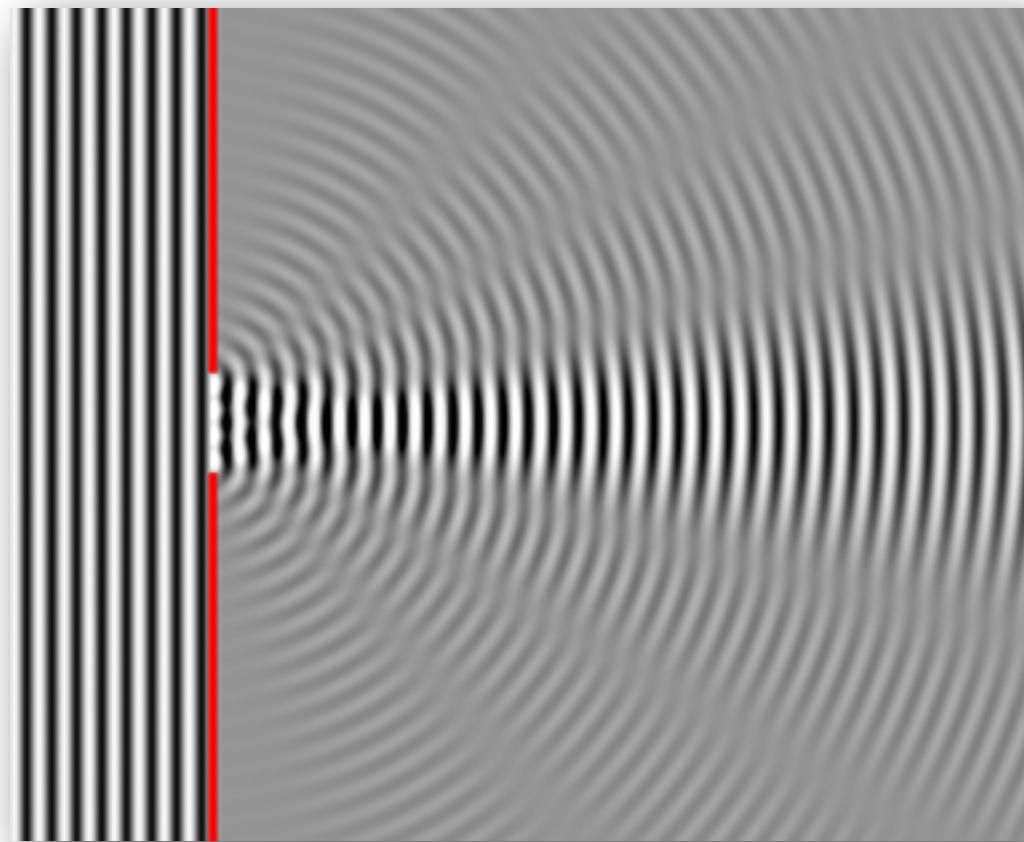
3D Schematic

- ★ Wave Nature of Light
- ★ Smaller Aperture means more Diffraction

Light
Diffracts



3D Schematic

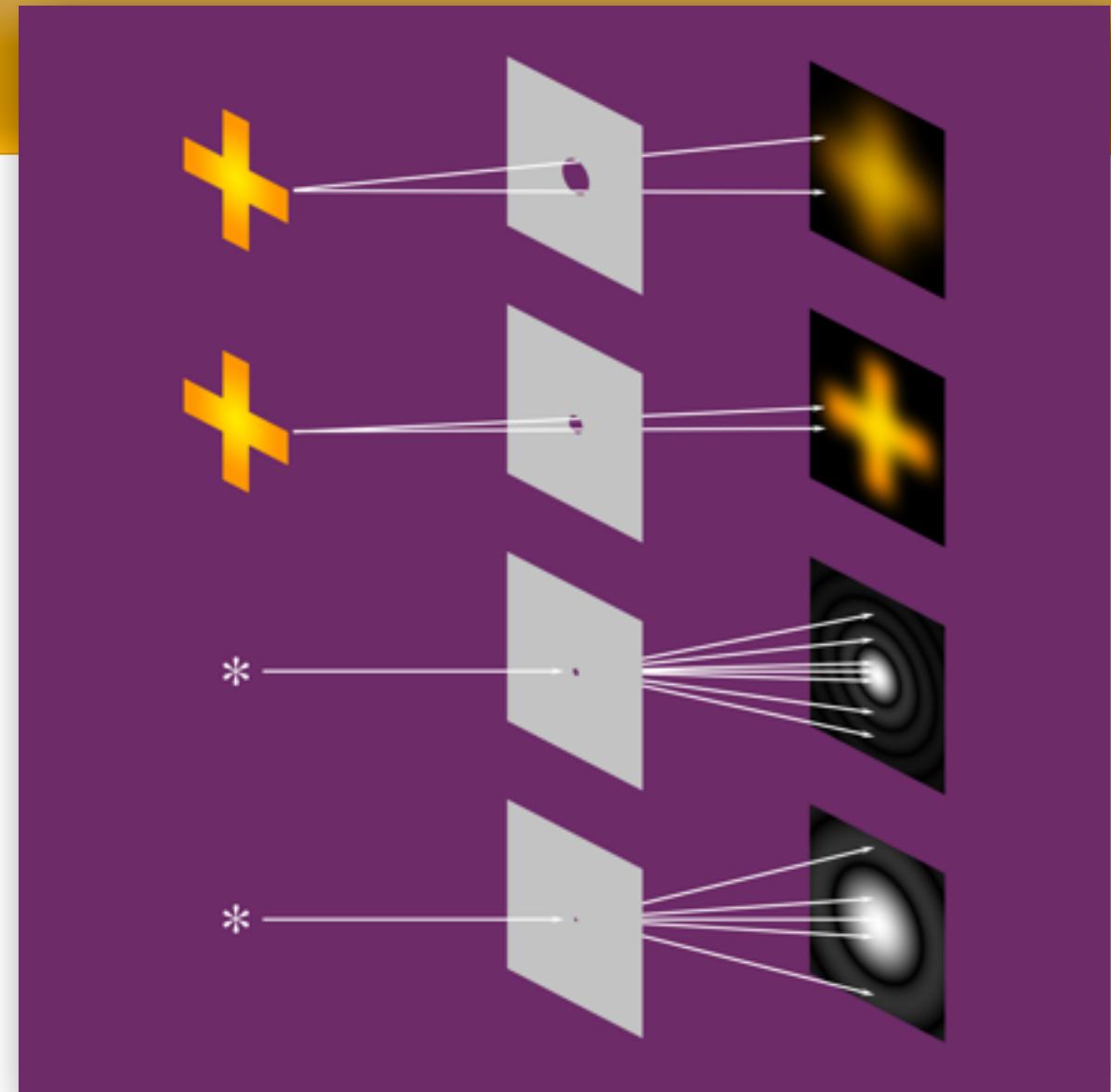


Actual Diffraction Pattern

Light **Diffracts**

- ★ Wave Nature of Light
- ★ Smaller Aperture means more Diffraction

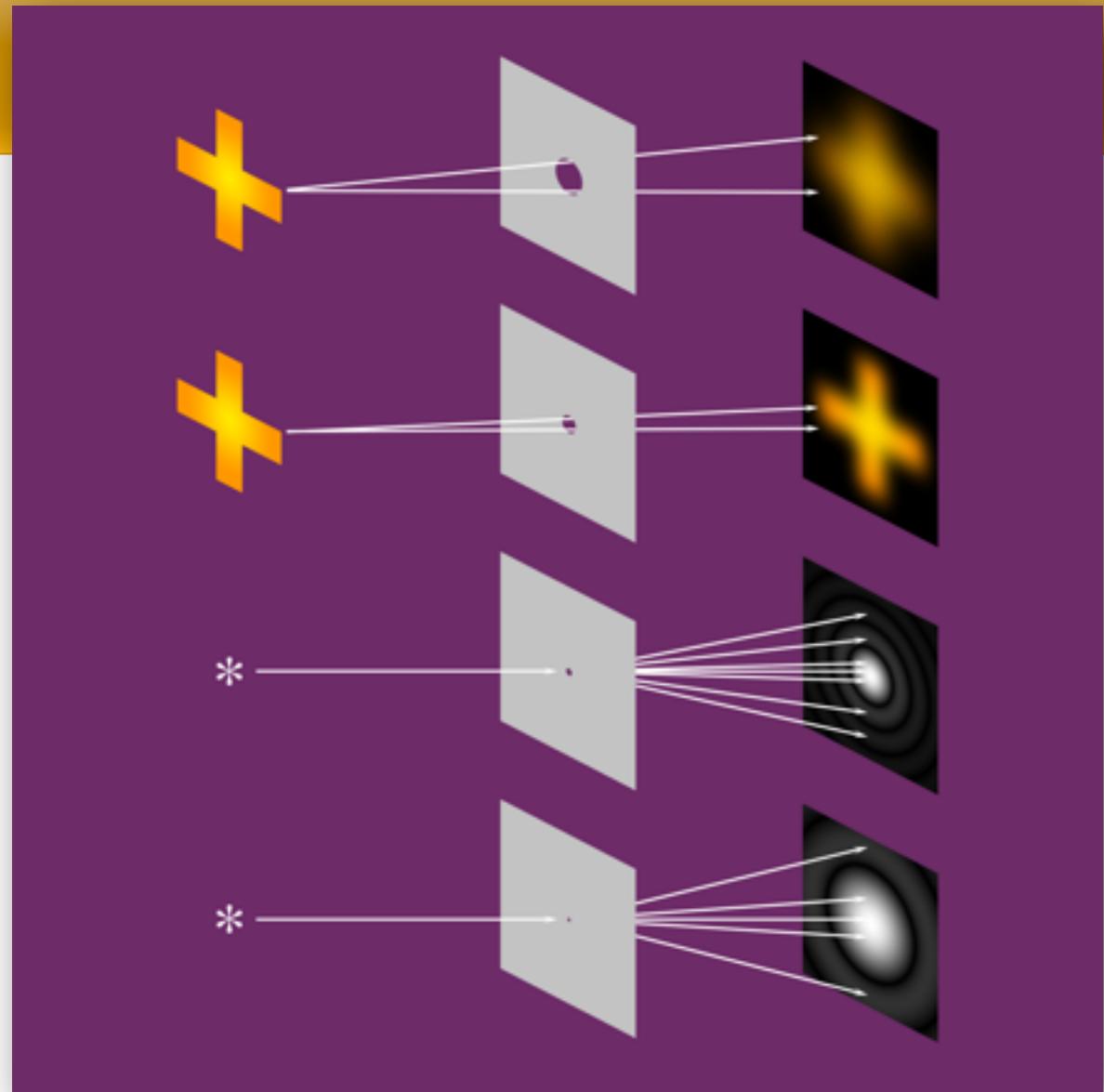
Effect of Pinhole Size



Slide adapted from Marc Levoy

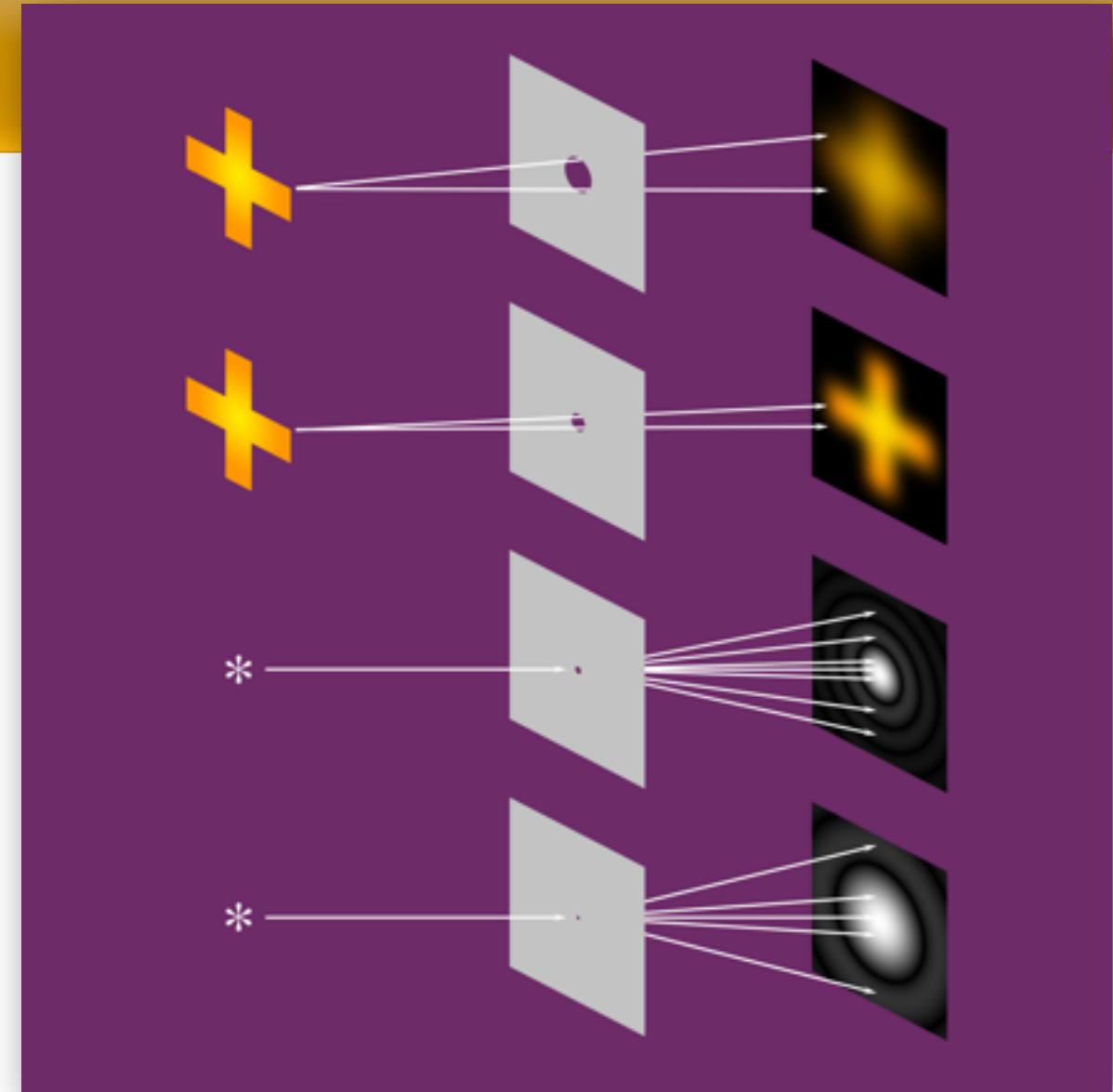
Effect of Pinhole Size

- ★ Large Pinhole = Geometric Blur



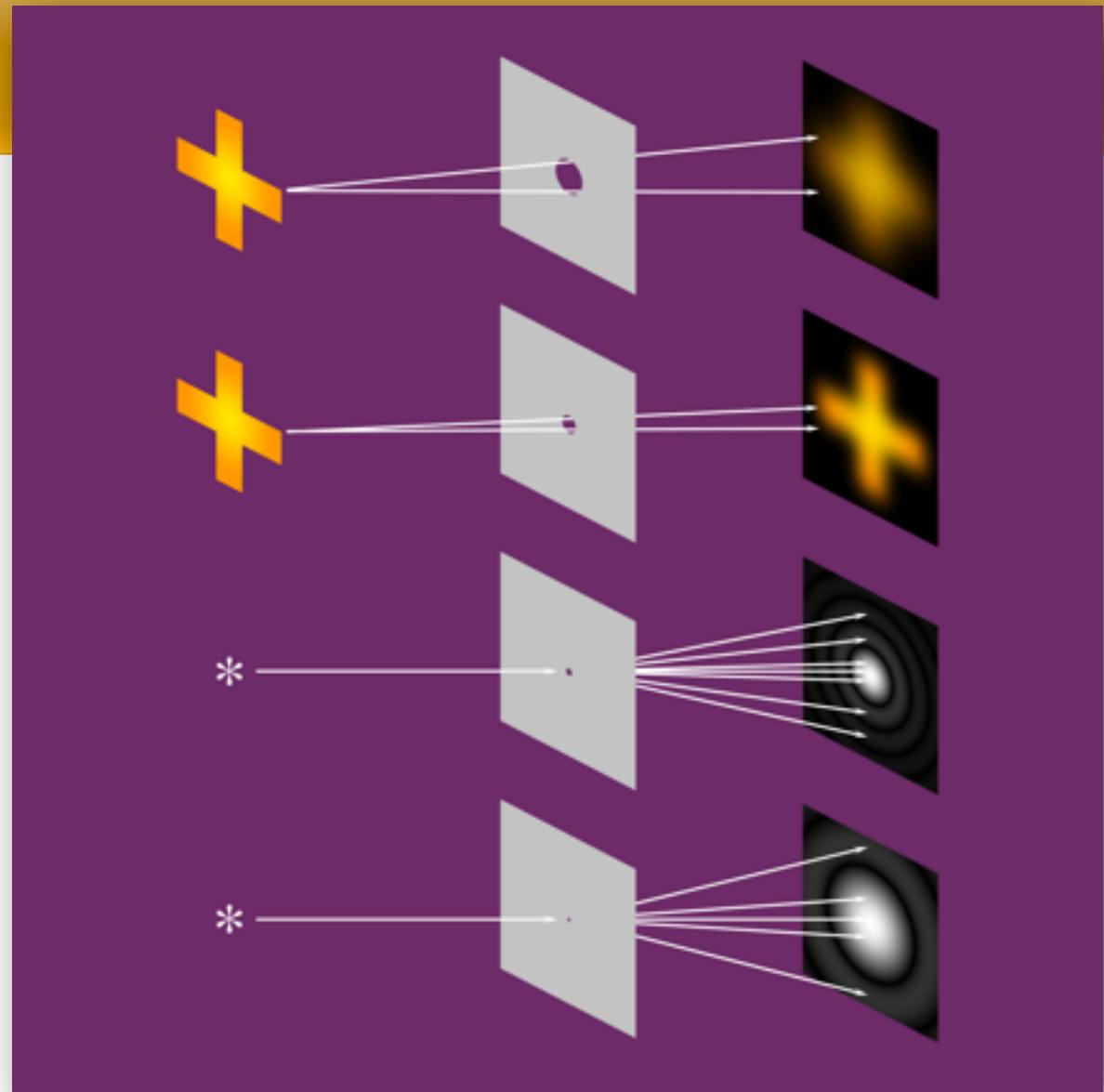
Effect of Pinhole Size

- ★ Large Pinhole = Geometric Blur
- ★ Small Pinhole = Diffraction Blur



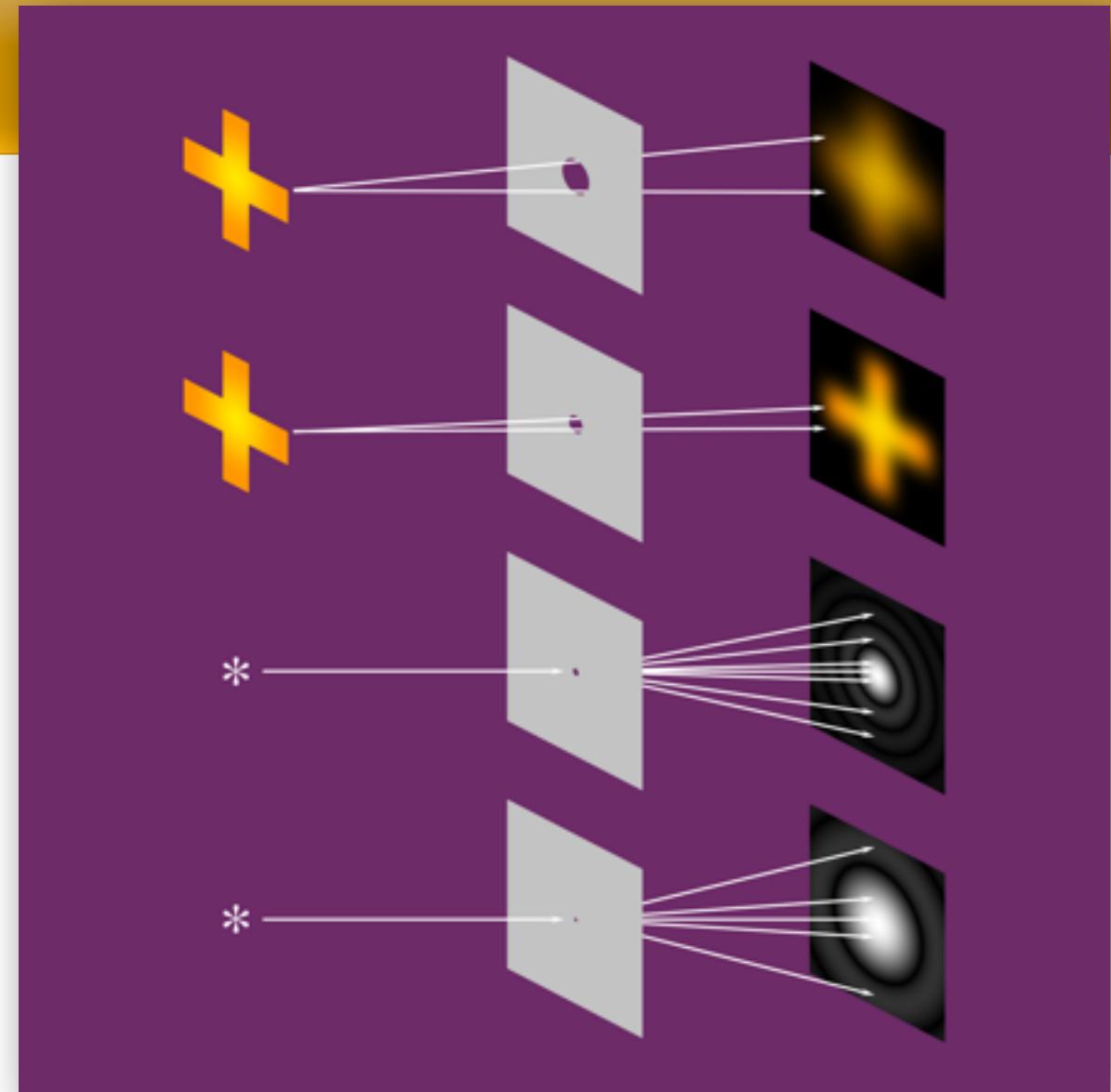
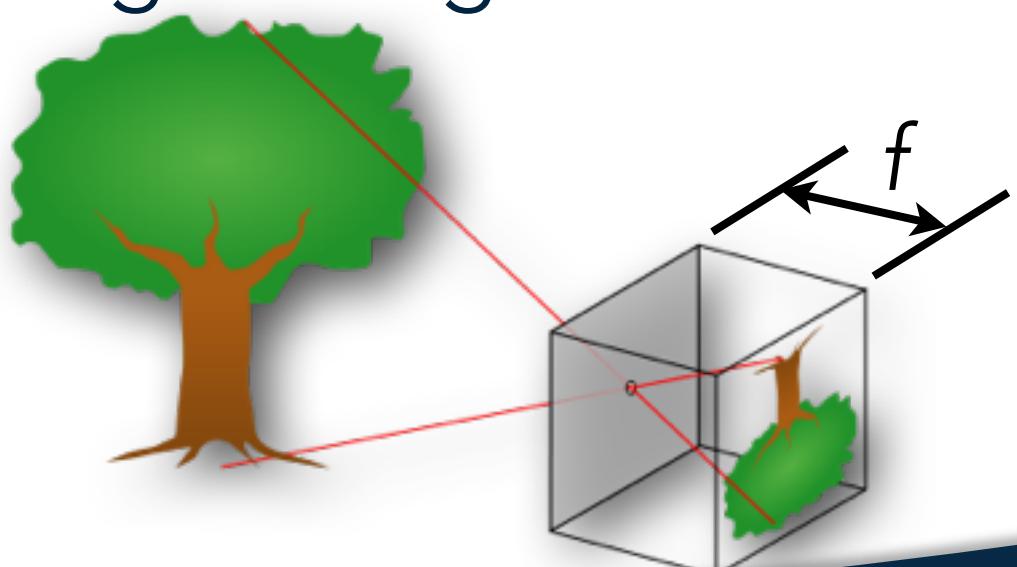
Effect of Pinhole Size

- ★ Large Pinhole = Geometric Blur
- ★ Small Pinhole = Diffraction Blur
- ★ Best Pinhole = Very Little Light



Effect of Pinhole Size

- ★ Large Pinhole = Geometric Blur
- ★ Small Pinhole = Diffraction Blur
- ★ Best Pinhole = Very Little Light
- ★ For d , the pinhole diameter, f (the distance from the pinhole to the sensor) and π as the wavelength of light:

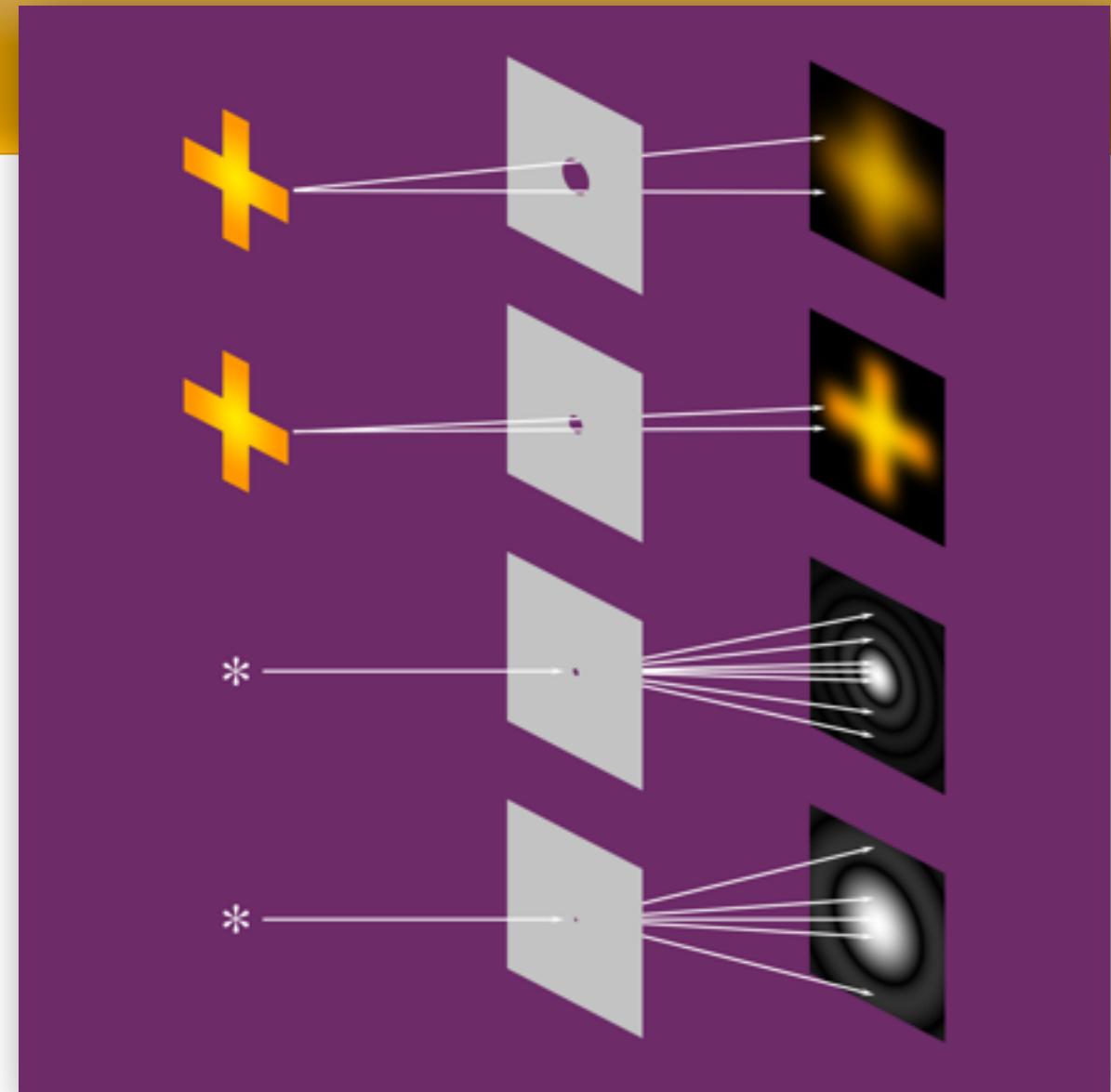
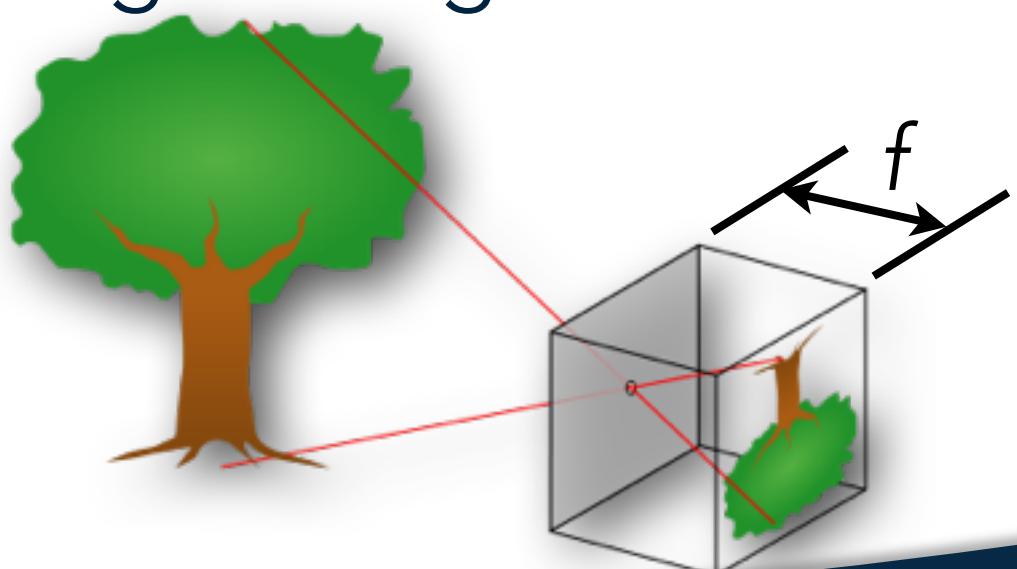


Slide adapted from Marc Levoy

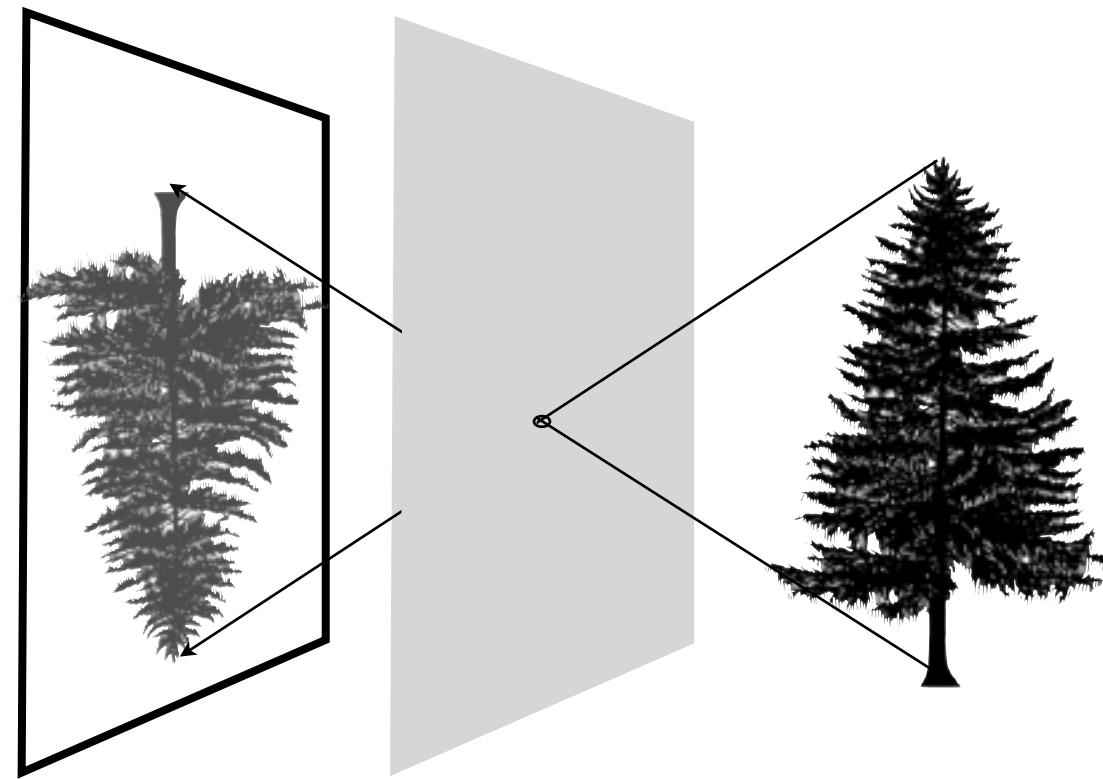
Effect of Pinhole Size

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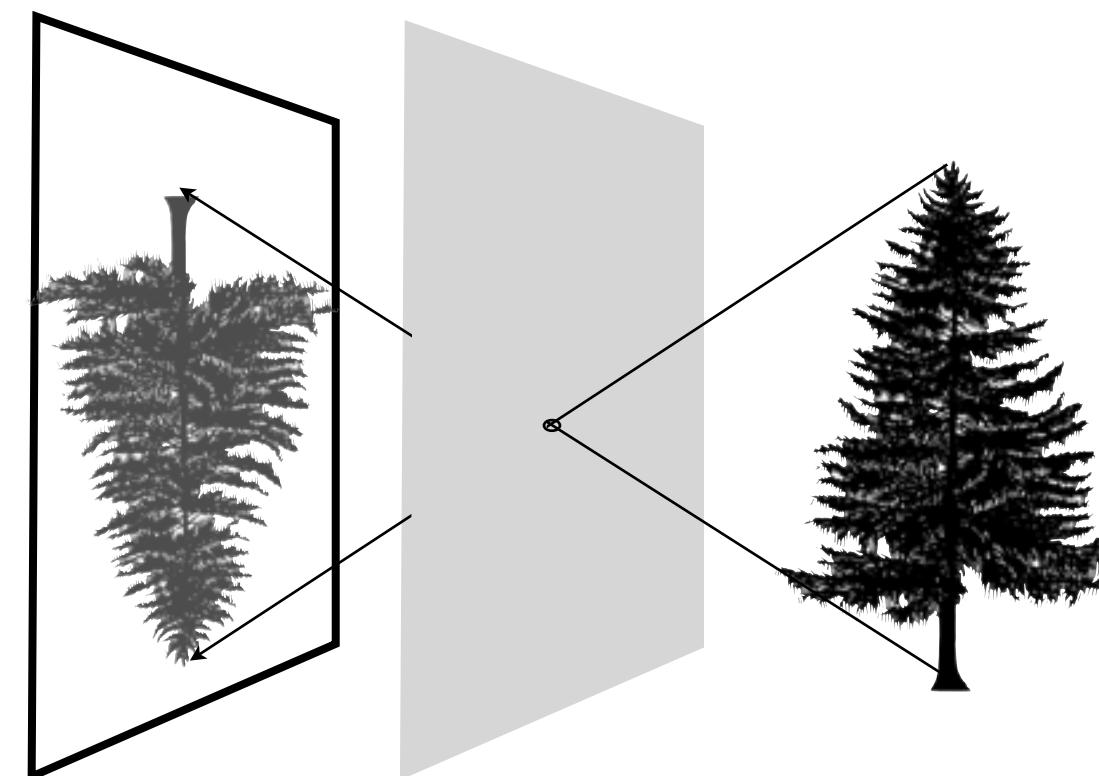
$$d = 2\sqrt{\frac{1}{2}f\pi}$$



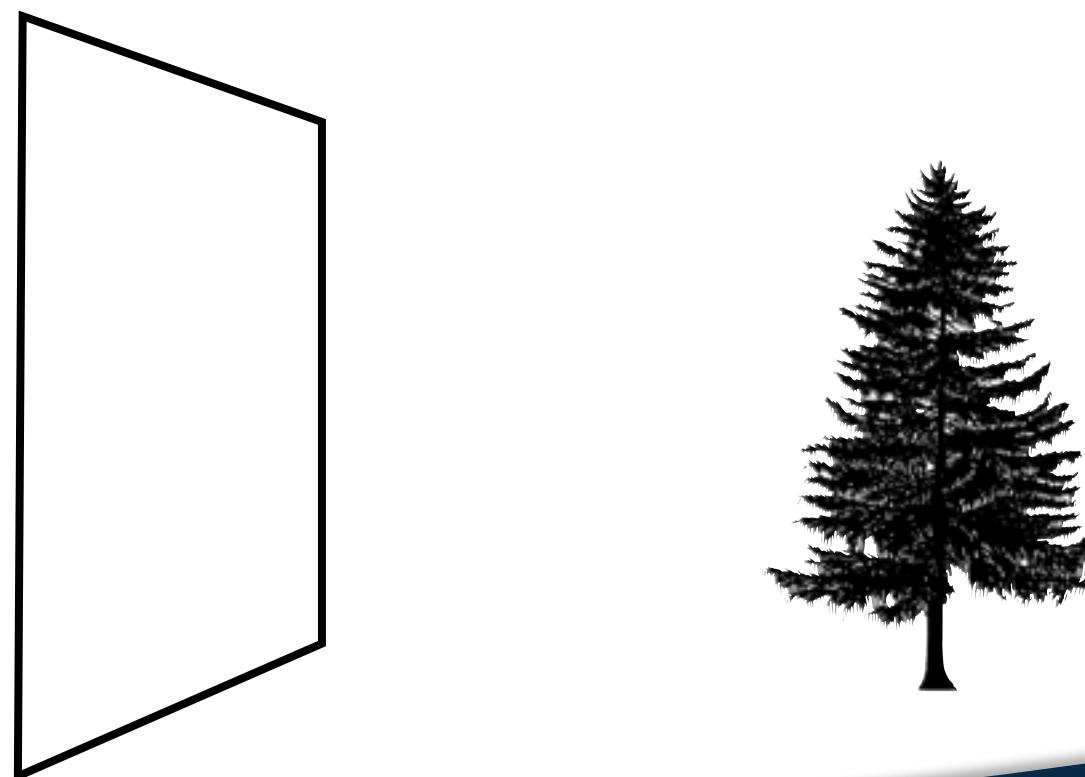
Slide adapted from Marc Levoy

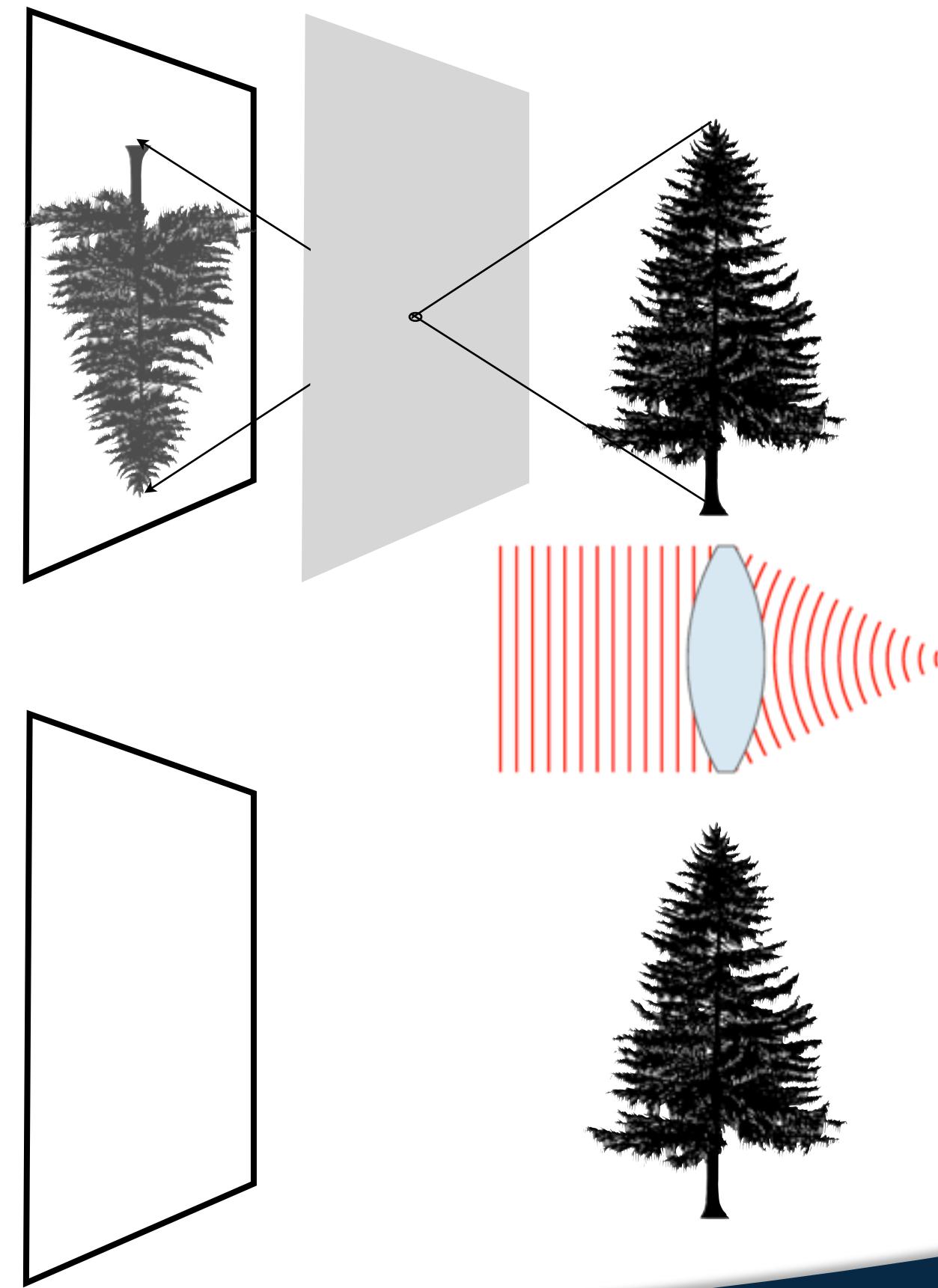


Replacing the Pinhole with a Lens

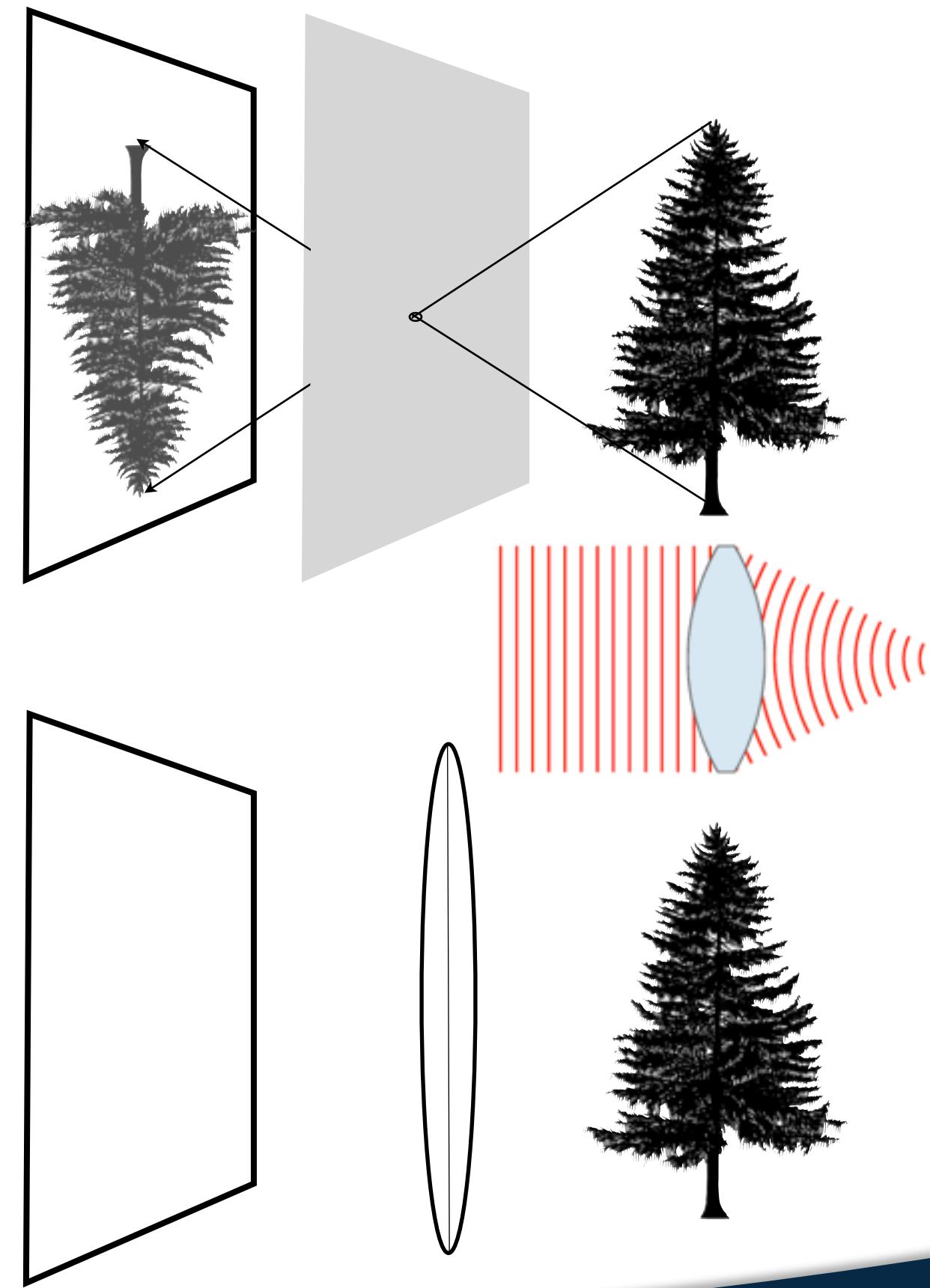


Replacing the Pinhole with a Lens

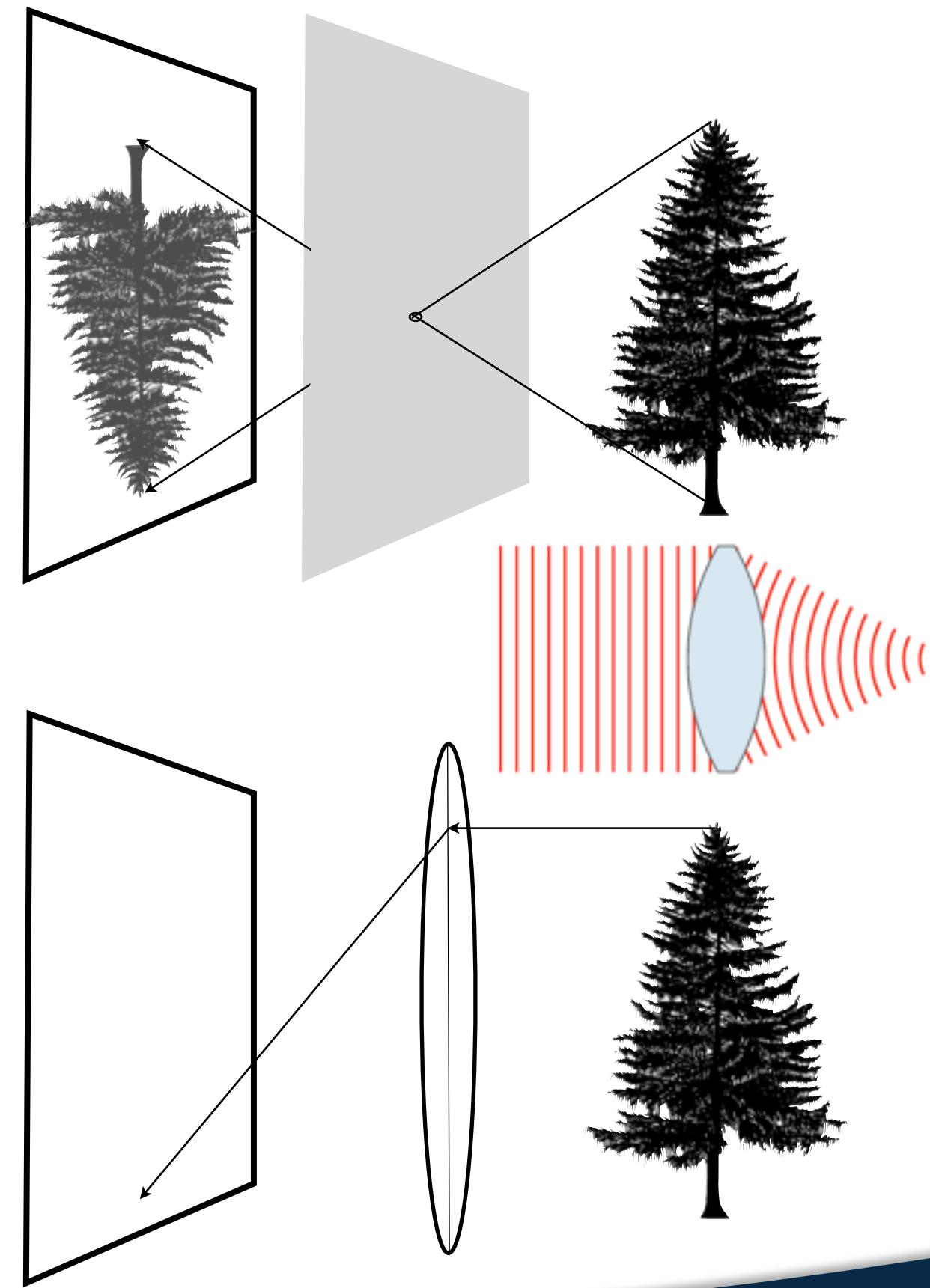




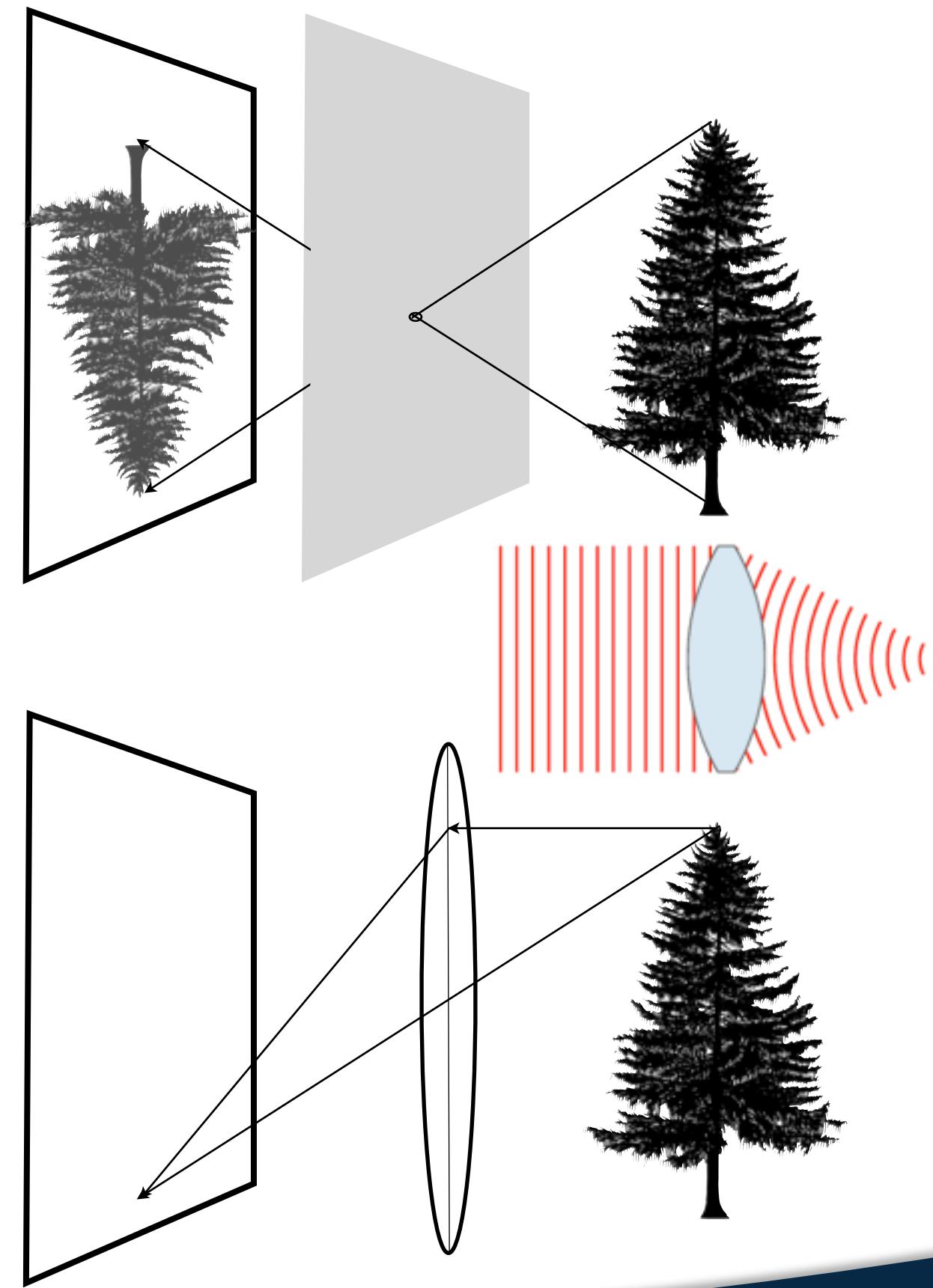
Replacing the Pinhole with a Lens



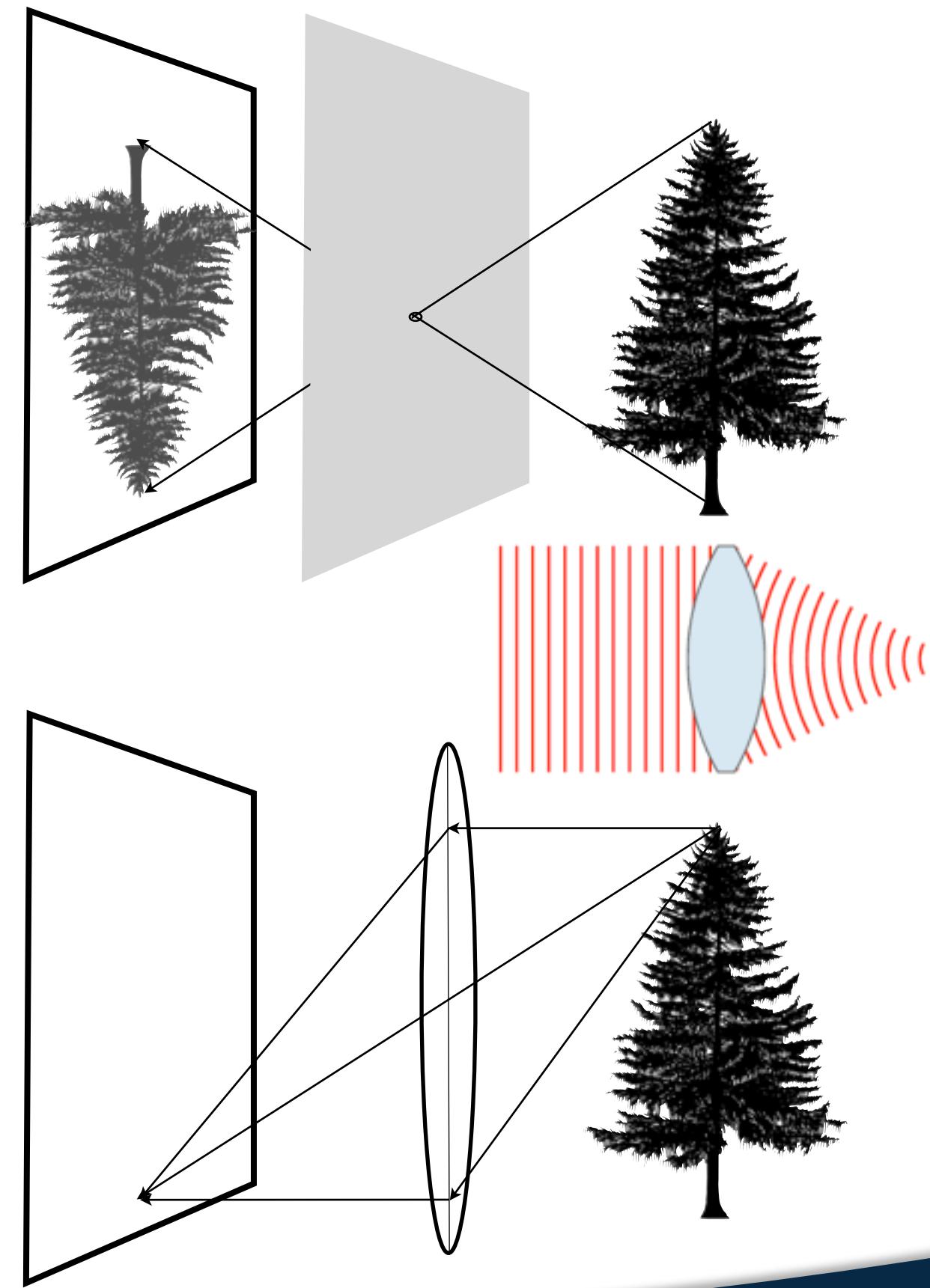
Replacing the Pinhole with a Lens



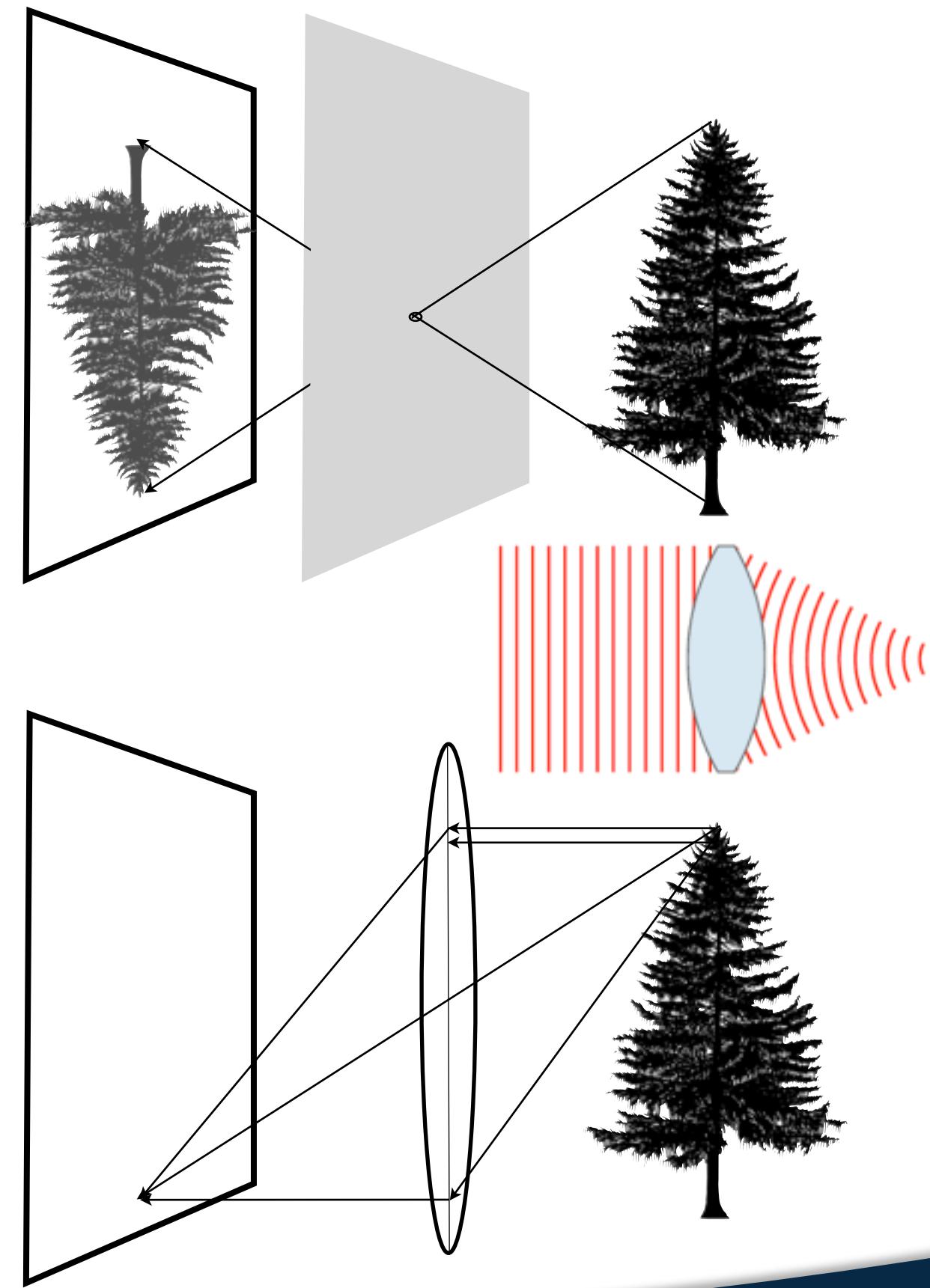
Replacing the Pinhole with a Lens



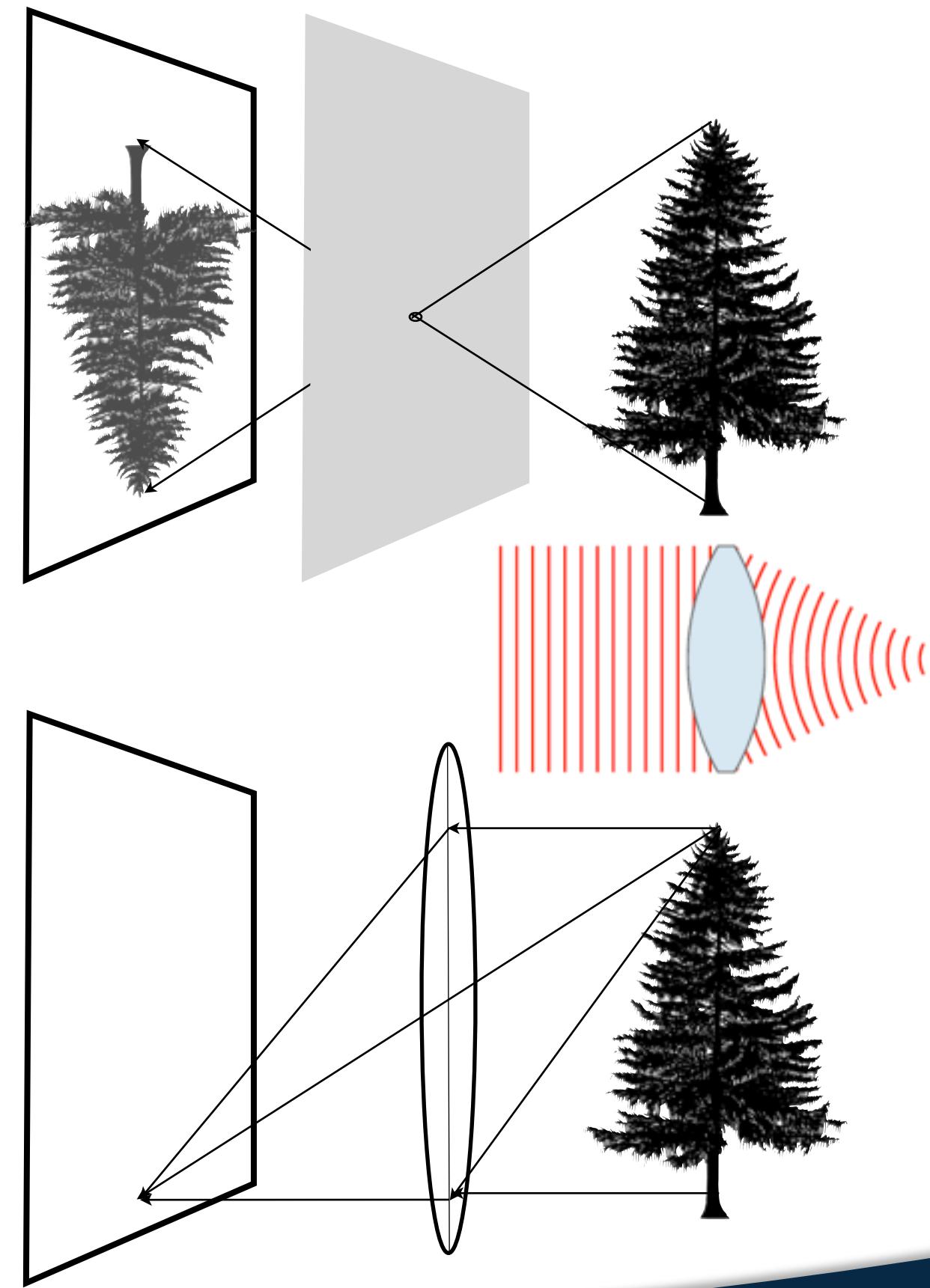
Replacing the Pinhole with a Lens



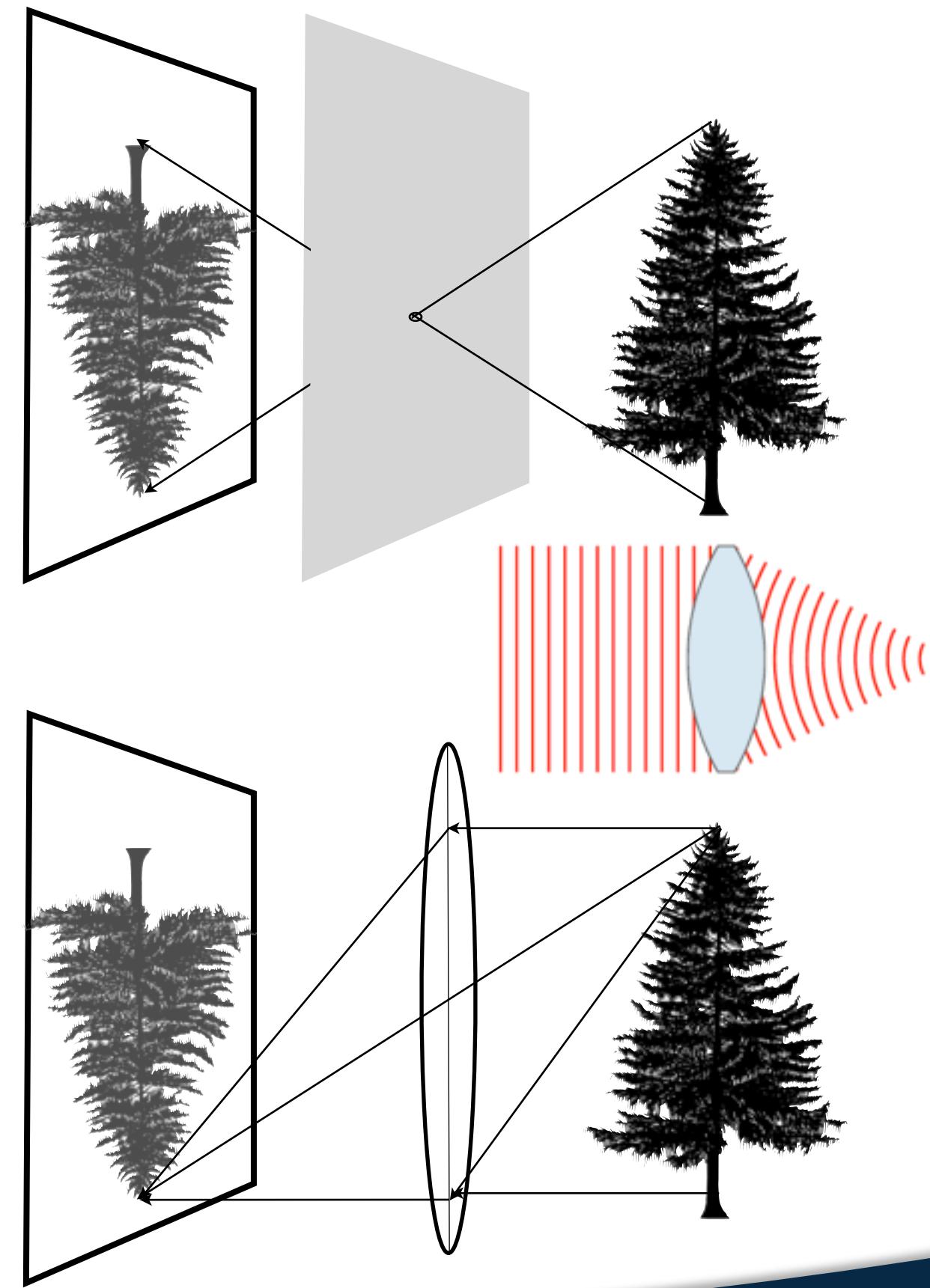
Replacing the Pinhole with a Lens



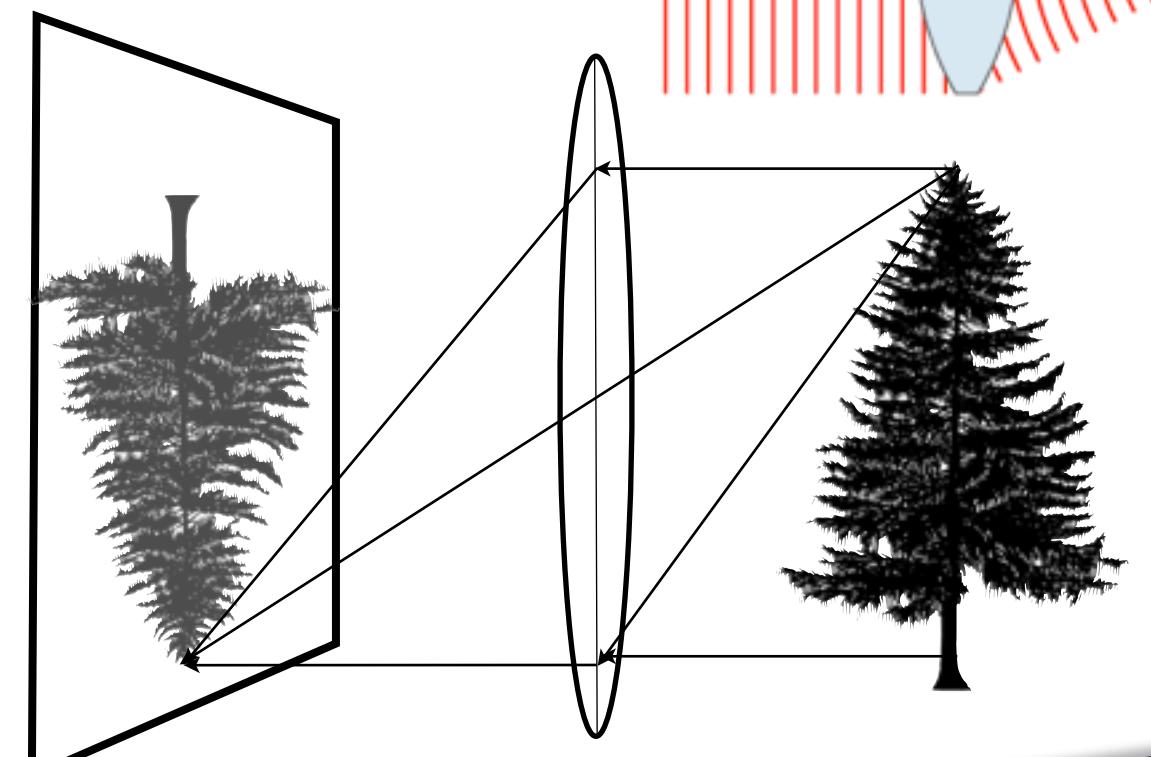
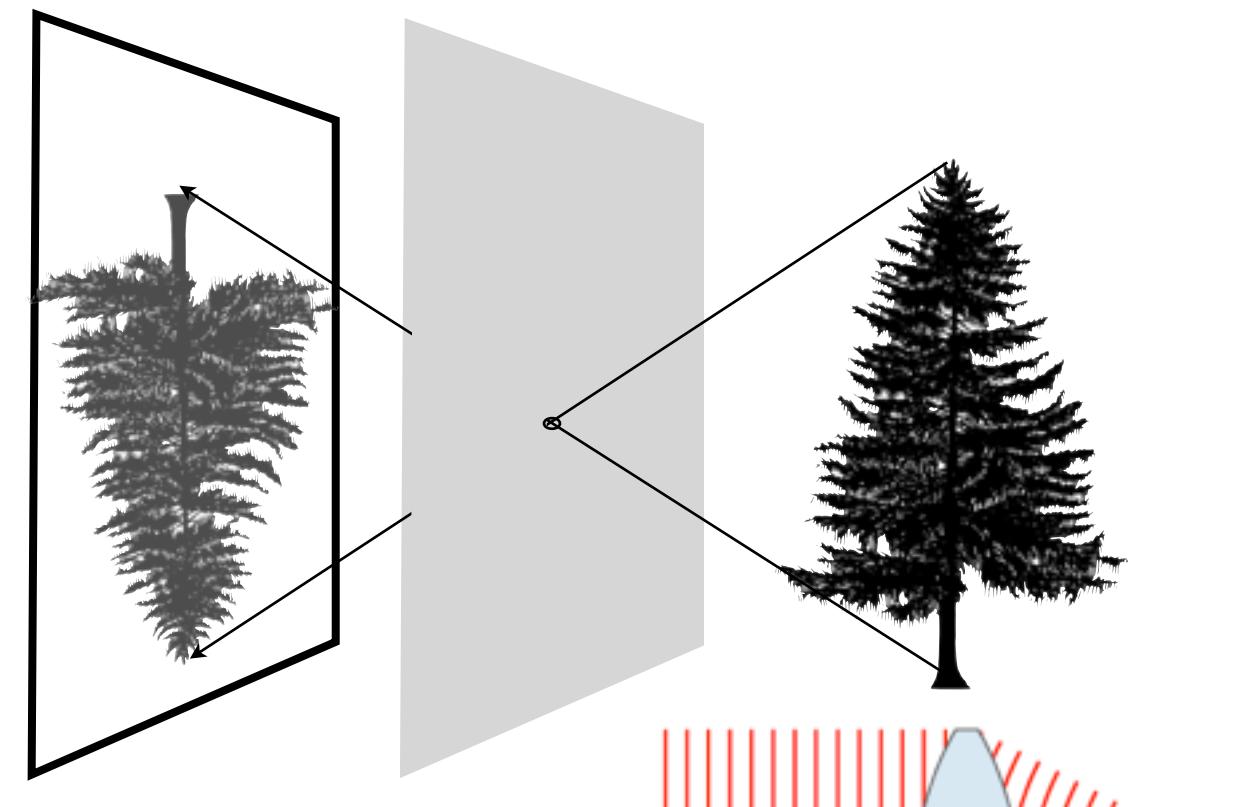
Replacing the Pinhole with a Lens



Replacing the Pinhole with a Lens

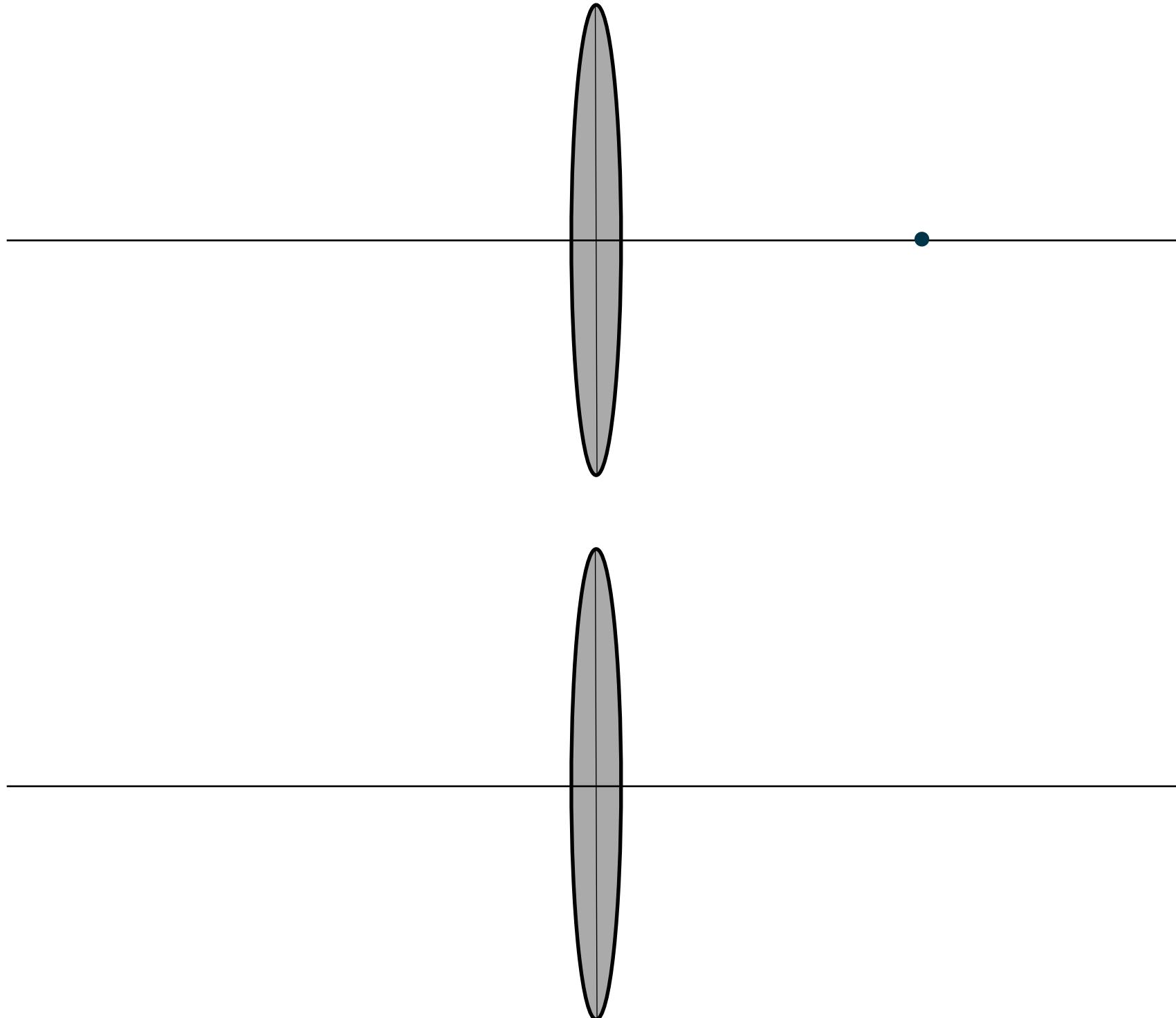


Replacing the Pinhole with a Lens

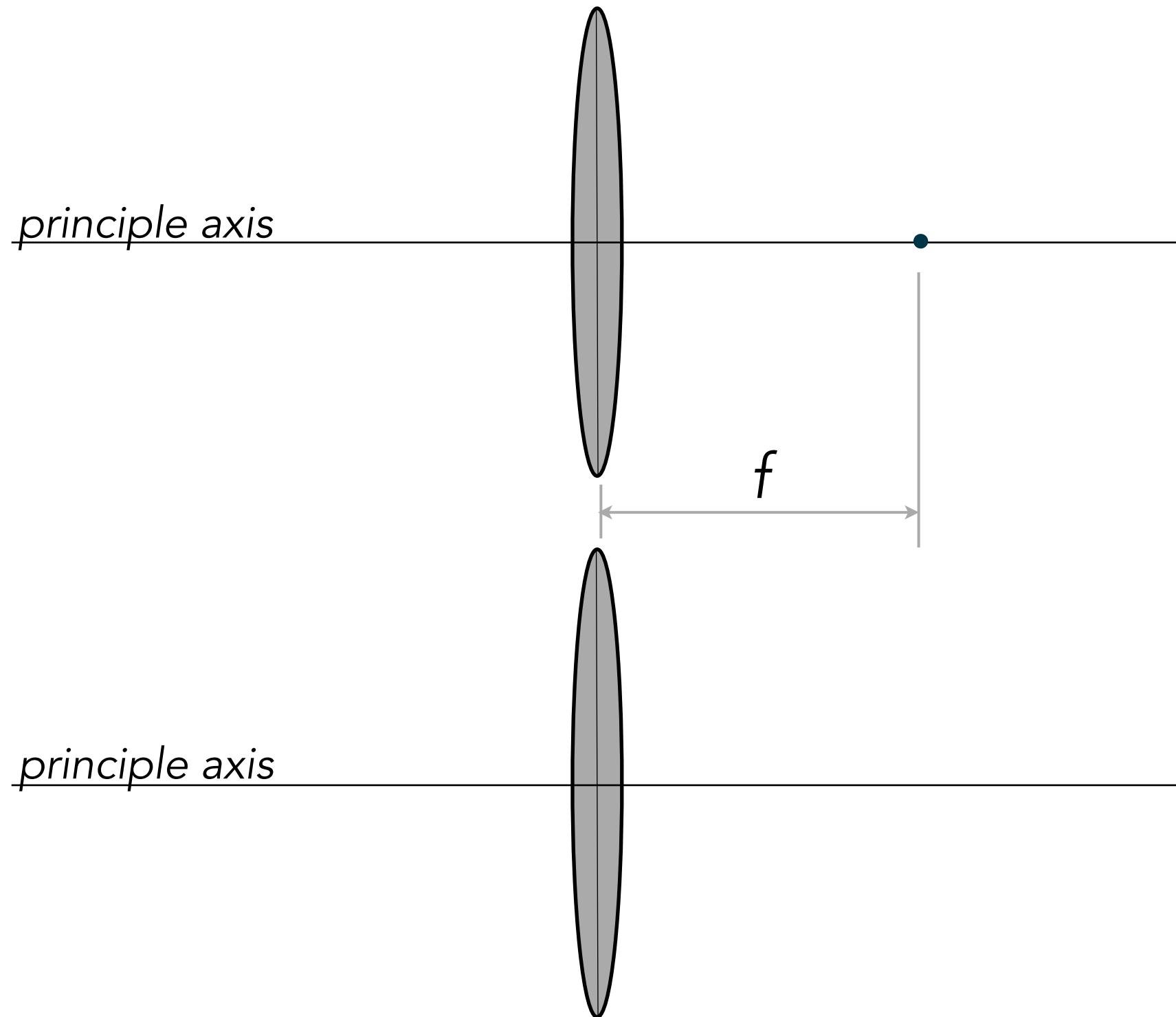


Replacing the Pinhole with a Lens

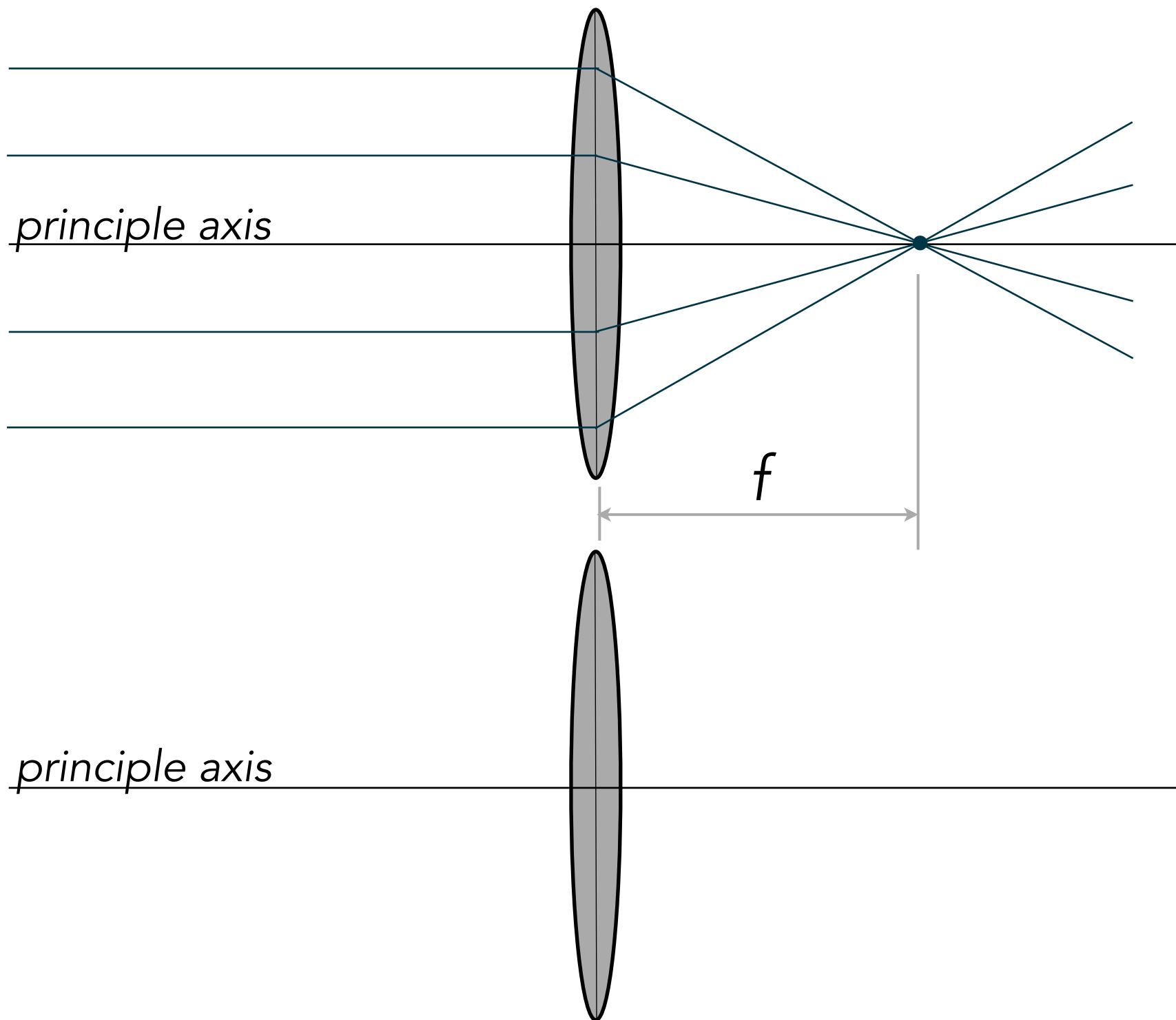
Geometrical Optics



Geometrical Optics

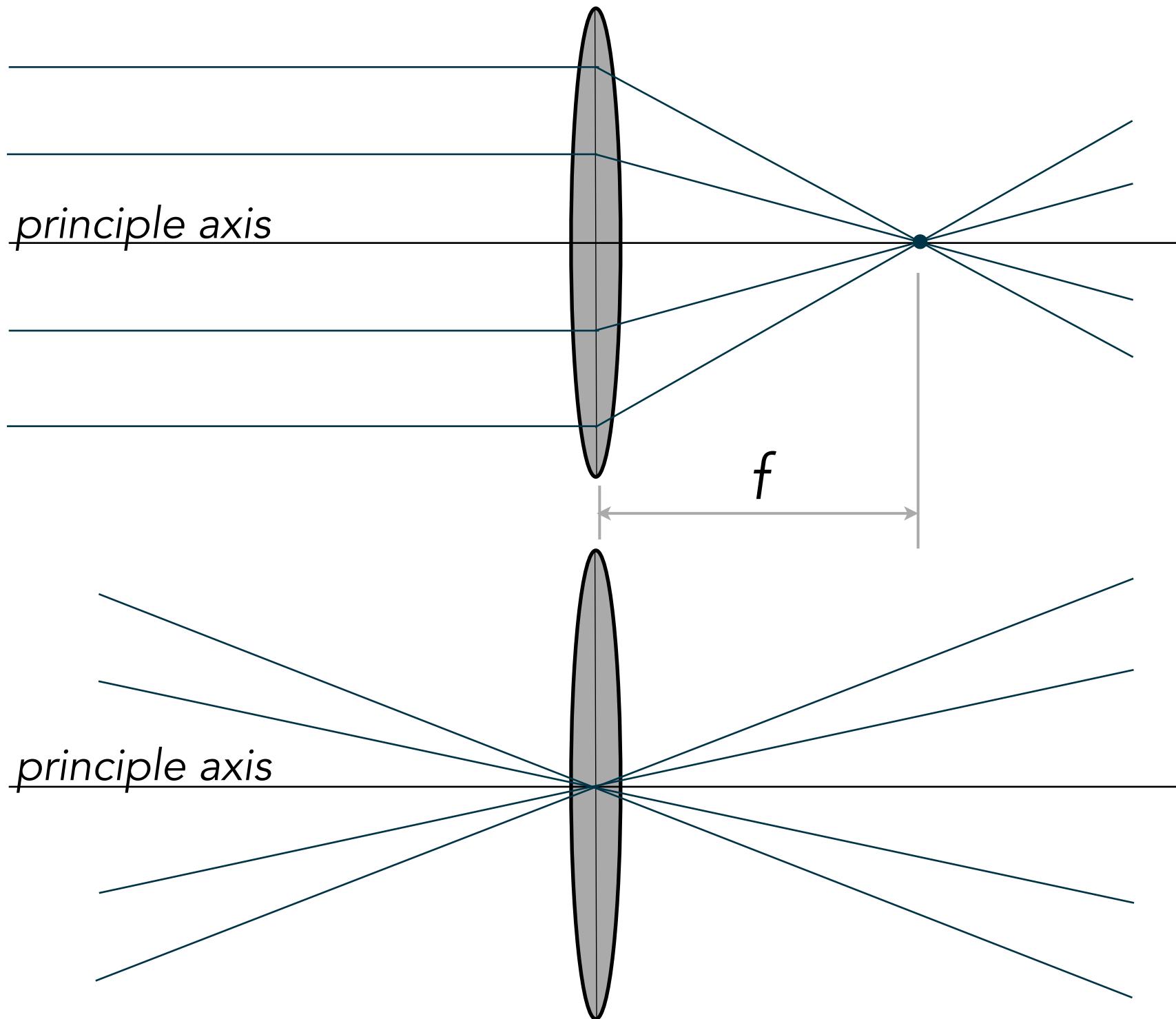


Geometrical Optics



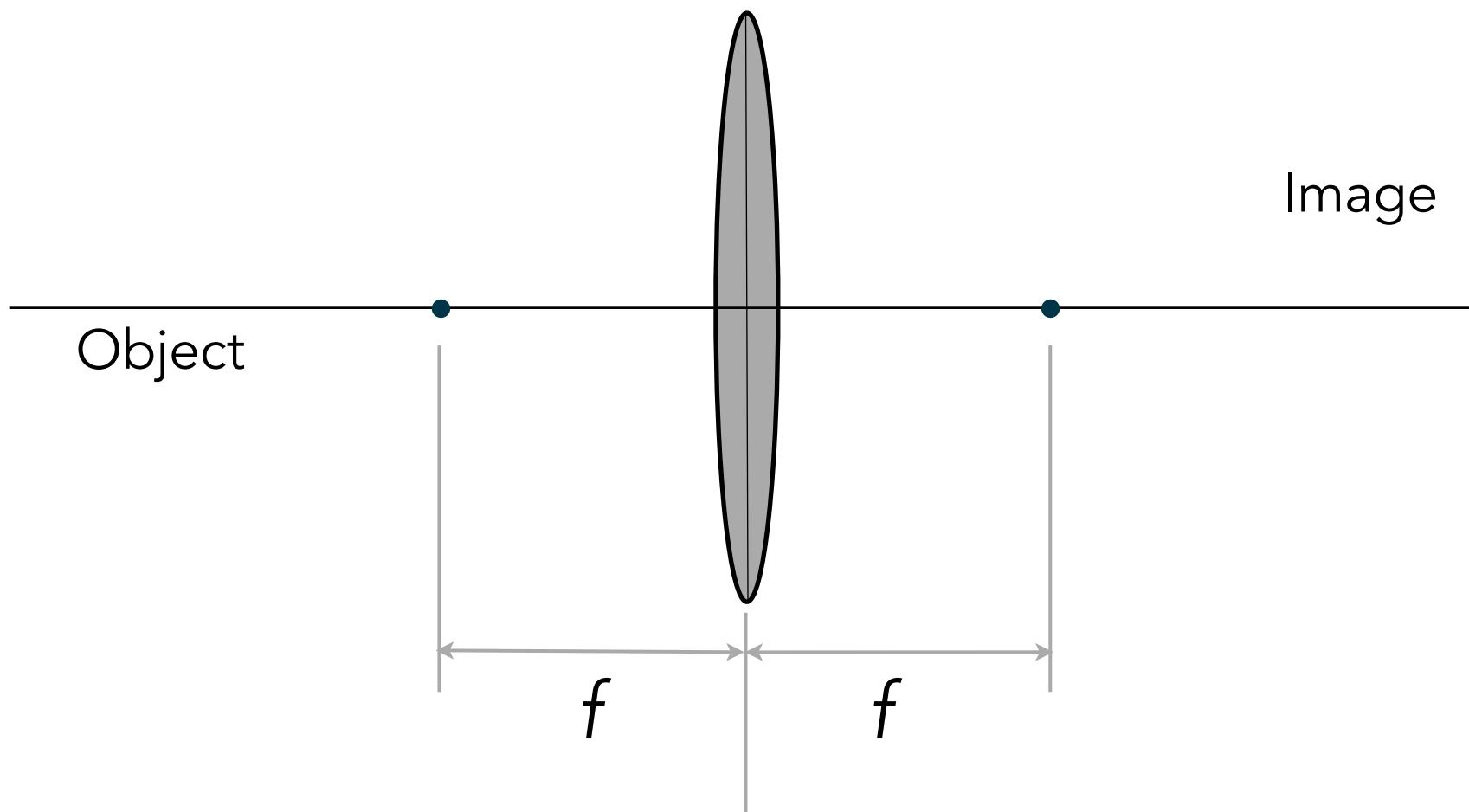
- ★ Parallel rays converge to a point located at focal length, f from lens

Geometrical Optics

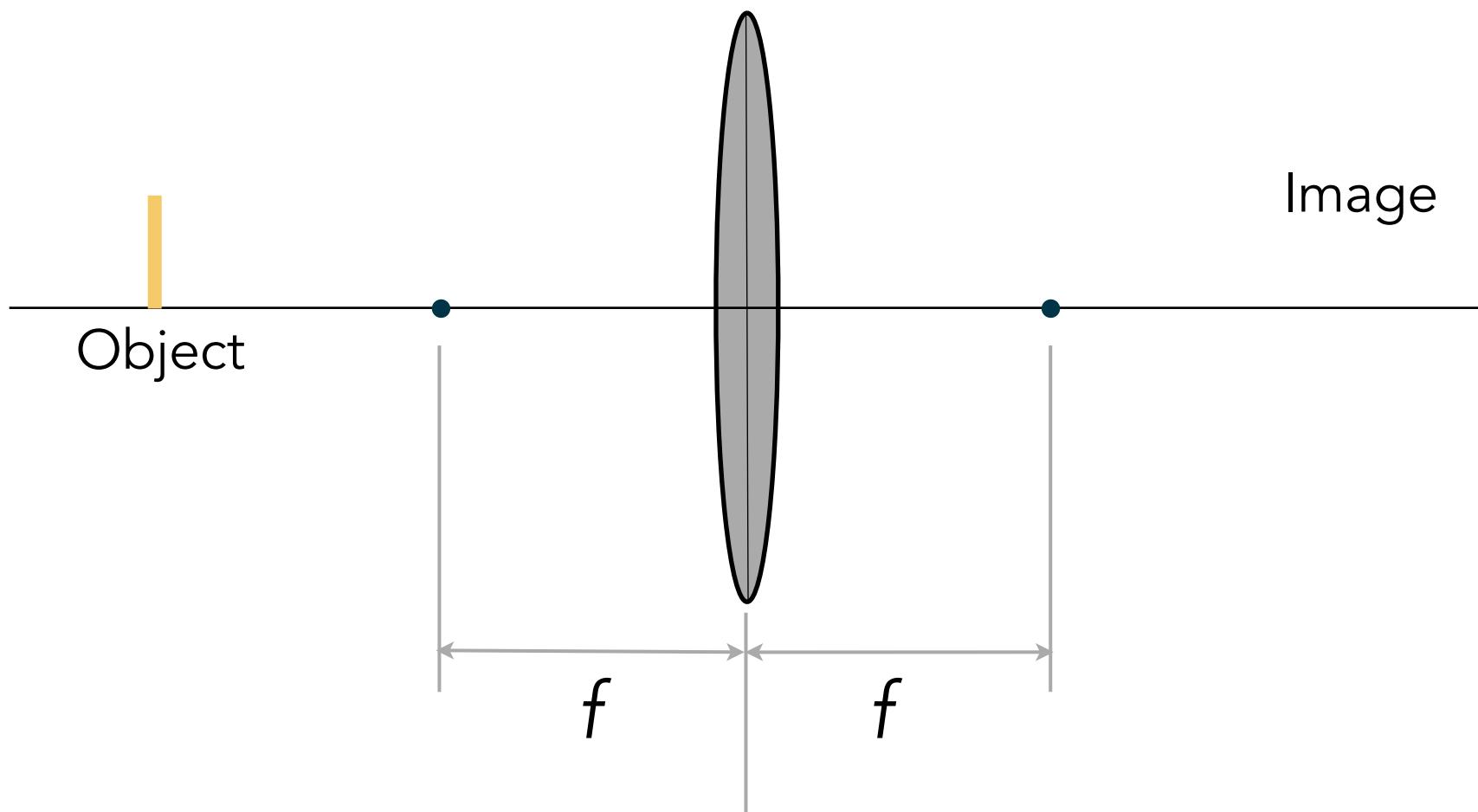


- ★ Parallel rays converge to a point located at focal length, f from lens
- ★ Rays going through center of lens do not deviate (functions like a pinhole)

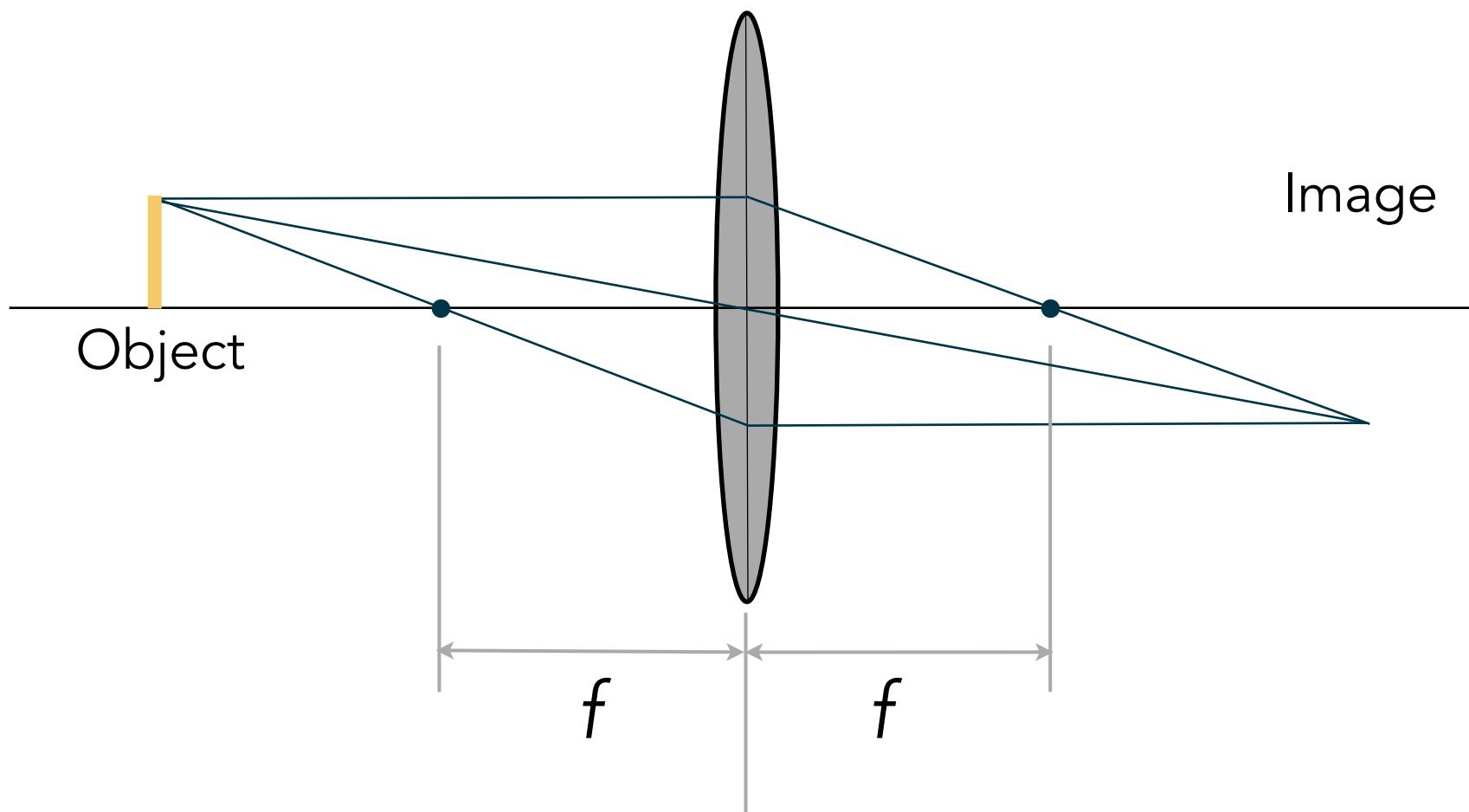
Ray Tracing with Lenses



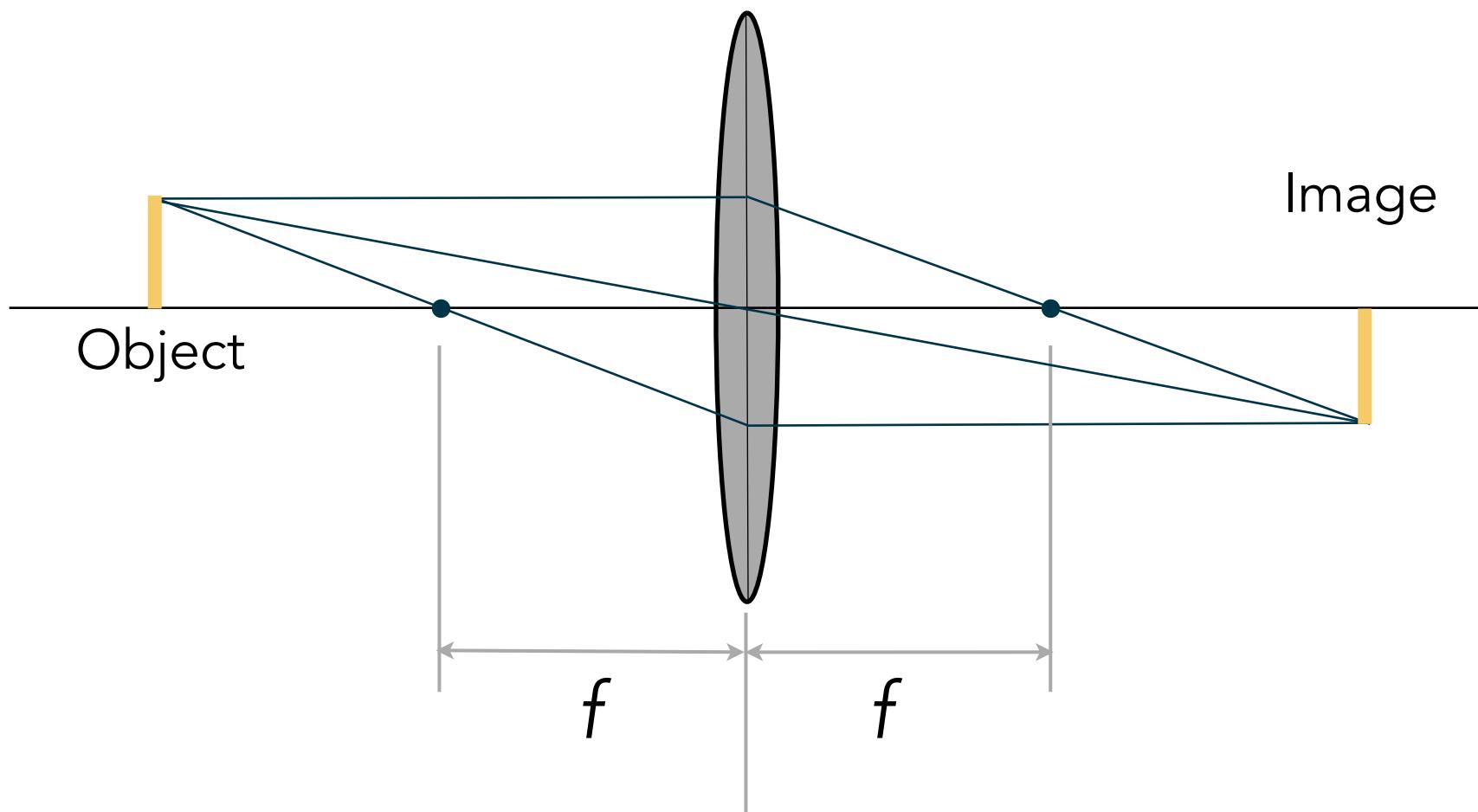
Ray Tracing with Lenses



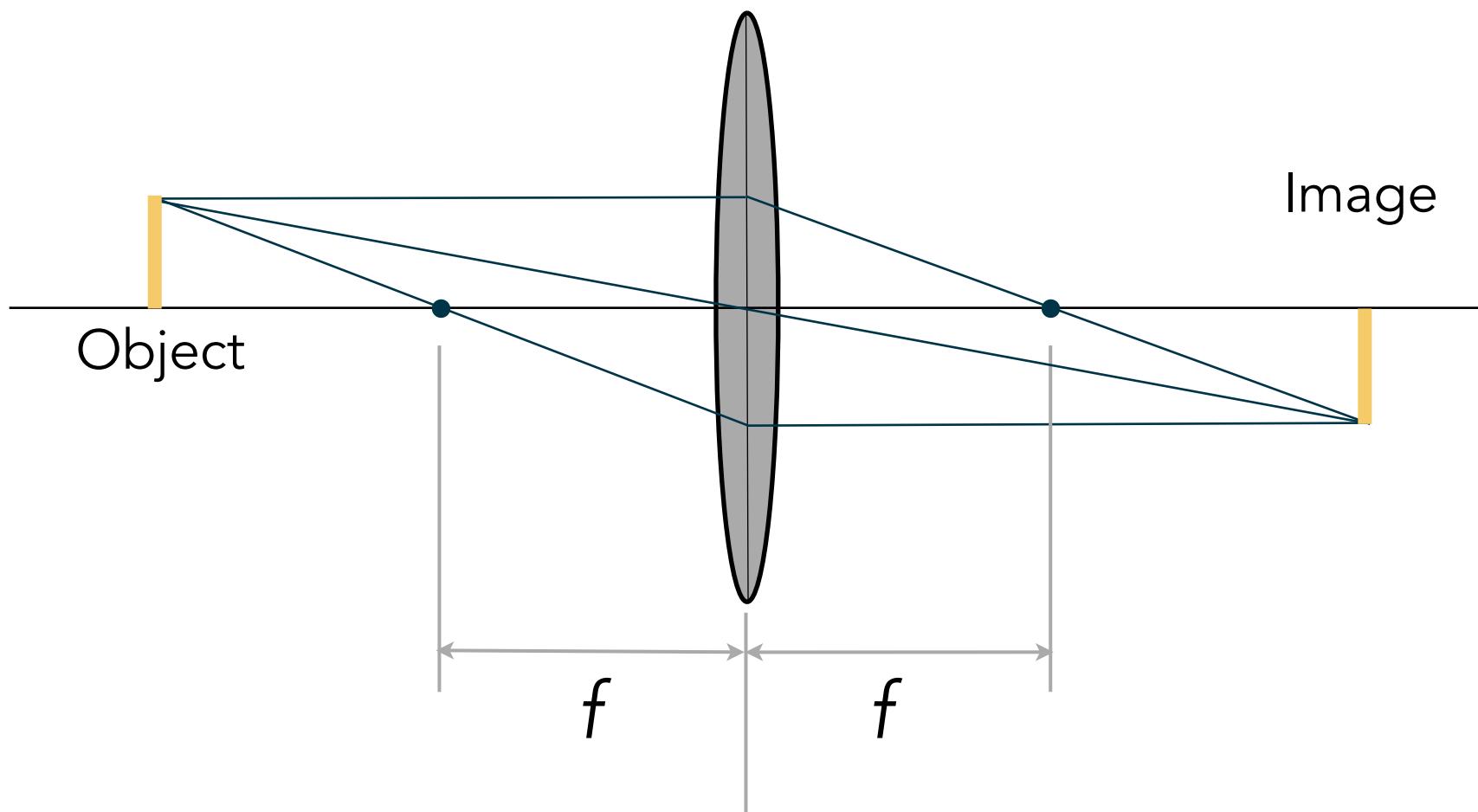
Ray Tracing with Lenses



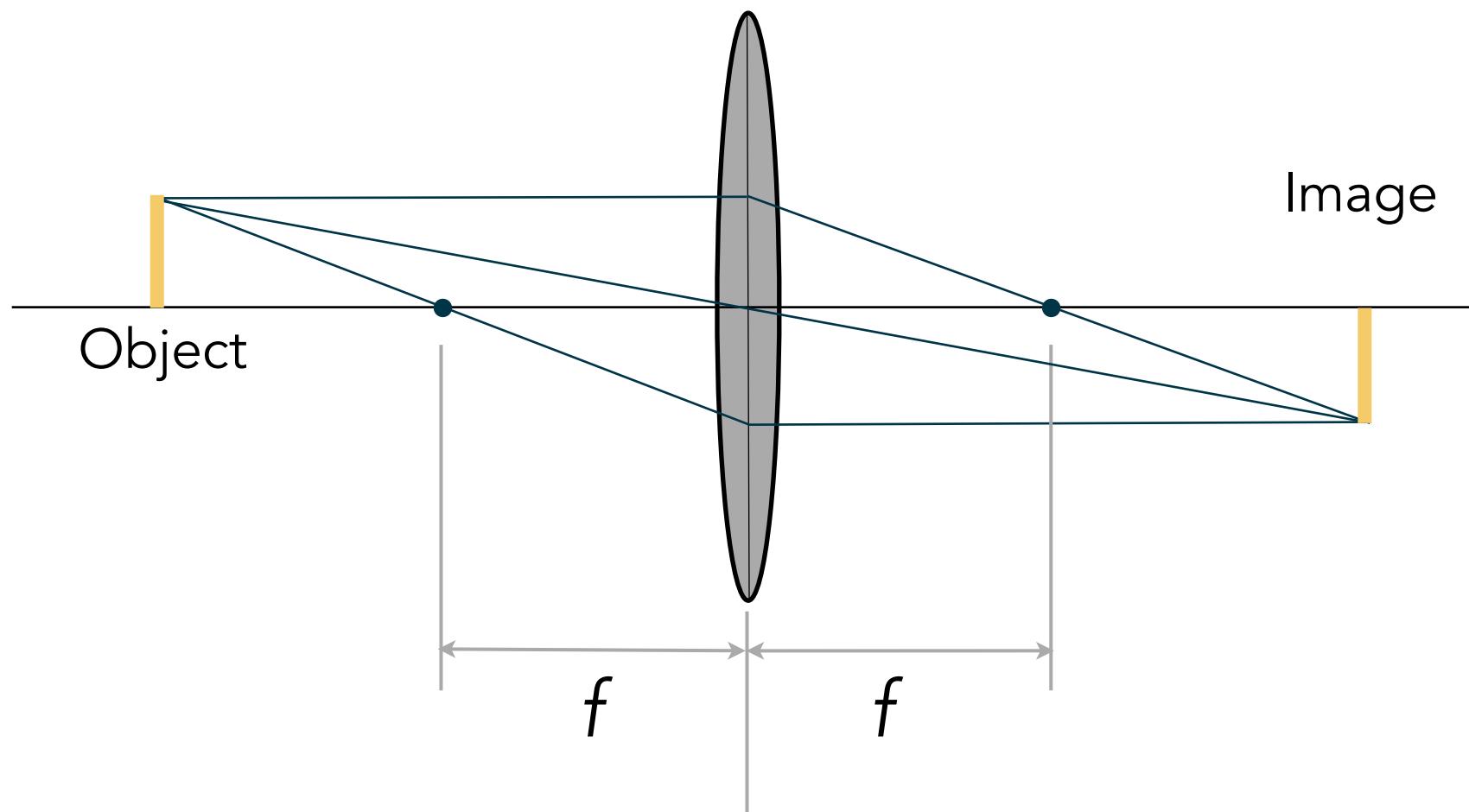
Ray Tracing with Lenses



Ray Tracing with Lenses

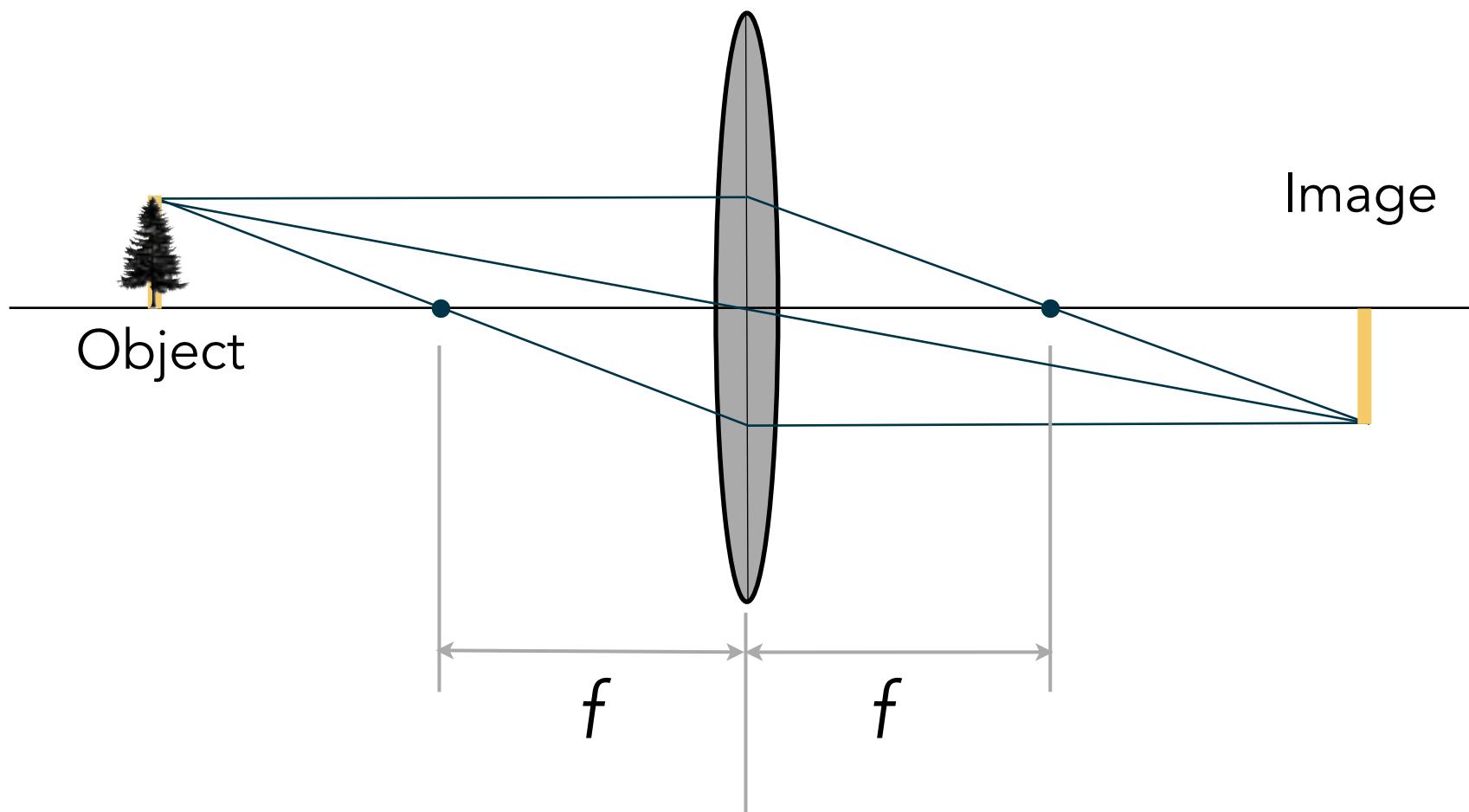


Ray Tracing with Lenses



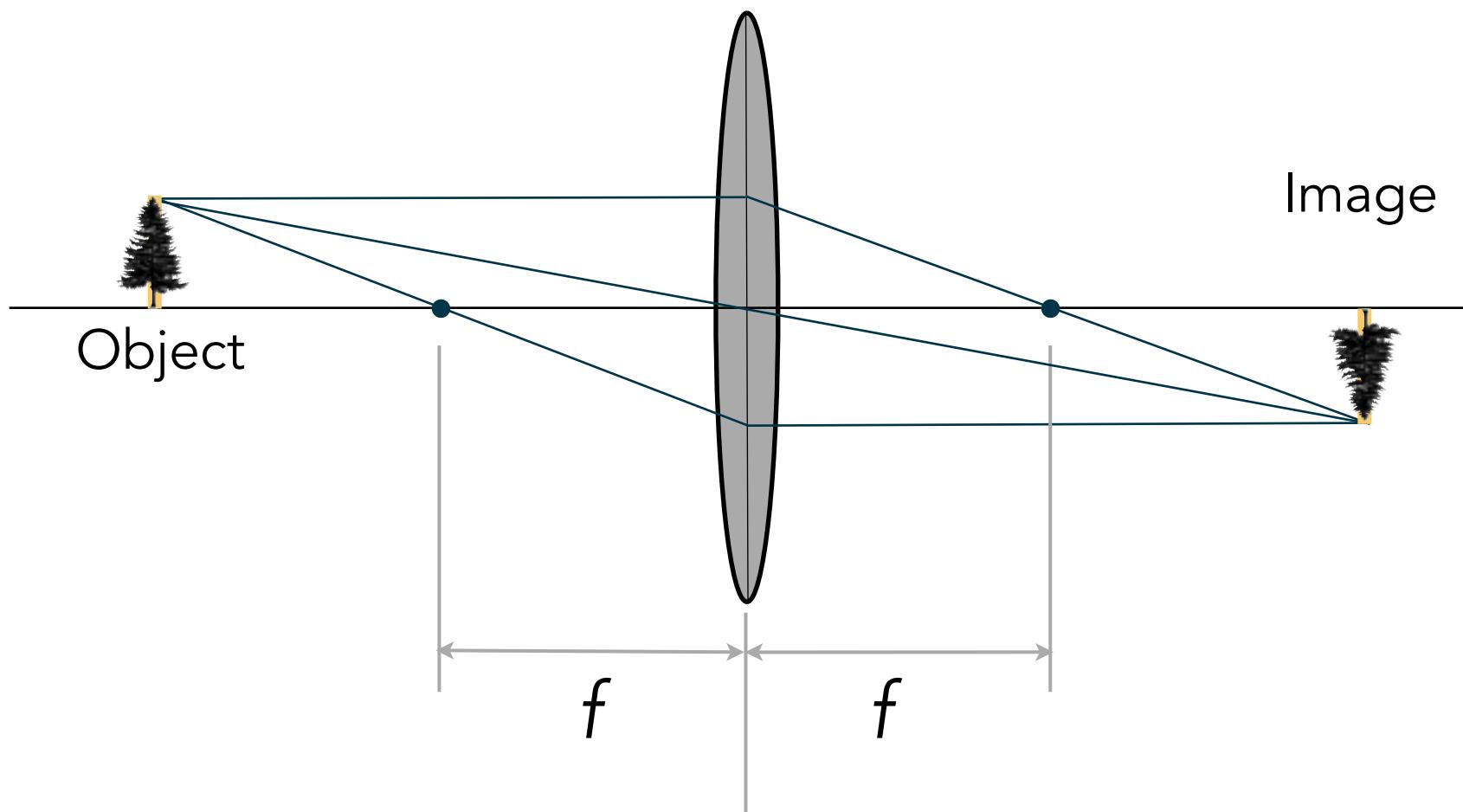
- ★ Rays from points on a plane parallel to the lens, focus on a plane parallel to the lens on the other side (and upside down).

Ray Tracing with Lenses



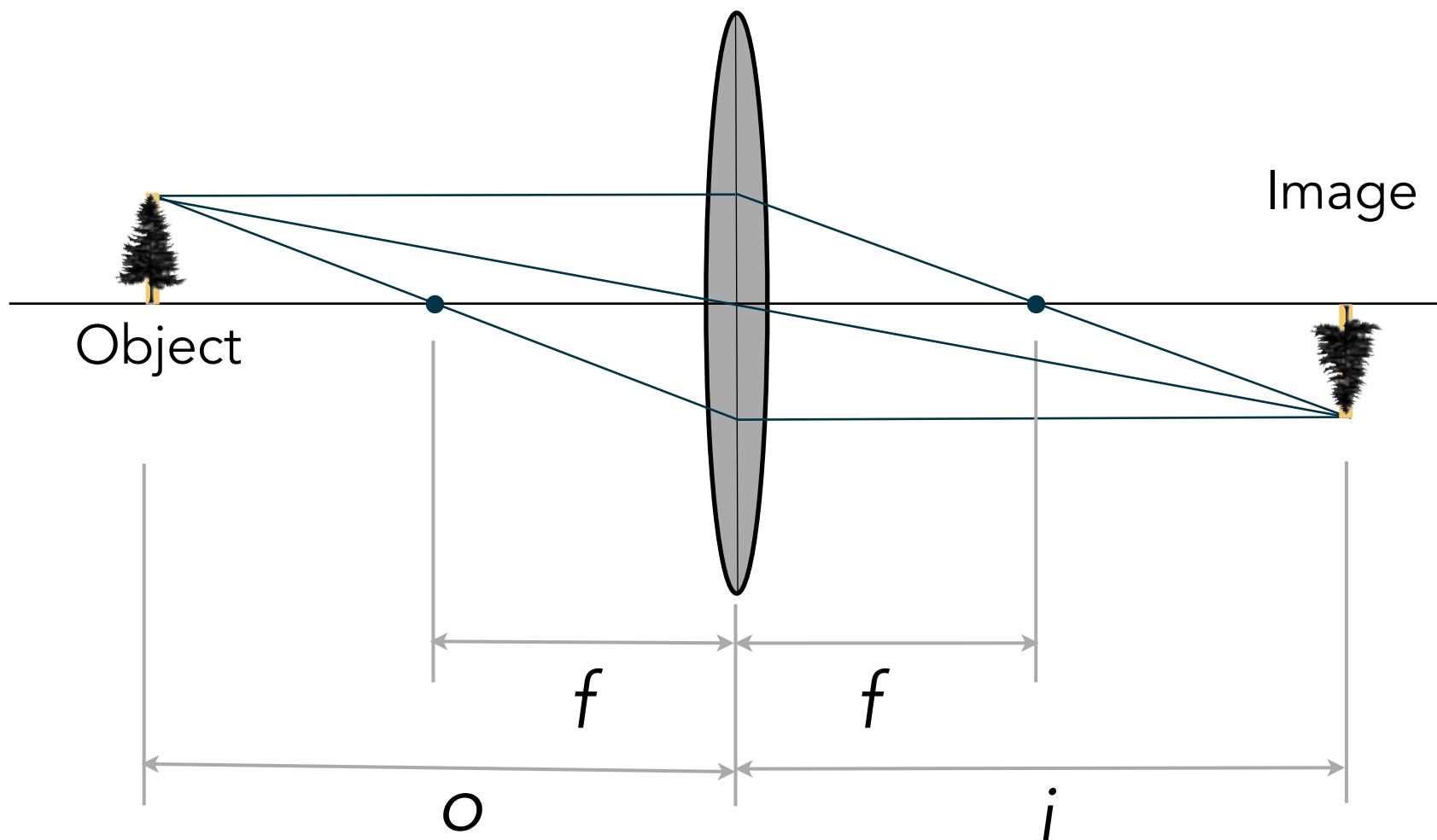
- ★ Rays from points on a plane parallel to the lens, focus on a plane parallel to the lens on the other side (and upside down).

Ray Tracing with Lenses



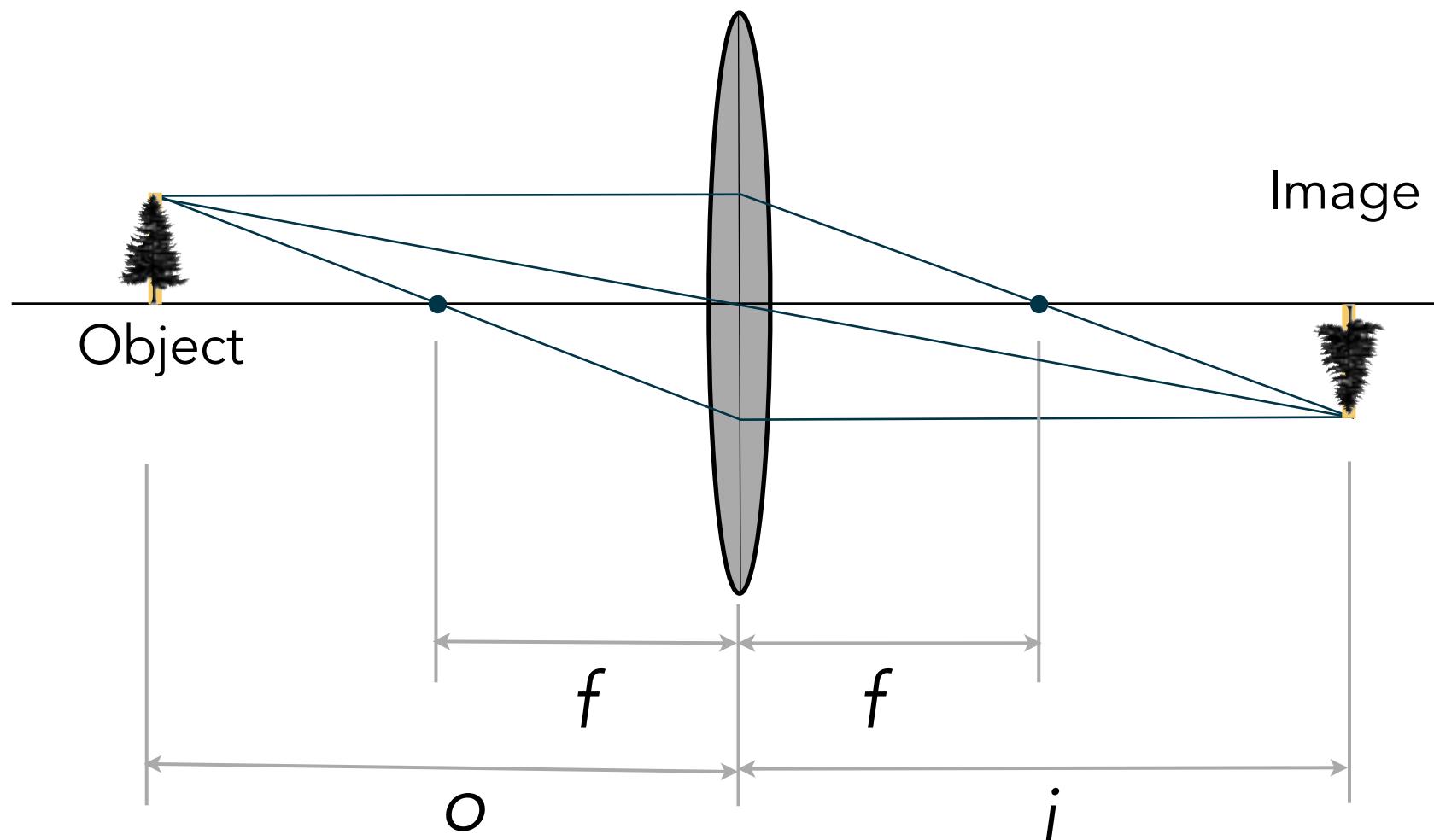
- ★ Rays from points on a plane parallel to the lens, focus on a plane parallel to the lens on the other side (and upside down).

Ray Tracing with Lenses



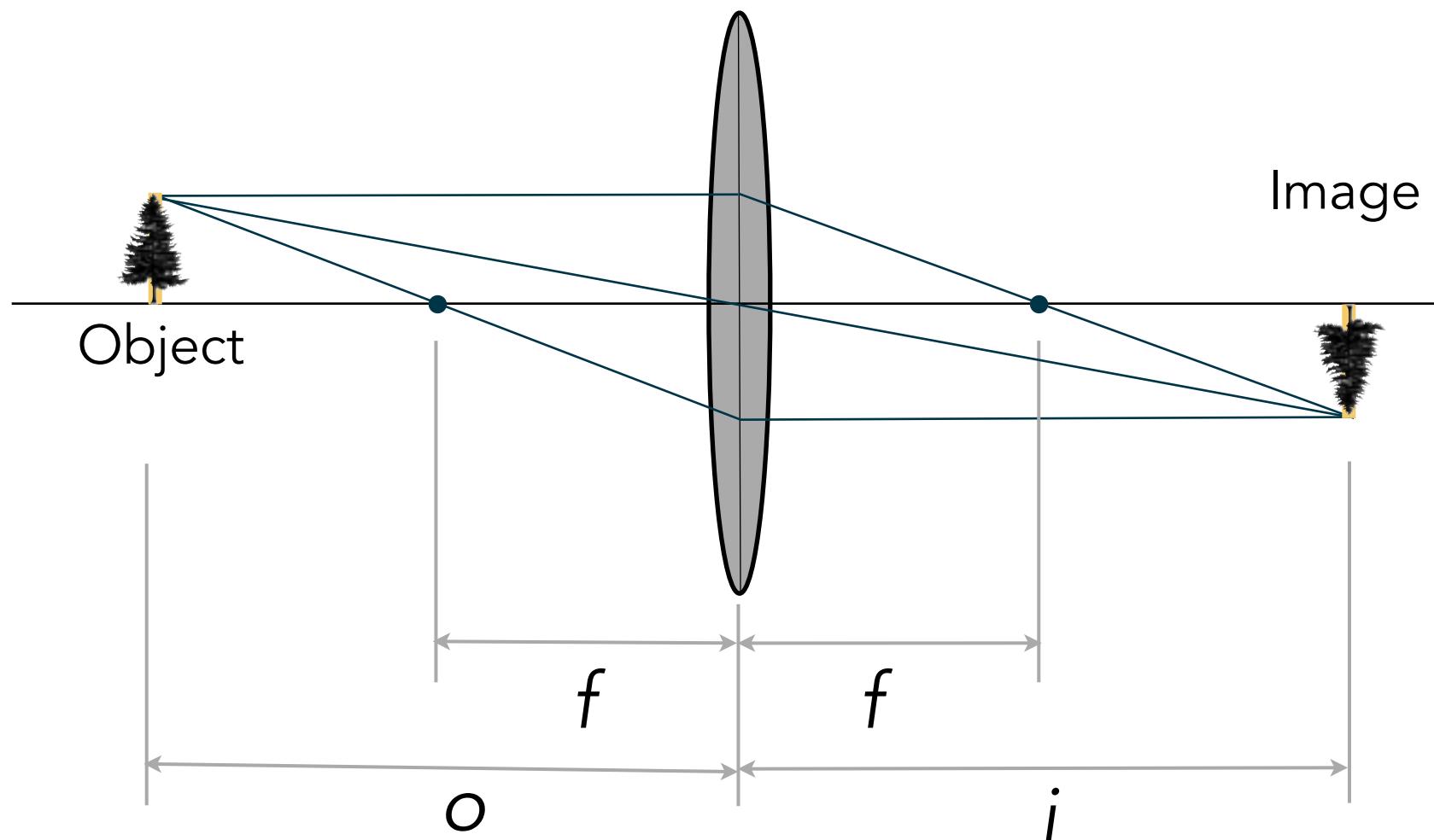
- ★ Rays from points on a plane parallel to the lens, focus on a plane parallel to the lens on the other side (and upside down).

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).
- ★ Lens Equation

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).
- ★ Lens Equation

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

Summary

- ★ Discussed the Foundations of How a Camera works
- ★ Presented the Concept of a Pinhole Camera
- ★ Introduced Optics and Lenses and the Role they play in a Camera



Next Class

★ Cameras: Changes in Focal Length, Aperture, Shutter and Sensor



Credits

- ★ For more information, see
 - Hecht, E. *Optics*, 4th ed. Reading, MA: Addison-Wesley and
 - London, B., Stone, J., & Upton, J., *Photography*, 10th ed. Upper Saddle River, NJ: Prentice Hall.

- ★ Images retrieved from
 - <http://commons.wikimedia.org/>
 - List will be available on website

- ★ Some Slides adapted from Mark Levoy

