Image Formation – Part 1

Computational Photography (CSCI 3240U)

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Acknowledgments

- These slides borrow and adapt materials developed by others, including
    - Michael Brown
    - Kyros Kutulakos
    - David Lindell
    - Gordon Wetzstein
    - Marc Levoy
    - Fredo Durand
    - Paul Debevec
    - Ramesh Raskar

Slide credits

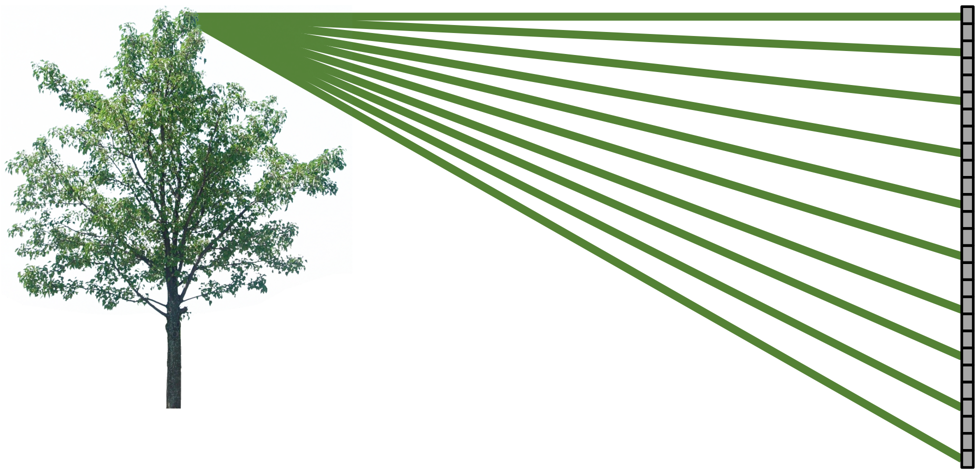
- A lot of inspiration and quite a few examples for these slides were taken directly from:
  - Kayvon Fatahalian (15-769, Fall 2016).
  - Michael Brown (CVPR 2016 Tutorial on understanding the image processing pipeline).
  - Marc Levoy (Stanford CS 178, Spring 2014).

Special thanks to Ioannis Gkioulekas

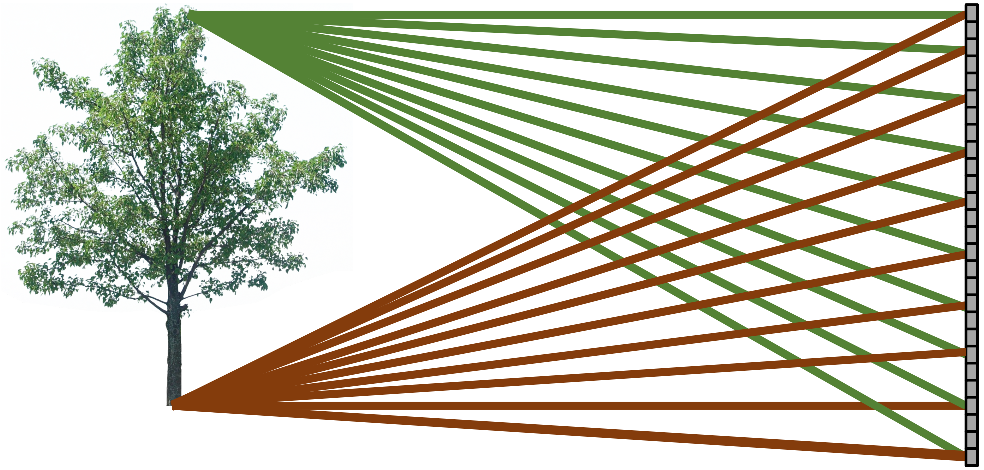
- Many of the slides are taken with his permission from the computational photography course that he has developed at CMU

Pinhole Cameras

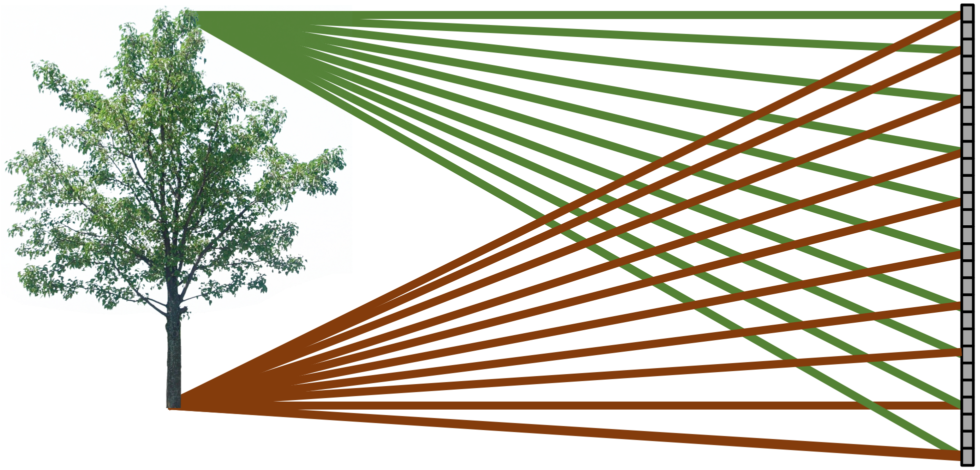
Pinhole Cameras



Pinhole Cameras



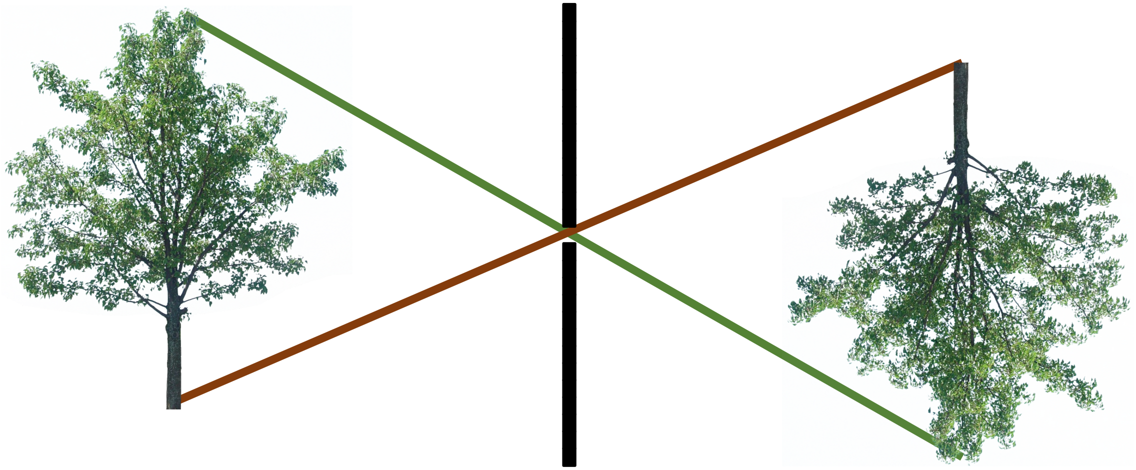
Pinhole Cameras



The image doesn't look anything like the tree on the left

Pinhole Cameras

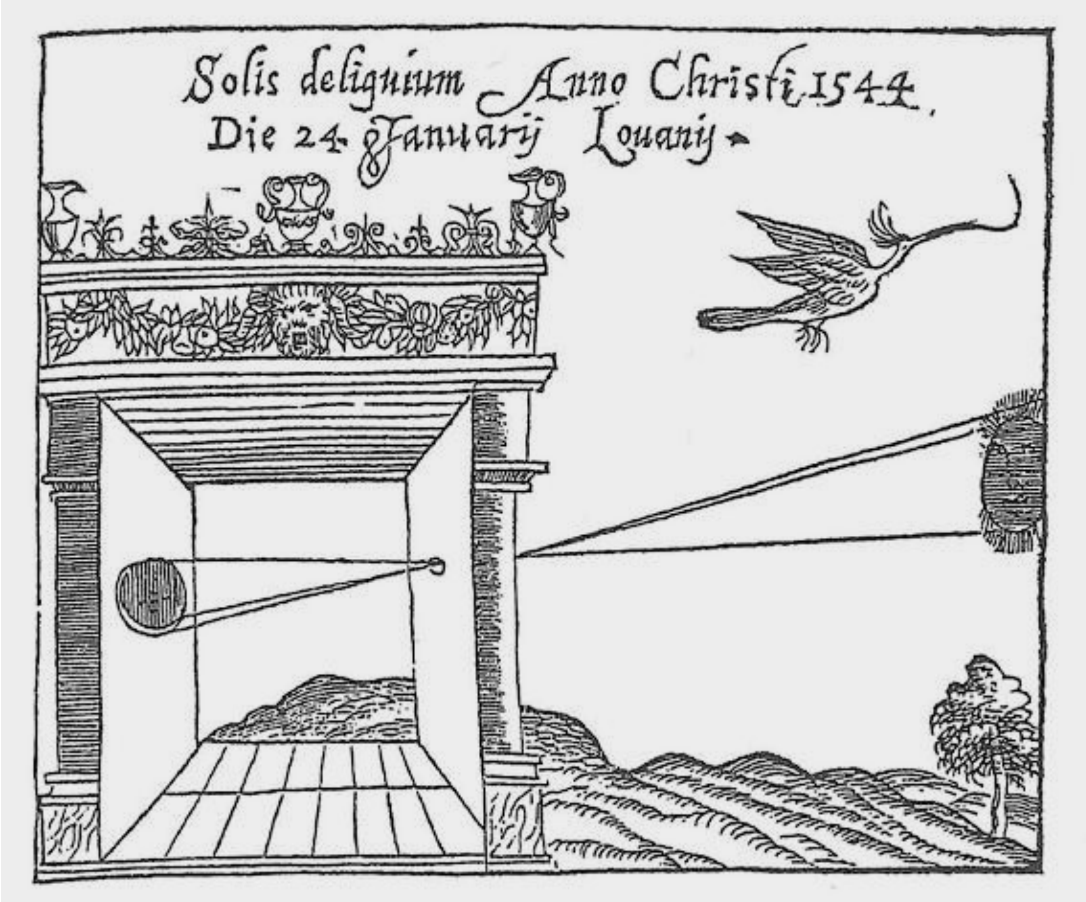
Pinhole Cameras



The image is inverted!

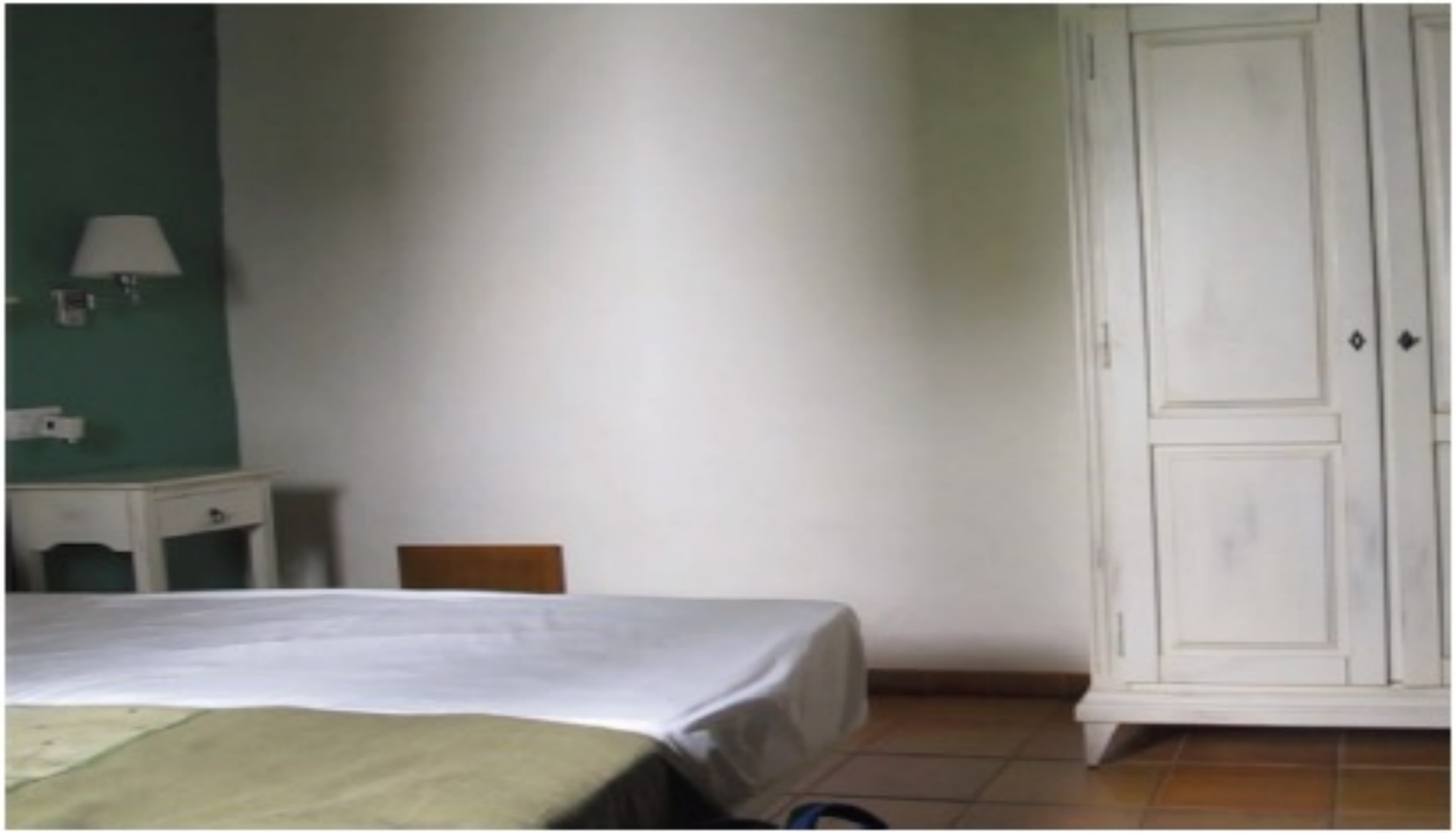
Camera Obscura

First Mention
Chinese philosopher Mozi
(470 to 390 BC)



First Camera
Greek philosopher Aristotle
(384 to 322 BC)

What does this image tell us about the outside?

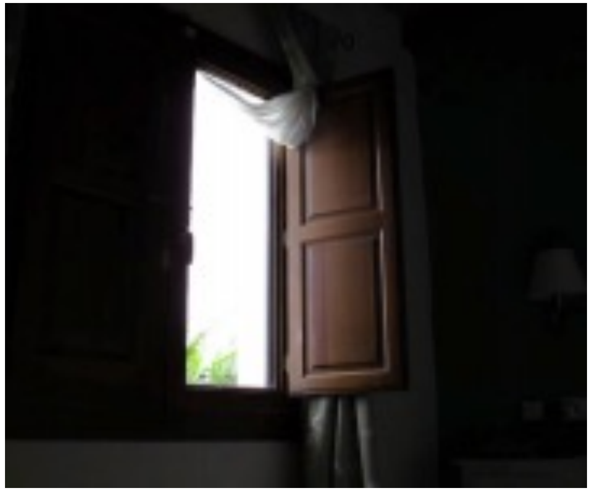


Windows as pinholes!

Antonio Torralba and William T. Freeman, CSAIL, MIT

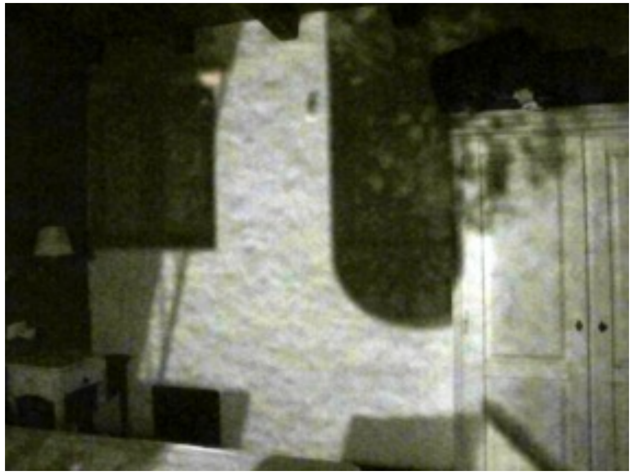
Windows as Pinholes!

Outside Scene



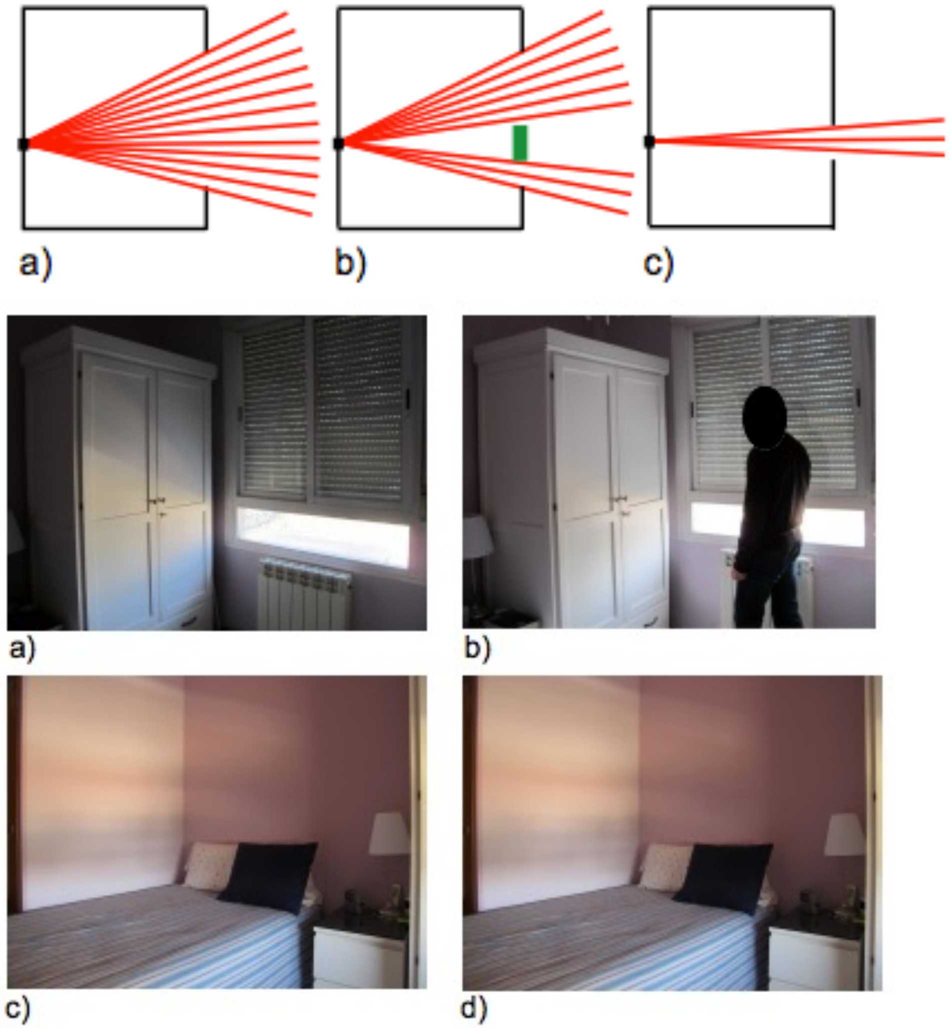
Window is an aperture
i.e. a pinhole

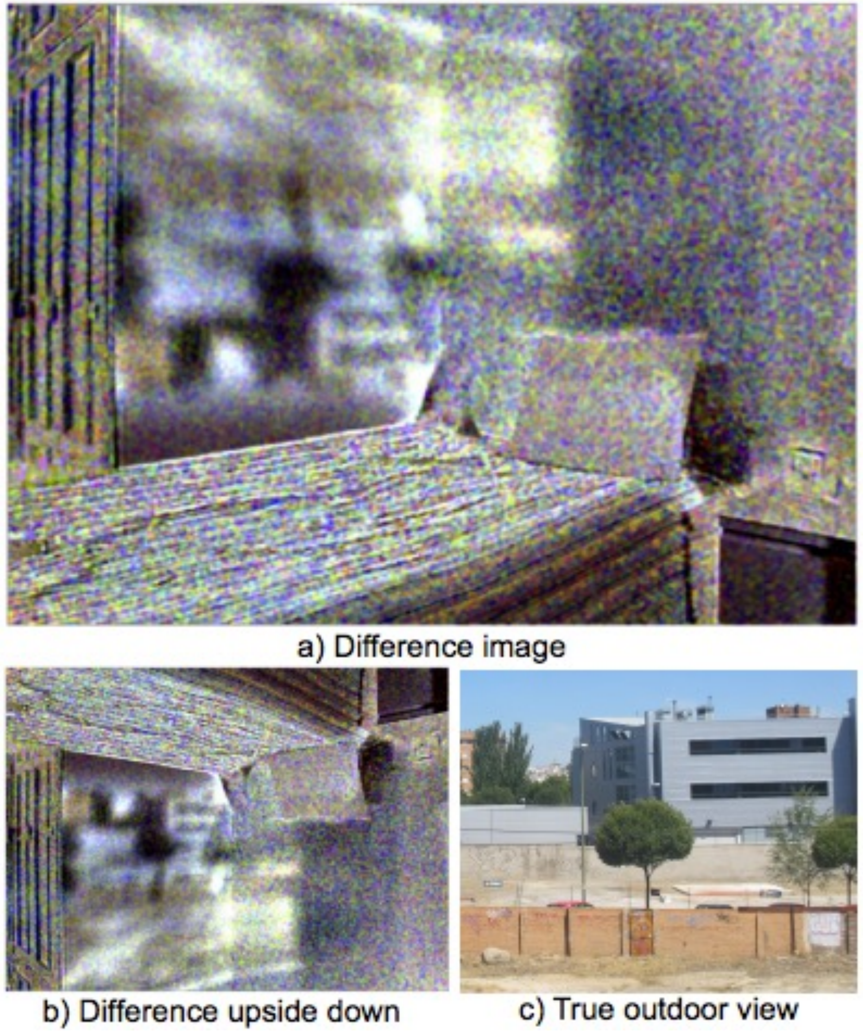
Lighting pattern on the
inside wall



Lighting pattern on the
inside wall as the window
gets smaller

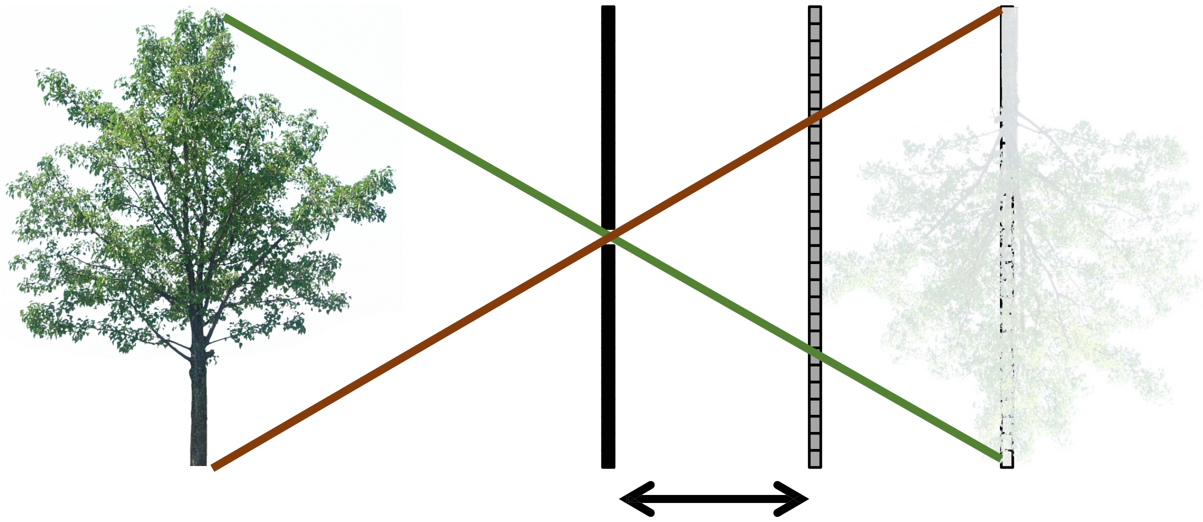
Accidental pinspeck Camera





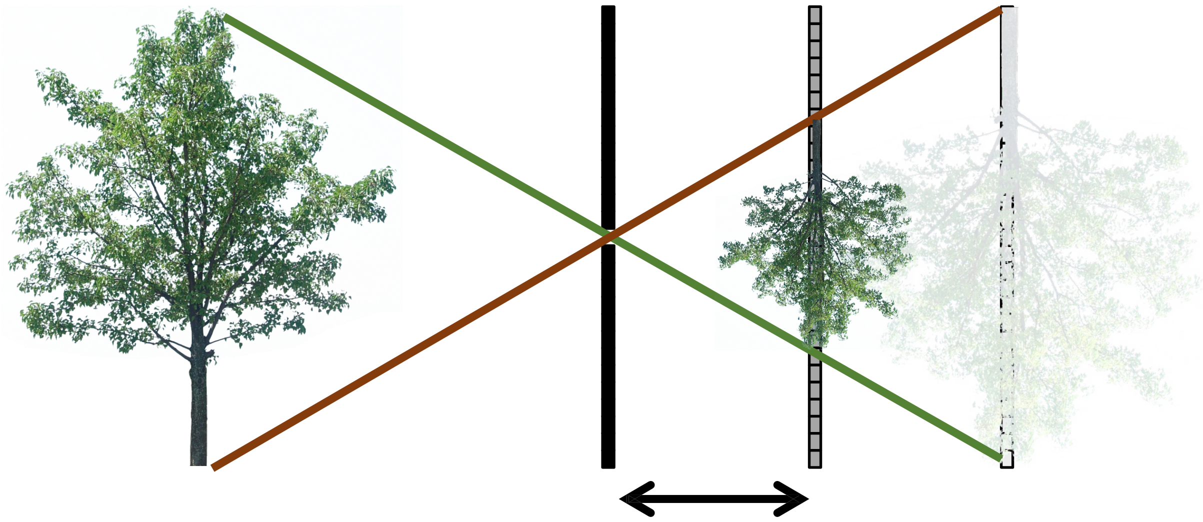
Pinhole Cameras

Pinhole Cameras



Focal length 0.5 f

Pinhole Cameras

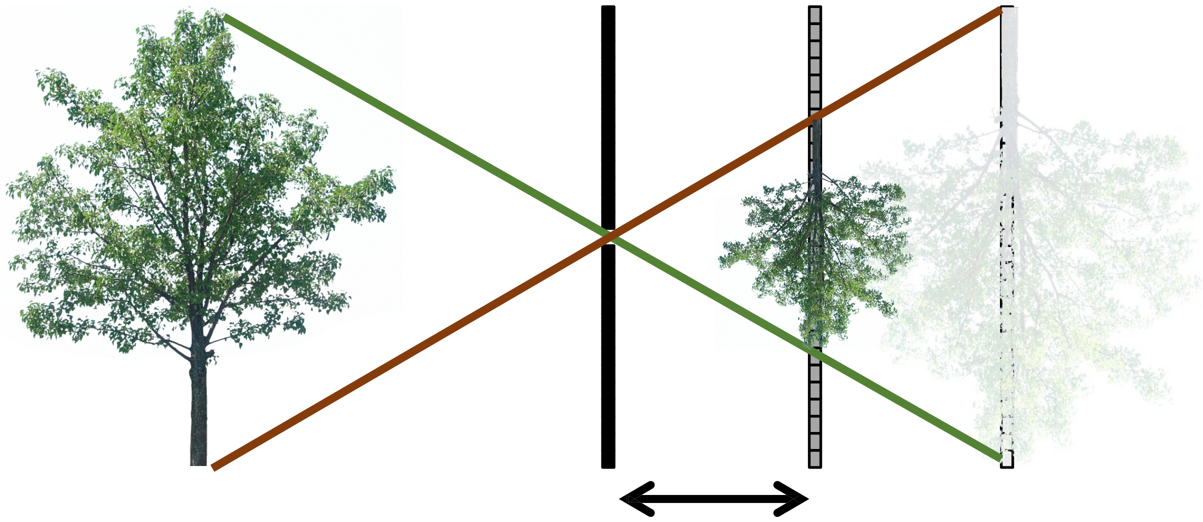


Focal length 0.5 f

The distance of the image plane to the pinhole effects the size of the image. The size of the object seen in the image shrinks as the distance between the image plan and the pinhole is reduced and vice-versa.

Pinhole Cameras

Can we say something more specific?



Focal length 0.5 f

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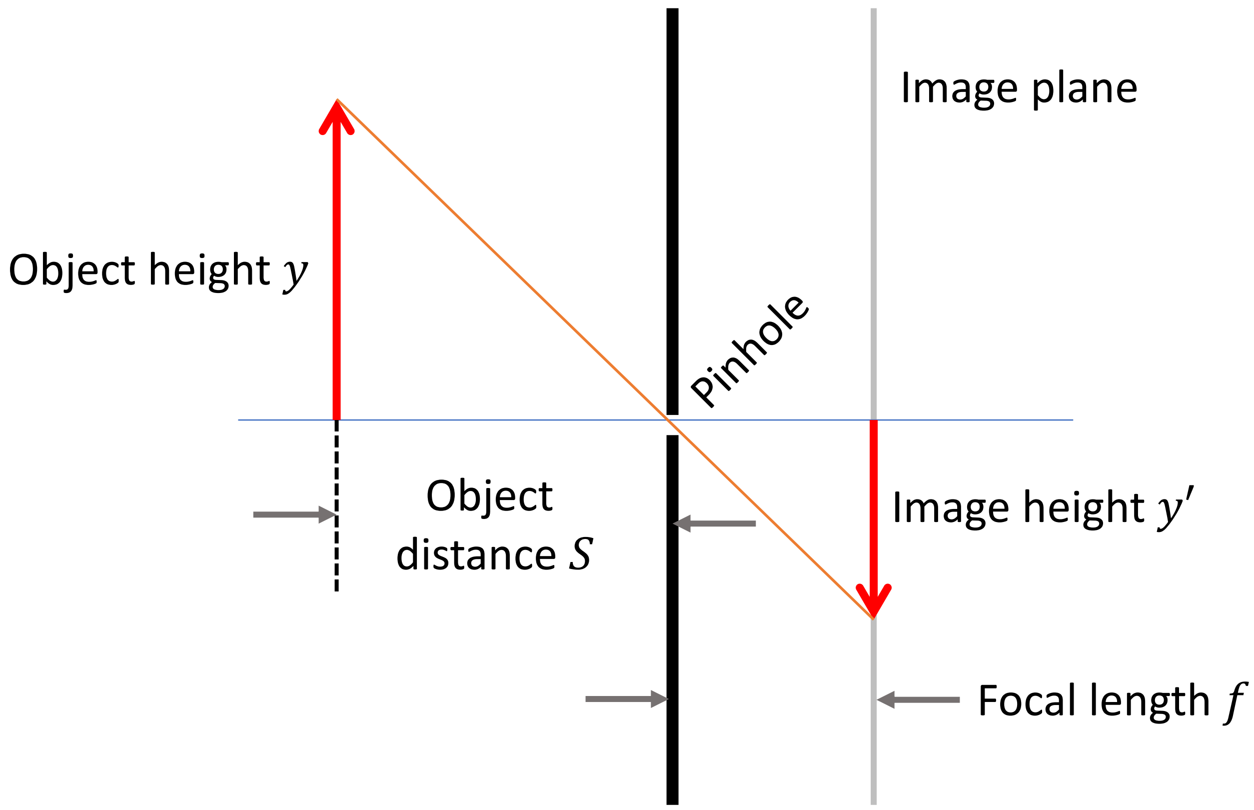
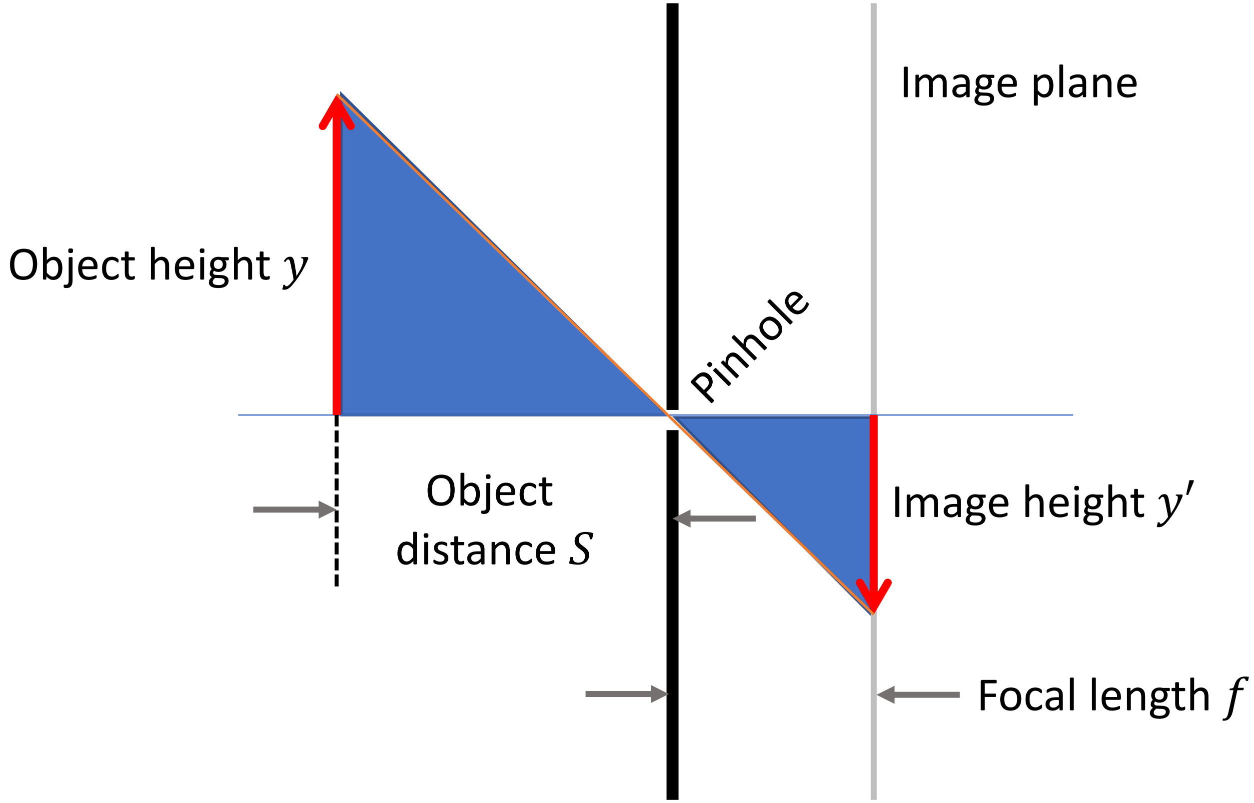
Pinhole Cameras

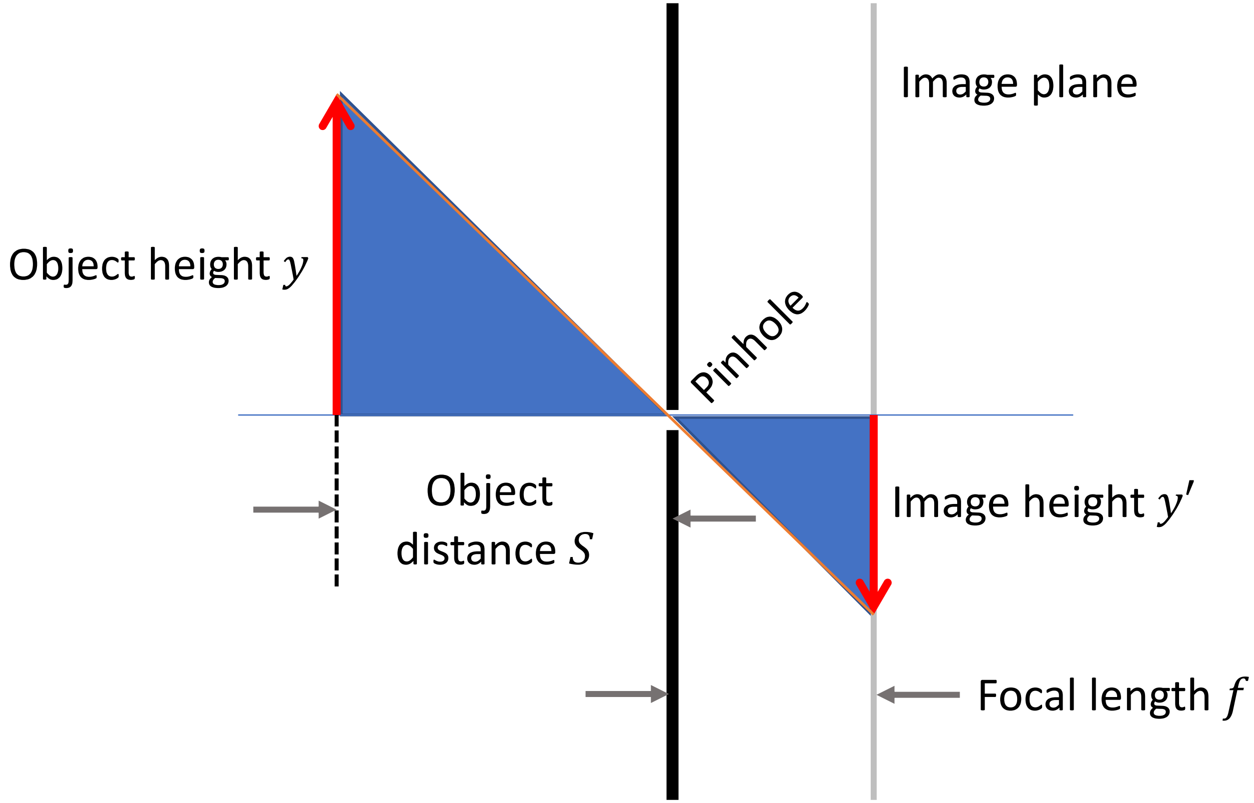


Pinhole Cameras



Similar triangles

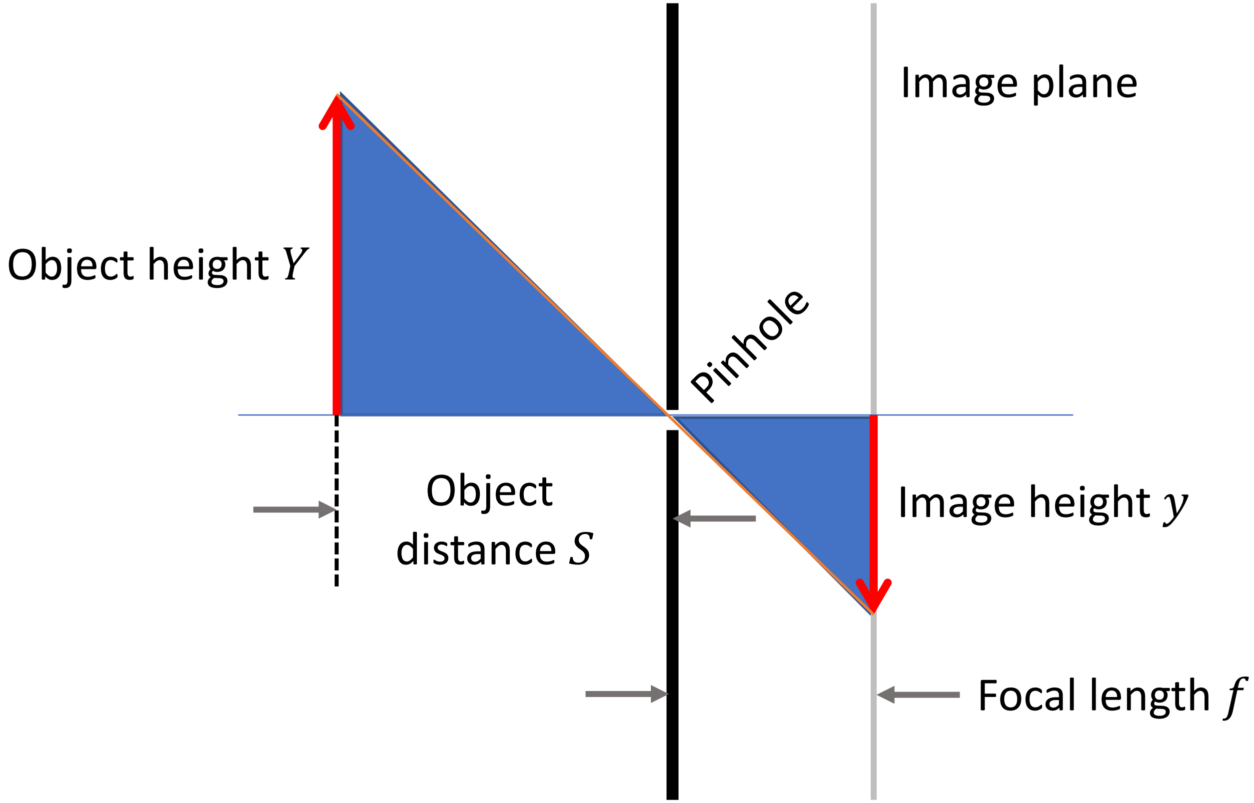
Pinhole Cameras



Similar triangles

$$\frac{y}{S} = \frac{y'}{f}$$

Pinhole Cameras



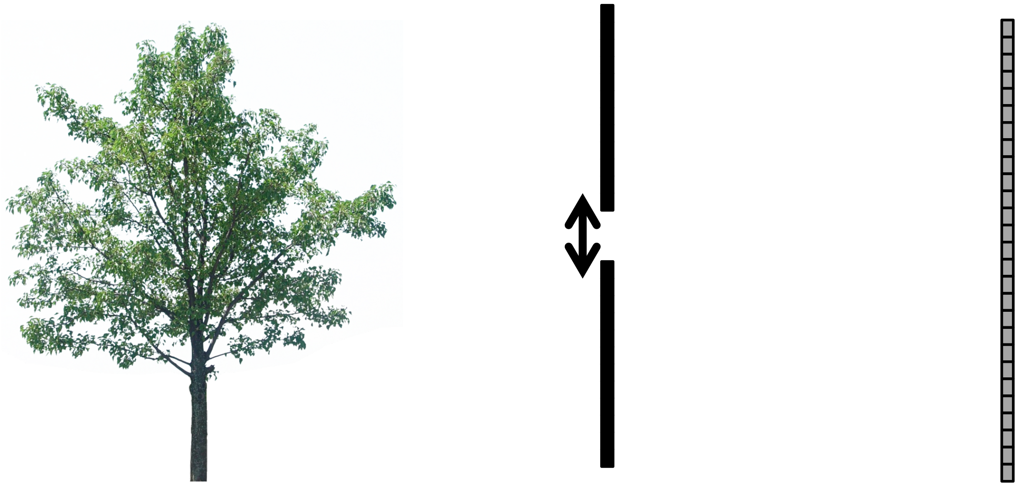
Similar triangles

$$\frac{y}{S} = \frac{y'}{f}$$

$$y' = f\frac{y}{S}$$

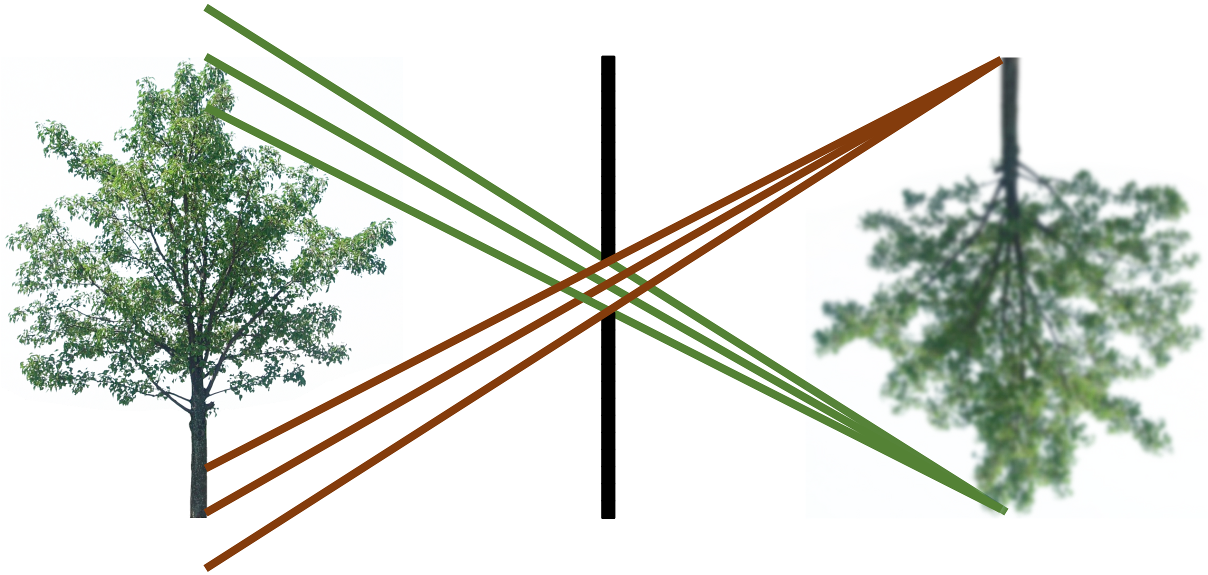
Farther objects appear smaller

Pinhole Cameras

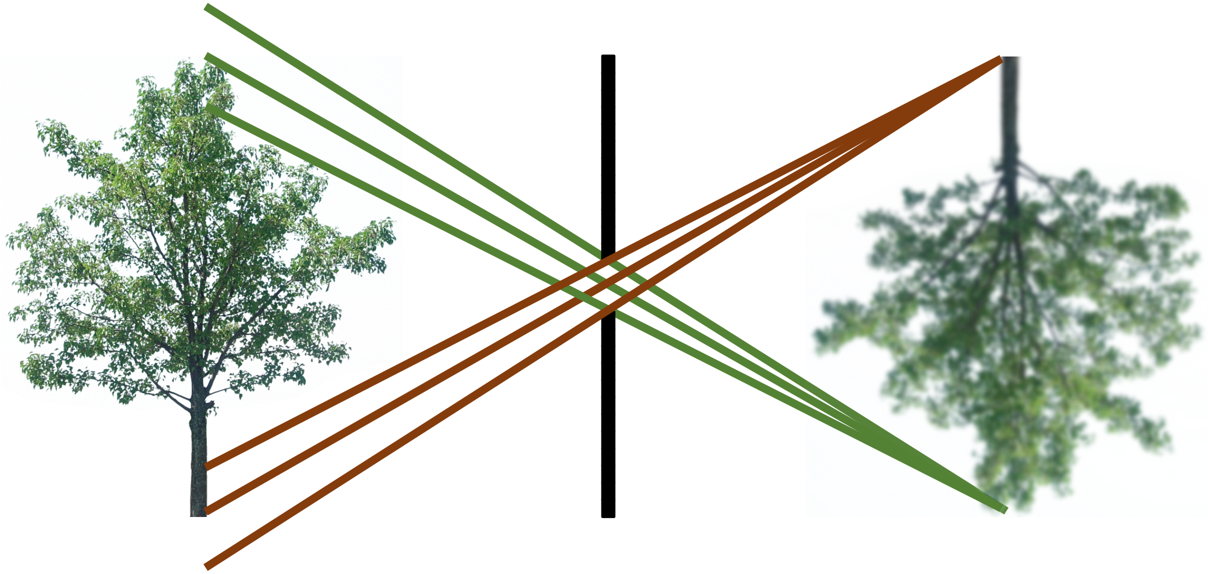


What happens if we increase the diameter of the pinhole?

Pinhole Cameras

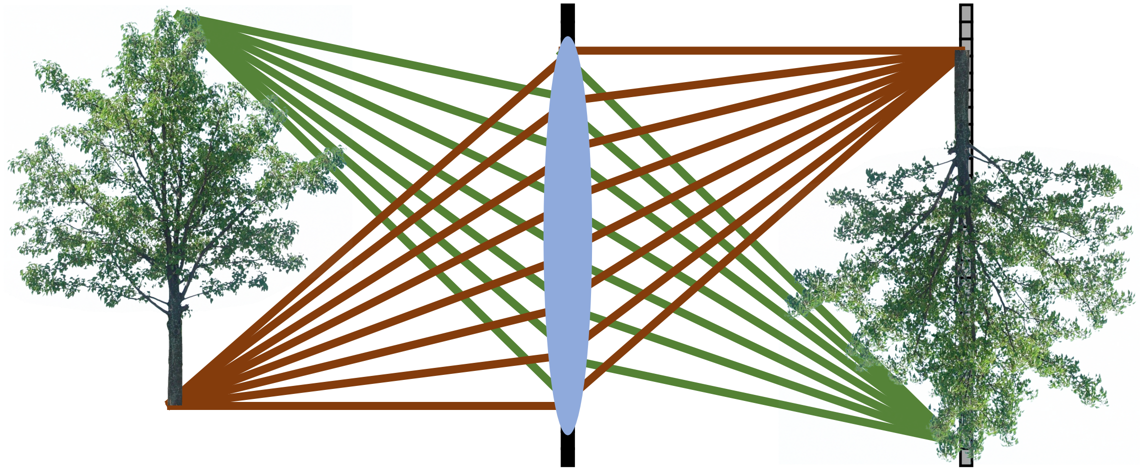


Pinhole Cameras



Increasing the size of the pinhole, i.e., aperture, blurs the image

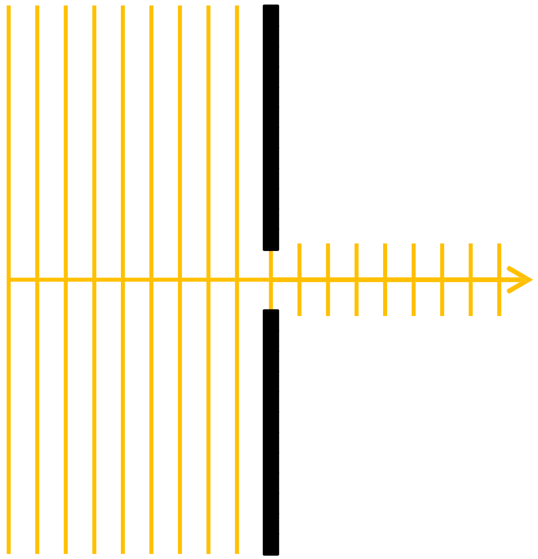
Using Lenses to Create Sharper Images



Lenses map “bundles” of rays from points on the scene to the sensor.

Size of the Pinhole

- We saw that increasing the size of the pinhole blurs the image
- What will happen if we continue to reduce the size of the pinhole?



If the wavelength of the light is much much smaller than the diameter of the pinhole (aperture), we can assume that light to travel in straight line

Size of the Pinhole

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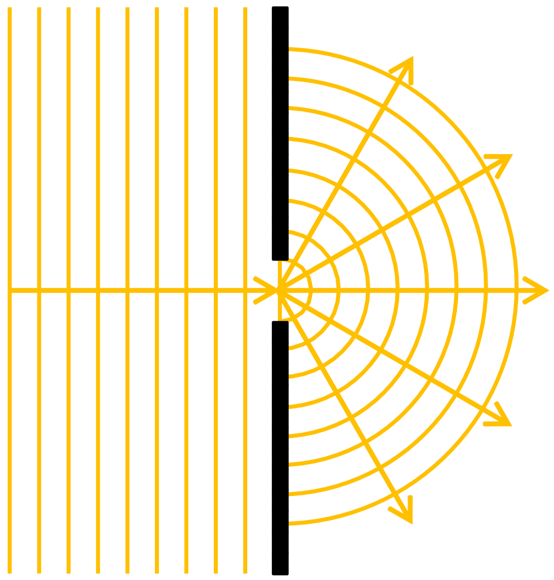
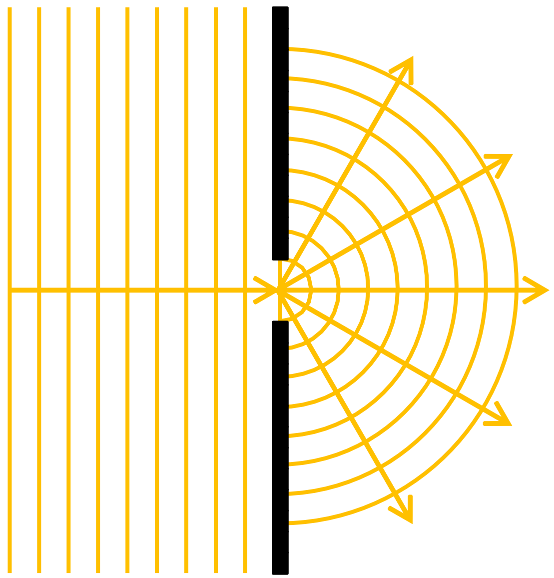
- What will happen if we continue to reduce the size of the pinhole?



If, however, wavelength of the light is similar to the diameter of the pinhole, the light rays spread out. This is called diffraction.

Size of the Pinhole

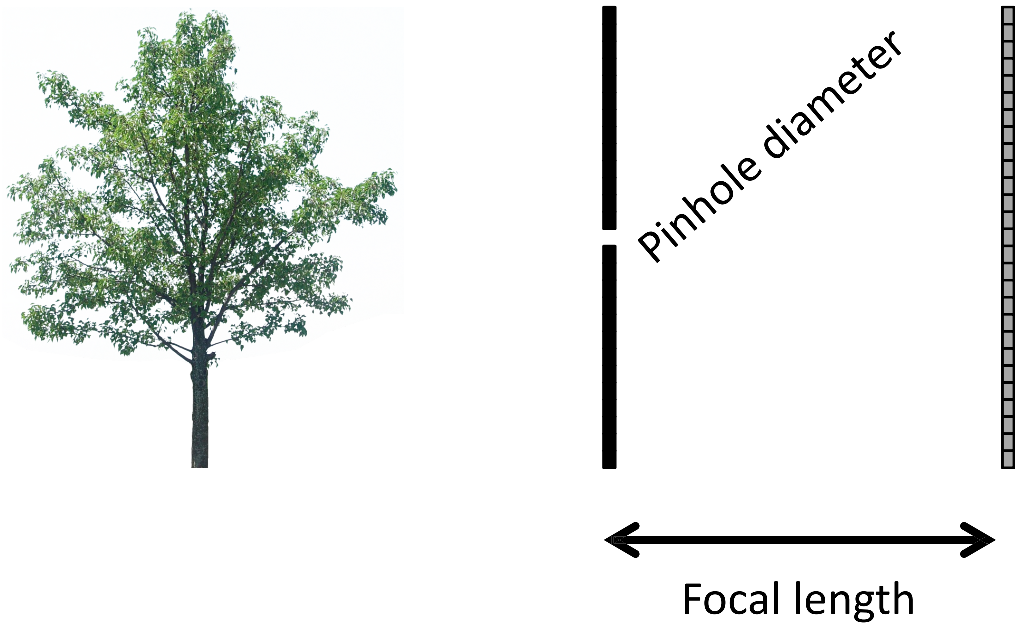
- We saw that increasing the size of the pinhole blurs the image
- What will happen if we continue to reduce the size of the pinhole?
  - Image will be blurry due to diffraction



If, however, wavelength of the light is similar to the diameter of the pinhole, the light rays spread out. This is called diffraction.

Light Efficiency

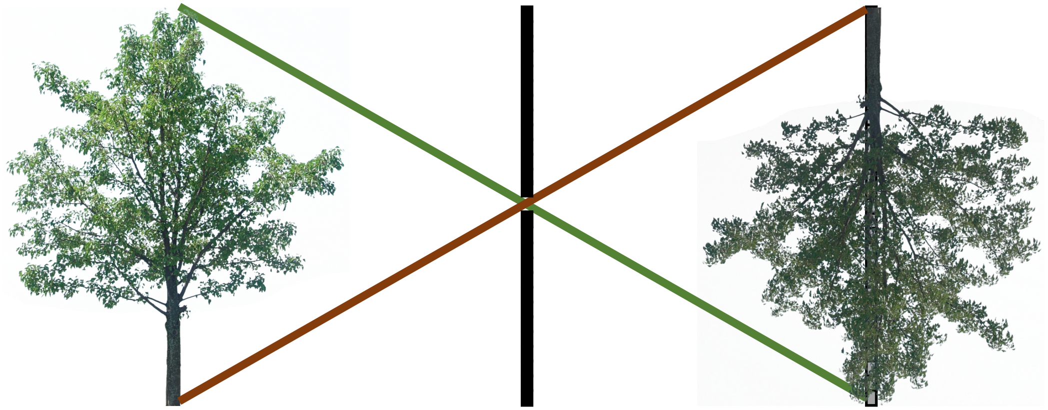
- Pinhole diameter x 2 = light x 4
- Focal length x 2 = light x 1/4



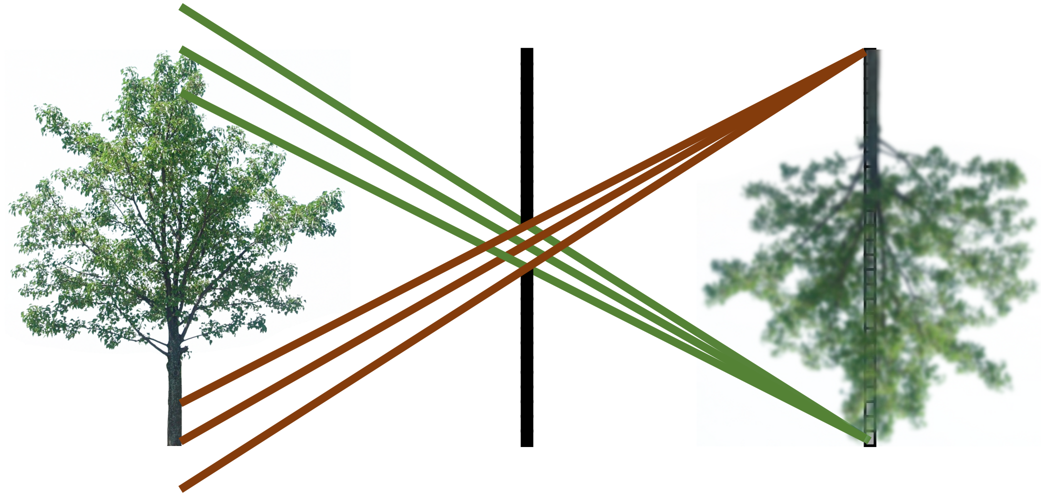
To gather more light in order to get better signal-to-noise ratio, we desire larger pinholes; however, larger pinholes result in blurry images. There, we use lenses.

Pinhole Camera Trade-off

- Small (ideal) pinhole
  - Sharp image
  - Low signal-to-noise ratio



- Large pinhole
  - Blurry image
  - High signal-to-noise ratio



Summary

- Pinhole Cameras
  - Image formation
  - Pinhole size
  - Tradeoff

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Onwards to part 2 that discusses lenses

Nimrud lens – 2700 years old