

# Digital Image : How To Capture Images

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CIVE 497 – CIVE 700: Smart Structure Technology



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FACULTY OF ENGINEERING

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# Real-World Scenes and Digital Images



What we see

Camera

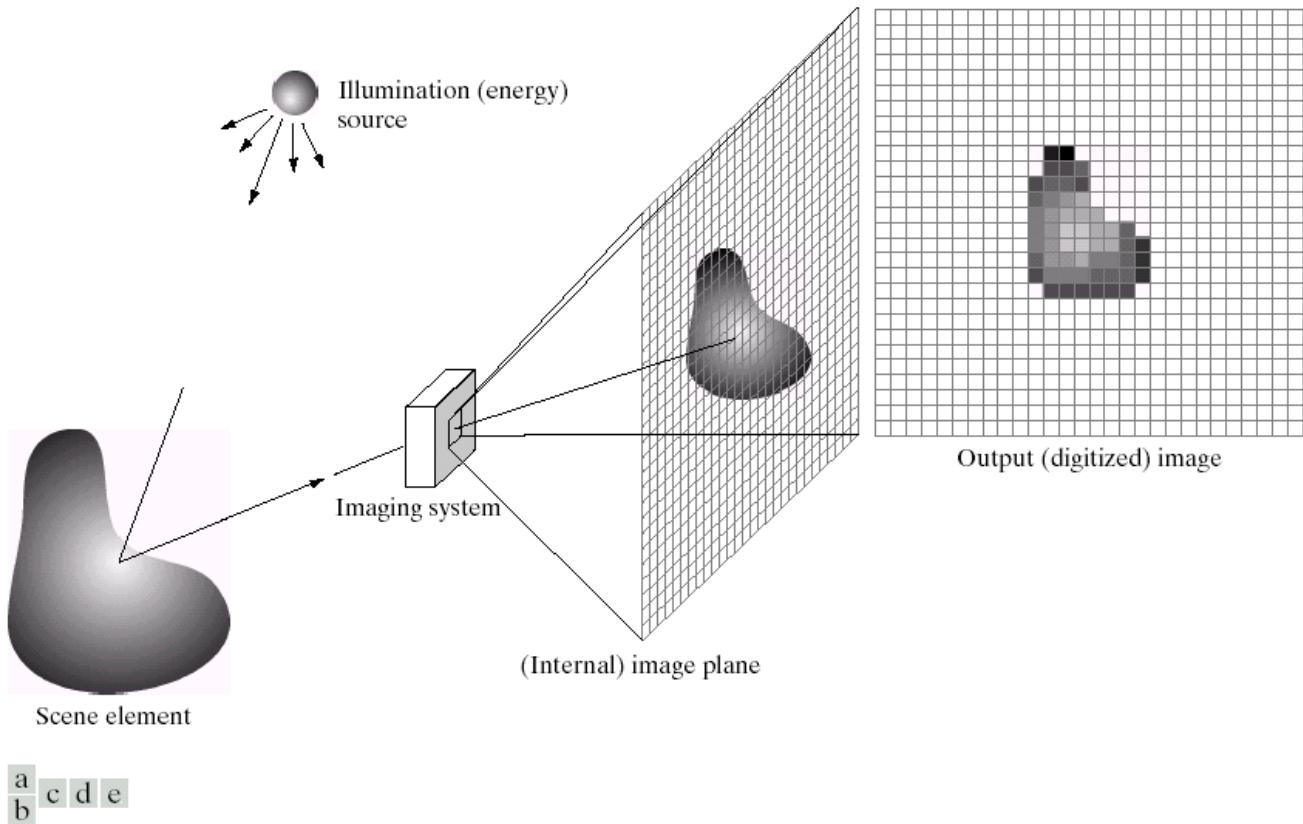


Image processing  
Computer Vision

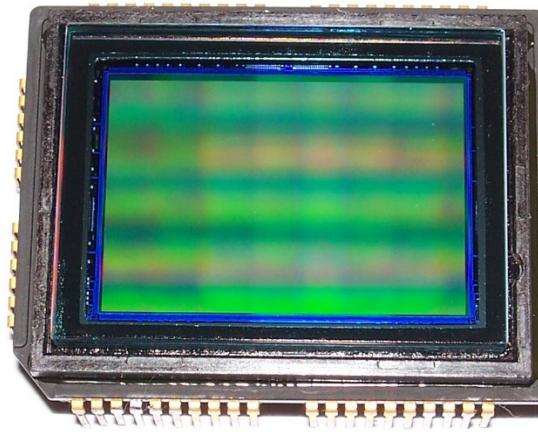
0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	3	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

What a computer sees

# What is the Pixel?



**FIGURE 2.15** An example of the digital image acquisition process. (a) Energy (“illumination”) source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

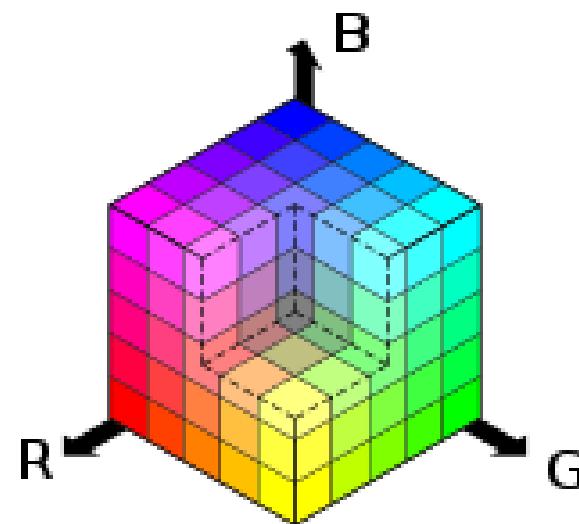
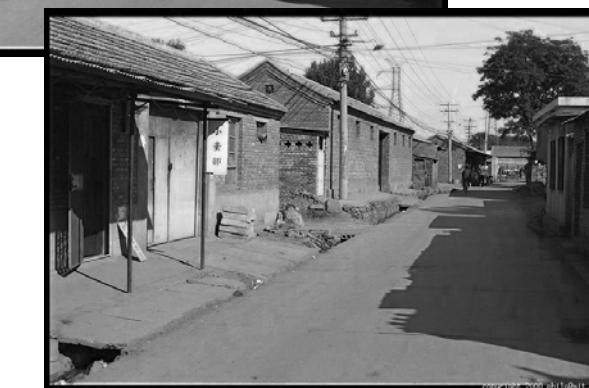
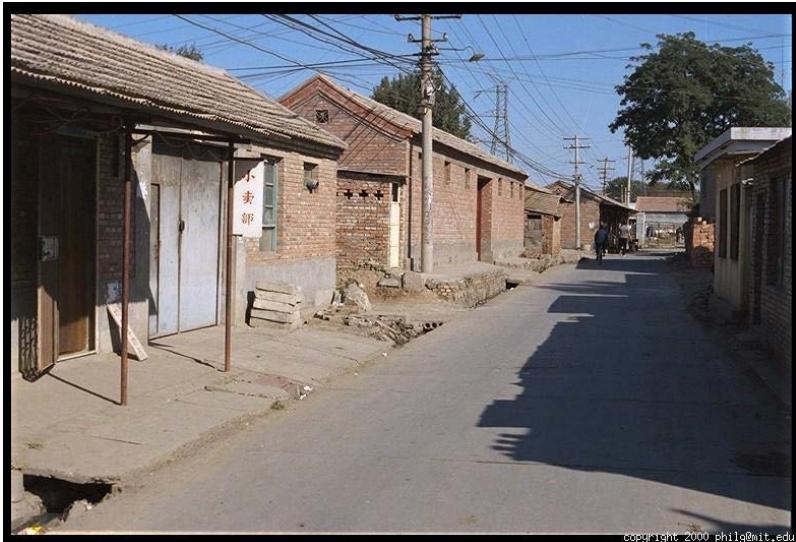


**Image sensor**

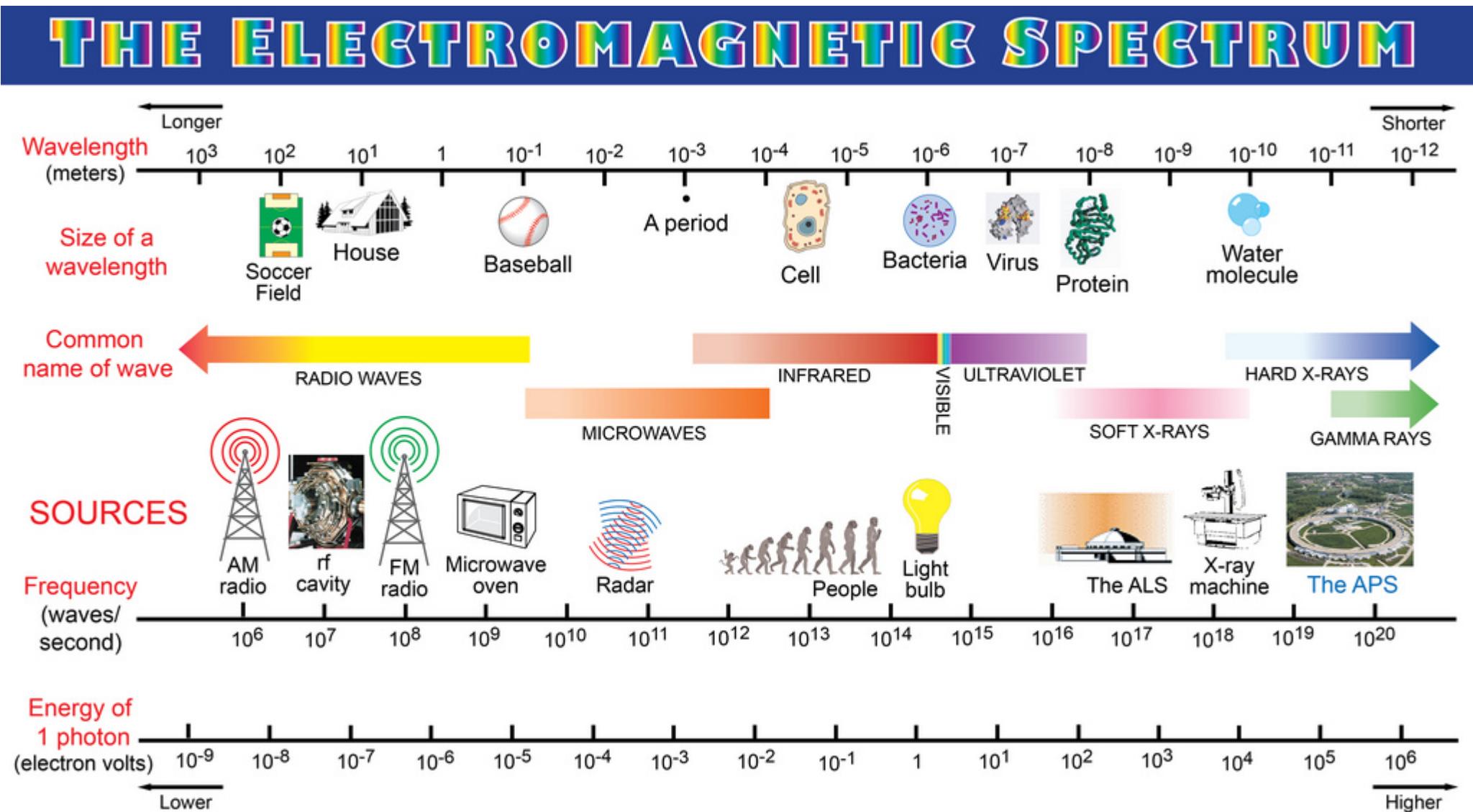


**DSLR camera**

# Color Images



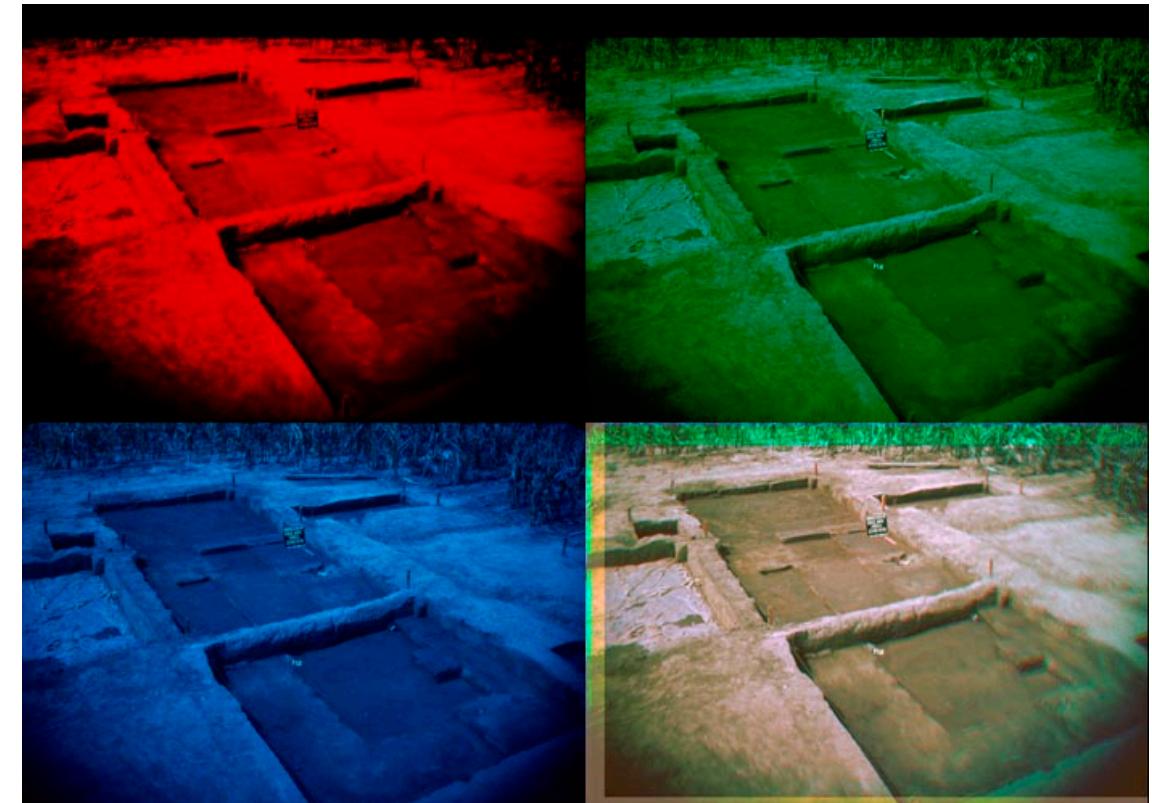
# Visible Light Spectrum



# RGB Filter

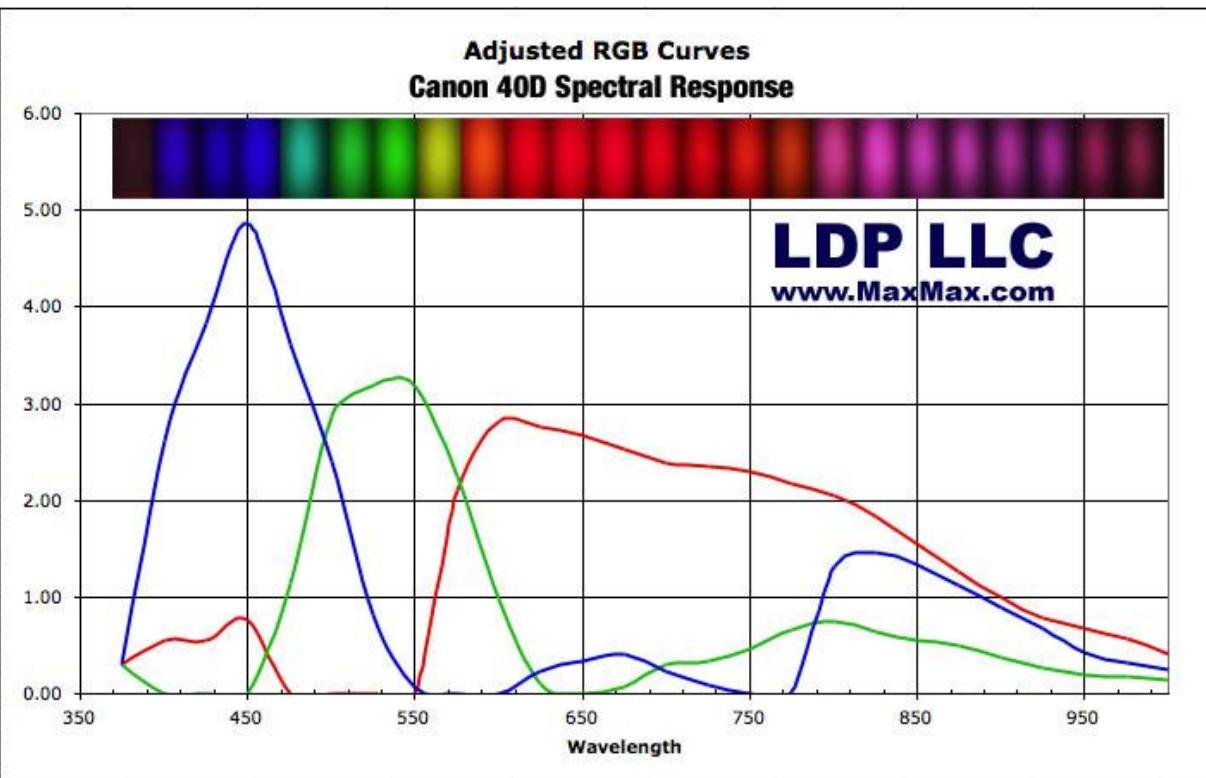


<https://tienda.lunatico.es/RGBUV/IR-Baader-2-filter-set>

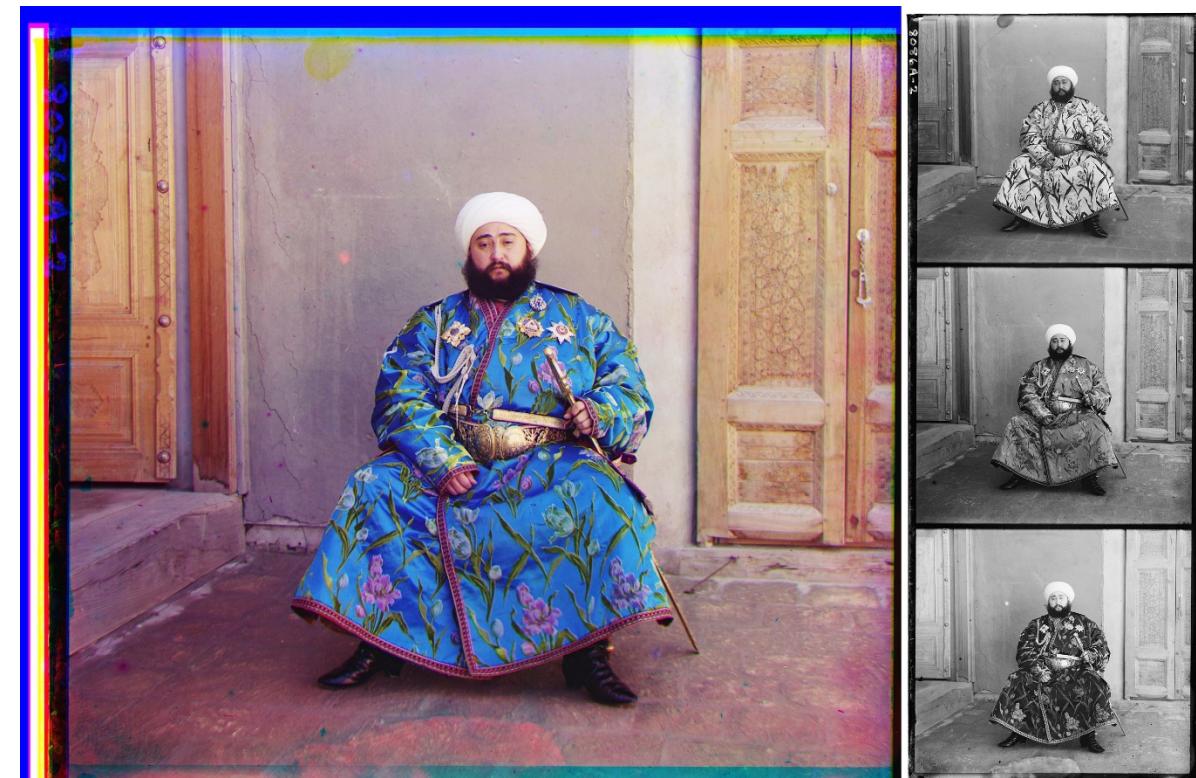


<https://www.photo.net/discuss/threads/rgb-filters-for-color-w-b-w-film.414924/>

# Spectral Response



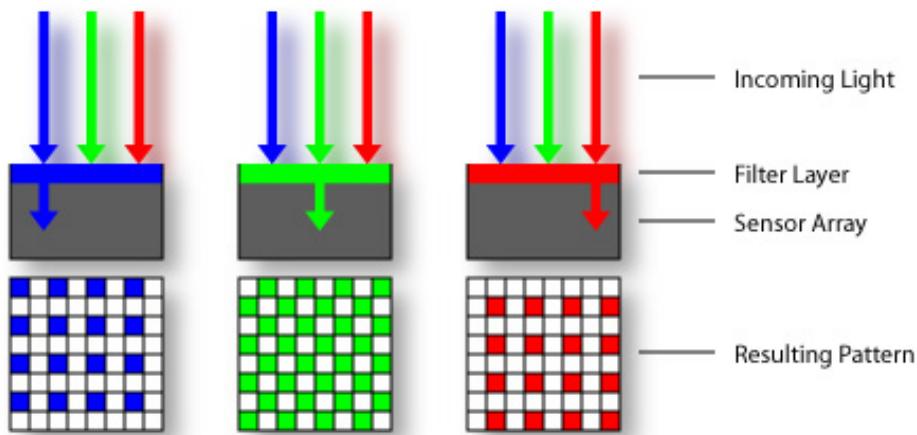
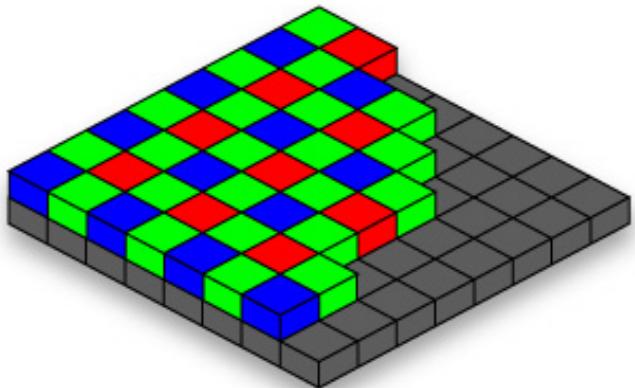
[https://maxmax.com/spectral\\_response.htm](https://maxmax.com/spectral_response.htm)



[https://en.wikipedia.org/wiki/RGB\\_color\\_model#/media/File:Rgb-compose-Alim\\_Khan.jpg](https://en.wikipedia.org/wiki/RGB_color_model#/media/File:Rgb-compose-Alim_Khan.jpg)

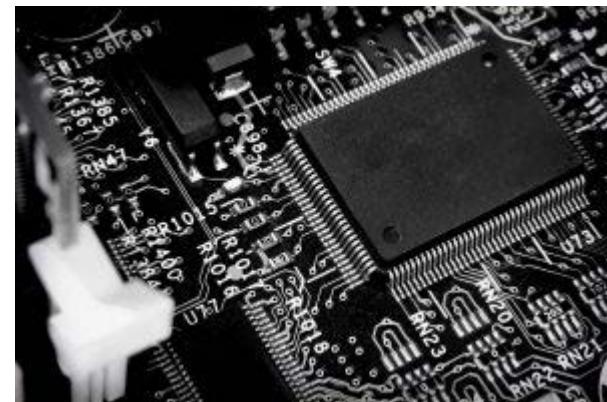
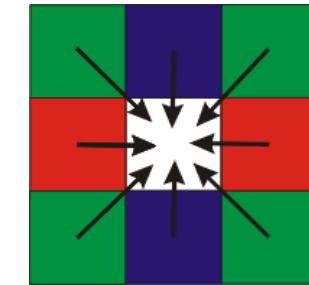
# Color Filter Arrays

# Bayer grid



# Demosaicing:

## Estimation of missing components from neighboring values



# Monochrome machine vision camera

# Image File Structure

- Images represented as a matrix
- Suppose we have a NxM RGB image called “im”
  - $\text{im}(1,1,1)$  = top-left pixel value in R-channel
  - $\text{im}(y, x, b)$  = y pixels down, x pixels to right in the  $b^{\text{th}}$  channel
  - $\text{im}(N, M, 3)$  = bottom-right pixel in B-channel
- `imread(filename)` returns a uint8 image (values 0 to 255)
  - Convert to double format (values 0 to 1) with `im2double`

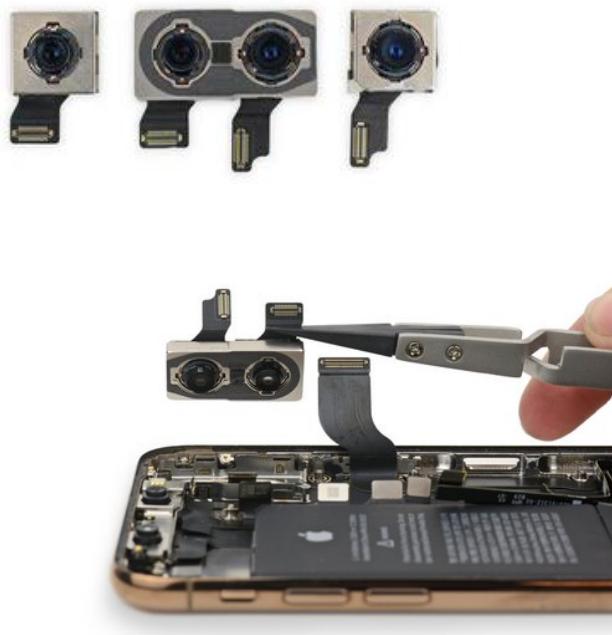
The diagram illustrates the structure of an RGB image as a matrix. A 10x10 grid of numbers represents the pixel values. A vertical blue arrow labeled "row" points downwards, and a horizontal blue arrow labeled "column" points to the right, indicating the matrix's orientation.

Three separate columns on the right represent the Red (R), Green (G), and Blue (B) channels. The R channel has 10 rows. The G channel has 10 rows. The B channel has 10 rows. The first few rows of each channel are highlighted with a blue border.

0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93
0.69	0.75	0.58	0.68	0.45	0.42	0.77	0.75	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93
0.69	0.75	0.58	0.68	0.45	0.42	0.77	0.75	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

# Example: Smart Phones

Apple iPhone XS Max	
Size	157.5 x 77.4 x 7.7 mm (6.2 x 3.05 x 0.30 inches)
Weight	208 grams (7.34 ounces)
Screen size	6.5-inch Super Retina AMOLED display
Screen resolution	2688 x 1242 pixels (458 pixels-per-inch)
Operating system	iOS 12
Storage space	64GB, 256GB, 512GB
MicroSD card slot	No
Tap-to-pay services	Apple Pay
Processor	A12 Bionic
RAM	4GB
Camera	Dual 12MP rear, 7MP FaceTime HD front
Video	2160p at 60 fps, 1080p at 240 fps



## 6D MK II



## Image Sensor

26 MP.  
24.0 × 35.9mm CMOS.  
Anti-alias filter.  
5.67 µm pixel pitch.  
3:2 aspect ratio.  
1.0× [crop factor](#) (full-frame).  
Ultrasonic cleaner.

<https://www.ifixit.com/Guide/Image/meta/JyuleQEJbHHs1BrU>  
<https://kenrockwell.com/canon/6d-mk-ii.htm>

# Questions

**Case 1: Apple watch with a 4k screen.**

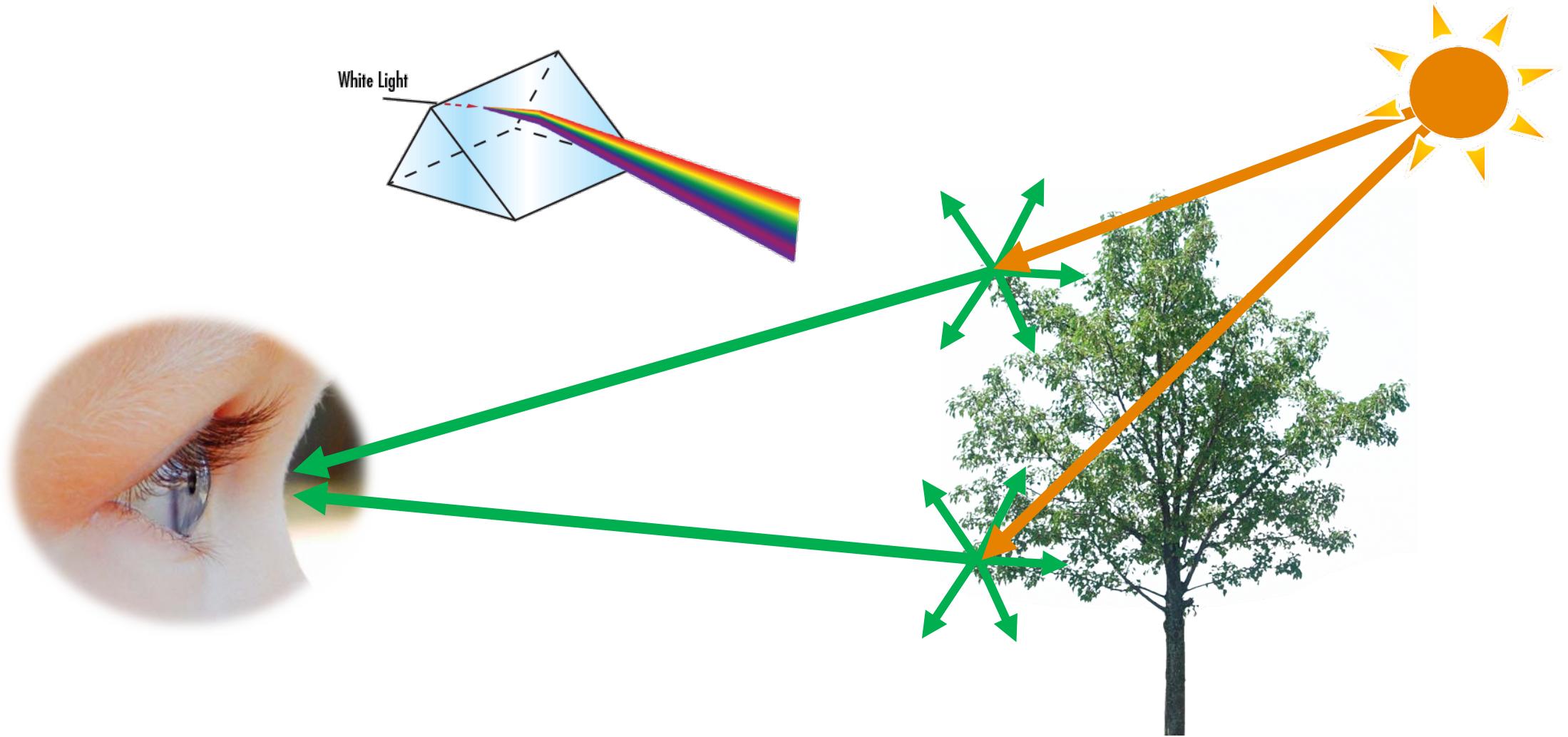
**Case 2: 80 inch high-definition full-HD TV.**

**Case 3: 4k monitor for Skype meeting**

**Case 4: 5 inch smart phone with 4k resolution for VR gaming**

**Case 5: 8K 80 inch TV for NETFLIX watching**

# Role of Light to Sight



Rays from the sun reflect off plant and the green rays go in all directions

# Camera Sensor



digital sensor  
(CCD or CMOS)

# Object We Like to Take

real-world  
object



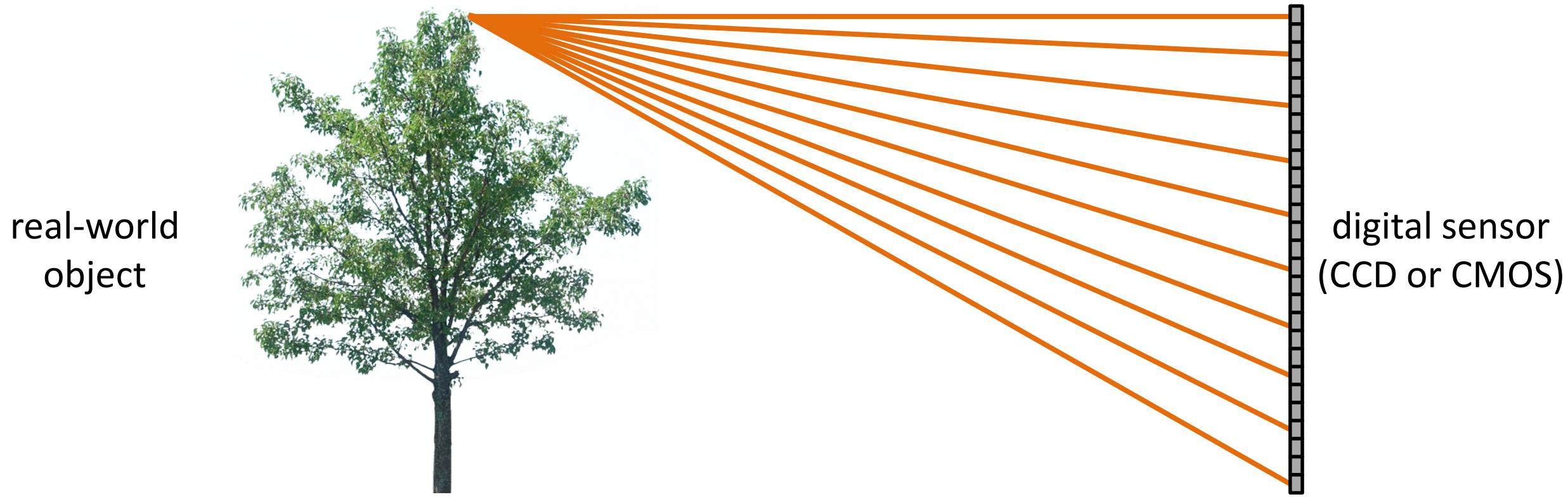
digital sensor  
(CCD or CMOS)

What would an image taken like this look like?

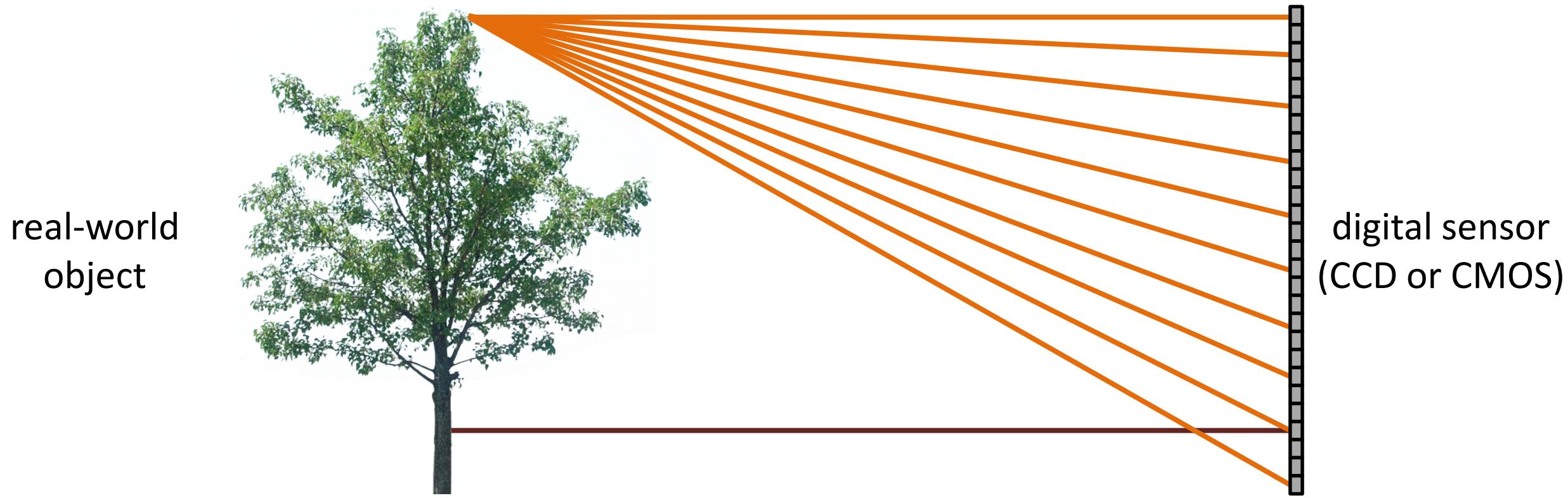
# Bare-Sensor Imaging



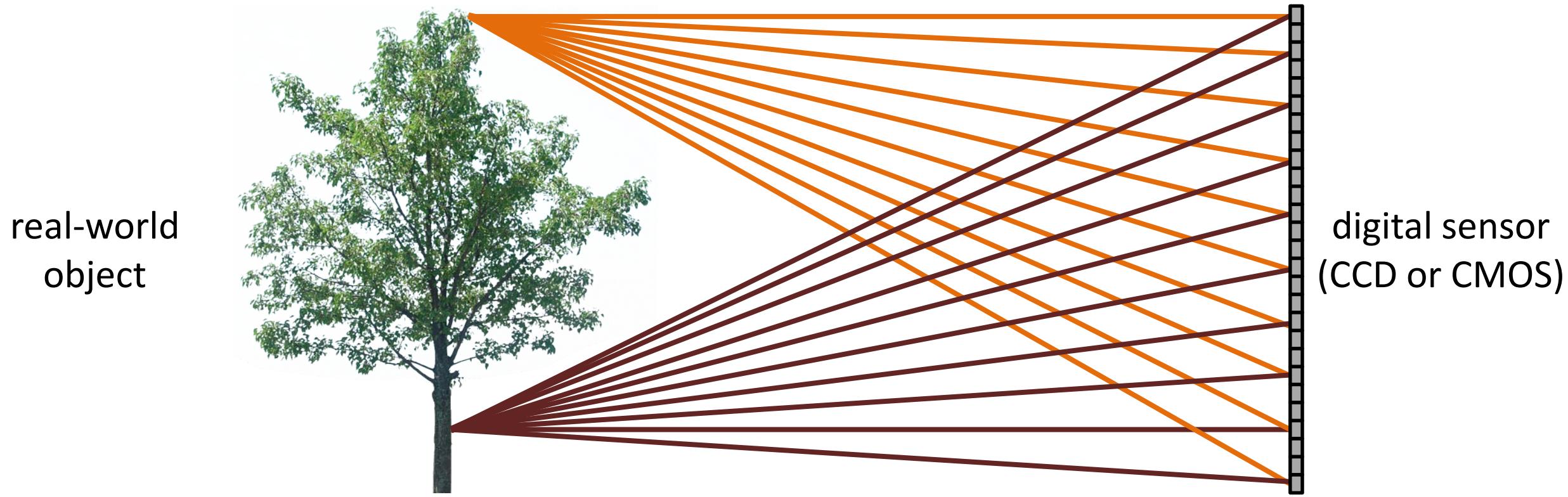
# Light Reflect off All Positions on the Object and Goes in All Directions



# Light Reflect off All Points on the Object and Goes in All Directions

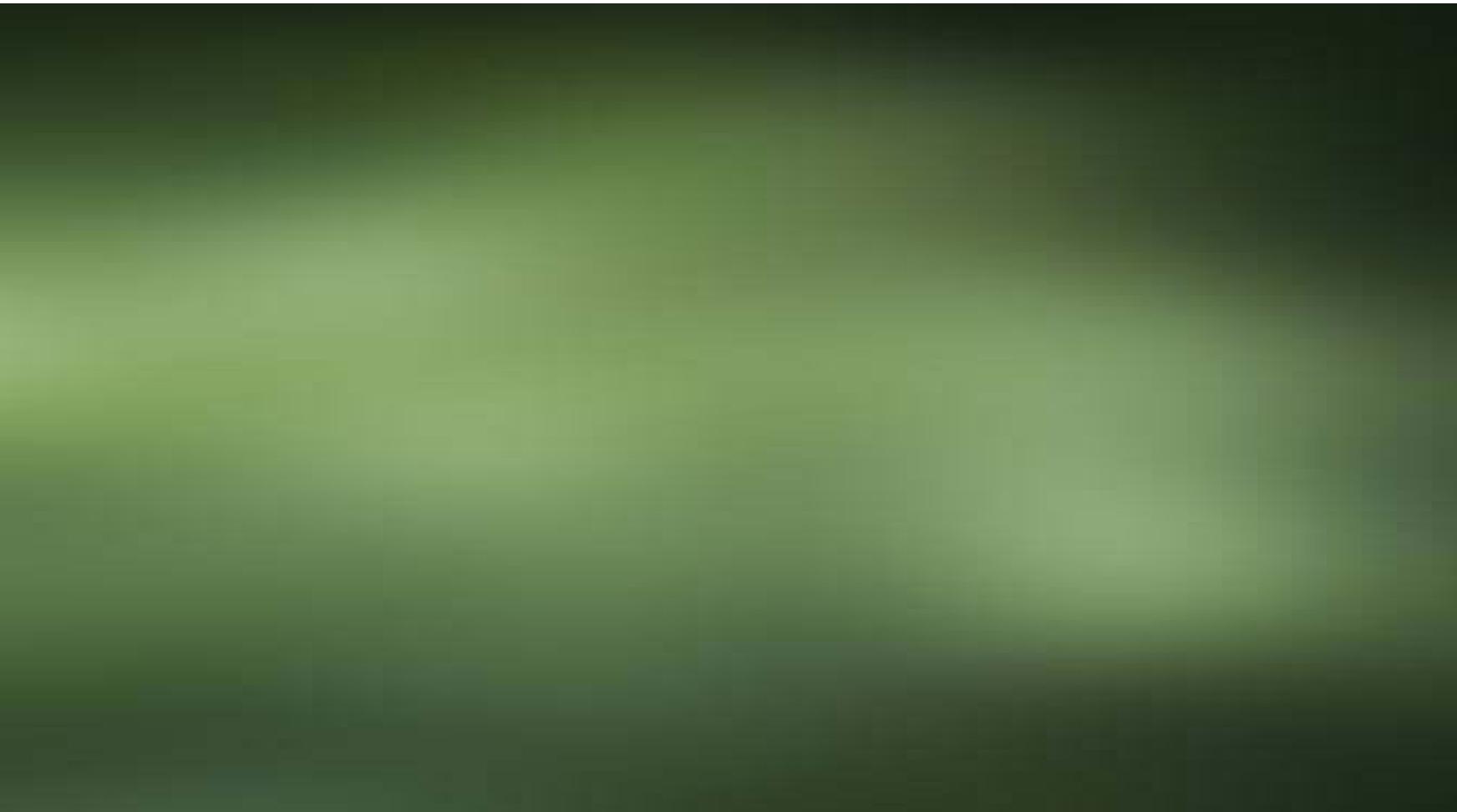


# What Does the Image on the Sensor Look Like?



All scene points contribute to all sensor pixels

# All Scene Points Contribute to All Sensor Pixels



# What can We Do to Make Our Image Look Better?

real-world  
object



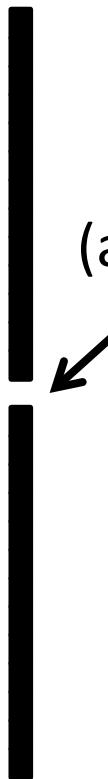
digital sensor  
(CCD or CMOS)

# Pinhole Imaging

real-world  
object



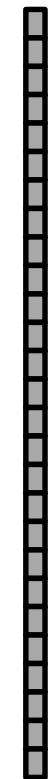
barrier (diaphragm)



pinhole  
(aperture)

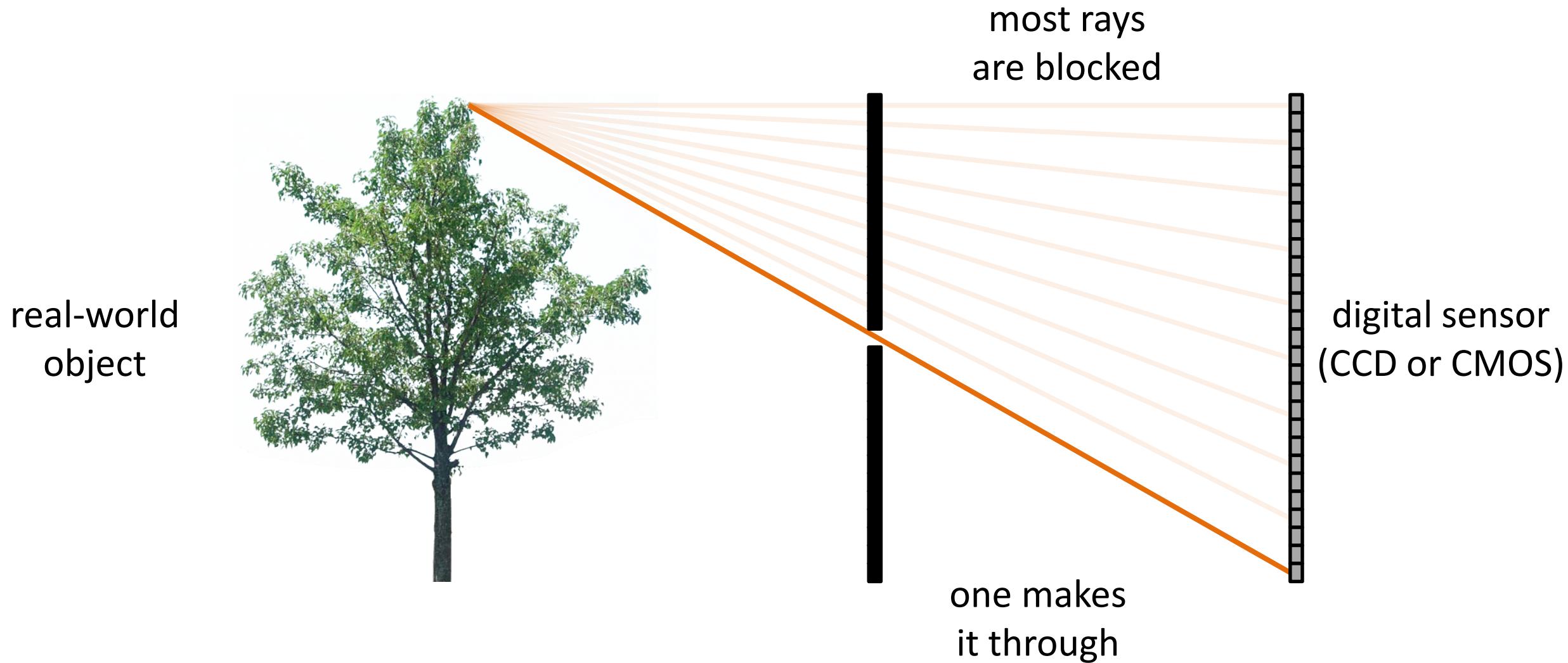


Very small  
pinhole

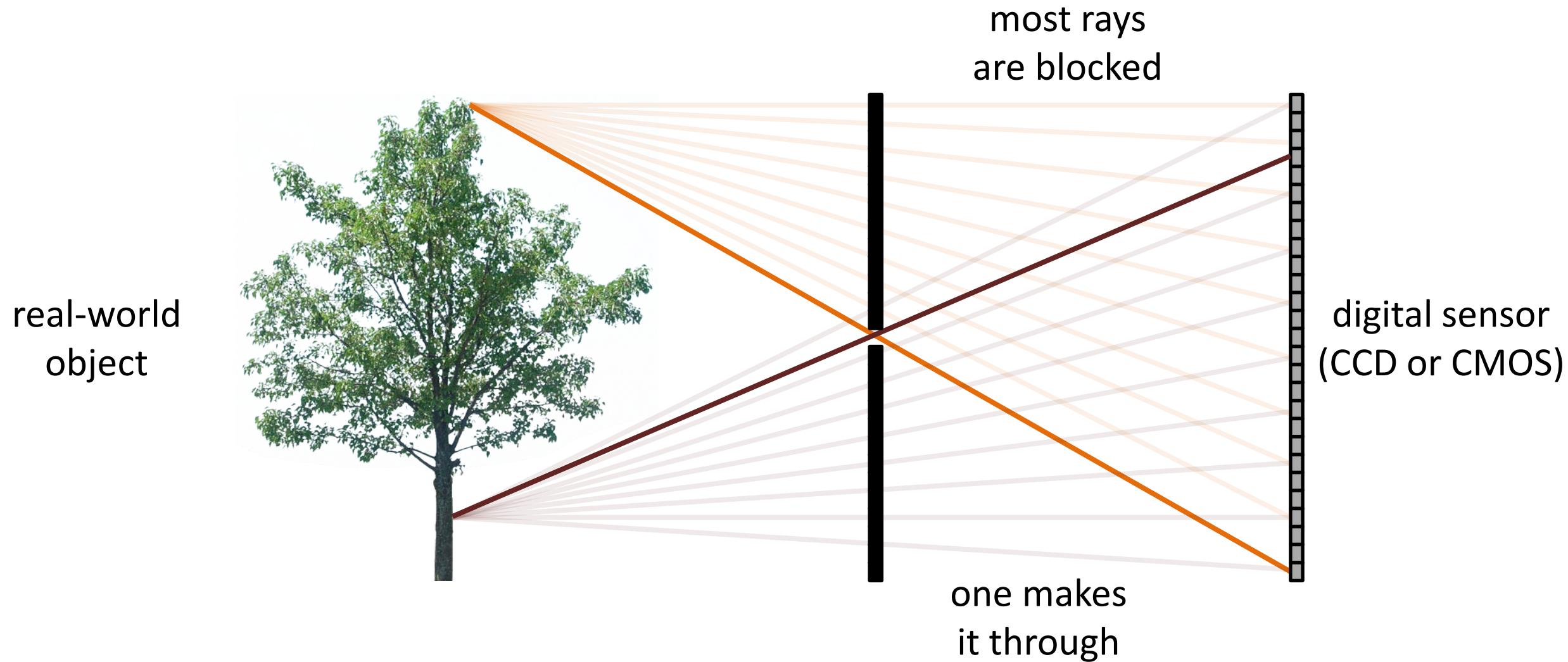


digital sensor  
(CCD or CMOS)

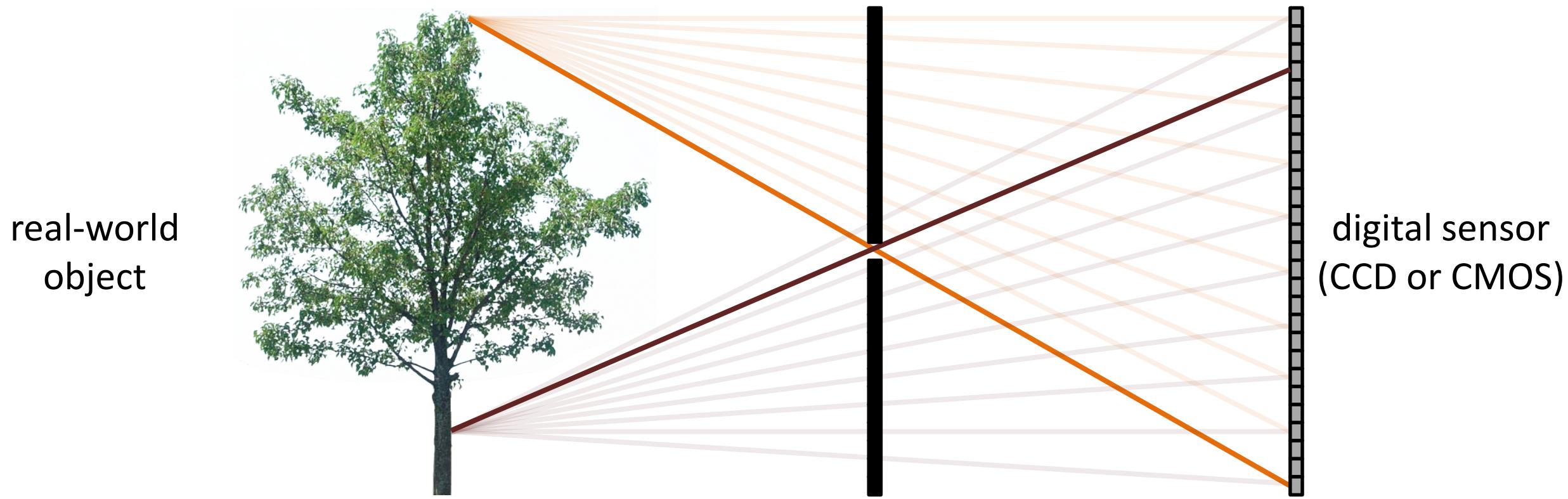
# Pinhole Imaging



# Pinhole Imaging

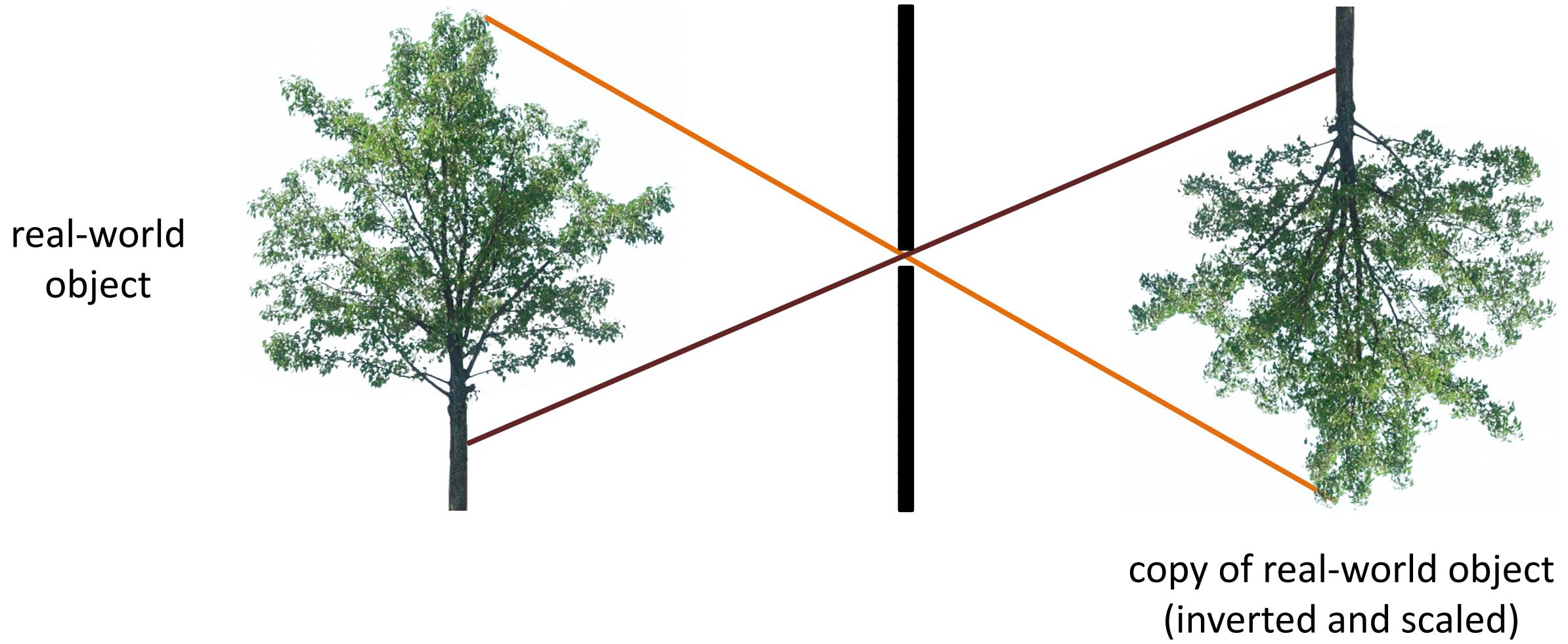


# What Does the Image on the Sensor Look Like?

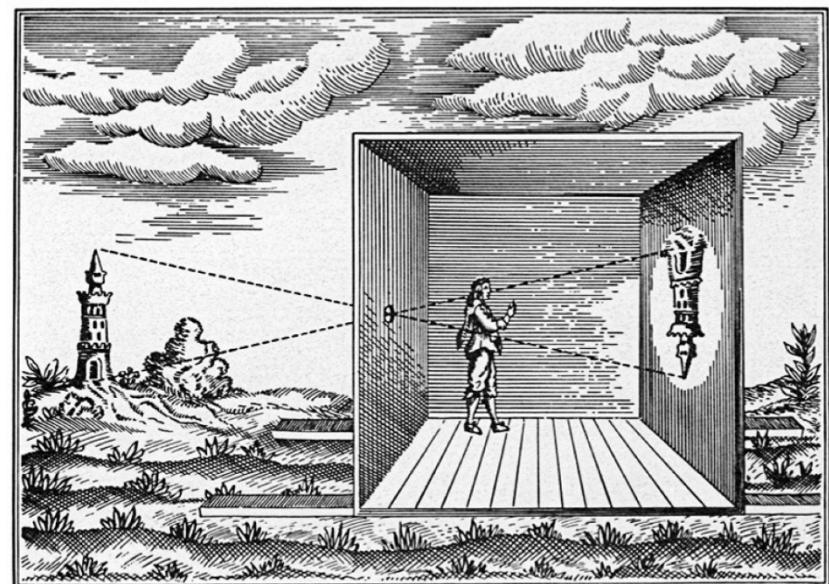
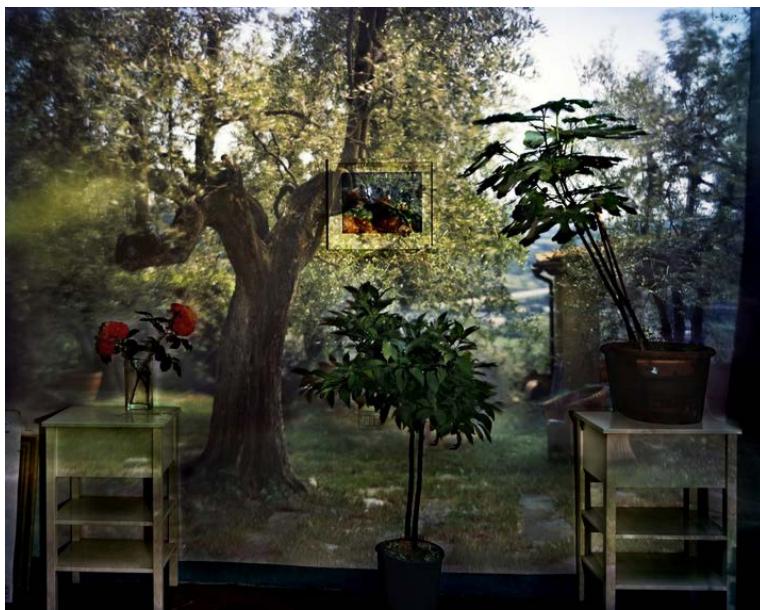


Let's assume that each scene point contributes to only one sensor pixel

# Pinhole Imaging: the Object can be Captured !!



# Camera Obscure



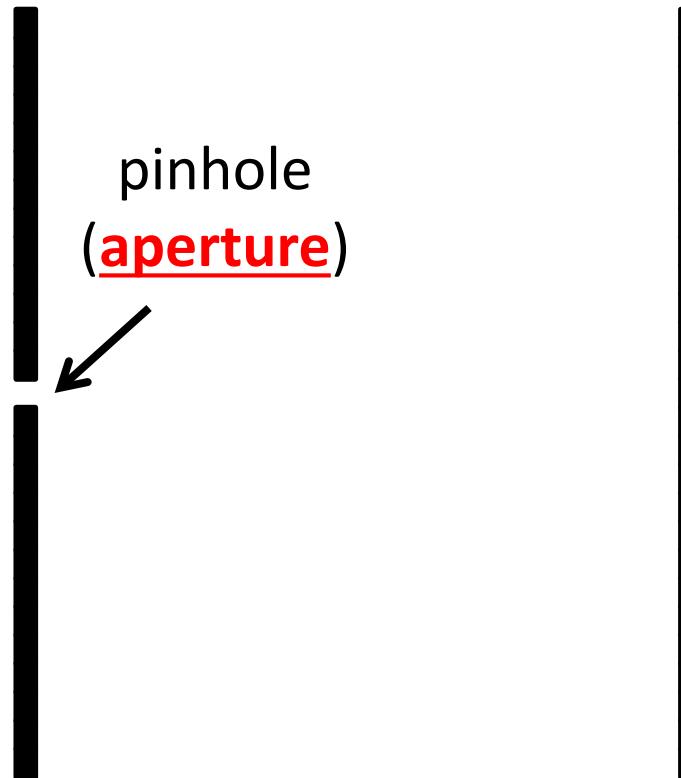
<https://fstoppers.com/natural-light/camera-obscura-flips-outside-world-4971>

# Pinhole Camera Terms (Aperture)

real-world  
object



barrier (diaphragm)



digital sensor  
(CCD or CMOS)

# Pinhole Camera Terms (Camera Center)

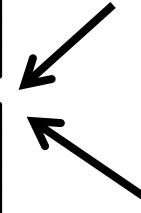
real-world  
object



barrier (diaphragm)



pinhole  
(aperture)



camera center (or  
optical center)

image plane

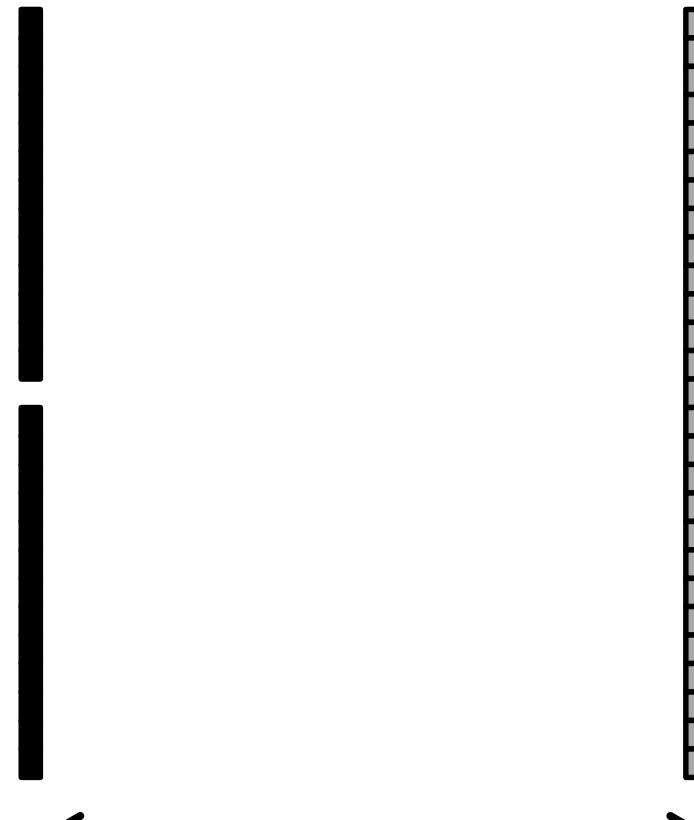


digital sensor  
(CCD or CMOS)



# Pinhole Camera Terms (Focal Length)

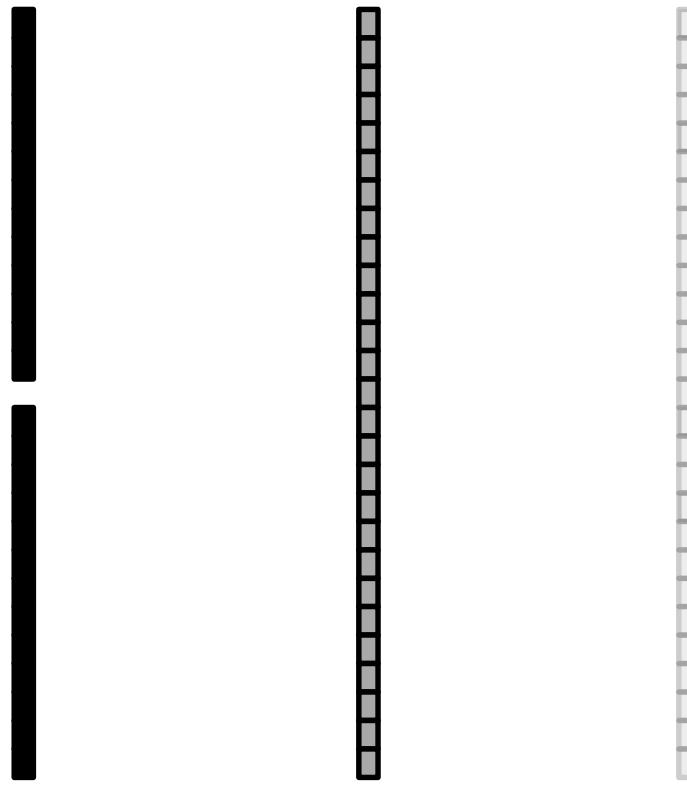
real-world  
object



focal length  $f$

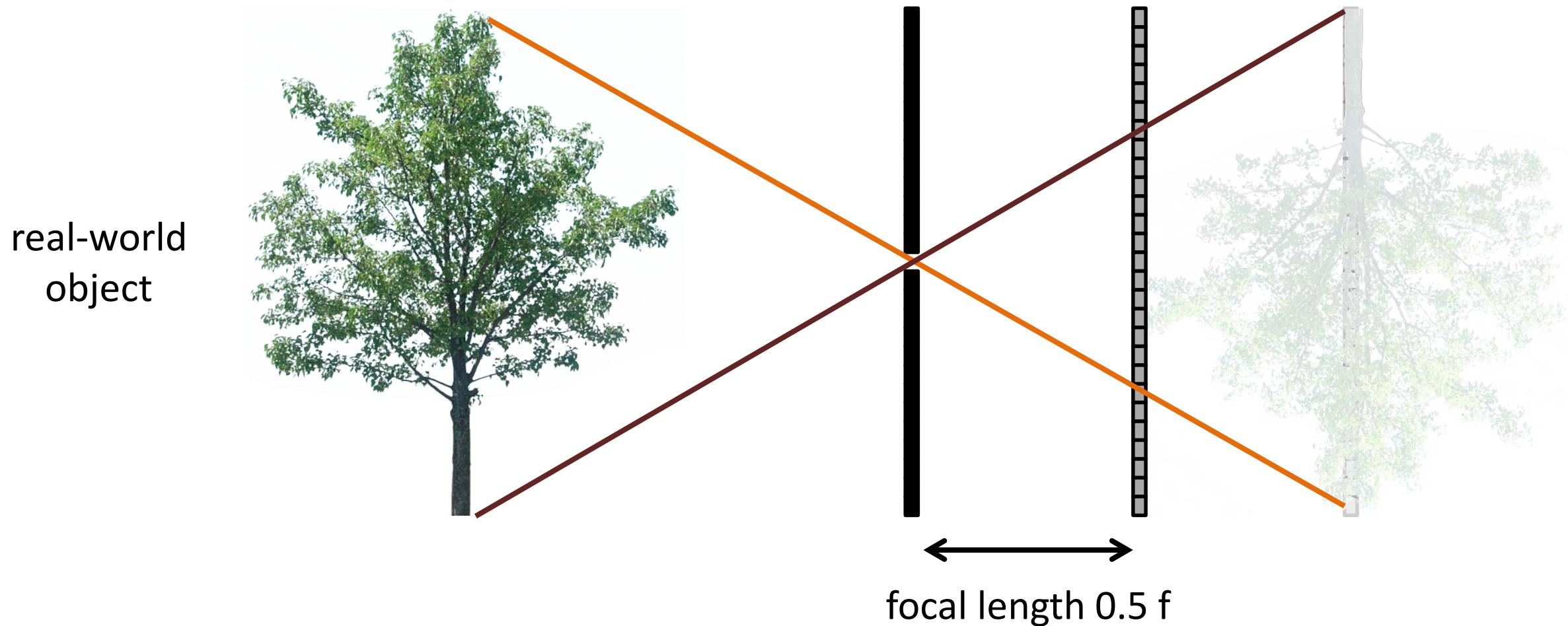
# What Happens as We Change the Focal Length?

real-world  
object

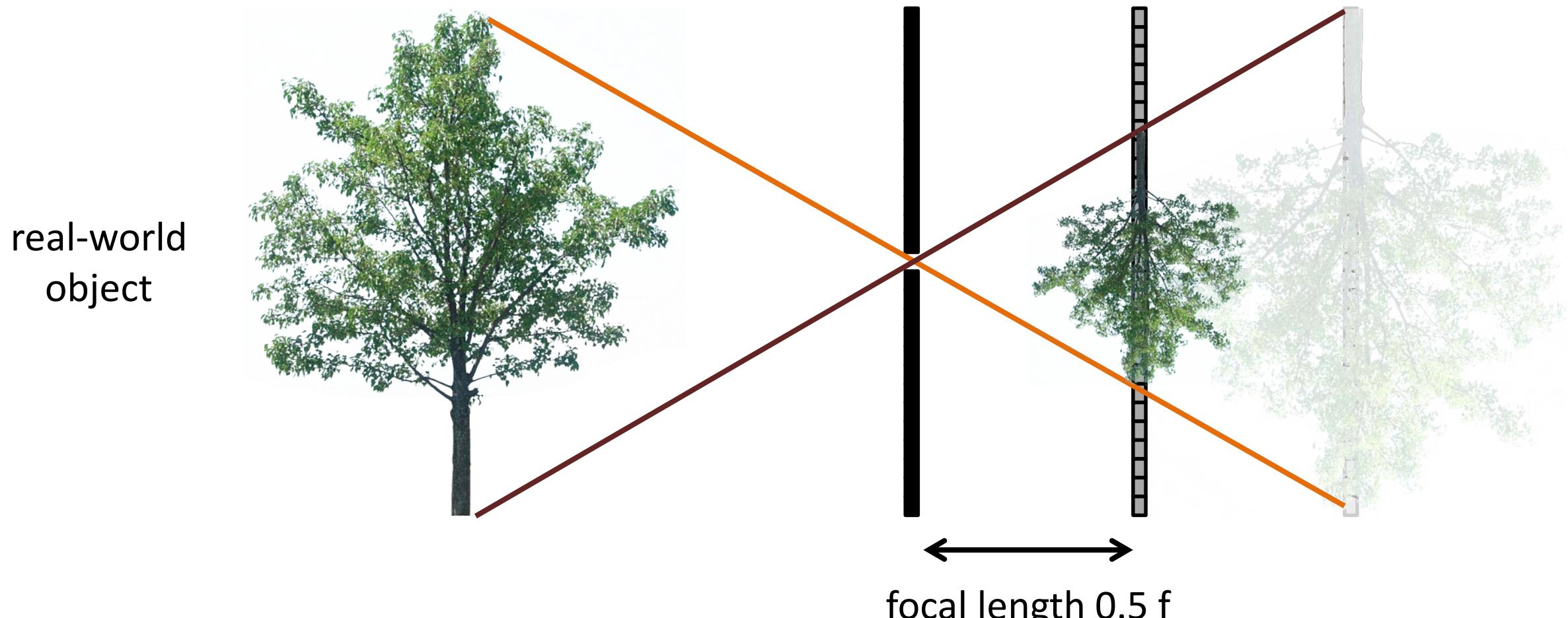


focal length  $0.5 f$

# What Happens as We Change the Focal Length?



# What Happens as We Change the Focal Length?



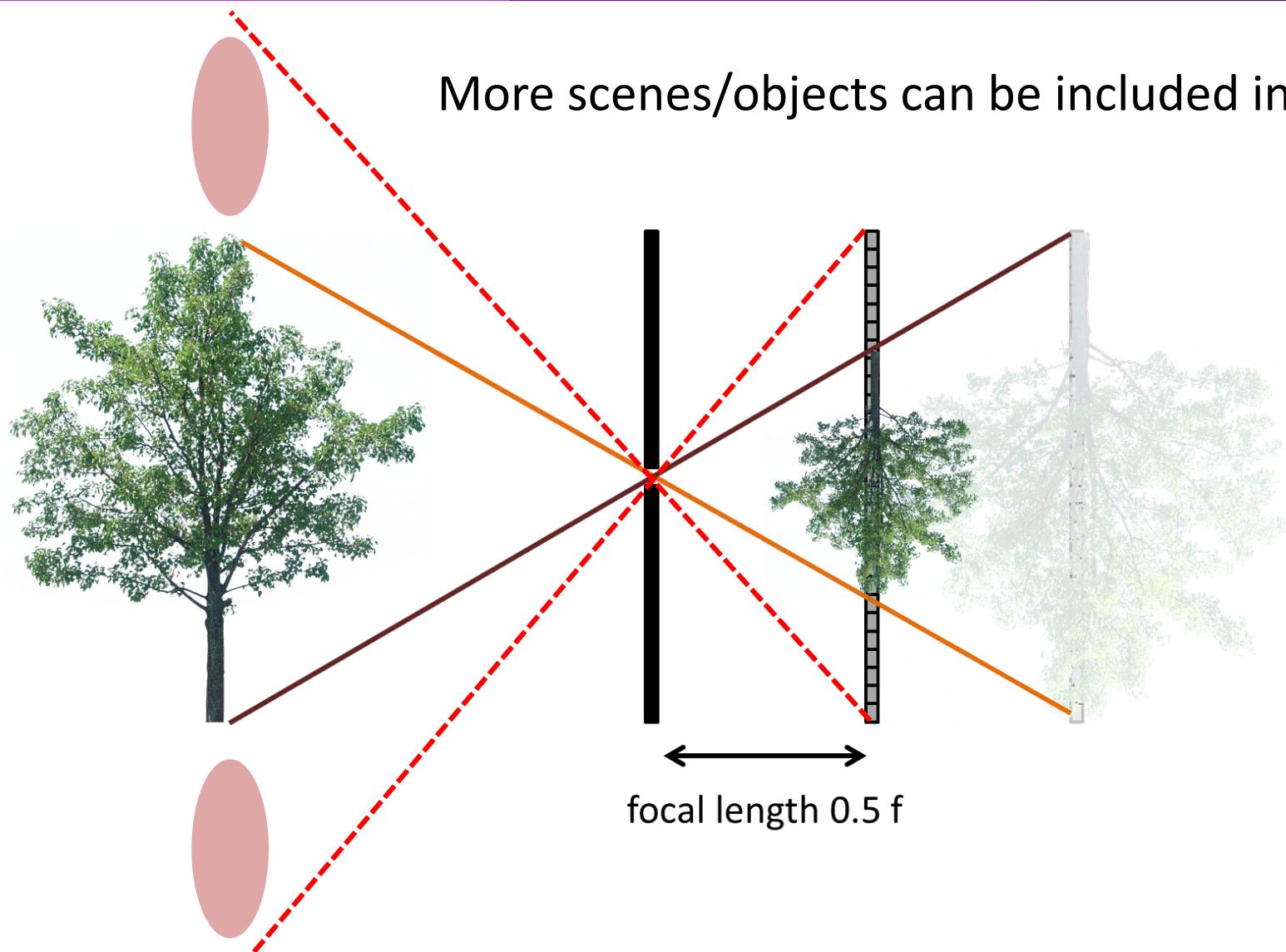
Which image has better quality?

# What Happens as We Change the Focal Length?



real-world  
object

Zoom-in or  
Zoom-out

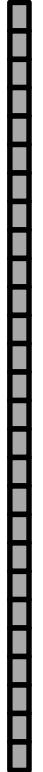


# What Happens as We Change the Aperture Size?

real-world  
object



pinhole  
diameter



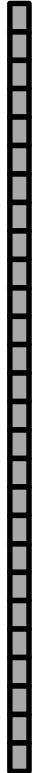
- Ideal pinhole has infinitesimally small size
- In practice that is impossible.

# What Happens as We Change the Aperture Size?

real-world  
object

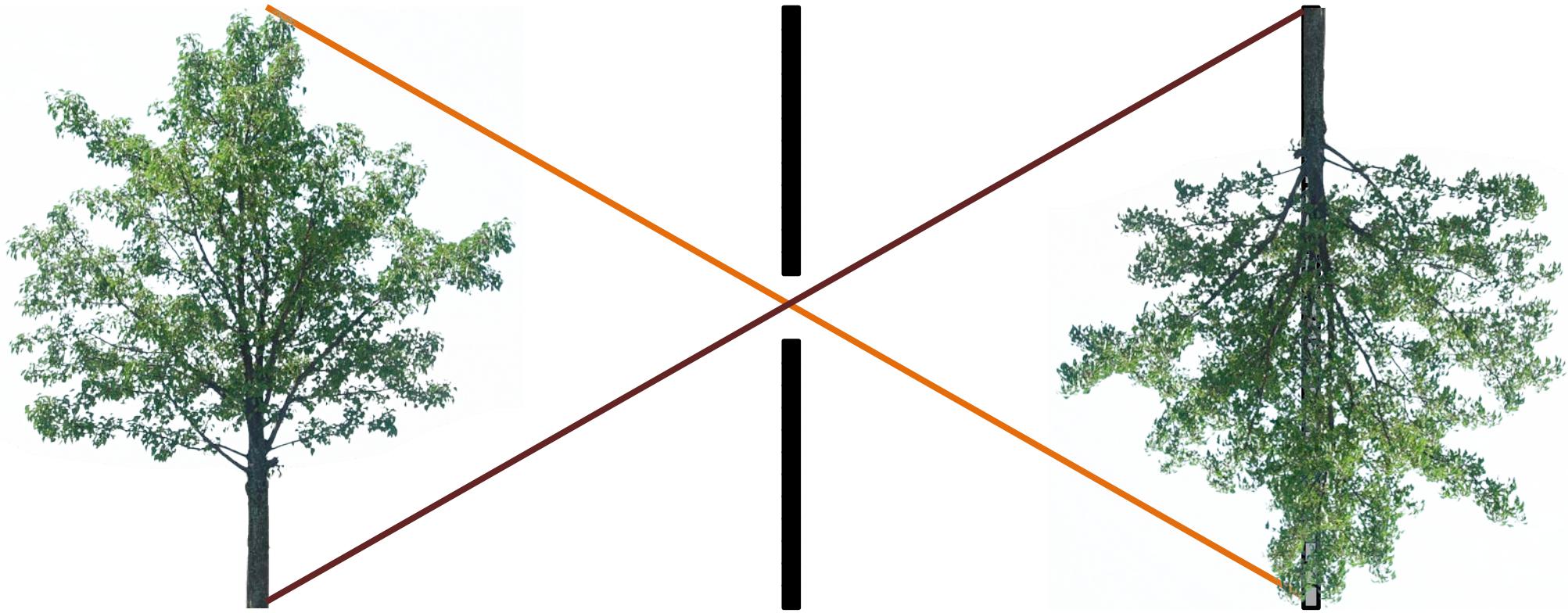


pinhole  
diameter



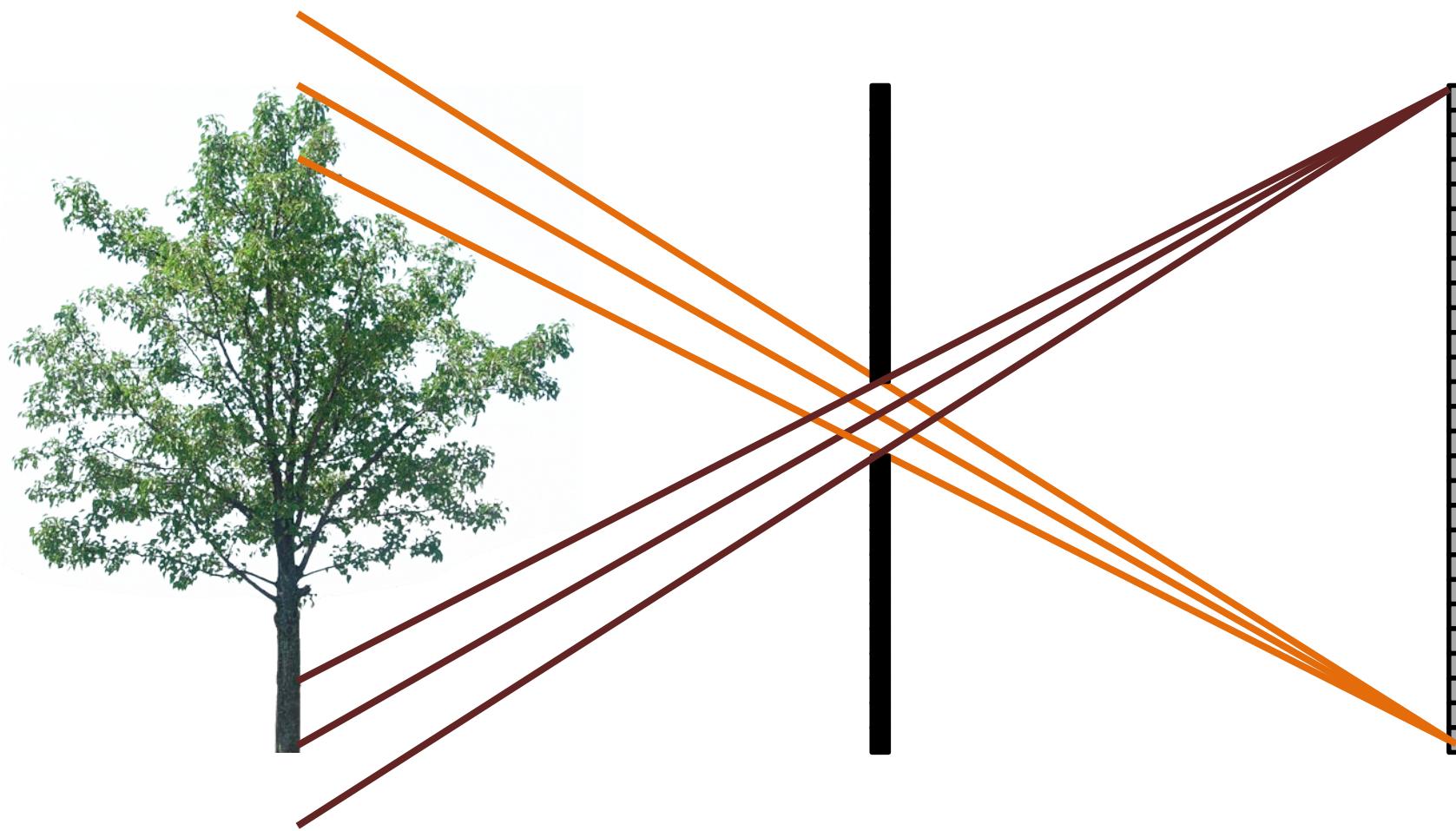
# What Happens as We Change the Aperture Size?

real-world  
object

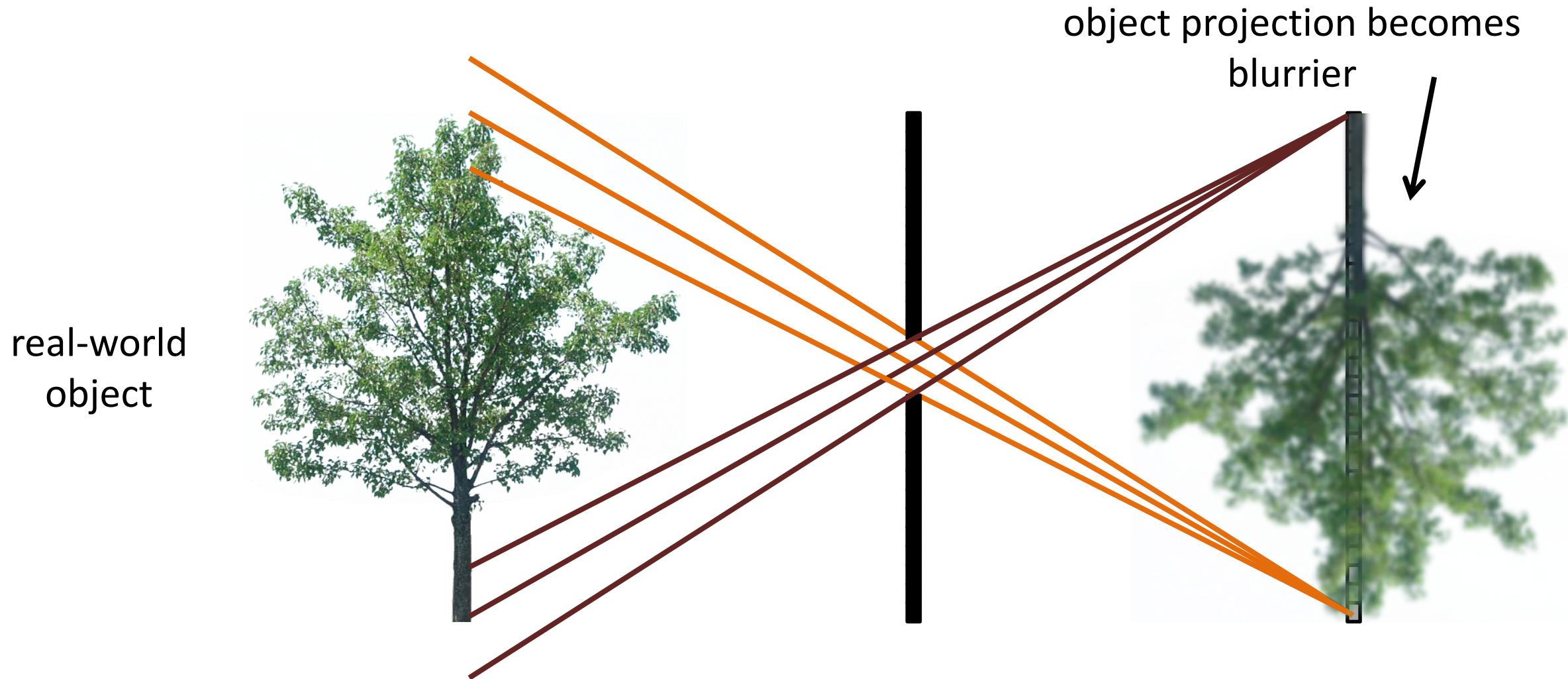


# What Happens as We Change the Aperture Size?

real-world  
object

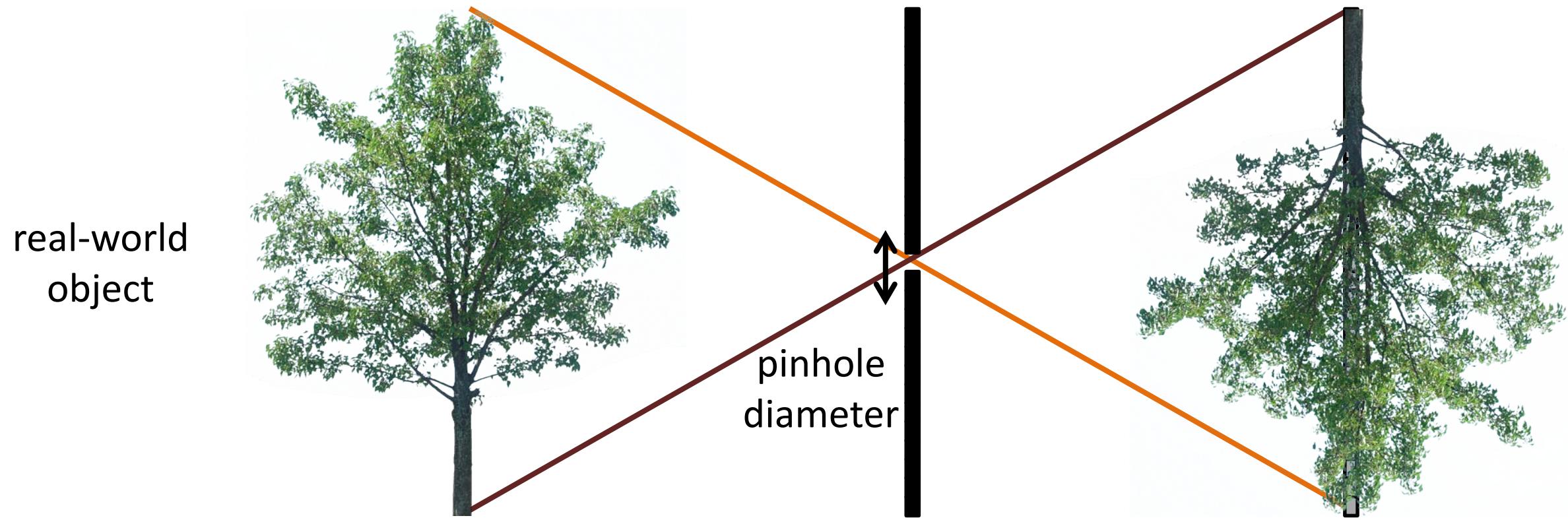


# What Happens as We Change the Aperture Size?



When do we open aperture?

# Will the Image Keep Getting Sharper the Smaller We Make the Pinhole?

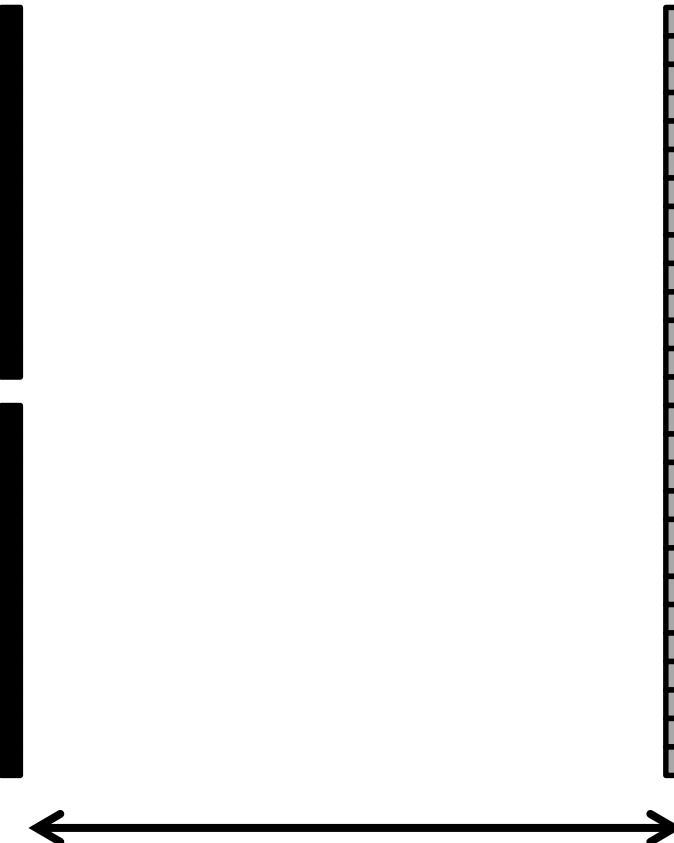


# Light Efficiency

real-world  
object



pinhole  
diameter



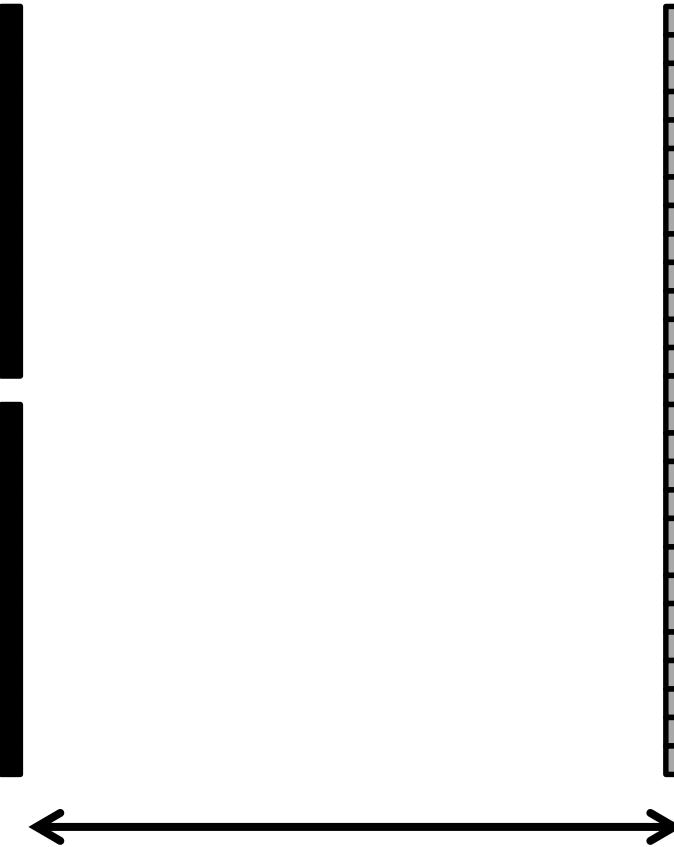
- What is the effect of doubling the pinhole diameter?
- What is the effect of doubling the focal length?

# Light Efficiency (Continue)

real-world  
object



pinhole  
diameter



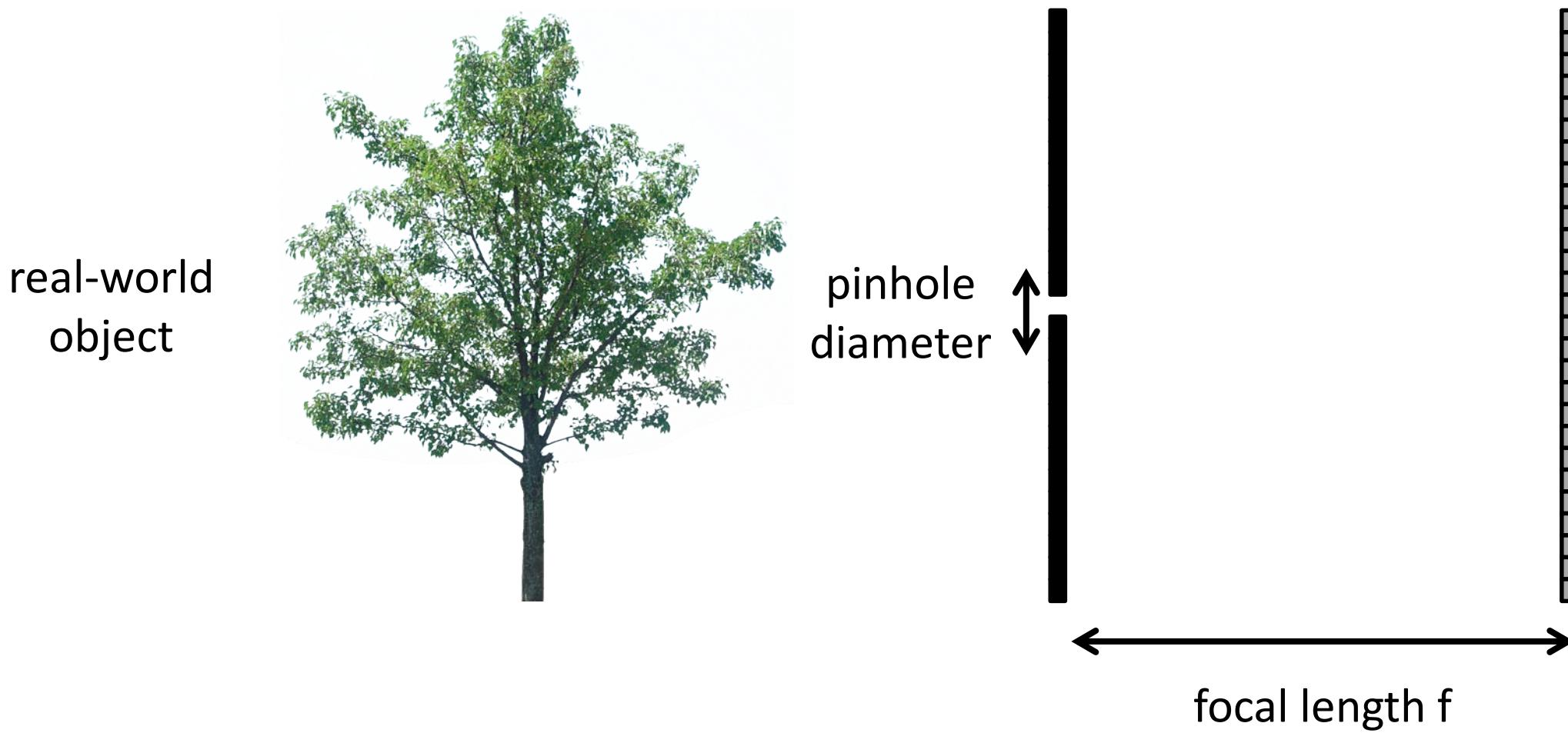
focal length  $f$

**2 x pinhole diameter and 2x focal length**

- $2 \times \text{pinhole diameter} \rightarrow 4 \times \text{light}$
- $2 \times \text{focal length} \rightarrow \frac{1}{4} \times \text{light}$

# F-Number or F-Stop

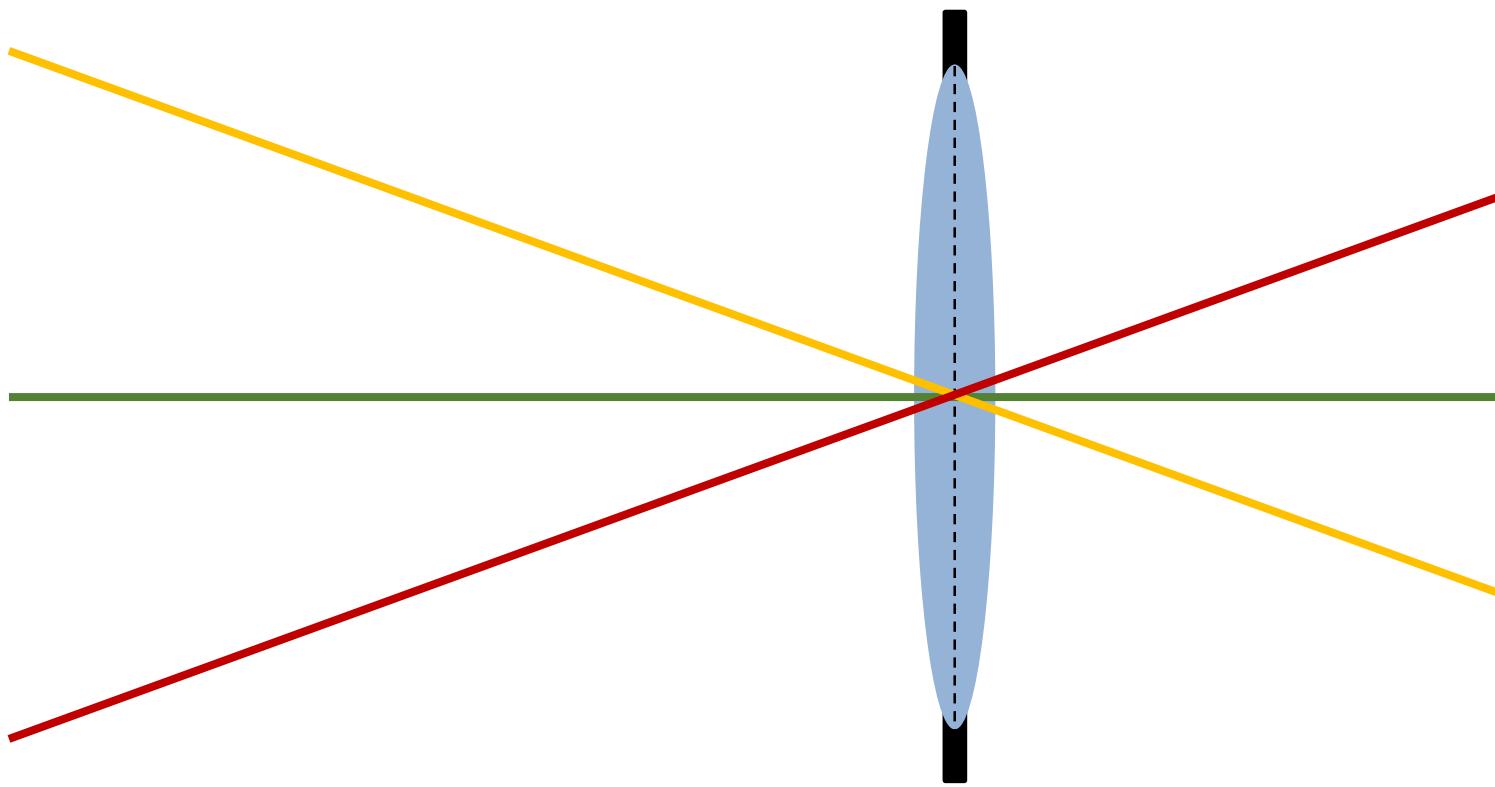
A “stop” is a change in camera settings that changes amount of light by a factor of 2



The “f-number” is the ratio: focal length / pinhole diameter

# Thin Lens Model

Simplification of geometric optics for well-designed lenses.

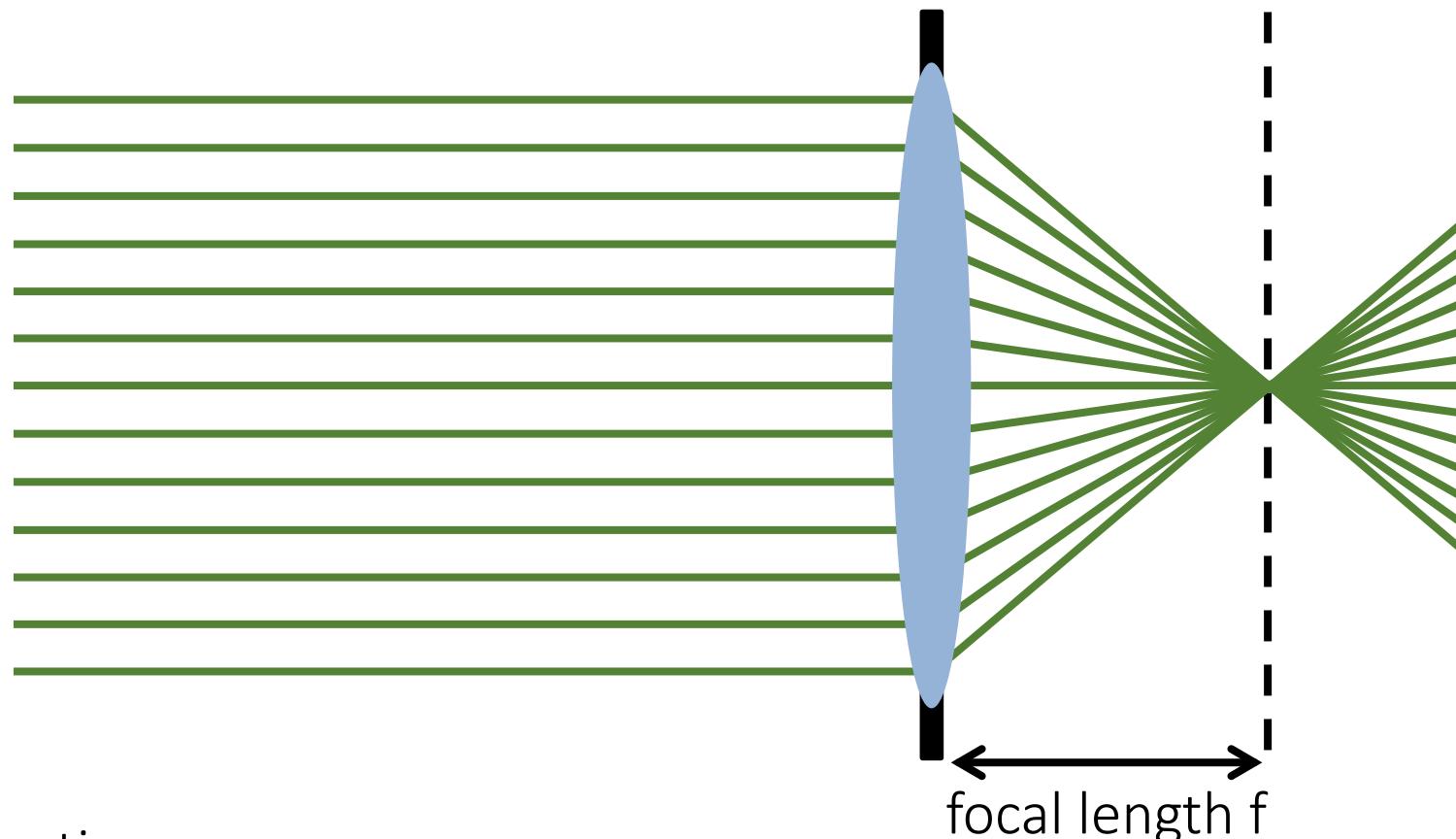


Two assumptions:

1. Rays passing through lens center are unaffected.

# Thin Lens Model (Continue)

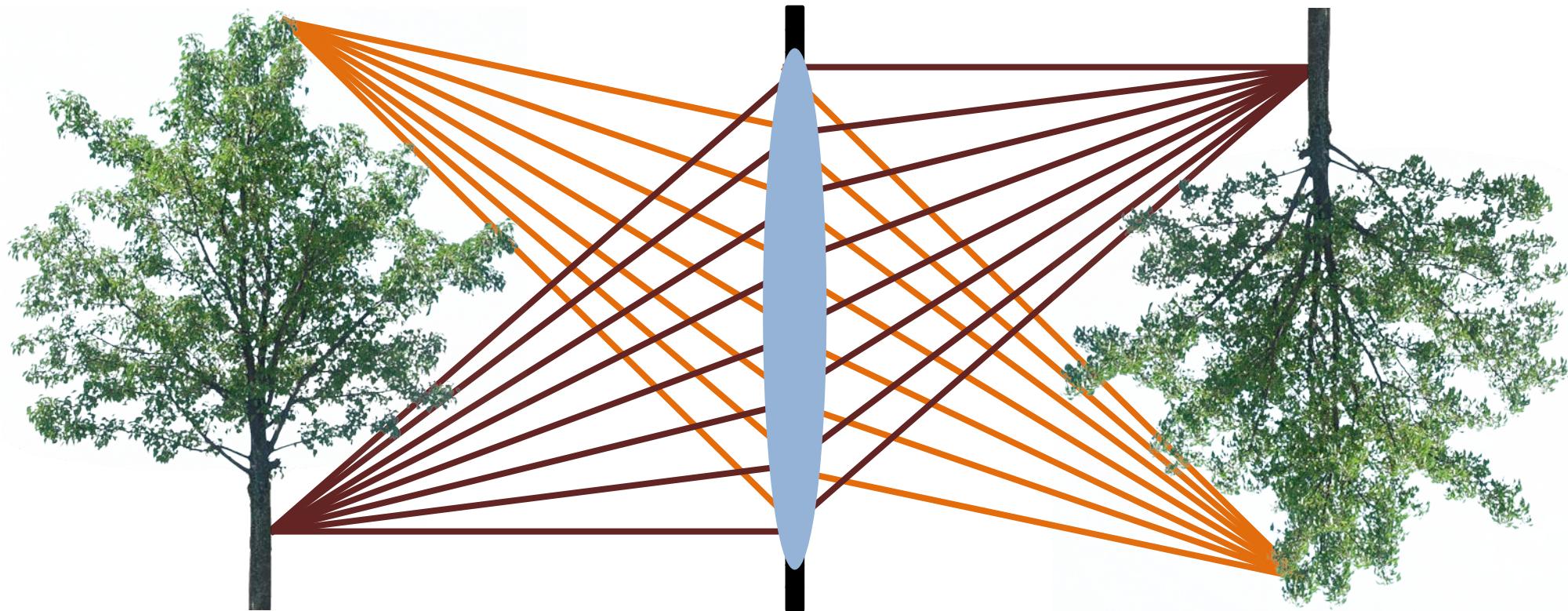
Simplification of geometric optics for well-designed lenses.



Two assumptions:

1. Rays passing through lens center are unaffected.
2. Parallel rays converge to a single point located on focal plane.

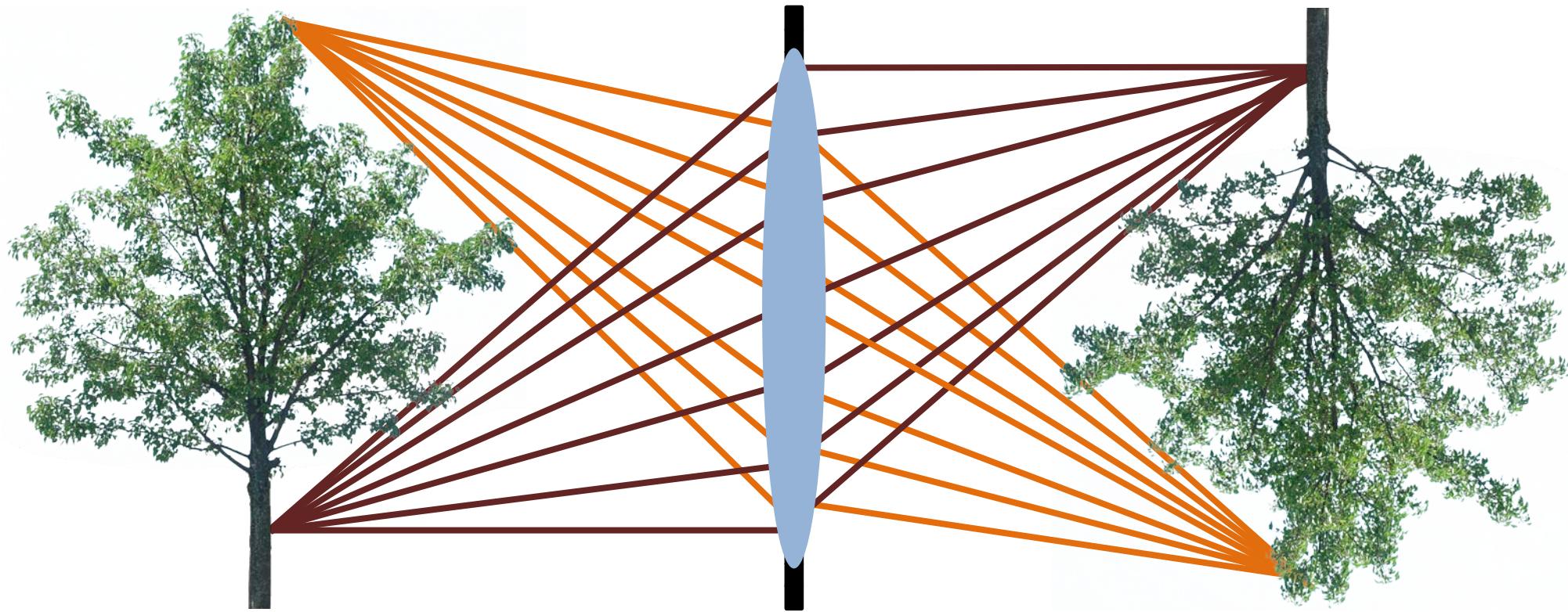
# Replace the Pinhole with Lens



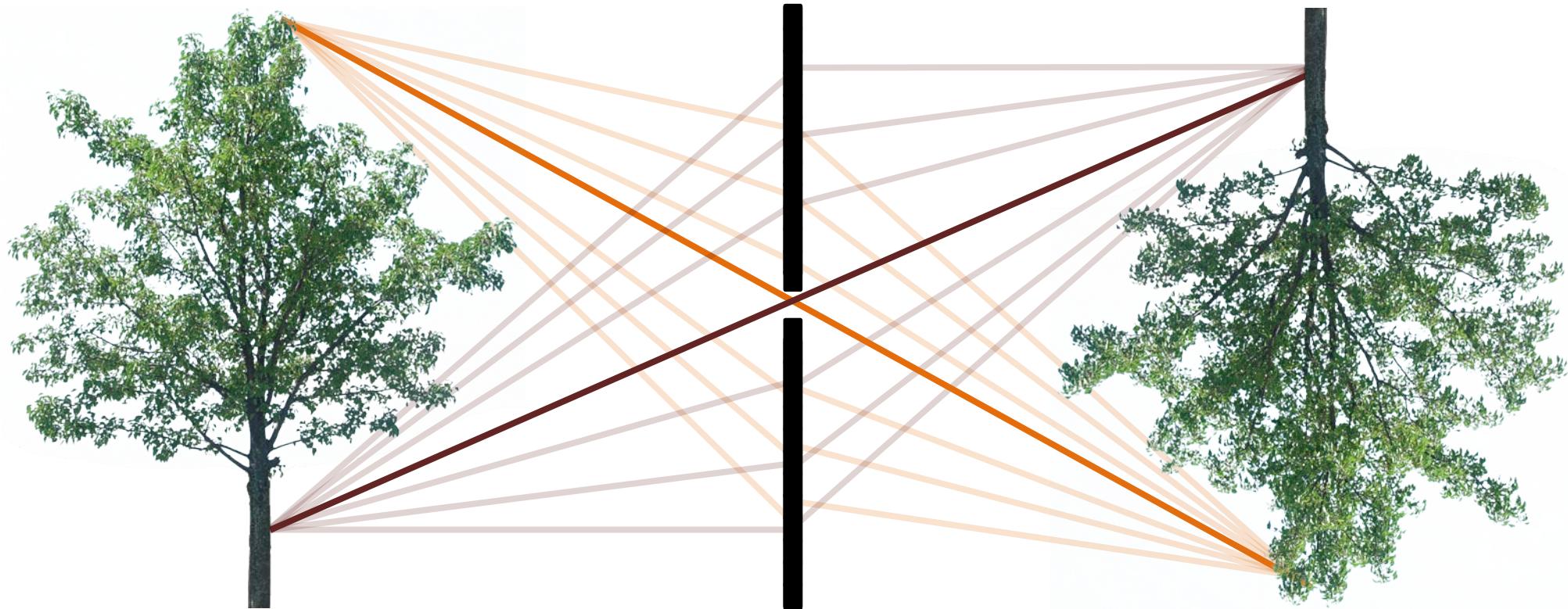
Lenses map “bundles” of rays from points on the scene to the sensor.

How does this mapping work exactly?

# Difference Between Lens and Pinhole Cameras



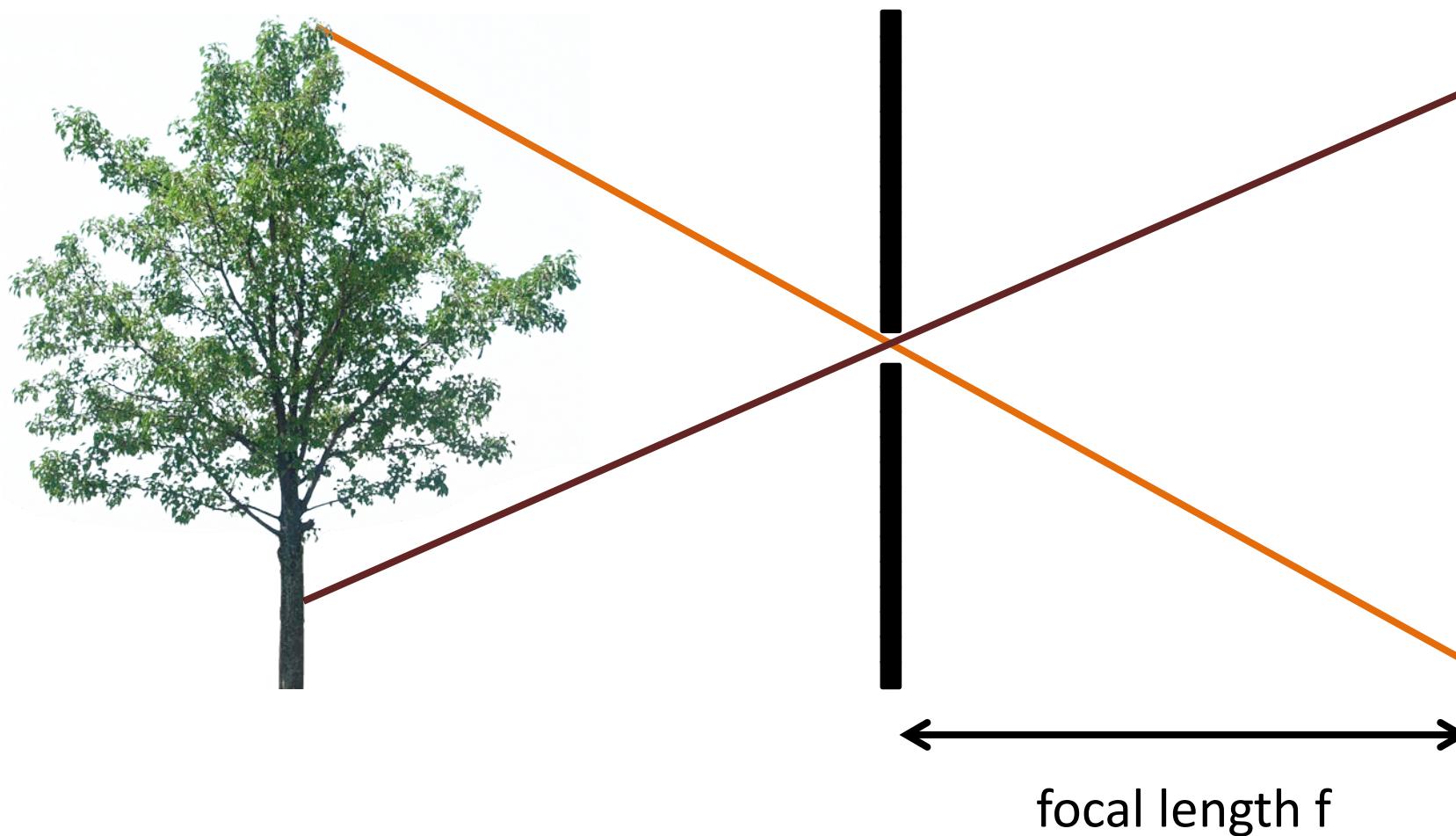
# Pinhole Camera



Central rays propagate in the same way for both models!

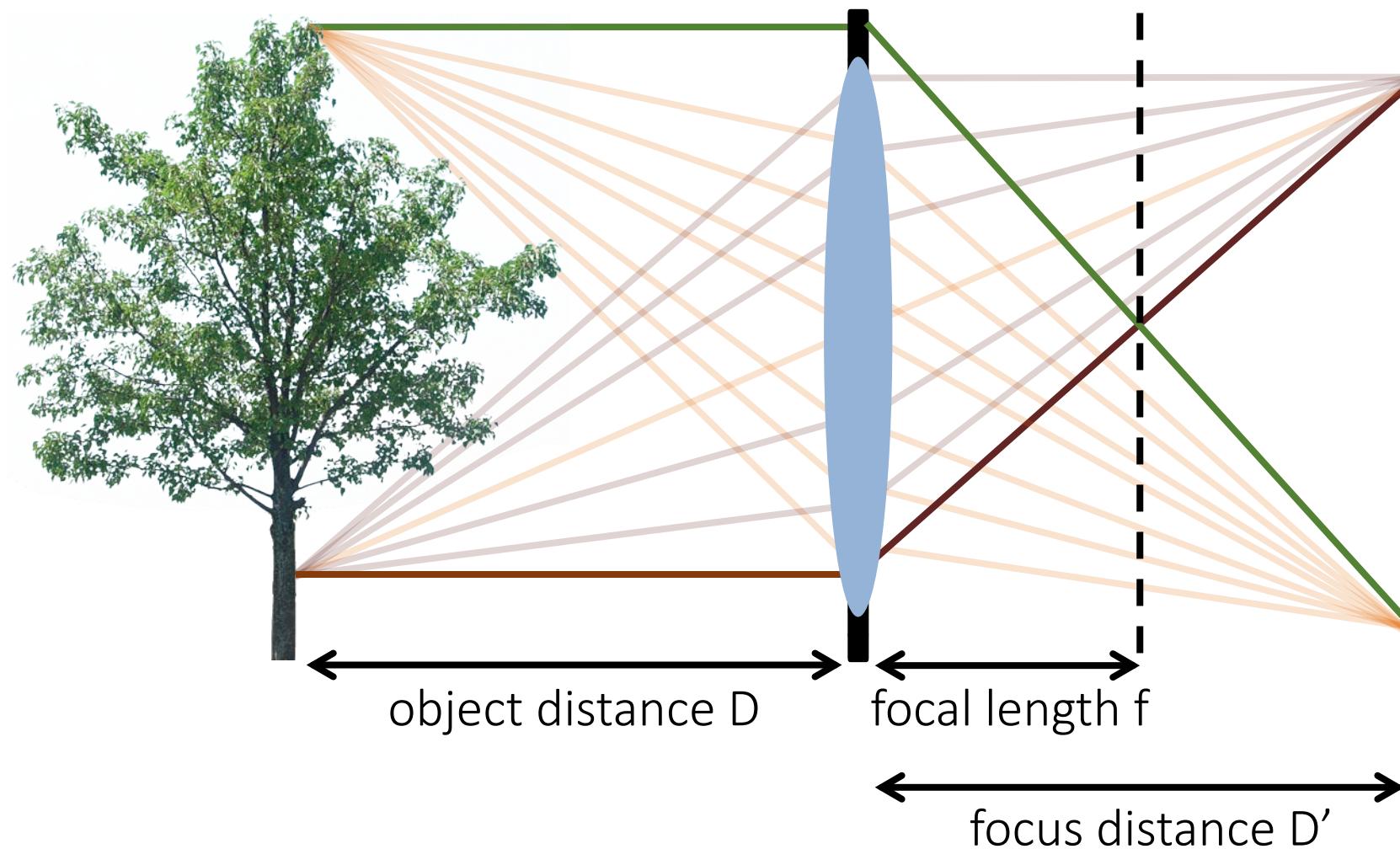
# Focal Length in a Pinhole Camera

In a pinhole camera, focal length is distance between aperture and sensor

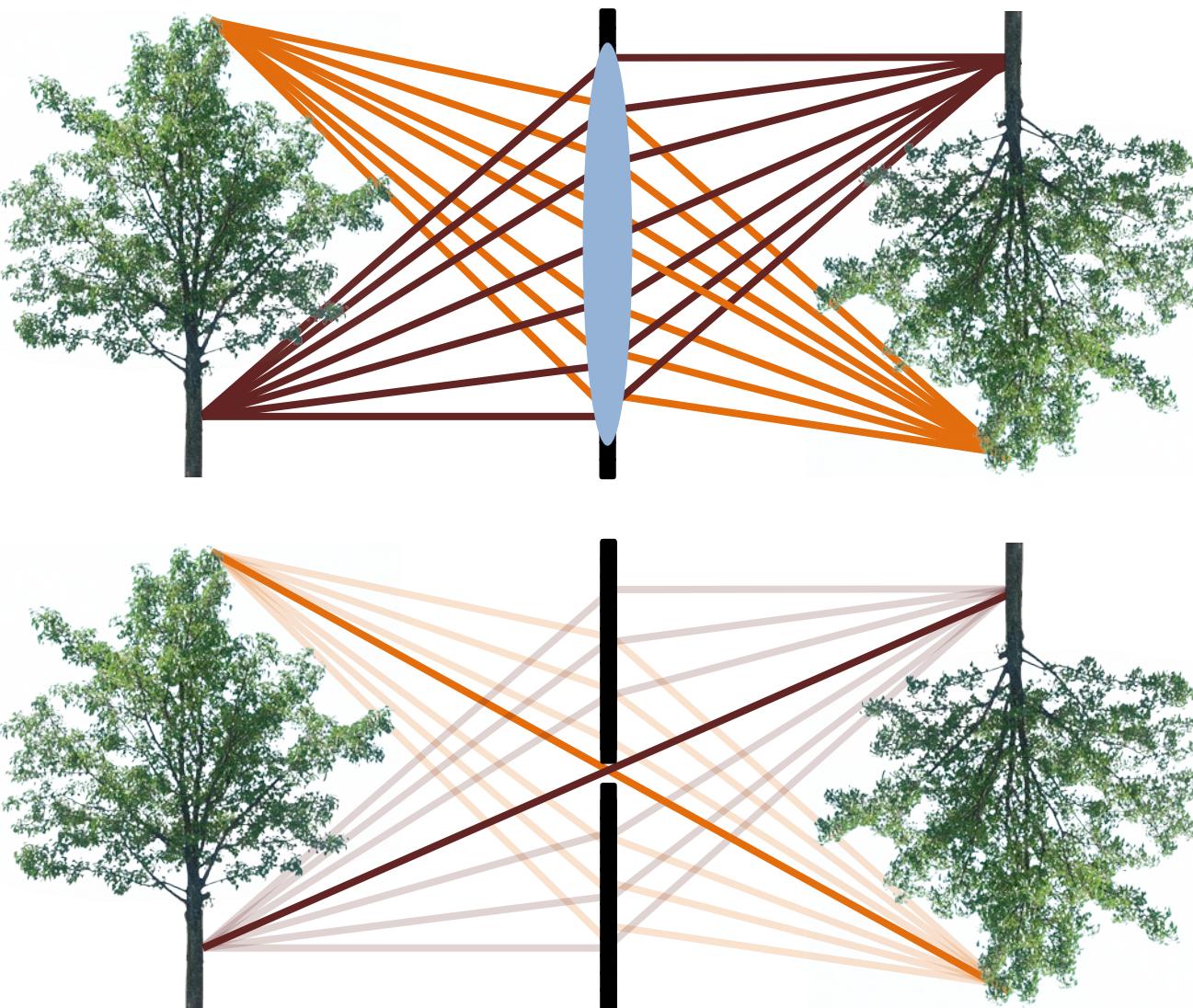


# Focal Length in a Lens Camera

In a lens camera, focal length is distance where parallel rays intersect



# Describing Both Lens and Pinhole Cameras



We can derive properties and descriptions that hold for both camera models if:

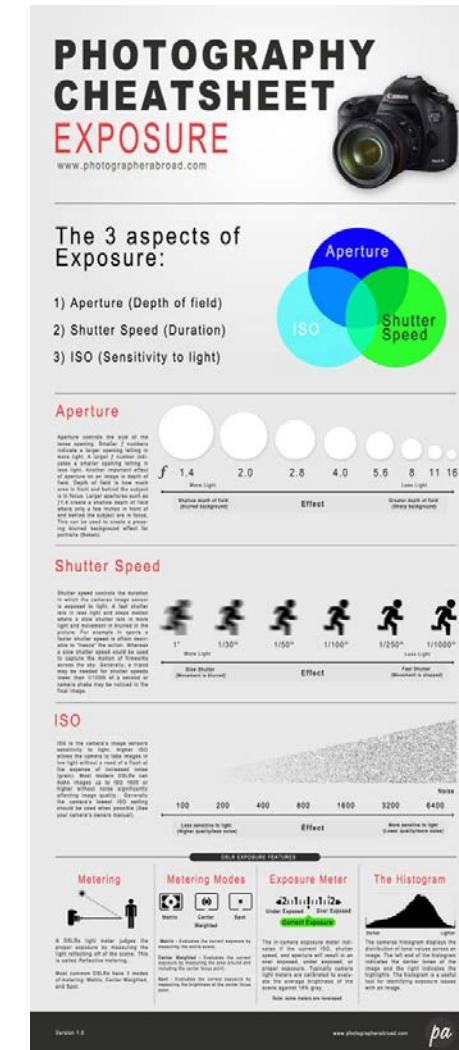
- We use only central rays.
- We assume the lens camera is in focus.
- We assume that the focus distance of the lens camera is equal to the focal length of the pinhole camera.

# Understanding the Language of Photography

- Aperture
- Depth of field
- Exposure
- F-Number
- ISO
- RAW
- Shutter speed
- Flash
- Shutter prior mode
- Aperture prior mode
- Tripod
- Aspect Ratio
- Focal length
- Long exposure

<https://www.creativelive.com/blog/common-photography-terms/>

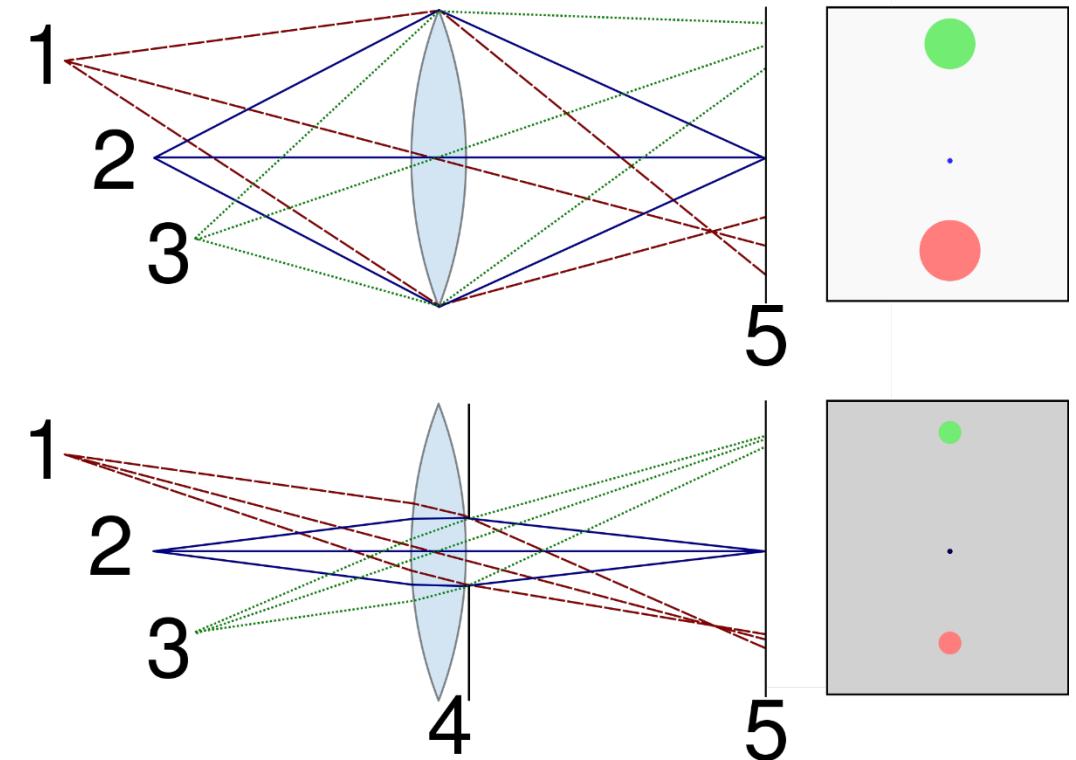
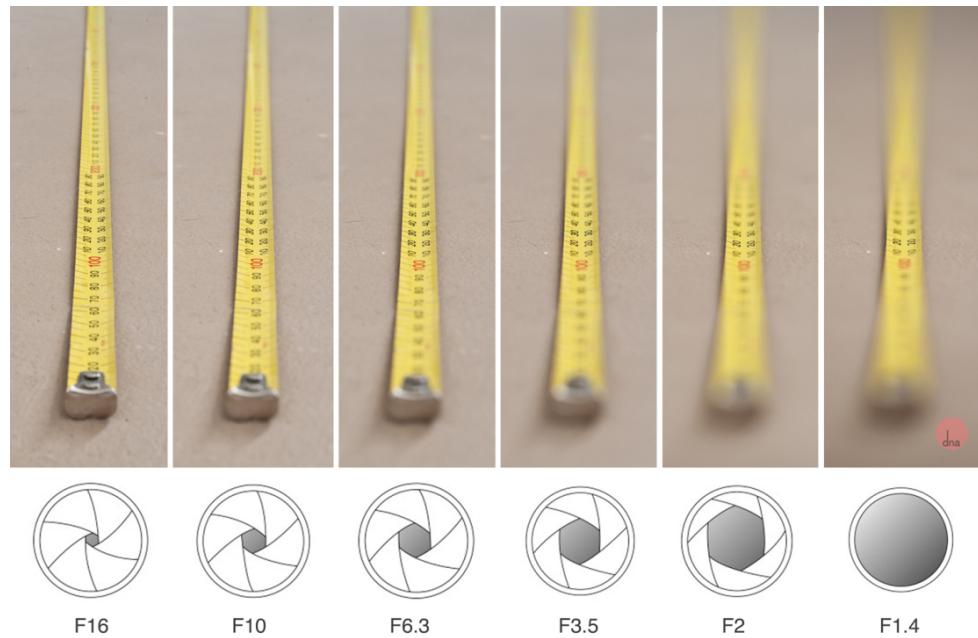
# DSLR Cheat Sheet



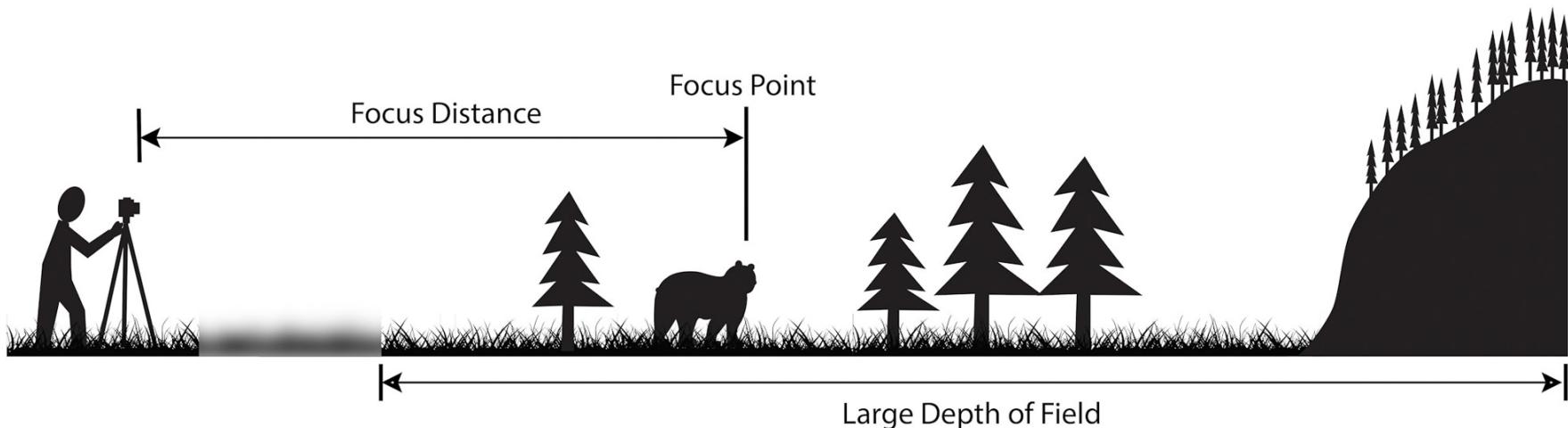
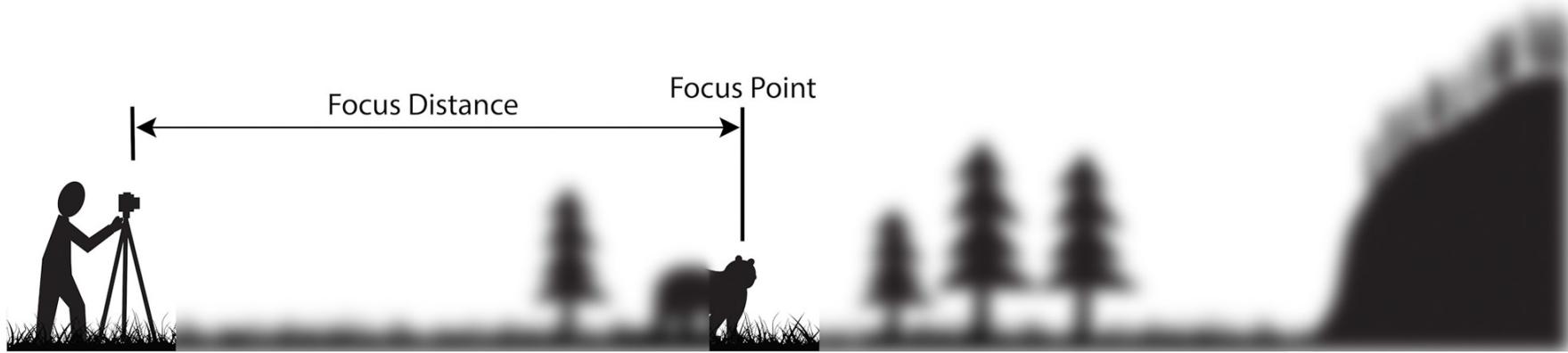
# Why Do We Use a Tripod?

- When taking night time shots and sunsets
- When you need to be flexible
- When you are taking close up shots
- When you are taking action shots and doing sport photography
- When you are doing natural photography

# Effect of Aperture



# Understanding Depth of Field

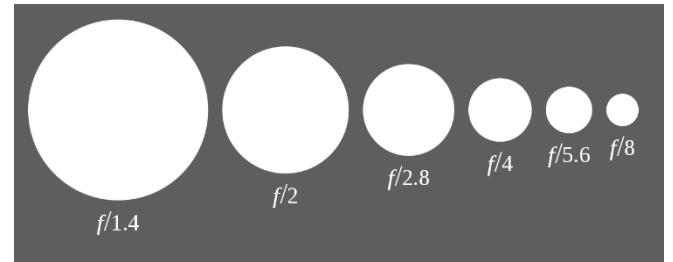


# F-Number or F-Stop

The f-number  $N$  is given by:

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

where  $f$  is the [focal length](#), and  $D$  is the diameter of the entrance pupil ([effective aperture](#)). It is customary to write f-numbers preceded by  $f/$ , which forms a mathematical expression of the entrance pupil diameter in terms of  $f$  and  $N$ .<sup>[1]</sup> For example, if a lens's focal length is 10 mm and its entrance pupil diameter is 5 mm, the f-number is 2, expressed by writing "f/2", and the aperture diameter is equal to  $f/2$ , where  $f$  is the focal length.



## The amount of light entering in the lens

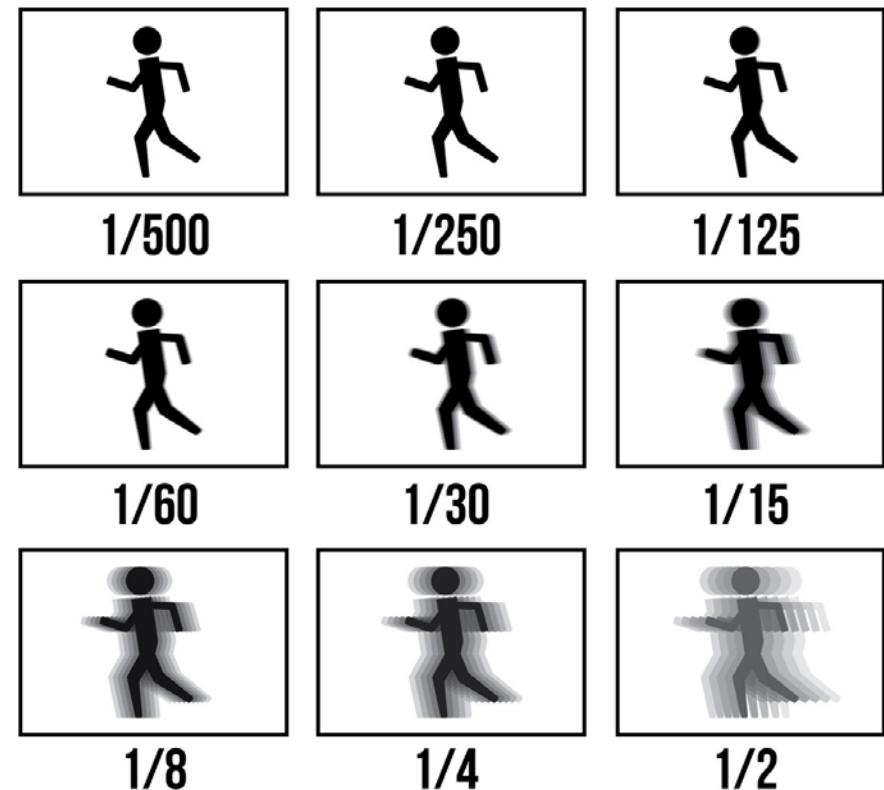
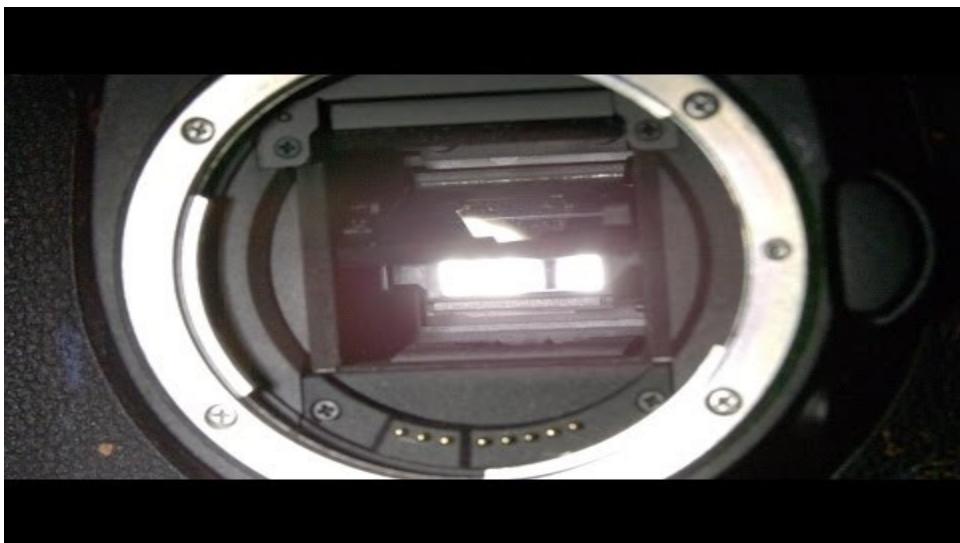
- Large f-number, Small aperture, Long focal length
- Small f-number, Large aperture, Short focal length

# Different Depth of Fields



Why is it better?

# Effect of Shutter Speed

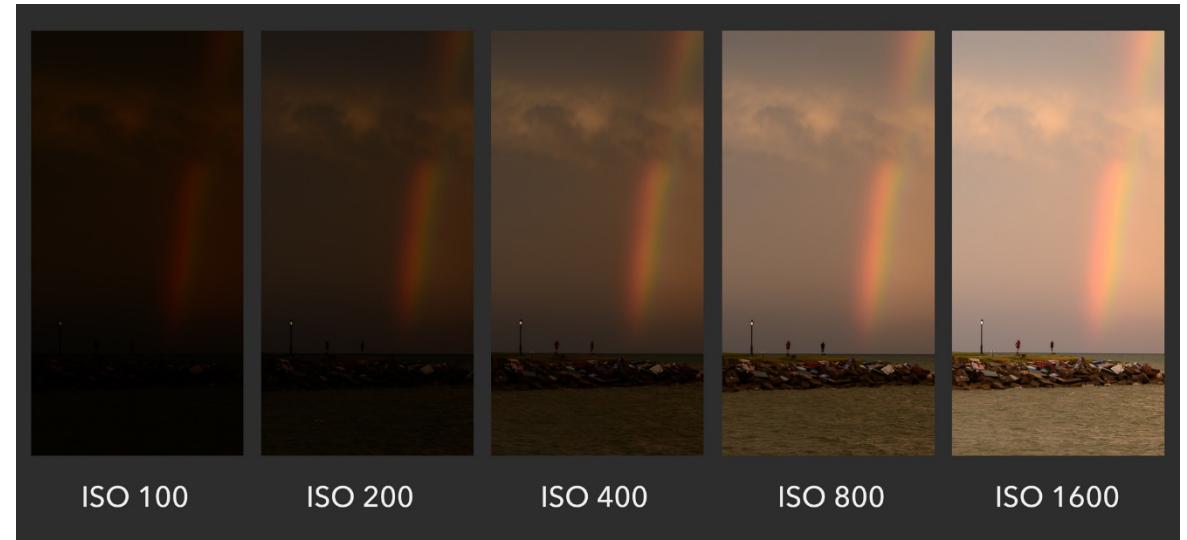


<https://www.creativelive.com/photography-guides/what-is-shutter-speed>

## Example: Night Photography



# Effect of ISO

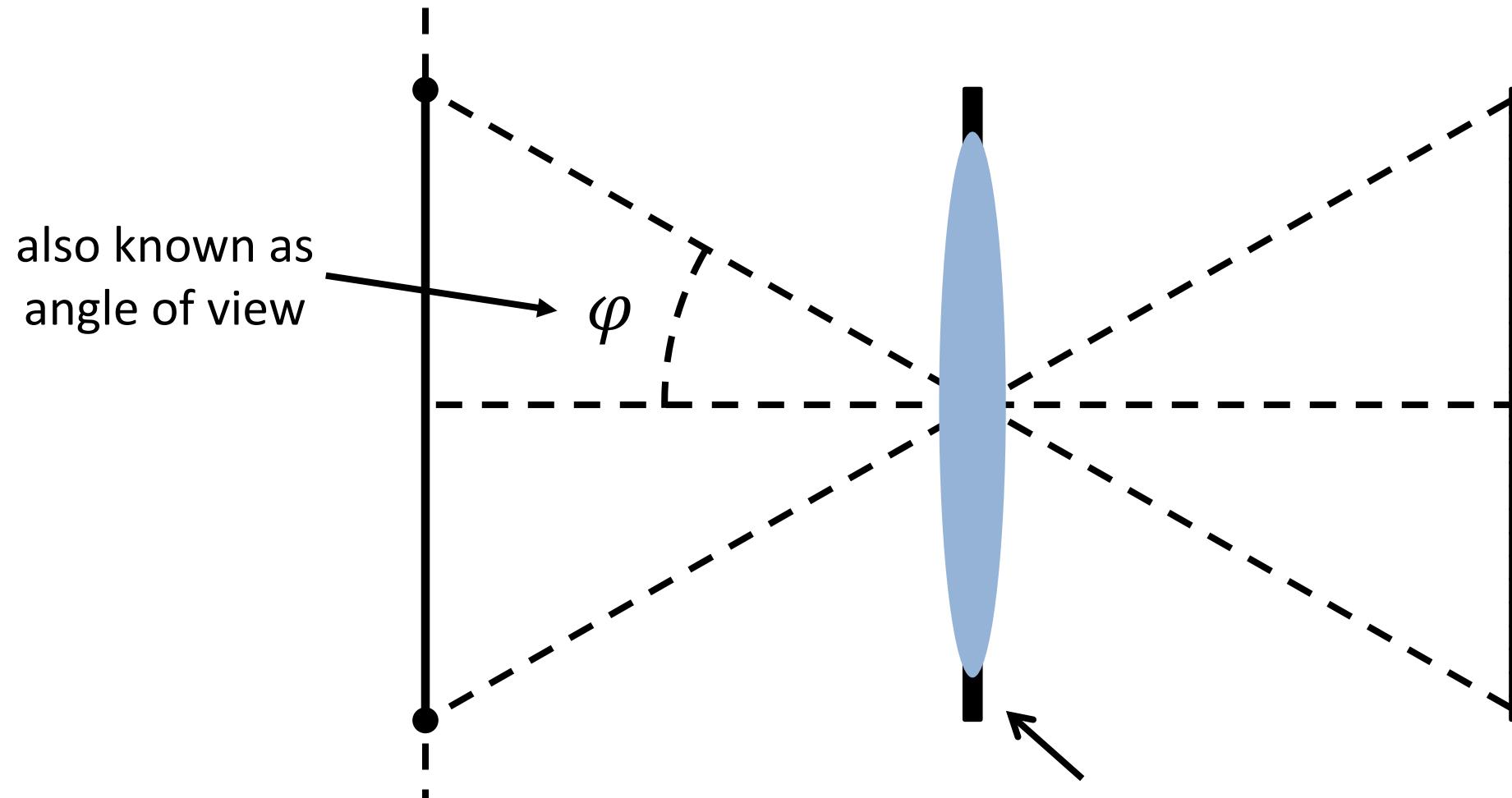


<https://www.shawacademy.com/blog/everything-you-need-to-know-about-iso/>    <https://photographylife.com/what-is-iso-in-photography>

# Situations that Affects How You Choose an ISO

- If your subject is moving and you're trying to freeze the motion for a still, a higher ISO will allow for a faster shutter speed.
- If you're using a tripod to stabilize your camera, you can usually get away with a slower shutter speed, which in turn allows you to use a lower ISO. Note that a tripod doesn't help you freeze subject motion, however.
- If you're shooting an image that doesn't require a large depth-of-field, you can increase the aperture (thus allowing more light into the lens) and use a lower ISO. Keep in mind that different lenses have different maximum aperture values, however, meaning not all lenses can let in the same amount of light.
- If you're shooting with artificial light — e.g., a flash — you can typically get away with a lower ISO setting.
- If you plan to only show a small version of an image, such as on Instagram, you can get away with a higher ISO.
- Subjectively, the noise characteristics of a high ISO setting can lend a vintage look to your photos, although this is an effect that is often better left for post-processing.

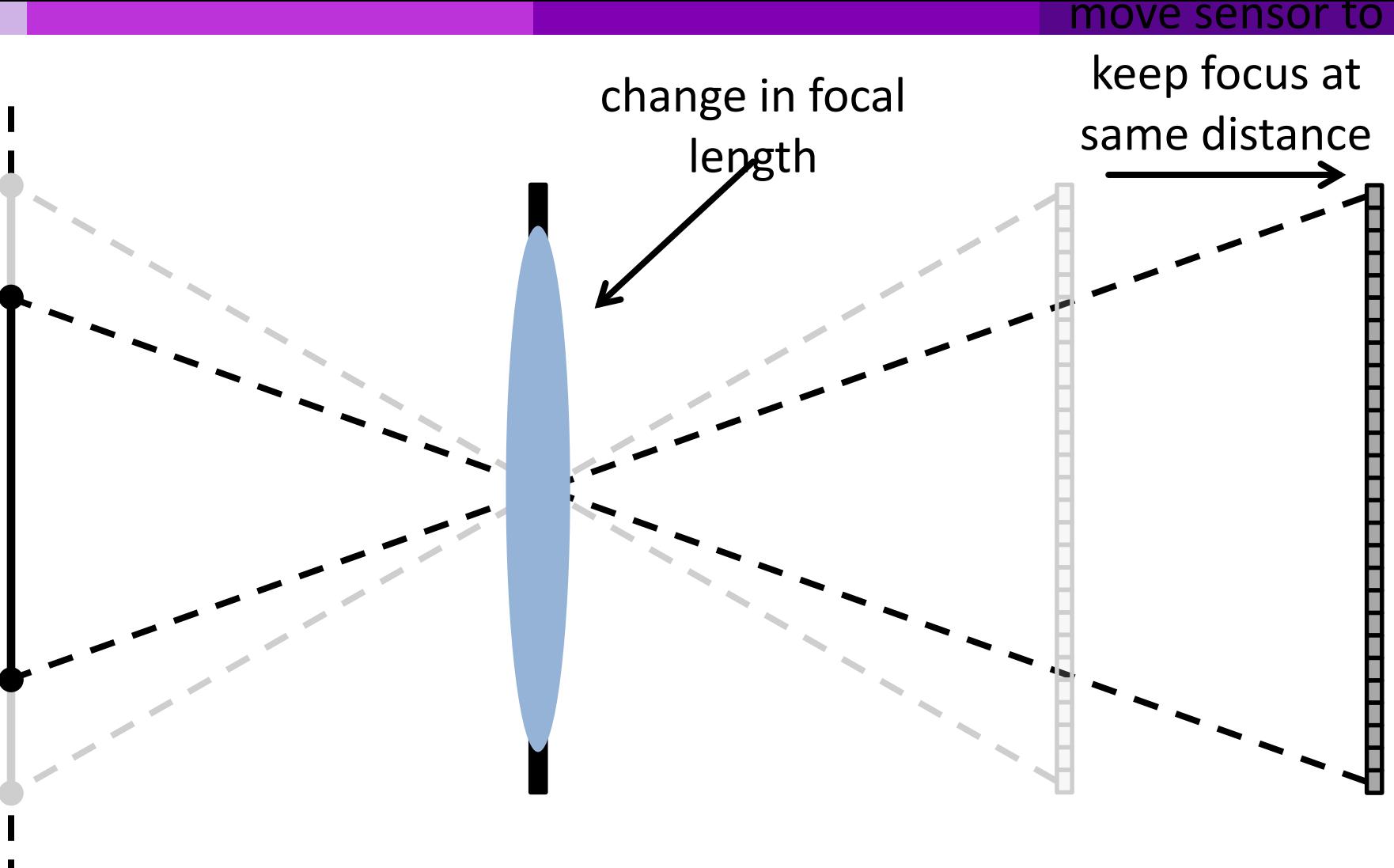
# Field of view



Note: here I drew a lens, but I could have just as well drawn a pinhole

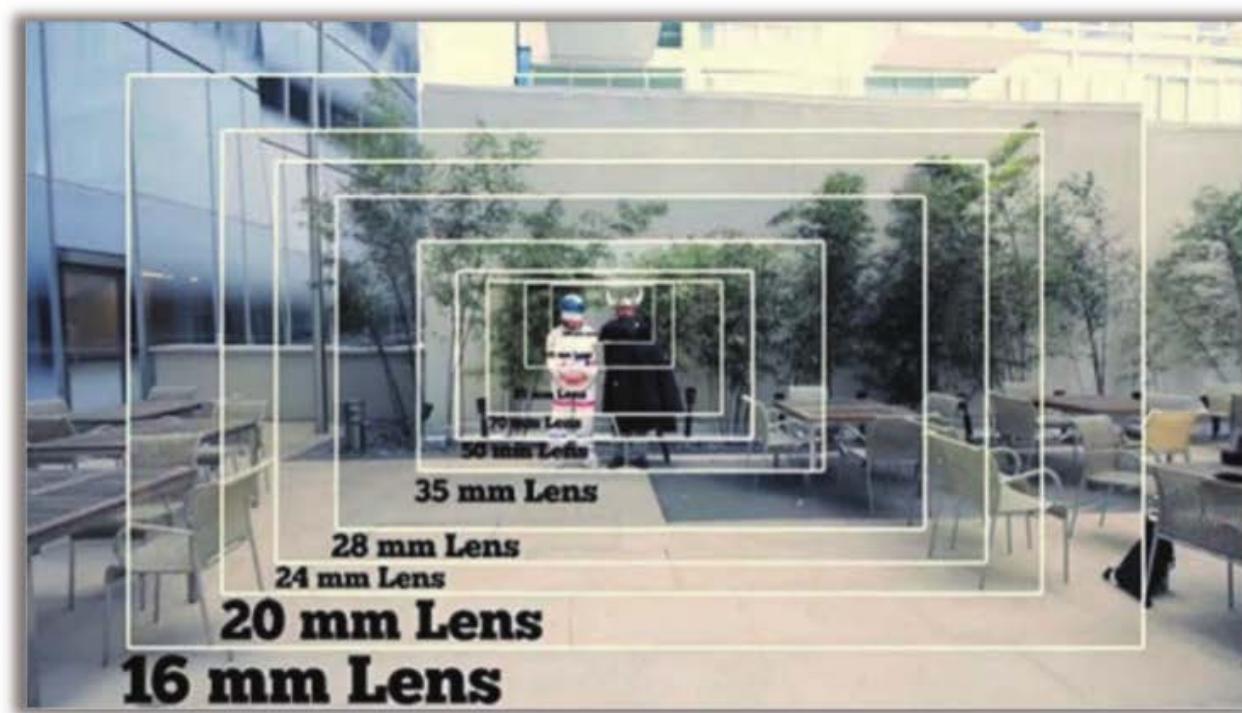
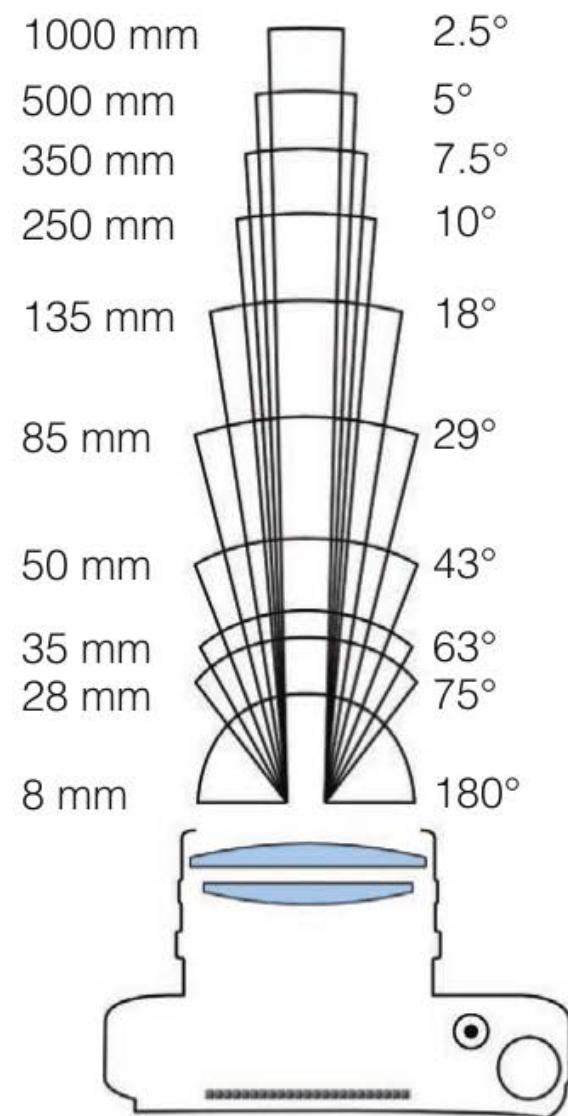
## Field of View (Continue)

Note: “zooming” means changing focal length, which is different from refocusing



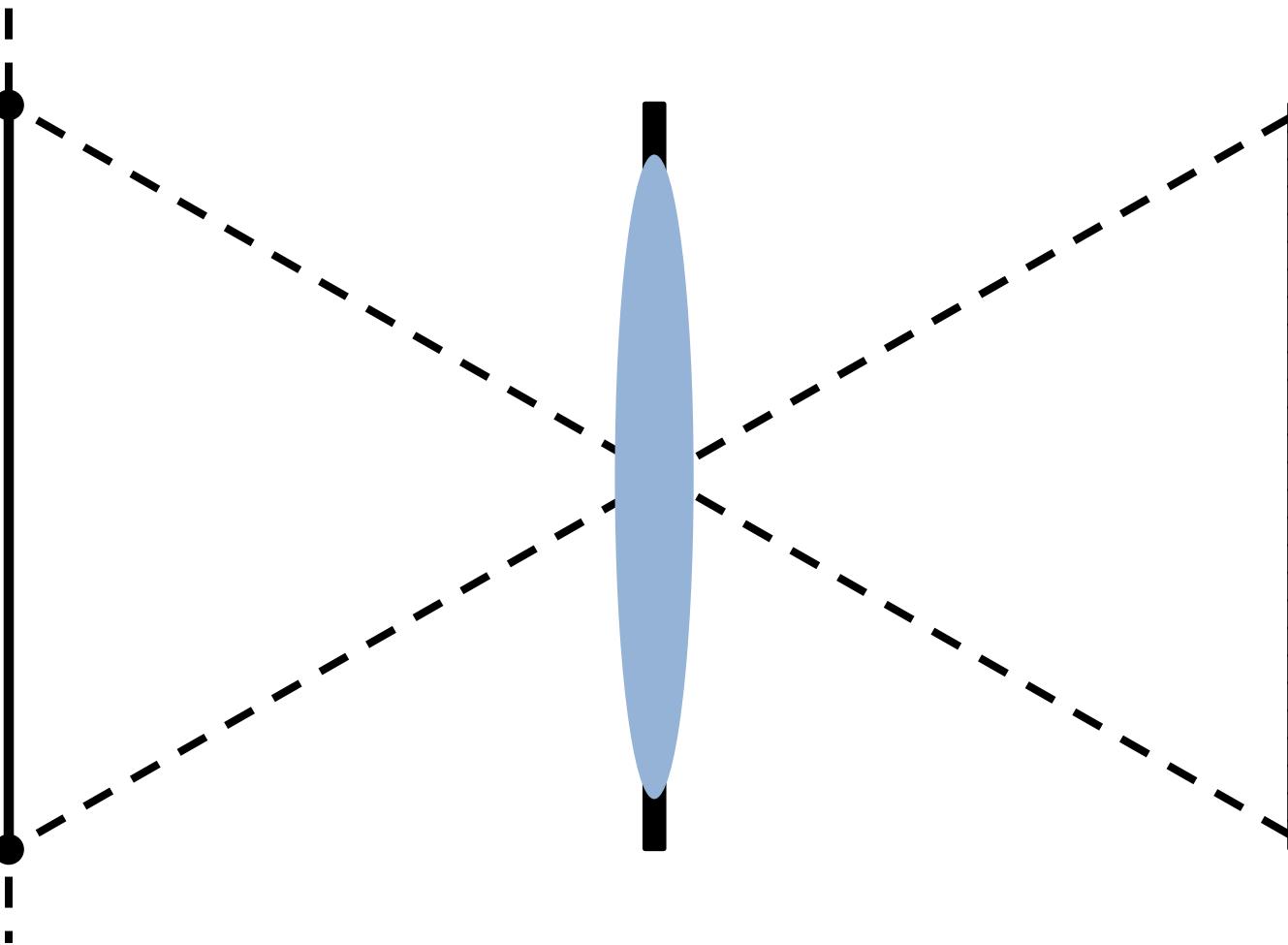
- What happens to field of view when we focus closer? → It decreases.
- What happens to field of view when we increase lens focal length? → It decreases.

# Field of View (Continue)



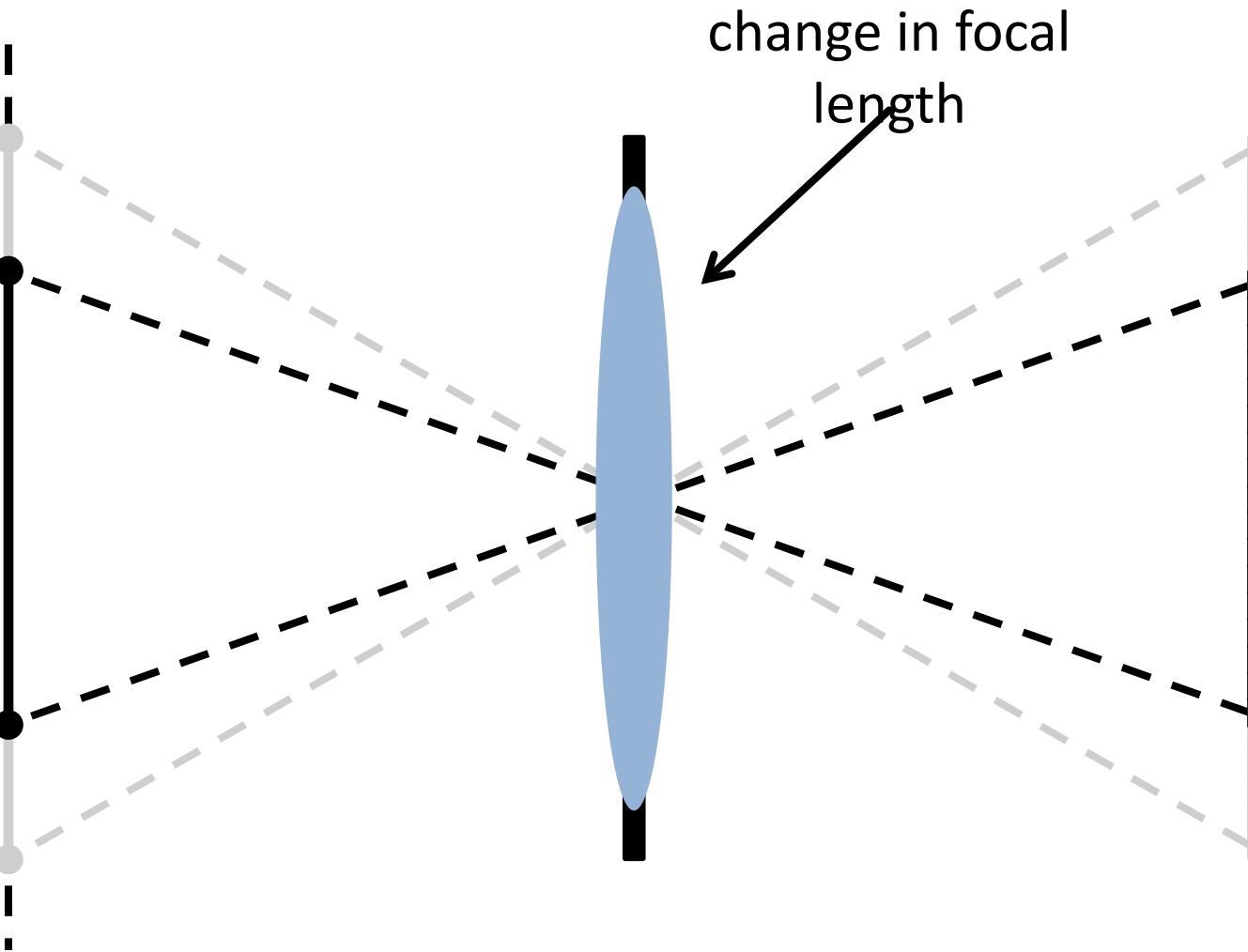
Andrew McWilliams

# Field of View Depending on Sensor Size



- What happens to field of view when we reduce sensor size?

# Field of View Depending on Sensor Size



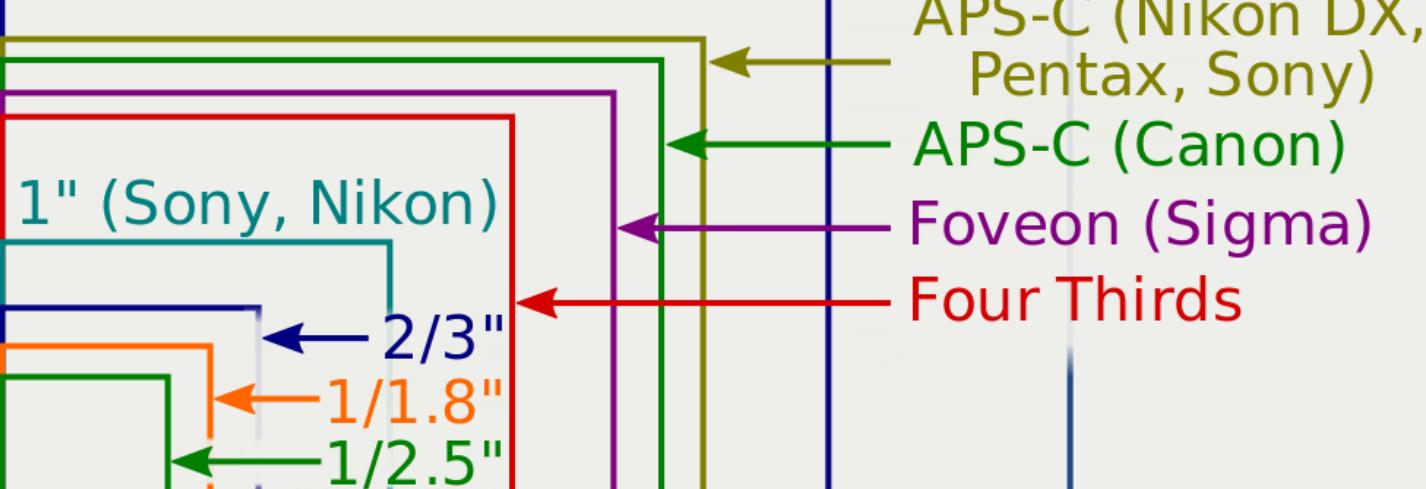
- What happens to field of view when we reduce sensor size? → It decreases.

# Field of View Depending on Sensor Size

Medium format (Kodak KAF 39000 sensor)

35 mm "full frame"

APS-H (Canon)



- “Full frame” corresponds to standard film size.
- Digital sensors come in smaller formats due to manufacturing limitations (now mostly overcome).
- Lenses are often described in terms of field of view on film instead of focal length.
- These descriptions are invalid when not using full-frame sensor.

# Field of View Depending on Sensor Size

Medium format (Kodak KAF 39000 sensor)

35 mm "full frame"

APS-H (Canon)

APS-C (Nikon DX,  
Pentax, Sony)

APS-C (Canon)

1" (Sony, Nikon)

Foveon (Sigma)

Four Thirds

2/3"

1/1.8"

1/2.5"



How much field of view is  
cropped when using a sensor  
smaller than full frame.

# DSLR Camera (Shutter Priority vs Aperture Priority Modes)

## Mode P (Programmed Auto)

The camera automatically adjusts aperture and shutter speed for optimal exposure, but the photographer can choose from different combinations of aperture and shutter speed that will produce the same exposure. This is known as flexible program.

## Mode S (Shutter-Priority Auto)

The photographer chooses the shutter speed and the camera automatically adjusts aperture for optimal exposure.

## Mode A (Aperture-Priority Auto)

The photographer chooses the aperture and the camera automatically adjusts shutter speed for optimal exposure.

Mode	Shutter Speed	Aperture
P (programmed auto)	Selected by <b>camera</b>	Selected by <b>camera</b>
S (shutter-priority auto)	Selected by <b>photographer</b>	Selected by <b>camera</b>
A (aperture-priority auto)	Selected by <b>camera</b>	Selected by <b>photographer</b>
M (manual)	Selected by <b>photographer</b>	Selected by <b>photographer</b>

# Question

- **Quantization**
- **Clipping**
- **Aliasing**
- **Oversampling**

# Slide Credits

- Lecture notes: Rob Fergus.
- Lecture notes: Steve Seitz
- Lecture notes: Mohammad Jahanshahi
- Lecture notes: Svetlana Lazebnik
- Lecture notes: Derek Hoiem
- Lecture notes: Ioannis (Yannis) Gkioulekas
- Lecture notes: Kris Kitani
- Lecture notes: Fredo Durand
- Lecture notes: Gordon Wetzstein

# Camera Rent

<https://doodle.com/poll/x2aqnk3f92yighm9>