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

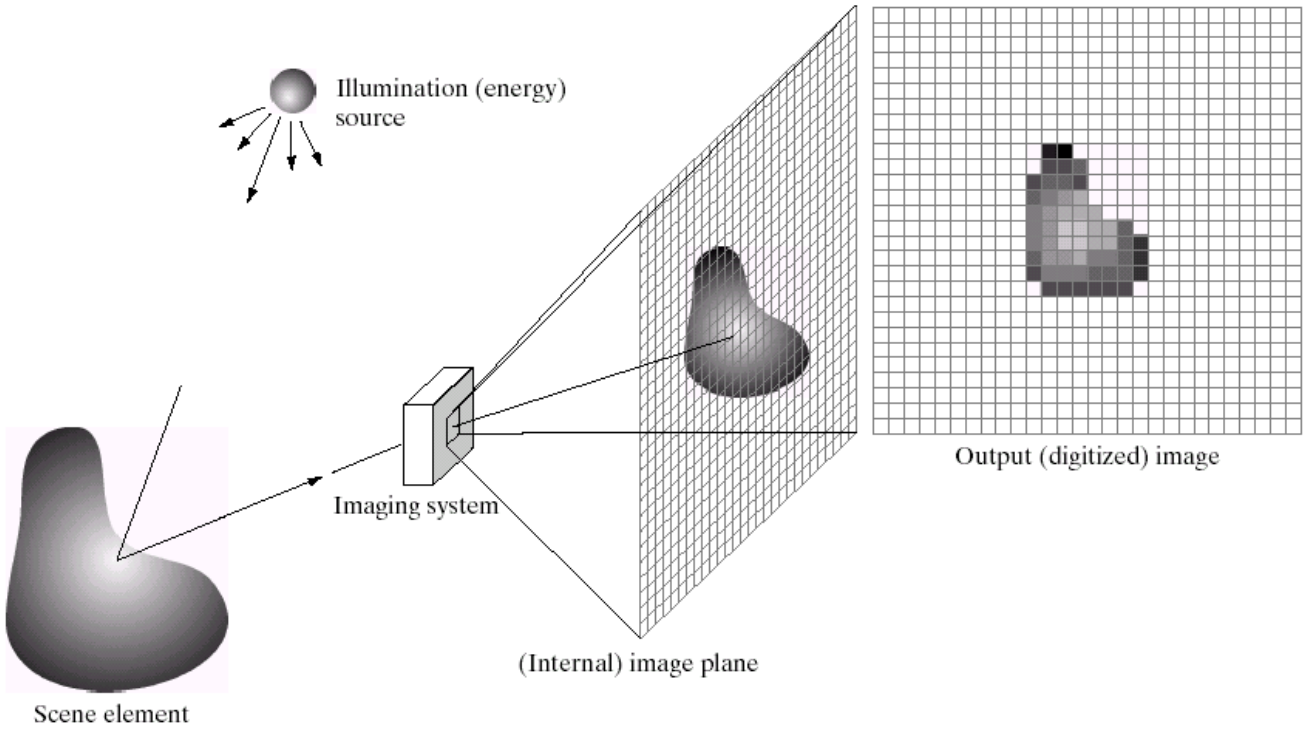
Camera

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?



a
b c d e

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.

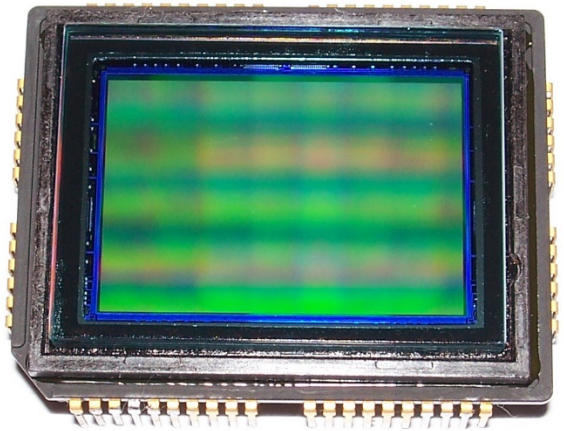
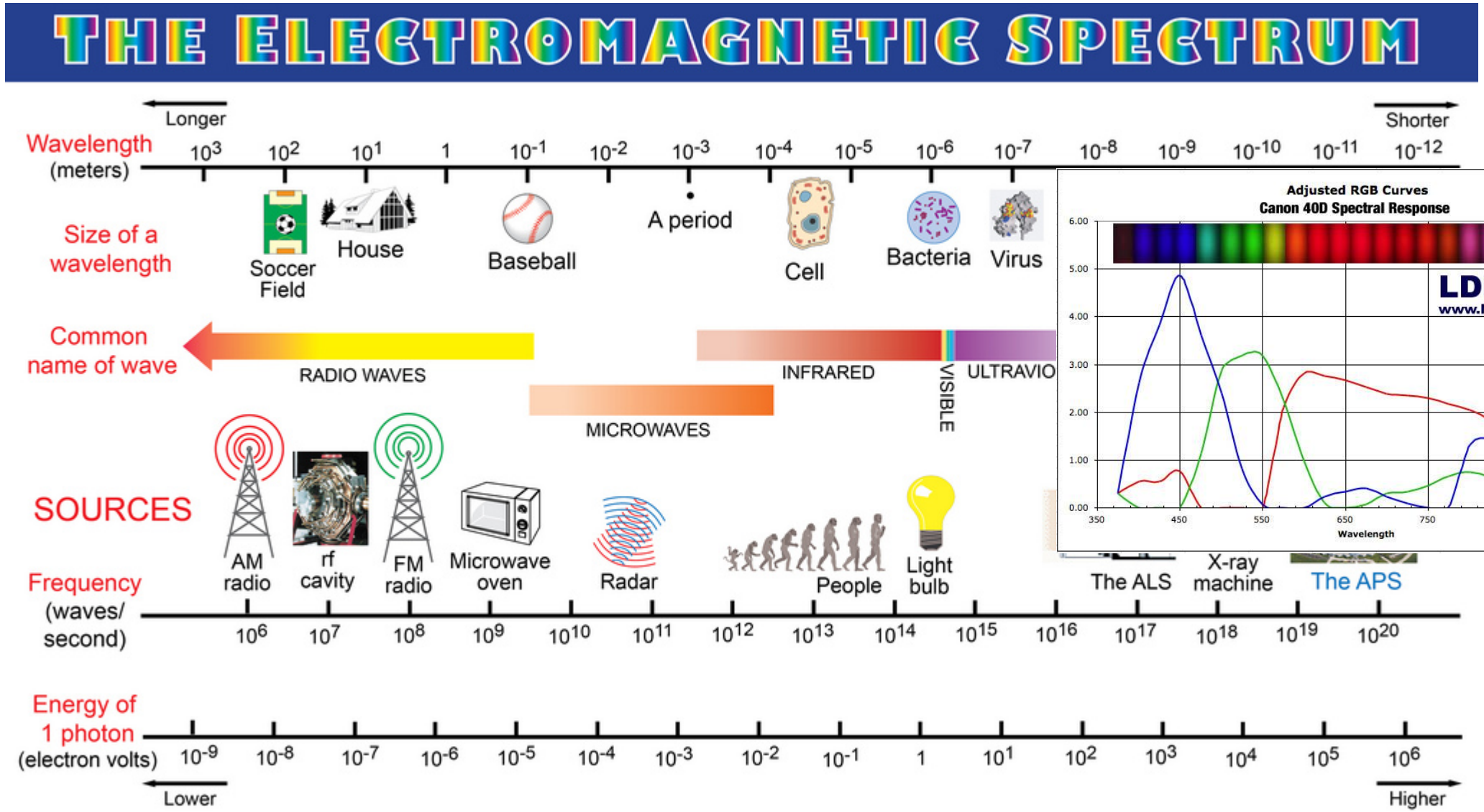


Image sensor

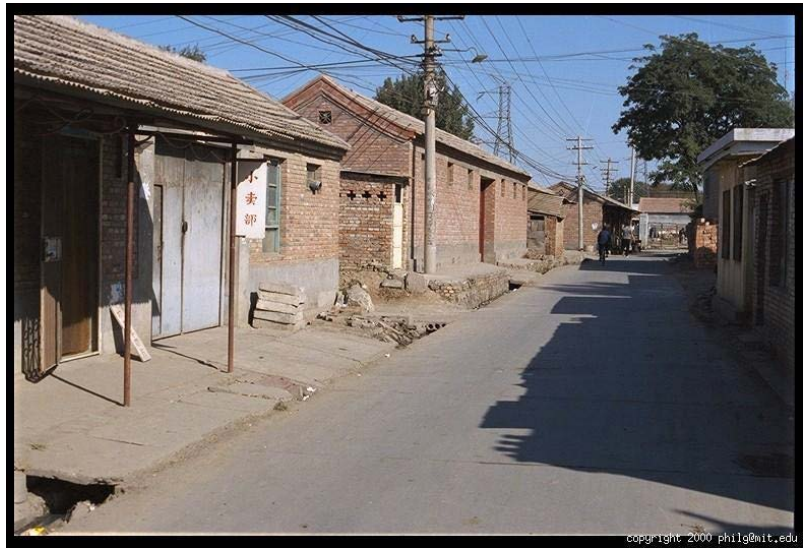
DSLR camera

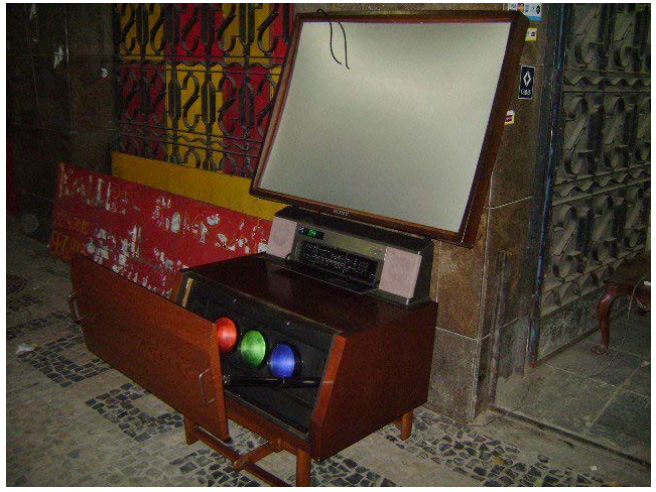
Visible Light Spectrum

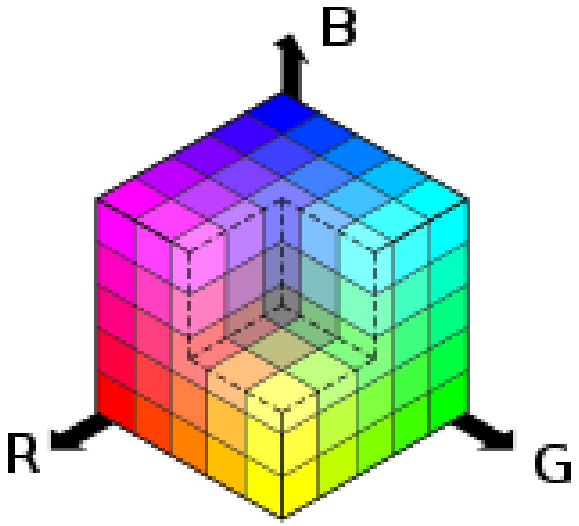


Wavelength!

Color Images





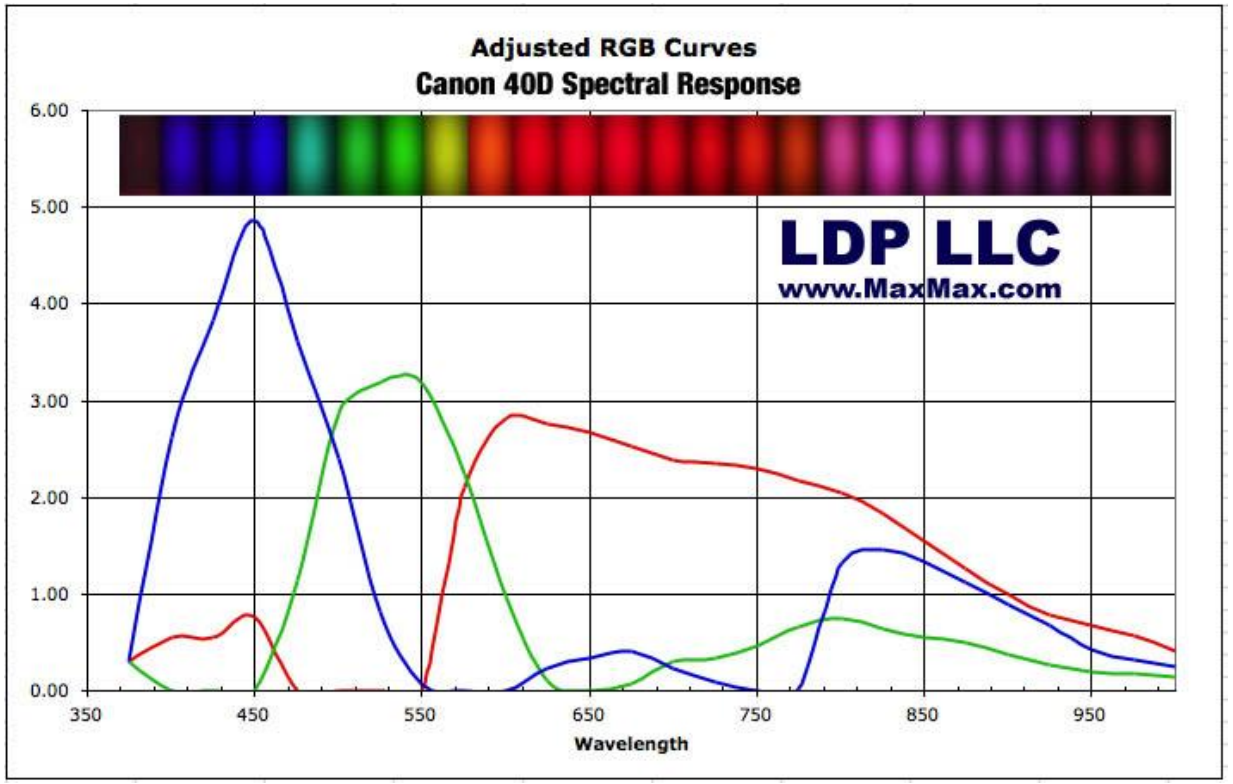


RGB Filter

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

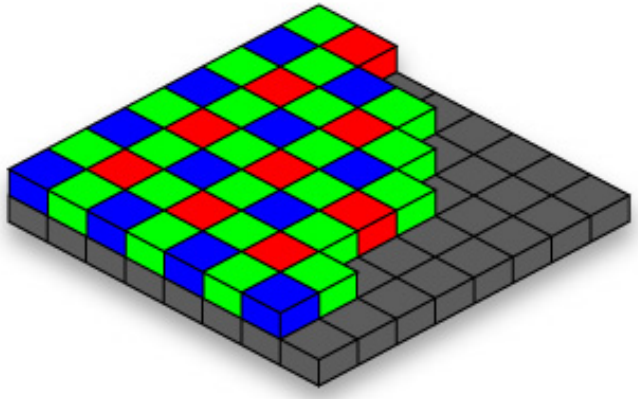


https://maxmax.com/spectral_response.htm

https://en.wikipedia.org/wiki/RGB_color_model#/media/File:Rgb-compose-Alim_Khan.jpg

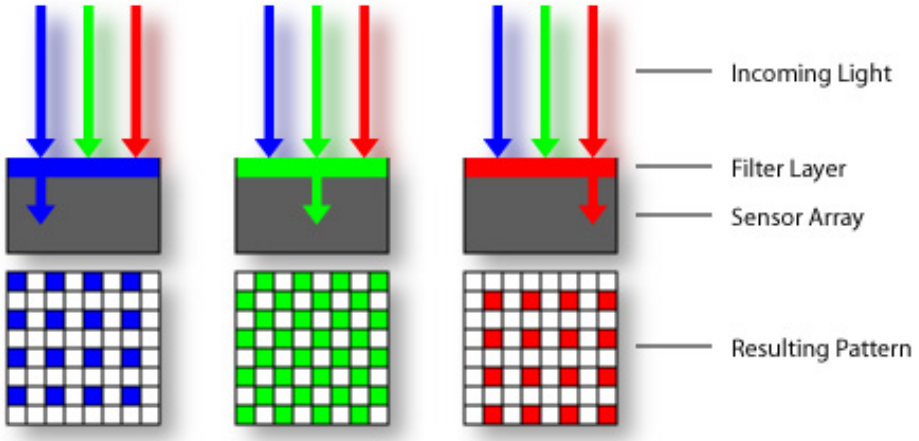
Color Filter Arrays

Bayer grid

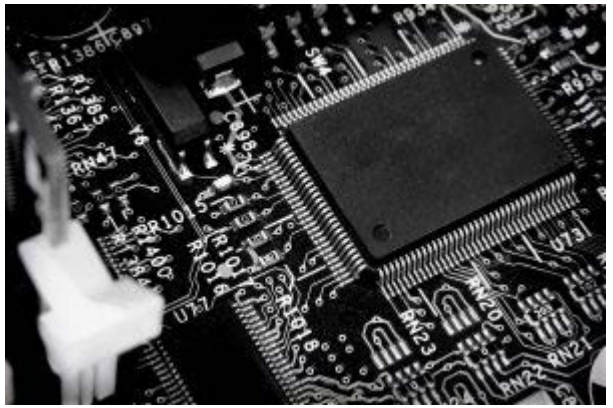


Demosaicing:

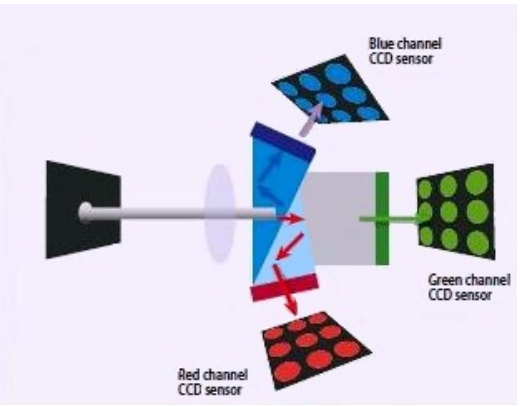
Estimation of missing components from neighboring values



The filter pattern is 50% green, 25% red and 25% blue.



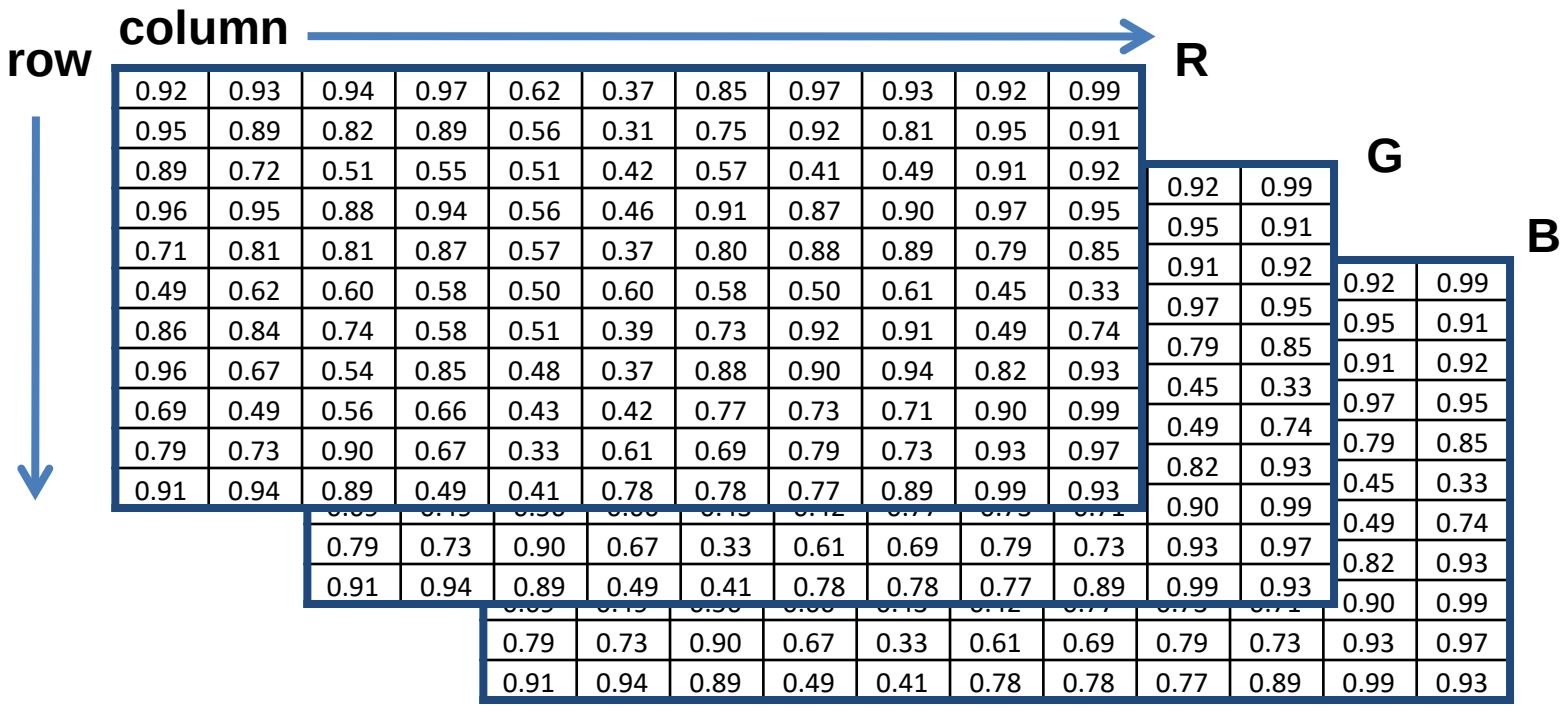
Monochrome machine vision camera



3CCD

Image File Structure

- Images represented as a matrix
- Suppose we have a NxM RGB image called “im”
  - im(1,1,1) = top-left pixel value in R-channel
  - im(y, x, b) = y pixels down, x pixels to right in the b^{th} channel
  - 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



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.

Q. difference?

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

Questions

Product 1: Apple watch with a 4k screen.

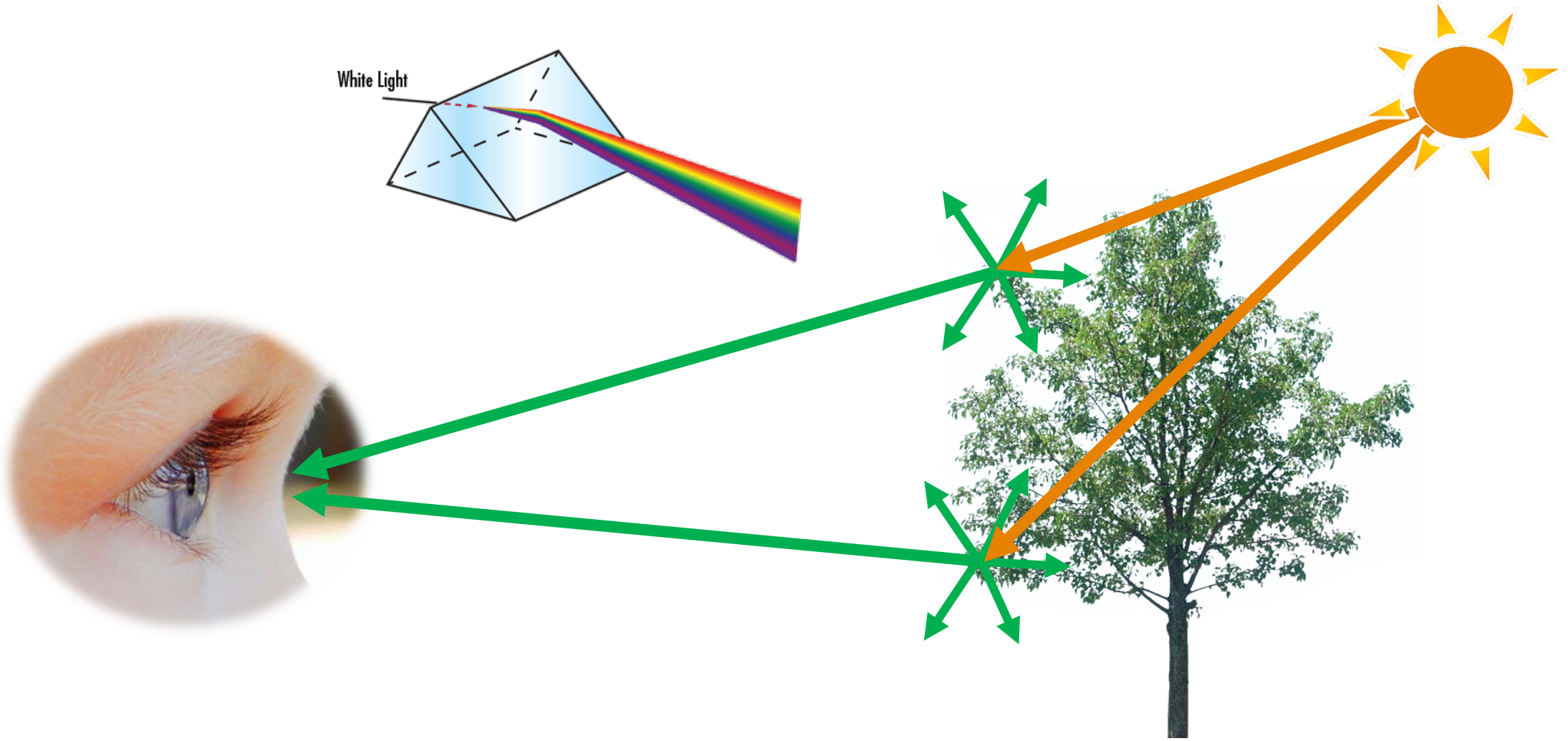
Product 2: 80 inch high-definition full-HD TV.

Product 3: 4k monitor for Skype, Zoom meeting

Product 4: 5-inch smart phone with 4k resolution for VR gaming

Product 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?

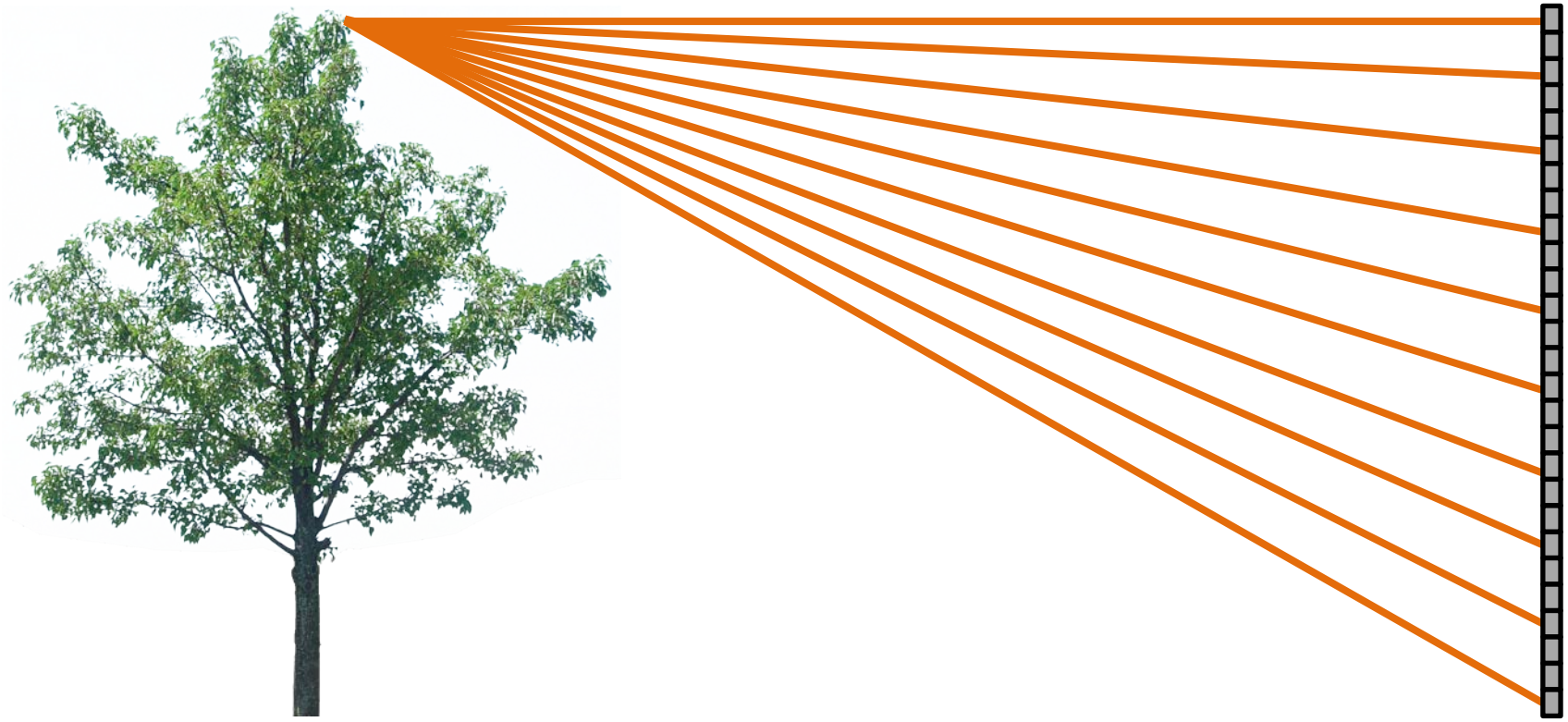
Bare-Sensor Imaging

real-world object

digital sensor (CCD or CMOS)

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

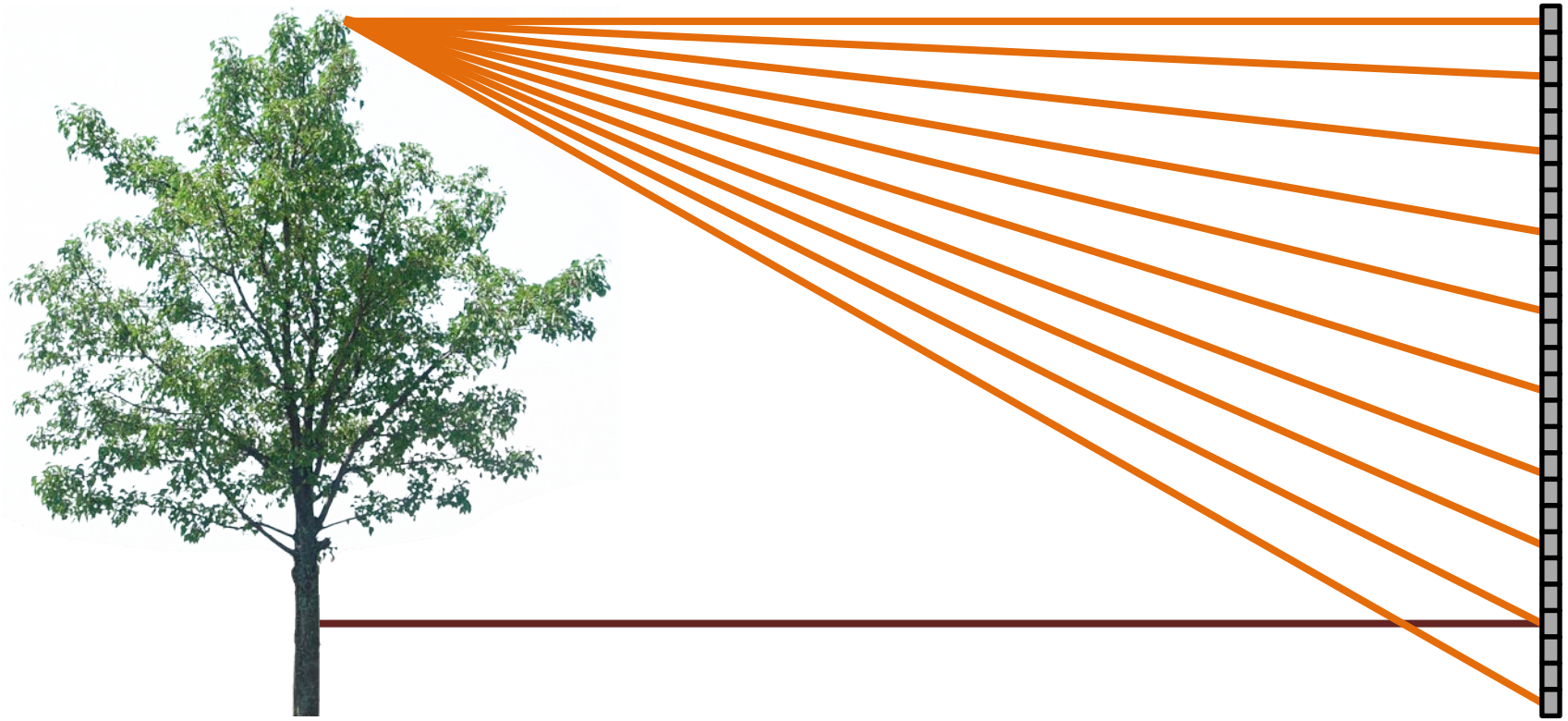
real-world object



digital sensor (CCD or CMOS)

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

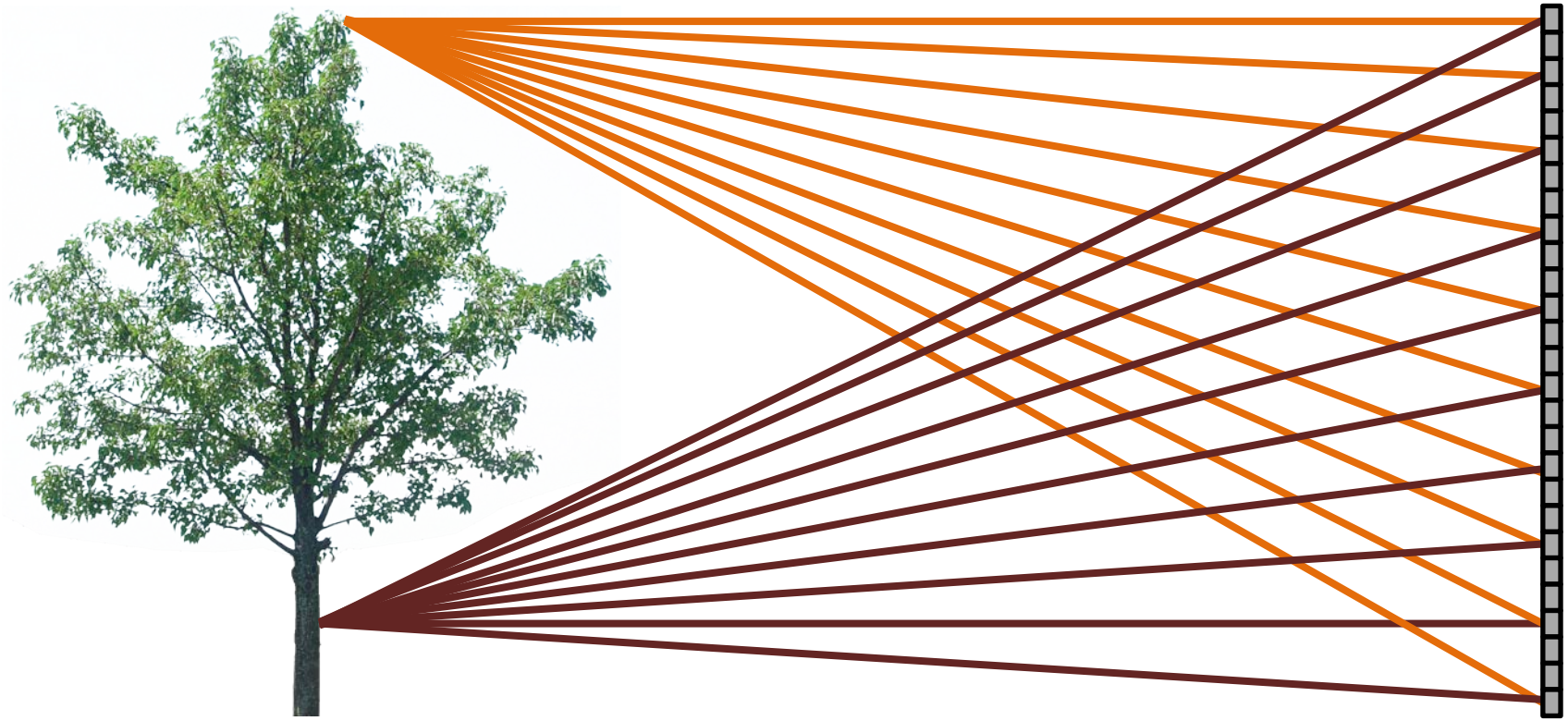
real-world object



digital sensor (CCD or CMOS)

What Does the Image on the Sensor Look Like?

real-world object



digital sensor (CCD or CMOS)

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

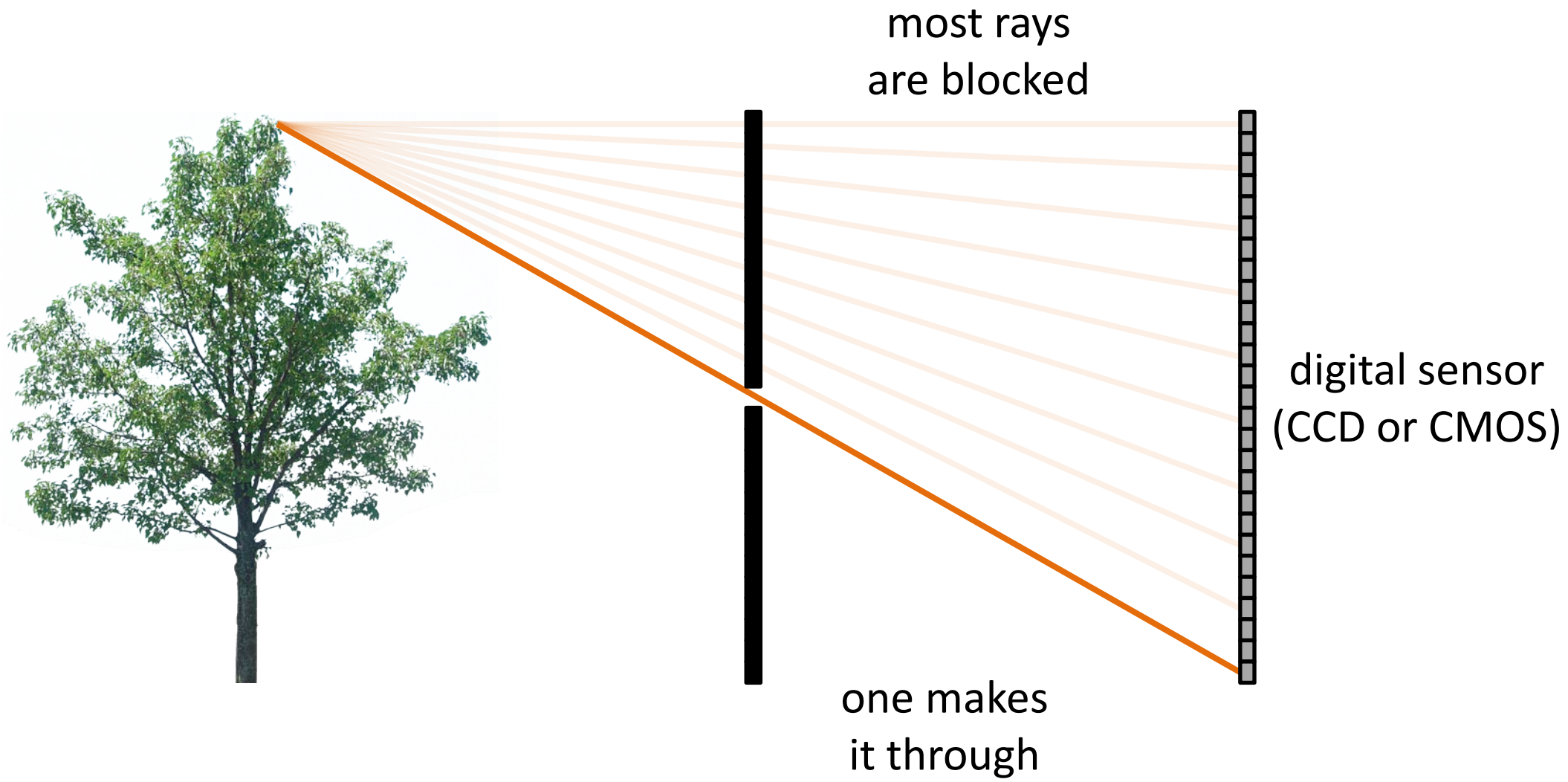
barrier (diaphragm)

pinhole (aperture)

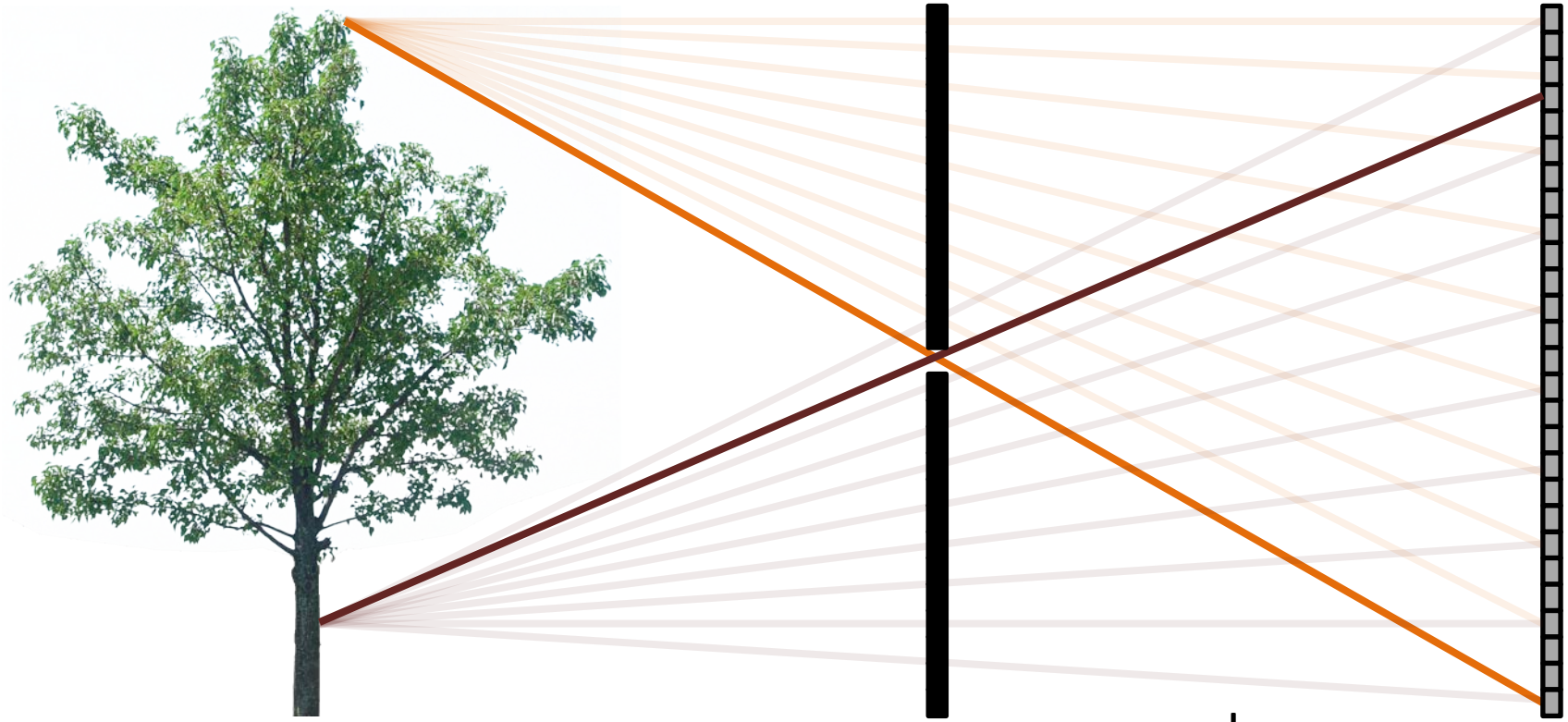
digital sensor (CCD or CMOS)

Very small pinhole

Pinhole Imaging



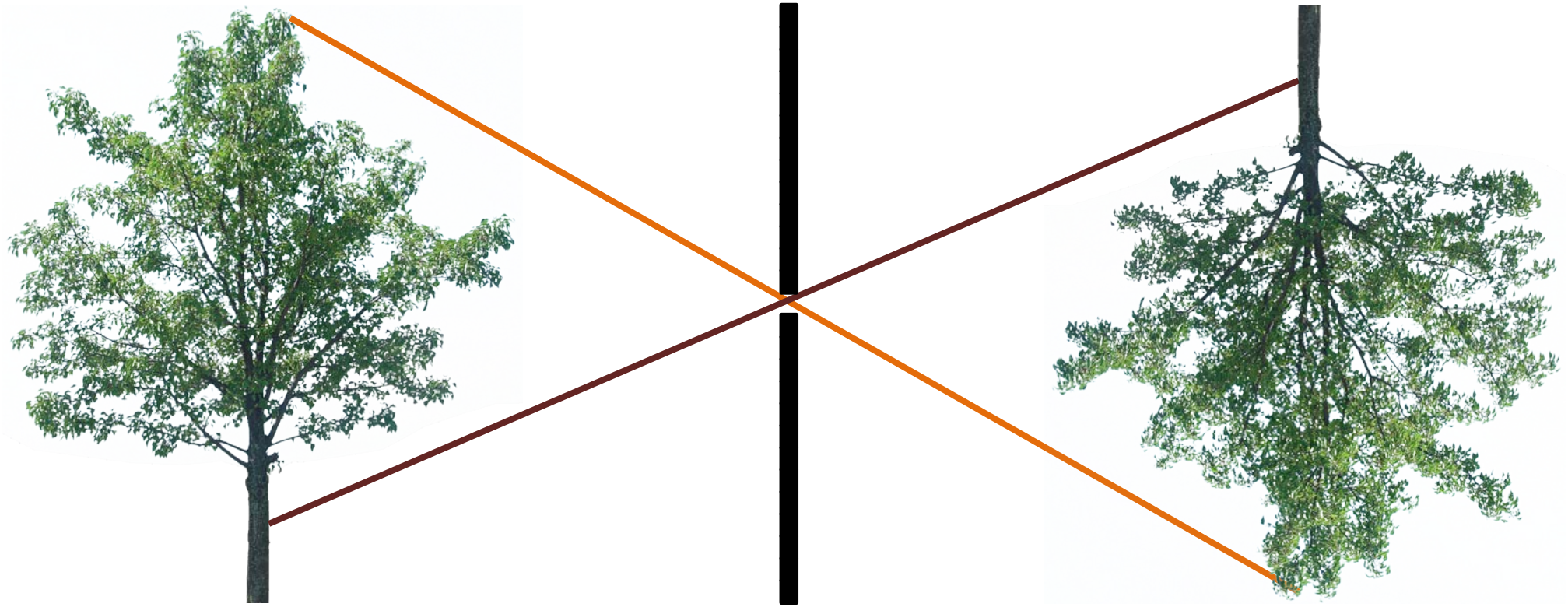
Pinhole Imaging



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

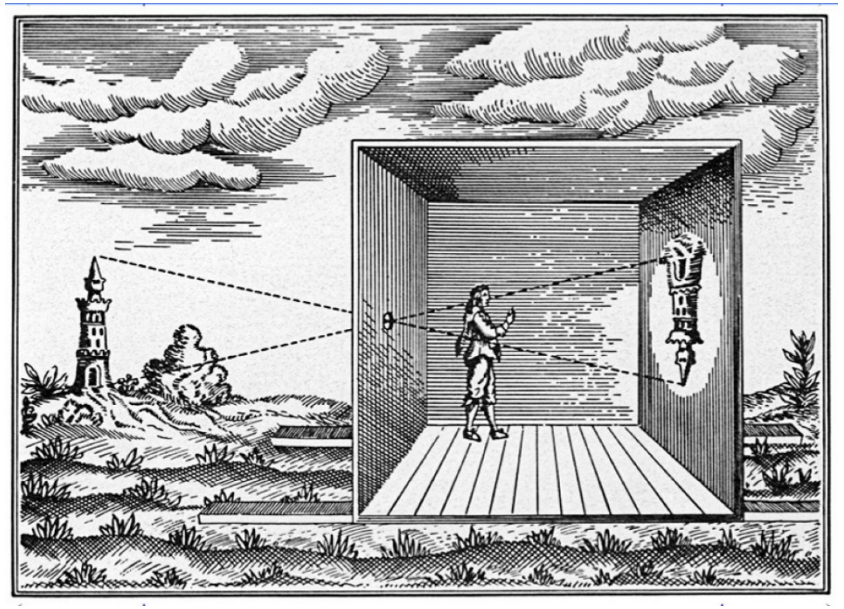
Pinhole Imaging: the Object can be Captured !!

real-world object



copy of real-world object (inverted and scaled)

Camera Obscure

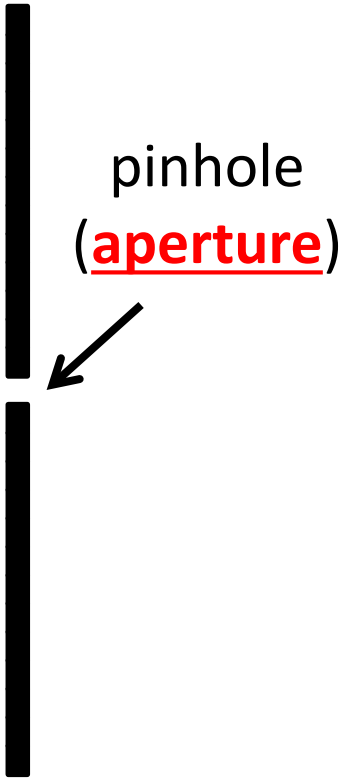


http://www.abelardomorell.net/project/camera-obscura/

Pinhole Camera Terms (Aperture)

real-world object

barrier (diaphragm)

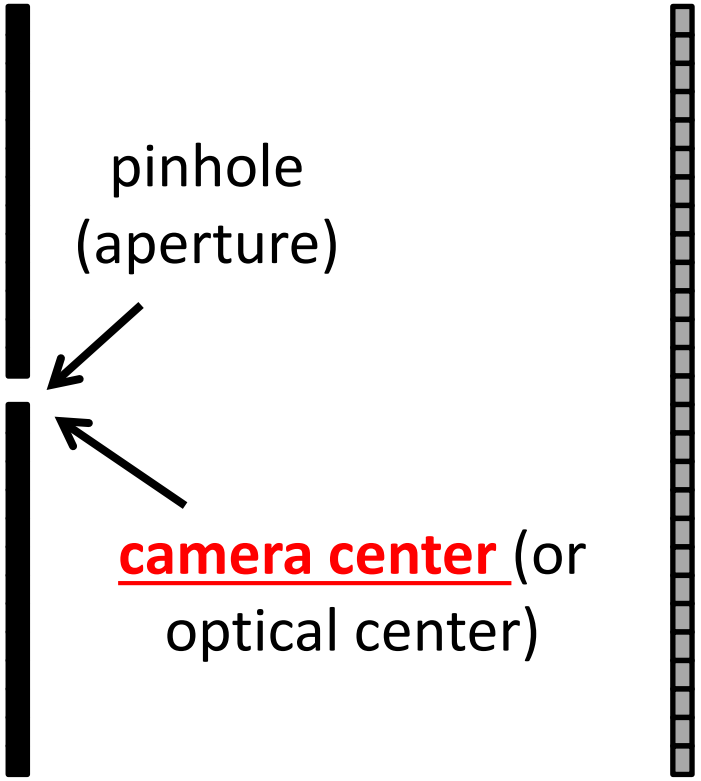


pinhole (**aperture**)

digital sensor (CCD or CMOS)

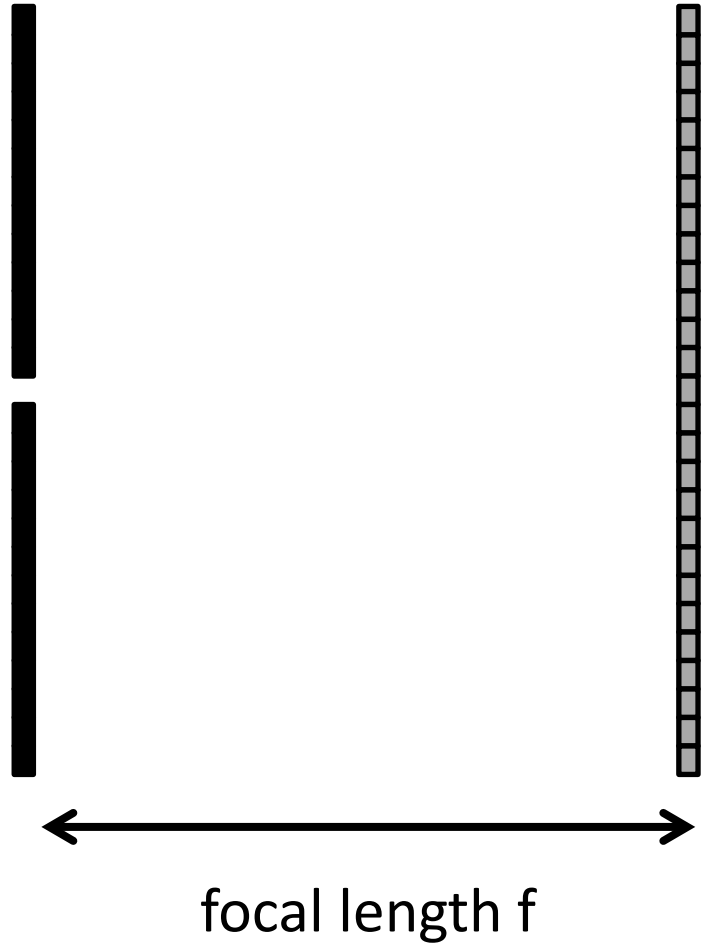
Pinhole Camera Terms (Camera Center)

real-world object



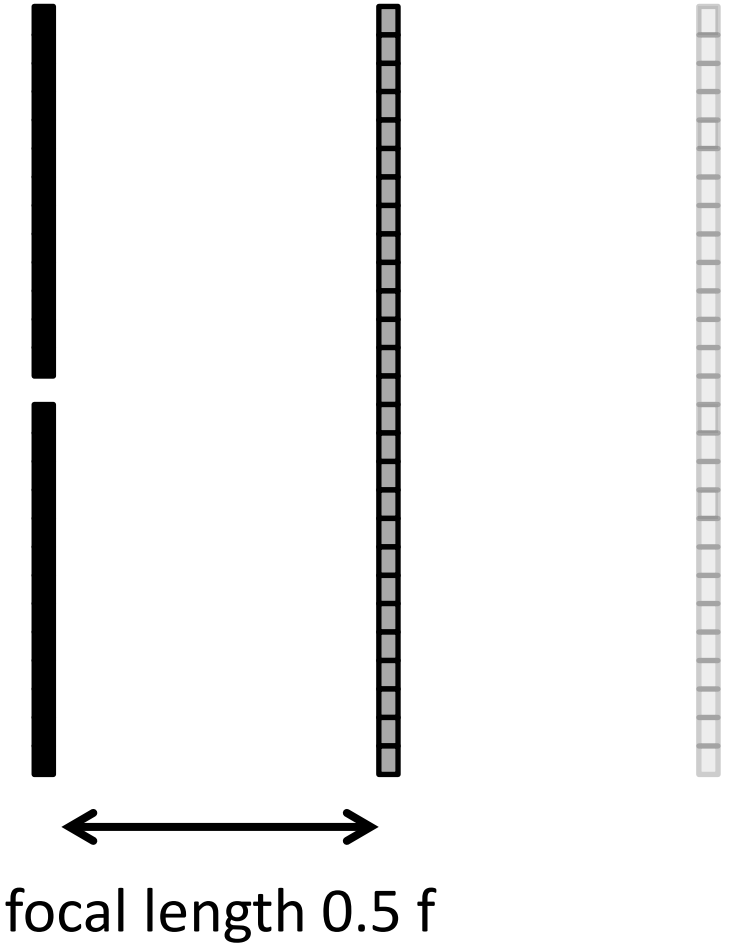
Pinhole Camera Terms (Focal Length)

real-world object



What Happens as We Change the Focal Length?

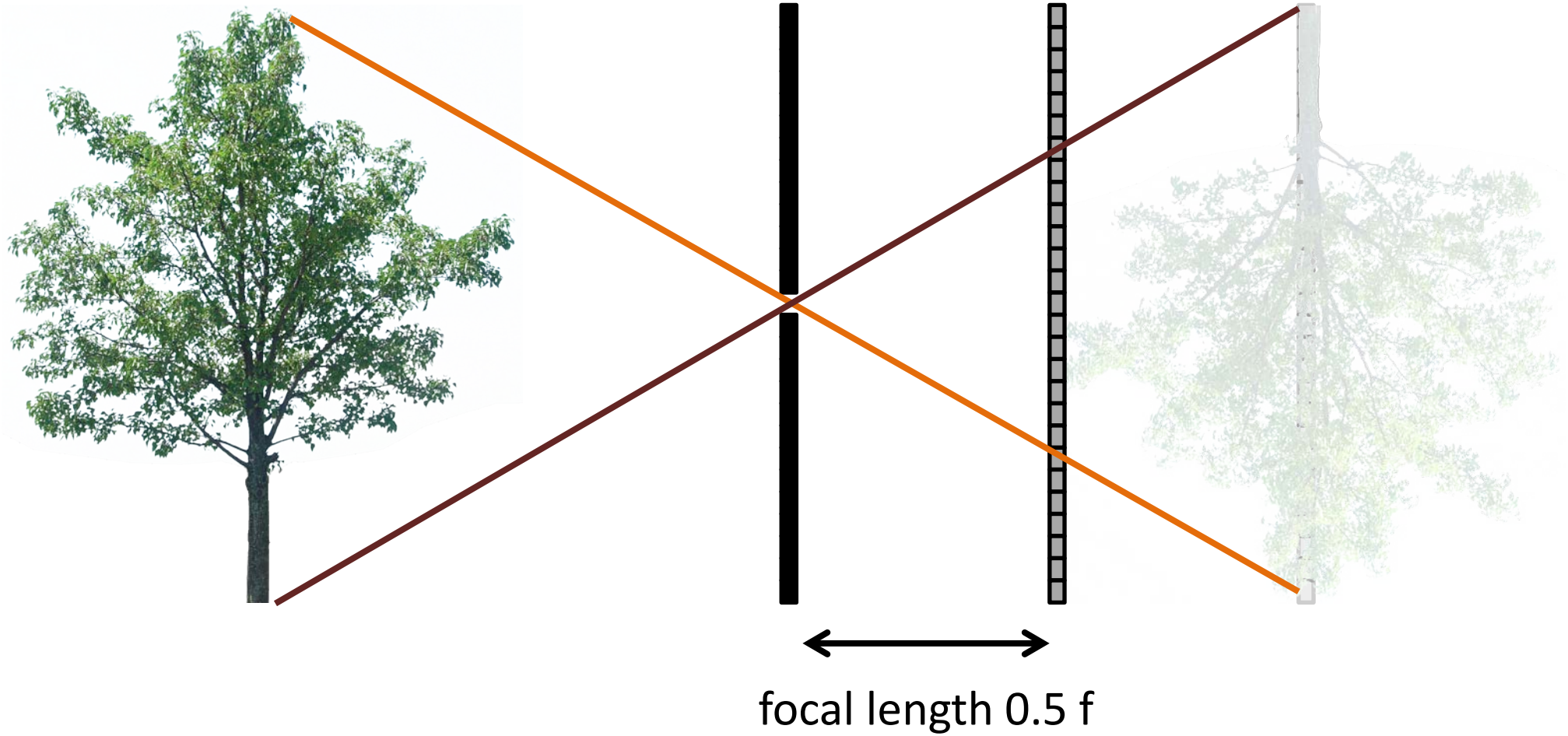
real-world object



focal length 0.5 f

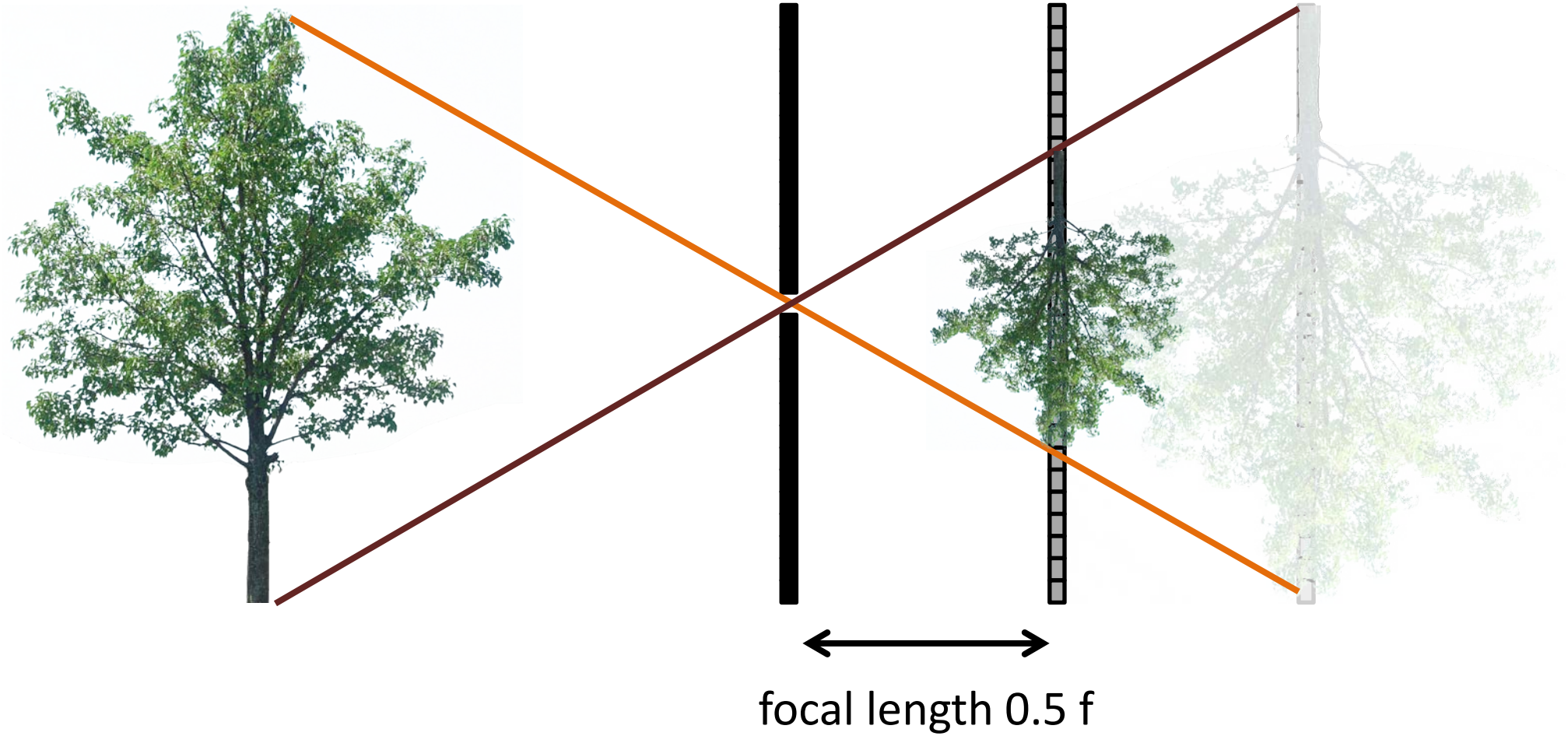
What Happens as We Change the Focal Length?

real-world object



What Happens as We Change the Focal Length?

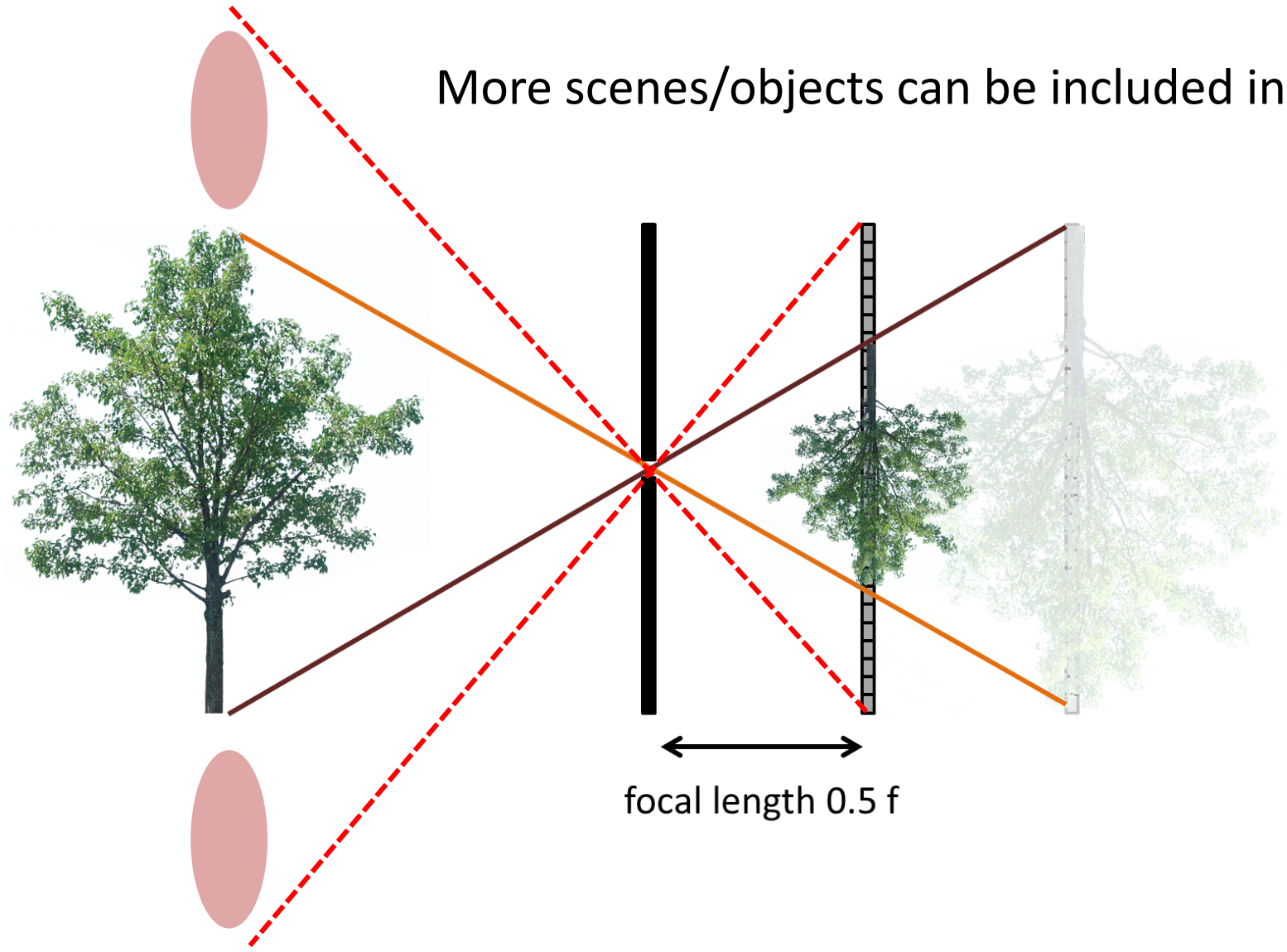
real-world object



What Happens as We Change the Focal Length?

More scenes/objects can be included in the image

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.

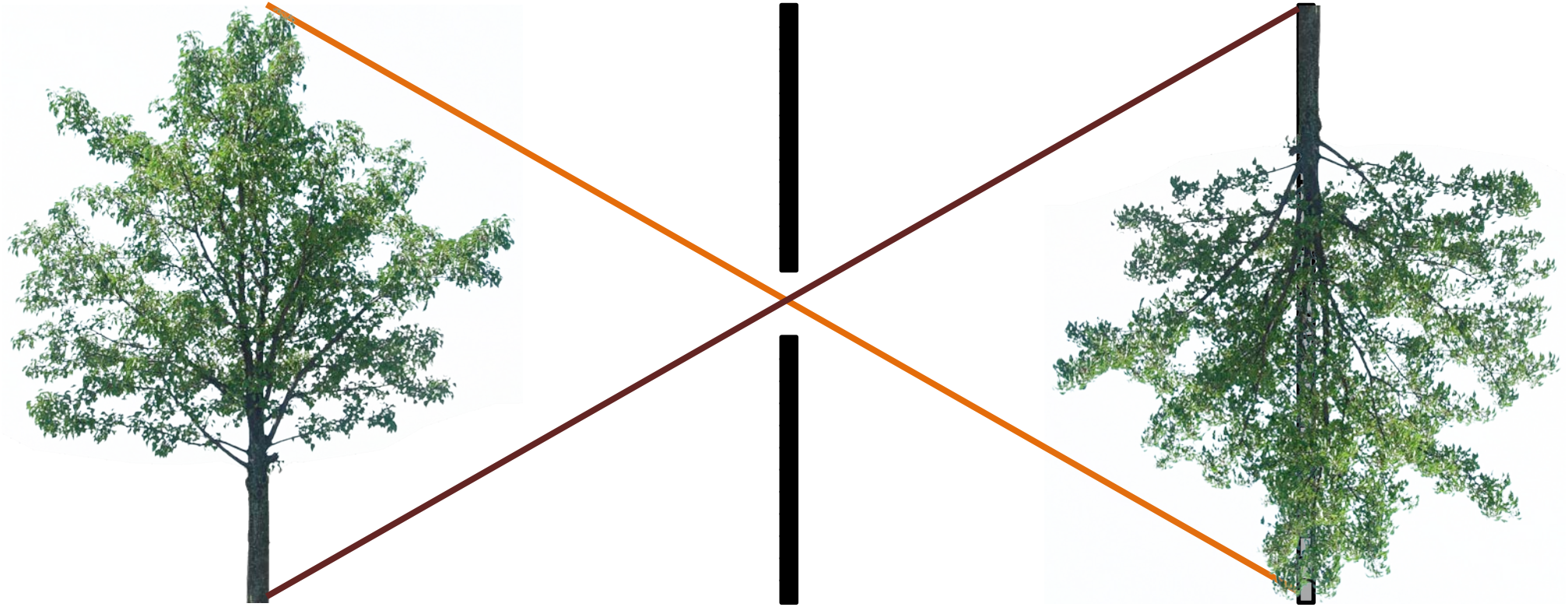
What Happens as We Change the Aperture Size?

real-world object

pinhole diameter

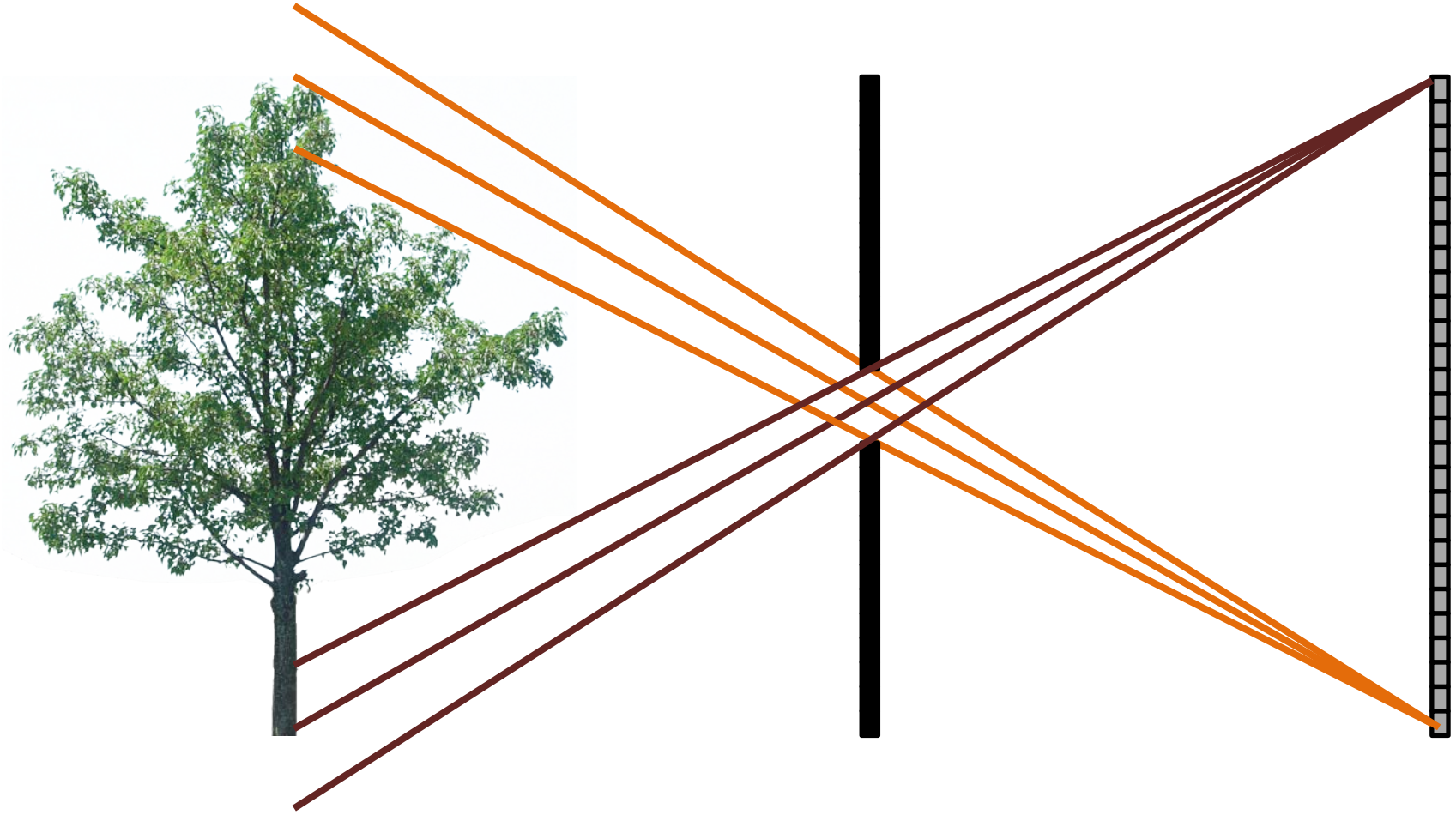
What Happens as We Change the Aperture Size?

real-world object



What Happens as We Change the Aperture Size?

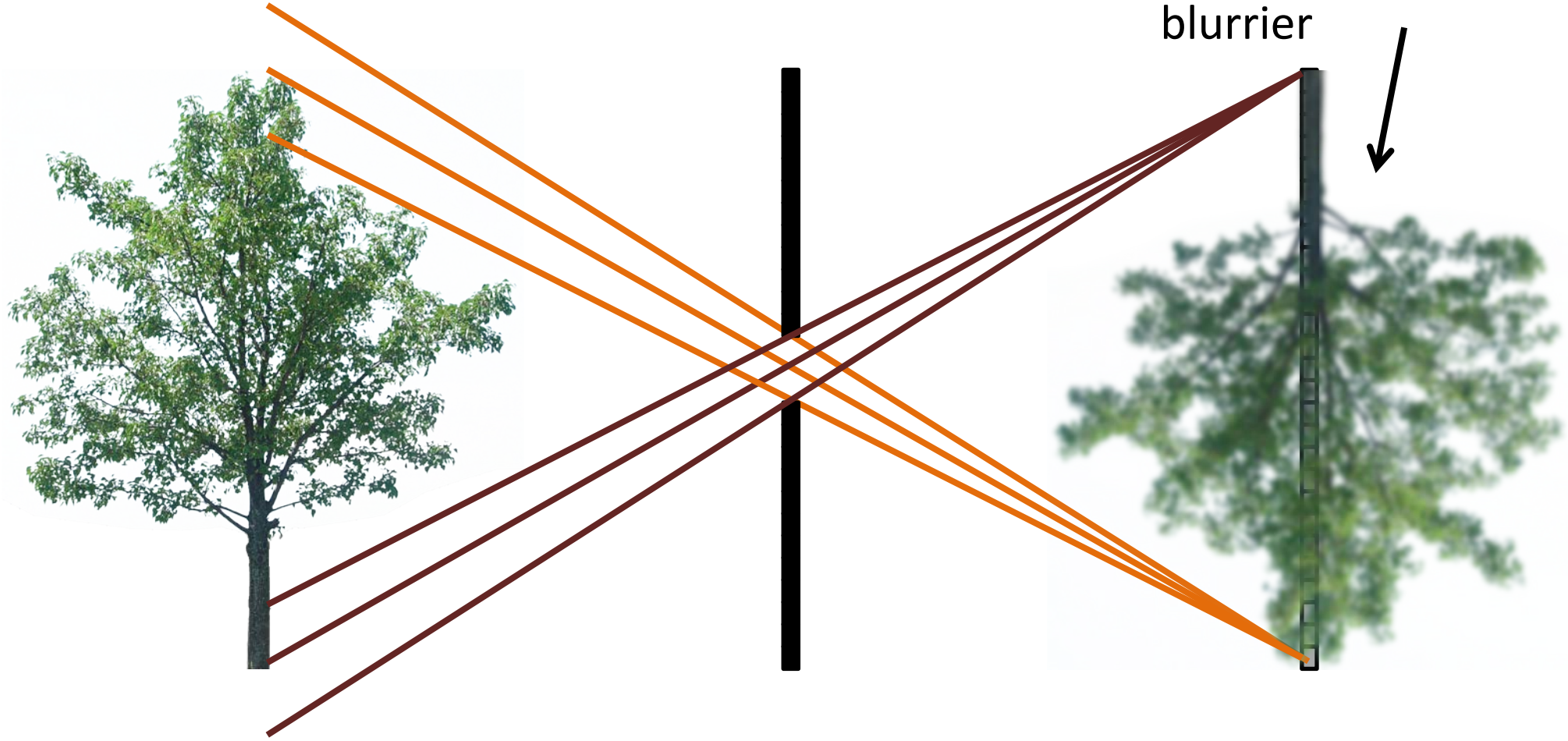
real-world object



What Happens as We Change the Aperture Size?

object projection becomes blurrier

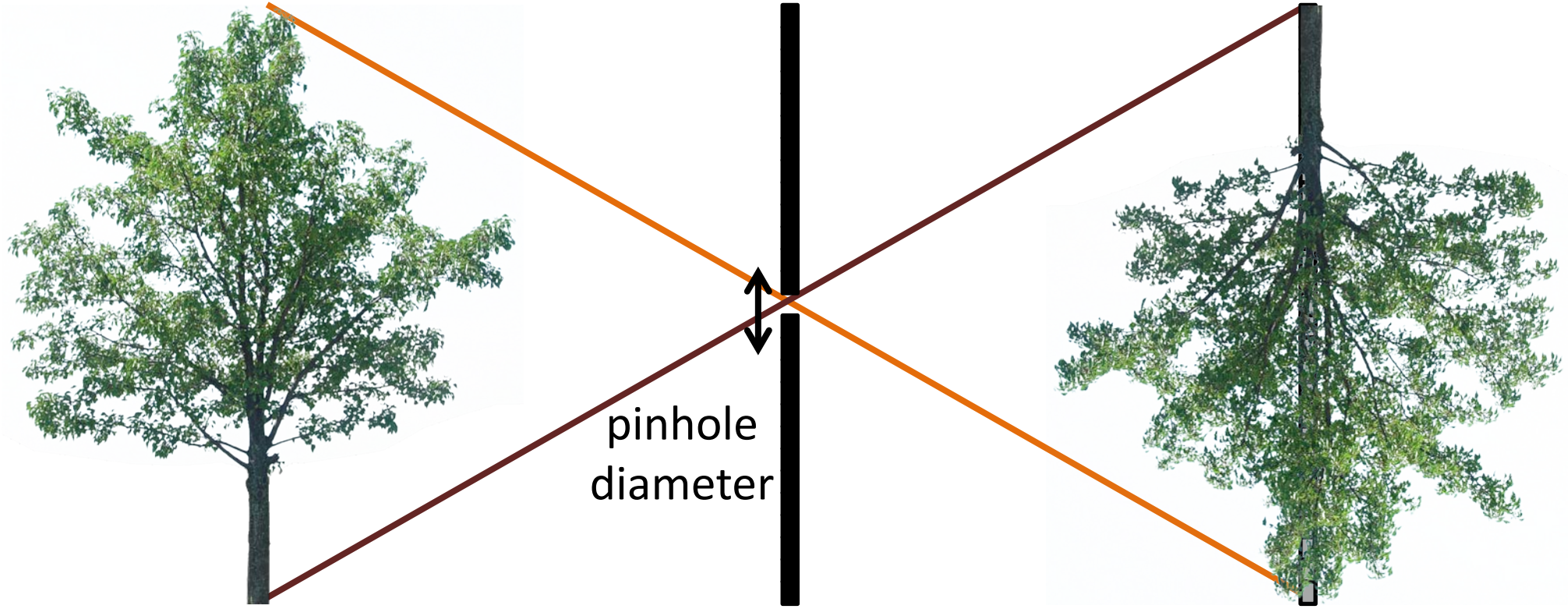
real-world object



When do we open aperture?

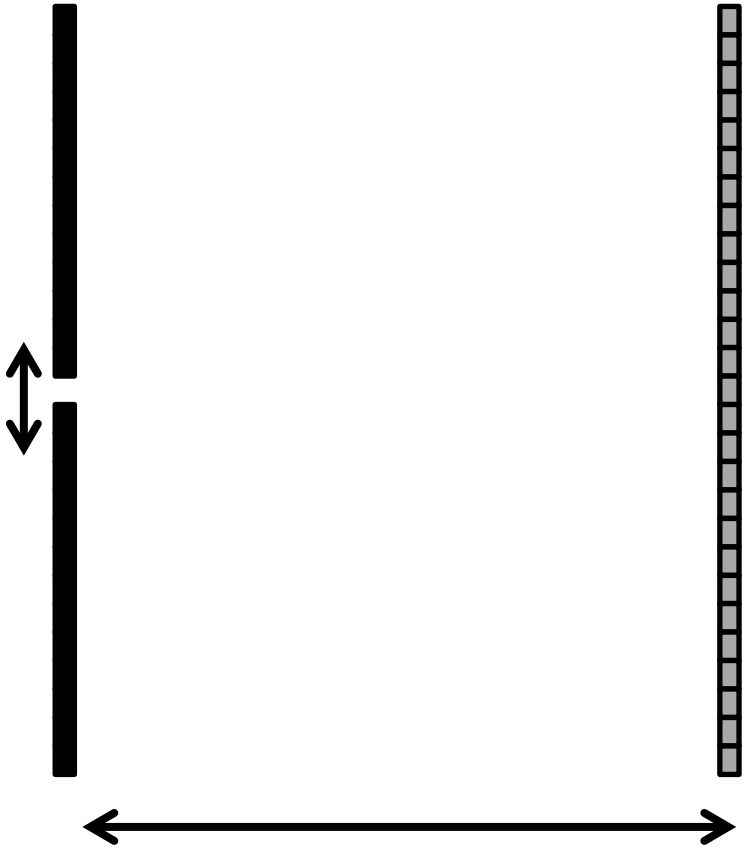
Will the Image Keep Getting Sharper the Smaller We Make the Pinhole?

real-world object



Light Efficiency

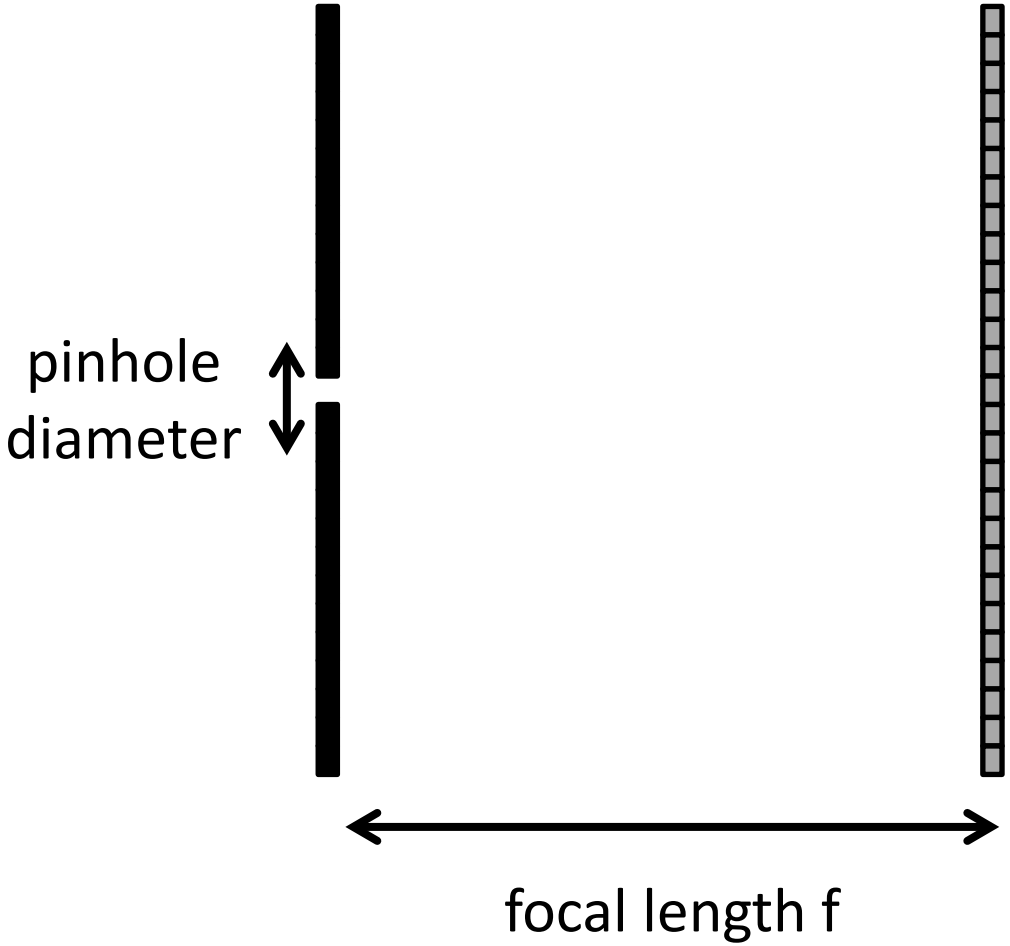
real-world object



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

Light Efficiency (Continue)

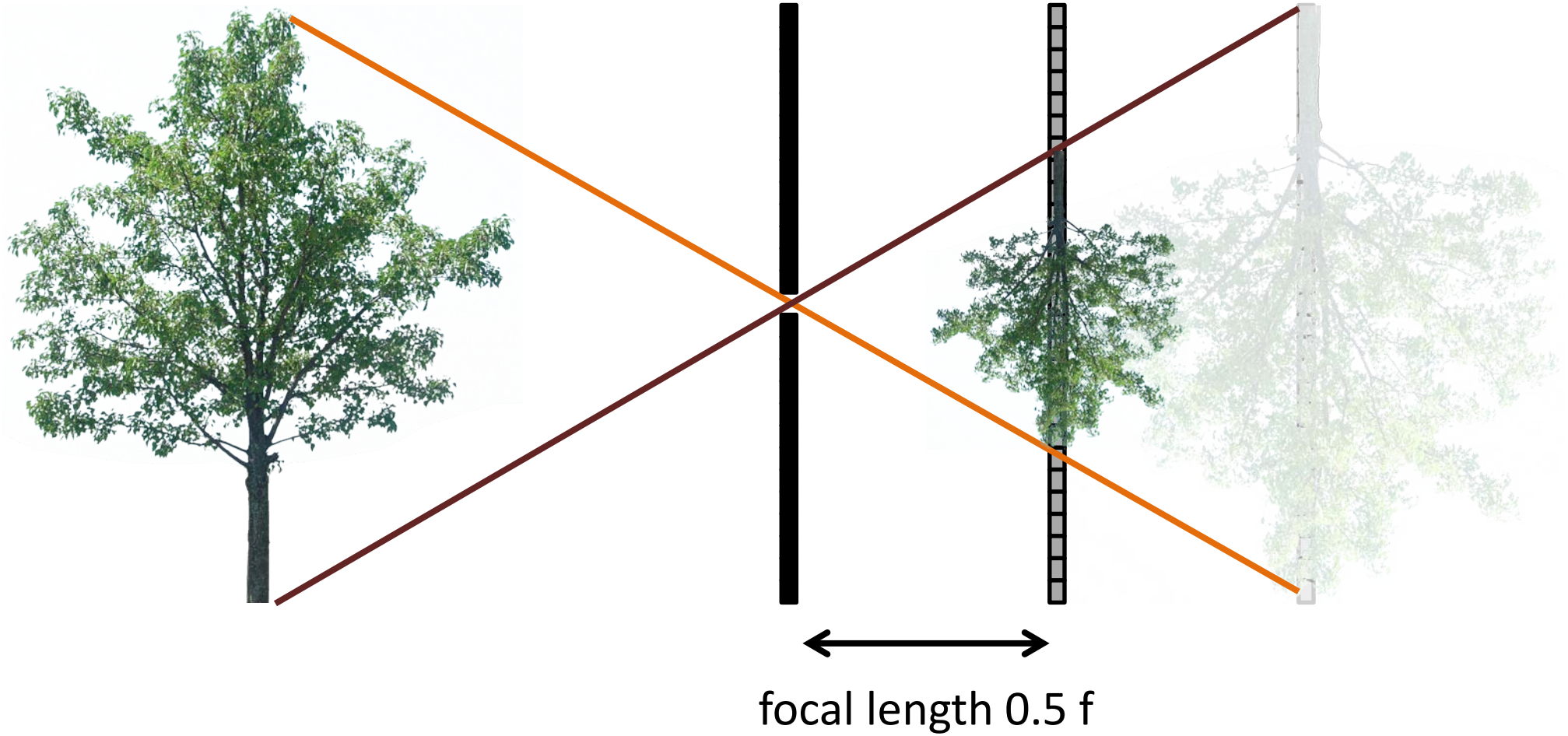
real-world object



- 2x pinhole diameter → 4x light

Light Efficiency (Continue)

real-world object

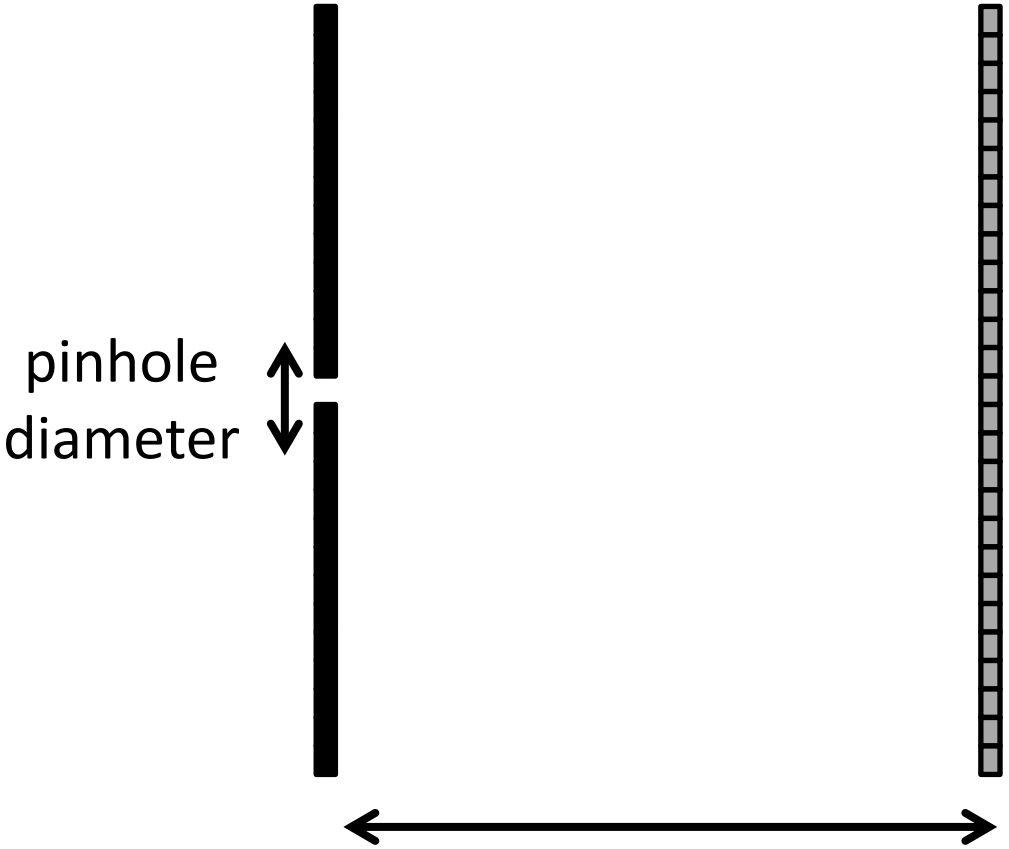


- 2x focal length → ¼x light

F-Number or F-Stop

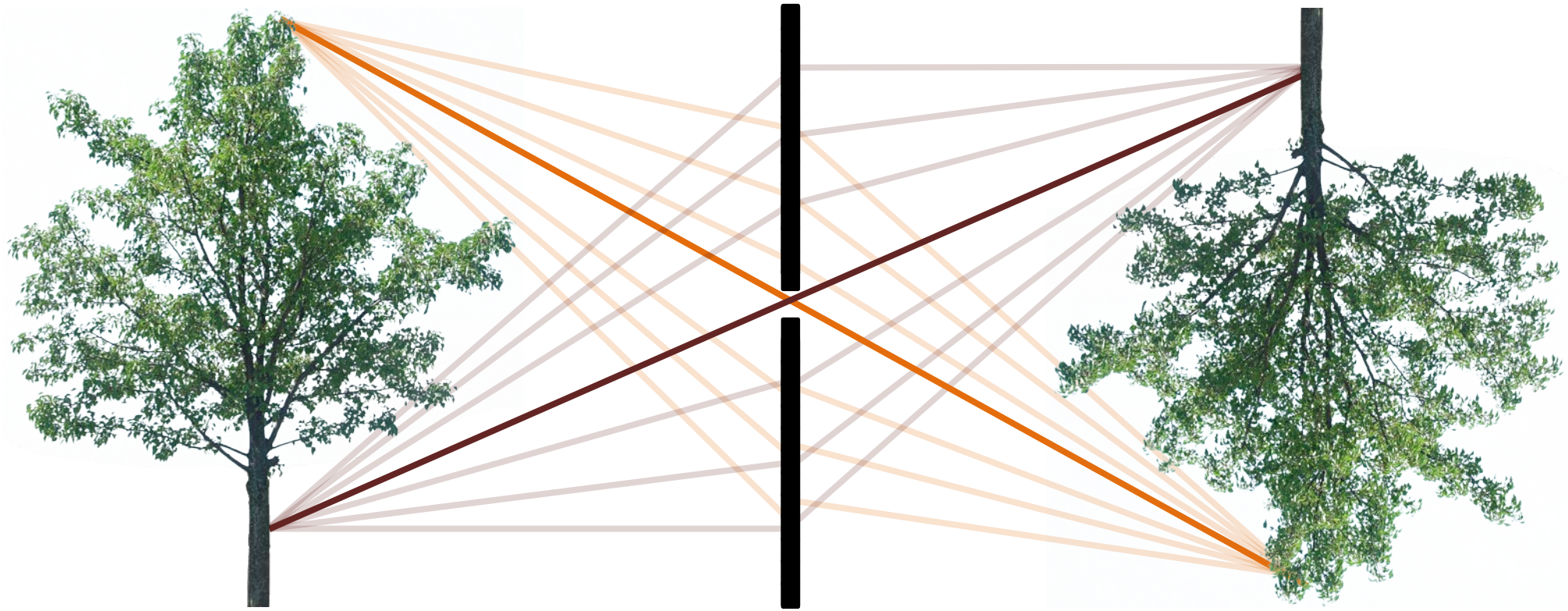
A “stop” is a change in camera settings that changes amount of light by a factor of 2

real-world object



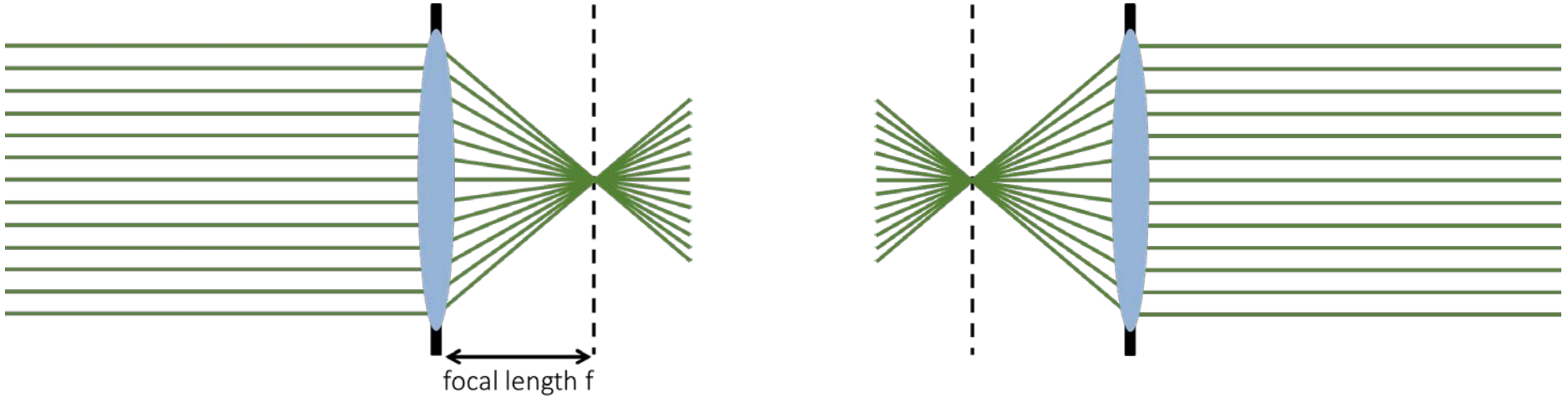
The “f-number” is the ratio: focal length / pinhole diameter

Pinhole Camera



Central rays propagate in the same way for both models!

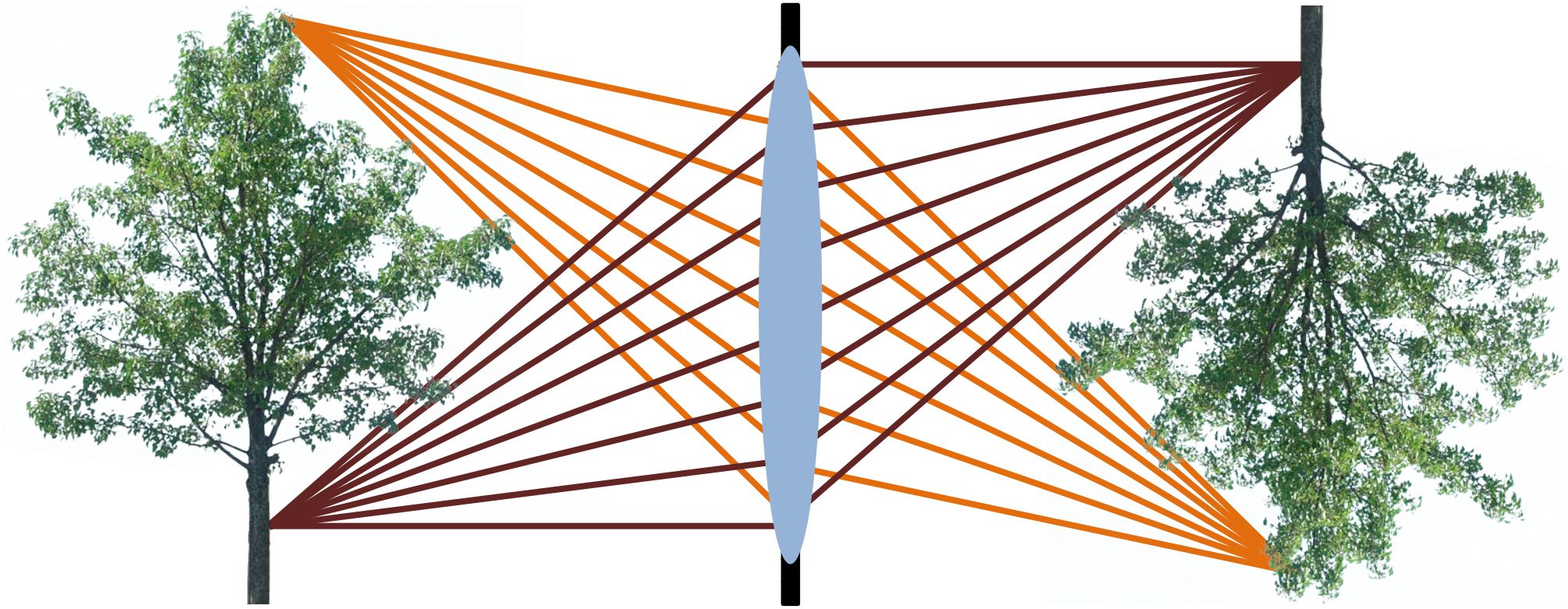
Thin Lens Model



Thin Certain rays follow simple rules when passing through a thin lens, in the paraxial ray approximation:

- Any ray that enters parallel to the axis on one side of the lens proceeds towards the focal point F on the other side.
- Any ray that arrives at the lens after passing through the focal point on the front side, comes out parallel to the axis on the other side.
- Any ray that passes through the center of the lens will not change its direction.

Replace the Pinhole with Lens

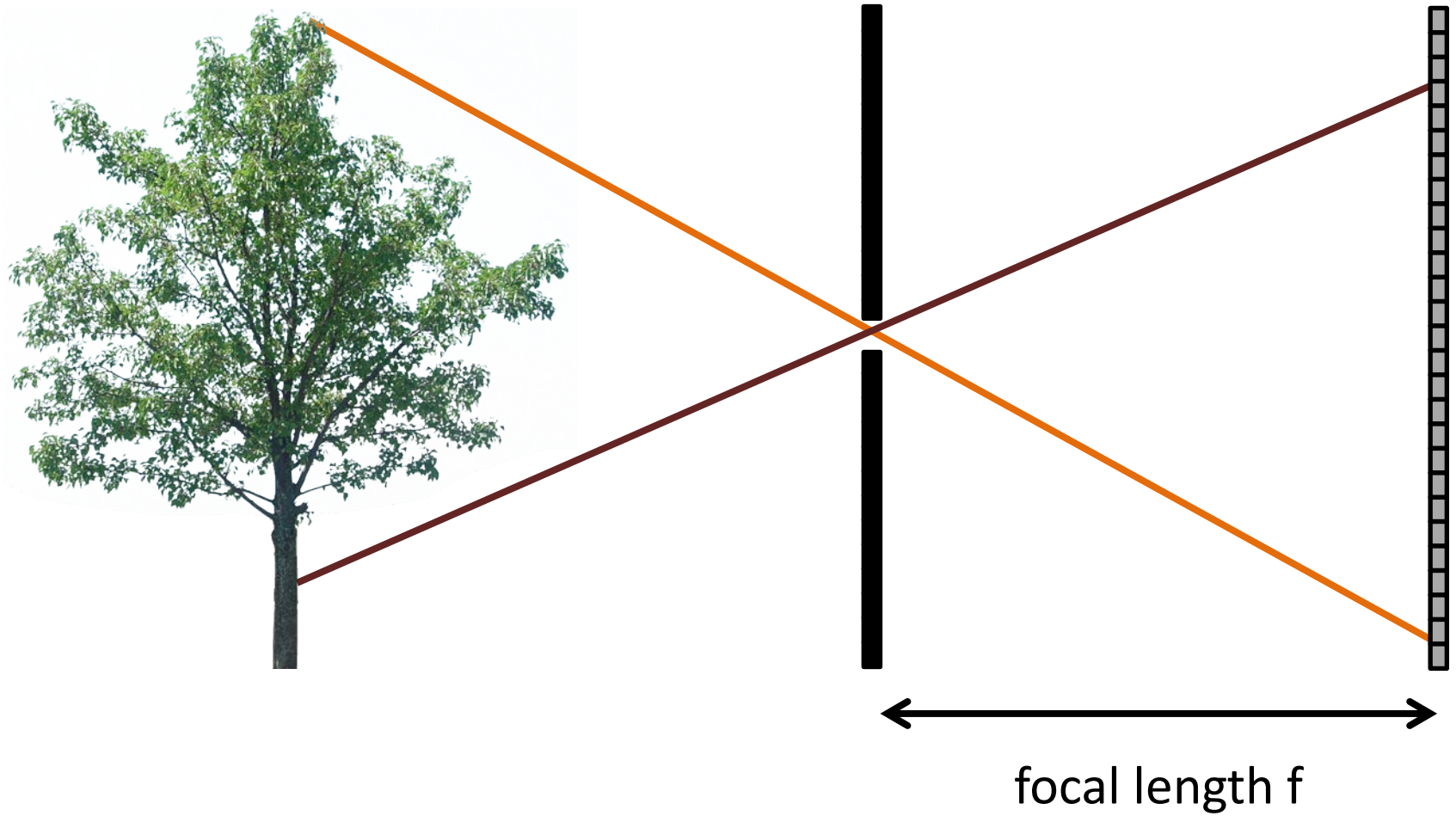


Lenses map “bundles” of rays from points on the scene to the sensor.

How does this mapping work exactly?

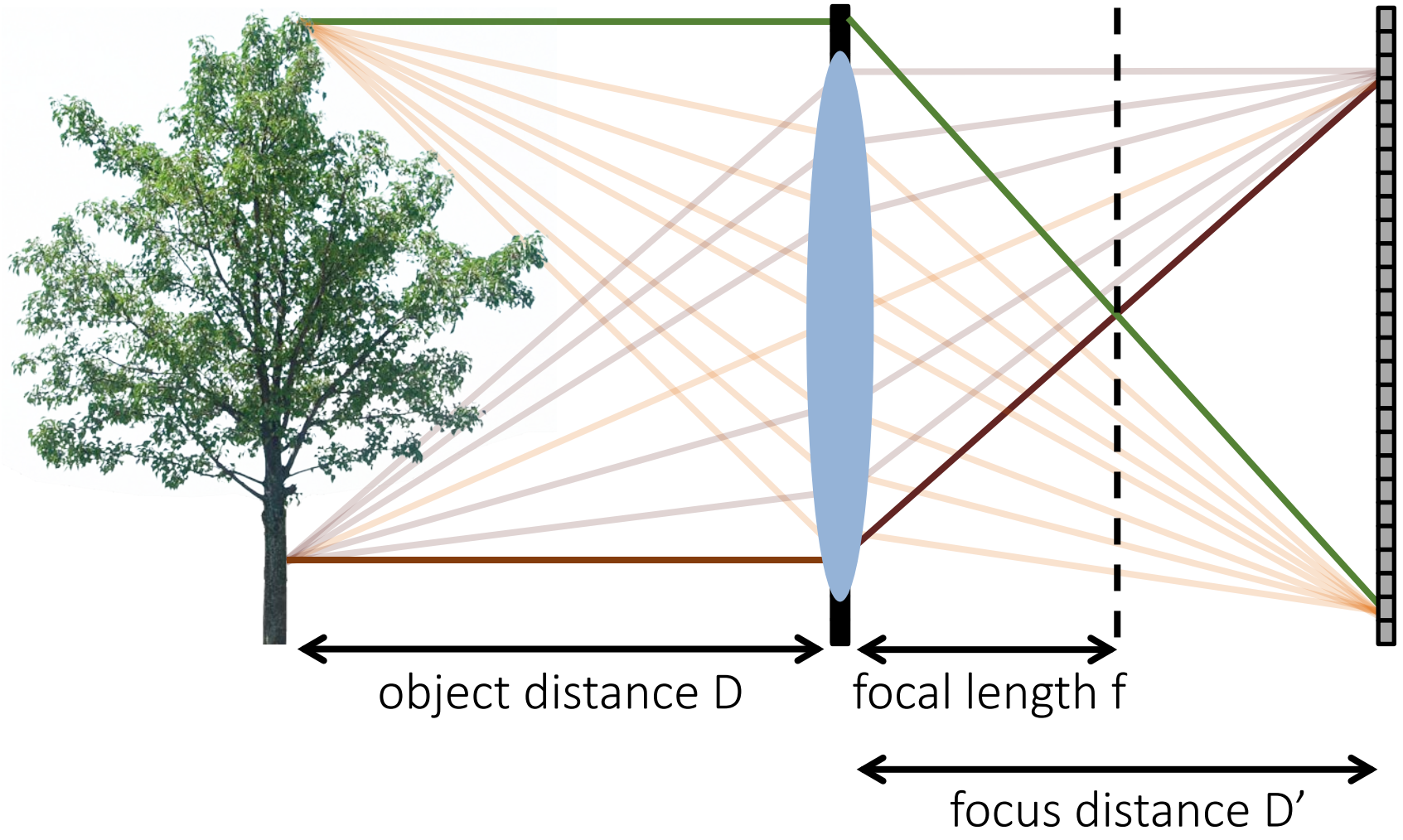
Focal Length in a Pinhole Camera

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

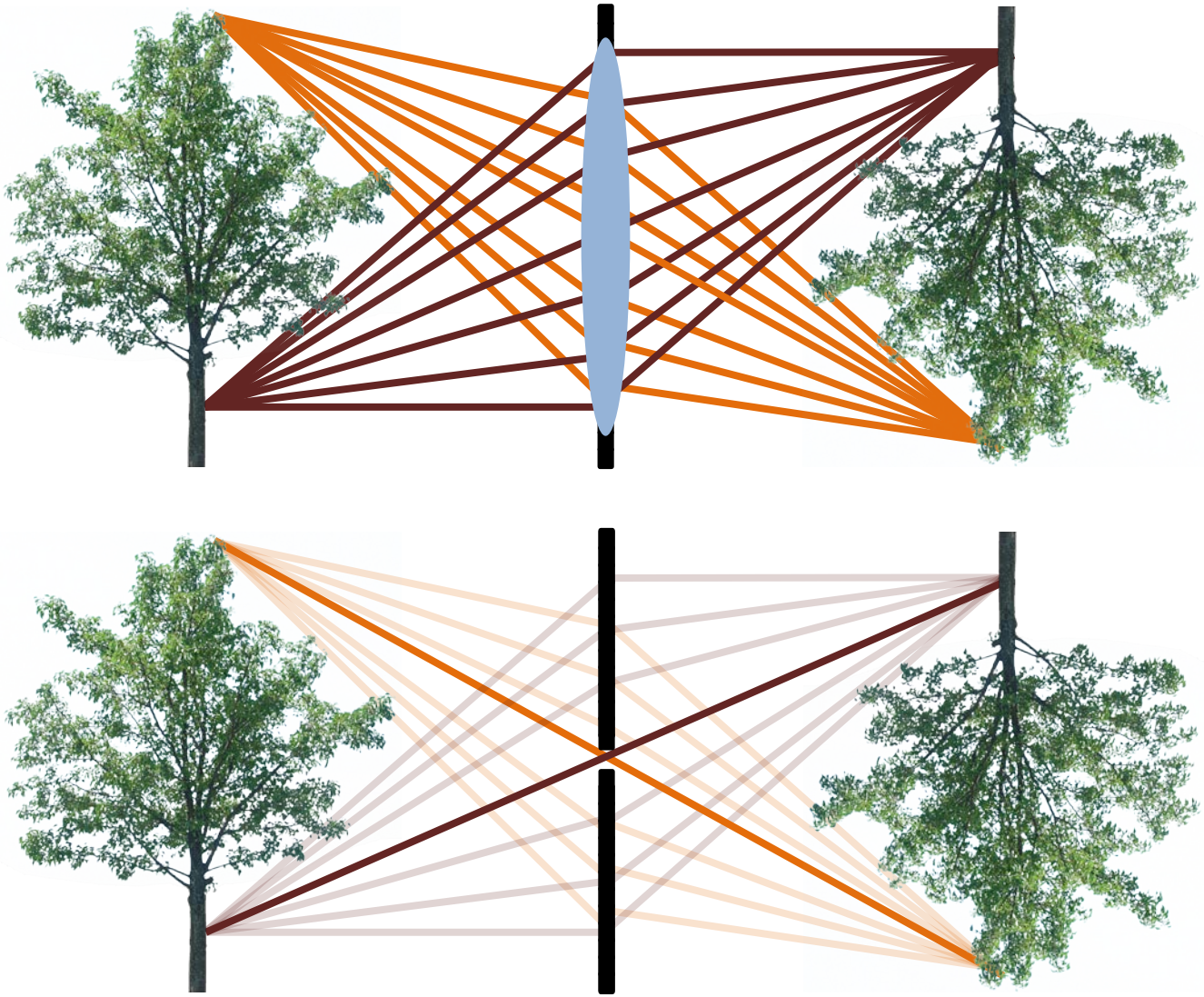


Focal Length in a Lens Camera

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



Describing Both Les and Pinhole Cameras



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

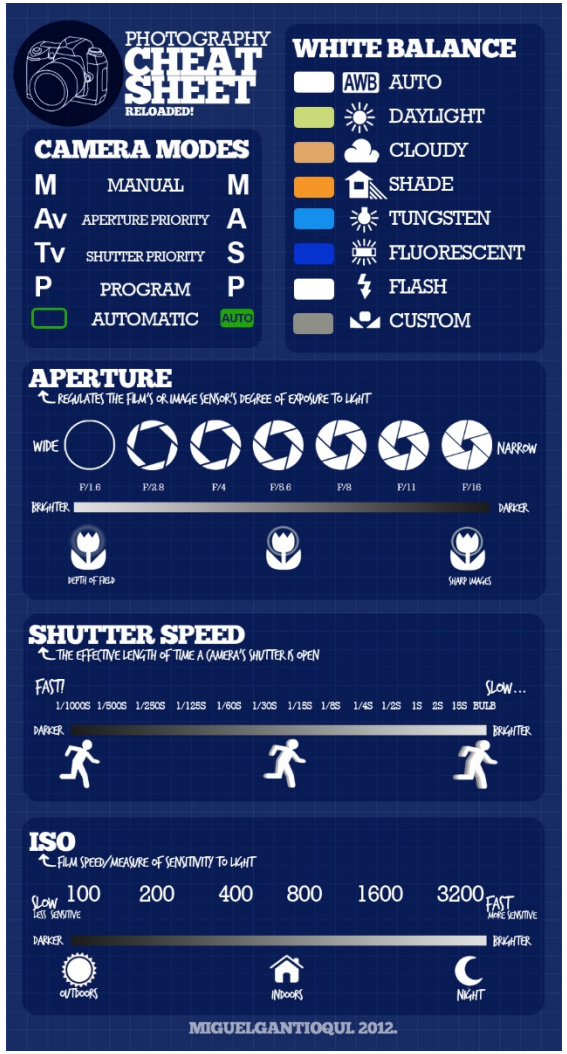
- We use only central rays.
- We assume the lens camera is in focus.
- We assume that the focus distance of the lens camera is equal to the focal length of the pinhole camera.

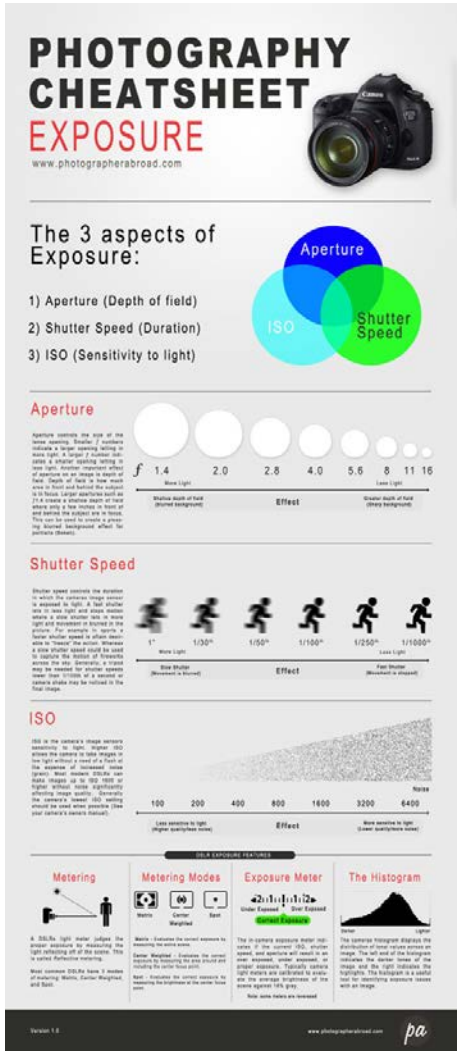
Understanding the Language of Photography

- 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



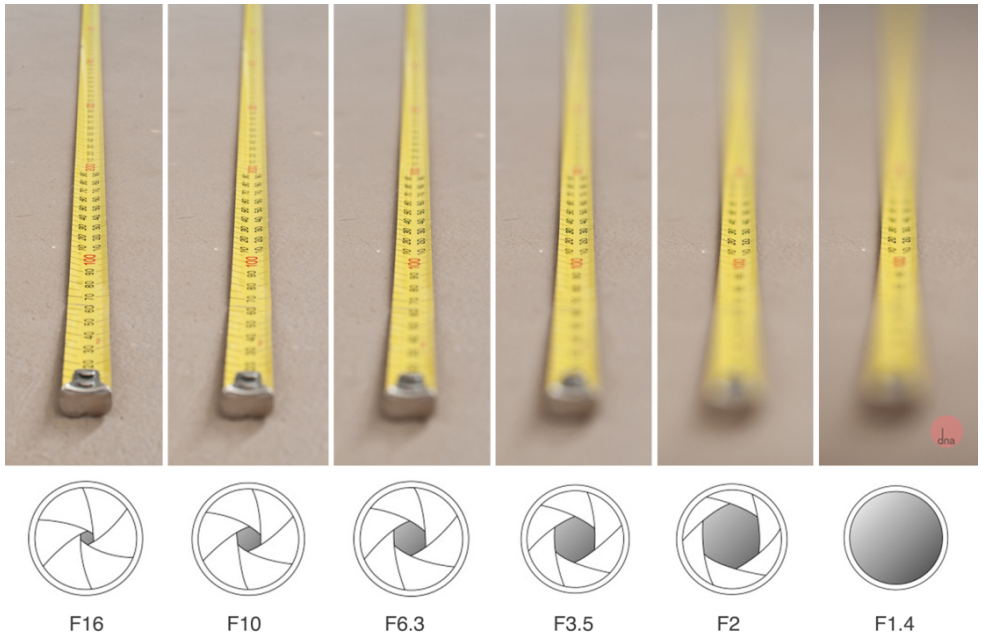


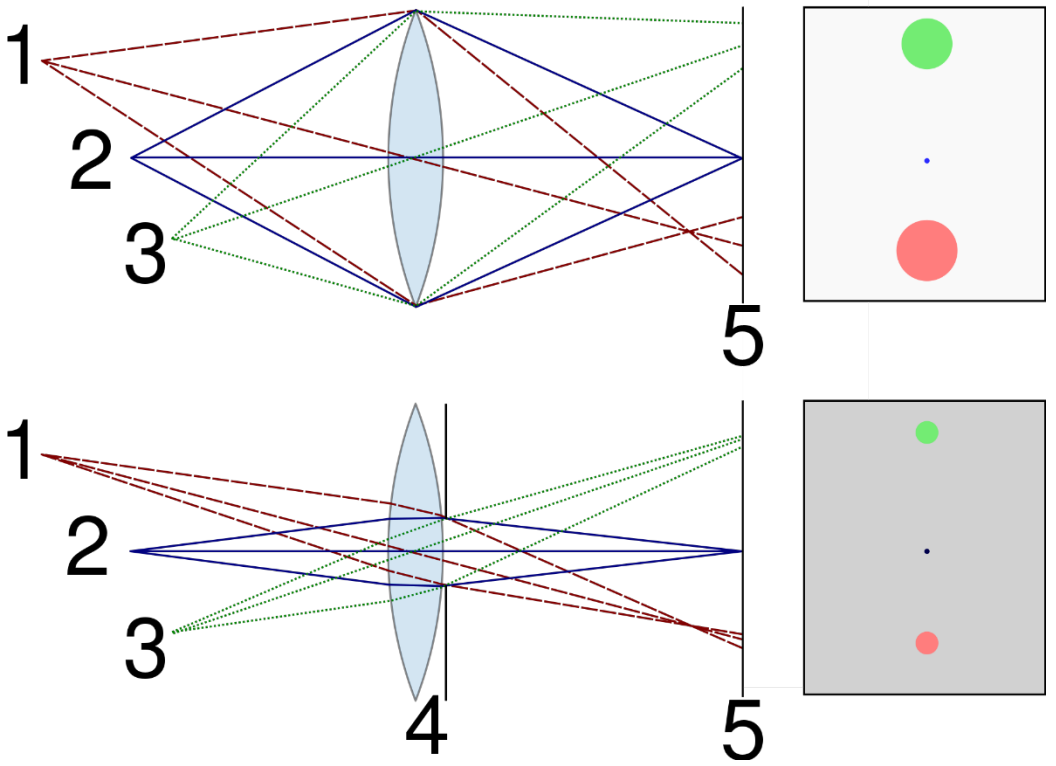
Why Do We Use a Tripod?

- When you need to be flexible
- **When taking nighttime shots and sunsets**
- **When you are using a zoom**
- When you are taking action shots and doing sport photography
- When you are doing natural photography

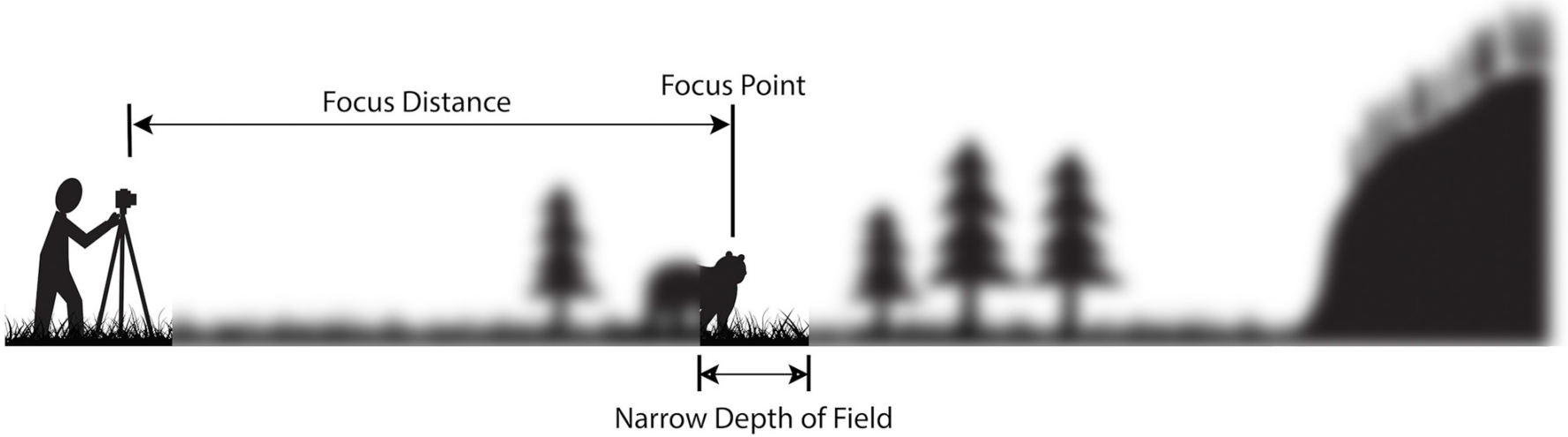
https://www.photographyblog.com/articles/7_reasons_why_you_should_use_a_tripod

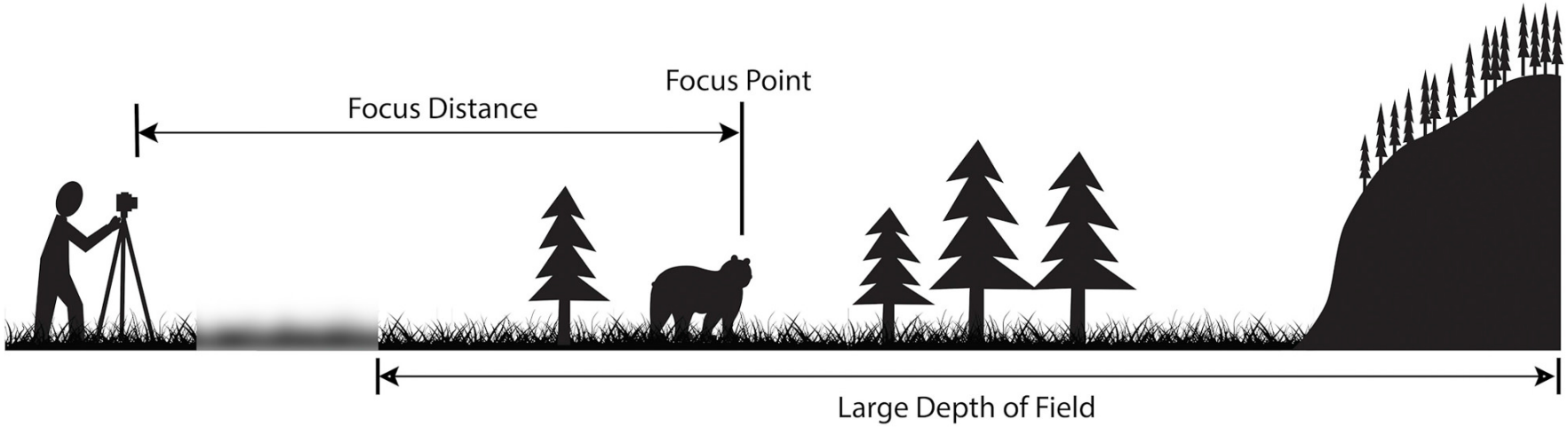
Effect of Aperture





Understanding Depth of Field

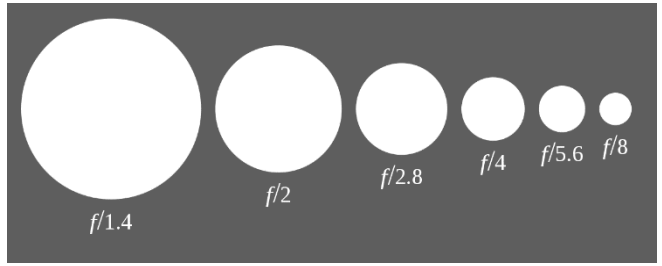




Different Depth of Fields

Q. Why is it better? resolution?

F-Number or F-Stop



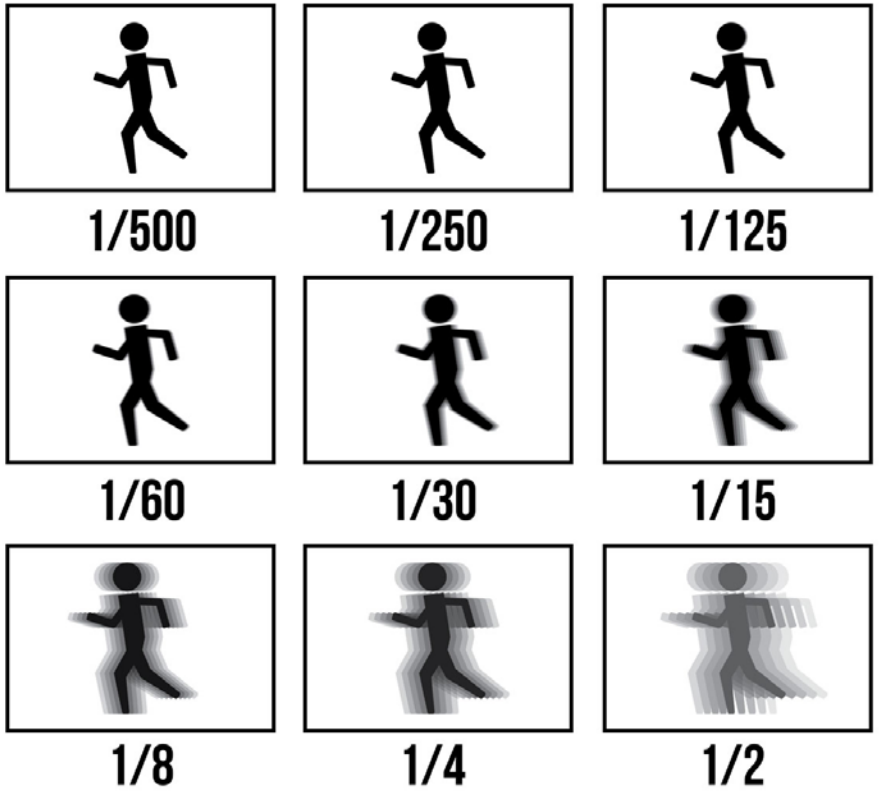
The f-number N is given by:

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

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*.[1] 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

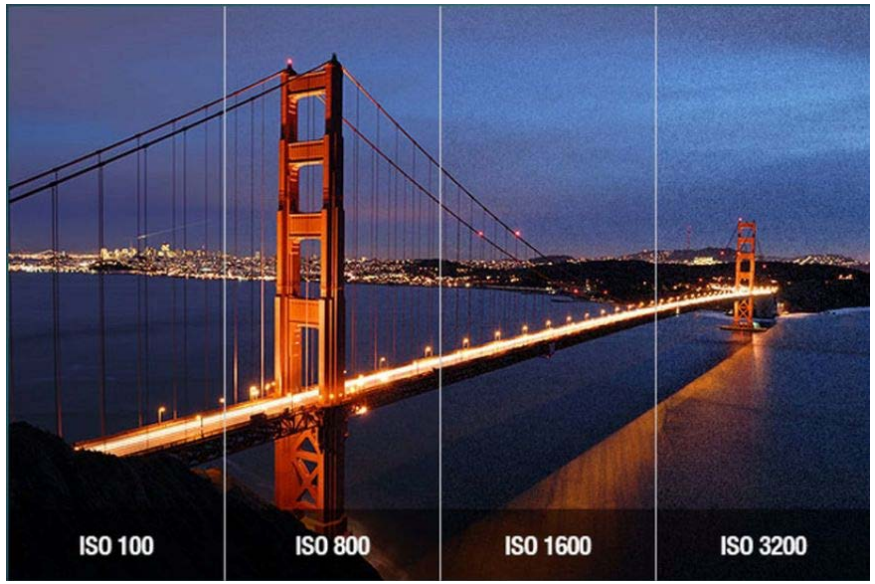
Effect of Shutter Speed

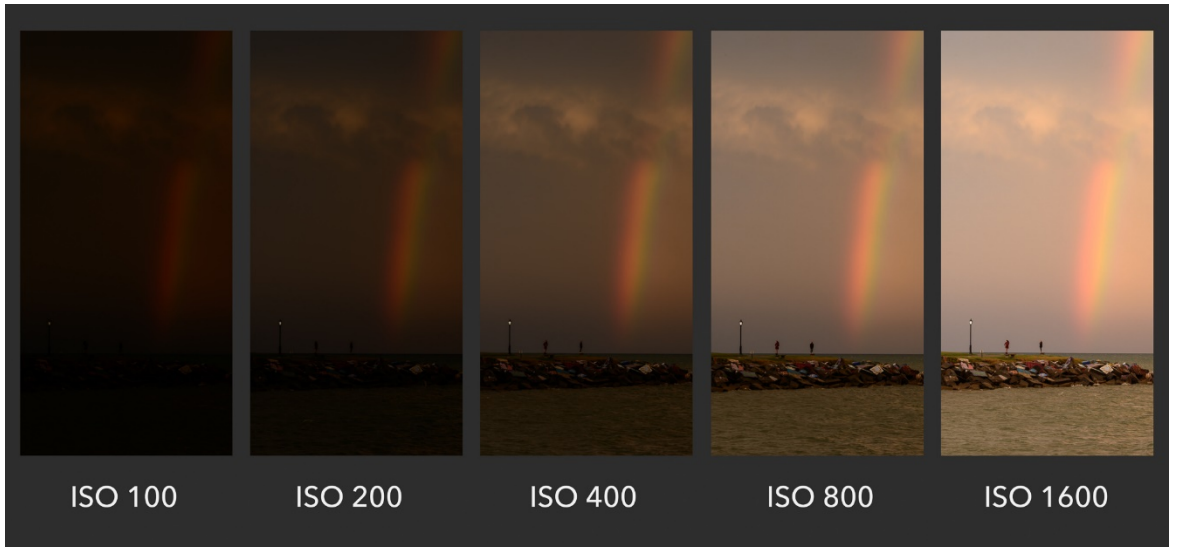


https://www.creativelive.com/photography-guides/what-is-shutter-speed

Example: Night Photography

Effect of ISO





https://www.shawacademy.com/blog/everything-you-need-to-know-about-iso/

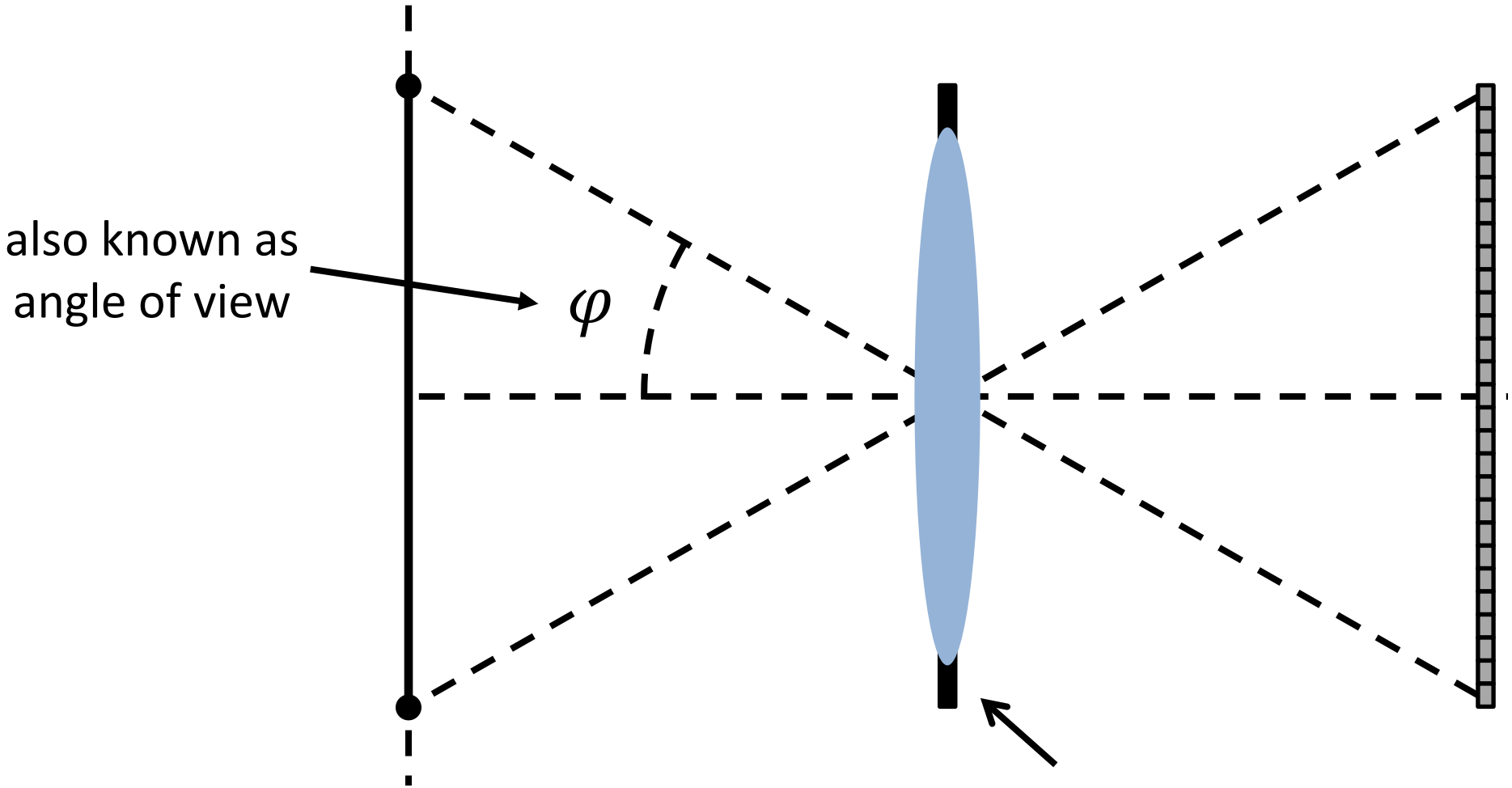
https://photographylife.com/what-is-iso-in-photography

Situations that Affects How You Choose an ISO

- If your subject is moving and you're trying 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.
- If you're shooting with artificial light — e.g., a flash — you can typically get away with a lower ISO setting.

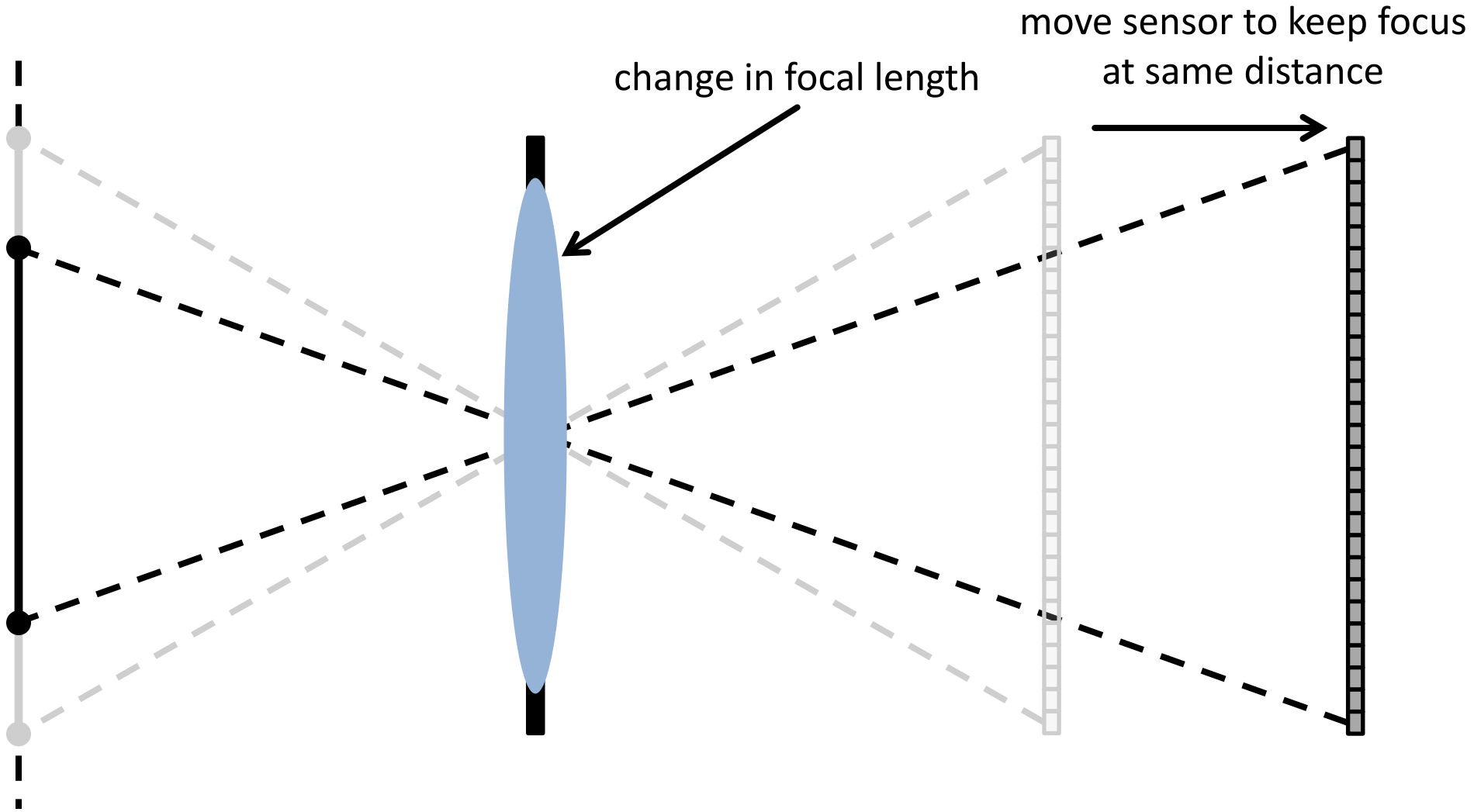
https://www.digitaltrends.com/photography/what-is-iso/

Field of view



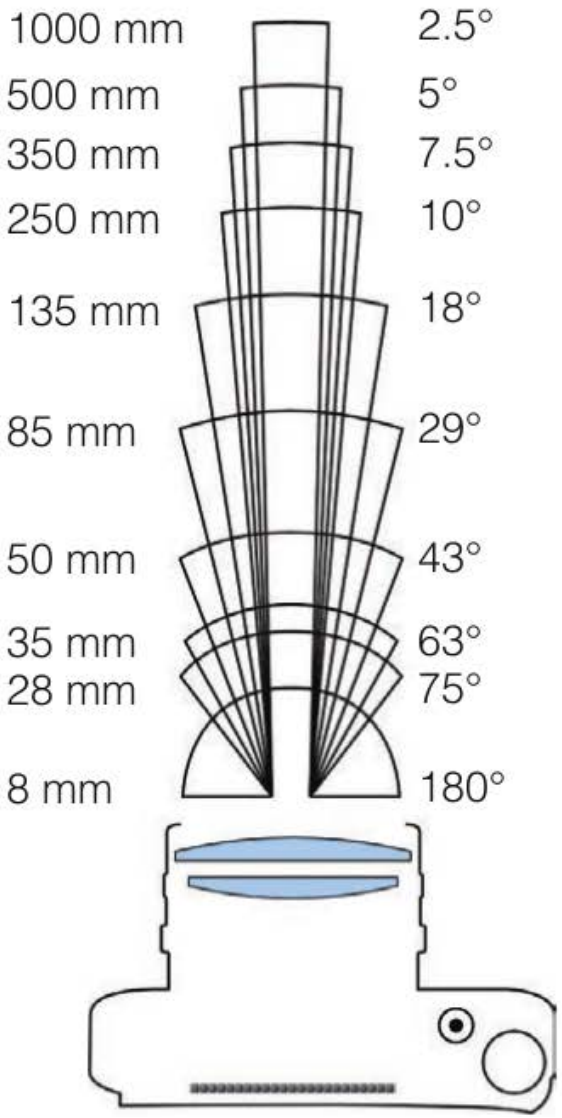
Note: here I drew a lens, but I could have just as well drawn a pinhole

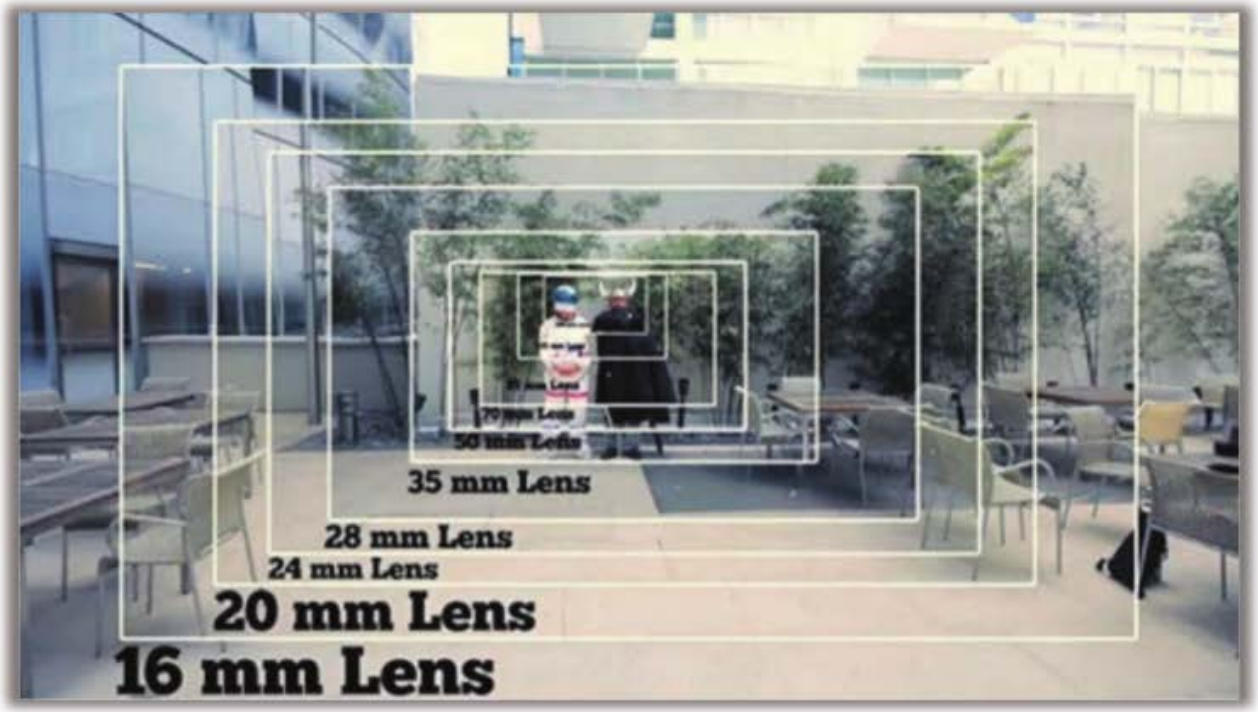
Field of View (Continue)



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

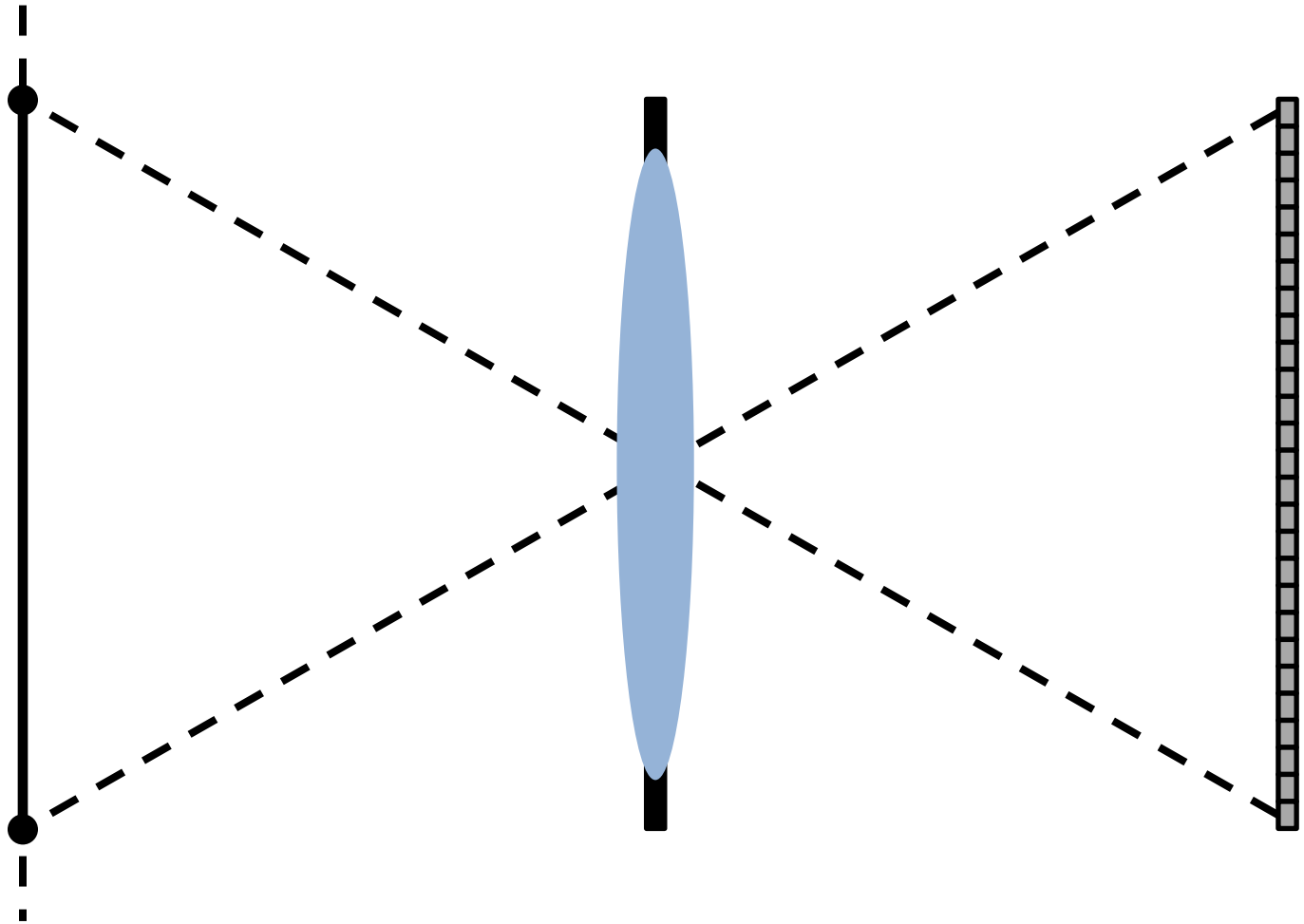
Field of View (Continue)





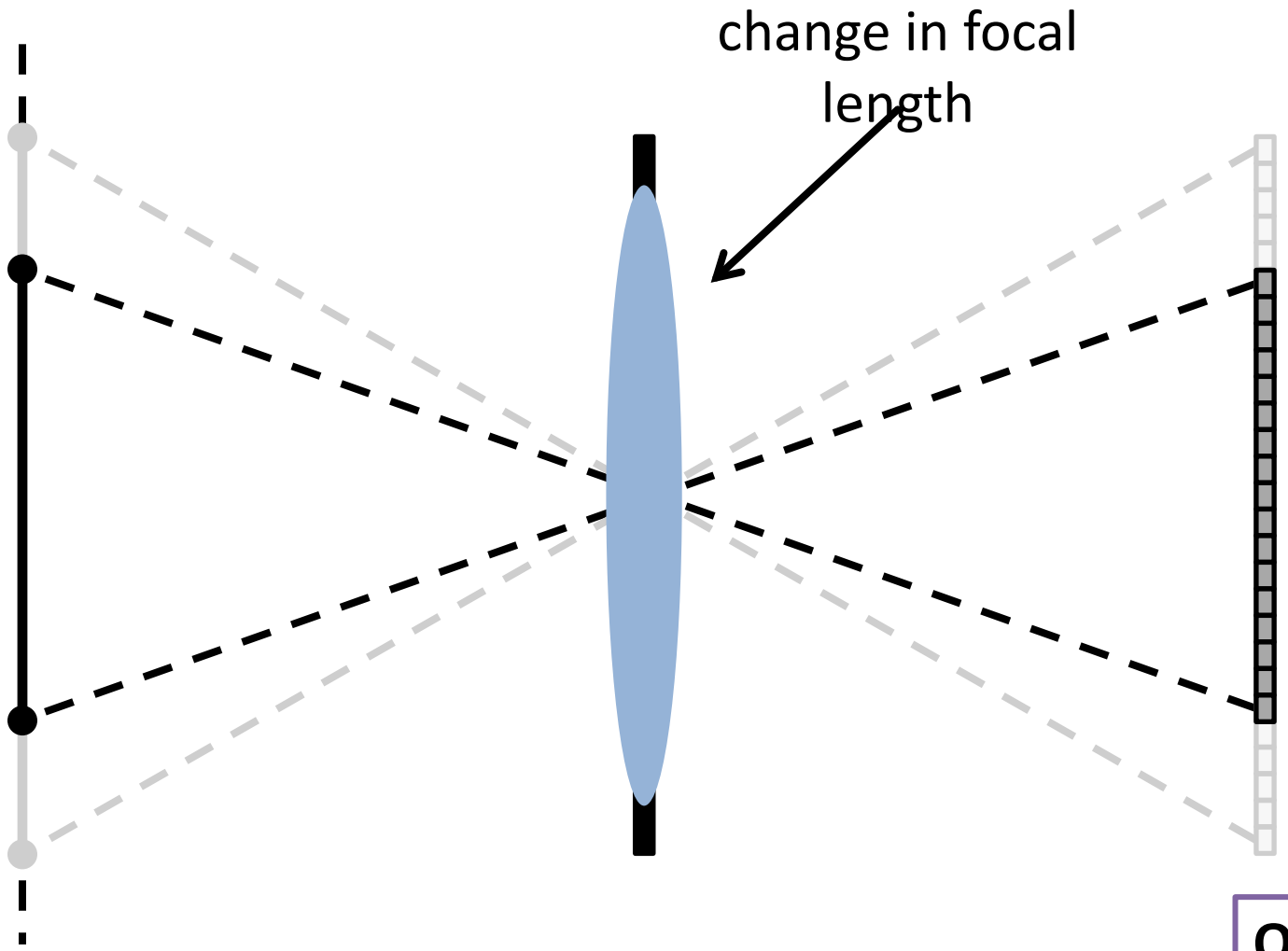
Andrew McWilliams

Field of View Depending on Sensor Size



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

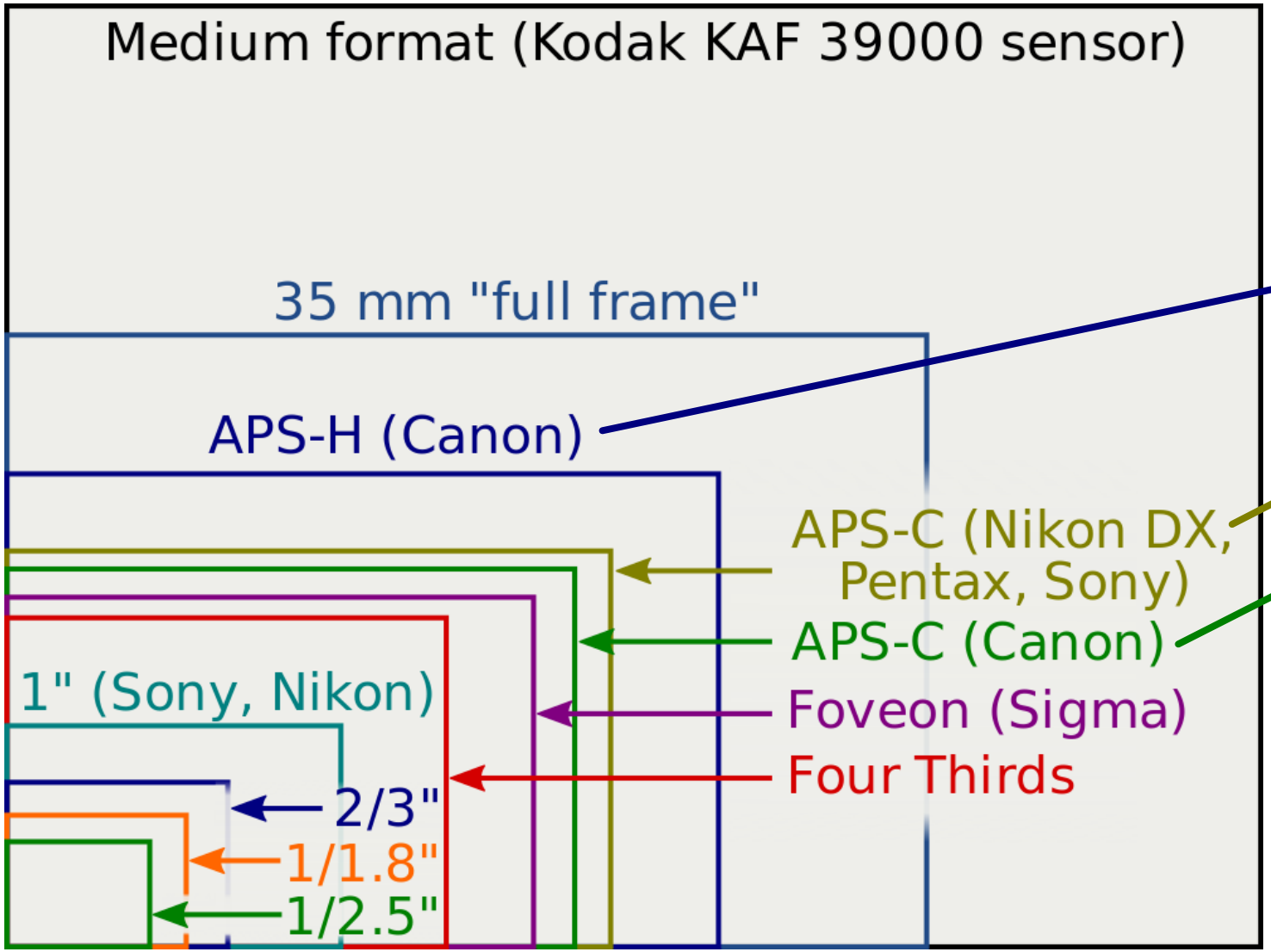
Field of View Depending on Sensor Size



Q. Your smartphone?

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

Field of View Depending on Sensor Size



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

Example: Ultra Telephoto Prime Lens

Example: Macro Videography

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 **camera**	Selected by **camera**
S (shutter-priority auto)	Selected by **photographer**	Selected by **camera**
A (aperture-priority auto)	Selected by **camera**	Selected by **photographer**
M (manual)	Selected by **photographer**	Selected by **photographer**

https://imaging.nikon.com/lineup/dslr/basics/04/06.htm

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