Digital Image
: How To Capture Images

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CIVE 497 – CIVE 700: Smart Structure Technology

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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?

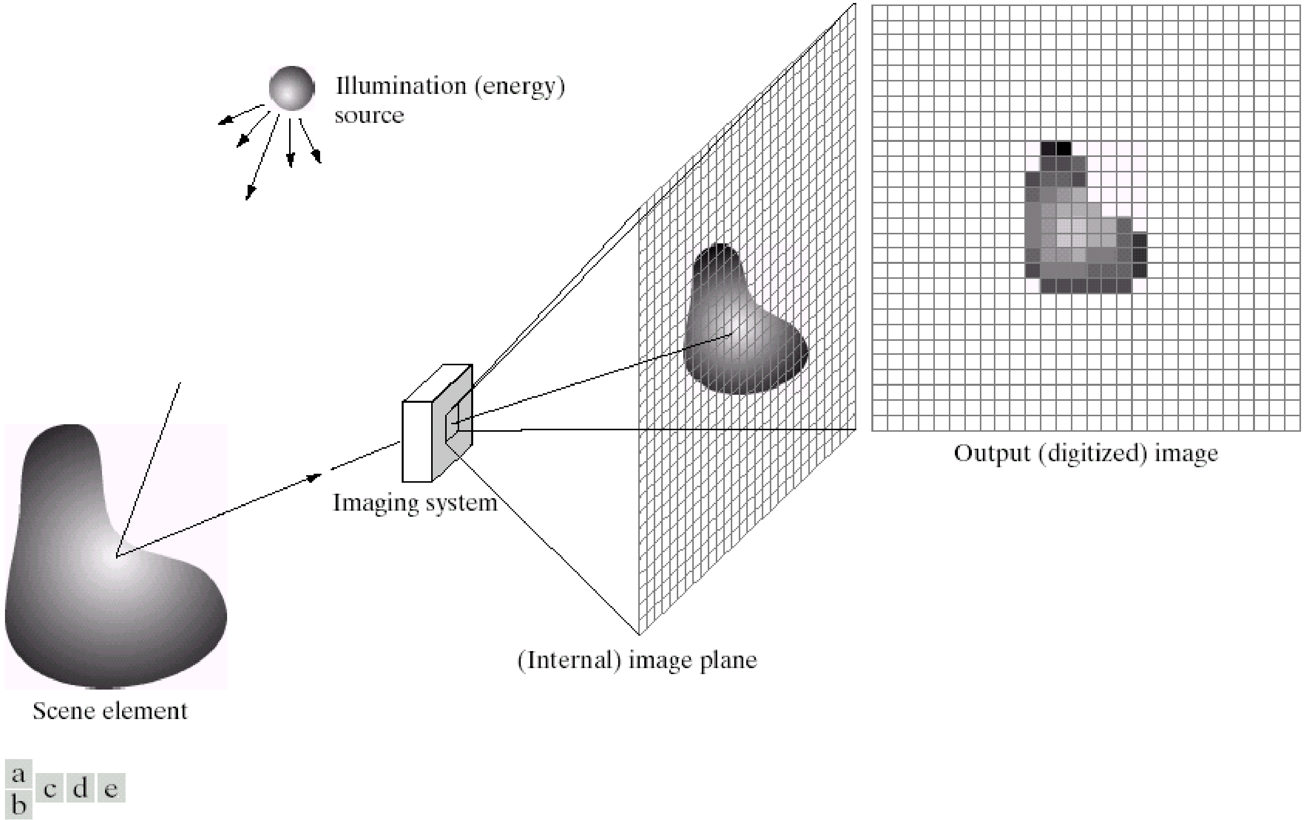


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

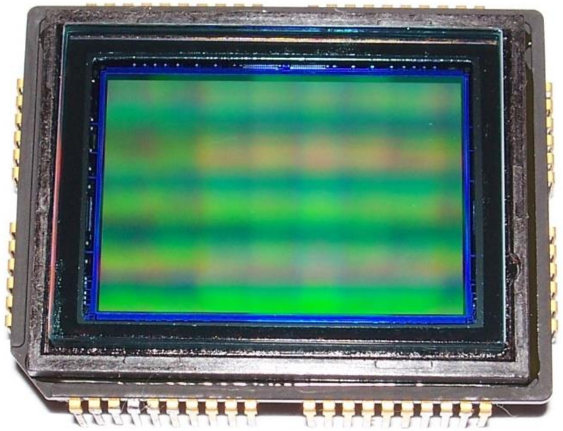
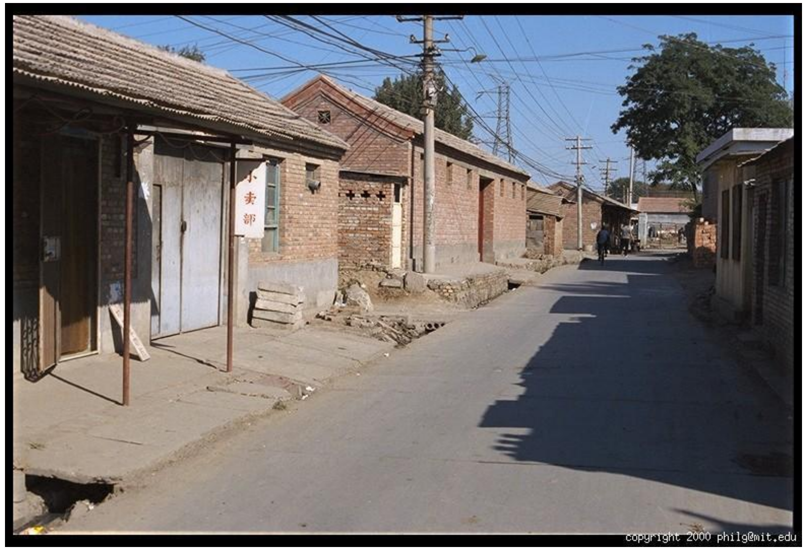
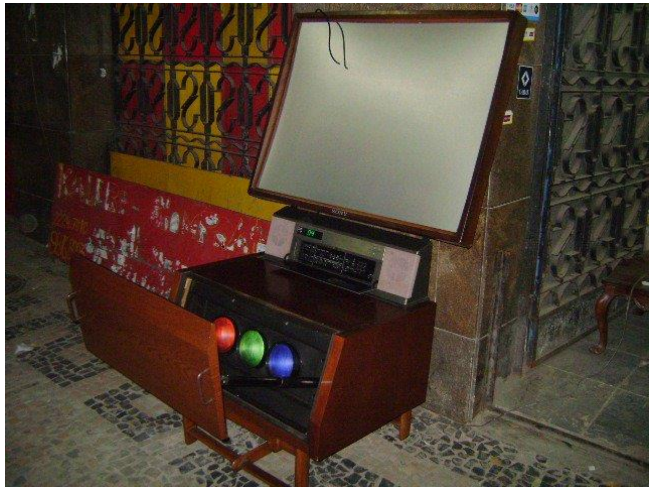


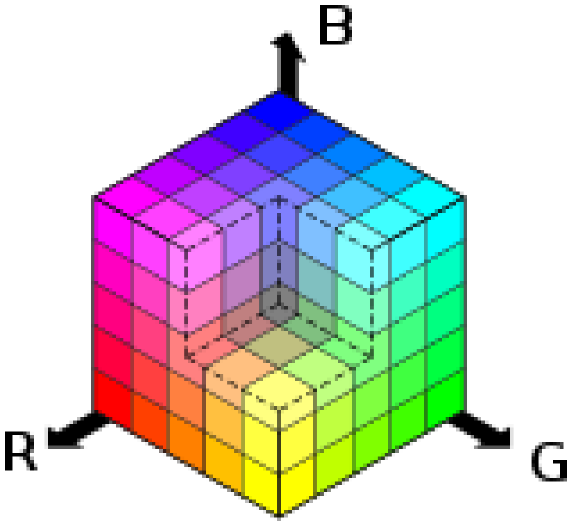
Image sensor

DSLR camera

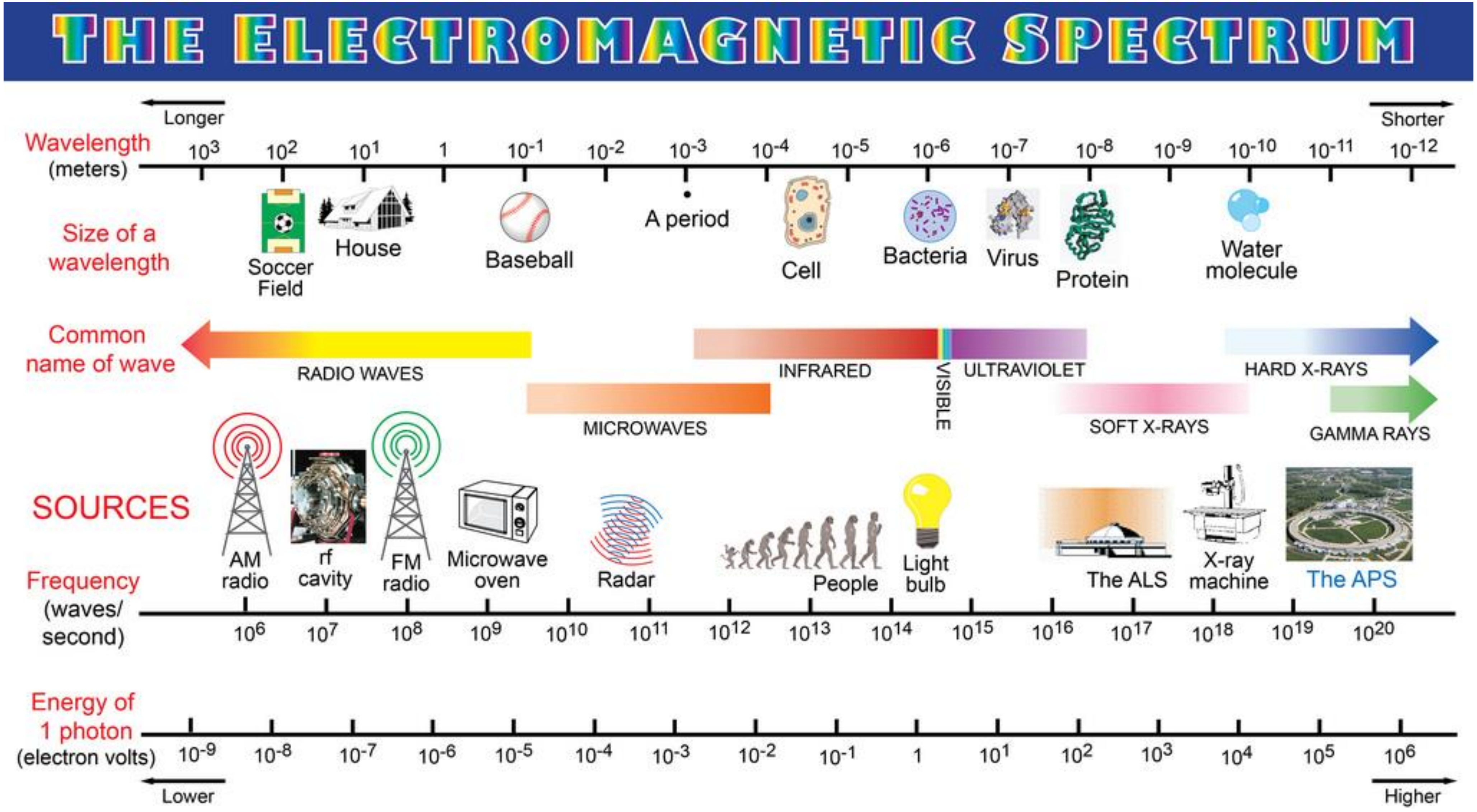
Color Images







Visible Light Spectrum

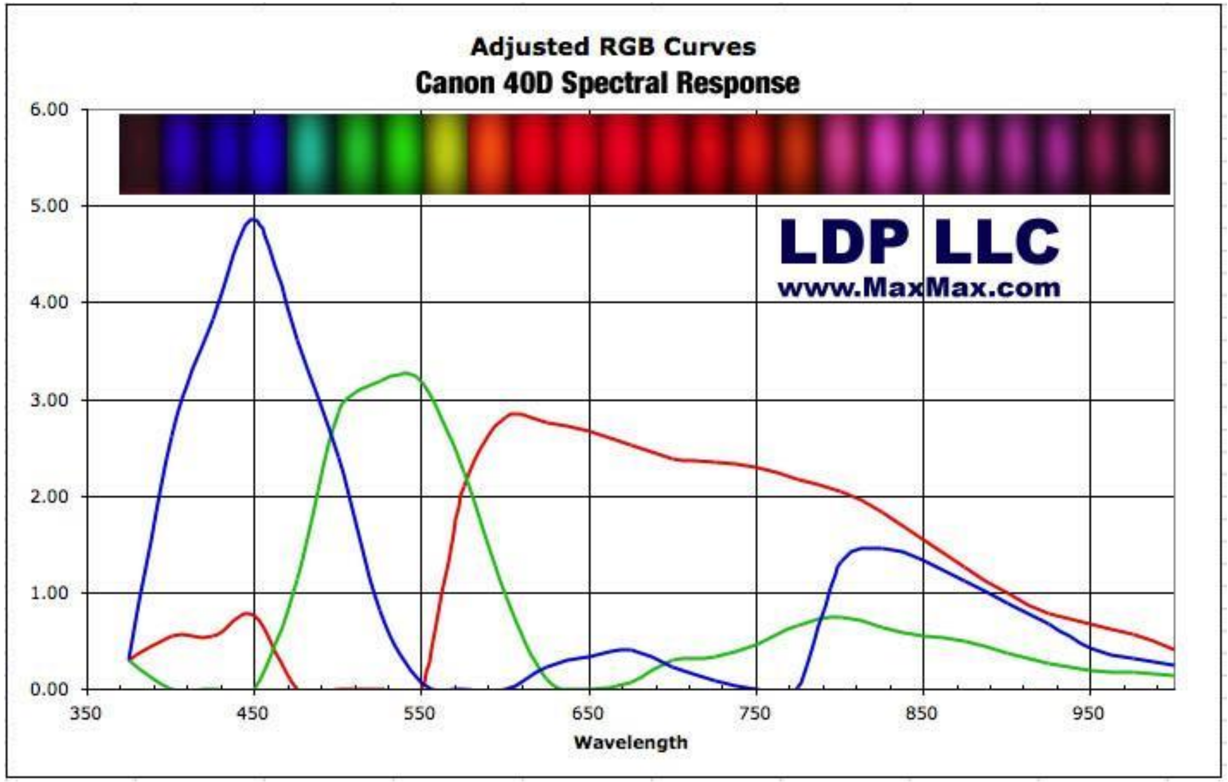


RGB Filter

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

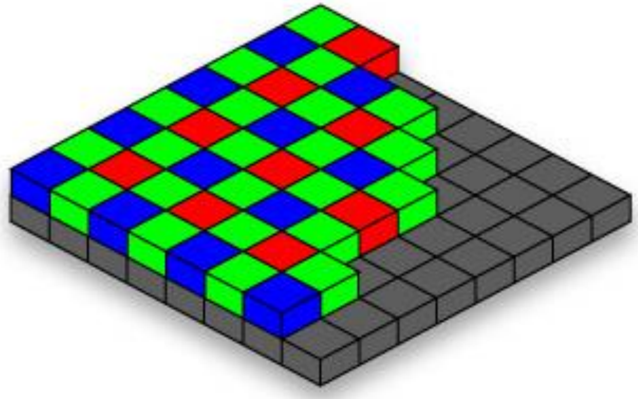


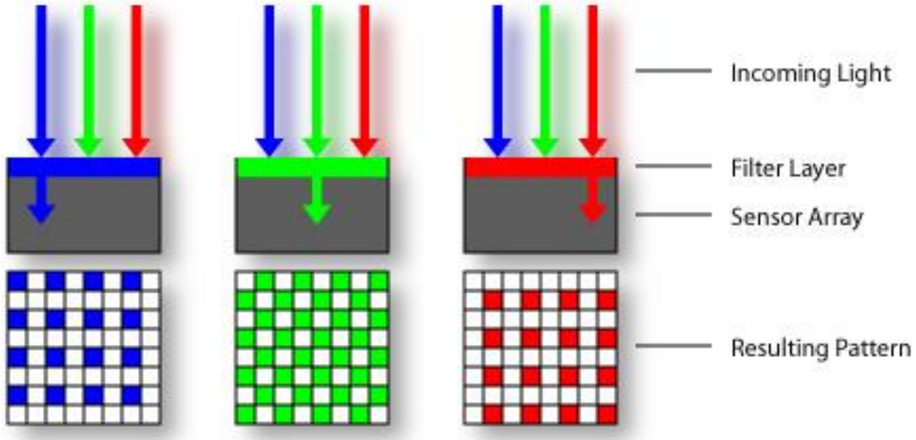
https://maxmax.com/spectral_response.htm

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

Color Filter Arrays

Bayer grid

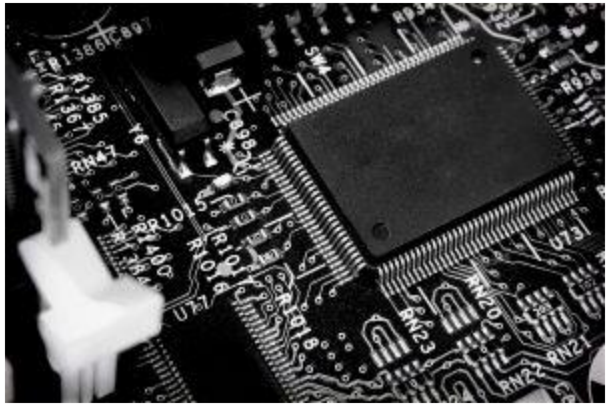




The filter pattern is 50% green, 25% red and 25% blue.

Demosaicing:

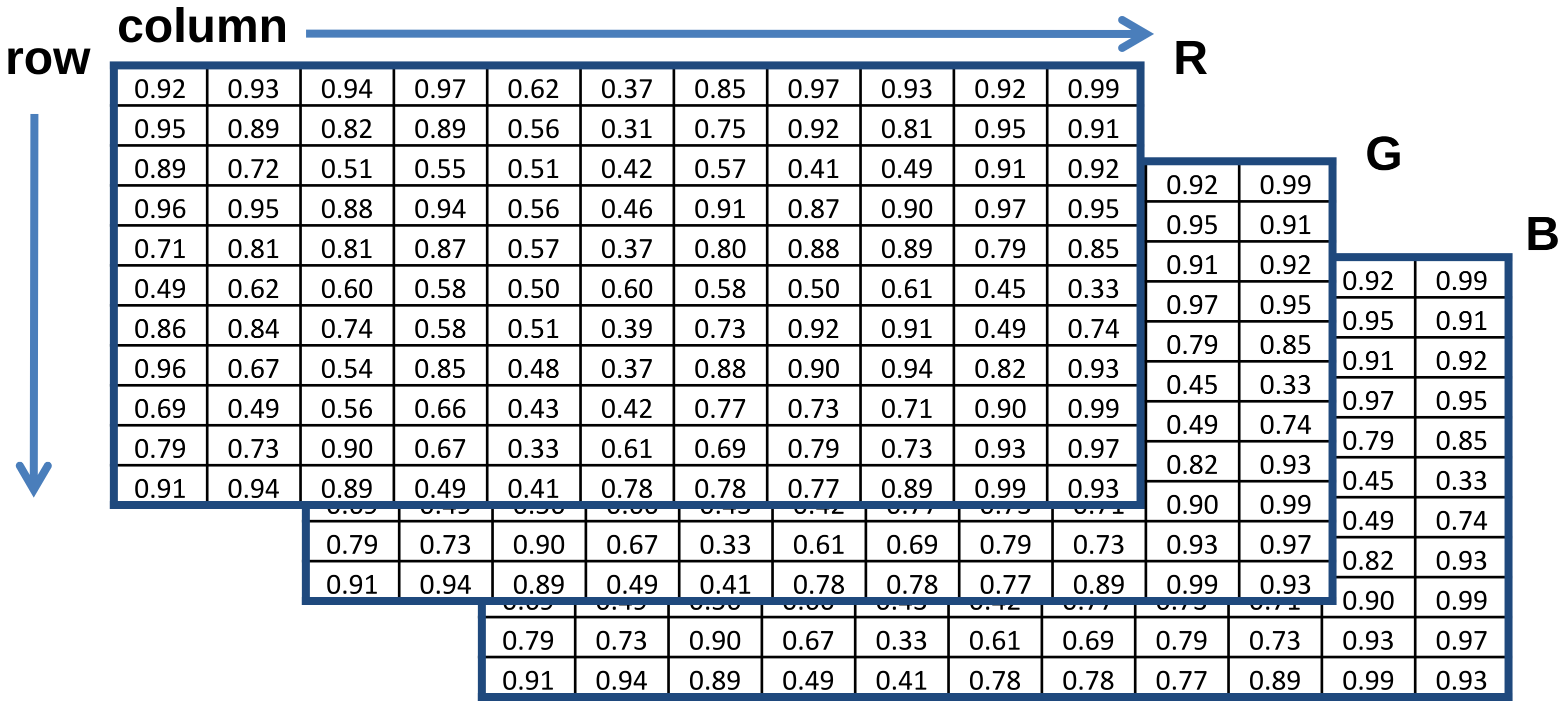
Estimation of missing components from neighboring values



Monochrome machine vision camera

Image File Structure

- Images represented as a matrix
- Suppose we have a NxM RGB image called “im”
  - 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



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

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

Case 1: Apple watch with a 4k screen.

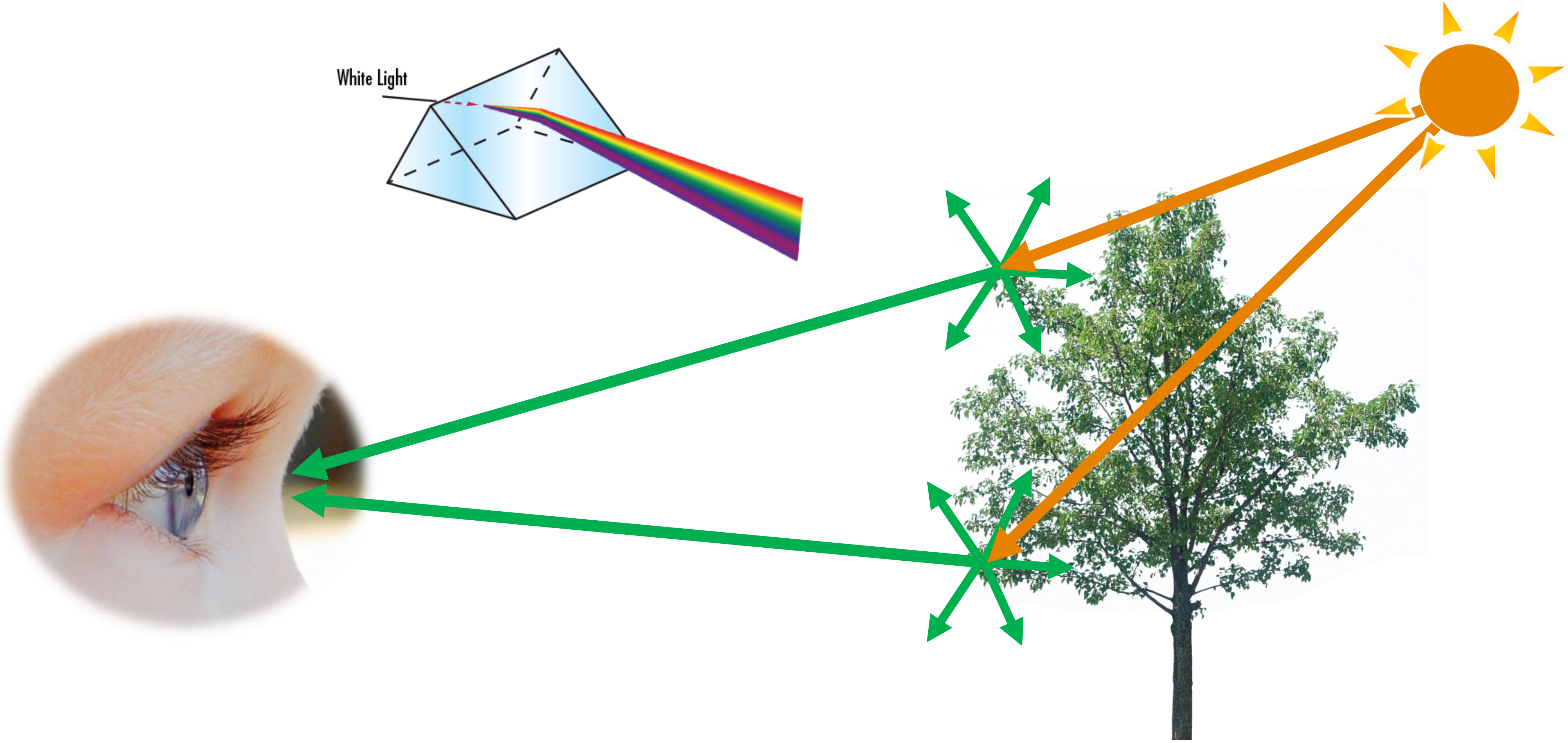
Case 2: 80 inch high-definition full-HD TV.

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 <u>all directions</u>

Camera Sensor

digital sensor
(CCD or CMOS)

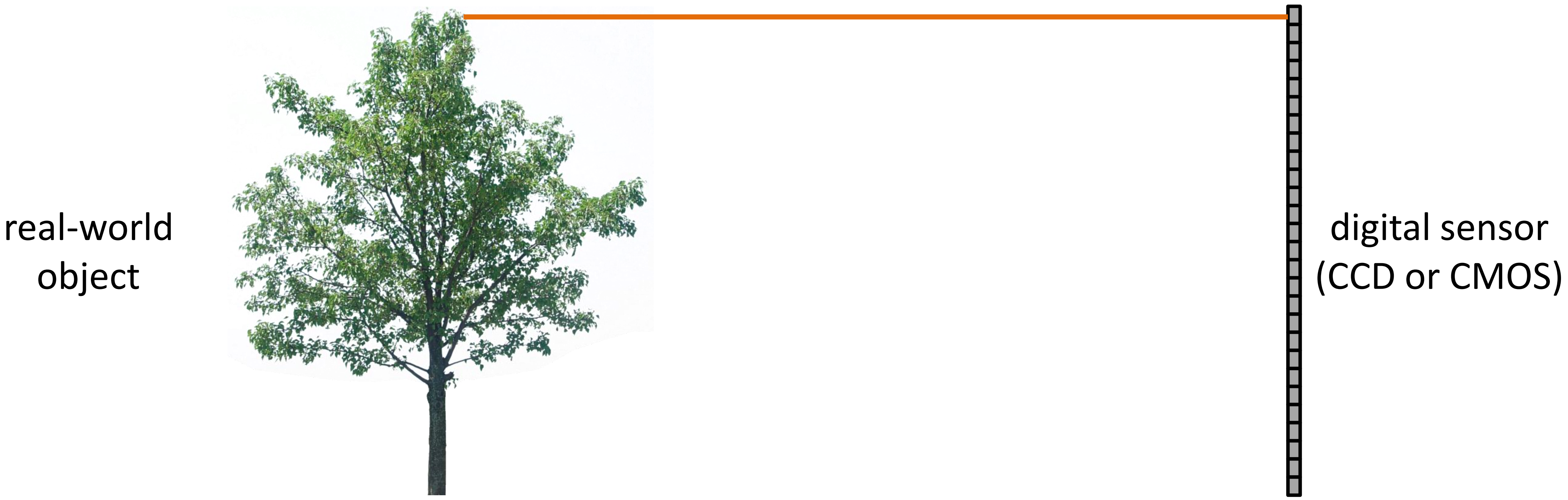
Object We Like to Take

real-world
object

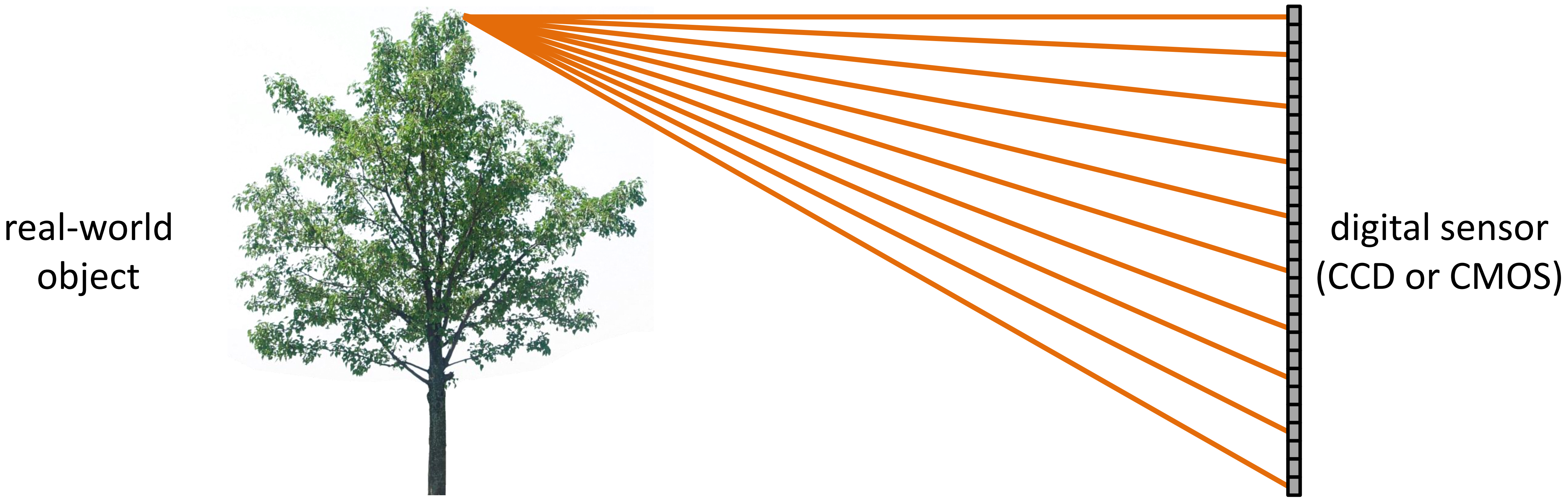
digital sensor
(CCD or CMOS)

What would an image taken like this look like?

Bare-Sensor Imaging

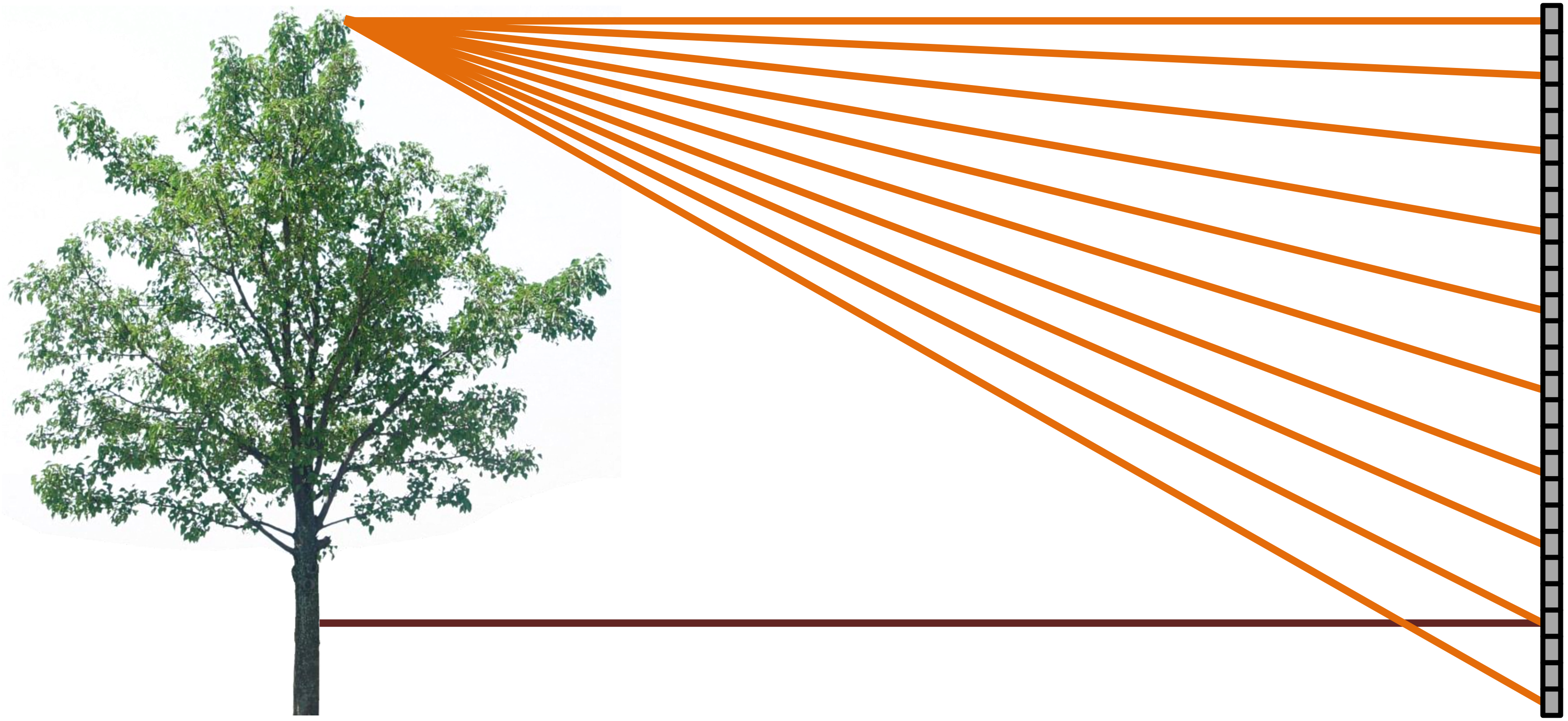


Light Reflect off All Positions on the Object and Goes in All Directions



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

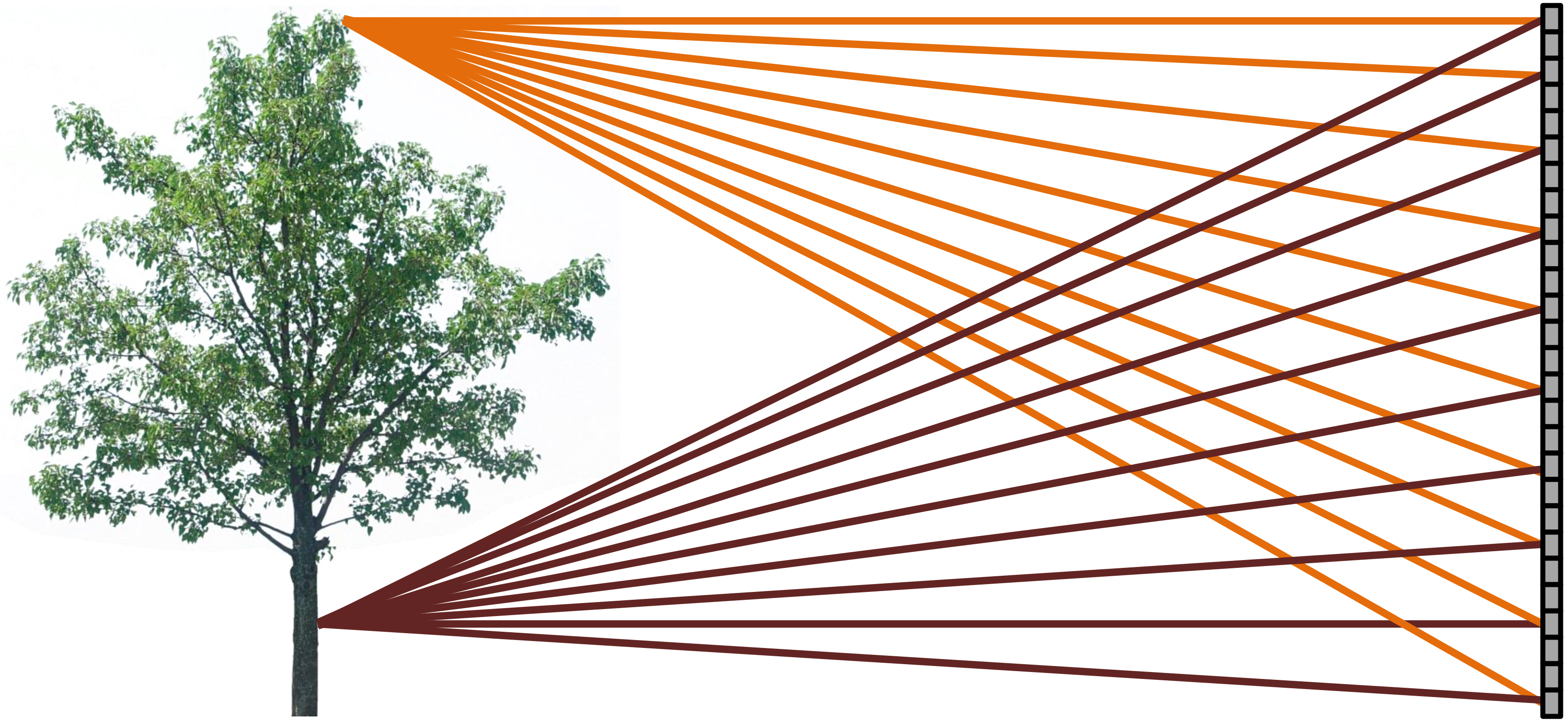
real-world object



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

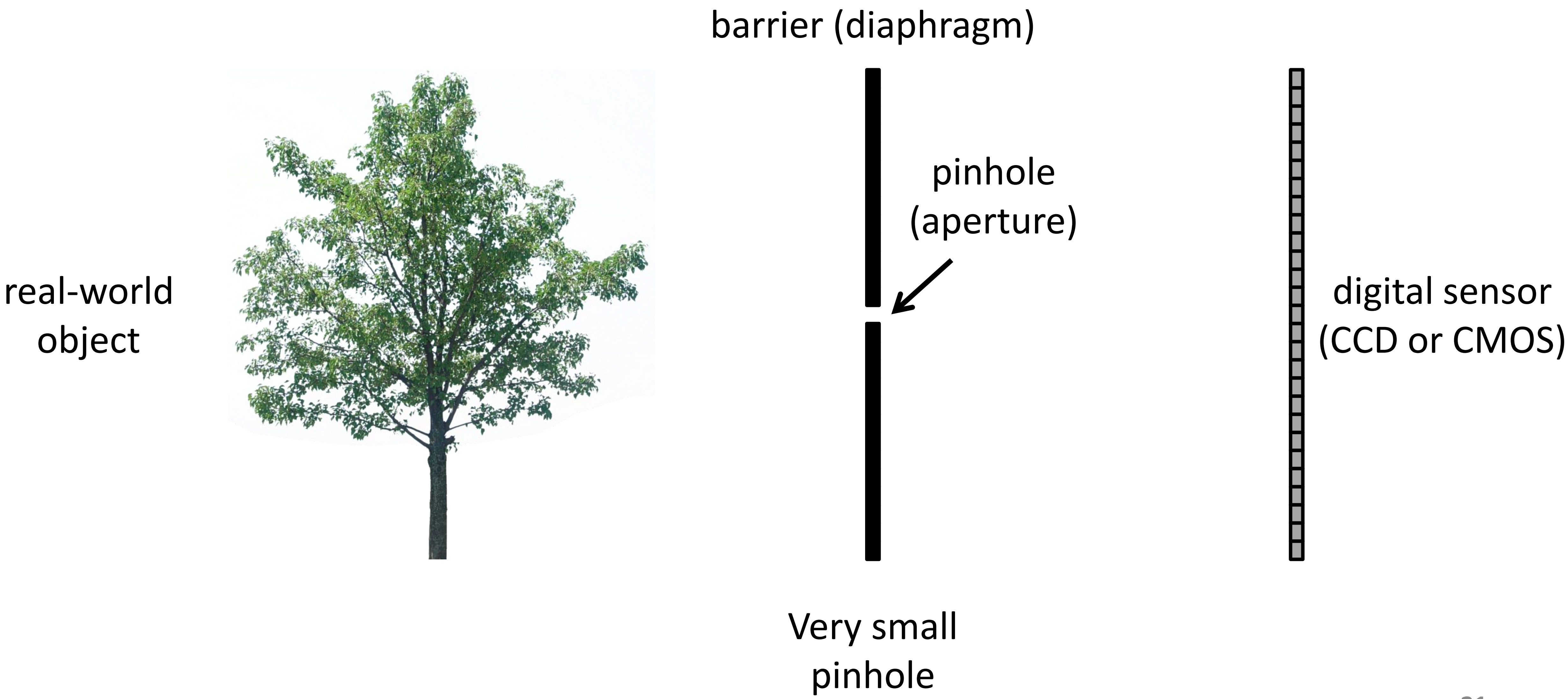
All Scene Points Contribute to All Sensor Pixels

What can We Do to Make Our Image Look Better?

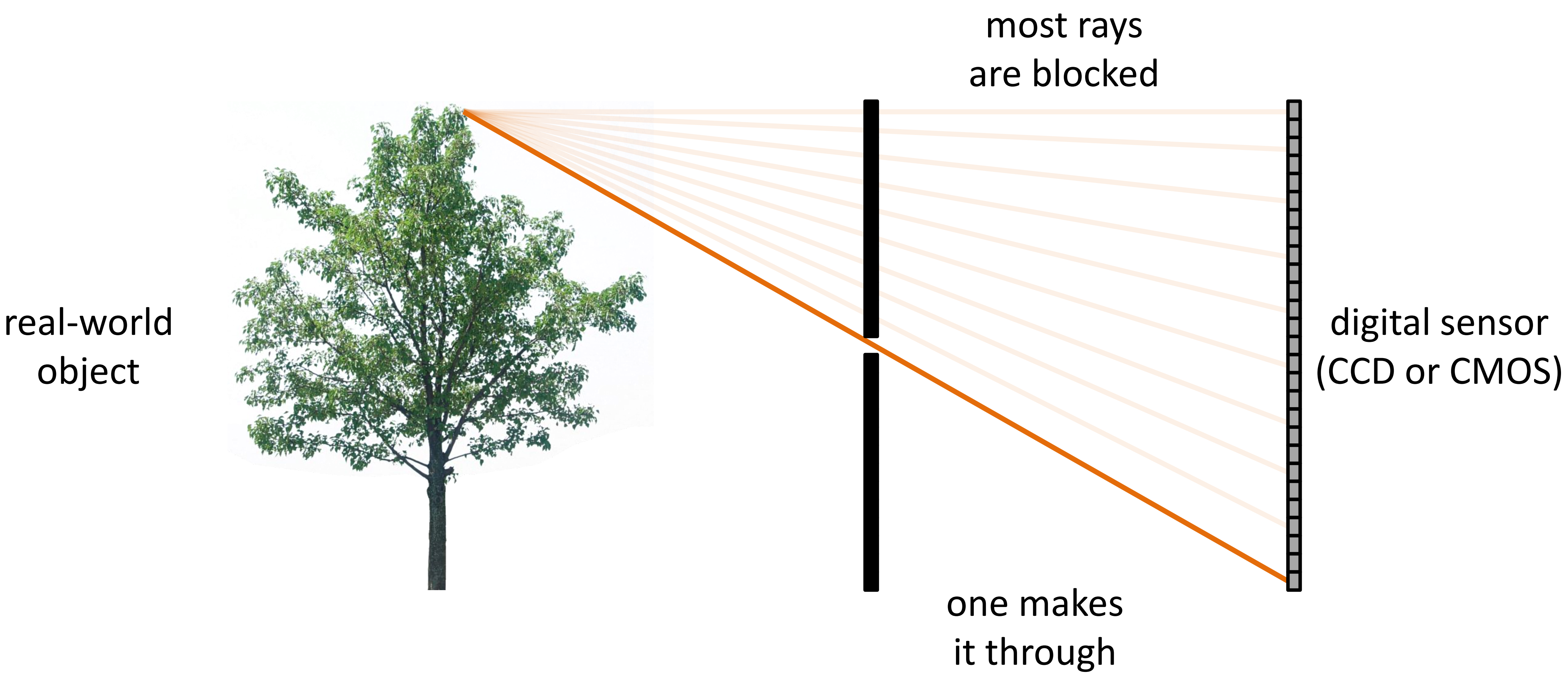
real-world
object

digital sensor
(CCD or CMOS)

Pinhole Imaging



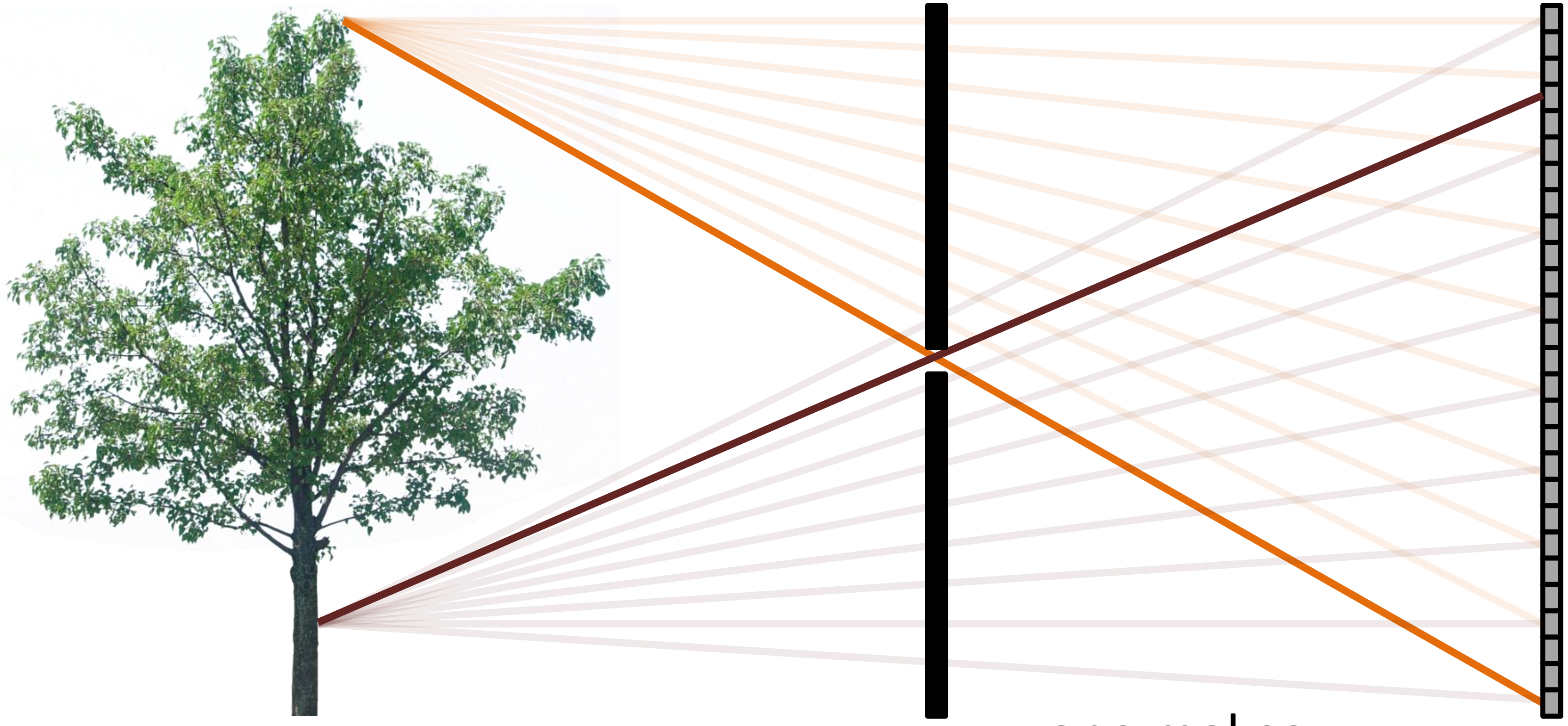
Pinhole Imaging



Pinhole Imaging

most rays
are blocked

real-world
object

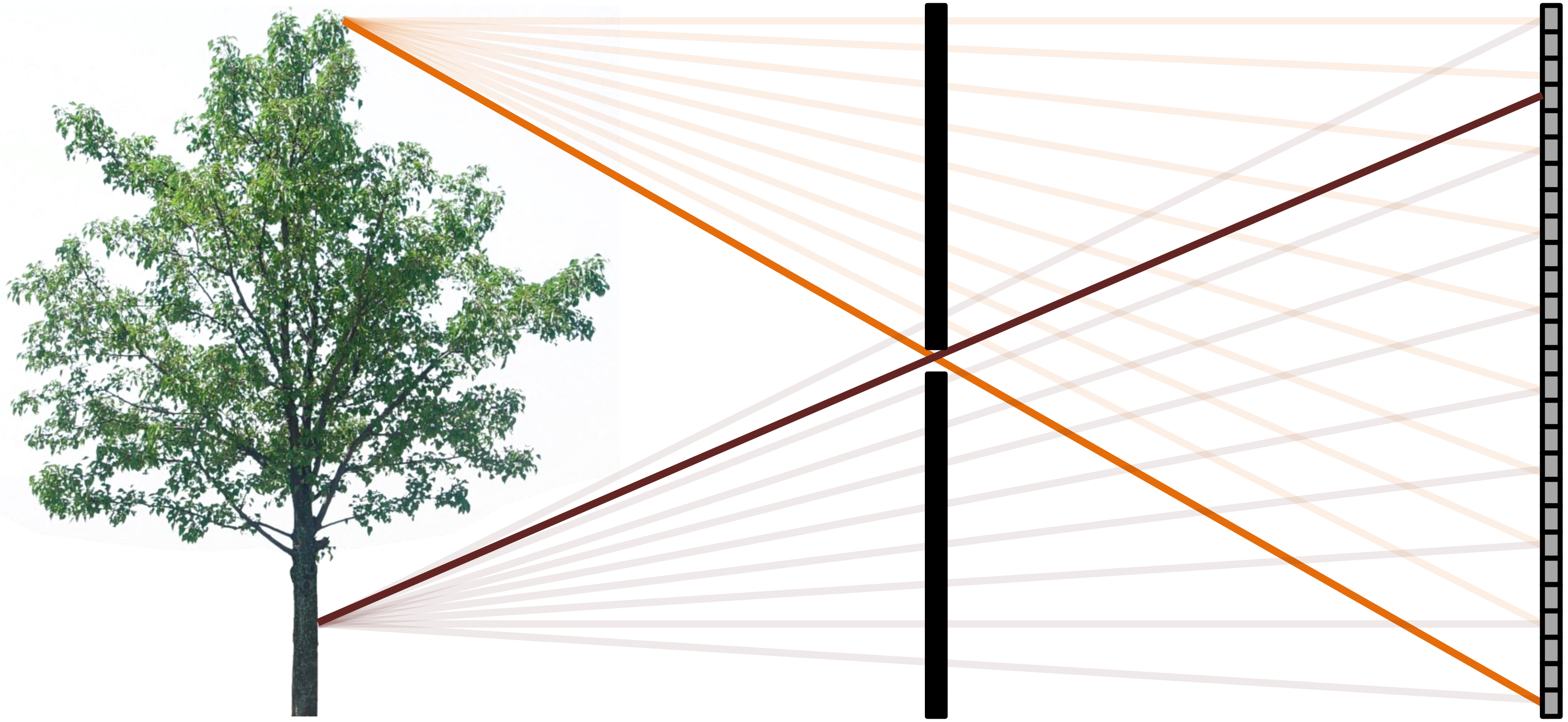


digital sensor
(CCD or CMOS)

one makes
it through

What Does the Image on the Sensor Look Like?

real-world object

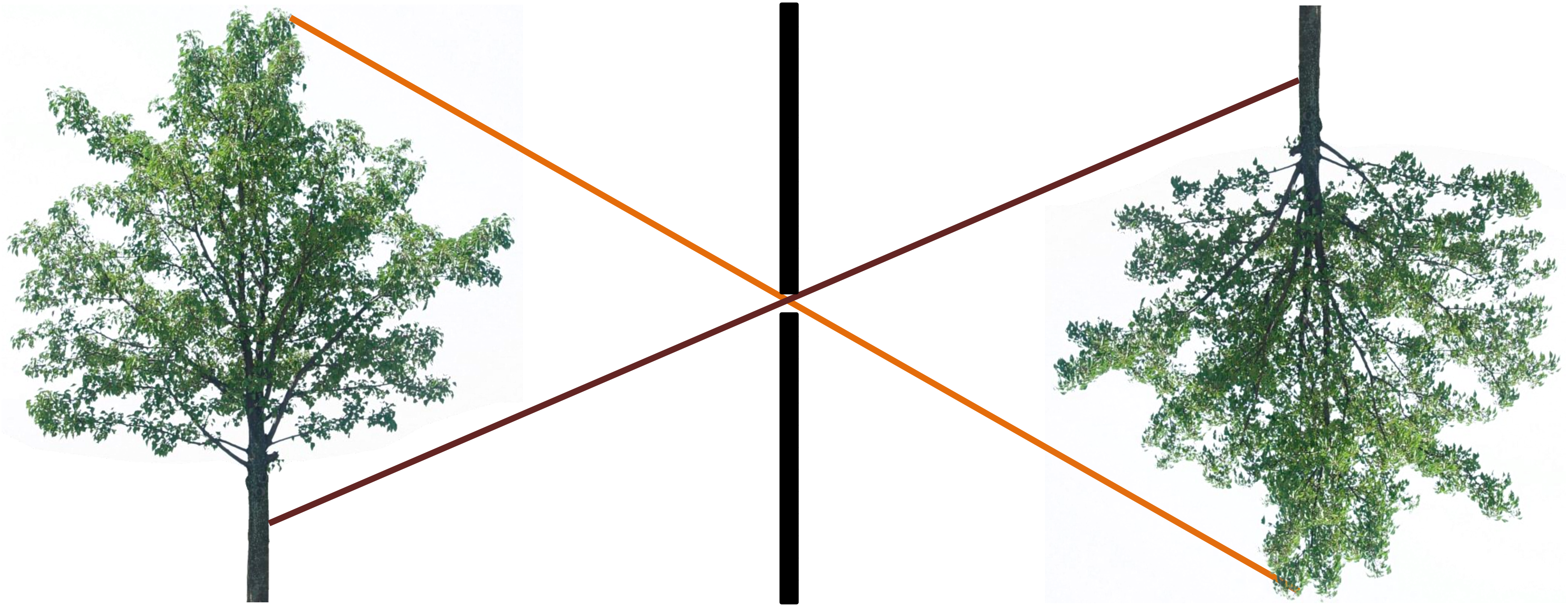


digital sensor (CCD or CMOS)

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

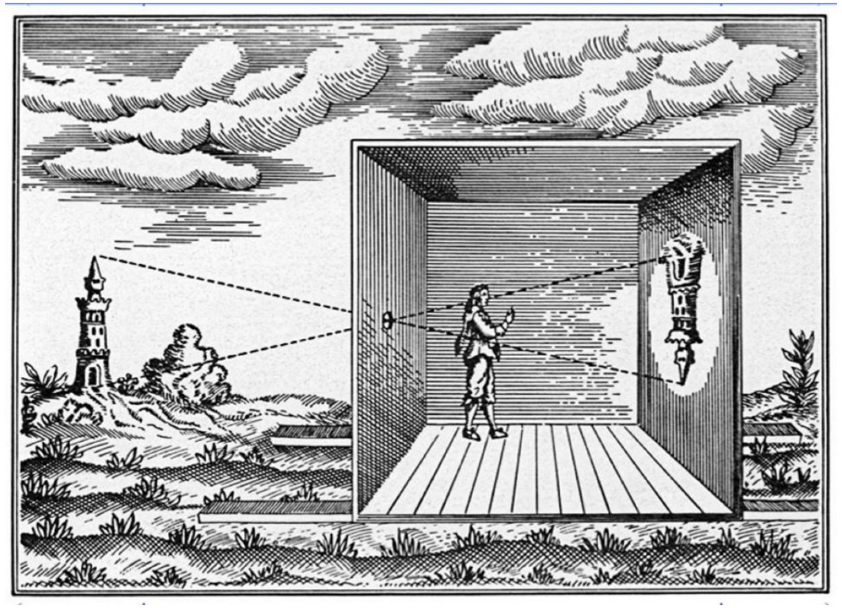
Pinhole Imaging: the Object can be Captured !!

real-world object



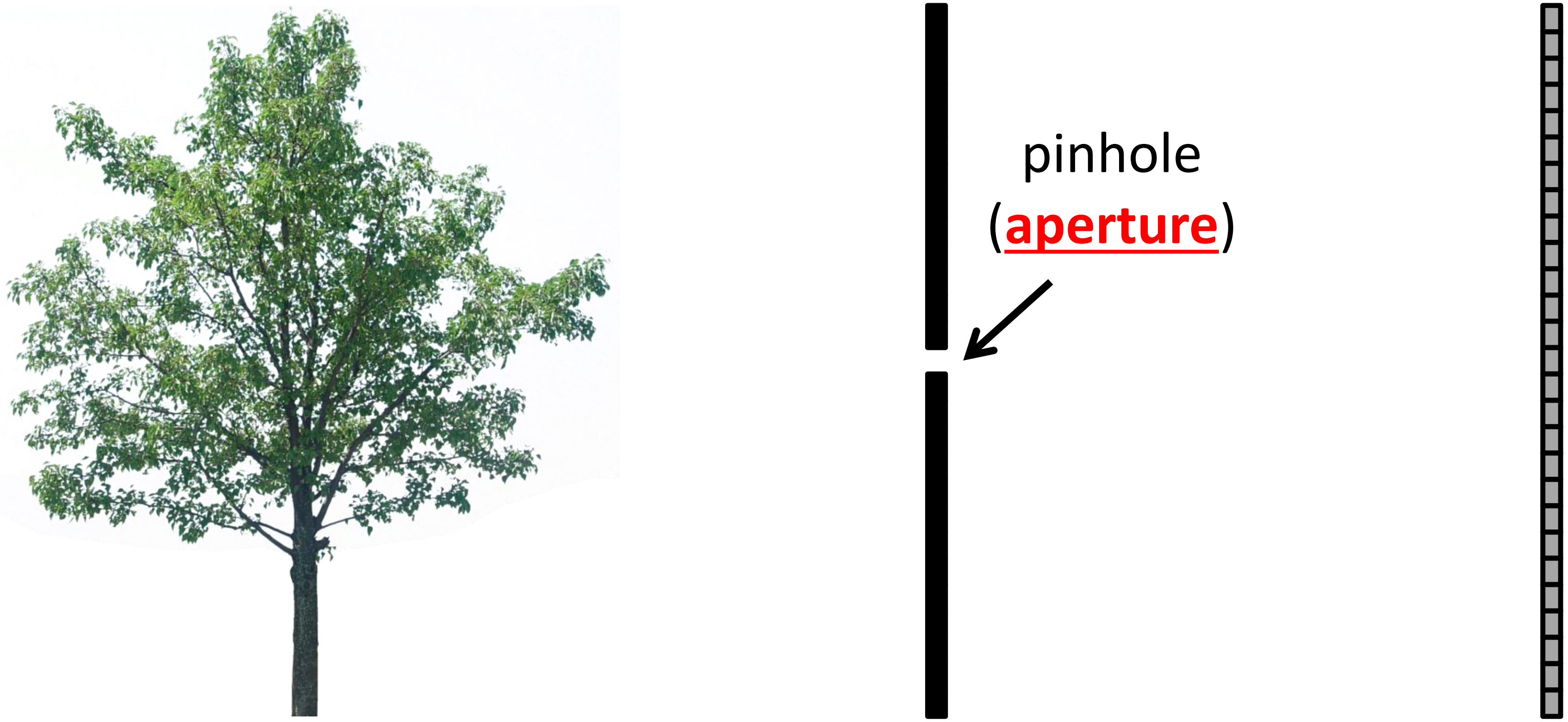
copy of real-world object (inverted and scaled)

Camera Obscure

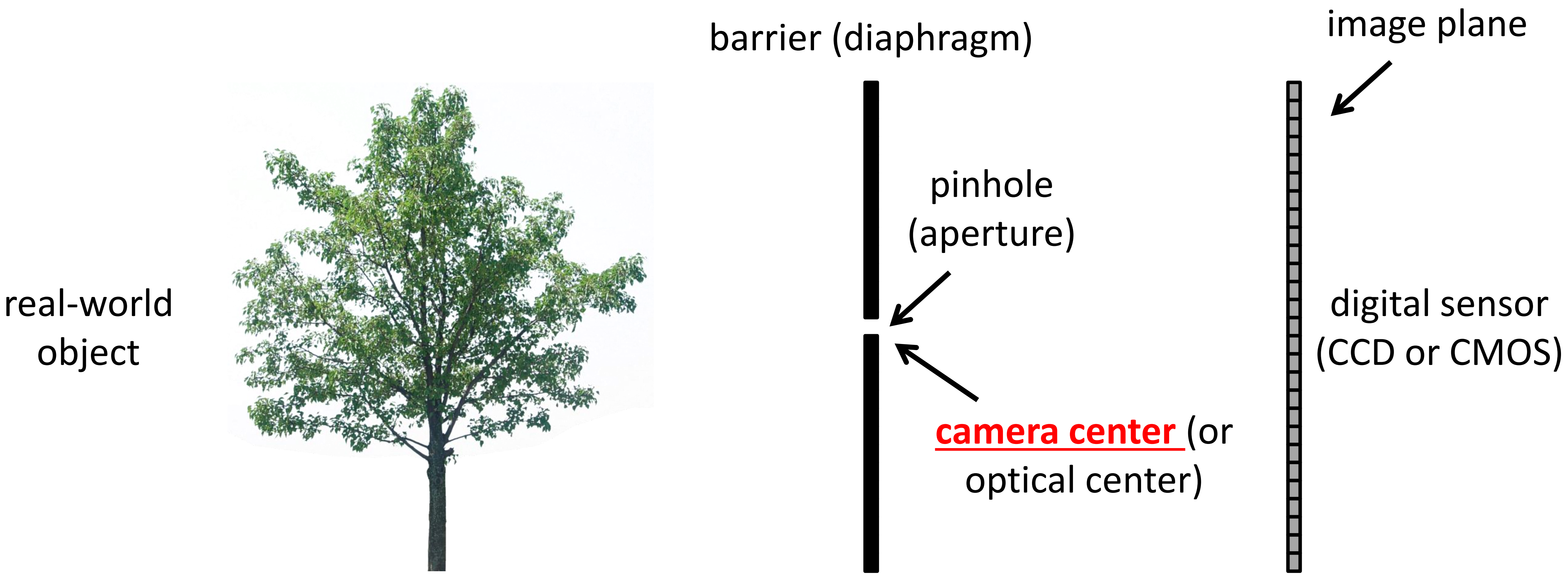


http://www.abelardomorell.net/project/camera-obscura/

Pinhole Camera Terms (Aperture)

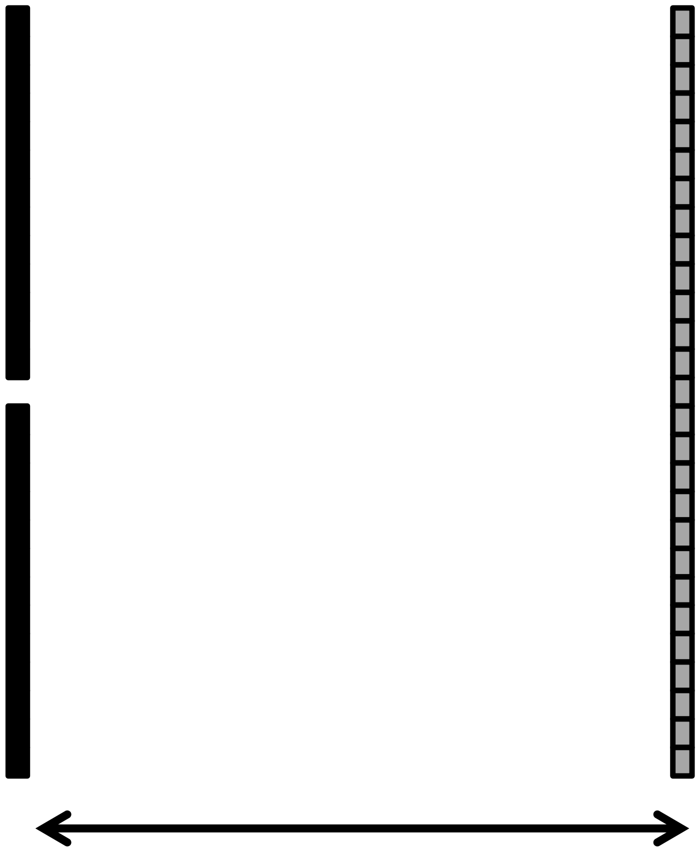


Pinhole Camera Terms (Camera Center)



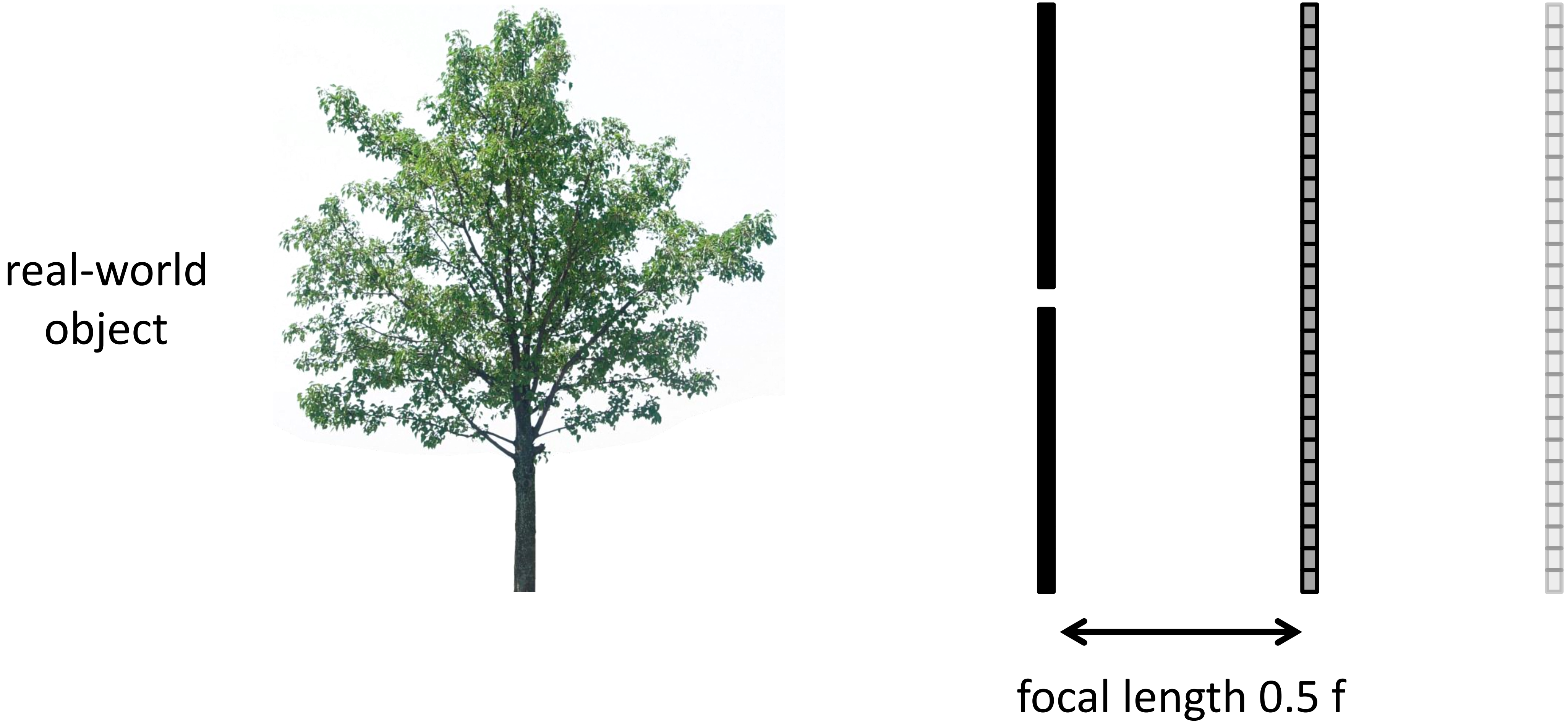
Pinhole Camera Terms (Focal Length)

real-world
object



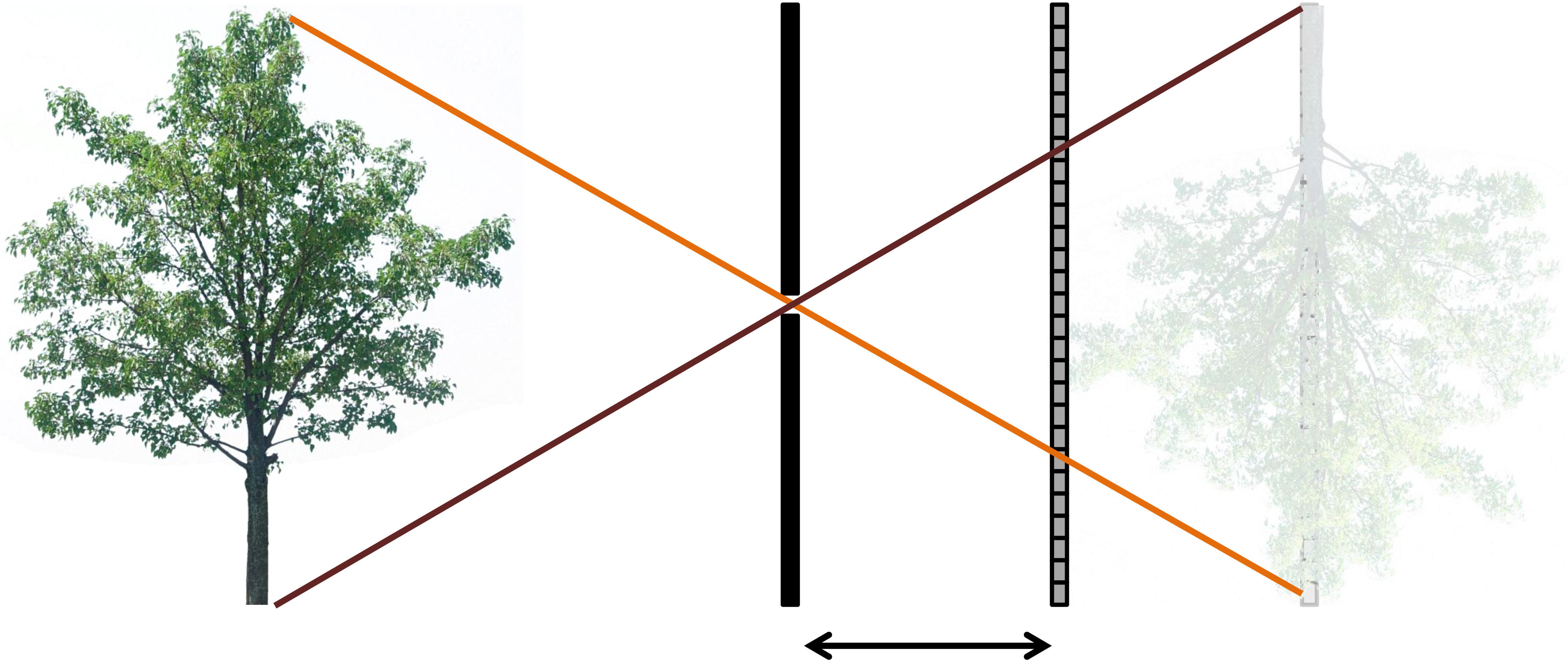
focal length f

What Happens as We Change the Focal Length?



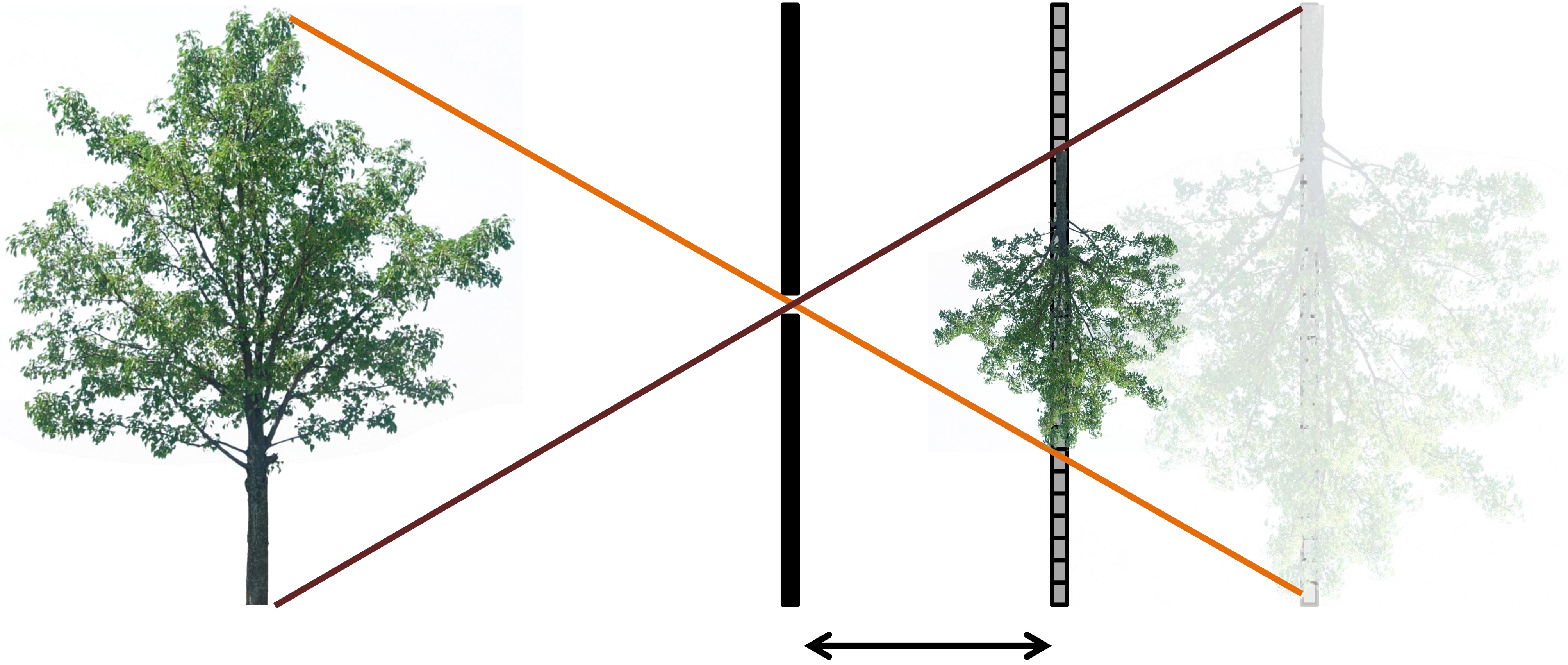
What Happens as We Change the Focal Length?

real-world object



What Happens as We Change the Focal Length?

real-world
object



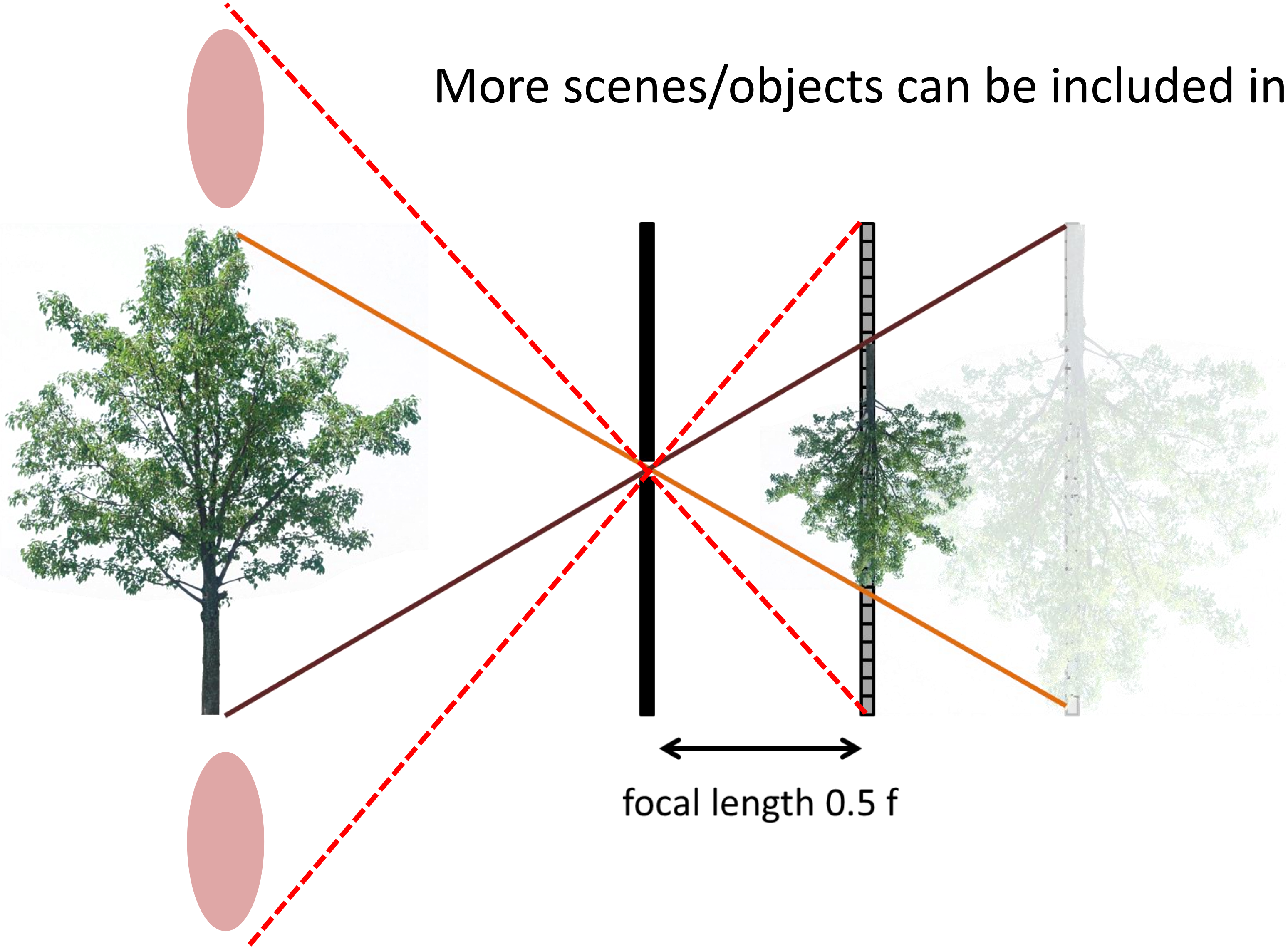
focal length 0.5 f

Which image has better quality?

What Happens as We Change the Focal Length?

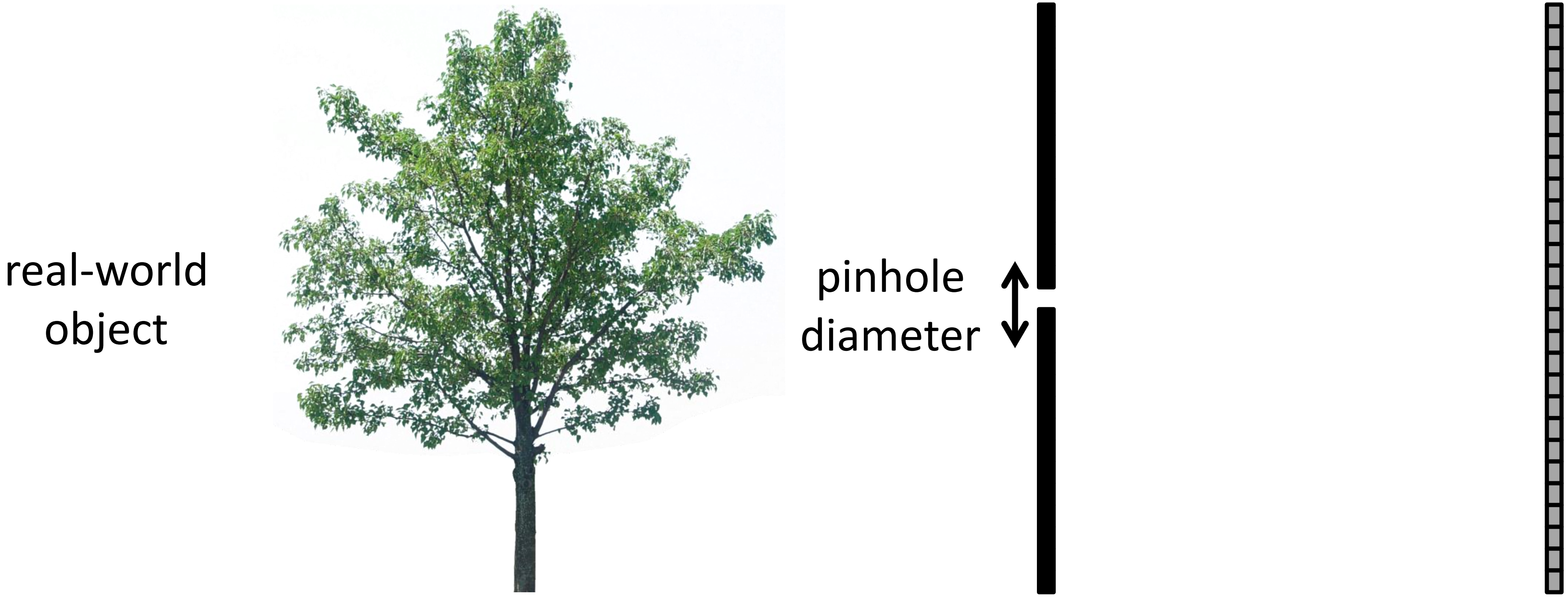
More scenes/objects can be included in the image

real-world object



Zoom-in or Zoom-out

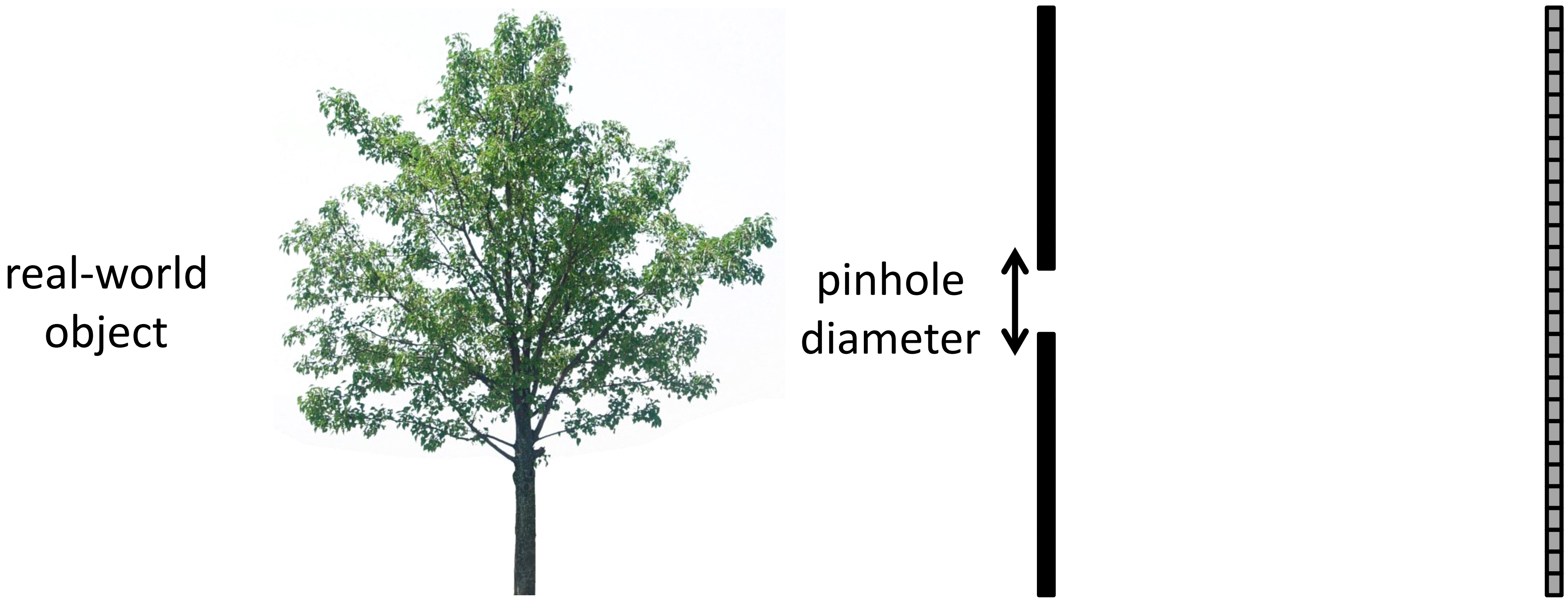
What Happens as We Change the Aperture Size?



Ideal pinhole has infinitesimally small size

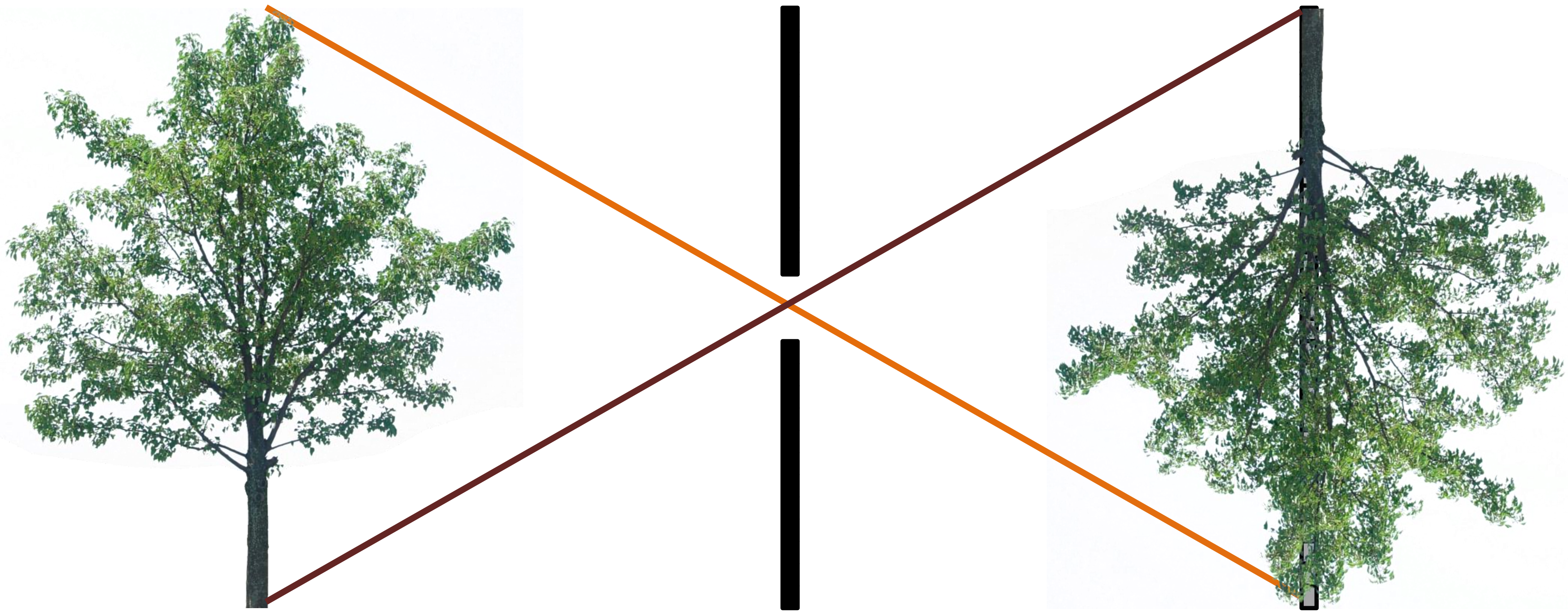
- In practice that is impossible.

What Happens as We Change the Aperture Size?



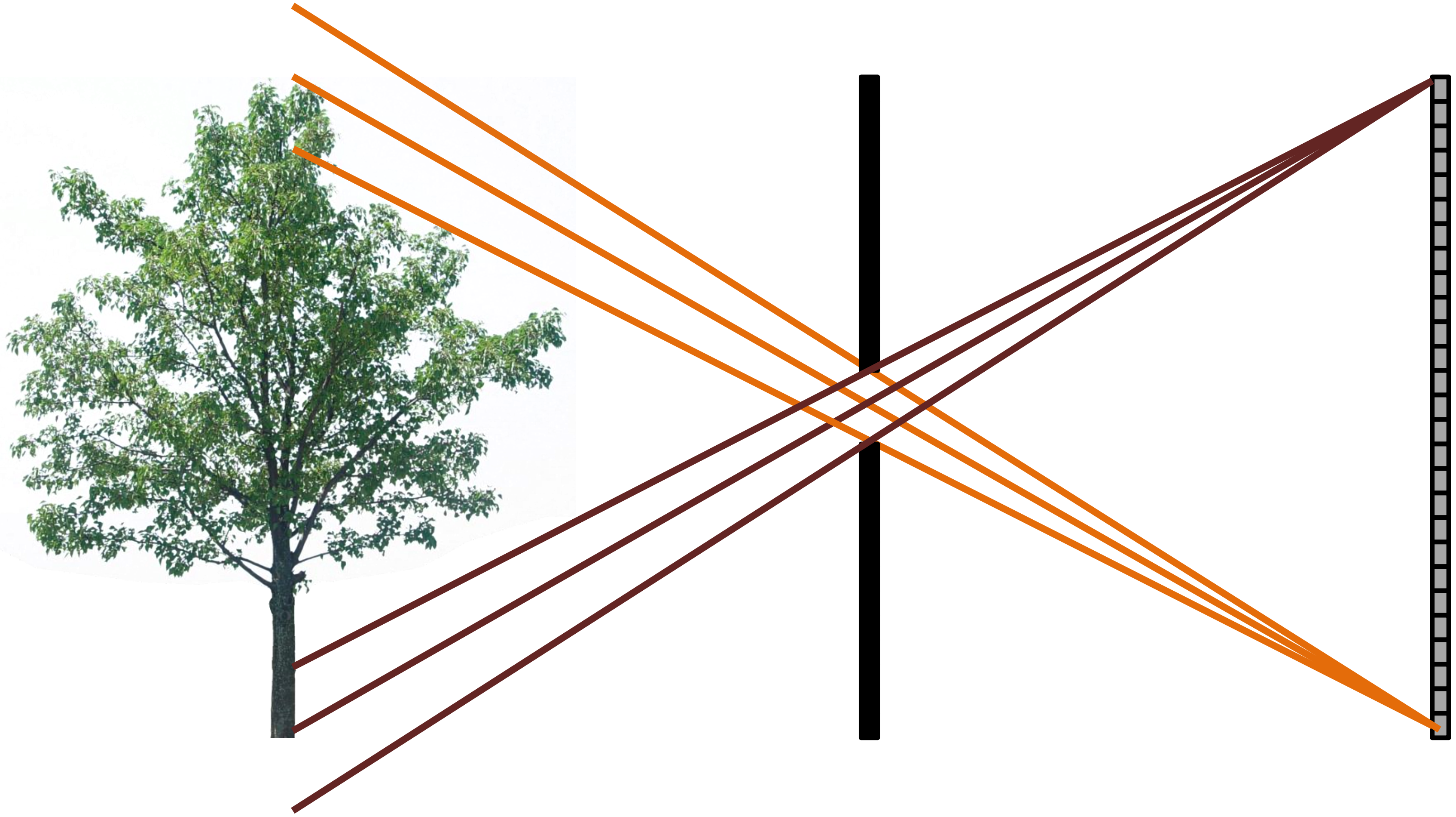
What Happens as We Change the Aperture Size?

real-world
object

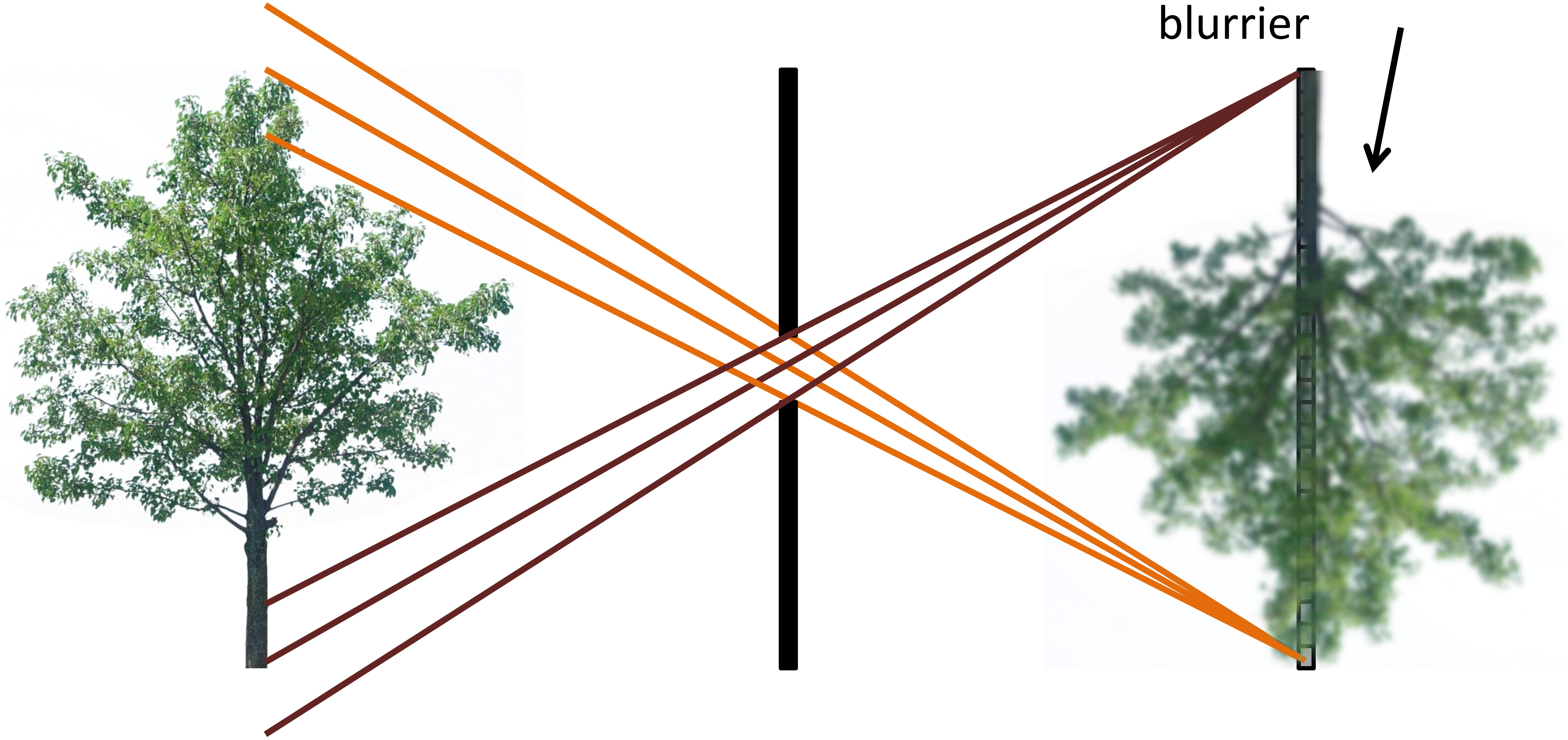


What Happens as We Change the Aperture Size?

real-world
object

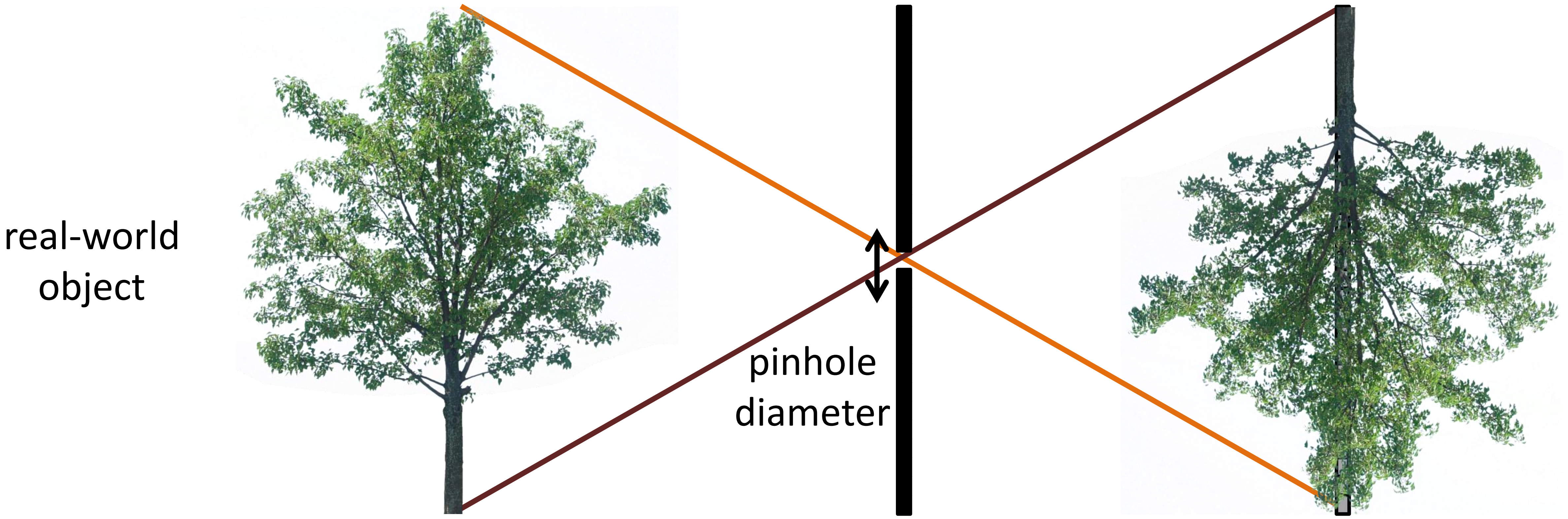


What Happens as We Change the Aperture Size?

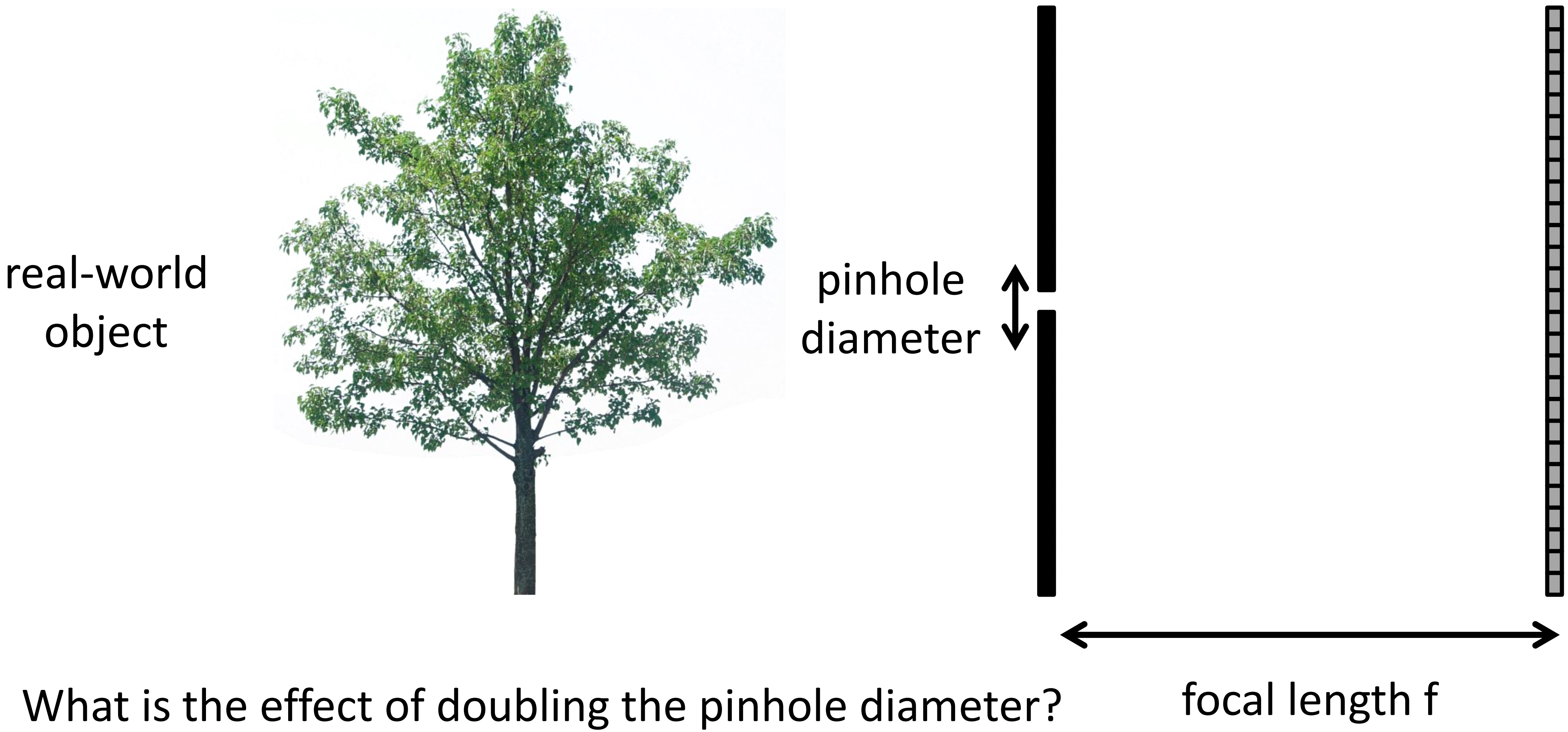


When do we open aperture?

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



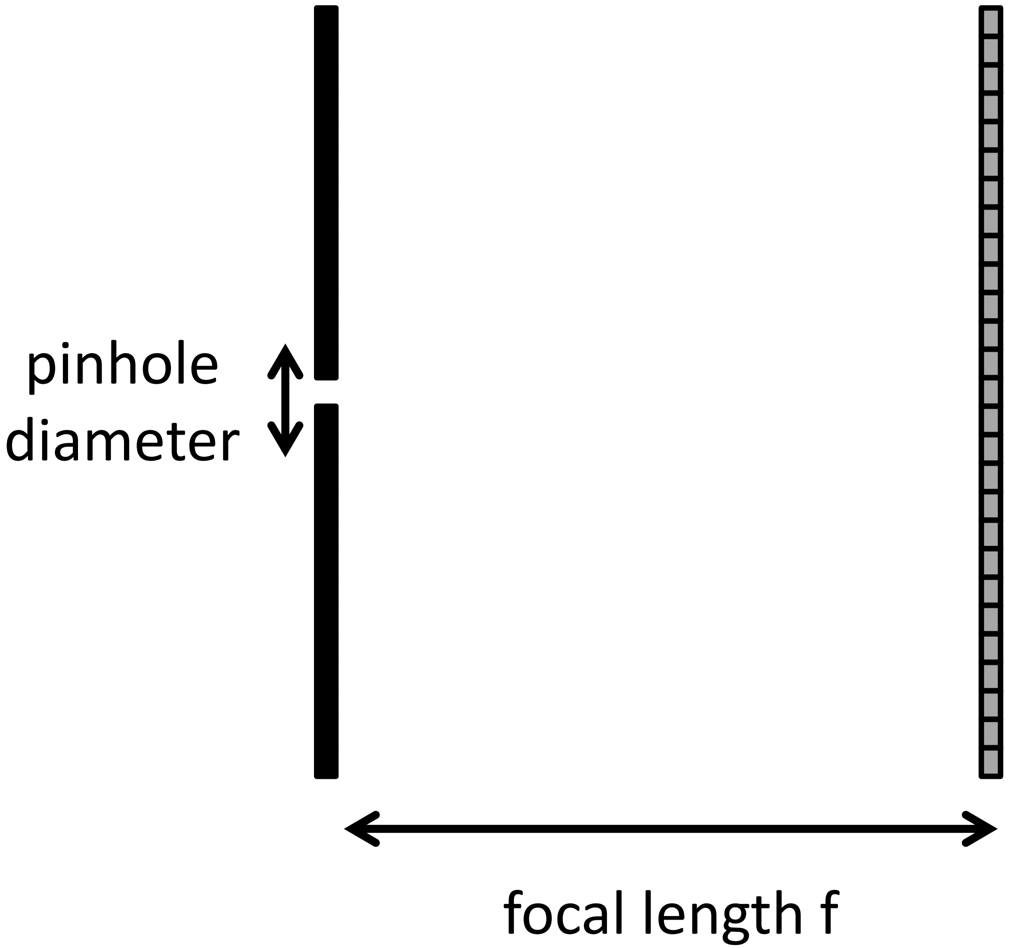
Light Efficiency



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

Light Efficiency (Continue)

real-world object

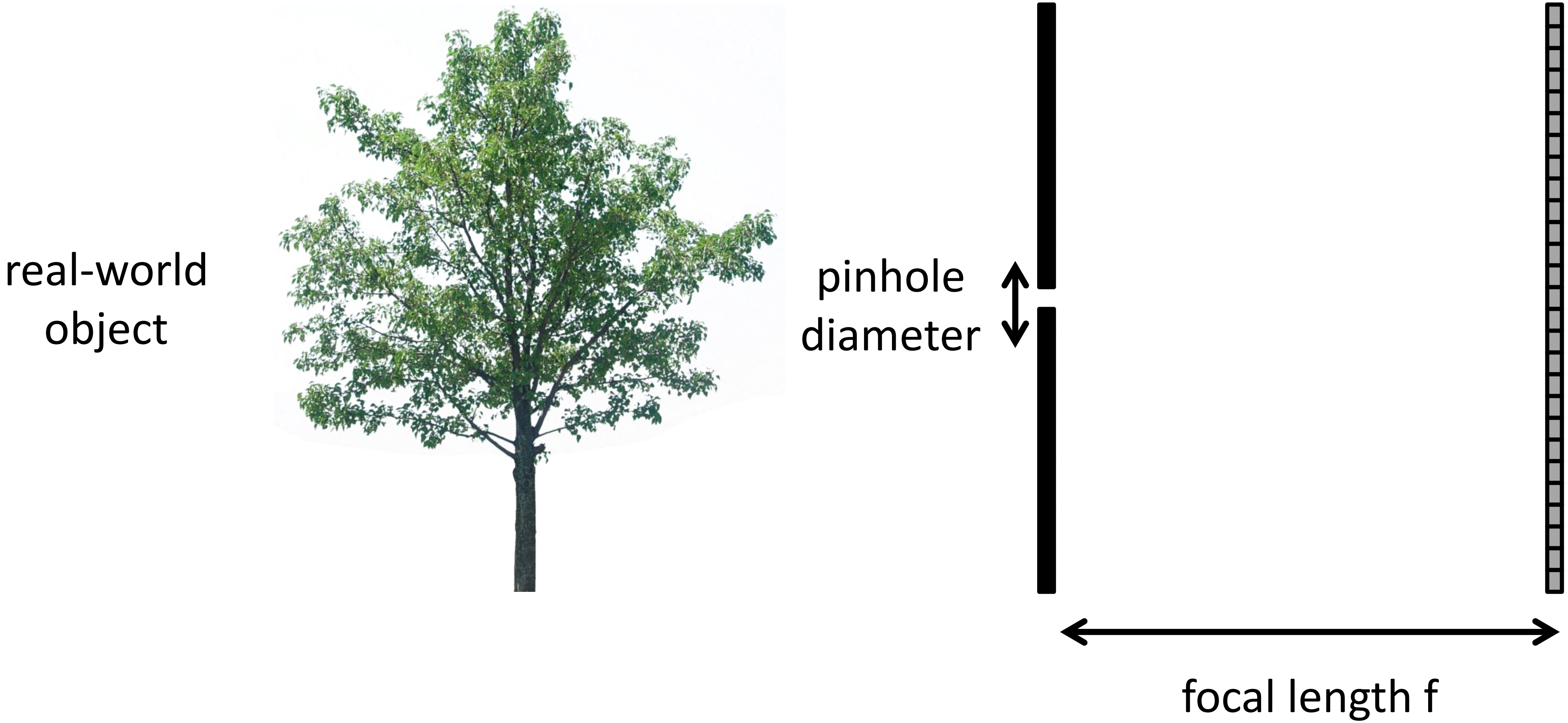


- 2x pinhole diameter → 4x light
- 2x focal length → ¼x light

<u>**2 x pinhole diameter and 2x focal length**</u>

F-Number or F-Stop

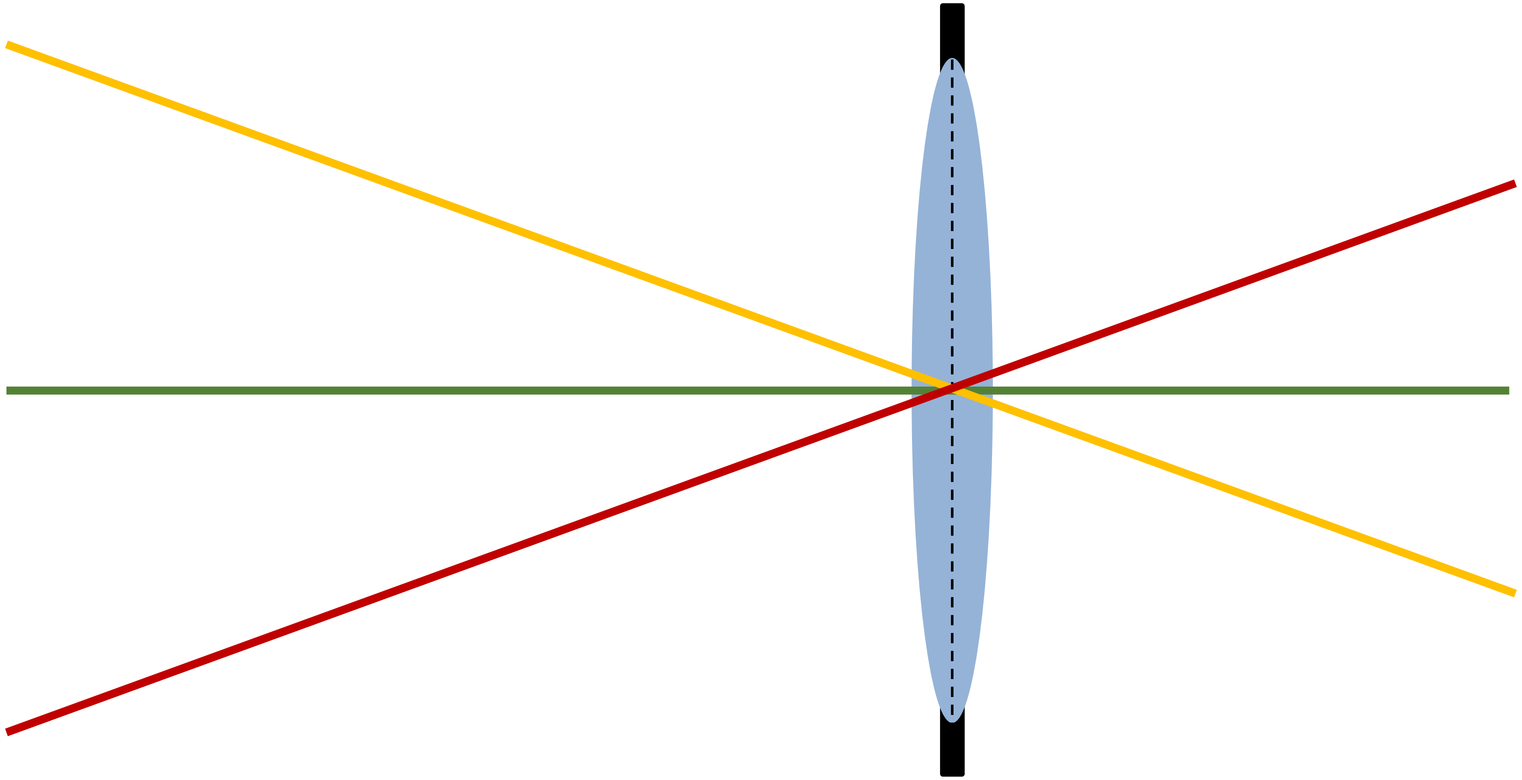
A “stop” is a change in camera settings that changes amount of light by a factor of 2



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

Thin Lens Model

Simplification of geometric optics for <u>well-designed</u> lenses.

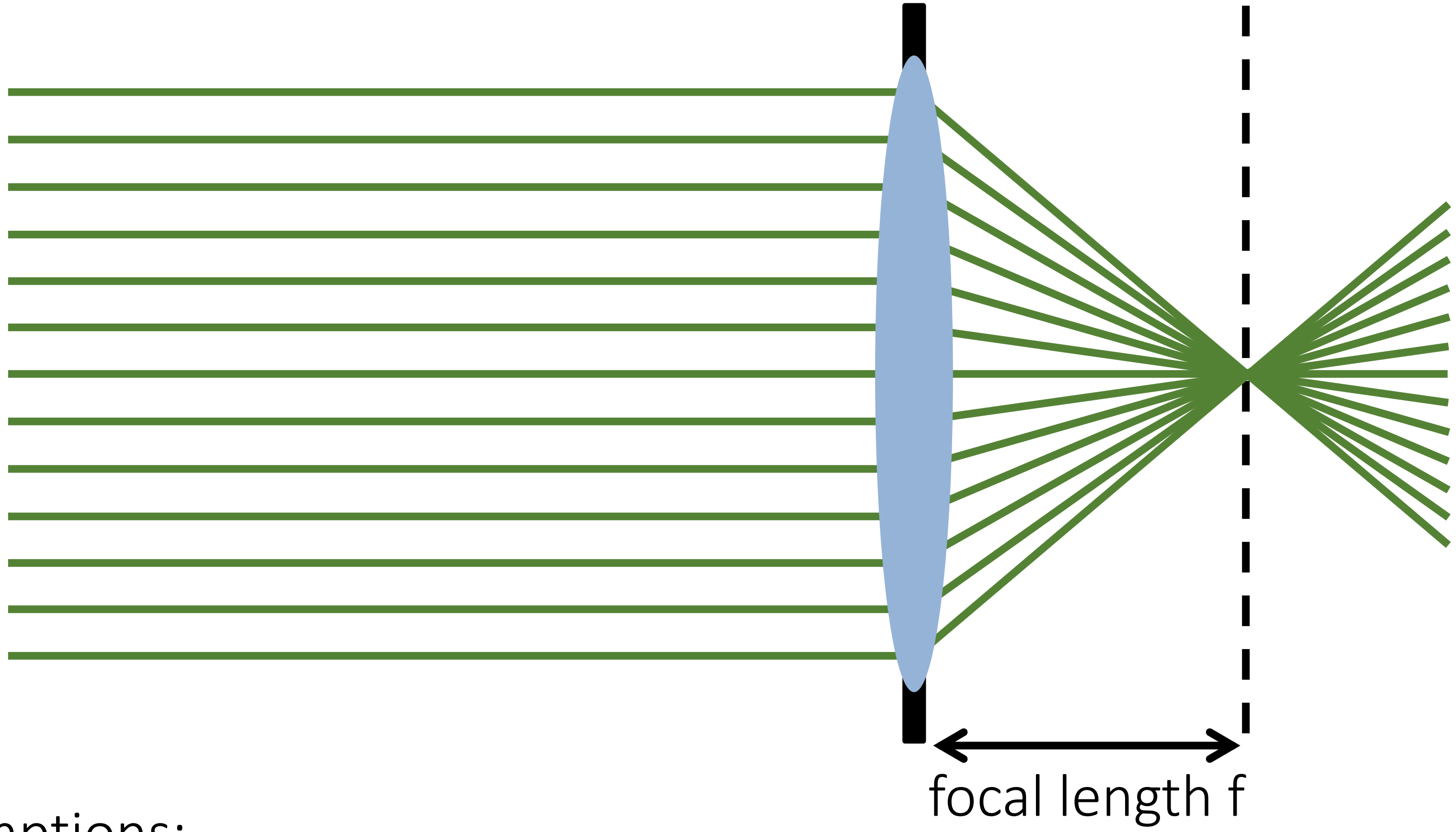


Two assumptions:

1. Rays passing through lens center are unaffected.

Thin Lens Model (Continue)

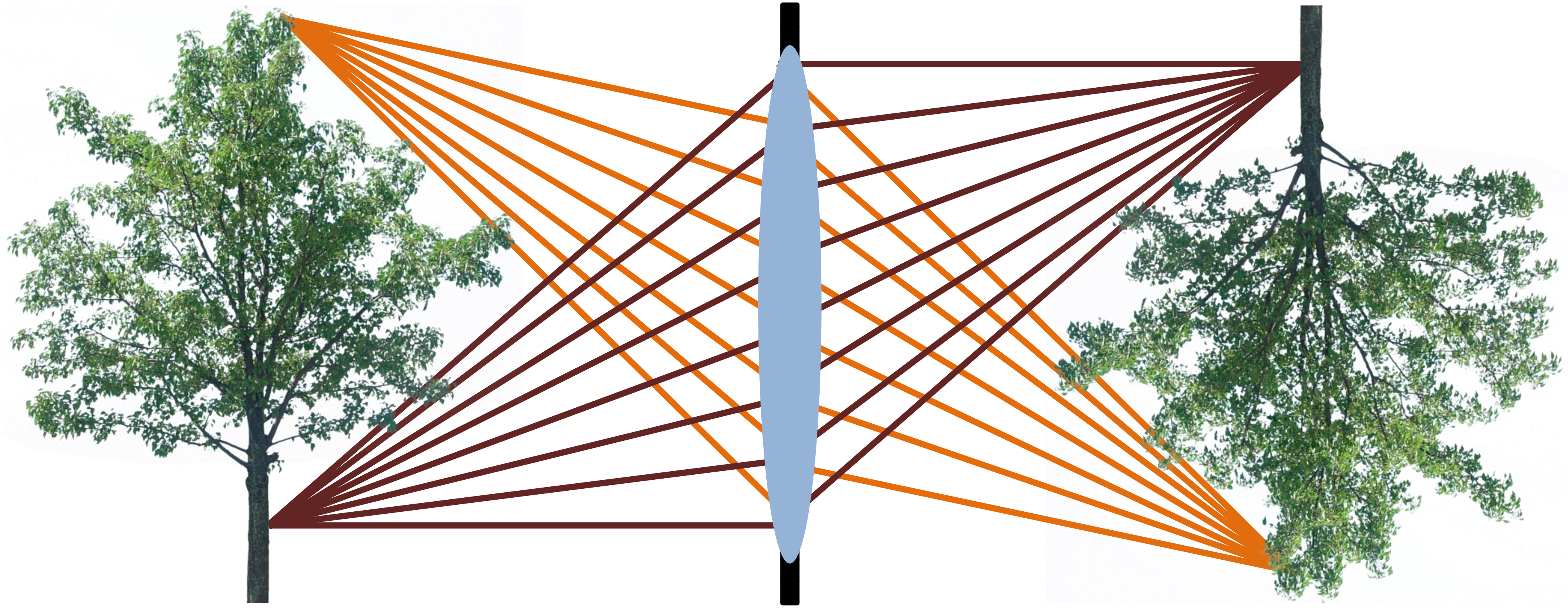
Simplification of geometric optics for well-designed lenses.



Two assumptions:

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

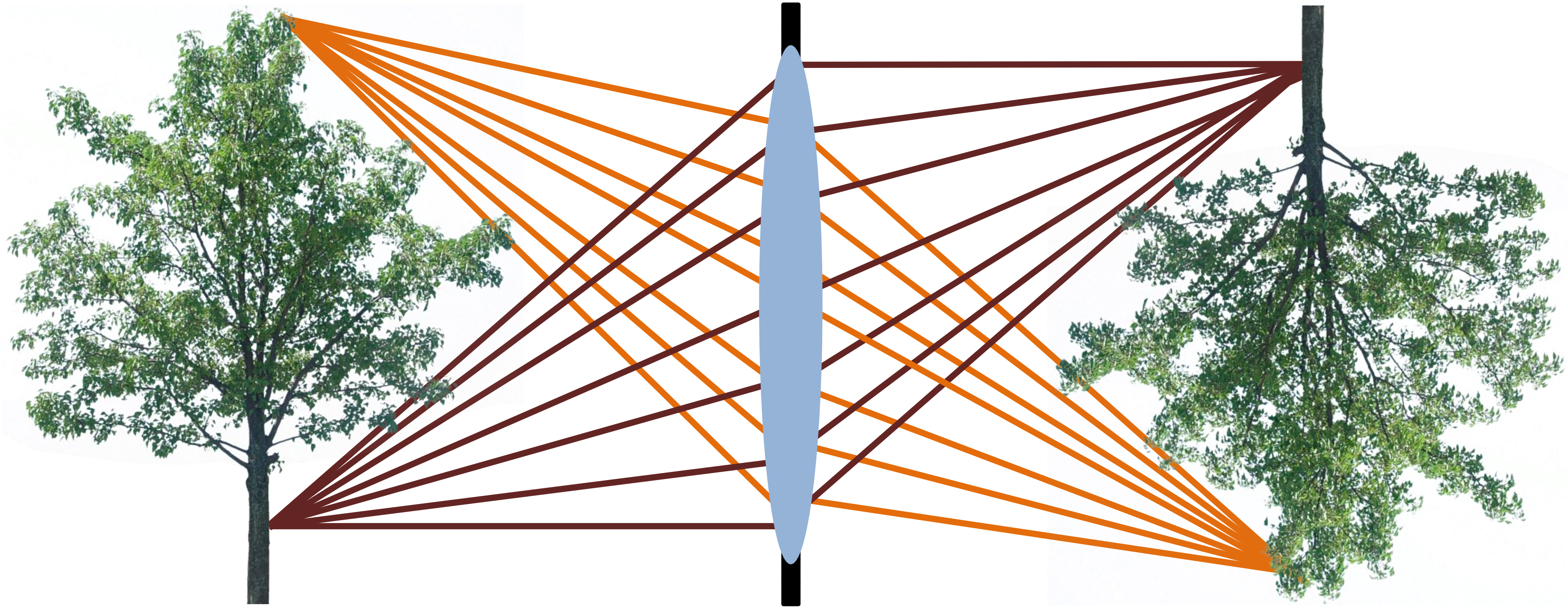
Replace the Pinhole with Lens



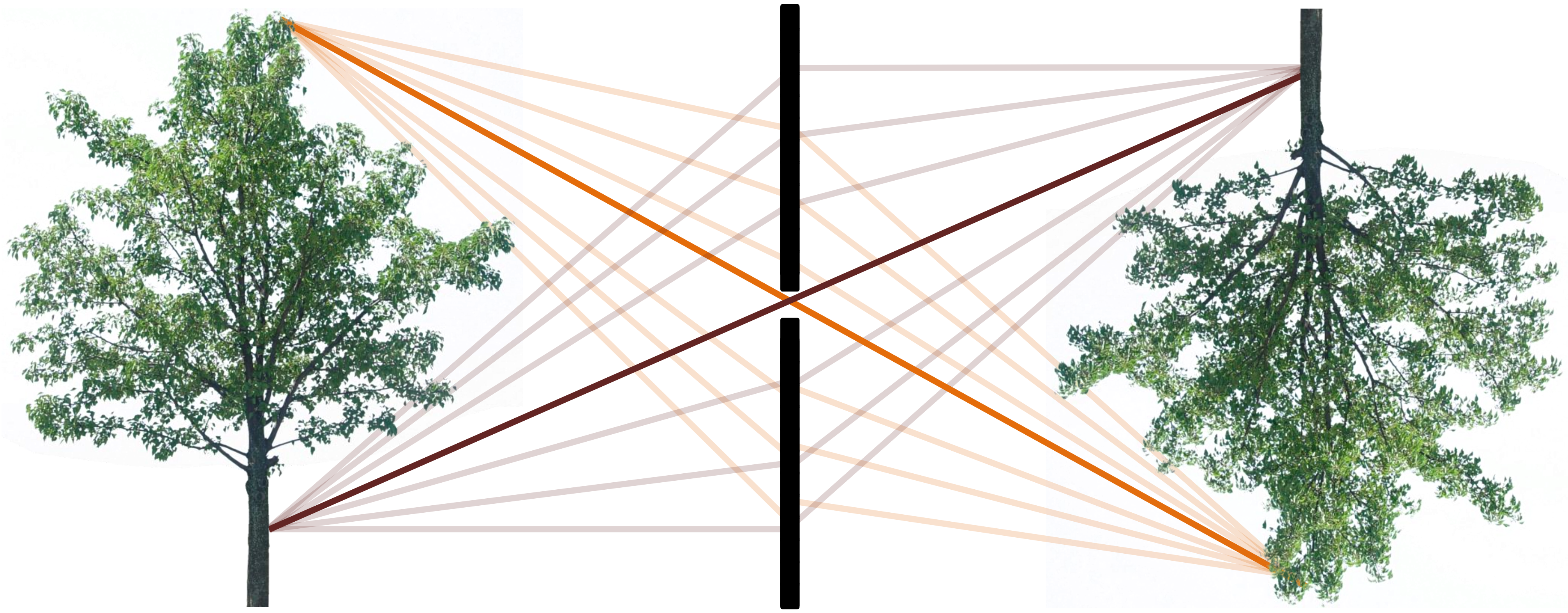
Lenses map “bundles” of rays from points on the scene to the sensor.

How does this mapping work exactly?

Difference Between Lens and Pinhole Cameras



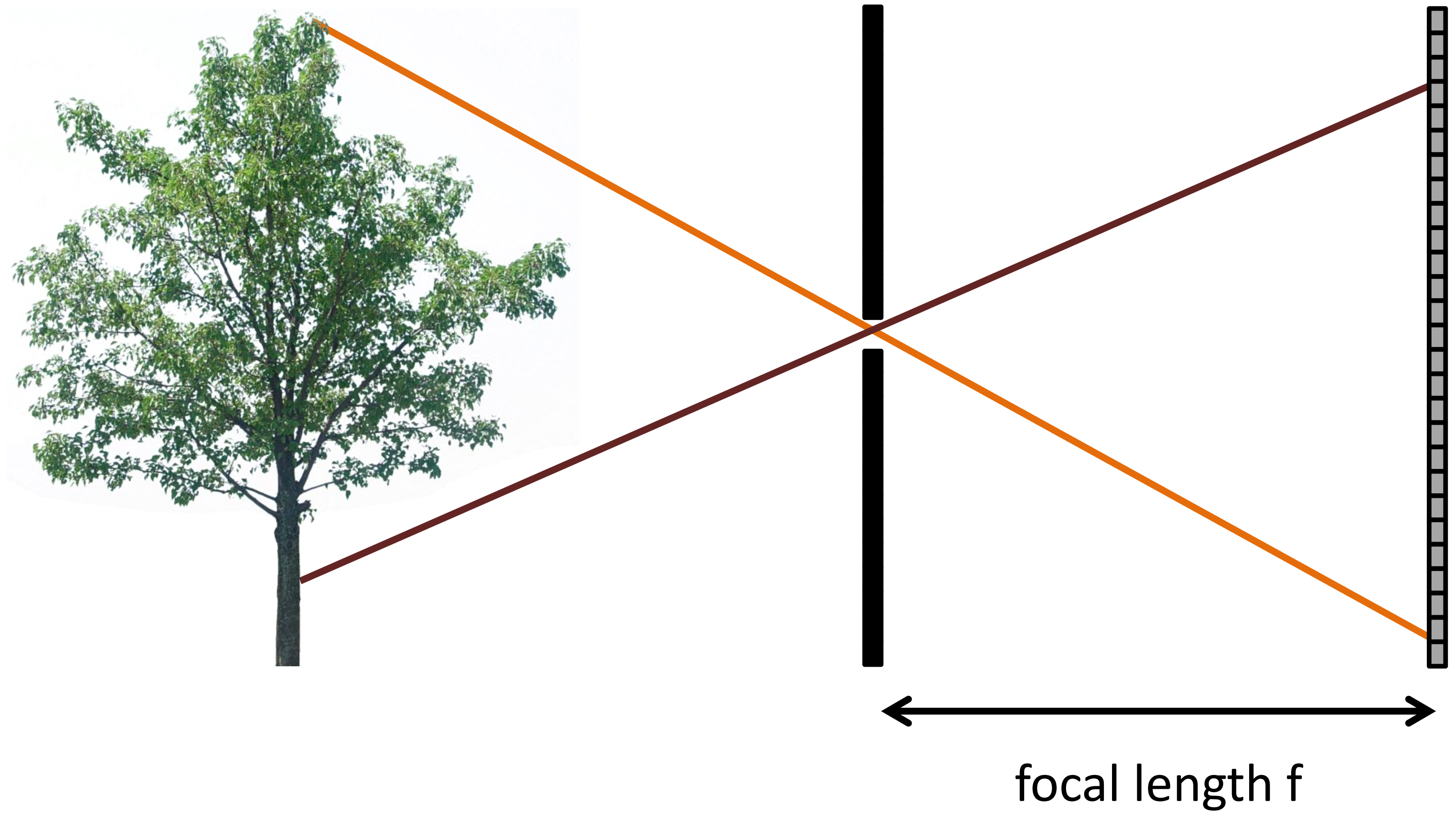
Pinhole Camera



Central rays propagate in the same way for both models!

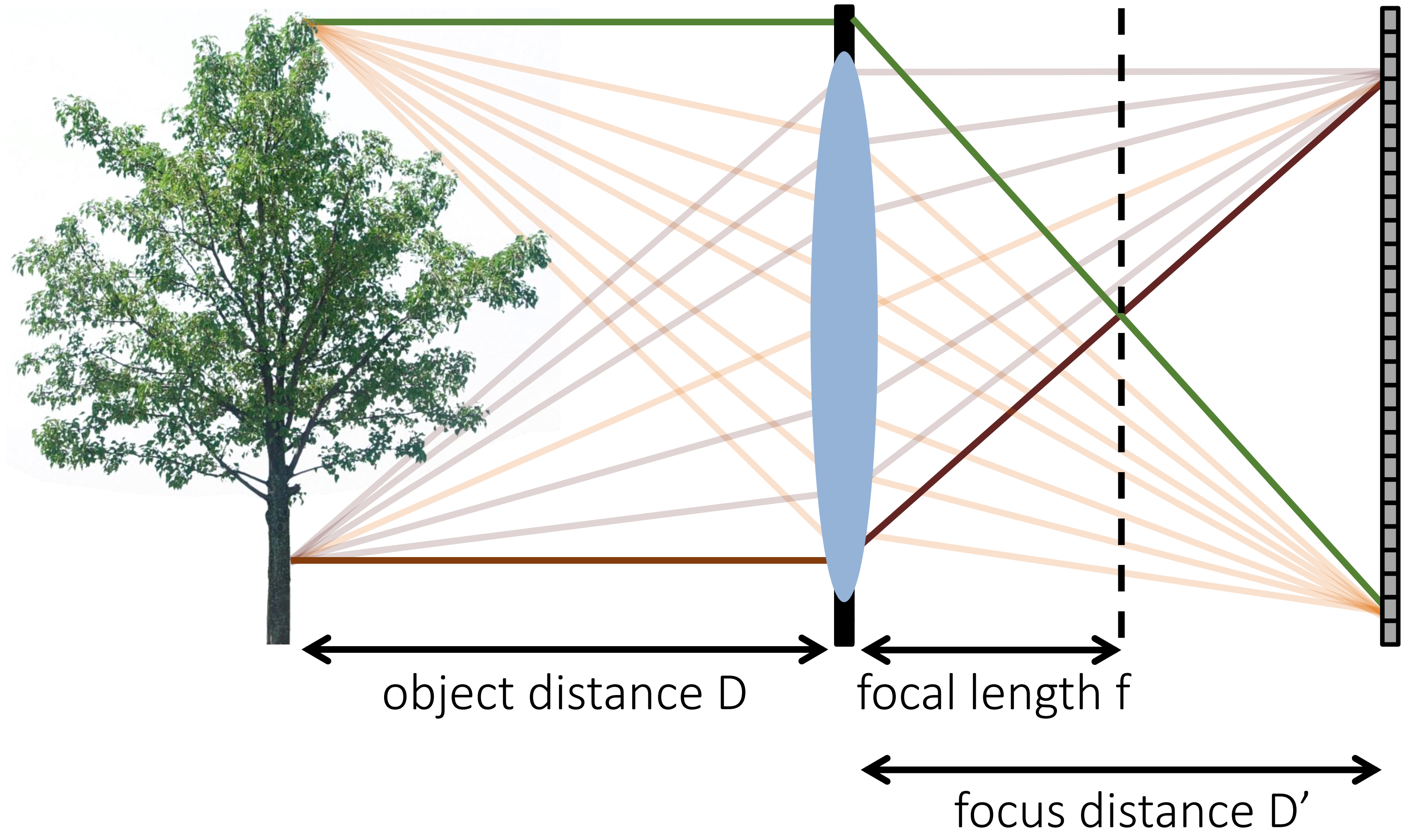
Focal Length in a Pinhole Camera

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

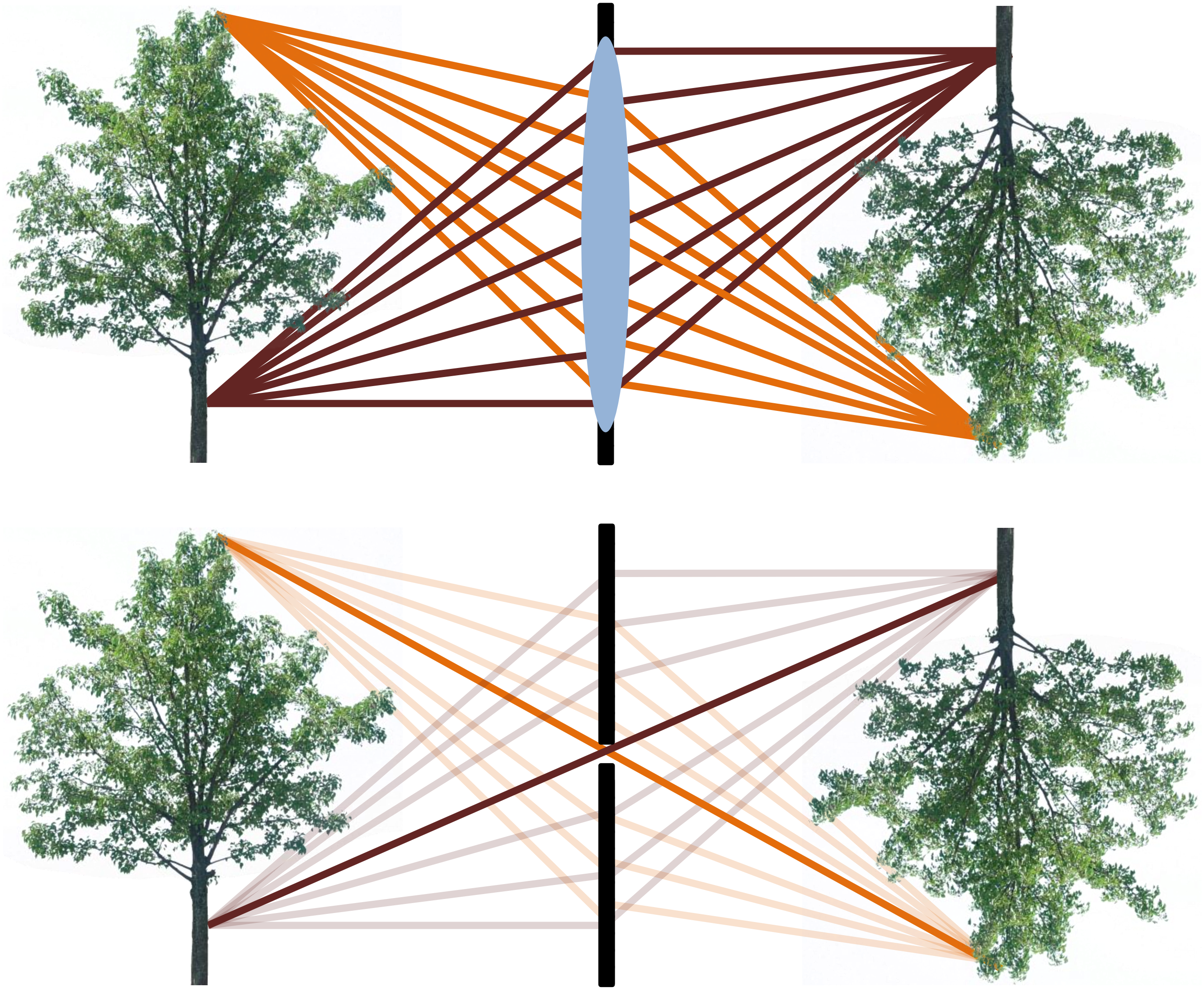


Focal Length in a Lens Camera

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



Describing Both Les and Pinhole Cameras



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

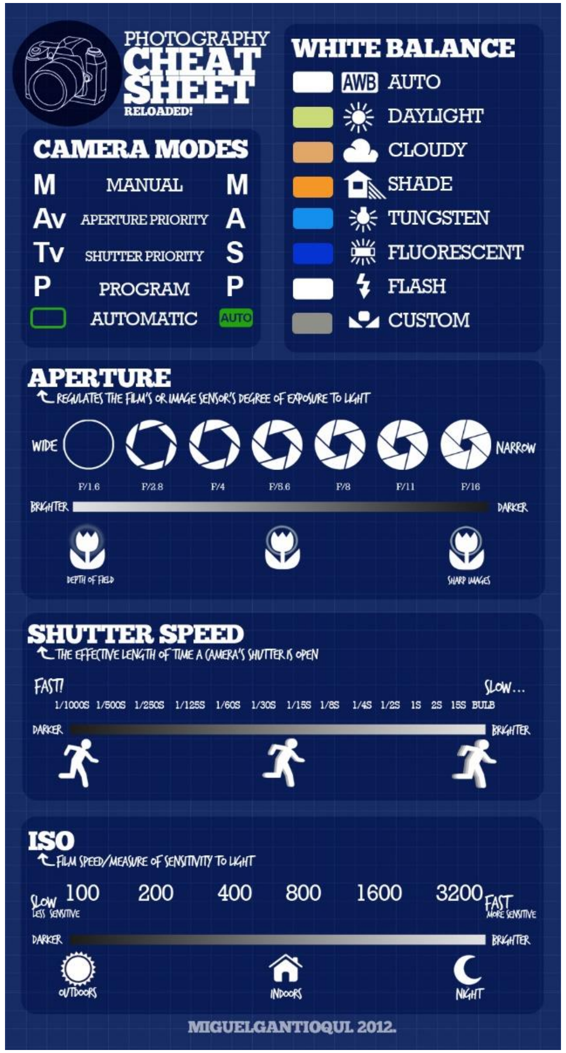
- We use only central rays.
- We assume the lens camera is in focus.
- We assume that the focus distance of the lens camera is equal to the focal length of the pinhole camera.

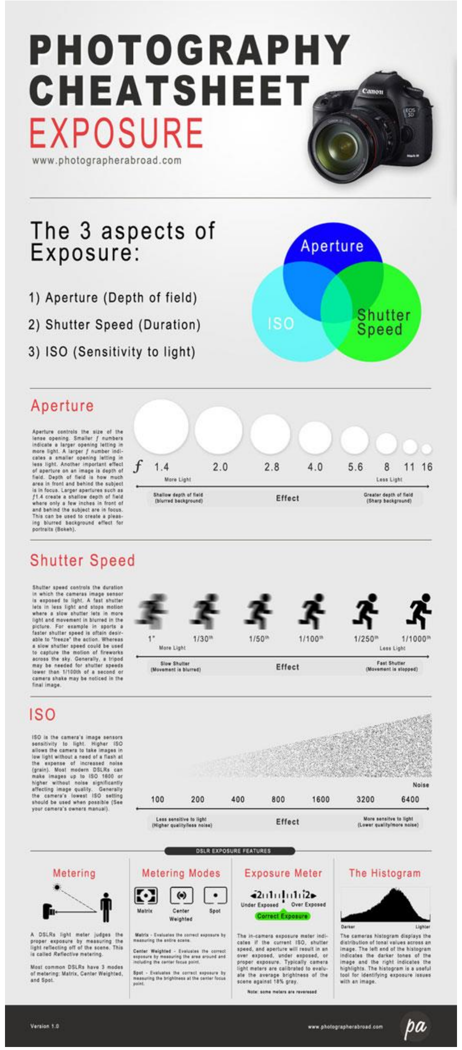
Understanding the Language of Photography

- 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



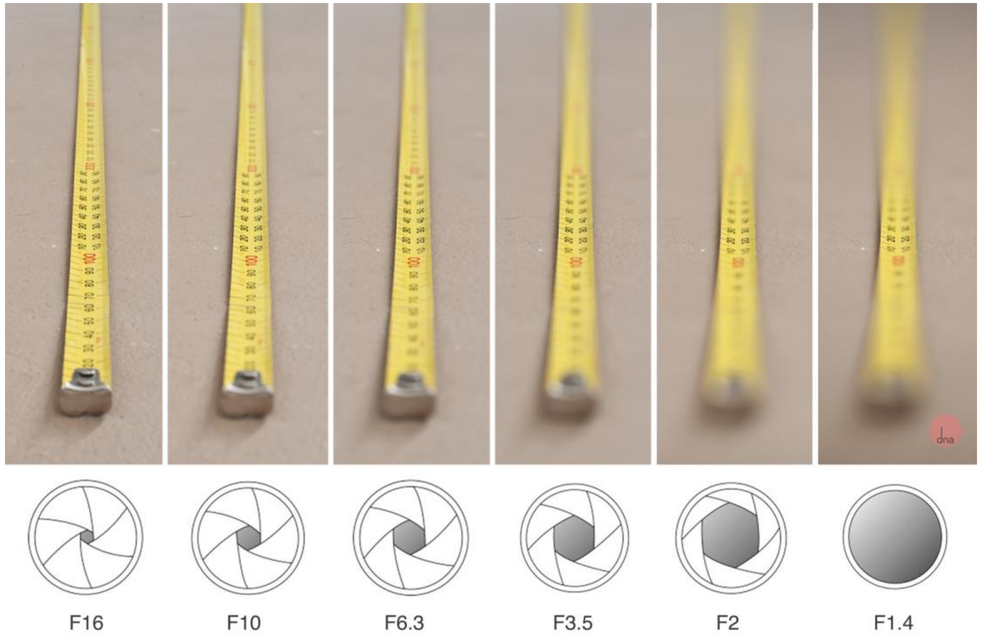


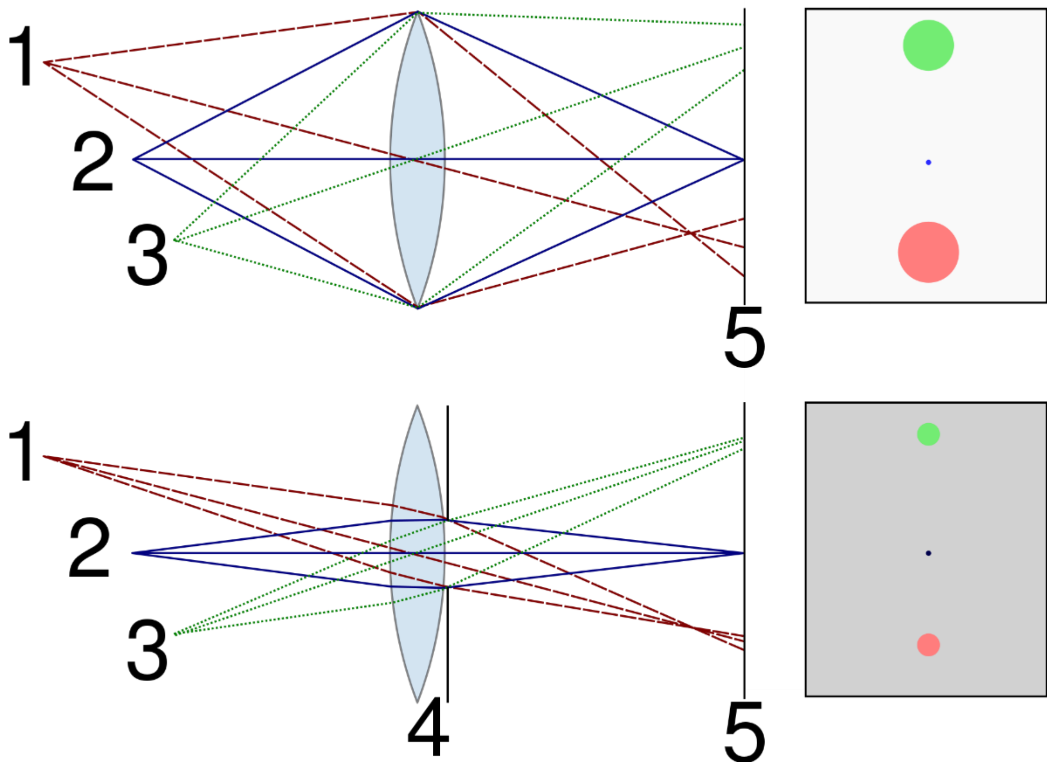
Why Do We Use a Tripod?

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

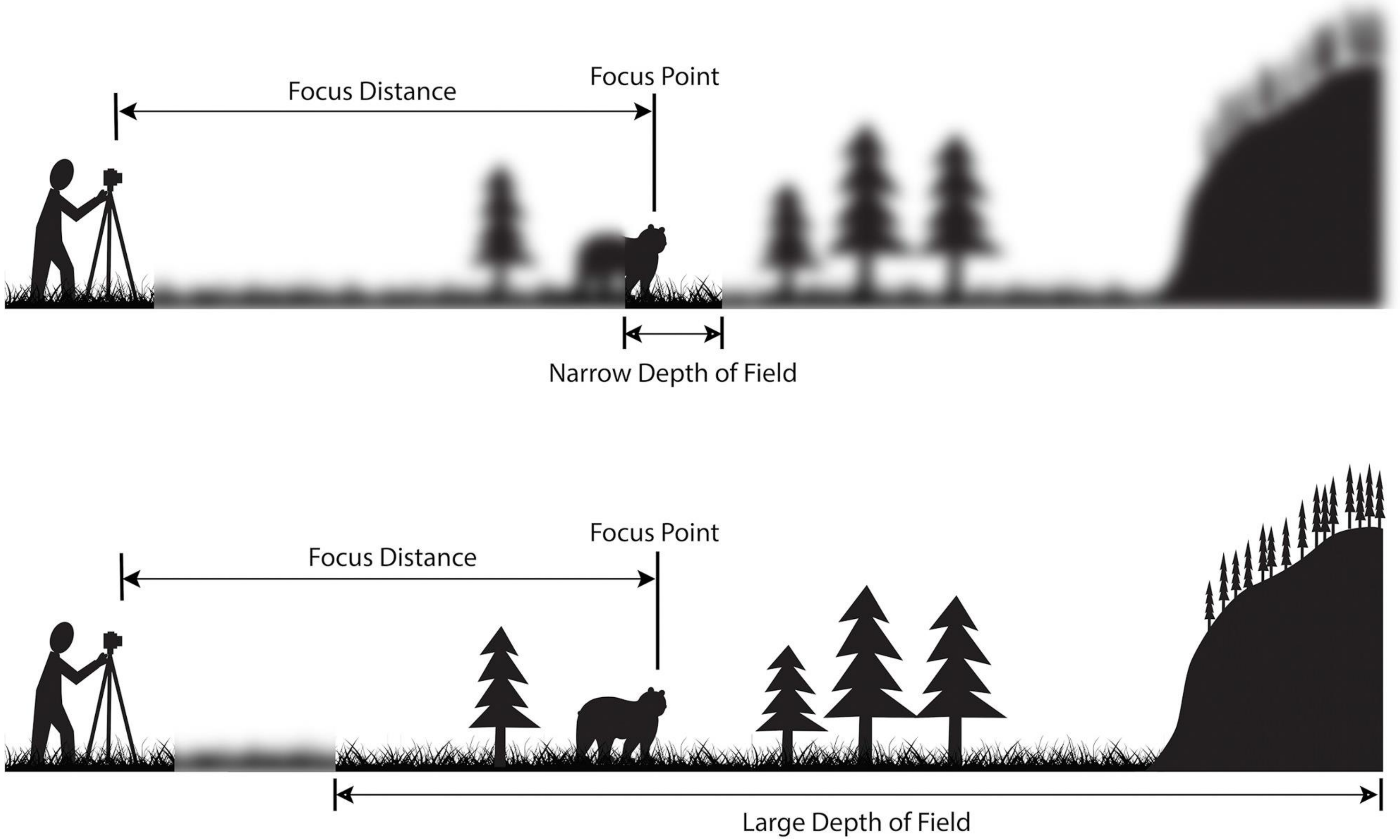
https://www.photographyblog.com/articles/7_reasons_why_you_should_use_a_tripod

Effect of Aperture

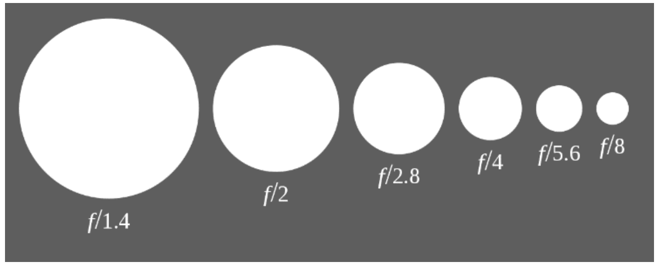




Understanding Depth of Field



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.

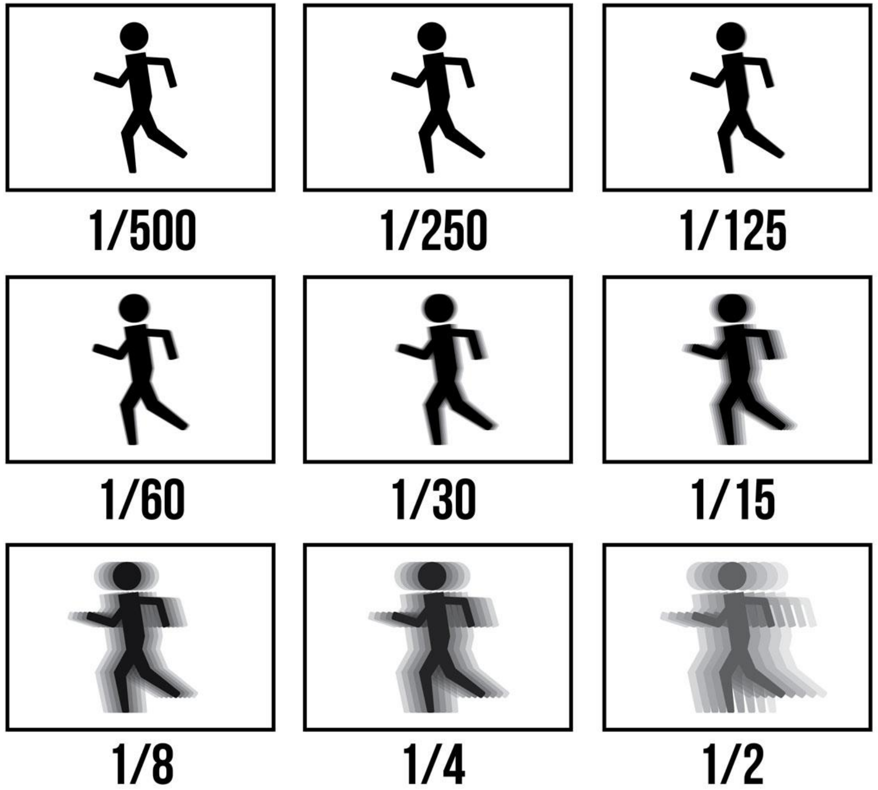
The amount of light entering in the lens

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

Different Depth of Fields

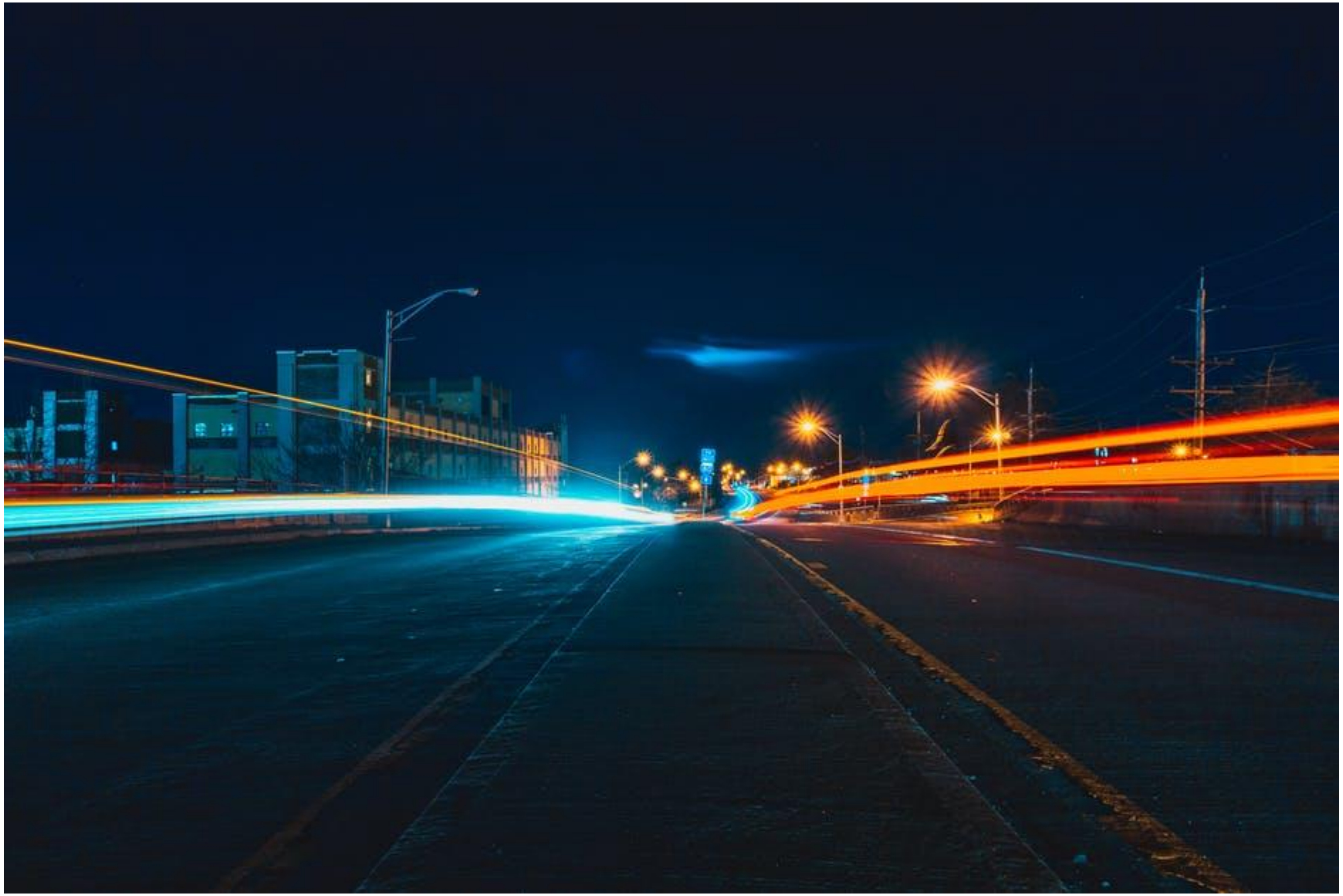
Q. Why is it better? resolution?

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/

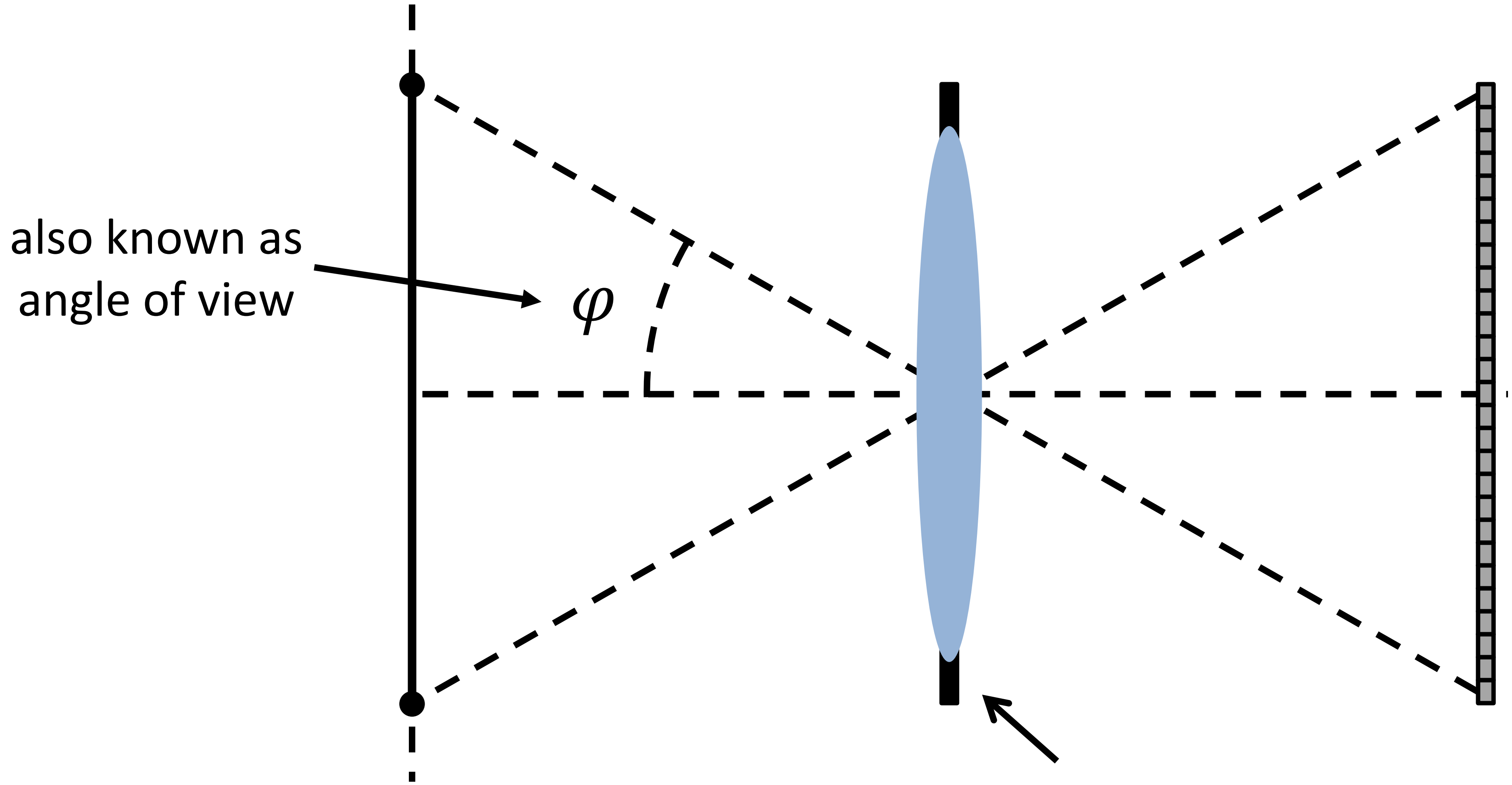
https://photographylife.com/what-is-iso-in-photography

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. 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.

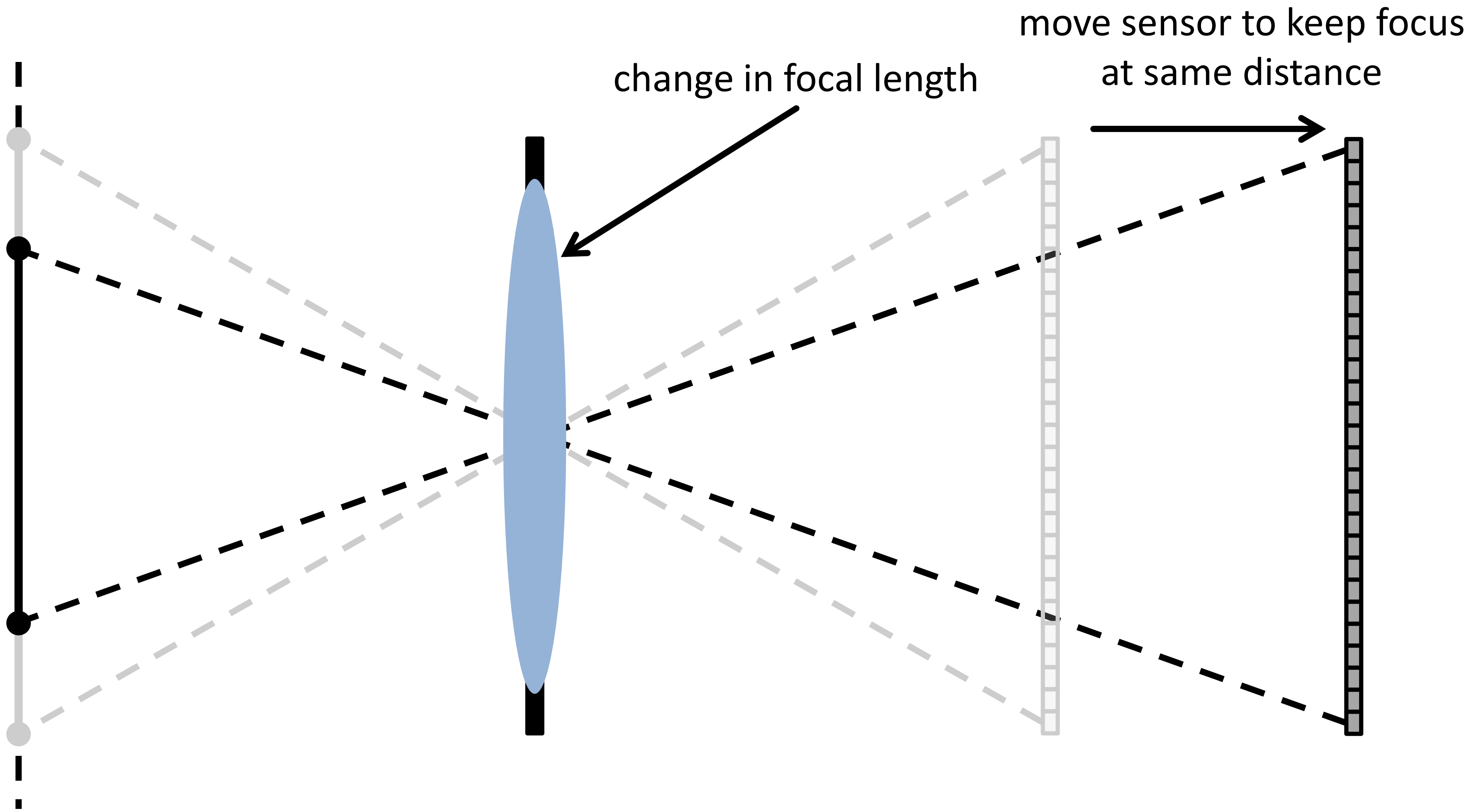
https://www.digitaltrends.com/photography/what-is-iso/

Field of view



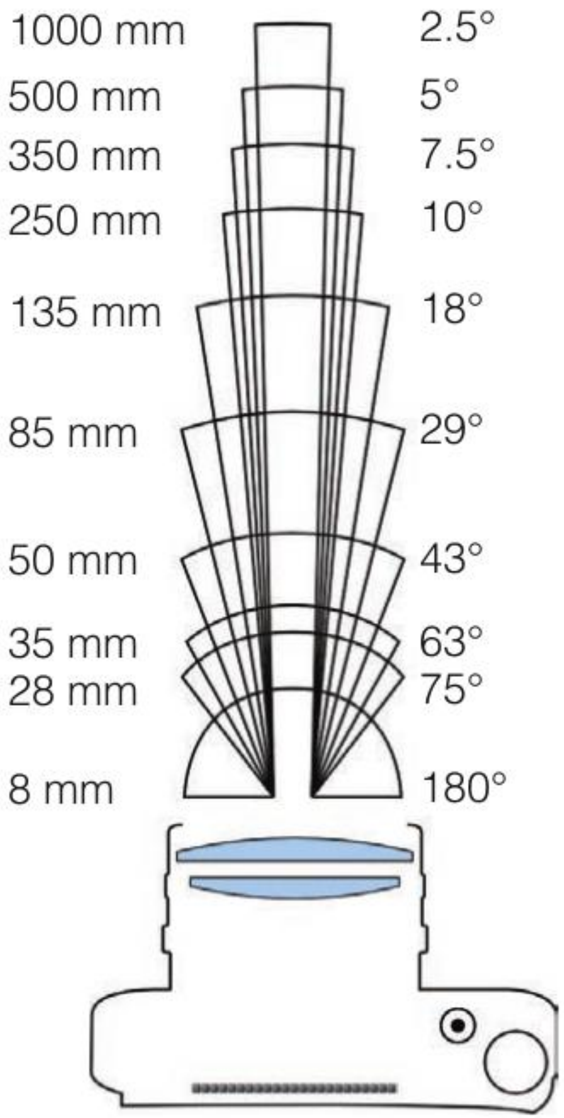
Note: here I drew a lens, but I could have just as well drawn a pinhole

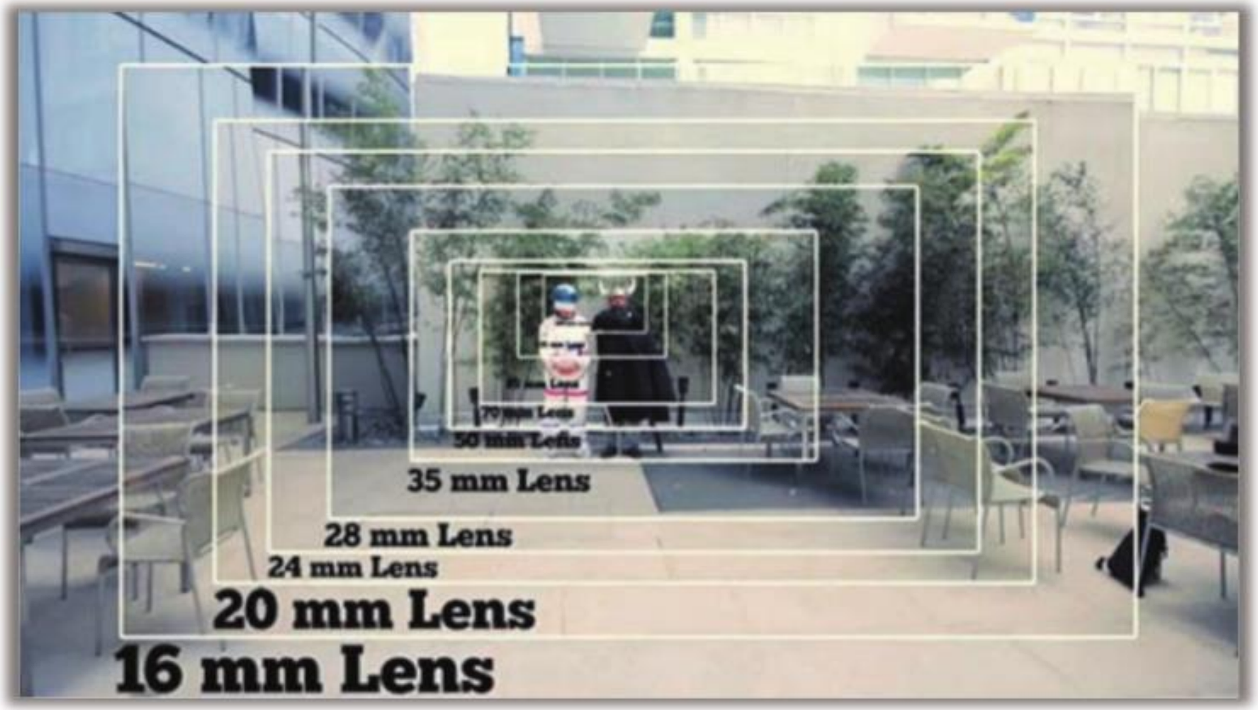
Field of View (Continue)



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

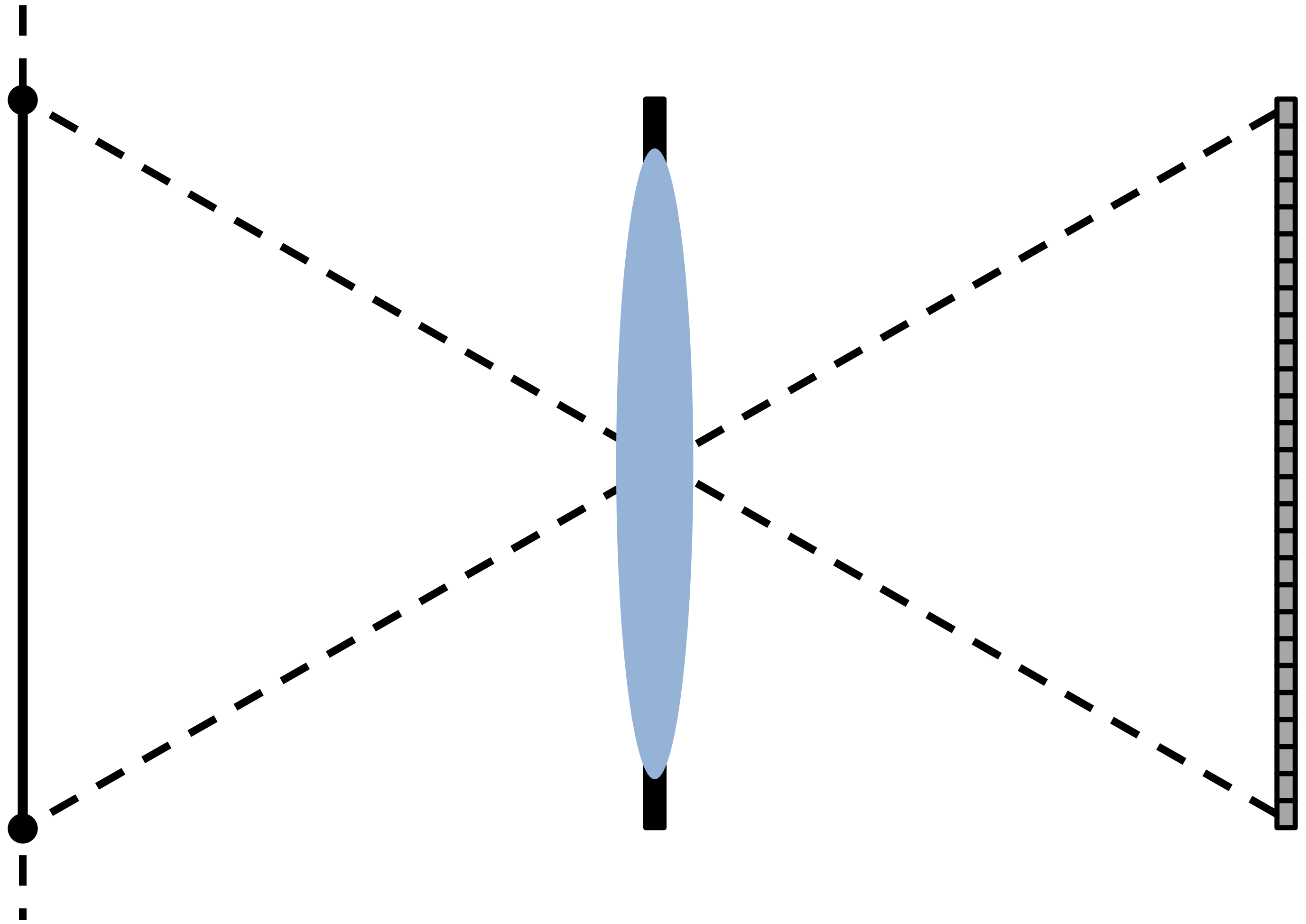
Field of View (Continue)





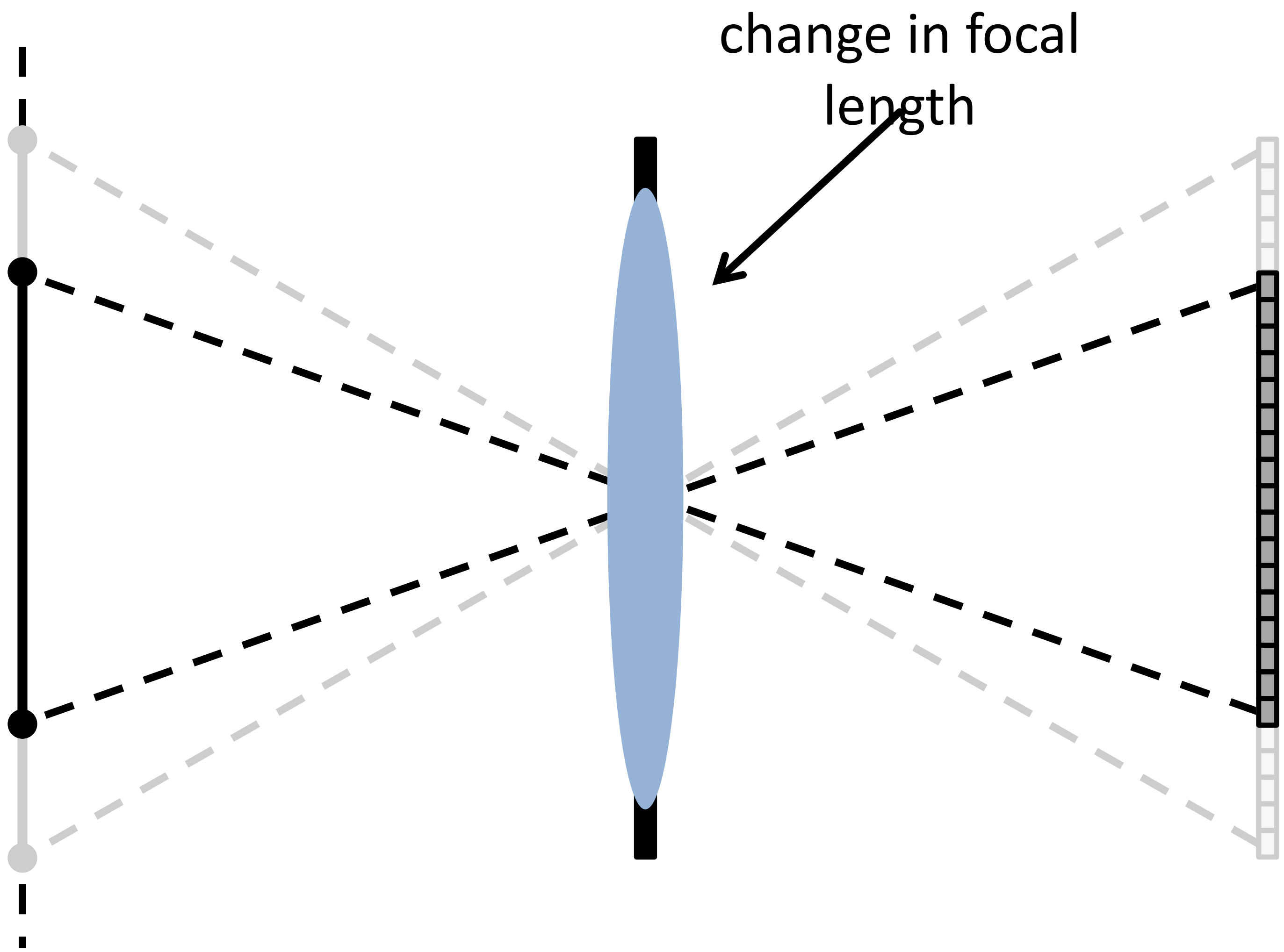
Andrew McWilliams

Field of View Depending on Sensor Size



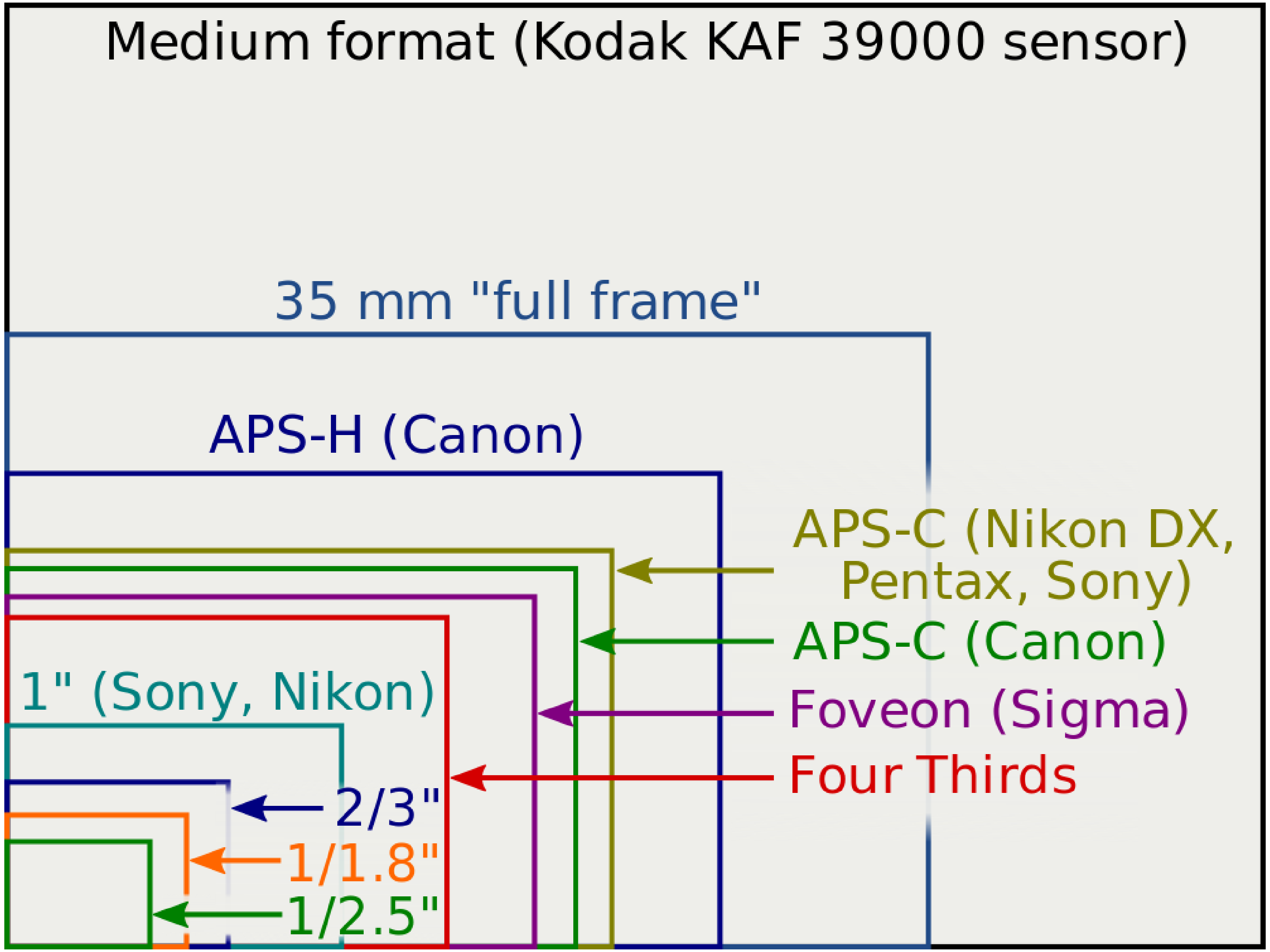
- What happens to field of view when we reduce sensor size?

Field of View Depending on Sensor Size



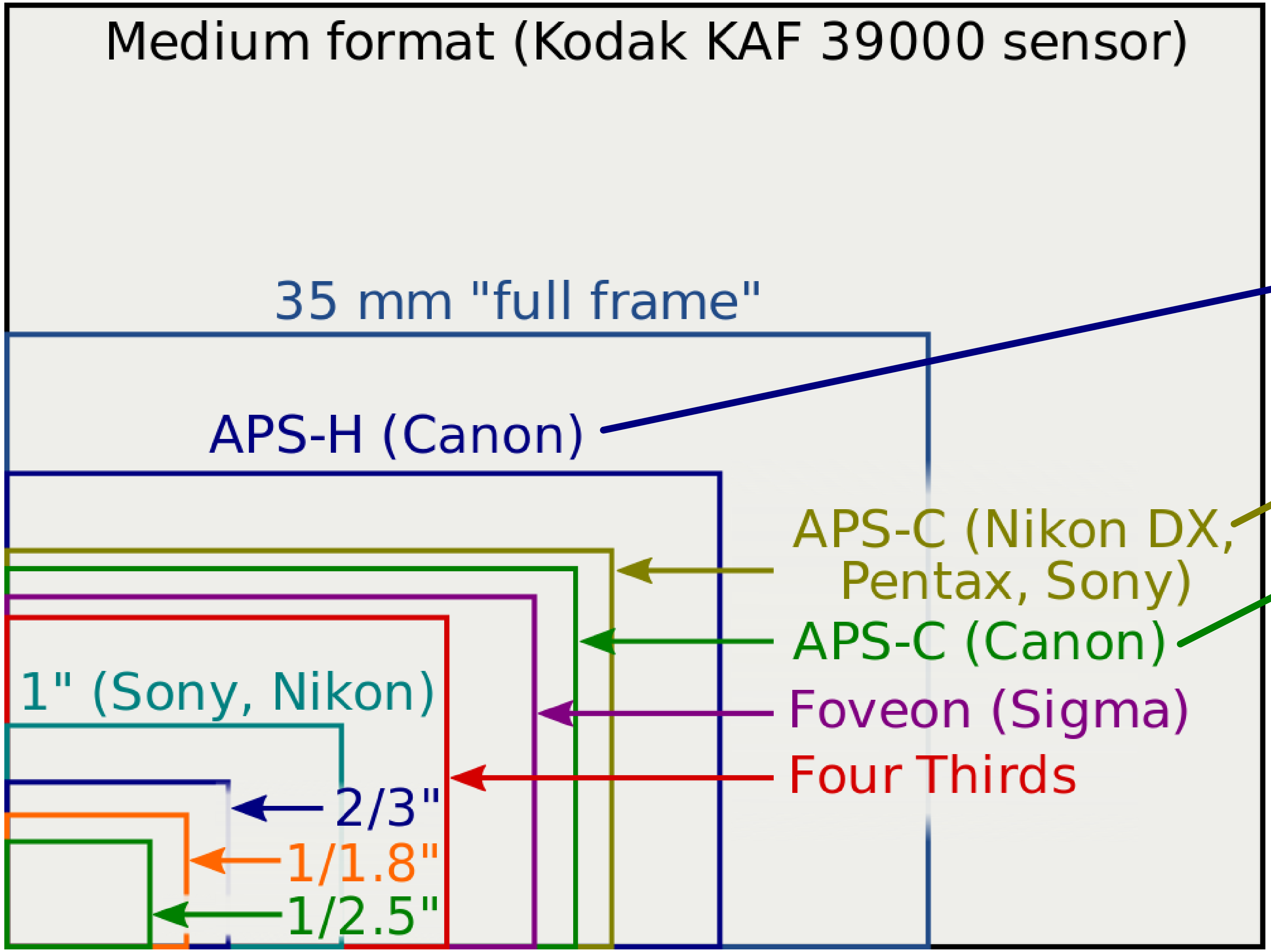
- What happens to field of view when we reduce sensor size? → It decreases.

Field of View Depending on Sensor Size



- “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



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

Example: Camera Obscura

I made my first picture using camera obscura techniques in my darkened living room in 1991. In setting up a room to make this kind of photograph, I cover all windows with black plastic in order to achieve total darkness. Then, I cut a small hole in the material I use to cover the windows. This opening allows an inverted image of the view outside to flood onto the back walls of the room. Typically then I focused my large-format camera on the incoming image on the wall then make a camera exposure on film. In the beginning, exposures took from five to ten hours.

Over time, this project has taken me from my living room to all sorts of interiors around the world. One of the satisfactions I get from making this imagery comes from my seeing the weird and yet natural marriage of the inside and outside.

Several years ago, in order to push the visual potential of this process, I began to use color film and positioned a lens over the hole in the window plastic in order to add to the overall sharpness and brightness of the incoming image. Now, I often use a prism to make the projection come in right side up. I have also been able to shorten my exposures considerably thanks to digital technology, which in turn makes it possible to capture more momentary light. I love the increased sense of reality that the outdoor has in these new works .The marriage of the outside and the inside is now made up of more equal partners.

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

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

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