CMPE 362
Digital Image Processing

Image Formation

Asst. Prof. Dr. Aslı Gençtav
Department of Computer Engineering
TED University

Imaging Process

- Light reaches surfaces in 3D.
- Surfaces reflect.
- Sensor element receives light energy.

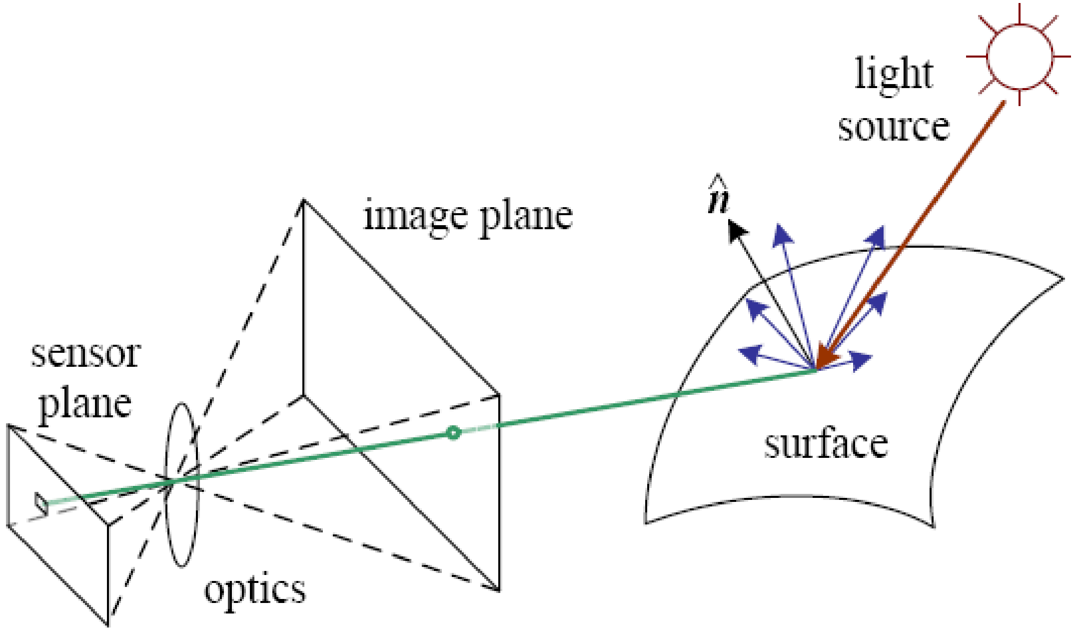


Image from Computer Vision: Algorithms and Applications by R. Szeliski, Springer, 2010

Physical parameters

- Geometric
  - Type of projection
  - Camera pose
- Optical
  - Sensor's lens type
  - Focal length, aperture
- Photometric
  - Type, direction, intensity of light reaching sensor
  - Surfaces' reflectance properties
- Sensor
  - Sampling, etc.

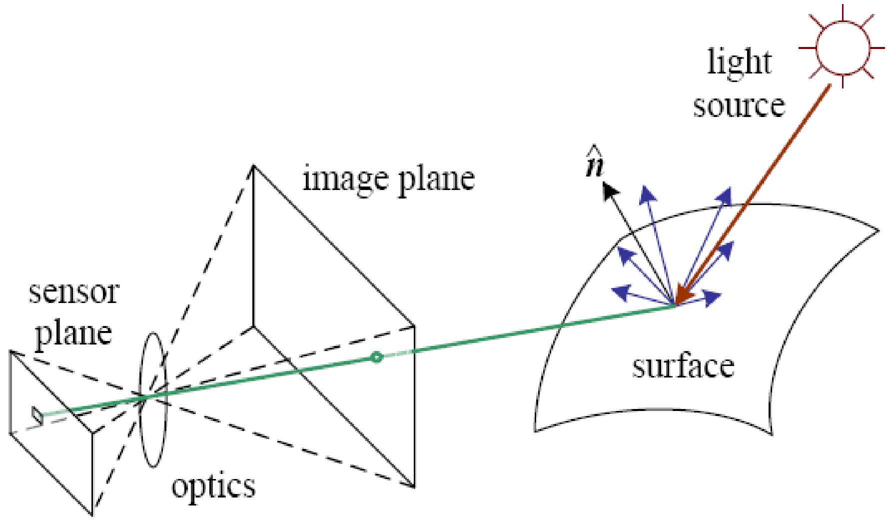


Image from Computer Vision: Algorithms and Applications by R. Szeliski, Springer, 2010

Adapted from Trevor Darrell, UC Berkeley

Image acquisition

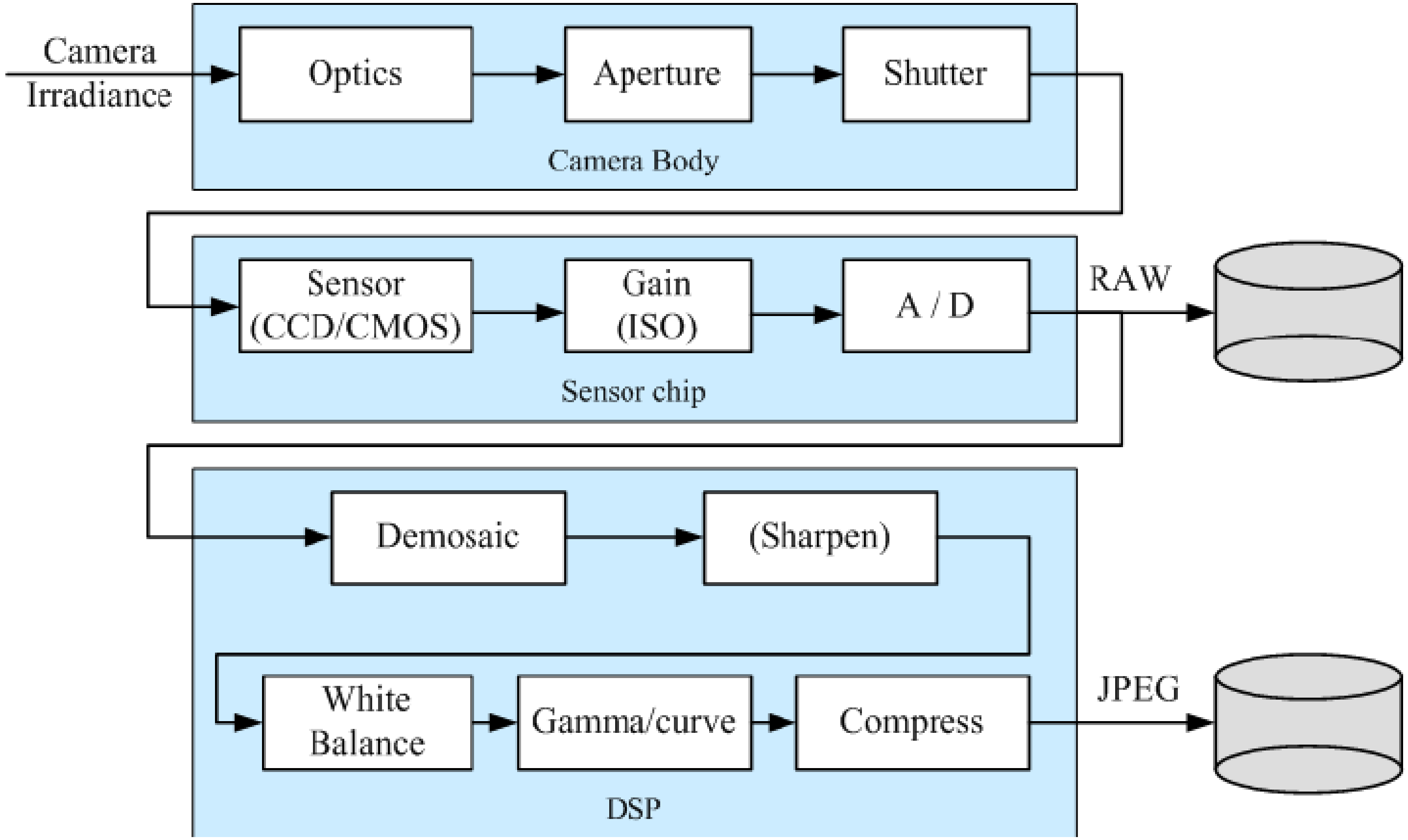


Figure 2.26: *Image sensing pipeline, showing the various sources of noise as well as the typical digital post-processing steps.*

Figure from Computer Vision: Algorithms and Applications by R. Szeliski, Springer, 2010

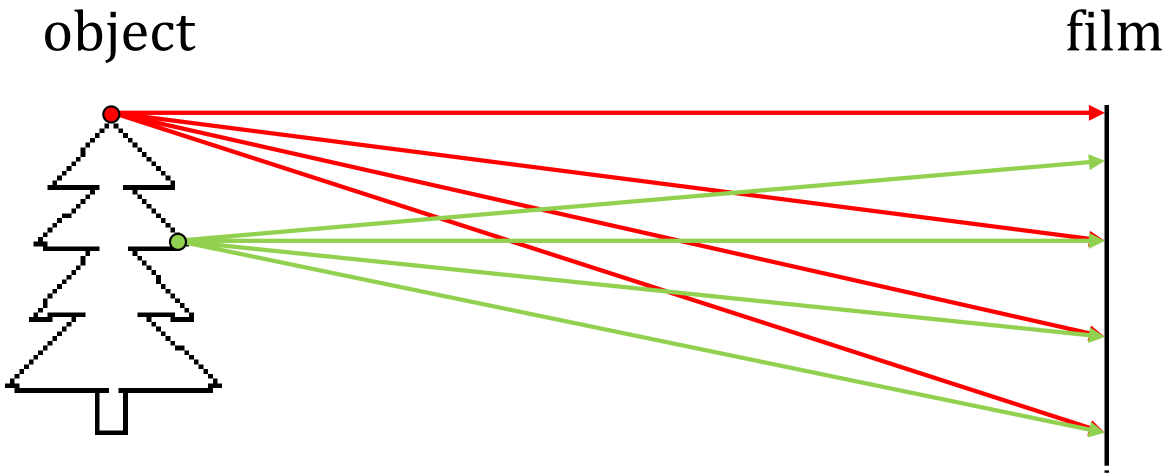
Let’s design a camera

Poll 1

Idea 1: put a piece of film (or sensor) in front of an object

Do we get a reasonable image?

Let’s design a camera



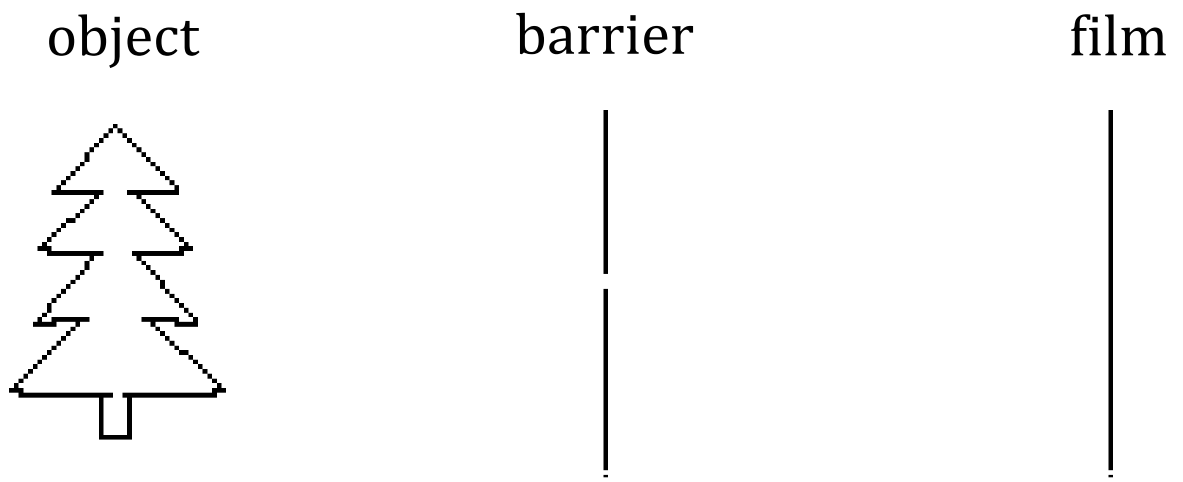
Idea 1: put a piece of film (or sensor) in front of an object

Do we get a reasonable image?

No, the film receives light from all directions.

Let’s design a camera

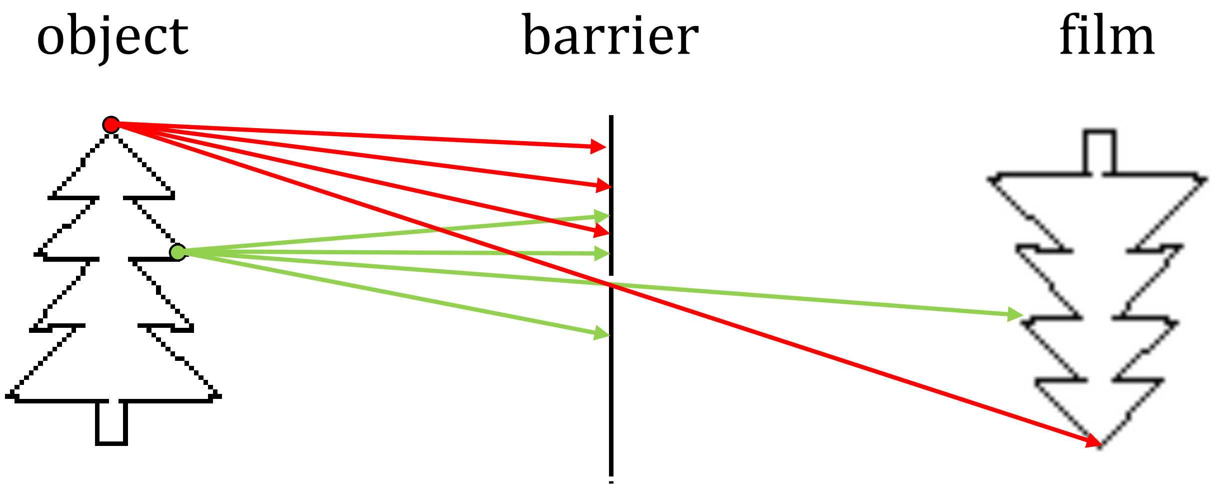
Poll 2



Idea 2: Add a barrier to block off most of the rays

Do we get a reasonable image?

Pinhole camera

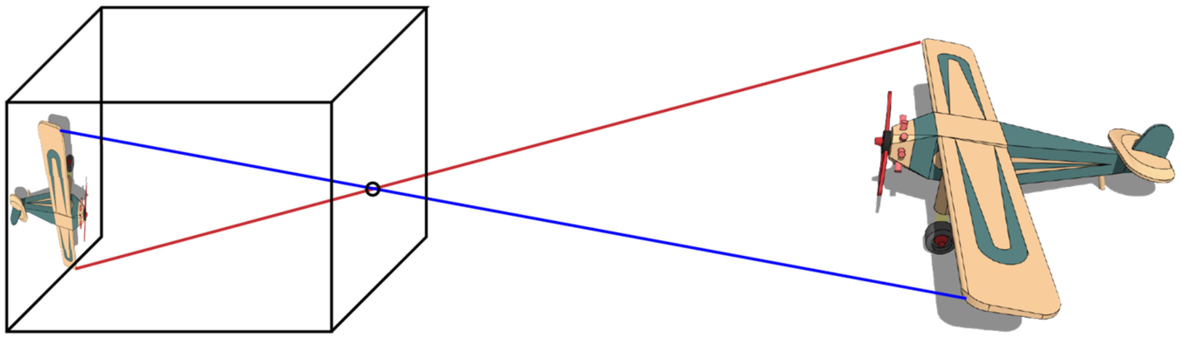


Idea 2: Add a barrier to block off most of the rays

Captures all rays through a single point.

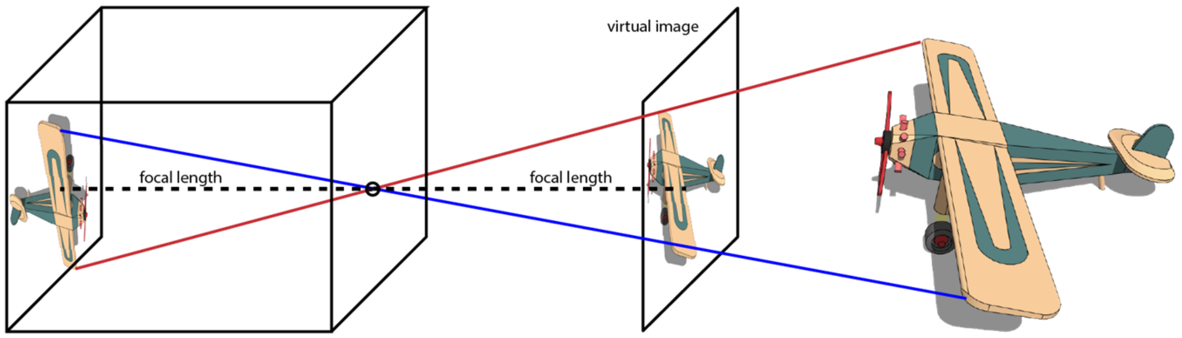
The image is formed on the image plane.

Model: pinhole camera



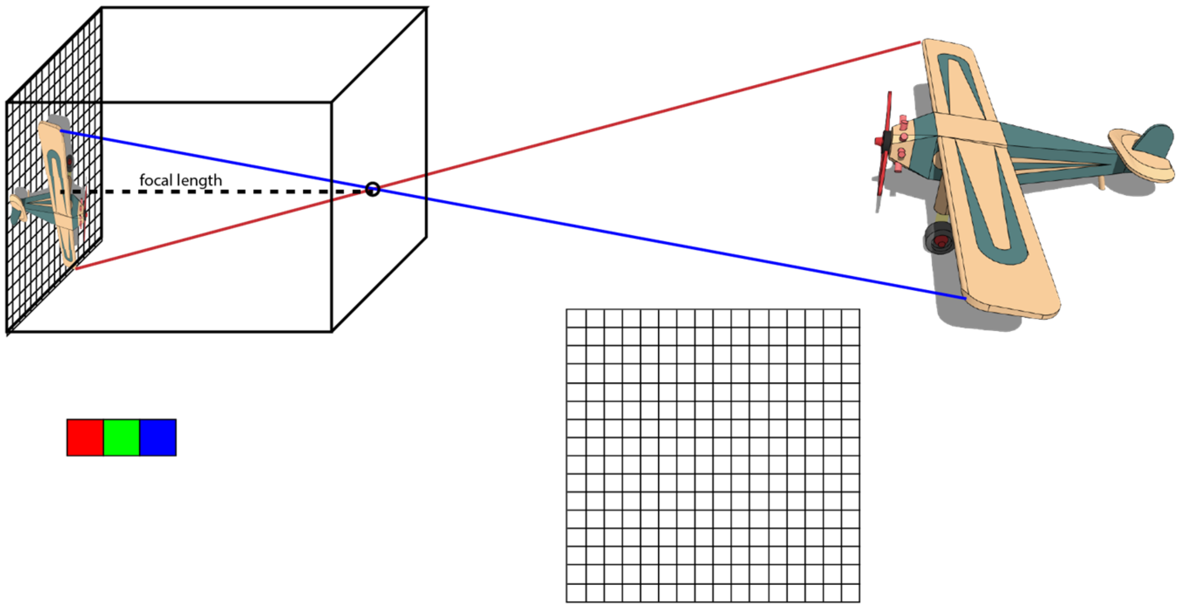
Adapted from Joseph Redmon, U of Washington

Model: pinhole camera



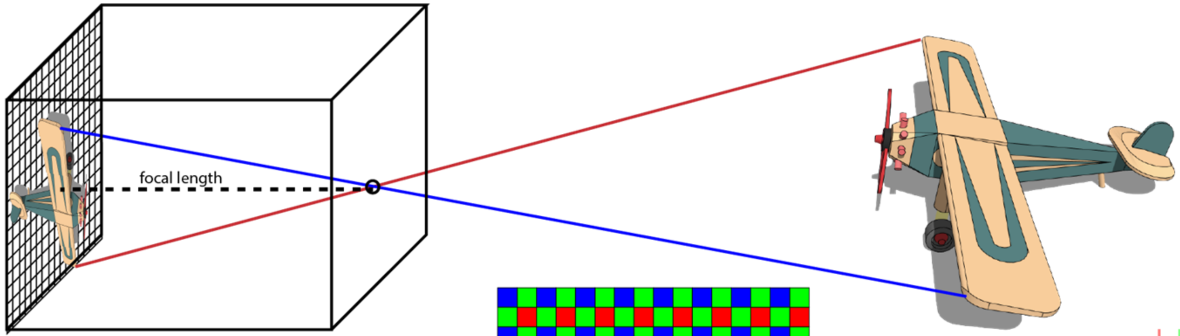
Adapted from Joseph Redmon, U of Washington

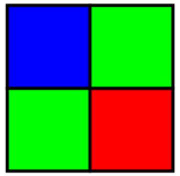
How do we record color?

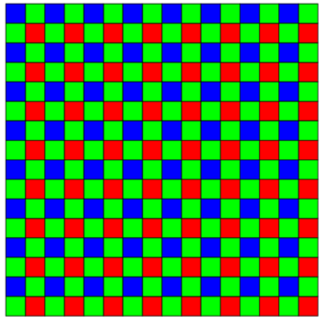


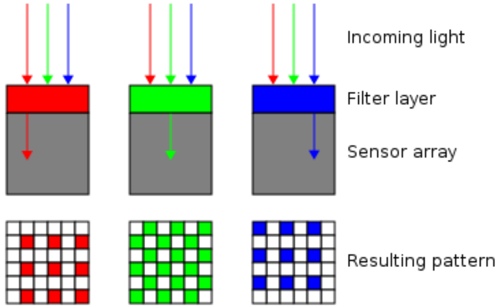
Adapted from Joseph Redmon, U of Washington

How do we record color?







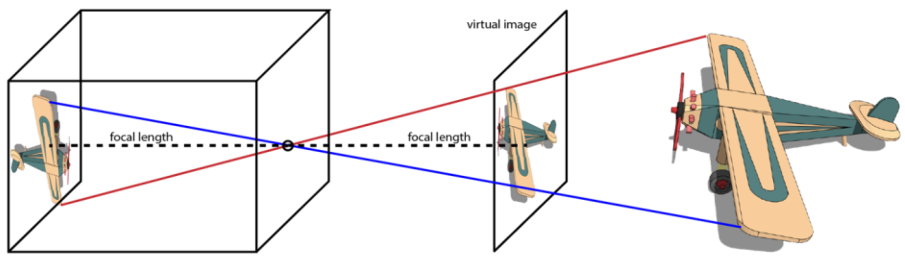


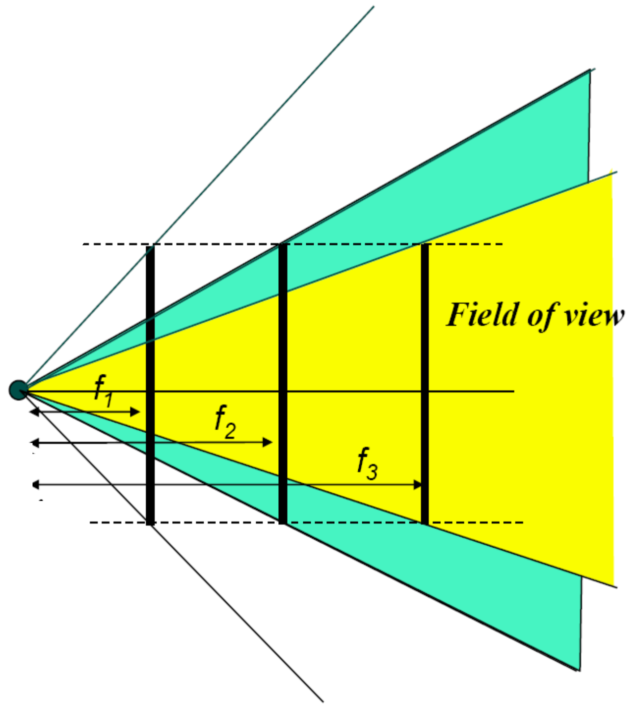
Bayer pattern for CMOS sensors

Adapted from Joseph Redmon, U of Washington

Focal length

- Field of view depends on focal length.
- As f gets smaller, image becomes more wide angle
  - more world points project onto the finite image plane
- As f gets larger, image becomes more telescopic
  - smaller part of the world projects onto the finite image plane



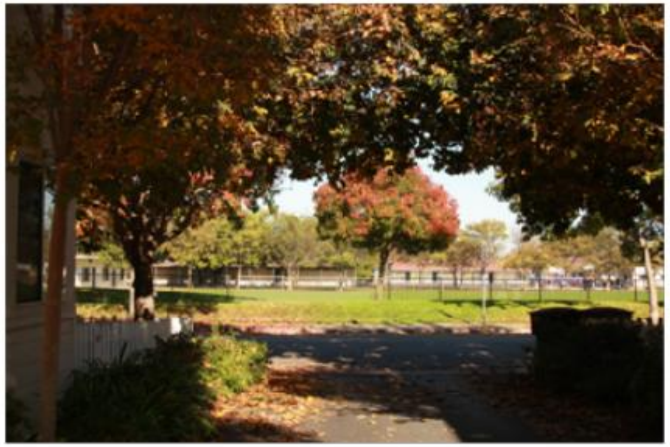


Adapted from Trevor Darrell, UC Berkeley

Focal length

Poll 3

A



B

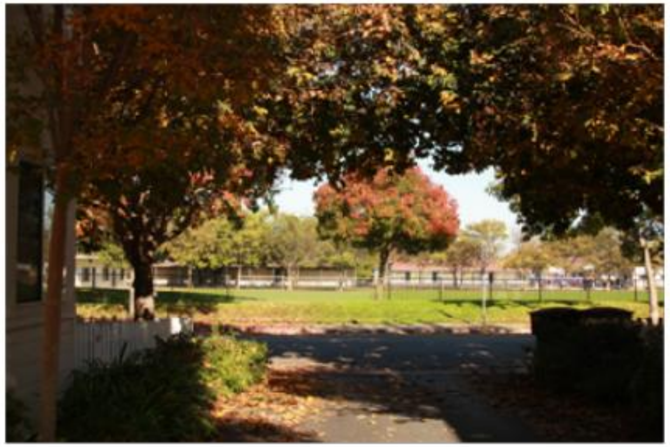
C

D

Adapted from Matthew Brown, U of Washington

Focal length

A



28 mm

B

35 mm

C

50 mm

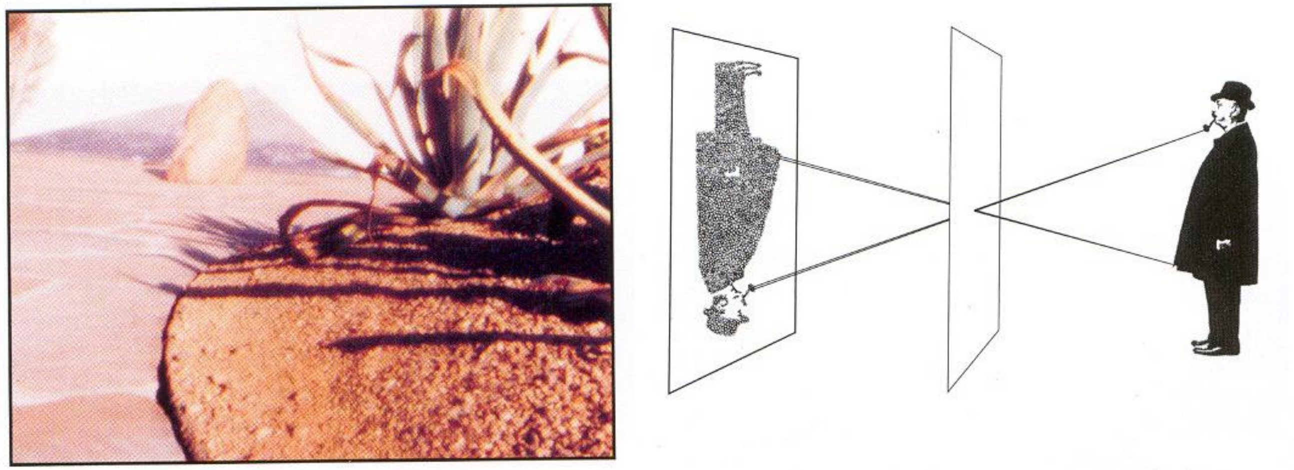
D

70 mm

Adapted from Matthew Brown, U of Washington

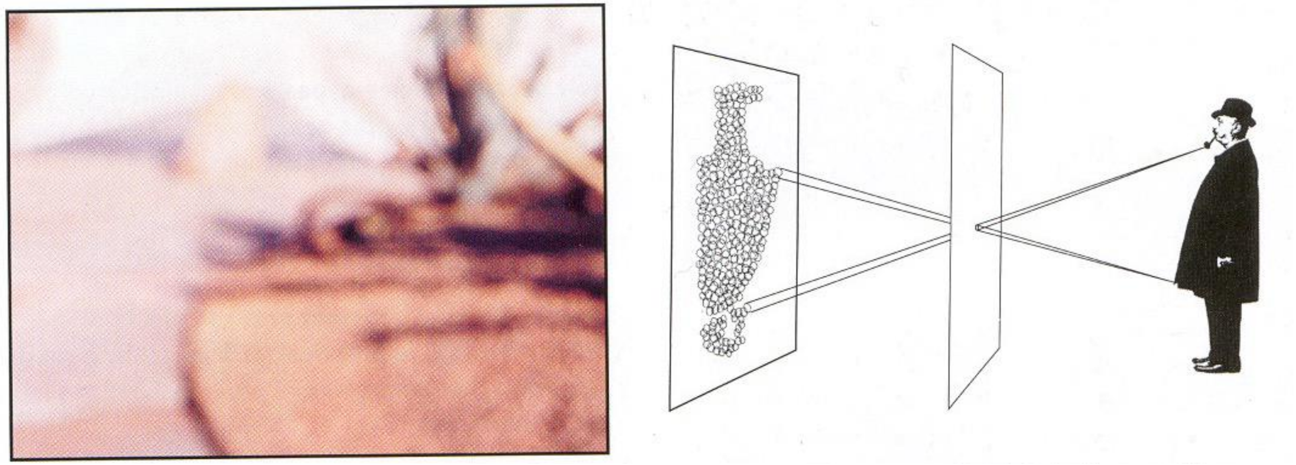
Aperture

Photograph made with small pinhole



Small aperture
- Sharp but hard to collect enough light

Photograph made with larger pinhole

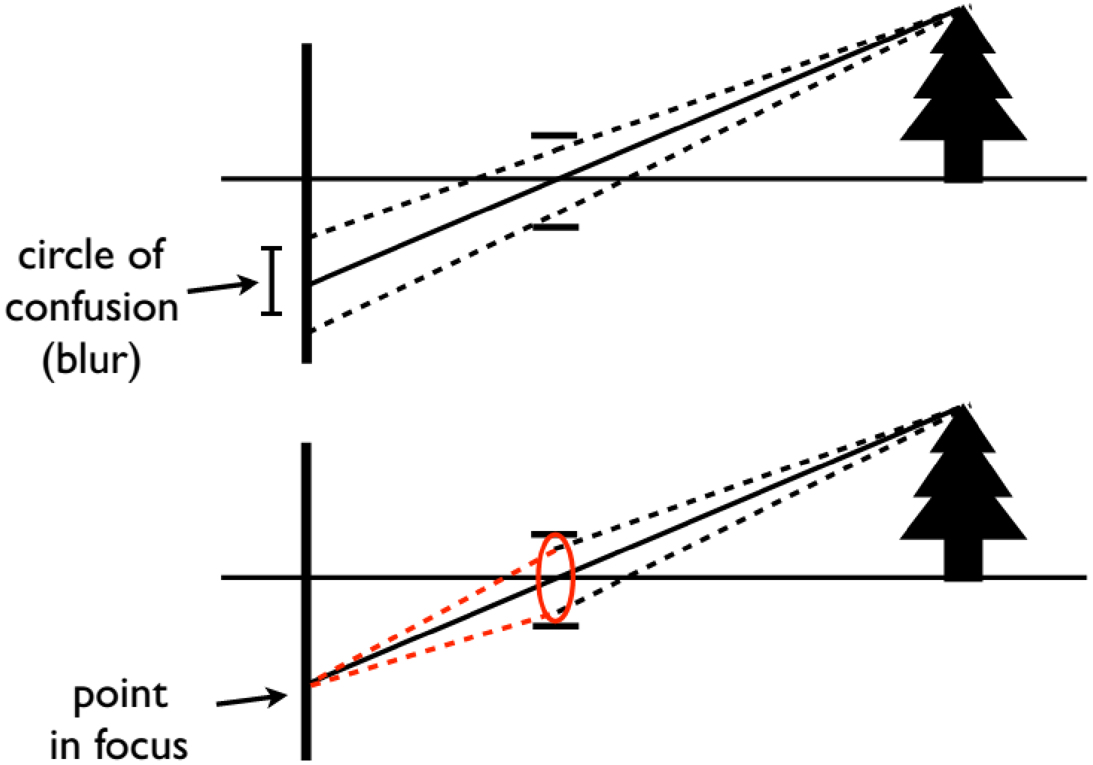


Larger aperture
- Blur

From Photography, London et al.

Aperture

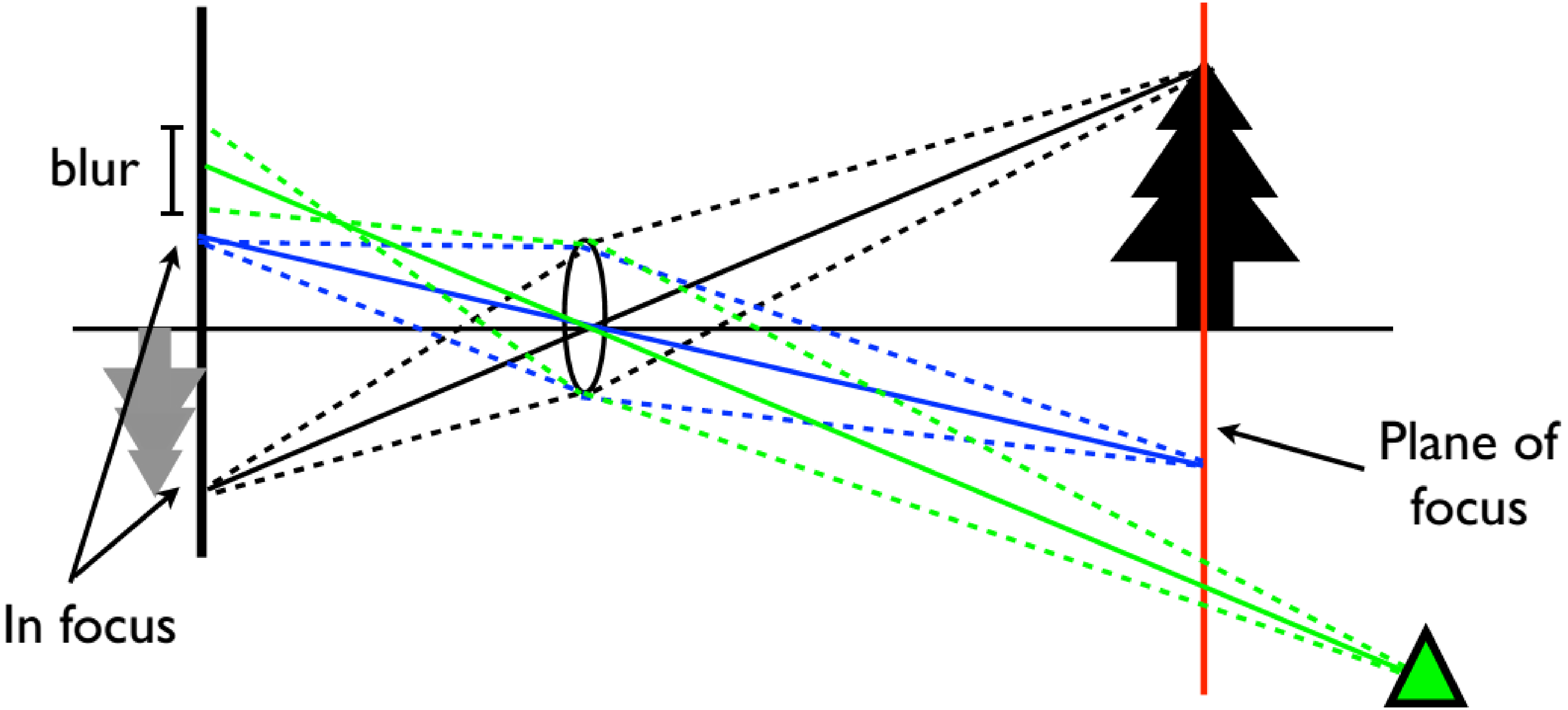
- A real camera must have a finite aperture to get enough light, but this causes blur in the image



- Solution: use a lens to focus light onto the image plane

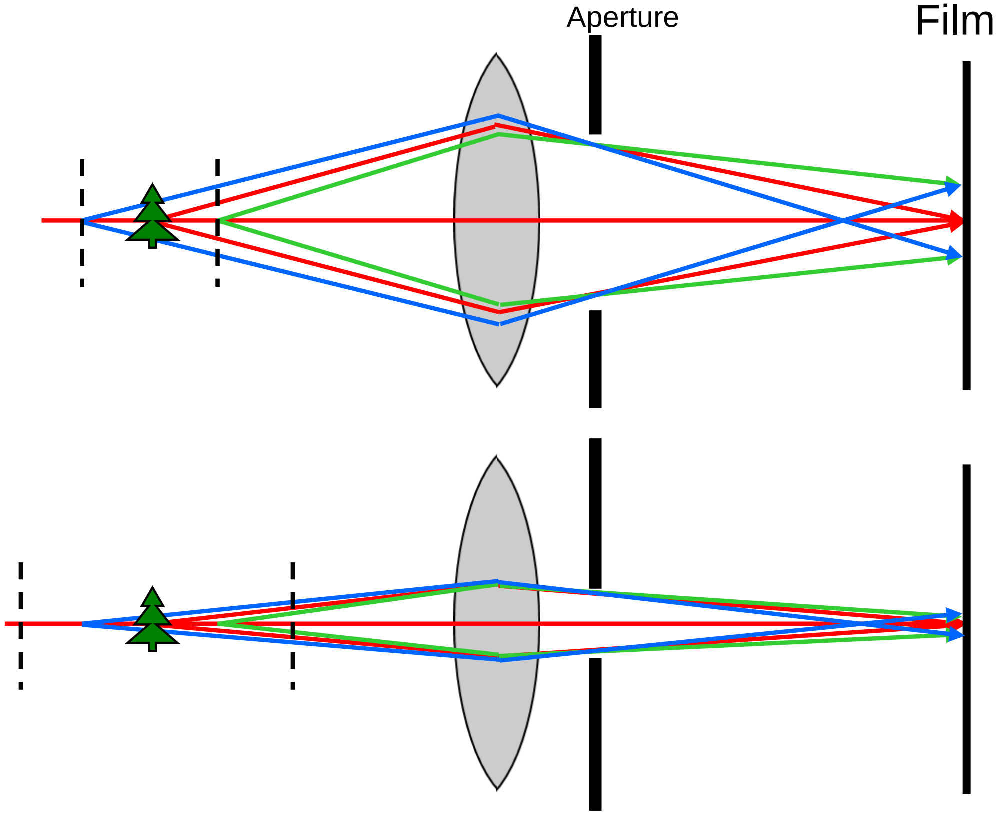
Aperture

- Note that lenses focus all rays from a plane in the world
- Objects off the plane are blurred depending on distance



Adapted from Matthew Brown, U of Washington

Aperture



f / 5.6

f / 32

- Changing the aperture size affects depth of field → the range in which the object is approximately in focus
  - A smaller aperture increases depth of field

Aperture

Poll 4

A B C D

Adapted from Matthew Brown, U of Washington

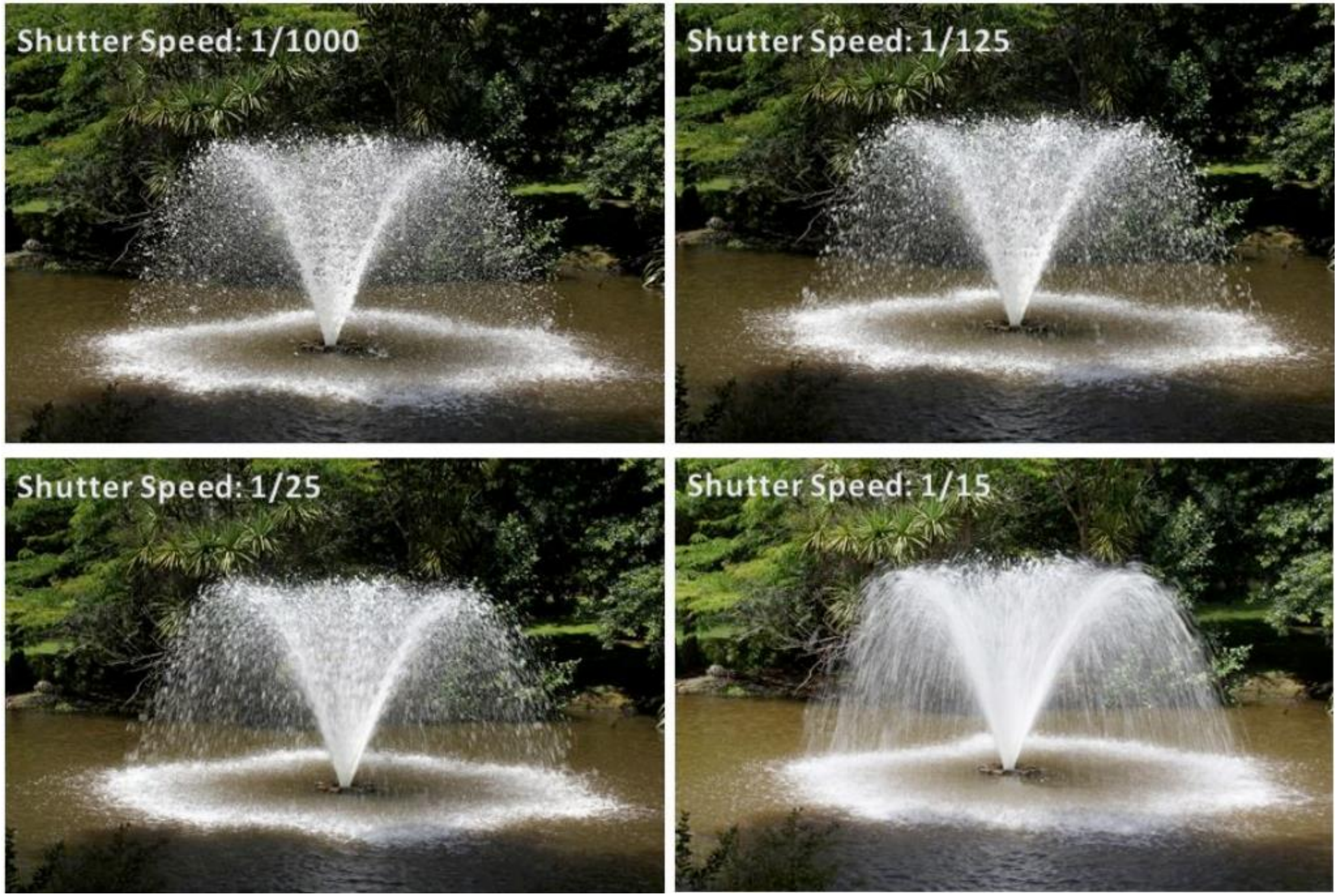
Aperture

- Smaller aperture → smaller blur, larger depth of field

A **B** **C** **D**

Adapted from Matthew Brown, U of Washington

Shutter speed



Adapted from Matthew Brown, U of Washington

Sampling and quantization

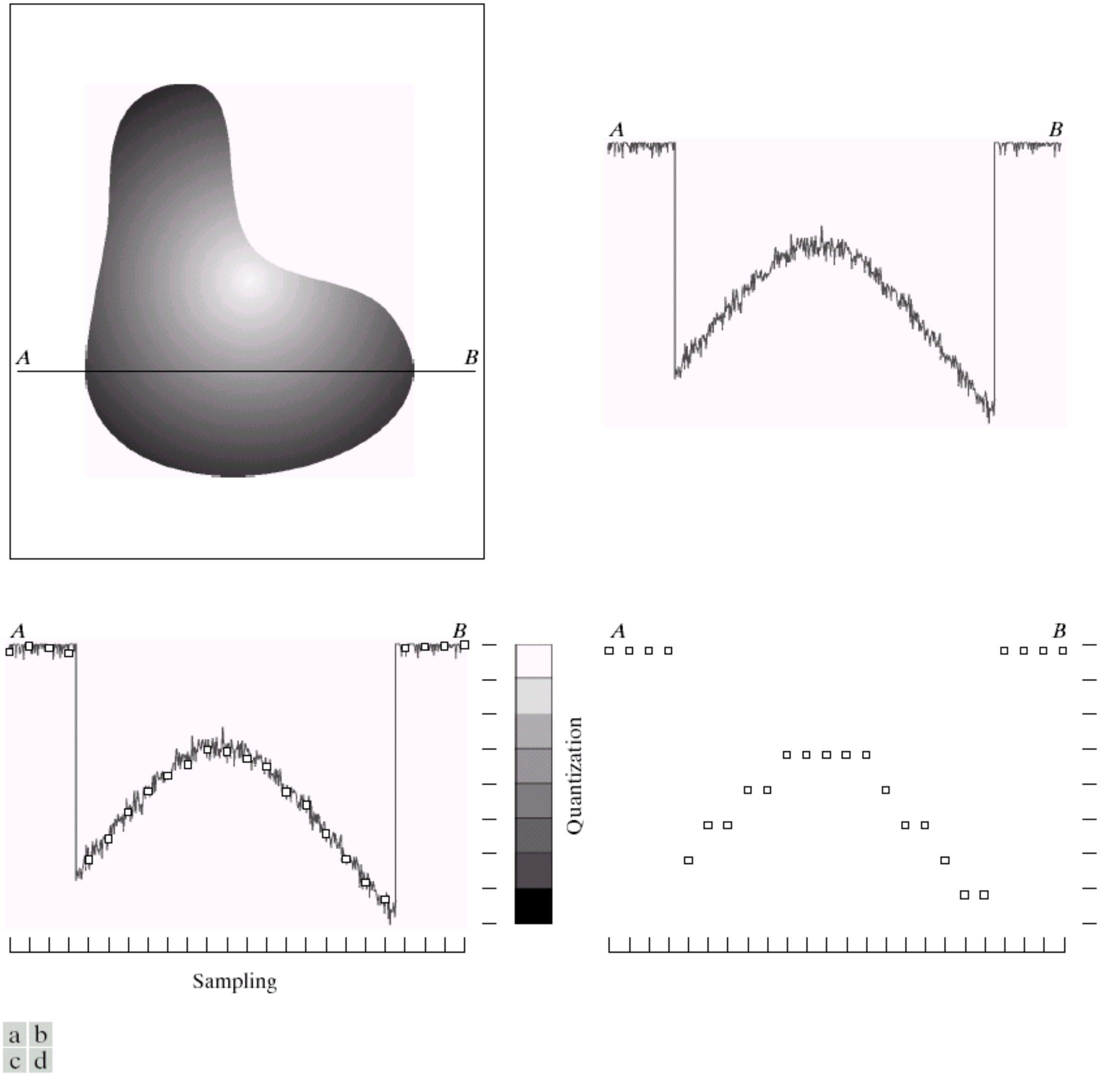
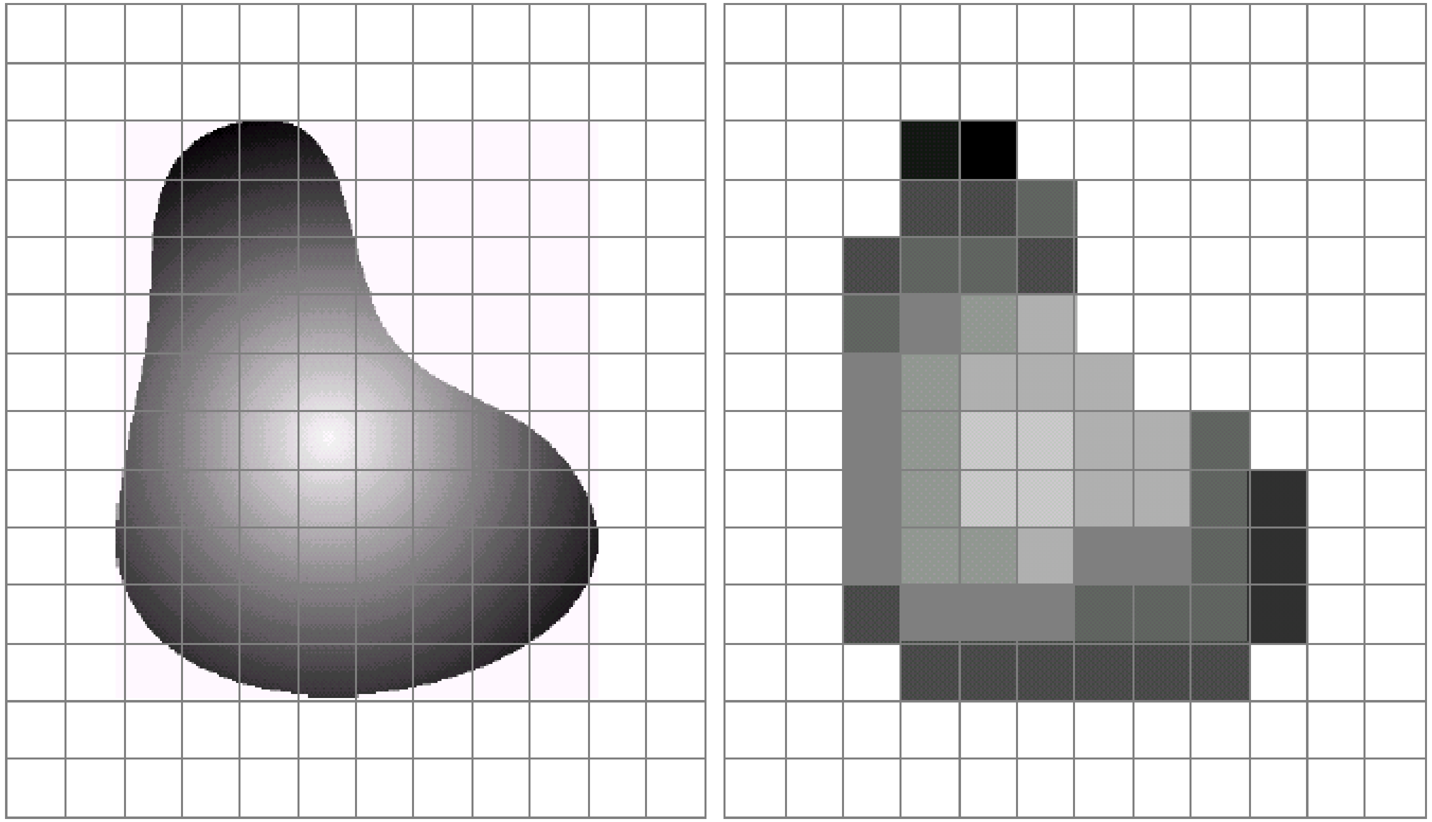


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling and quantization



a b

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Spatial resolution

- Spatial resolution is the smallest discernible detail in an image.
- Sampling is the principal factor determining spatial resolution.

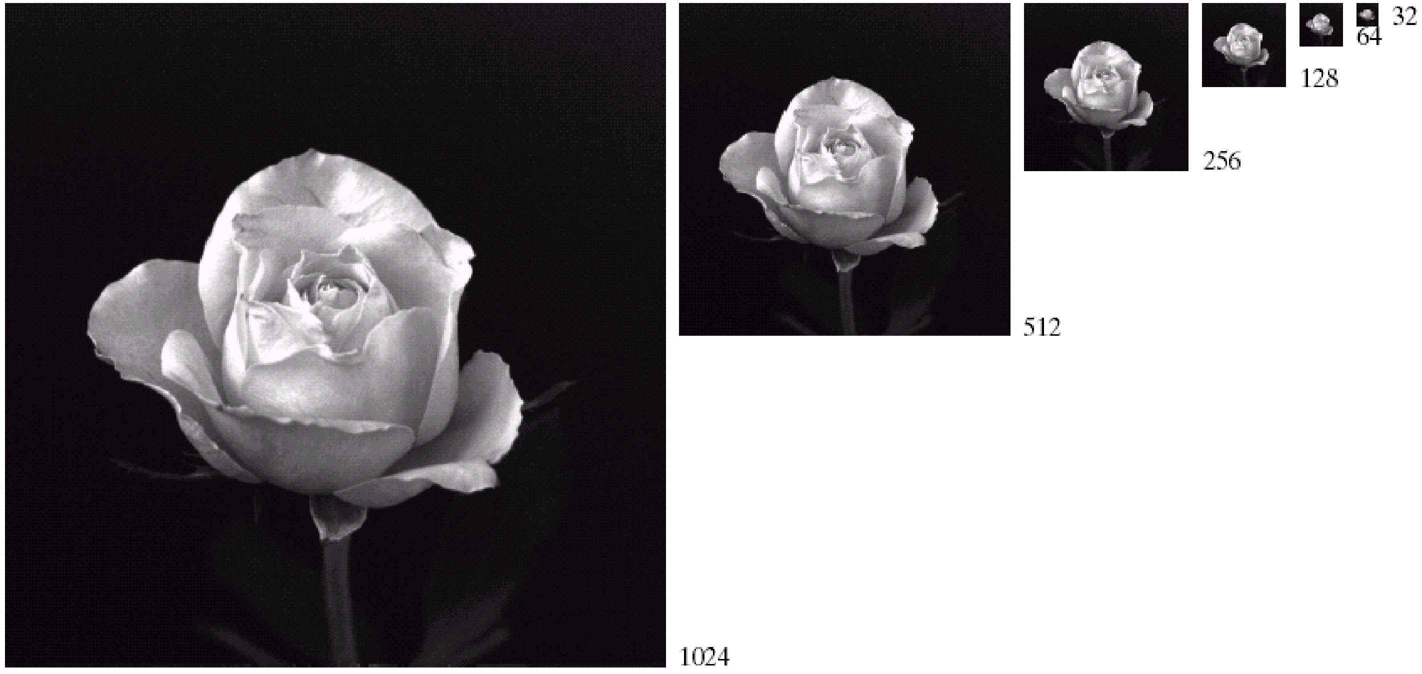
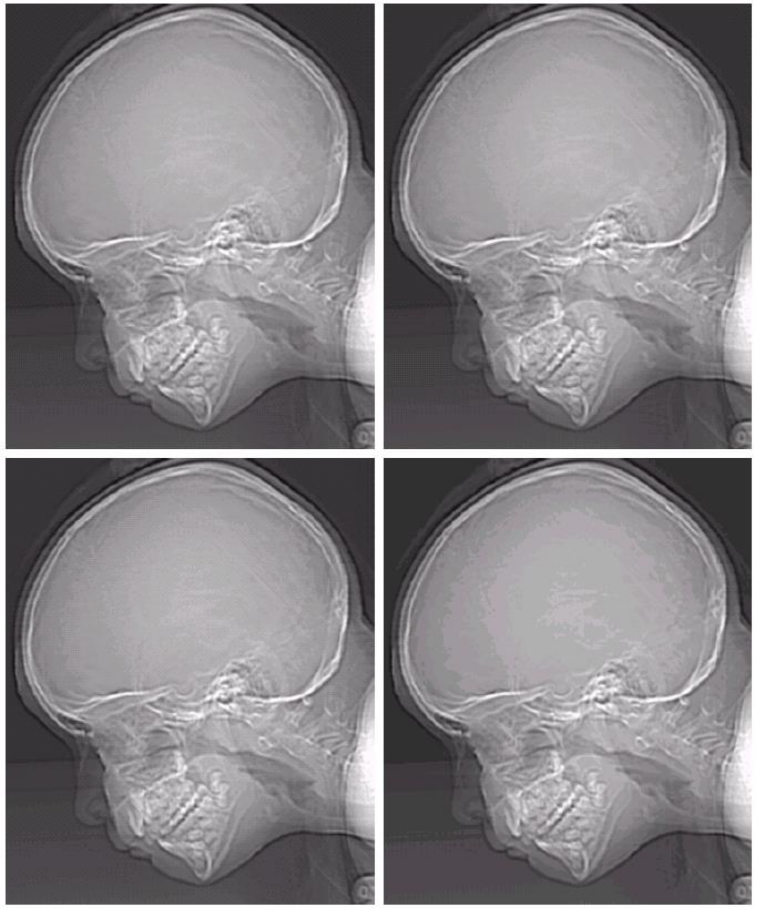


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Gray level resolution

- Gray level resolution refers to the smallest discernible change in gray level (often power of 2).

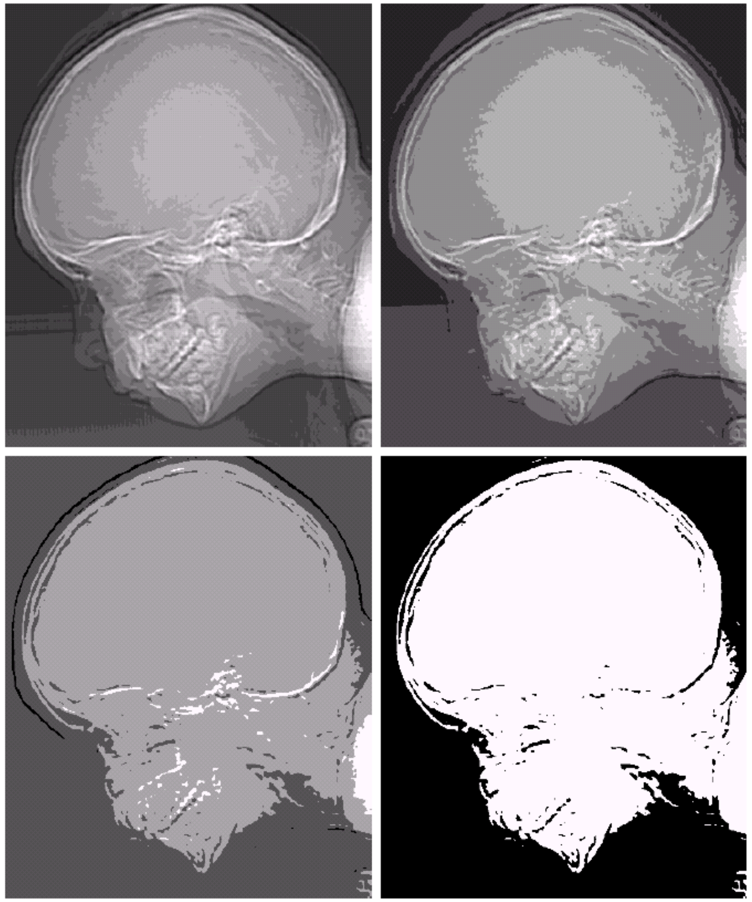


a b
c d

FIGURE 2.21
(a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

e f
g h

FIGURE 2.21
(Continued)
(e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)



Data types for raster images

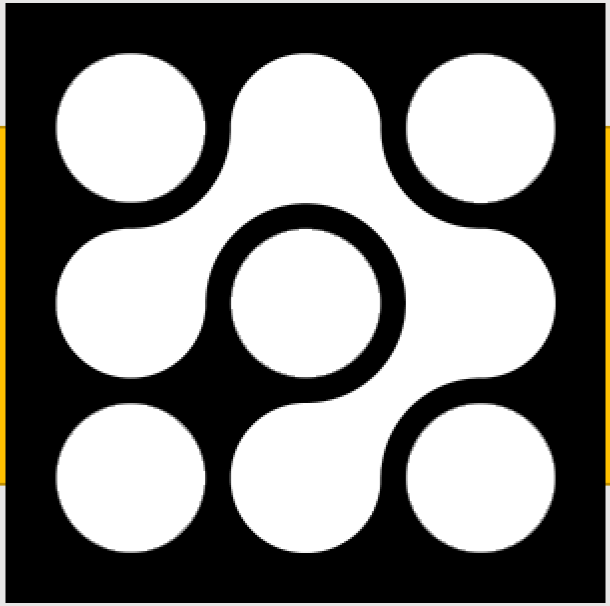
- Bitmaps: boolean per pixel (1 bpp) $I: R^2 \to \{0,1\}$
  - interpretation: black and white
- Grayscale: integer per pixel $I: R^2 \to [0,1]$
  - interpretation: shades of gray
  - precision: usually 1 byte (8 bpp); sometimes 10, 12, or 16 bpp
- Color: 3 integers per pixel $I: R^2 \to [0,1]^3$
  - interpretation: full range of displayable color
  - precision: usually byte[3] (24 bpp); sometimes 16 (5+6+5) or 30 or 36 or 48 bpp
- Floating point: $I: R^2 \to R_+$ or $I: R^2 \to {R_+}^3$
  - more abstract, because no output device has infinite range
  - provides high dynamic range (HDR)
  - represent real scenes independent of display

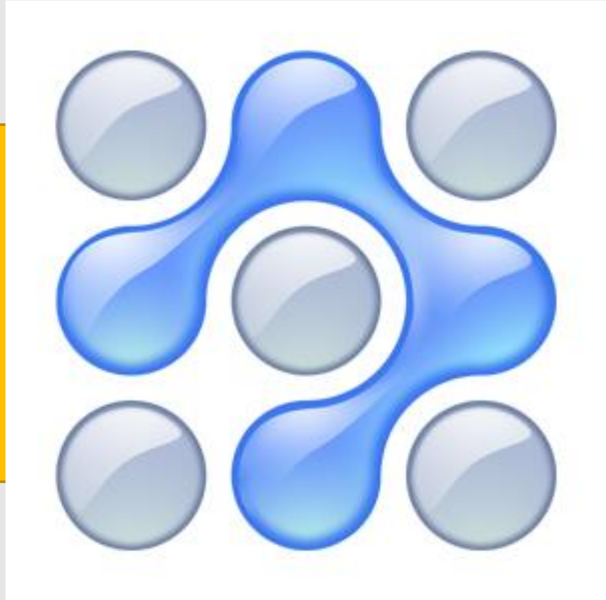
Intensity encoding in images

- What do the numbers in images (pixel values) mean?
  - they determine how bright that pixel is
  - bigger numbers are (usually) brighter

Datatypes for raster images

- For color or grayscale, sometimes alpha channel is added
  - describes transparency of images





Storage requirements for images

Poll 5

- 1024x1024 image (1 megapixel)
  - bitmap: 128KB
  - grayscale 8bpp: 1MB
  - grayscale 16bpp: 2MB
  - color 24bpp: 3MB
  - floating-point HDR color: 12MB