

14.08.2020

Digital Image Processing (CSE/ECE 478)

Lecture-2: Digital Imaging Fundamentals

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Announcements

- Teaching Assistants - TBA
- Tutorial hours: Saturday 4.00p – 4.45p (as needed, no session this week)

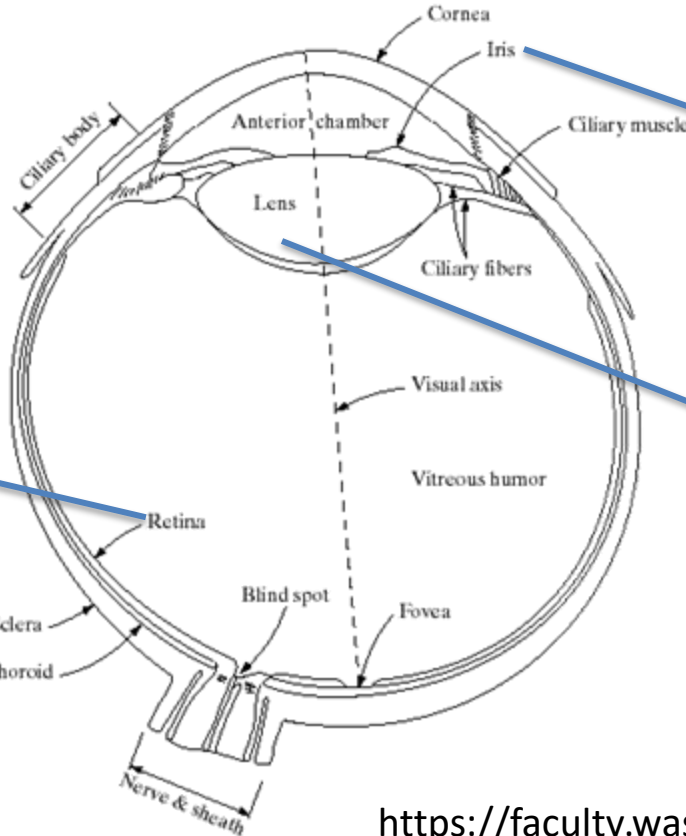
Elements of Visual Perception

- Often, consumers of Image Processing are humans.
- Important to understand basic workings of **human visual system**.

The Human Eye

Diameter: 20 mm

FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.



2-8mm width,
Contracts / Expands to
control amount of
light entering the eye

- Light is imaged on this
- Absorbs 8% of visible light spectrum
- IR, UV also absorbed

Reduces backscatter

The Retina

- The retina lines the entire backside portion.
- Discrete light receptors are distributed over the surface of the retina:
 - cones (6-7 million per eye)
 - rods (75-150 million per eye)

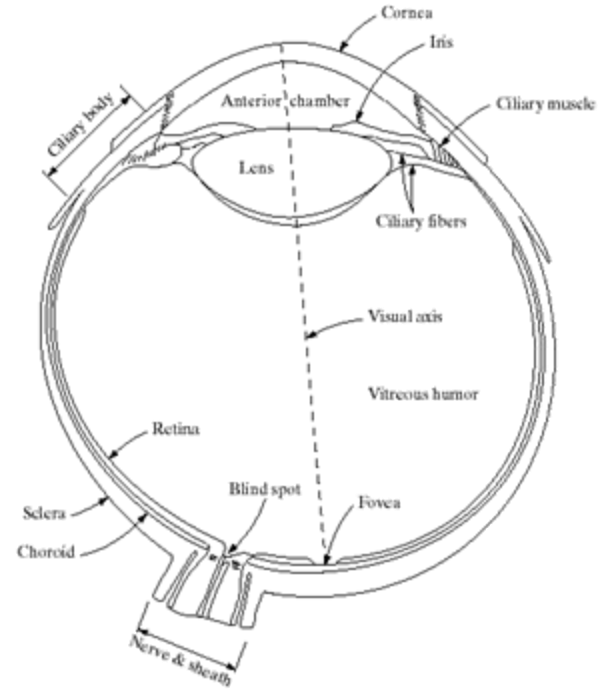


FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.

Cones

- Located in the fovea
- Sensitive to **color**
- Each cone connected to its own nerve end.
- Sensitive to bright-light: *photopic* vision

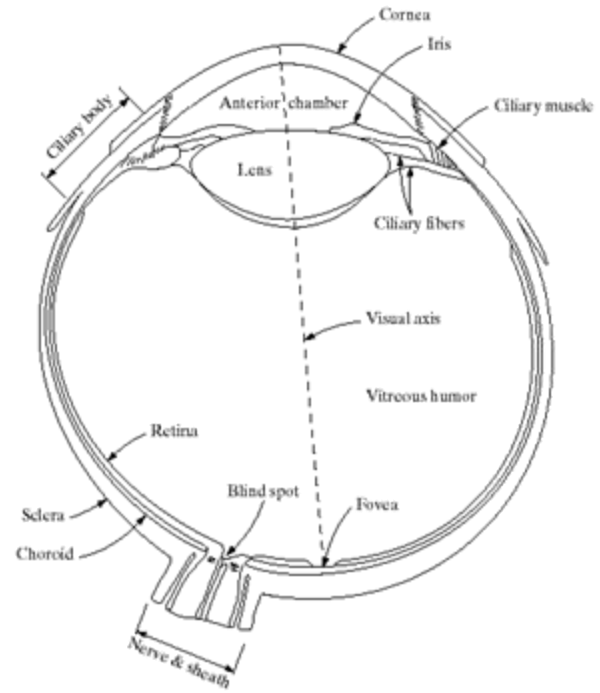
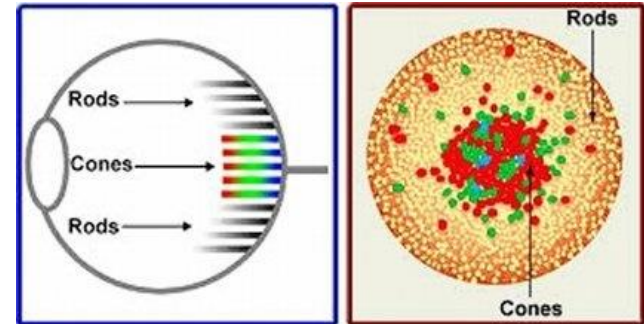


FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.



Rods

- Provide general, overall picture of the field of view
- Not involved in color vision.
- Several rods are connected to a single nerve.
- Sensitive to low illumination levels (*scotopic* vision).

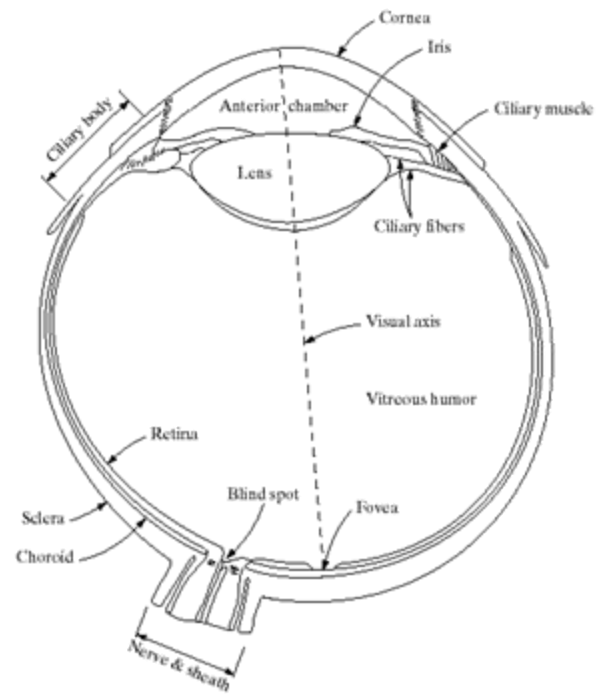
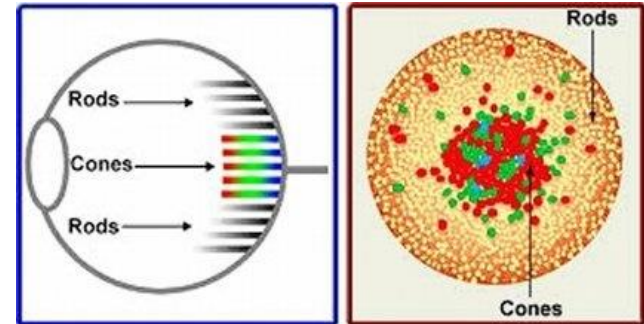


FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.



Receptor Distribution

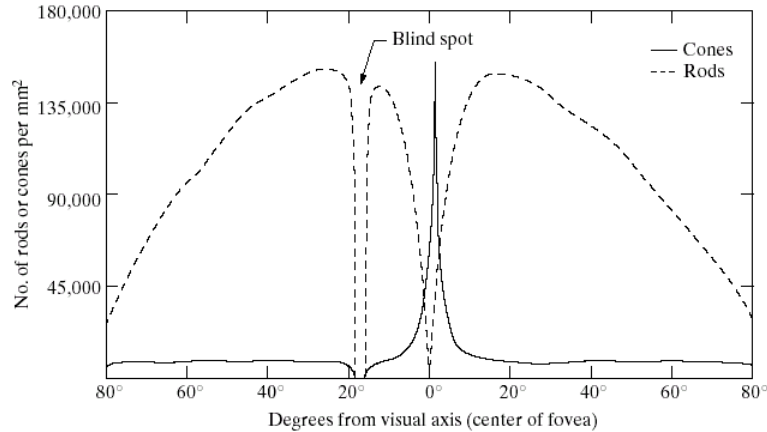


FIGURE 2.2
Distribution of rods and cones in the retina.

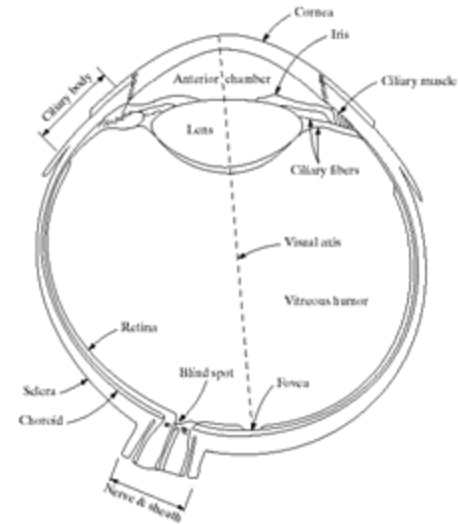


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

- Radially symmetric about the fovea.
- Cones are most dense in the center of the fovea
- Rods increase in density from the center to approximately 20% off axis and then decrease.

The Fovea

- Circular (1.5 mm diameter)
 - can be assumed to be a square sensor array (1.5 mm x 1.5 mm).
- Density of cones
 - 150,000 elements/mm² ~ 337,000
 - A CCD imaging chip of medium resolution needs 5 mm x 5 mm for this number of elements

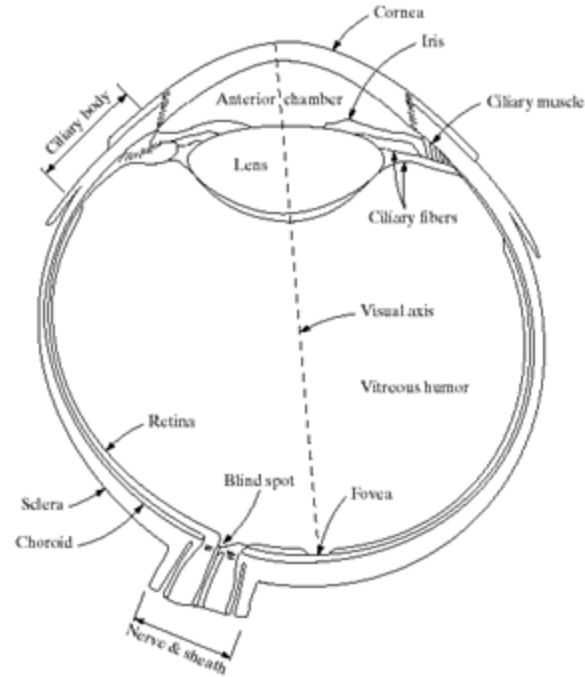
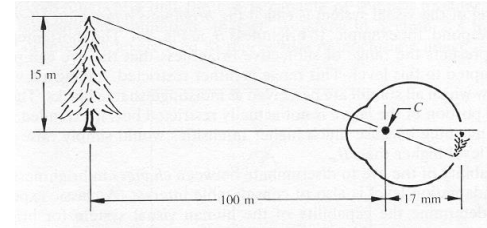


FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.

Image Formation in the Eye

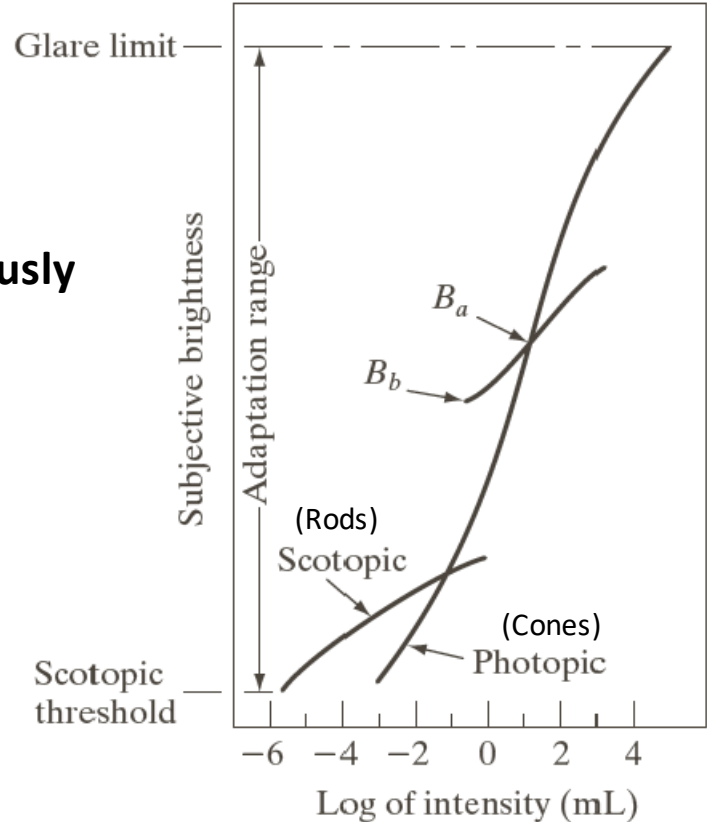
- Eye lens (compared to an optical lens) is flexible.



- Lens controlled by fibers of ciliary body
 - To focus on distant objects, it gets flatter (and vice versa)
 - Focal length varies from 14-17 mm

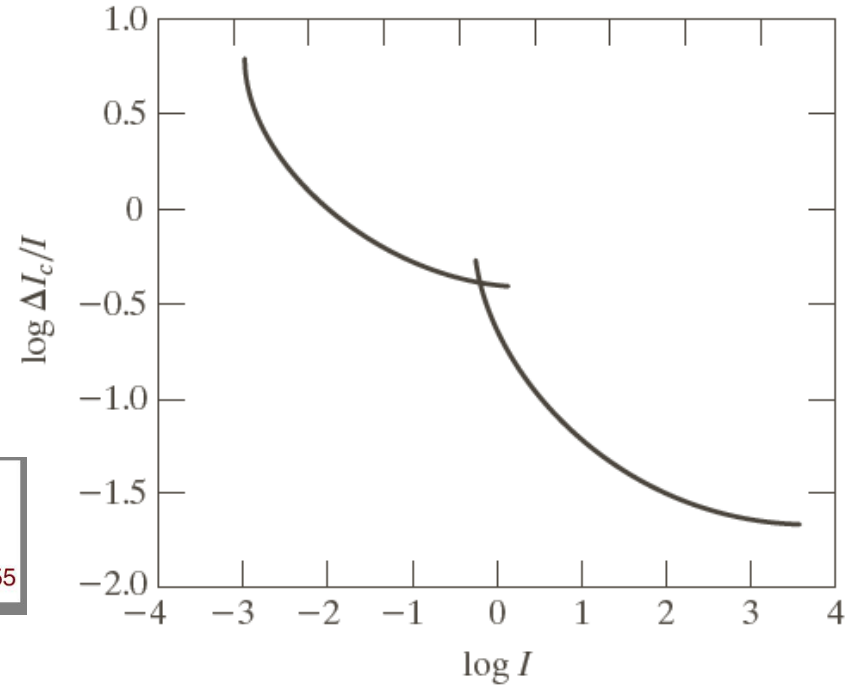
Brightness adaptation

- Dynamic range of human visual system (HVS)
 - $10^{-6} \sim 10^4$
- But HVS cannot accomplish this range **simultaneously**



Brightness discrimination

- Weber ratio (the experiment) $\Delta I_c / I$
 - I : the background illumination
 - ΔI_c : the increment of illumination
 - Small Weber ratio \rightarrow good discrimination
 - Larger Weber ratio \rightarrow poor discrimination



https://www.youtube.com/watch?v=hWT_LO8U7uE

<https://www.youtube.com/watch?v=wVhiezByMSU>: an audio example

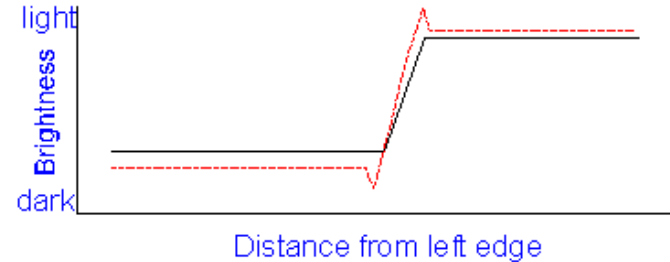
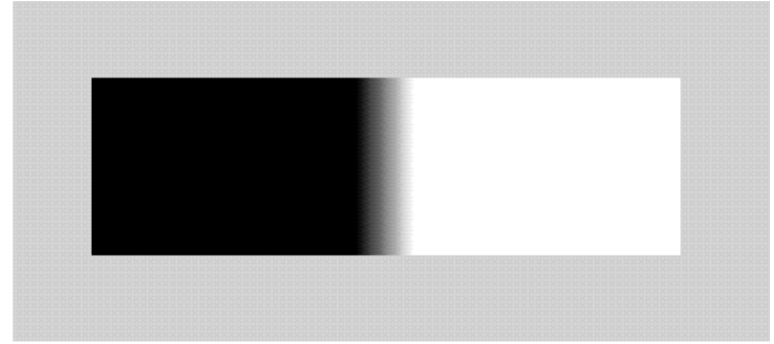
Psychovisual effects

- The perceived brightness is not a simple function of intensity
 - Mach band pattern
 - Simultaneous contrast



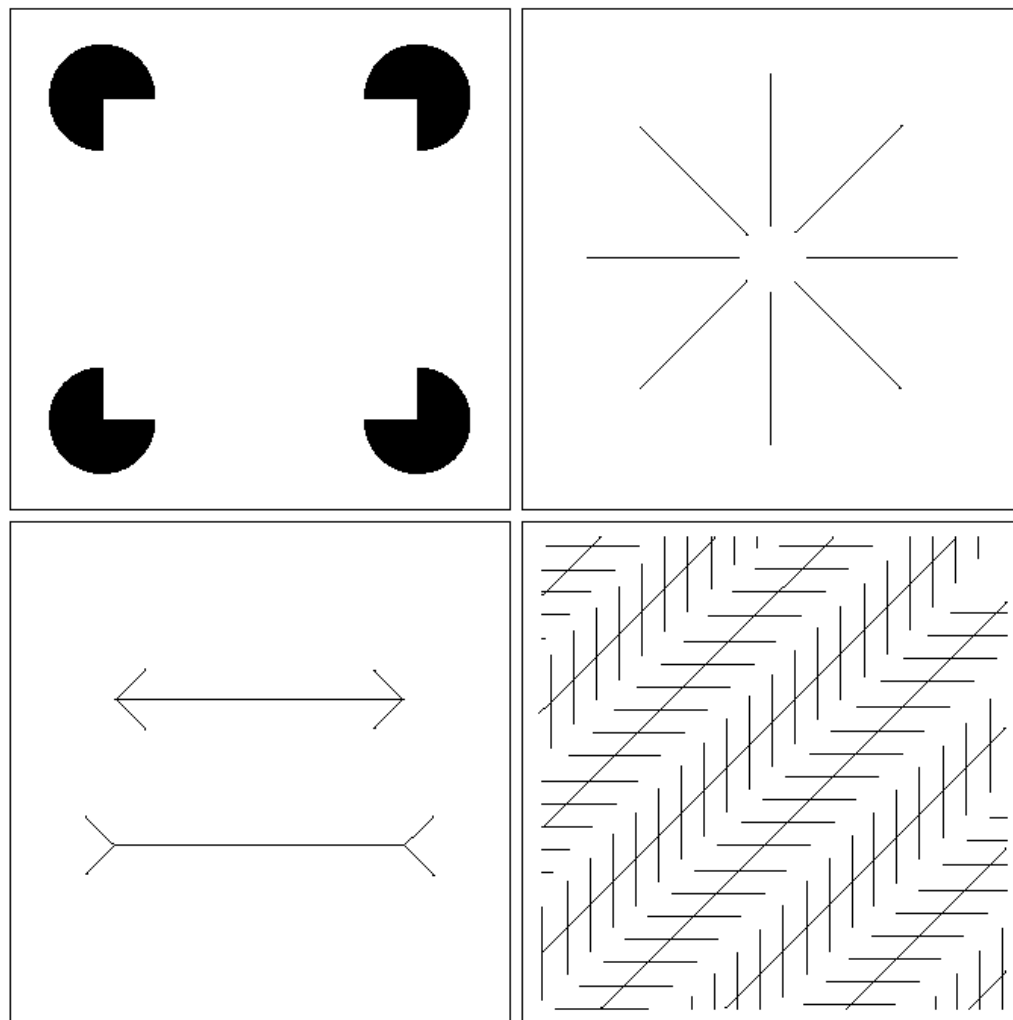
a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.



a b
c d

FIGURE 2.9 Some well-known optical illusions.



- **Digital Image Acquisition**



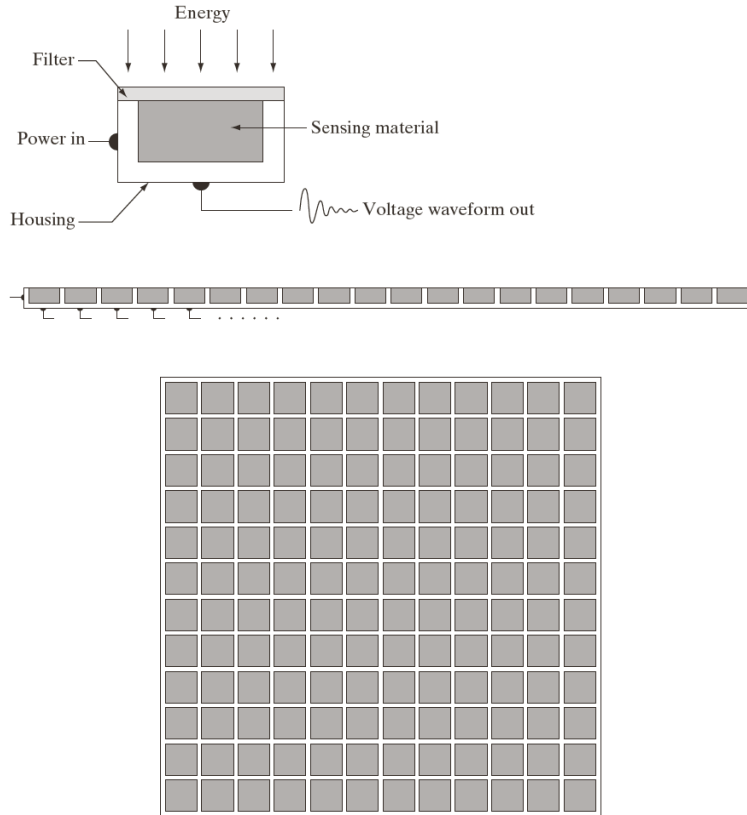
How images are
acquired

- Image Sampling and Quantization



How images end
up in digital form

Image Sensing and Acquisition



a
b
c

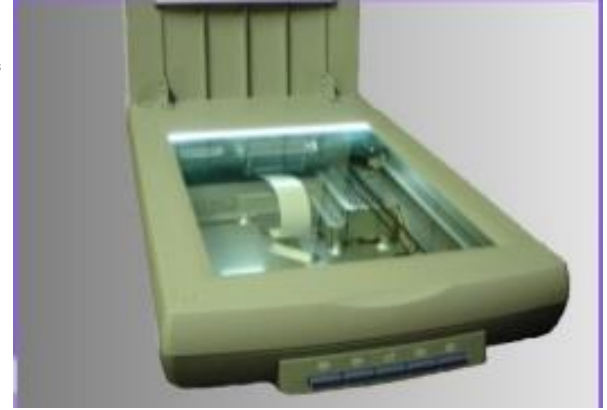
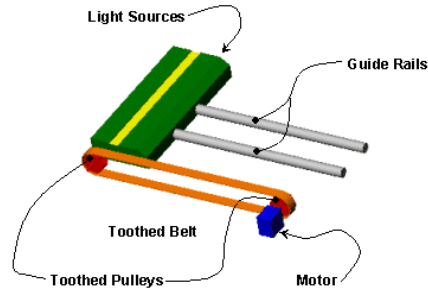
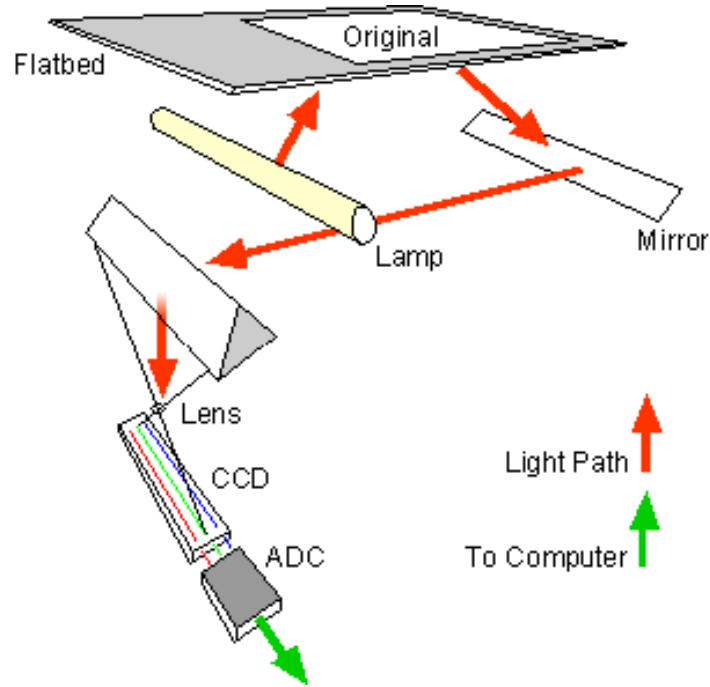
FIGURE 2.12

(a) Single imaging sensor.

(b) Line sensor.

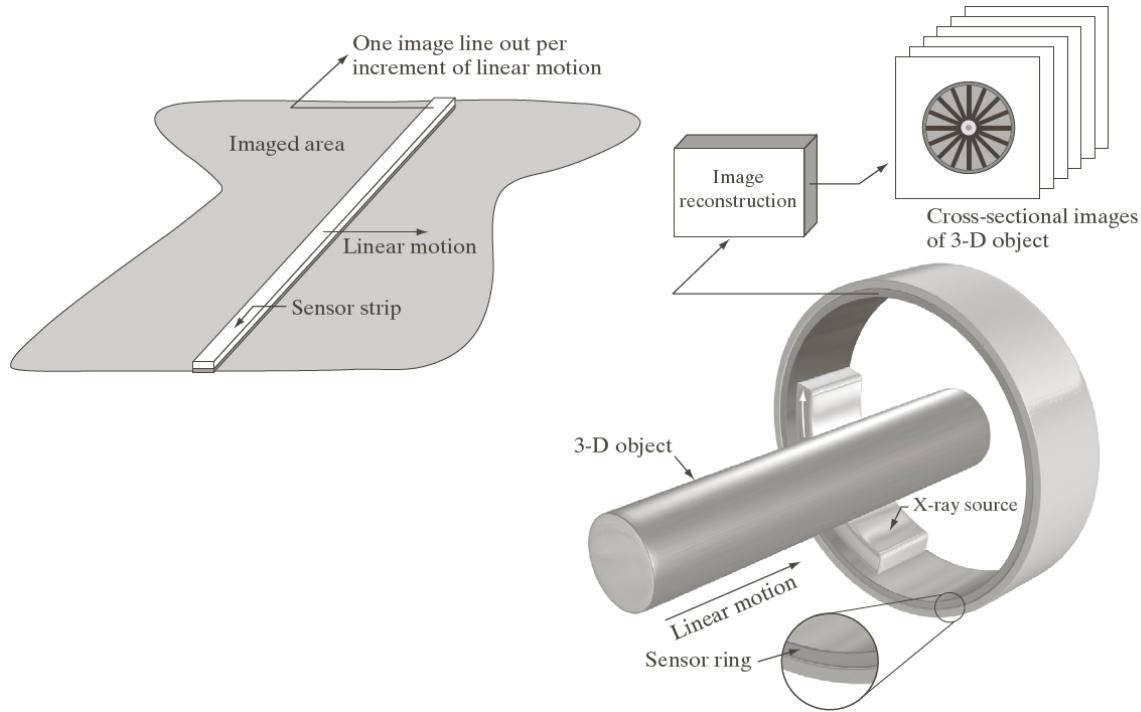
(c) Array sensor.

Image Sensing and Acquisition



How does a scanner work: <https://www.youtube.com/watch?v=OpBDTjw9yho>

Image Sensing and Acquisition



a b

FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

Light as a particle stream

- Energy carried by light
 - Not wave-like
 - Discrete (Quantized) particles = Photons

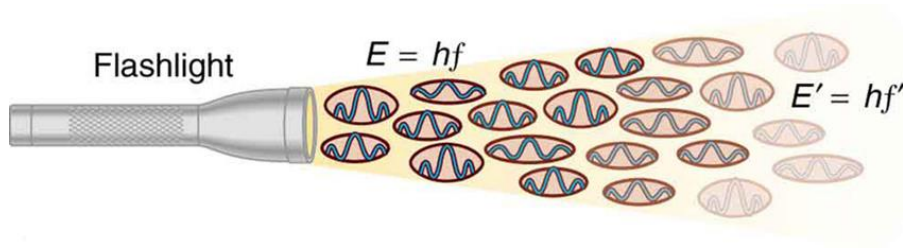
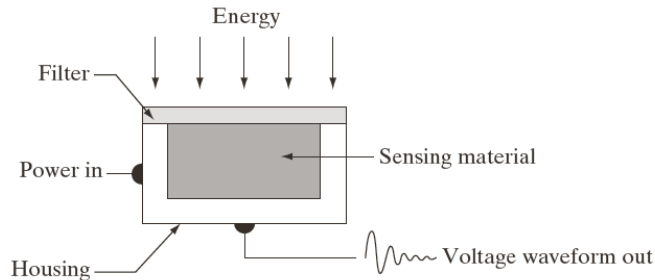
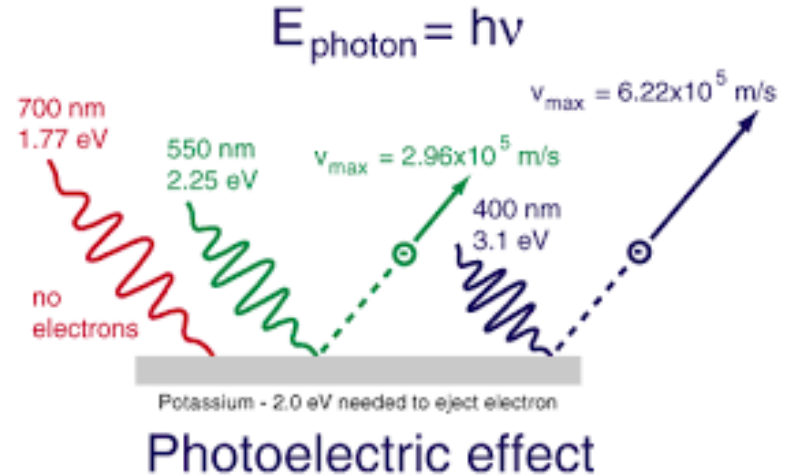
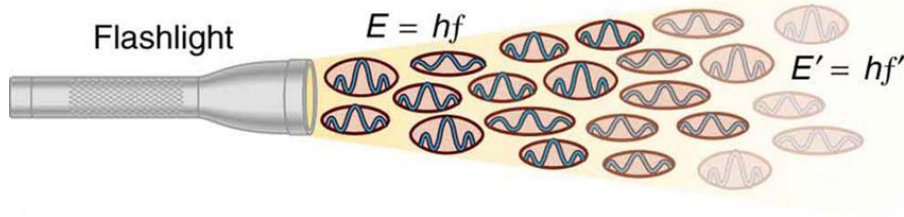


Photo-electric effect



Cross-section of typical smartphone camera

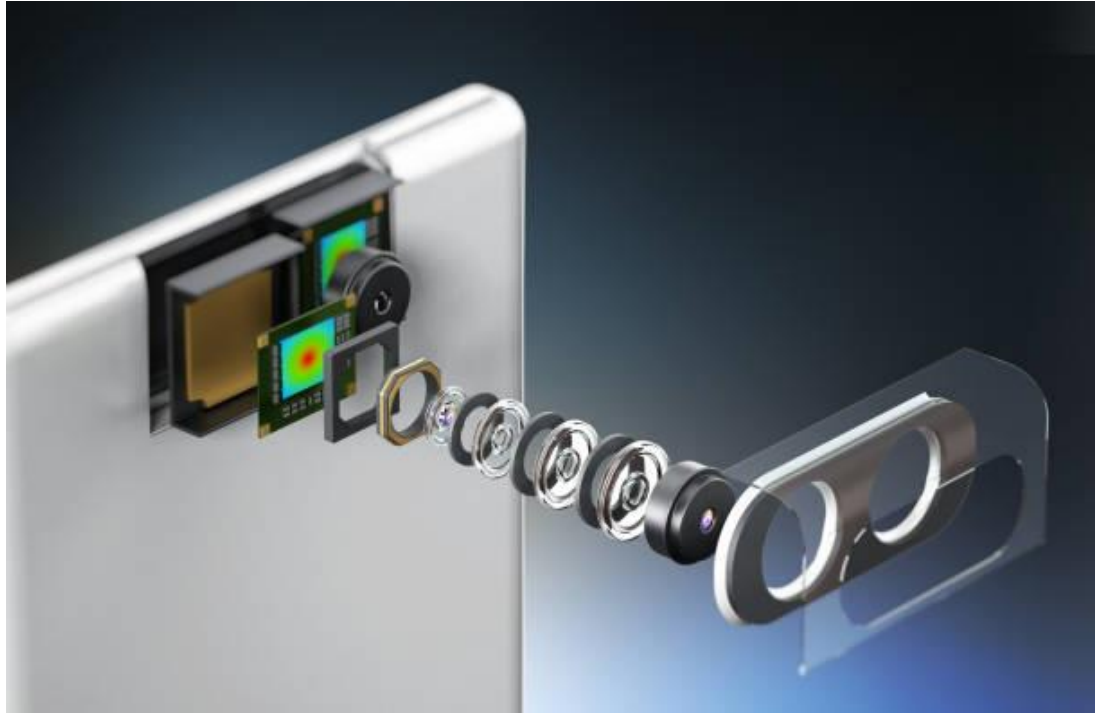
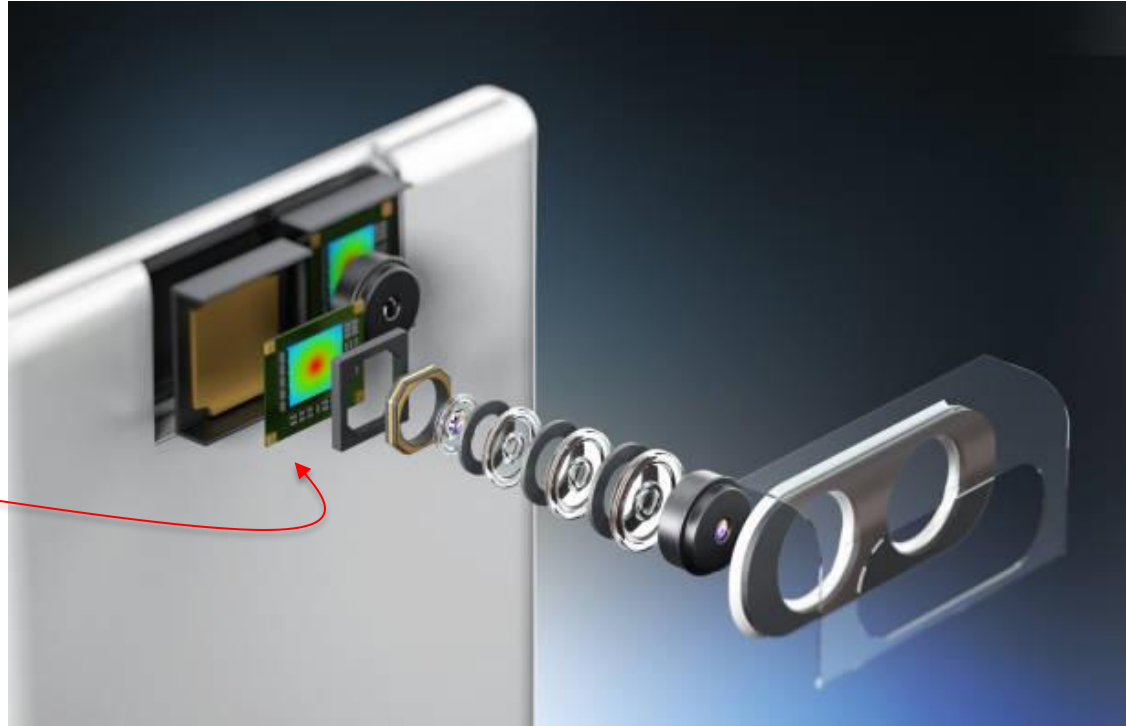
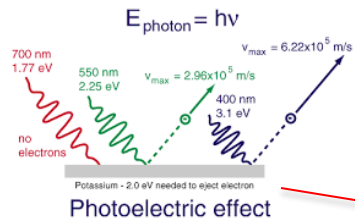
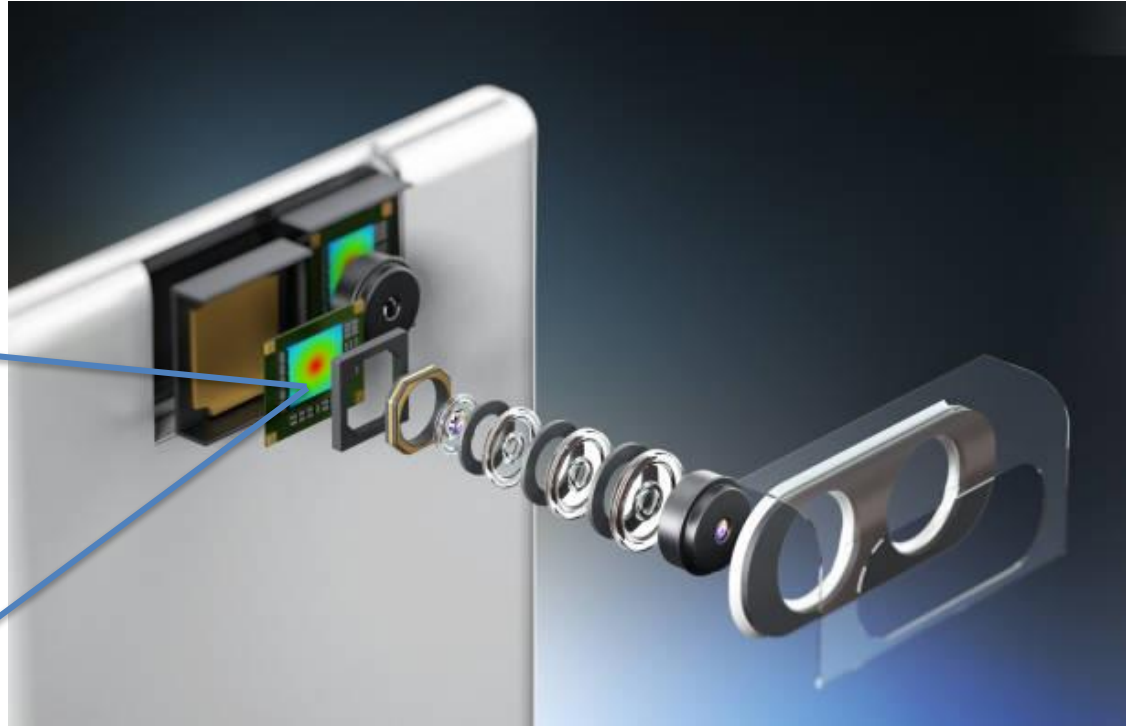
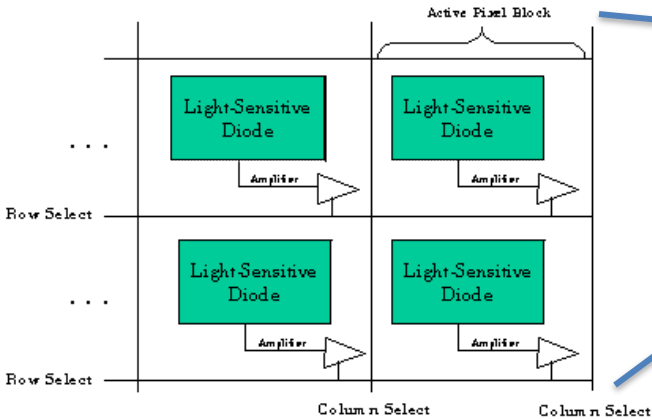
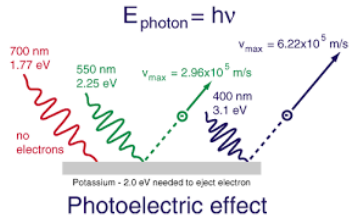


Photo-electric effect in cameras



CMOS photo-electric sensor

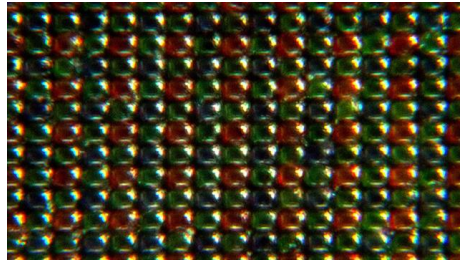
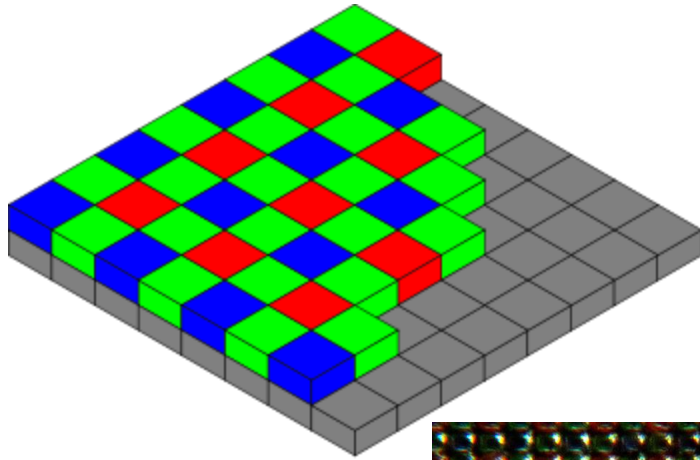
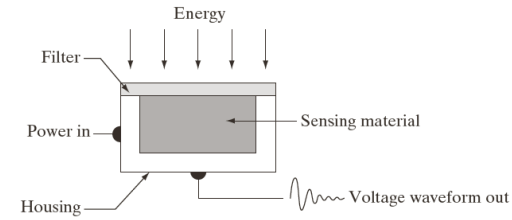


Light → Color

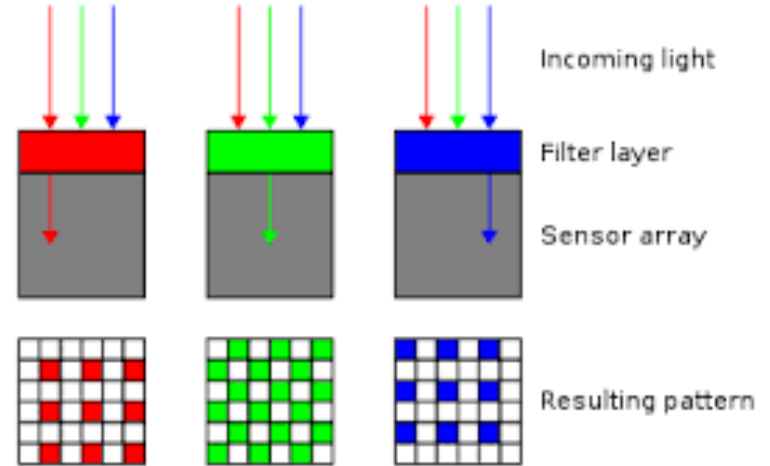
- CMOS sensitive to “light”, not “color”



Bayer Filter

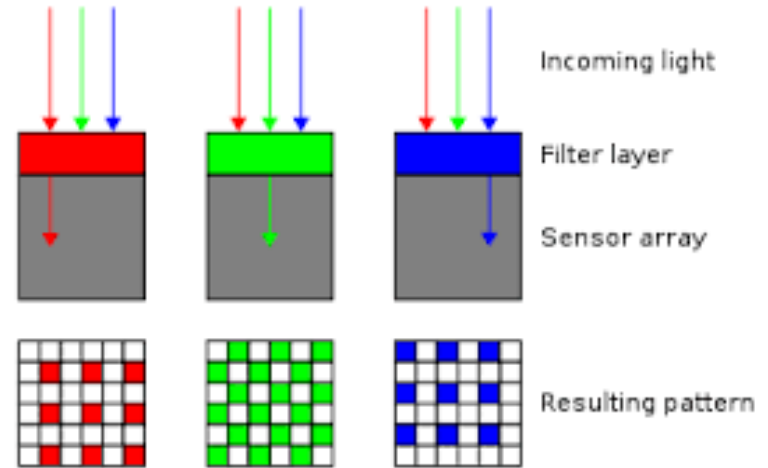
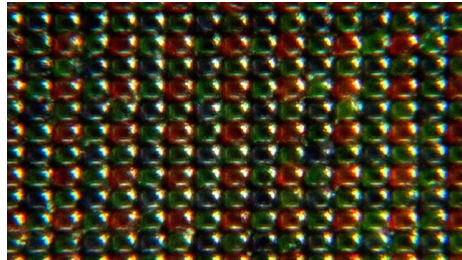
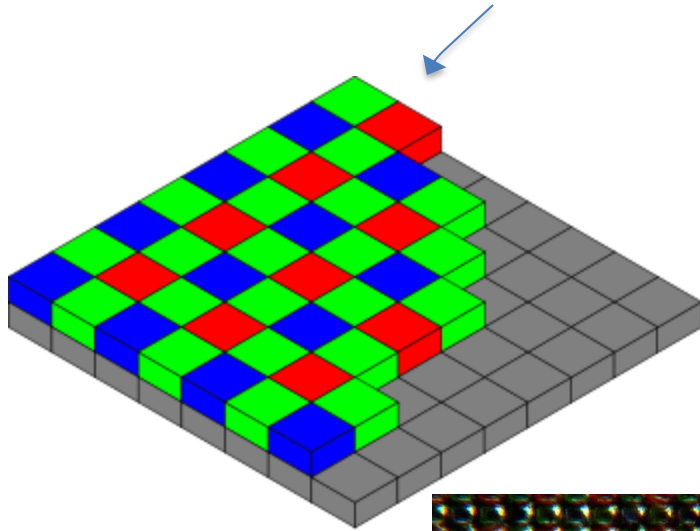


600x



Bayer Filter

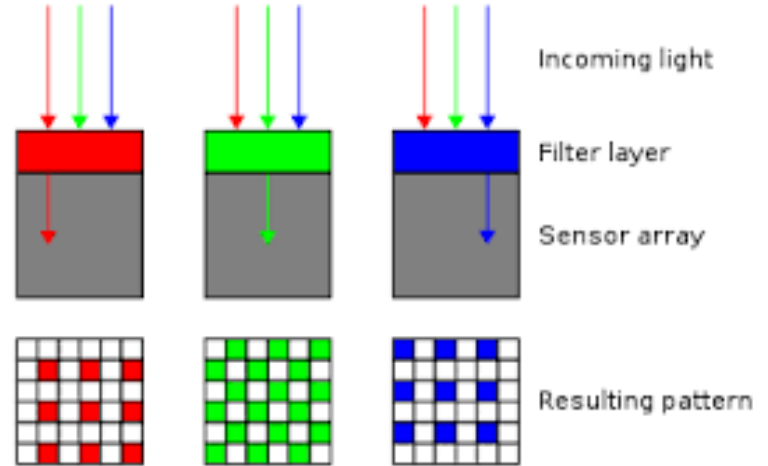
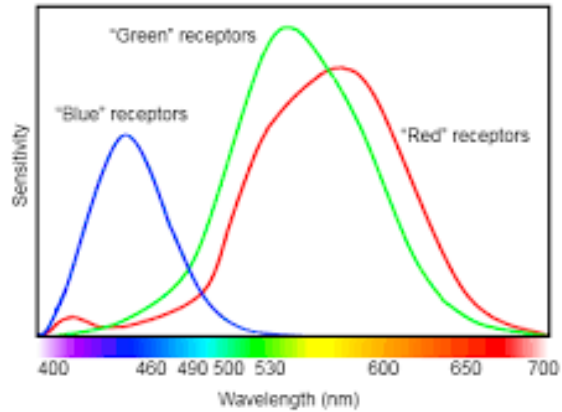
Relatively more green filters. Why ?



Bayer Filter

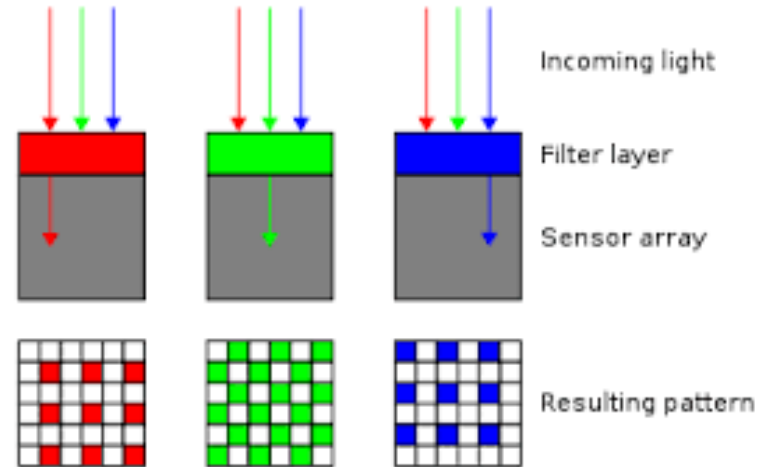
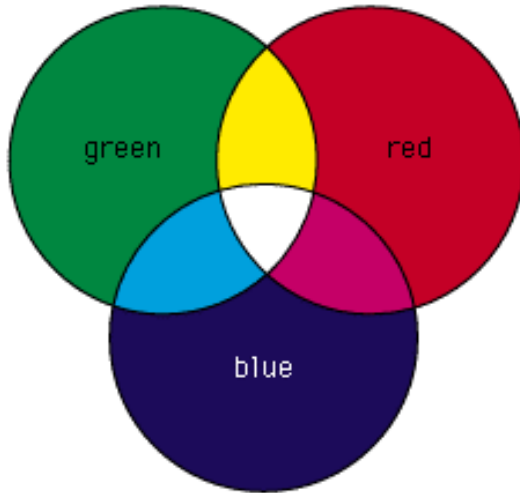
<https://petapixel.com/2016/03/30/people-can-see-100-times-colors/>

Human color receptor relative sensitivity



Bayer Filter

- How do we get color now ?



Demosaicing

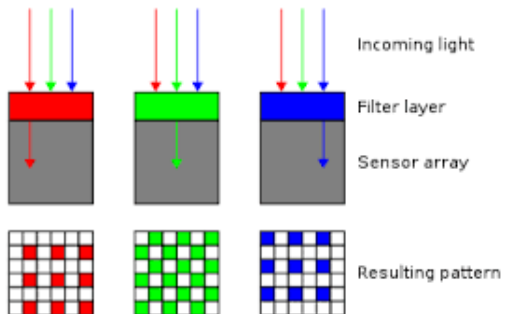
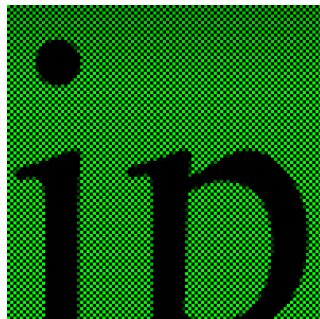
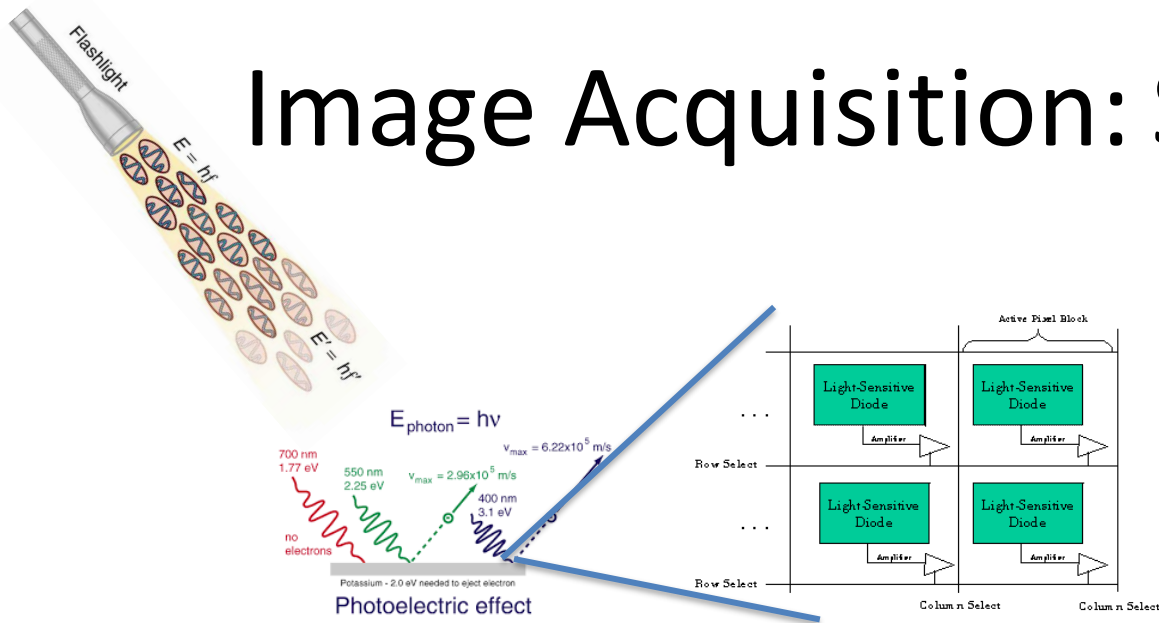
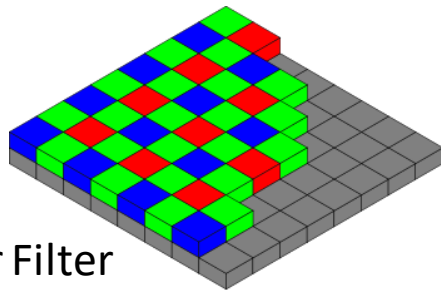


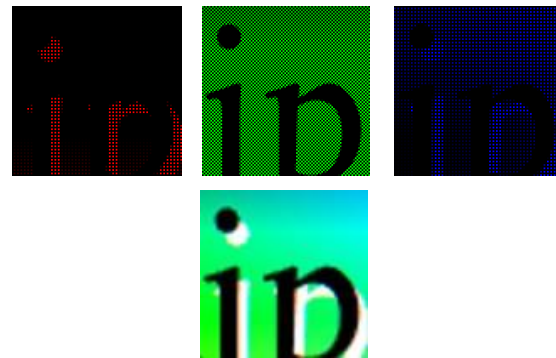
Image Acquisition: Summary



Bayer Filter



Demosaicing



- Digital Image Acquisition



How images are
acquired

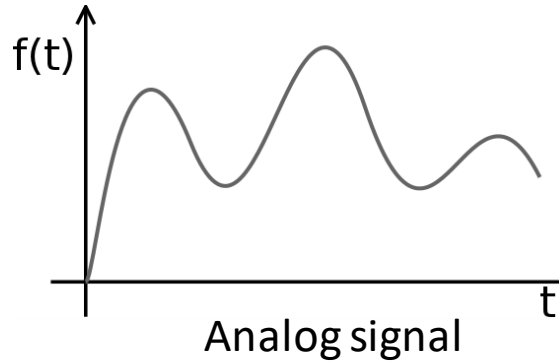
- **Image Sampling and Quantization**



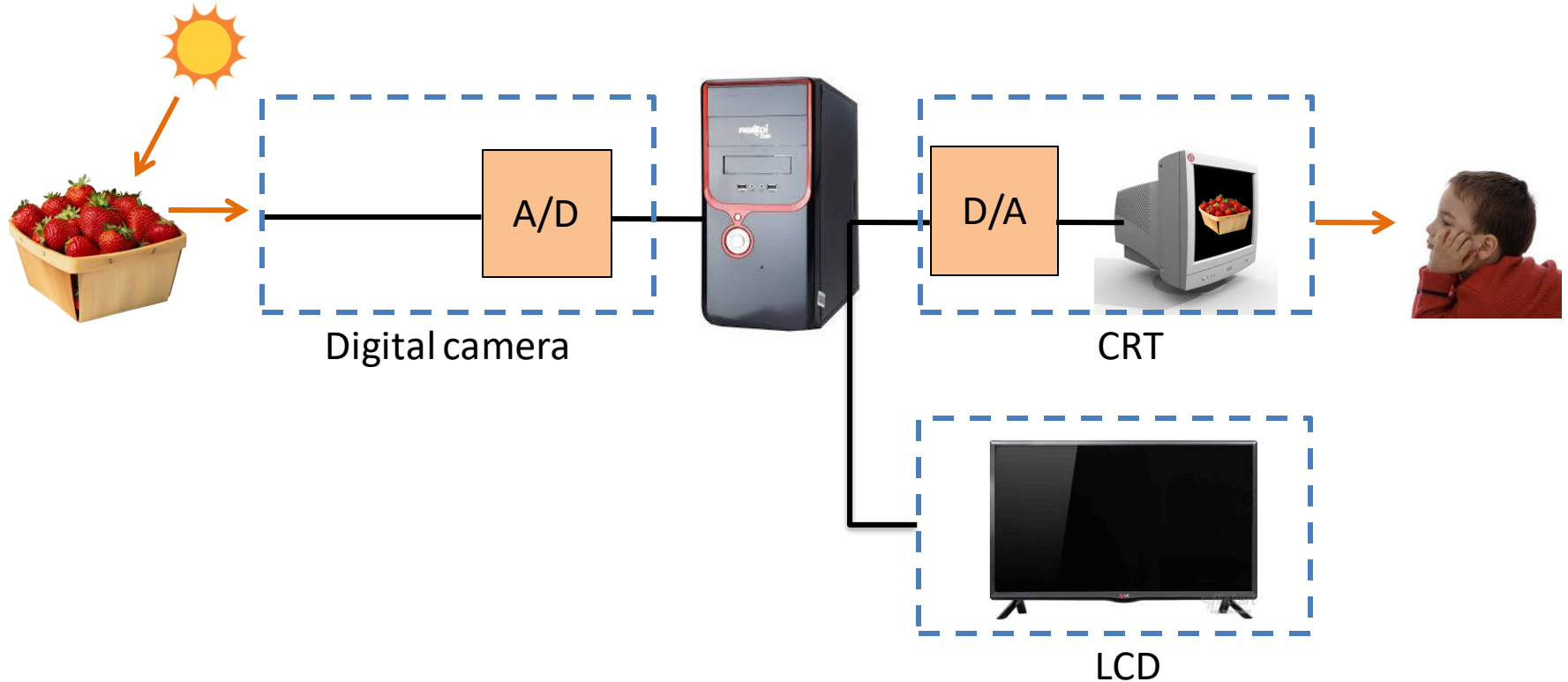
How images end
up in digital form

Signal

"Function that conveys information about the behavior or attributes of some phenomenon" (Wikipedia)



Analog vs. Digital signal (**2-D signal**)



2-D Image 'signal' = $f(x,y)$

A function of discretized space

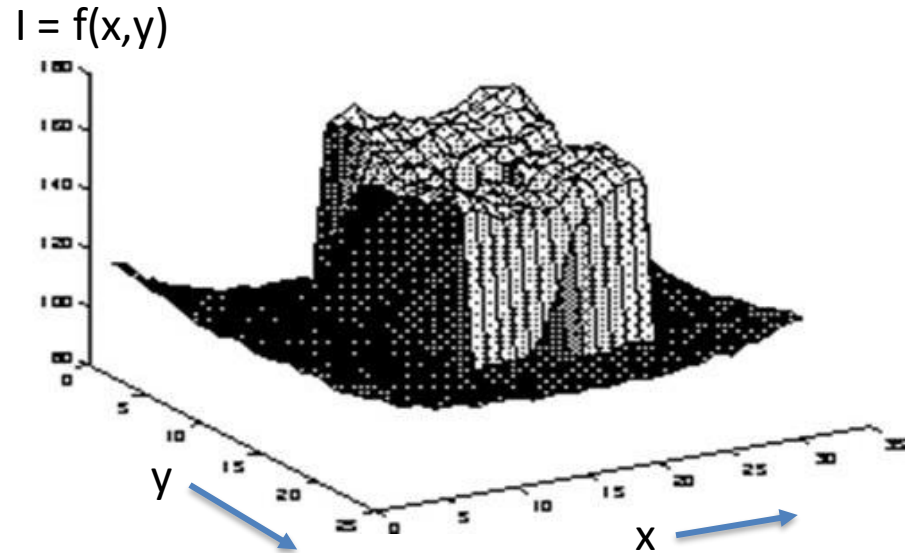
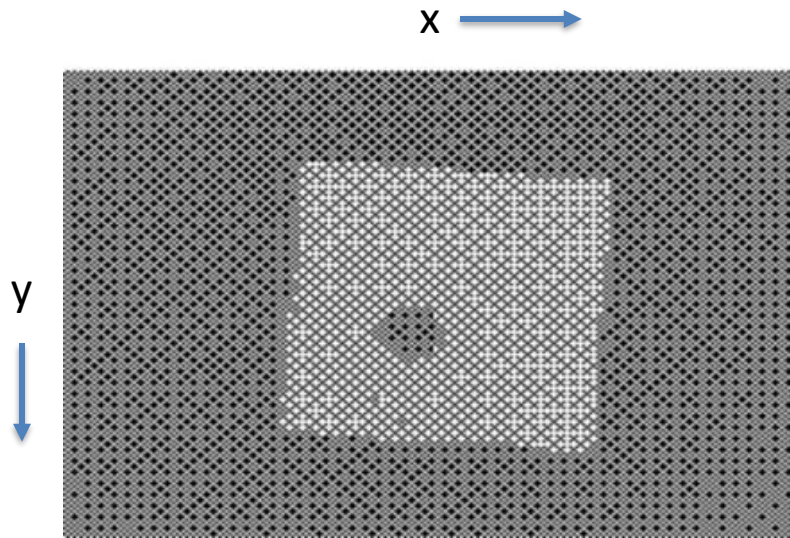
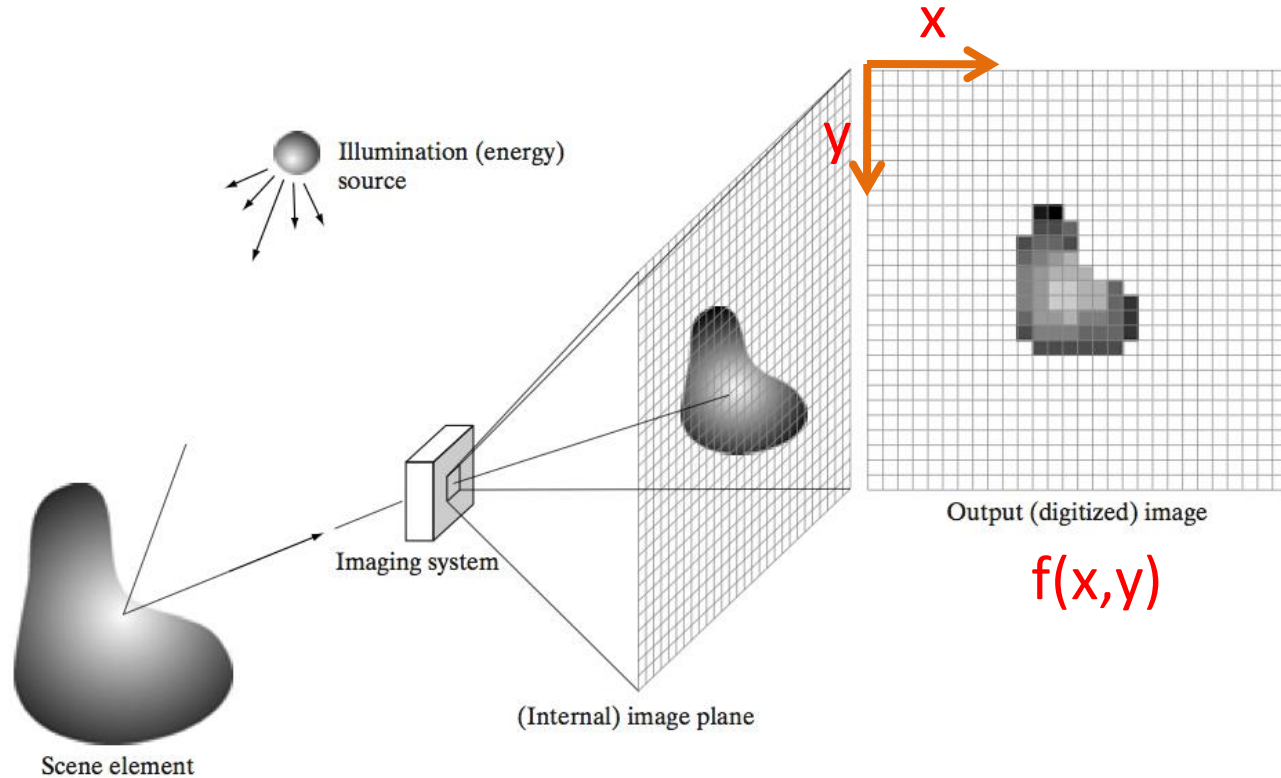
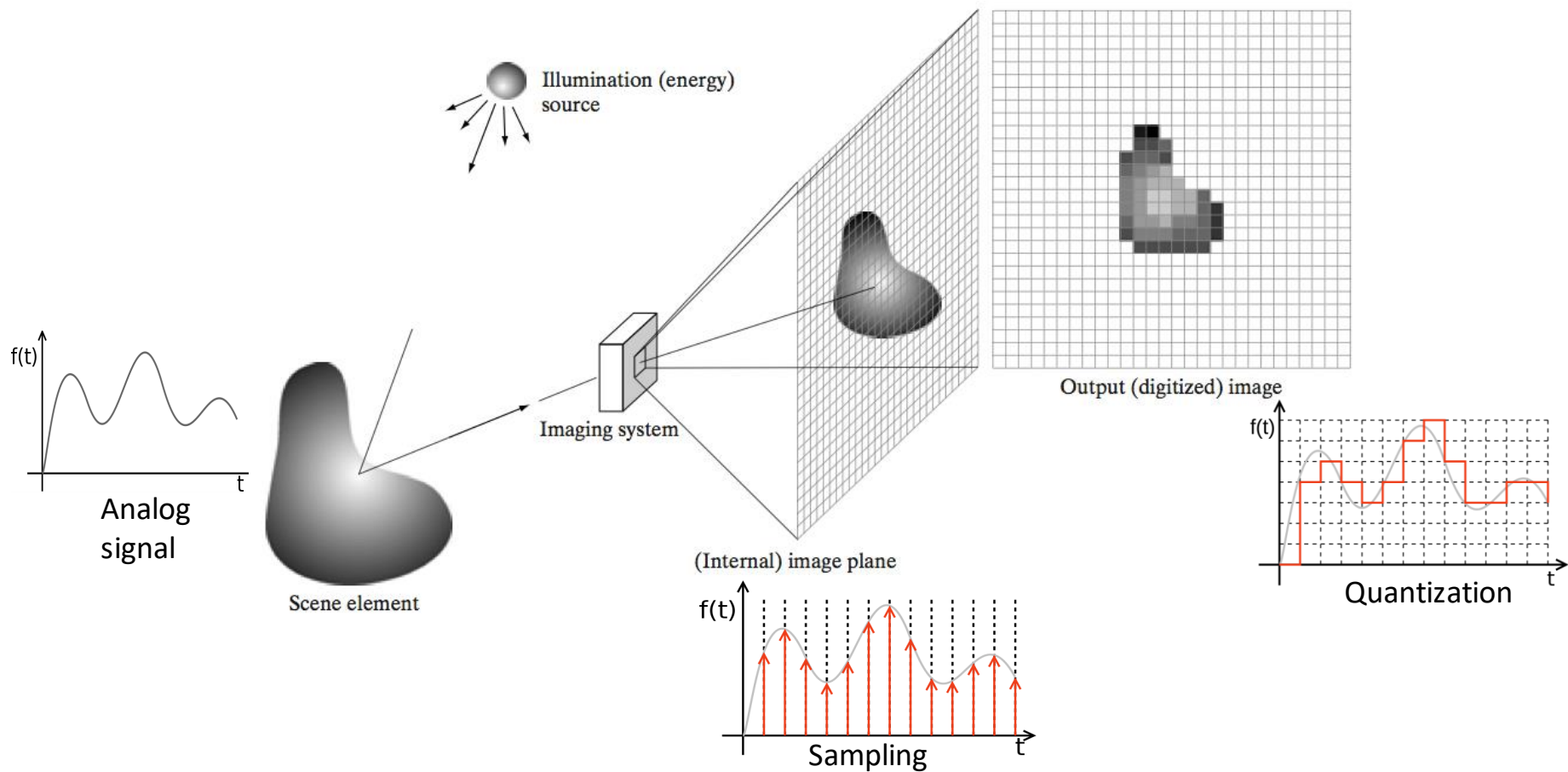


Image acquisition process





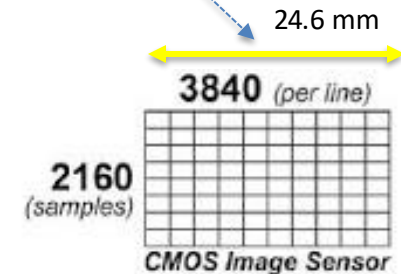
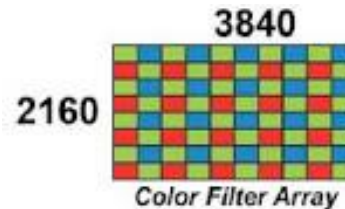
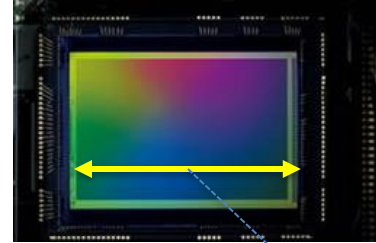
Cross-section of typical smartphone camera



Physical Characteristics

Active image area size	24.6 (H) x 13.8 (V) mm
Total number photosites	4206 (H) x 2340 (V)
Number photosites for active image	3840 (H) x 2160 (V)
Color filter array (with microlens)	RGB Bayer
Size of photosite (microns)	6.4 (H) x 6.4 μm
Pixel pitch	6.4 μm
Power supply	3.3v / 1.8v
Power consumption	950mW

Resolution (of the sensor)



SONY
make.believe

α

Size matters. Larger sensor provides better quality images.



Sony 35mm Full frame

Exmor
CMOS

30 x



Sony APS-C

Exmor
CMOS

13 x



Micro Four Thirds

7.9 x



CX Format

4.1 x



Compact Camera
(1/2.3 format)

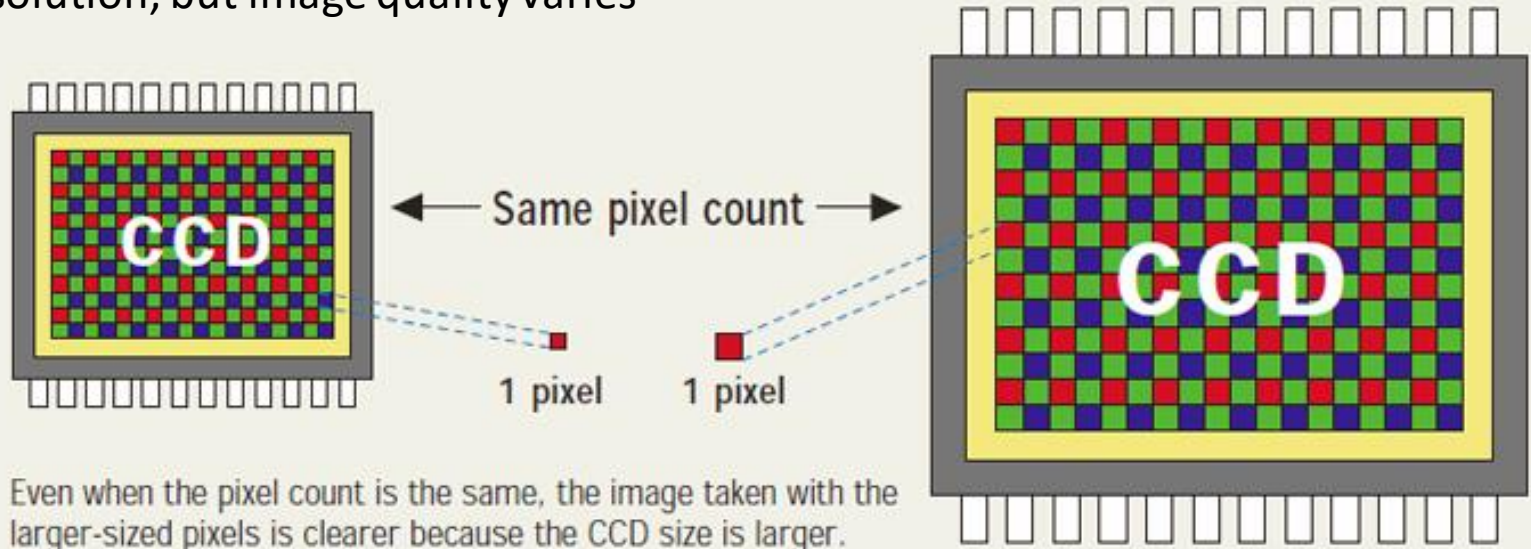
1 x

Approximate Size Ratio

PHOTOGRAPHY BAY



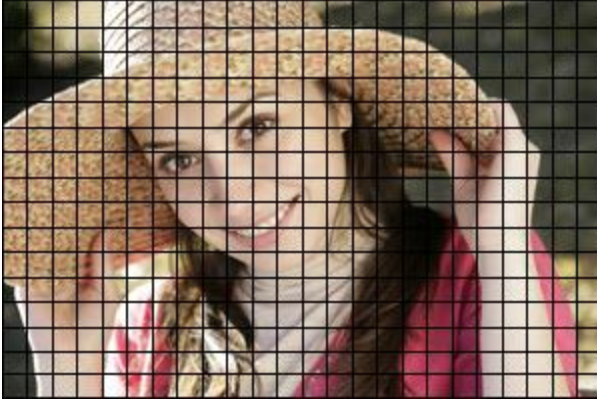
Same resolution, but image quality varies



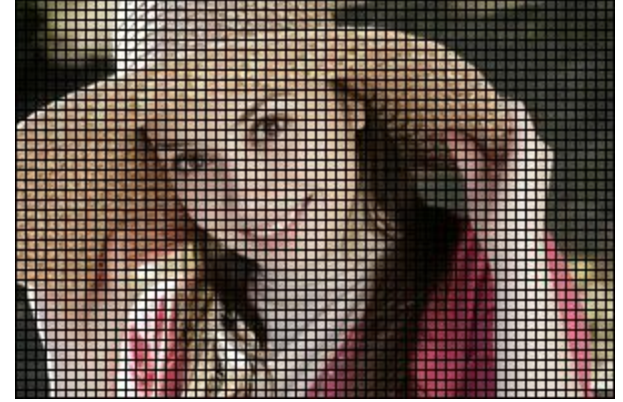
Even when the pixel count is the same, the image taken with the larger-sized pixels is clearer because the CCD size is larger.



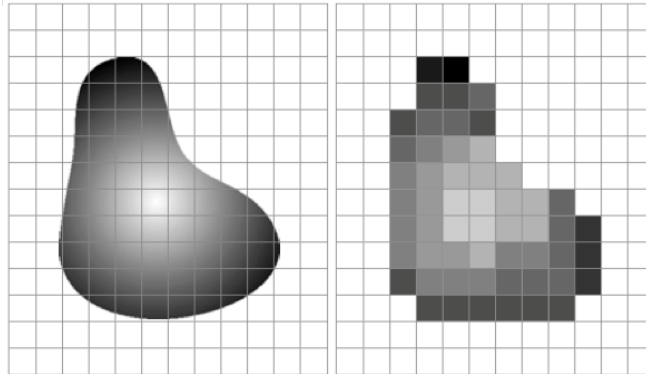
Same sensor size, but # of sensor pixels/mm varies



Small number of CCD pixels



Large number of CCD pixels



Full HD

1920 x 1080

4K

3840 x 2160

5K

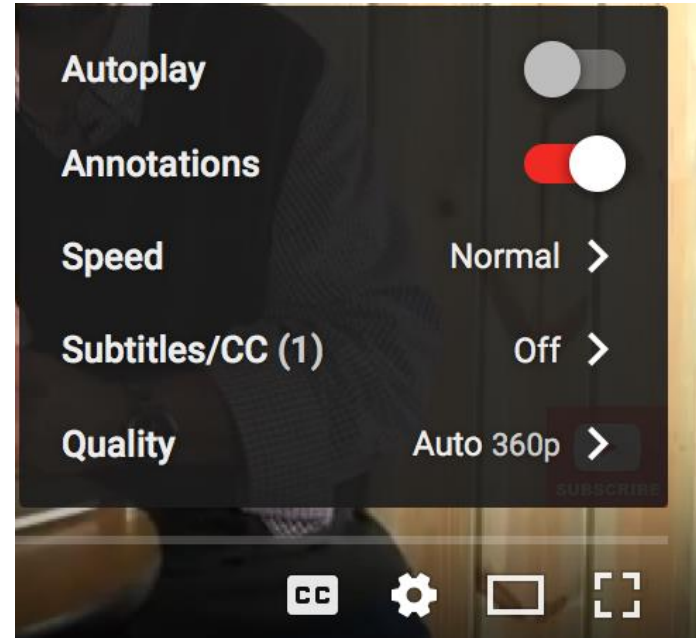
5120 x 2160

8K

7680 x 4320



- Video resolution example
 - Settings in YouTube



Aspect Ratios

TV ASPECT RATIOS

4:3 (1.33:1)
Standard (SDTV)

16:9 (1.78:1)
Wide Screen (HDTV)

MOVIE THEATER ASPECT RATIOS

1.37:1
Academy Standard

1.85:1
Academy Flat

2.39:1 (2.35:1 prior to 1970)
Anamorphic Scope
(Panavision/Cinemascope)

Key Terms

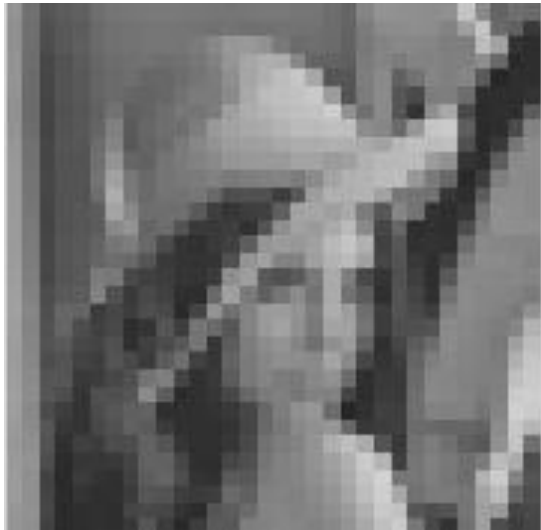
Standard Video Qualities: Standard combinations of aspect ratio and video resolution

Video Quality	4:3 Aspect Ratio Resolution	16:9 Aspect Ratio Resolution
360p	480 x 360	640 x 360
480p	640 x 480	854 x 480
720p	Not generally used	1280 x 720
1080p	Not generally used	1920 x 1280

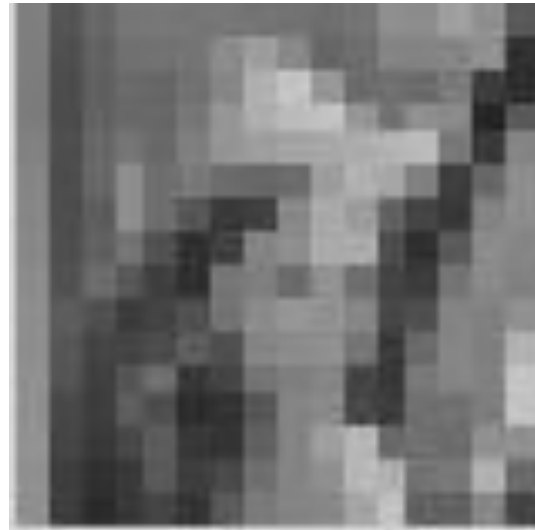
Sampling = Spatial Quantization



256×256



32×32



16×16

Image acquisition process

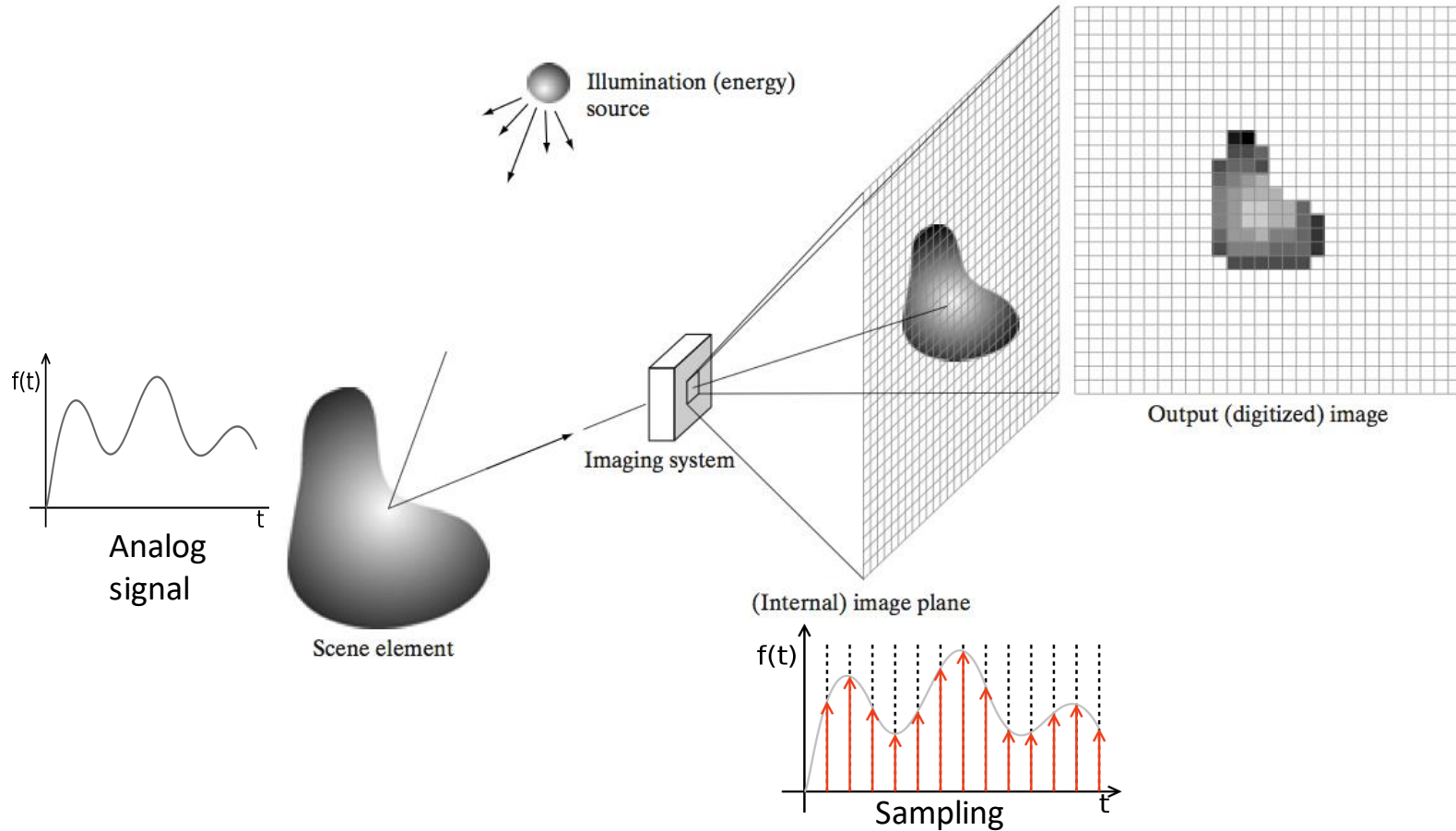
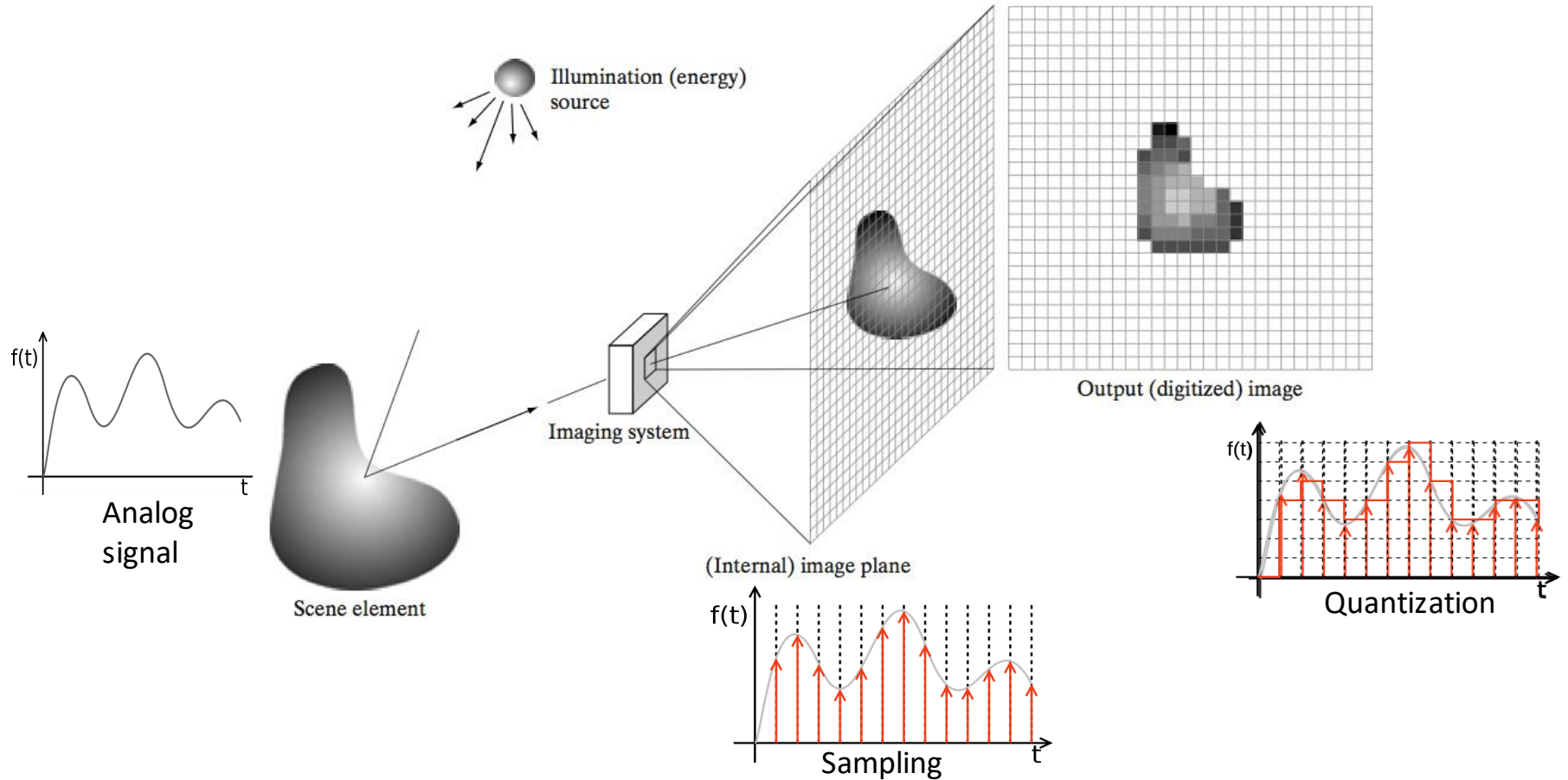


Image acquisition process



Intensity Quantization



8 bits per pixel



4 bits per pixel

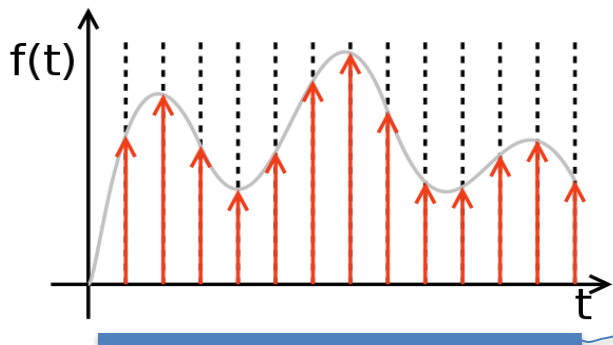


2 bits per pixel



1 bit per pixel

Summary



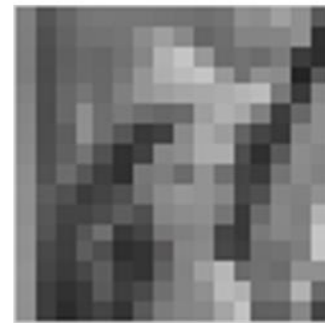
Sampling



256 × 256

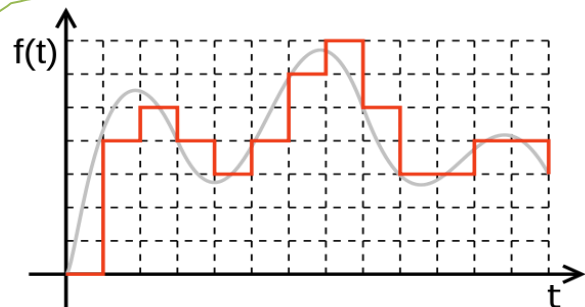


32 × 32



16 × 16

Quantization



8 bits per pixel



4 bits per pixel

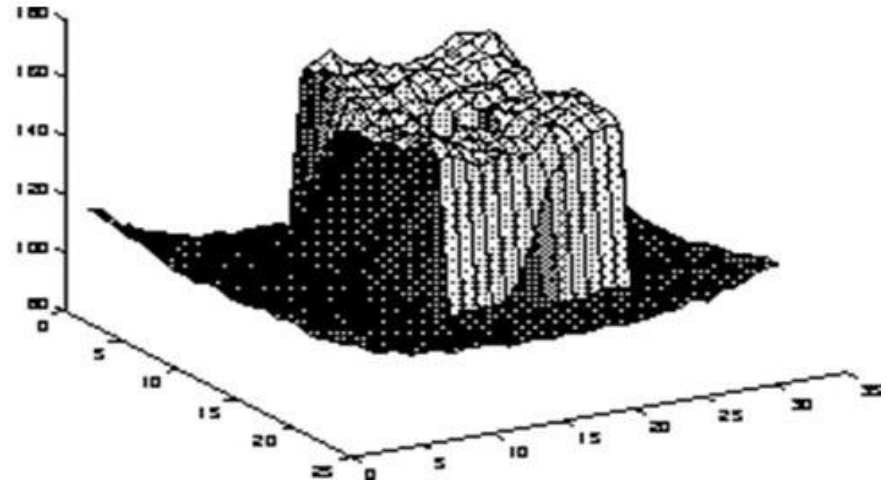
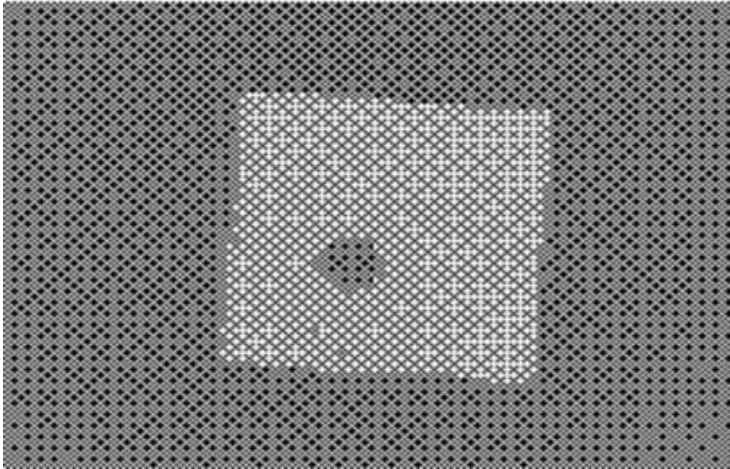


2 bits per pixel

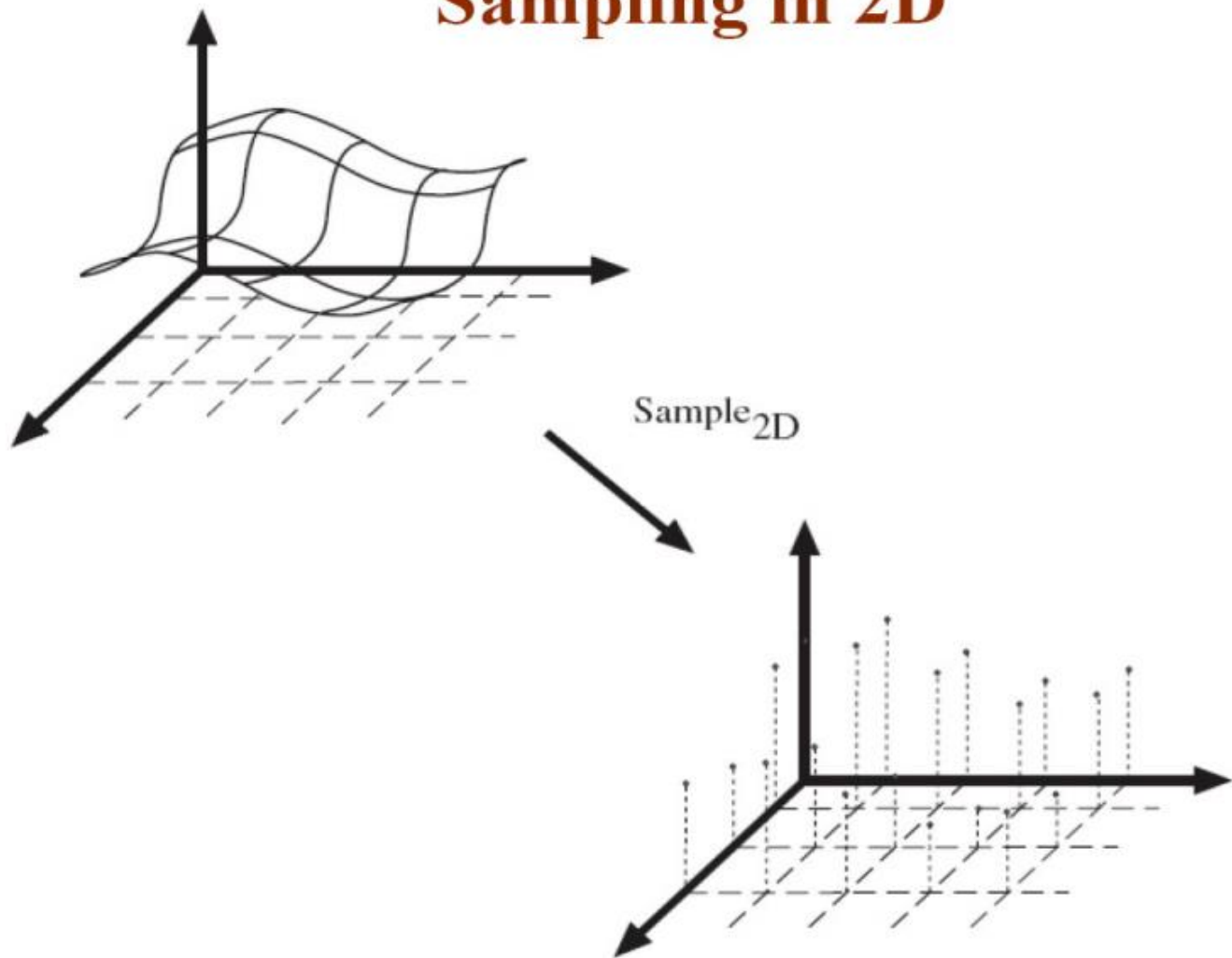


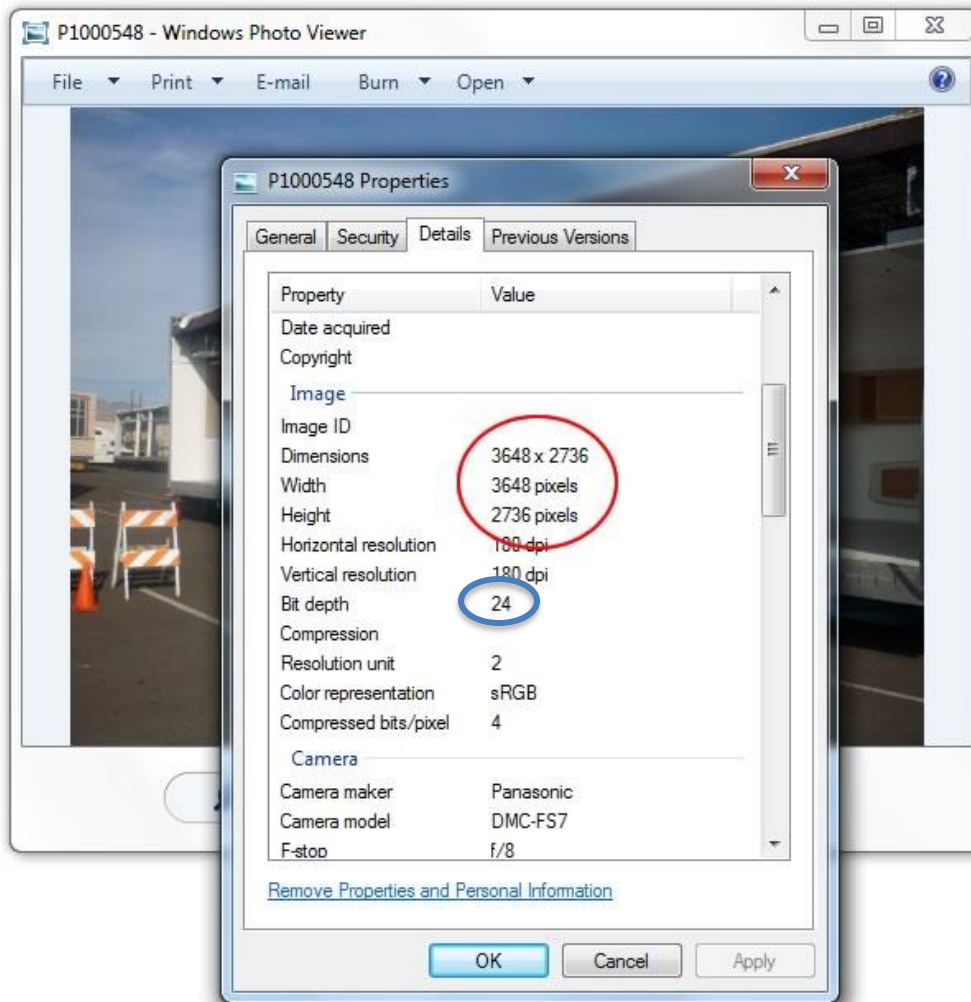
1 bit per pixel

Image as a 3D surface



Sampling in 2D





Quantization

- In Hardware (# of voltage levels, # of bits)
- In Software (raw \rightarrow JPEG)



Summary: HVS

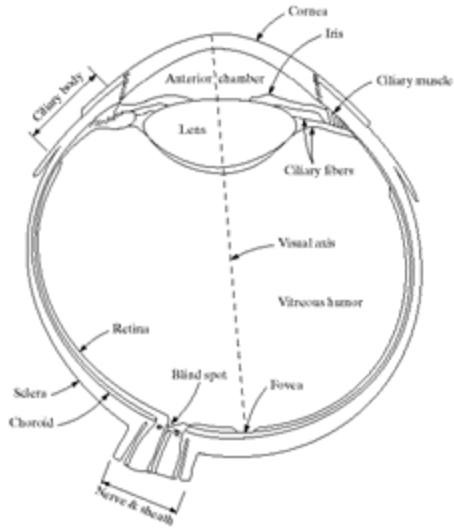
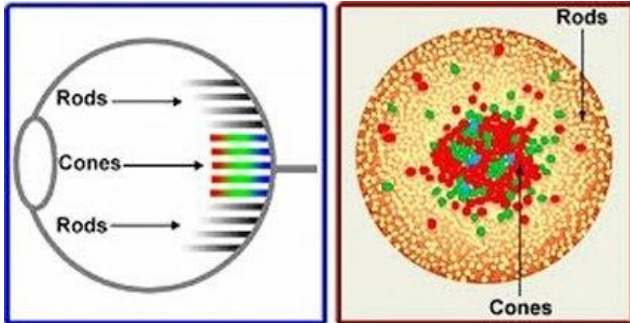
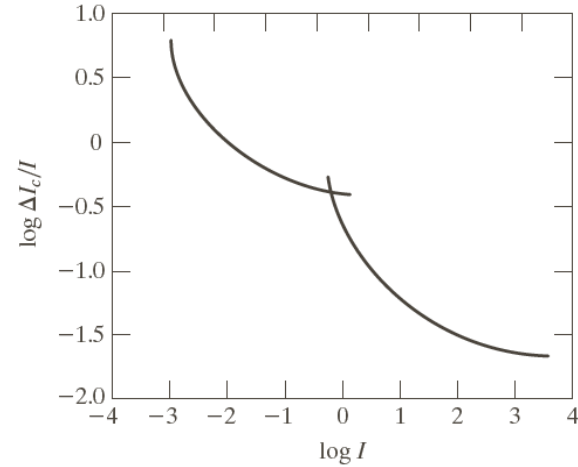
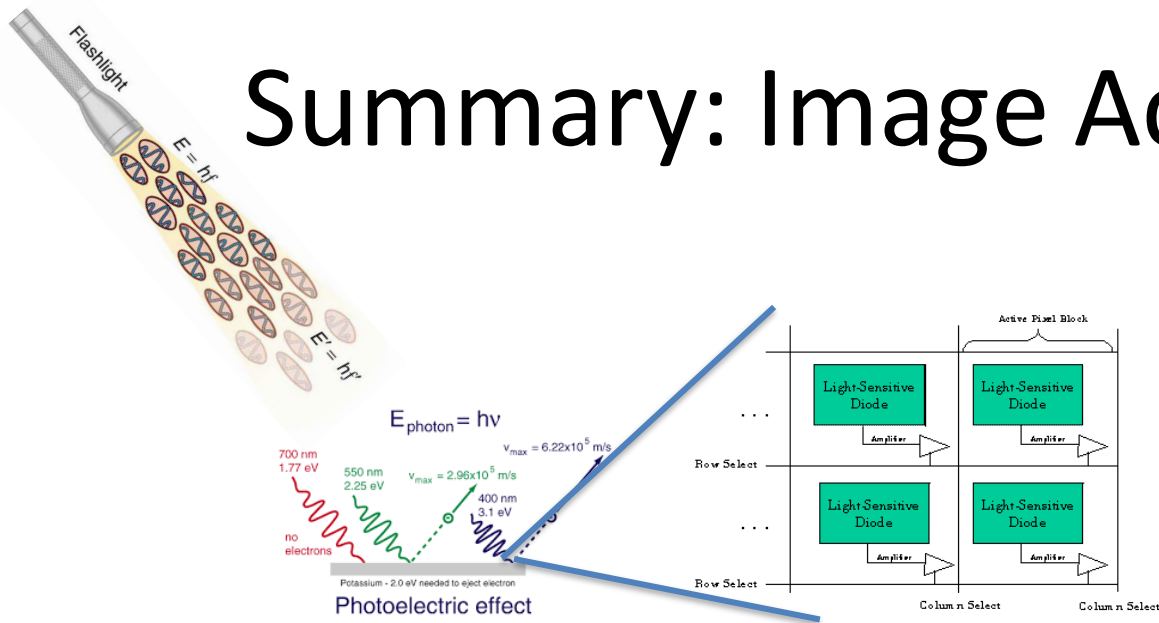


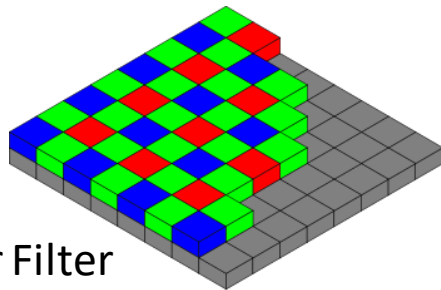
FIGURE 2.1
Simplified
diagram of a cross
section of the
human eye.



Summary: Image Acquisition



Bayer Filter



Demosaicing

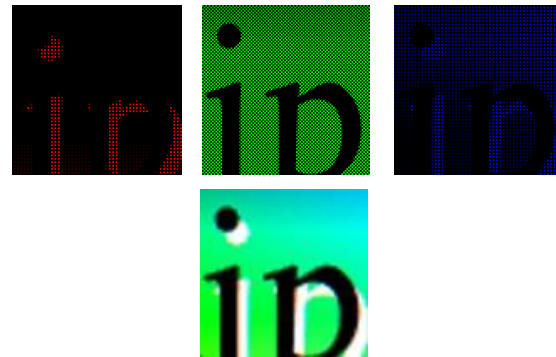
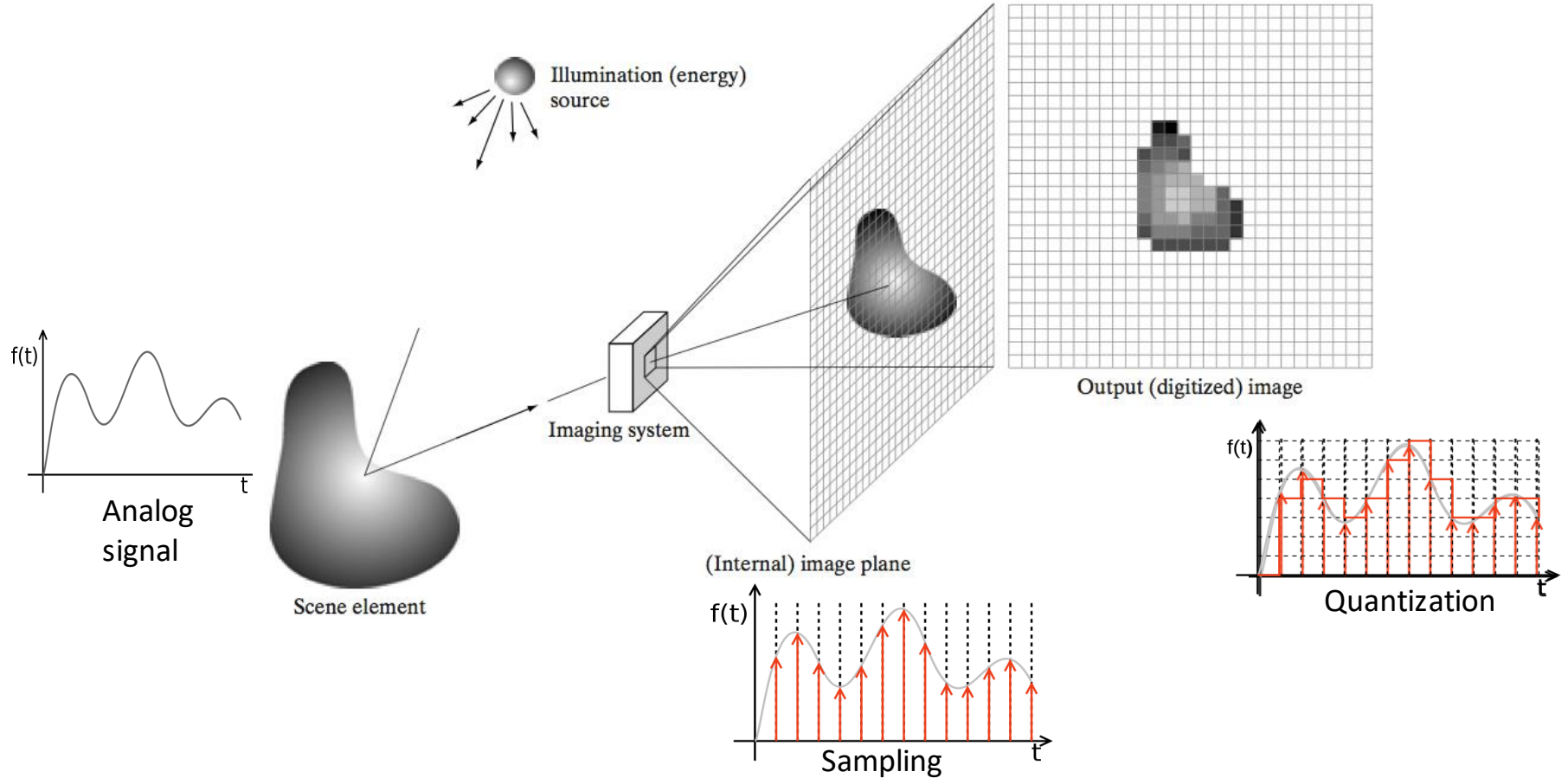
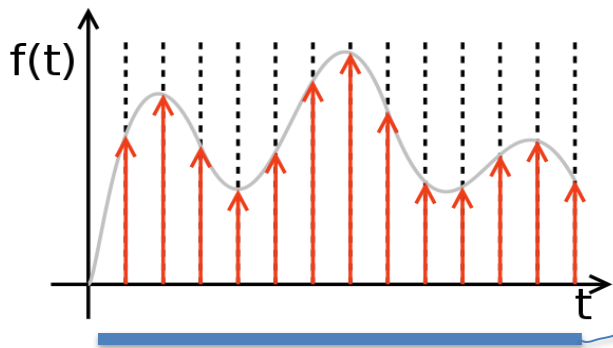


Image acquisition process

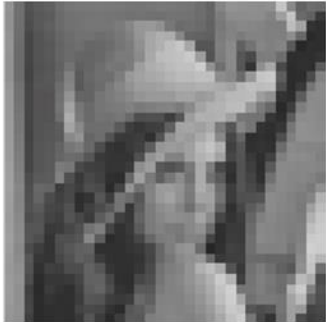


Summary: Image Sampling and Quantization

Sampling



256 × 256

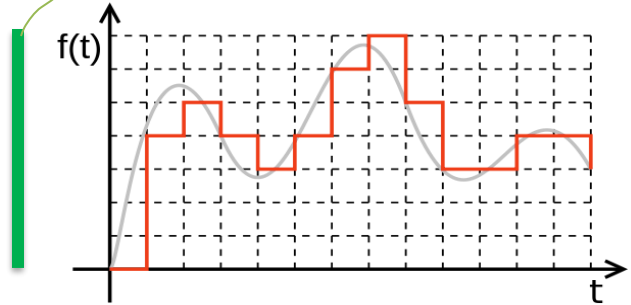


32 × 32



16 × 16

Quantization



8 bits per pixel



4 bits per pixel



2 bits per pixel



1 bit per pixel

References

- Gonzalez and Woods (2.1,2.3-2.4)
 - Problems : 2.1 – 2.10

Optional Reading

- <https://www.edmundoptics.com/resources/application-notes/imaging/camera-resolution-for-improved-imaging-system-performance/>
- <http://www.andor.com/learning-academy/ccd-spatial-resolution-understanding-spatial-resolution>
- <http://av.jpn.support.panasonic.com/support/global/cs/dsc/knowhow/knowhow26.html>
- <http://www.vision-doctor.com/en/camera-technology-basics/sensor-and-pixel-sizes.html>
- <https://nostalgicmedia.com/pages/resolution-scanning-dpi-ppi>
- <http://www.ubergizmo.com/what-is/ppi-pixels-per-inch/>