20.08.2021

Digital Image Processing (CSE/ECE 478)

Lecture-2: Digital Imaging Fundamentals

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Announcements

- Teaching Assistants - TBA
- Tutorial hours: Saturday 4.00p – 6.00p

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

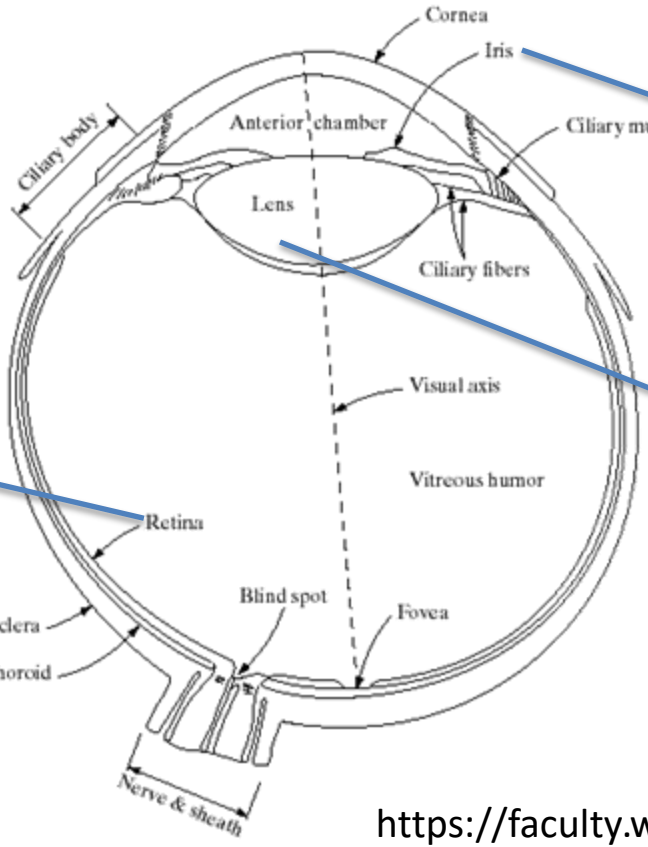
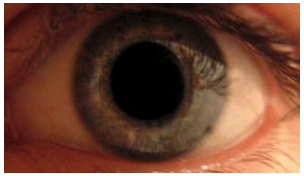


FIGURE 2.1 Simplified diagram of a cross section of the human eye.



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

- Absorbs 8% of visible light spectrum
- IR, UV also absorbed

- Light is imaged on this

Reduces backscatter

https://faculty.washington.edu/chudler/chvision.html

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)

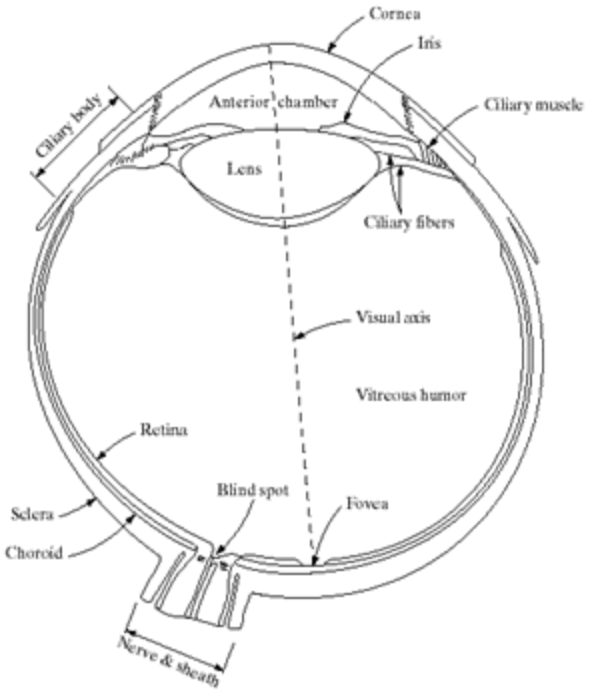


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Cones

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

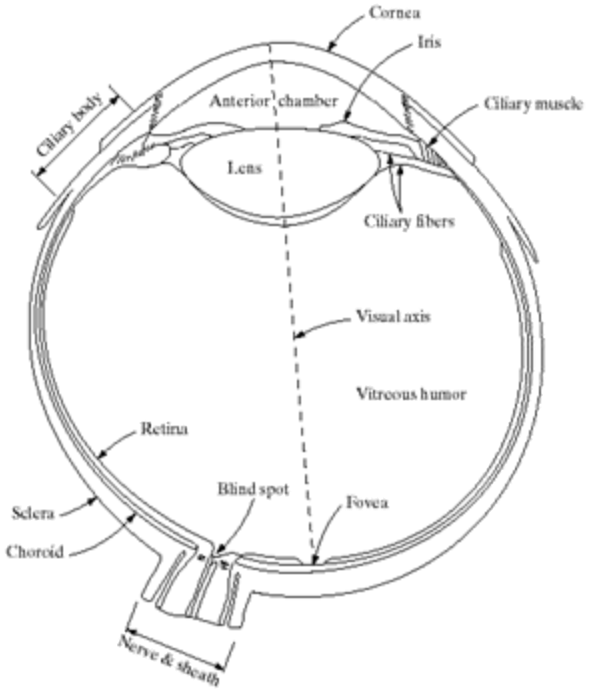
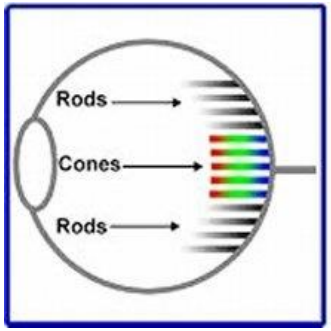
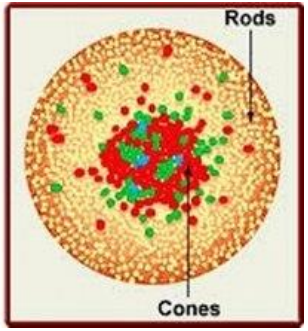


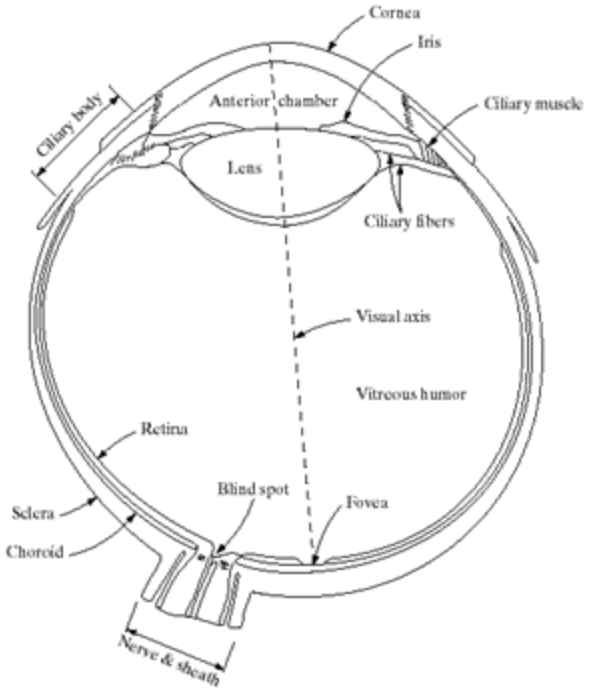
FIGURE 2.1
Simplified diagram of a cross section of the human eye.





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).



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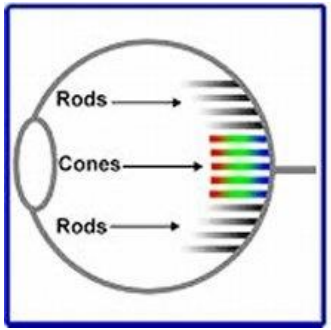
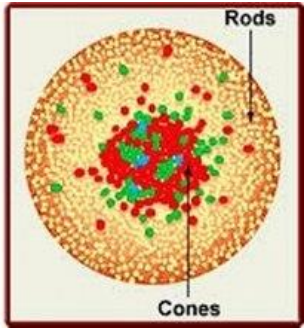




Receptor Distribution

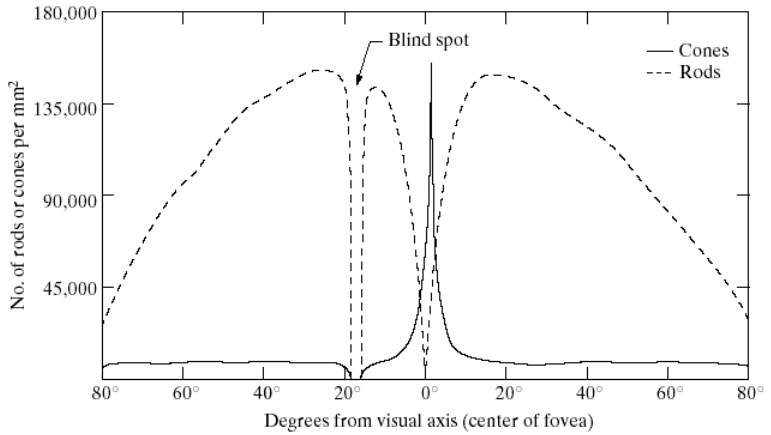


FIGURE 2.2
Distribution of rods and cones in the retina.

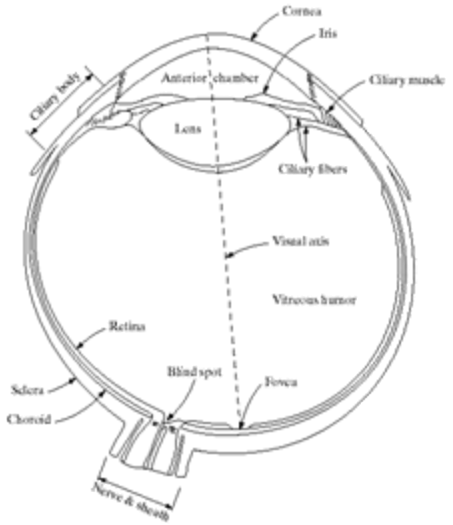


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

- 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/mm^2 ~ 337,000
  - A CCD imaging chip of medium resolution needs 5 mm x 5 mm for this number of elements

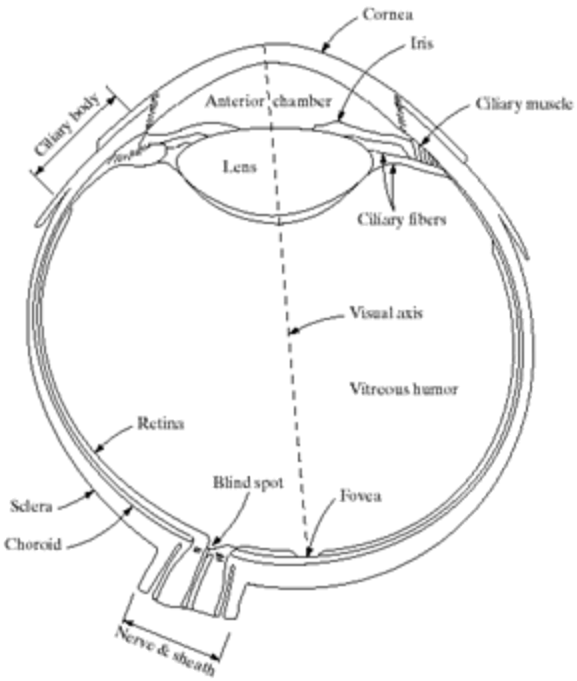
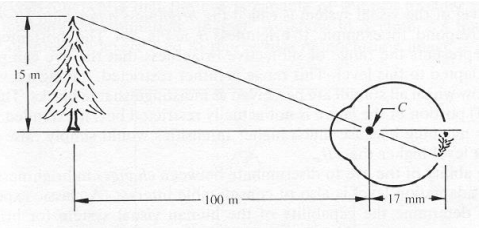


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

Image Formation in the Eye

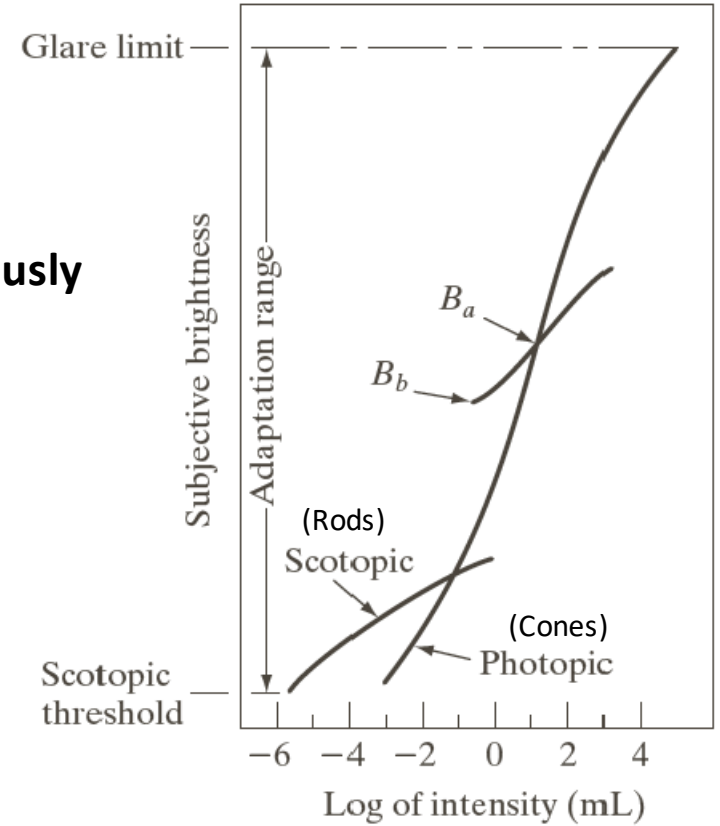
- Eye lens (compared to an optical lens) is flexible.



- 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

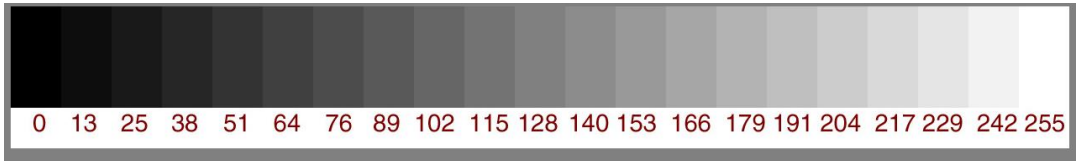
Brightness adaptation

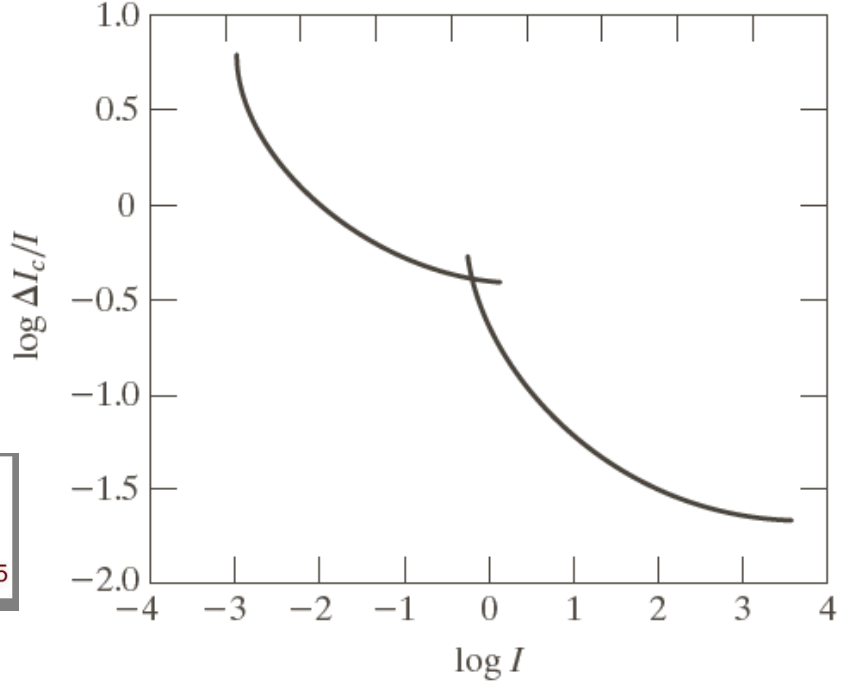
- Dynamic range of human visual system (HVS)
  - 10^{-6} ~ 10^{4}
- But HVS cannot accomplish this range **simultaneously**



Brightness discrimination

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



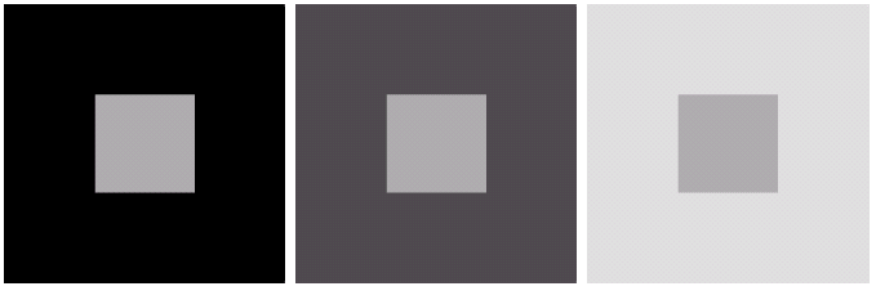


https://www.youtube.com/watch?v=hWT_LO8U7uE

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

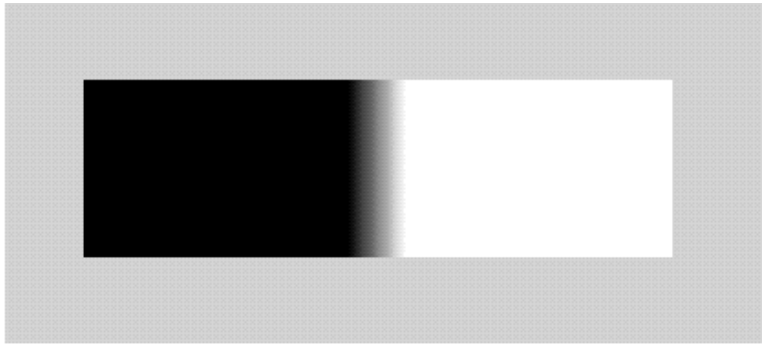
Psychovisual effects

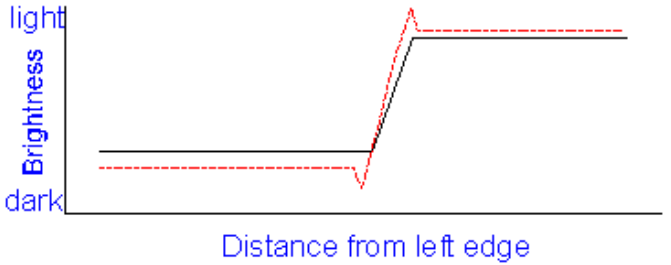
- The perceived brightness is not a simple function of intensity
  - Mach band pattern
  - Simultaneous contrast



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

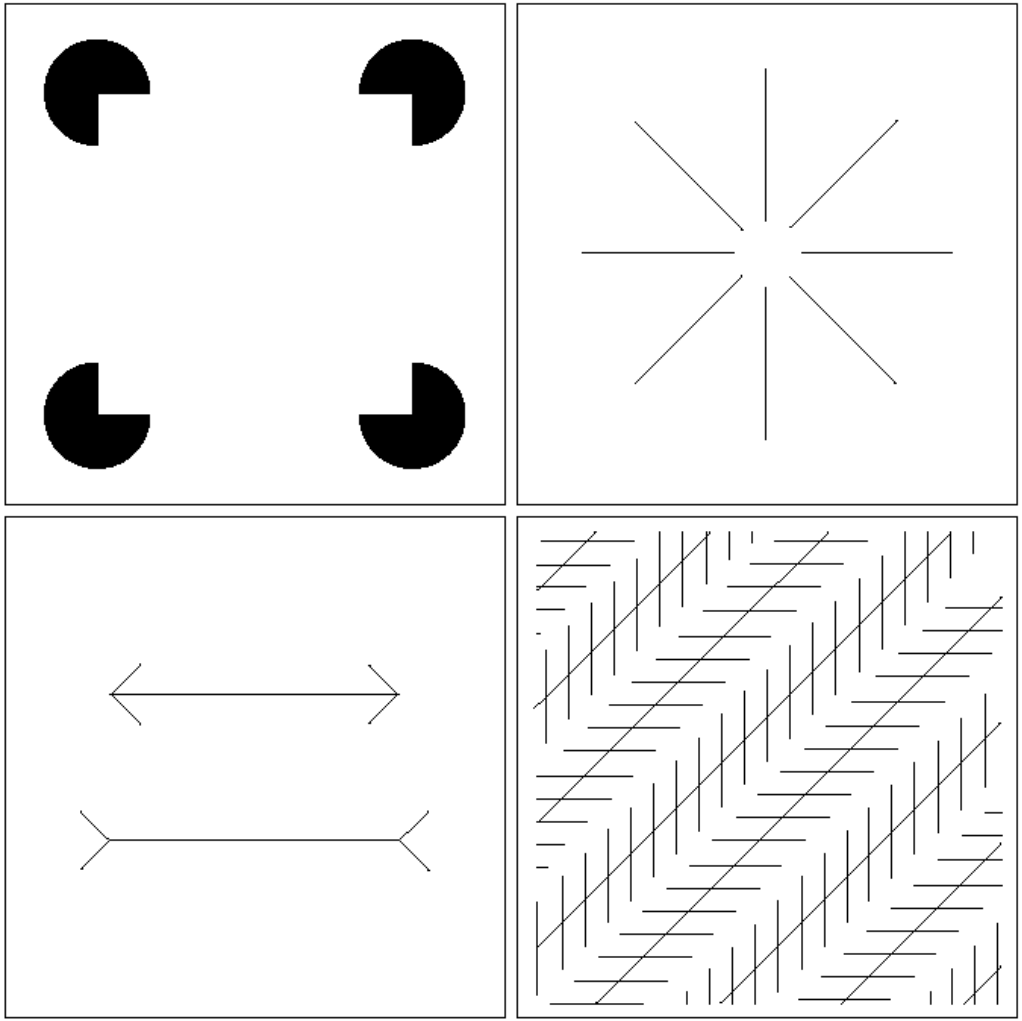


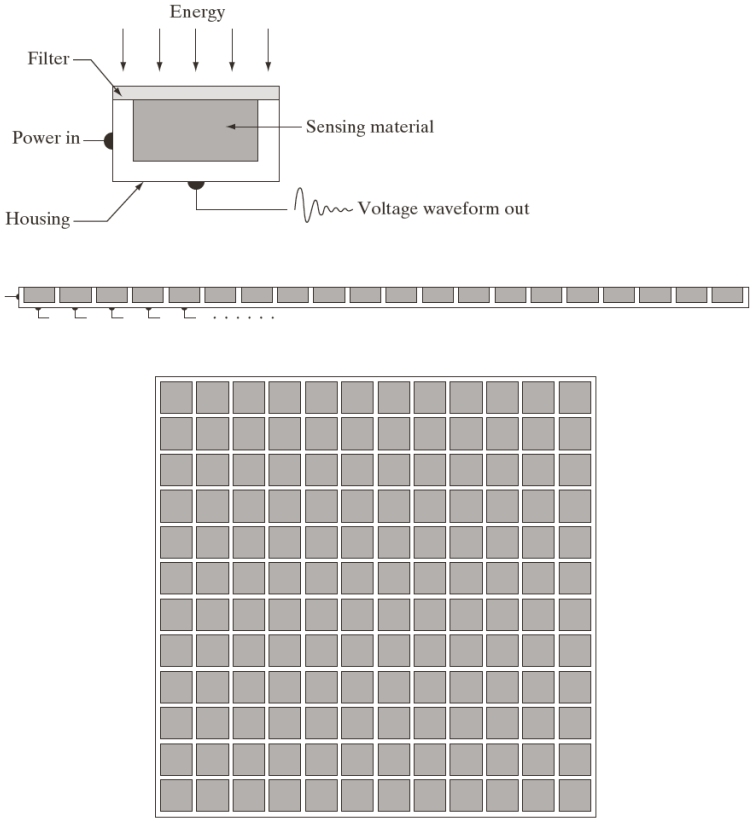
FIGURE 2.9 Some well-known optical illusions.

- **Digital Image Acquisition**
- Image Sampling and Quantization

How images are acquired

How images end up in digital form

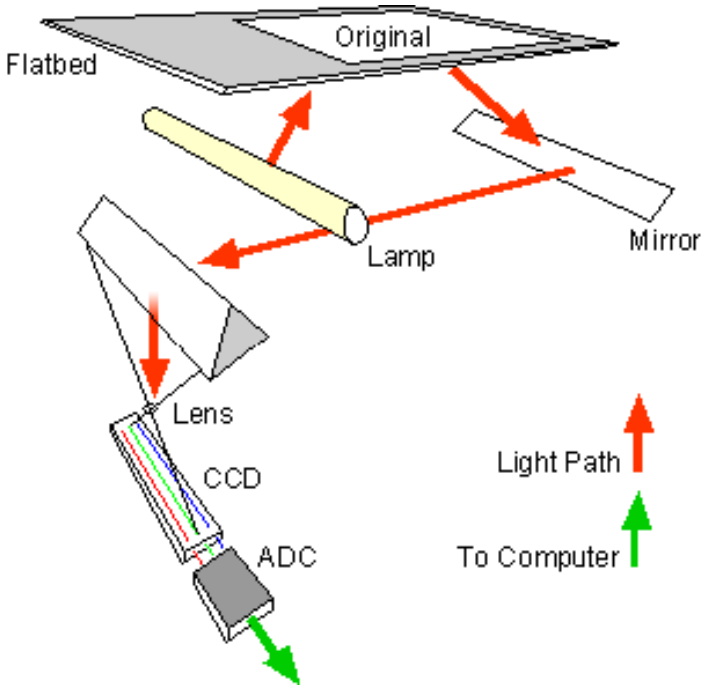
Image Sensing and Acquisition

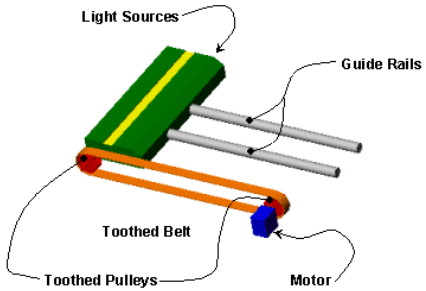


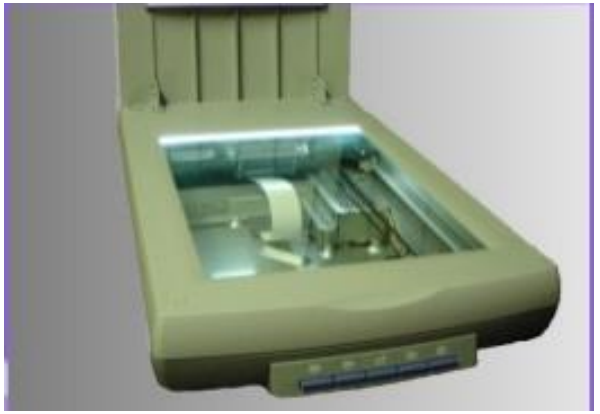
a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Image Sensing and Acquisition

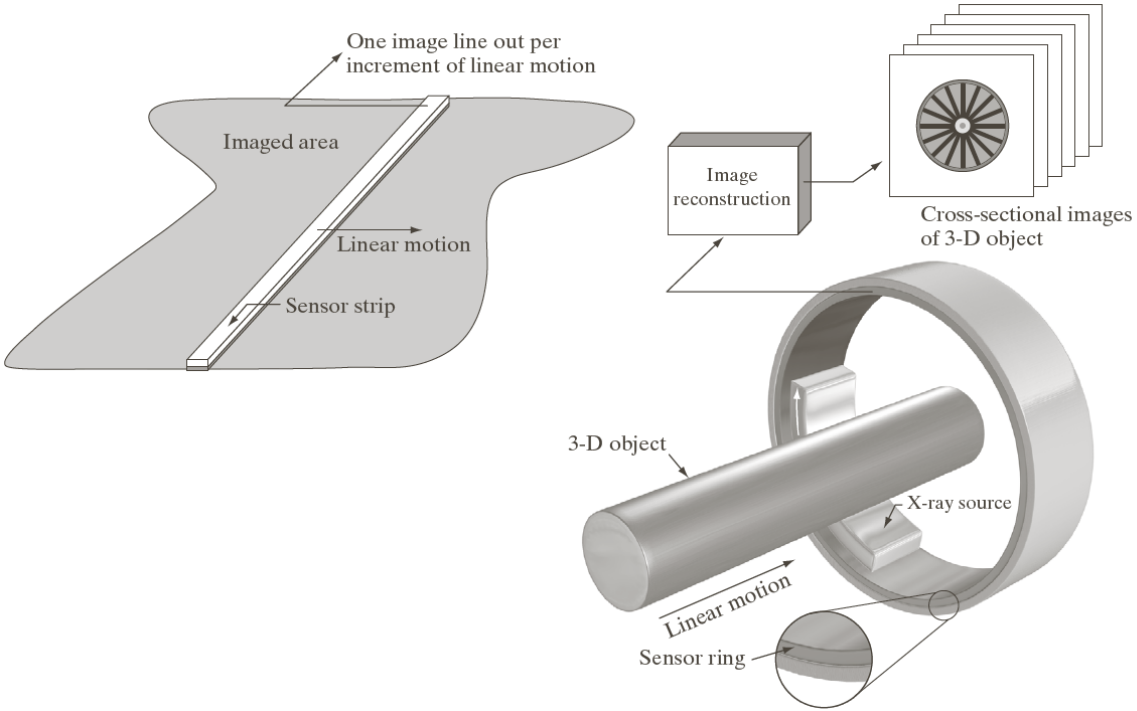






How does a scanner work: https://www.youtube.com/watch?v=OpBDTjw9yho

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

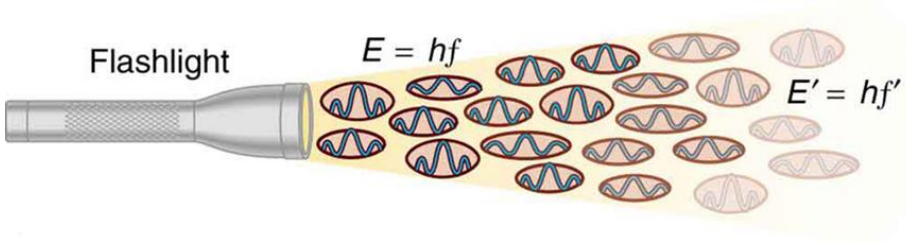
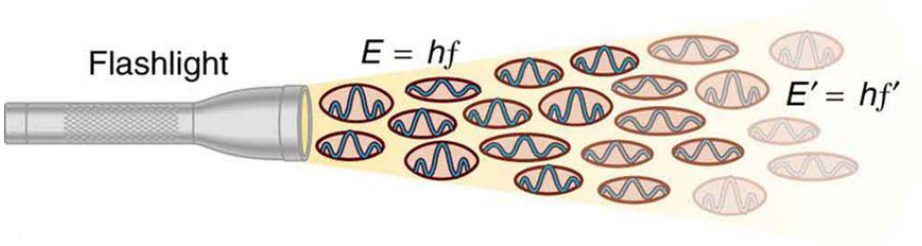
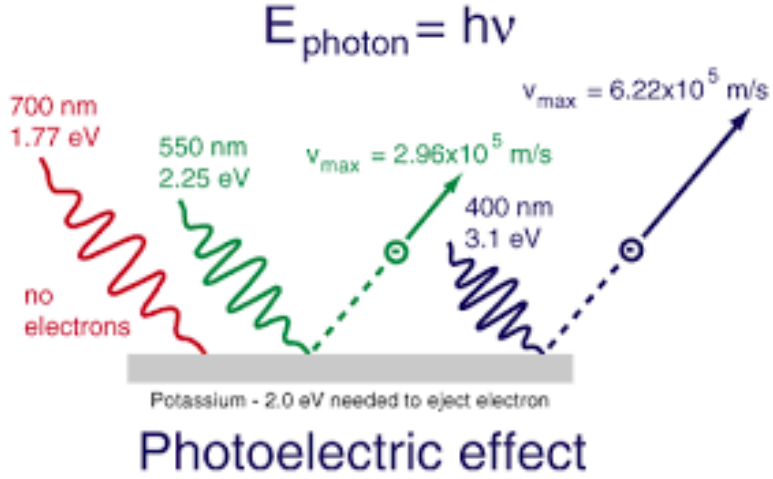
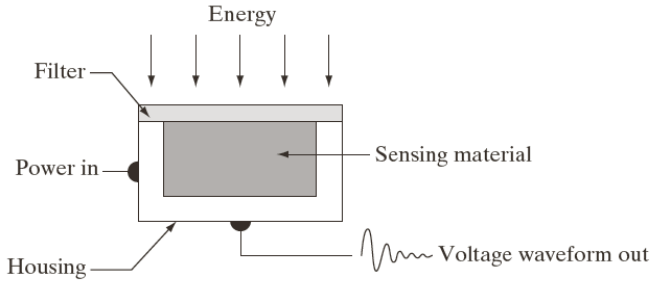


Photo-electric effect

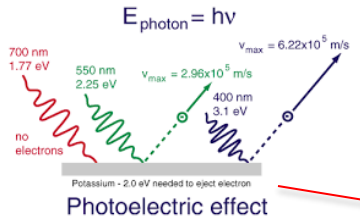


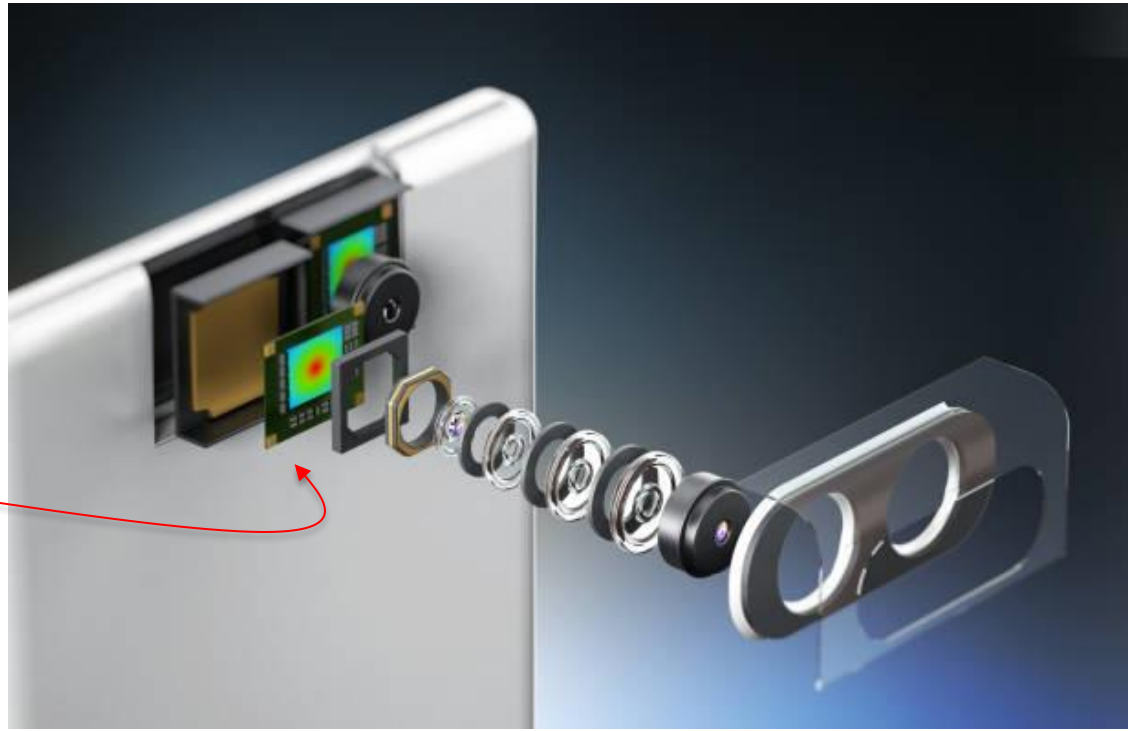




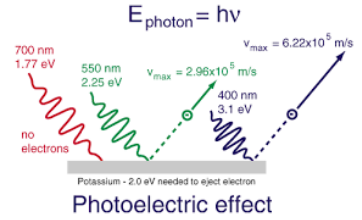
Cross-section of typical smartphone camera

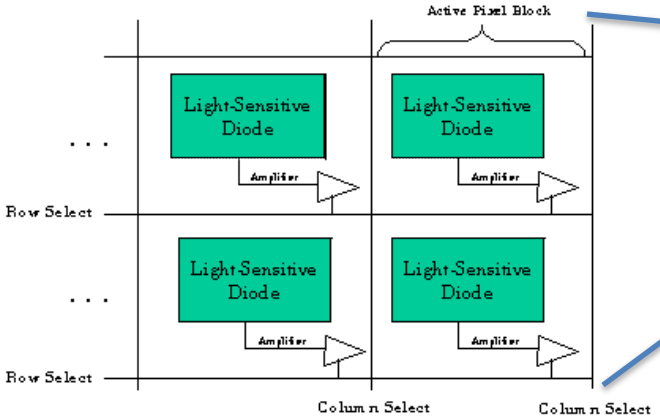
Photo-electric effect in cameras

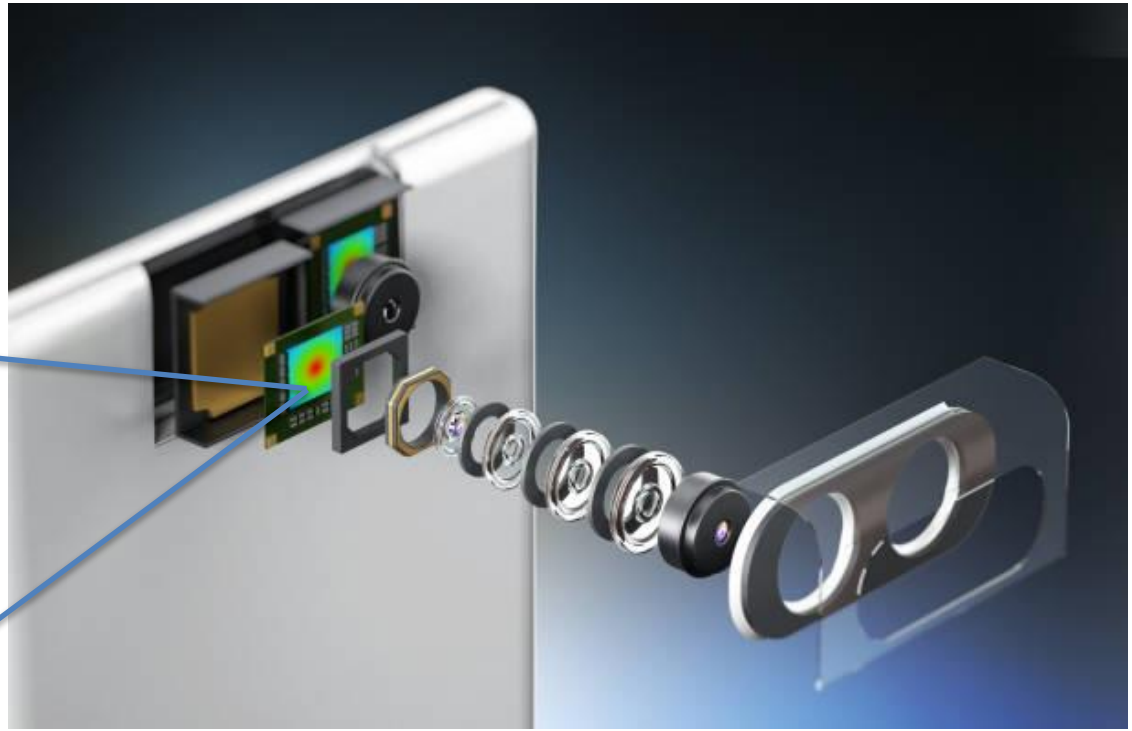




CMOS photo-electric sensor



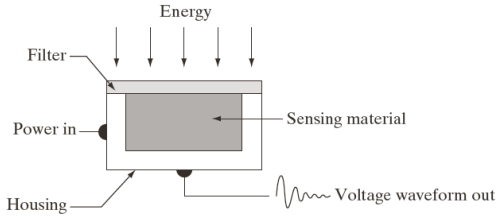


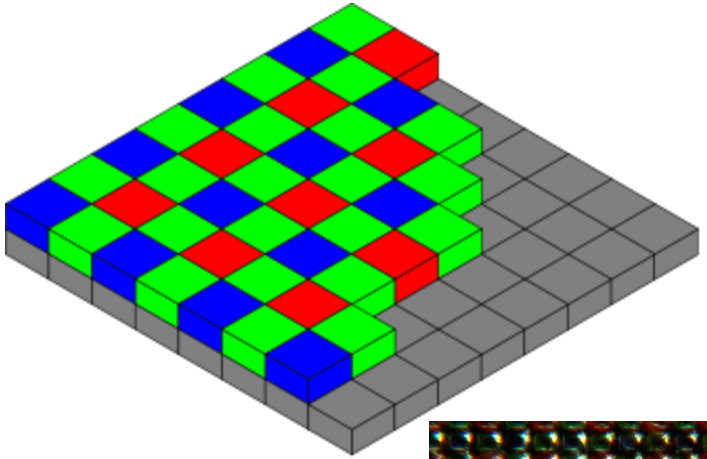


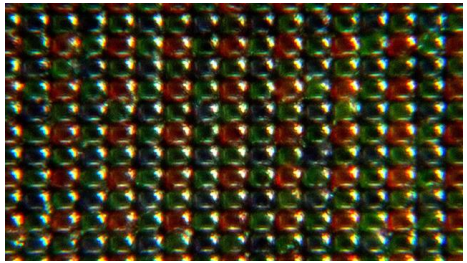
Light → Color

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

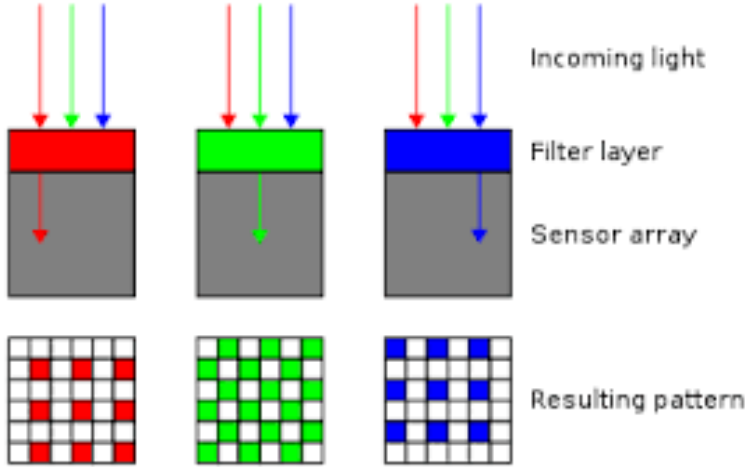
Bayer Filter







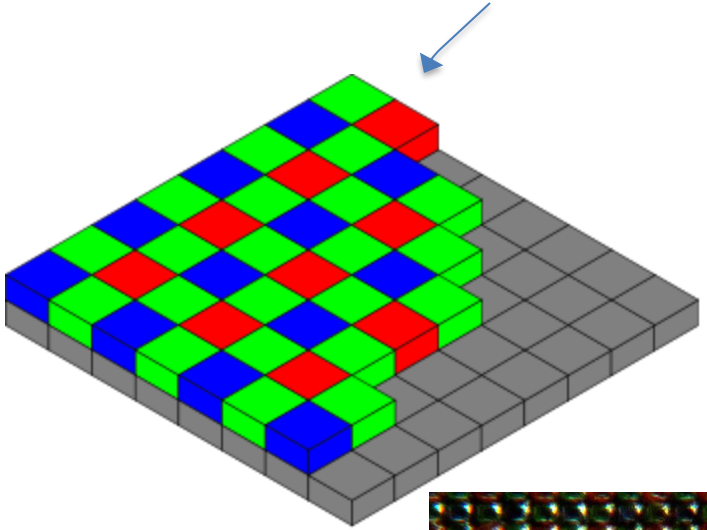
600x

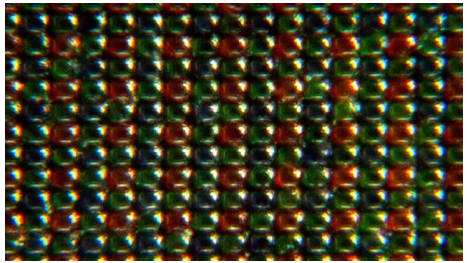


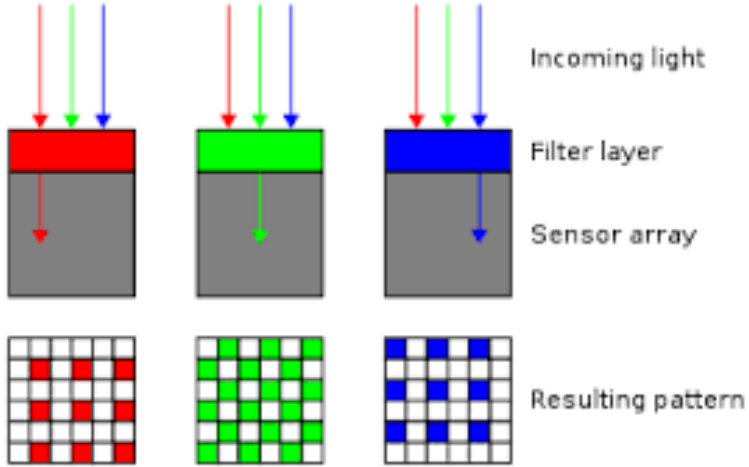
https://en.wikipedia.org/wiki/Bayer_filter

Bayer Filter

Relatively more green filters. Why ?

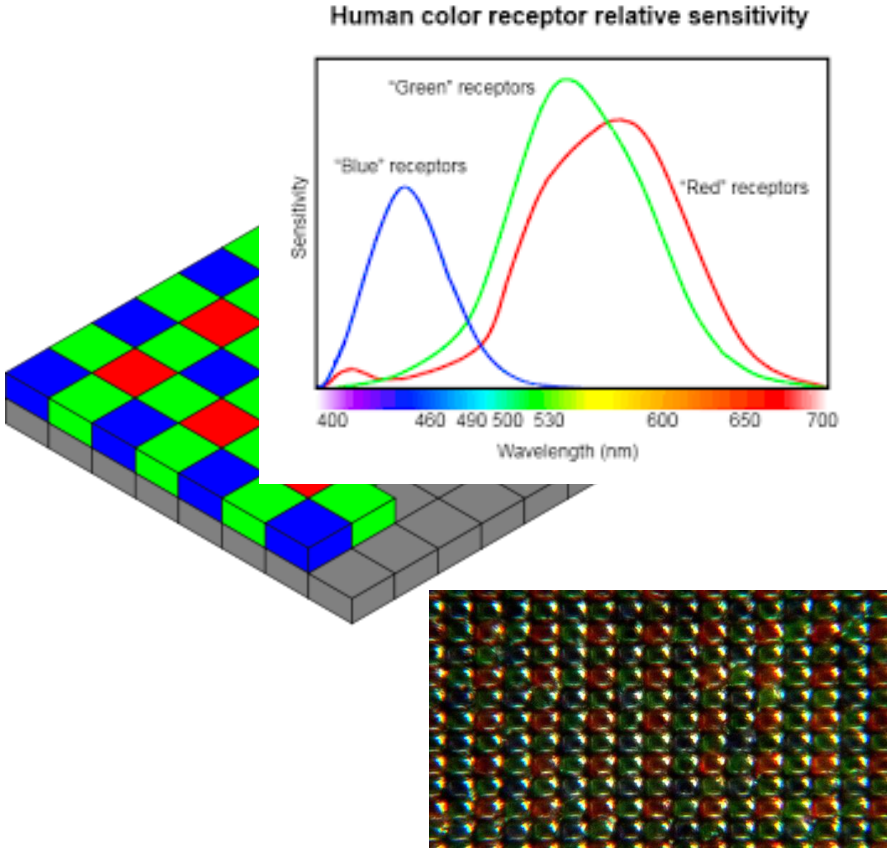




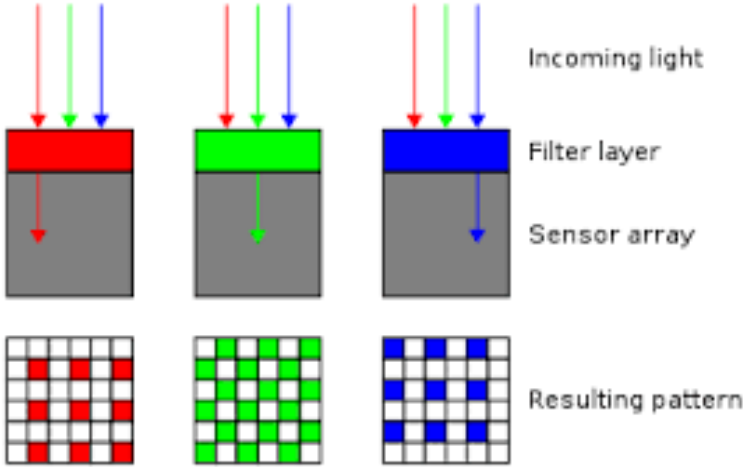


https://en.wikipedia.org/wiki/Bayer_filter

Bayer Filter



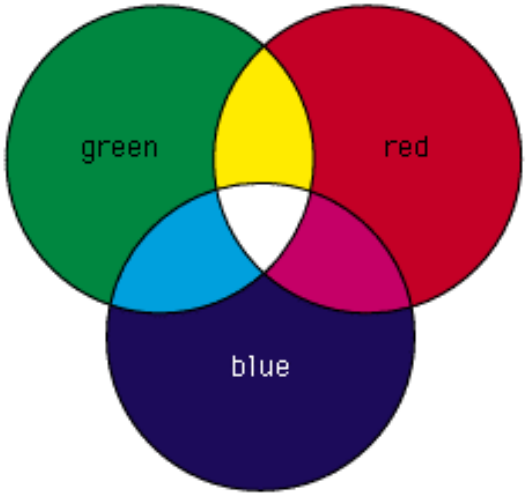
https://petapixel.com/2016/03/30/people-can-see-100-times-colors/

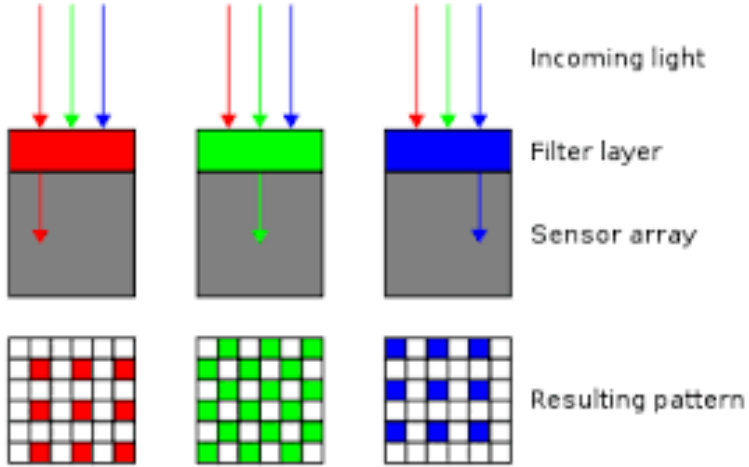


https://en.wikipedia.org/wiki/Bayer_filter

Bayer Filter

- How do we get color now ?





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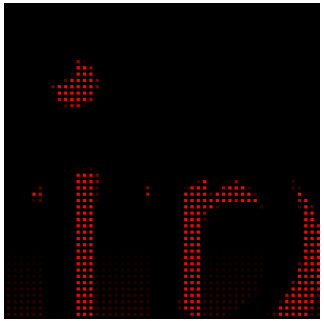
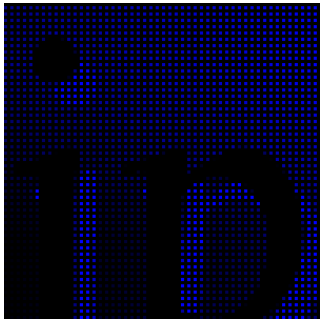
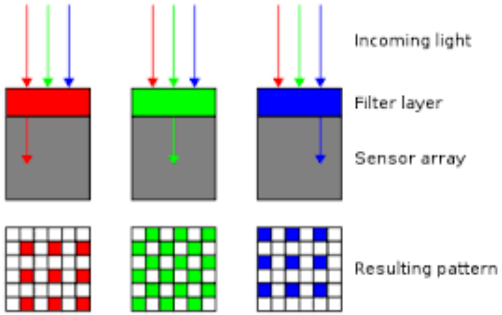
Demosaicing

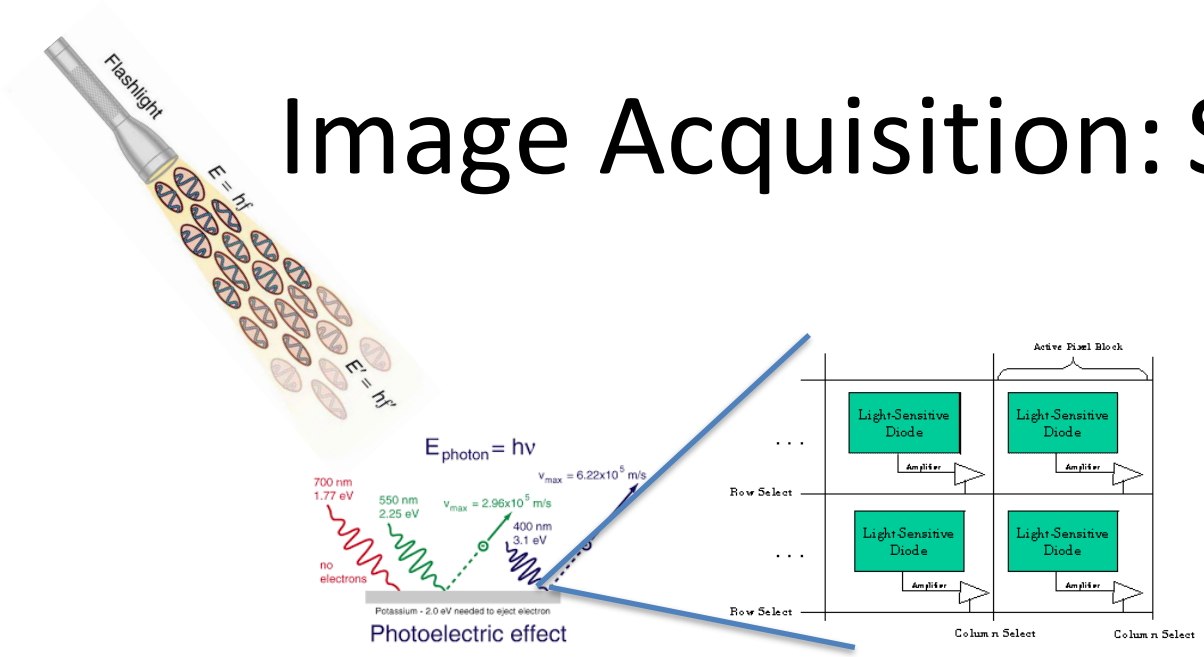


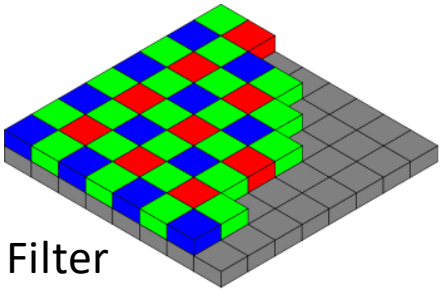




https://en.wikipedia.org/wiki/Demosaicing

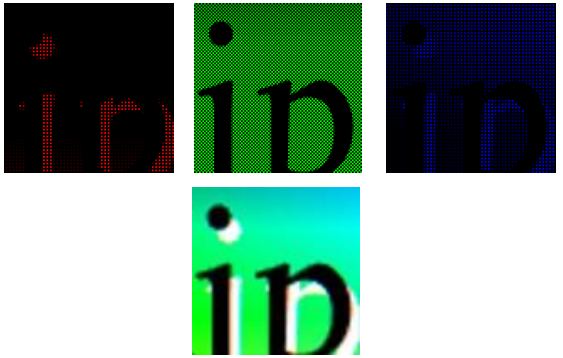
Image Acquisition: Summary





Bayer Filter

Demosaicing



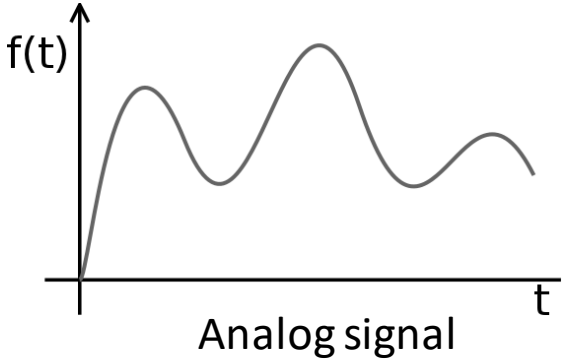
- Digital Image Acquisition
- **Image Sampling and Quantization**

How images are acquired

How images end up in digital form

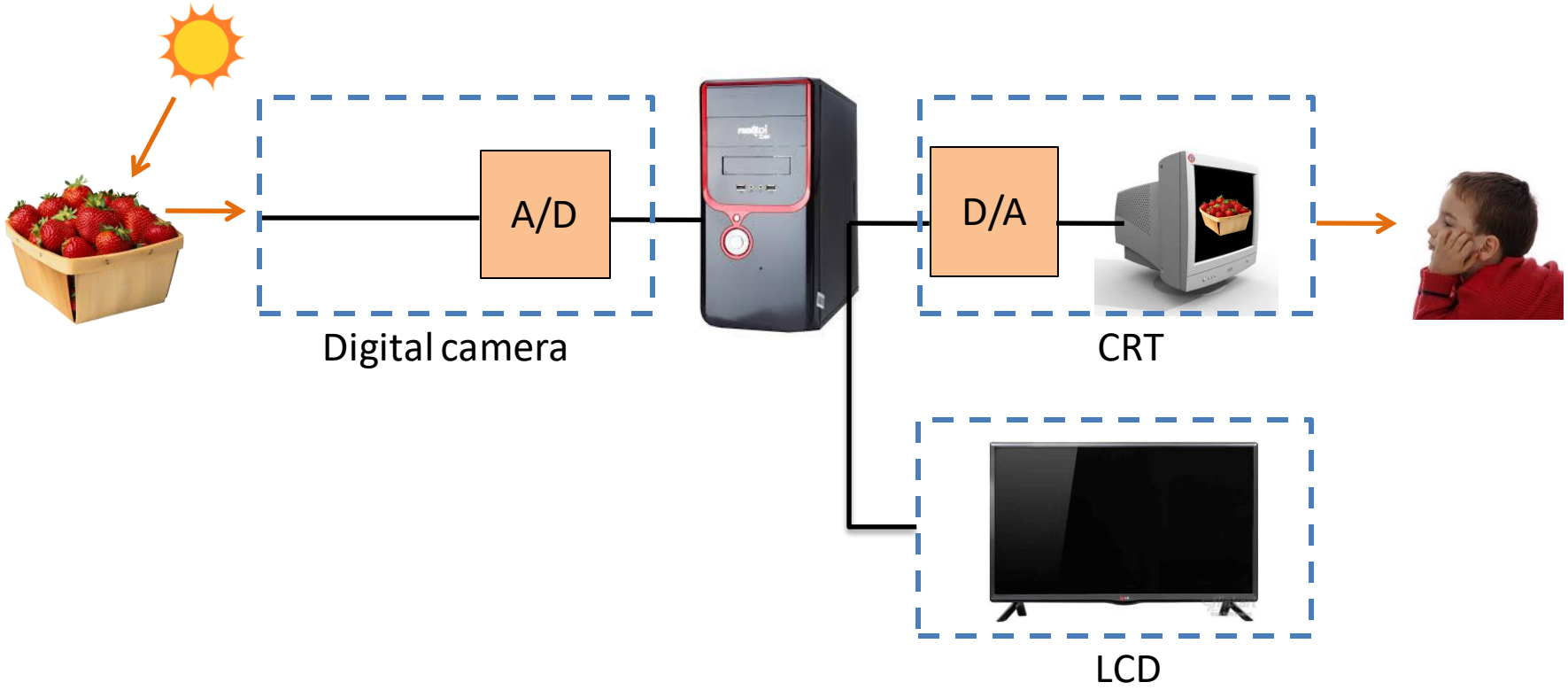
Signal

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

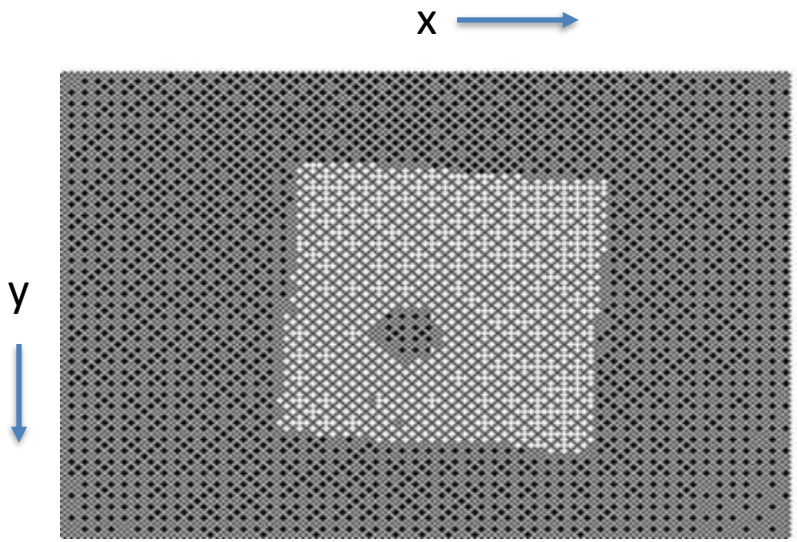


Analog signal

Analog vs. Digital signal (2-D signal)



2-D Image ‘signal’ = *f(x,y)*
A function of discretized space



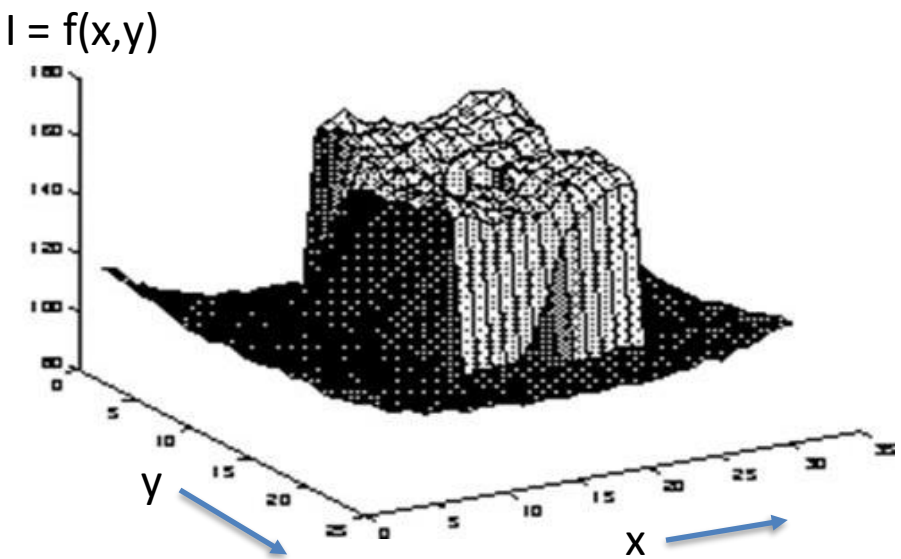


Image acquisition process

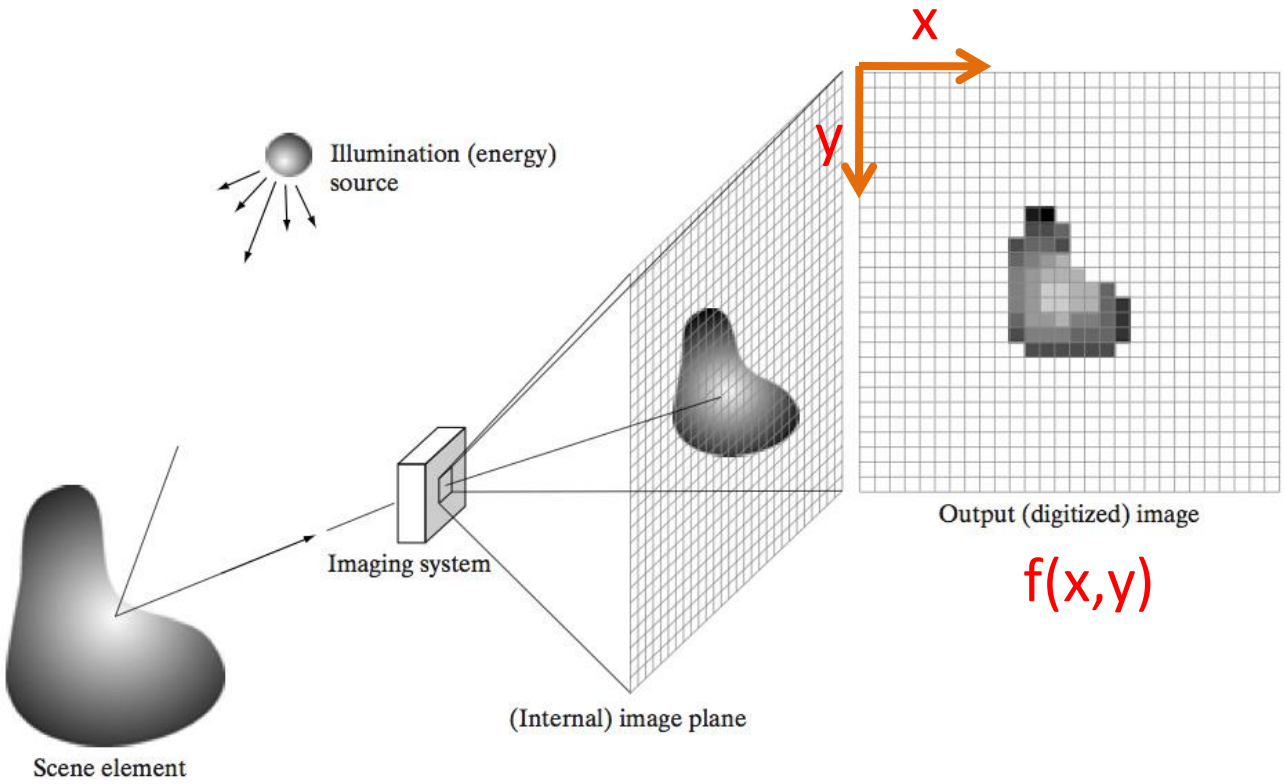


Image courtesy: Gonzalez and Woods

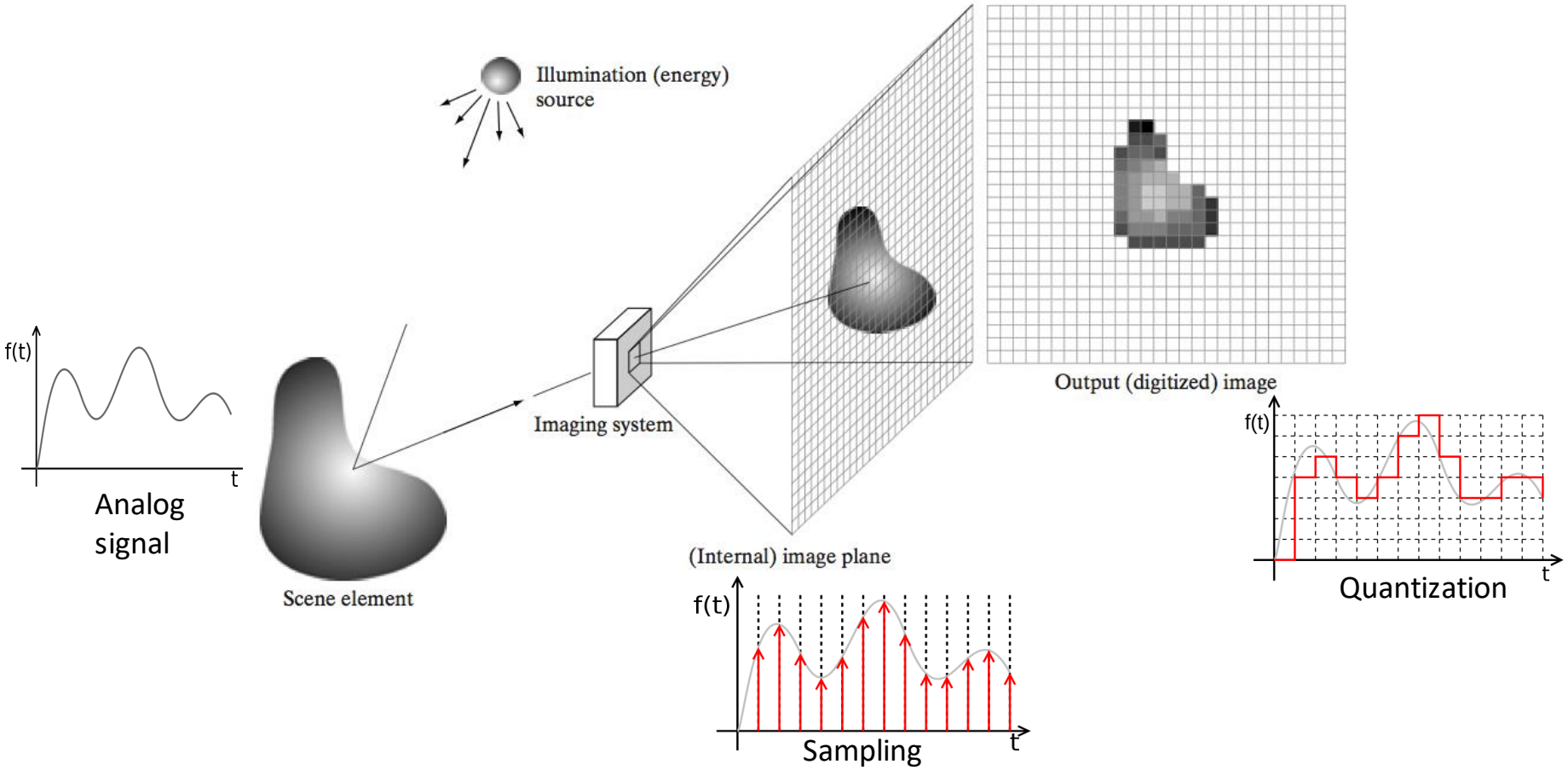
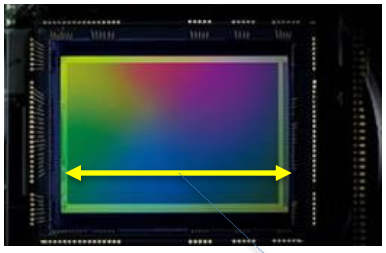


Image courtesy: Gonzalez and Woods

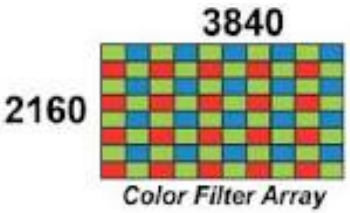
Cross-section of typical smartphone camera

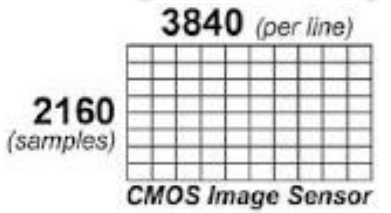
Physical Characteristics	
Active image area size	24.6 (H) x 13.8 (V) mm
Total number photosites	4206 (H) x 2340 (V)
Number photosites for active image	3840 (H) x 2160 (V)
Color filter array (with microlens)	RGB Bayer
Size of photosite (microns)	6.4 (H) x 6.4 µm
Pixel pitch	6.4 µm
Power supply	3.3v /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

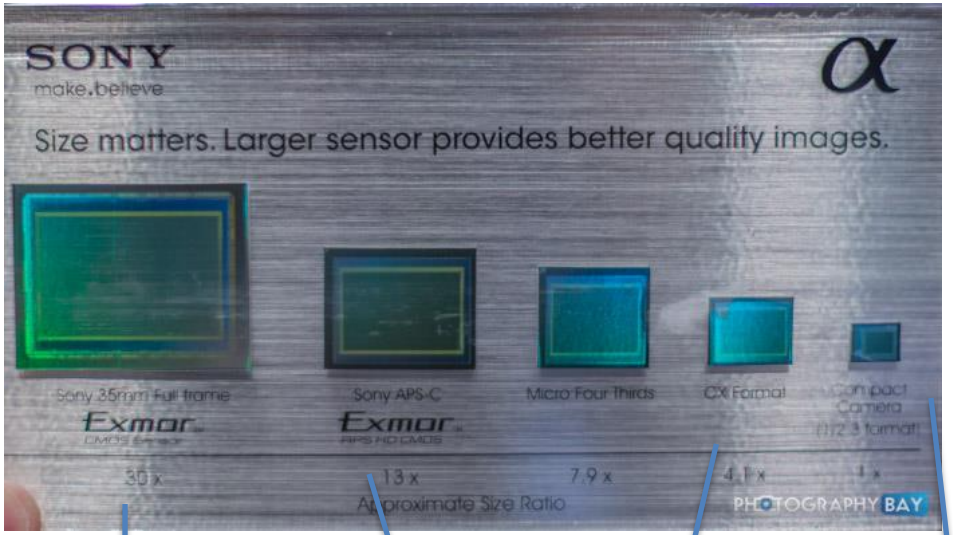
Resolution (of the sensor)



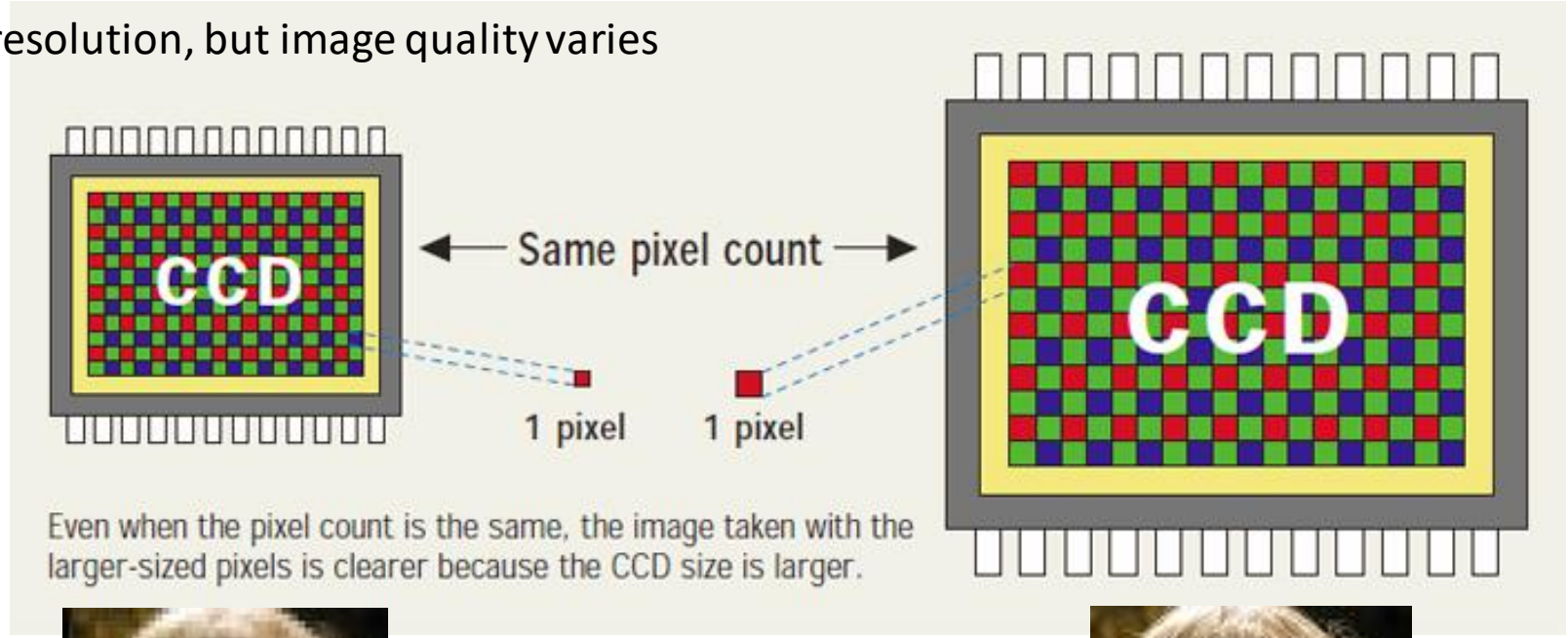
24.6 mm





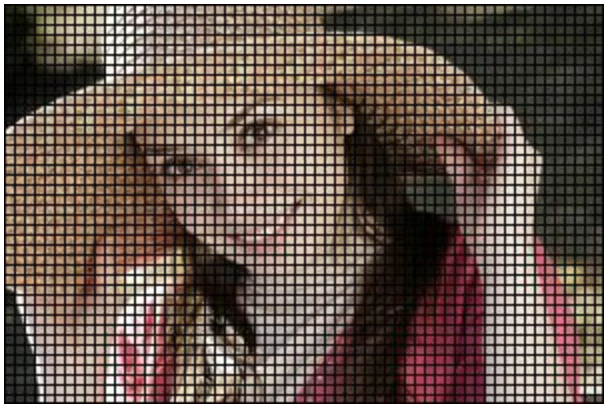

SONY
make.believe
α
Size matters. Larger sensor provides better quality images.
Sony 35mm Full frame
Exmor
Sony APS-C
Exmor
Micro Four Thirds
CX Format
Compact Camera
1/2.3 format
30 x
13 x
7.9 x
4.1 x
1 x
Approximate Size Ratio
PHOTOGRAPHY BAY

Same resolution, but image quality varies

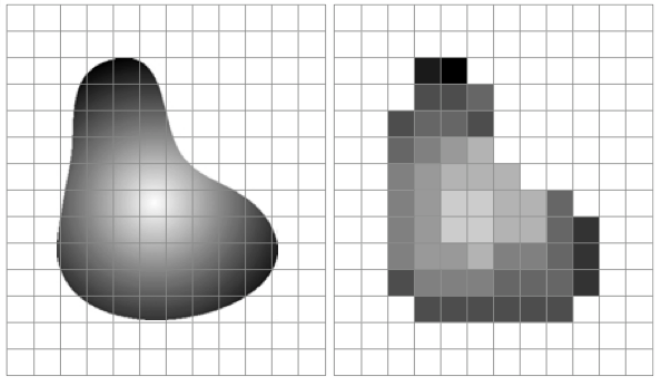


Same sensor size, but # of sensor pixels/mm varies

Small number of CCD pixels



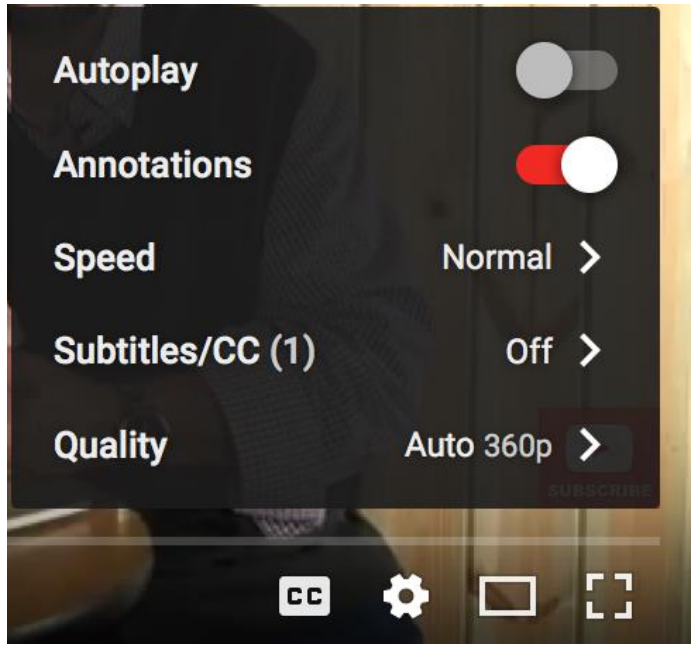
Large number of CCD pixels



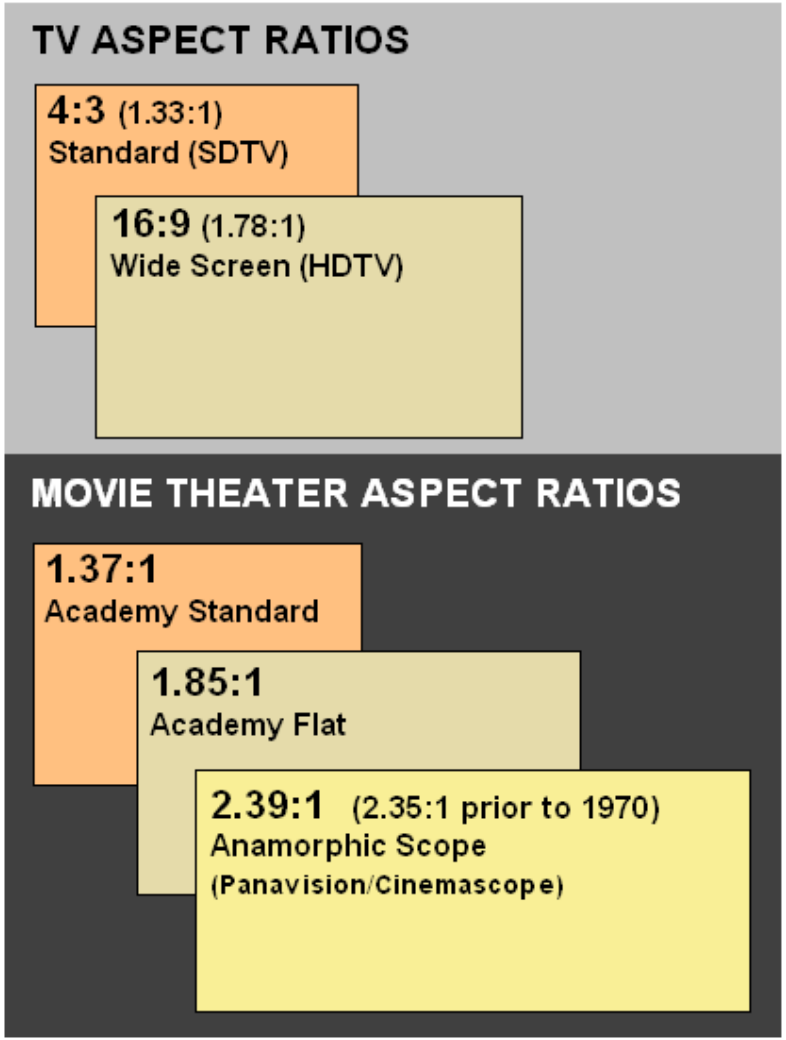
https://av.jpn.support.panasonic.com/support/global/cs/dsc/knowhow/knowhow26.html


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



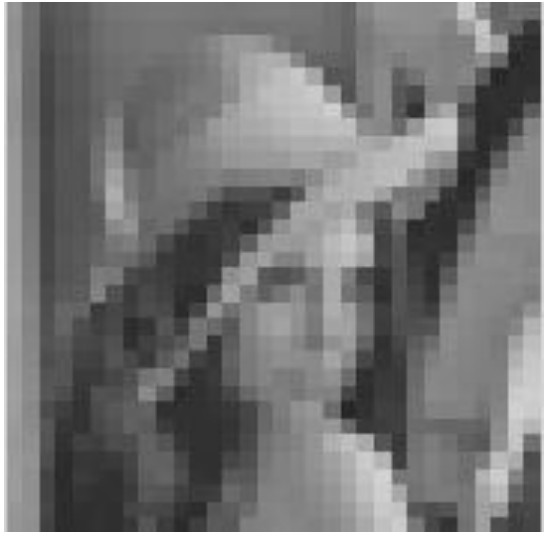
Key Terms

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

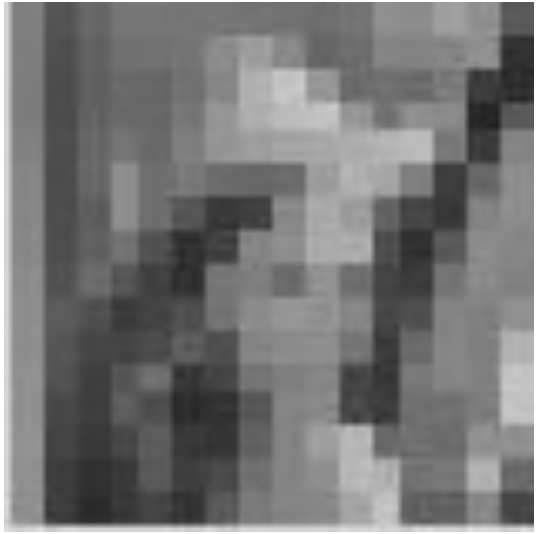
Video Quality	4:3 Aspect Ratio Resolution	16:9 Aspect Ratio Resolution
360p	480 x 360	640 x 360
480p	640 x 480	854 x 480
720p	Not generally used	1280 x 720
1080p	Not generally used	1920 x 1280

Sampling = Spatial Quantization

256 × 256



32 × 32



16 × 16

Image acquisition process

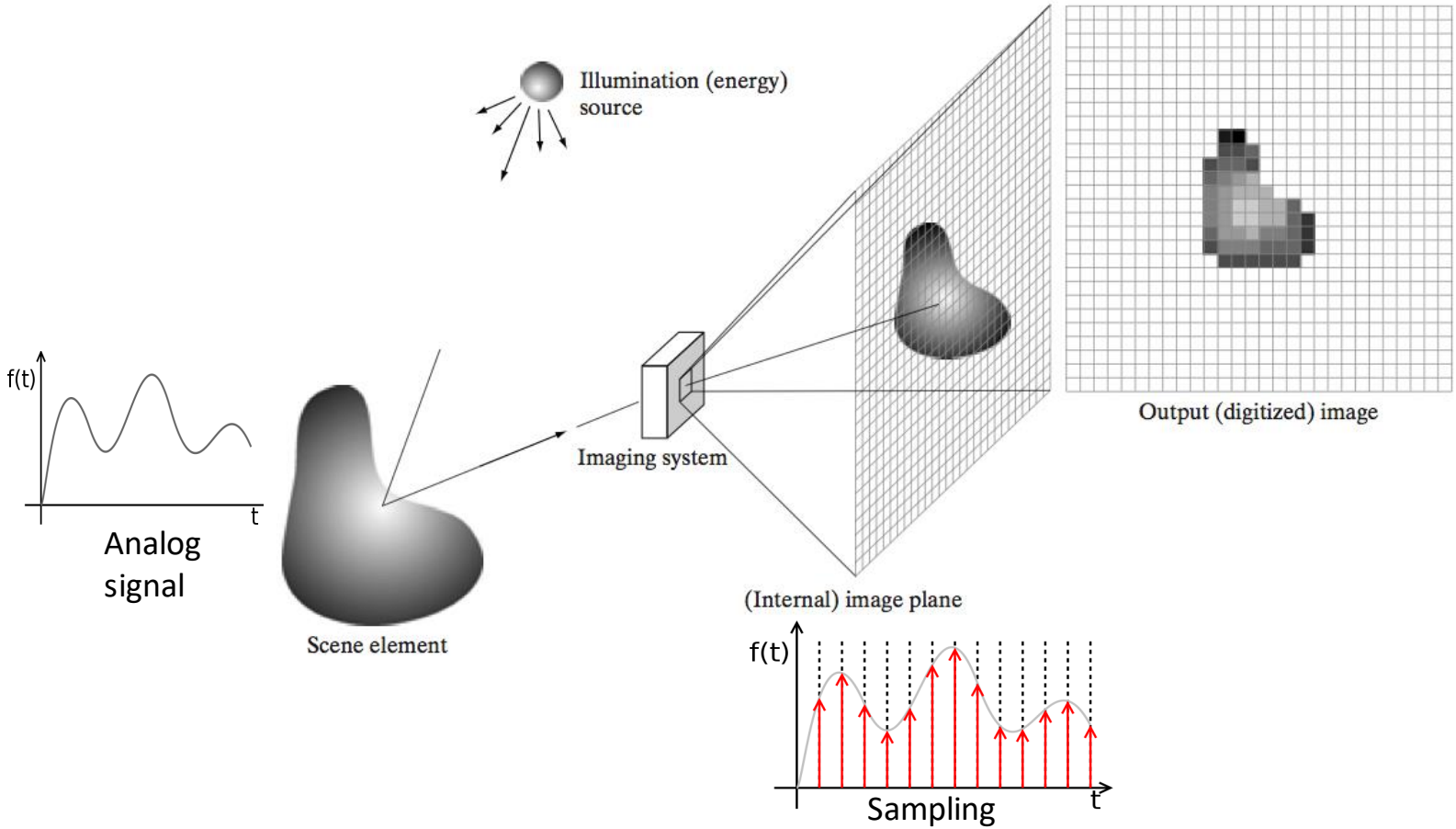


Image courtesy: Gonzalez and Woods

Image acquisition process

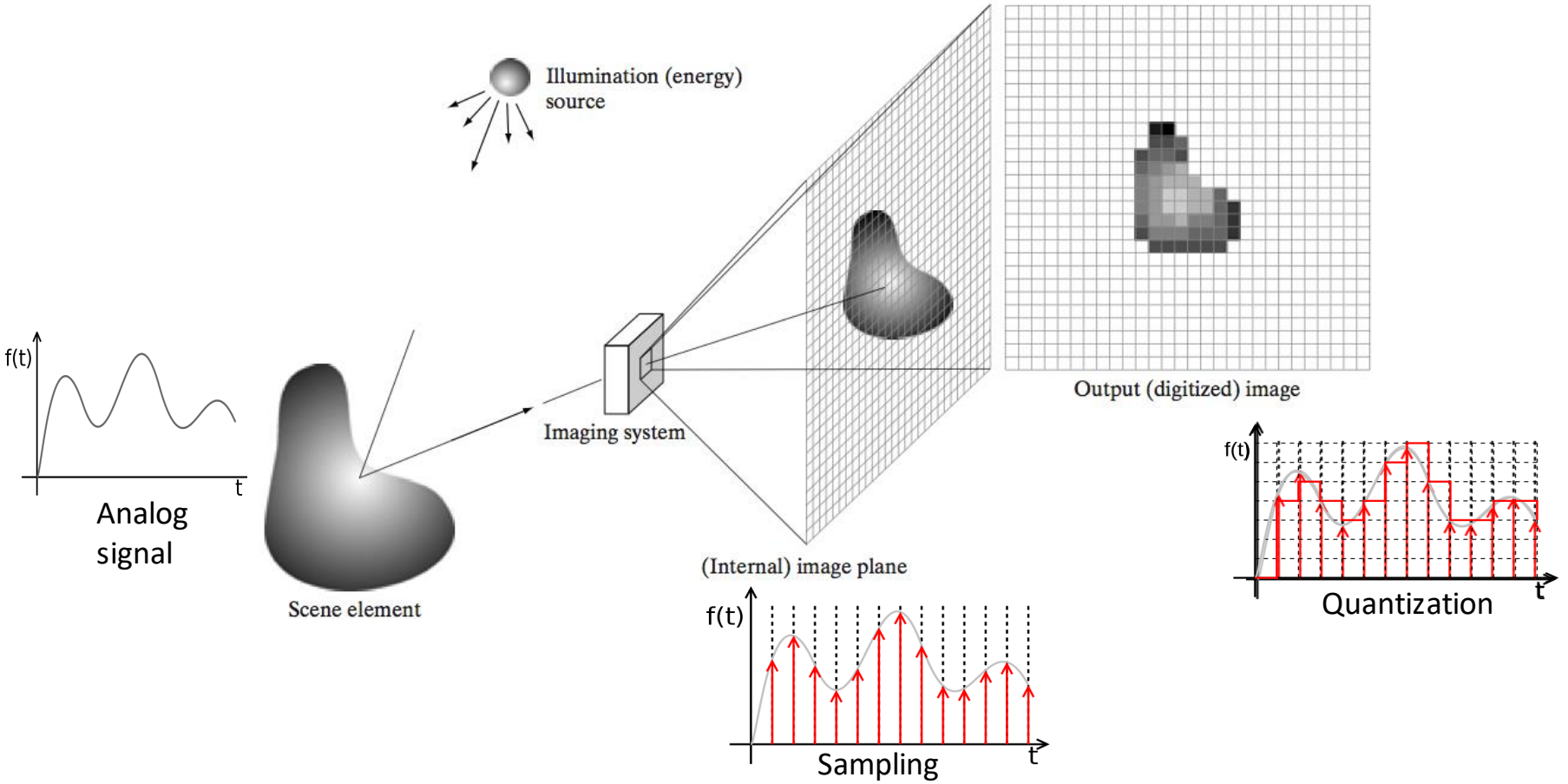


Image courtesy: Gonzalez and Woods

Intensity Quantization

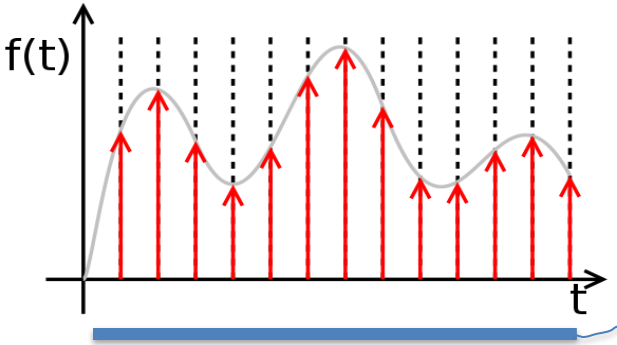
8 bits per pixel

4 bits per pixel

2 bits per pixel

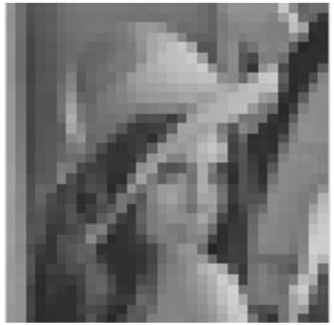
1 bit per pixel

Summary

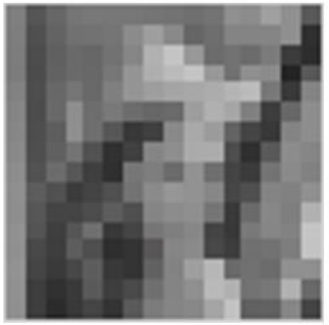


Sampling

256 × 256

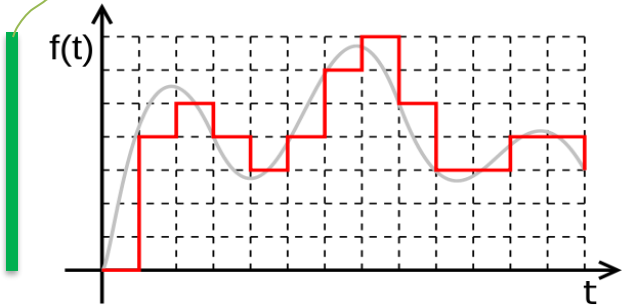


32 × 32



16 × 16

Quantization



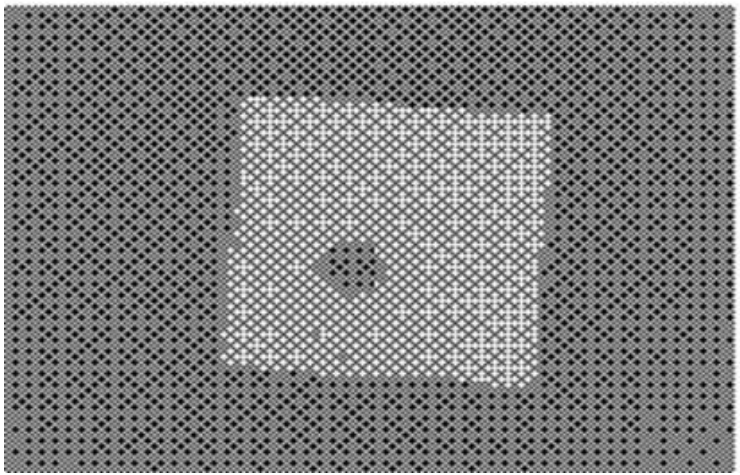
8 bits per pixel

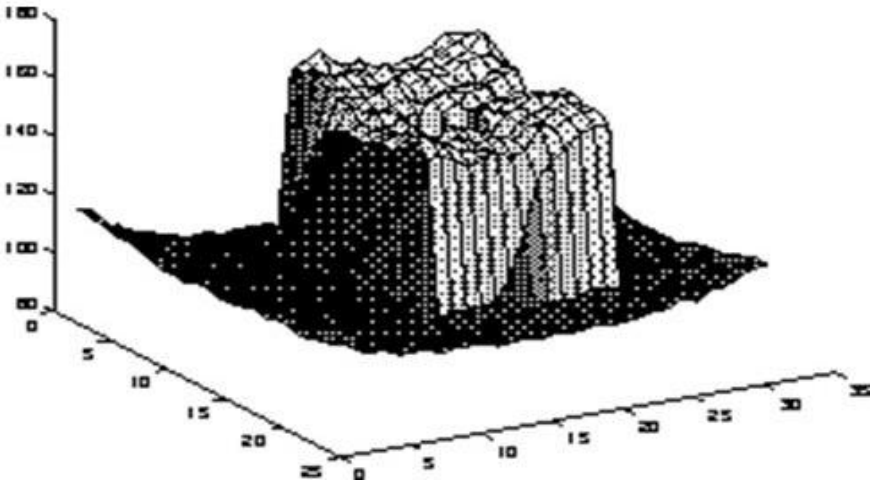
4 bits per pixel

2 bits per pixel

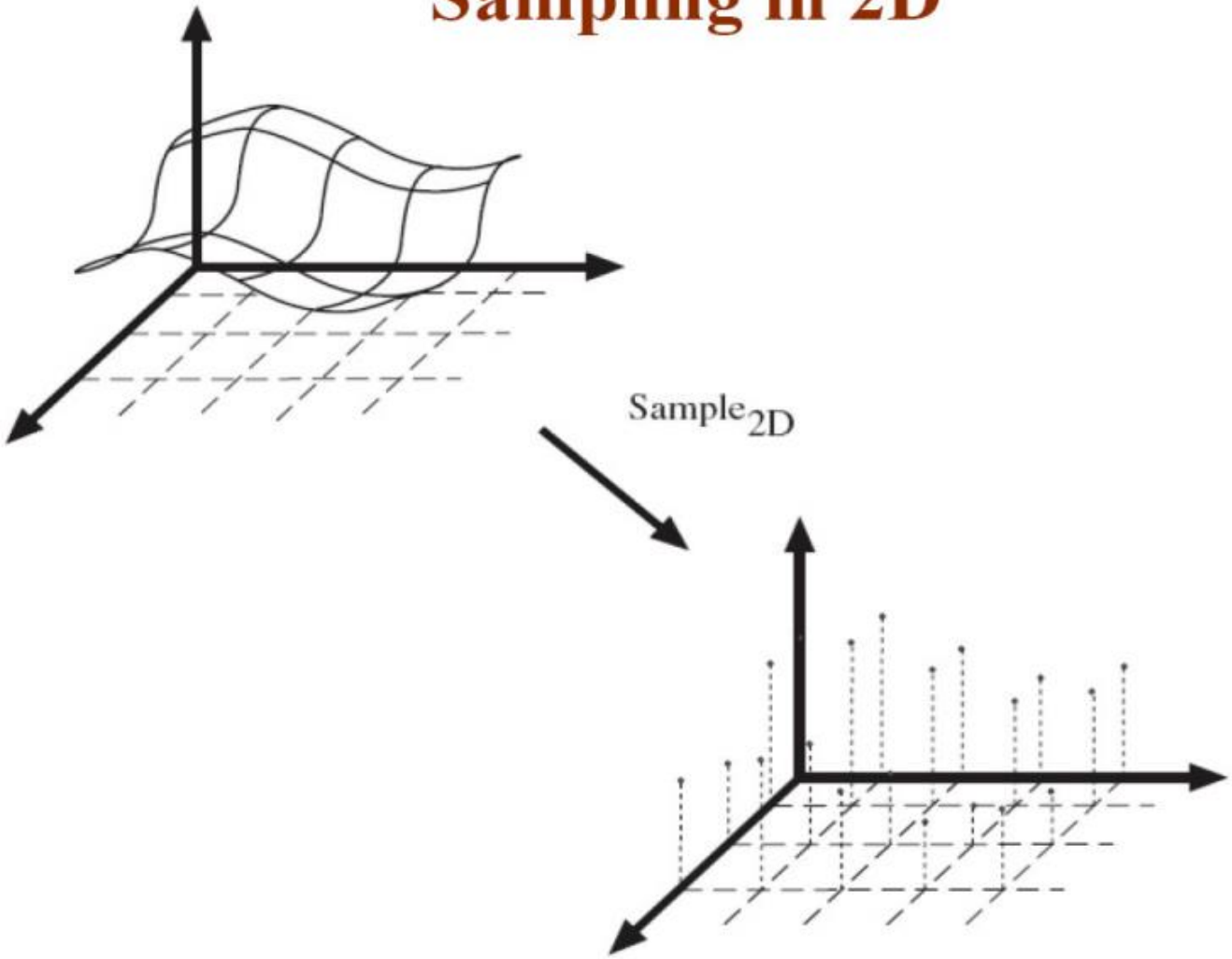
1 bit per pixel

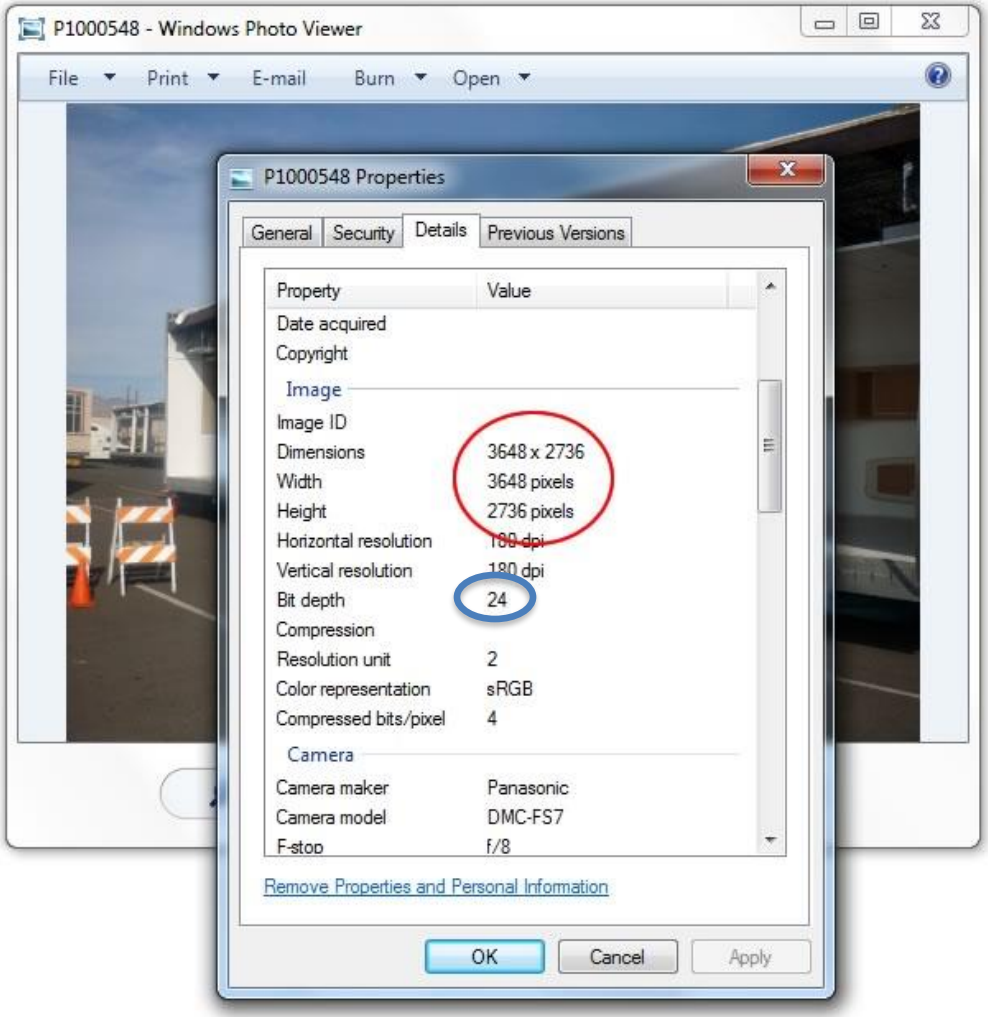
Image as a 3D surface





Sampling in 2D




P1000548 - Windows Photo Viewer
File
Print
E-mail
Burn
Open
P1000548 Properties
General
Security
Details
Previous Versions
Property
Value
Date acquired
Copyright
Image
Image ID
Dimensions
3648 x 2736
Width
3648 pixels
Height
2736 pixels
Horizontal resolution
180 dpi
Vertical resolution
180 dpi
Bit depth
24
Compression
Resolution unit
2
Color representation
sRGB
Compressed bits/pixel
4
Camera
Camera maker
Panasonic
Camera model
DMC-FS7
F-stop
f/8
Remove Properties and Personal Information
OK
Cancel
Apply

Quantization

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

Summary: HVS

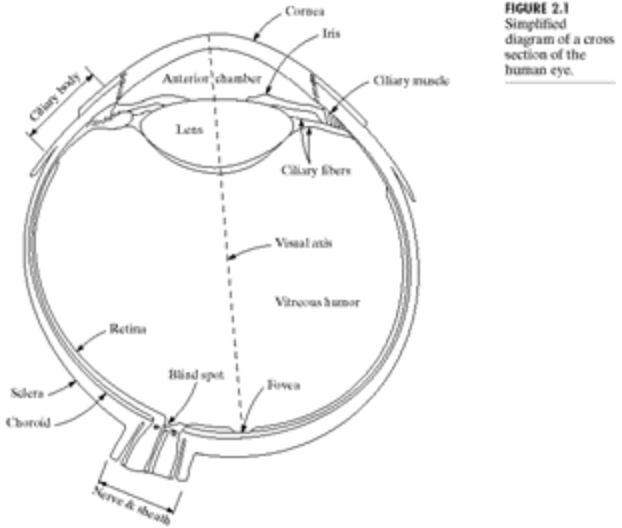
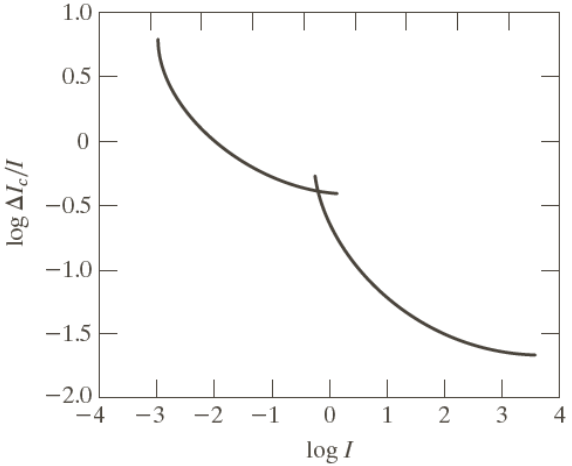
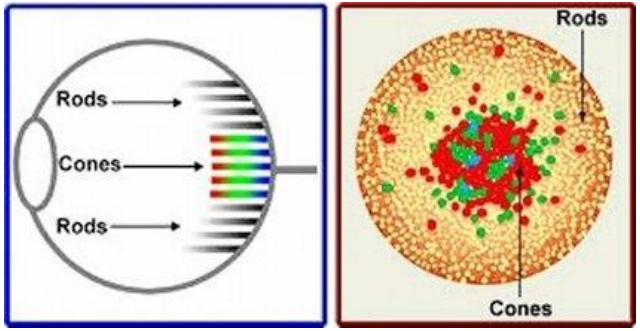
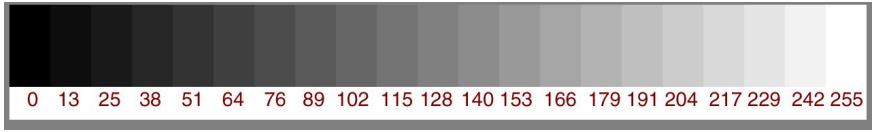


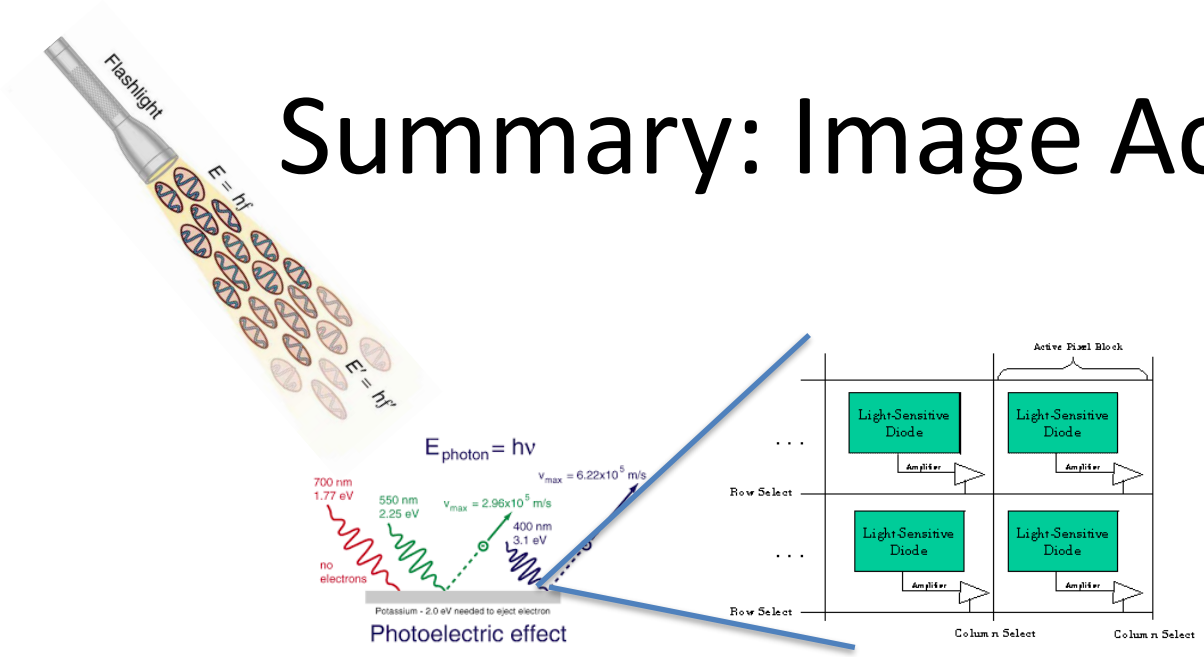
FIGURE 2.1
Simplified diagram of a cross section of the human eye.

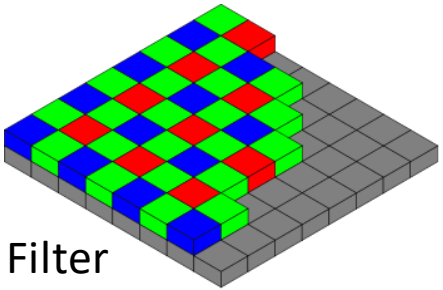






Summary: Image Acquisition





Bayer Filter

Demosaicing

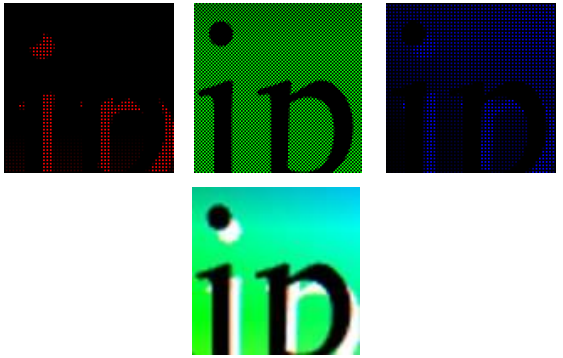


Image acquisition process

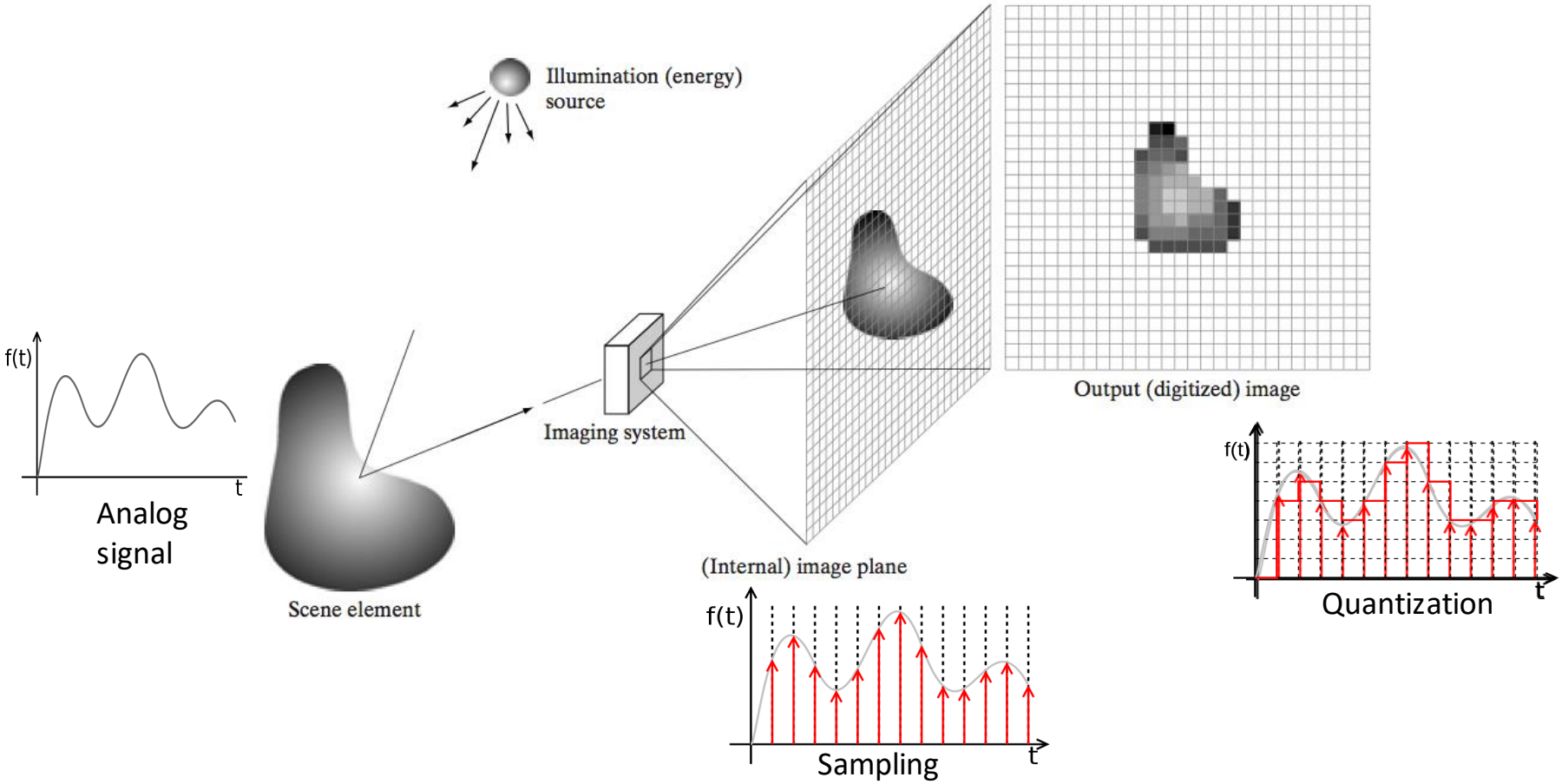
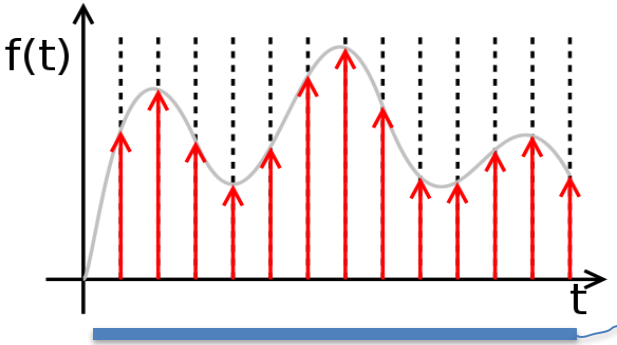


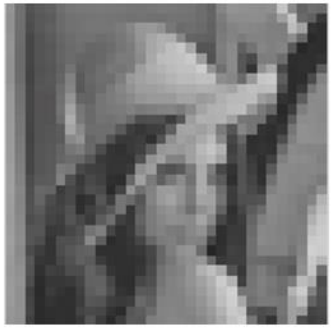
Image courtesy: Gonzalez and Woods

Summary: Image Sampling and Quantization

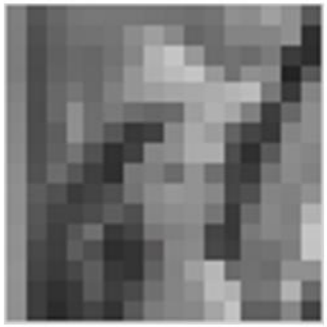
Sampling



256 × 256

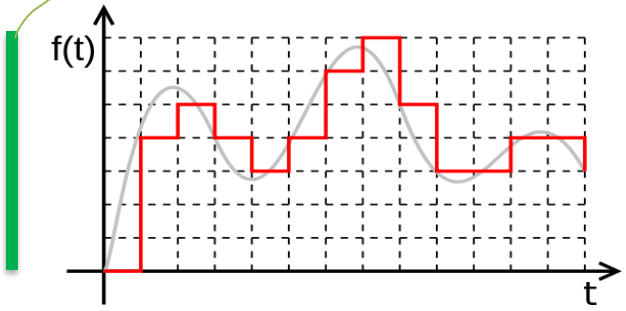


32 × 32



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/