Teaching Assistants

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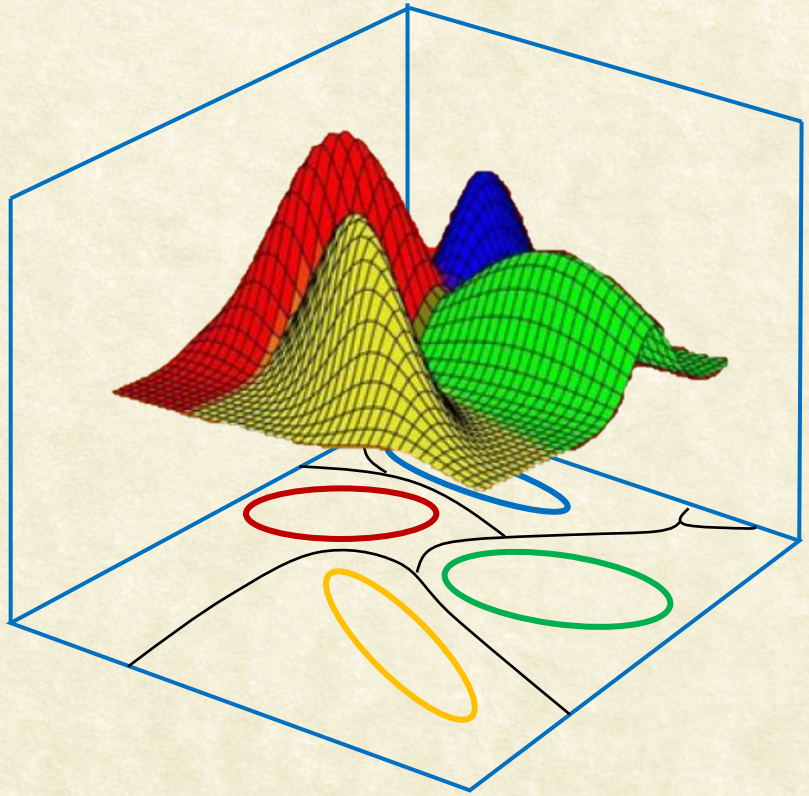
CS7.404: Digital Image Processing

Monsoon 2023: **Imaging**



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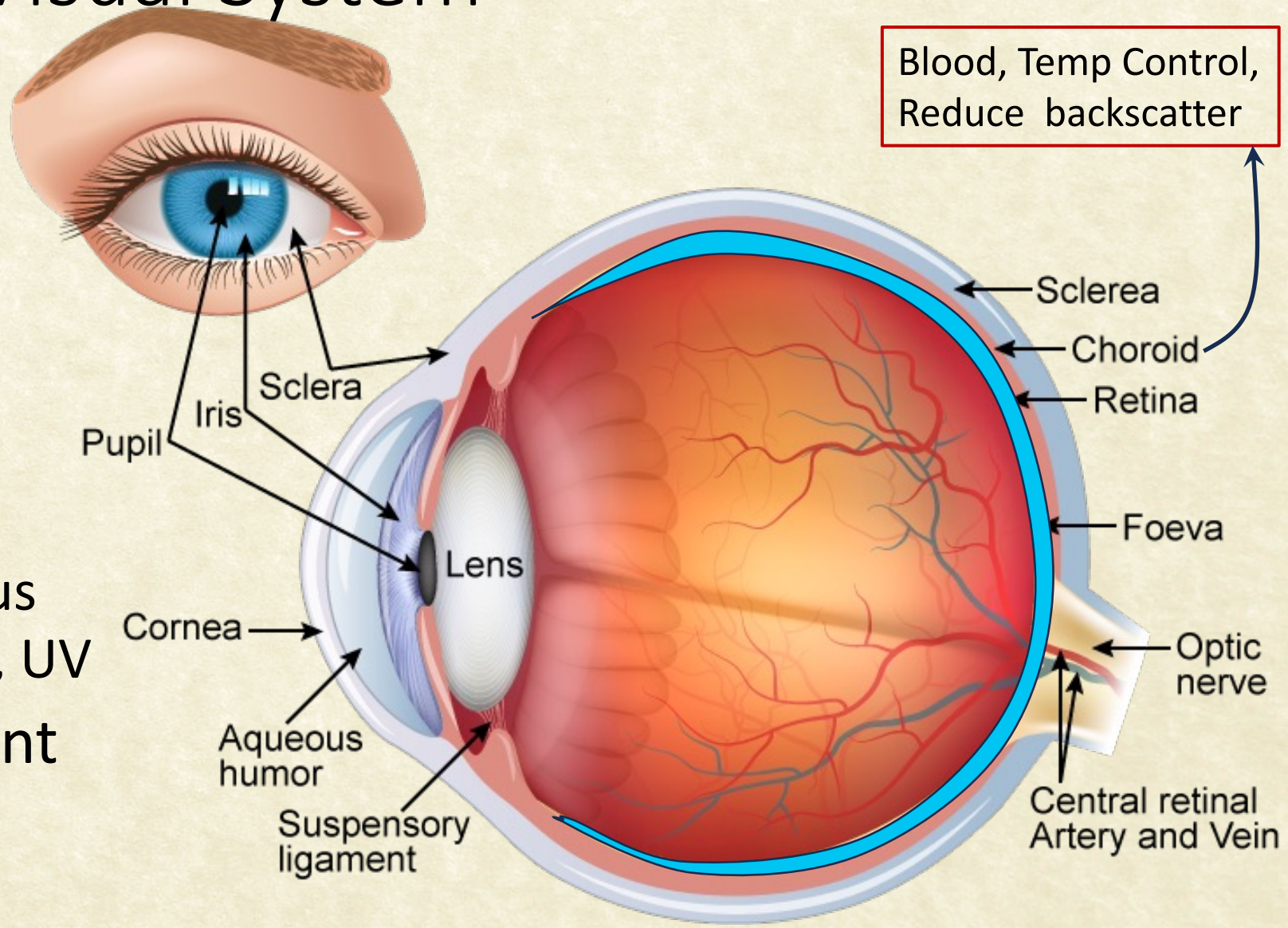
The Human Visual System

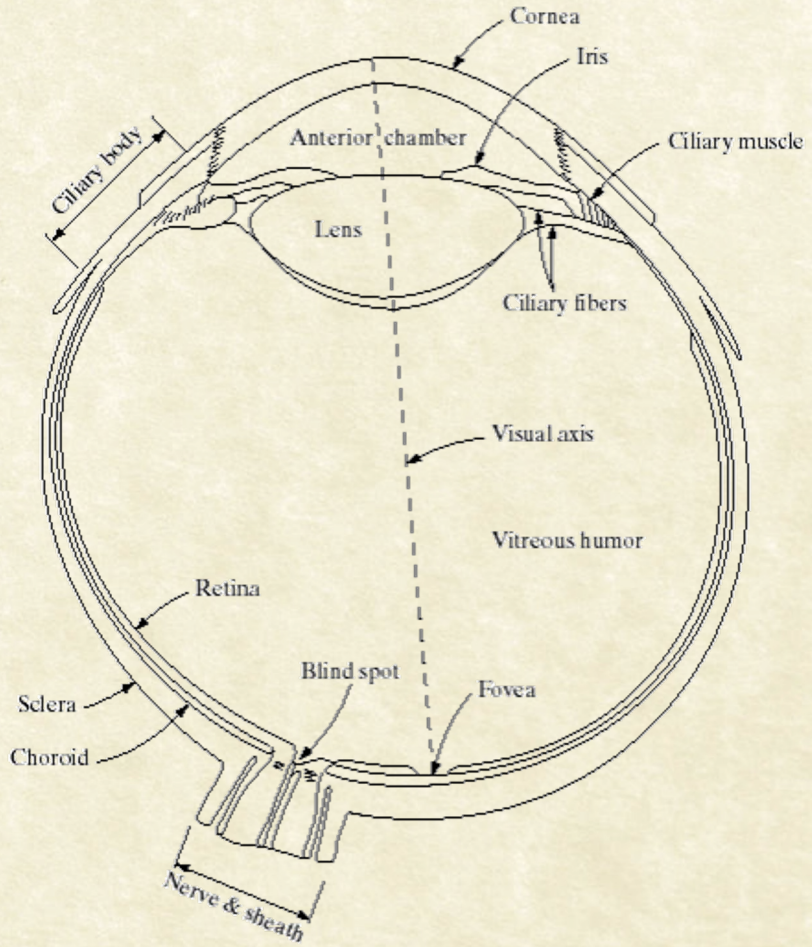
- **Retina**: The imaging surface (not flat)
  - 6 - 7M cones
  - 75 - 150M rodes
- **Lens** is a jelly
  - Changes shape to focus
  - Absorbs 8% of VLS; IR, UV
- **Iris** controls the amount of light
  - 2 – 8mm dia.

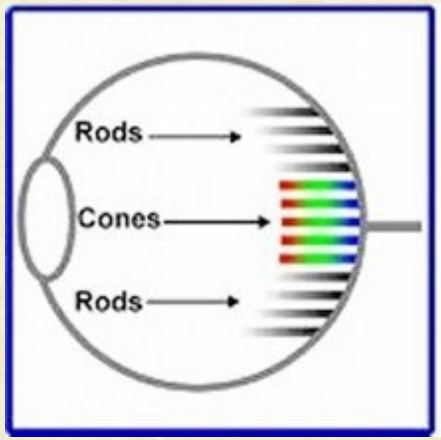


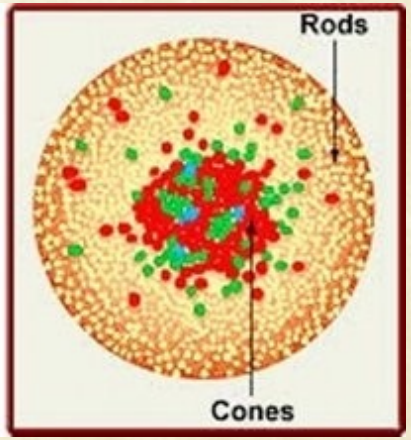
Diameter: 20 mm

Cones

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

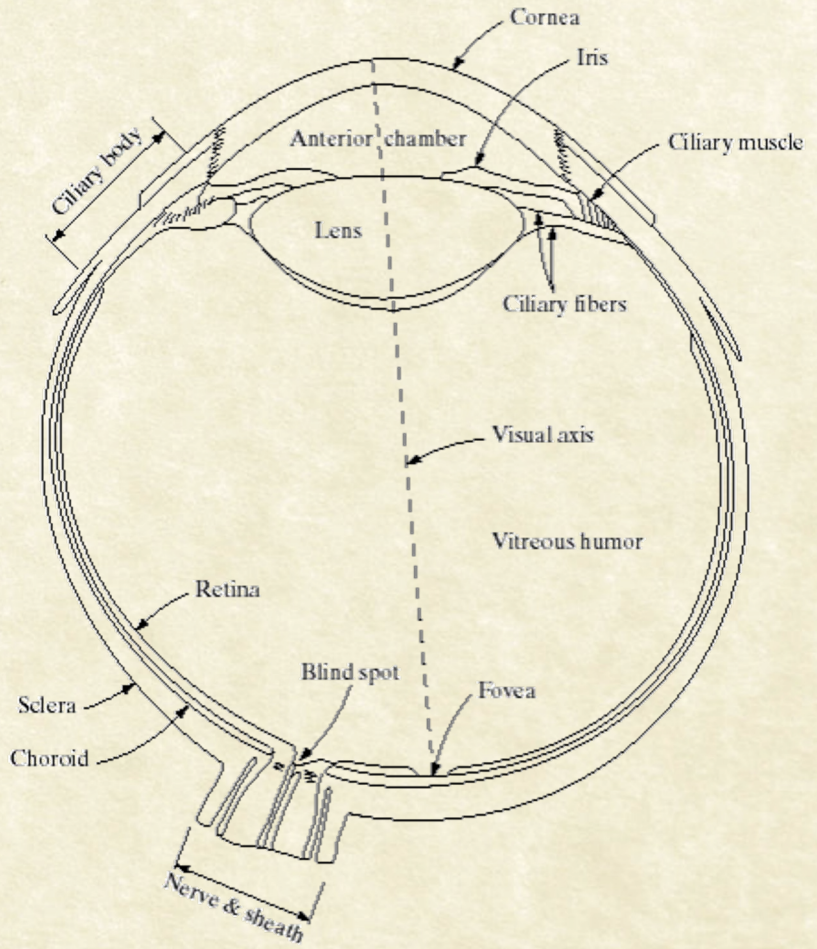


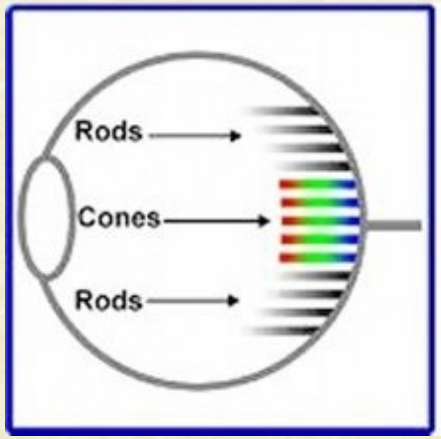


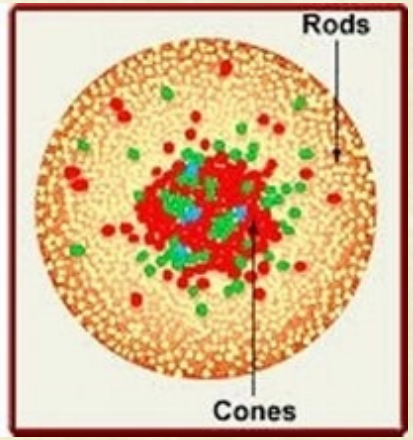


Rods

- 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).







Receptor Distribution

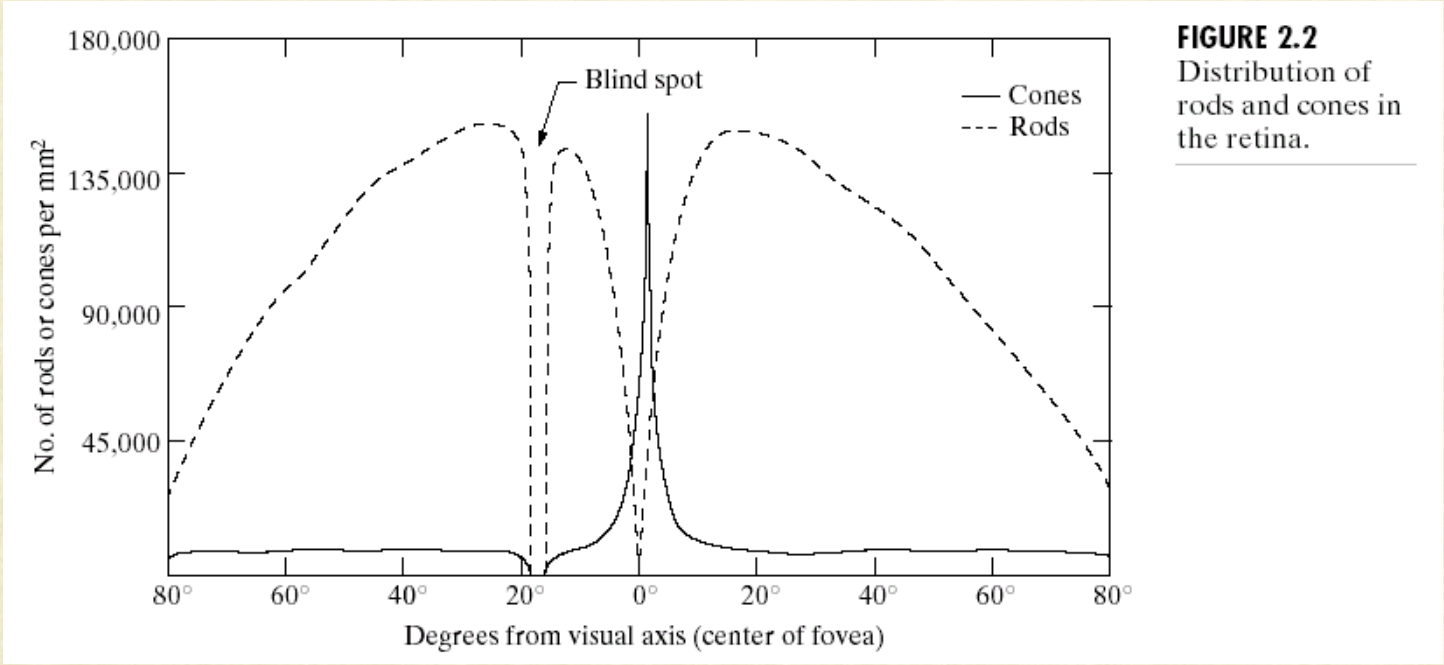
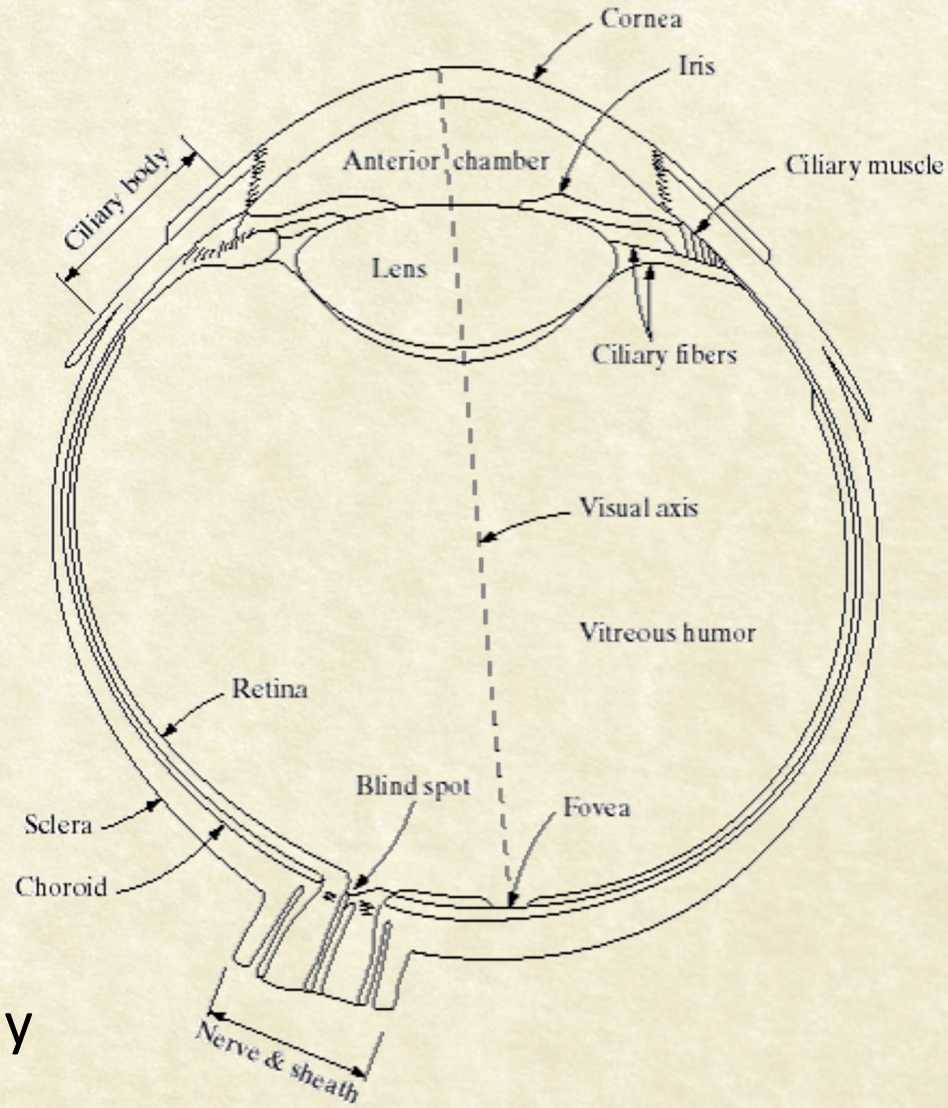


FIGURE 2.2
Distribution of rods and cones in the retina.



- 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

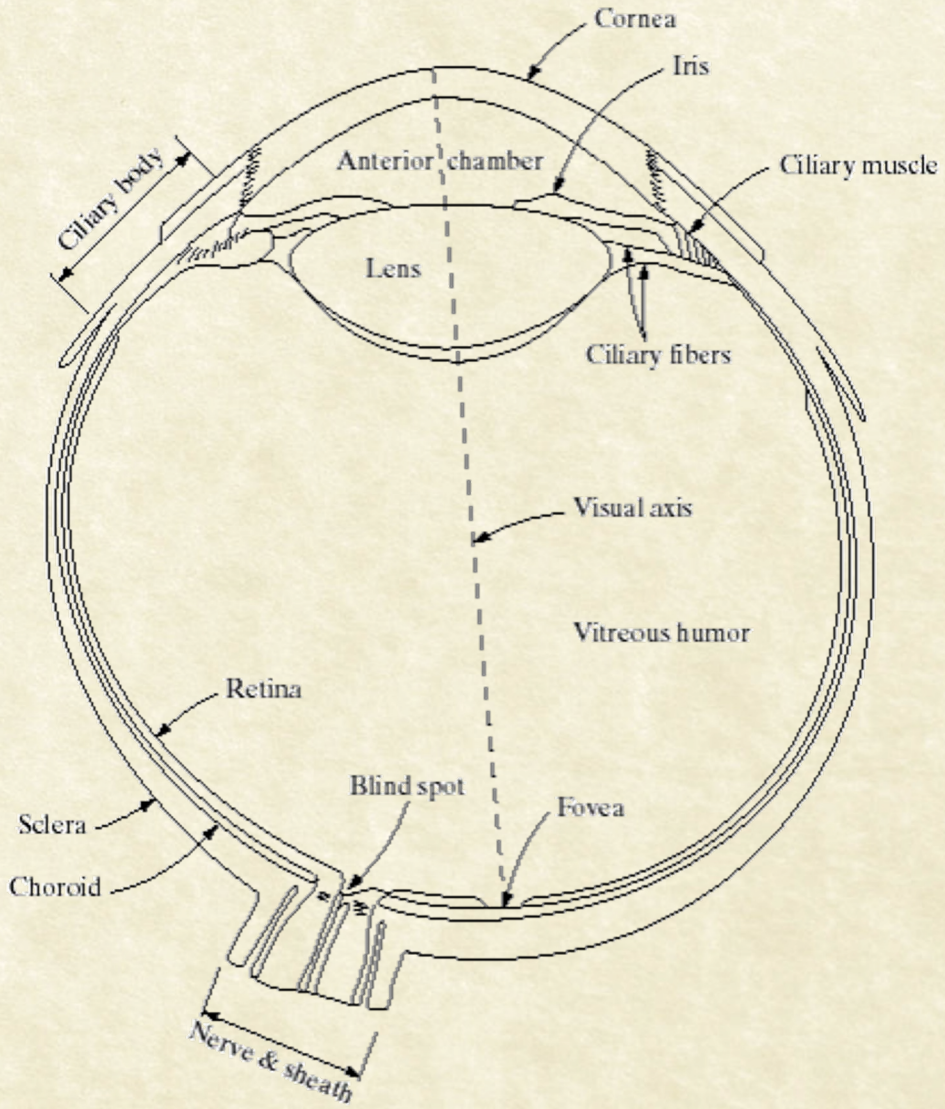
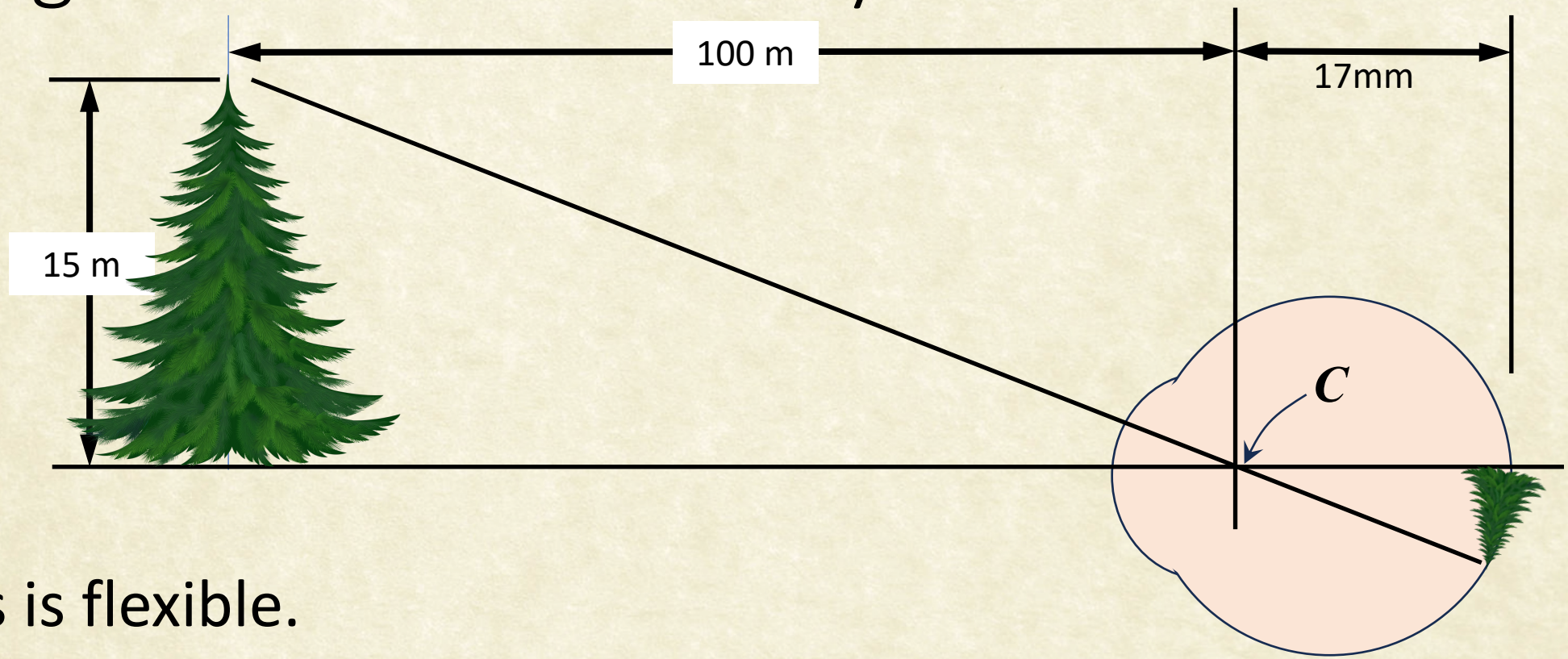


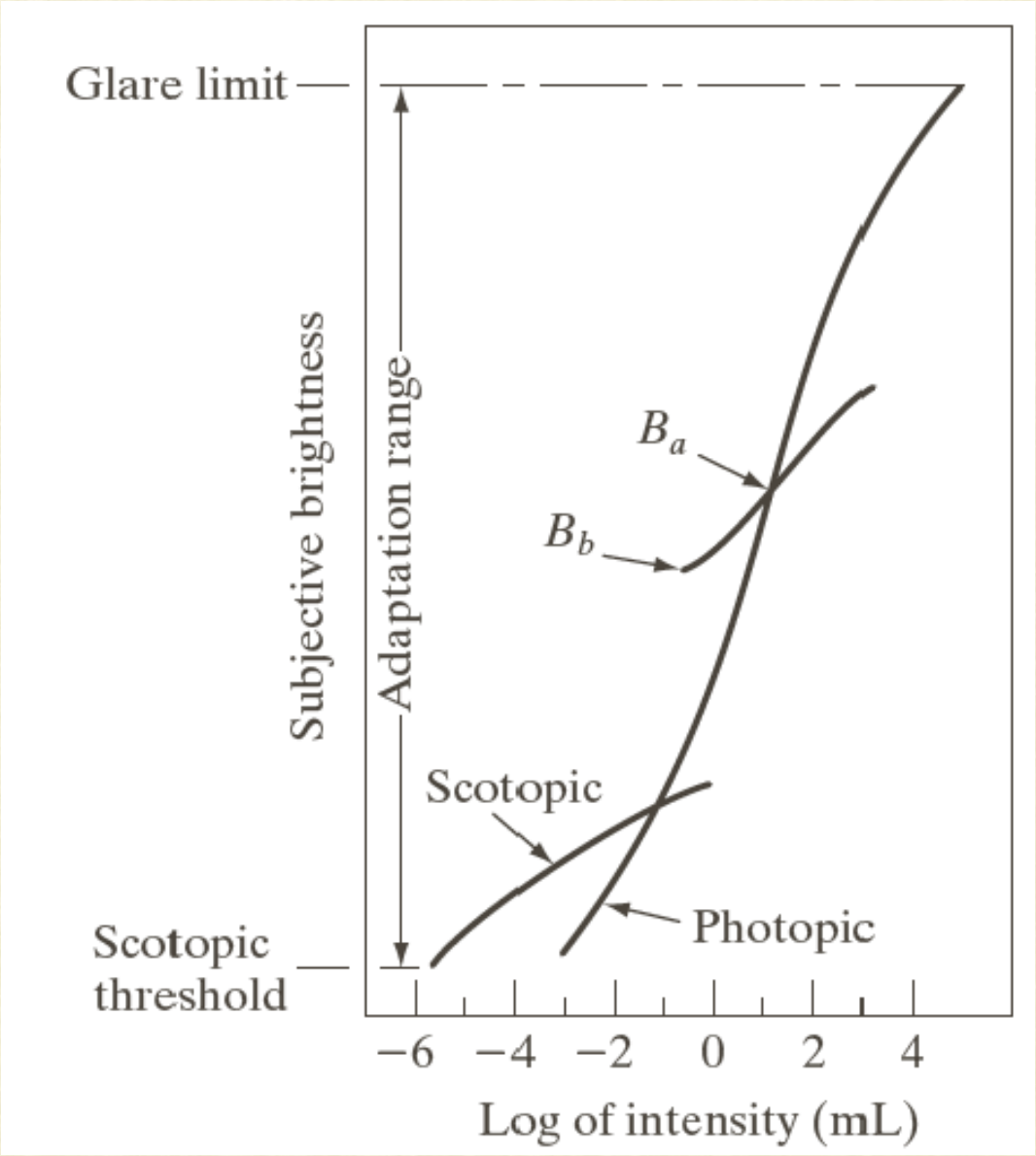
Image Formation in the Eye



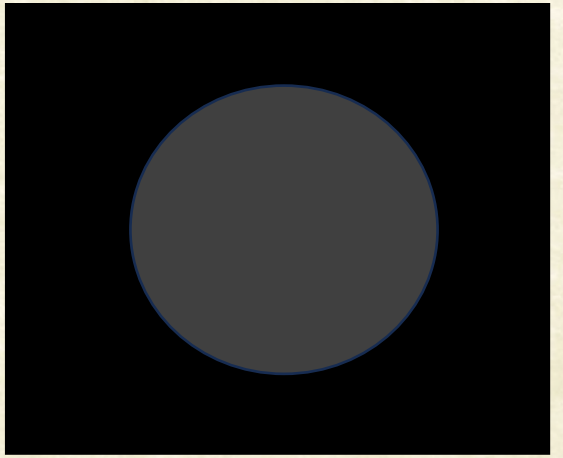
- Eye lens is flexible.
- Lens controlled by fibers of ciliary body
  - To focus on distant objects, it gets flatter (and vice versa)
  - Focal length varies from 14-17 mm

Brightness Adaptation

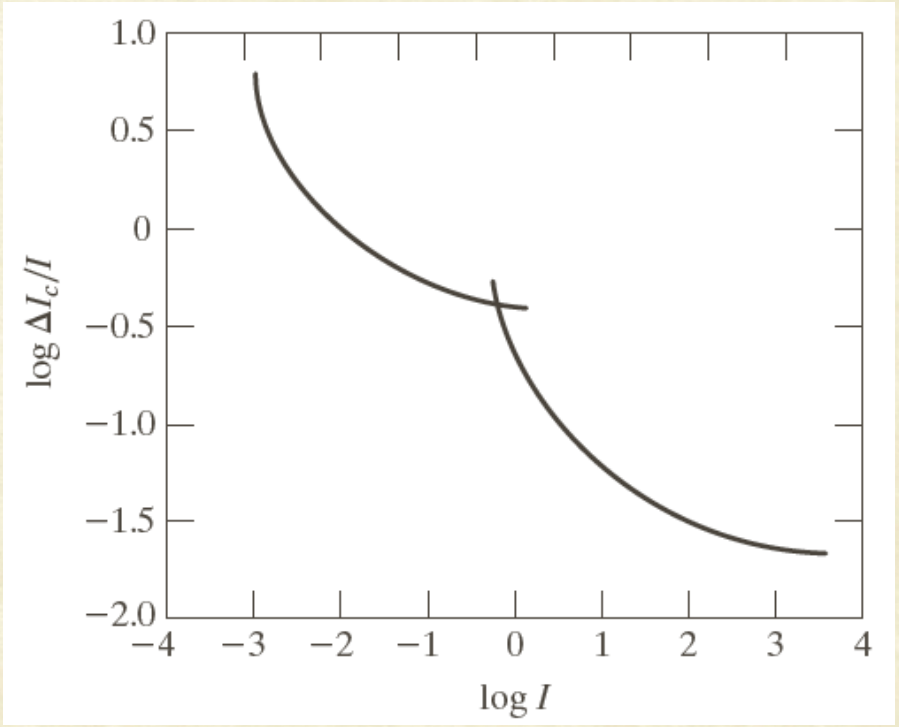
- Dynamic range of human visual system (HVS)
  - $10^{-6} \sim 10^{4}$
- But HVS cannot accomplish this range simultaneously



Brightness Discrimination



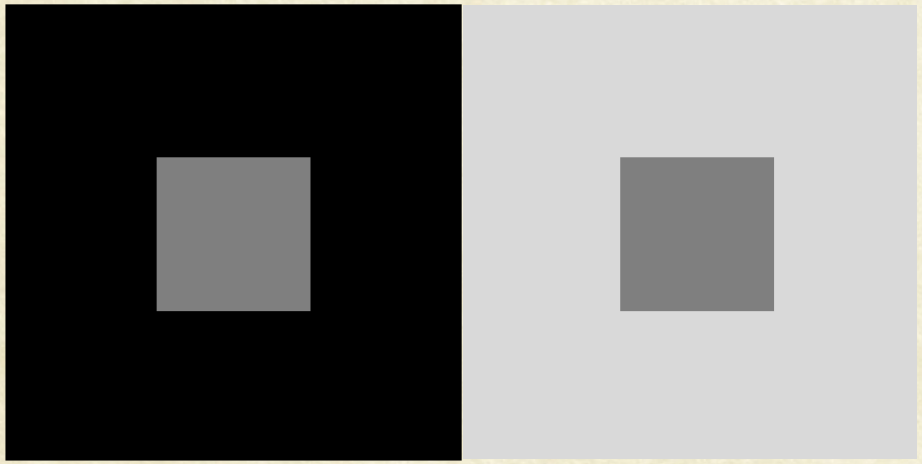
- Weber ratio: $\Delta I_c / I$
  - I : the background illumination
  - ΔI_c : the increment of illumination
- Small Weber ratio → good discrimination
- Larger Weber ratio → poor discrimination

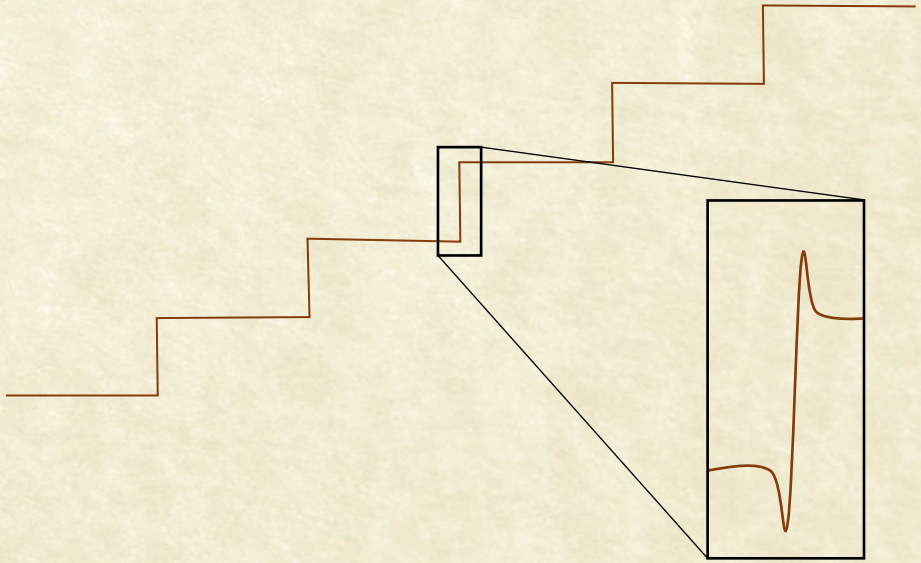


Psychovisual Effects

Perceived brightness and contrast are not a simple function of intensities:

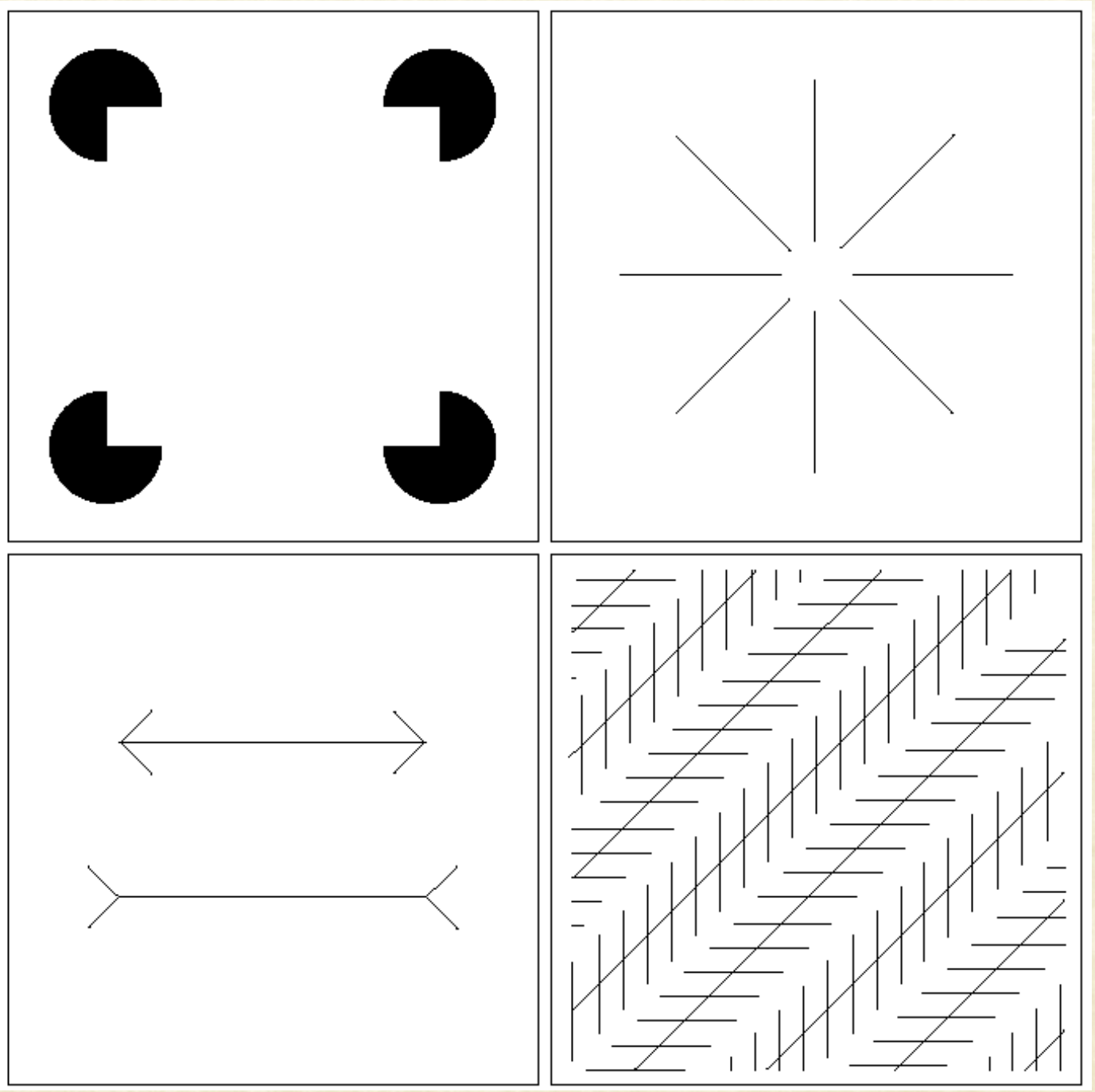
1. Simultaneous Contrast
2. Mach Band Effect





Optical Illusions

We perceive edges, incidence, length, parallelism, all in context.



Questions?

CS7.404: Digital Image Processing

Monsoon 2023: Image Acquisition

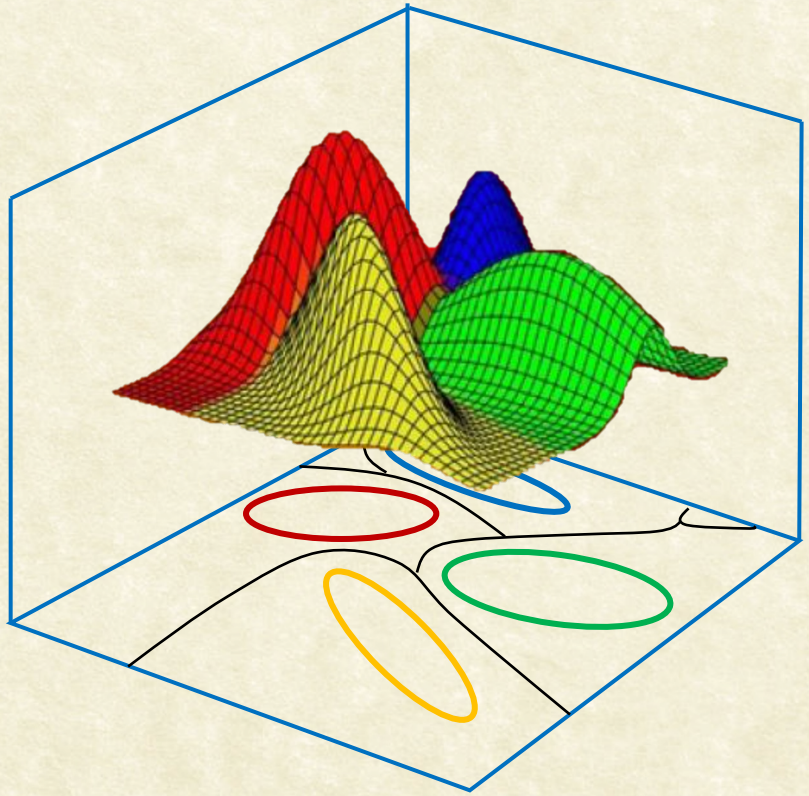


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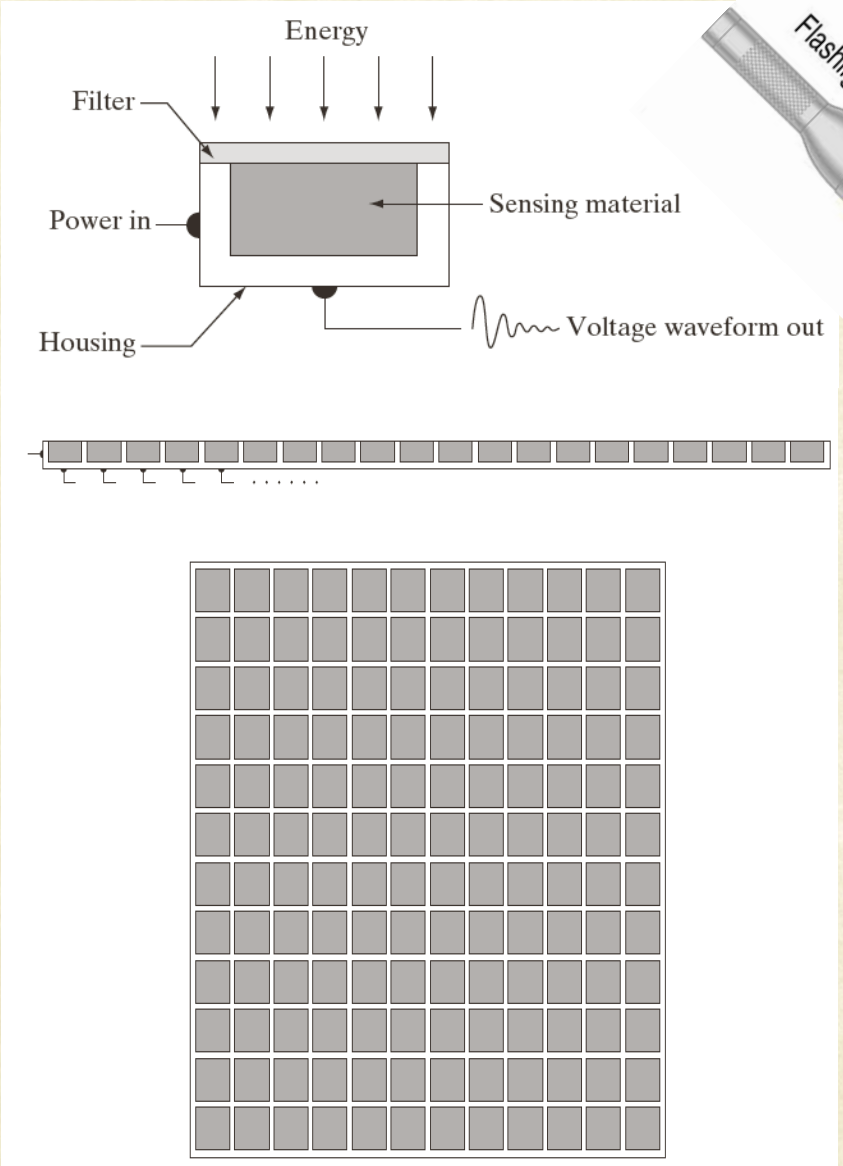
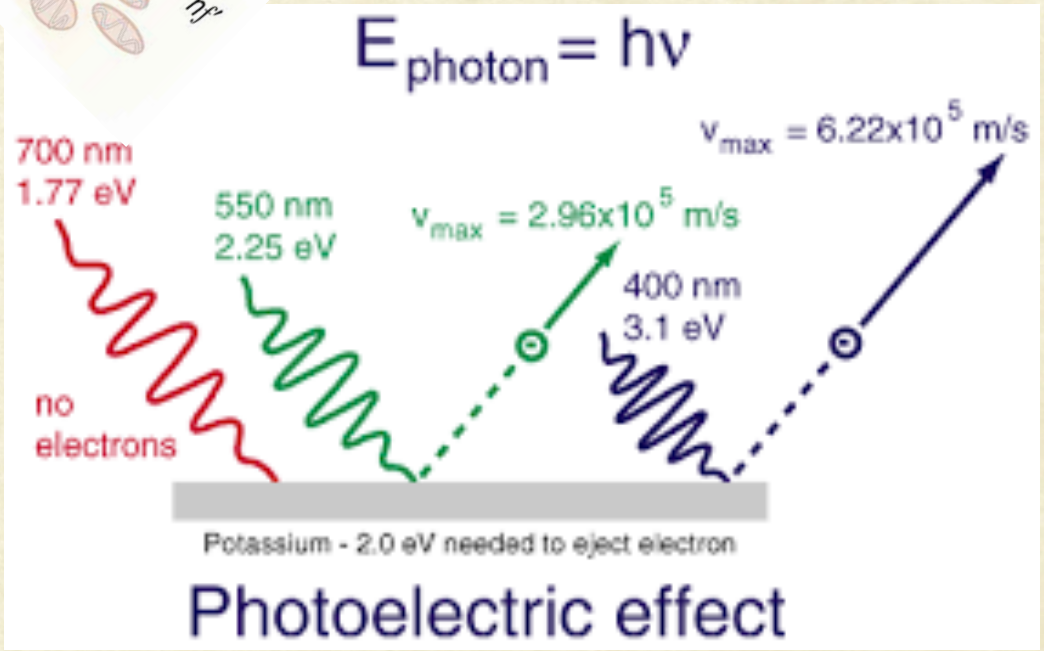
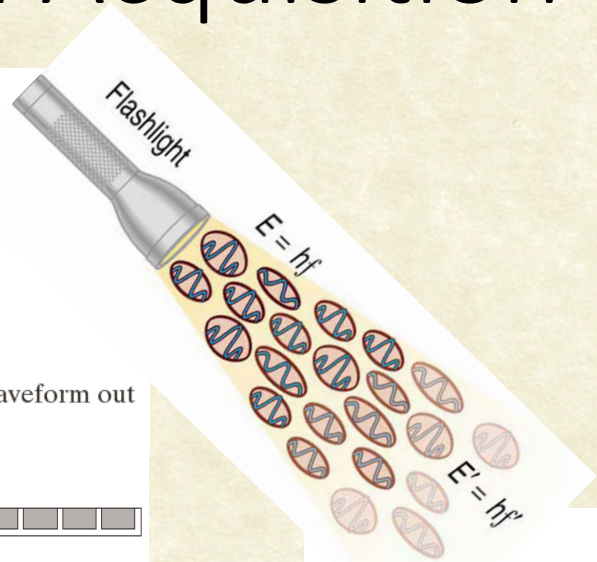
Image Sensing and Acquisition

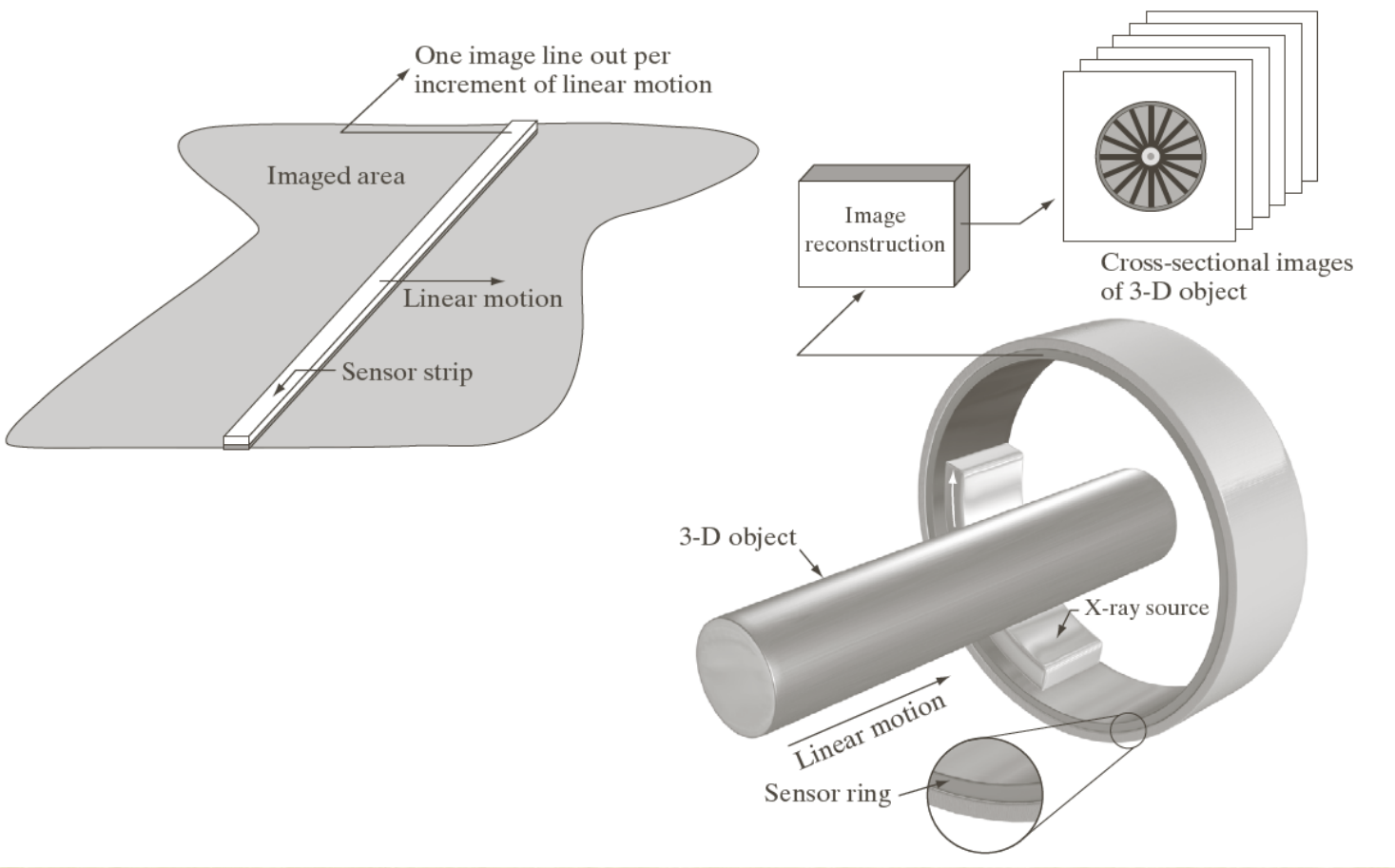
- Single Sensor
- Line Sensor
- Array Sensor

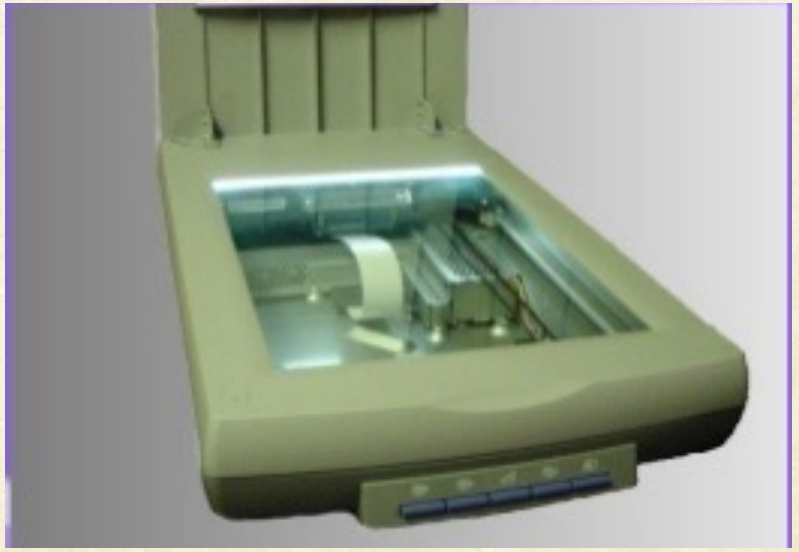


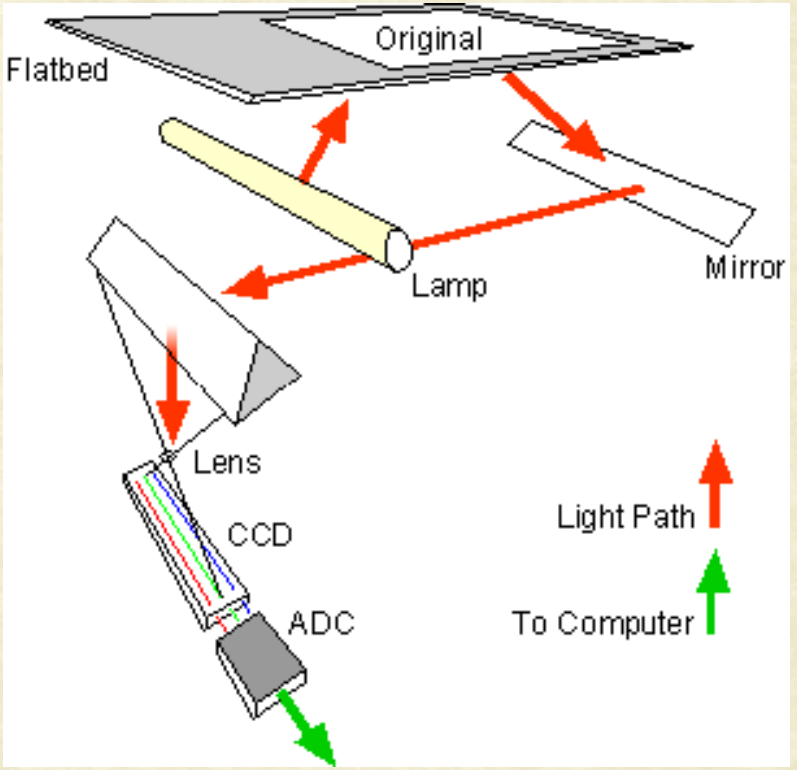




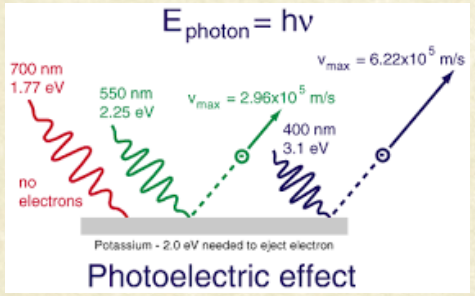
Line Sensors

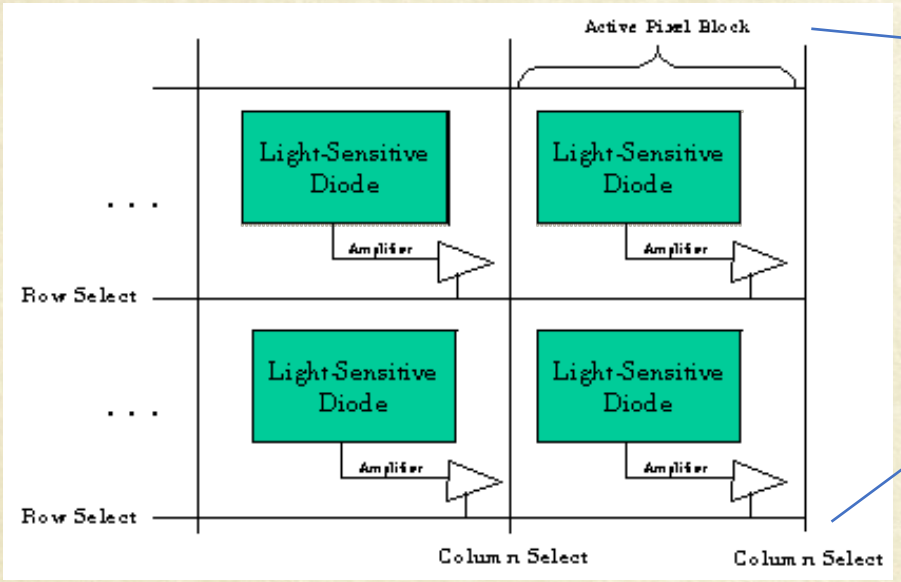


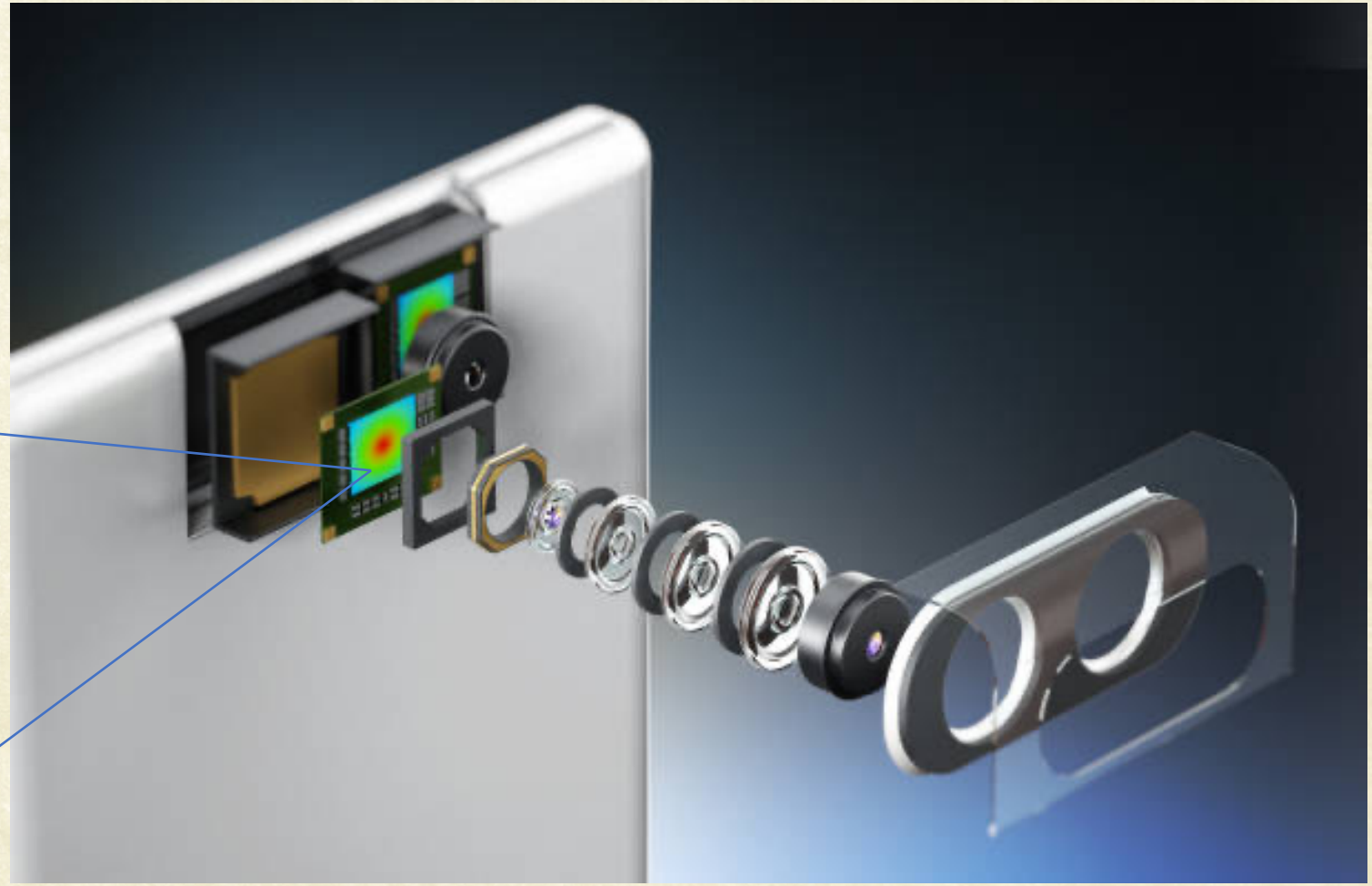




CMOS photo-electric sensor





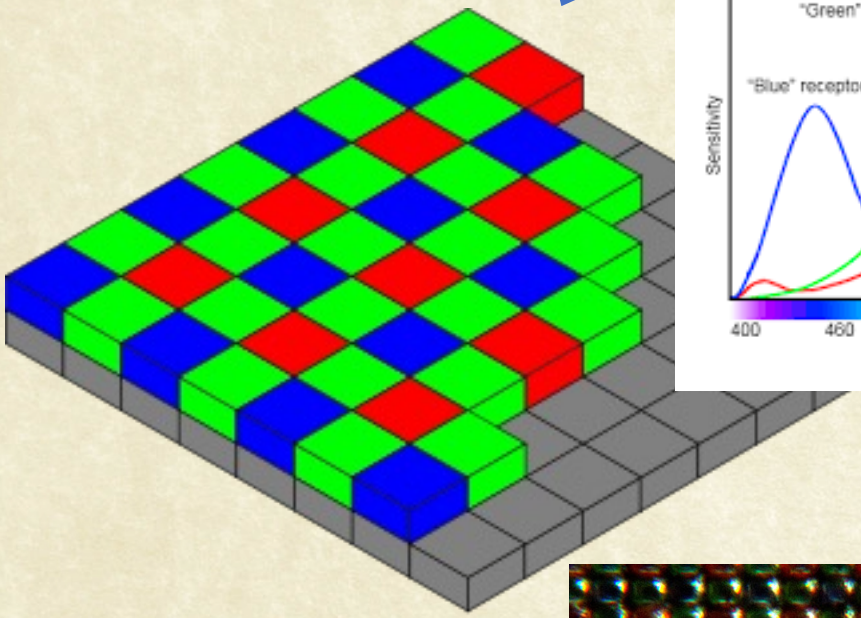


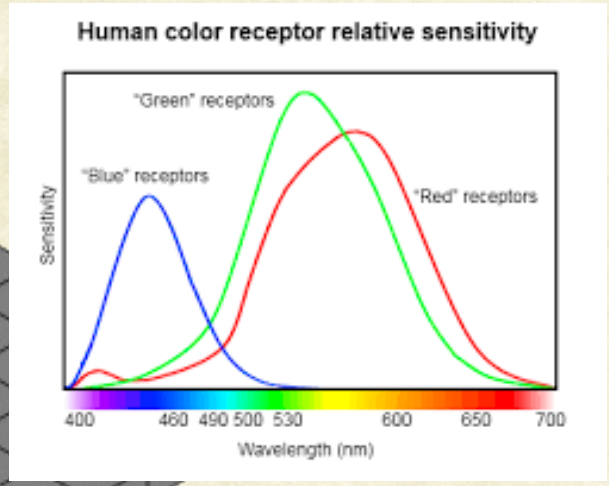
Light → Color

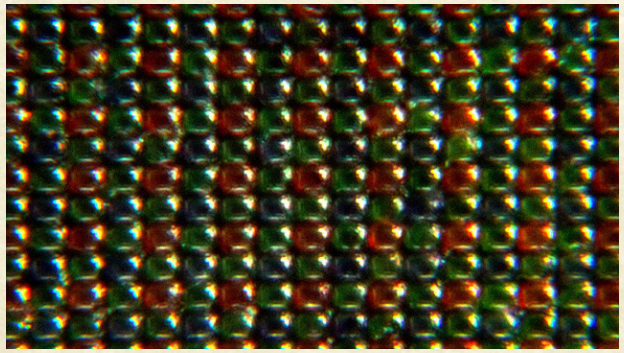
- CMOS sensitive to “light”, not “color”

Bayer Filter

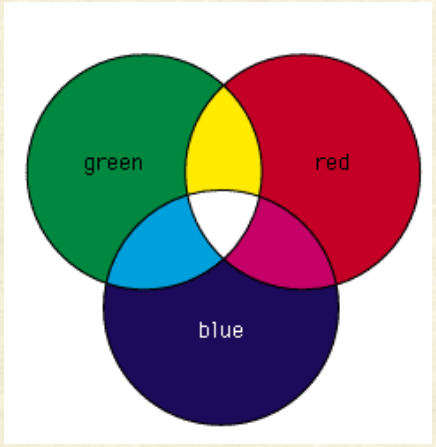
Relatively more green filters. Why ?

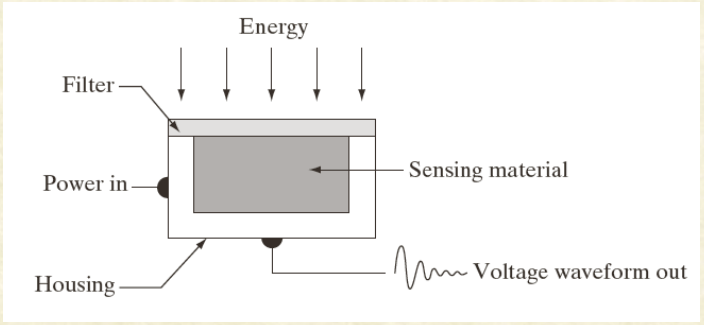


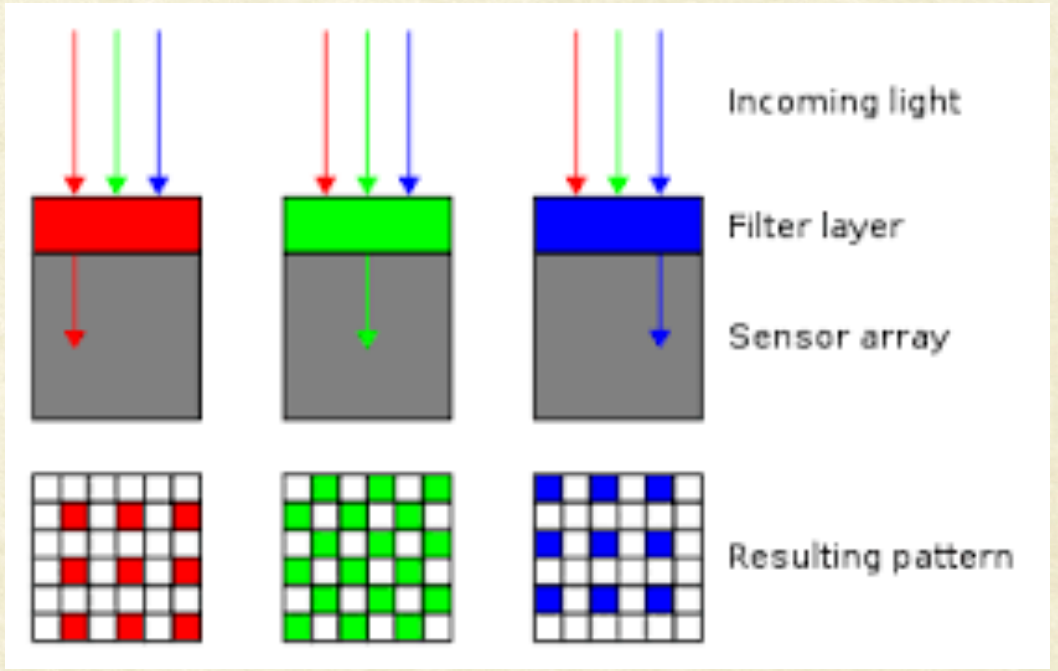




600x

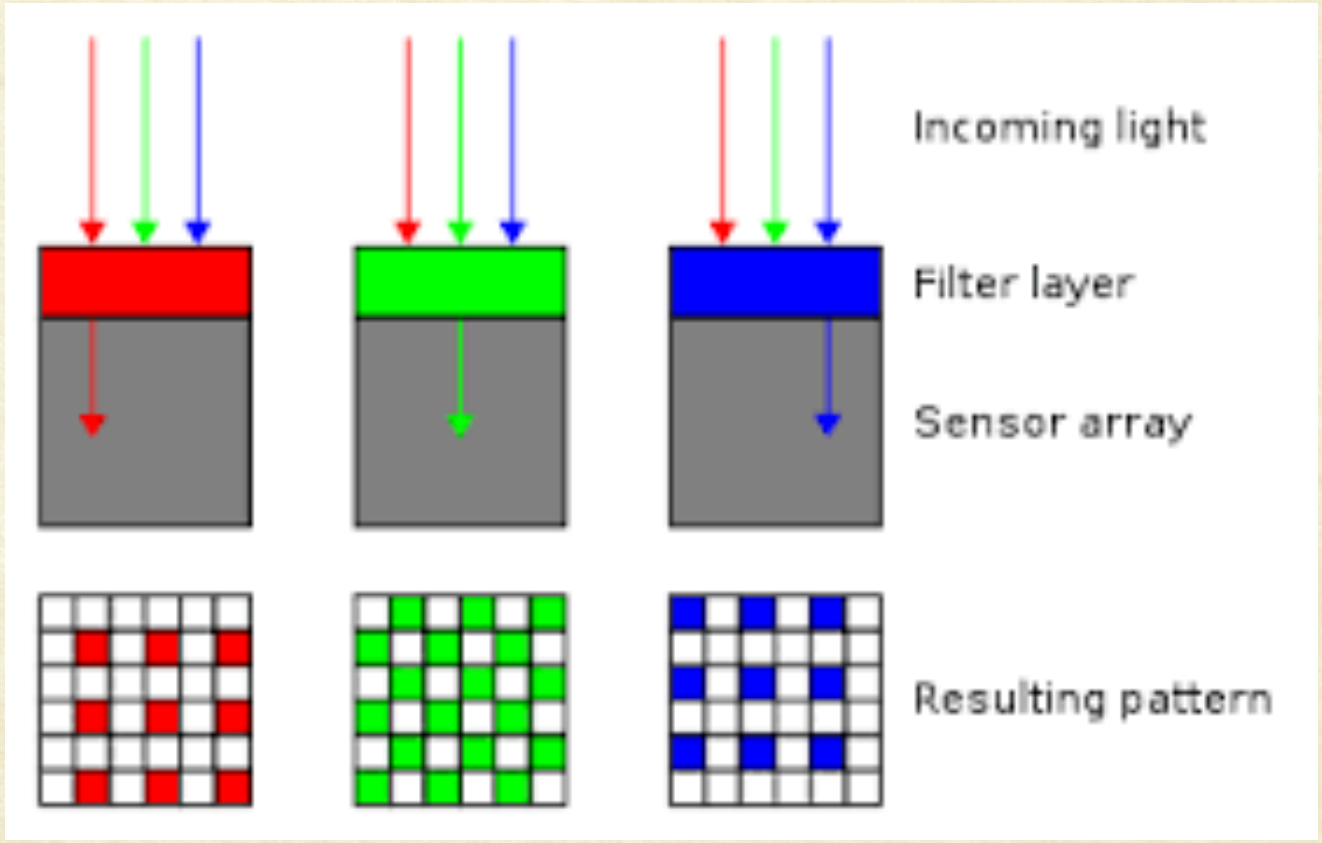






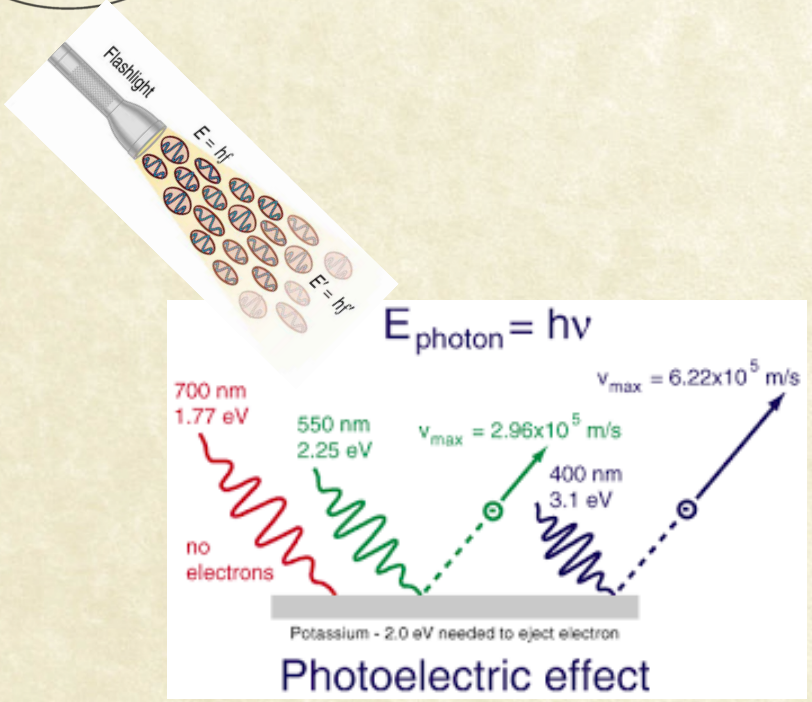
https://en.wikipedia.org/wiki/Bayer_filter

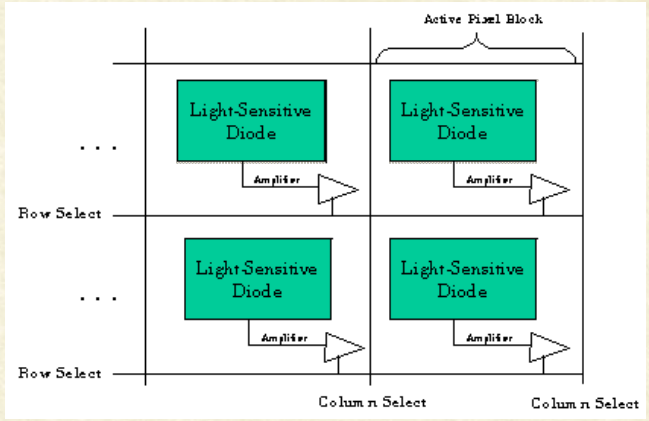
Demosaicing



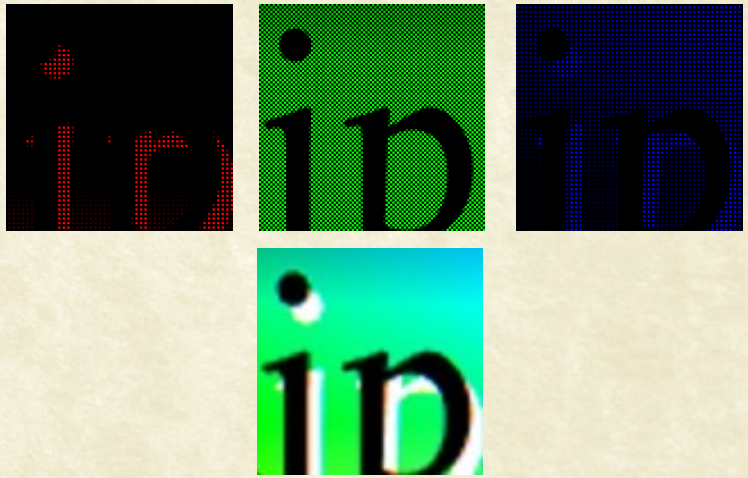
https://en.wikipedia.org/wiki/Demosaicing

Imaging Summary

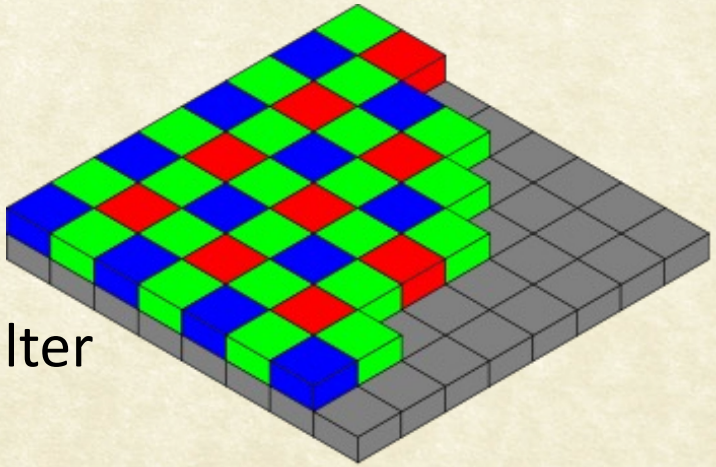




Demosaicing



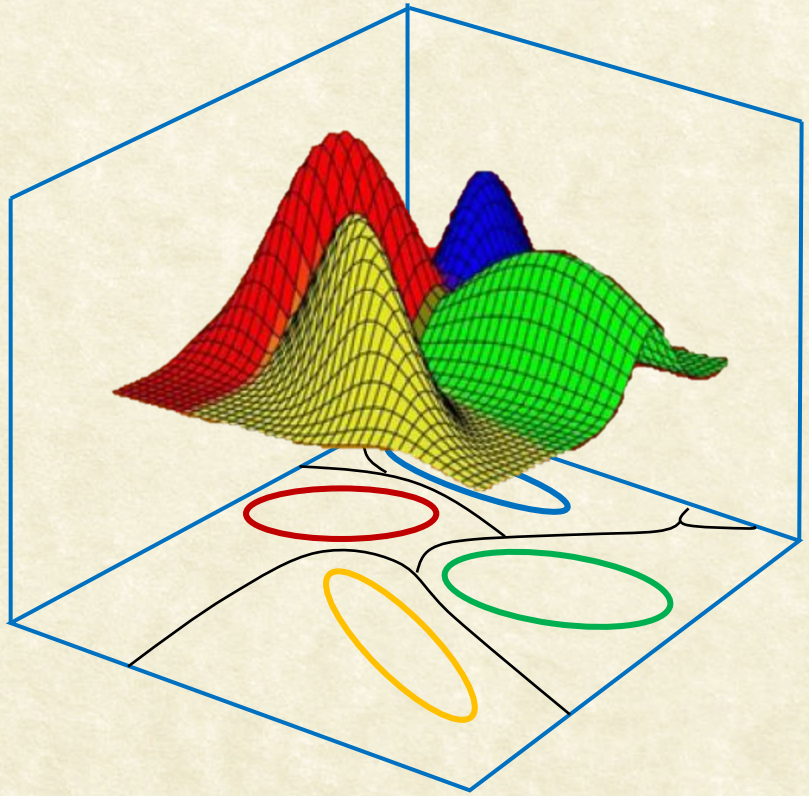
Bayer Filter



Questions?

CS7.404: Digital Image Processing

Monsoon 2023: Sampling and Quantization



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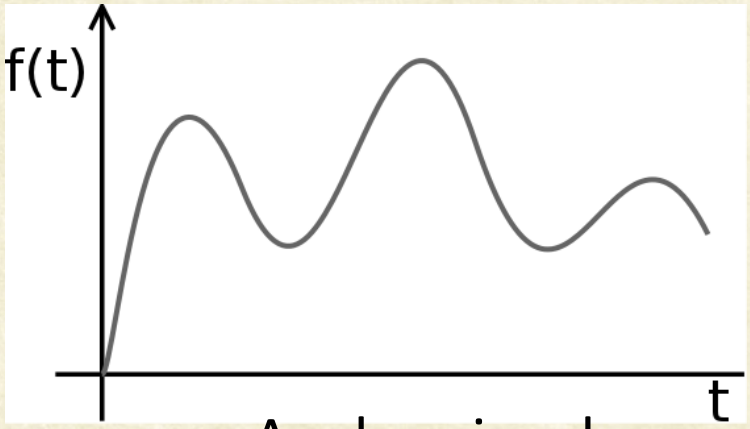
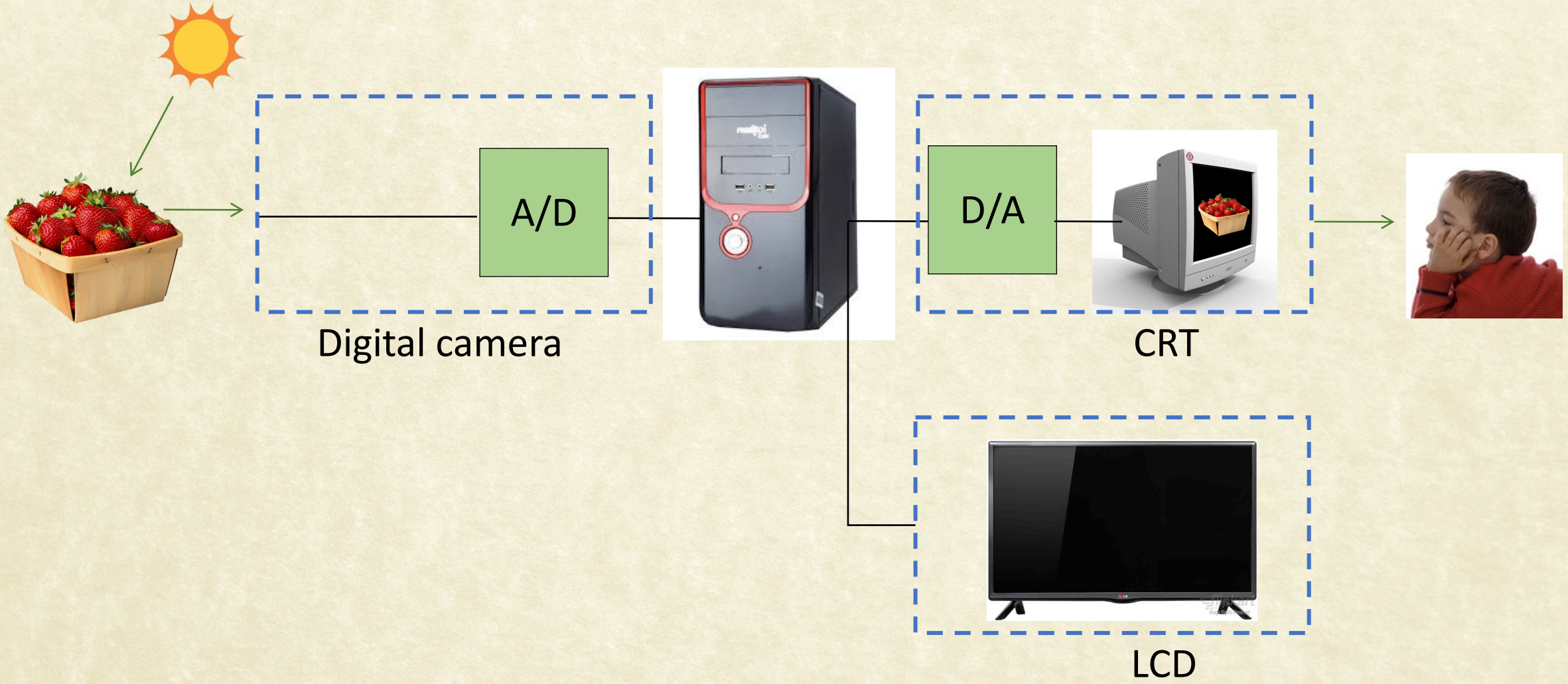
Signal

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



Analog signal

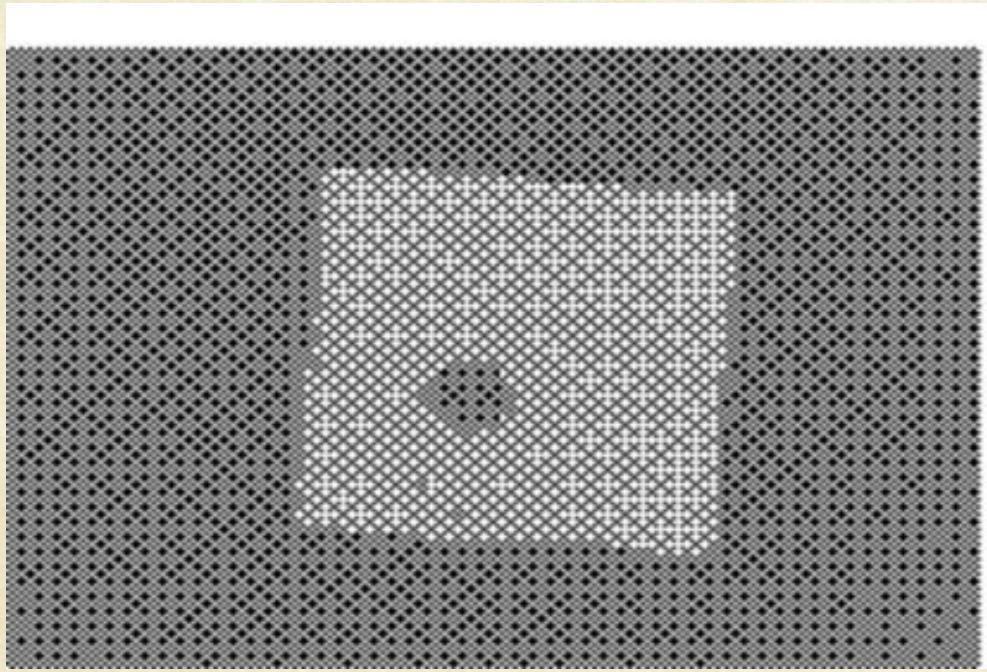
Analog vs. Digital signal (2-D signal)



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

x

y



I = f(x,y)

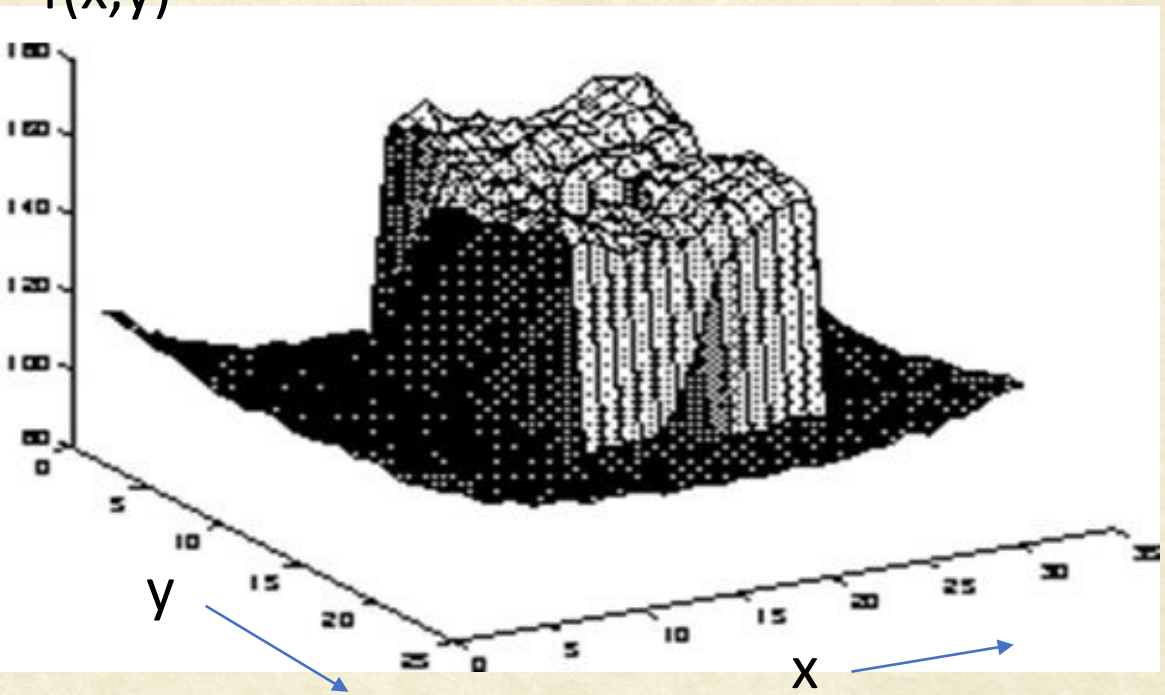


Image Acquisition Process

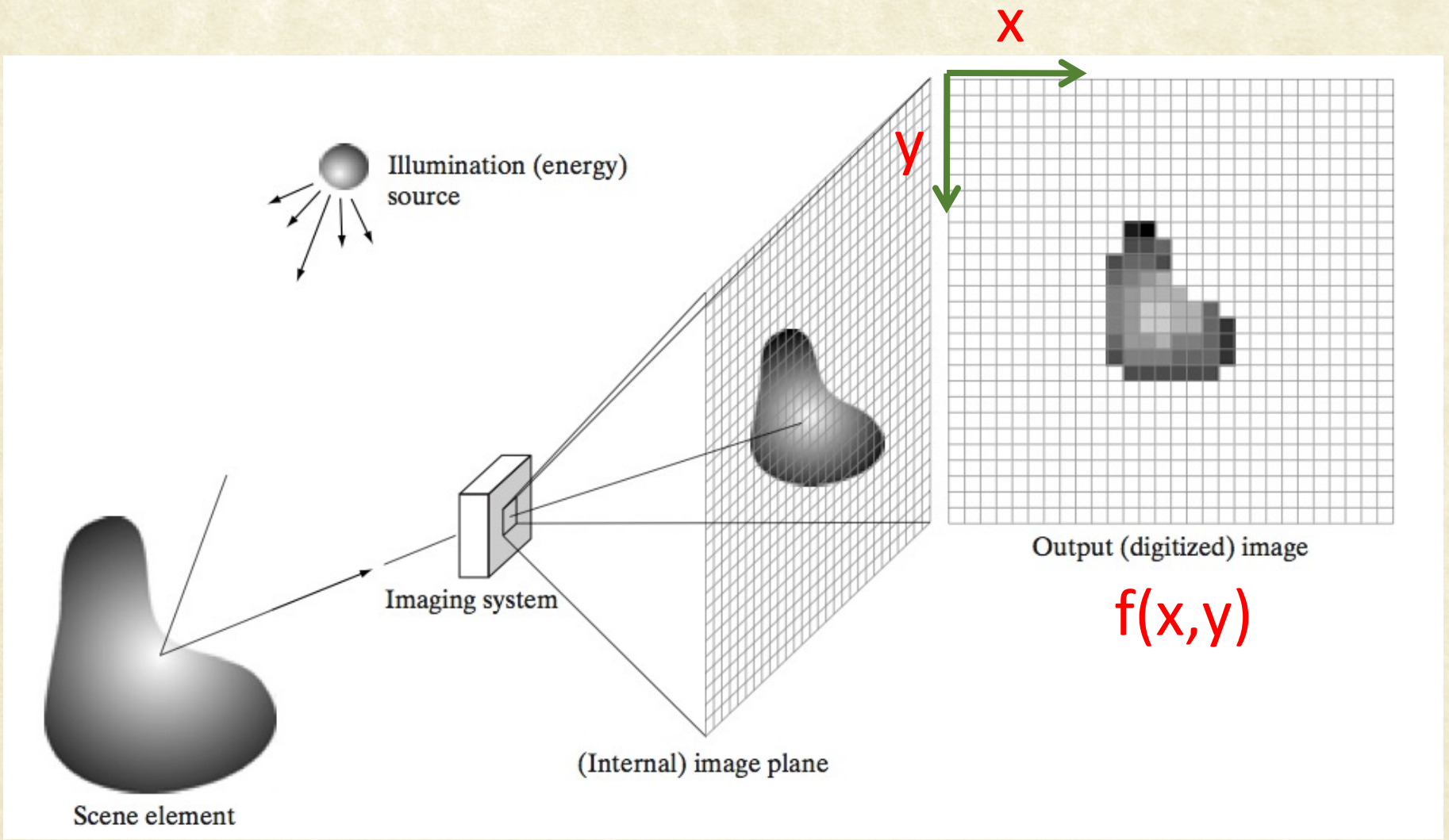
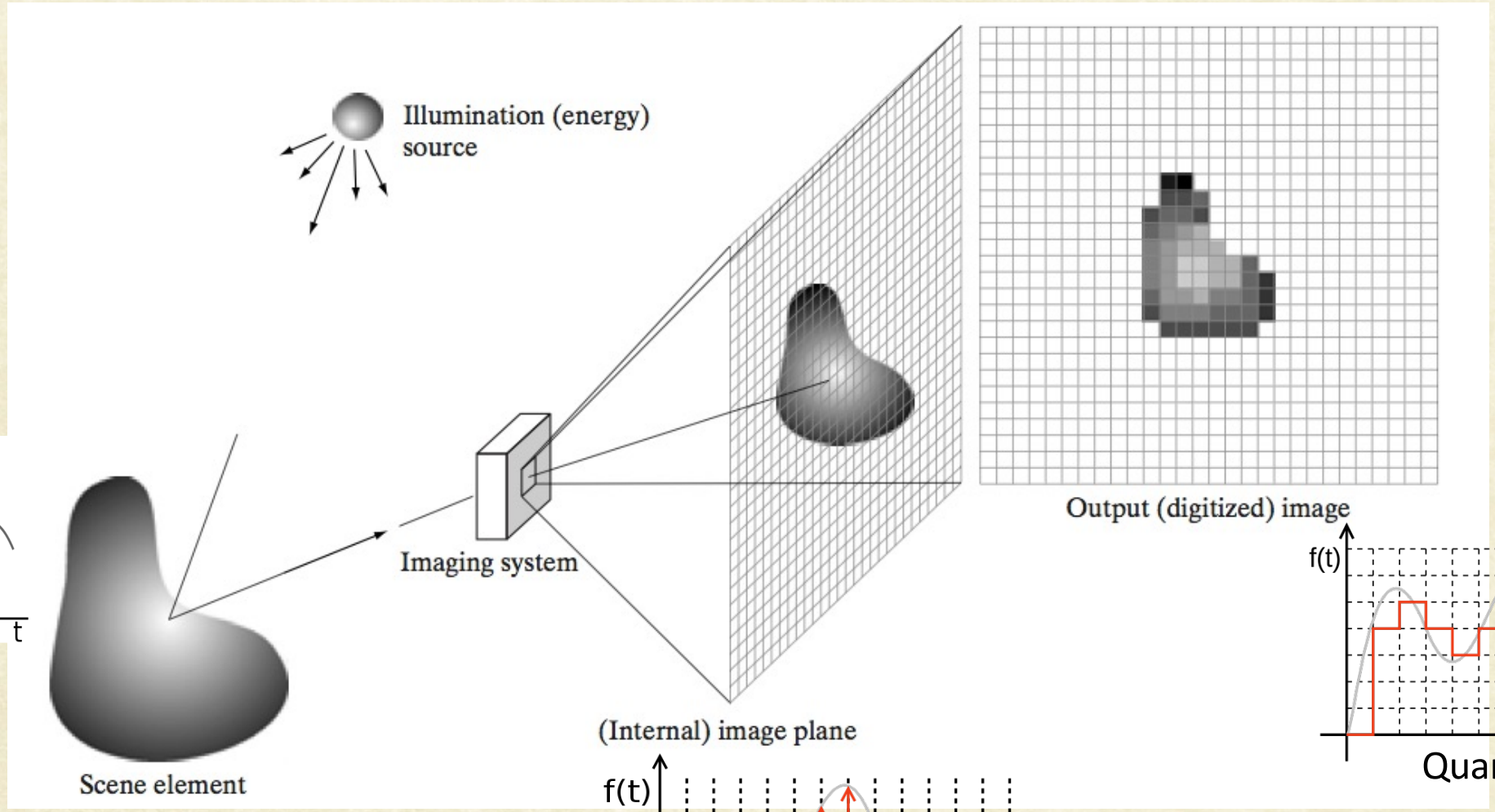
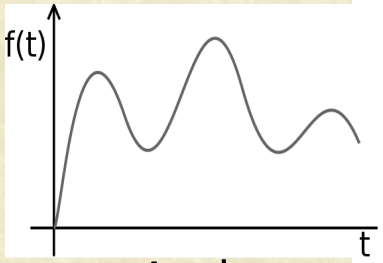
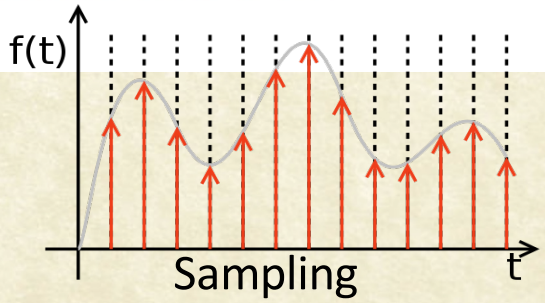


Image courtesy: Gonzalez and Woods

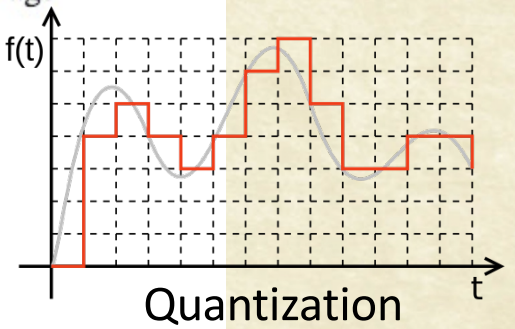




Analog signal



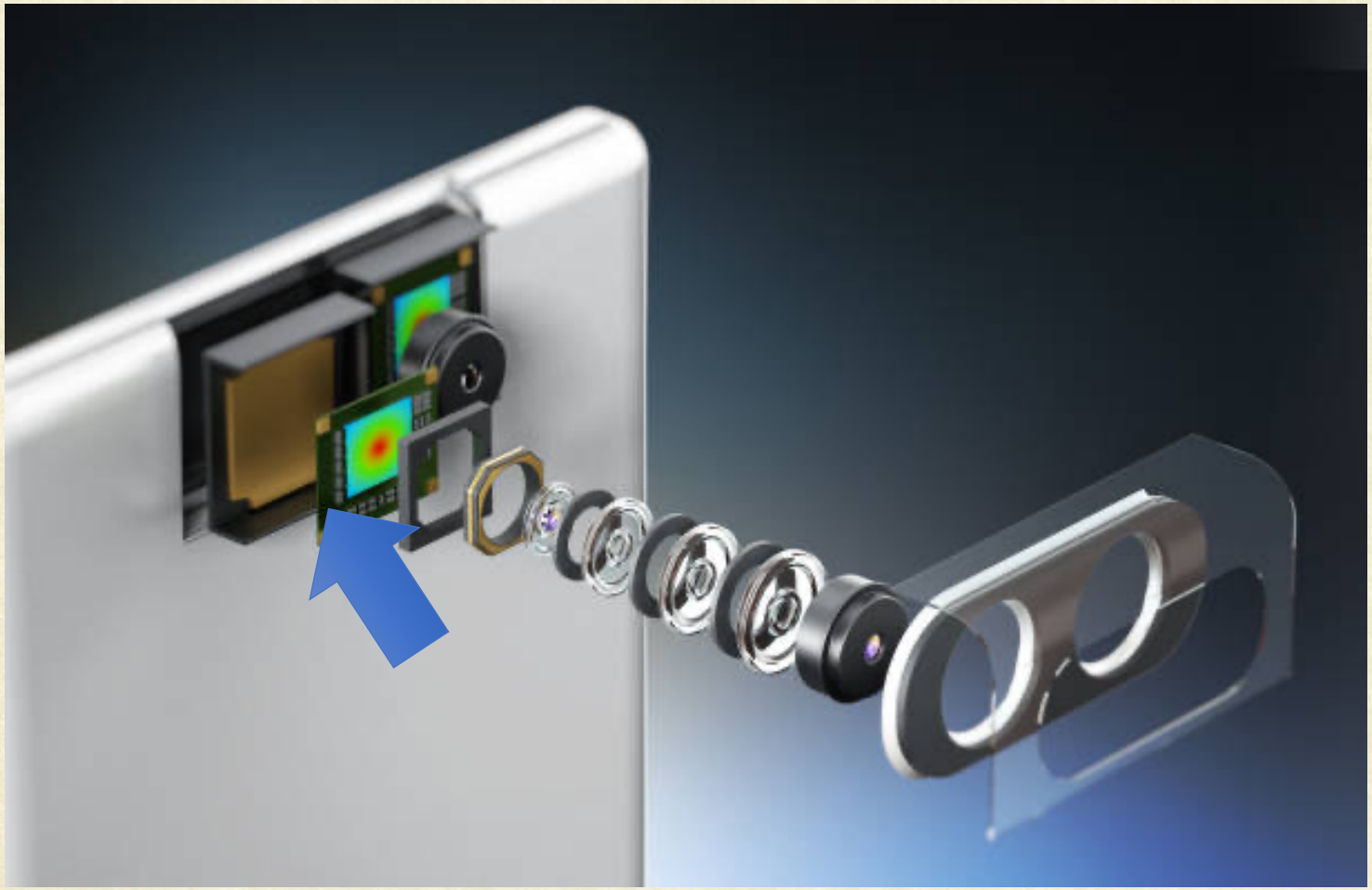
Sampling



Quantization

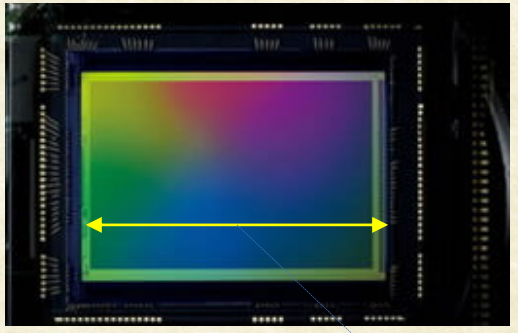
Image courtesy: Gonzalez and Woods

Cross-section of typical smartphone camera

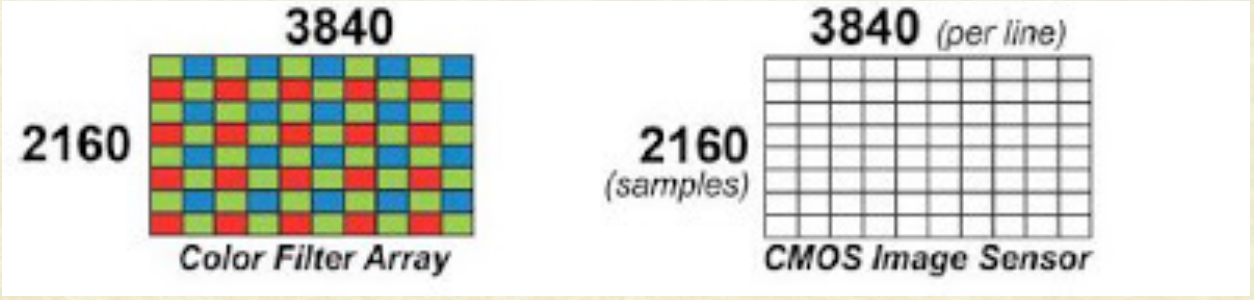


Physical Characteristics	
Active image area size	24.6 (H) x 13.8 (V) mm
Total number photosites	4206 (H) x 2340 (V)
Number photosites for active image	3840 (H) x 2160 (V)
Color filter array (with microlens)	RGB Bayer
Size of photosite (microns)	6.4 (H) x 6.4 µm
Pixel pitch	6.4 µm
Power supply	3.3v /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

Resolution (of the sensor)

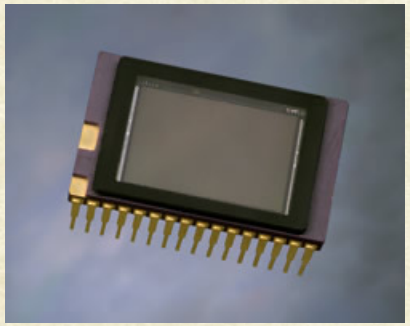


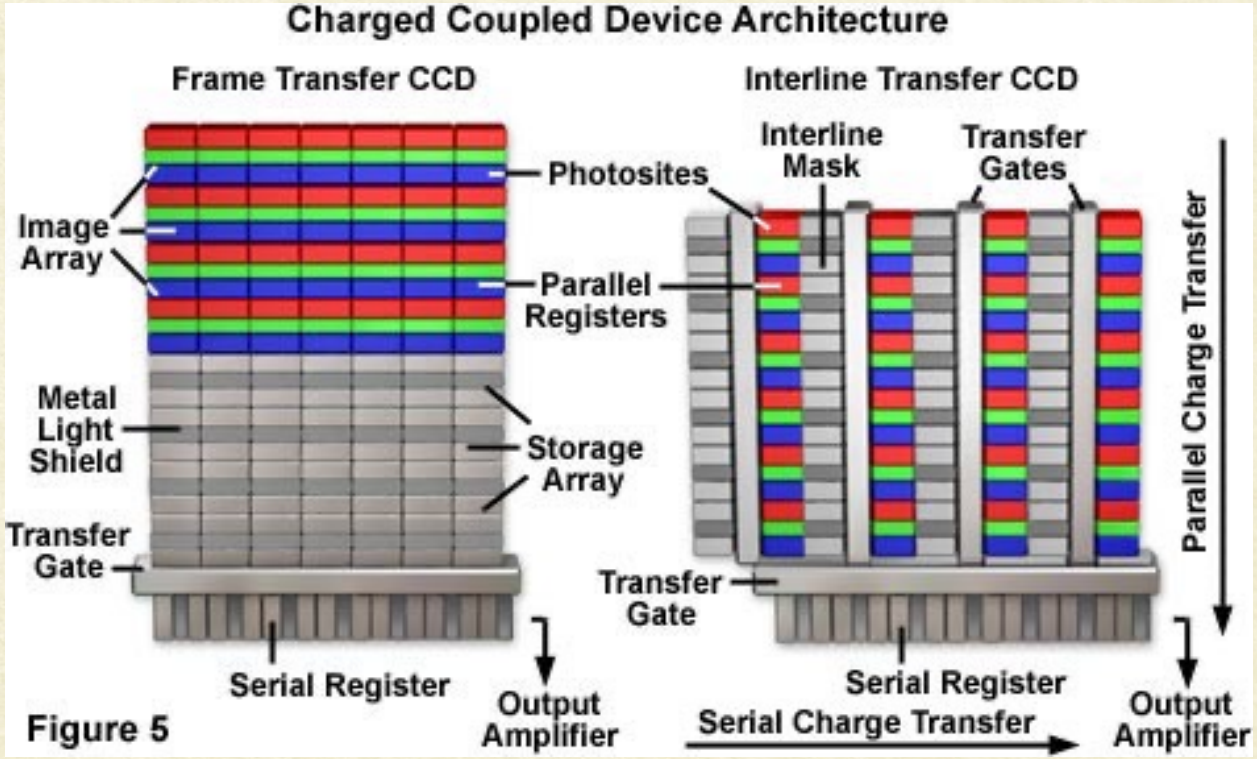
24.6 mm



CCD and CMOS cameras

- Non-Bayer Arrangements





http://micro.magnet.fsu.edu/primer/digitalimaging/

Sampling

- Grayscale Image

  A two-dimensional function ***f(x,y)*** of real values on the continuous image plane.

- Sampling

  The process of converting a continuous image $f(x,y)$ to a discrete representation $f_s[m,n]$ by recording the function values at points of intersection of a 2D grid.

  The process is equivalent to multiplying the image function with an ideal 2D impulse train $\delta(x,y)$. X_0 and Y_0 are called sampling distances or intervals.

$$f_s[m,n] = f(x,y).\sum_{m=-\infty}^{+\infty}\sum_{n=-\infty}^{+\infty}\delta(x-mX_0, y-nY_0)$$

$$= \sum_{m=-\infty}^{+\infty}\sum_{n=-\infty}^{+\infty} f(mX_0, nY_0)\delta(x-mX_0, y-nY_0)$$

Sampling

Image function

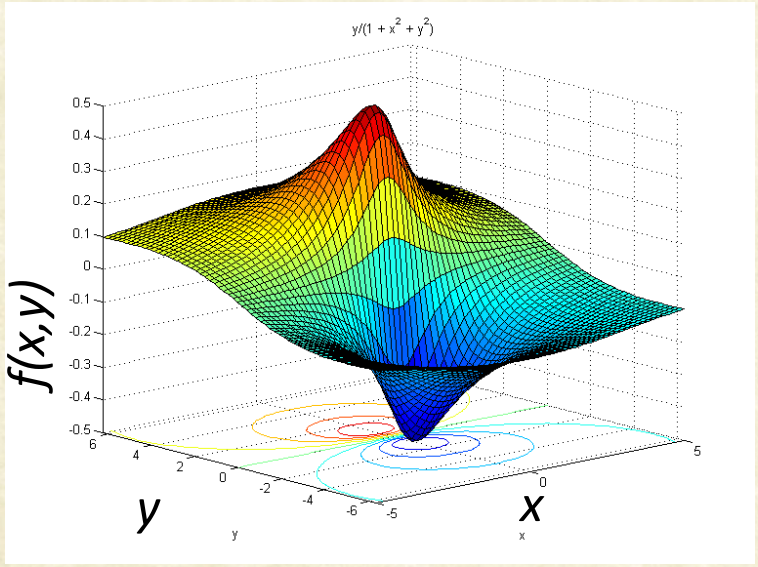
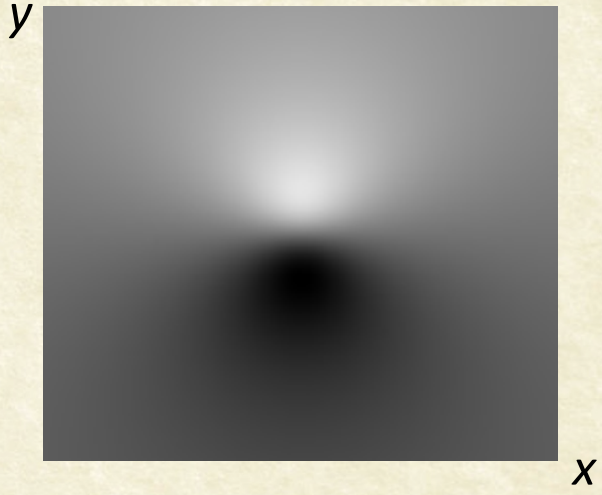
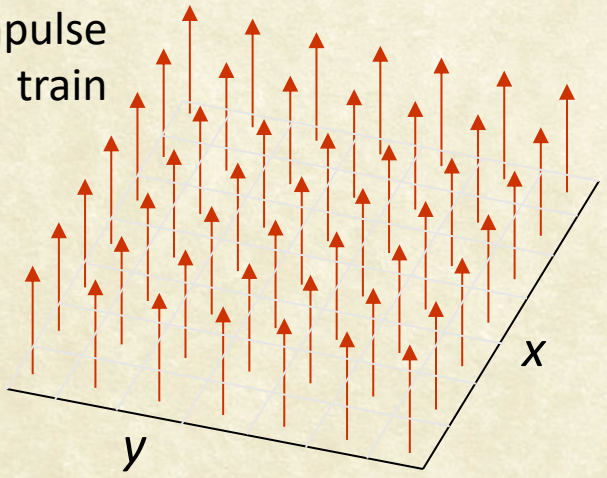


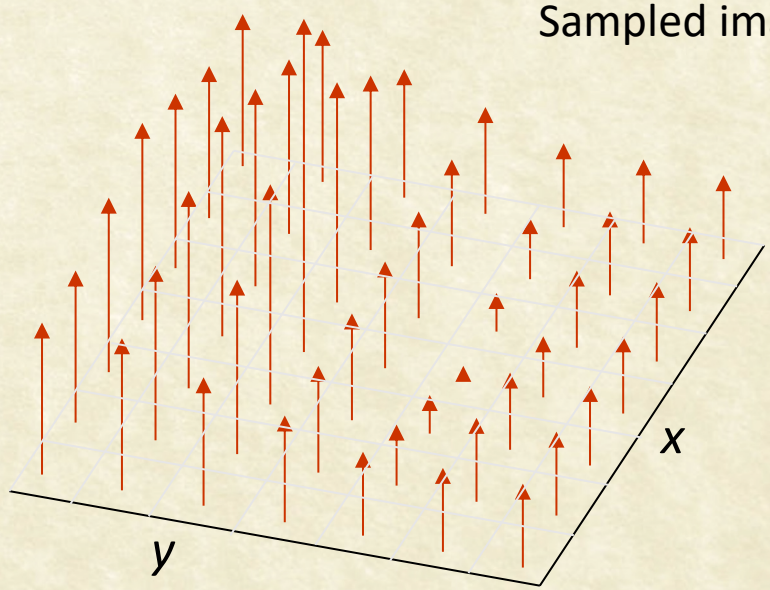
Image formed by the lens on the sensor



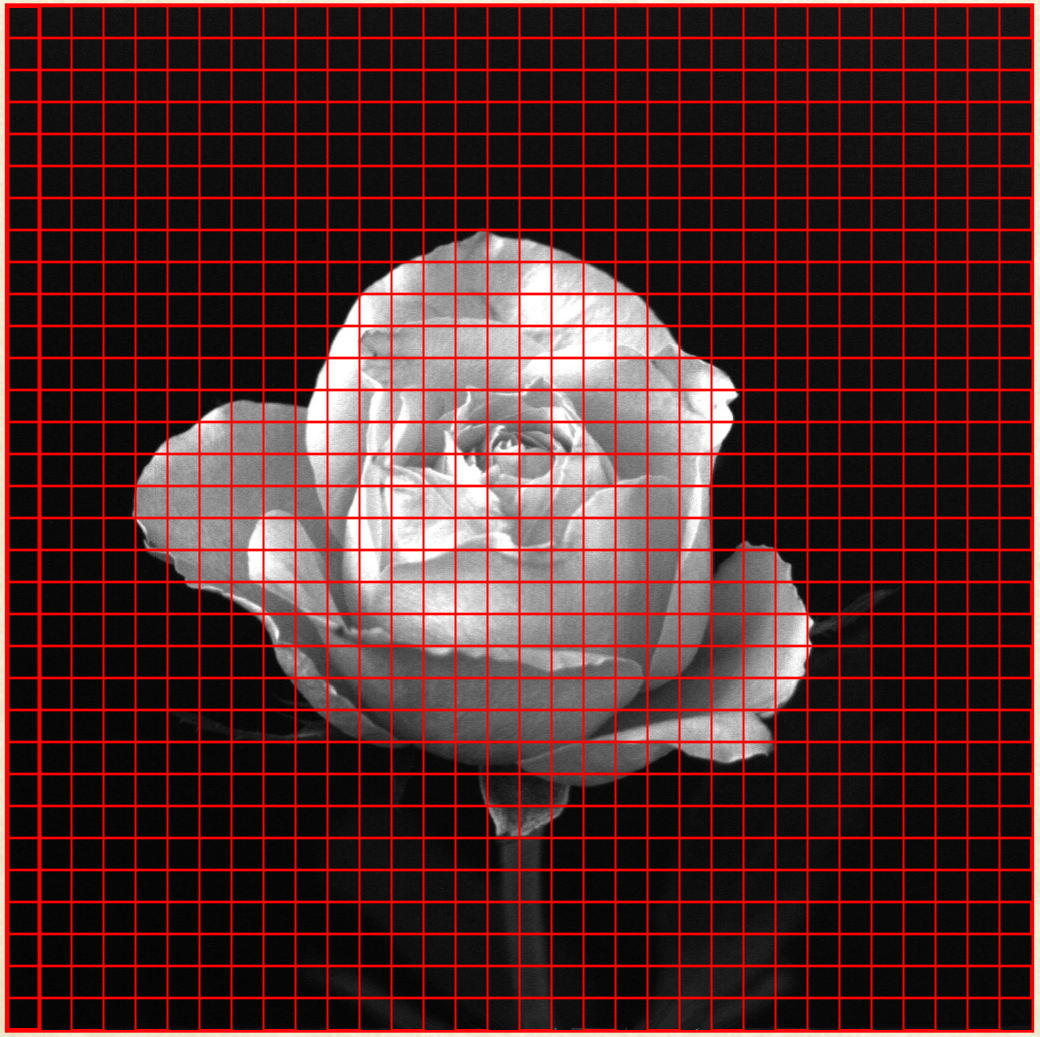
2D impulse train



Sampled image



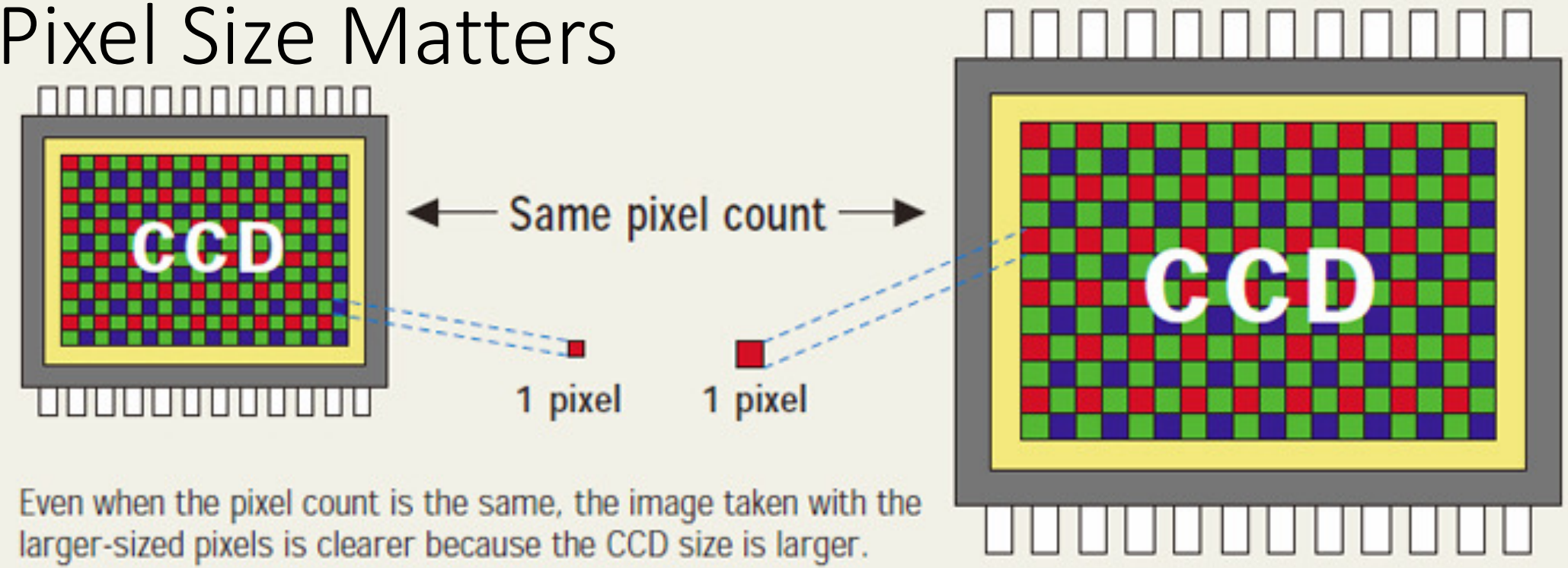
Sampling an Image



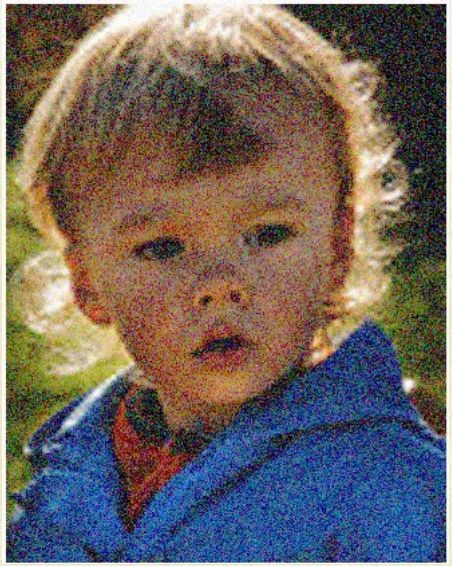
Effect of Resolution


Full HD
1920 x 1080
4K
3840 x 2160
5K
5120 x 2160
8K
7680 x 4320

Pixel Size Matters



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



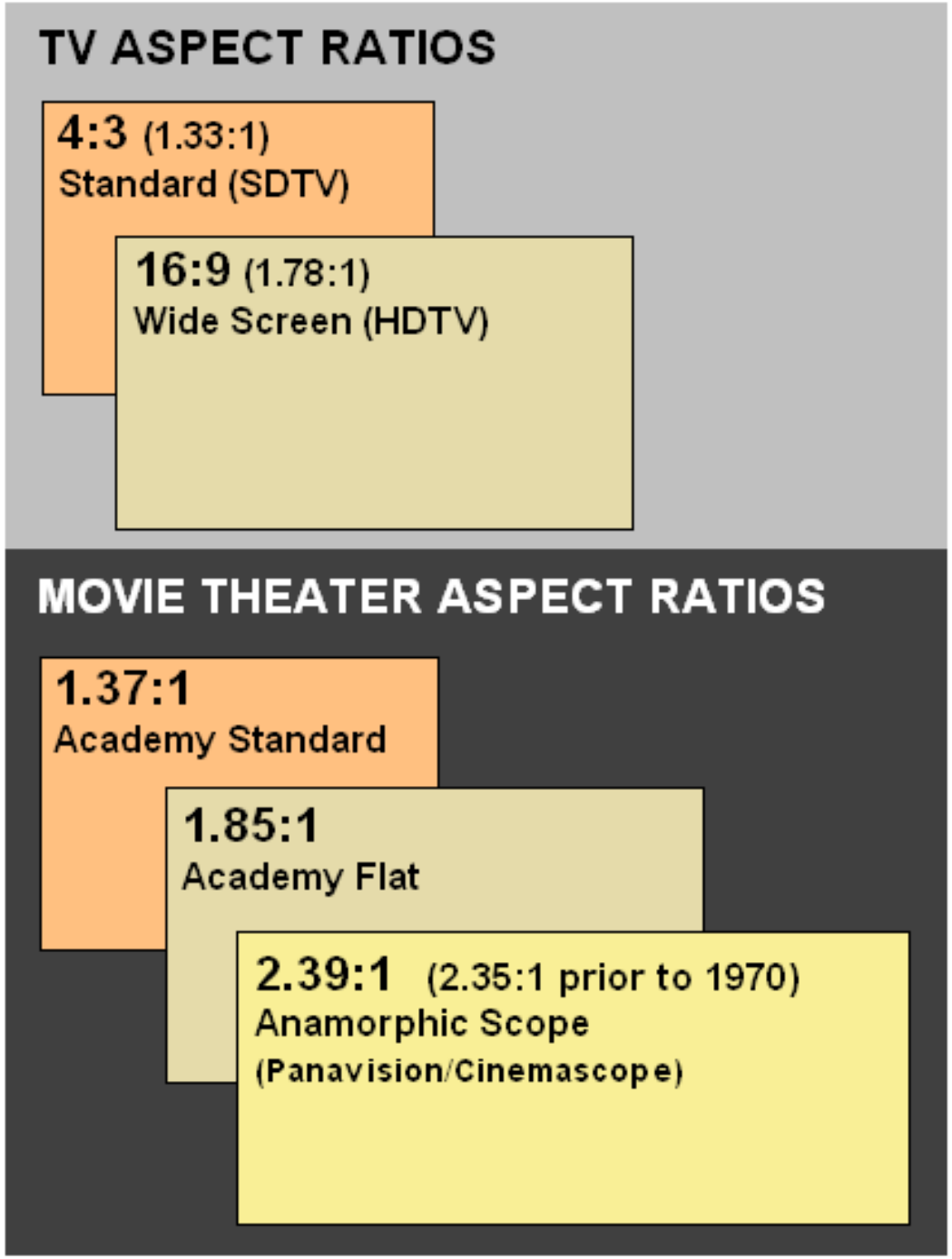
Aspect Ratios

- The ratio of horizontal to vertical image dimensions

Key Terms

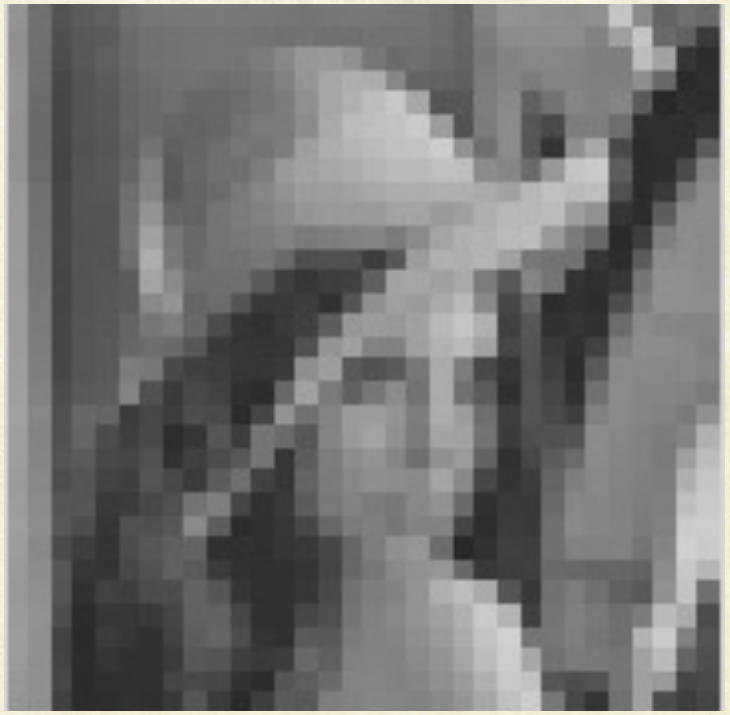
Standard Video Qualities: Standard combinations of aspect ratio and video resolution

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

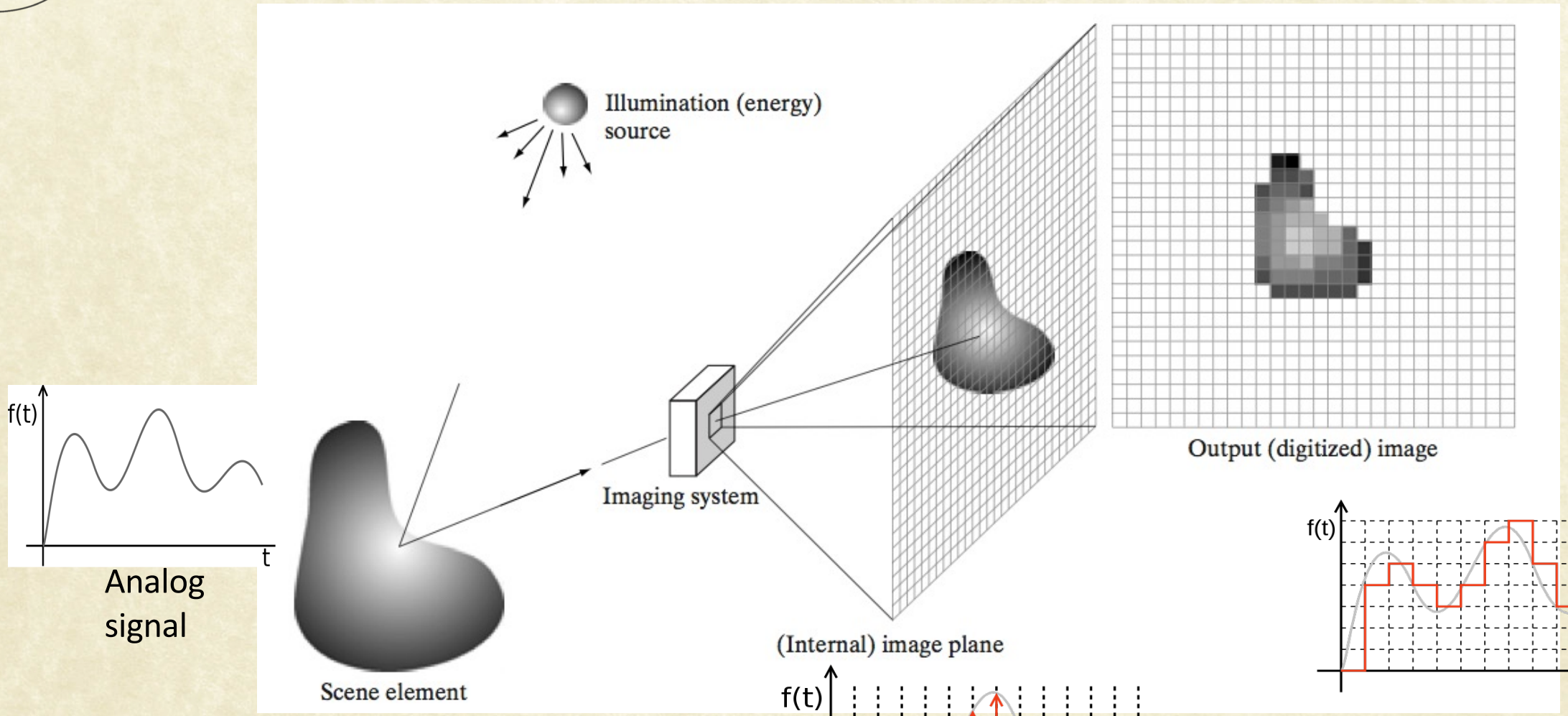


Image courtesy: Gonzalez and Woods

Intensity Quantization

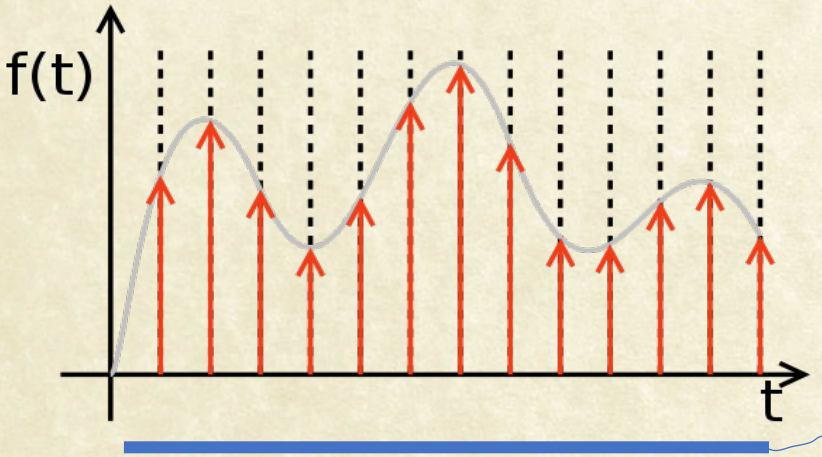
8 bits per pixel

4 bits per pixel

2 bits per pixel

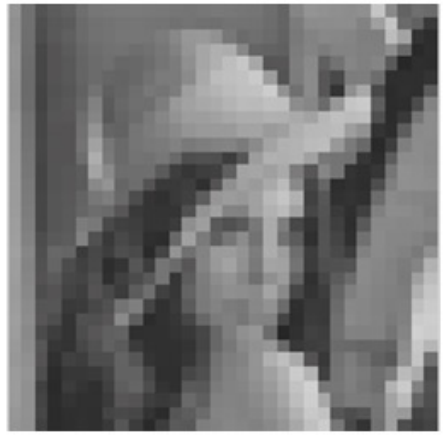
1 bit per pixel

Summary



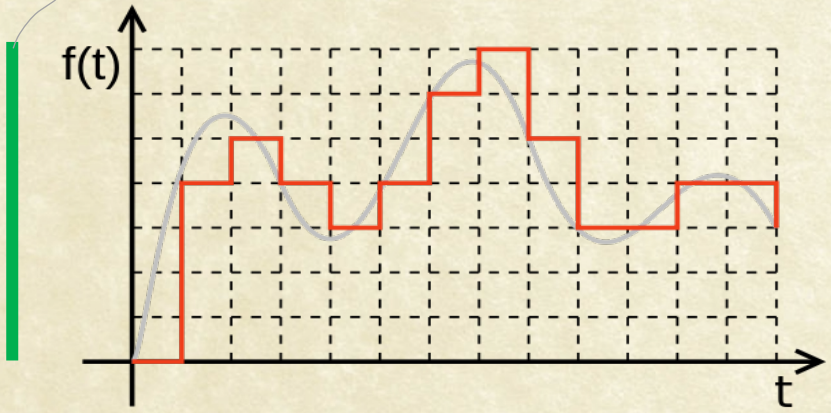
Sampling

256 × 256



32 × 32

16 × 16



Quantization

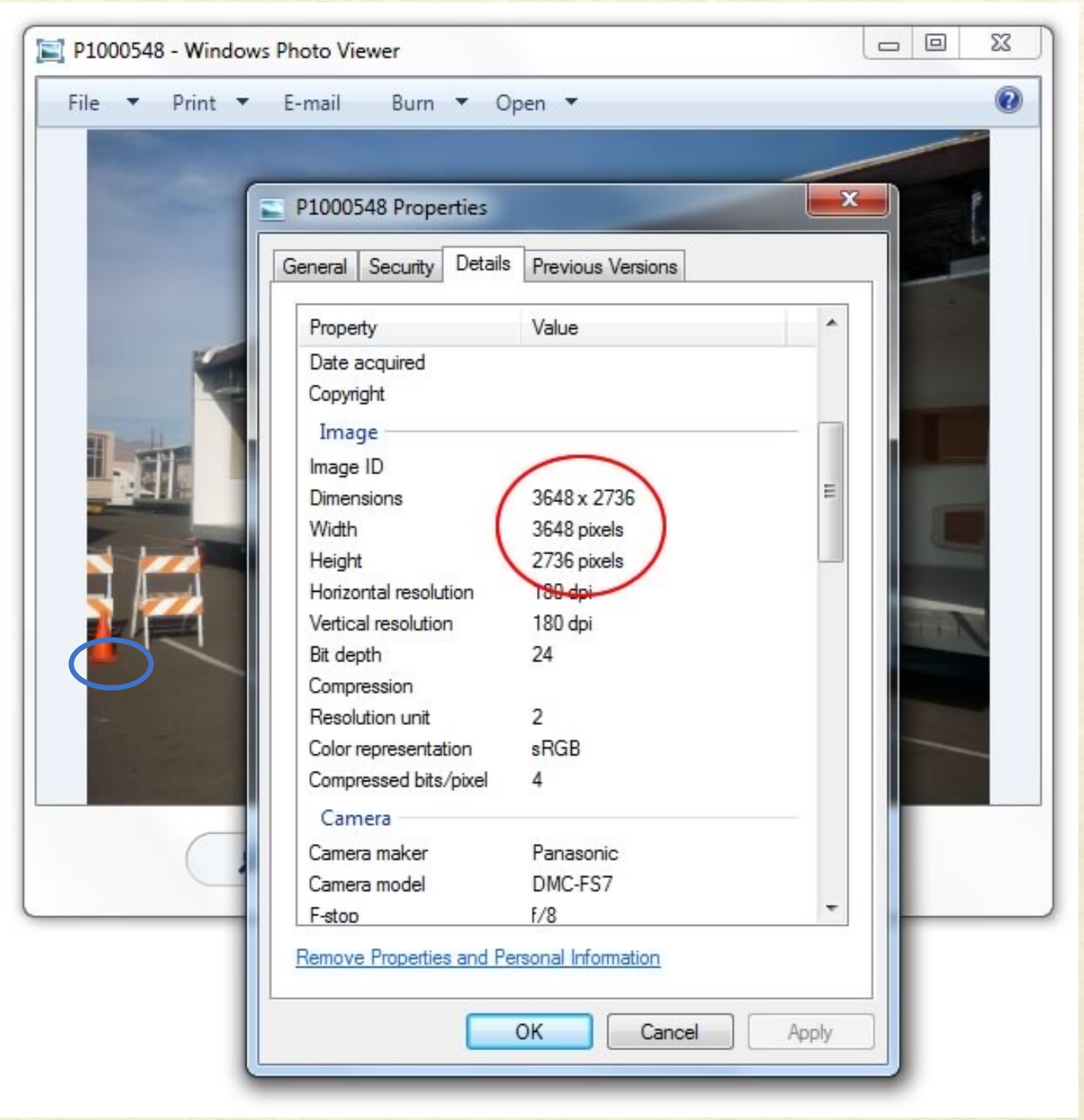
8 bits per pixel

4 bits per pixel

2 bits per pixel

1 bit per pixel

Image Properties



Quantization

- In Hardware (# of voltage levels, # of bits)
- RAW has 24bits or higher capacity (pixels many not have data)
- JPEG is limited to fewer bits per pixel

Summary: HVS

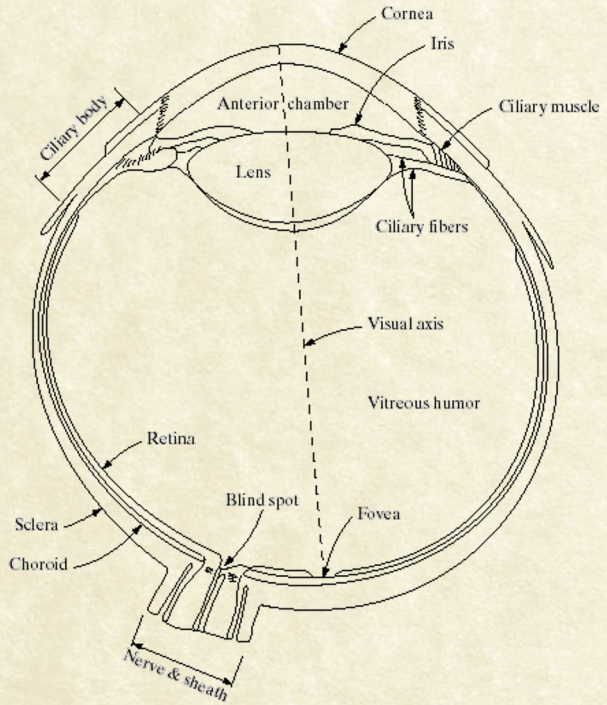
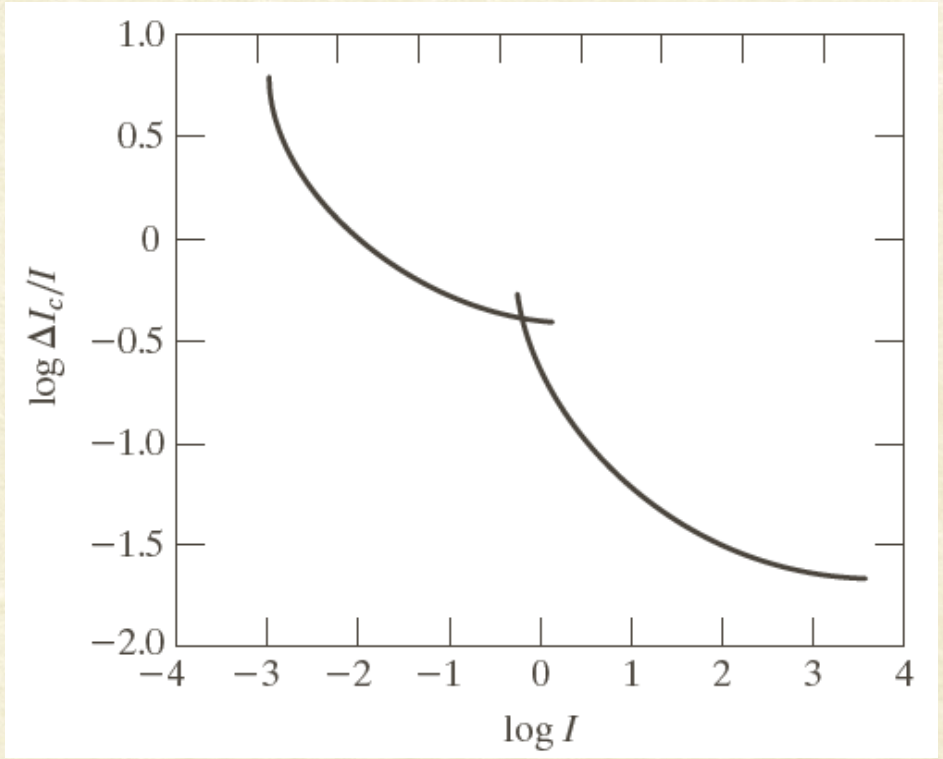
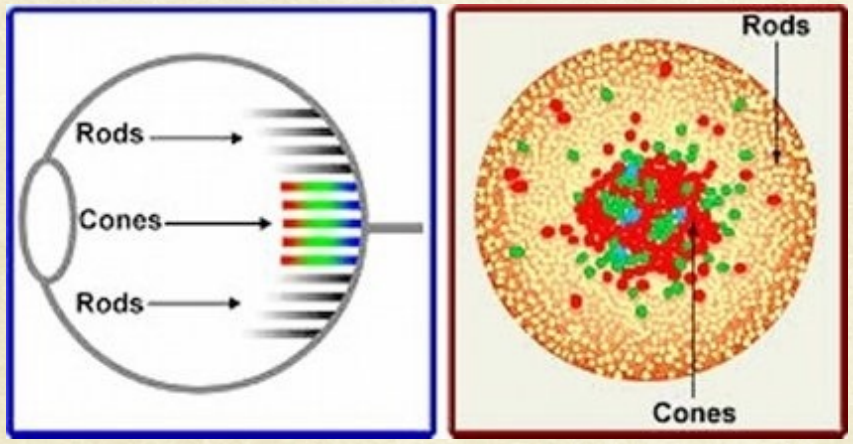
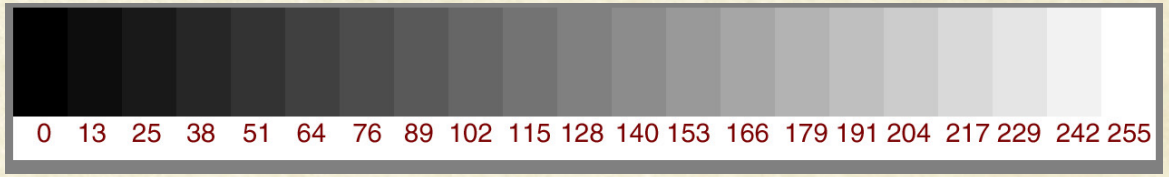


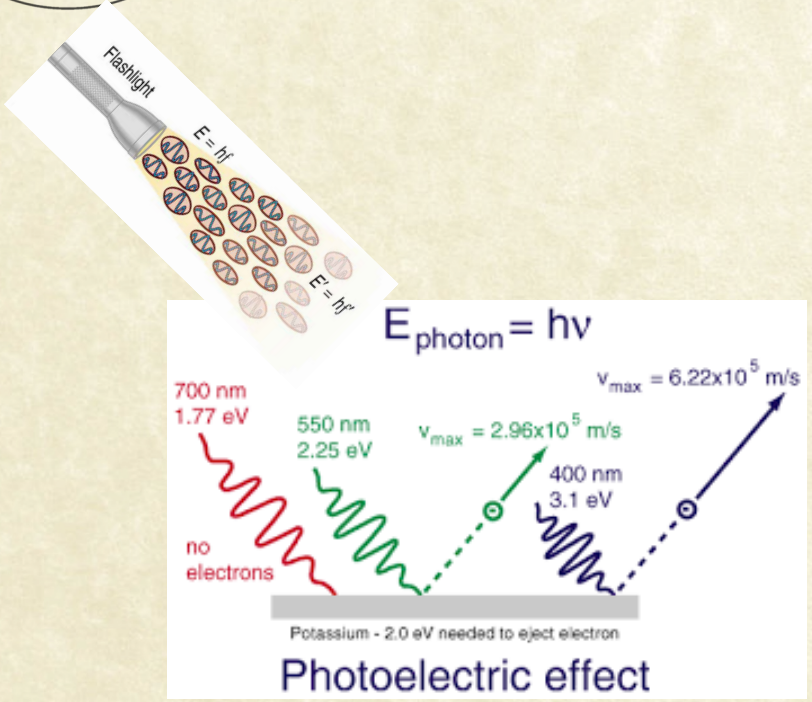
FIGURE 2.1
Simplified diagram of a cross section of the human eye.

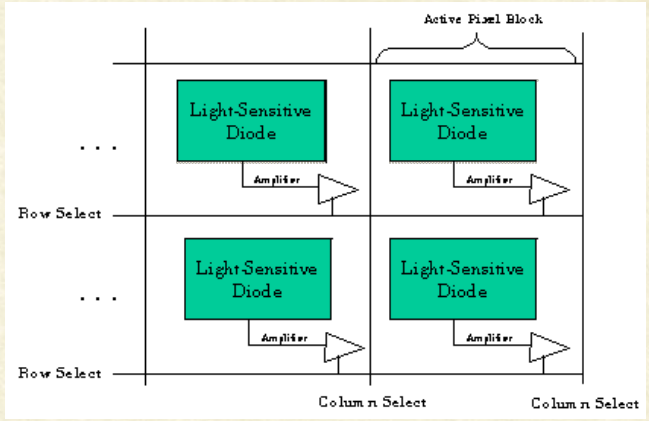




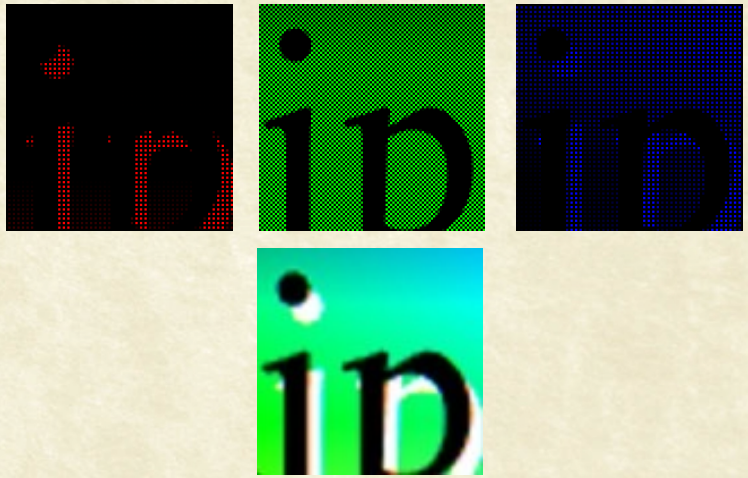


Summary: Image Acquisition





Demosaicing



Bayer Filter

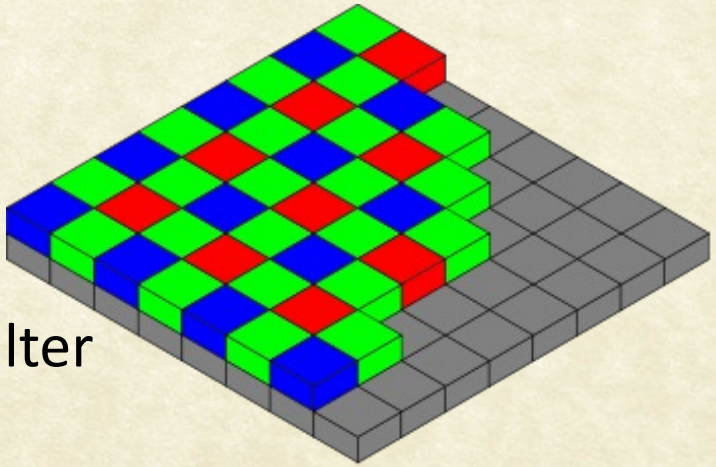


Image Acquisition Process

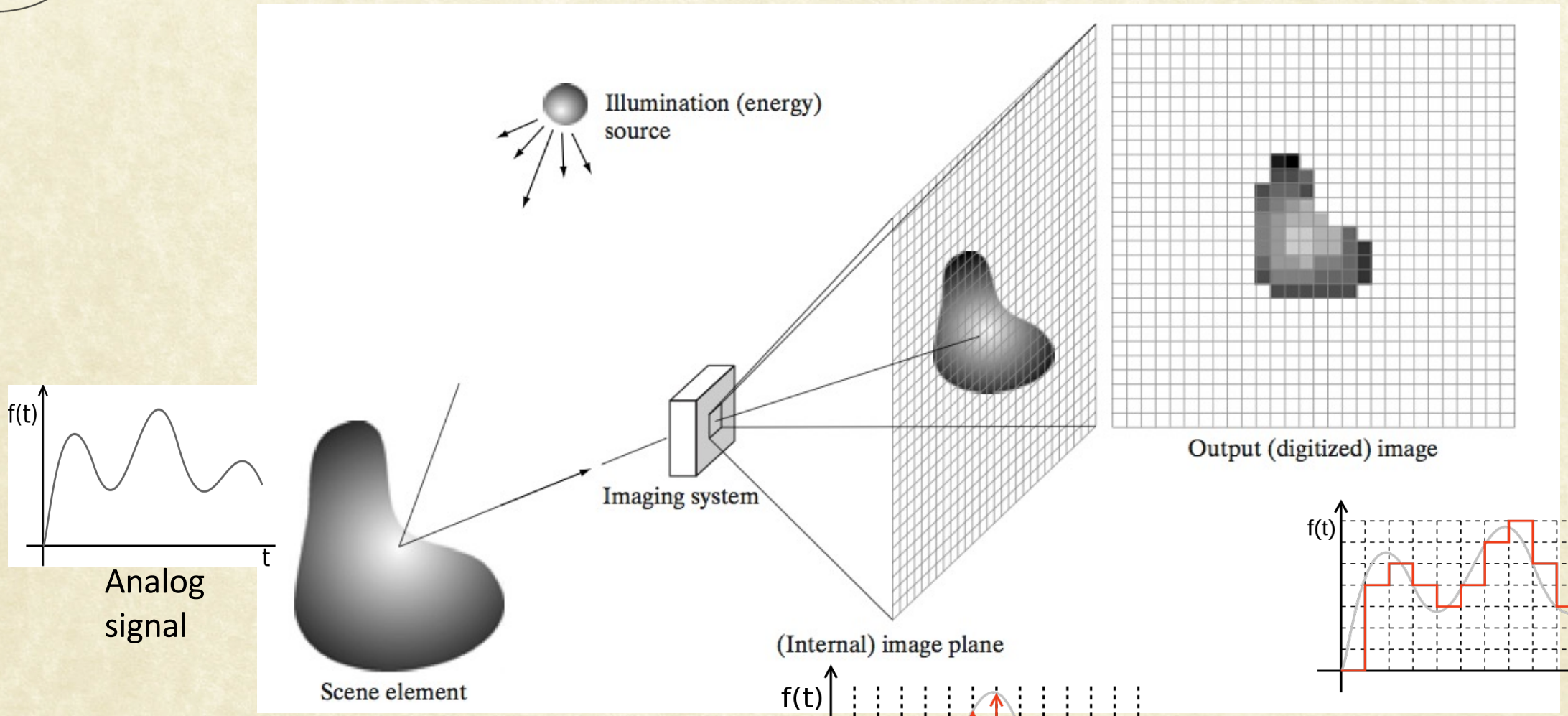
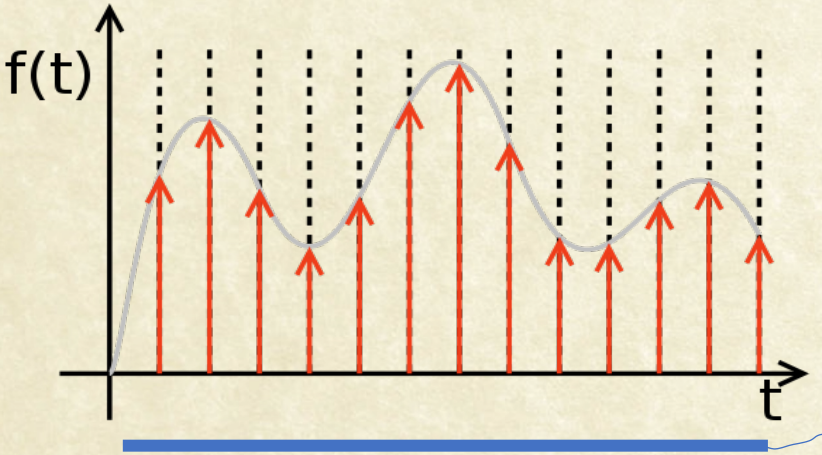


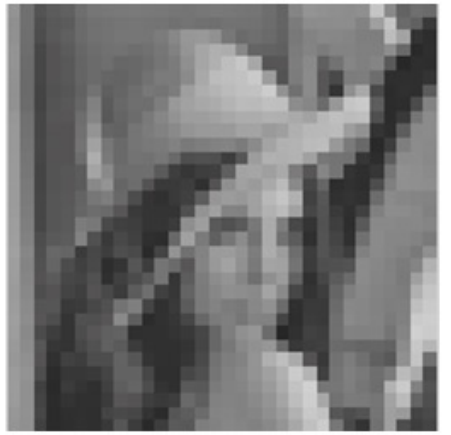
Image courtesy: Gonzalez and Woods

Summary: Image Sampling and Quantization



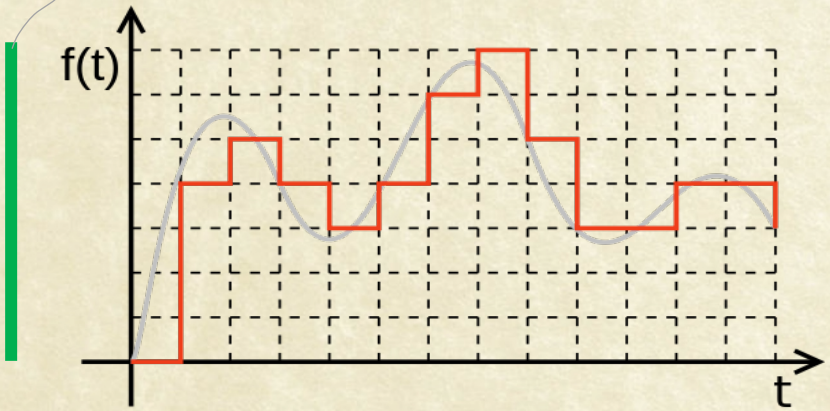
Sampling

256 × 256



32 × 32

16 × 16



Quantization

8 bits per pixel

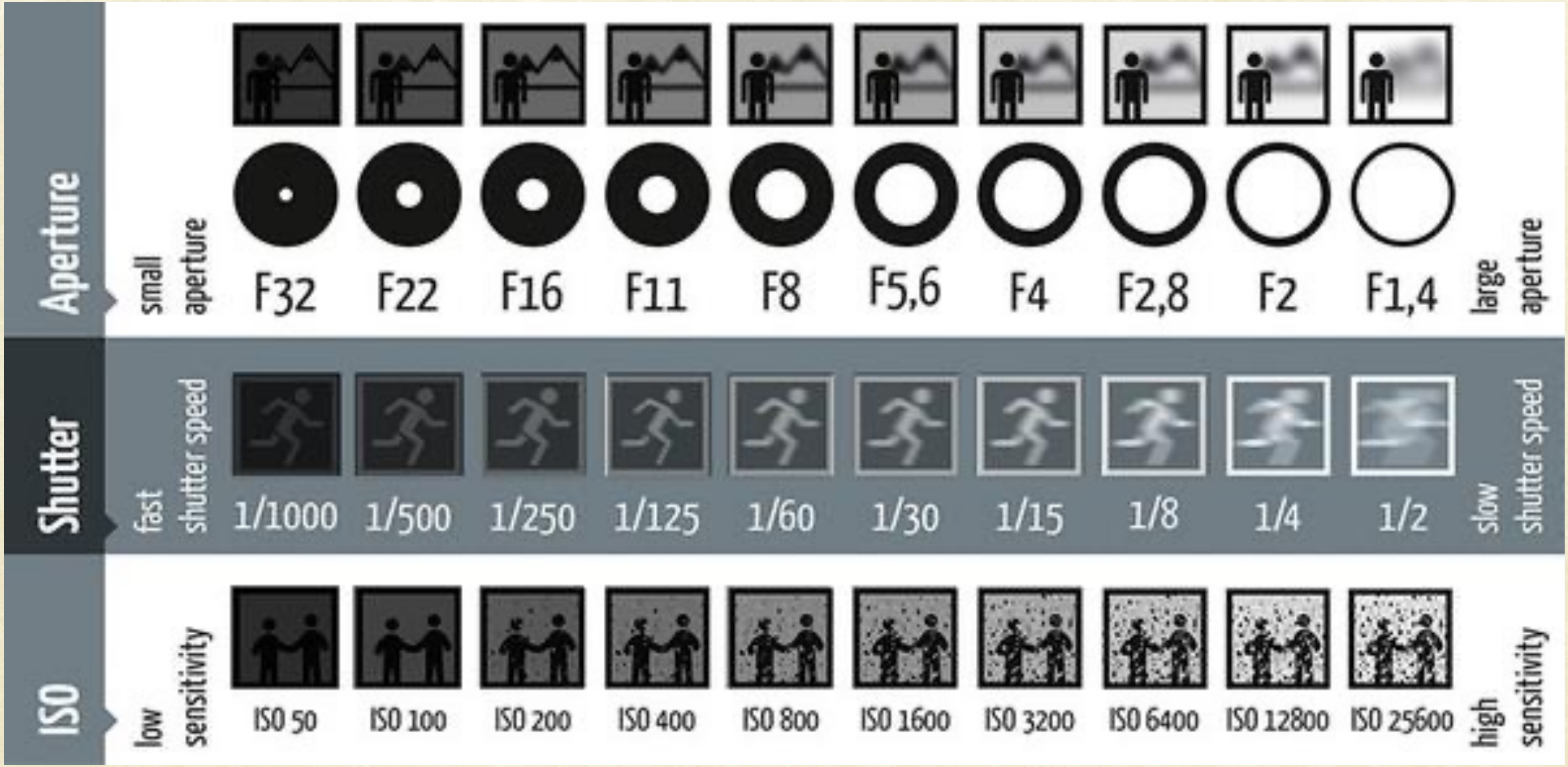
4 bits per pixel

2 bits per pixel

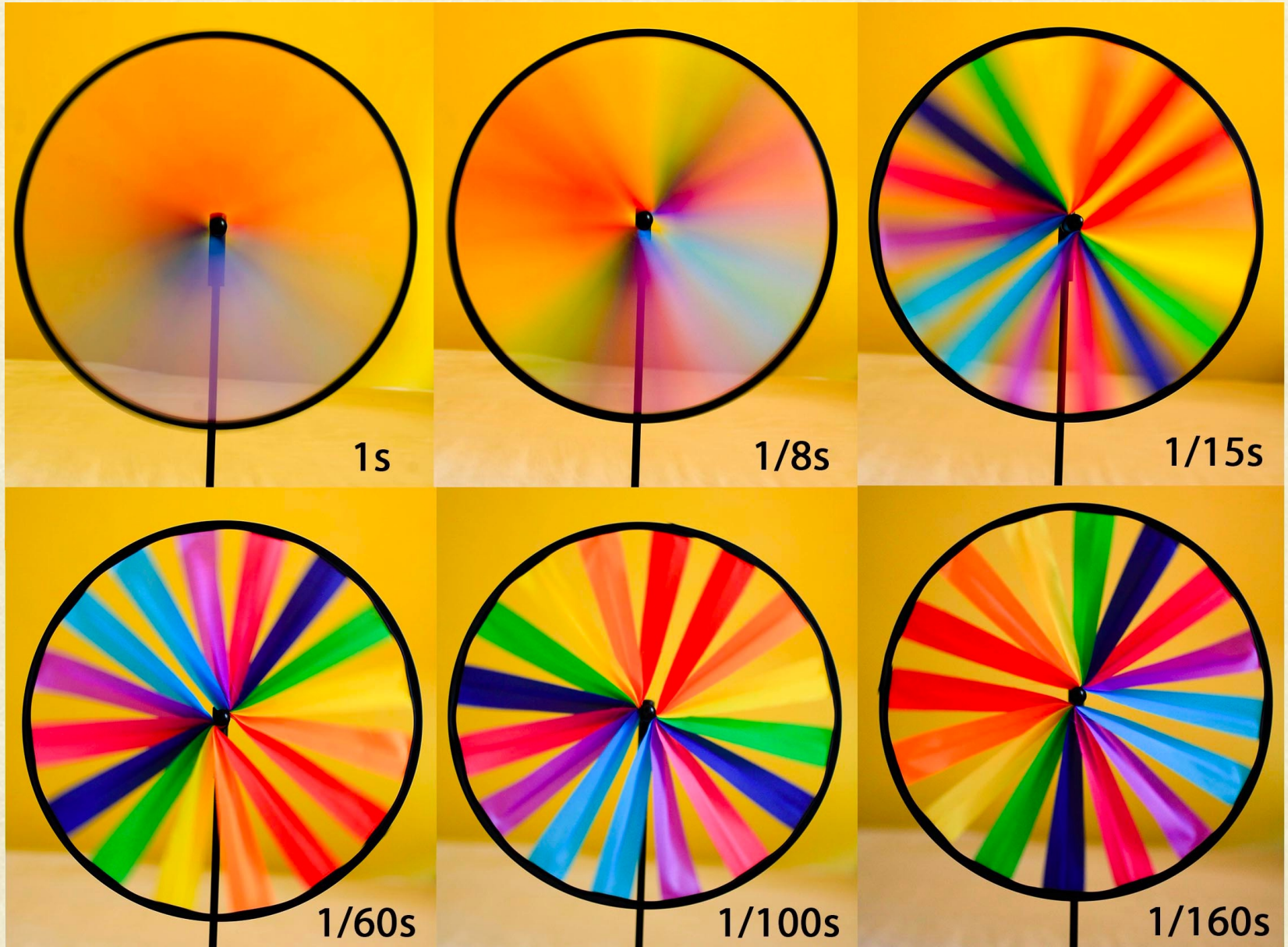
1 bit per pixel

Temporal Sampling

Imaging Controls



Temporal Sampling



Temporal Sampling

Questions?