

02.08.2018

# Digital Image Processing (CSE/ECE 478)

## Lecture-2: Digital Imaging Fundamentals

Ravi Kiran

Center for Visual Information Technology (CVIT), IIIT Hyderabad



# Announcements

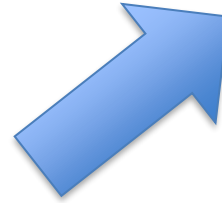
- Teaching Assistants

- Abhishek Prusty ([abhishek.prusty@students.iiit.ac.in](mailto:abhishek.prusty@students.iiit.ac.in))
- Aditya Aggarwal ([aditya.aggarwal@students.iiit.ac.in](mailto:aditya.aggarwal@students.iiit.ac.in))
- Prathyakshun Rajashankar ([prathyakshun.r@students.iiit.ac.in](mailto:prathyakshun.r@students.iiit.ac.in))
- Karandeep Singh Juneja ([karandeepsingh.juneja@students.iiit.ac.in](mailto:karandeepsingh.juneja@students.iiit.ac.in))

- Tutorial hours: **Saturday 3.30p – 4.30p**, location: **H-203**

# Announcements

- NO class next Tuesday
- Make-up class: Wednesday, 3.30p - 5.00p, H-103

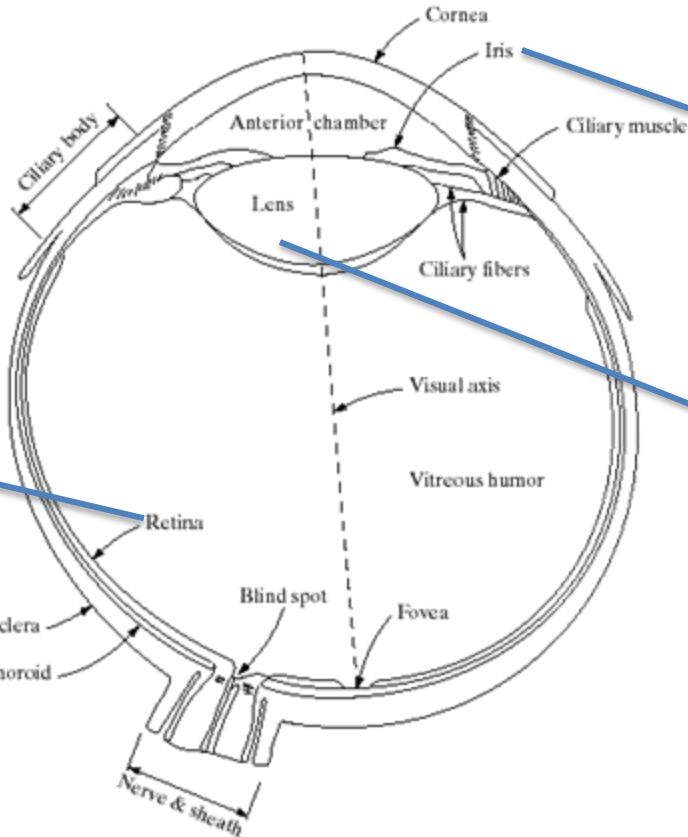


# Elements of Visual Perception

- Designers and often, consumers of Image Processing Techniques, are humans.
- Therefore, it is important to understand the basic workings of the **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

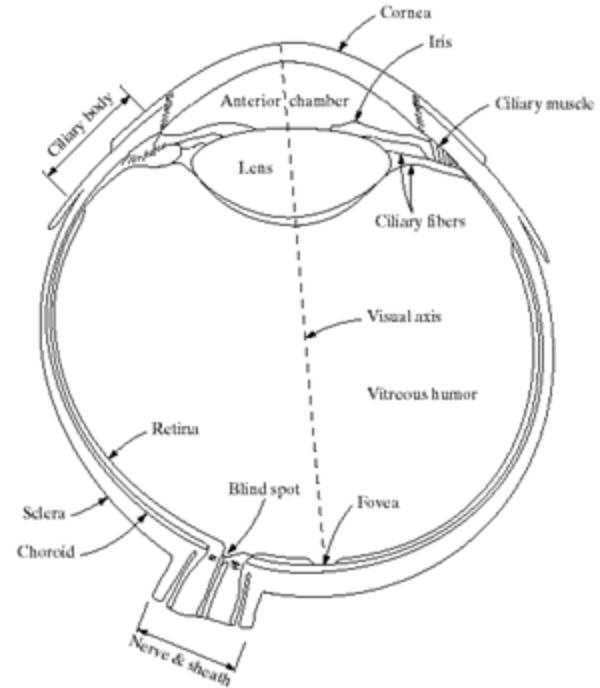
- Absorbs 8% of visible light spectrum
- IR, UV also absorbed

- Light is imaged on this

Reduces backscatter

# The Retina

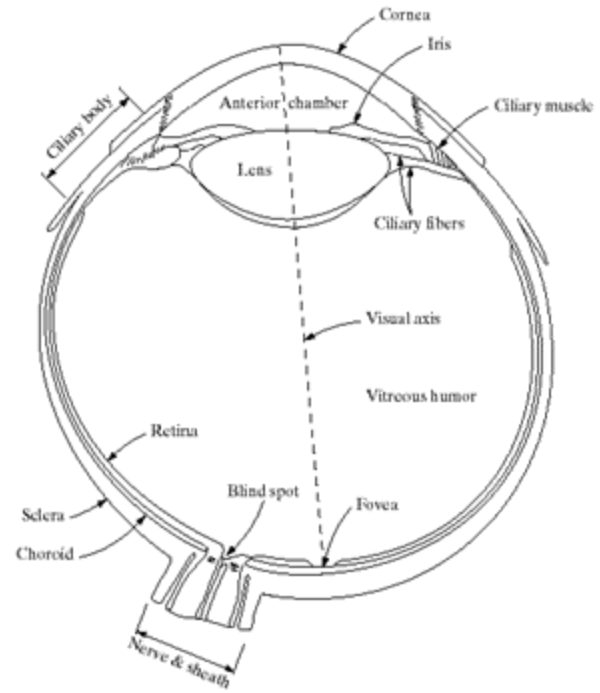
- The retina lines the entire posterior portion.
- Discrete light receptors are distributed over the surface of the retina:
  - cones (6-7 million per eye) and
  - rods (75-150 million per eye)



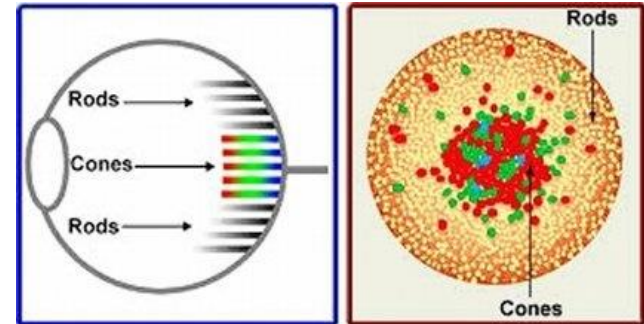
**FIGURE 2.1**  
Simplified  
diagram of a cross  
section of the  
human eye.

# Cones

- Cones are located in the fovea and are sensitive to **color**.
- Each one is connected to its own nerve end.
- Sensitive to bright-light: *photopic* vision

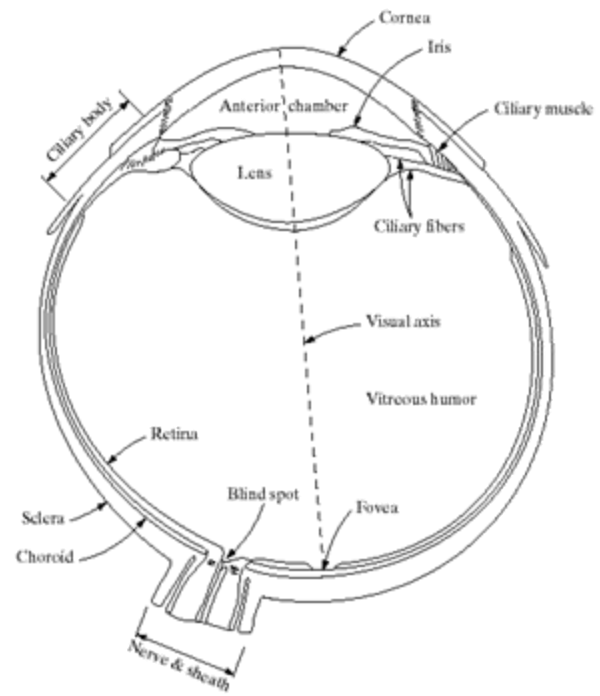


**FIGURE 2.1**  
Simplified  
diagram of a cross  
section of the  
human eye.

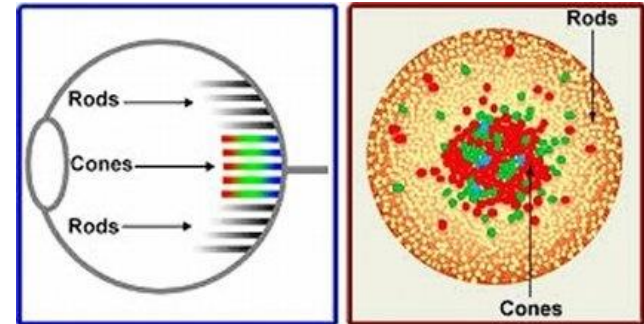


# Rods

- Rods give a general, overall picture of the field of view and are not involved in color vision.
- Several rods are connected to a single nerve.
- Rods are sensitive to low levels of illumination (*scotopic* or dim-light vision).

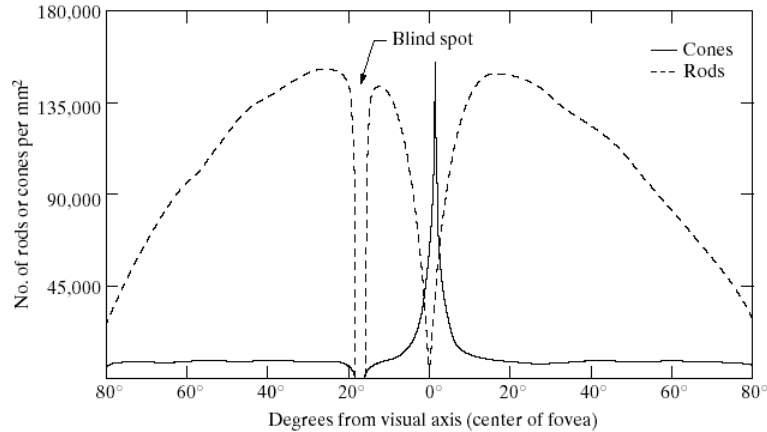


**FIGURE 2.1**  
Simplified diagram of a cross section of the human eye.

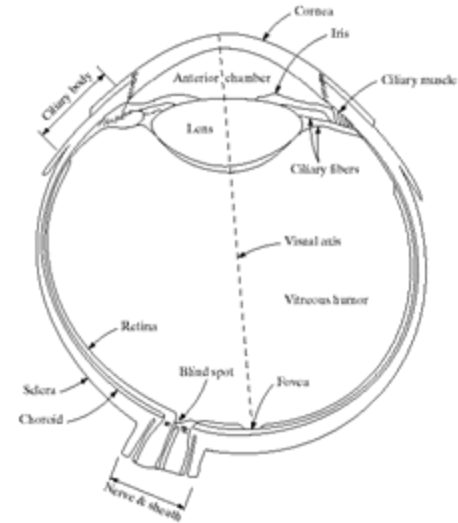




# Receptor Distribution



**FIGURE 2.2**  
Distribution of rods and cones in the retina.

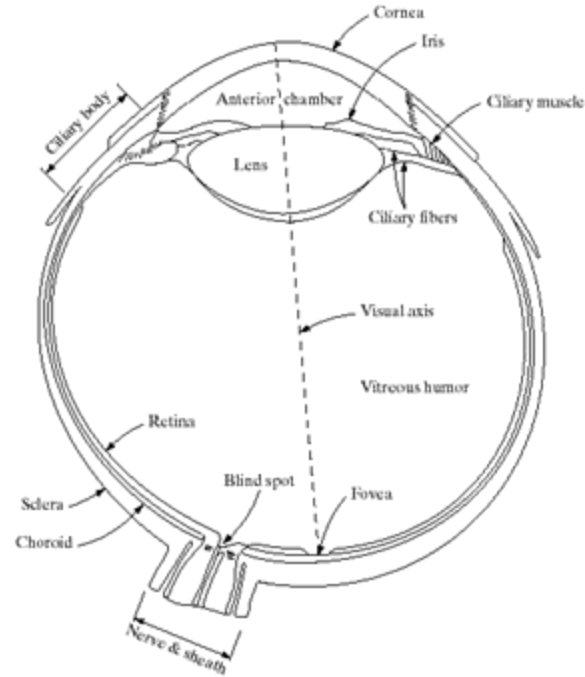


**FIGURE 2.1**  
Simplified diagram of a cross section of the human eye.

- The distribution of receptors is radially symmetric about the fovea.
- Cones are most dense in the center of the fovea
- Rods increase in density from the center out 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).
- The density of cones: 150,000 elements/mm<sup>2</sup> ~ 337,000 for the fovea.
  - A CCD imaging chip of medium resolution needs 5 mm x 5 mm for this number of elements



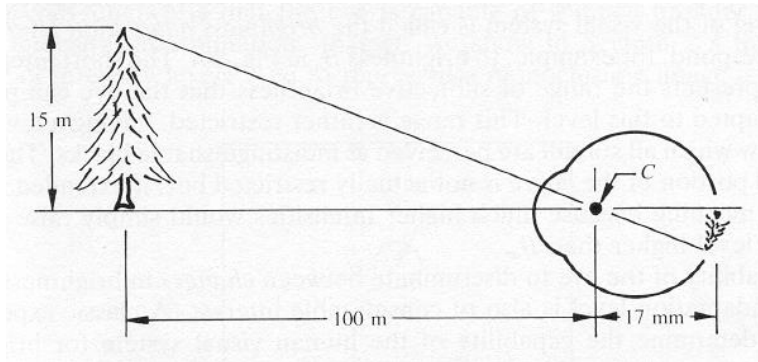
**FIGURE 2.1**  
Simplified  
diagram of a cross  
section of the  
human eye.

# Image Formation in the Eye

- The eye lens (compared to an optical lens) is flexible.
- It gets controlled by fibers of the ciliary body
  - To focus on distant objects it gets flatter (and vice versa)
  - Focal length varies from 17 mm to 14 mm

# Image Formation in the Eye

- **Example:**
  - Calculation of retinal image of an object

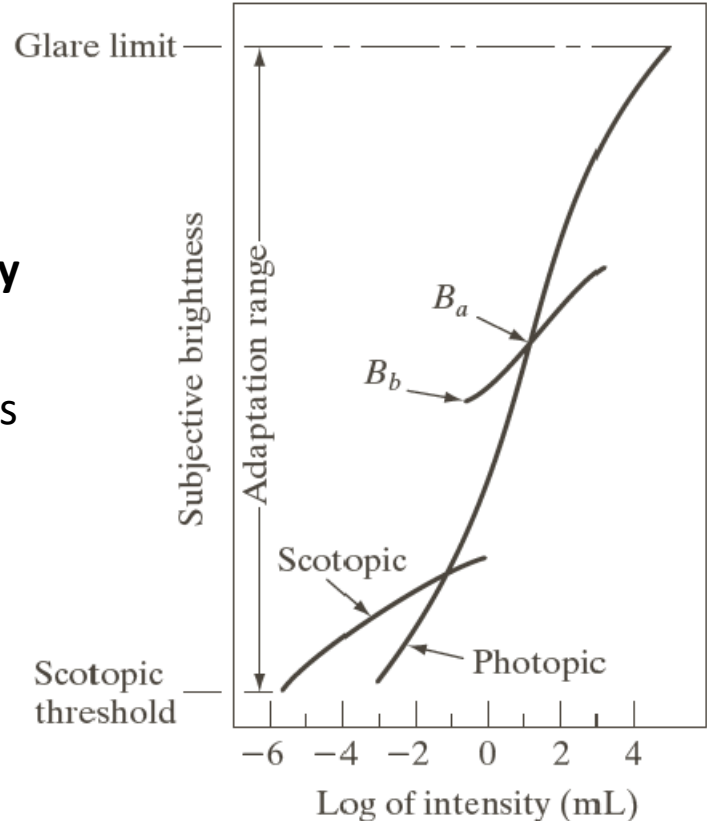


$$\frac{15}{100} = \frac{x}{17}$$

$$x = 2.55 \text{ mm}$$

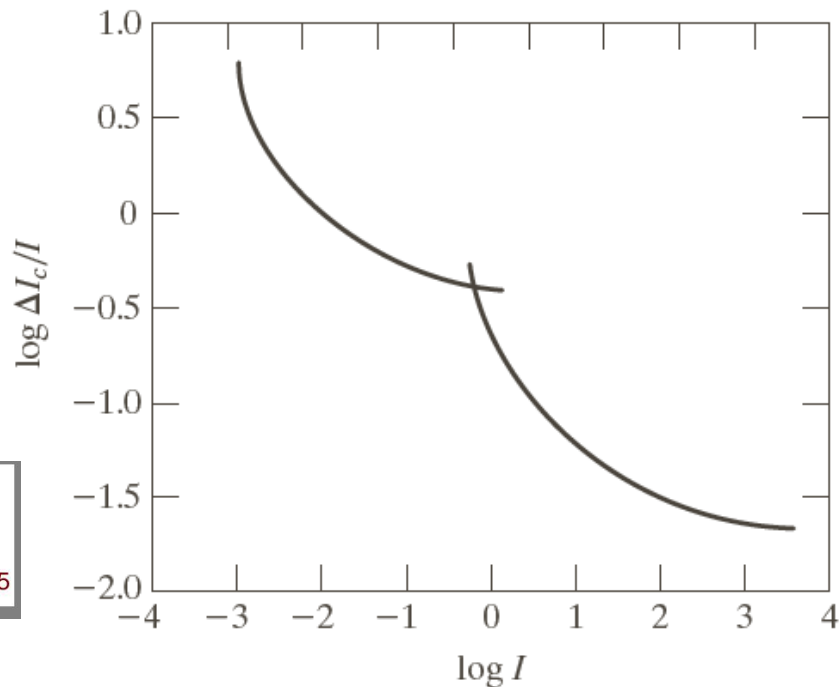
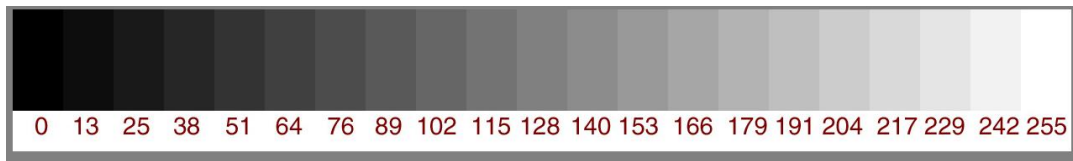
# Brightness adaptation

- Dynamic range of human visual system
  - $10^{-6} \sim 10^4$
- HVS cannot accomplish this range **simultaneously**
- The current sensitivity level of the visual system is called the **brightness adaptation** level



# Brightness discrimination

- Weber ratio (the experiment)  $\Delta I_c / I$ 
  - $I$ : the background illumination
  - $\Delta I_c$ : 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=hWT_LO8U7uE)

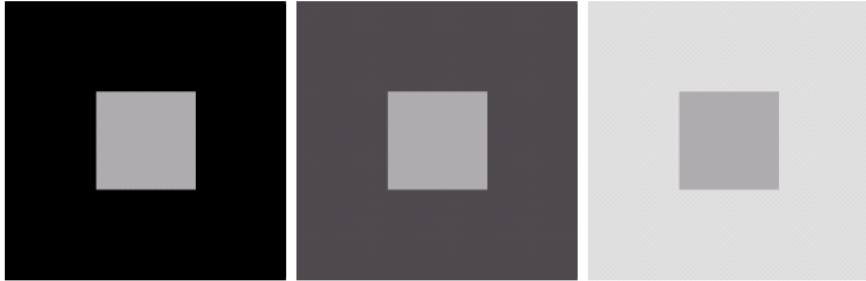
<https://www.youtube.com/watch?v=wVhiezByMSU>: an audio example

# Brightness Adaptation & Discrimination

- Another experiment: Background illumination constant, other source incrementally varies
- The typical observer can discern one to two dozen different intensity changes

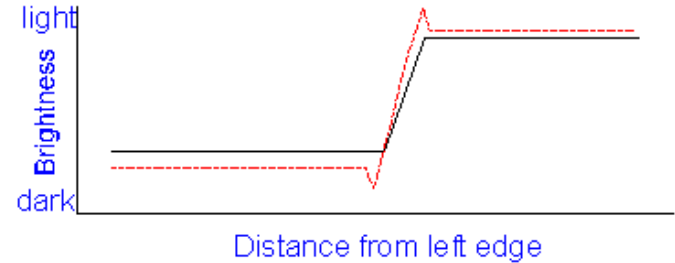
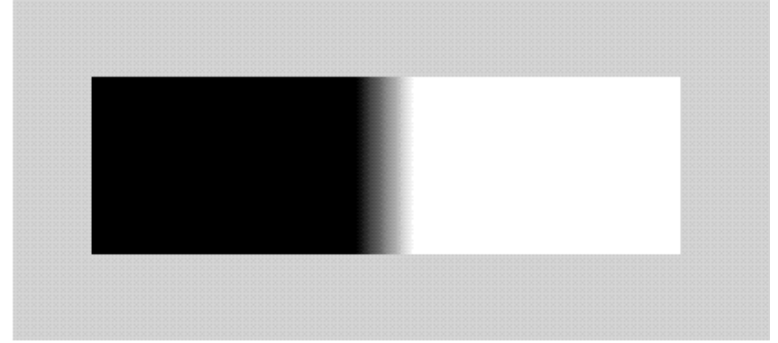
# Psychovisual effects

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



a b c

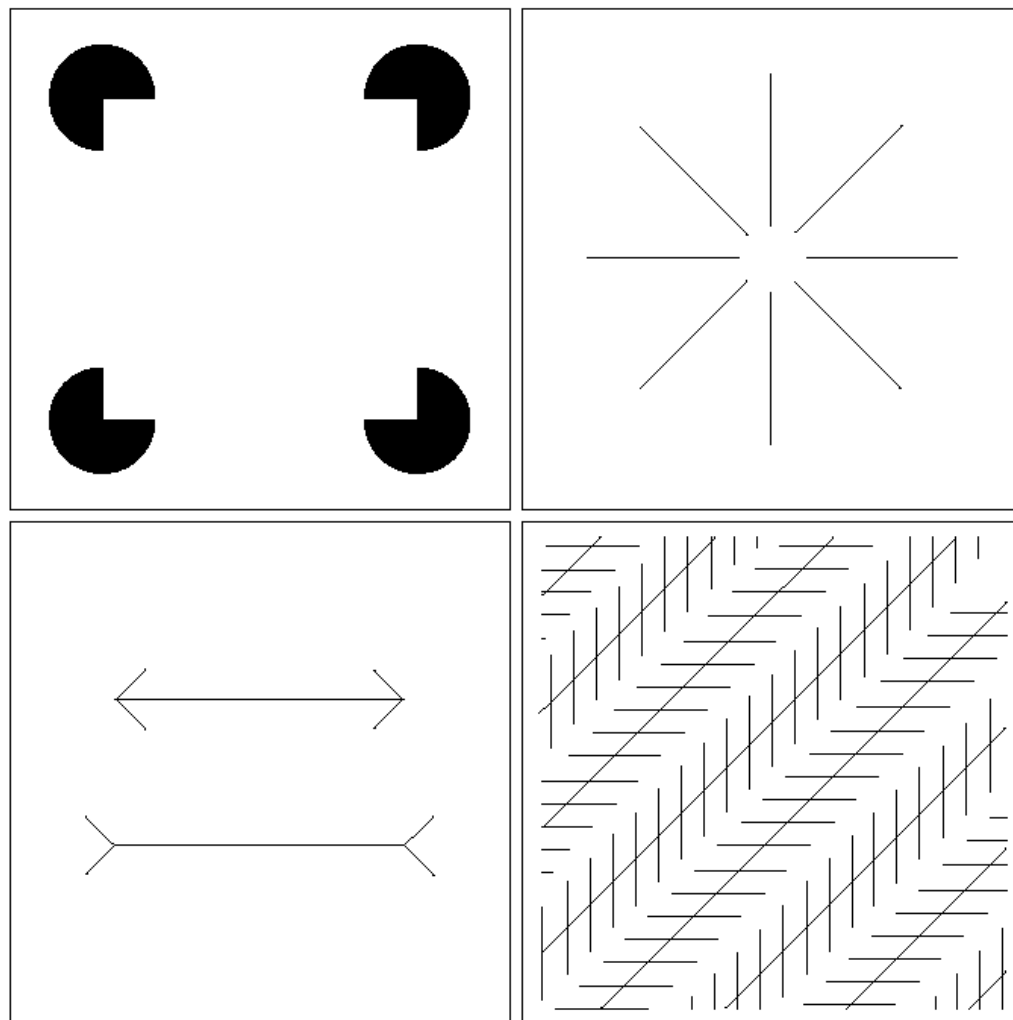
**FIGURE 2.8** Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.



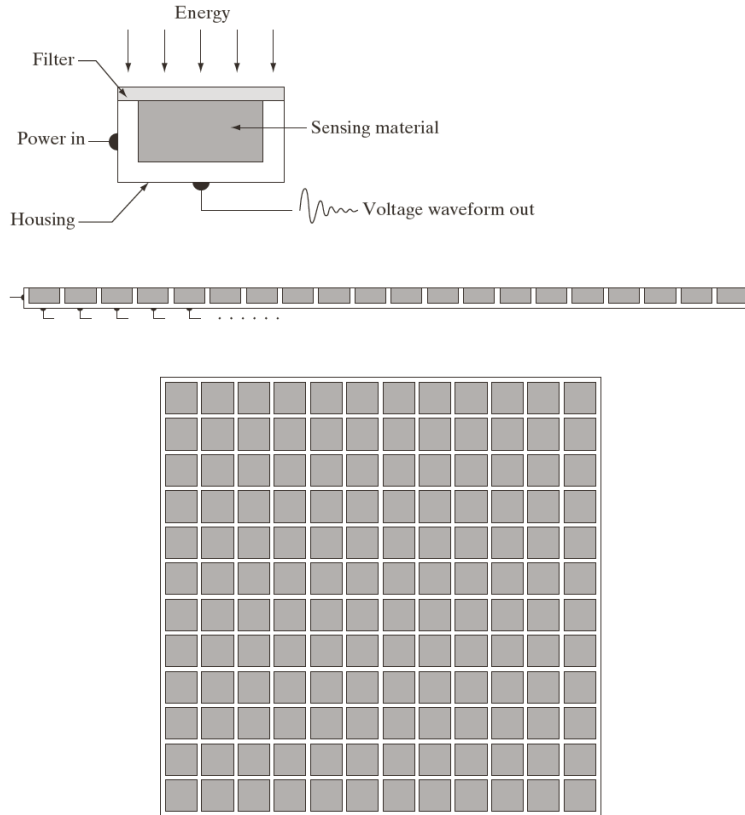


a b  
c d

**FIGURE 2.9** Some well-known optical illusions.



# Image Sensing and Acquisition



a  
b  
c

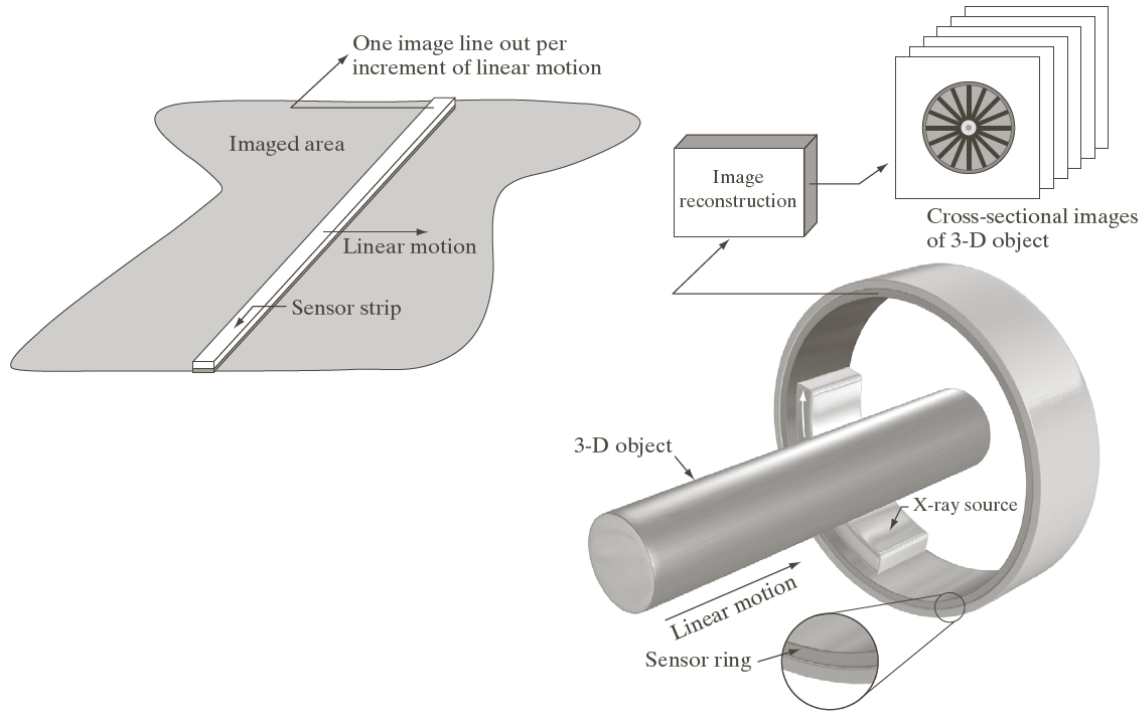
**FIGURE 2.12**

(a) Single imaging sensor.

(b) Line sensor.

(c) Array sensor.


# 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.

- **Digital Image Acquisition**



How images  
are acquired

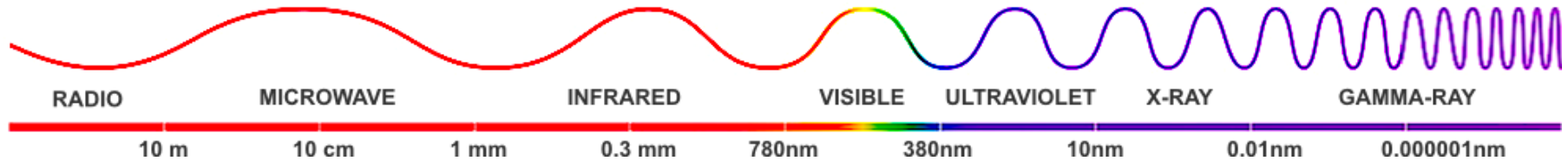
- Image Sampling and Quantization



How images end  
up in digital form

- Fundamental Steps in Image Processing

# EM spectrum



- EM radiation
  - Energy travelling as a wave
  - Produced by oscillating charge or energy source

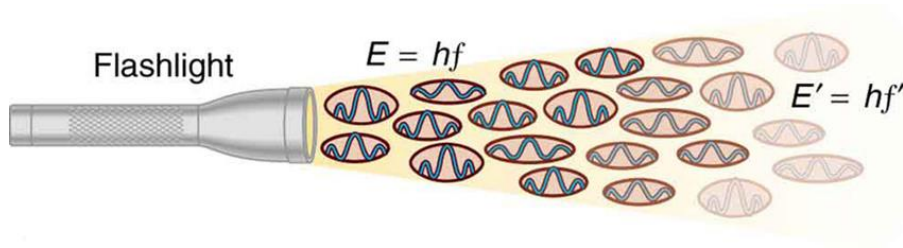
# EM spectrum



- EM radiation
  - Energy travelling as a wave
  - Produced by oscillating charge or energy source
- Visible light
  - Band of EM radiation sensed by human eye

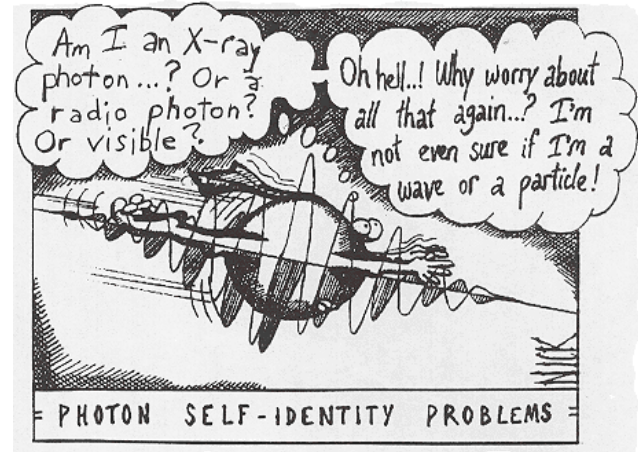
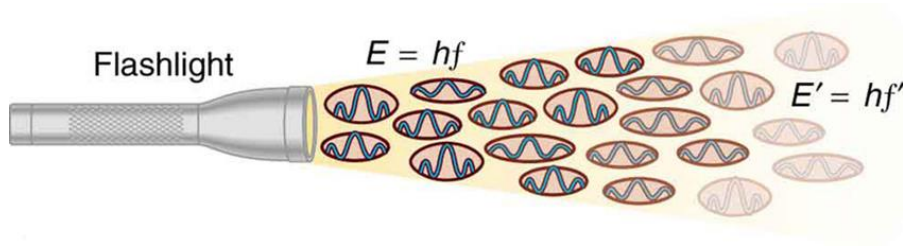
# Light as a particle stream

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



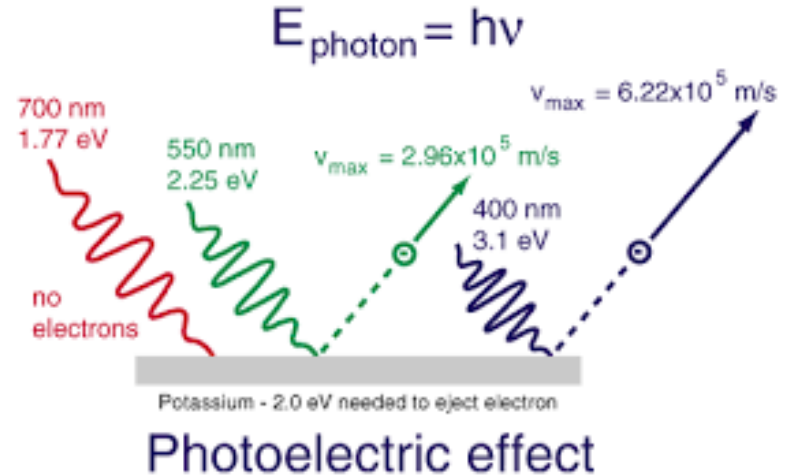
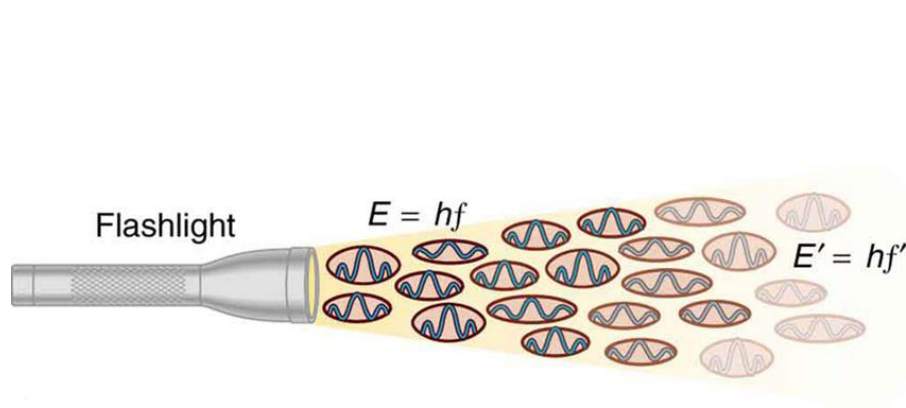
# Light as a particle stream

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

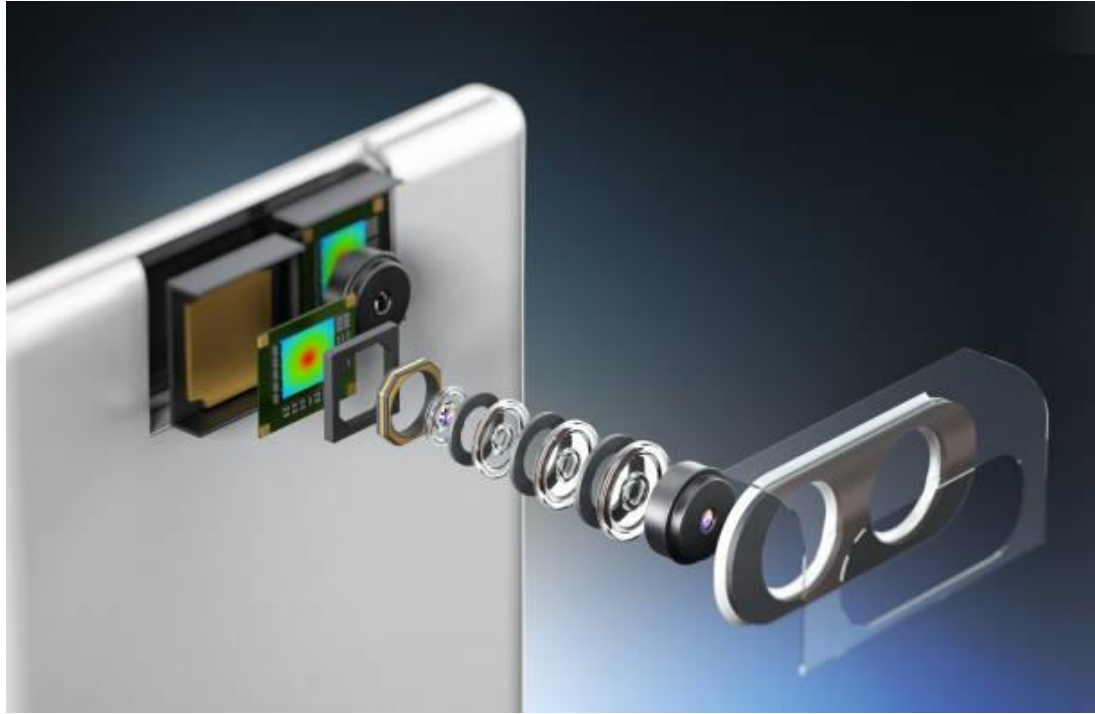




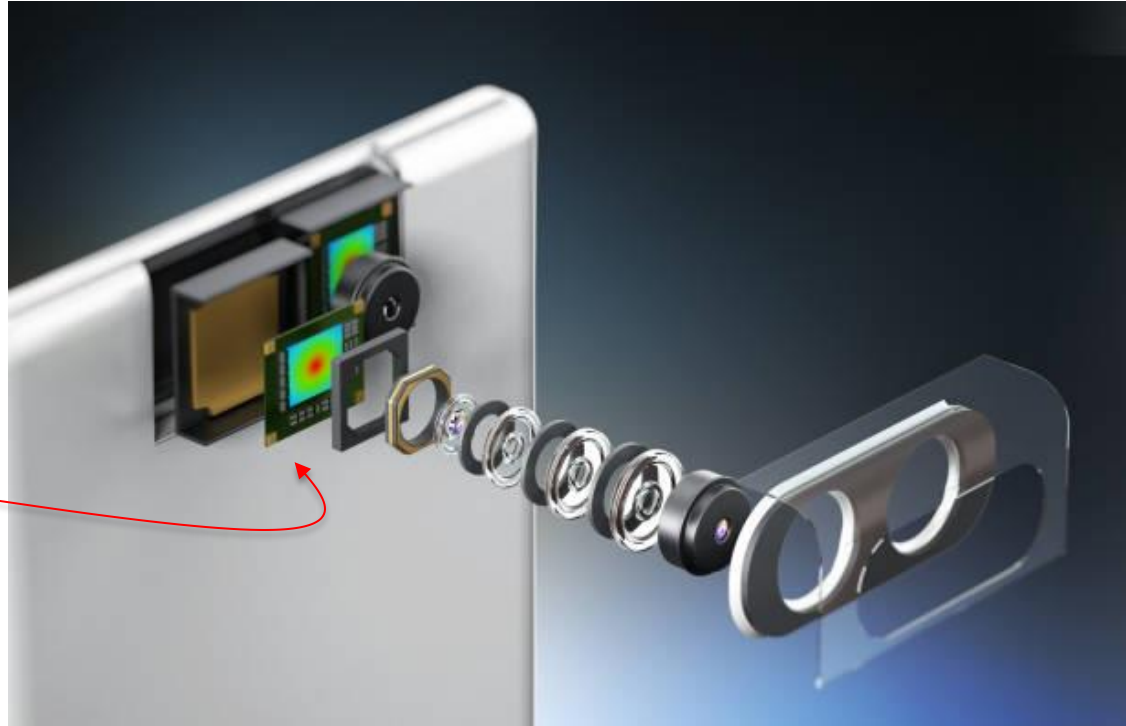
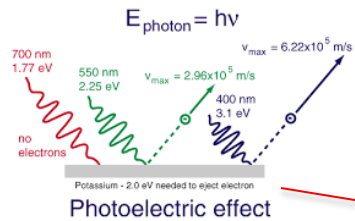
# Photo-electric effect



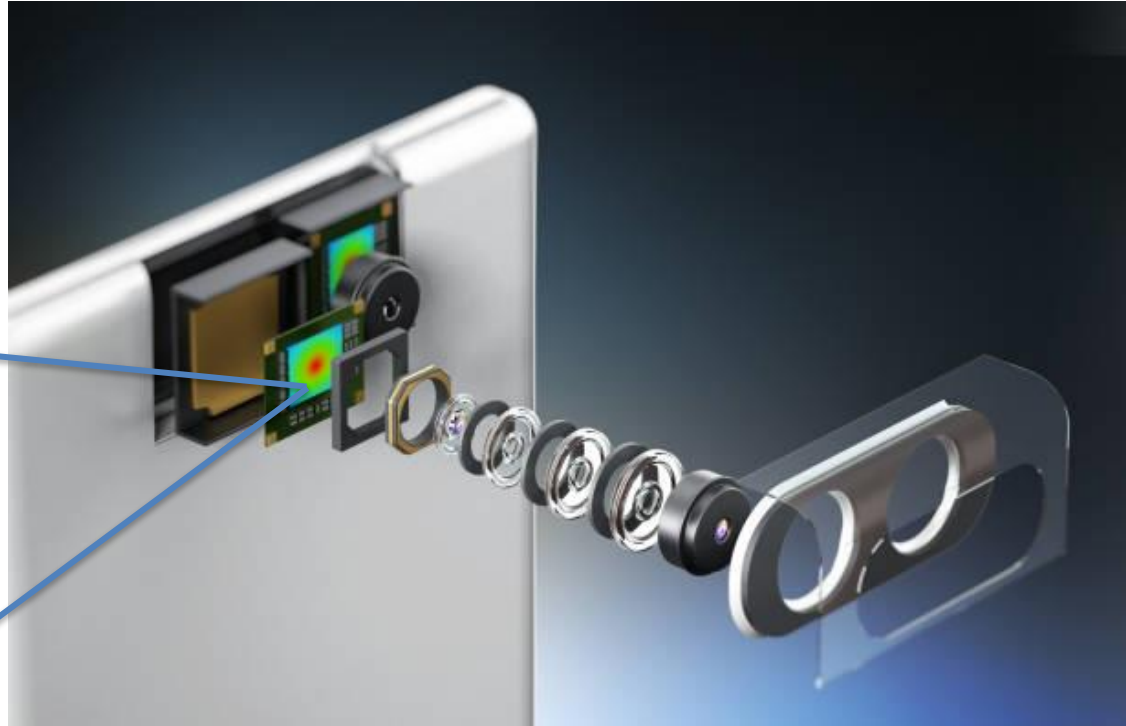
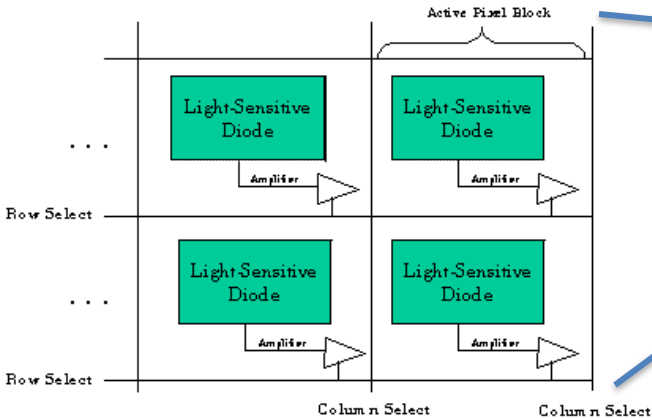
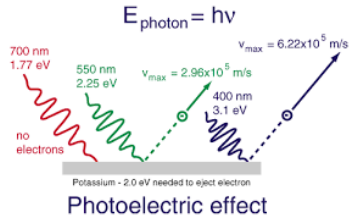
# Cross-section of typical smartphone camera



# Photo-electric effect in cameras



# CMOS photo-electric sensor

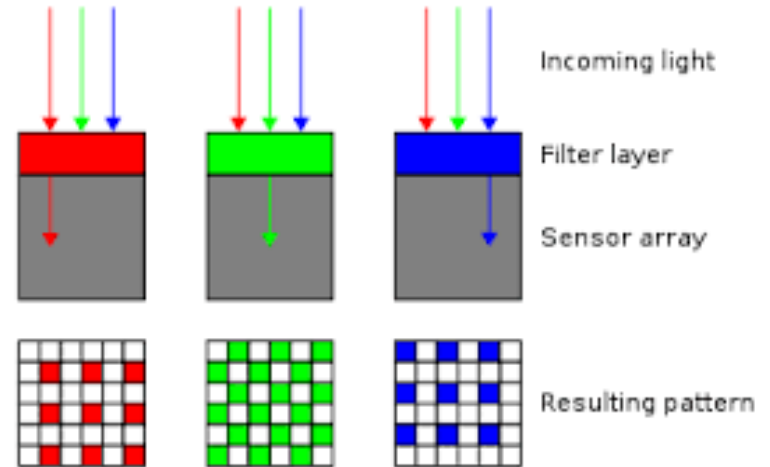
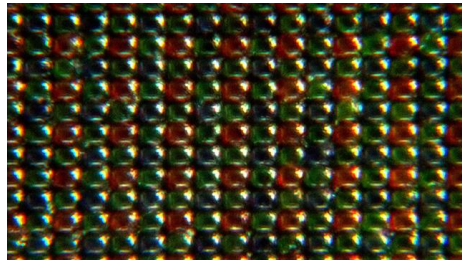
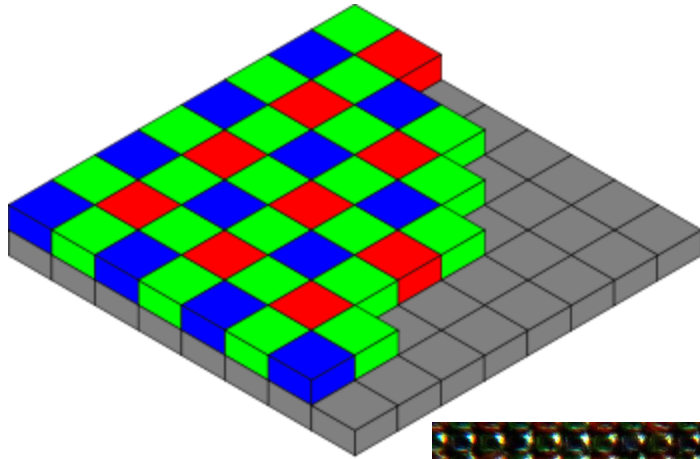


# Light → Color

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

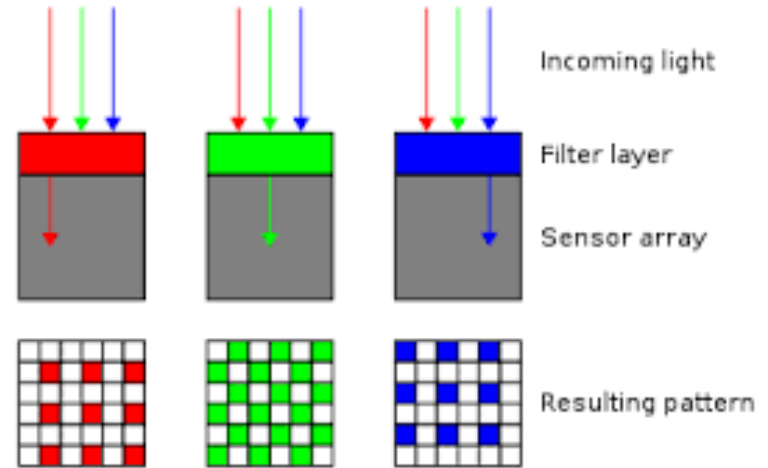
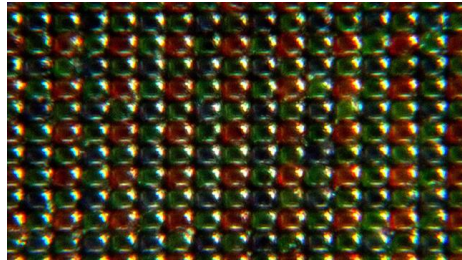
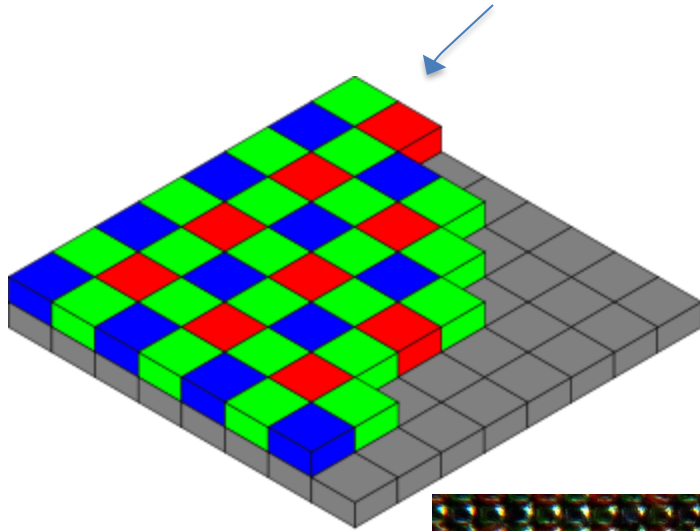


# Bayer Filter



# Bayer Filter

Relatively more green filters. Why ?

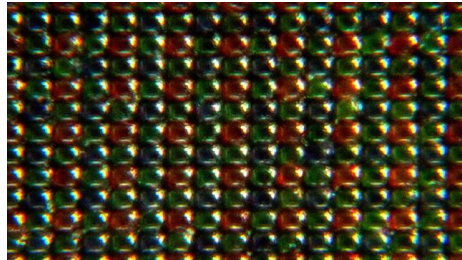
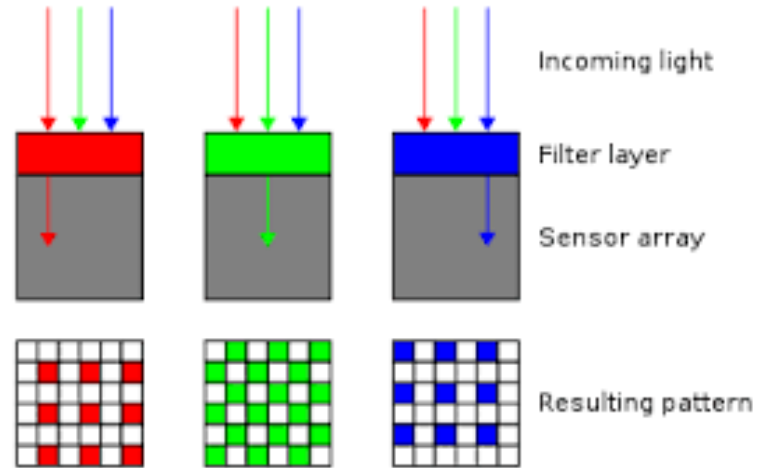
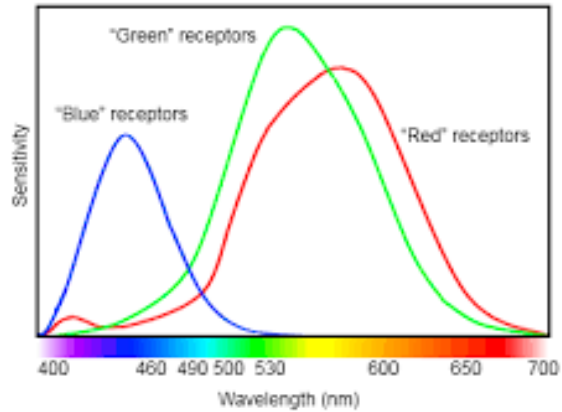




# Bayer Filter

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

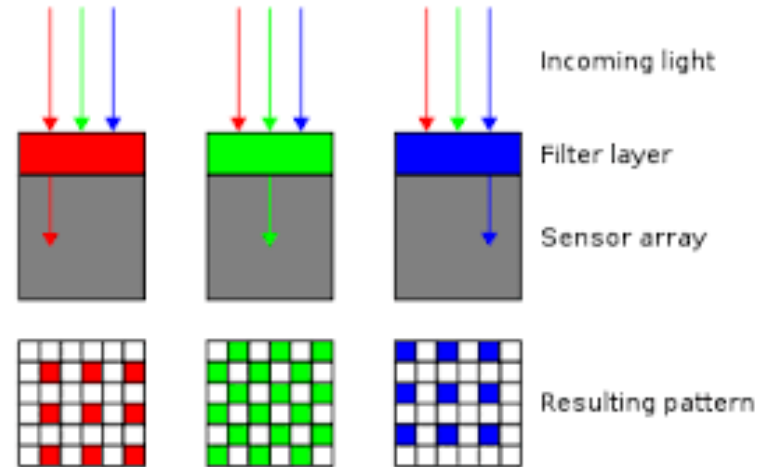
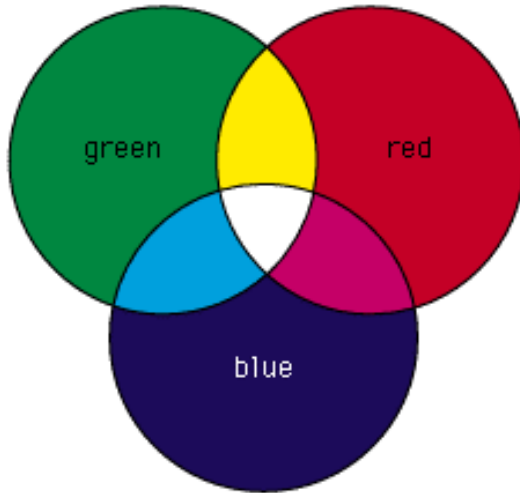
Human color receptor relative sensitivity



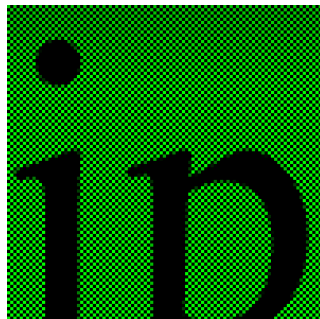


# Bayer Filter

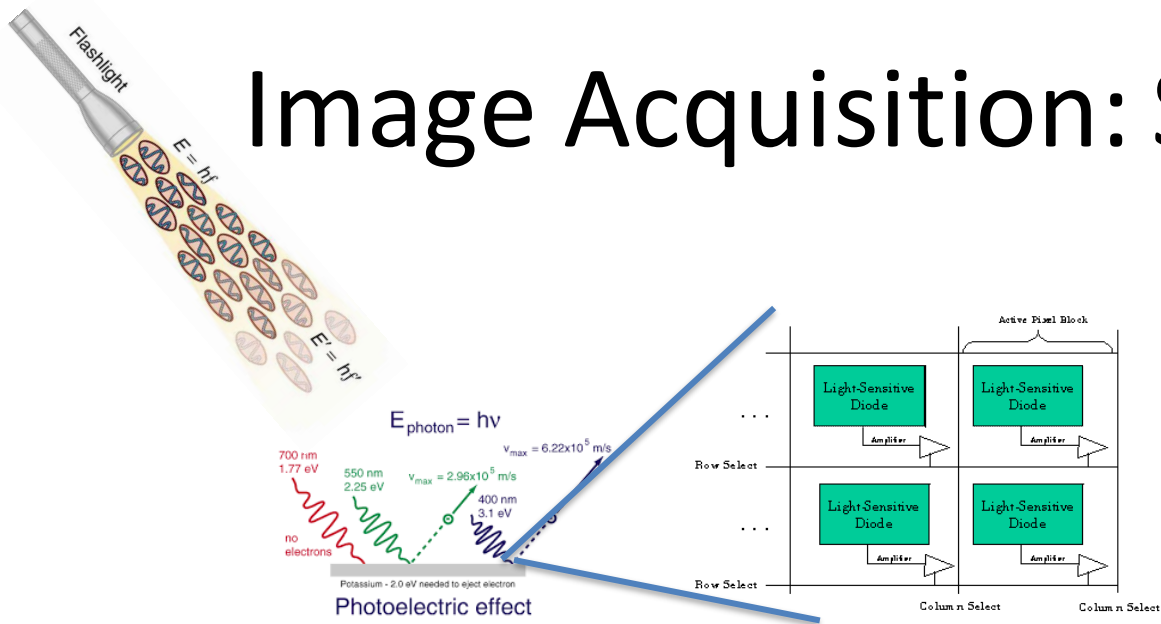
- How do we get color now ?



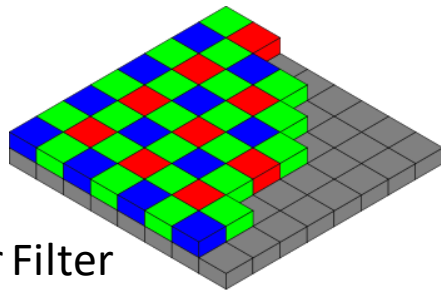
# Demosaicing



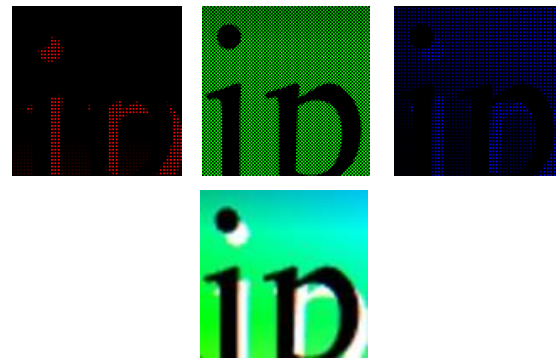
# Image Acquisition: Summary



Bayer Filter



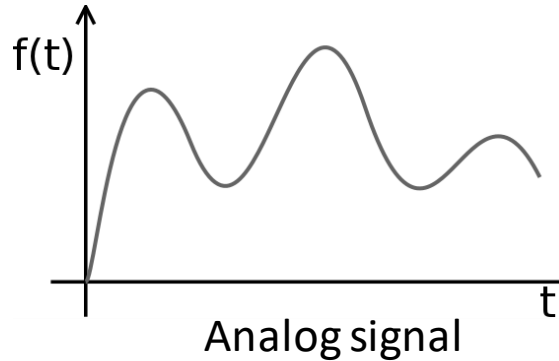
Demosaicing



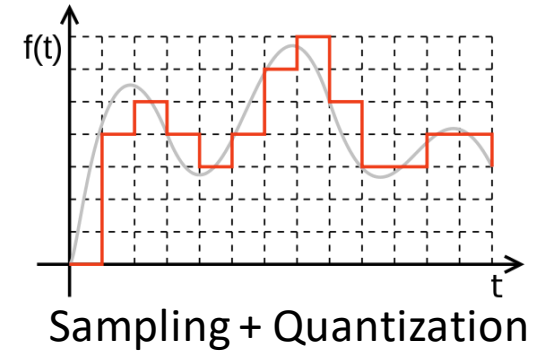
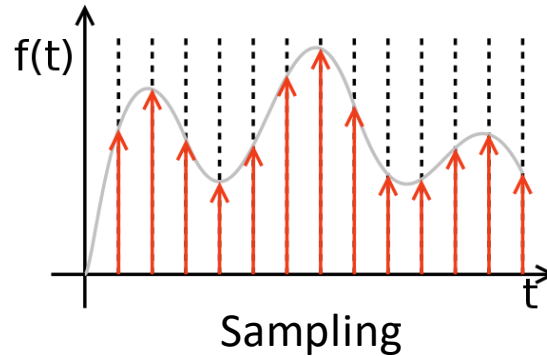
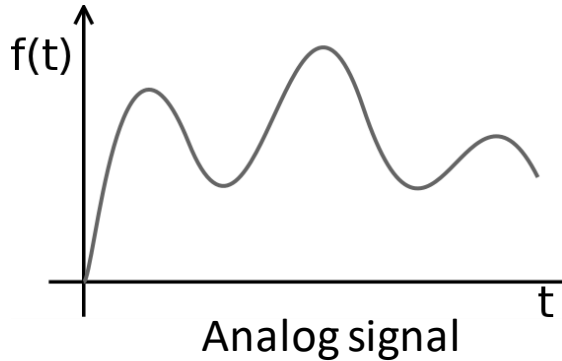
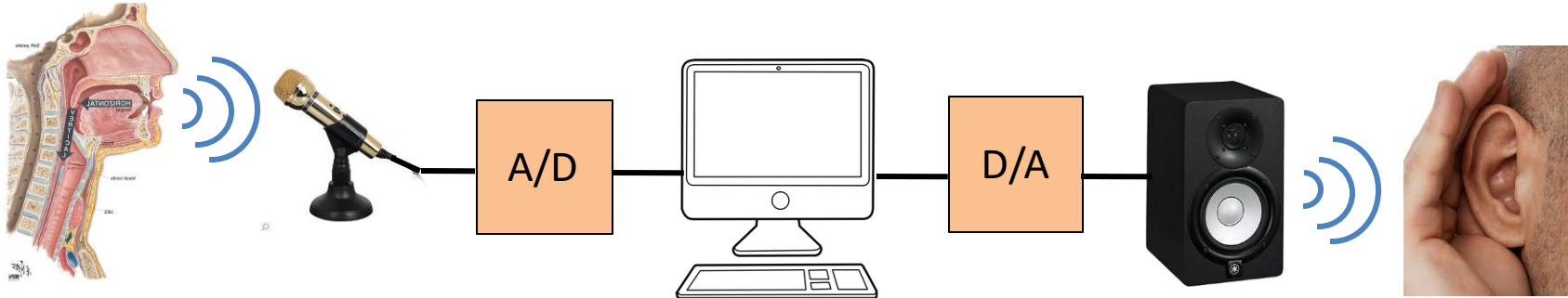
- Digital Image Acquisition
- **Image Sampling and Quantization**
- Fundamental Steps in Image Processing

# Signal

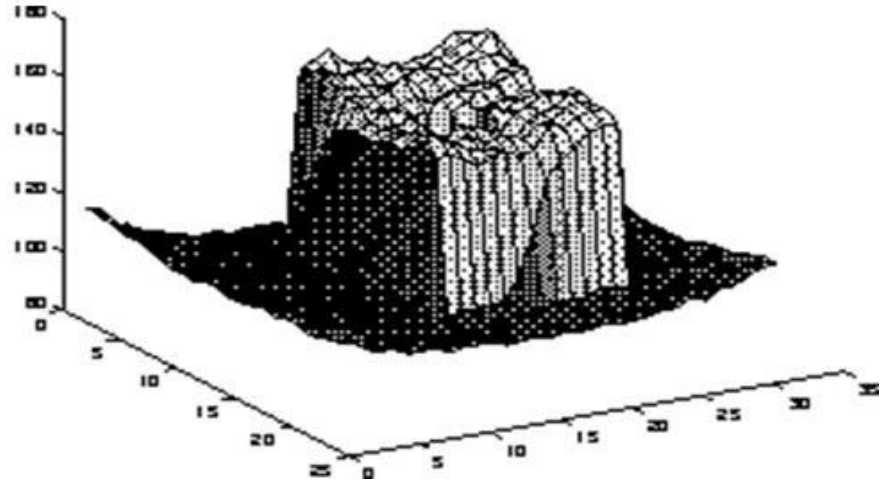
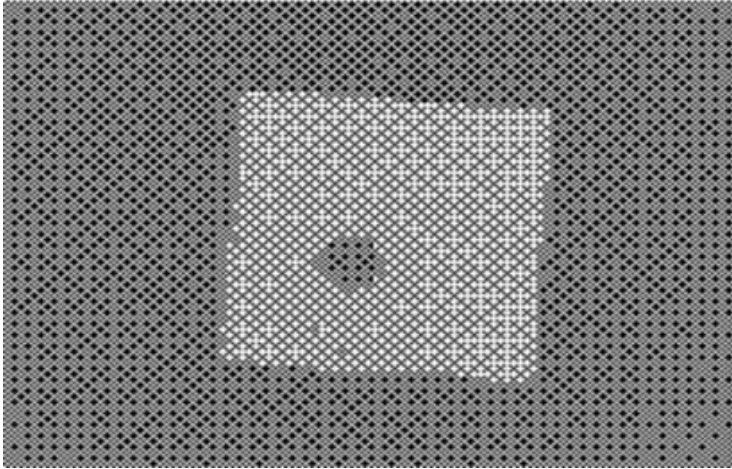
"Function that conveys information about the behavior or attributes of some phenomenon" (wikipedia)



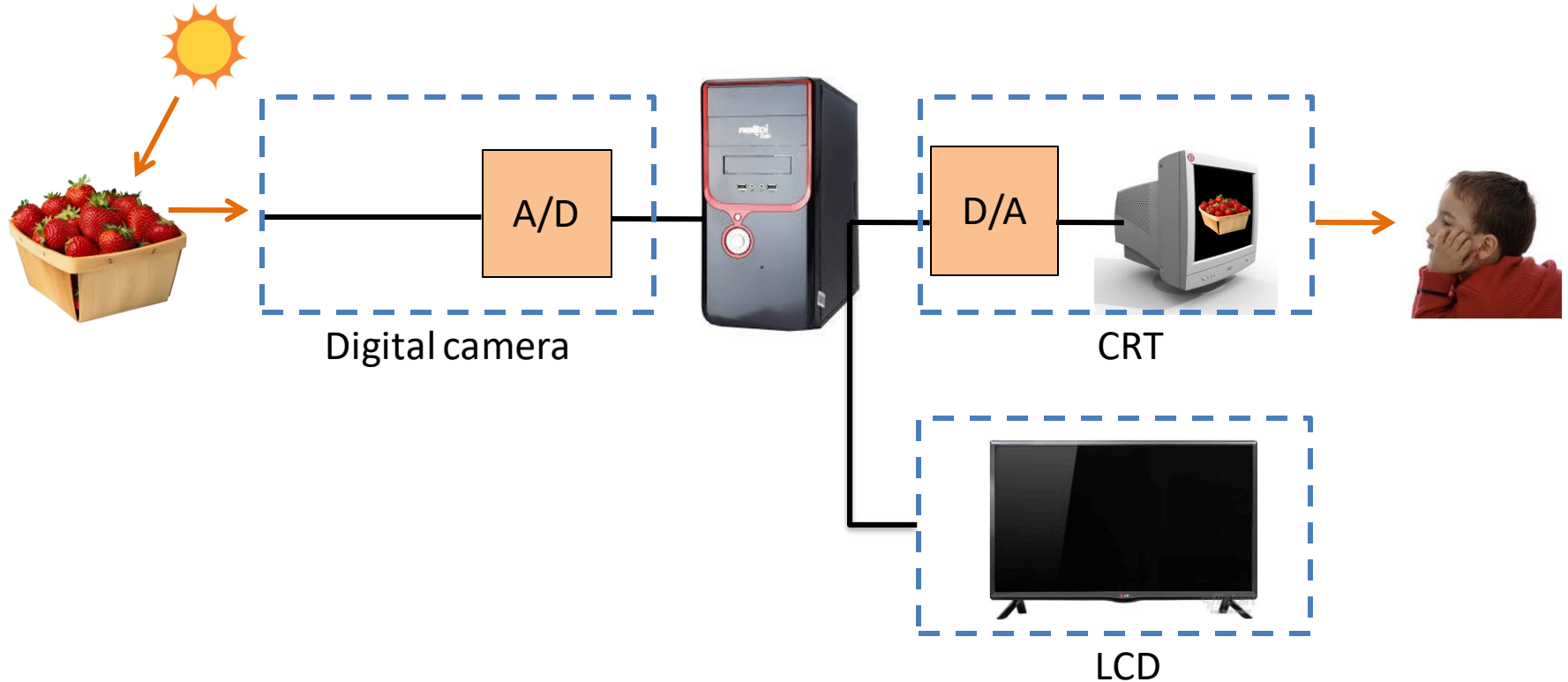
# Analog vs. Digital signal (1-D)



$$\text{Image} = f(x, y)$$

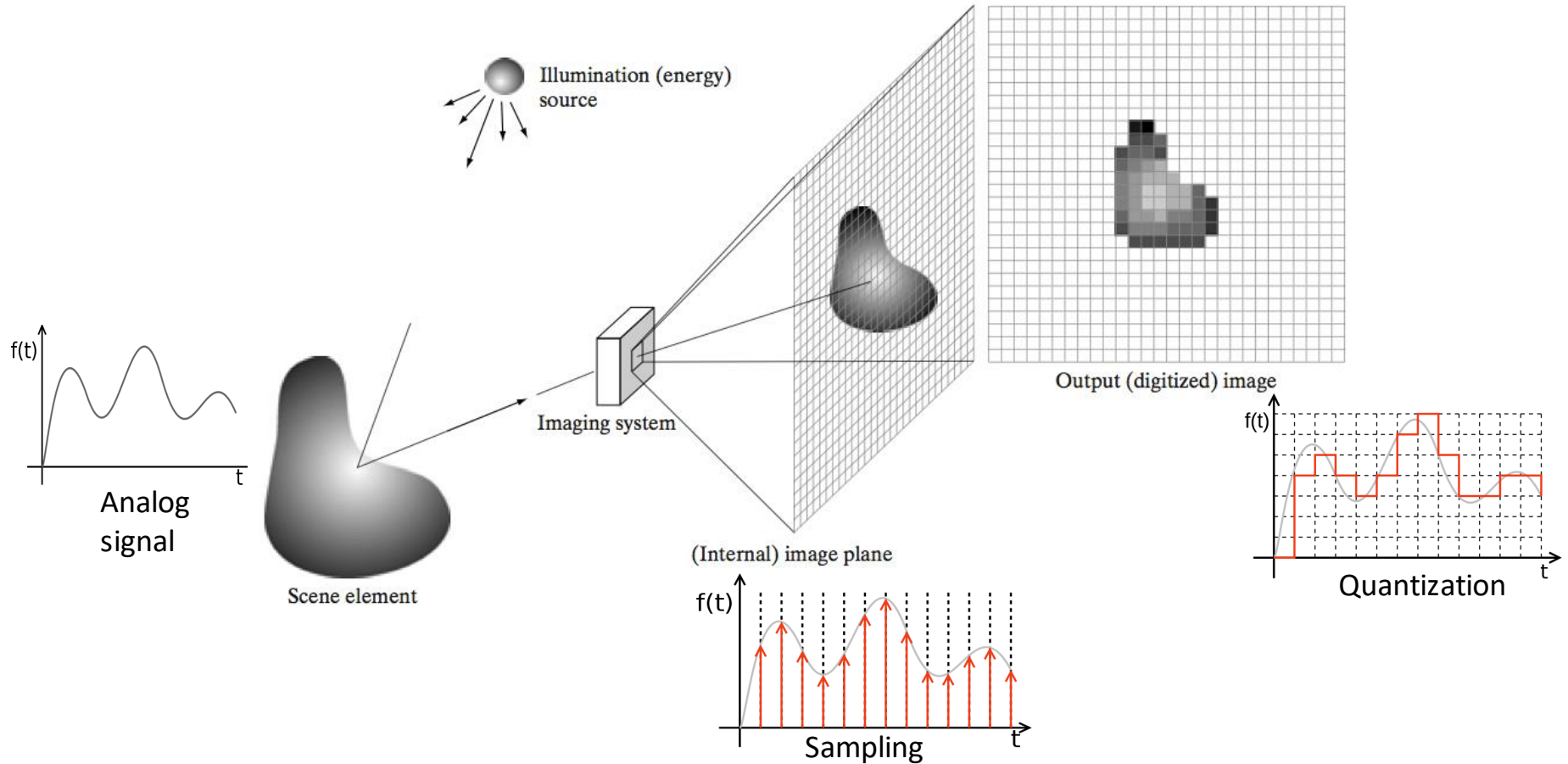


# Analog vs. Digital signal (**2-D signal**)





# Image acquisition process



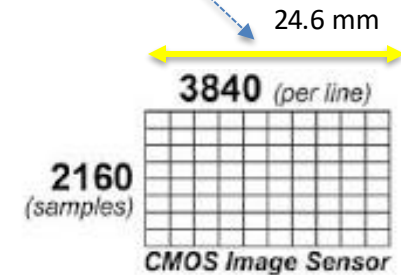
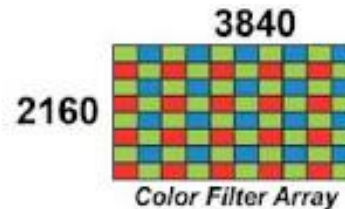
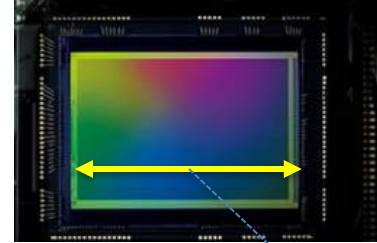
# Cross-section of typical smartphone camera



## 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 $\mu\text{m}$
Pixel pitch	6.4 $\mu\text{m}$
Power supply	3.3v / 1.8v
Power consumption	950mW

Resolution (of the sensor)



## Digital Camera Sensor Sizes



Full Frame Sensor



APS Size Sensor

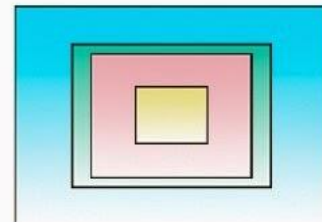


Micro Four Thirds Sensor



Point and Shoot Sensor

Sensor Size Comparison



SONY  
make.believe

$\alpha$

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

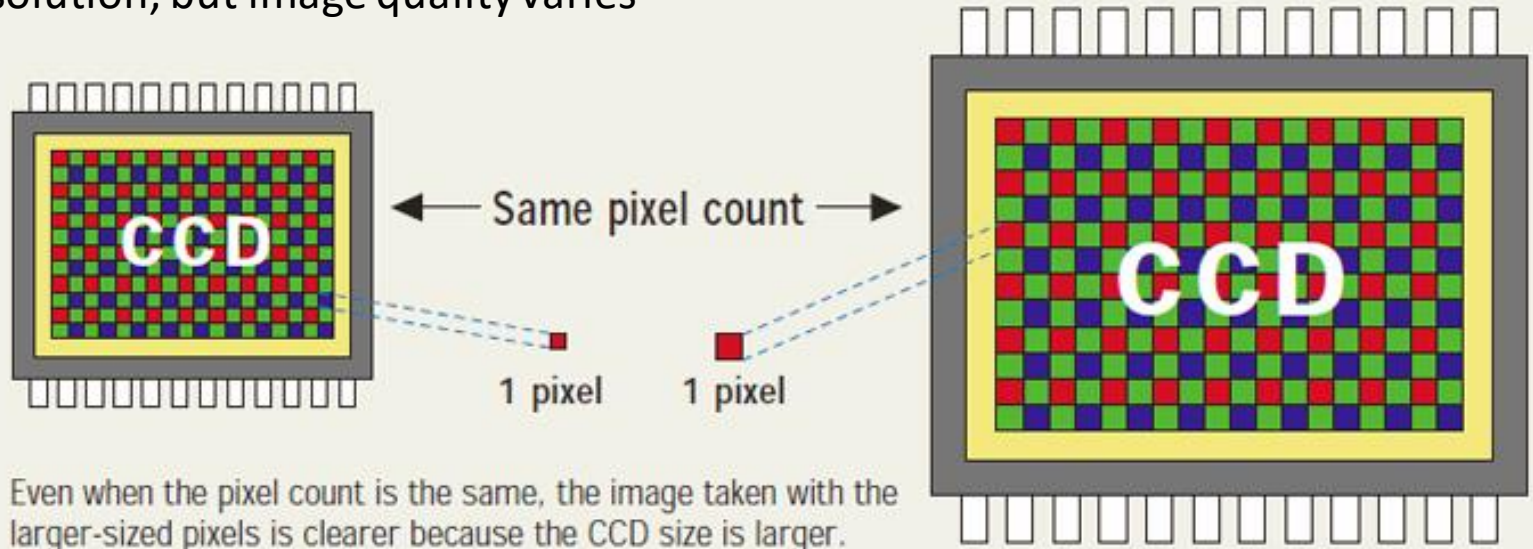
Approximate Size Ratio

PHOTOGRAPHY BAY





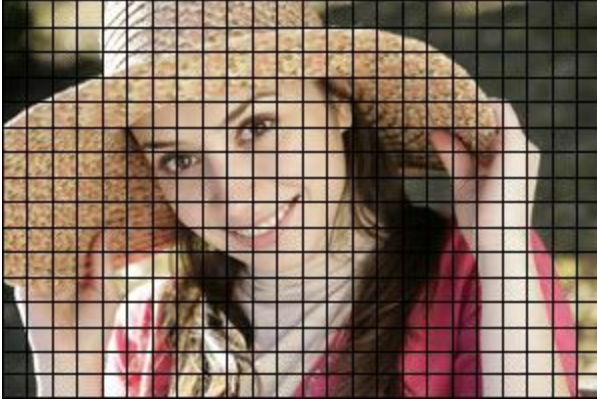
Same resolution, but image quality varies



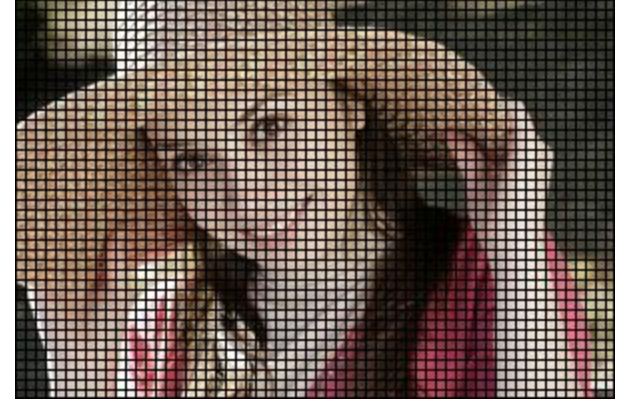
Even when the pixel count is the same, the image taken with the larger-sized pixels is clearer because the CCD size is larger.



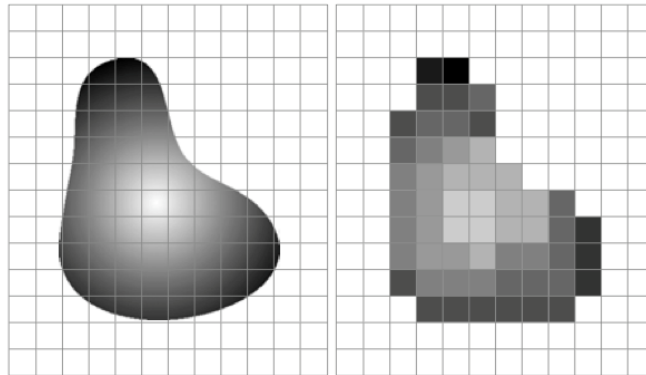
Same sensor size, but # of sensor pixels/mm varies



**Small number of CCD pixels**



**Large number of CCD pixels**



# Sampling – Spatial Quantization



$256 \times 256$



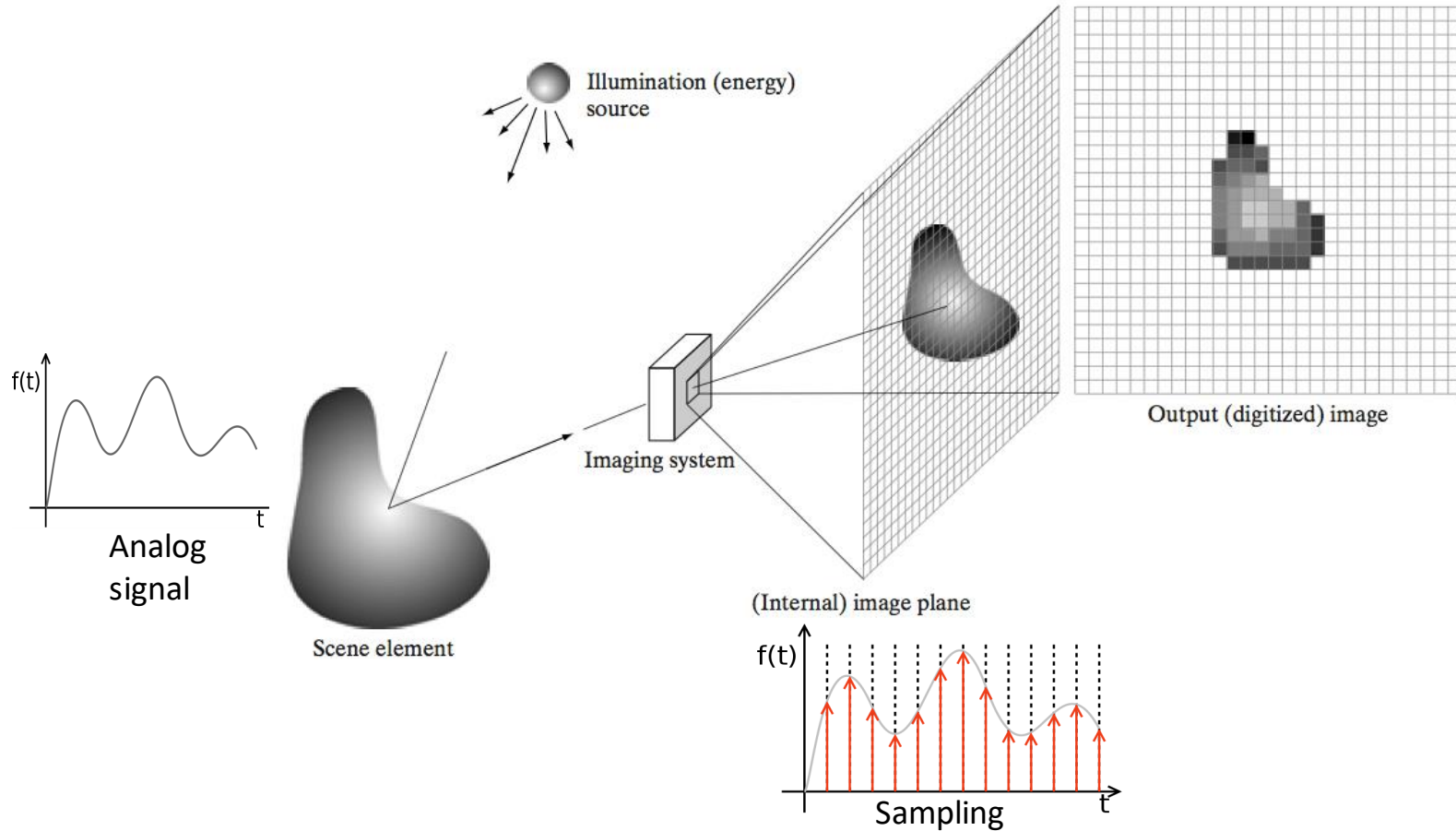
$32 \times 32$



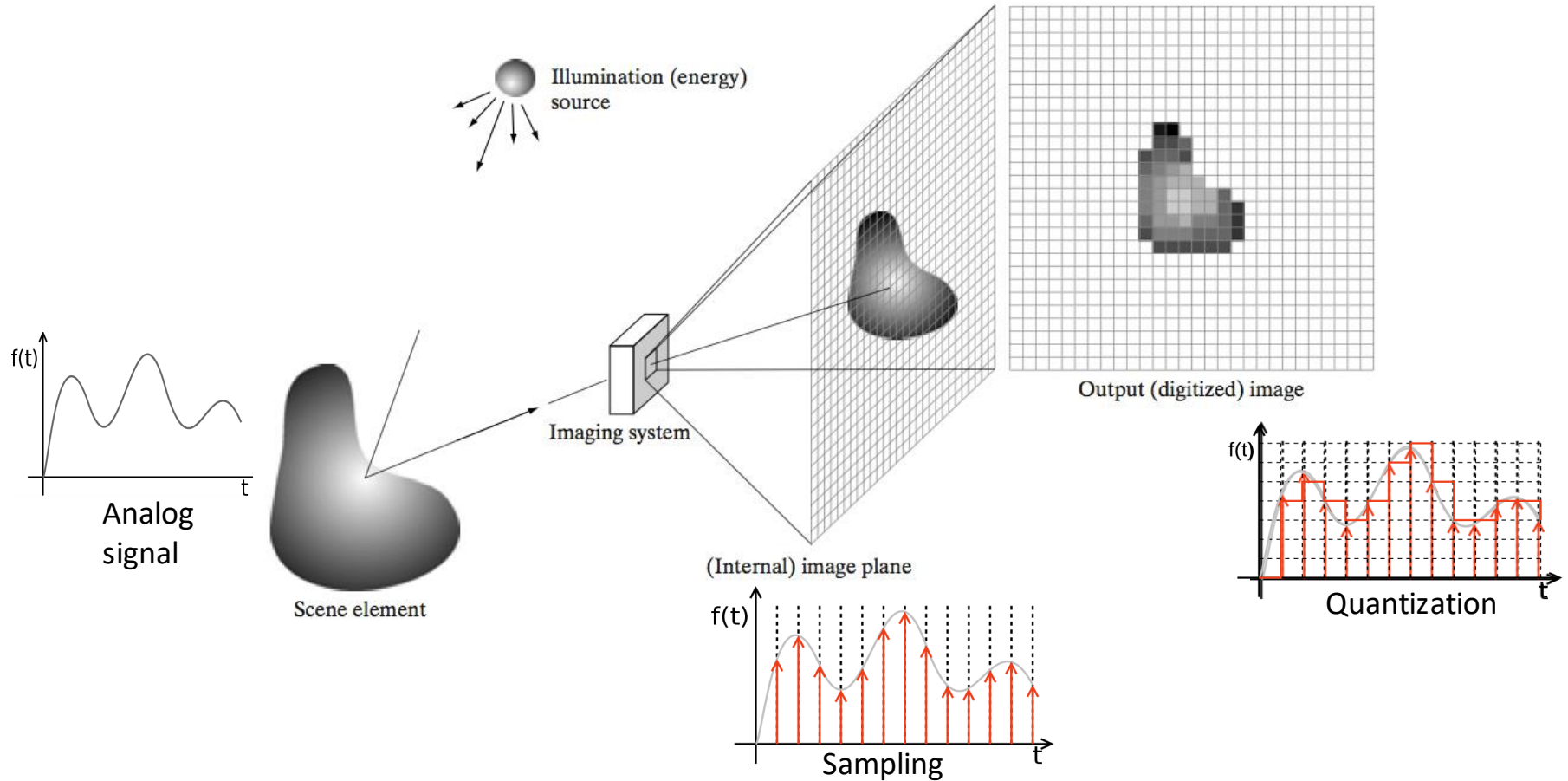
$16 \times 16$



# Image acquisition process



# Image acquisition process



# Intensity Quantization



8 bits per pixel



4 bits per pixel

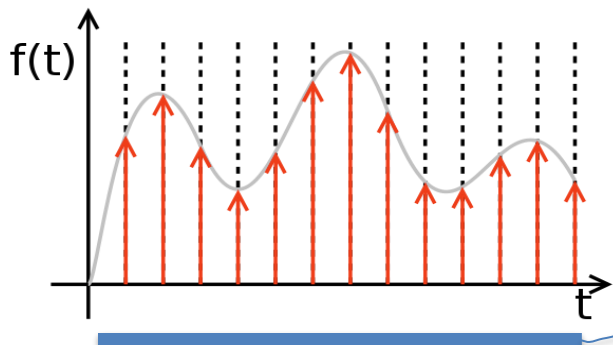


2 bits per pixel



1 bit per pixel

# Summary



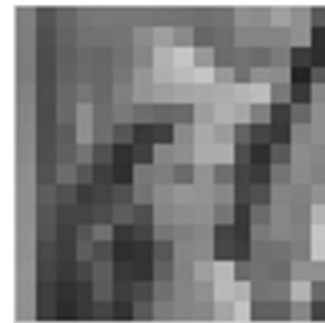
Sampling



256 × 256

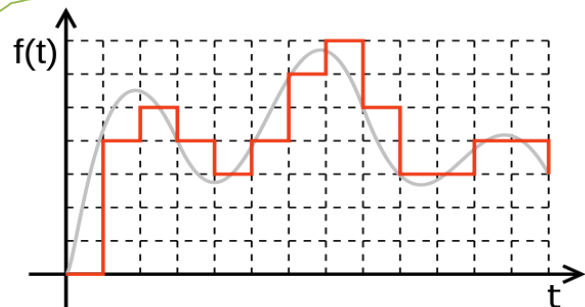


32 × 32



16 × 16

Quantization



8 bits per pixel



4 bits per pixel

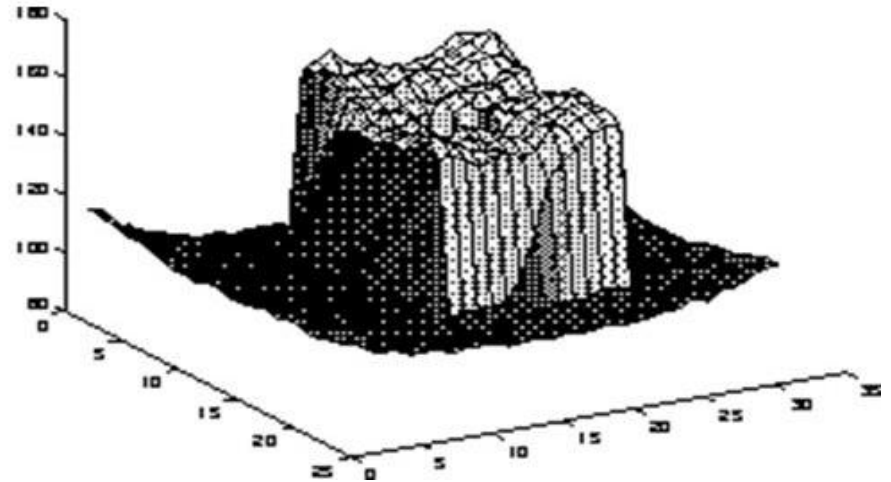
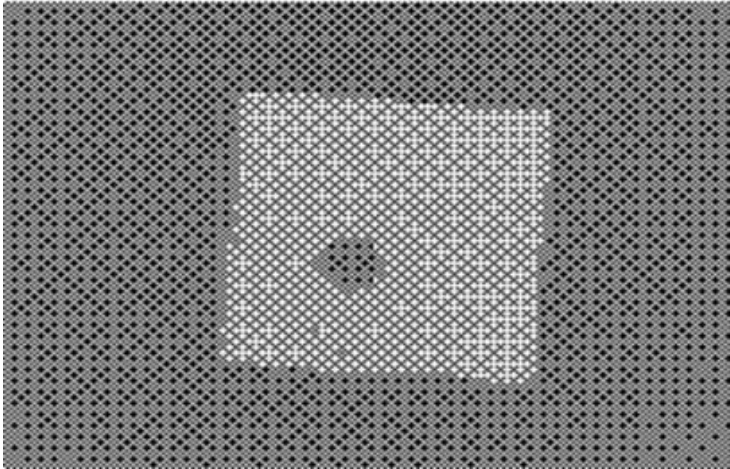


2 bits per pixel

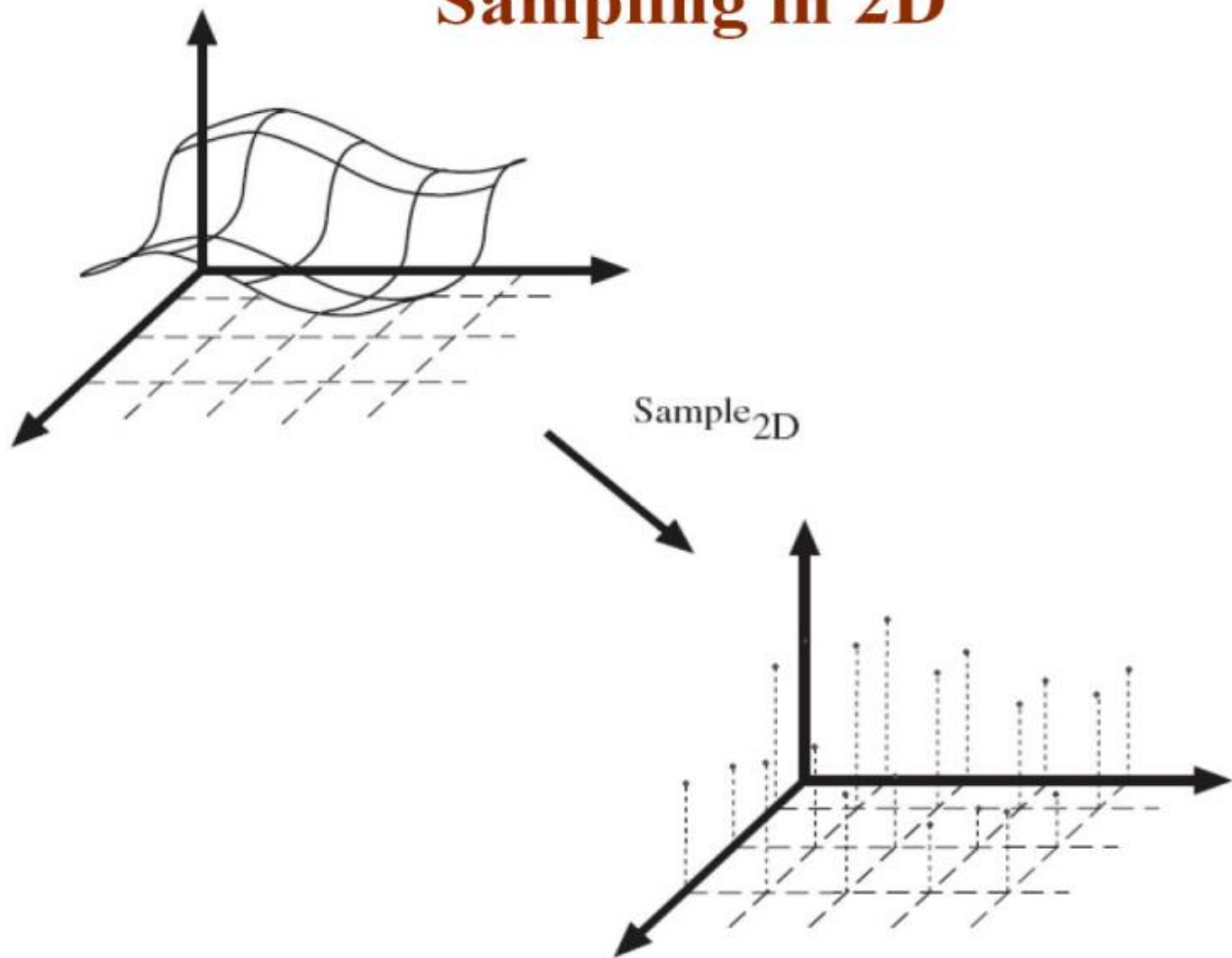


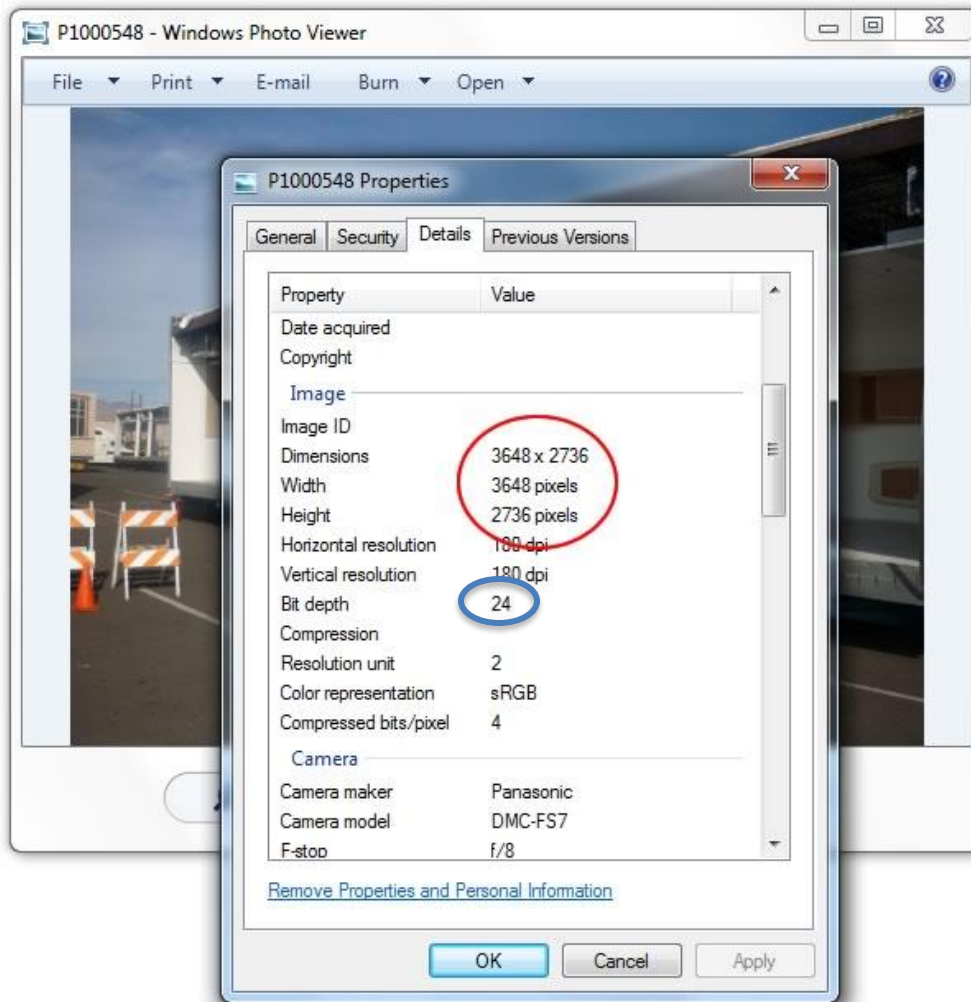
1 bit per pixel

# Image as a 3D surface



# Sampling in 2D





# Additional Notes on Sampling and Quantization

- Temporal sampling  $\rightarrow$  exposure time



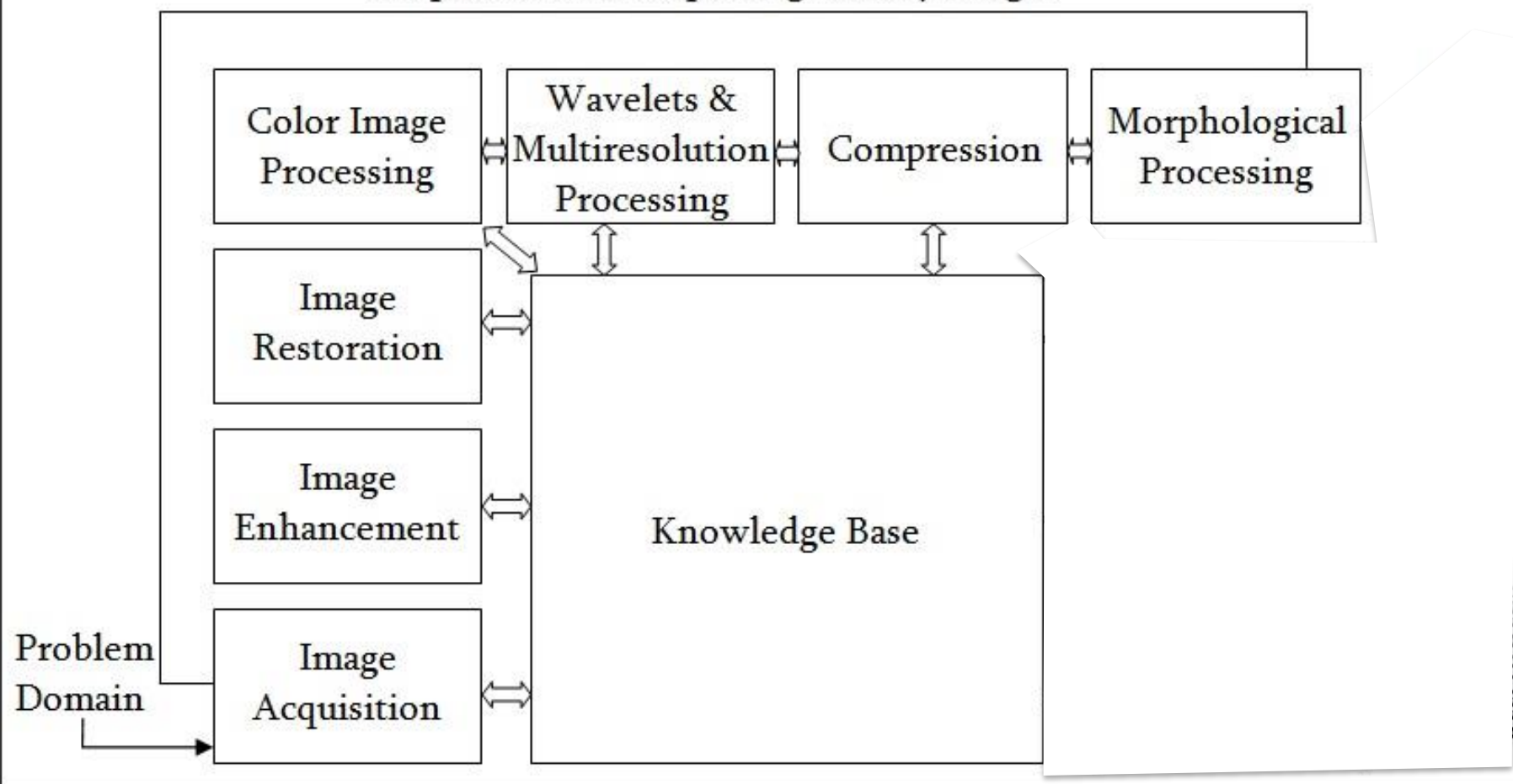


# Quantization

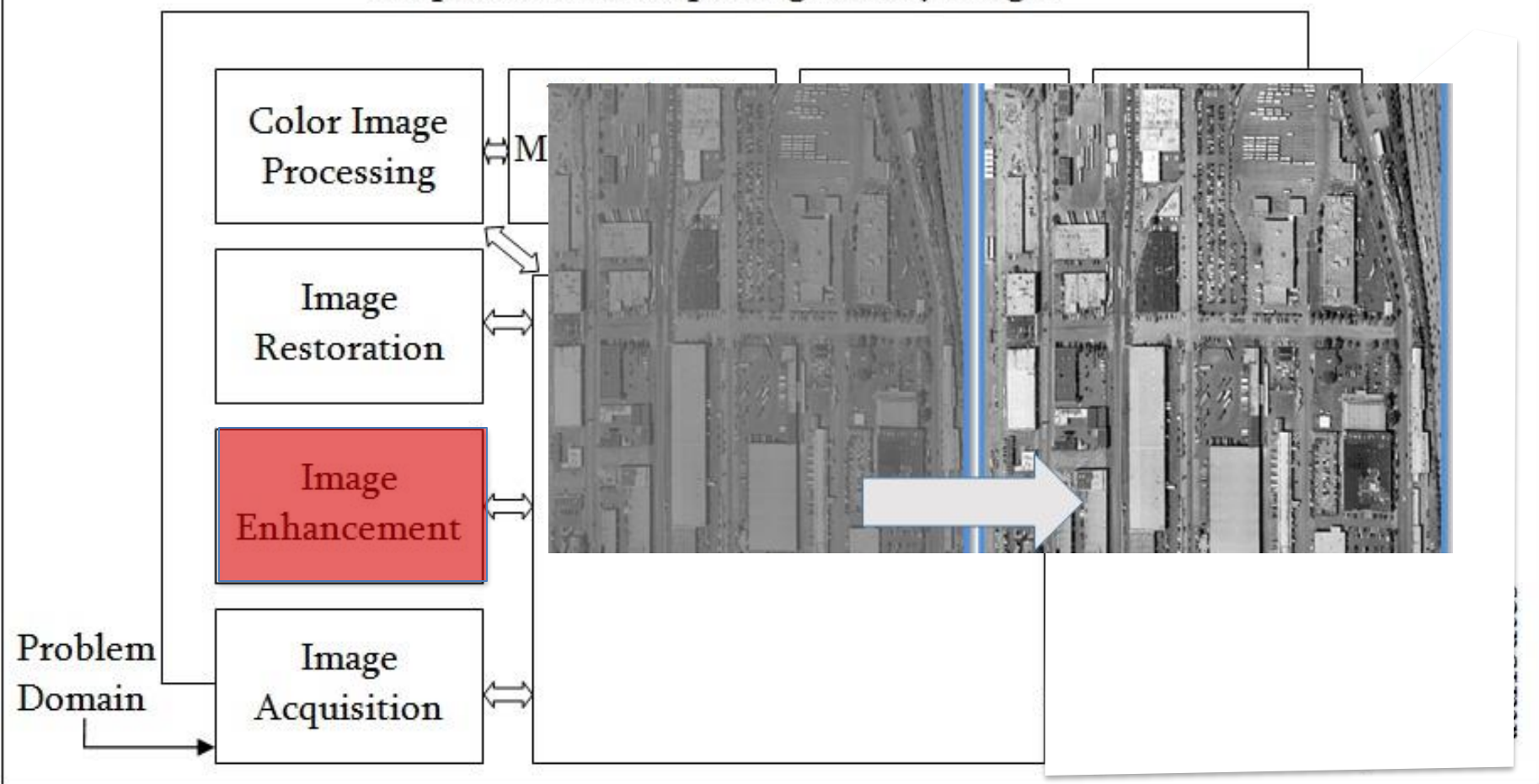
- Hardware (# of voltage levels, # of bits)
- Software (raw → JPEG)

- Digital Image Acquisition
- Image Sampling and Quantization
- **Fundamental Steps in Image Processing**

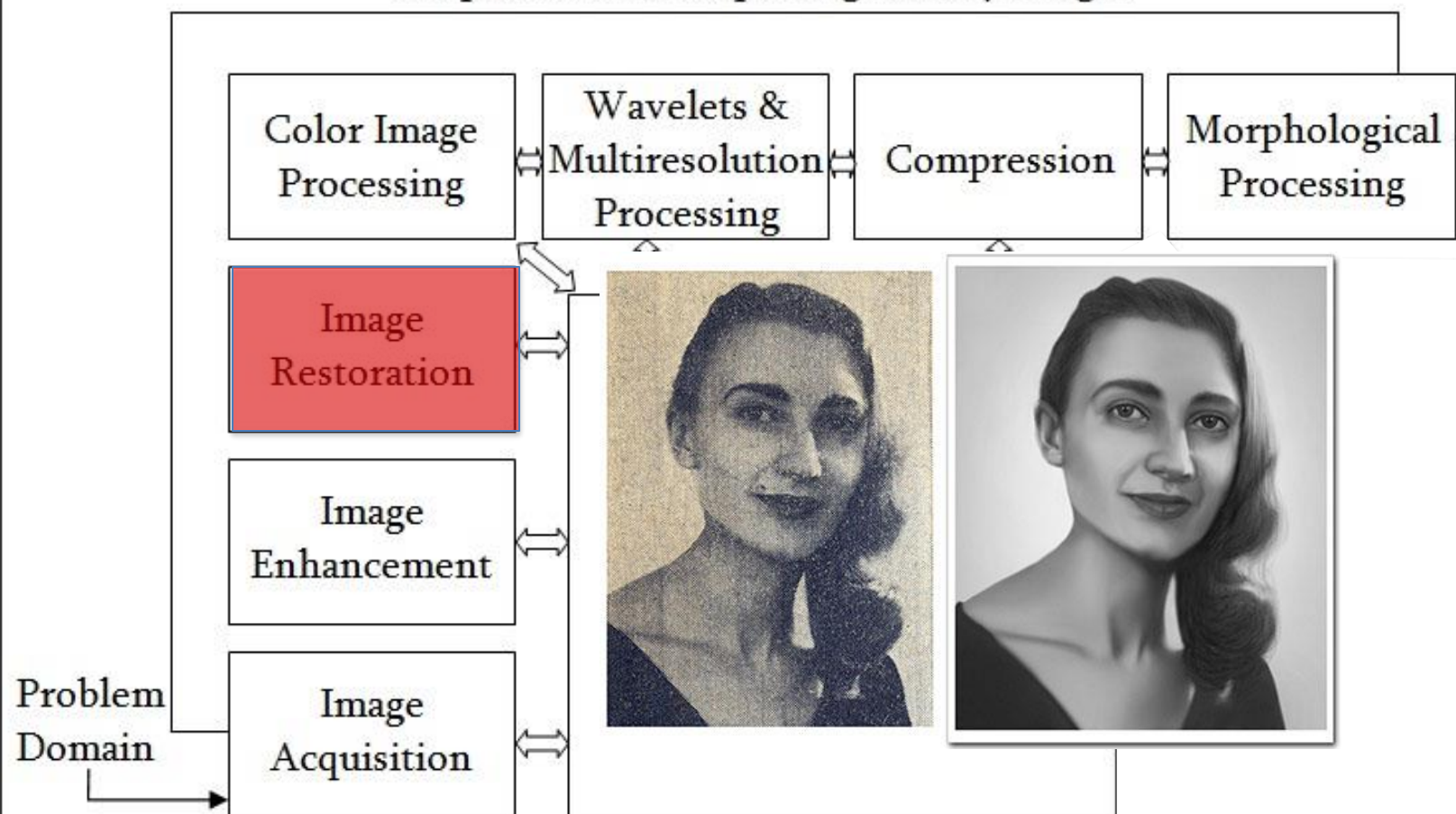
Outputs of these steps are generally images



Outputs of these steps are generally images



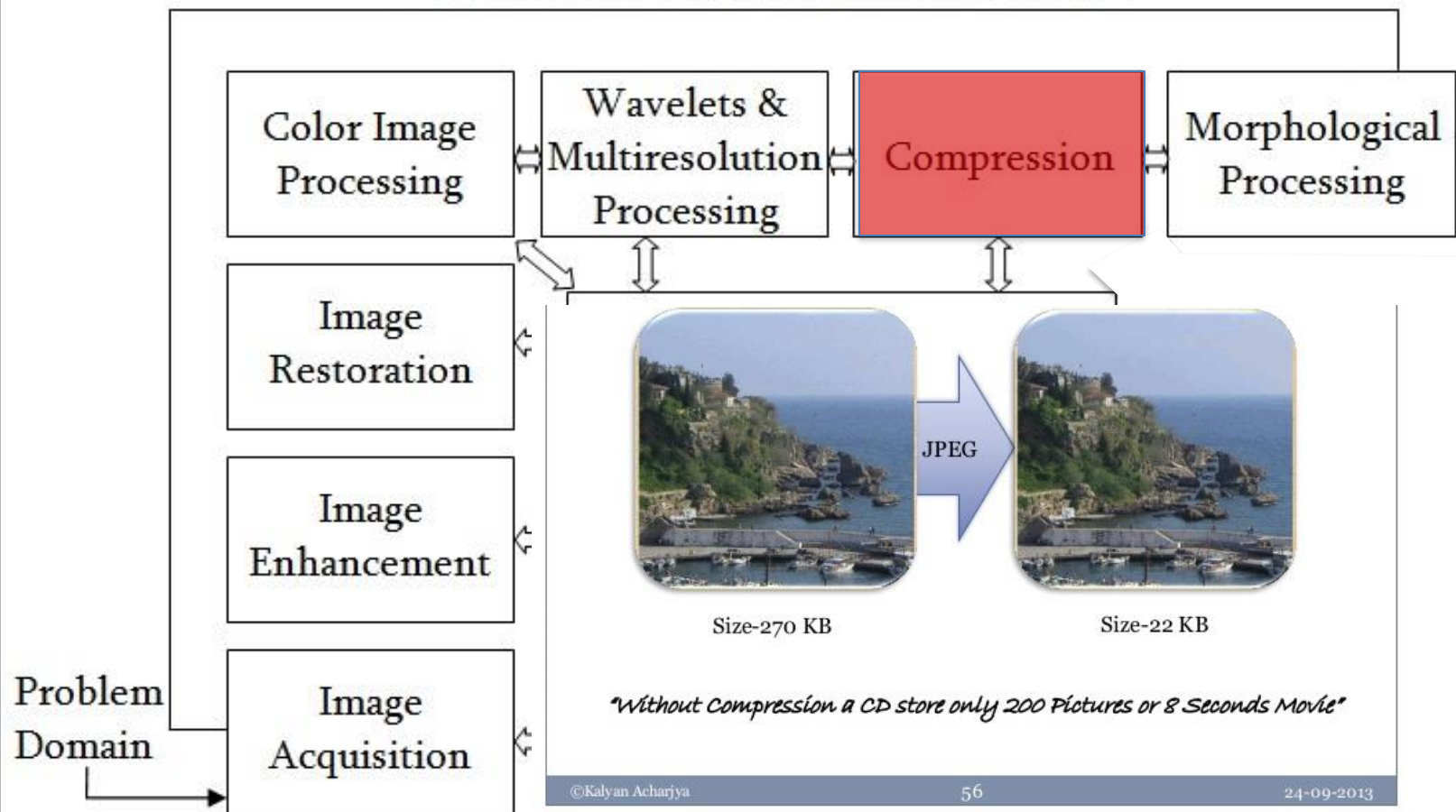
Outputs of these steps are generally images



Outputs of these steps are generally images

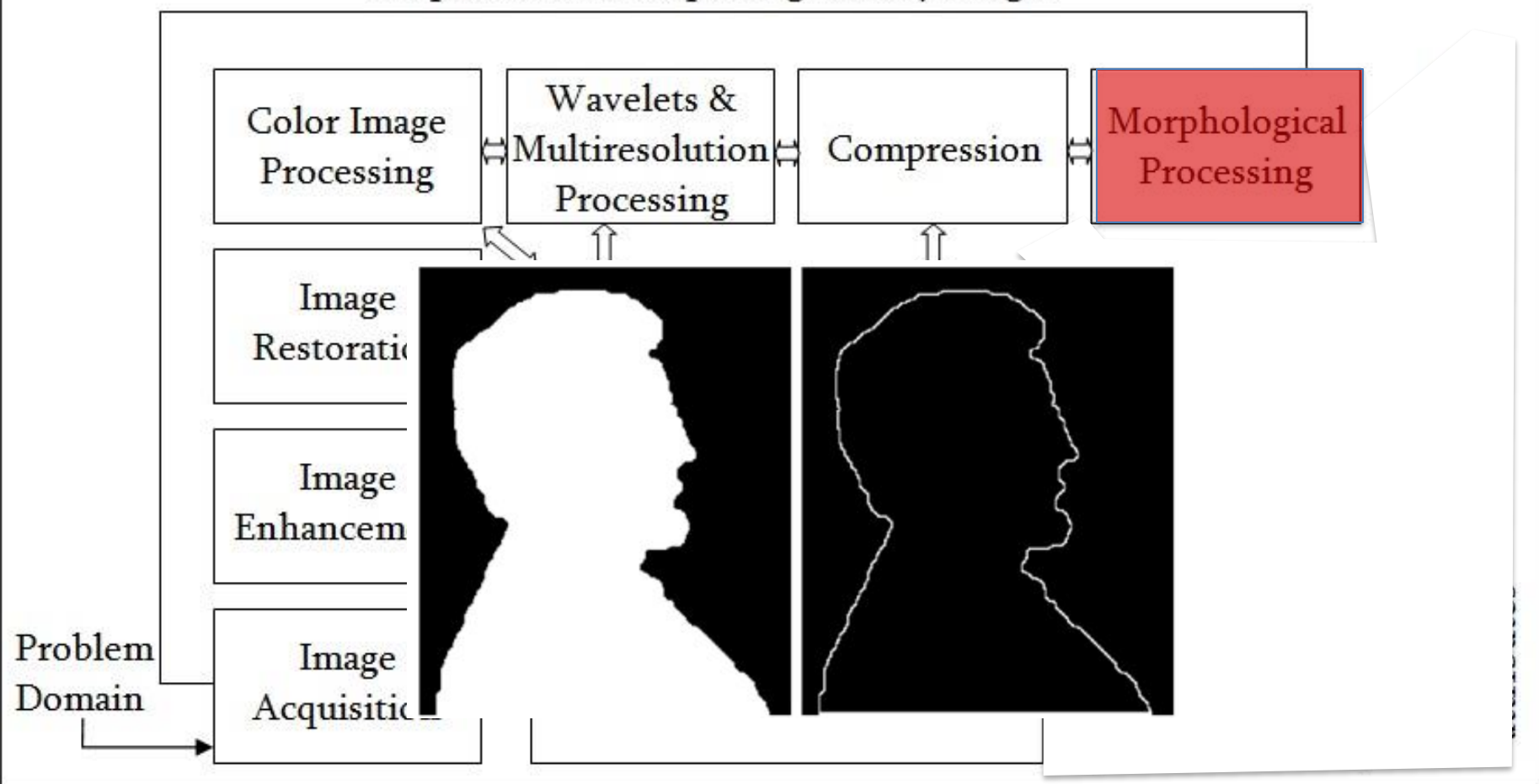


Outputs of these steps are generally images



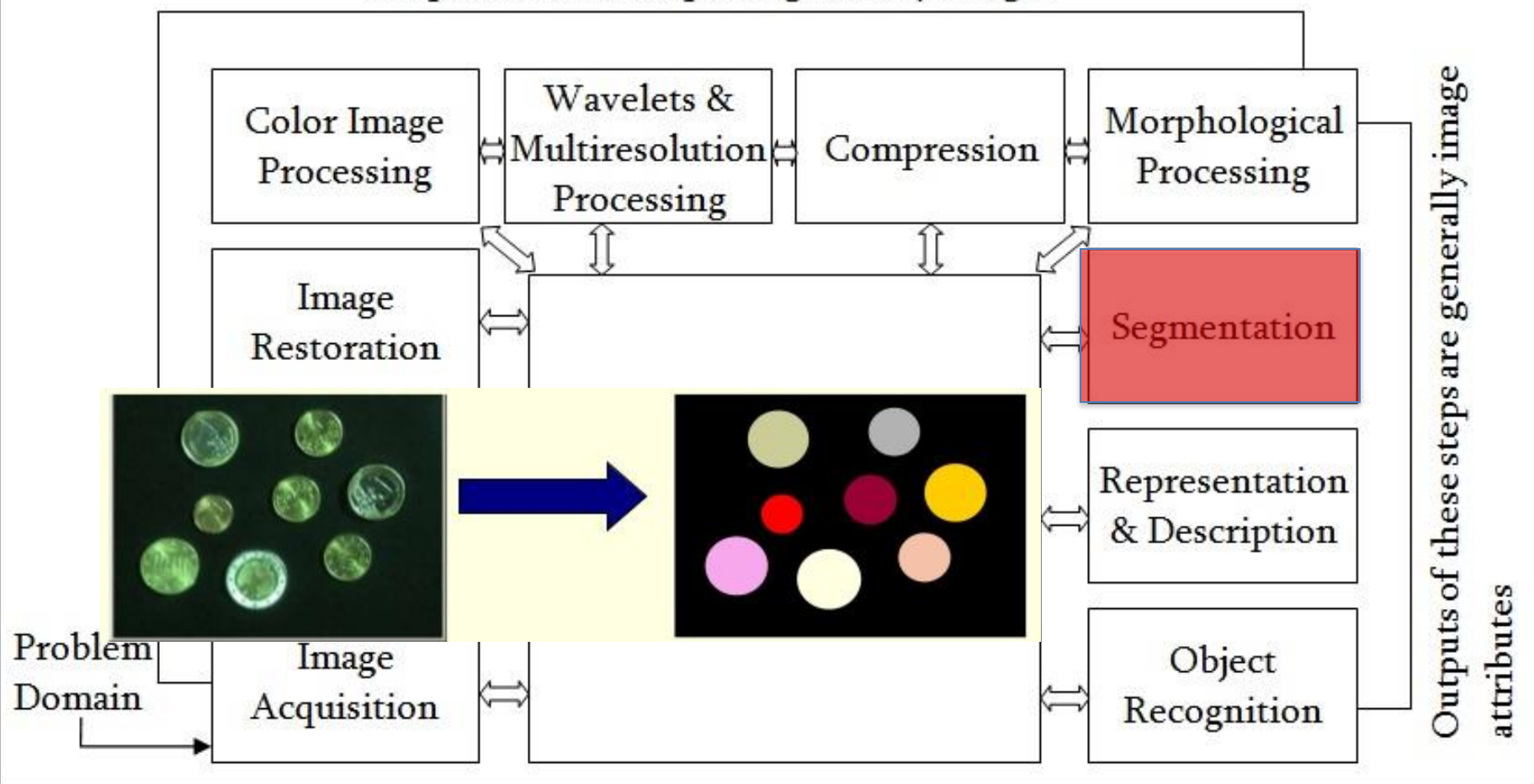


Outputs of these steps are generally images

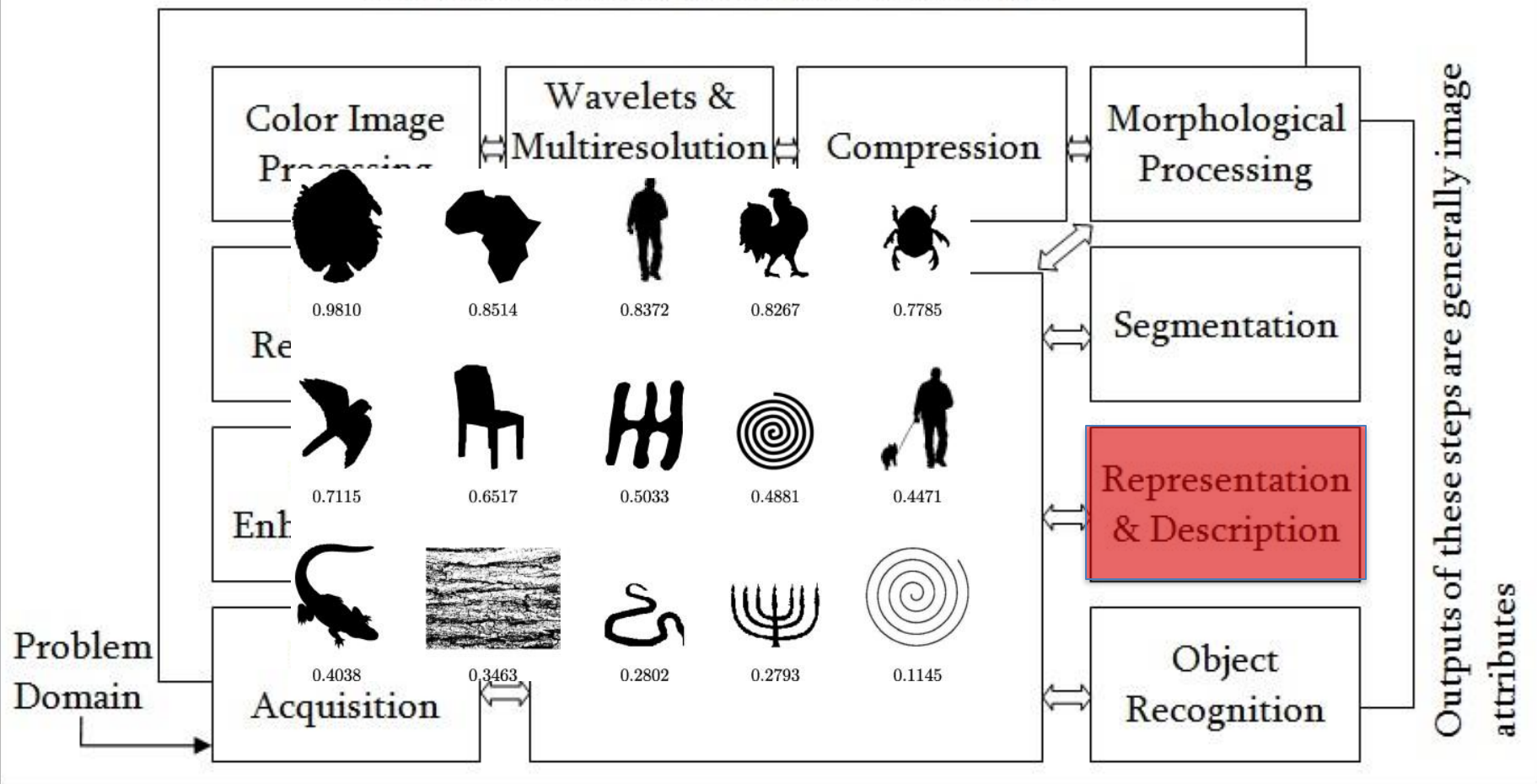




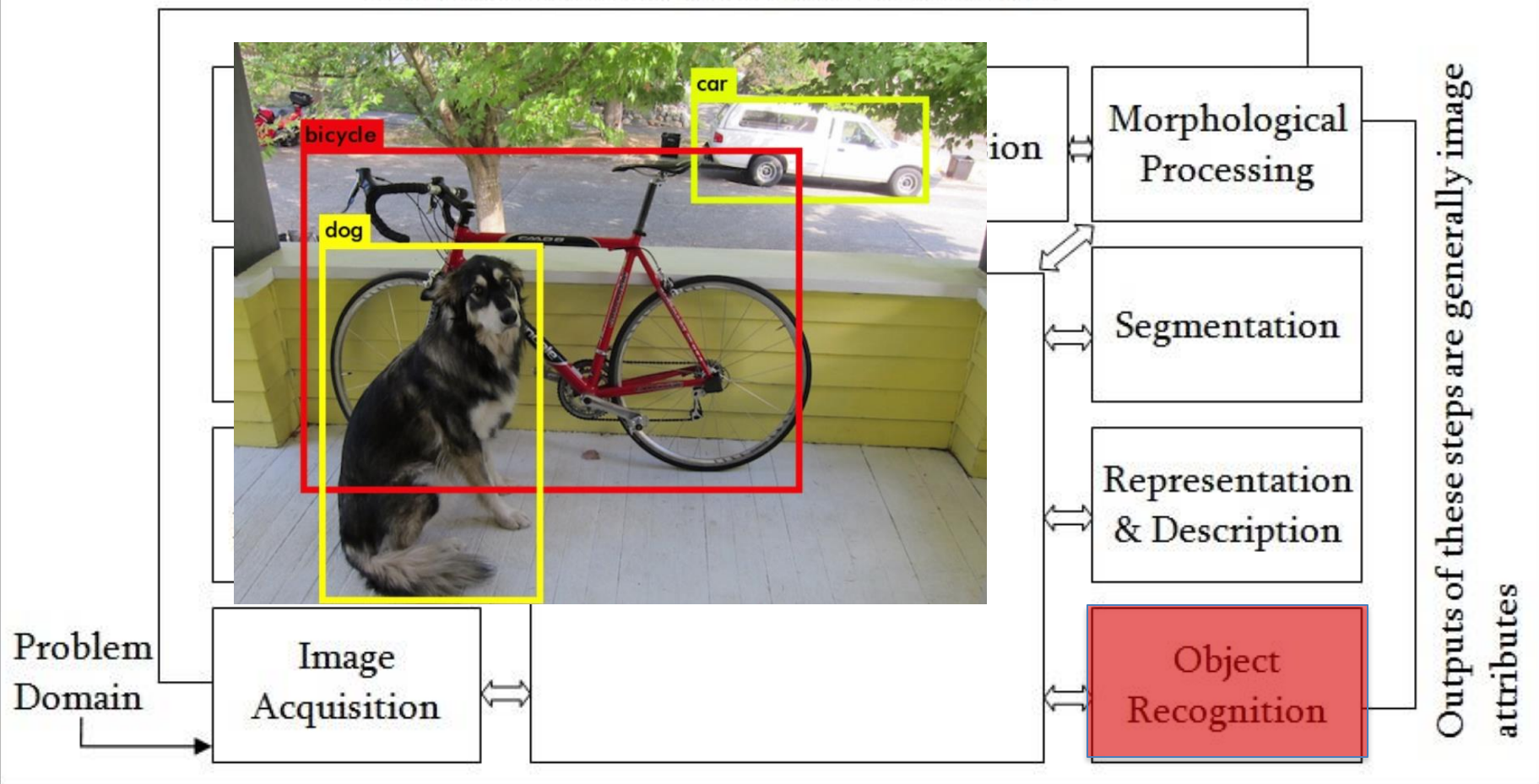
Outputs of these steps are generally images



Outputs of these steps are generally images

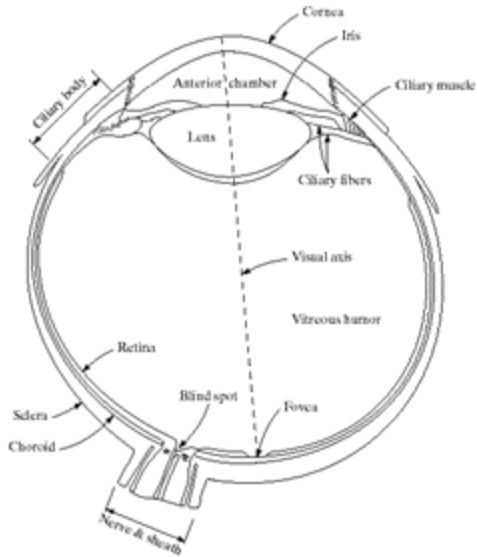


Outputs of these steps are generally images



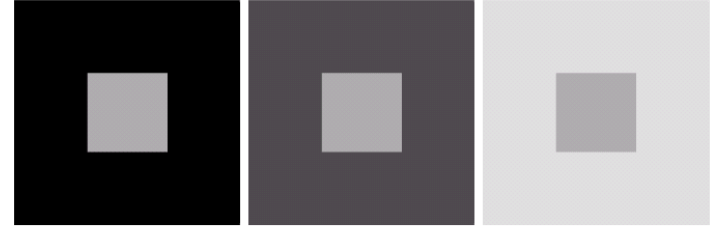
# What we saw today

## Human Eye



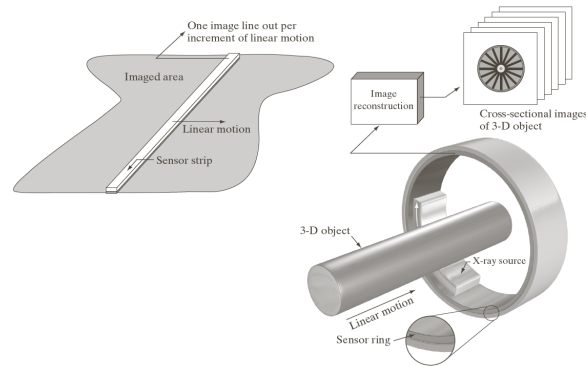
**FIGURE 2.1**  
Simplified  
diagram of a cross  
section of the  
human eye.

## Brightness adaptation & Psychovisual effects



a b c

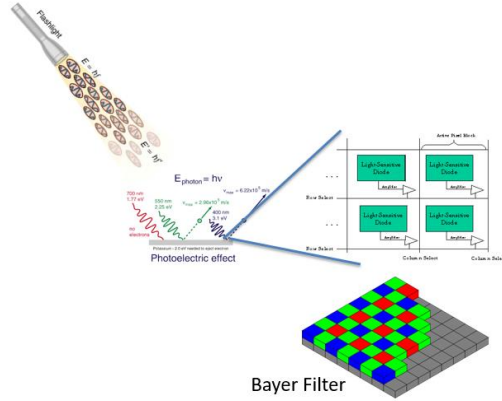
**FIGURE 2.8** Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.



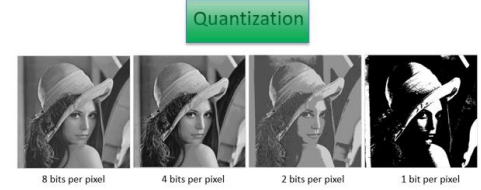
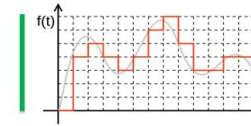
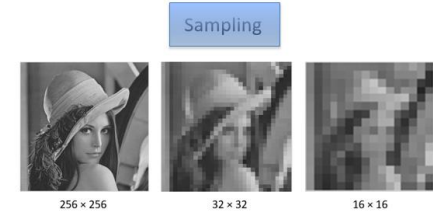
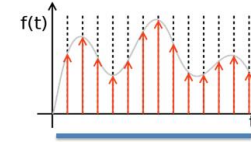
## Image Sensing and Acquisition

# What we saw today

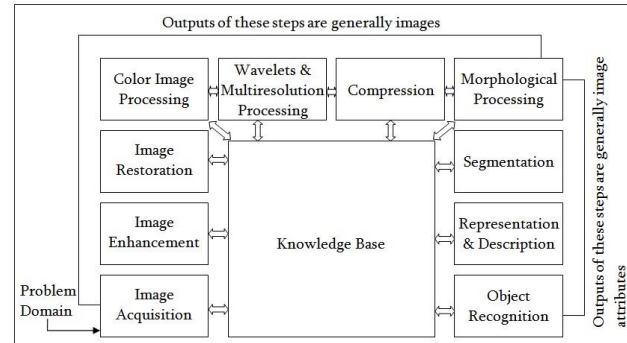
## Digital Image Acquisition



## Sampling and Quantization

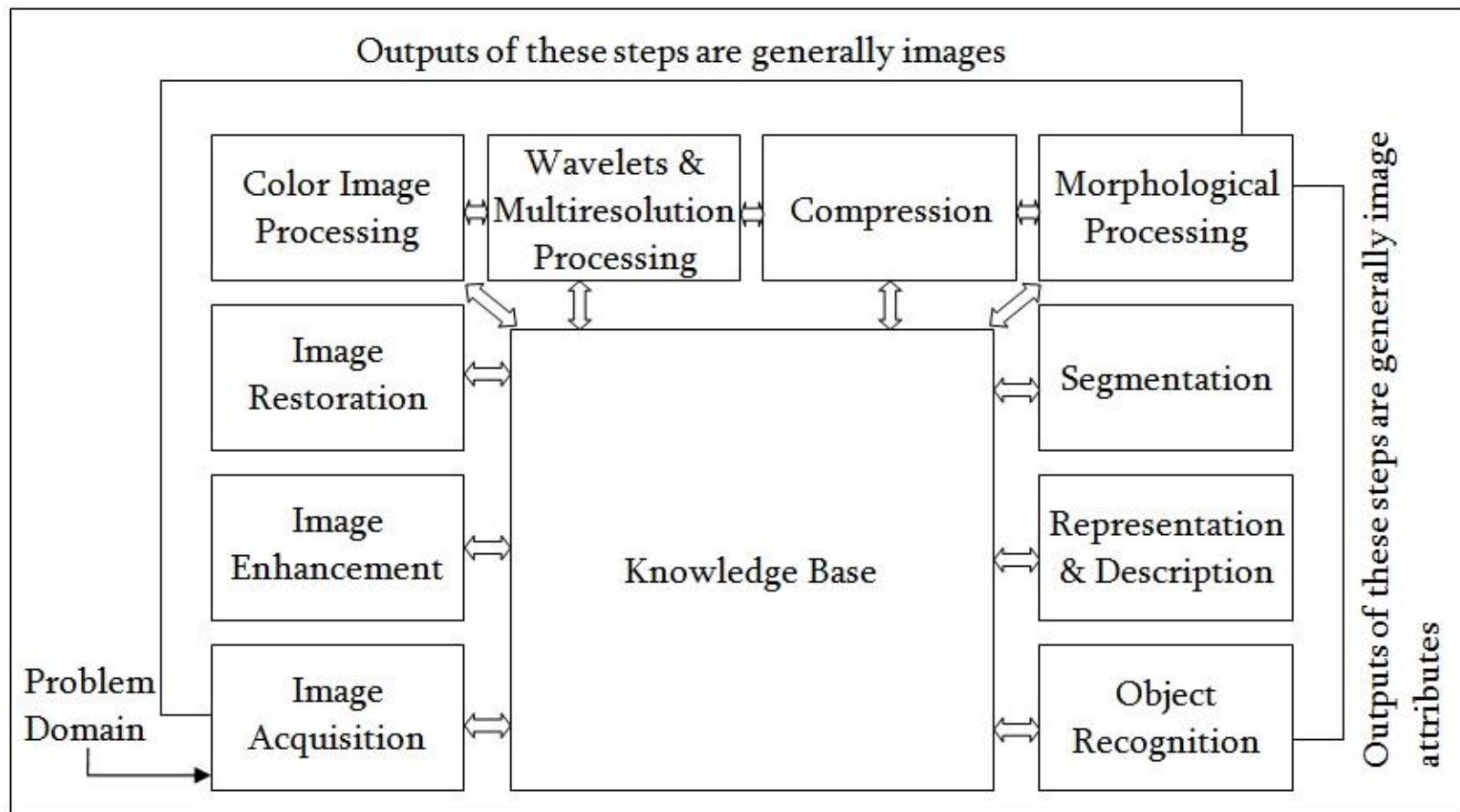


### Demoisaicing



## Fundamental Steps in Image Processing

# What we saw today



# References

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