Introduction to Digital Image Processing
CENG 503

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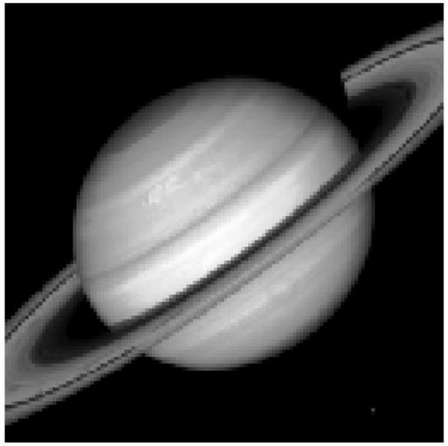
Outline

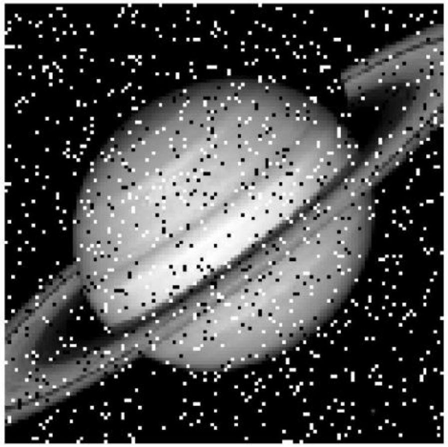
- Image processing applications
- Image formation process
- Sampling and Quantization
- Basic relationships between pixels

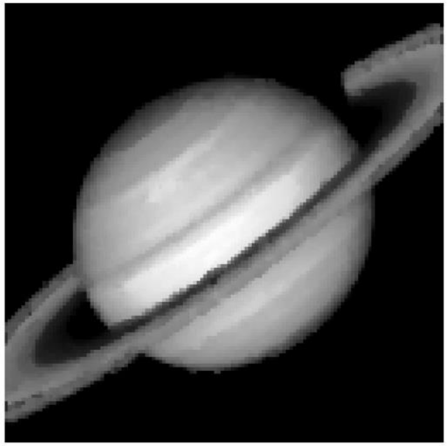
Applications

- Image processing has numerous applications in industry, medicine, military, etc.
- Processed images are more suitable for human or machine use.

Examples: Image Correction







- Needed when image data is erroneous:
  - Bad transmission
  - Some bits are missing: *Salt & Pepper Noise*

Image Deblurring: Motion Blur

- Can be used when camera moved during exposure!

Deblurring

Original Image

Blurred Image

Deblurred Image

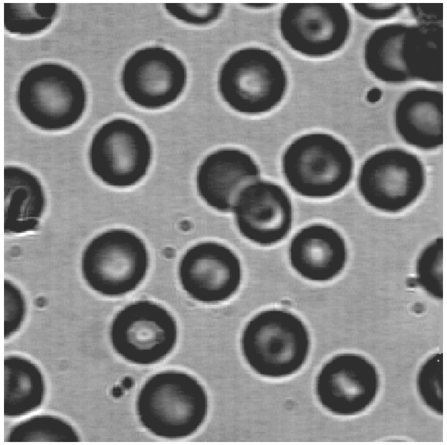
- Can be used when the camera was not focused properly!!

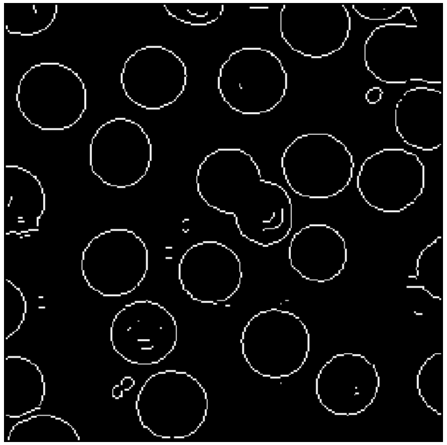
Image manipulation

- Image improvement, e.g. too dark image

- Rotate + scale

Medical Image Processing





- Image Processing becomes widely used in medicine
- E.g. Analysis of microscopic images

Medical Image Processing

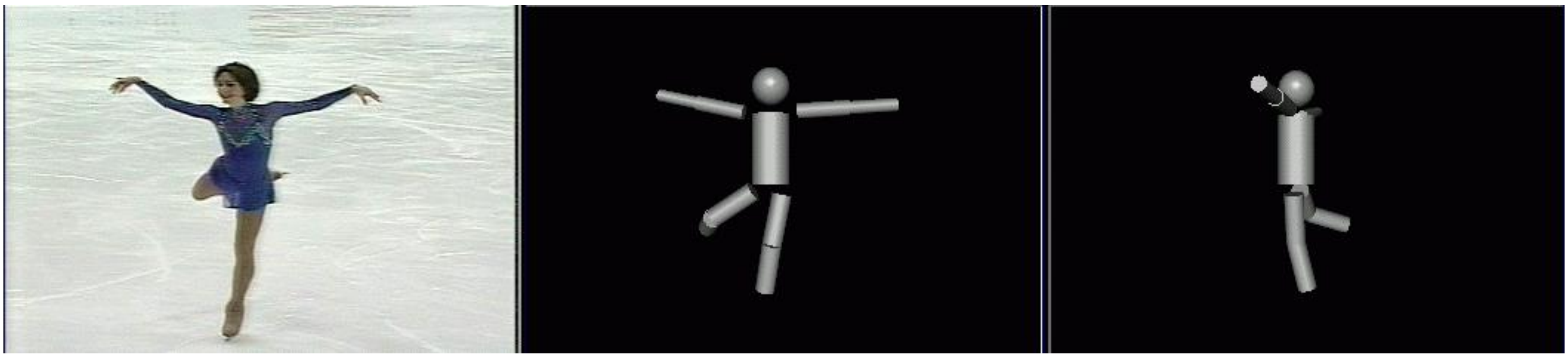
- MR/CT Imaging of a human body
- Used for Brain Surgery

Conveyer belt applications

- Checking and sorting
  - For example: checking bottles in the supermarket
- Quality control
  - Does the object have the correct dimensions, color, shape, etc.?
  - Is the object broken?
- Robot control
  - Find precise location of the object to be picked

Chroma keying

Analysis of Sport Motions



- 3D Tracking of body parts
- Motion interpretation
- Action recognition, Identification (Surveillance)

Image formation process

Image Formation in Man and Machine

- Computer Vision Systems try to mimic Human Visual System. Therefore a comparative study of both is necessary
- Besides, images may be perceived very differently in our visual system. Therefore, humans and computers may interpret an image very differently

Where does an image come from?

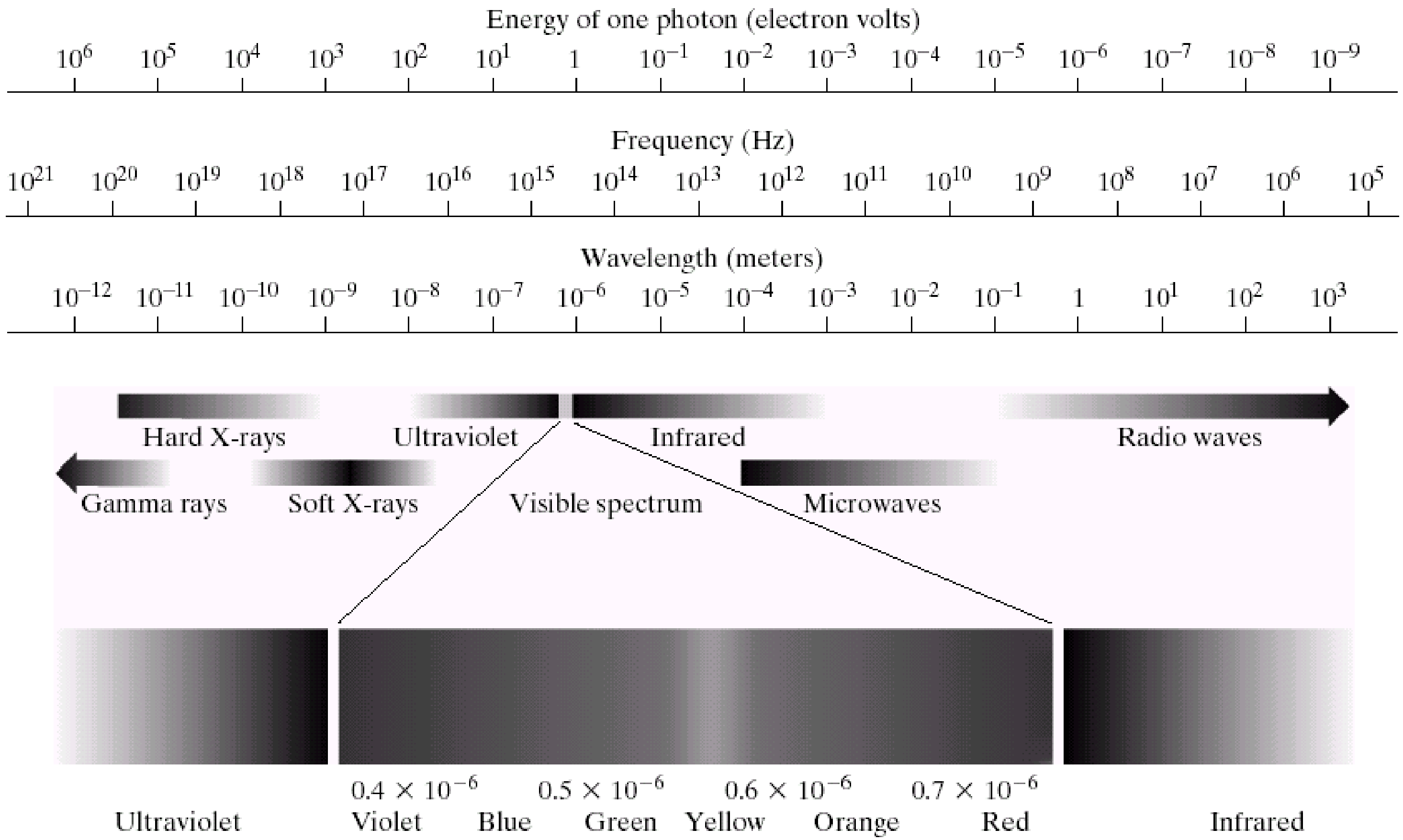
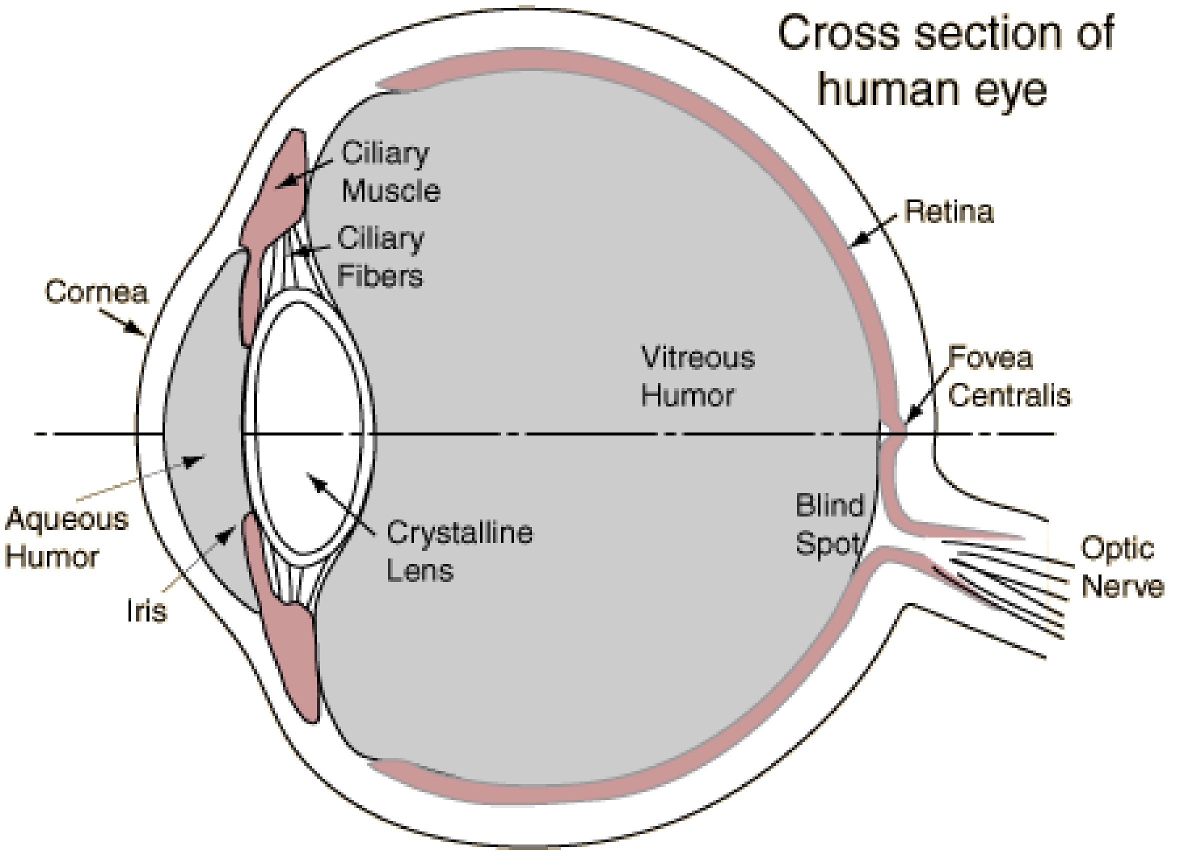


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Human Eye (1)


Cross section of
human eye
Ciliary
Muscle
Ciliary
Fibers
Cornea
Retina
Vitreous
Humor
Fovea
Centralis
Aqueous
Humor
Iris
Crystalline
Lens
Blind
Spot
Optic
Nerve

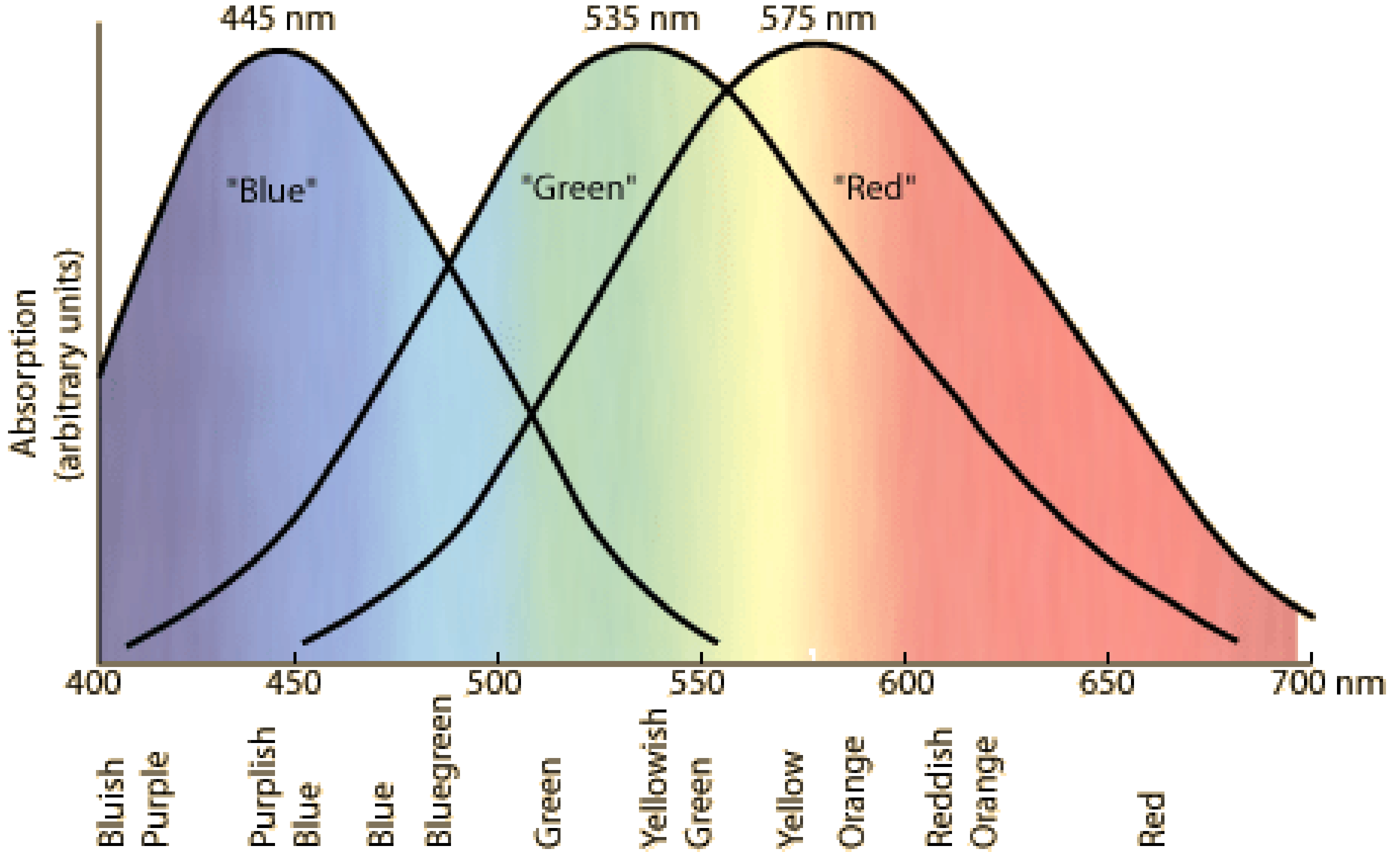
Human Eye (2)

- The retina contains two types of photoreceptors, rods and cones.
- The rods are more numerous, some 120 million, and are more sensitive than the cones. However, they are not sensitive to color.
- The 6 to 7 million cones provide the eye's color sensitivity and they are mostly concentrated in the central yellow spot known as the macula.
- In the center of that region is the " fovea centralis ", a 0.3 mm diameter rod-free area with very thin, densely packed cones.

Human Eye (3)

- Rod photoreceptors are more active under dark circumstances. But as rods cannot discriminate colors, we perceive only shades of grey. We call this *scotopic* or night vision.
- Cone photoreceptors are most active at brightness, and we experience *photopic* or day vision.
- In dim light there is an intermediate stage where both rods and cones are active This is called *mesopic* vision.

Color-Sensitive Cones



Reflectivity

- Images are created by sensing the reflected light from the objects.
- The reflected light is found from

$$I(\lambda) = \rho(\lambda)\ E(\lambda)$$

$E(\lambda)$ is the light source

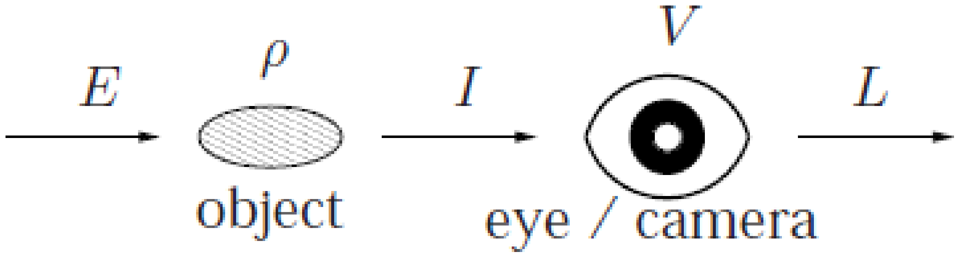
$\rho(\lambda)$ is the reflectivity of that object

Luminance

- Luminance is defined as

$$L = \int_0^\infty I(\lambda)V(\lambda)\, d\lambda$$

This function $V(\lambda)$ shows how well a visual system is able to detect light of a certain wavelength.

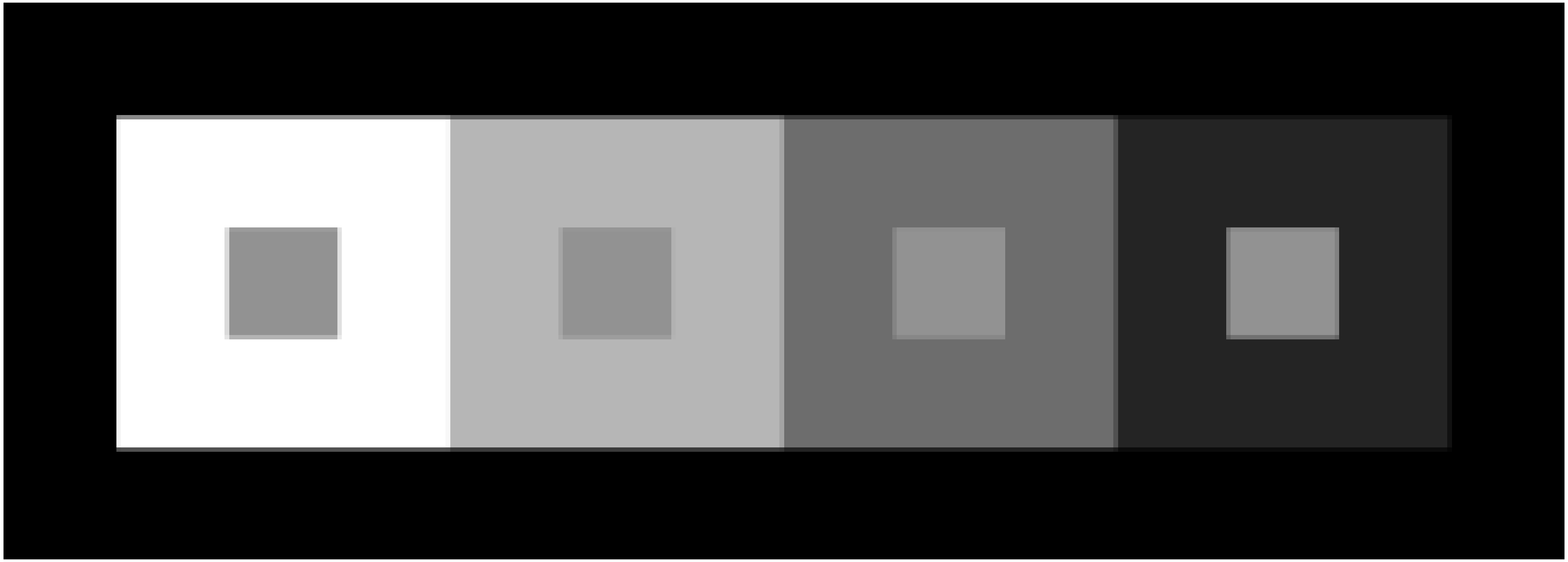


Contrast

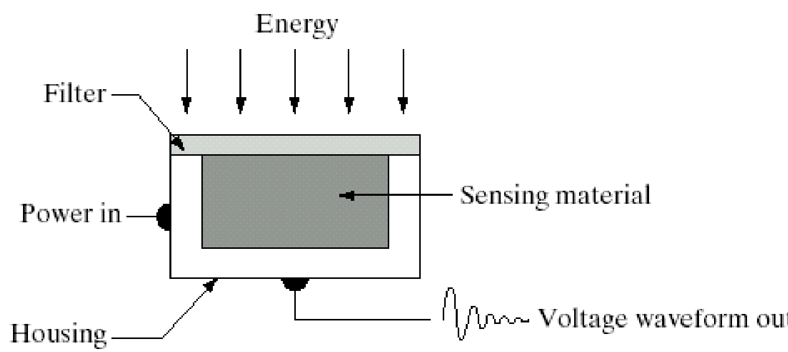
- Contrast is the difference in luminance of a point (area) and background its background.

- The ability to detect a spot of light does not depend so much on the luminance of the spot itself as on the contrast.

Contrast Example



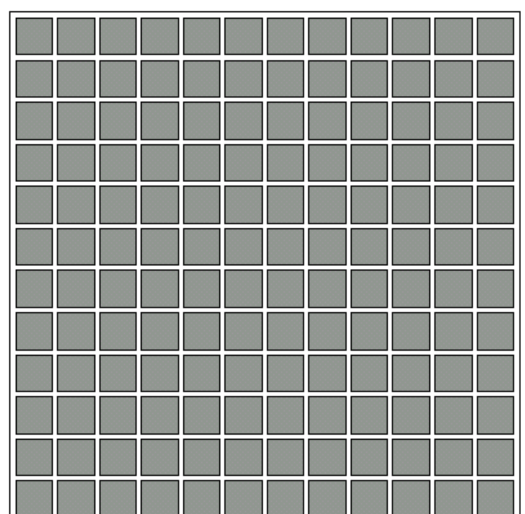
Digital Image Formation Process (1)



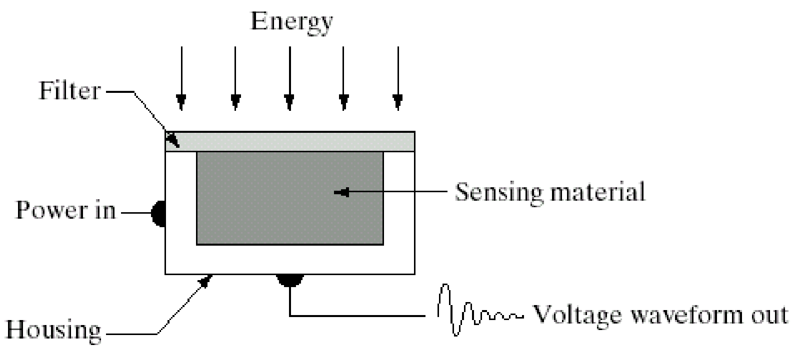
a
b
c

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

Charged coupled device
CCD-chip



Digital Image Formation Process (2)



- Integration over time
  - Exposure time
- Integration over space
  - Sensor area

Under exposed

Correct exposed

Over exposed

Digital Image Formation Process (3)

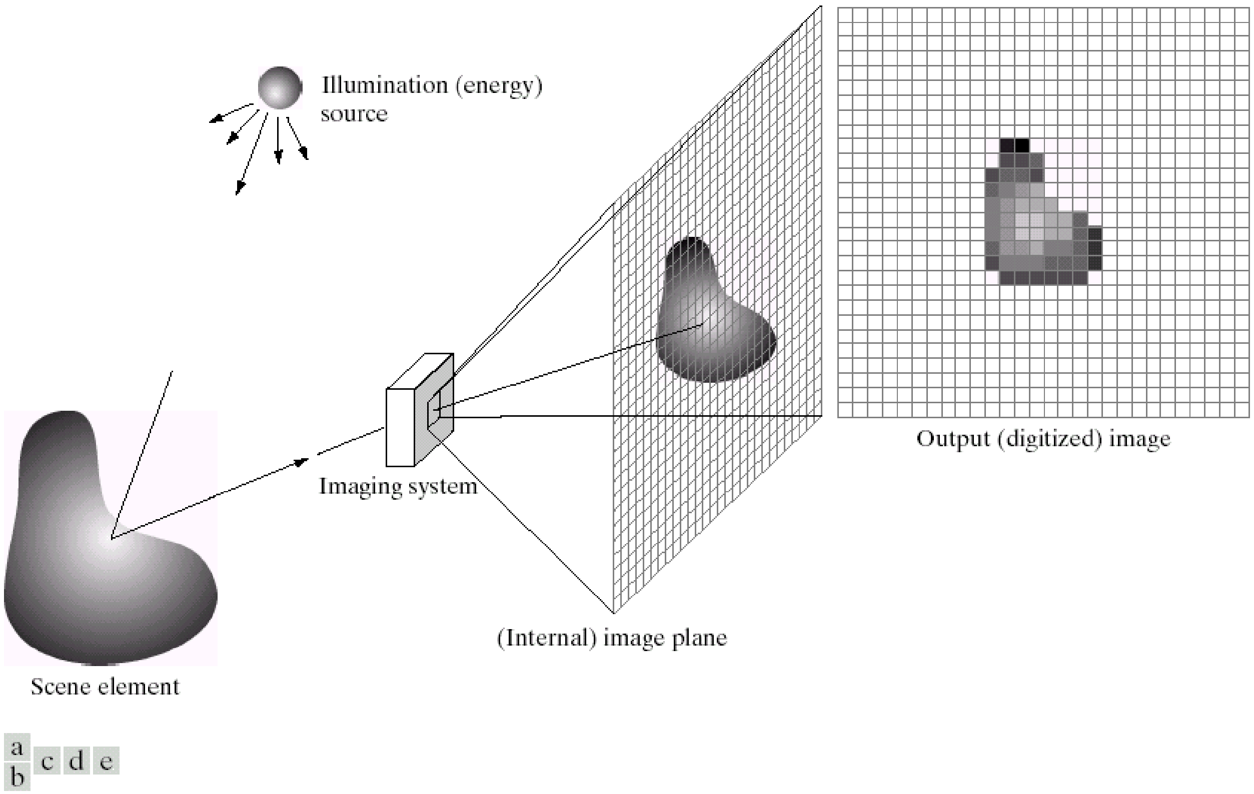


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

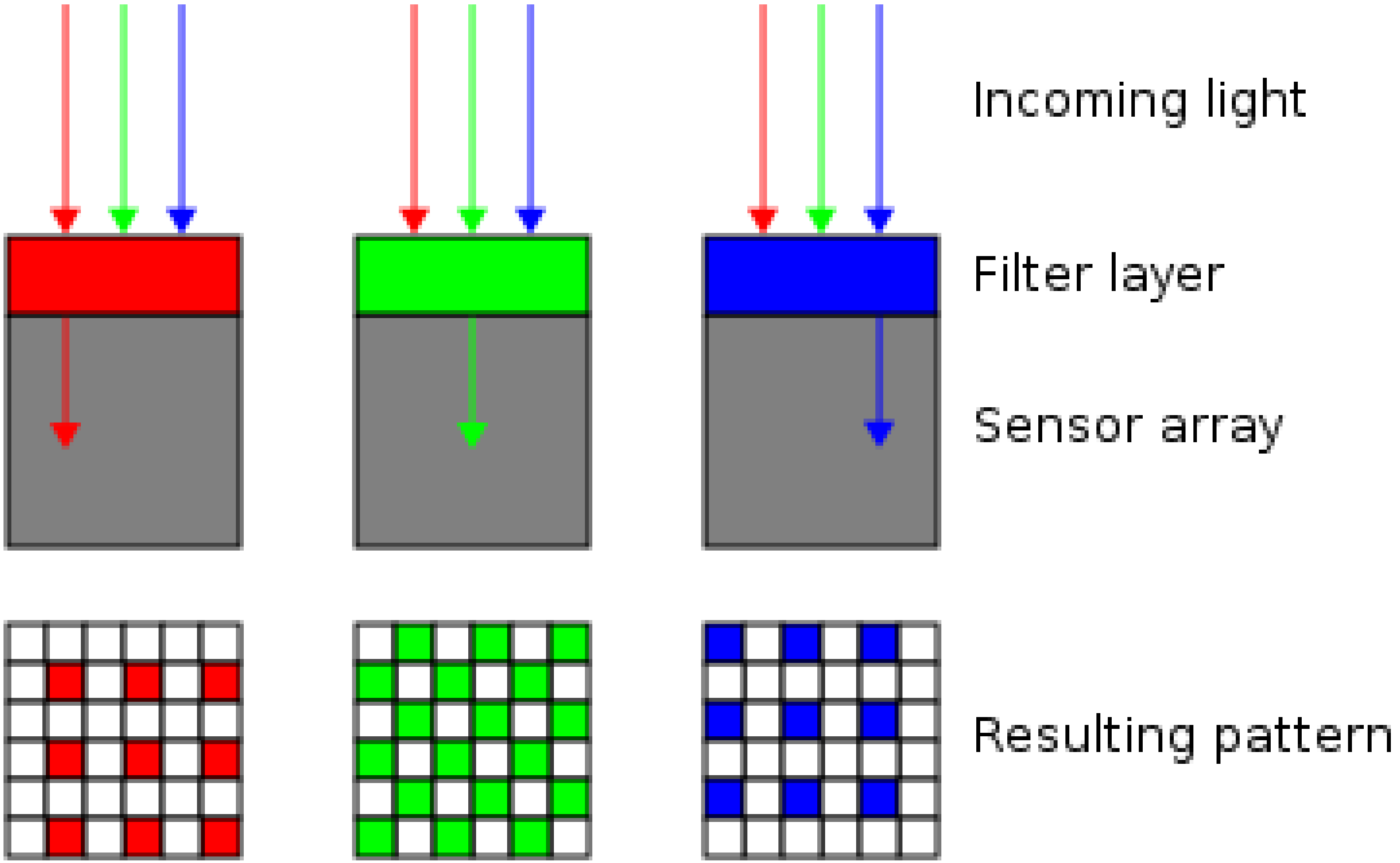
- Image elements, picture elements, pels, **pixels**

Color Separation

- Human Visual System is sensitive to the light waves in three wavelengths
- Cameras are designed to measure the light intensity at these wavelengths
- This is called color separation

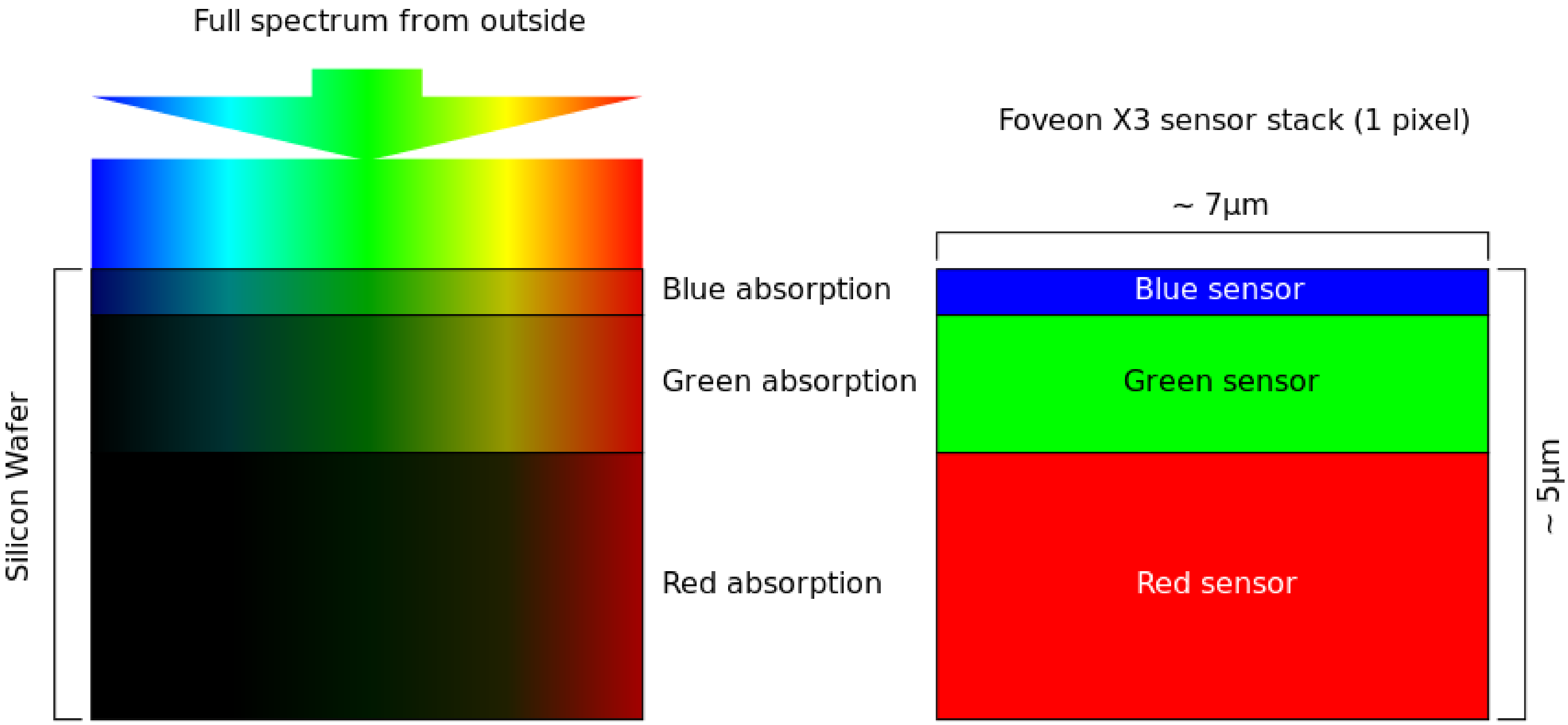
Bayer Filter Sensor

- Bayer Filter Sensor uses a color filter array that passes red, green, or blue light to selected pixel sensors, forming interlaced grids sensitive to red, green, and blue
- The missing color samples are interpolated.


Incoming light
Filter layer
Sensor array
Resulting pattern

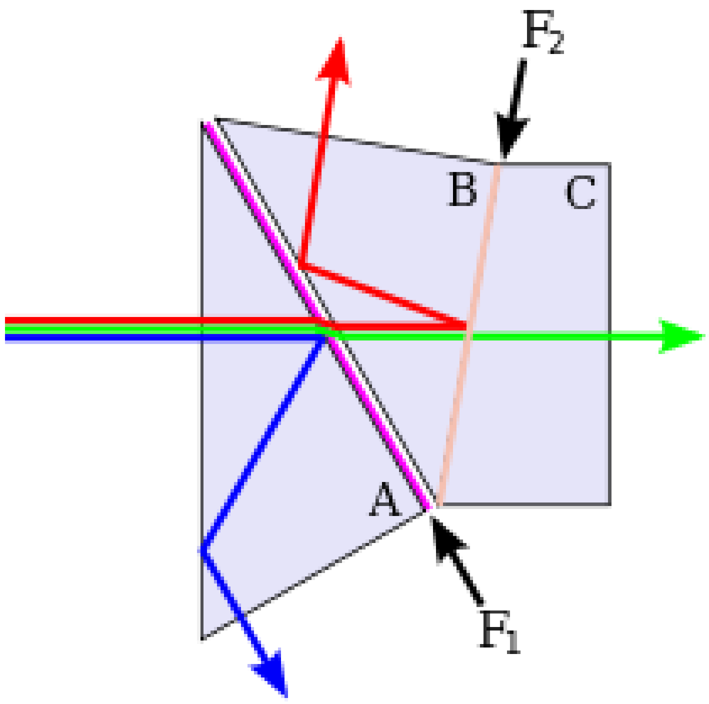
Foveon X3 Sensor

- Fovean X3 Sensors use an array of layered pixel sensors, separating light via the inherent wavelength-dependent absorption property of silicon, such that every location senses all three color channels.

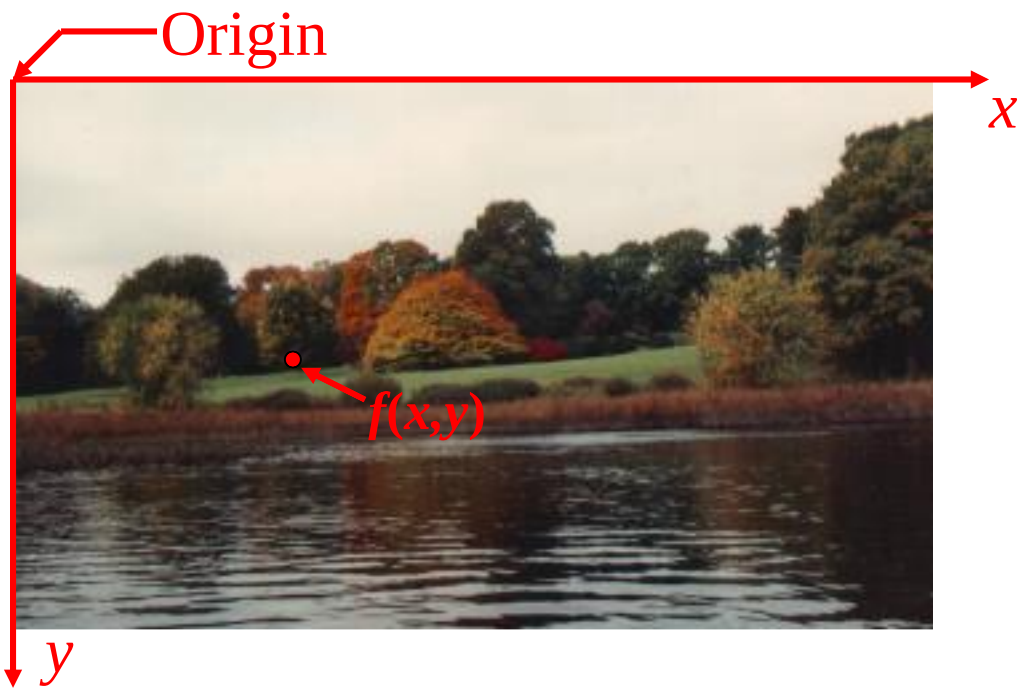

Full spectrum from outside
Foveon X3 sensor stack (1 pixel)
~ 7µm
Silicon Wafer
Blue absorption
Green absorption
Red absorption
Blue sensor
Green sensor
Red sensor
~ 5µm

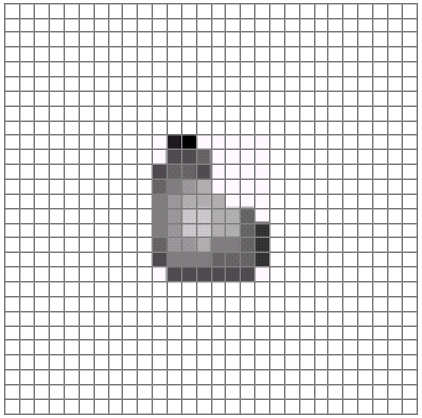
Three CCD (3CCD)

- 3CCD uses three discrete image sensors, with the color separation done by a prism.



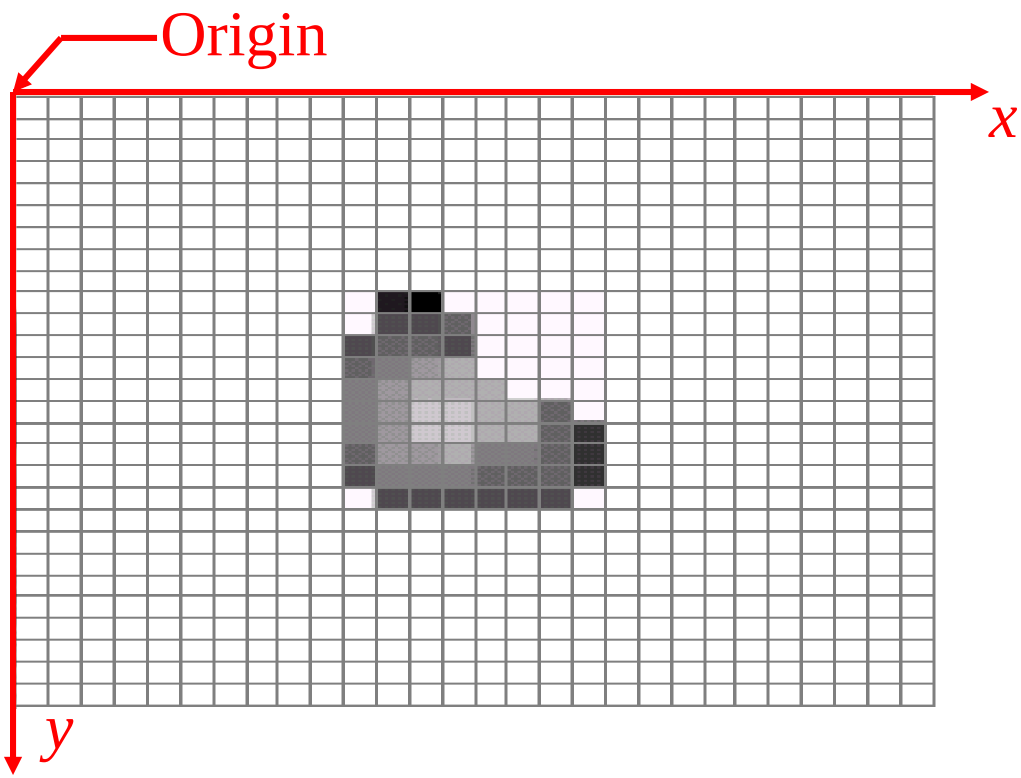
Digital Image Representation

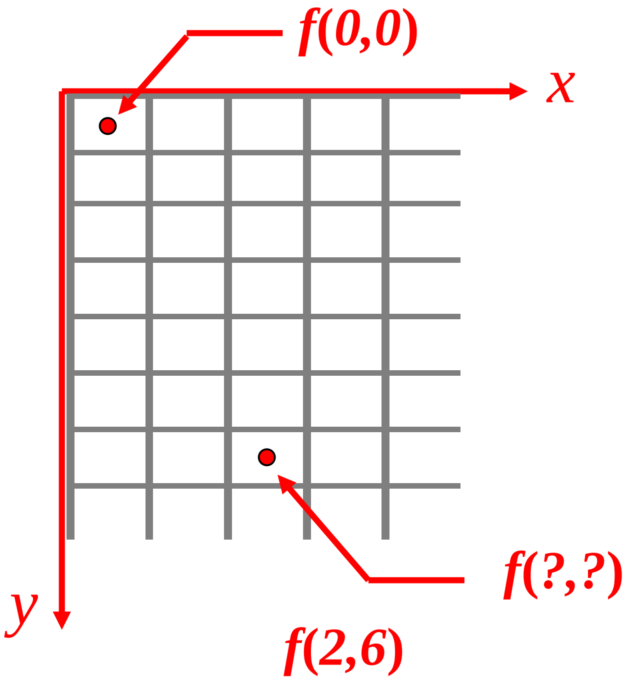




- Image is seen as a **discrete function *f*(*x*,*y*)** as opposed to a continuous function
- x and y **cannot** take on any value!

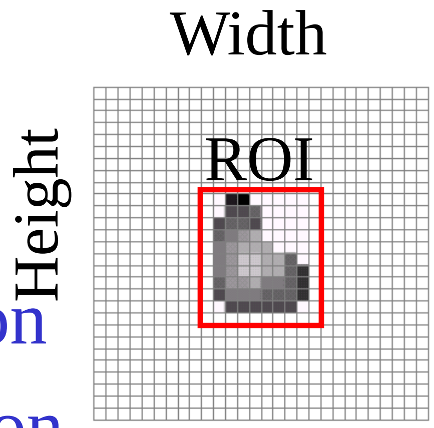
Discrete image coordinate system





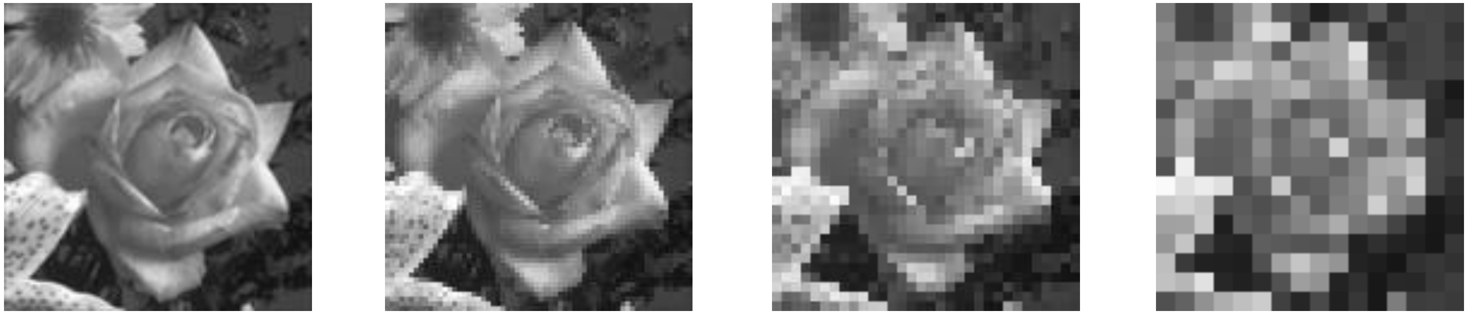
Digital Image Representation

- An image ***f(x,y)*** is represented as an ***Array***
- Width = number of pixels in x-direction
- Height = number of pixels in y-direction
- Size (width x height, width > height)
- ROI = region of interest
  - To reduce the amount of data



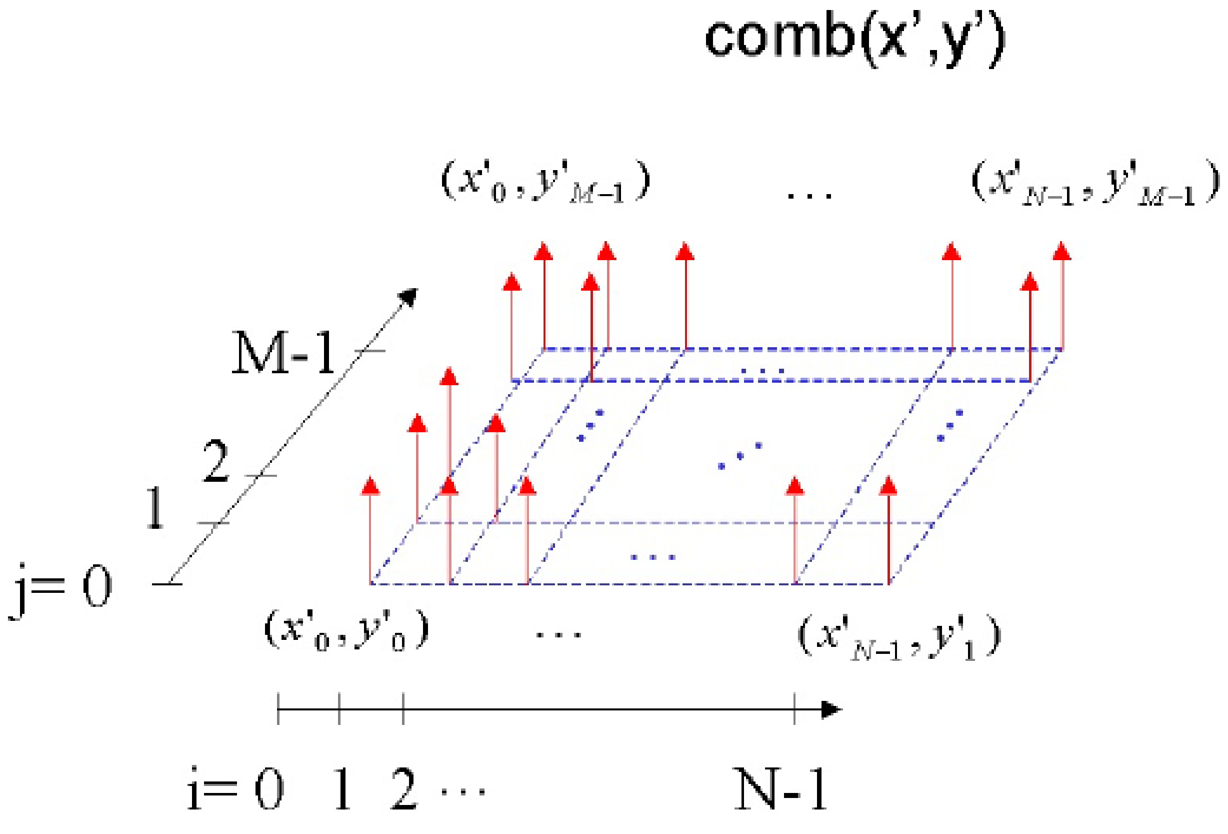
Spatial Image Resolution:

- Resolution
  - The size of an area in a scene that is represented by one pixel in the image
- Different Resolutions are possible (256x256….16x16)



- Lower resolution leads to data reduction!

Sampling



$$comb(x', y') = \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \delta(x' - i\Delta_x, y' - j\Delta_y)$$

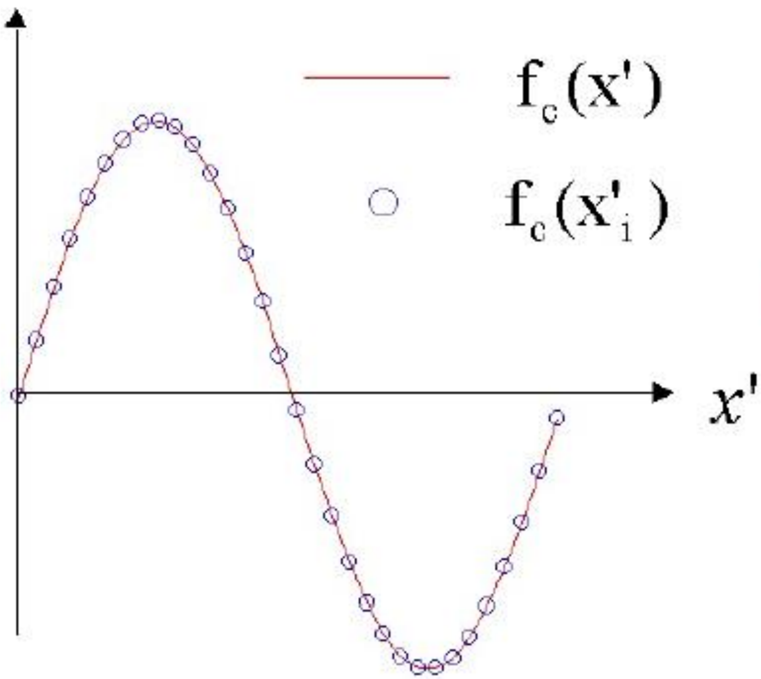
Sampling

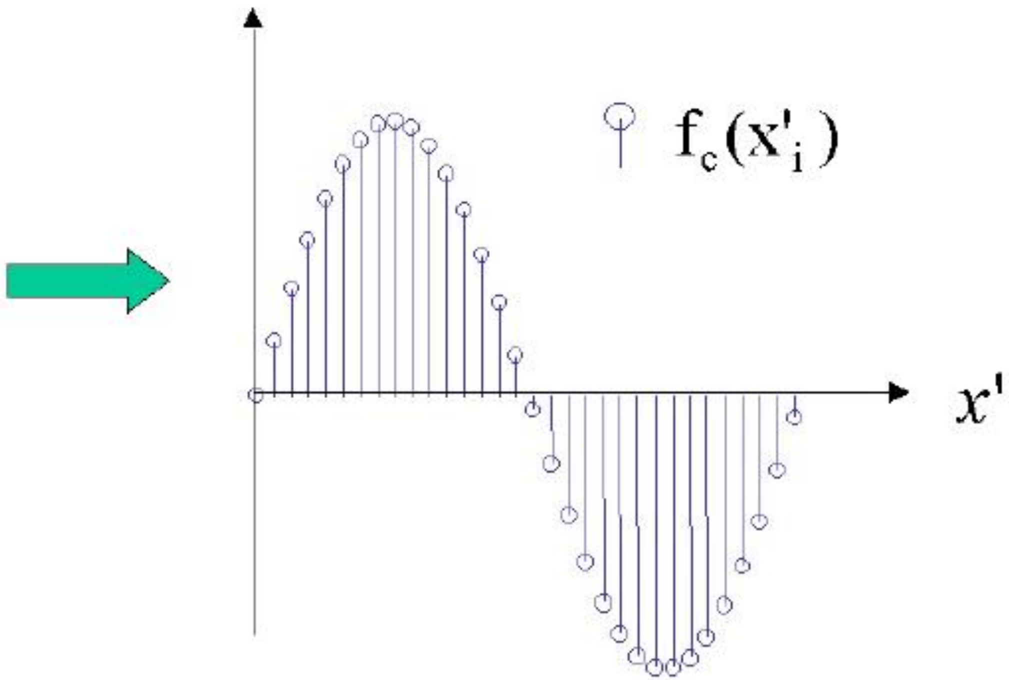
- Obtain sampling by utilizing

$$f(x';y') * comb(x';y')$$

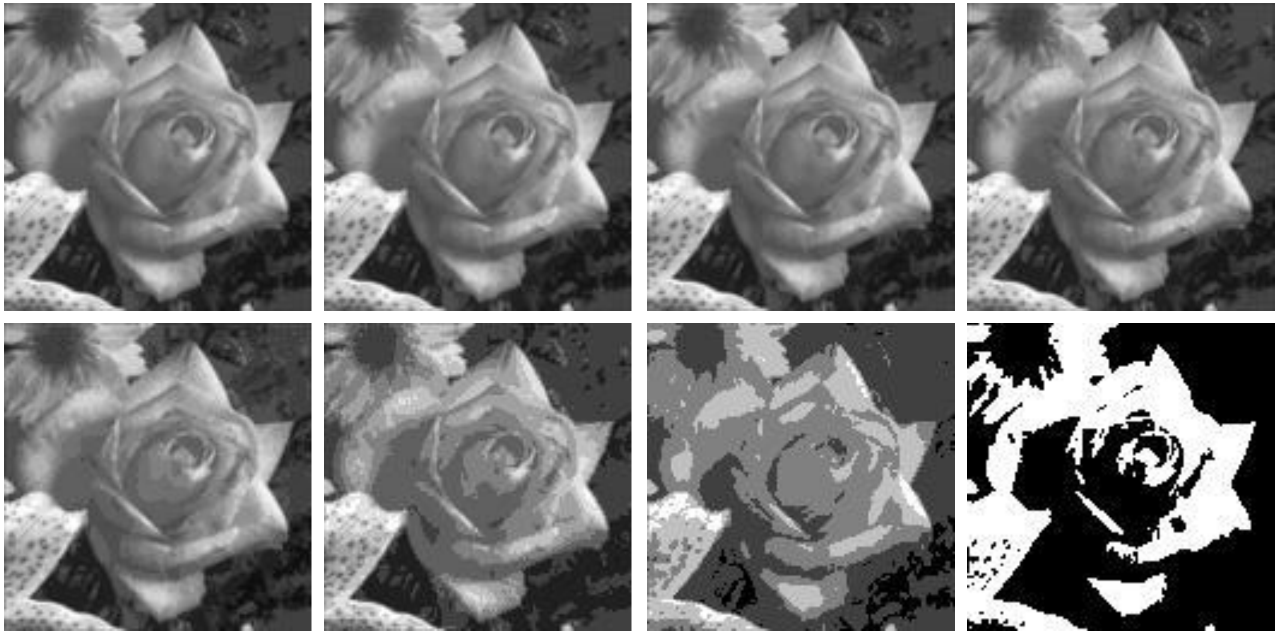
- Smaller Δ values give denser samplers and higher resolution

Sampling





Gray-level Resolution: Quantization

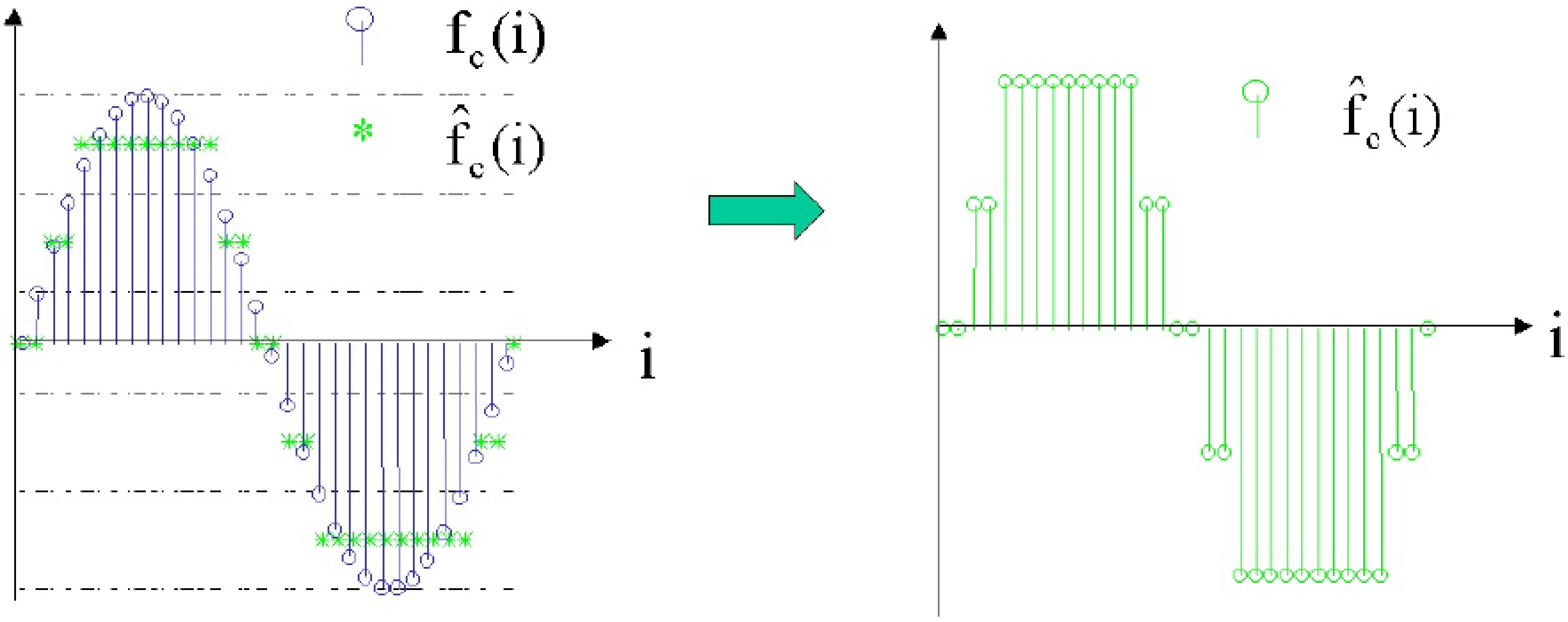


- Different gray-level resolutions: 256, 128, …, 2
- Less gray-levels leads to data reduction.
- For 256, 128, 64 gray-levels: Difference hardly visible

Quantization

- Discretize the values $f(i; j)$ to P *levels* as follows:
- Let $\Delta Q = (fmax\text{-}fmin)/P$
- $f'(i; j) = Q(f(i; j))$
- $Q(f(i; j)) = (k + 1/2)\Delta Q + fmin$

Quantization



Relationships Between Pixels

Relationship between pixels

- Neighbors of a pixel
  - 4-neighbors $N_4(q)$
  - 8-neighbors $N_8(q)$
  - Diagonal neighbors $N_p(q)$

Connectivity

Assuming p and q with values V,

- 4-connectivity: iff P is in the set $N_4(q)$
- 8-connectivity : iff P is in the set $N_8(q)$
- m-connectivity: if p is in $N_4(q)$ or

  p in $N_8(q)$ and $N_4(p)$ and $N_4(q)$ have no common members (empty intersection set)

Distance Measure

- A distance measure should satisfy:
  - $D(p,q) \geq 0$ (0 iff $p=q$)
  - $D(p,q) = D(q,p)$
  - $D(p,z) \leq D(p,q) + D(q,z)$

Example Distance Measures

- Euclidean distance $[(x-s)^2 + (y-r)^2]^{1/2}$
- City block $|x-s| + |y-r|$
- Chess board distance $\max(|x-s| , |y-r|)$

Exercise

Sensors used in cameras are sensitive to the signals in red, green and blue bands. Can we get information if we sense the signal in other bands too?

Prepare a report on how a hyper-spectral camera works. Give main advantages and disadvantages, and mention its probable applications