CSE4227 Digital Image Processing

Lecture 02 – **Chapter 2: Digital Image Fundamentals**

Dr. Kazi A Kalpoma
Professor, Department of CSE

Ahsanullah University of Science & Technology (AUST)

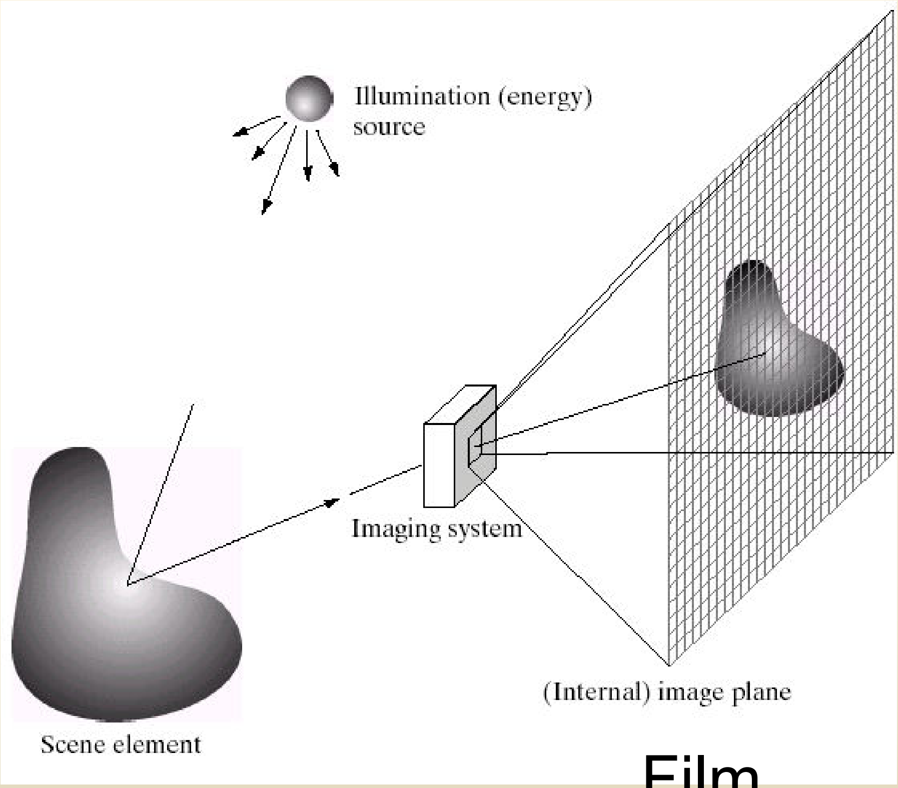
Contact: kalpoma@aust.edu

Today's Contents

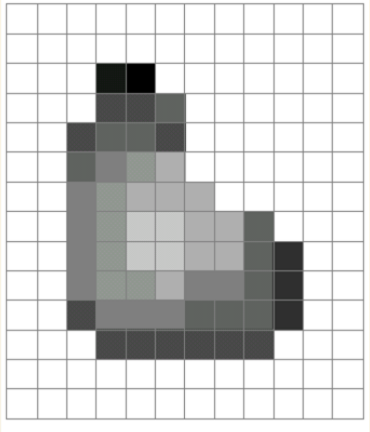
- ❑ **Image Sensing and Acquisition**
- ❑ **Sampling and quantization**
- ❑ **Image Representation**
- ❑ **Spatial and Intensity Resolution**

•Chapter 2 from R.C. Gonzalez and R.E. Woods, Digital Image Processing (3rd Edition), Prentice Hall, 2008 [**Section 2.3, 2.4**]

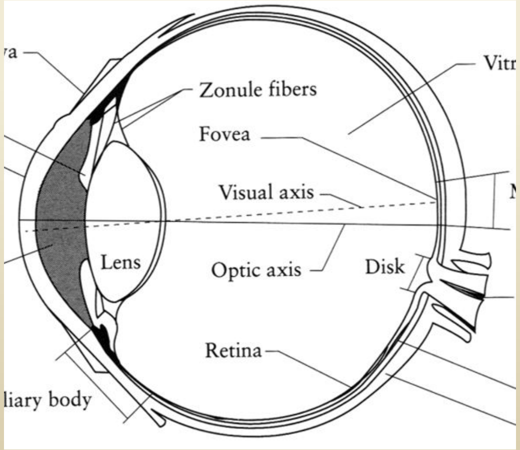
Image Formation



Film



Digital Camera



The Eye

IMAGE SENSING AND ACQUISITION

Image Acquisition

❑ Three main elements

1. **Illumination source**
2. **Scene**
3. **Sensor (imaging system)**

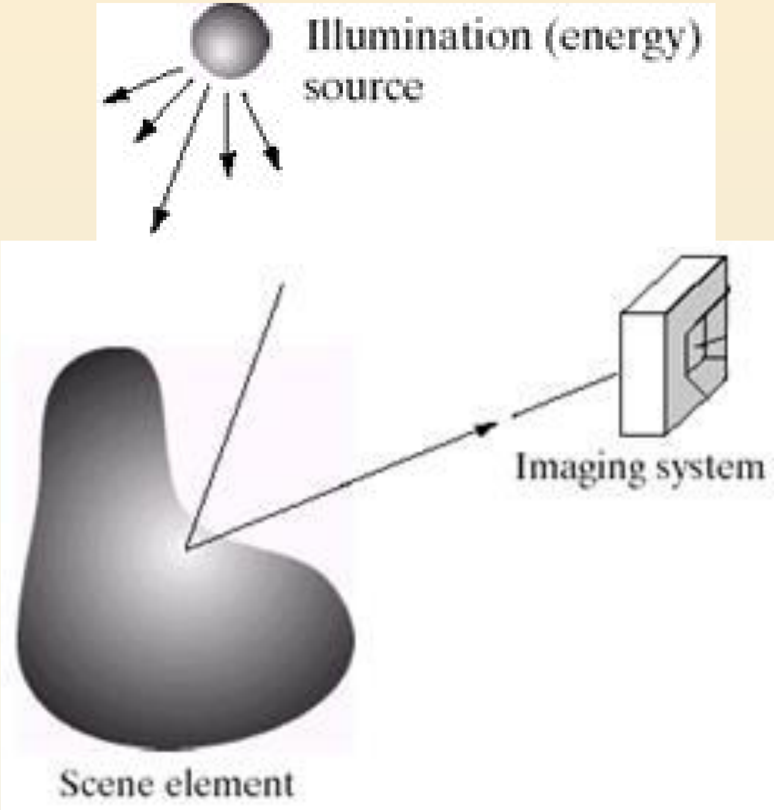
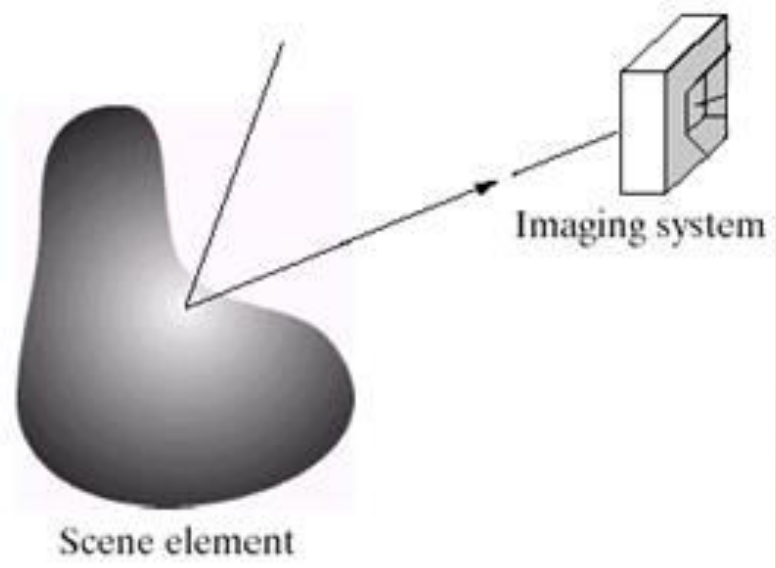


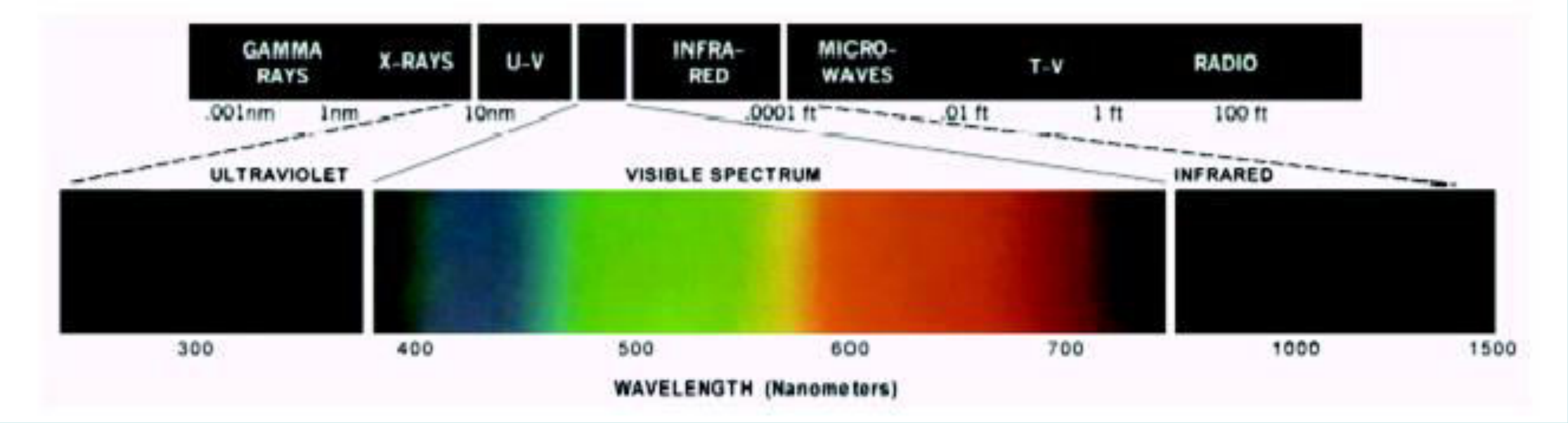
Image Acquisition

1. Illumination source:
   - Can be light energy or
   - EM spectrum
   - Even less tradition sources like
     - Sound, heat
2. **Scene:**
   - Any object: visible or hidden
   - Source itself
3. **Sensor:**
   - Should be capable of sensing the energy



Light And The Electromagnetic Spectrum

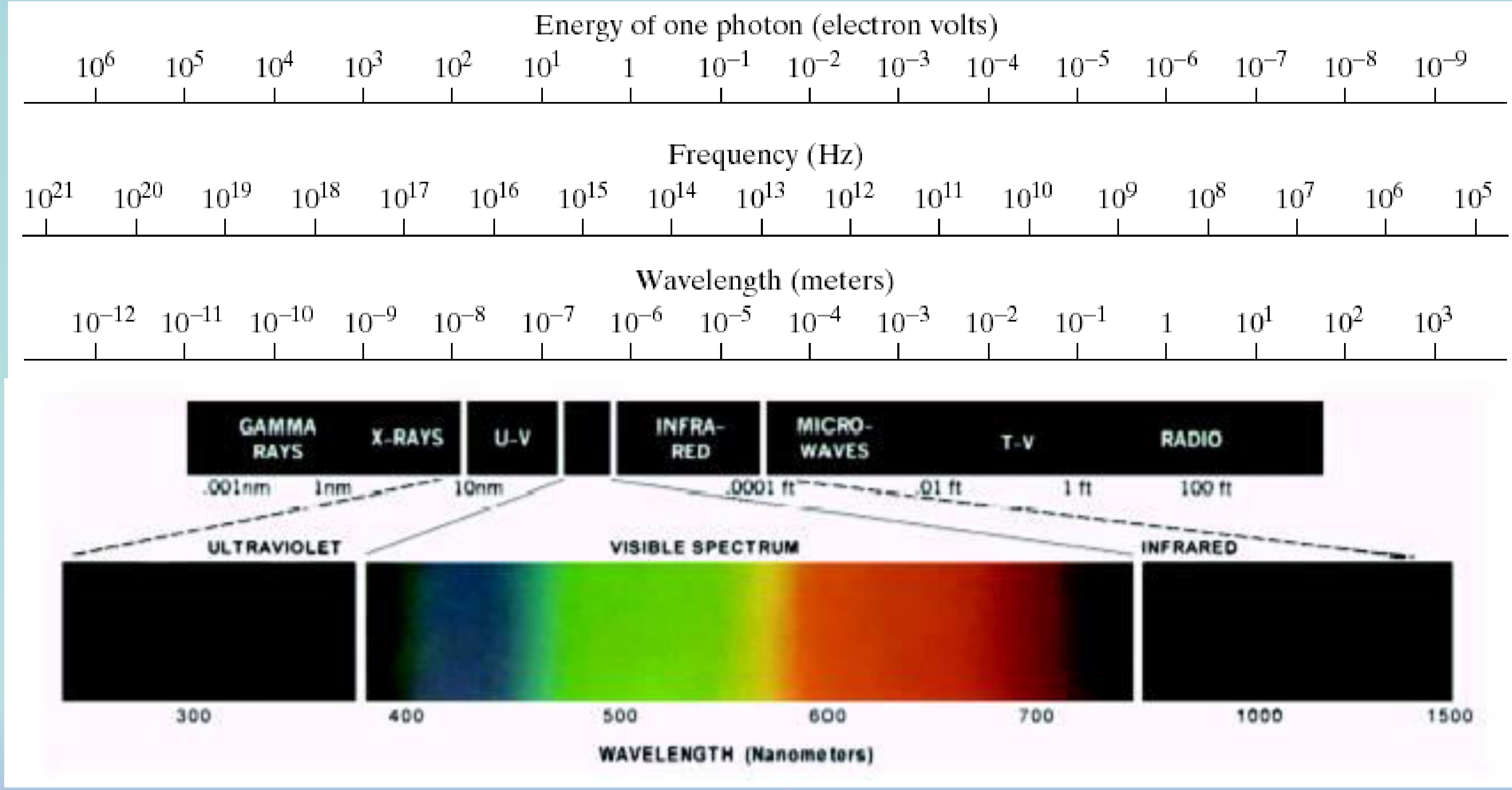
❑In 1666 Sir Isaac Newton discovered that sunlight passed through a prism splits into a continuous spectrum of colors



❑Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye

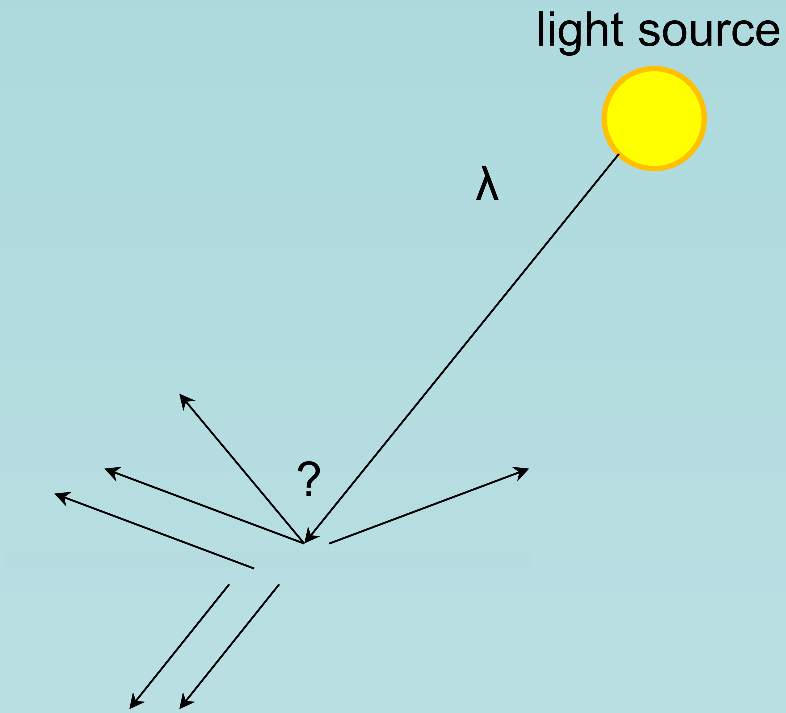
❑The electromagnetic spectrum is split up according to the wavelengths of different forms of energy

- A discrete bundle (or *quantum*) of electromagnetic (or light) energy, PHOTON is proportional to frequency.



A photon's life choices

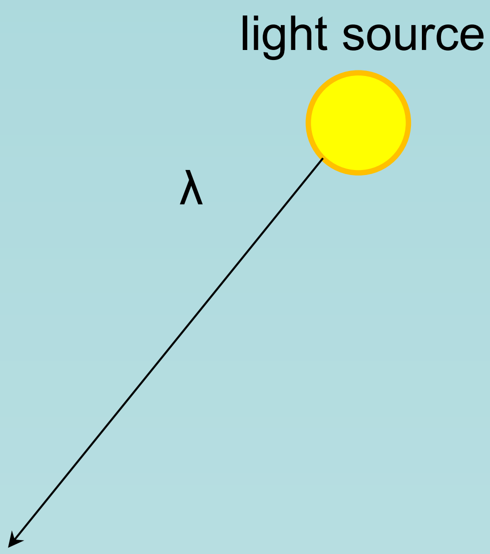
- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



Chapter 2 of Szeliski

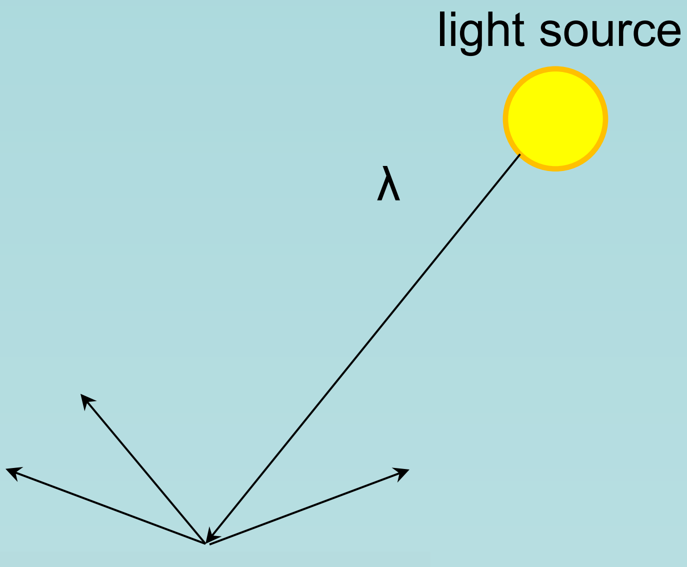
A photon's life choices

- **Absorption**
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



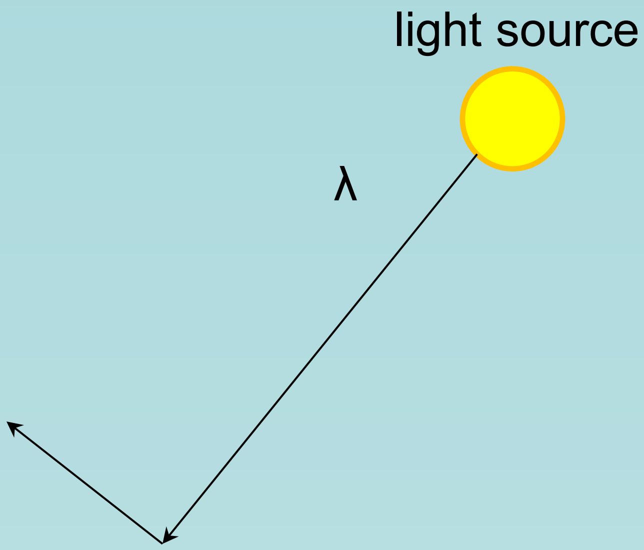
A photon's life choices

- Absorption
- **Diffuse Reflection**
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



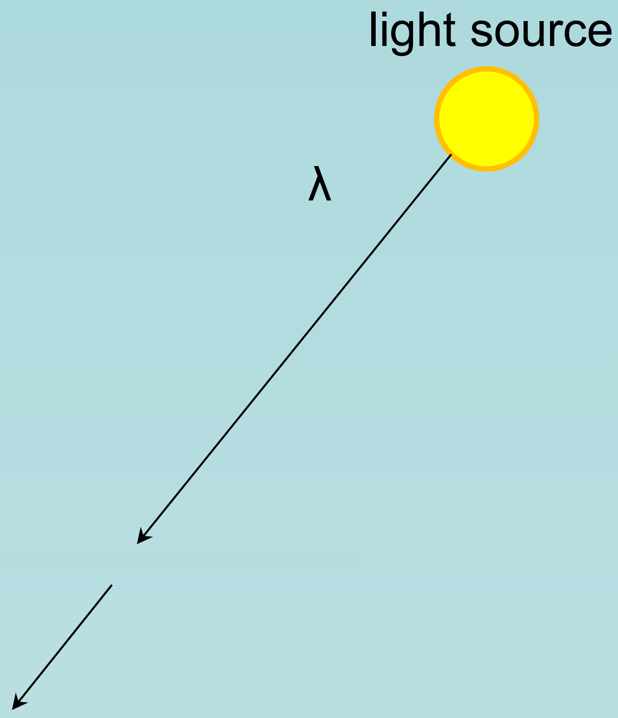
A photon's life choices

- Absorption
- Diffusion
- **Specular Reflection**
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



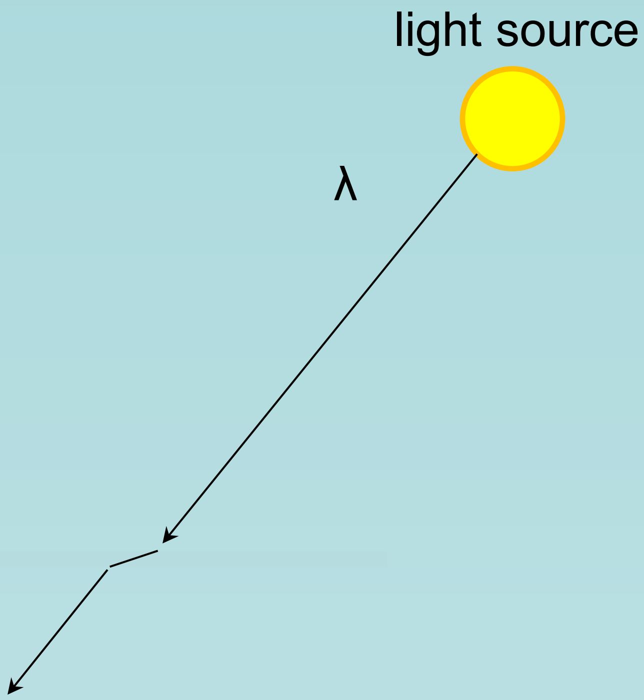
A photon's life choices

- Absorption
- Diffusion
- Reflection
- **Transparency**
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



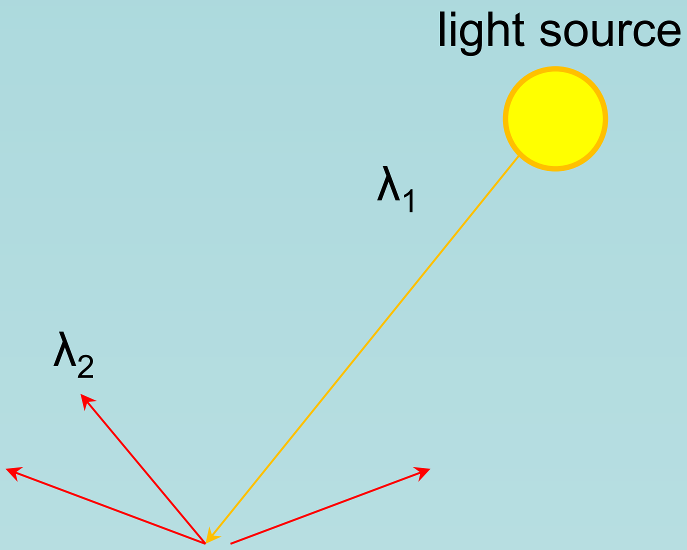
A photon’s life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- **Refraction**
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



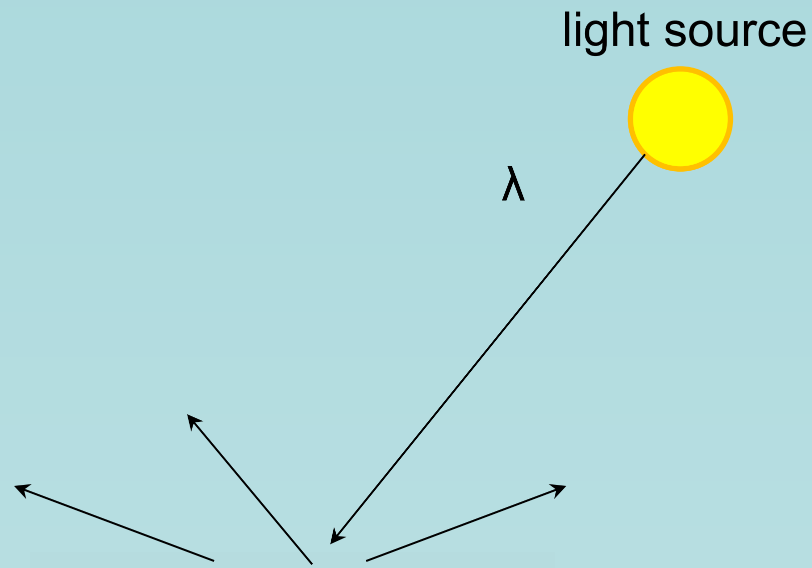
A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- **Fluorescence**
- Subsurface scattering
- Phosphorescence
- Interreflection



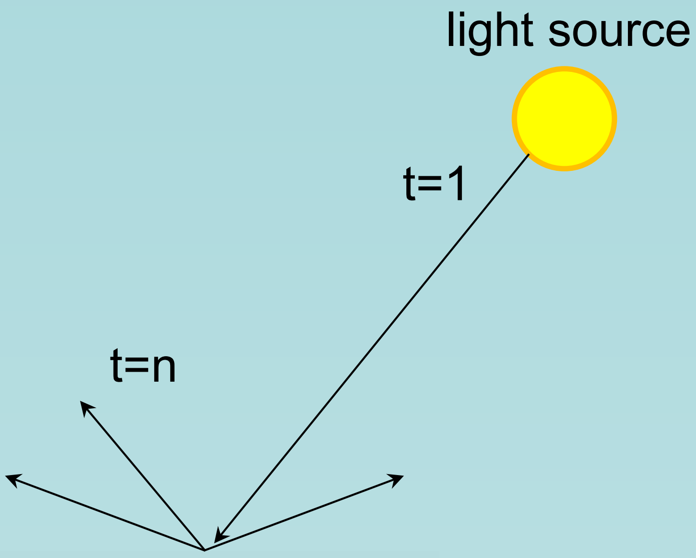
A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- **Subsurface scattering**
- Phosphorescence
- Interreflection



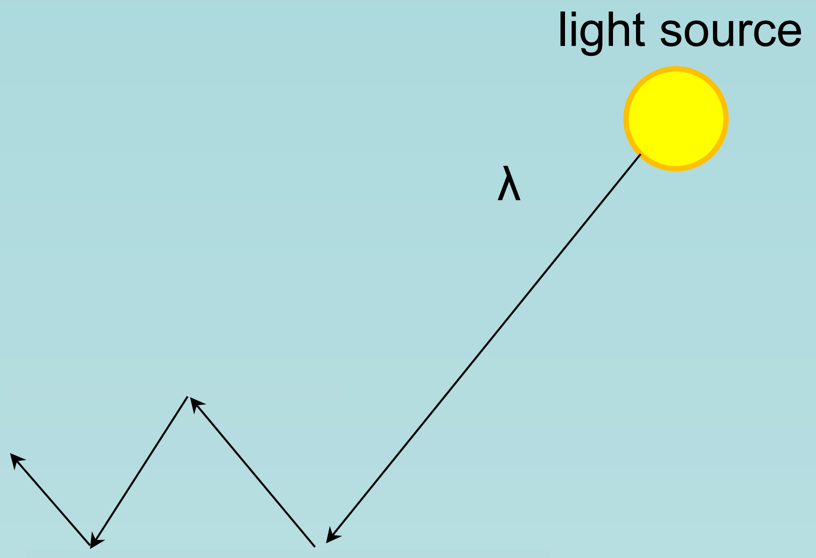
A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- **Phosphorescence**
- Interreflection



A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- **Interreflection**



(Specular Interreflection)

Image Sensors

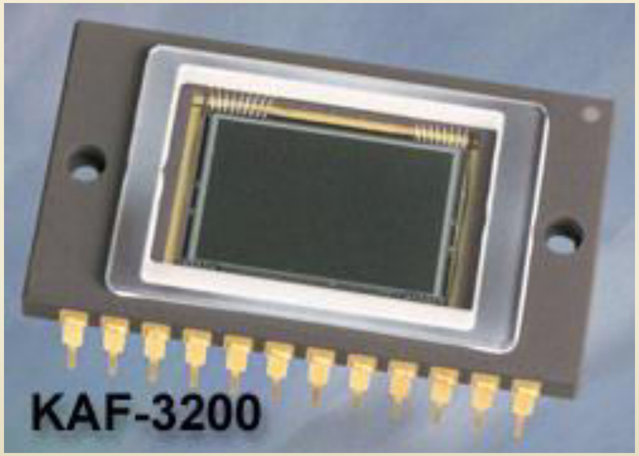
- ❑ Incoming energy lands on a sensor material responsive to that type of energy and this generates a voltage
- ❑ Collections of sensors are arranged to capture images

Charge-Coupled Device (CCD) or
Complementary Metal Oxide Semiconductor (CMOS)

✓ Used for convert a continuous image into a digital image

✓ Contains an array of light sensors

✓ Converts photon into electric charges accumulated in each sensor unit

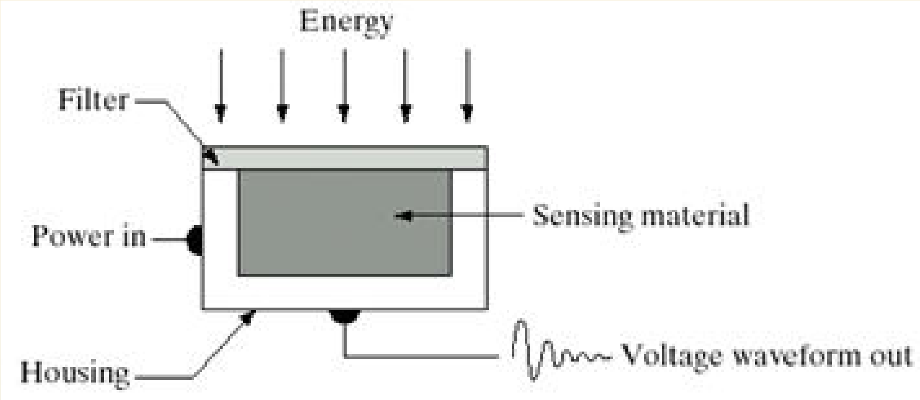


CCD KAF-3200E from Kodak.
(2184 x 1472 pixels,
Pixel size 6.8 microns^2)

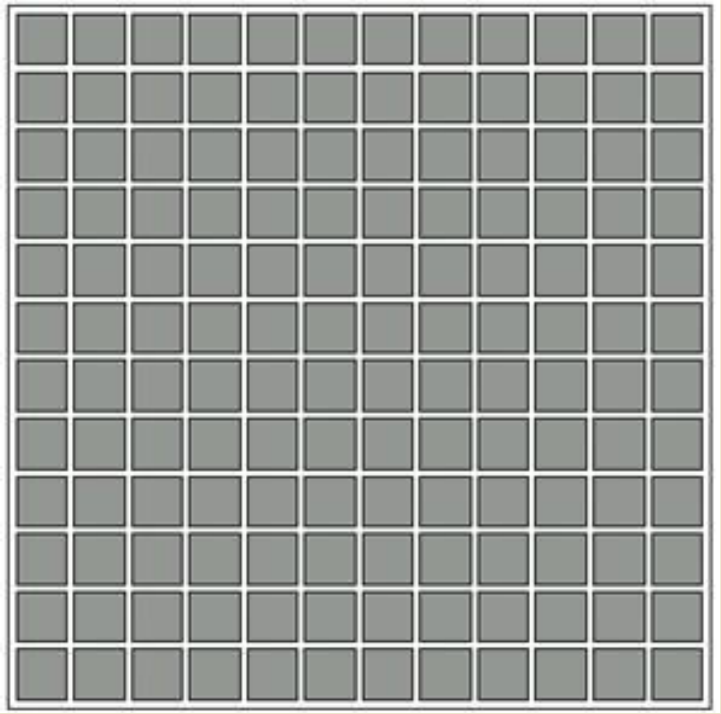
Image Sensors used to transform illumination energy to digital images.

3 main sensor arrangements:

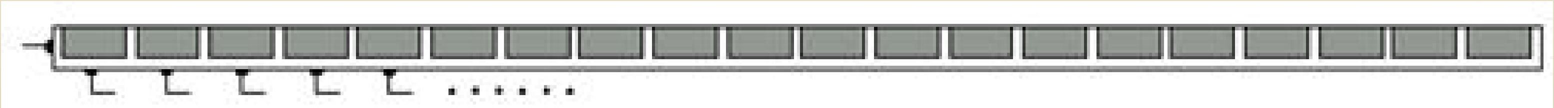
1. **Single sensor**
2. **Line sensor**
3. **Array sensor**



Single sensor



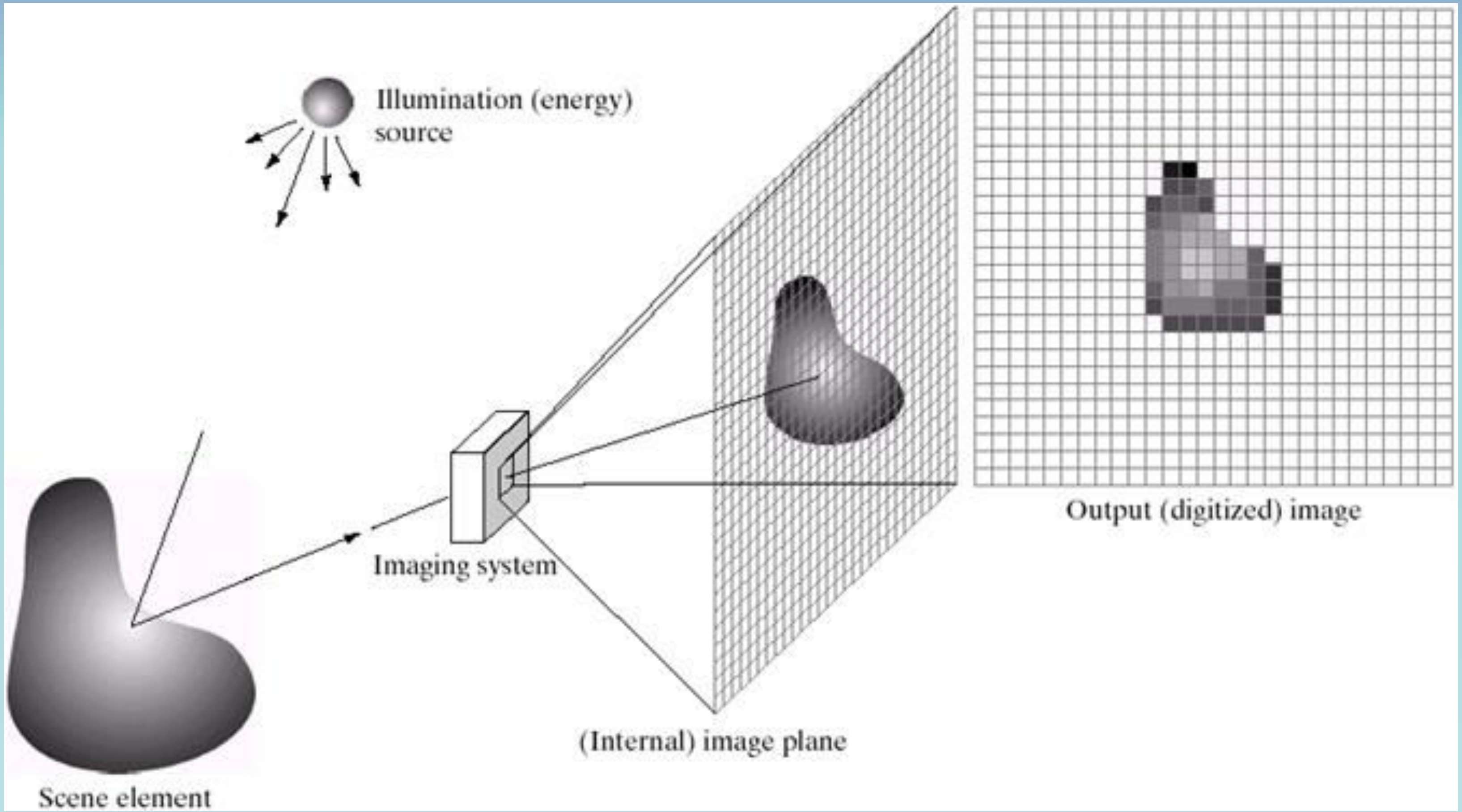
Array sensor



Line sensor

- Sensing element can be a photodiode
- Filter absorbs extra energy or acts as pass-band

Image Acquisition using Sensor Array



❑ Images are typically generated by *illuminating* a *scene* and absorbing the energy reflected by the objects in that scene.

Human Vision VS Computer Vision

What we see

0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	3	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

What a computer sees

Image Digitization

- Computers use discrete form of the pictures
- The process transforming continuous analog image into discrete approximated image is called digitization.

- Two steps:
  - Sampling and
  - Quantization

Image Sampling And Quantisation

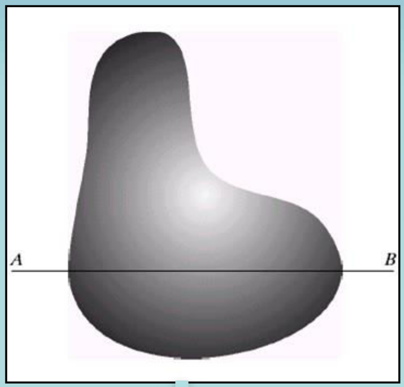
Sampling:

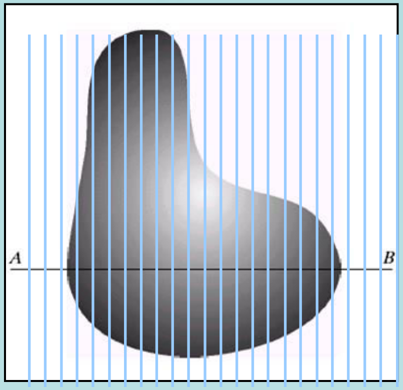
- Digitizing coordinates
- A process which converts the continuous analog space into a discrete space

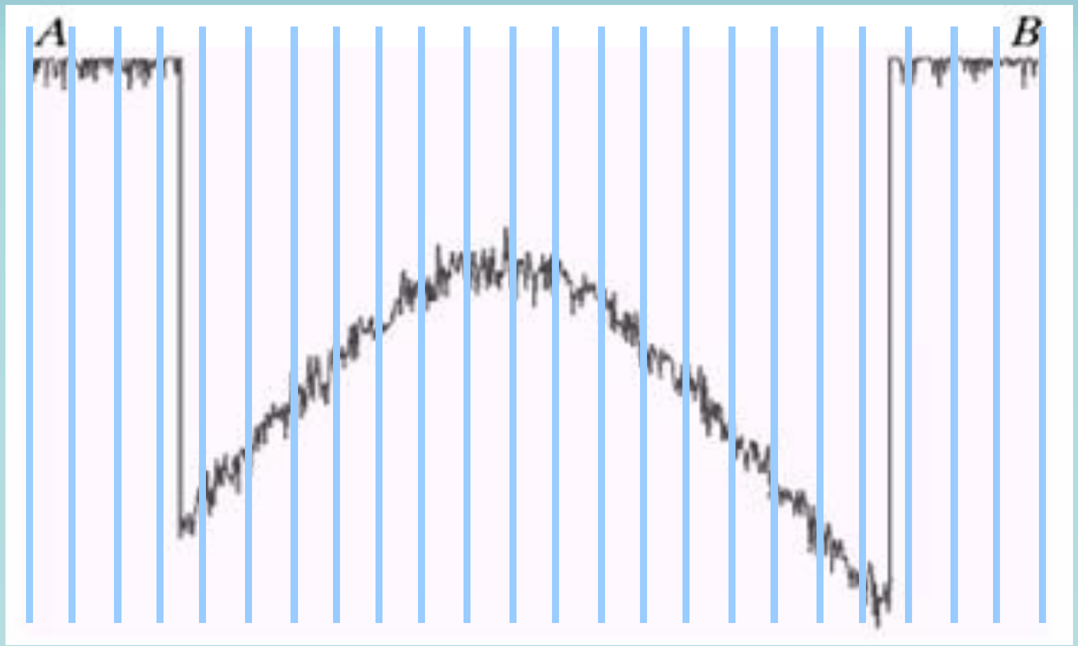
Quantization:

- Digitizing amplitudes (gray scale values)
- A process of converting a continuous analogue signal into a digital representation of that signal

Image Sampling



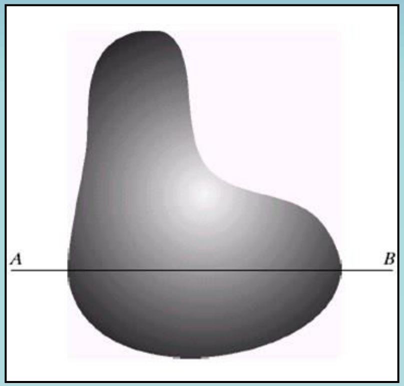


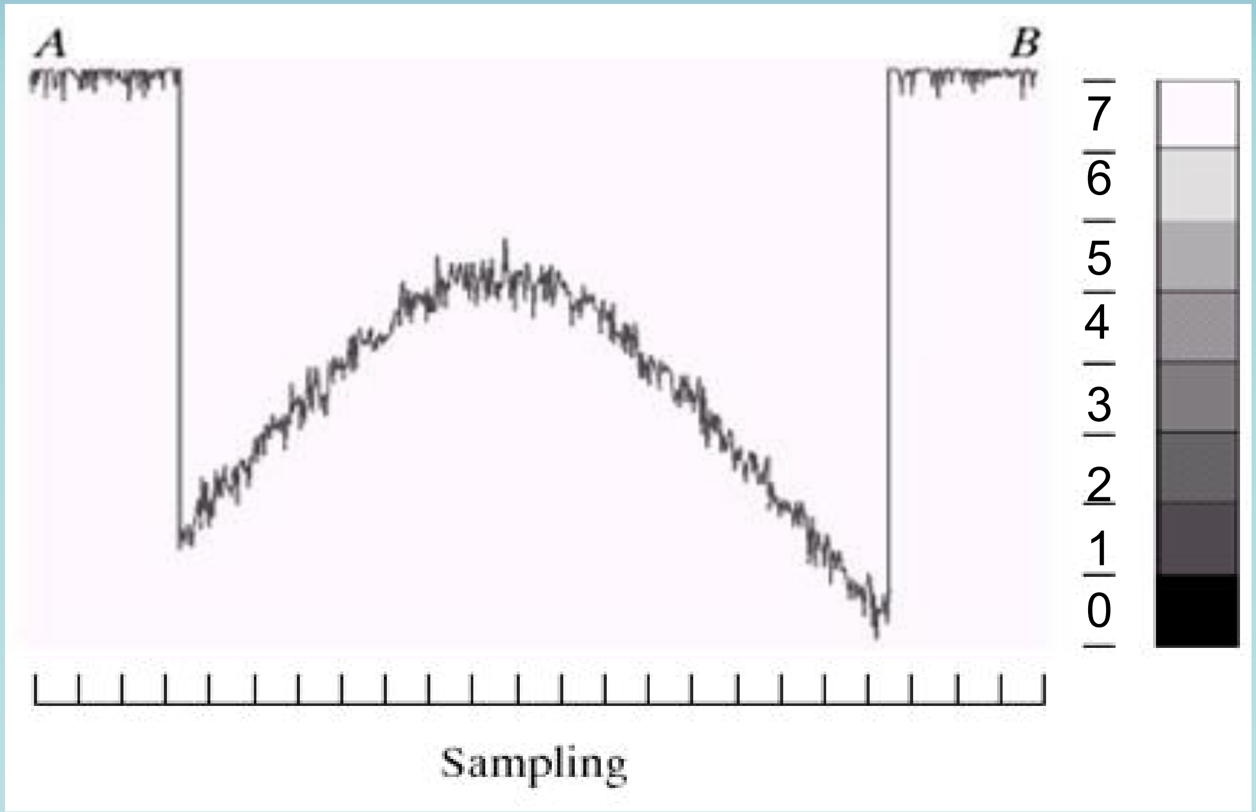


1-Dimensional Sampling

Digitizing the coordinate values

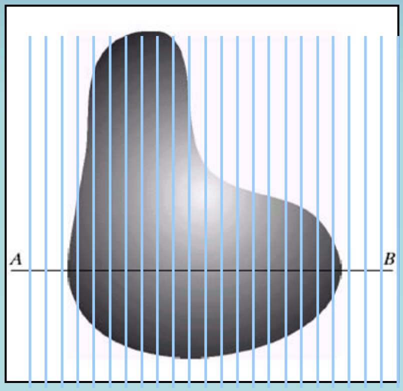
Image Quantization

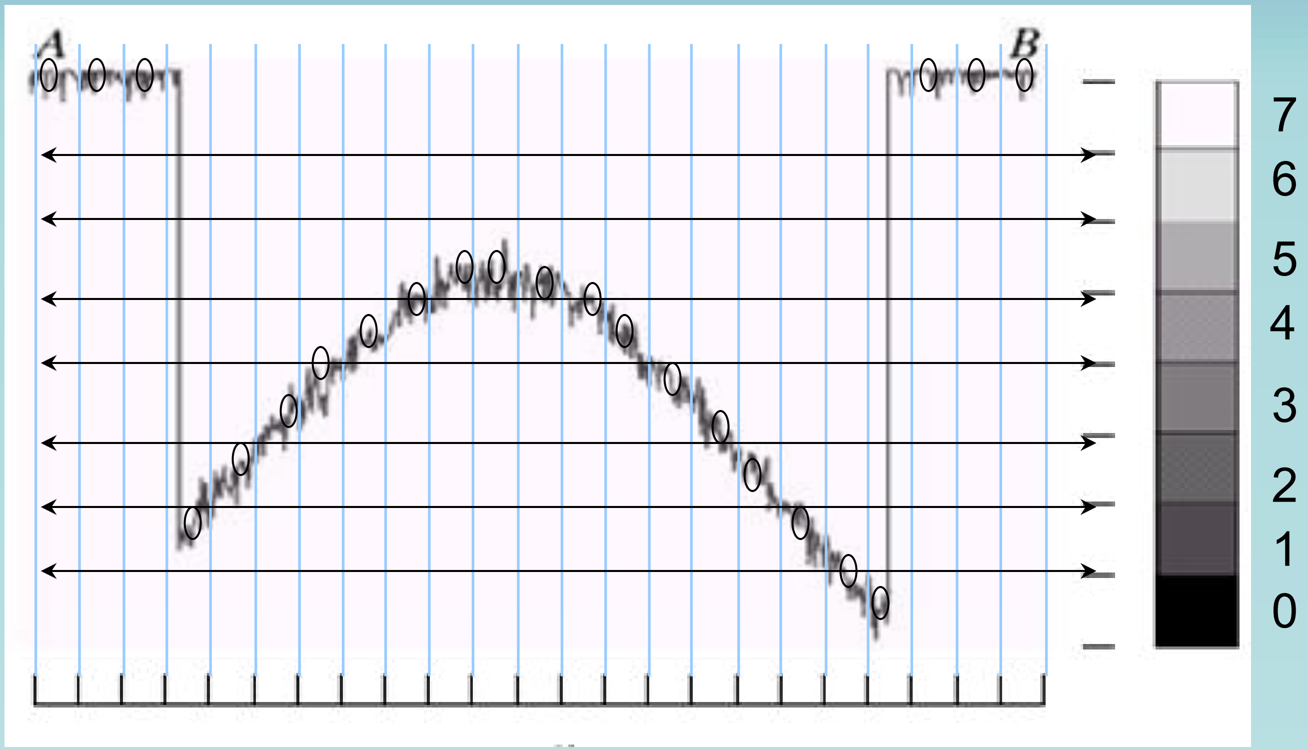




Digitizing the amplitude values

Image Sampling And Quantisation



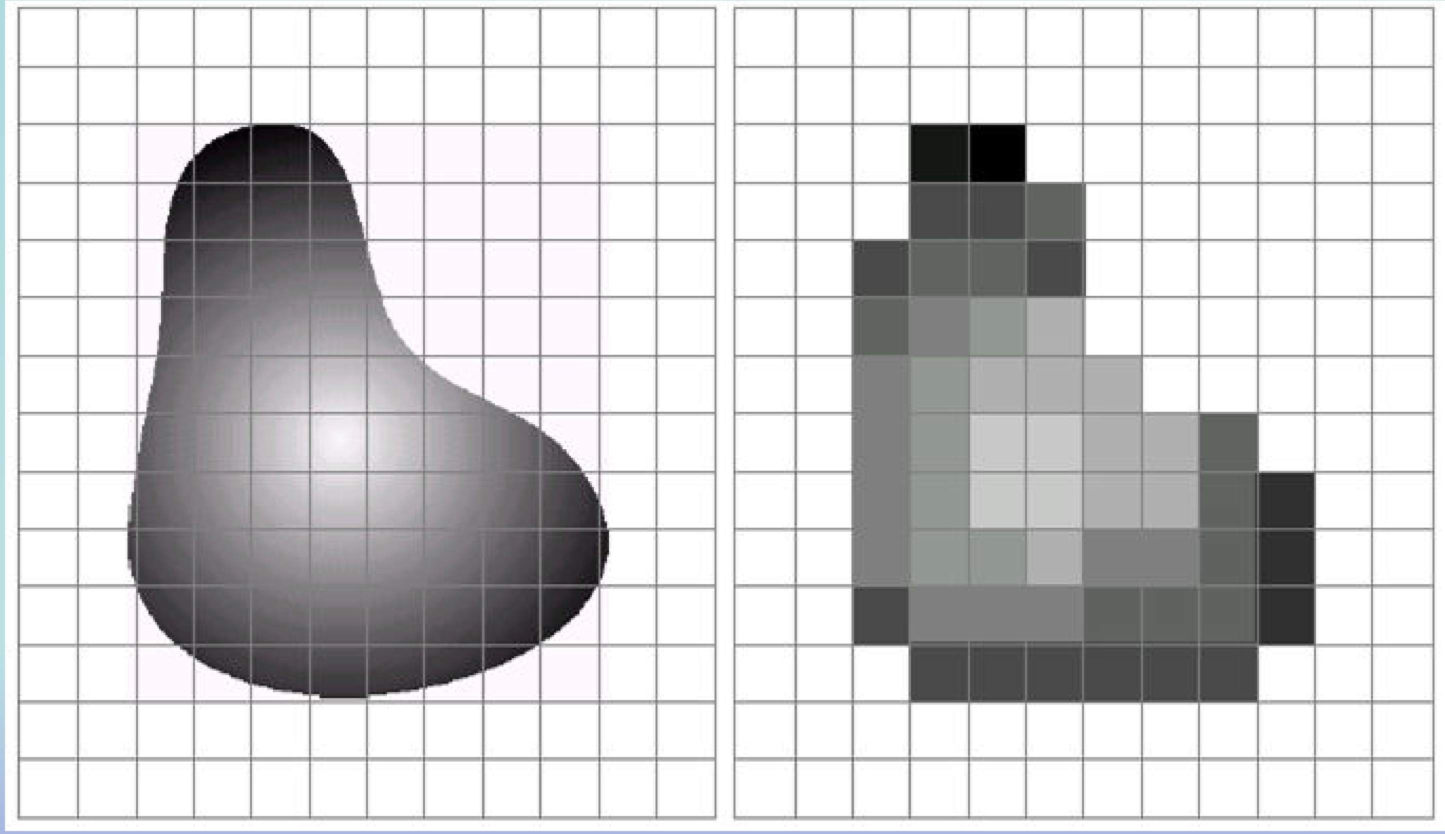


A	7	7	7	1	2	3	4	4	5	5	5	5	5	4	3	3	2	1	0	0	7	7	7	**B**

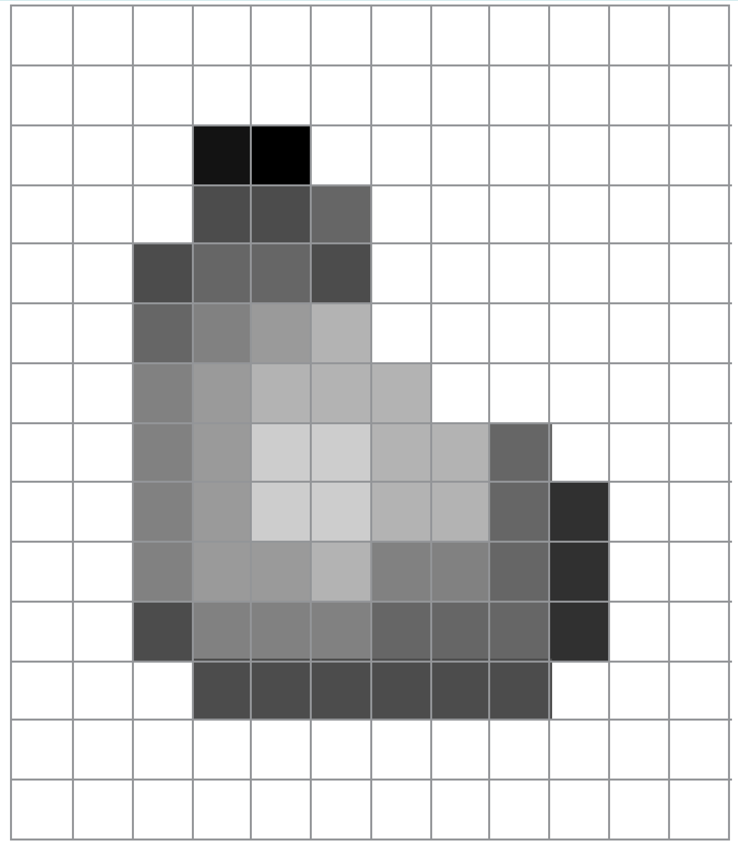
Digitization

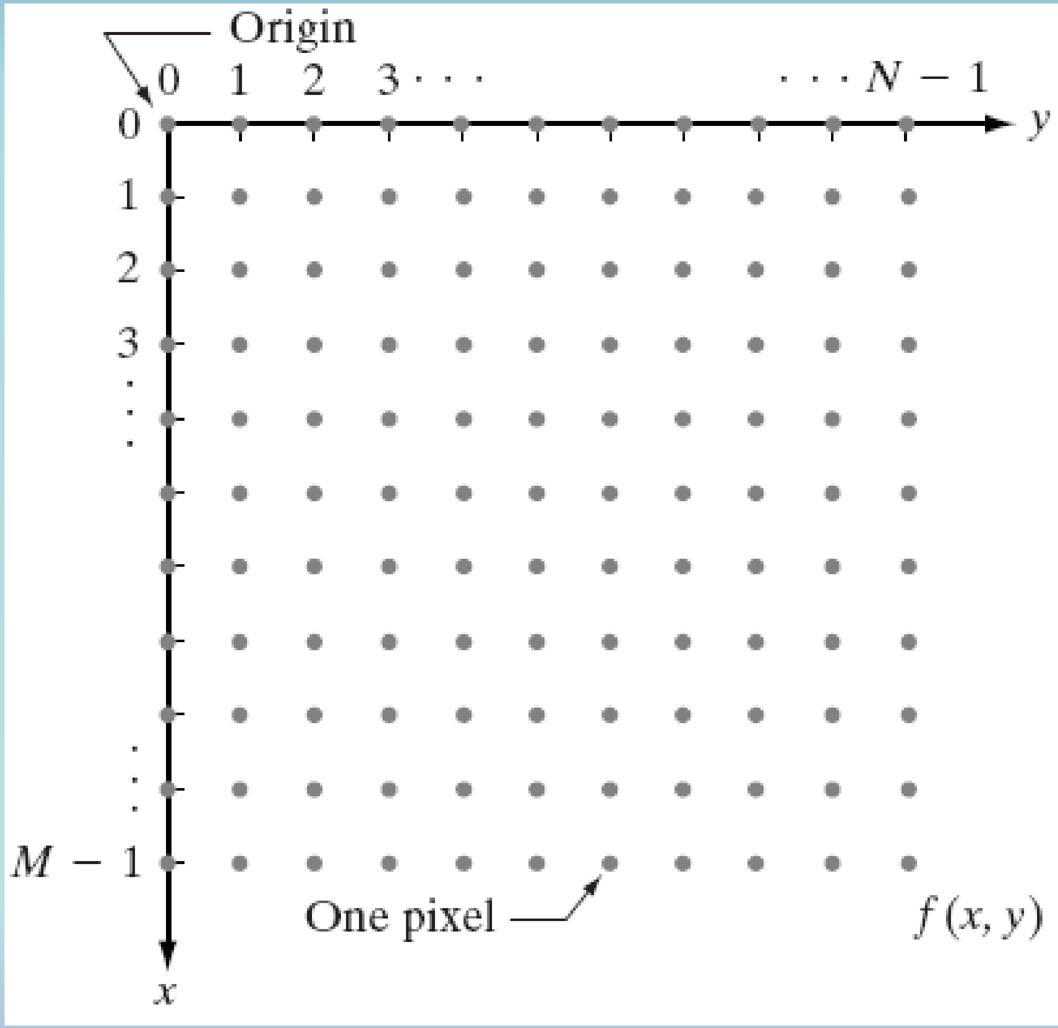
Digital Image

- Remember that a digital image is always only an **approximation** of a real world scene



Representation of Digital Image





Matrix Representation

Representation of Digital Image

- The representation of an M×N numerical array as

$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \dots & \dots & \dots & \dots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Representation of Digital Image

- The representation of an M×N numerical array in MATLAB

$$f(x,y)=\begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \dots & \dots & \dots & \dots \\ f(M,1) & f(M,2) & \dots & f(M,N) \end{bmatrix}$$

Representation of Digital Image

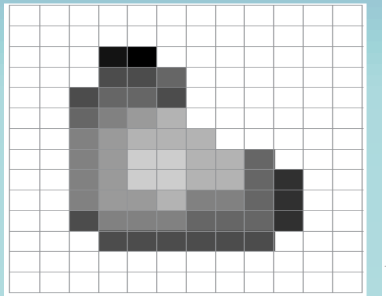
Formally,

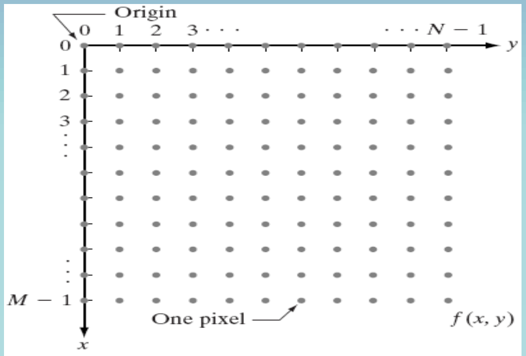
- Sampling:
  - Dividing (x, y) plane into grid with coordinate (z_i, z_j), where,

$$z_i, z_j \in Z$$

- Quantization:
  - Assign gray level value from Z to $f(z_i, z_j)$

Spatial Resolution





- **Spatial resolution**: *M x N*
  - Number of Rows (*M*) and Columns (*N*) can be any integer
- Bit size of an image: $$b = M \times N \times k$$
- For Square image, $$b = N^2 k$$

An image that is 2048 pixels in width and 1536 pixels in height has a total of 2048×1536 = 3,145,728 pixels or 3.1 megapixels.
Here, spatial resolution is 3.1-megapixel.
One could refer to it as 2048 by 1536 or a 3.1-megapixel image.

Intensity (Gray) Level Resolution

Intensity level resolution refers to the number of intensity levels used to represent the image

- **Intensity (Gray) level resolution**: L
- Number of gray levels, L, is usually power of 2:

$$L = 2^k$$

- k = Bit depth

Where k = 8

$L = 2^8$

$L = 256.$

- Gray level range = [0 – L-1]
  = [0 – 255]

Intensity (Gray) Level Resolution

- The more intensity levels used, the finer the level of detail discernable in an image
- Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

Number of storage of bits:

N * M: the no. of pixels in all the image.

K: no. of bits in each pixel

L: grayscale levels the pixel can represent

$L = 2^K$

all bits in image= N*N*k

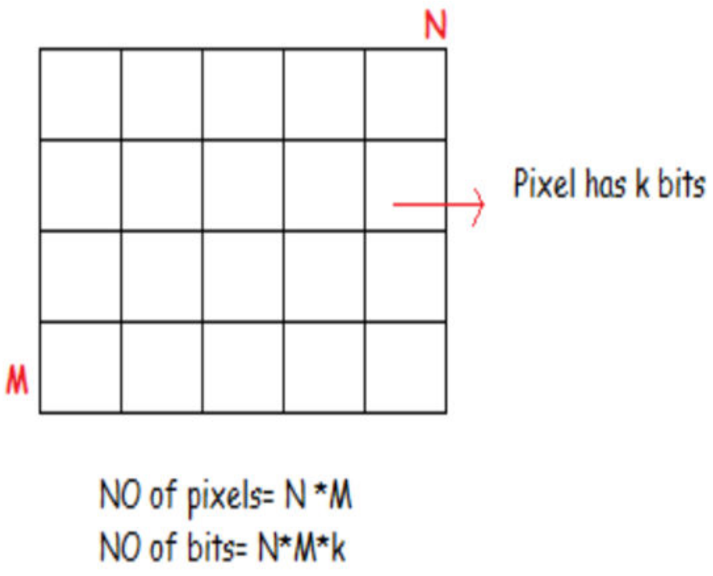


Image Sizes in bits for Different Spatial and Gray Level Resolutions

N/k	1 (L = 2)	2 (L = 4)	3 (L = 8)	4 (L = 16)	5 (L = 32)	6 (L = 64)	7 (L = 128)	8 (L = 256)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

- The calculation is for square images
  - N = number of row/column
  - L = gray level resolution
  - K= bit required to represent gray levels

Answer the questions:

Q1: Suppose a pixel has 1 bit, how many gray levels can it represent?

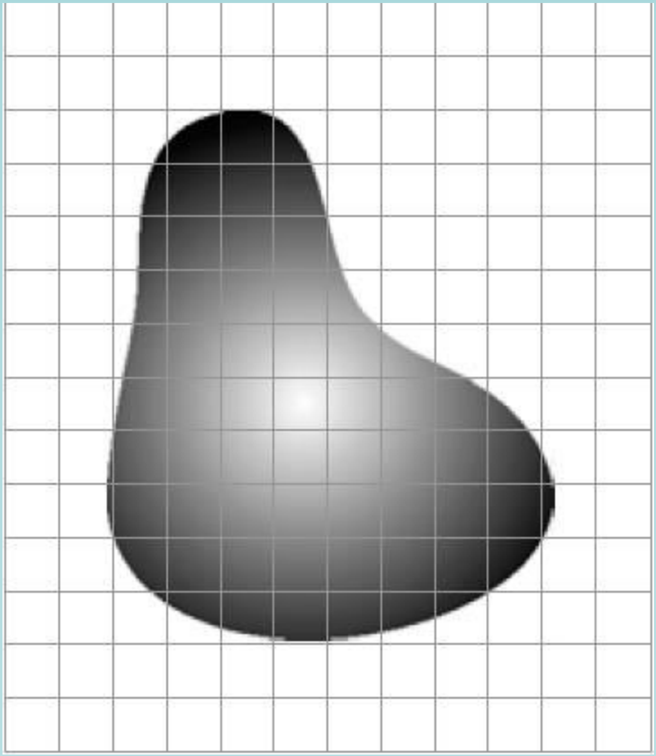
Q2: Suppose a pixel has 2 bit, how many gray levels can it represent?

Q3: Suppose a pixel has p bit, how many gray levels can it represent?

Q4: if we want to represent 256 intensities of grayscale, how many bits do we need?

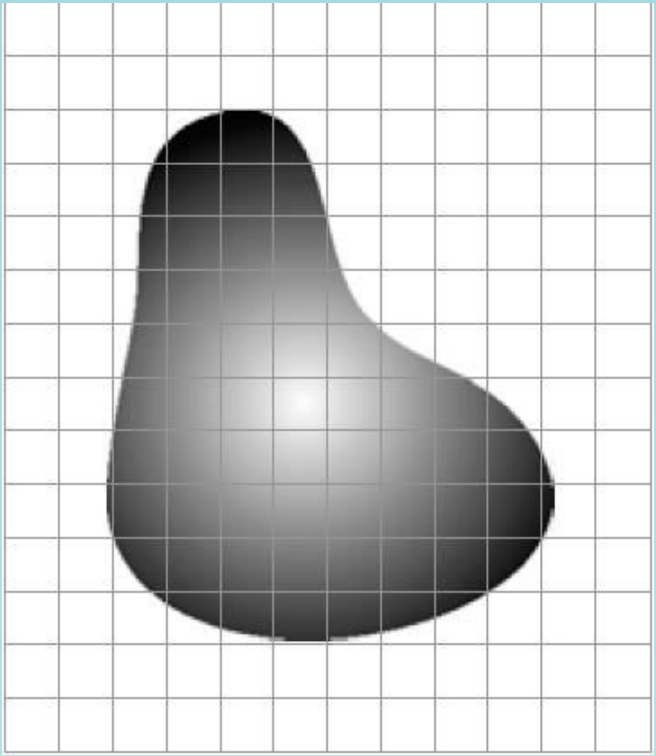
Q5: What is the Gray Level Resolution and Spatial Resolution of a 3 bit 5x5 image? What will be the image size in bits? How many gray levels can be there in the image? What is bit depth?

Effect of Spatial and Gray Level **Resolutions**



- 14X12 resolution means samples from **14X12**
- What happens, if we sample from **8X8** locations?

Effect of Spatial and Gray Level Resolutions



- 14X12 resolution means samples from **14X12**
- What happens, if we sample from **8X8** locations?

- Larger cell size
- Lower spatial resolution
- Lower features spatial accuracy
- Lower file size, faster display and faster processing time

Effect of Spatial Resolutions

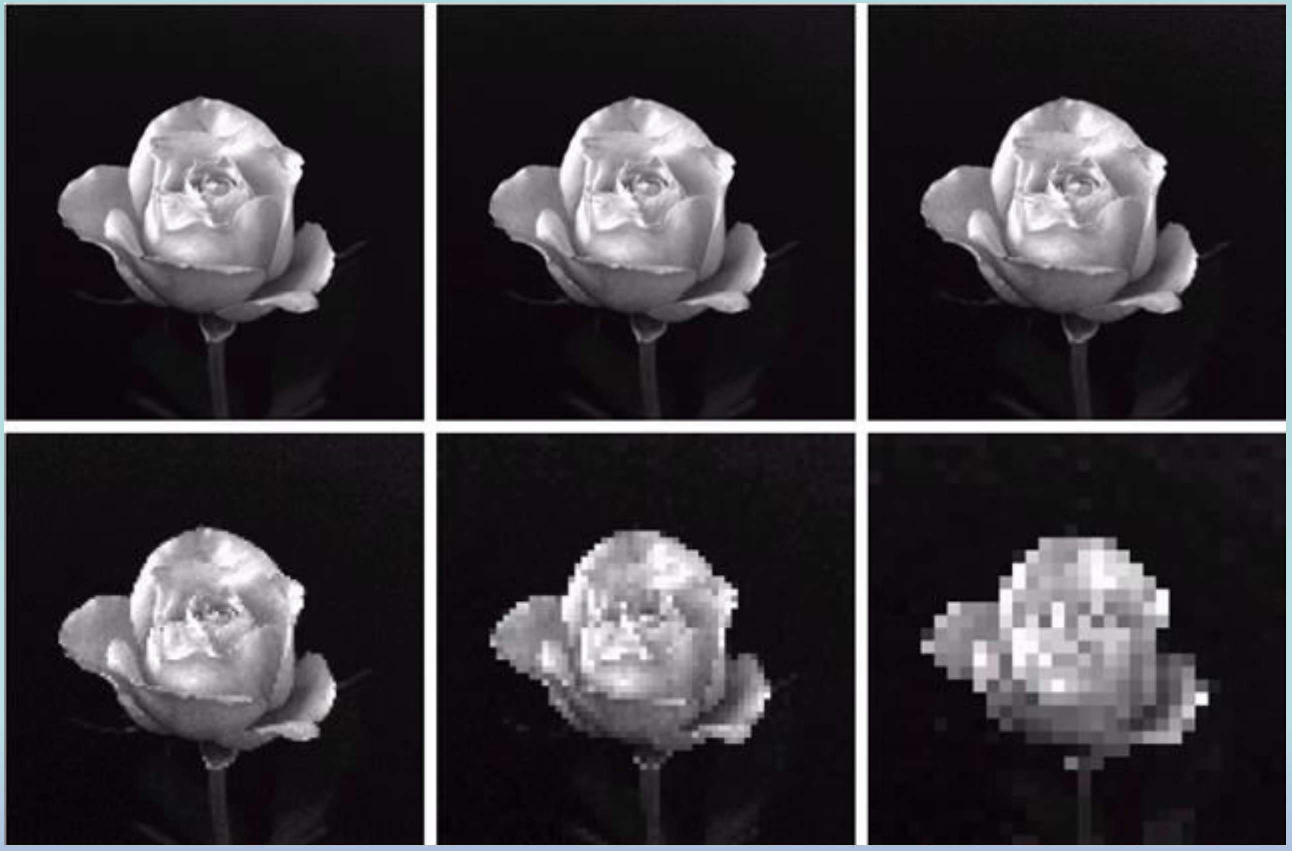
- Sub sampled from 1024X1024 up to 32X32
- unchanged gray level (intensity)
- **Delete** alternate row and column while **sub sampling**

Effect of Spatial Resolutions

Resized to 1024 x 1024

From → 1024X1024 512X512 256X256

Using column duplication process



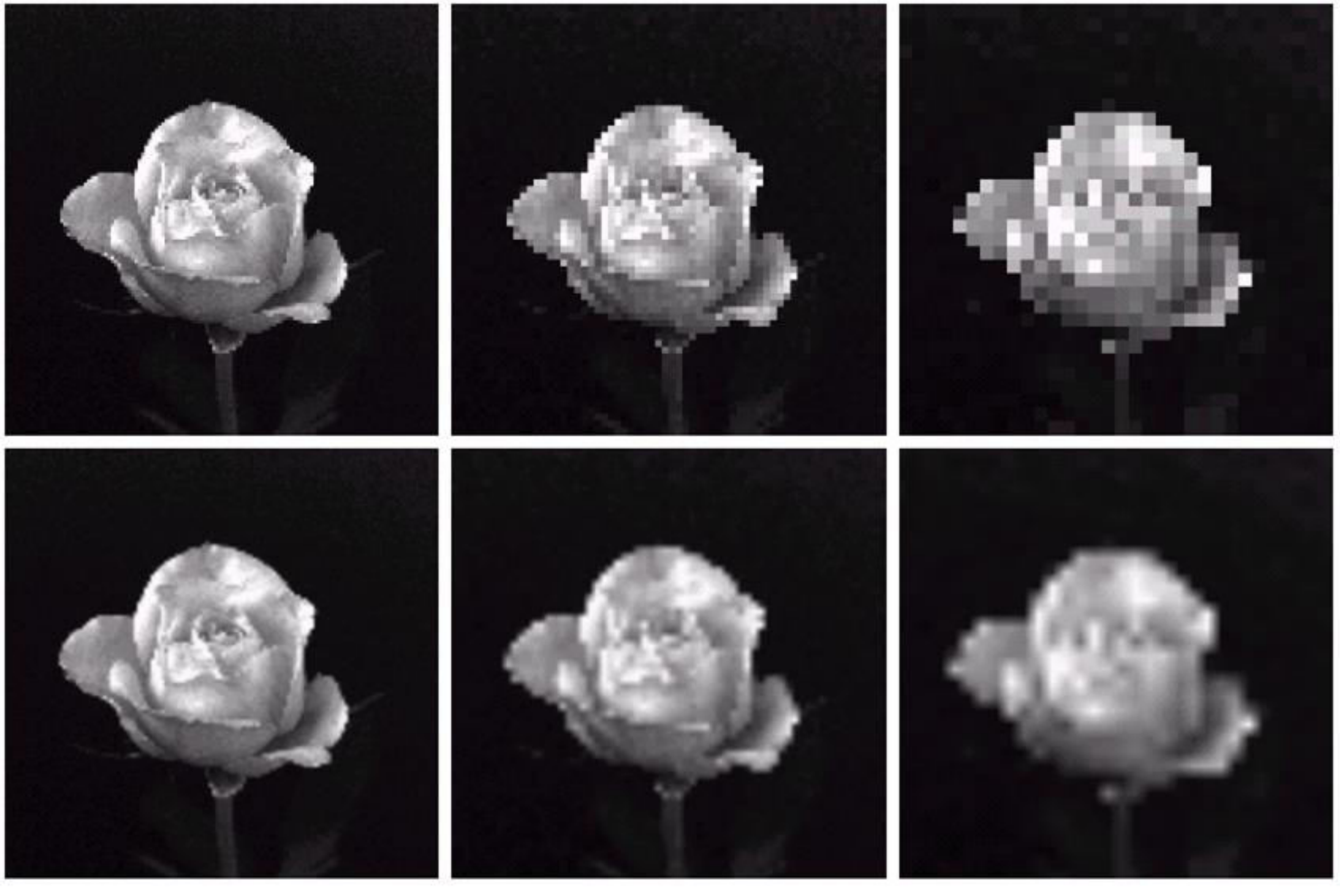
From → 128X128 64X64 32X32

Can we increase spatial resolution ?

From → 128X128 64X64 32X32

Using nearest neighbor

Using bilinear interpolation



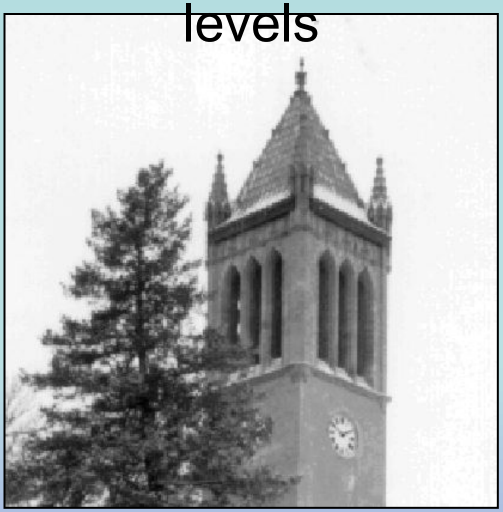
From → 128X128 64X64 32X32

Down sampling is an irreversible process.

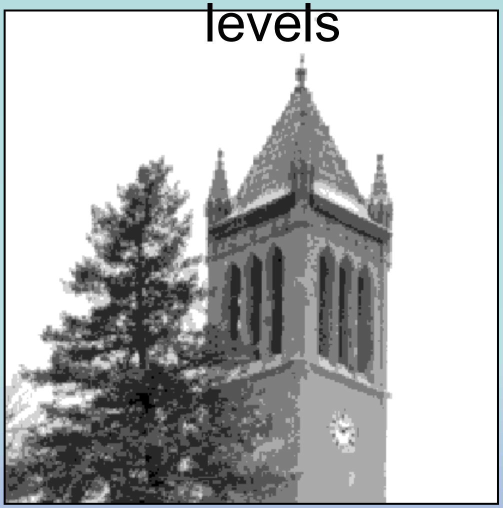
Effect of Gray level Resolutions

256 levels

128 levels



64 levels



32 levels

- unchanged spatial resolution
- Gray level changed from 256 to 32

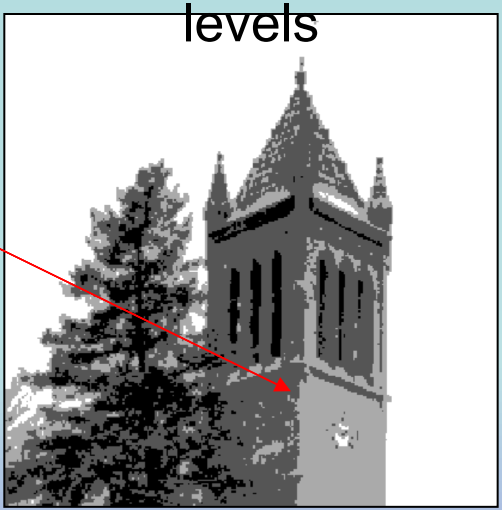
Effect of Gray level Resolutions

- Gray level changed from 16 to 2

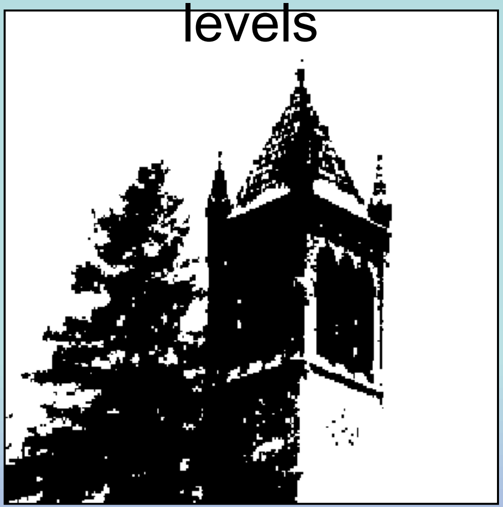
16 levels

8 levels

In this image,
it is easy to see
false contour.

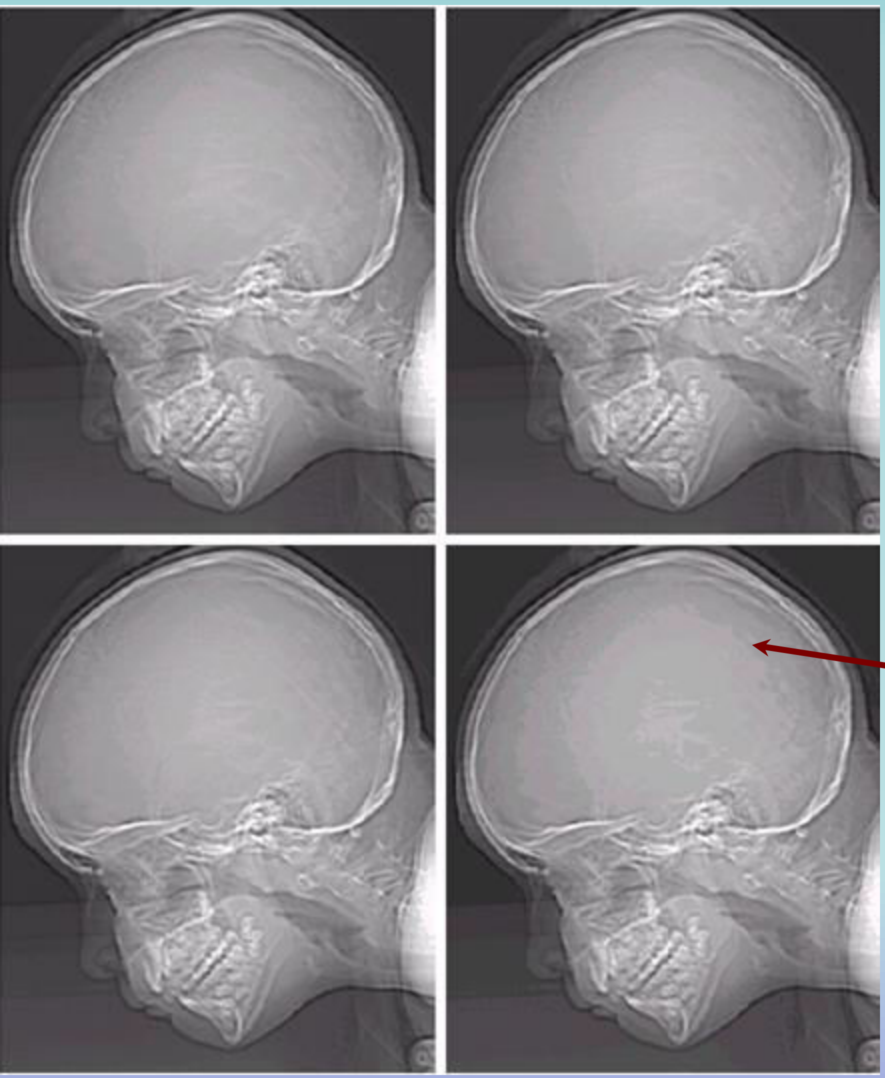


4 levels



2 levels

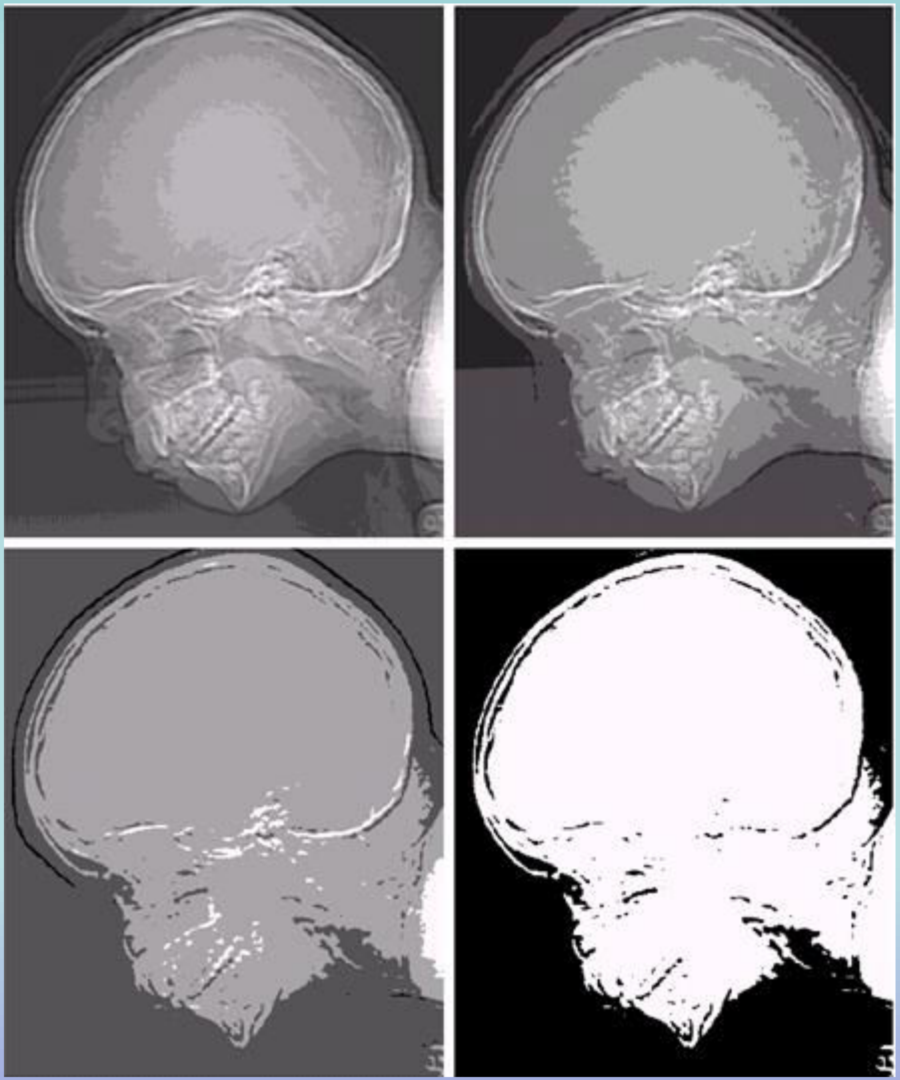
Effect of Gray level Resolutions



- unchanged spatial resolution
- Gray level changed from 256 to 32

Ridge-like structure in the smooth area

Effect of Spatial and Gray Level Resolutions



- Gray level changed from 16 to 2

  - Ridge-like structure is more prominent
  - Reason: insufficient number of gray levels used

Resolution: How Much Is Enough?

- The big question with resolution is always *how much is enough*?
  - This all depends on what is in the image and what you would like to do with it
  - Key questions include
    - Does the image look aesthetically pleasing?
    - Can you see what you need to see within the image?

Resolution: How Much Is Enough? (cont…)

- The picture on the right is fine for counting the number of cars, but not for reading the number plate

How to select the suitable size and pixel depth of images

The word “suitable” is subjective: depending on “subject”.

Low detail image | Medium detail image | High detail image

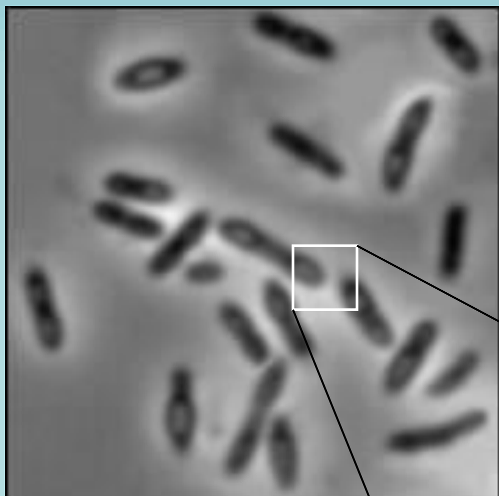
Lena image | Cameraman image

To satisfy human mind

1.For images of the same size, the low detail image may need more pixel depth.

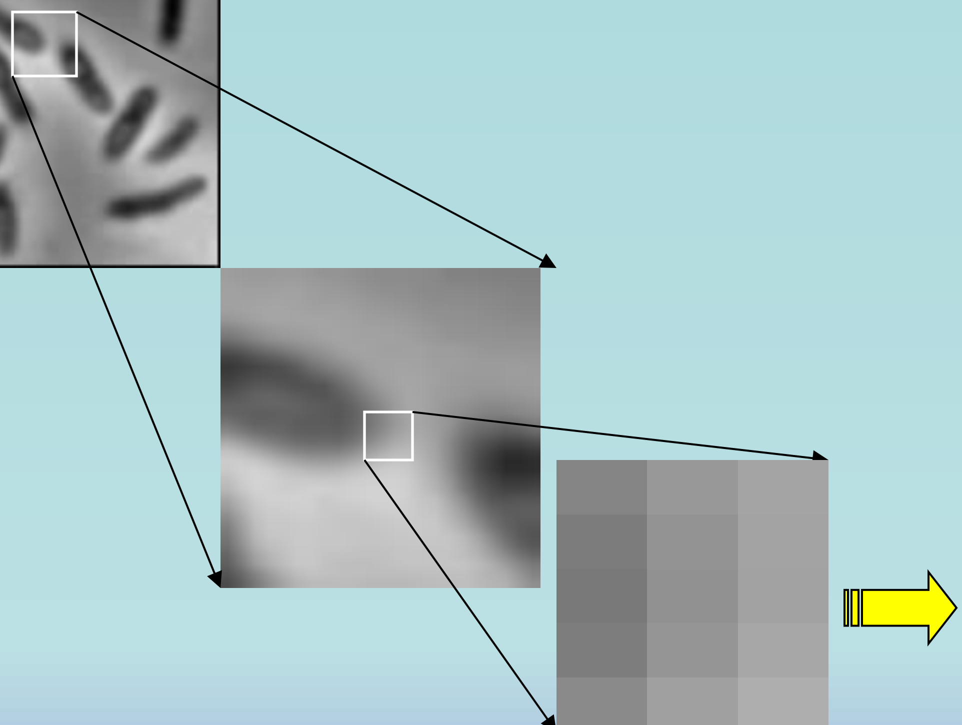
2. As an image size increase, fewer gray levels may be needed.

Digital Image Types : **Intensity Image**



Intensity image or monochrome image

each pixel corresponds to light intensity normally represented in gray scale (gray level).



Gray scale values

$$\begin{bmatrix} 10 & 10 & 16 & 28 \\ 9 & 6 & 26 & 37 \\ 15 & 25 & 13 & 22 \\ 32 & 15 & 87 & 39 \end{bmatrix}$$

Digital Image Types : **RGB Image**

Color image or RGB image: each pixel contains a vector representing red, green and blue components.

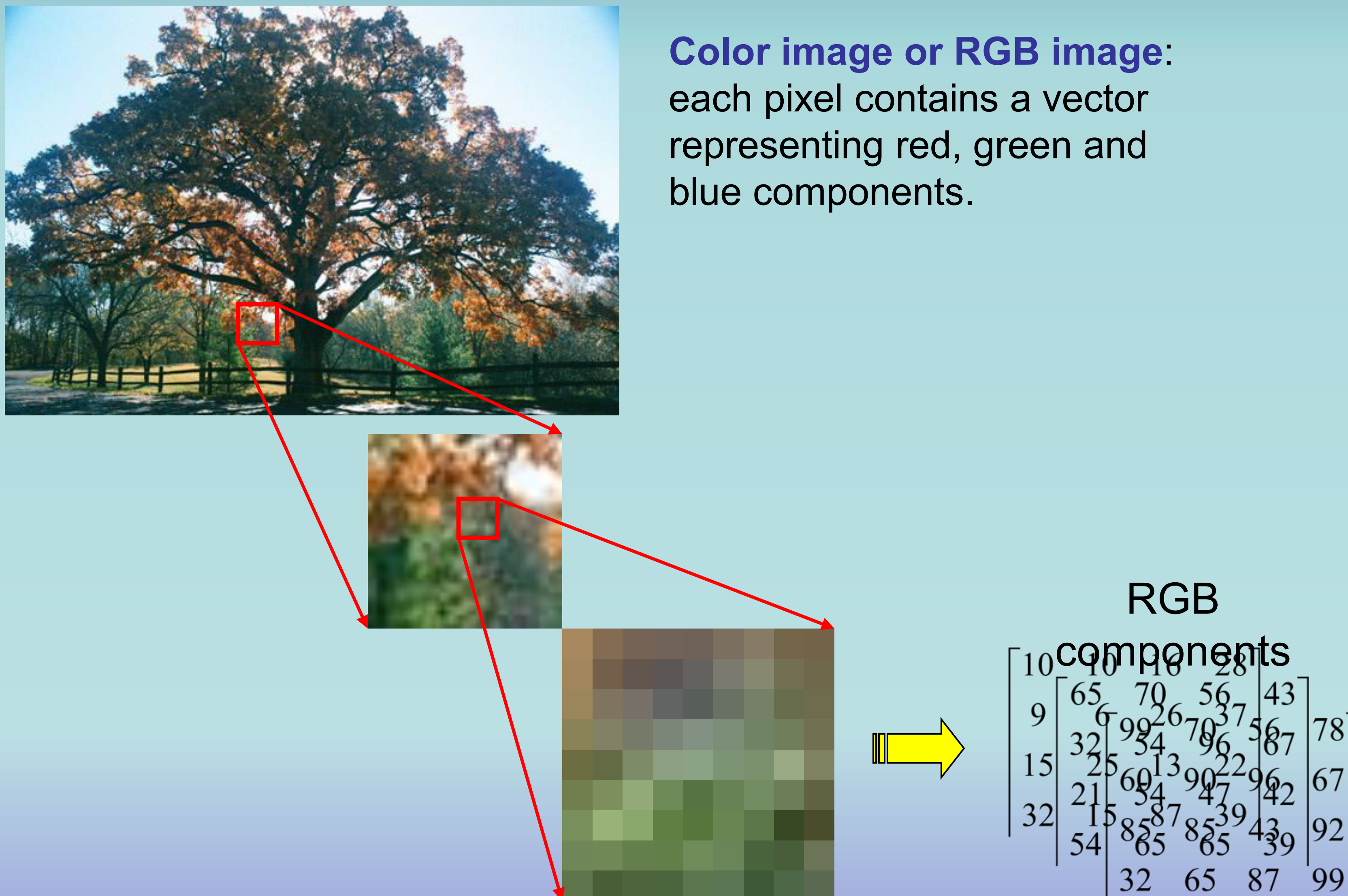


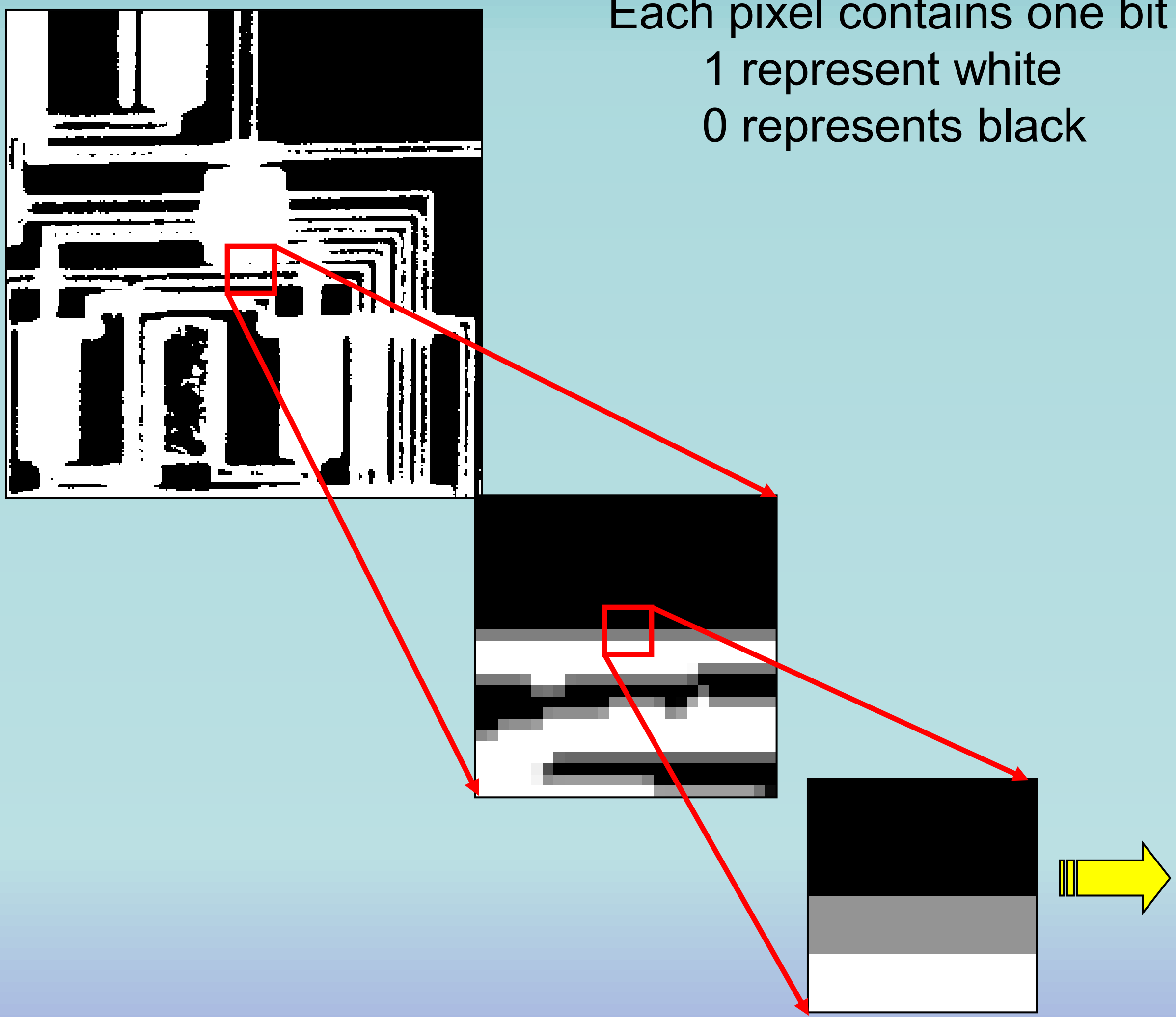
Image Types : **Binary Image**

Binary image or black and white image

Each pixel contains one bit :

1 represent white

0 represents black



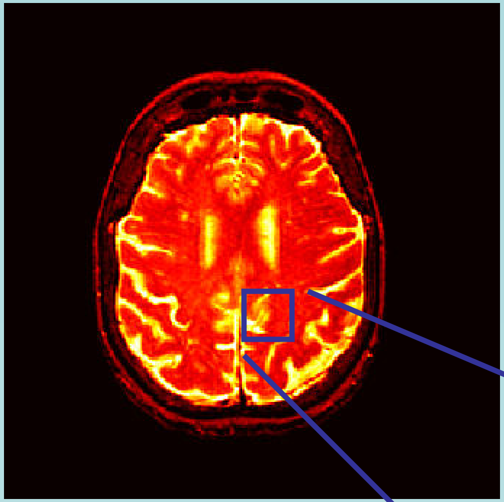
Binary data

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

Image Types : **Index Image**

Index image

Each pixel contains index number pointing to a color in a color table



$$\begin{bmatrix} 1 & 4 & 9 \\ 6 & 4 & 7 \\ 6 & 5 & 2 \end{bmatrix}$$

Index value

Color Table

Index No.	Red component	Green component	Blue component
1	0.1	0.5	0.3
2	1.0	0.0	0.0
3	0.0	1.0	0.0
4	0.5	0.5	0.5
5	0.2	0.8	0.9
…	…	…	…

Image Scaling (Zooming & Shrinking)

- Zooming/up scaling/resizing upward can be achieved by the following techniques:
  - ❑Pixel Replication
  - ❑Interpolation
    - –Nearest Neighbor Interpolation
    - –Bilinear Interpolation
    - –Bicubic Interpolation

Image Scaling (Zooming and Shrinking)

- **Pixel Replication**

  - Pixel replication is applicable when we want to increase the size of an image an integer number of times.
  - For example to double the size of an image we can duplicate each column, this doubles the size of image in horizontal direction. Then we duplicate each row of the enlarged image to double the size in the vertical direction
  - The same procedure can be applied to enlarge the image by any integer number of times (triple, quadruple and so on)
  - The gray level assignment of each pixel is predetermined by the fact that new locations are exact duplicate of old locations

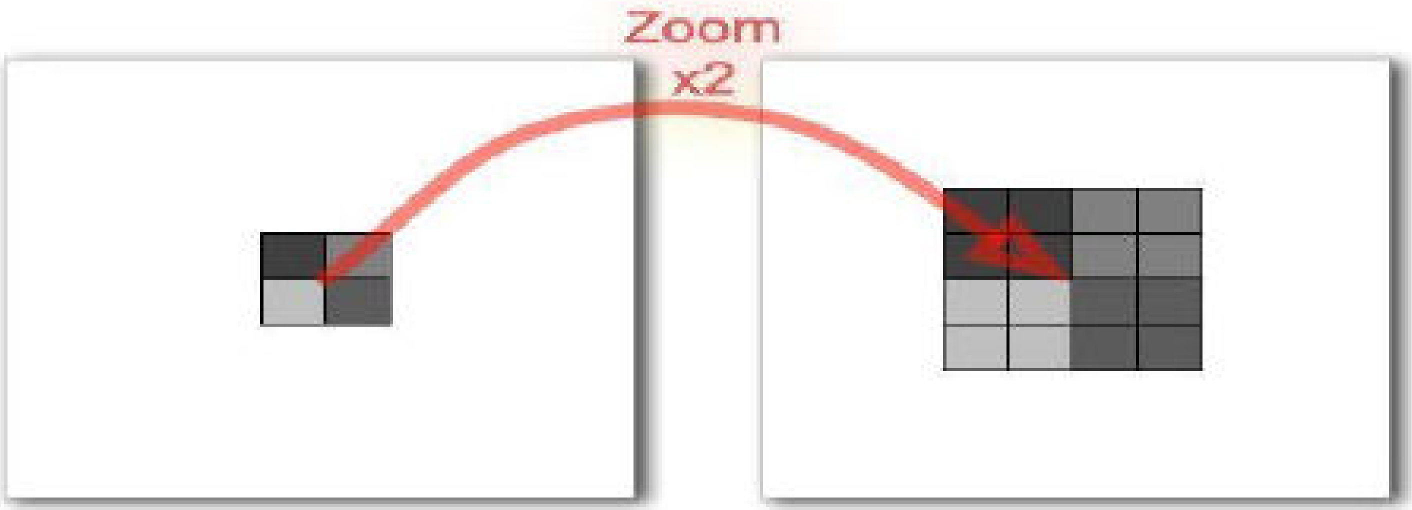


Image Scaling (Zooming and Shrinking)

- **Nearest neighbor Interpolation**

  - Suppose that we have an image of size 500 x 500 and we want to enlarge it to 1.5 times 750 x 750 pixels.

  - For any zooming approach we have to create an imaginary grid of the size which is required over the original image. In that case we will have an imaginary grid of 750 x 750 over an original image.

  - Obviously the spacing in the grid would be less than one pixel because we fitting it over a smaller image. In order to perform gray level assignment for any point in the overlay, we look for the closest pixel in the original image and assign its gray level to new pixel in the grid.

  - When finished with all points in the grid, we can simply expand it to the originally specified size to obtain the zoomed image. **This method of gray level assignment is called nearest neighbor interpolation**

3x3 matrix is interpolated to 6x6 matrix

10	4	22
2	18	7
9	14	25

10	10	4	4	22	22
10	10	4	4	22	22
2	2	18	18	7	7
2	2	18	18	7	7
9	9	14	14	25	25
9	9	14	14	25	25

Steps to be performed:

1. Consider a matrix A = $\begin{bmatrix} 10 & 4 & 22 \\ 2 & 18 & 7 \\ 9 & 14 & 25 \end{bmatrix}$ where number of rows = 3 and number of columns = 3
2. Define the new size for the matrix , number of rows = 6 and number of columns = 6
3. Find the Ratio of the new size and old size,

   $Ratio_{Row} = \frac{3}{6}$ and $Ratio_{Column} = \frac{3}{6}$
4. Normalize the row-wise pixel positions and column wise pixel positions based on the new size

   $$Row_{Positions} = \frac{[1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6]}{Ratio\_Row} = [0.5 \quad 1 \quad 1.5 \quad 2 \quad 2.5 \quad 3]$$

5. By using ceil function that gives the least integer greater than or equal to the value, the $Row_{position} = \begin{bmatrix} 1 \\ 1 \\ 2 \\ 2 \\ 3 \\ 3 \end{bmatrix}$ and

$Column_{position} = \begin{bmatrix} 1 & 1 & 2 & 2 & 3 & 3 \end{bmatrix}$

6. Perform row-wise interpolation on the columns of the matrix, For instance, consider the first column of the matrix,

$$\begin{bmatrix} \color{red}{10} \\ \color{green}{2} \\ 9 \end{bmatrix} \quad Row_{position} = \begin{bmatrix} \color{red}{1} \\ \color{red}{1} \\ \color{green}{2} \\ \color{green}{2} \\ 3 \\ 3 \end{bmatrix},$$

so the first column after interpolation $\begin{bmatrix} \color{red}{10} \\ \color{red}{10} \\ \color{green}{2} \\ \color{green}{2} \\ 9 \\ 9 \end{bmatrix}$,

7. Similarly, perform the row-wise interpolation on all the columns of the matrix,

$$\begin{bmatrix} 10 & 4 & 22 \\ 10 & 4 & 22 \\ 2 & 18 & 7 \\ 2 & 18 & 7 \\ 9 & 14 & 25 \\ 9 & 14 & 25 \end{bmatrix}$$

8. Perform column wise interpolation,

Take the first row from the row-wise interpolated matrix A, $[10 \quad 4 \quad 22]$ and based on the column_position, the values are interpolated. The column position 1 indicates the 1st element ie. 10 , 2 indicates the 2nd element (i.e) 4 so the interpolated first row is $[10 \quad 10 \quad 4 \quad 4 \quad 22 \quad 22]$

$$First\ row = [10 \quad 4 \quad 22], Column_{position} = [1 \quad 1 \quad 2 \quad 2 \quad 3 \quad 3]$$

$$Interpolated\ first\ row\ is\ [10 \quad 10 \quad 4 \quad 4 \quad 22 \quad 22]$$

9. Similarly, perform this column wise interpolation on all the row wise interpolated rows,

10. The interpolated 6x6 matrix is

$$\begin{bmatrix} 10 & 10 & 4 & 4 & 22 & 22 \\ 10 & 10 & 4 & 4 & 22 & 22 \\ 2 & 2 & 18 & 18 & 7 & 7 \\ 2 & 2 & 18 & 18 & 7 & 7 \\ 9 & 9 & 14 & 14 & 25 & 25 \\ 9 & 9 & 14 & 14 & 25 & 25 \end{bmatrix}$$

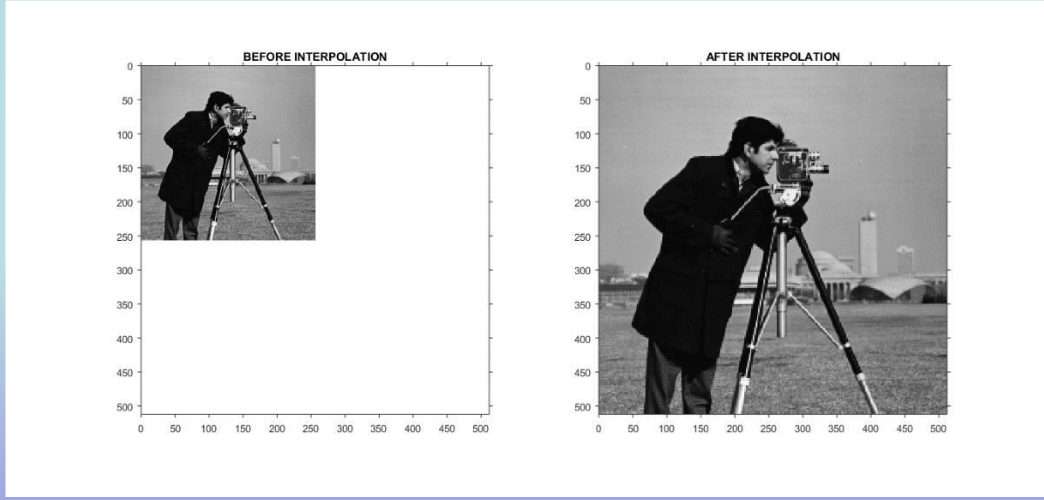


Image Scaling (Zooming and Shrinking)

- **Shrinking (Down scaling, resizing downward)**

  - Image shrinking is done in the similar manner as zooming with one difference as now the process of pixel replication is row column deletion. Now we can delete every second column and row for shrinking

Class Work:

- Interpolate a 2x2 matrix [1, 4, 3, 7] to 4x4
- Interpolate a 3x3 matrix [1,4,3,7,2,3,5,6,0] to 9x9
- Interpolate a 2x2 matrix [1, 2, 3, 4] to 8x8
- Interpolate a 3x3 matrix [1,4,3, 7, 5, 6] to 6x6

Image Scaling (Zooming and Shrinking)

- **Bilinear Interpolation**

    - Bilinear interpolation considers the closest 2x2 neighborhood of known pixel values surrounding the unknown pixel.

    - It then takes a weighted average of these 4 pixels to arrive at its final interpolated value. This results in much smoother looking images than nearest neighbor.

    - The diagram below is for a case when all known pixel distances are equal, so the interpolated value is simply their sum divided by four.

    - In case the distance varies then The closer pixels are given more weightage in the calculation

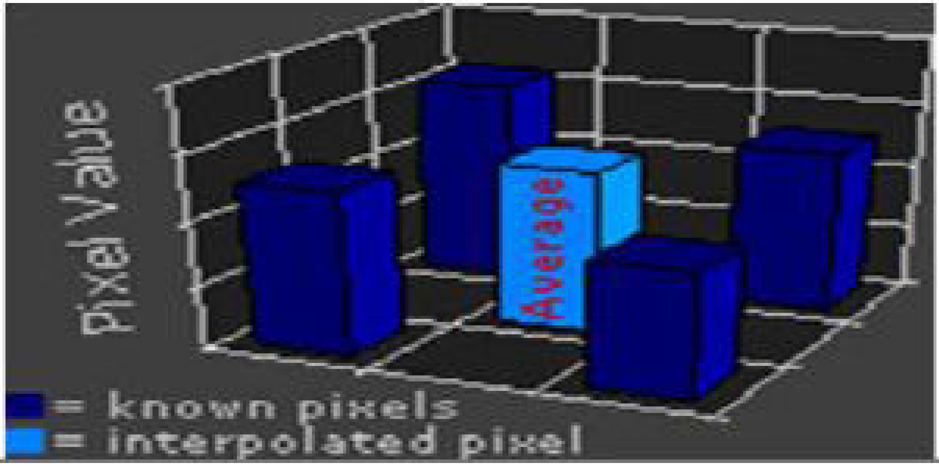


Image Scaling (Zooming and Shrinking)

- The key idea is to perform linear interpolation first in one direction, and then again in the other direction.

- Suppose that we want to find the value of the unknown function *f* at the point $P = (x, y)$.

- It is assumed that we know the value of *f* at the four points $Q11 = (x1, y1)$, $Q12 = (x1, y2)$, $Q21 = (x2, y1)$, and $Q22 = (x2, y2)$.

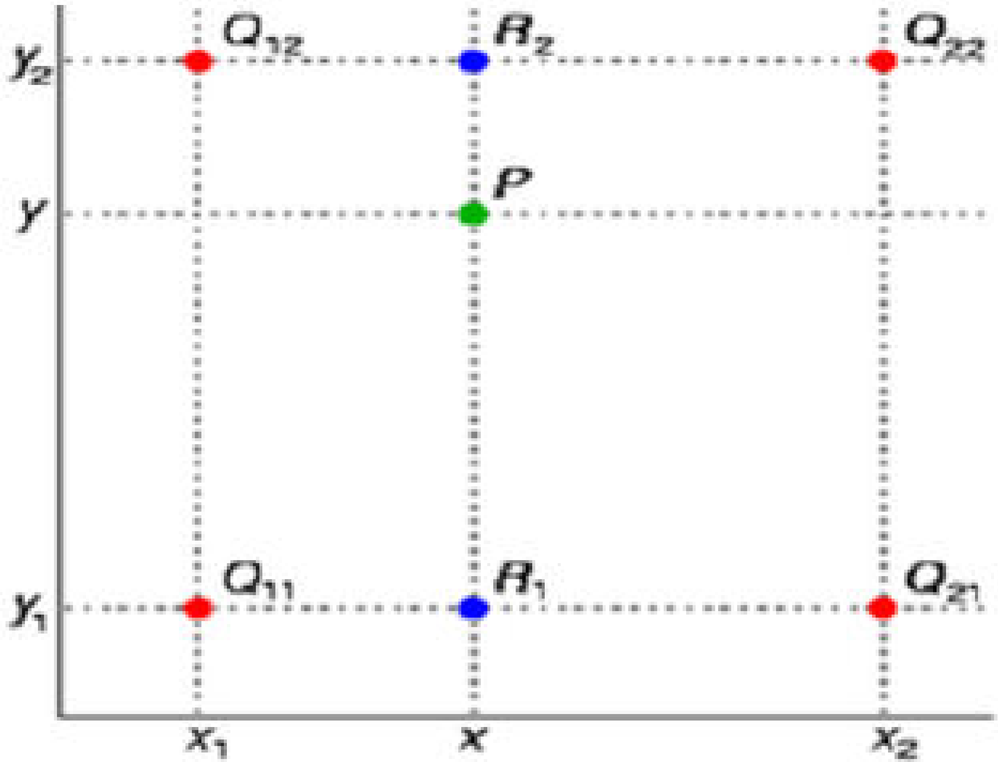


Image Scaling (Zooming and Shrinking)

We first do linear interpolation in the *x*-direction. This yields

$$f(R_1) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{11}) + \frac{x - x_1}{x_2 - x_1} f(Q_{21})$$

where *R*1 = (*x*,*y*1),

$$f(R_2) \approx \frac{x_2 - x}{x_2 - x_1} f(Q_{12}) + \frac{x - x_1}{x_2 - x_1} f(Q_{22})$$

where *R*2 = (*x*,*y*2).

$$f(P) \approx \frac{y_2 - y}{y_2 - y_1} f(R_1) + \frac{y - y_1}{y_2 - y_1} f(R_2).$$

We proceed by interpolating in the *y*-direction.

Image Scaling (Zooming and Shrinking)

This gives us the desired estimate of $f(x, y)$.

$$
\begin{aligned}
f(x,y) \approx\ & \frac{f(Q_{11})}{(x_2-x_1)(y_2-y_1)}(x_2-x)(y_2-y) \\
& + \frac{f(Q_{21})}{(x_2-x_1)(y_2-y_1)}(x-x_1)(y_2-y) \\
& + \frac{f(Q_{12})}{(x_2-x_1)(y_2-y_1)}(x_2-x)(y-y_1) \\
& + \frac{f(Q_{22})}{(x_2-x_1)(y_2-y_1)}(x-x_1)(y-y_1).
\end{aligned}
$$

https://theailearner.com/2018/12/29/image-processing-bilinear-interpolation/

https://theailearner.com/2018/12/29/image-processing-bicubic-interpolation//