Image Sensing & Acquisition

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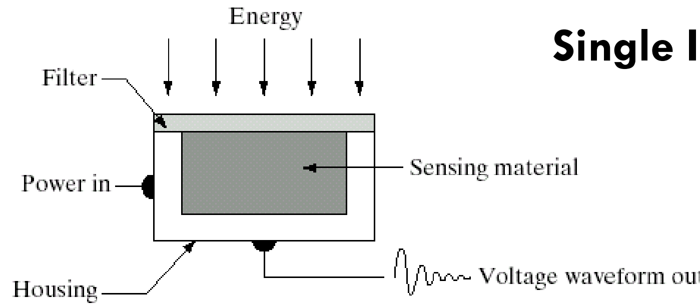
Sensors

Sensors are use to transform illumination energy into digital images.

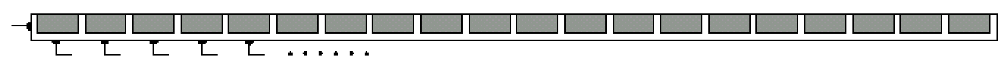
Sensors are three types:

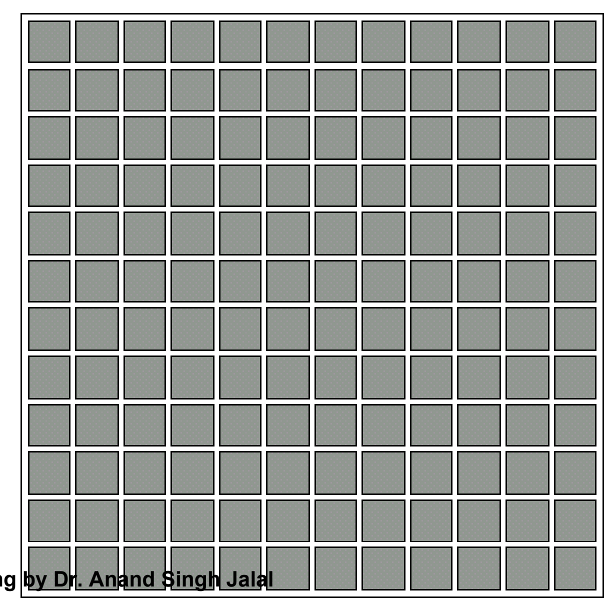
- **Single Imaging Sensor**
- **Line sensor**
- **Array Sensor**



Single Imaging Sensor

Line sensor

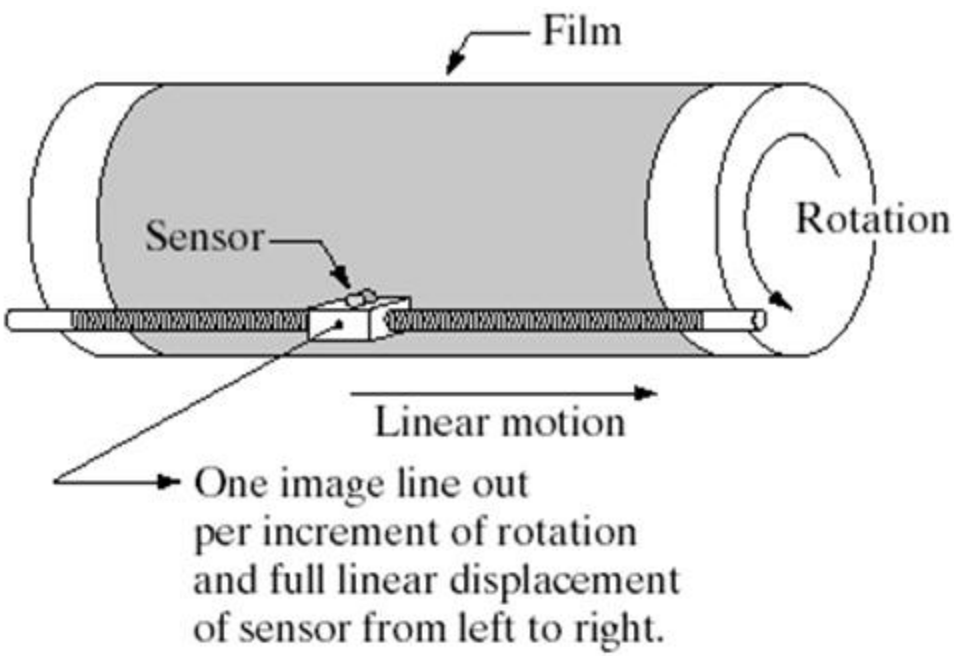




Array Sensor

Sensors: Single Sensors

- **Image acquisition using a single sensor**
- To generate a 2-D image using a single sensor, there has to be relative displacements in both the x- and y-directions between the sensor and the area to be imaged.

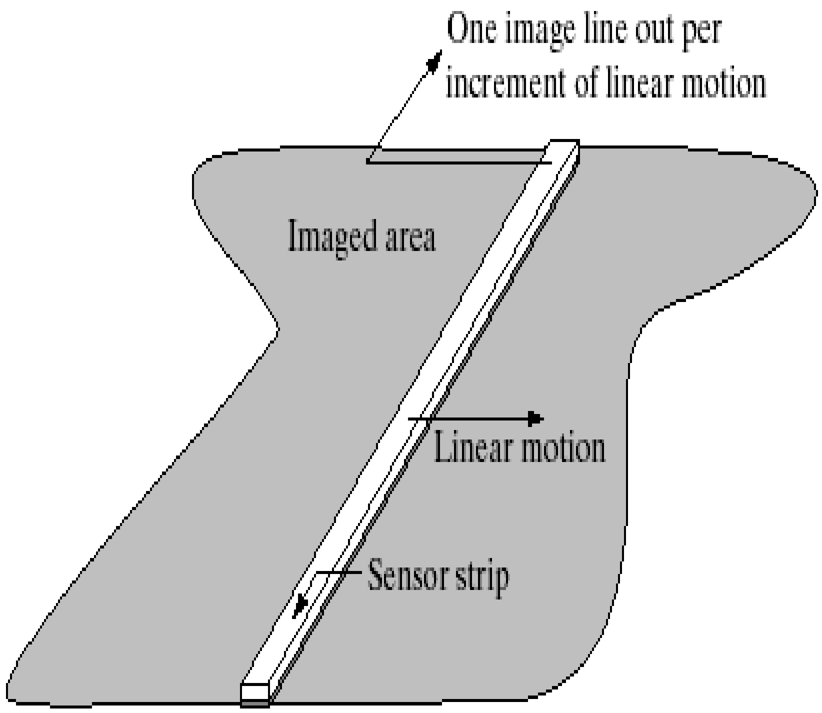


Combining a single sensor with motion to generate a 2-D image.

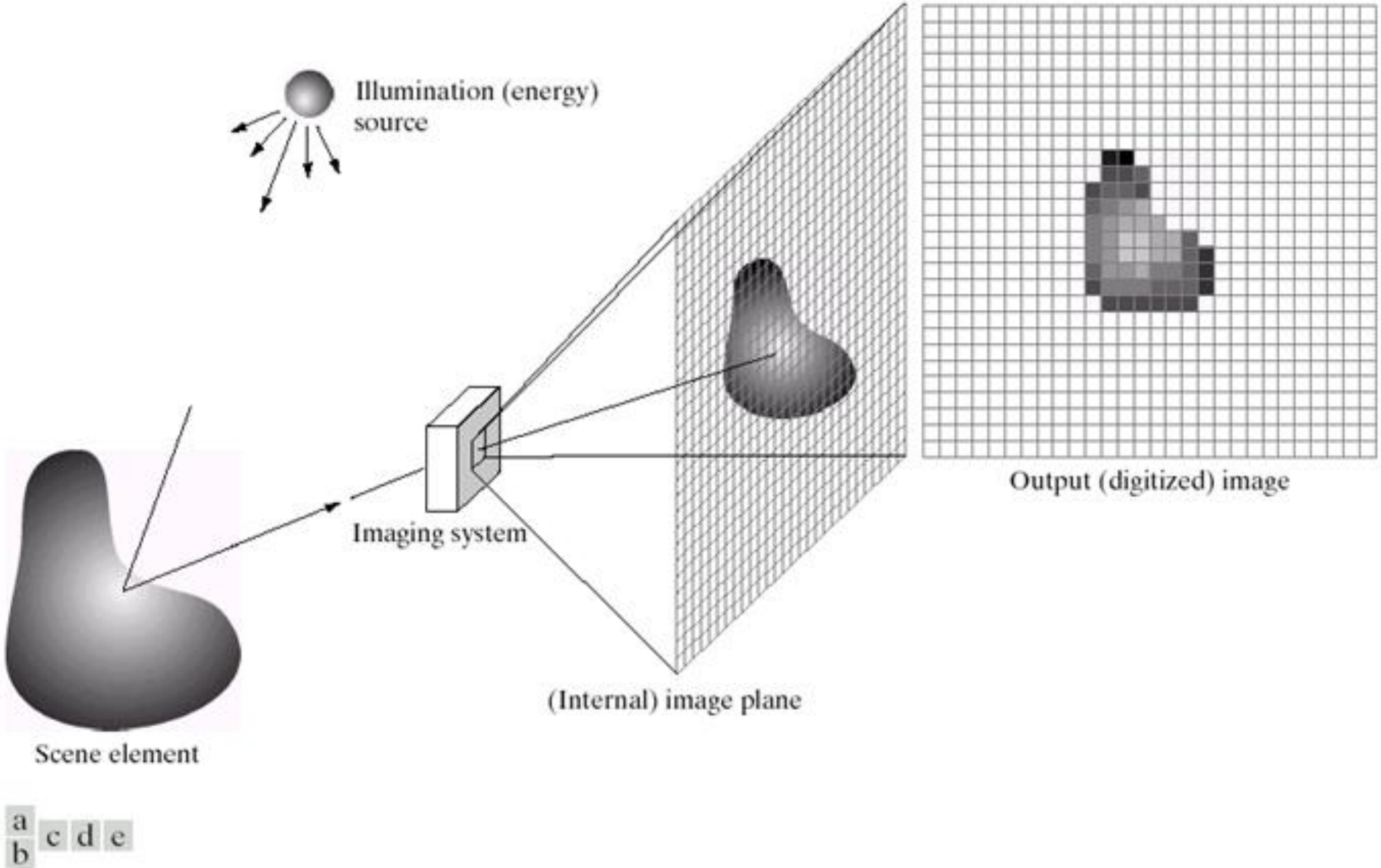
Sensors: Linear Sensor

A geometry that is used much more frequently than single sensors consists of an in-line arrangement of sensors in the form of a sensor strip.

The strip provides imaging elements in one direction. Motion perpendicular to the strip provides imaging in the other direction



Sensors: Array Sensor



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.

A simple image formation model

- Image: a 2-D light-intensity function f(x,y)
- f(x,y): the intensity is called the **gray level** for monochrome image
- $0 < f(x,y) < \infty$

- Nature of f(x,y):
  - The amount of source light incident on the scene being viewed
  - The amount of light reflected by the objects in the scene

A simple image formation model

- Illumination & reflectance components:

  - ✓ Illumination: $i(x,y)$
  - ✓ Reflectance: $r(x,y)$

  - ✓ **$f(x,y) = i(x,y) \cdot r(x,y)$**

  - ✓ $0 < i(x,y) < \infty$

    and $0 < r(x,y) < 1$

    (from total absorption to total reflectance)

A simple image formation model

$$f(x,y) = i(x,y) \cdot r(x,y)$$

Typical values of i(x, y)

- On a sunny day, illumination on earth's surface is 90,000 lm/m^2
- On a cloudy day it is 10,000 lm/m^2
- Full moon yields 0.01 lm/m^2
- Commercial office yields 1000 lm/m^2

Typical values of r(x, y)

- for black velvet – 0.01
- Stainless steel – 0.65
- Flat white wall paint – 0.90
- Snow – 0.93

Image Digitization

- Why do we need digitization?
- What is digitization?
- How to digitize an image?

Why Digitization?

- **Theory of Real numbers -** between any two given points there are infinite number of points
  - An image can be represented by infinite number of points
  - Each such image point may contain one of the infinitely many possible intensity/color values needing infinite number of bits
- **Obviously such a representation is not possible in any digital computer**

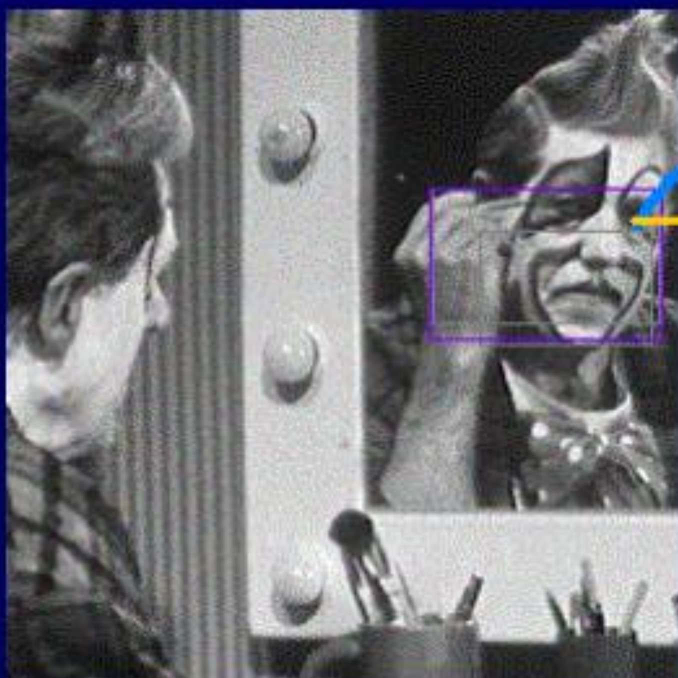
What is desired?

- An image to be represented in the form of a finite 2-D matrix

$$
I = \begin{bmatrix}
f(0,0) & f(0,1) & f(0,2) \ldots\ldots\ldots & f(0,N-1) \\
f(1,0) & f(1,1) & f(1,2) \ldots\ldots\ldots & f(1,N-1) \\
f(2,0) & f(2,1) & f(2,2) \ldots\ldots\ldots & f(2,N-1) \\
\vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots \\
f(M-1,0) & f(M,1) & f(M,2) .. & f(M-1,N-1)
\end{bmatrix}
$$

Each of the matrix elements should assume one of finite discrete values

Image as a Matrix of Numbers



189	184	181	190
183	185	186	183
182	179	185	193
188	192	202	195
194	196	197	198

What is Digitization?

- Image representation by 2-D finite matrix

Sampling

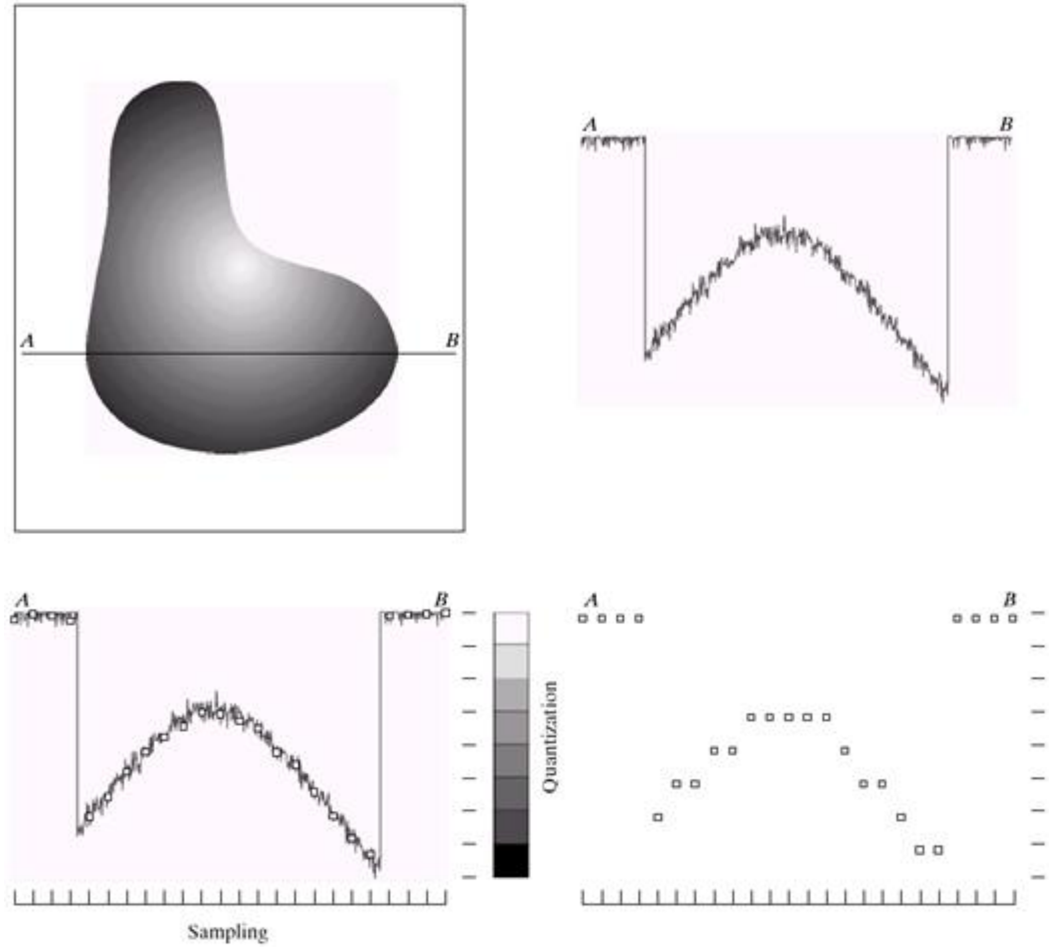
- Each Matrix element represented by one of the finite set of discrete values-

Quantization

Image Sampling and Quantization

- To convert an Image to digital form, we have to sample the Image in both coordinates (spatial domain) and in amplitude.
- Digitizing the coordinate (spatial domain) values is called ***sampling.***
- Digitizing the amplitude values is called ***quantization.***

Sampling and Quantization



a b
c d

Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Sampling and Quantization

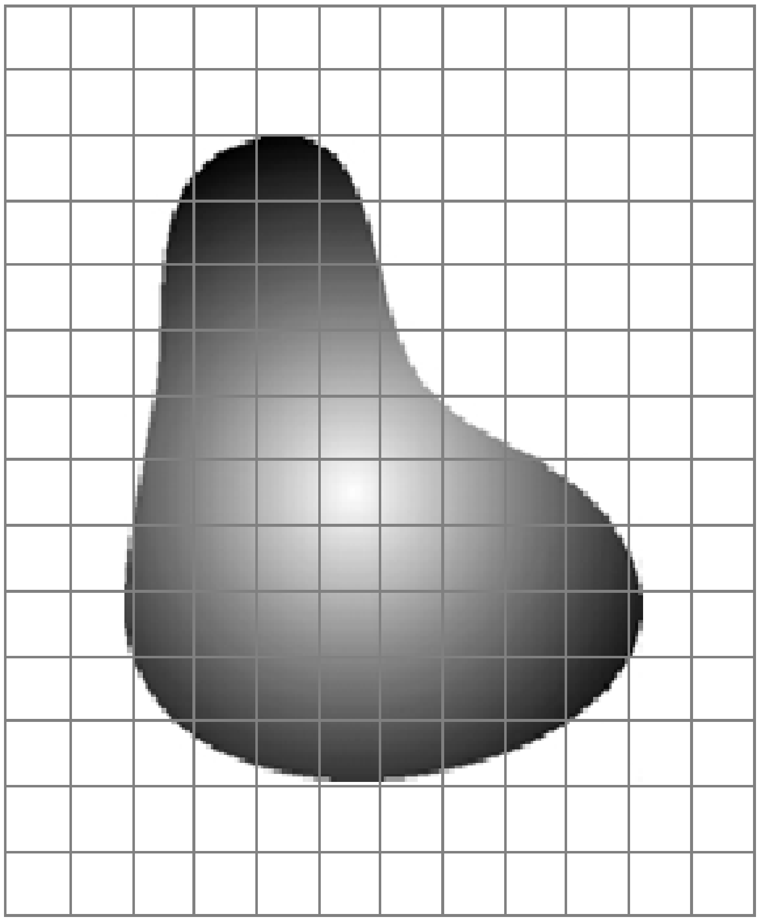
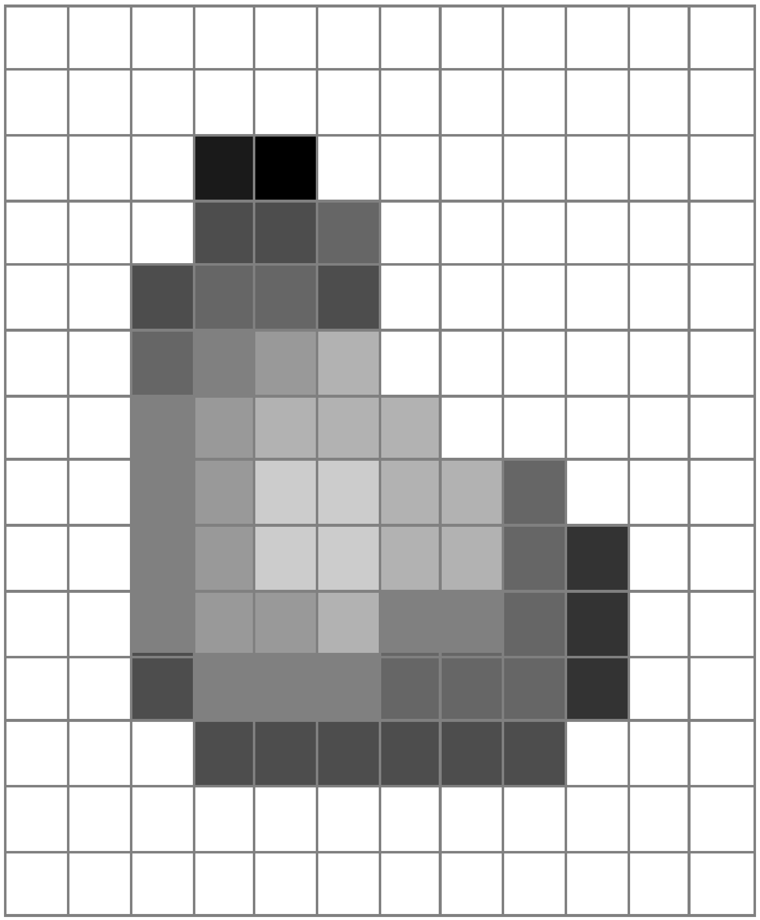


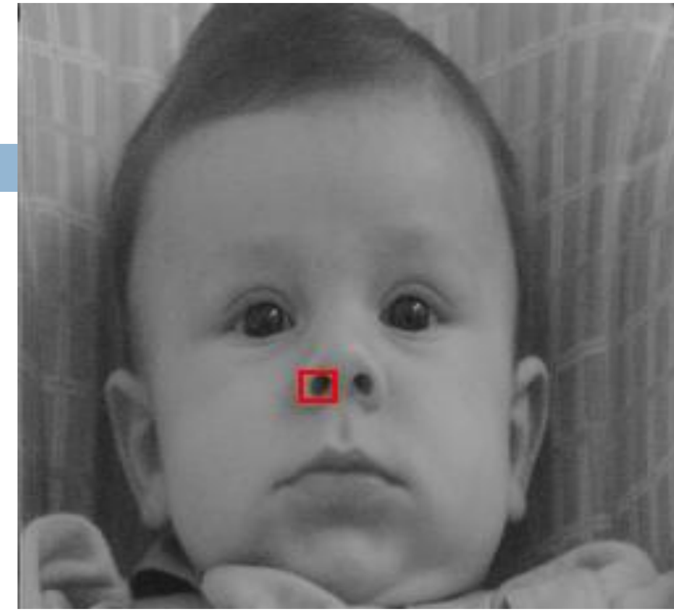
Image before sampling and quantization



Result of sampling and quantization

Digital Image?

- When x, y and the amplitude values of f are finite, discrete quantities, the image is called digital image
- A digital image is composed of a finite number of elements, each of which has a particular location and value. These elements are referred to as picture elements, image elements, pels and pixels.



99	71	61	51	49	40	35	53	86	99
93	74	53	56	48	46	48	72	85	102
101	69	57	53	54	52	64	82	88	101
107	82	64	63	59	60	81	90	93	100
114	93	76	69	72	85	94	99	95	99
117	108	94	92	97	101	100	108	105	99
116	114	109	106	105	108	108	102	107	110
115	113	109	114	111	111	113	108	111	115
110	113	111	109	106	108	110	115	120	122
103	107	106	108	109	114	120	124	124	132

Image Size

- This digitization process requires decisions about values for M, N, and for the number, L, of discrete gray levels allowed for each pixel. Where *M* and *N*, are positive integers. However, due to processing, storage, and sampling hardware considerations, the number of gray levels typically is an integer power of 2:

$$\mathbf{L = 2^K}$$

  Where k is number of bits require to represent a grey value
- The discrete levels should be equally spaced and that they are integers in the interval [0, L-1].

Image Size

- The number, b, of bits required to store a digitized image is

$$b=M*N*k.$$

- For an image of 512 by 512 pixels, with 8 bits per pixel:
  - Memory required = 256K bytes= 0.25 megabytes

Coordinate Convention used

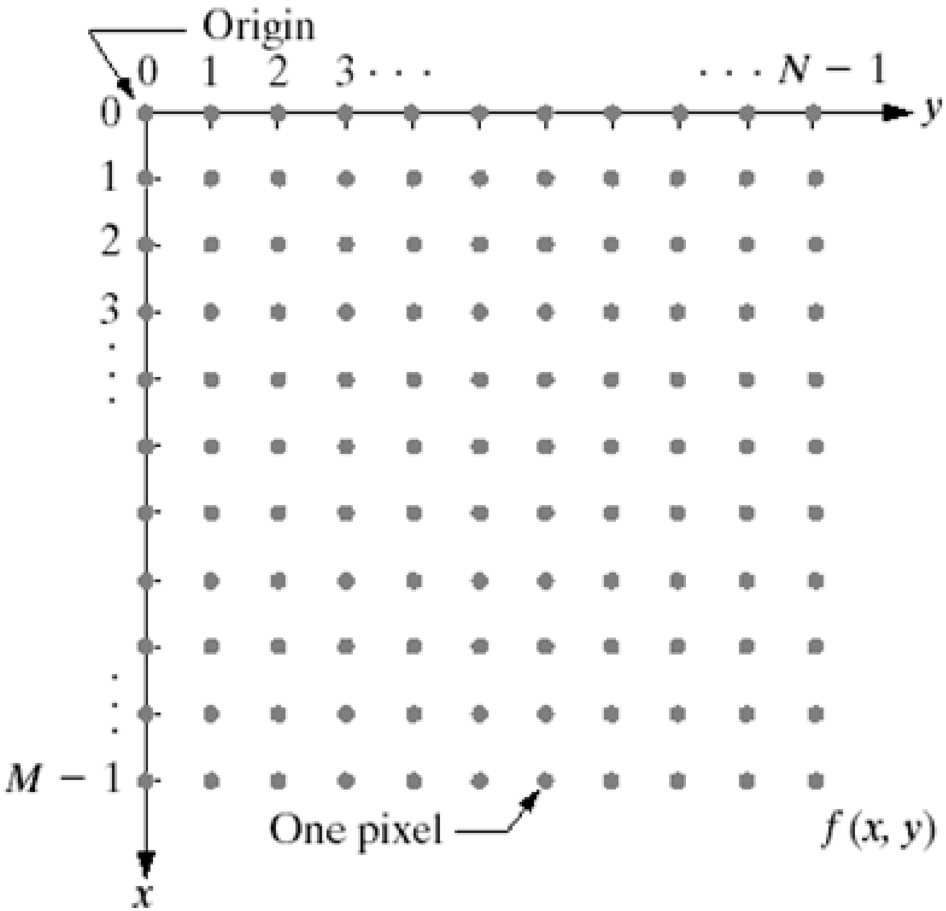


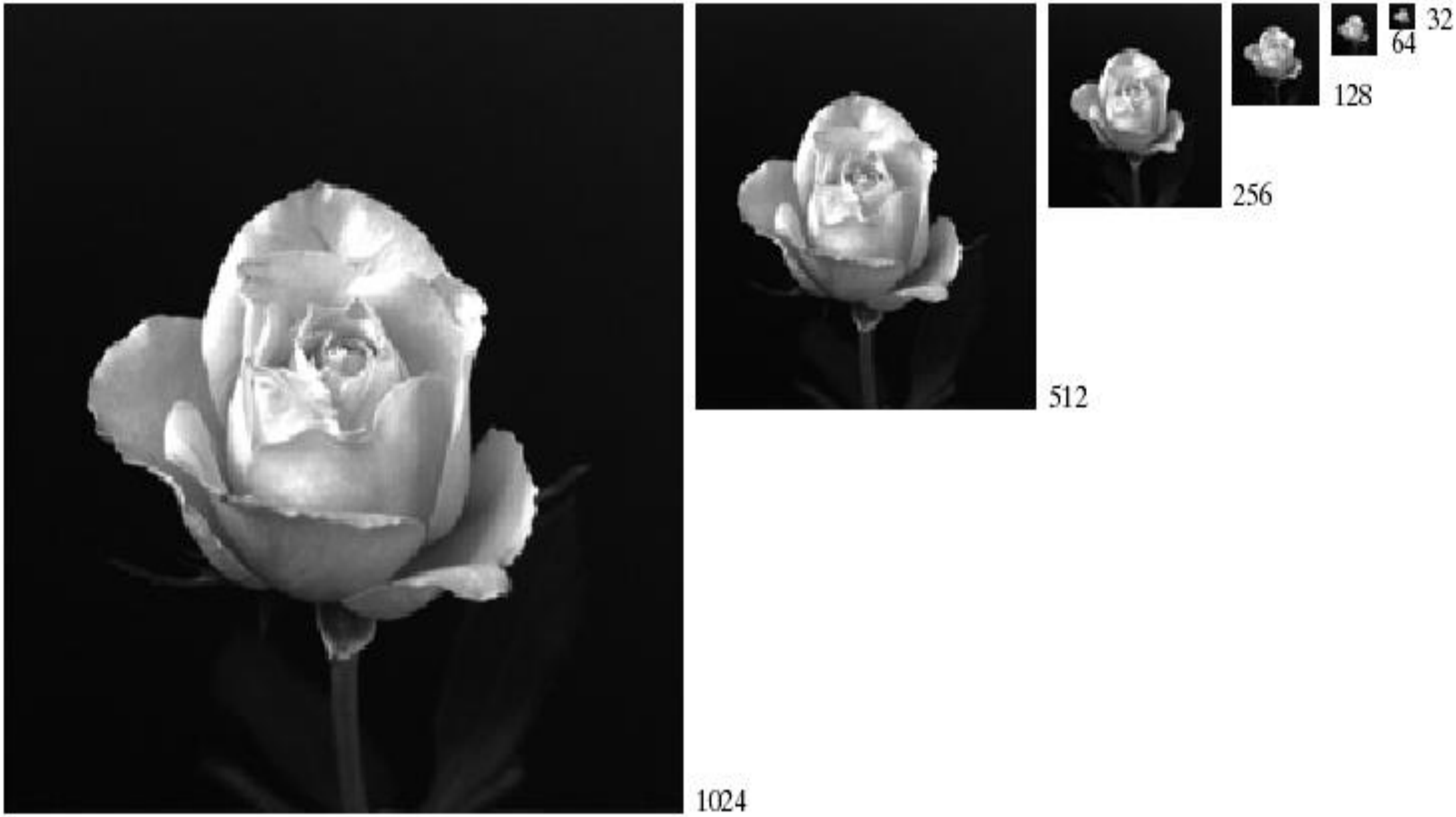
Image Resolution

- **How many samples and gray levels are required for a good approximation?**
  - Resolution (the degree of discernible detail) of an image depends on sample number and gray level number.
  - i.e. the more these parameters are increased, the closer the digitized array approximates the original image.
  - **But: storage & processing requirements increase rapidly as a function of N, M, and k**

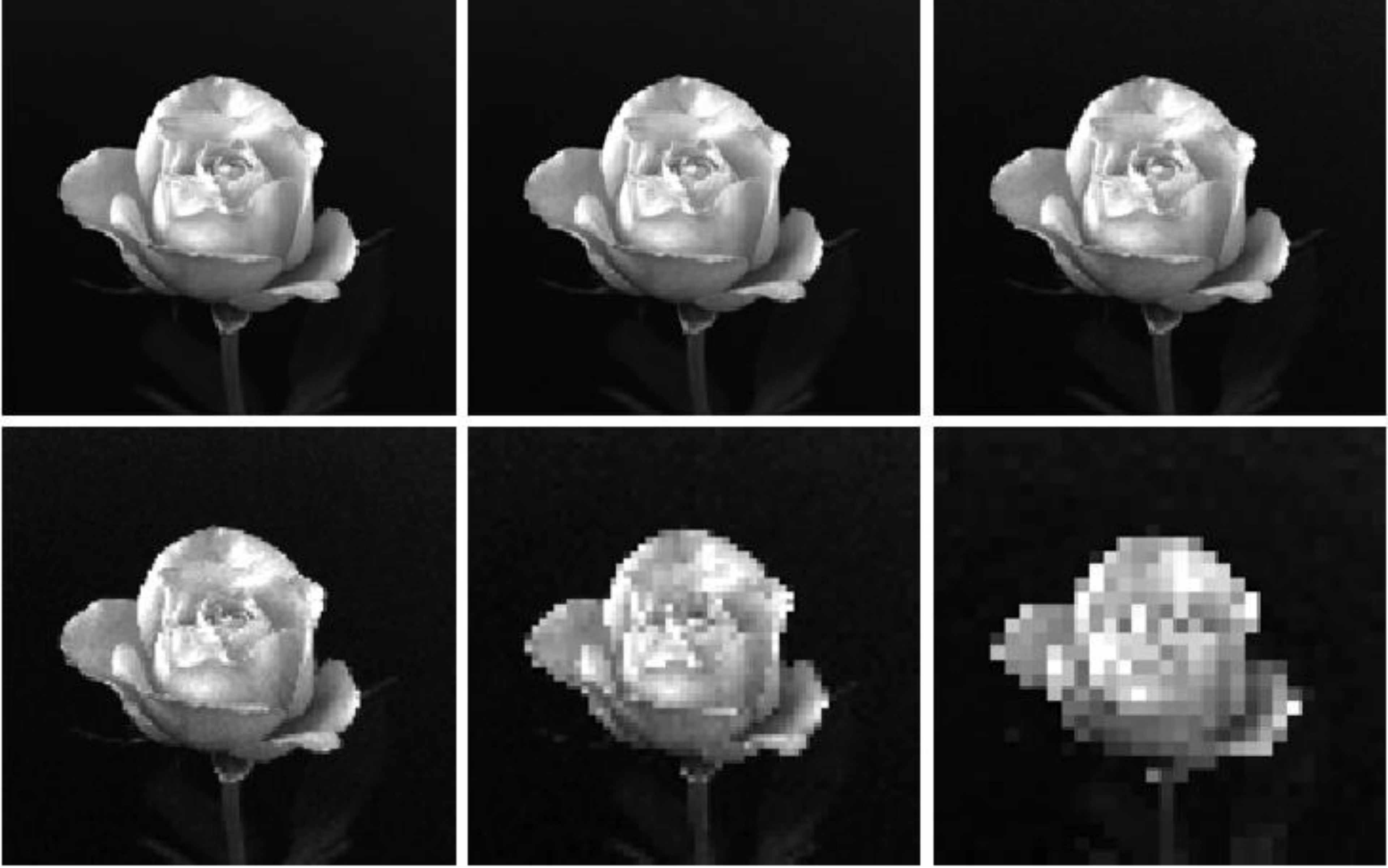
Image Resolution

- **Spatial Resolution:** Spatial resolution is the smallest detectable detail in an image.
  - Line pairs per unit distance
  - Dots/pixels per unit distance
    - dots per inch – dpi
- **Grey level (Intensity) Resolution:** Gray-level resolution similarly refers to the smallest detectable change in gray level.

- **The more samples in a fixed range, the higher the resolution**
- **The more bits, the higher the resolution**



- A 1024*1024, 8-bit image subsampled down to size 32*32 pixels. The number of allowable gray levels was kept at 256



- (a) 1024*1024, 8-bit image. (b) 512*512 image resampled into 1024*1024 pixels by row and column duplication. (c) through (f) 256*256, 128*128, 64*64, and 32*32 images resampled into 1024*1024 pixels.

Reducing spatial resolution

a b
c d

Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

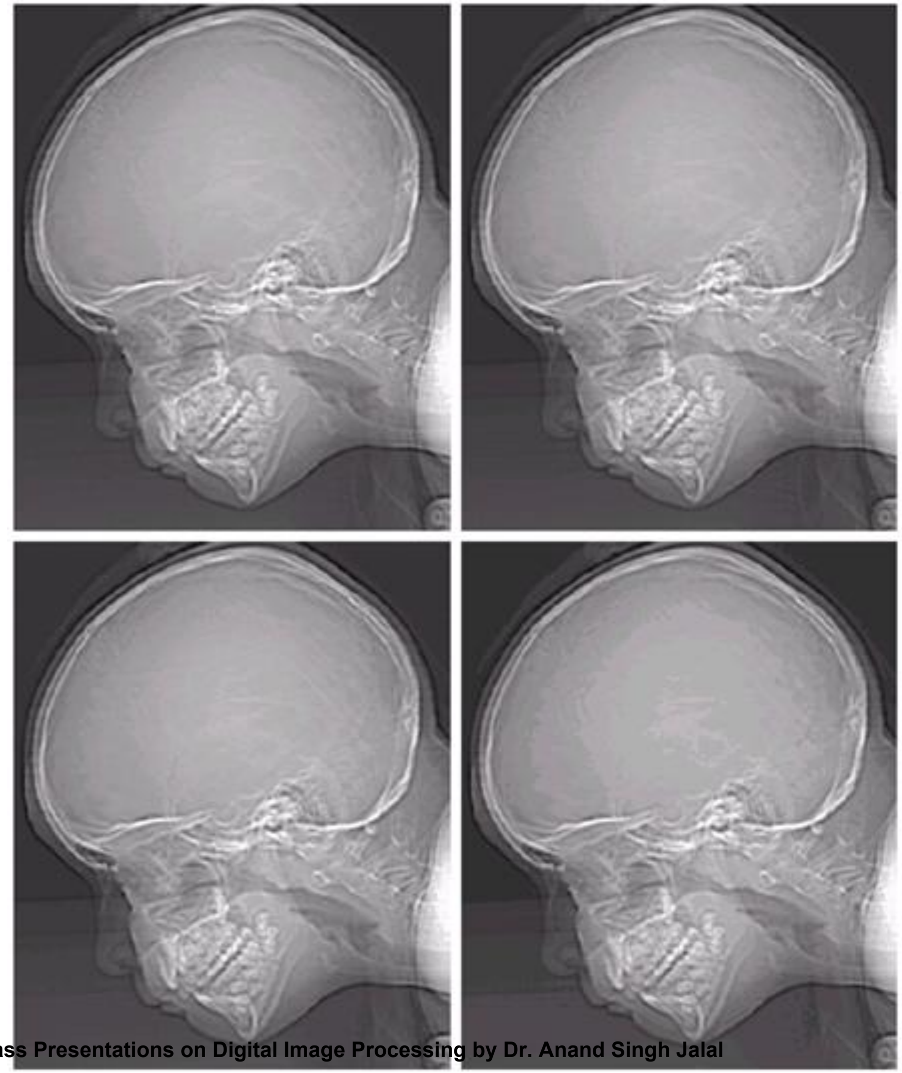
Checkerboard Effect

- When the no. of pixels in an image is reduced keeping the no. of gray levels in the image constant, fine checkerboard patterns are found at the edges of the image. This effect is called the checker board effect.

False Contouring

- When the no. of gray-levels in the image is low, the foreground details of the image merge with the background details of the image, causing ridge like structures. This degradation phenomenon is known as false contouring.

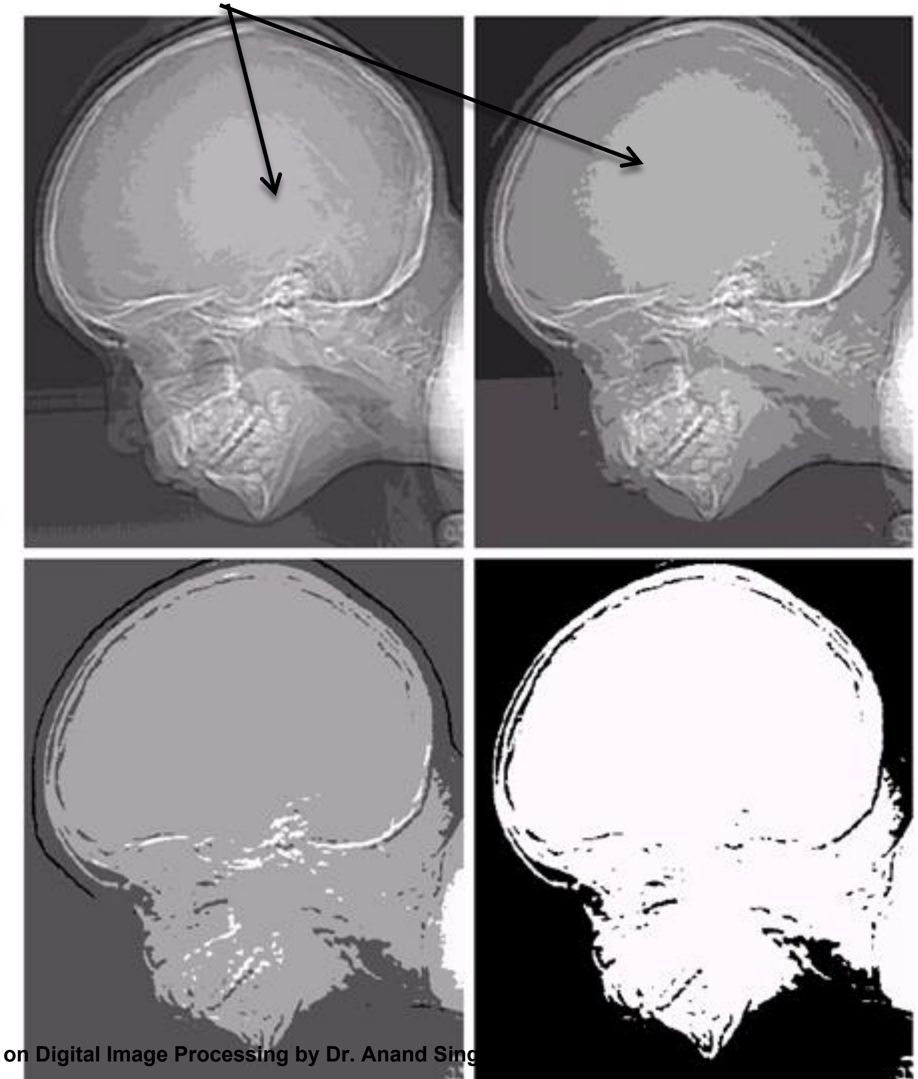
Varying the number of gray levels



(a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

False contouring

Varying the number of gray levels



e f
g h

(Continued) (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

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 pleasing?
    - Can you see what you need to see within the image?

Resolution: How Much Is Enough? ...

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

- **Question:** If we want to resize a 1024x768 image to one that is 600 pixels wide with the same aspect ratio as the original image, what should be the height of the resized image?

- **Sol:**

$$\text{Aspect Ratio} = \frac{\text{width}}{\text{height}}$$

- For the original image the Aspect ratio is: 1027/768=1.33
- Now for the resized image, we want the same aspect ratio but a width of 600 pixels.

$$height = \frac{width}{Aspect\ ratio} = \frac{600}{1.33} = 451$$

- Hence the resized image will be 600x451

- **Question:** A common measure of transmission for digital data is the **baud rate**, defined as the number of bits transmitted per second. Transmission is accomplished in packets consisting of a start bit, a byte(8 bits) of information and a stop bit.

  a) How many minutes would it take transmit a 1024x1024 image with 256 gray levels if we use a 56 k baud modem?

  b) What would be the time required if we use a 750 k band transmission line?

Basic Relationship between Pixels

- An image is denoted by a function f(x,y).
- Each element f(x,y) at location (x,y) is called a pixel.
- There exist some basic but important relationships between pixels.

Basic Relationship between Pixels …

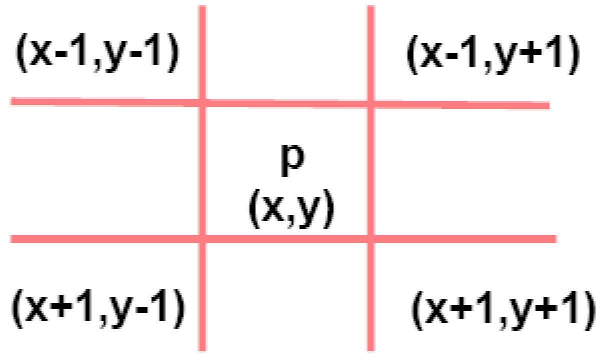
- A pixel p at location (x,y) has two horizontal and two vertical neighbors.

	(x-1,y)	
(x,y-1)	p (x,y)	(x,y+1)
	(x+1,y)	

- This set of four pixels is called 4-neighbors of $p = N_4(p)$.
- Each of these neighbors is at a unit distance from p.
- If p is a boundary pixel then it will have less number of neighbors.

Basic Relationship between Pixels …

- A pixel p has four diagonal neighbors=$N_D(p)$



- The points of $N_4(p)$ and $N_D(p)$ together are called 8-neighbors of p.
- $N_8(p) = N_4(p) \cup N_D(p)$
- If p is a boundary pixel then both $N_D(p)$ and and $N_8(p)$ will have less number of pixels.

Basic Relationship between Pixels …

- Two pixels are said to be connected if they are adjacent in some sense
  - They are neighbors(N_4,N_D or N_8) and
  - Their intensity values (gray levels) are similar

- For a binary image B, two points p and q will be connected if q€N(p) or p€N(q) and B(p) = B(q).

Basic Relationship between Pixels

- Neighborhood
- Adjacency
- Connectivity
- Paths
- Regions and boundaries

(i-1,j-1)	(i-1,j)	(i-1,j+1)
(i,j-1)	(i,j)	(i,j+1)
(i+1,j-1)	(i+1,j)	(i+1,j+1)

Adjacency

- Let V be the set of intensity values
  - **4-adjacency:** Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.
  - **8-adjacency:** Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$.
  - **m-adjacency:** Two pixels p and q with values from V are m-adjacent if

    (i) q is in the set $N_4(p)$, or

    (ii) q is in the set $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ **is empty** (has no pixels whose values are from V).

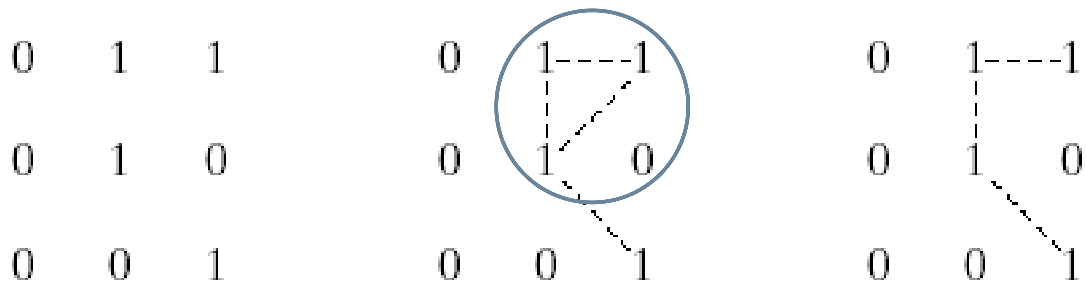
Examples: Adjacency and Path

0	1	1
0	1	0
0	0	1

Find 8-adjacency & m-adjacency of the pixel in the centre.

Note: V = {1}

Examples: Adjacency and Path



(a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

V = {1}

Fig (b) shows the ambiguity in 8-adjacency

Path

- A (digital) path (or curve) from pixel p with coordinates (x_0, y_0) to pixel q with coordinates (x_n, y_n) is a sequence of distinct pixels with coordinates

$$(x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n)$$

Where (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent for $1 \leq i \leq n$.

- Here *n* is the *length* of the path.
- If $(x_0, y_0) = (x_n, y_n)$, the path is ***closed*** path.
- We can define 4-, 8-, and m-paths based on the type of adjacency used.

Connectivity

- **Connected in S**

  Let S represent a subset of pixels in an image. Two pixels p with coordinates (x_0, y_0) and q with coordinates (x_n, y_n) are said to be **connected in S** if there exists a path

$$(x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n)$$

  Where

Region, Boundary and Edge

- **Region**
  - We call R a region of the image if R is a connected set
- **Boundary**
  - The boundary of a region R is the set of pixels in the region that have one or more neighbors that are not in R
- **Edge**
  - Pixels with derivative values that exceed a preset threshold

Distance Measures

- Given pixels *p*, *q* and *z* with coordinates (x, y), (s, t), (u, v) respectively, the distance function D has following properties:

1. $D(p, q) \geq 0$ $[D(p, q) = 0$, iff $p = q]$
2. $D(p, q) = D(q, p)$
3. $D(p, z) \leq D(p, q) + D(q, z)$

Distance Measures …

The following are the different Distance measures:

Euclidean Distance :

$$D_e(p, q) = [(x-s)^2 + (y-t)^2]^{1/2}$$

City Block Distance:

$$D_4(p, q) = |x-s| + |y-t|$$

Chess Board Distance:

$$D_8(p, q) = \max(|x-s|, |y-t|)$$

		2		
	2	1	2	
2	1	0	1	2
	2	1	2	
		2		

City Block Distance

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

Chess Board Distance

Problems

1. When you enter a dark theater on a bright day, it takes an appreciable interval of time before you can see well enough to find an empty seat. Which of the visual process is at play in this situation?
2. Consider the two image subsets, S1 and S2, shown in the following figure. For V={1}, determine whether these two subsets are a) 4-adjacent, b) 8-adjacent, or c) m-adjacent.

		S1				S2			
0	0	0	0	0	0	0	1	1	0
1	0	0	1	0	0	1	0	0	1
1	0	0	1	0	1	1	0	0	0
0	0	1	1	1	0	0	0	0	0
0	0	1	1	1	0	0	1	1	1

Problems …

3. Consider the image segment shown

   a) Let V={0,1} and compute the length of the shortest 4-,8-, and m-path between p and q. if a particular path does not exist between these two points, explain why.

   b) Repeat for V={1,2}

	3	**1**	**2**	**1**	**(q)**
	2	**2**	**0**	**2**	
	1	**2**	**1**	**1**	
(p)	**1**	**0**	**1**	**2**	

Any Questions ?