Digital Imaging Fundamentals

Dr. Pawan Kumar Singh

Department of Information Technology

Jadavpur University

Contents

This lecture will cover:

– The human visual system

– Light and the electromagnetic spectrum

– Image representation

– Image sensing and acquisition

– Sampling, quantisation and resolution

Human Visual System

The best vision model we have!

Knowledge of how images form in the eye can help us with processing digital images

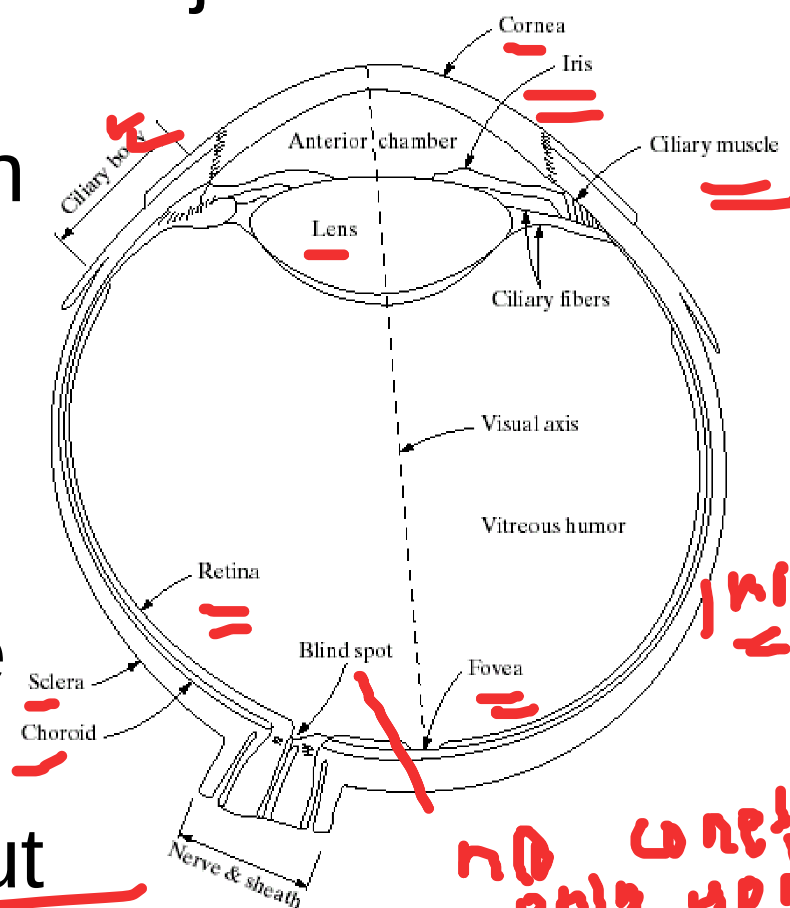
We will take just a whirlwind tour of the human visual system

Cones-sensitive to colour

Structure Of The Human Eye

rod- sensitive to low level illuminatn and not to colour

- The lens focuses light from objects onto the retina
- The retina is covered with light receptors called *cones* (6-7 million) and *rods* (75-150 million)
- Cones are concentrated around the fovea and are very sensitive to colour
- Rods are more spread out and are sensitive to low levels of illumination

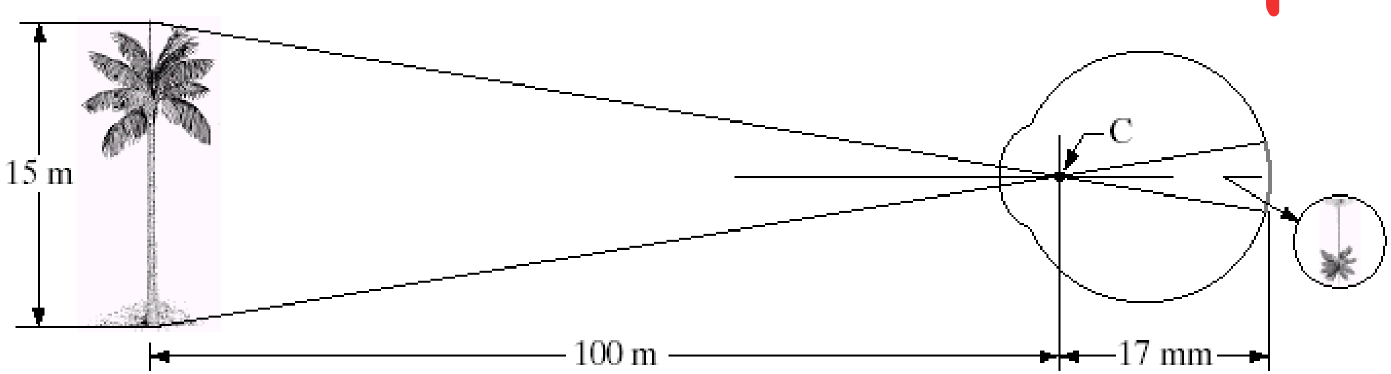


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Formation In The Eye

- Muscles within the eye can be used to change the shape of the lens allowing us focus on objects that are near or far away
- An image is focused onto the retina causing rods and cones to become excited which ultimately send signals to the brain

Imp



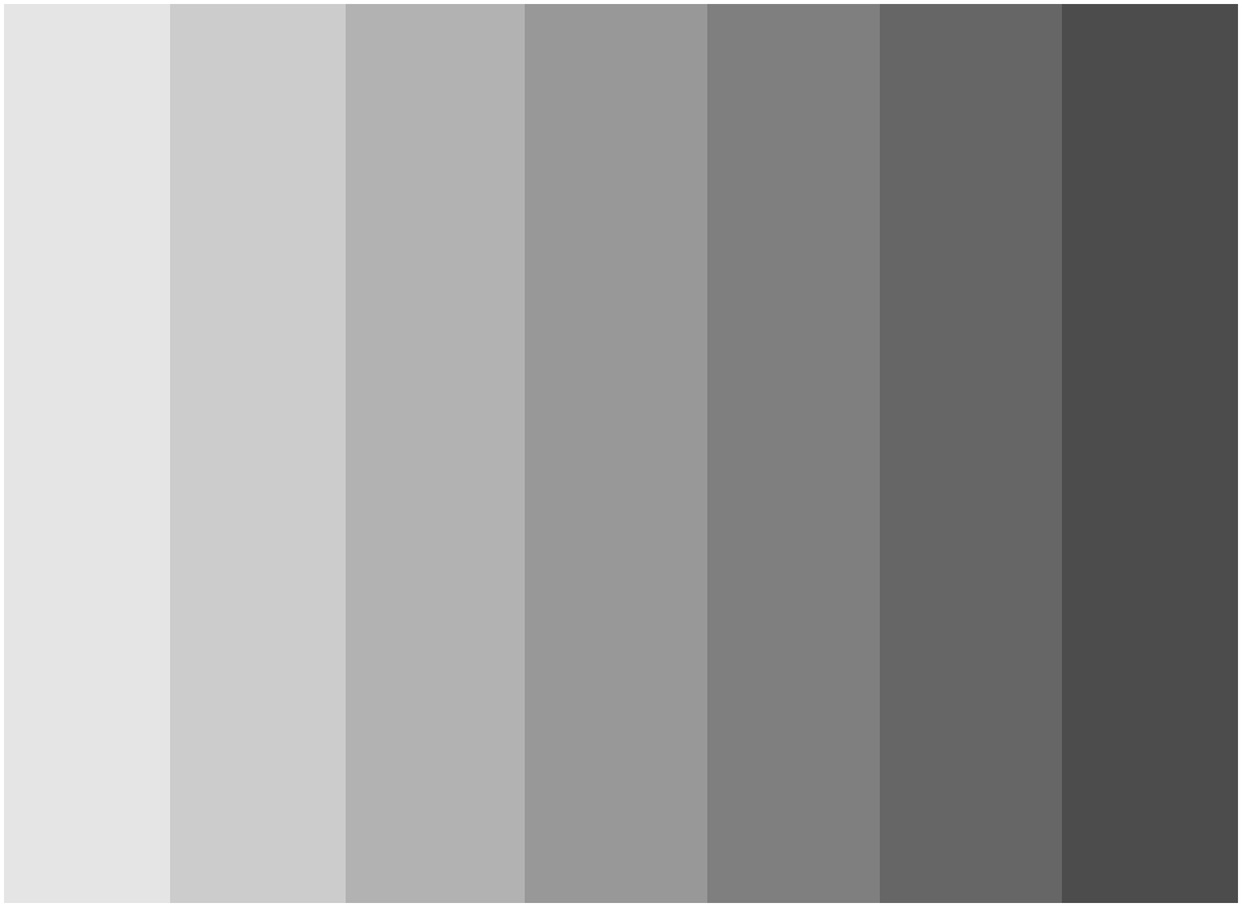
Brightness Adaptation & Discrimination

The human visual system can perceive approximately 10^{10} different light intensity levels

However, at any one time we can only discriminate between a much smaller number – *brightness adaptation*

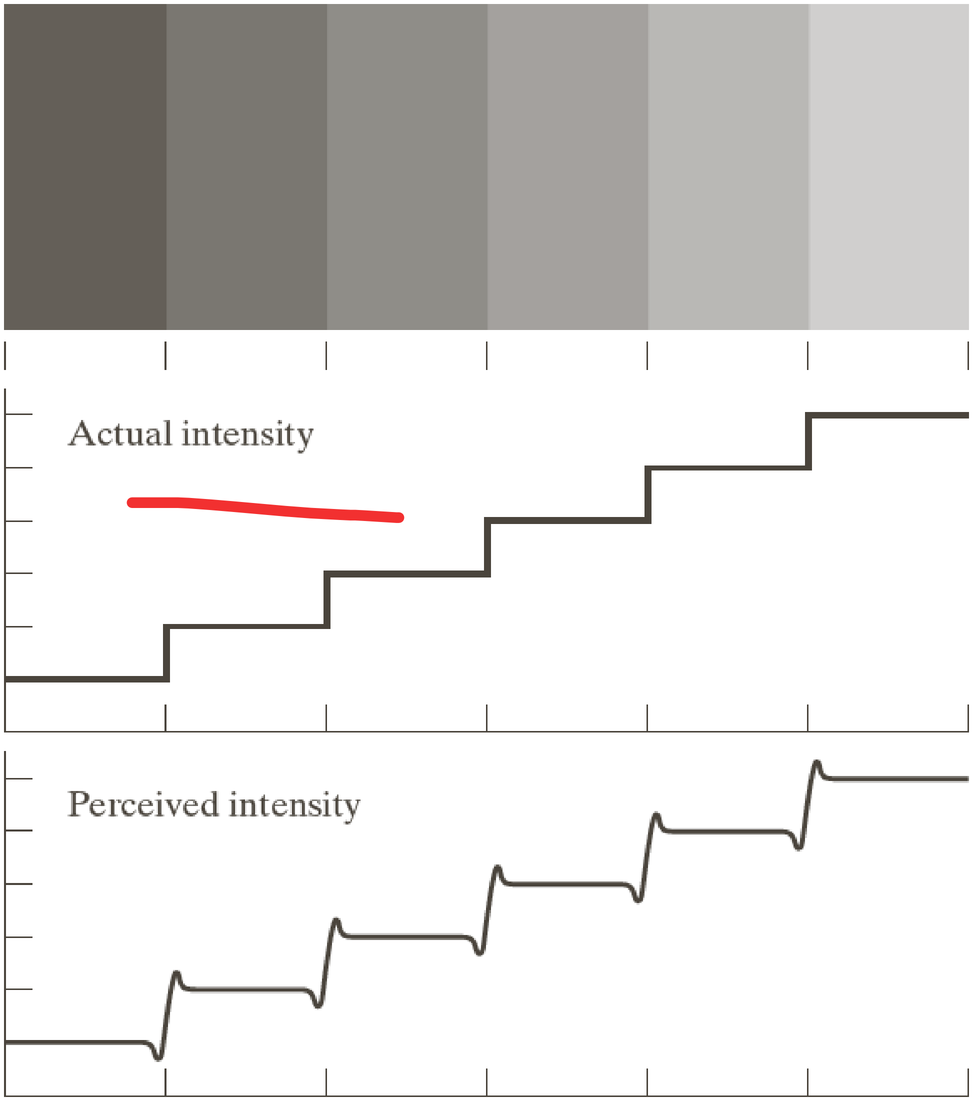
Similarly, the *perceived intensity* of a region is related to the light intensities of the regions surrounding it

Brightness Adaptation & Discrimination (cont…)

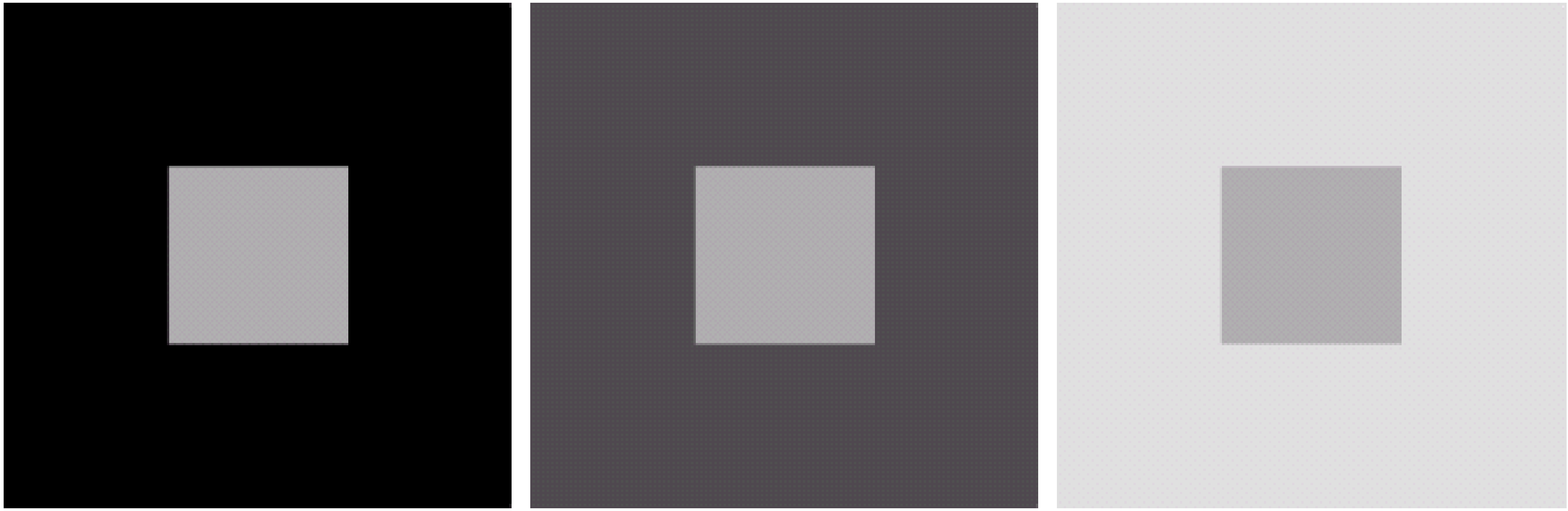


An example of Mach bands

Brightness Adaptation & Discrimination (cont…)



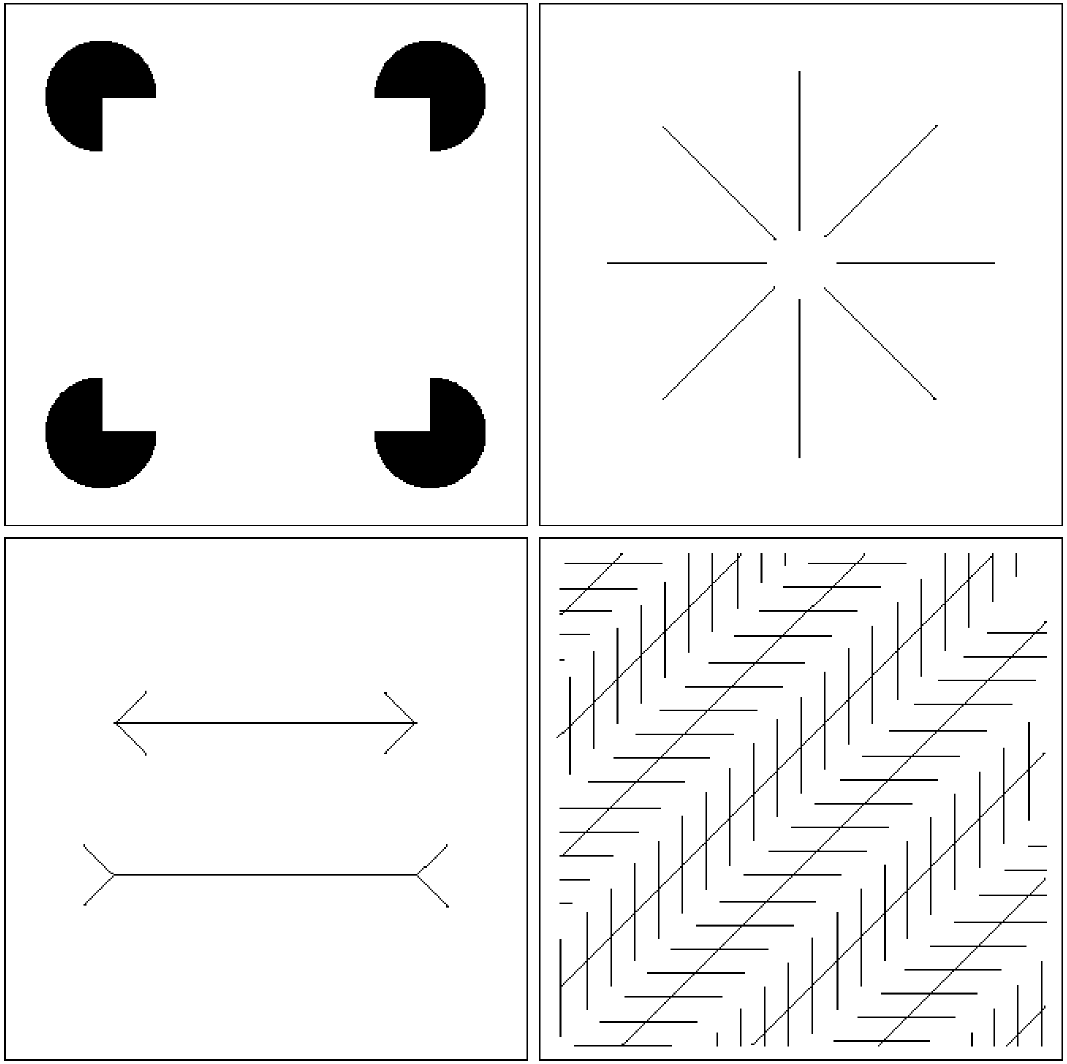
Brightness Adaptation & Discrimination (cont…)



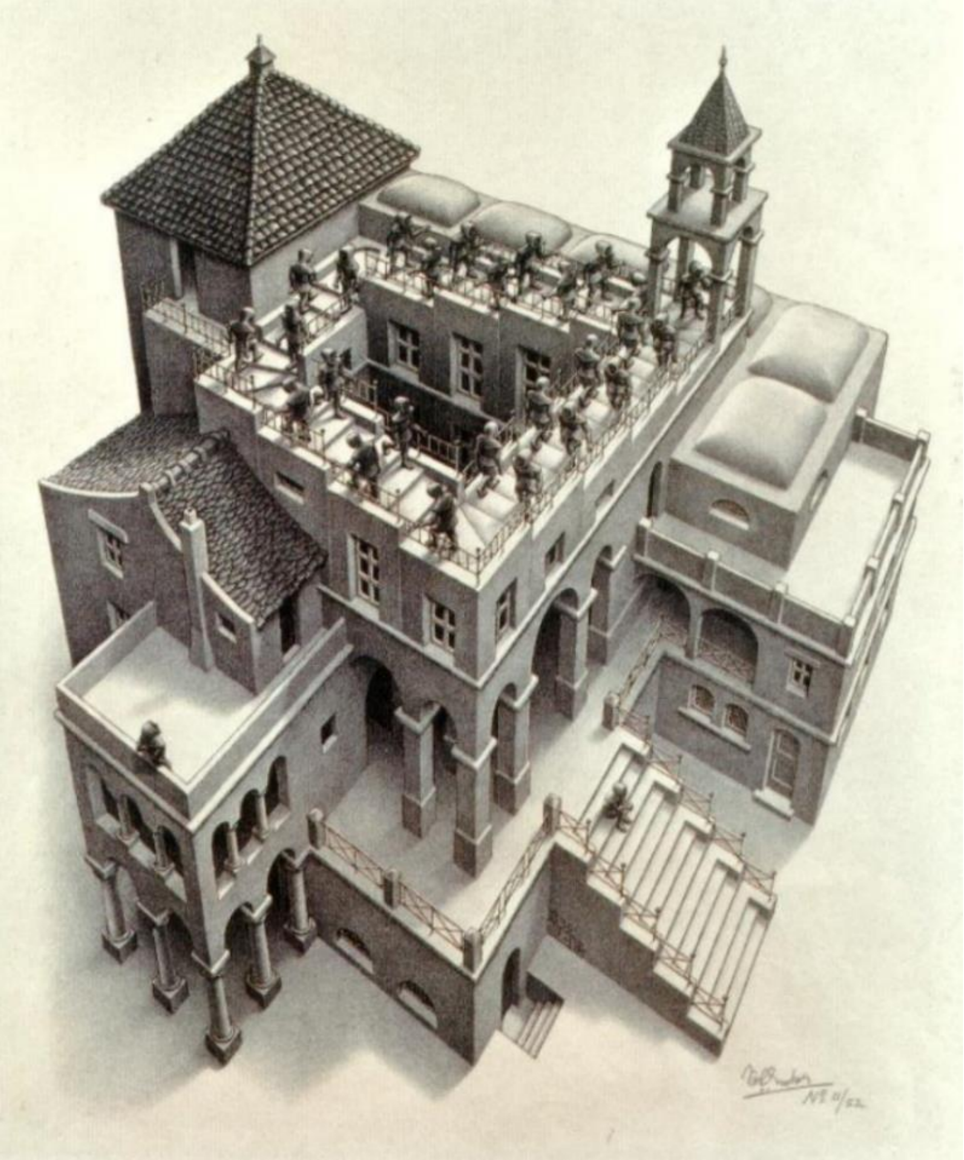
An example of *simultaneous contrast*

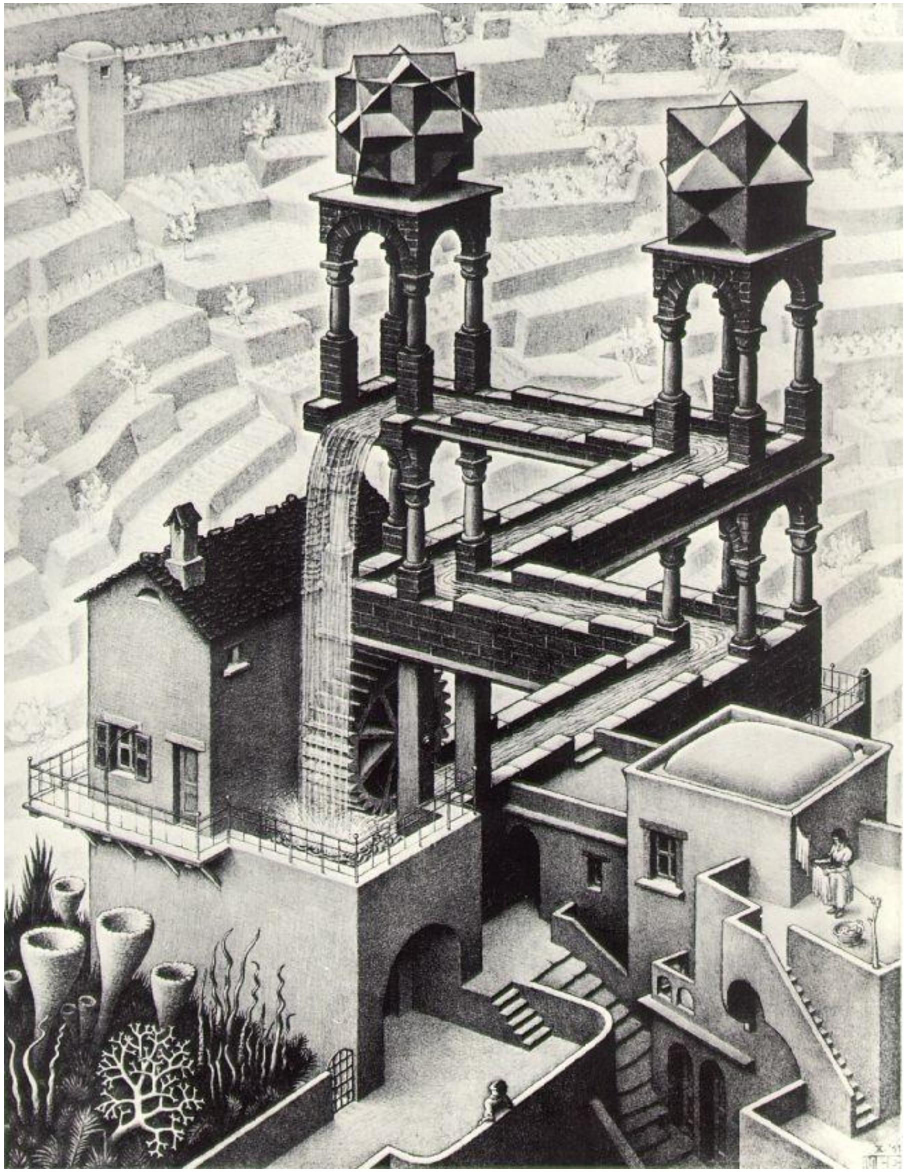
Optical Illusions

Our visual systems play lots of interesting tricks on us

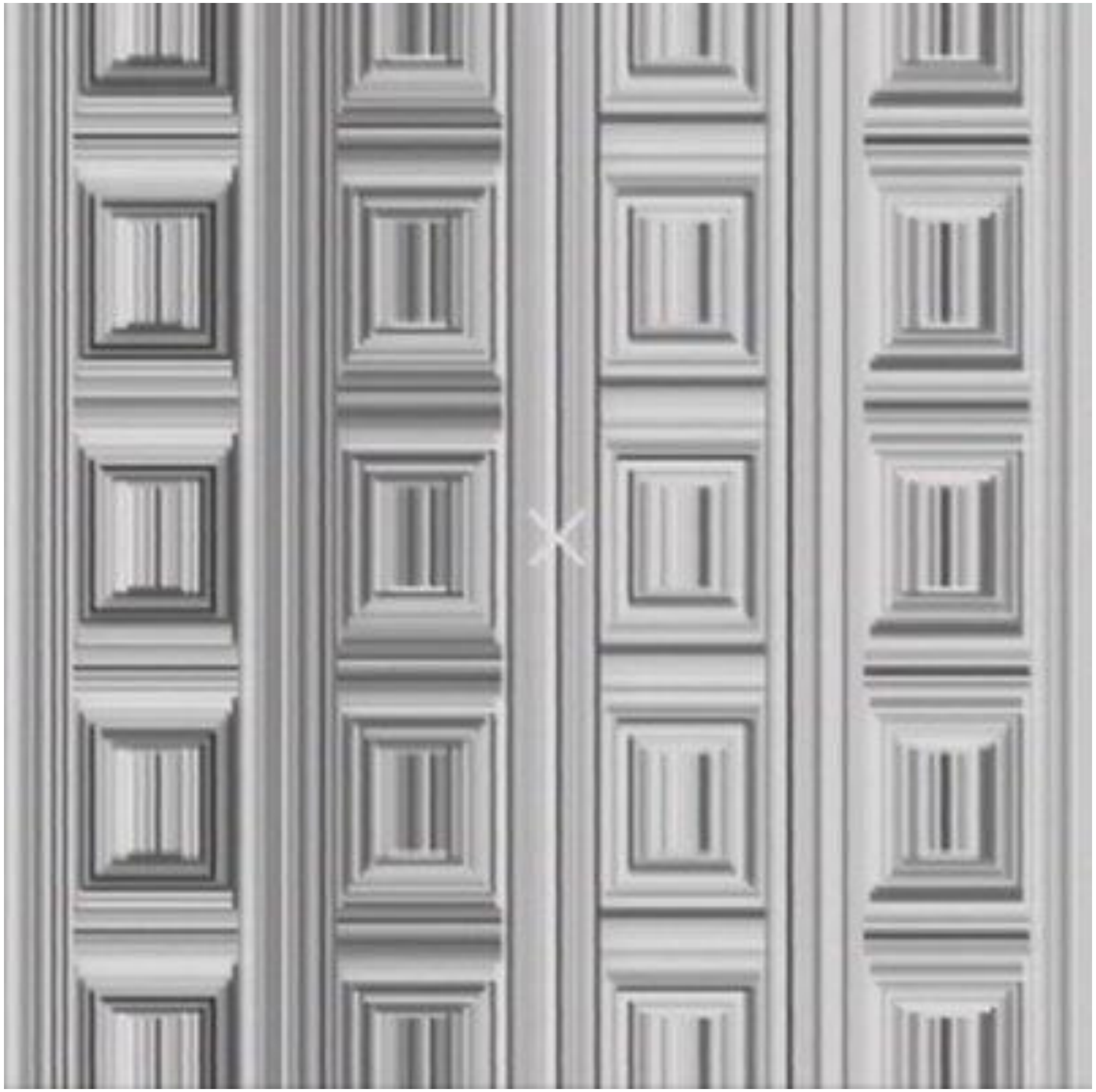


Optical Illusions (cont…)





Optical Illusions (cont…)



Stare at the cross in the middle of the image and think circles

Mind Map Exercise: Mind Mapping For Note Taking

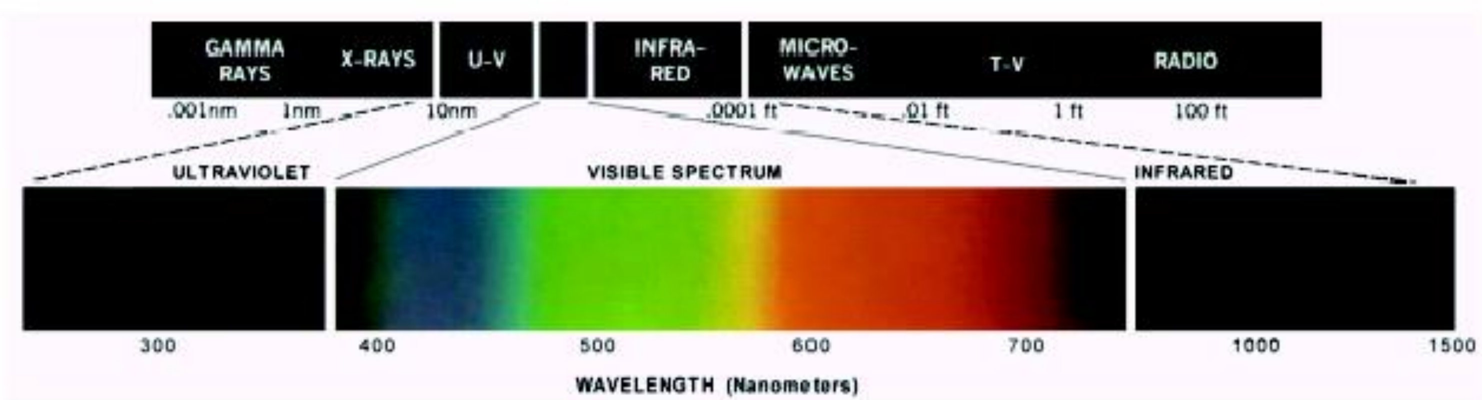
TED Ideas worth spreading

Beau Lotto: Optical Illusions Show How We See

http://www.ted.com/talks/lang/eng/beau_lotto_optical_illusions_show_how_we_see.html

Light And The Electromagnetic Spectrum

- 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

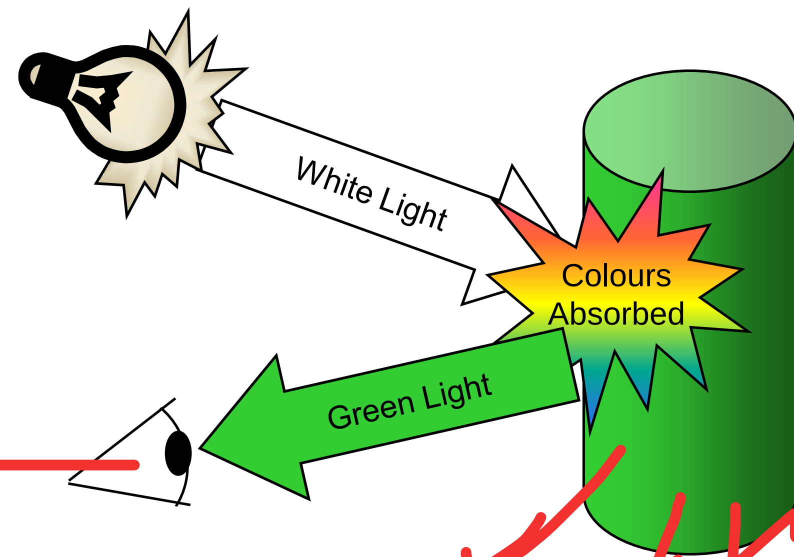


Reflected Light

V.V.I.P

The colours that we perceive are determined by the nature of the light reflected from an object

For example, if white light is shone onto a green object most wavelengths are absorbed, while green light is reflected from the object



Sampling, Quantisation And Resolution

In the following slides we will consider what is involved in capturing a digital image of a real-world scene

- Image sensing and representation
- Sampling and quantisation
- Resolution

Image Representation

- Before we discuss image acquisition recall that a digital image is composed of M rows and N columns of pixels each storing a value
- Pixel values are most often grey levels in the range 0-255(black-white)
- We will see later on that images can easily be represented as matrices

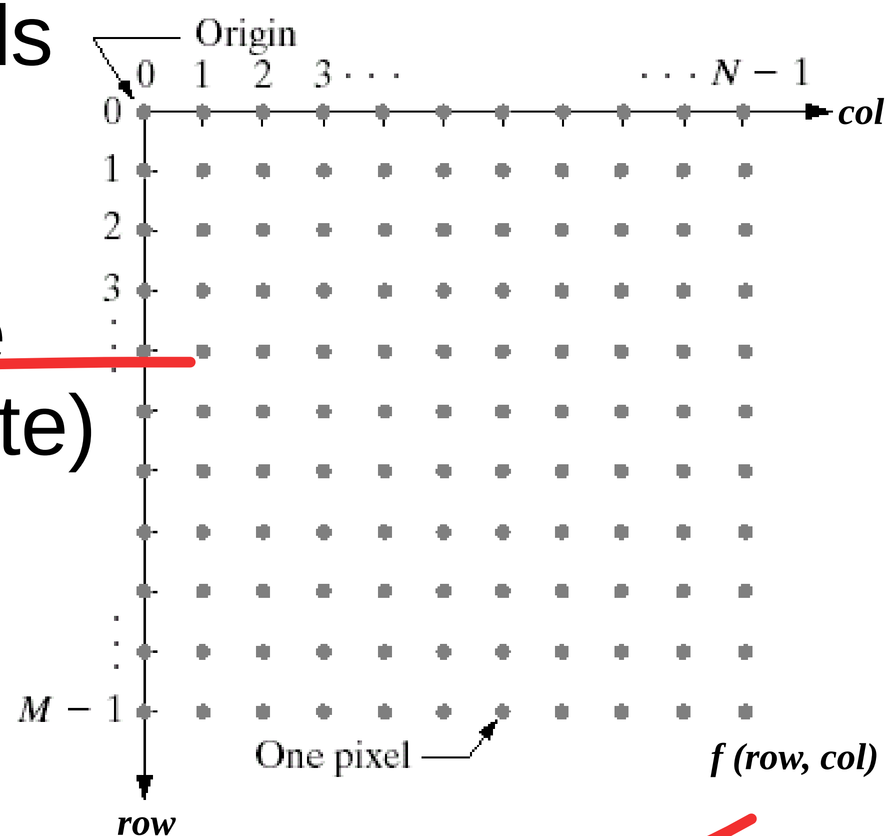
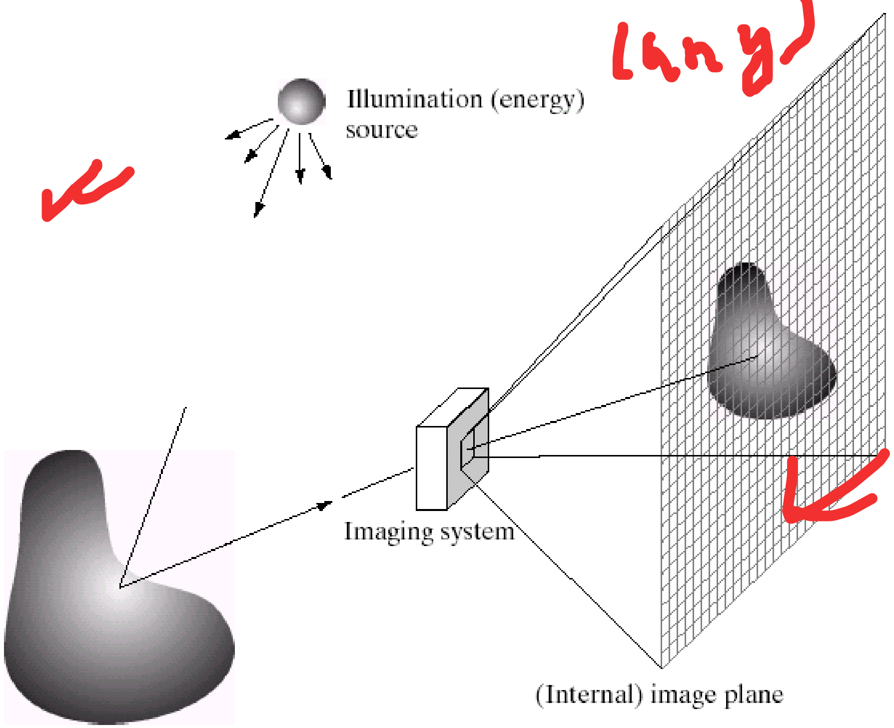


Image Acquisition

v.v.I!

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

(any)

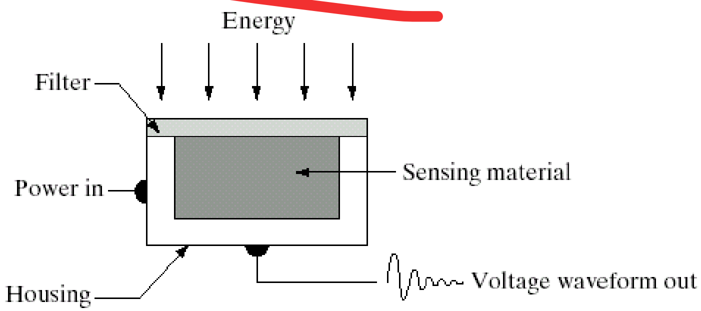


- Typical notions of illumination and scene can be way off:
  - X-rays of a skeleton
  - Ultrasound of an unborn baby
  - Electro-microscopic images of molecules

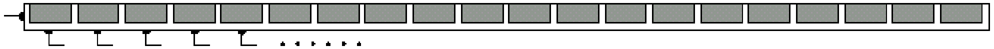
Image Sensing

Incoming energy lands on a sensor material responsive to that type of energy and this generates a voltage

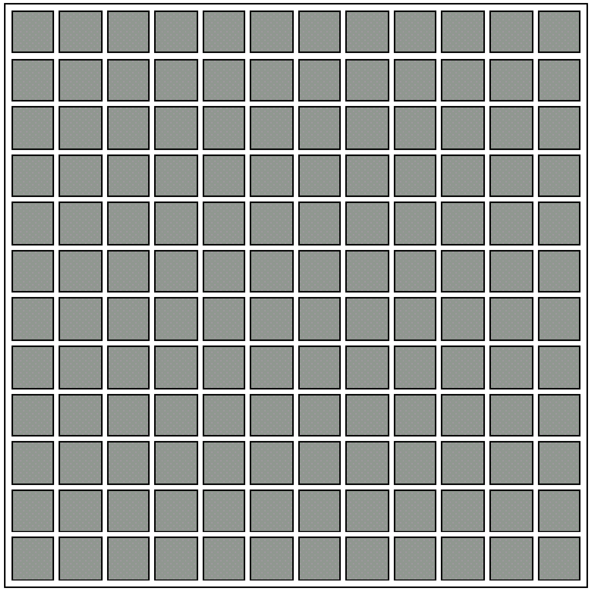
Collections of sensors are arranged to capture images



Imaging Sensor

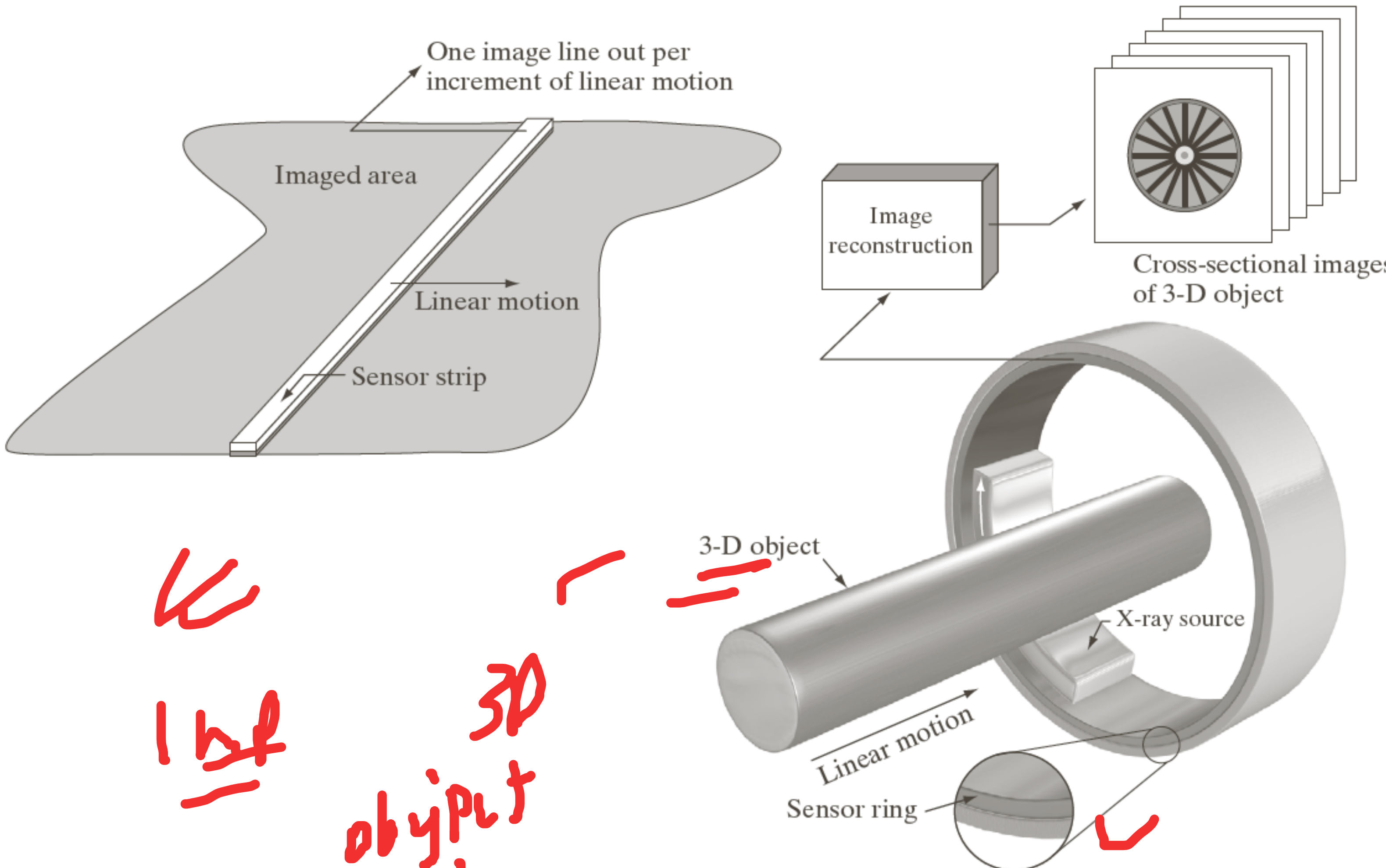


Line of Image Sensors



Array of Image Sensors

Image Sensing



1st

3D object

image

Using Sensor Strips and Rings

Image Sampling And Quantisation

A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels

Quantisation is the process of converting a continuous **analogue** signal into a digital representation of this signal

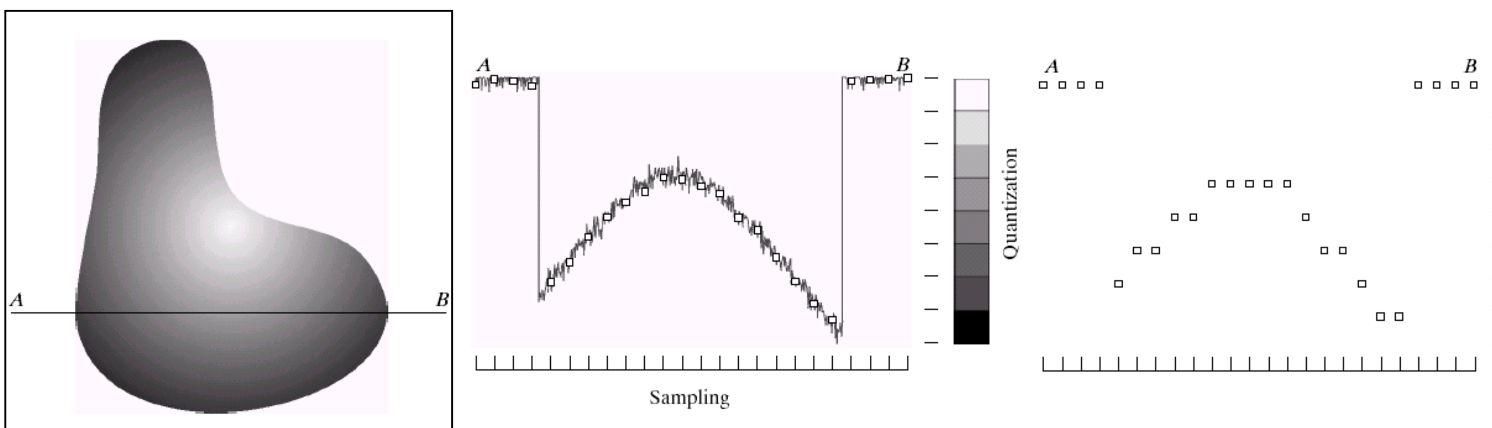


Image Sampling And Quantisation

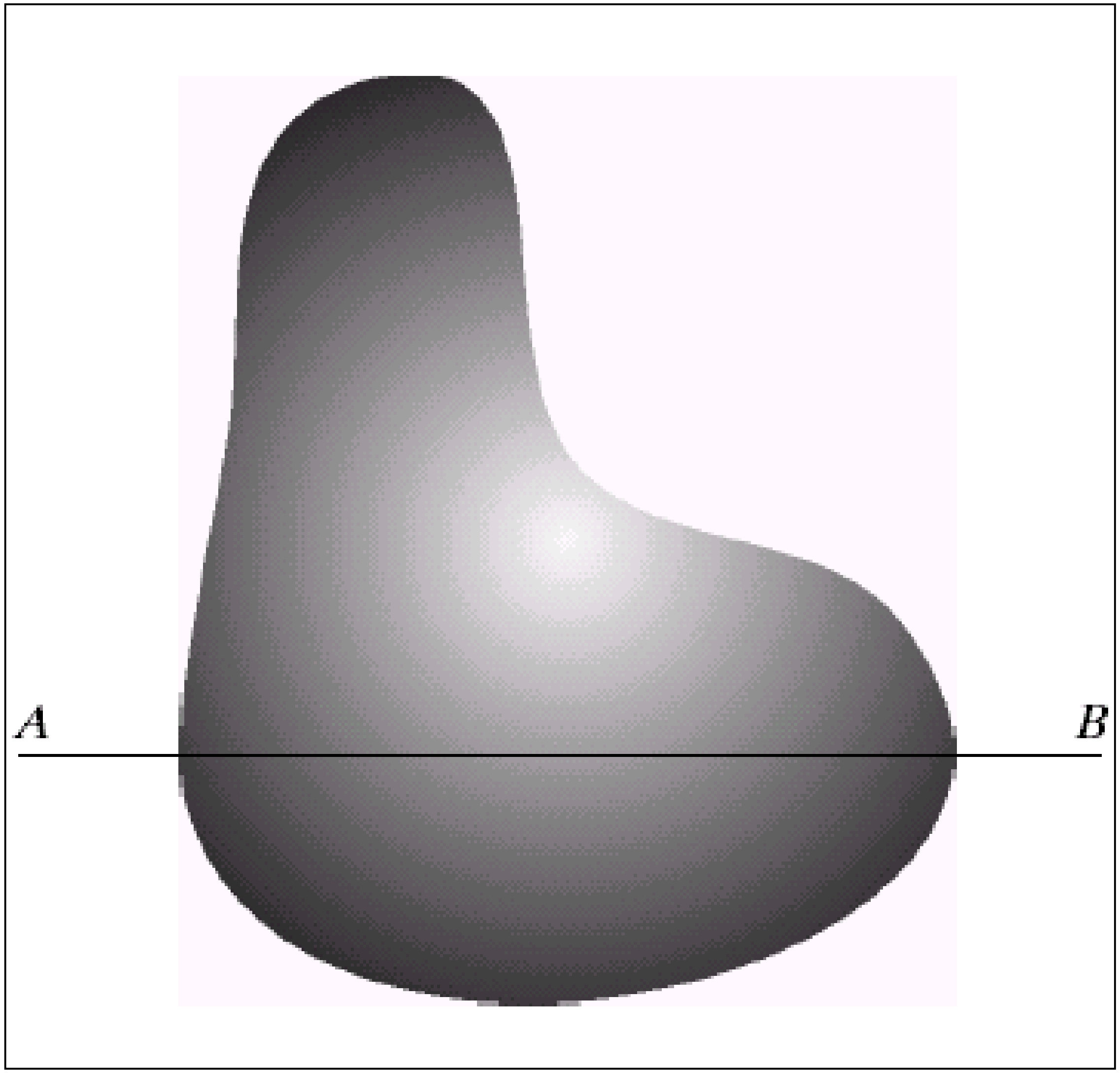
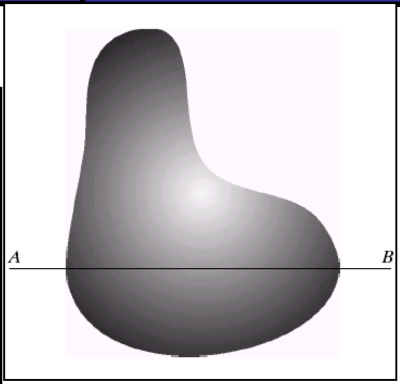


Image Sampling And Quantisation



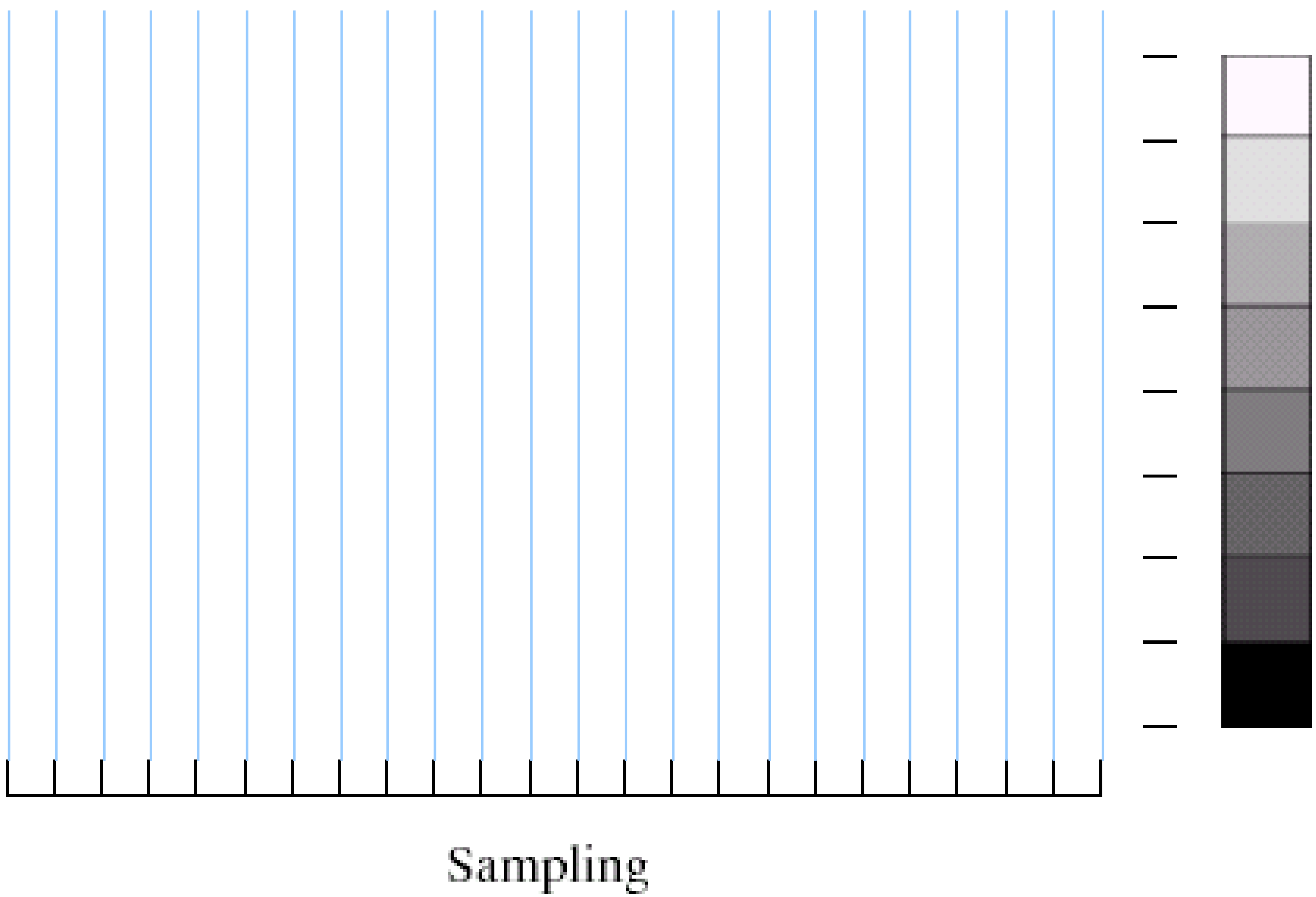


Image Sampling And Quantisation (cont…)

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

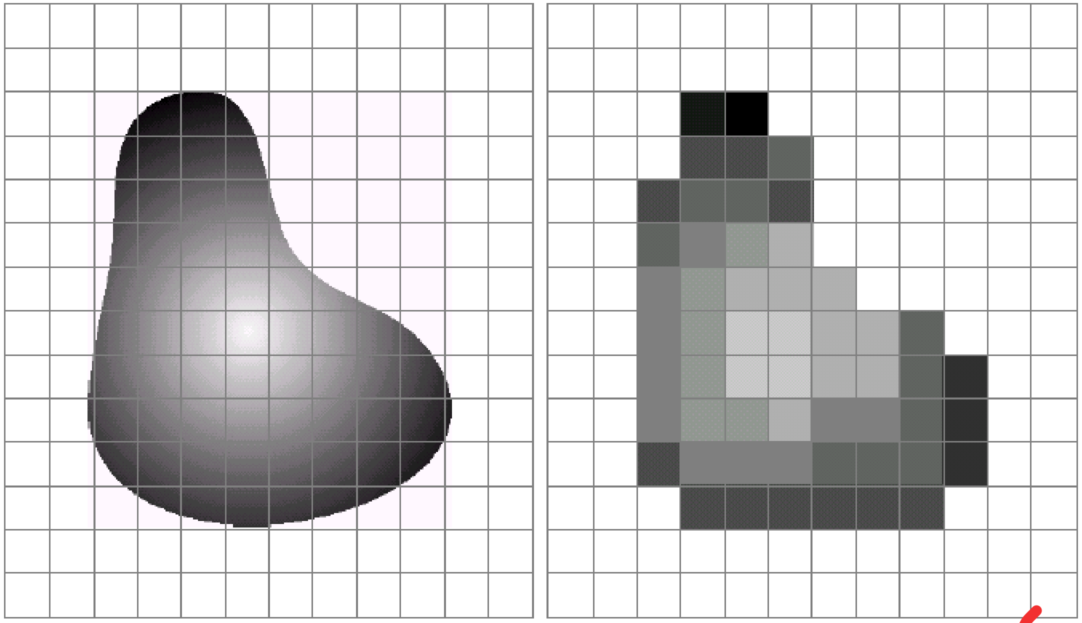


Image Representation

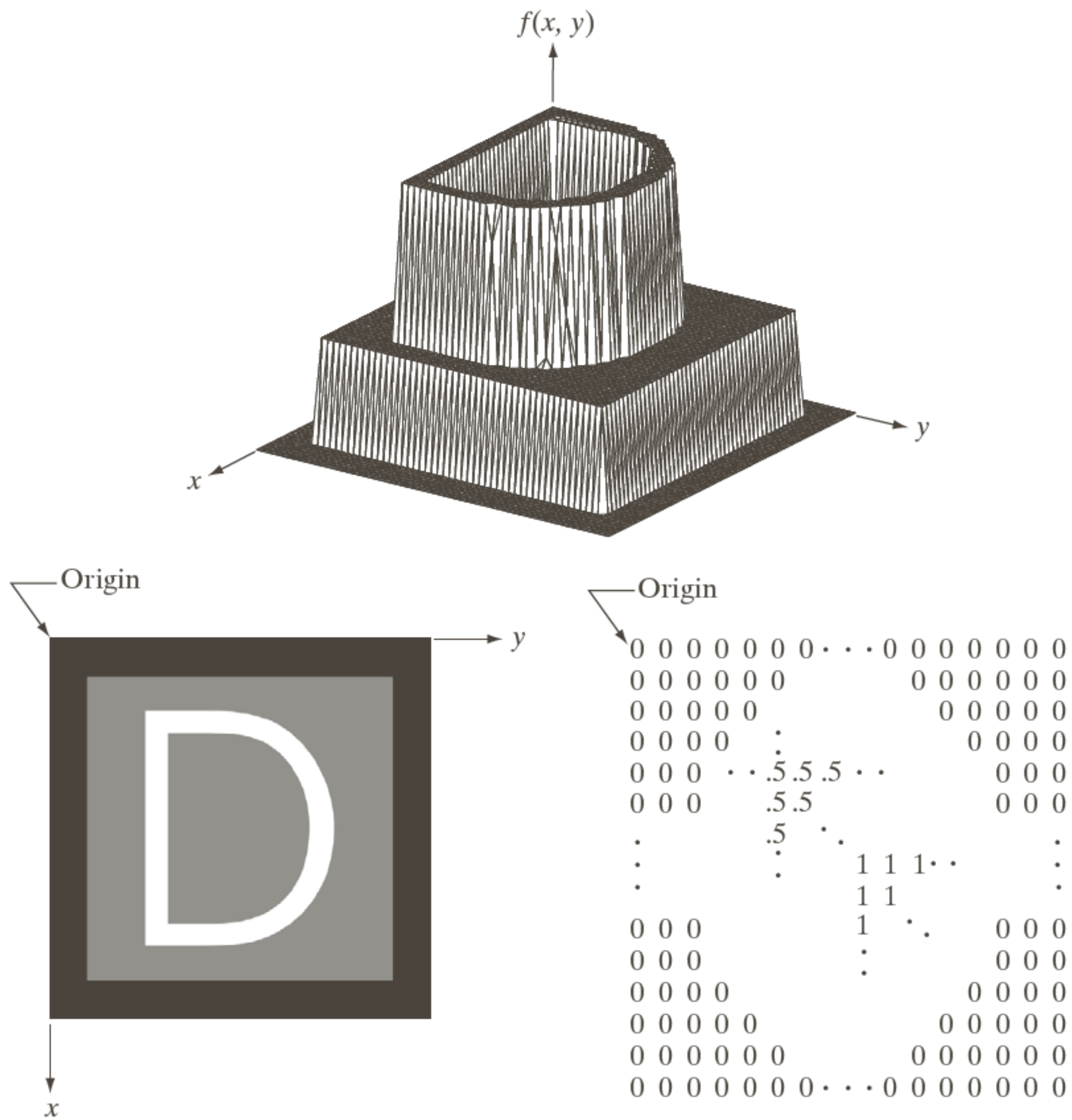


Image Representation

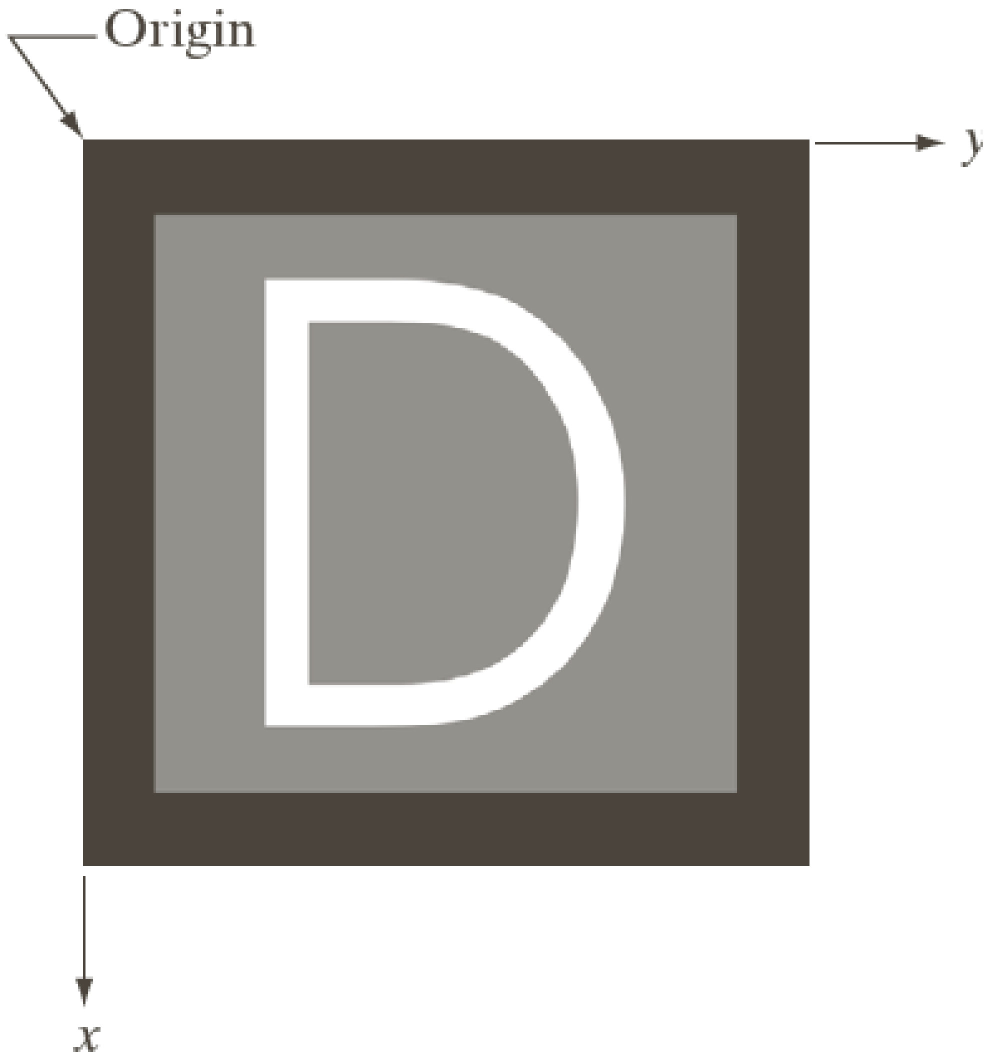


Image Representation

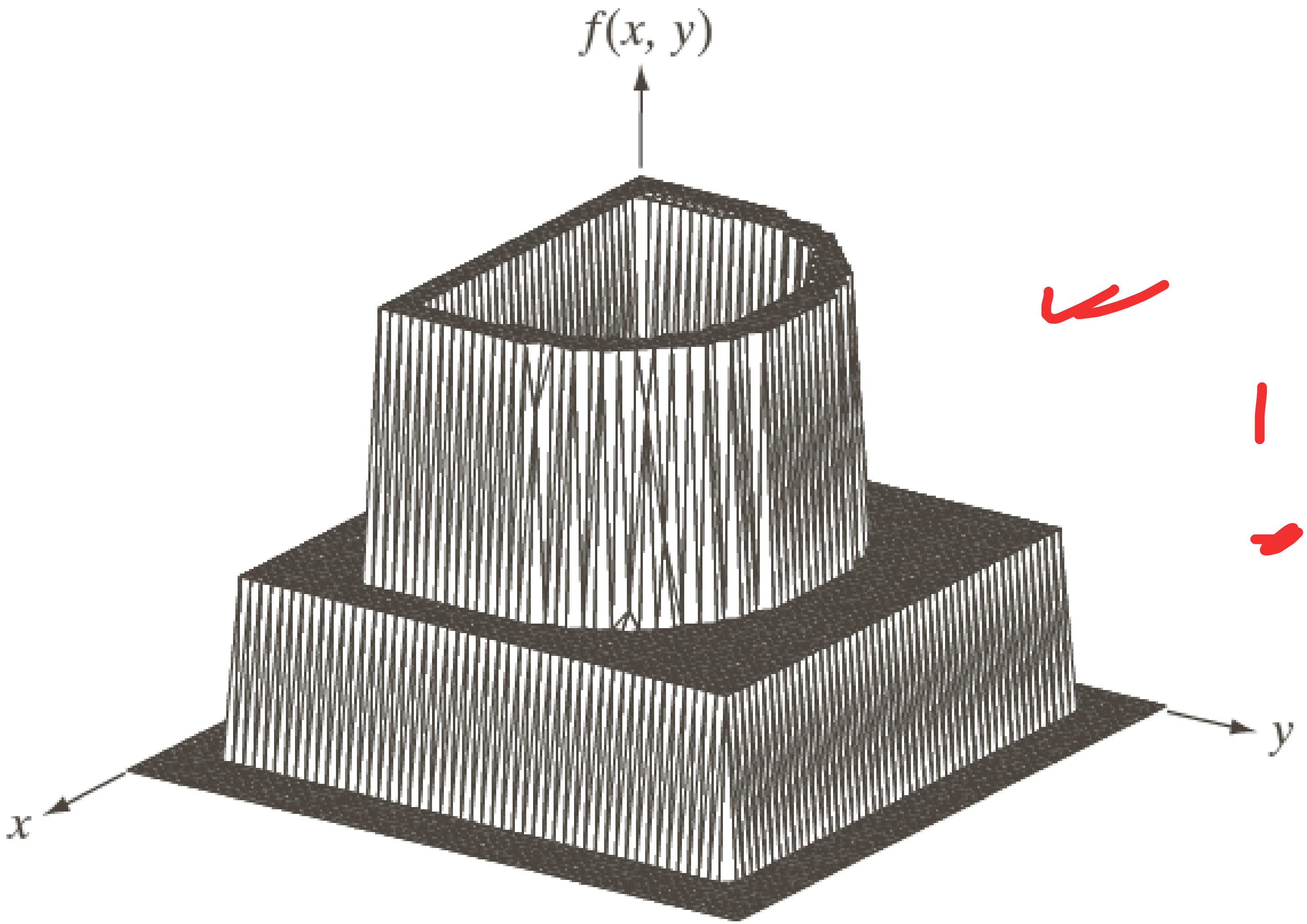
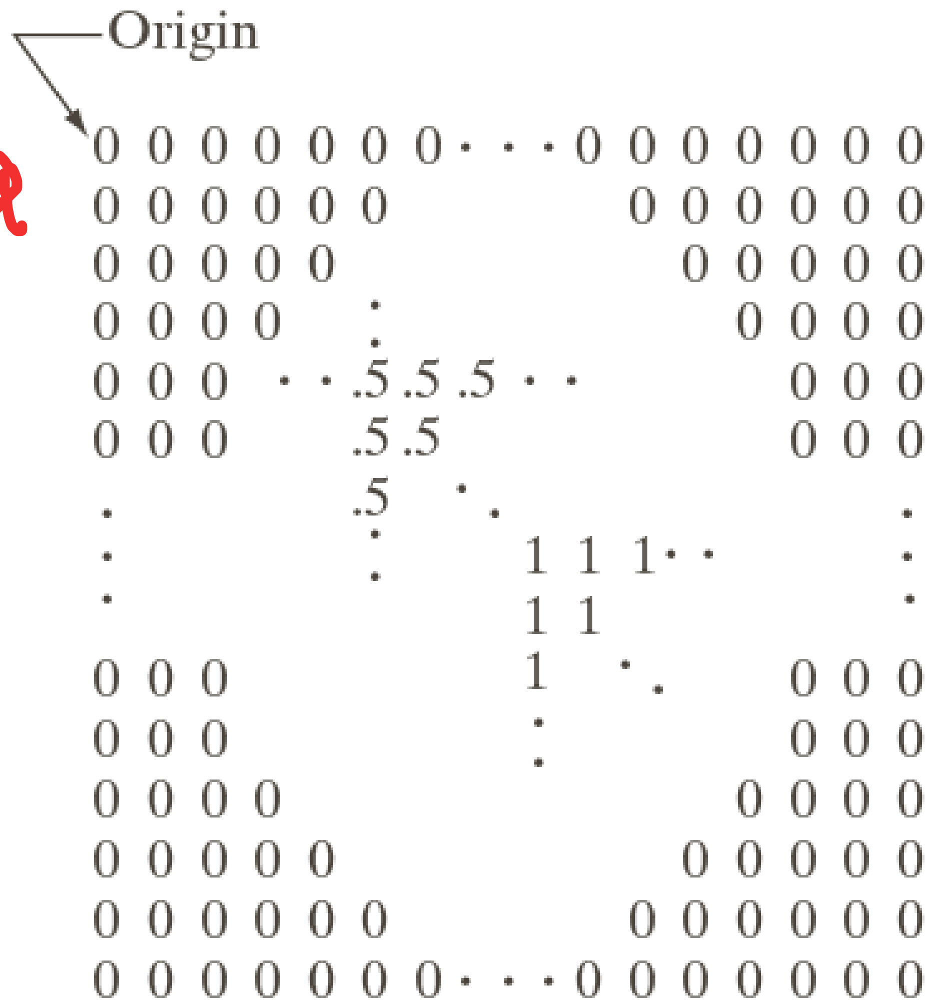


Image Representation

0 = Black

255 = white



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

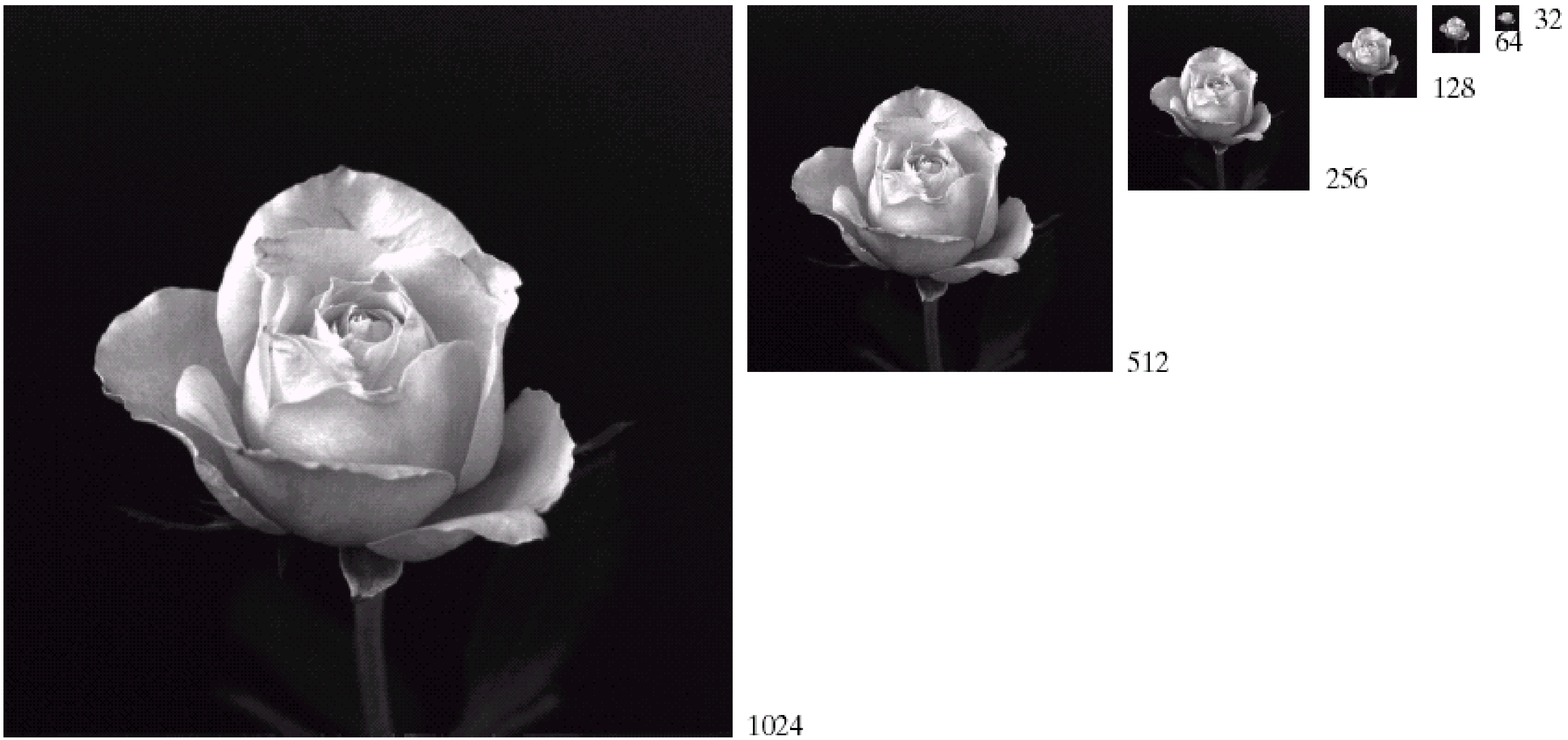
Img

Spatial Resolution

(Sampling)

- *The spatial resolution* of an image is determined by how sampling was carried out
- Spatial resolution simply refers to the smallest discernable detail in an image
  - Vision specialists will often talk about pixel size
  - Graphic designers will talk about *dots per inch* (DPI)

Spatial Resolution (cont…)



Spatial Resolution (cont…)

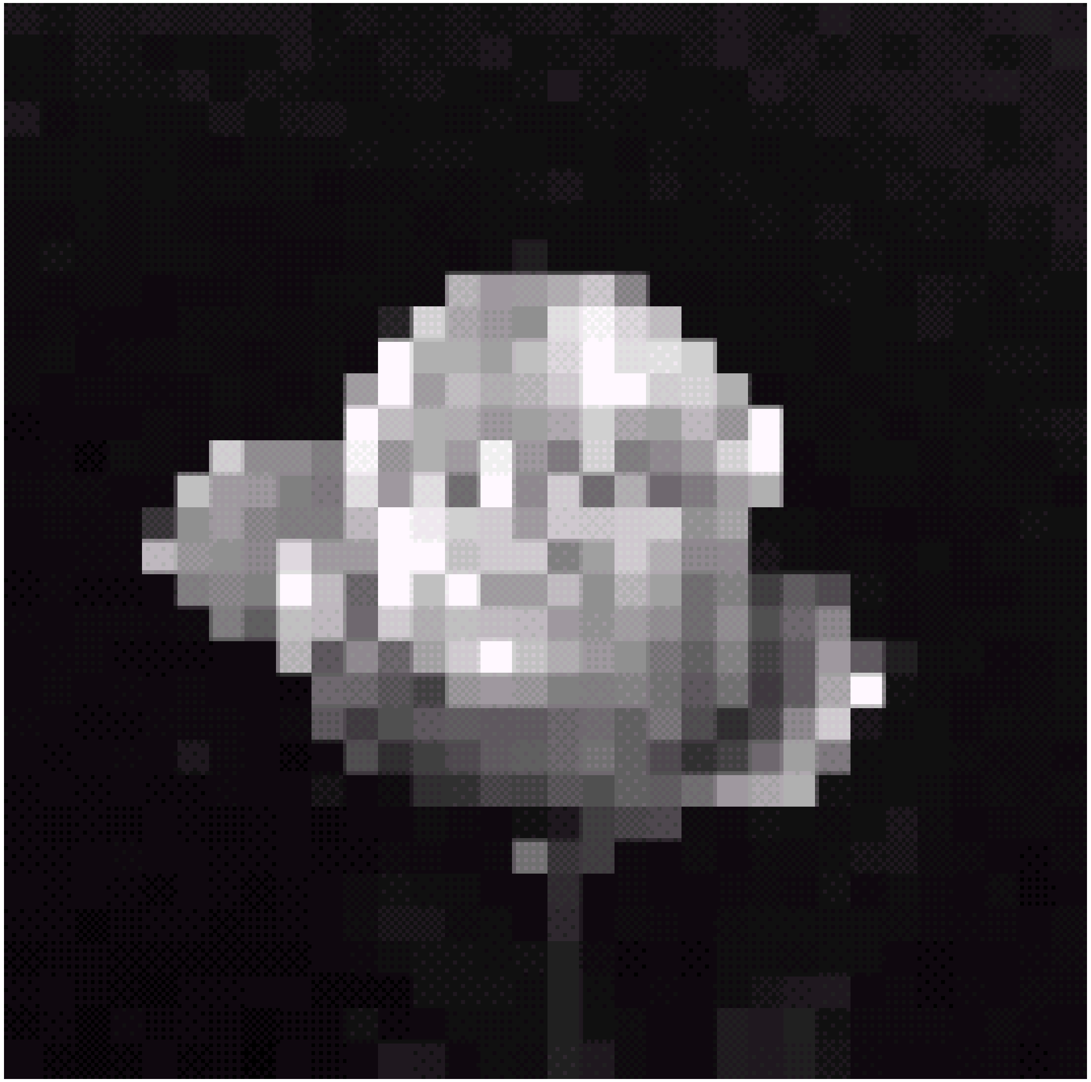
Spatial Resolution (cont…)

Spatial Resolution (cont…)

Spatial Resolution (cont…)

Spatial Resolution (cont…)

Spatial Resolution (cont…)



Intensity Level Resolution

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

– The more intensity levels used, the finer the level of detail discernable in an image

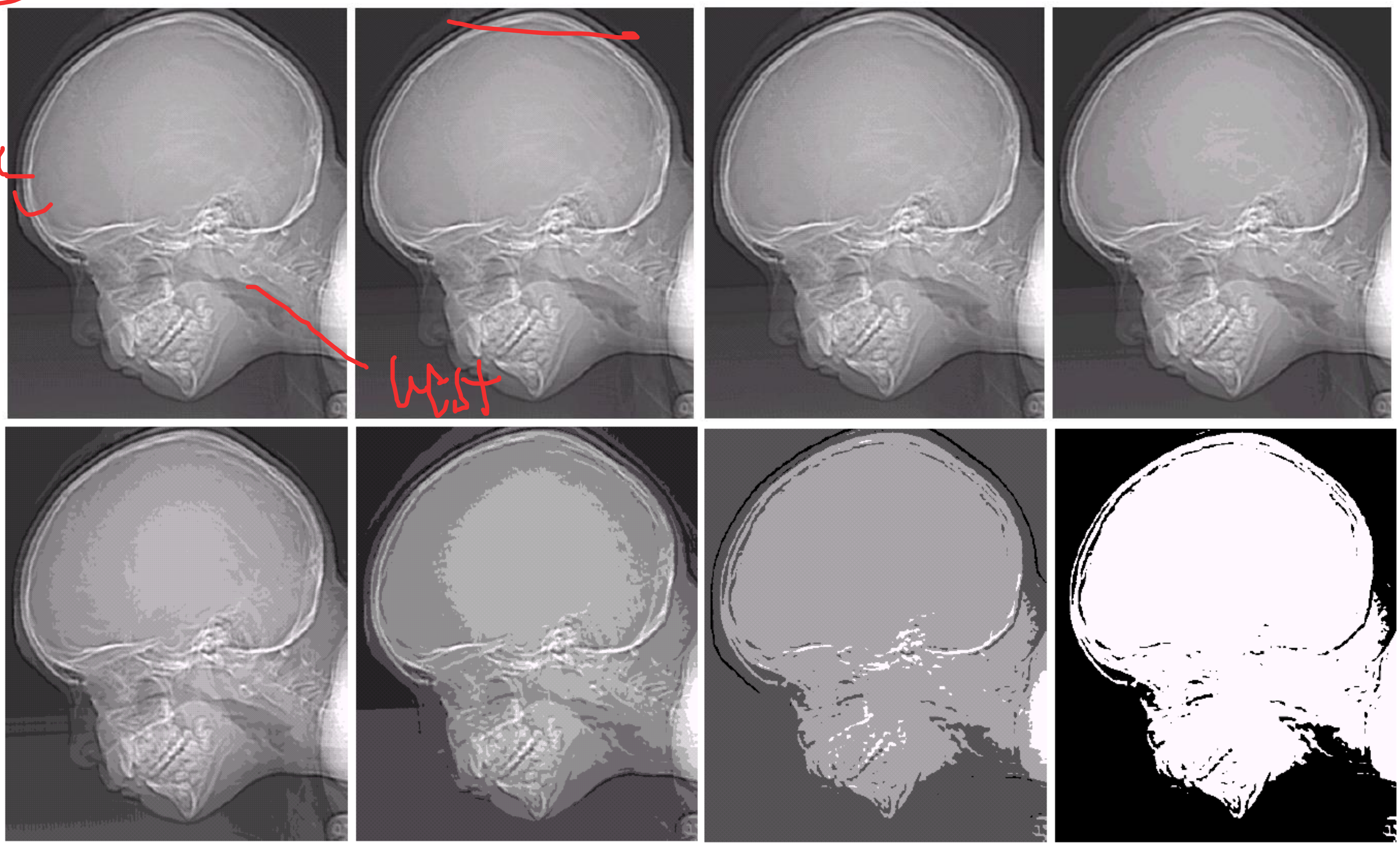
– Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

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

more bit

Intensity Level Resolution (cont…)

256 grey levels (8 bits per pixel) | 128 grey levels (7 bpp) | 64 grey levels (6 bpp) | 32 grey levels (5 bpp)



best

16 grey levels (4 bpp) | 8 grey levels (3 bpp) | 4 grey levels (2 bpp) | 2 grey levels (1 bpp)

Intensity Level Resolution (cont…)

Intensity Level Resolution (cont…)

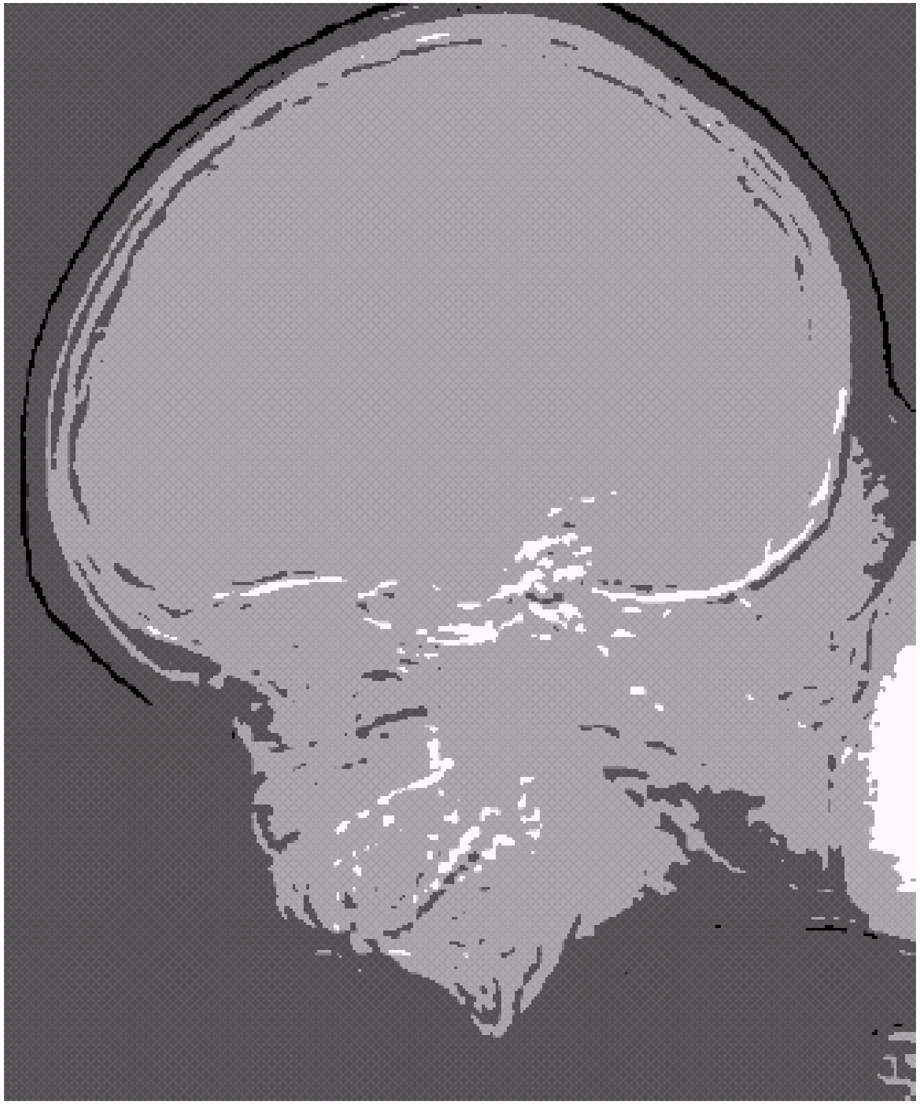
Intensity Level Resolution (cont…)

Intensity Level Resolution (cont…)

Intensity Level Resolution (cont…)

Intensity Level Resolution (cont…)

Intensity Level Resolution (cont…)



Intensity Level Resolution (cont…)

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

Intensity Level Resolution (cont…)

Low Detail

Medium Detail

High Detail

Intensity Level Resolution (cont…)

Intensity Level Resolution (cont…)

Intensity Level Resolution (cont…)

Some Basic Relationships Between Pixels

2.5.1 Neighbors of a Pixel

A pixel p at coordinates (x, y) has four *horizontal* and *vertical* neighbors whose coordinates are given by

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

This set of pixels, called the 4-*neighbors* of p, is denoted by $N_4(p)$. Each pixel is a unit distance from (x, y), and some of the neighbors of p lie outside the digital image if (x, y) is on the border of the image.

The four *diagonal* neighbors of p have coordinates

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

and are denoted by $N_D(p)$. These points, together with the 4-neighbors, are called the 8-*neighbors* of p, denoted by $N_8(p)$. As before, some of the points in $N_D(p)$ and $N_8(p)$ fall outside the image if (x, y) is on the border of the image.

Some Basic Relationships Between Pixels

– Adjacency

- three types of adjacency:

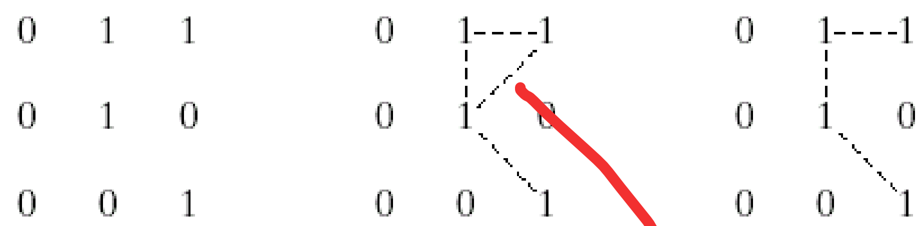
(a) *4-adjacency*. Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.

(b) *8-adjacency*. Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$.

(c) *m-adjacency* (mixed adjacency). Two pixels p and q with values from V are m-adjacent if

(i) q is in $N_4(p)$, *or*

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



a b c

FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

ambiguity

Some Basic Relationships Between Pixels

any way

– **Connectivity**

- Two pixels p and q are said to be *connected* in *S* if there exists a path between them consisting entirely of pixels in *S*.
- For any pixel p in *S*, the *set* of pixels that are connected to it in *S* is called a *connected component* of *S*.
- If it only has one connected component, then set *S* is called a *connected set*.

– **Regions**

- Let *R* be a subset of pixels in an image.We call *R* a *region* of the image if *R* is a connected set.

– **Boundaries**

- The *boundary* (also called *border* or *contour*) of a region *R* is the set of pixels in the region that have one or more neighbors that are not in *R*.

Some Basic Relationships Between Pixels

- **Distance Measures**

For pixels p, q, and z, with coordinates (x, y), (s, t), and (v, w), respectively, D is a *distance function* or *metric* if

(a) $D(p, q) \geq 0 \quad (D(p, q) = 0 \text{ iff } p = q)$,
(b) $D(p, q) = D(q, p)$, and
(c) $D(p, z) \leq D(p, q) + D(q, z)$.

The *Euclidean distance* between p and q is defined as

$$D_e(p, q) = \left[(x - s)^2 + (y - t)^2\right]^{\frac{1}{2}}. \tag{2.5-1}$$

For this distance measure, the pixels having a distance less than or equal to some value r from (x, y) are the points contained in a disk of radius r centered at (x, y).

The D_4 *distance* (also called *city-block distance*) between p and q is defined as

$$D_4(p, q) = |x - s| + |y - t|. \tag{2.5-2}$$

Some Basic Relationships Between Pixels

In this case, the pixels having a D_4 distance from (x, y) less than or equal to some value r form a diamond centered at (x, y). For example, the pixels with D_4 distance ≤ 2 from (x, y) (the center point) form the following contours of constant distance:

$$
\begin{array}{ccccc}
 & & 2 & & \\
 & 2 & 1 & 2 & \\
2 & 1 & 0 & 1 & 2 \\
 & 2 & 1 & 2 & \\
 & & 2 & &
\end{array}
$$

Rombus/kite

The pixels with $D_4 = 1$ are the 4-neighbors of (x, y).

Some Basic Relationships Between Pixels

The D_8 *distance* (also called *chessboard distance*) between p and q is defined as

$$D_8(p, q) = \max(|x - s|, |y - t|). \tag{2.5-3}$$

In this case, the pixels with D_8 distance from (x, y) less than or equal to some value r form a square centered at (x, y). For example, the pixels with D_8 distance ≤ 2 from (x, y) (the center point) form the following contours of constant 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

(x, y)

The pixels with $D_8 = 1$ are the 8-neighbors of (x, y).

Summary

We have looked at:

- – Human visual system
- – Light and the electromagnetic spectrum
- – Image representation
- – Image sensing and acquisition
- – Sampling, quantisation and resolution
- – Basic relationship between pixels