Digital Imaging Fundamentals

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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

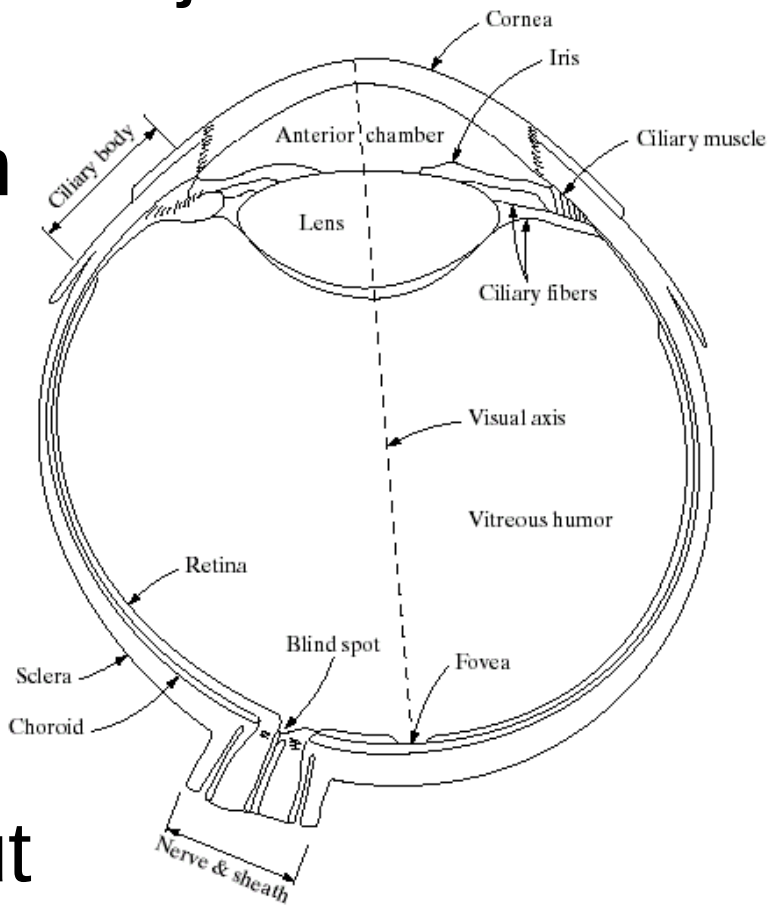
Structure Of The Human Eye

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

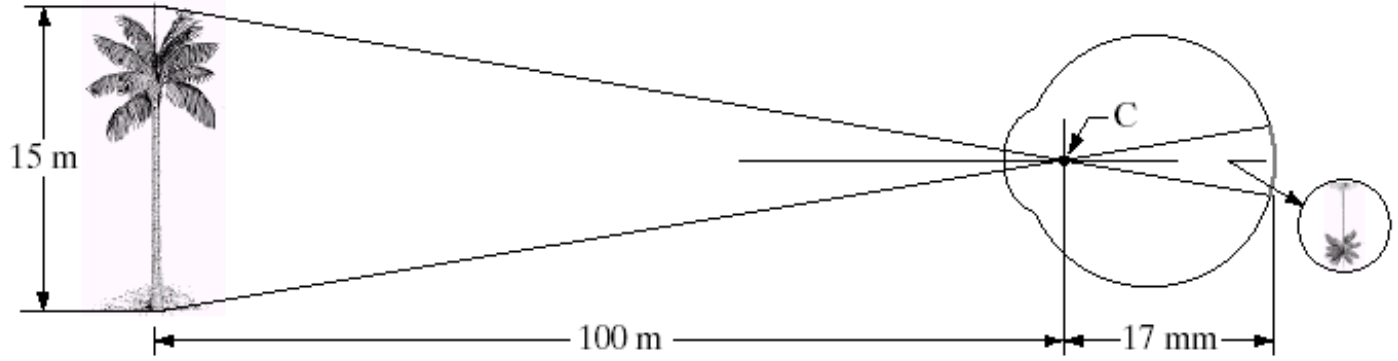


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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



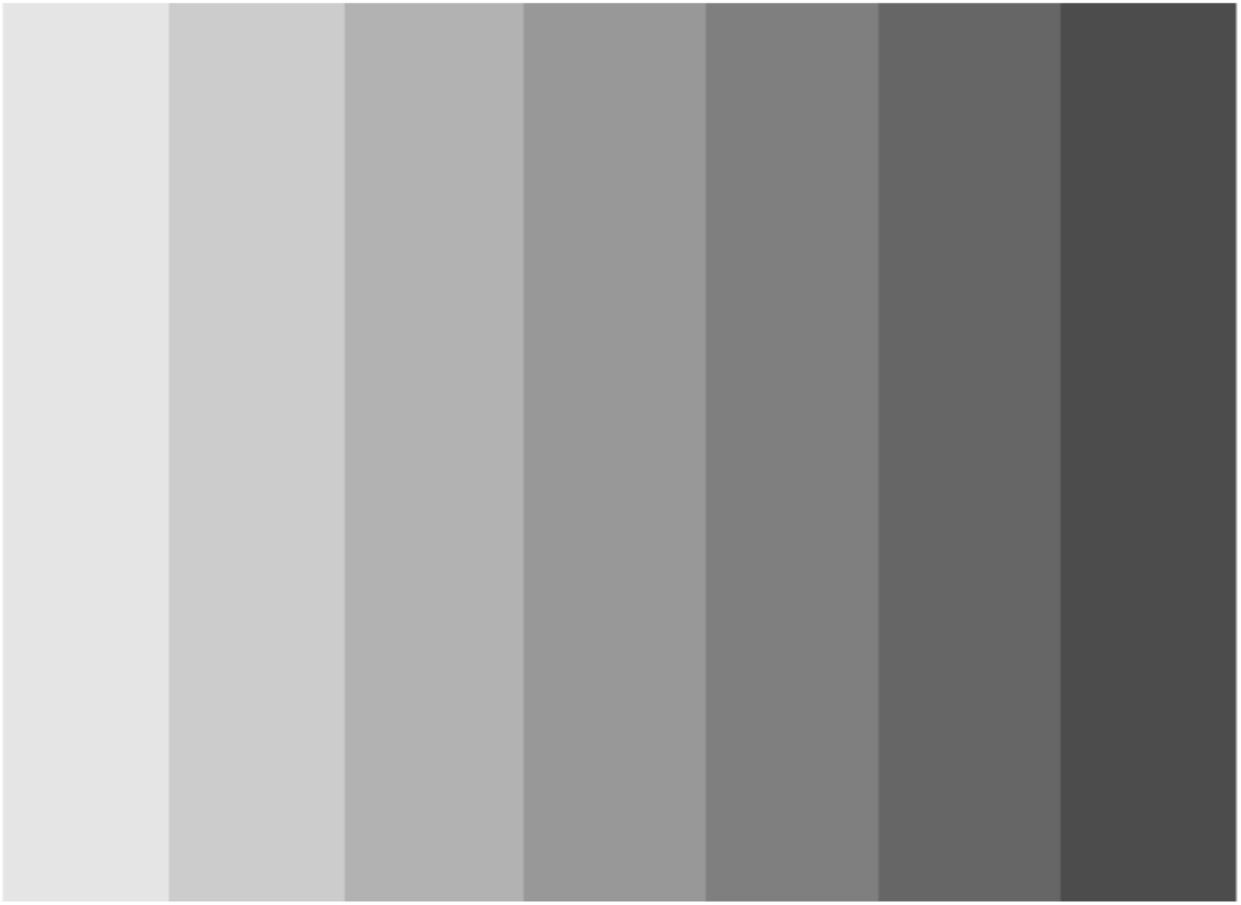
Brightness Adaptation & Discrimination

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

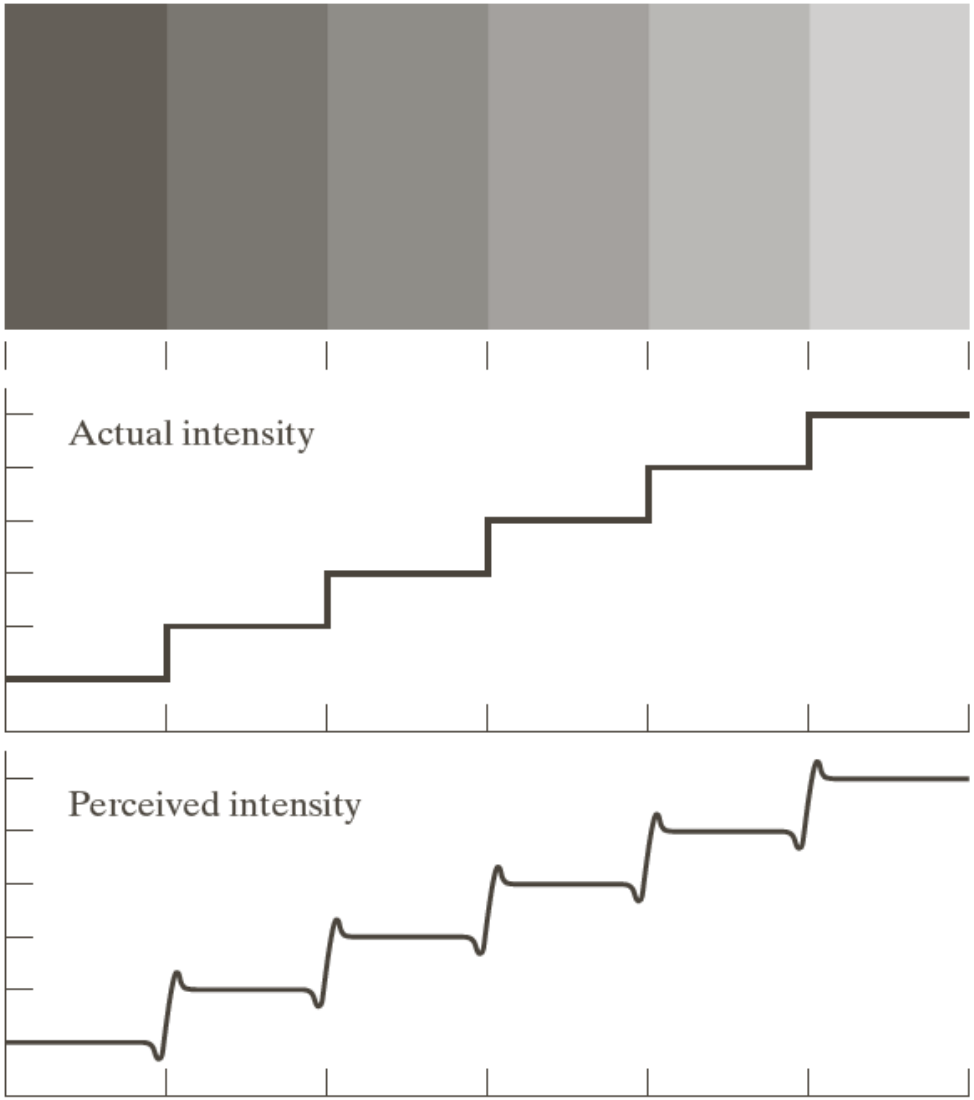
Brightness Adaptation & Discrimination (cont…)



An example of Mach bands

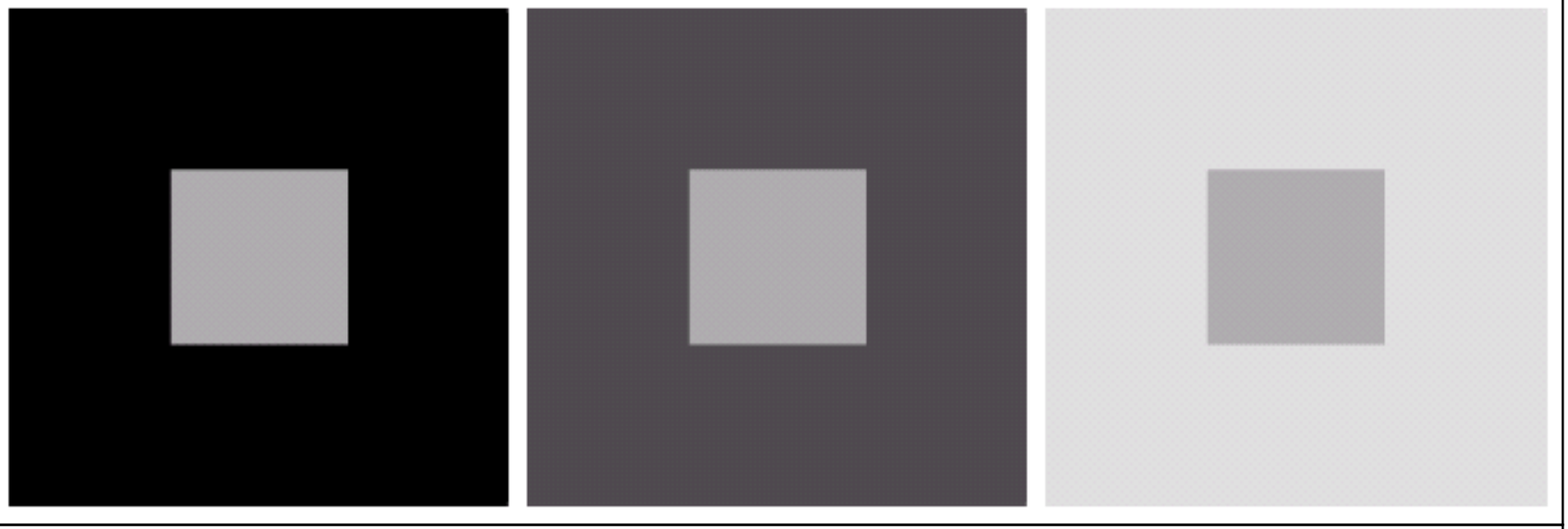
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Brightness Adaptation & Discrimination (cont…)



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

Brightness Adaptation & Discrimination (cont…)

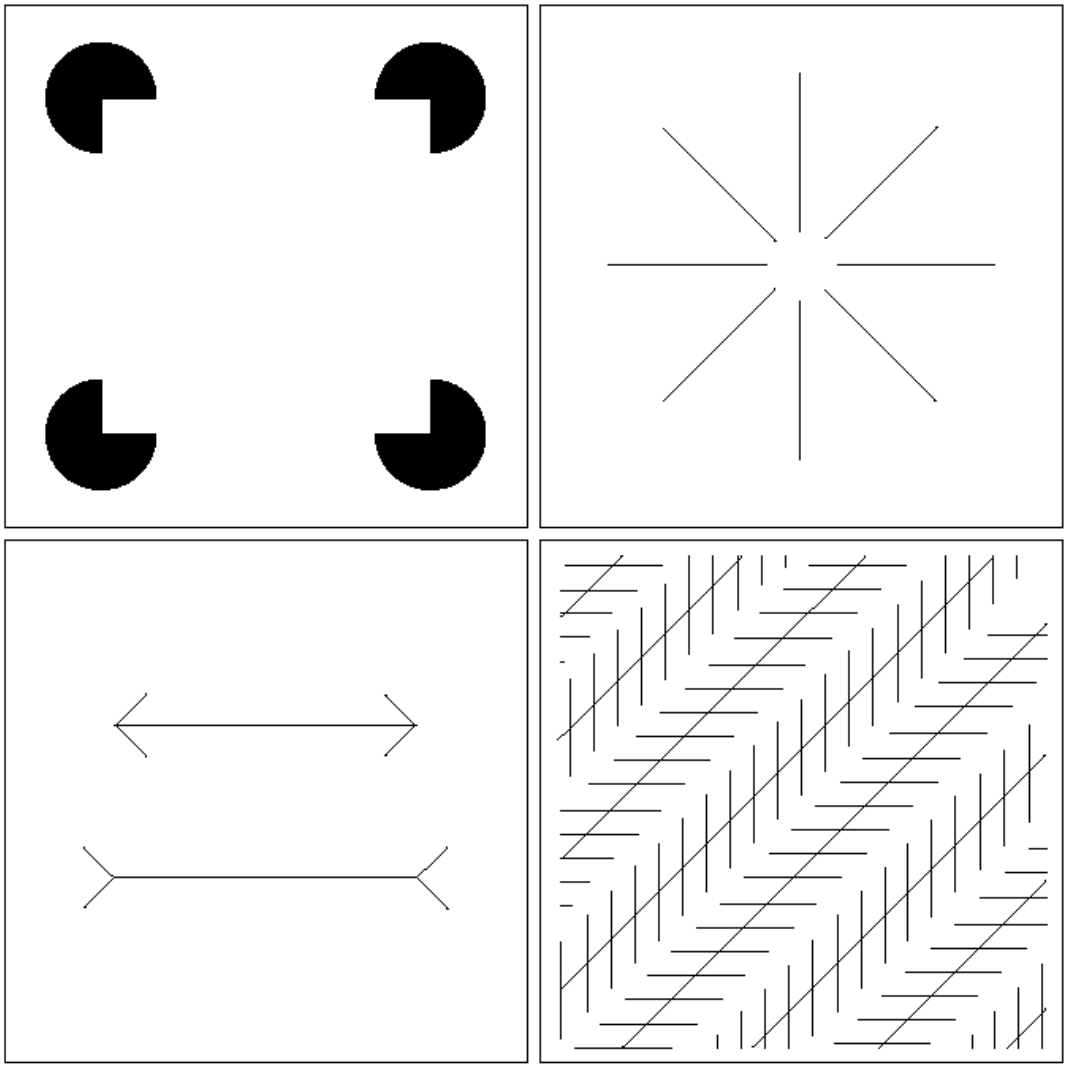


An example of *simultaneous contrast*

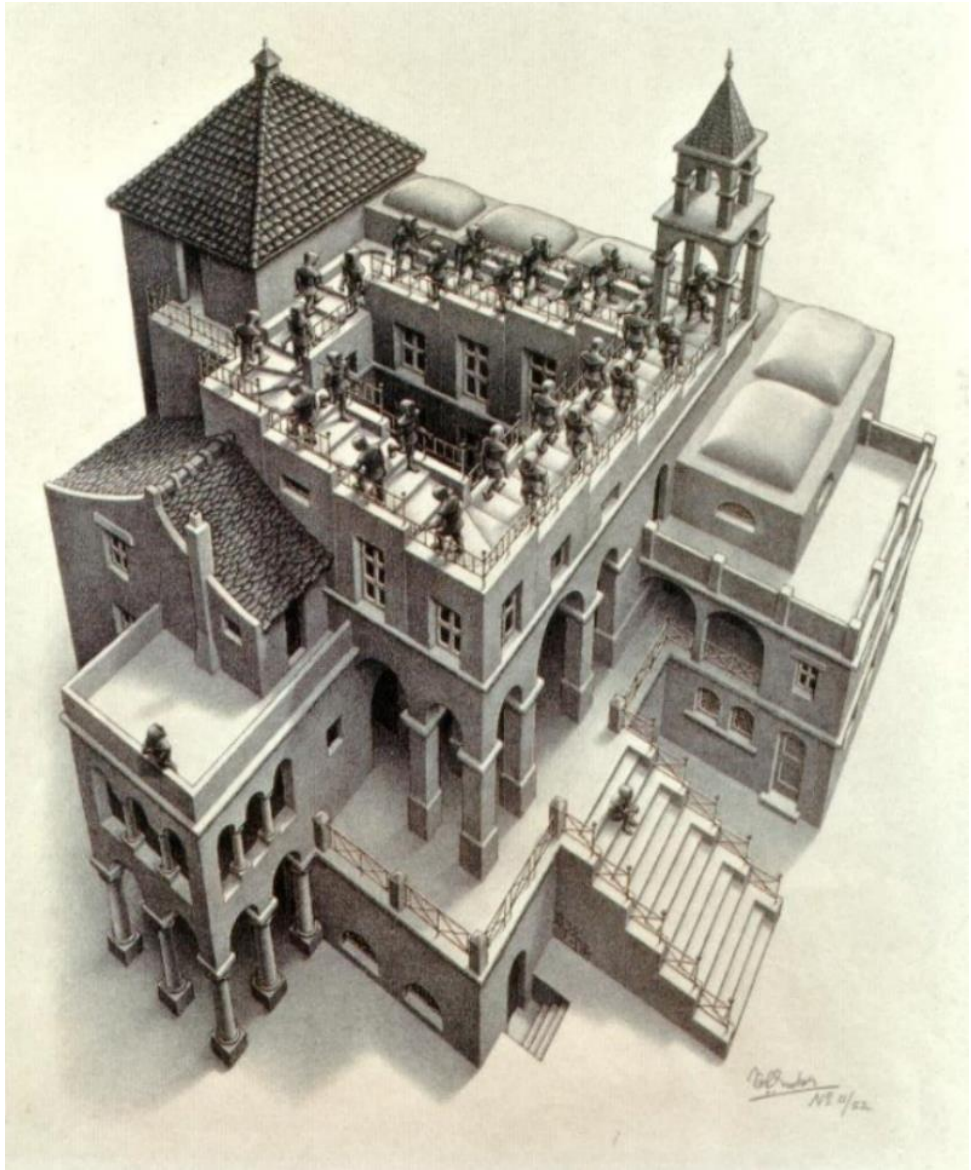
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

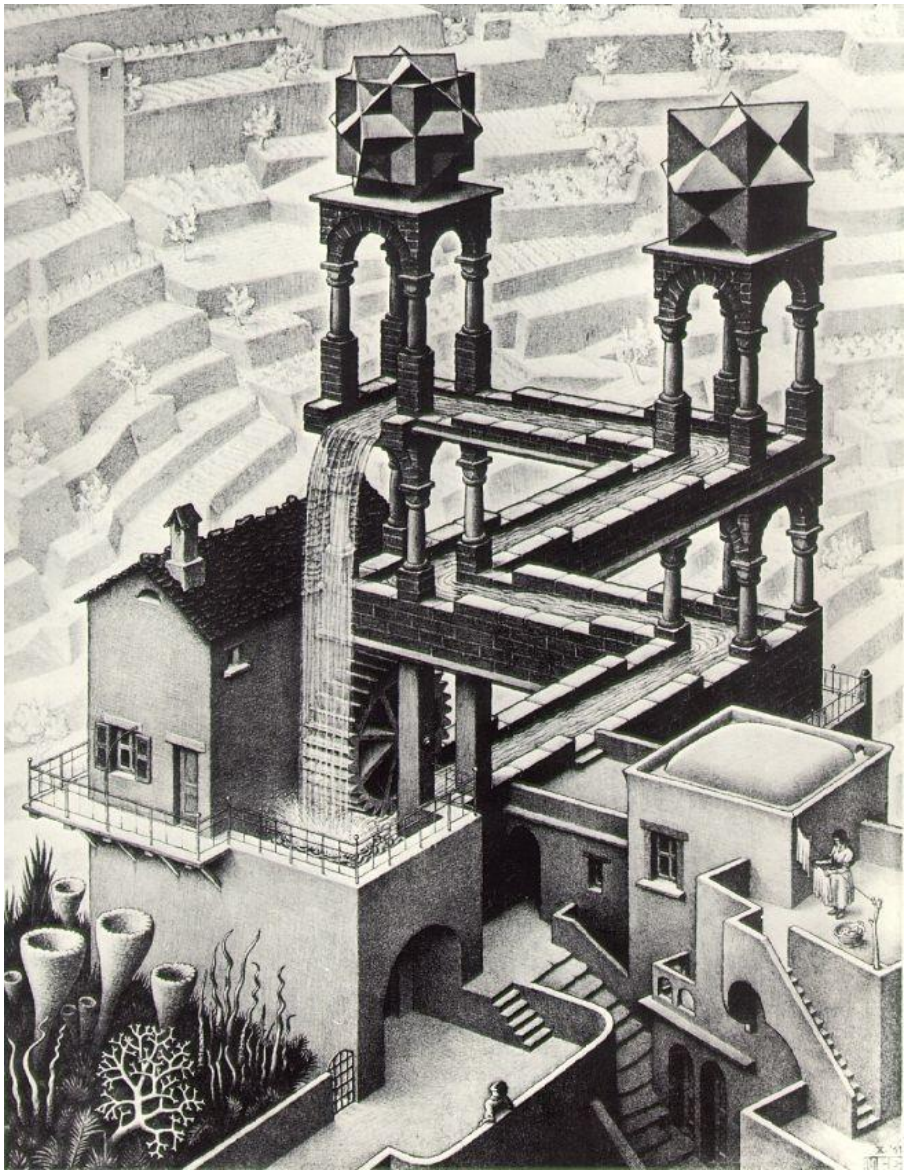
Optical Illusions

Our visual systems play lots of interesting tricks on us

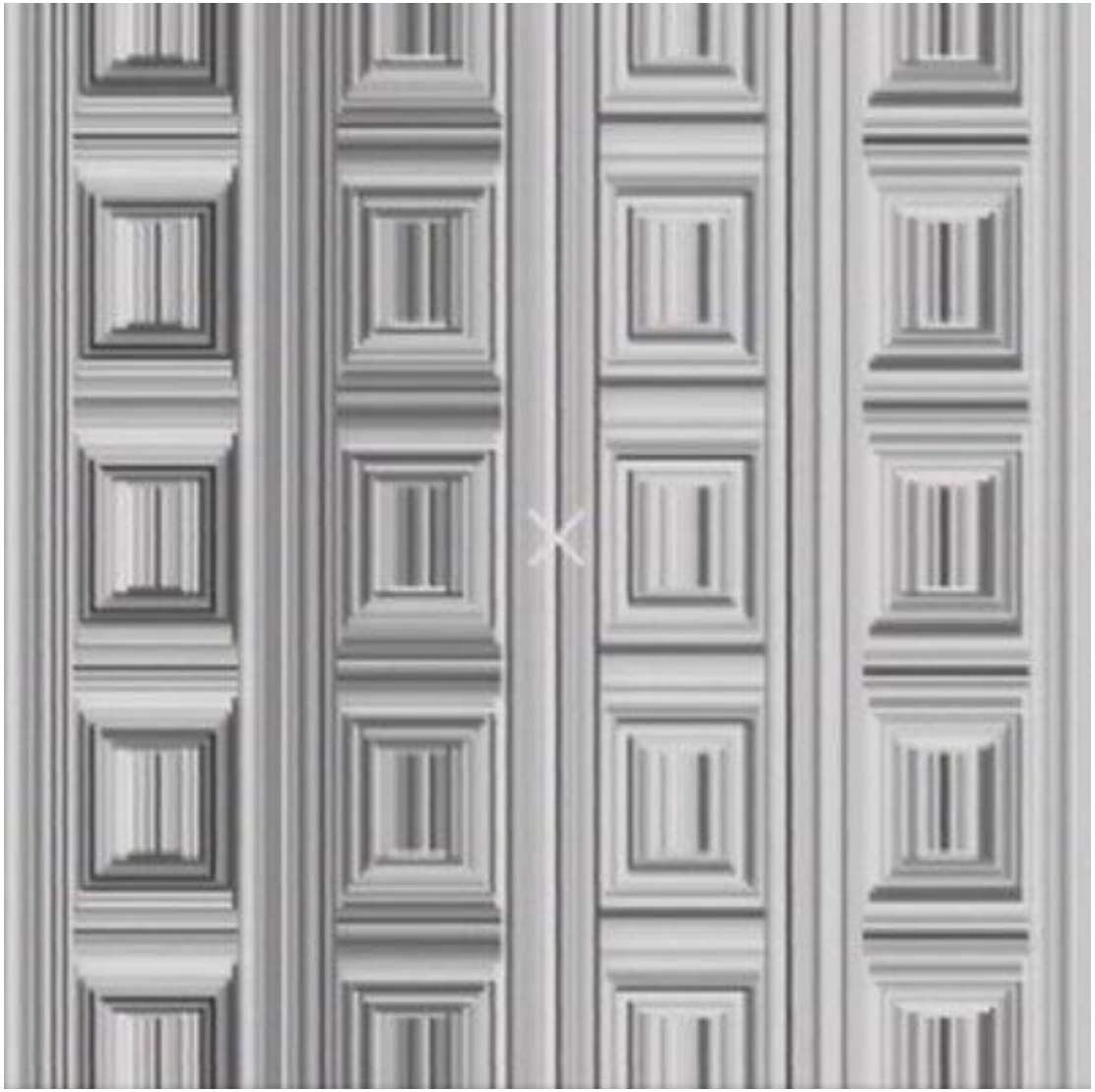


Optical Illusions (cont…)





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

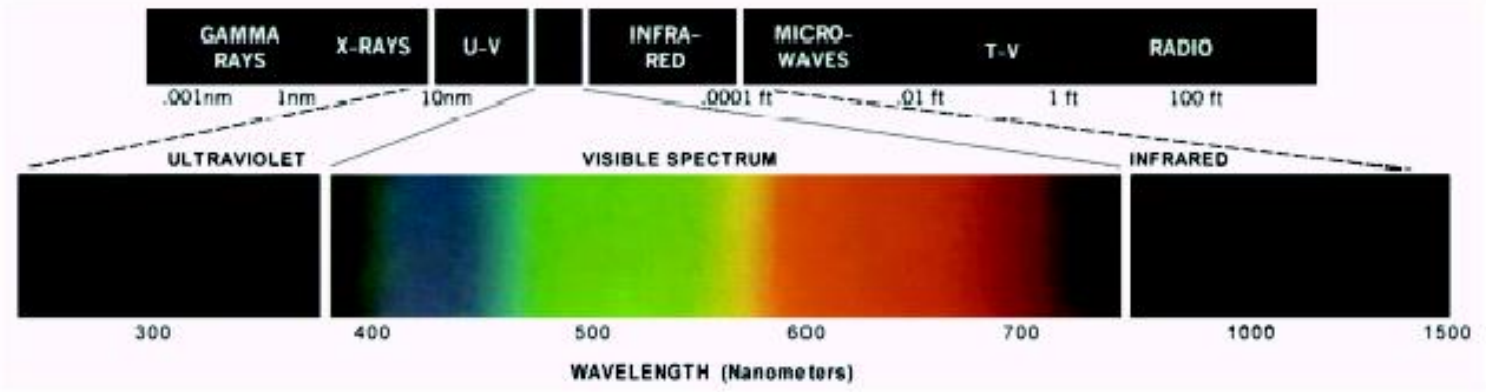
Beau Lotto: Optical Illusions Show How We See

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

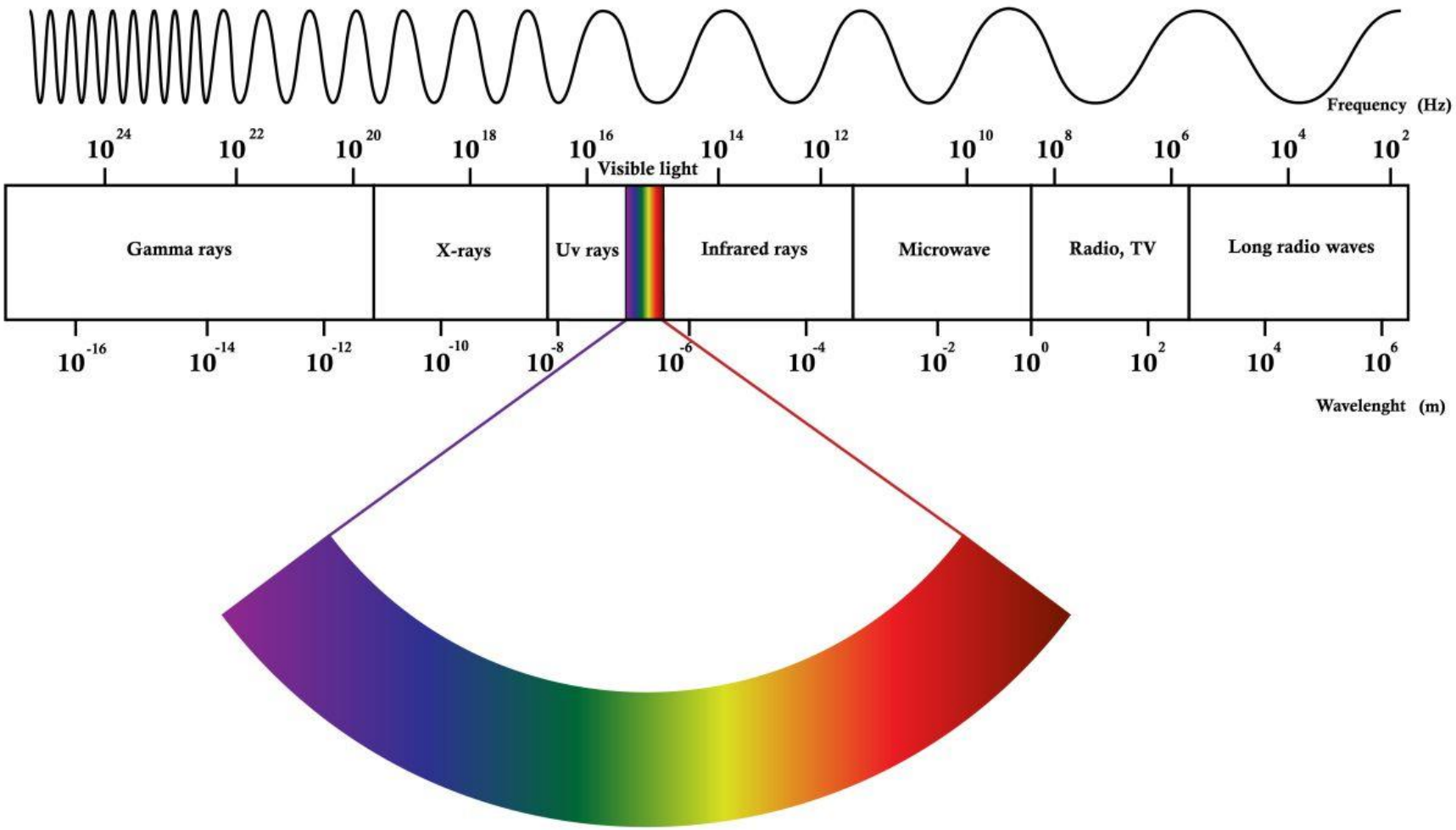
Light And The Electromagnetic Spectrum

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



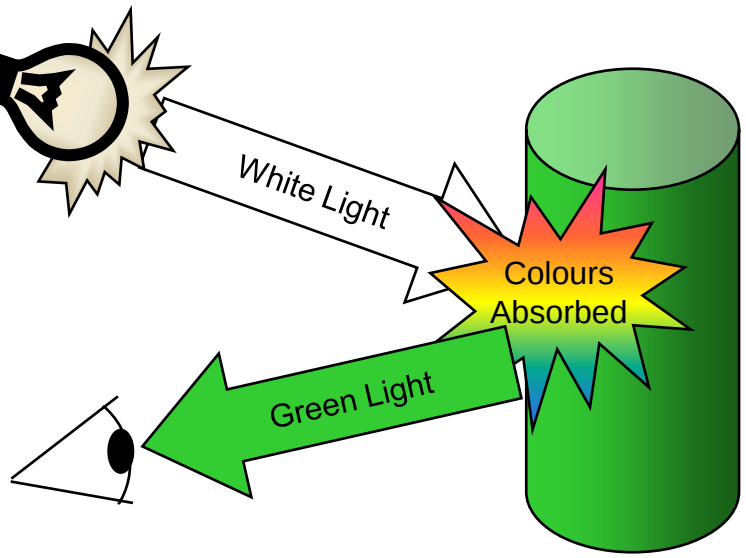
Electromagnetic Spectrum



Reflected Light

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

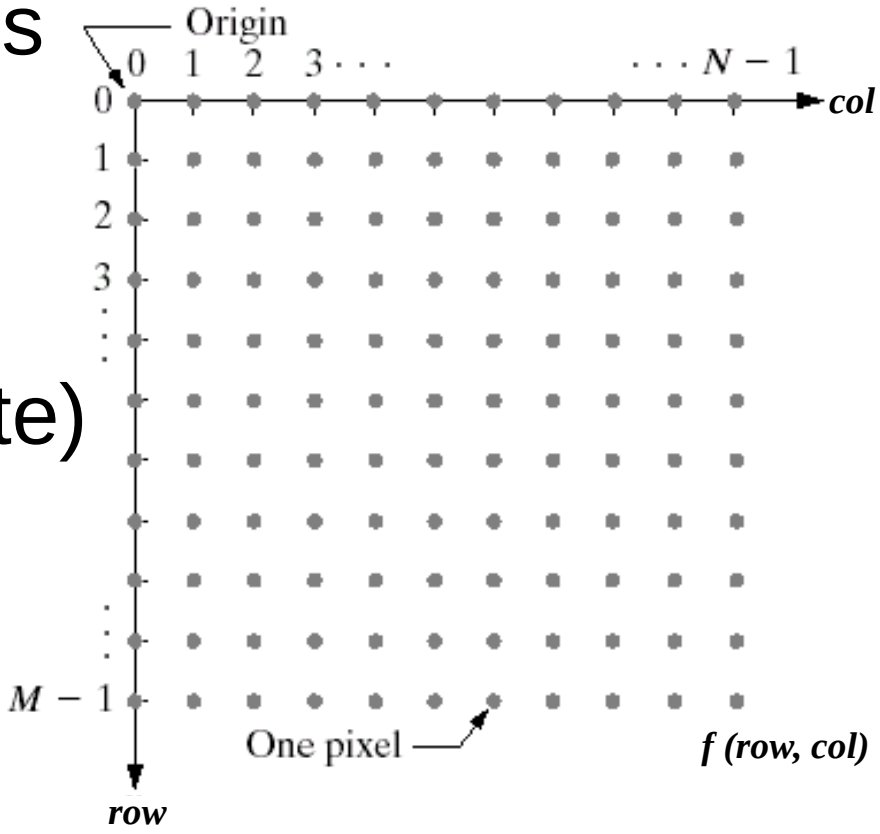
- Image sensing and representation
- Sampling and quantisation
- Resolution

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)

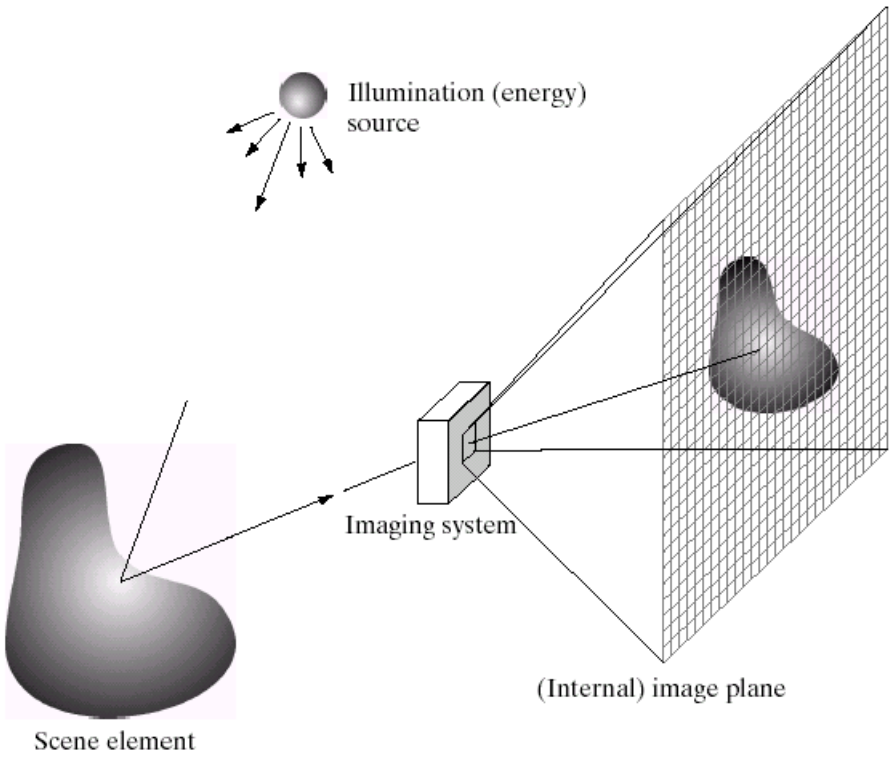
We will see later on that images can easily be represented as matrices



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

Image Acquisition

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



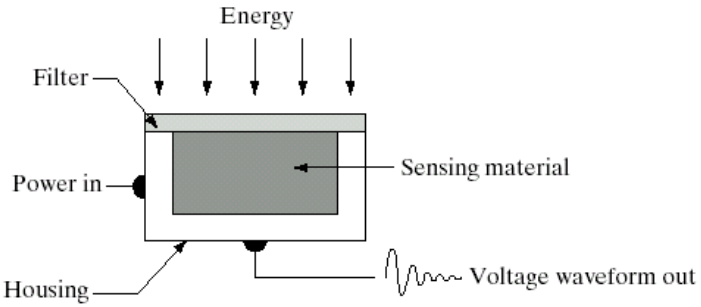
– Typical notions of illumination and scene can be way off:
  - X-rays of a skeleton
  - Ultrasound of an unborn baby
  - Electro-microscopic images of molecules

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

Image Sensing

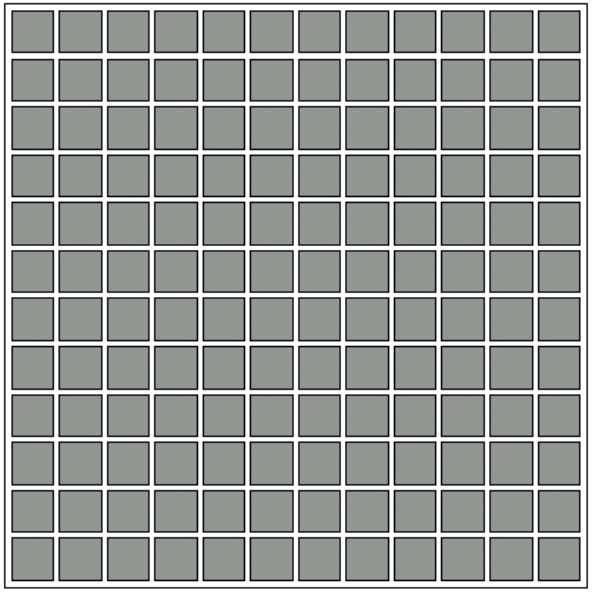
Incoming energy lands on a sensor material responsive to that type of energy and this generates a voltage

Collections of sensors are arranged to capture images



Imaging Sensor

Line of Image Sensors

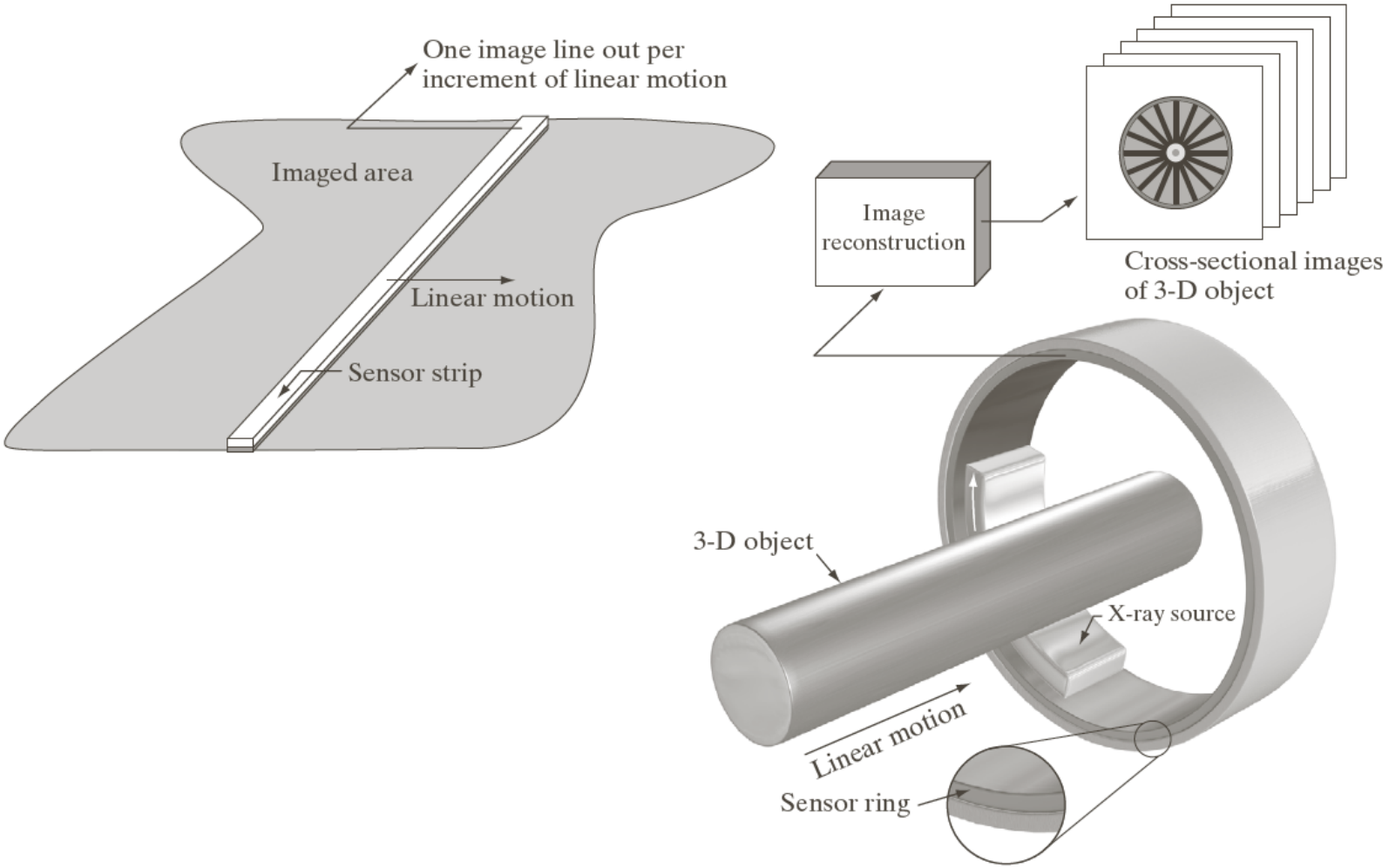


Array of Image Sensors

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

Image Sensing

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

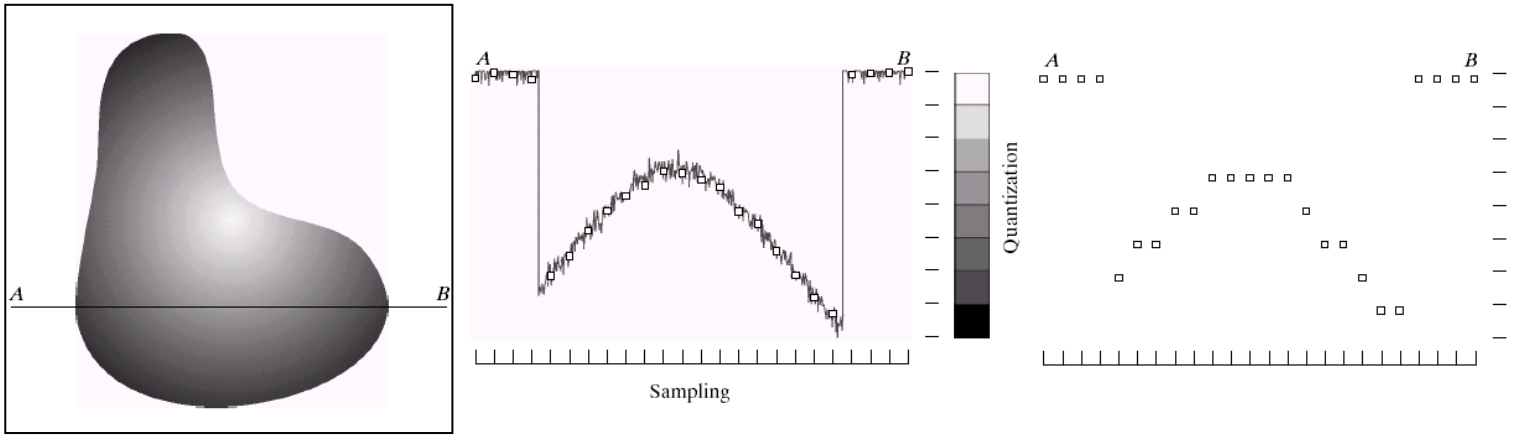


Using Sensor Strips and Rings

Image Sampling And Quantisation

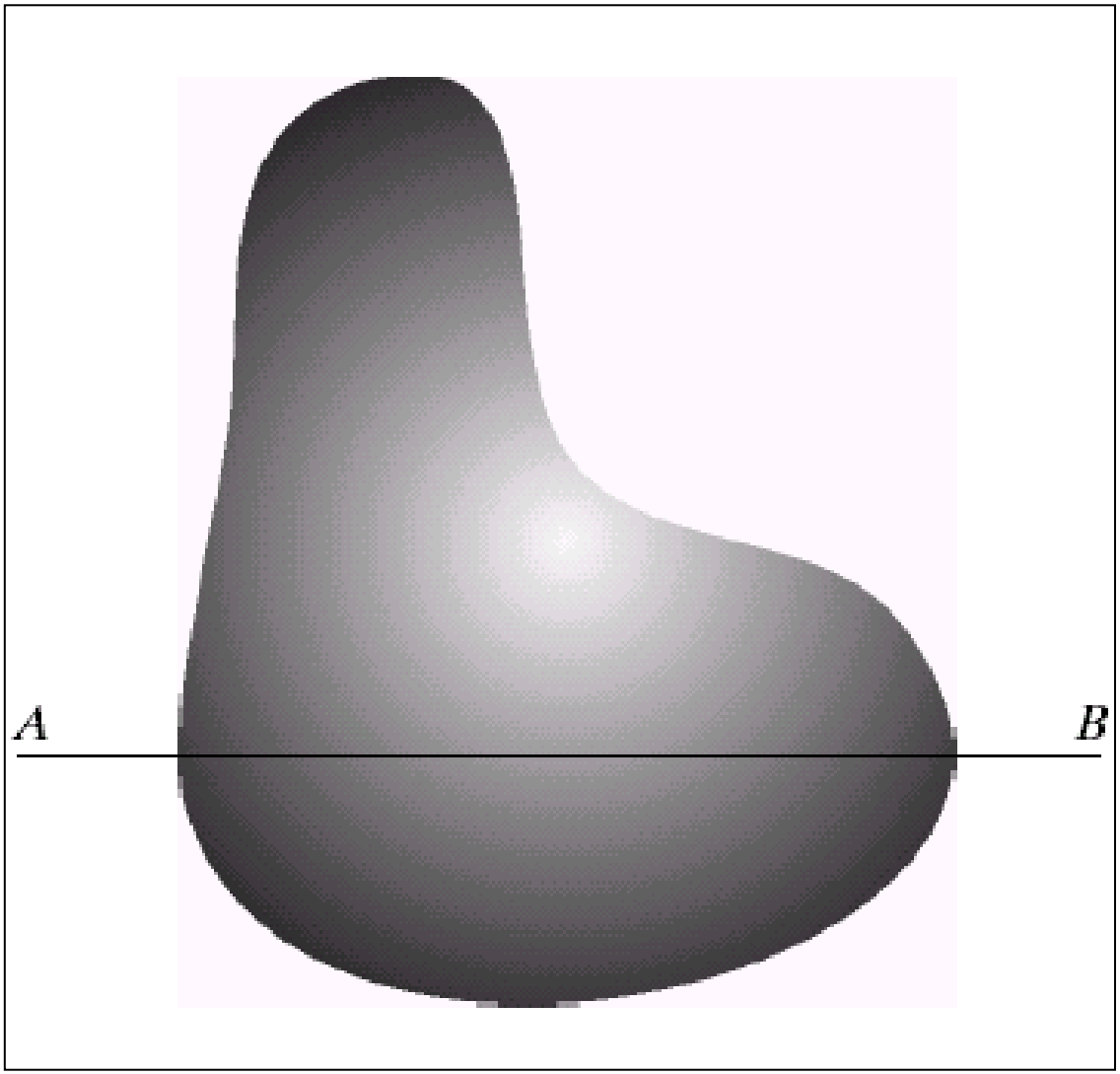
A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels

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



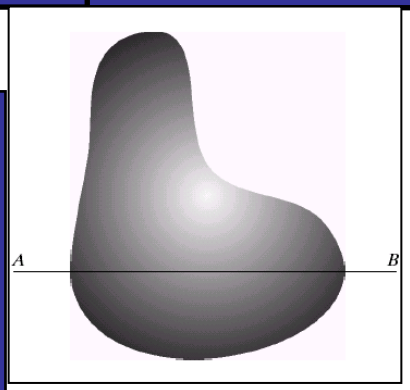
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

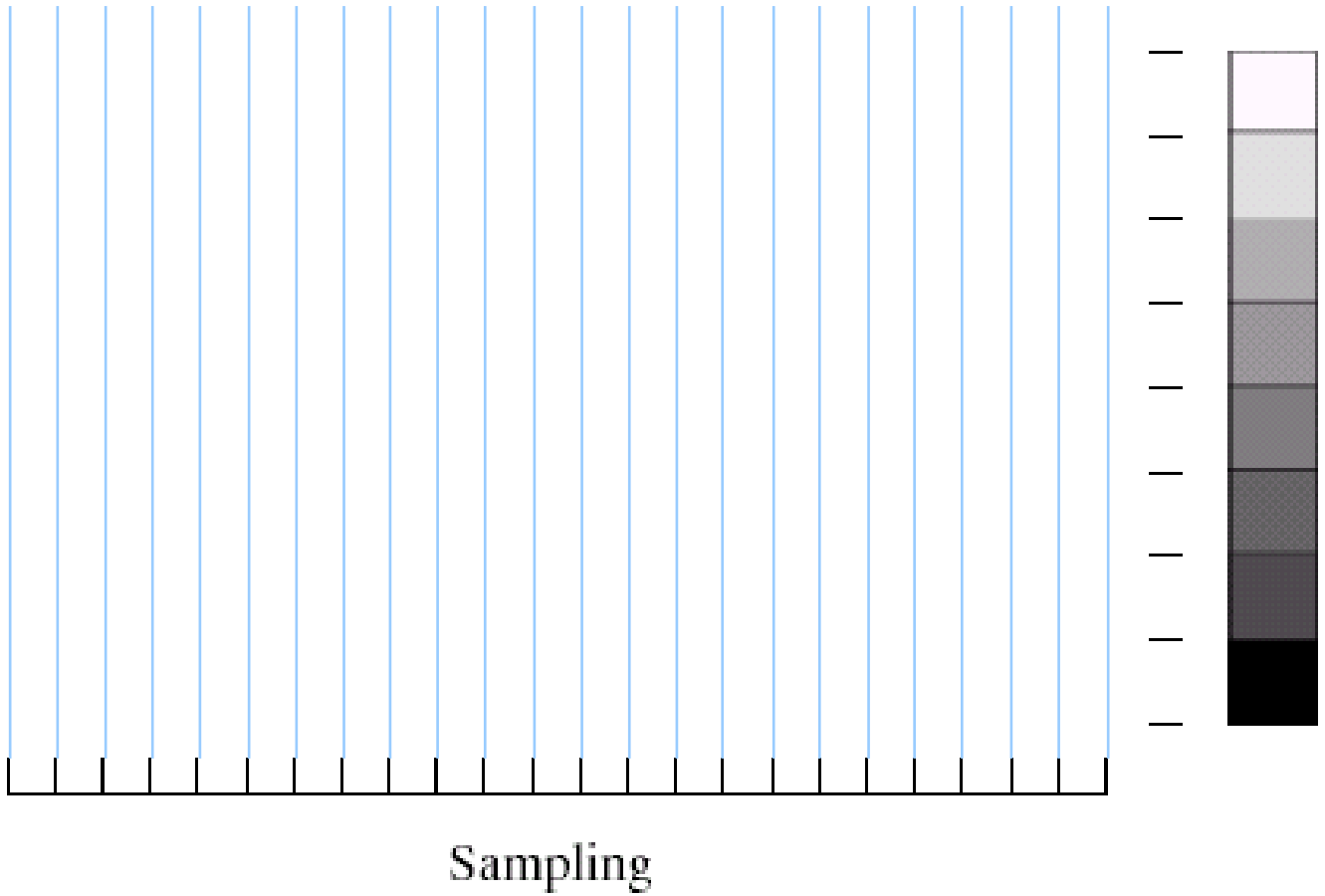
Image Sampling And Quantisation



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

Image Sampling And Quantisation

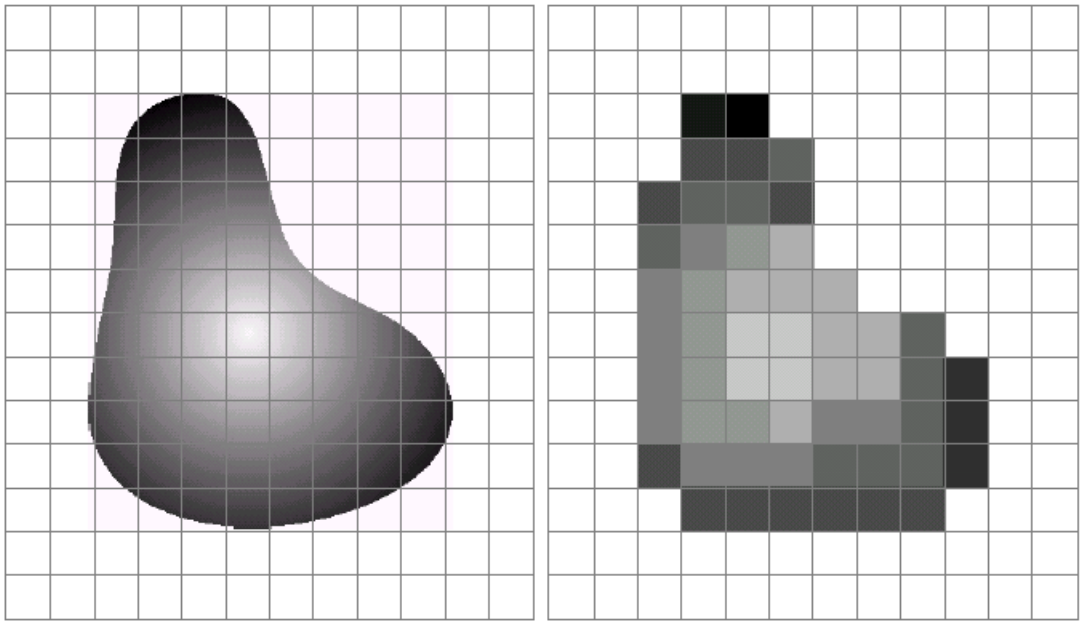




Images taken from Gonzalez & Woods, Digital Image Processing (2002)

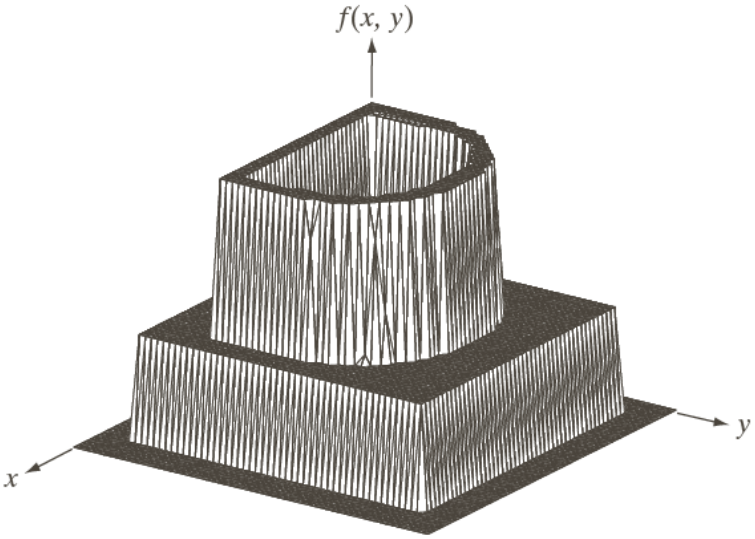
Image Sampling And Quantisation (cont…)

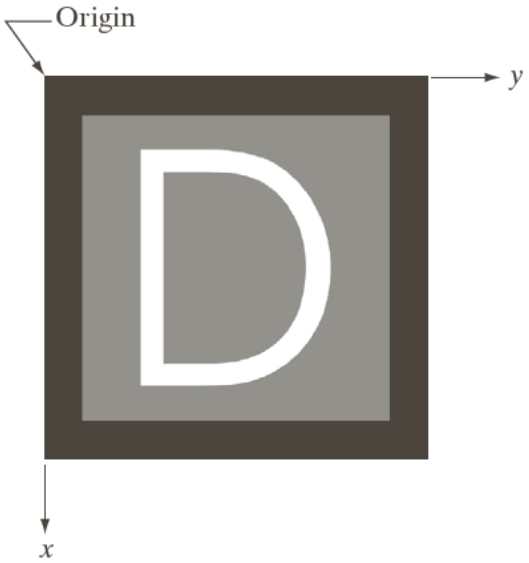
Remember that a digital image is always only an **approximation** of a real world scene

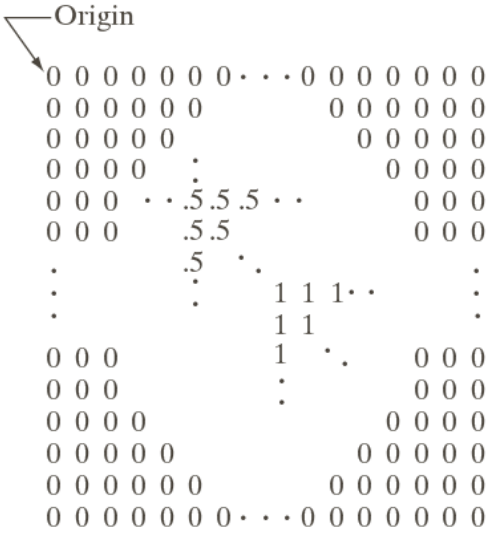


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Representation

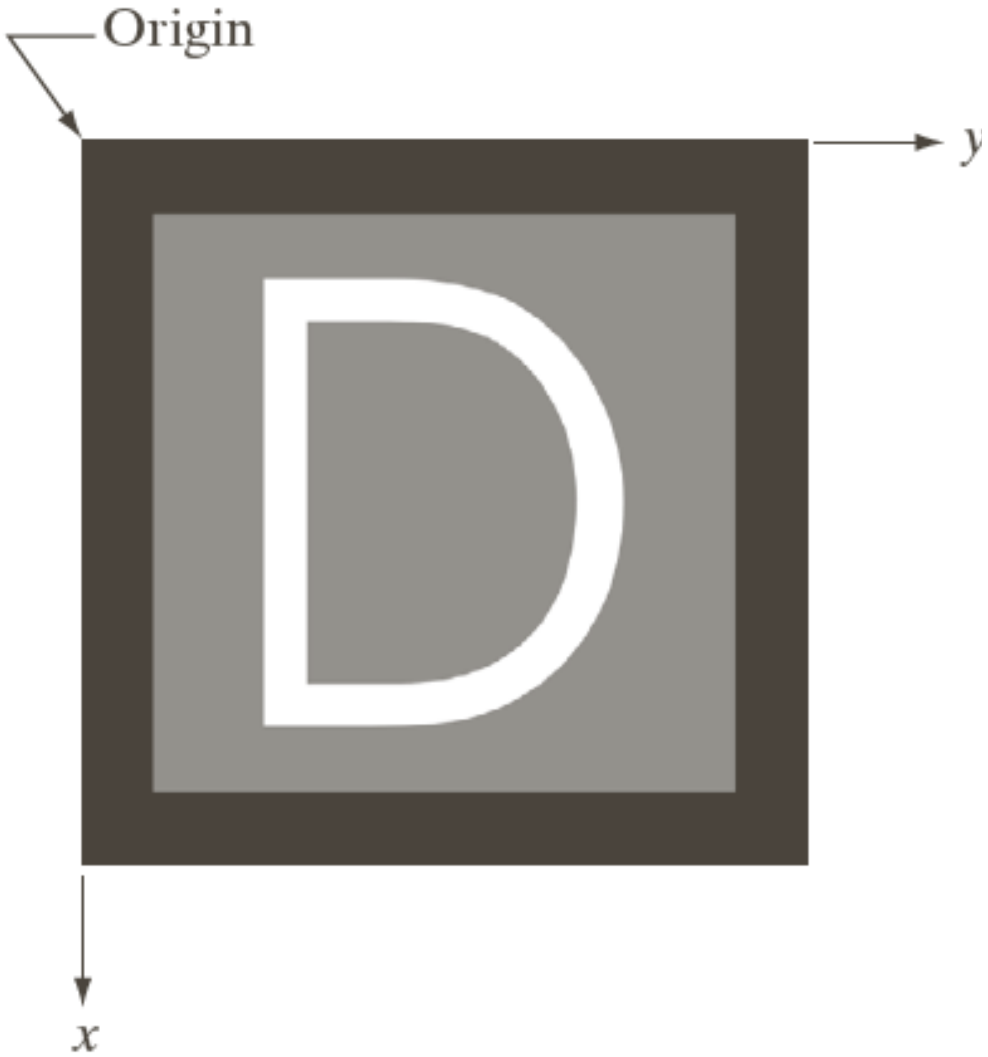






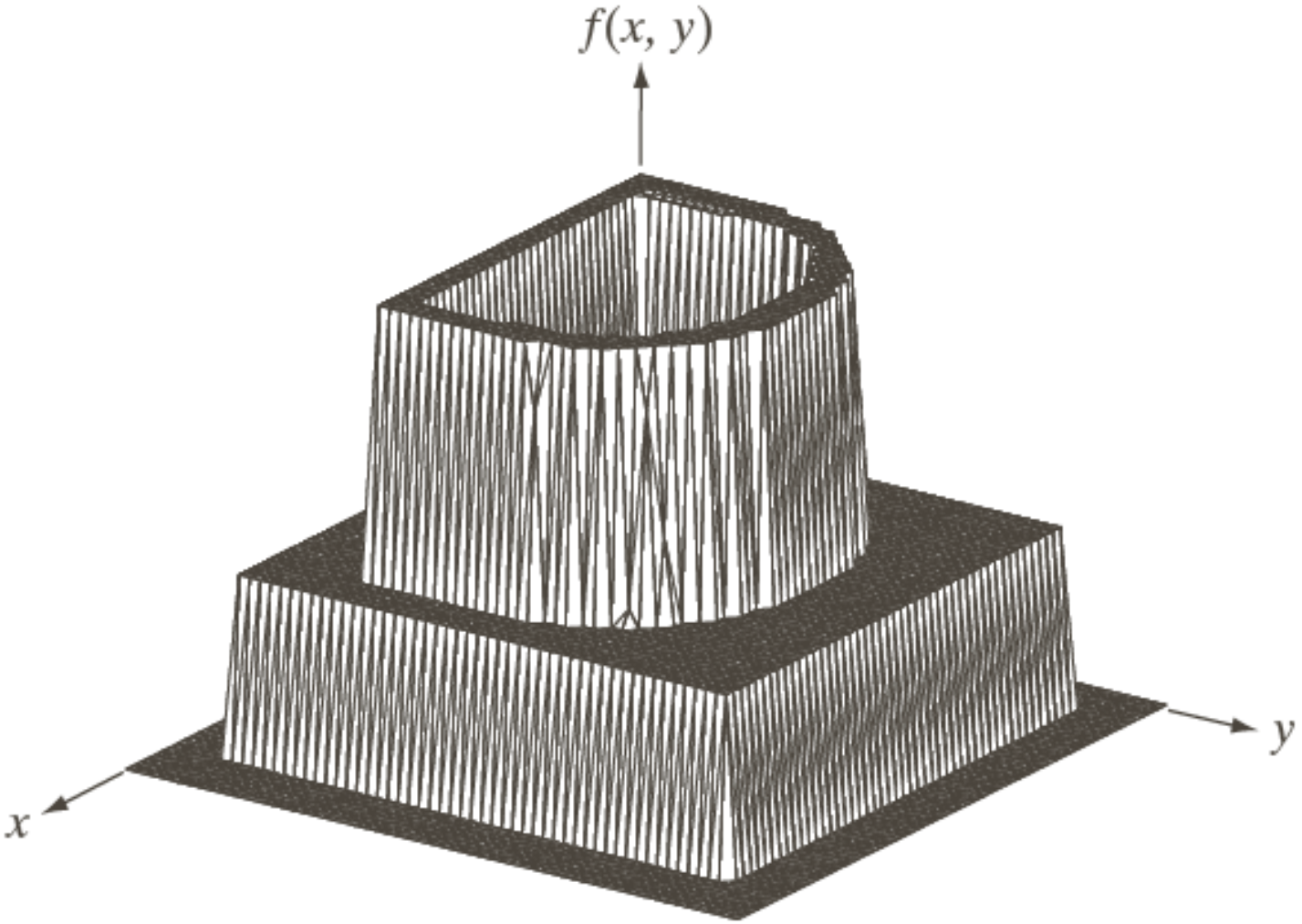
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Representation



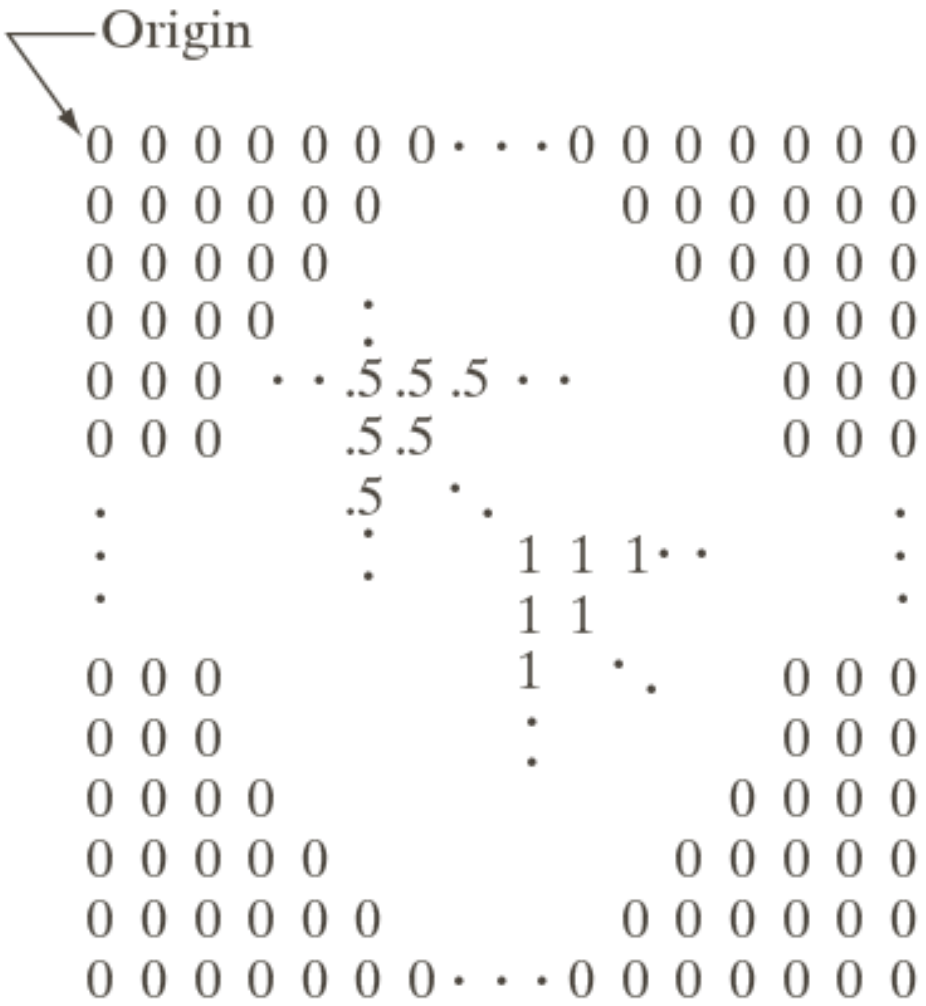
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Representation



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

Image Representation



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

Spatial Resolution

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…)

1024

512

256

128

64

32

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

Spatial Resolution (cont…)

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

Spatial Resolution (cont…)

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

Spatial Resolution (cont…)

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Spatial Resolution (cont…)

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Spatial Resolution (cont…)

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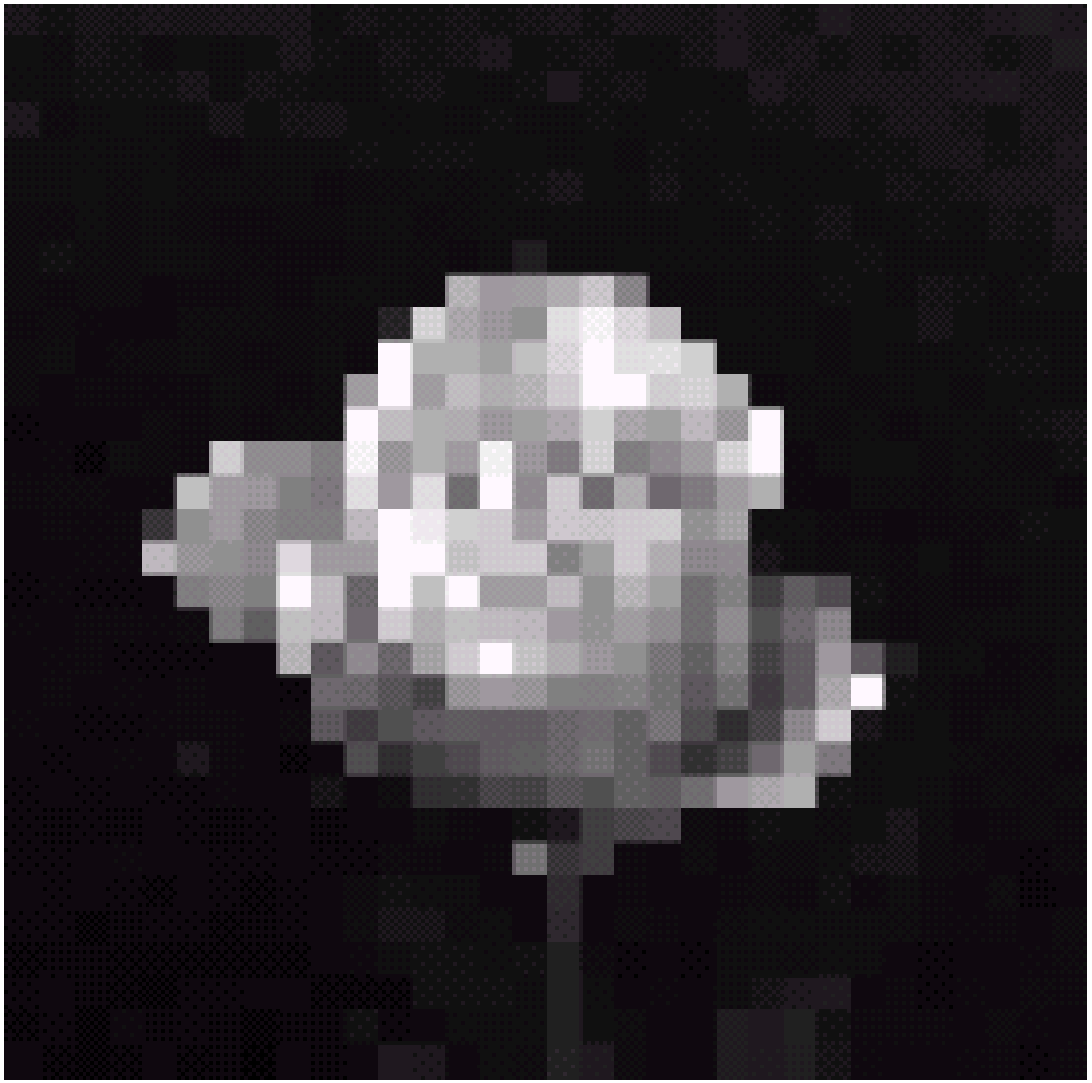
Spatial Resolution (cont…)



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

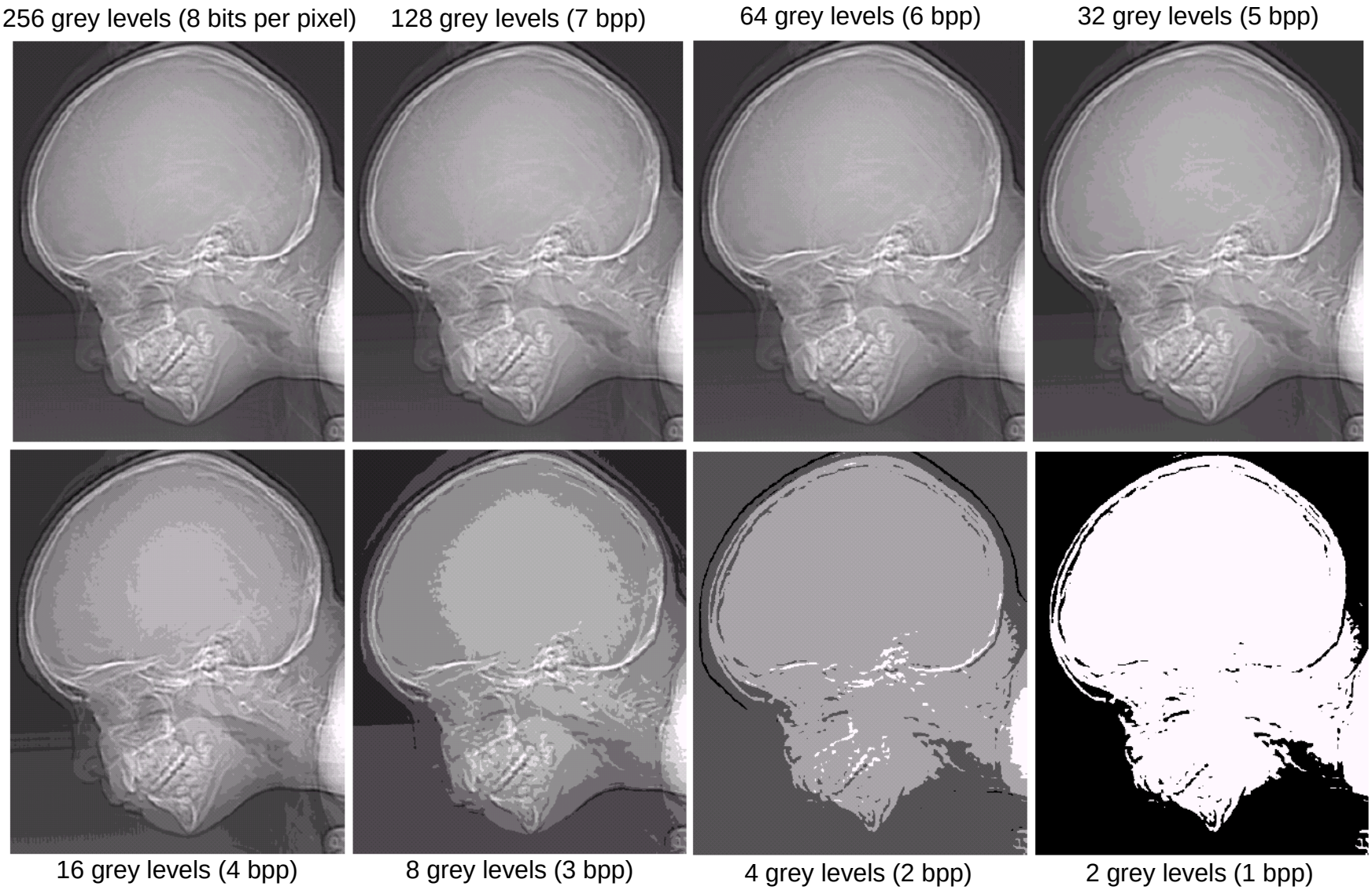
Intensity Level Resolution

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

Intensity Level Resolution (cont…)



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

Intensity Level Resolution (cont…)

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

Intensity Level Resolution (cont…)

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

Intensity Level Resolution (cont…)

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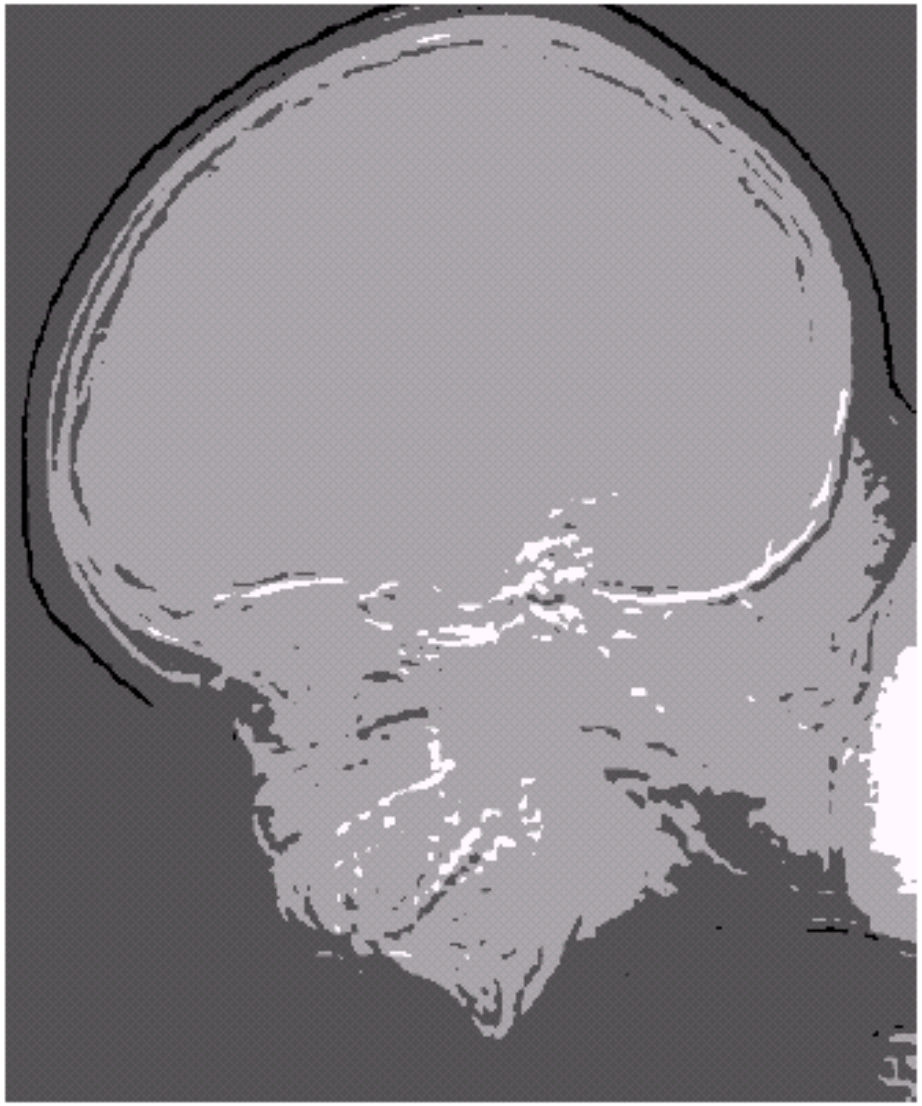
Intensity Level Resolution (cont…)

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

Intensity Level Resolution (cont…)



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

Intensity Level Resolution (cont…)

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

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

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

Intensity Level Resolution (cont…)

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

Intensity Level Resolution (cont…)

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

Intensity Level Resolution (cont…)

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

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:

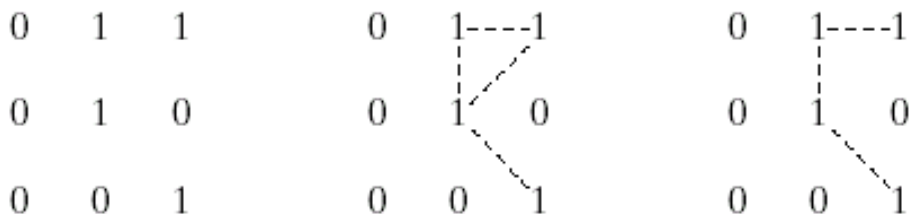
(a) 4-*adjacency*. Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.

(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.

Some Basic Relationships Between Pixels

- **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) $D(p, q) \geq 0 \quad (D(p, q) = 0 \quad \text{iff} \quad p = q)$,
(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

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

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

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

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:

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

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

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

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:

$$\begin{matrix} 2 & 2 & 2 & 2 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 1 & 0 & 1 & 2 \\ 2 & 1 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 2 \end{matrix}$$

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