Digital Image Processing: Digital Imaging Fundamentals

Contents

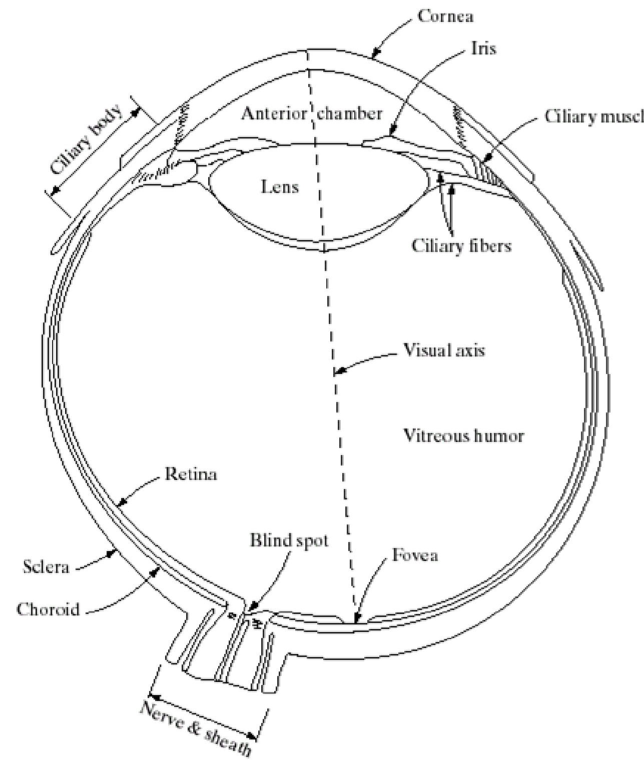
- This lecture will cover:
  - The human visual system
  - Light and the electromagnetic spectrum
  - Image representation
  - Image sensing and acquisition
  - Sampling, quantisation and resolution

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)

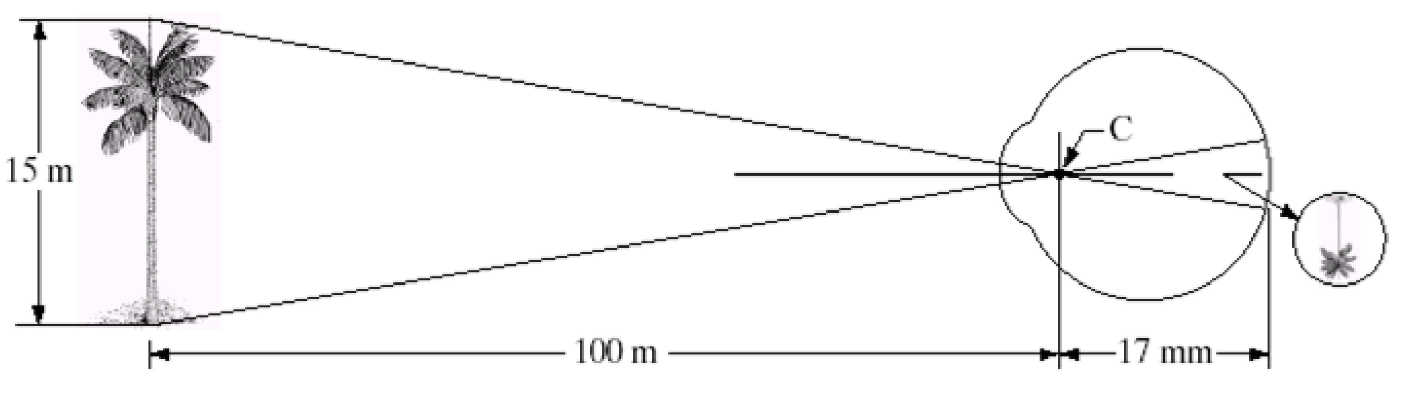
Blind-Spot Experiment

- Draw an image similar to that below on a piece of paper (the dot and cross are about 6 inches apart)

- Close your right eye and focus on the cross with your left eye
- Hold the image about 20 inches away from your face and move it slowly towards you
- The dot should disappear!

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

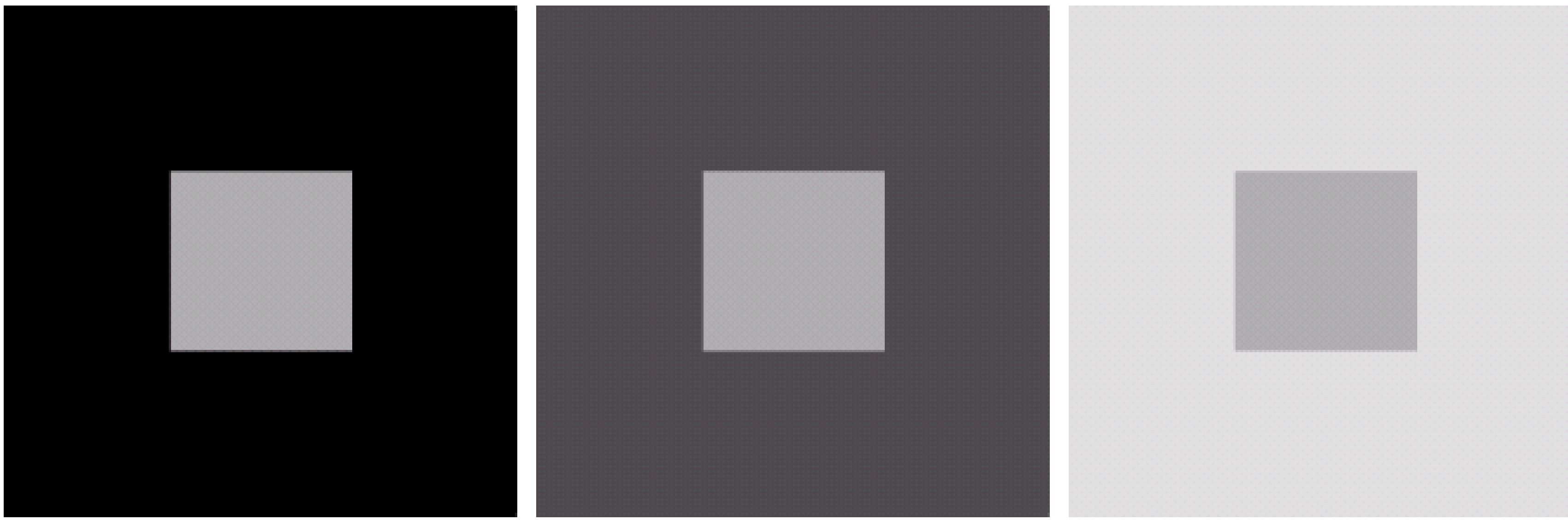
- The human visual system can perceive approximately 10^{10} different light intensity levels
- However, at any one time we can only discriminate between a much smaller number – *brightness adaptation*
- Similarly, the *perceived intensity* of a region is related to the light intensities of the regions surrounding it

Brightness Adaptation & Discrimination (cont…)

An example of Mach bands

Brightness Adaptation & Discrimination (cont…)

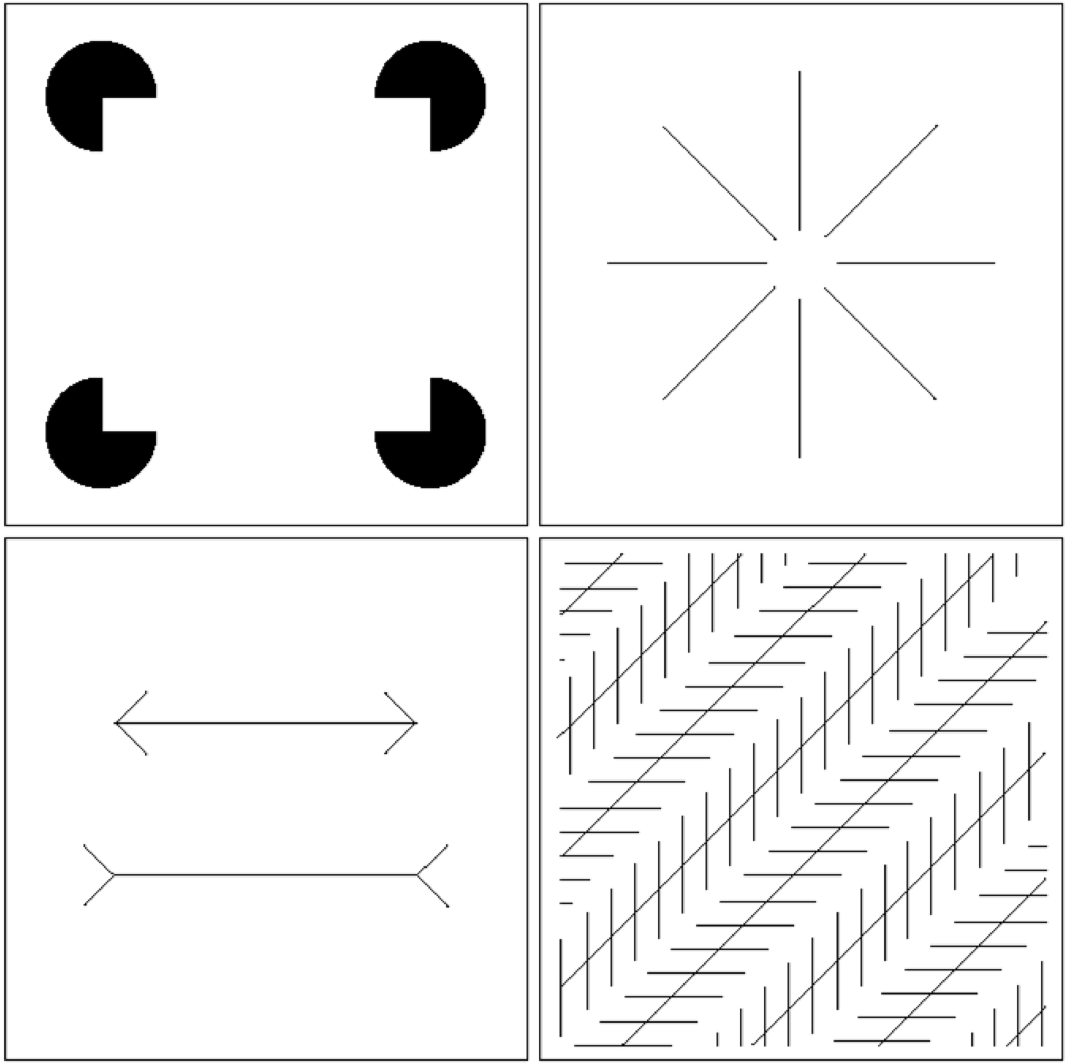
Brightness Adaptation & Discrimination (cont…)



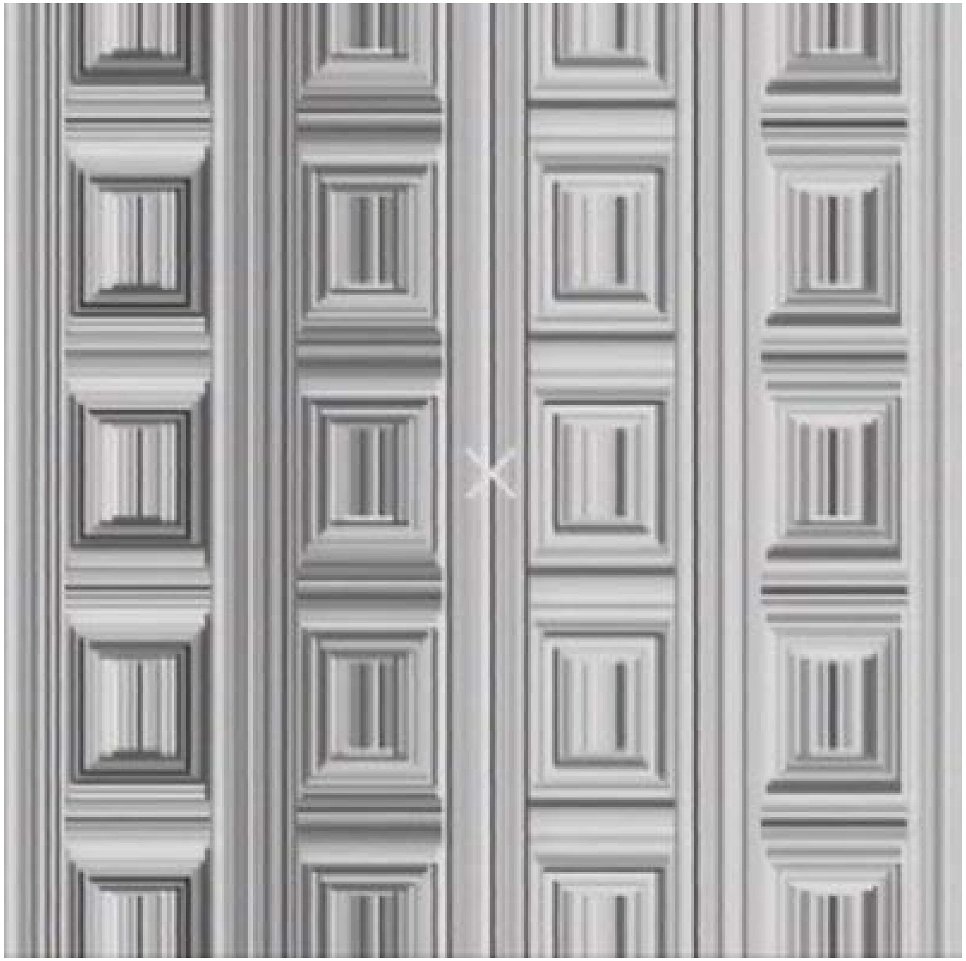
An example of *simultaneous contrast*

Optical Illusions

- Our visual systems play lots of interesting tricks on us



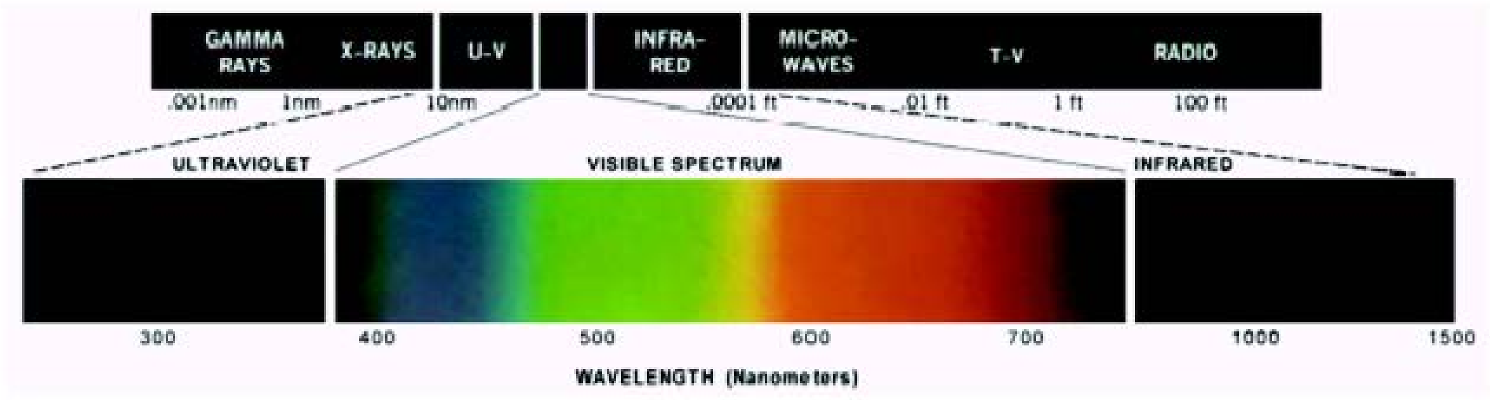
Optical Illusions (cont…)



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

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



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 rc... 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

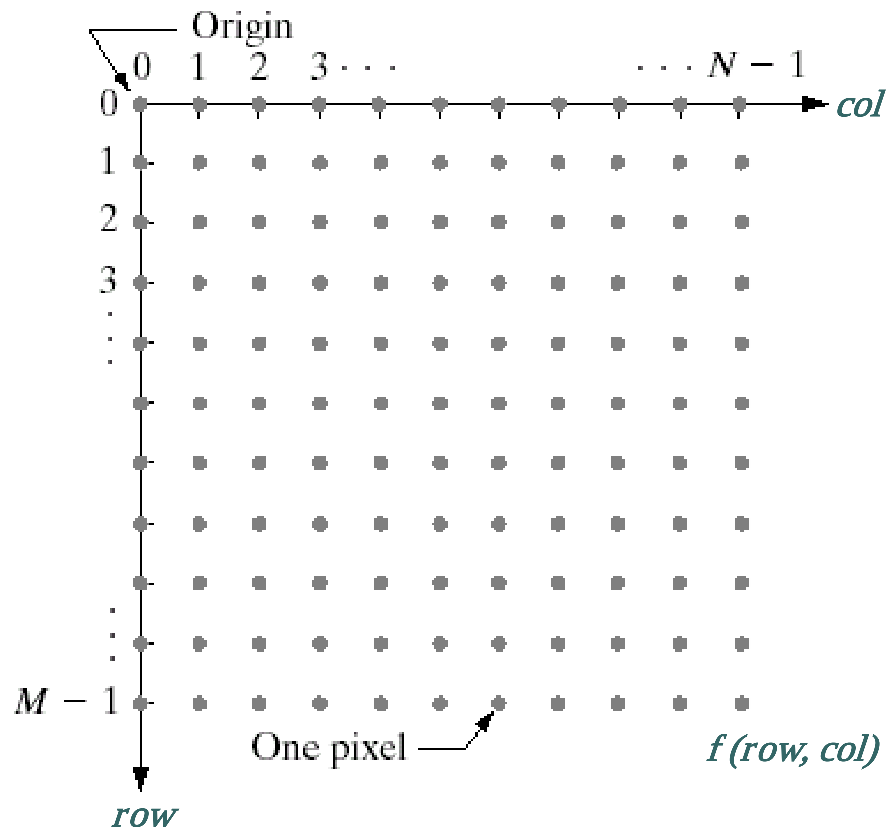
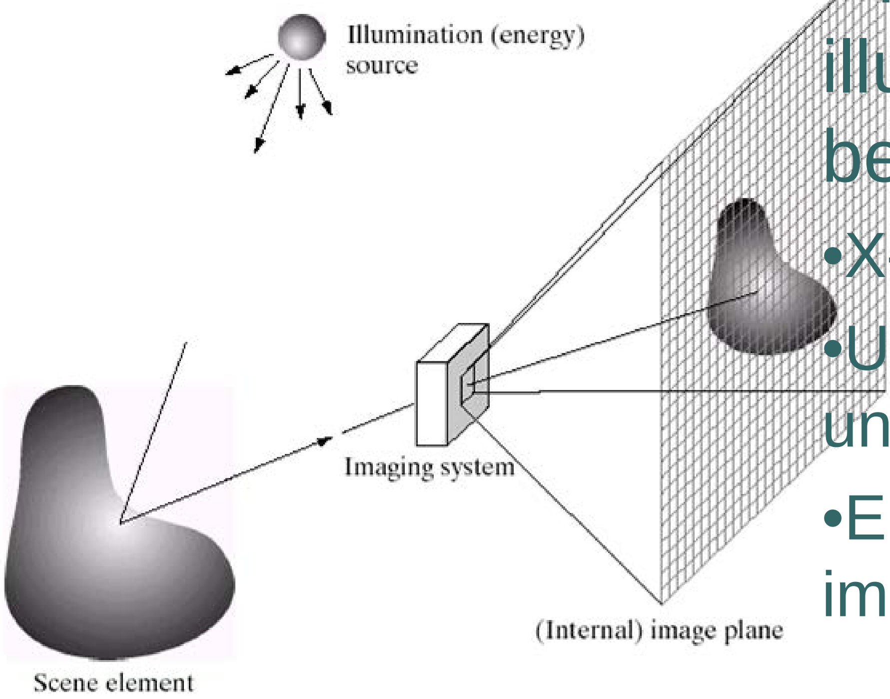


Image Acquisition

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

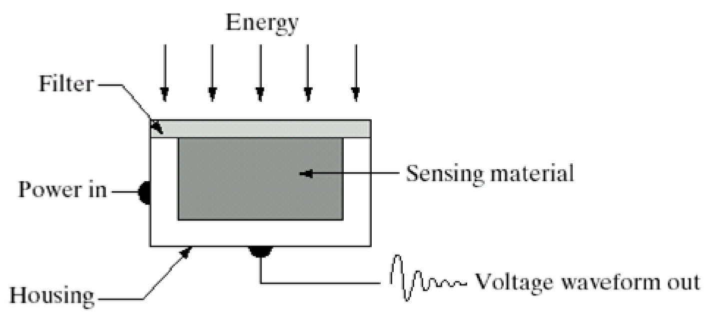


– Typical notions of illumination and scene can be way off:

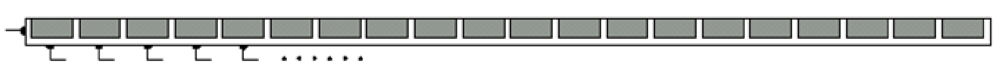
- X-rays of a skeleton
- Ultrasound of an unborn baby
- Electro-microscopic images of molecules

Image Sensing

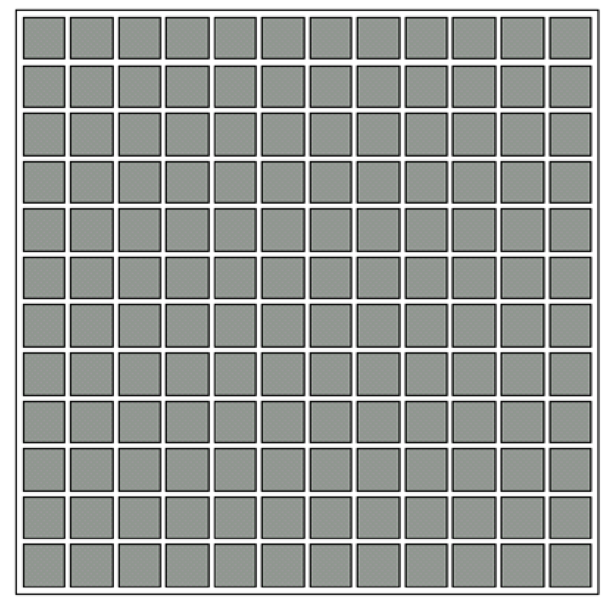
- Incoming energy lands on a sensor material responsive to that type of energy and this generates a voltage
- Collections of sensors are arranged to capture images



Imaging Sensor



Line of Image Sensors



Array of Image Sensors

Image Sensing

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

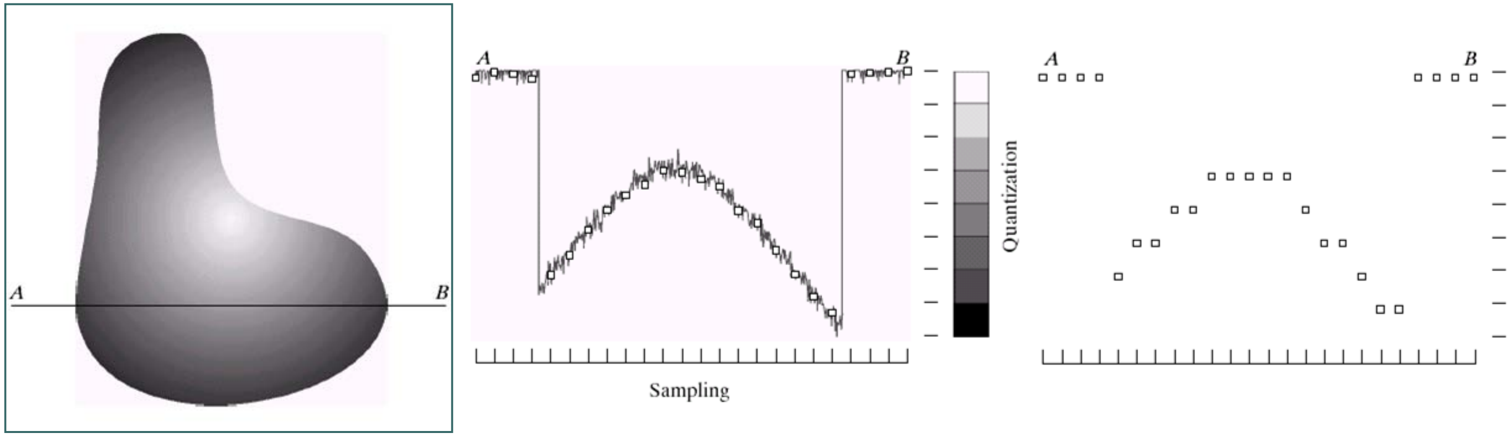


Image Sampling And Quantisation

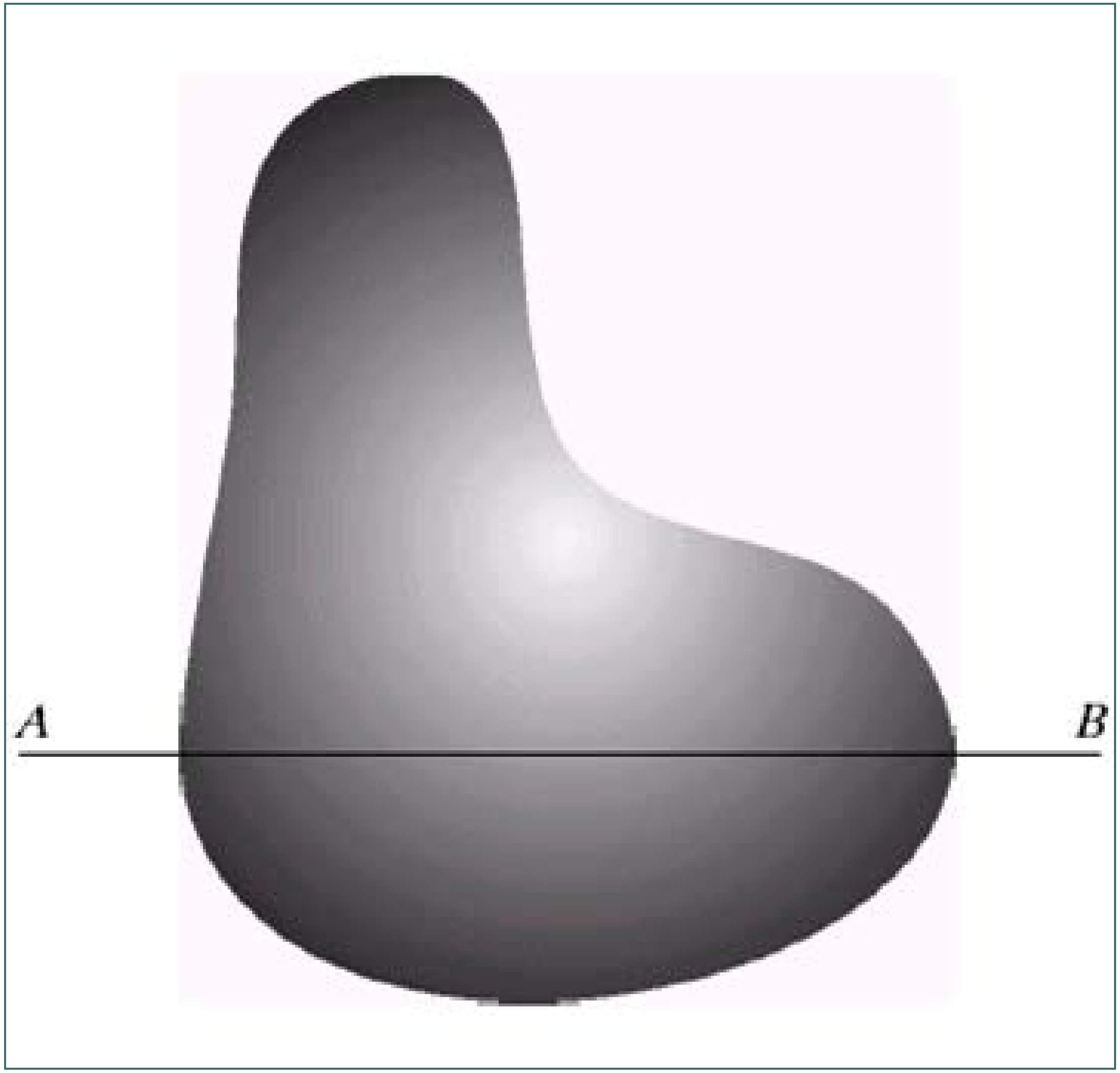
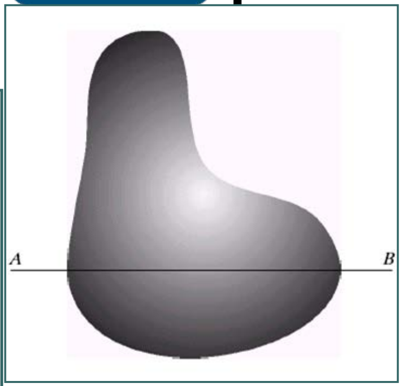
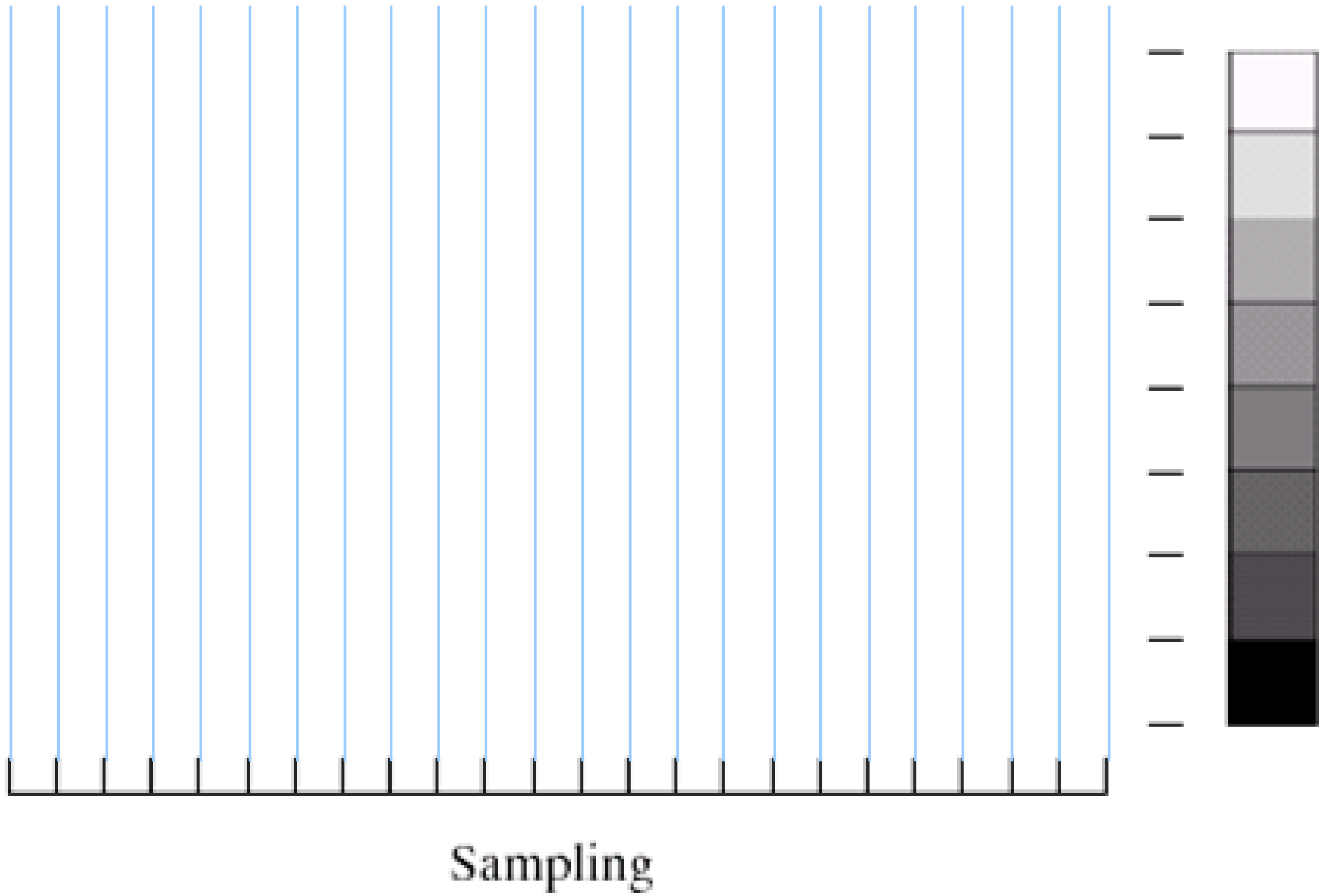


Image Sampling And Quantisation

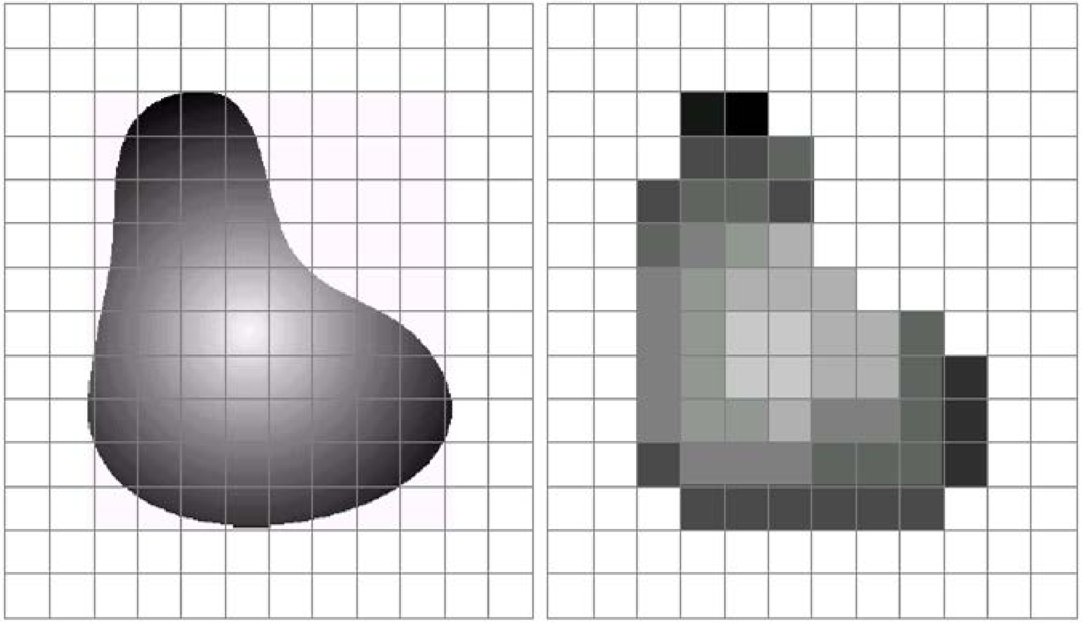




Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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

Image Representation

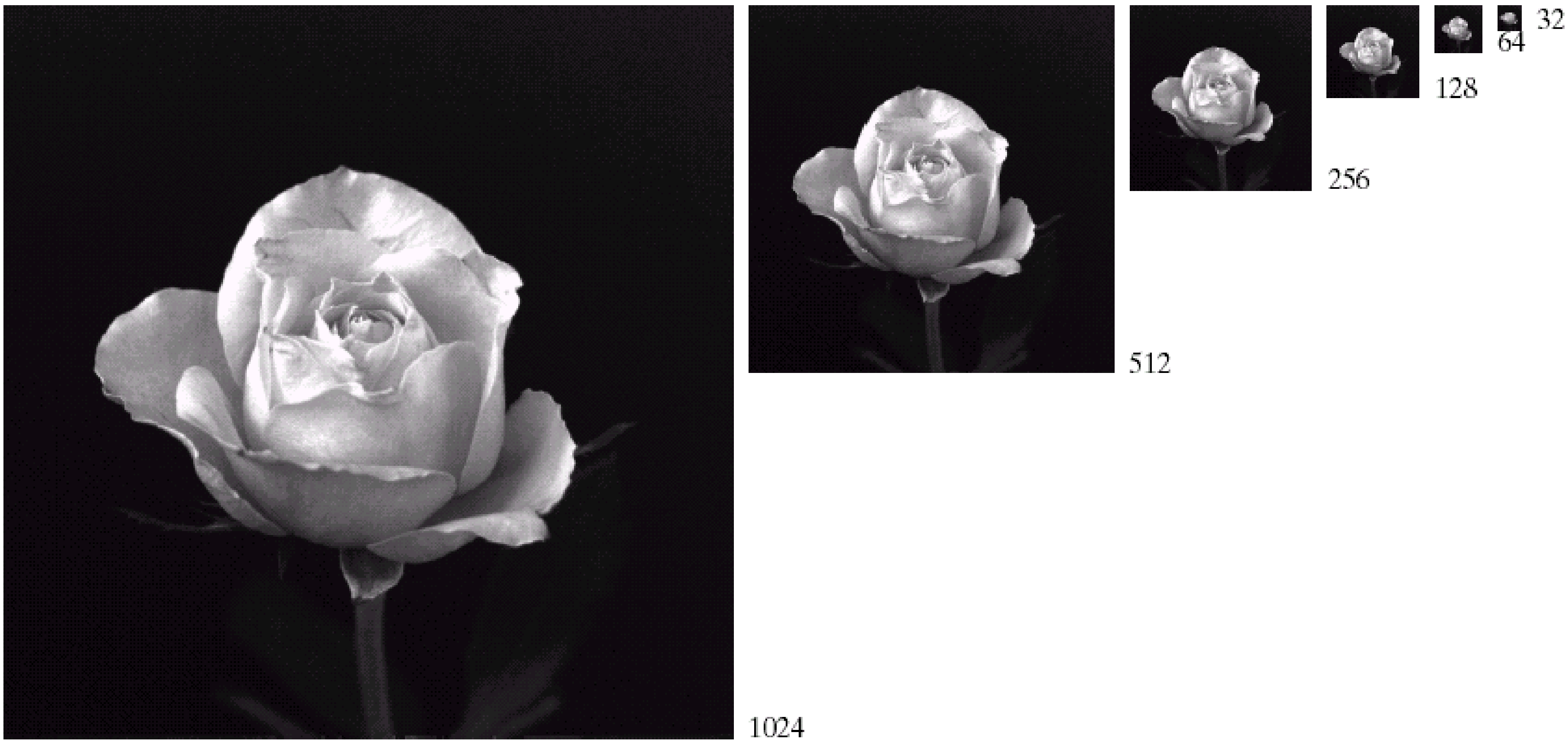
Image Representation

Image Representation

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)

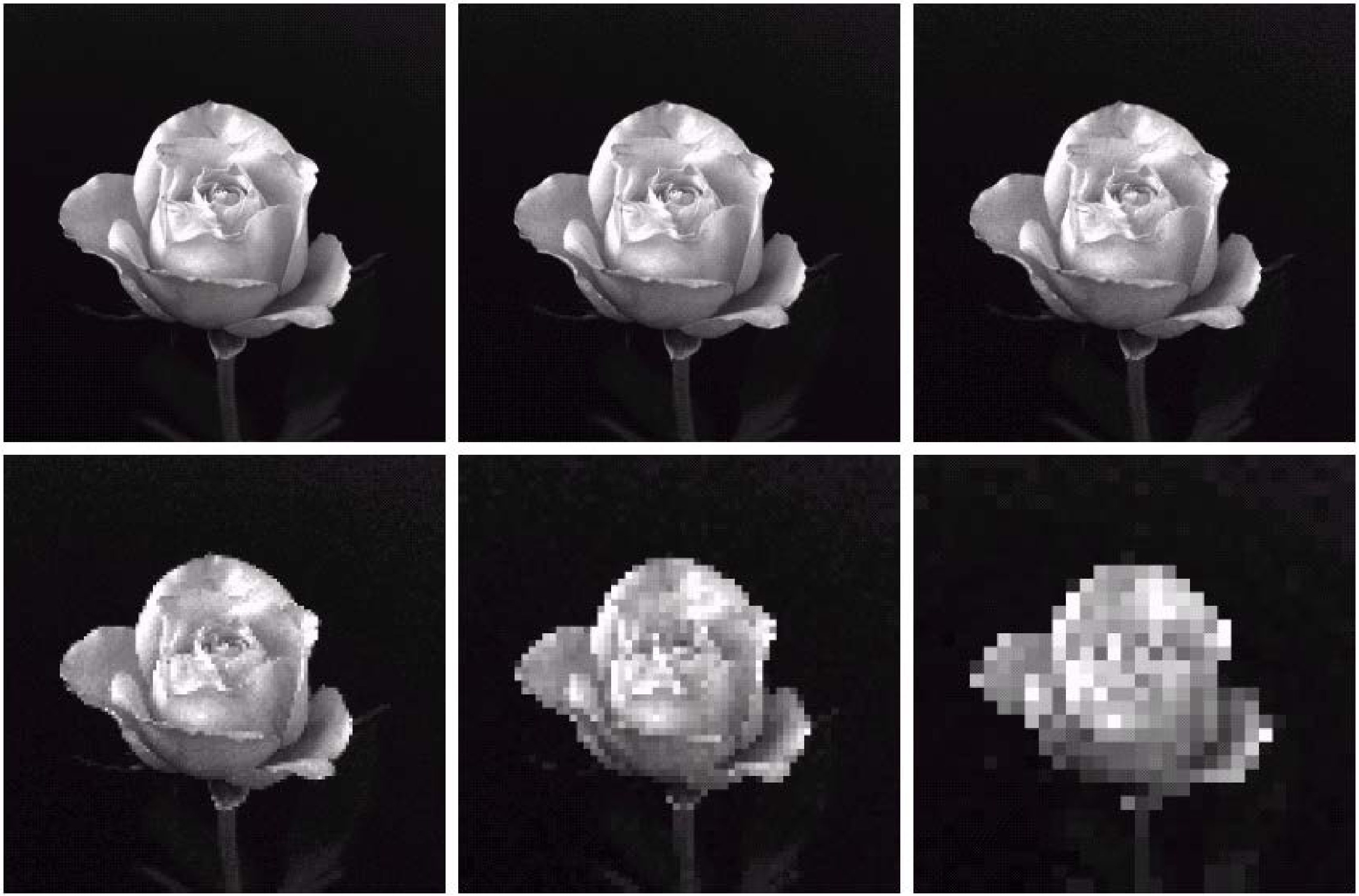
Spatial Resolution (cont…)



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

Spatial Resolution (cont…)

1024 * 1024 512 * 512 256 * 256



128 * 128 64 * 64 32 * 32

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

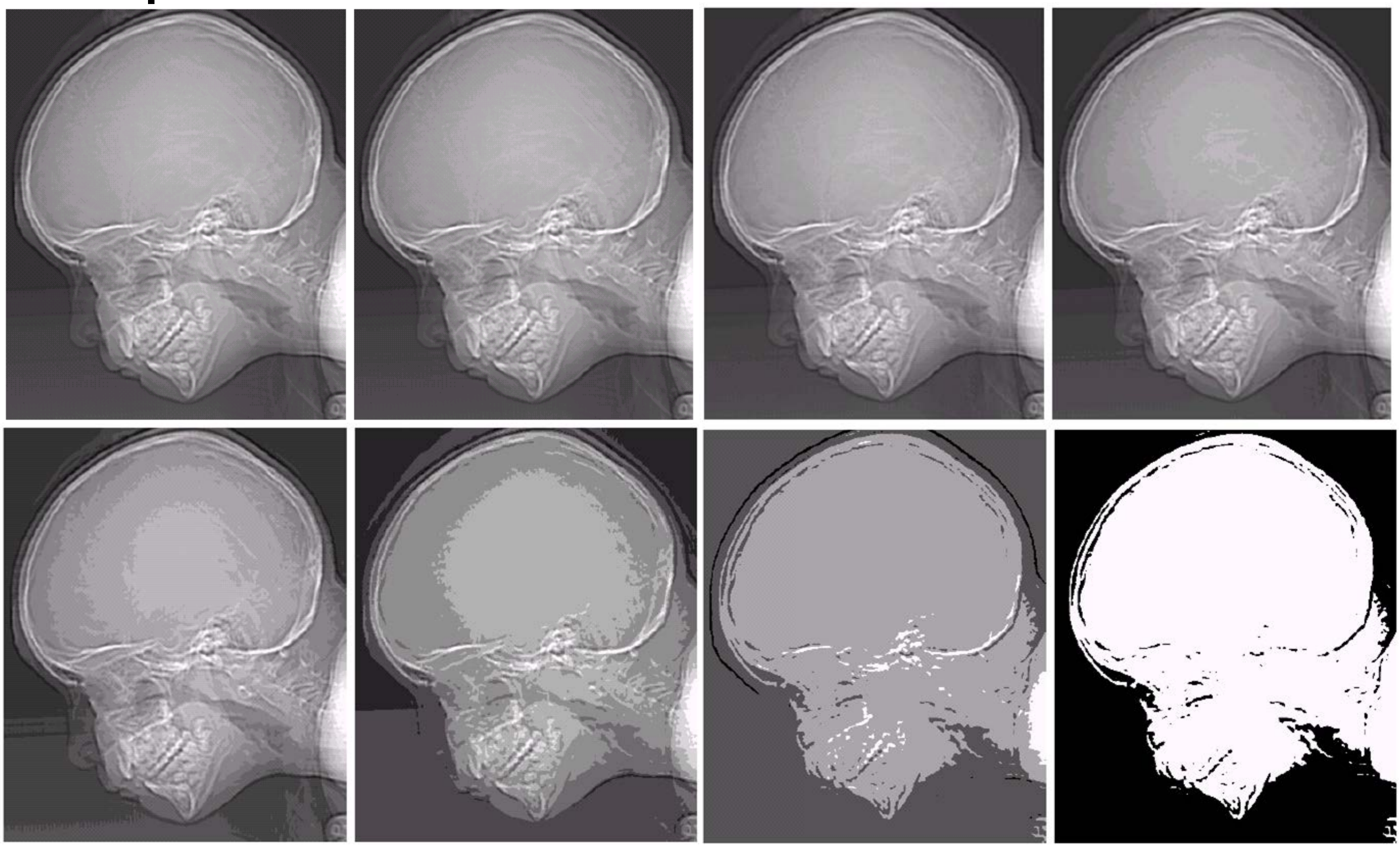
Intensity Level Resolution

- *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…)

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



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

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

Saturation & Noise

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…)

Some Basic Relationships Between Pixels

- Definitions:

- f(x,y): digital image
- Pixels: q, p
- Subset of pixels of f(x,y): S

Neighbors of a Pixel

- A pixel p at (x,y) has 2 horizontal and 2 vertical neighbors:
- (x+1,y), (x-1,y), (x,y+1), (x,y-1)
- This set of pixels is called the 4-neighbors of p: $N_4(p)$

Neighbors of a Pixel

- The 4 diagonal neighbors of p are: ($N_D(p)$)
- (x+1,y+1), (x+1,y-1), (x-1,y+1), (x-1,y-1)
- $N_4(p) + N_D(p) \rightarrow N_8(p)$: the 8-neighbors of p

Connectivity

- Connectivity between pixels is important:
  - Because it is used in establishing boundaries of objects and components of regions in an image

Connectivity

- Two pixels are connected if:

  - They are neighbors (i.e. adjacent in some sense -- e.g. $N_4(p)$, $N_8(p)$, …)
  - Their gray levels satisfy a specified criterion of similarity (e.g. equality, …)

- V is the set of gray-level values used to define adjacency (e.g. V={1} for adjacency of pixels of value 1)

Adjacency

- We consider three types of adjacency:

- 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 : p & q are 8- adjacent if q is in the set $N_8(p)$

Adjacency

- The third type of adjacency:

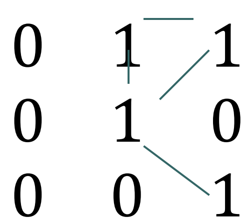
- m-adjacency: p & q with values from V are m-adjacent if

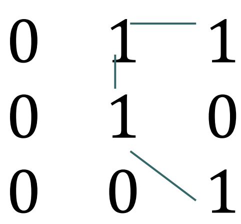
- q is in $N_4(p)$ or
- q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels with values from V

Adjacency

- Mixed adjacency is a modification of 8-adjacency and is used to eliminate the multiple path connections that often arise when 8-adjacency is used.

0	1	1
0	1	0
0	0	1





Adjacency

- Two image subsets S1 and S2 are adjacent if some pixel in S1 is adjacent to some pixel in S2.

Path

- A path (curve) from pixel p with coordinates (x,y) to pixel q with coordinates (s,t) is a sequence of distinct pixels:

  - (x_0,y_0), (x_1,y_1), …, (x_n,y_n)

  - where $(x_0,y_0)=(x,y)$, $(x_n,y_n)=(s,t)$, and (x_i,y_i) is adjacent to (x_{i-1},y_{i-1}), for $1 \le i \le n$; **n is the length of the path**.

- If (xo, yo) = (xn, yn): a closed path

Paths

- 4-, 8-, m-paths can be defined depending on the type of adjacency specified.

- If $p,q \in S$, then q is connected to p in S if there is a path from p to q consisting entirely of pixels in S.

Connectivity

- For any pixel p in S, the set of pixels in S that are connected to p is a connected component of S.

- If S has only one connected component then S is called a connected set.

Boundary

- R a subset of pixels: R is a region if R is a connected set.
- Its boundary (border, contour) is the set of pixels in R that have at least one neighbor not in R
- Edge can be the region boundary (in binary images)

Distance Measures

- For pixels p,q,z with coordinates (x,y), (s,t), (u,v), D is a distance function or metric if:

- $D(p,q) \geq 0$ ($D(p,q)=0$ iff $p=q$)
- $D(p,q) = D(q,p)$ and
- $D(p,z) \leq D(p,q) + D(q,z)$

Distance Measures

- Euclidean distance:

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

- Points (pixels) having a distance less than or equal to r from (x,y) are contained in a disk of radius r centered at (x,y).

Distance Measures

- D_4 distance (city-block distance):

- $D_4(p,q) = |x-s| + |y-t|$
- forms a diamond centered at (x,y)
- e.g. pixels with $D_4 \leq 2$ from p

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

$D_4 = 1$ are the 4-neighbors of p

Distance Measures

- D_8 distance (chessboard distance):

- $D_8(p,q) = \max(|x-s|,|y-t|)$
- Forms a square centered at p
- e.g. pixels with $D_8 \le 2$ from p

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

$D_8 = 1$ are the 8-neighbors of p

Distance Measures

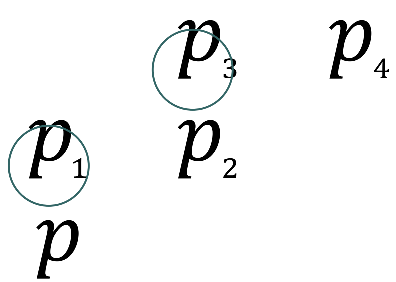
- D_4 and D_8 distances between p and q are independent of any paths that exist between the points because these distances involve only the coordinates of the points (regardless of whether a connected path exists between them).

Distance Measures

- However, for m-connectivity the value of the distance (length of path) between two pixels depends on the values of the pixels along the path and those of their neighbors.

Distance Measures

- e.g. assume $p, p_2, p_4 = 1$
  p_1, p_3 = can have either 0 or 1



If only connectivity of pixels valued 1 is allowed, and p_1 and p_3 are 0, the m-distance between p and p_4 is 2.

If either p_1 or p_3 is 1, the distance is 3.

If both p_1 and p_3 are 1, the distance is 4 ($pp_1p_2p_3p_4$)

Summary

- We have looked at:
  - Human visual system
  - Light and the electromagnetic spectrum
  - Image representation
  - Image sensing and acquisition
  - Sampling, quantisation and resolution
- Next time we start to look at techniques for image enhancement