Digital Image Fundamentals

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Image and Video Processing

Acknowledgements

- Gonzalez, Rafael C. Digital image processing. Pearson, 4th edition, 2018.
- Jain, Anil K. Fundamentals of digital image processing. Prentice-Hall, Inc., 1989.
- Digital Image Processing course by Brian Mac Namee, Dublin Institute of Technology
- Digital Image Processing course by Christophoros Nikou, University of Ioannina

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

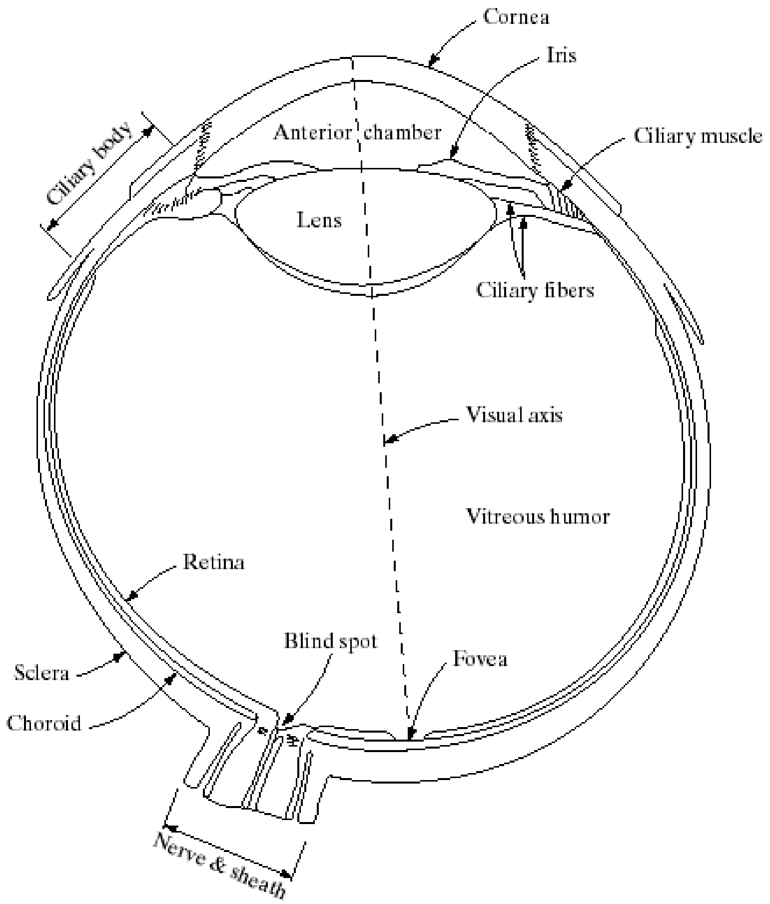
The best vision model we have!

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

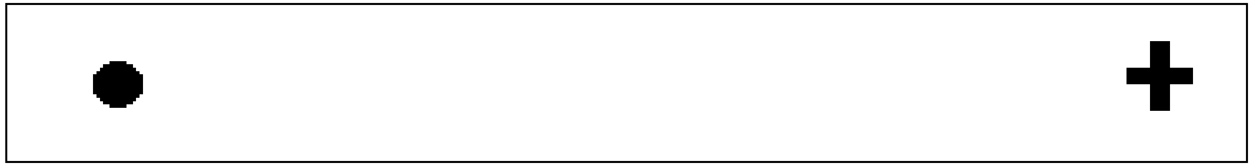
- The lens focuses light from objects onto the retina
- The retina is covered with light receptors called *cones* (6-7 million) and *rods* (75-150 million)
- Cones are concentrated around the fovea and are very sensitive to colour
- Rods are more spread out and are sensitive to low levels of illumination



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Blind-Spot Experiment

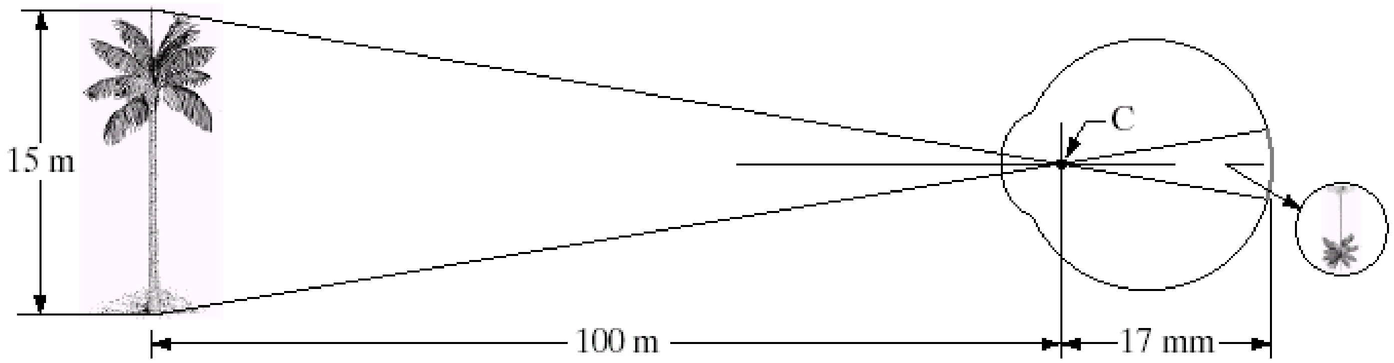
- Draw an image similar to that below on a piece of paper (the dot and cross are about 6 inches apart)



- 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



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

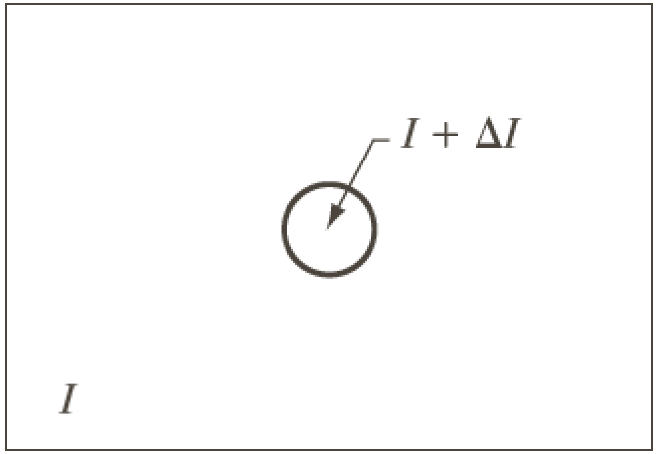
Brightness Adaptation & Discrimination

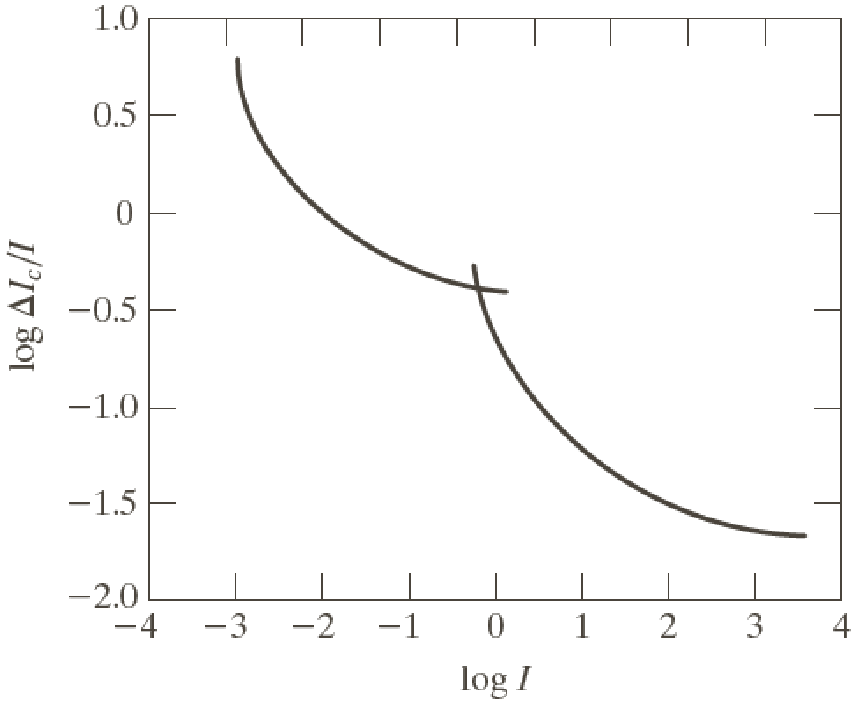
- The human visual system can perceive approximately 10^{10} different light intensity levels.
- However, at any one time we can only discriminate between a much smaller number – *brightness adaptation.*
- Similarly, the *perceived intensity* of a region is related to the light intensities of the regions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

Brightness Adaptation & Discrimination (cont…)

Weber ratio

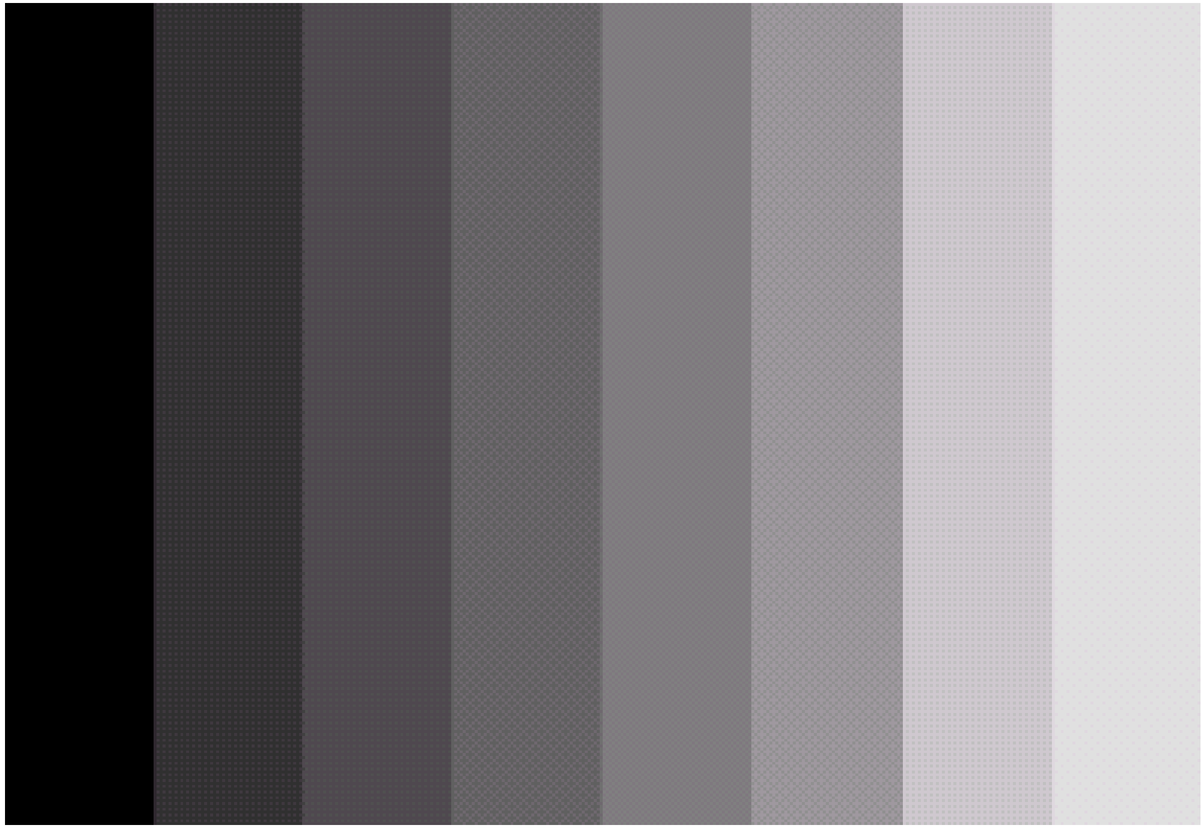
- $\Delta Ic / I$ where I is the light source intensity and ΔIc is increment in illumination.
- A small value of Weber ratio means Good brightness discrimination.
- A large value of Weber ratio means Poor brightness discrimination.





Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

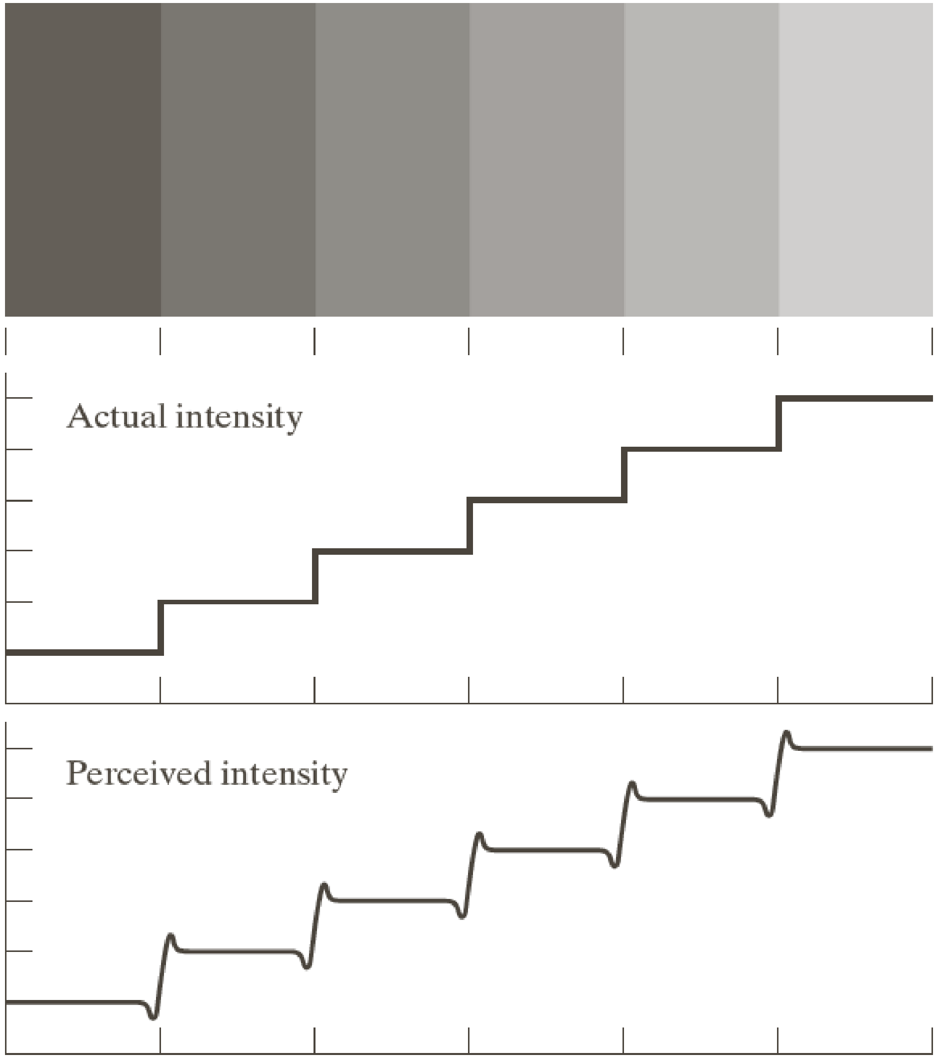
Brightness Adaptation & Discrimination (cont…)



An example of Mach bands

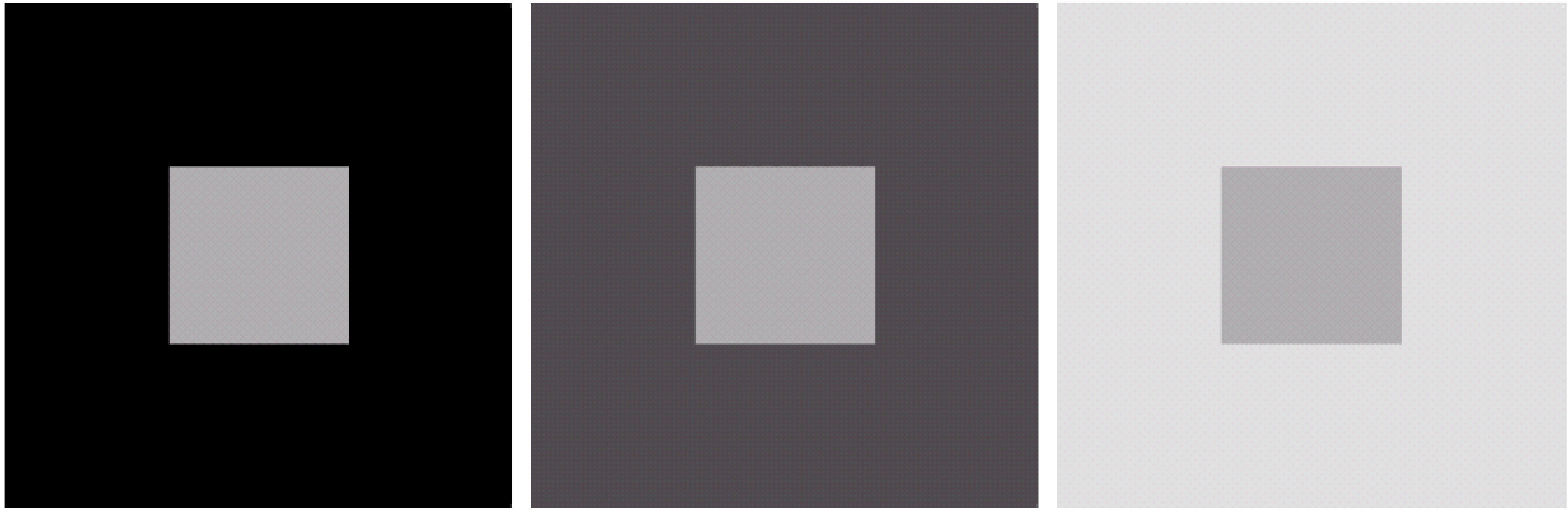
Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Brightness Adaptation & Discrimination (cont…)



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Brightness Adaptation & Discrimination (cont…)

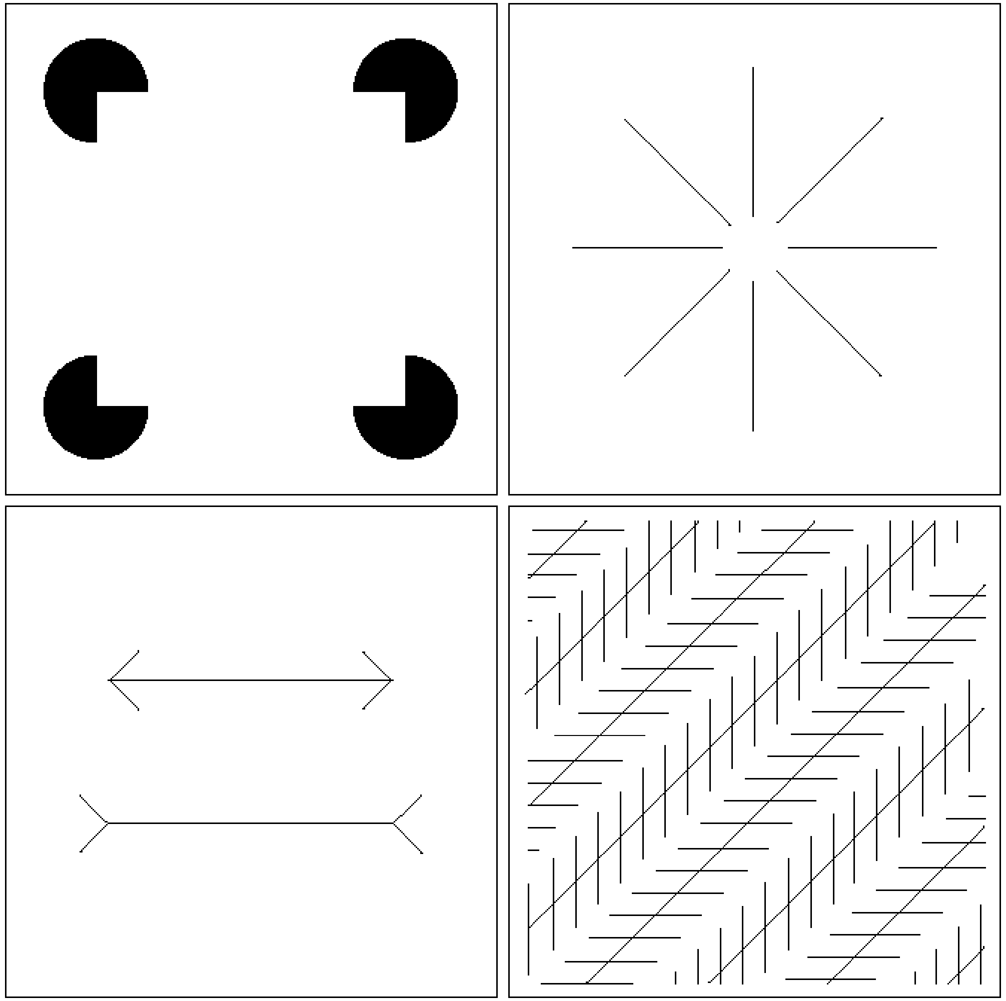


An example of *simultaneous contrast*

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

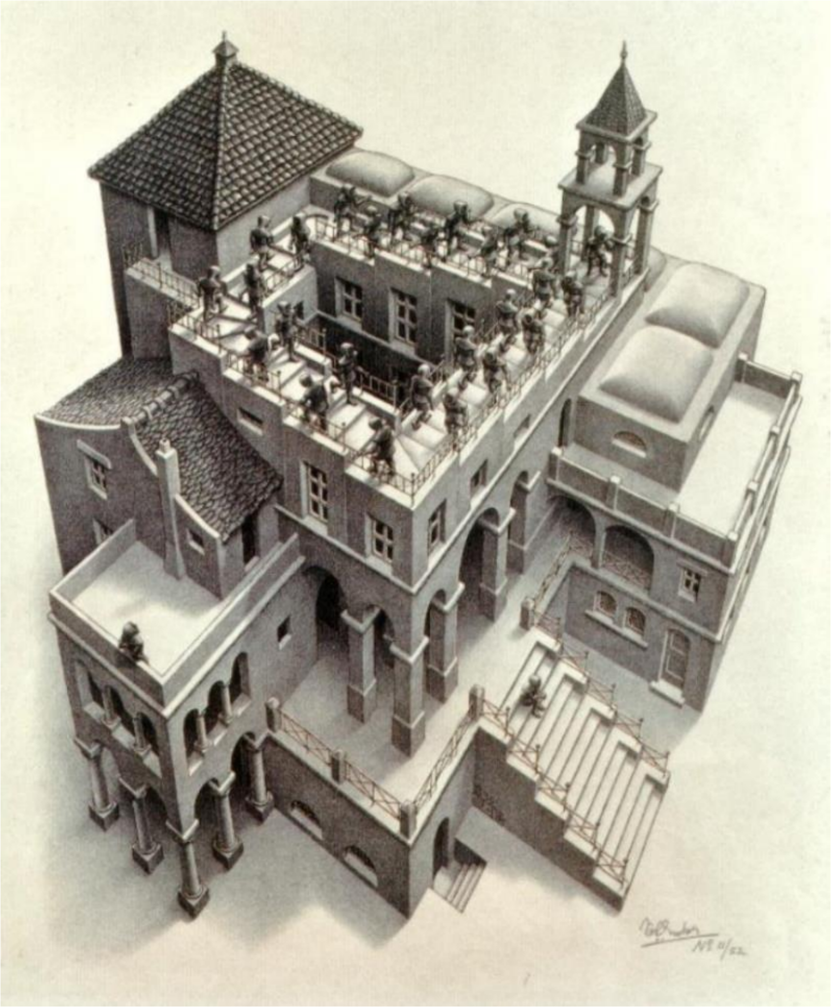
Optical Illusions

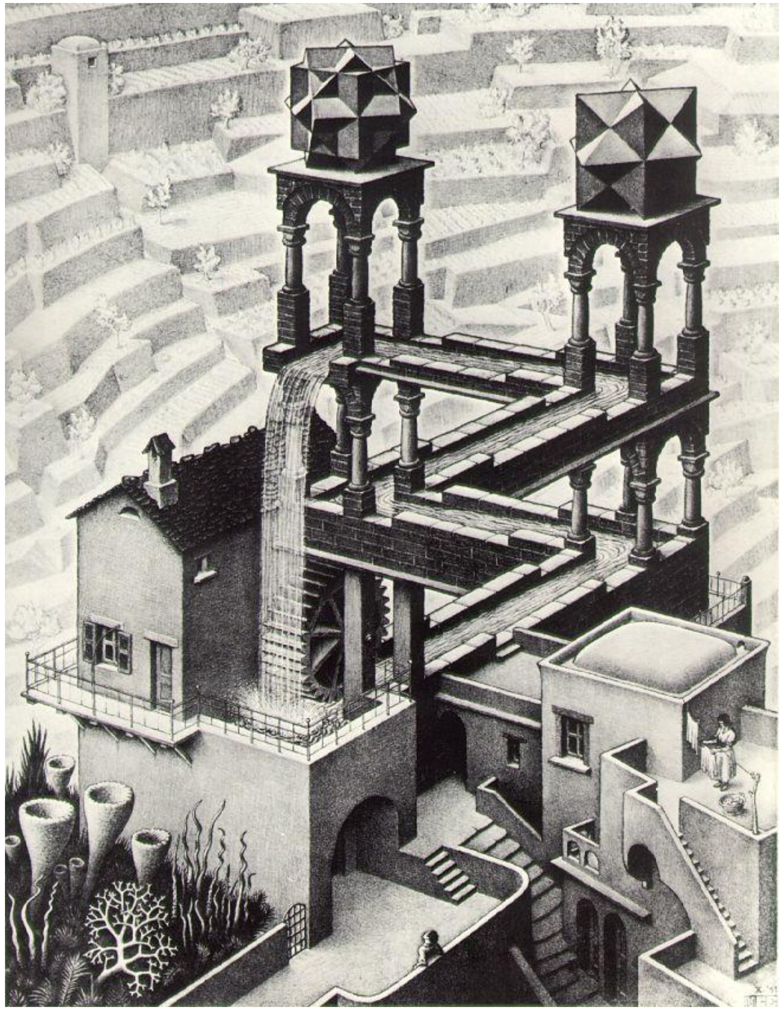
Our visual systems play lots of interesting tricks on us



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

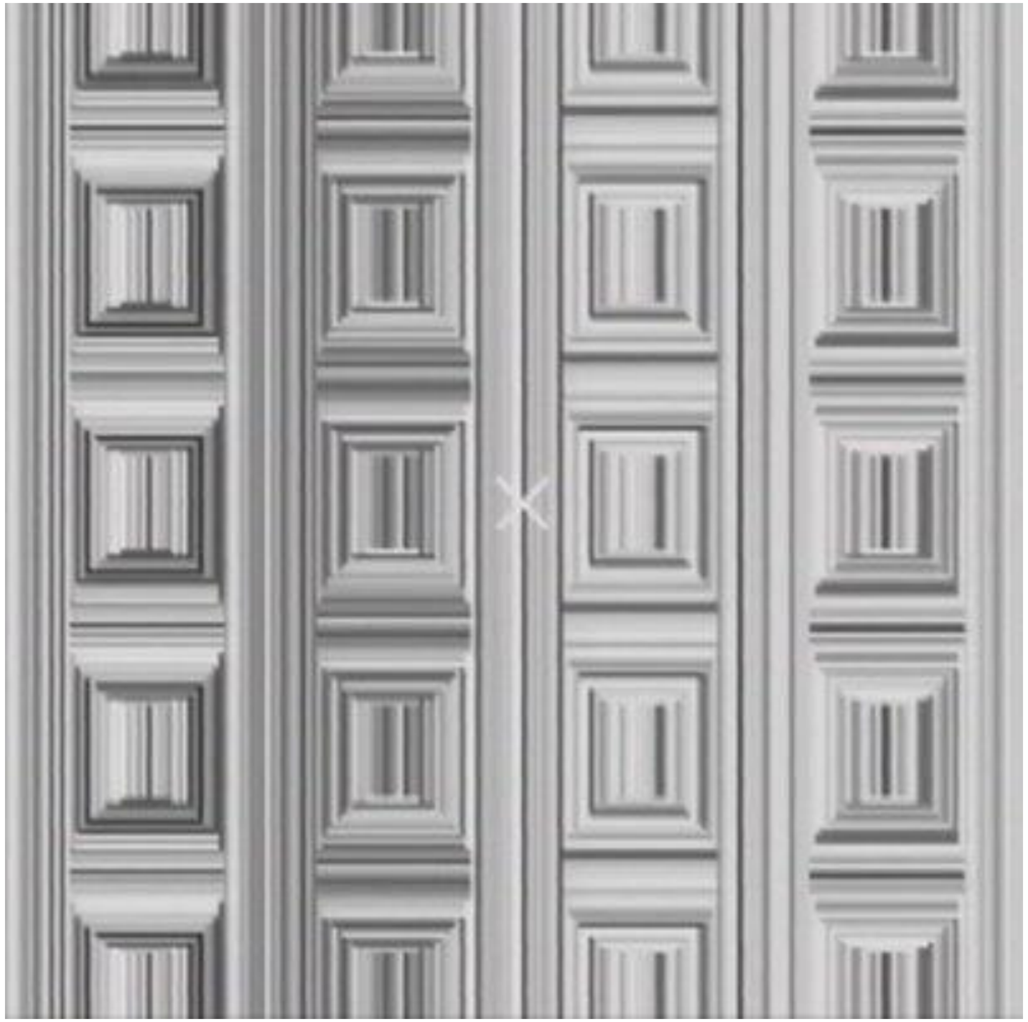
Optical Illusions (cont…)





Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Optical Illusions (cont…)

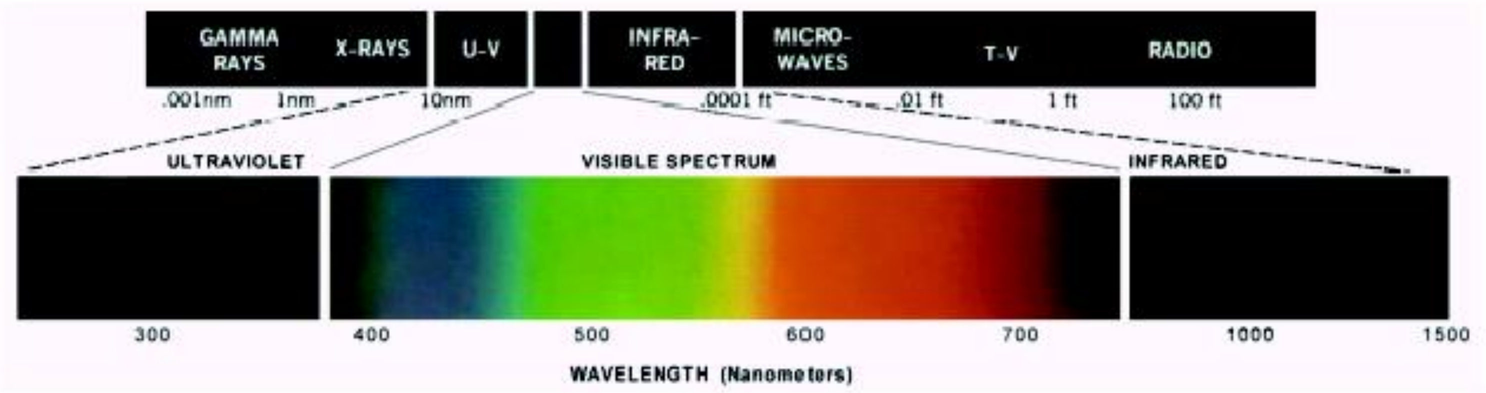


Stare at the cross in the middle of the image and think circles

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Light And The Electromagnetic Spectrum

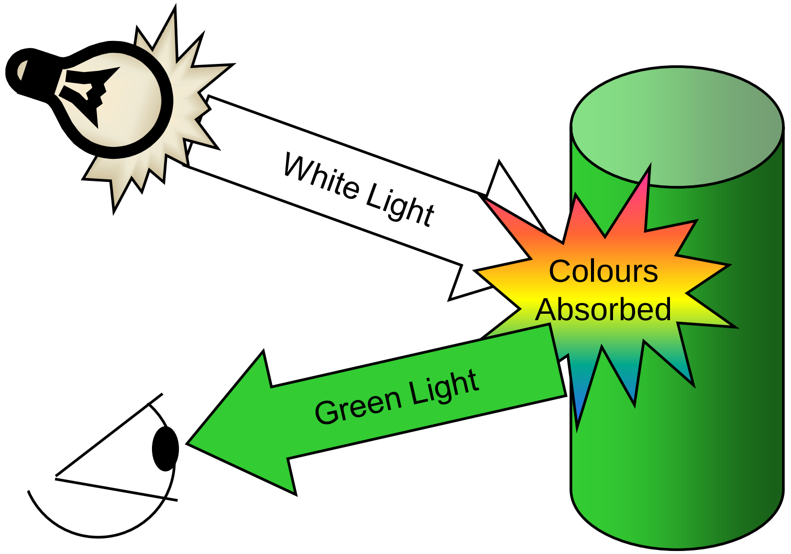
- Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye
- The electromagnetic spectrum is split up according to the wavelengths of different forms of energy



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

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



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

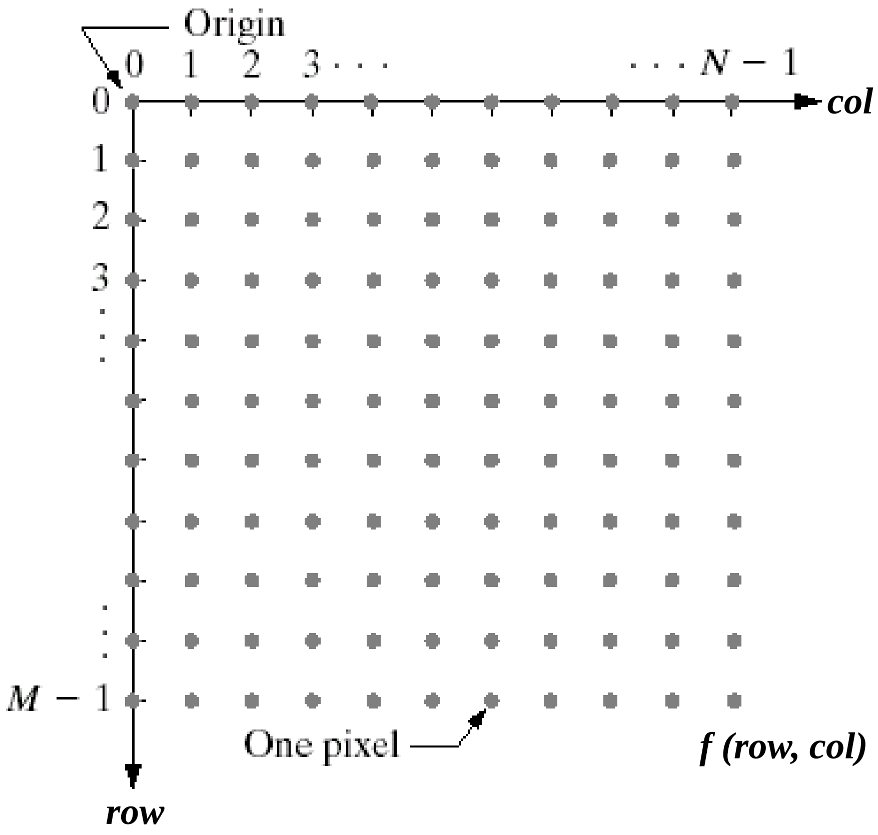
Sampling, Quantisation And Resolution

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



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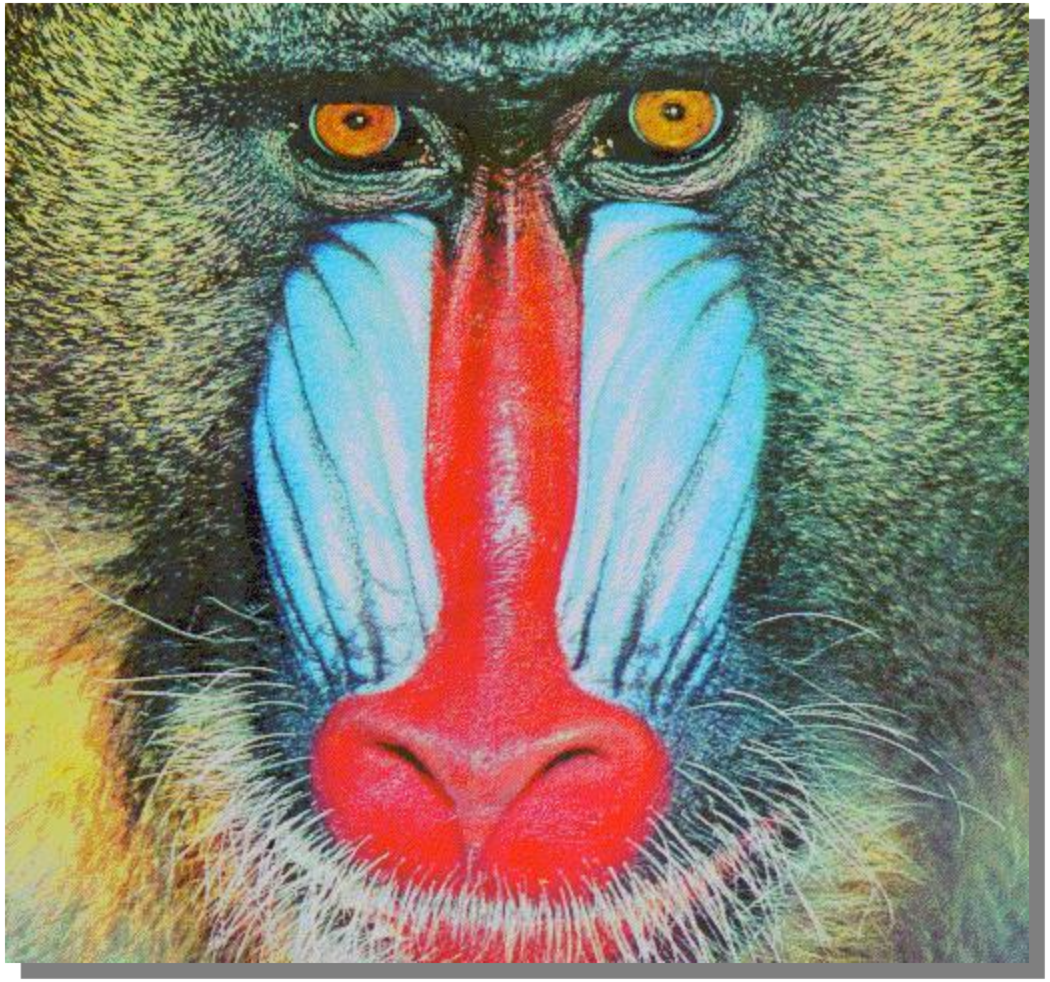
Colour images



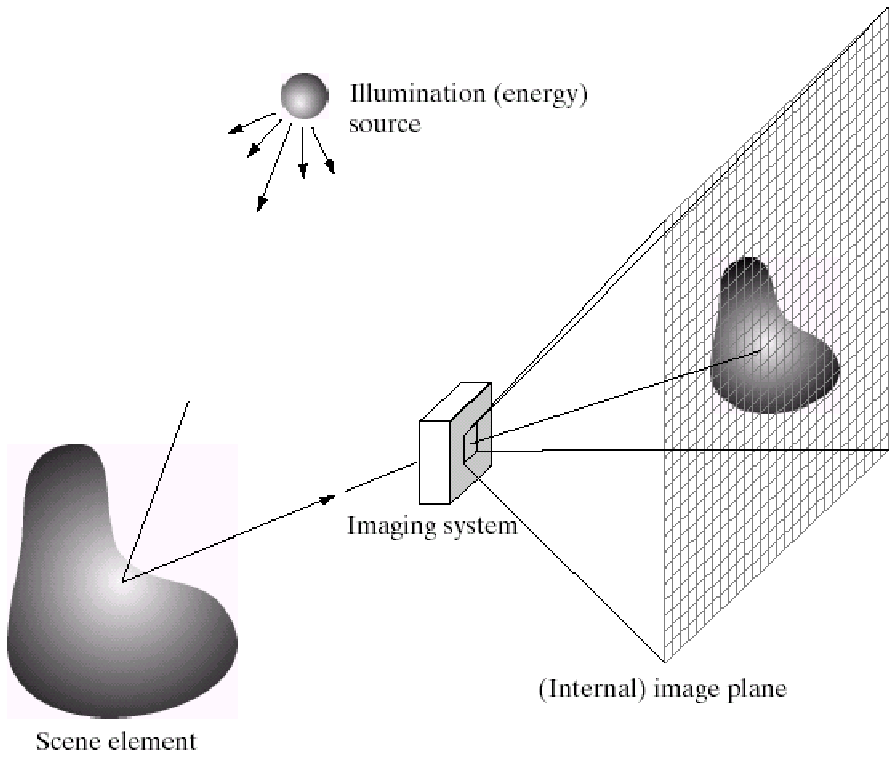
Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Colour images

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Image Acquisition

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



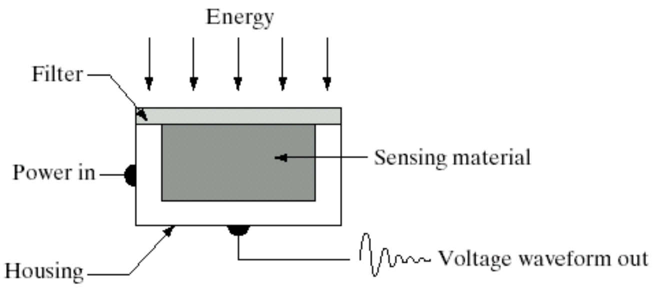
- Typical notions of illumination and scene can be way off:
  - X-rays of a skeleton
  - Ultrasound of an unborn baby
  - Electro-microscopic images of molecules

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

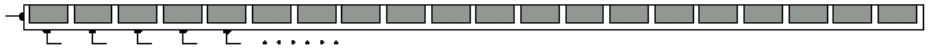
Image Sensing

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

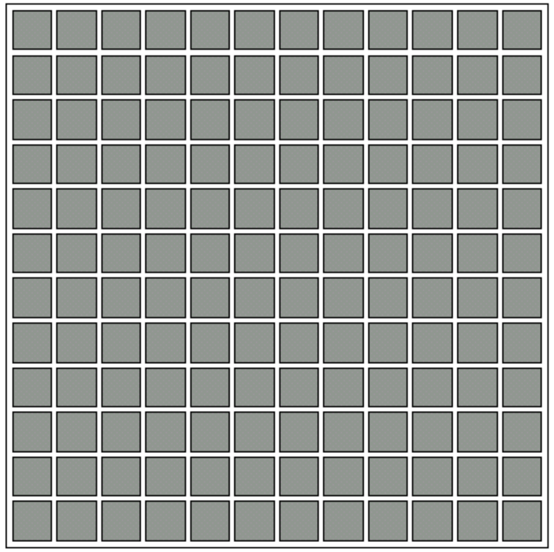
Collections of sensors are arranged to capture images



Imaging Sensor



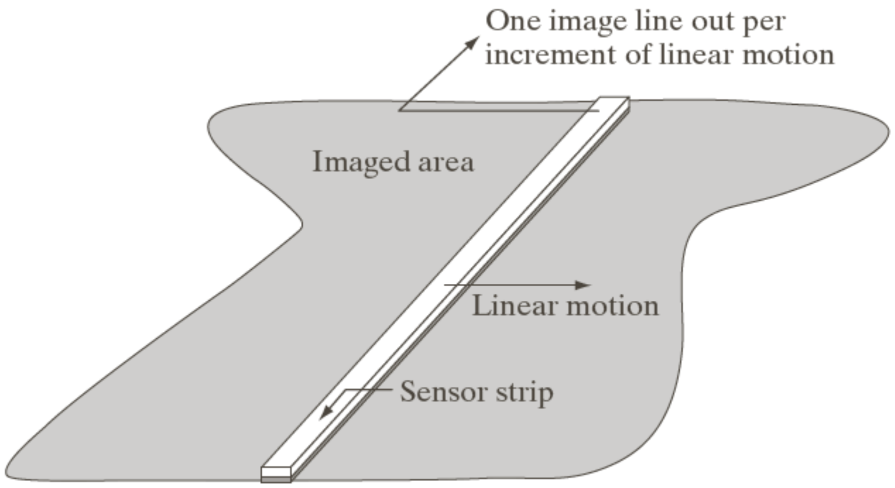
Line of Image Sensors

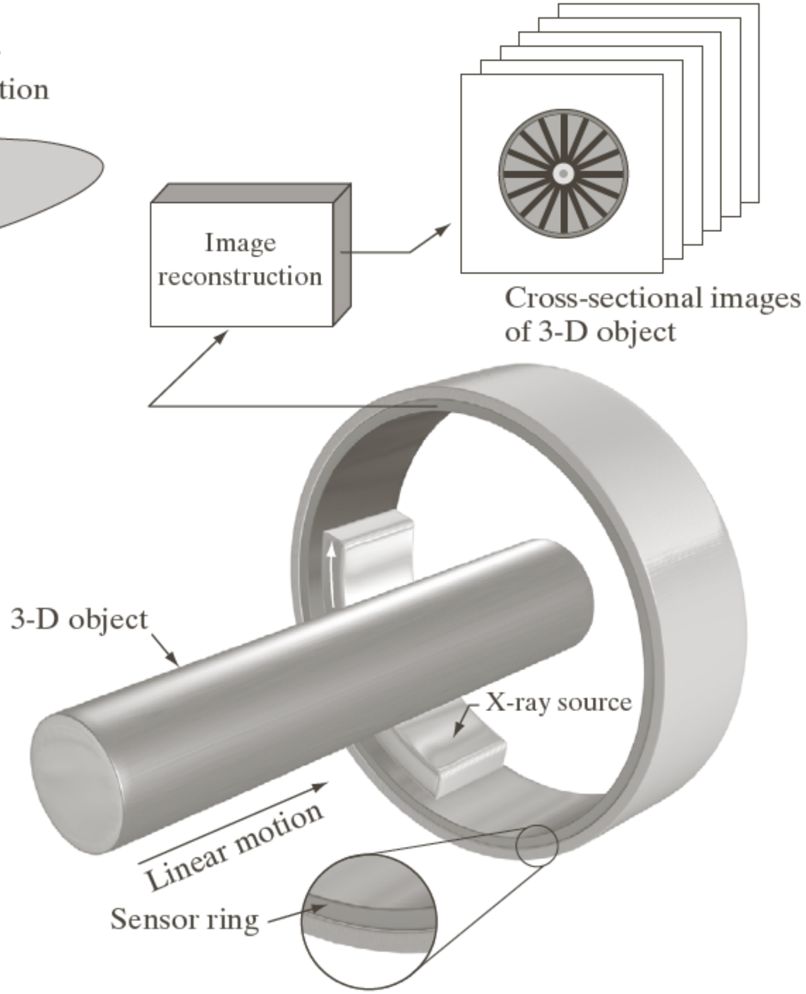


Array of Image Sensors

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Image Sensing



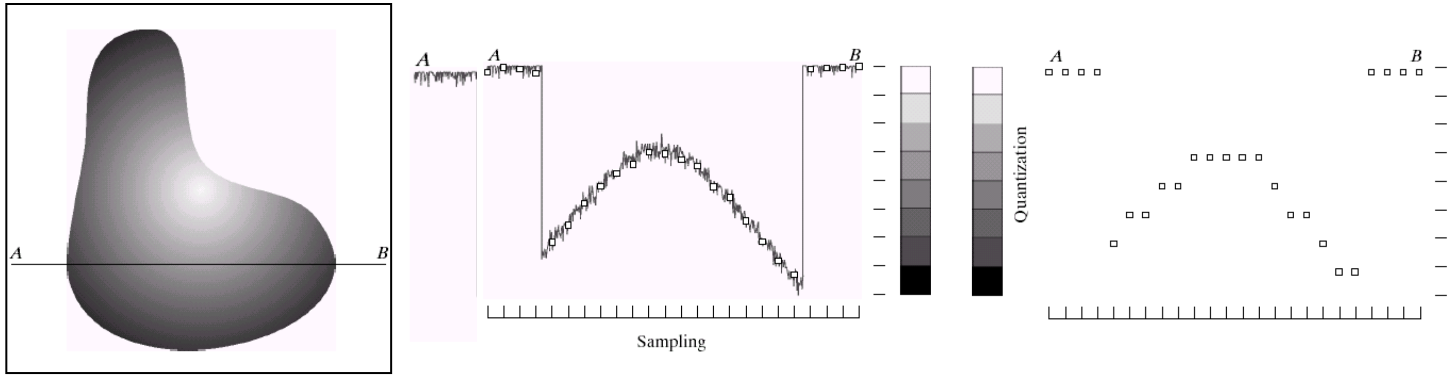


Using Sensor Strips and Rings

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

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



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Image Sampling And Quantisation

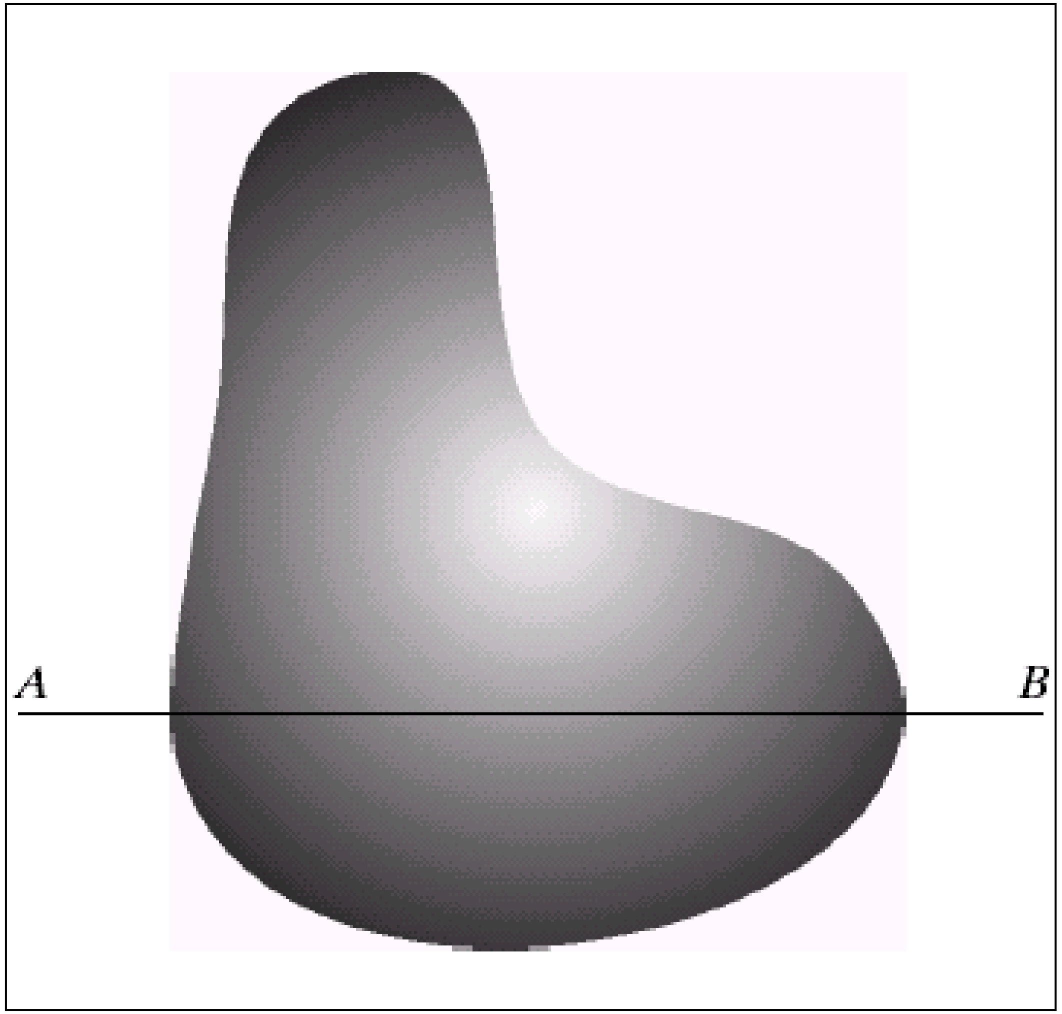


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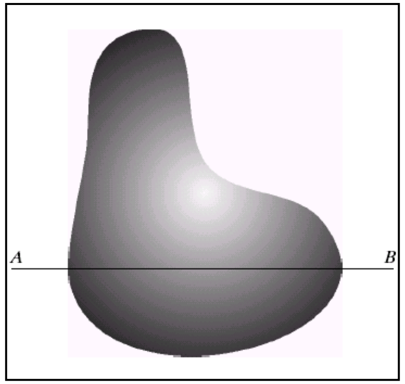
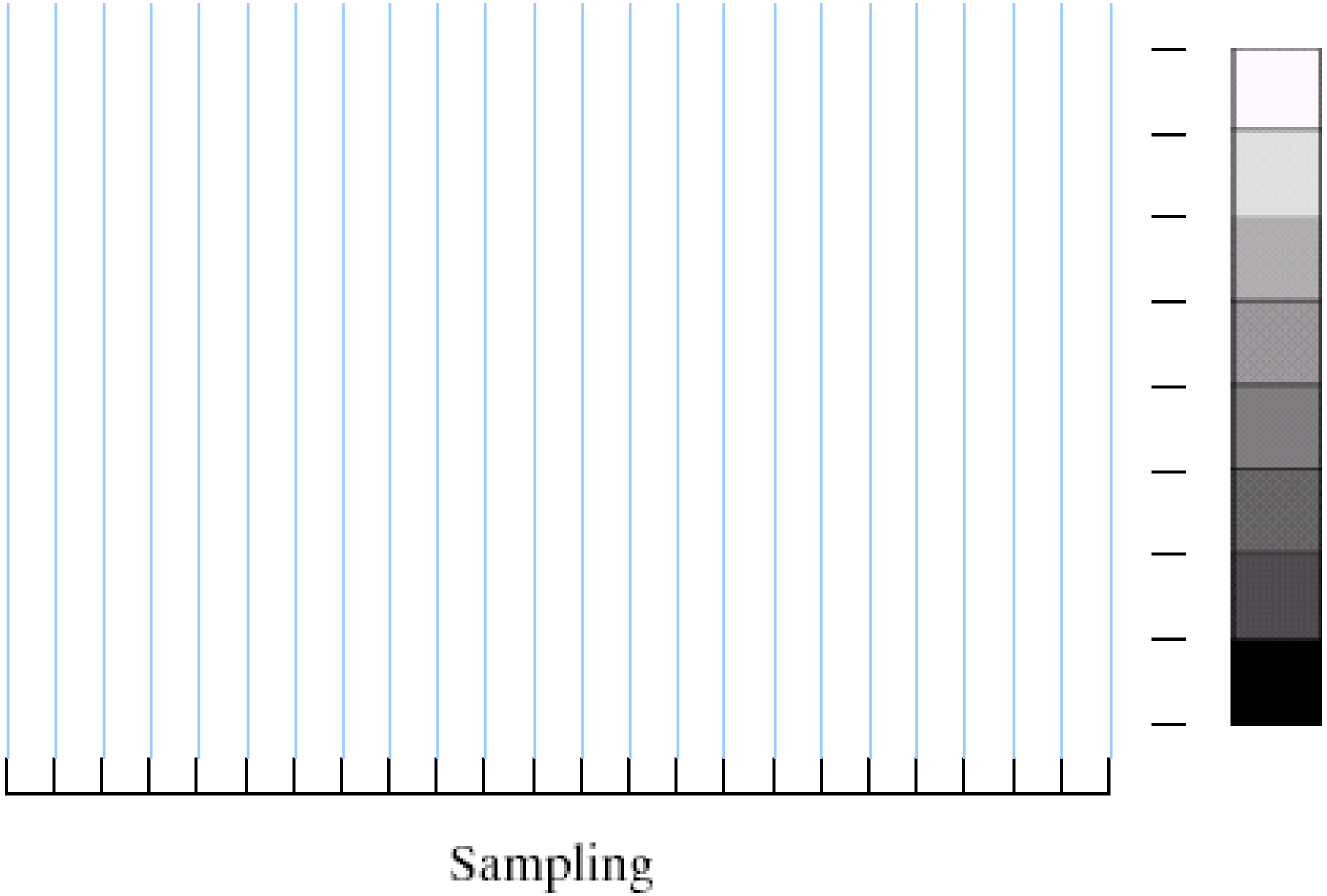
Image Sampling And Quantisation

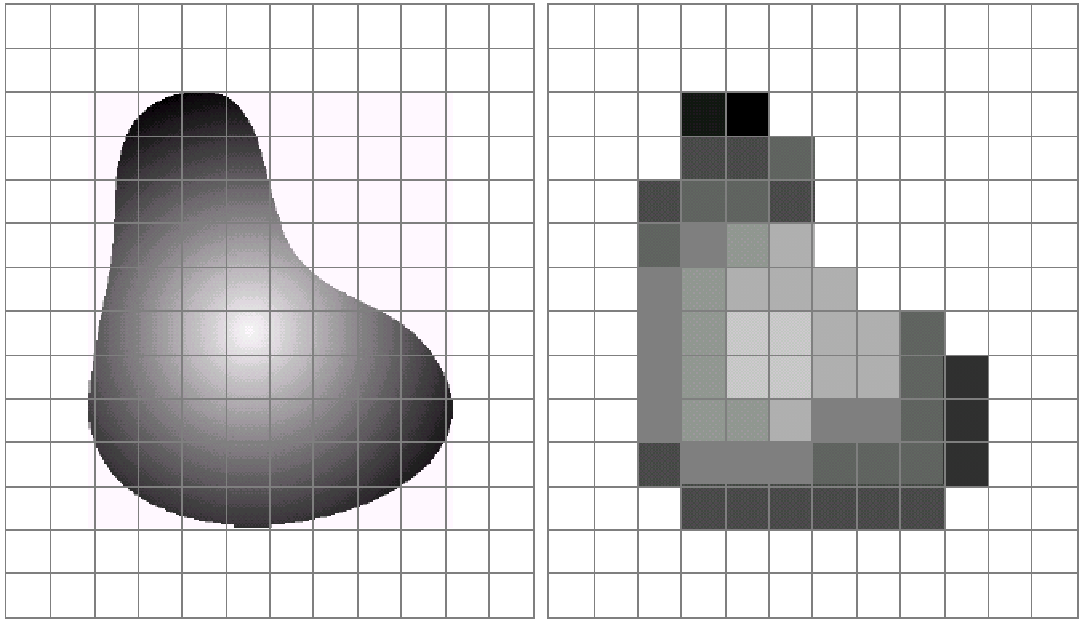




Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Image Sampling And Quantisation (cont…)

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



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Image Representation

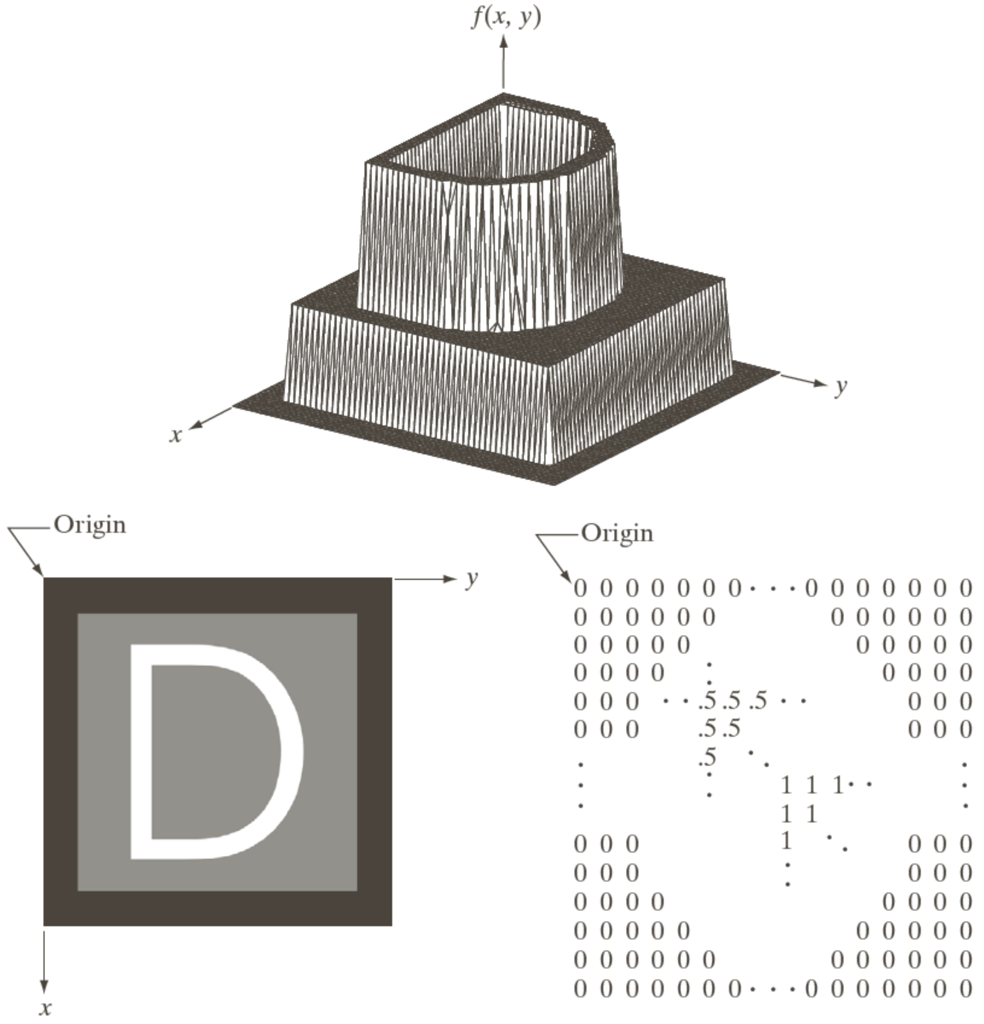


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Image Representation

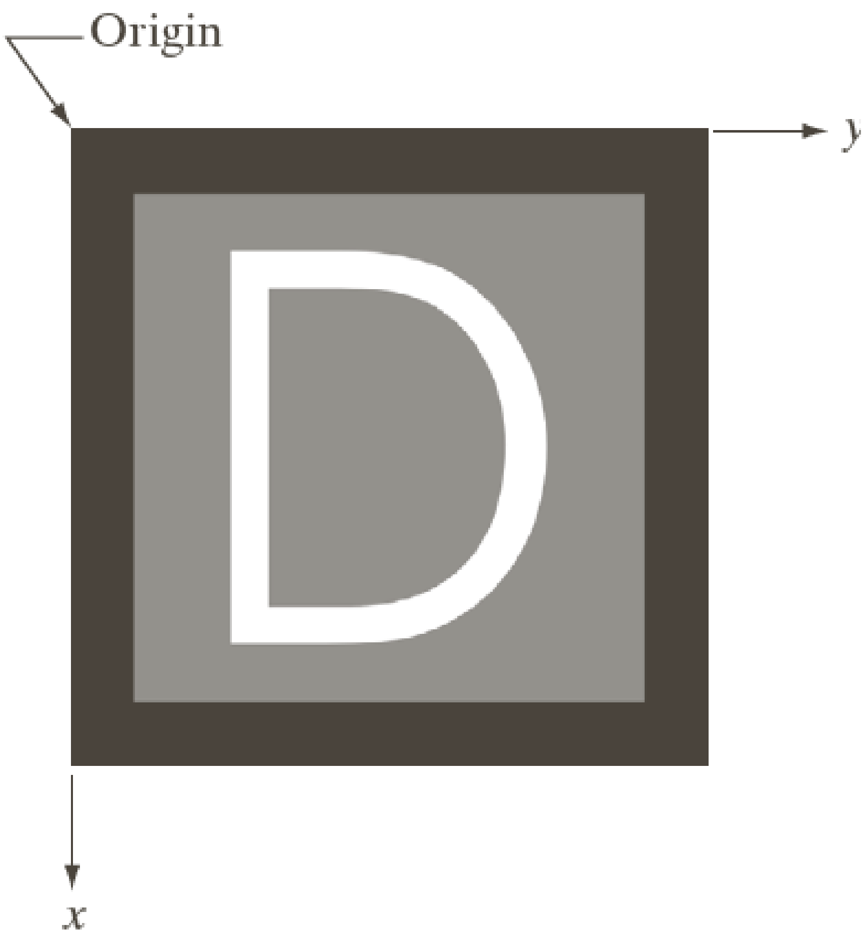

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Image Representation

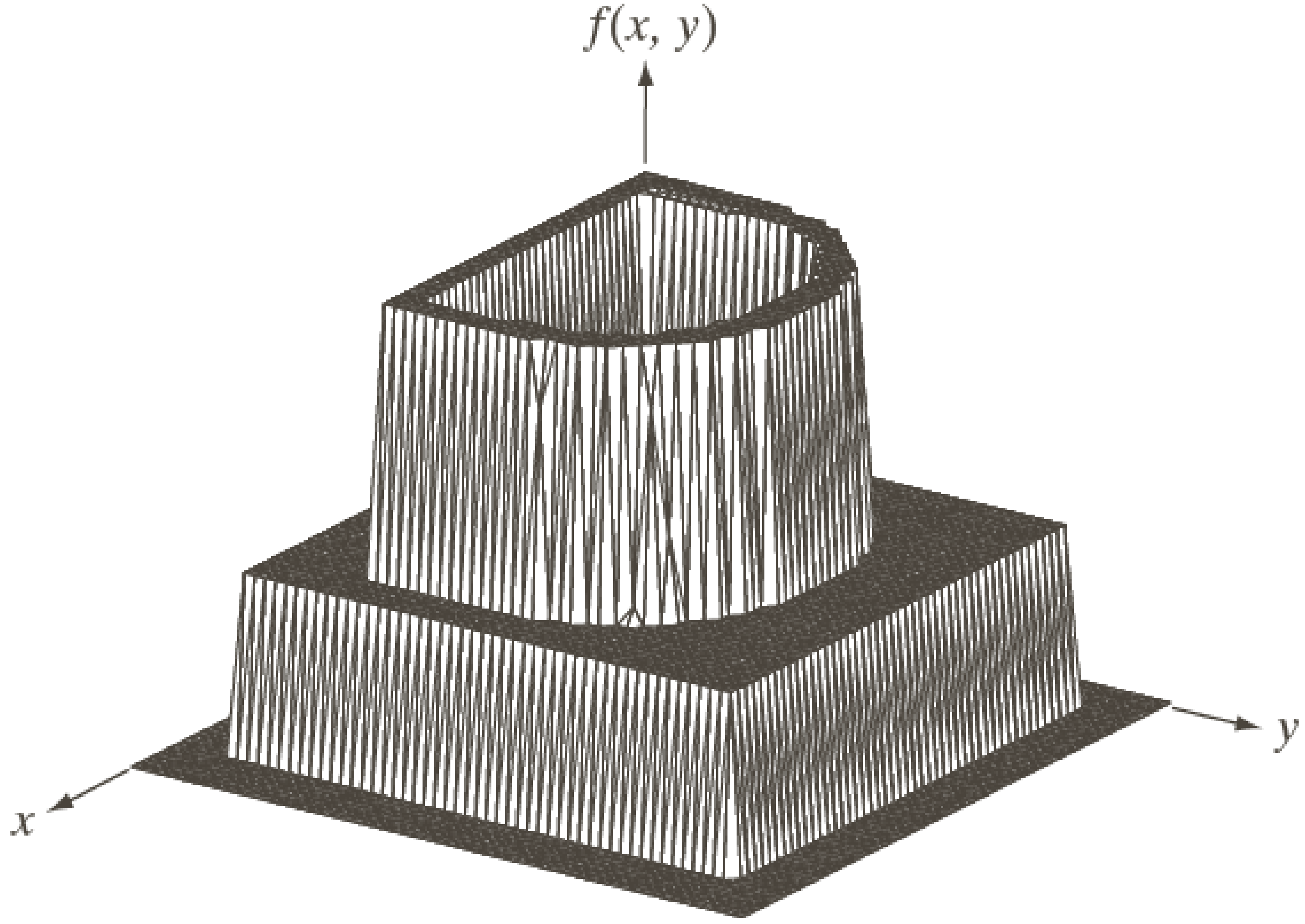

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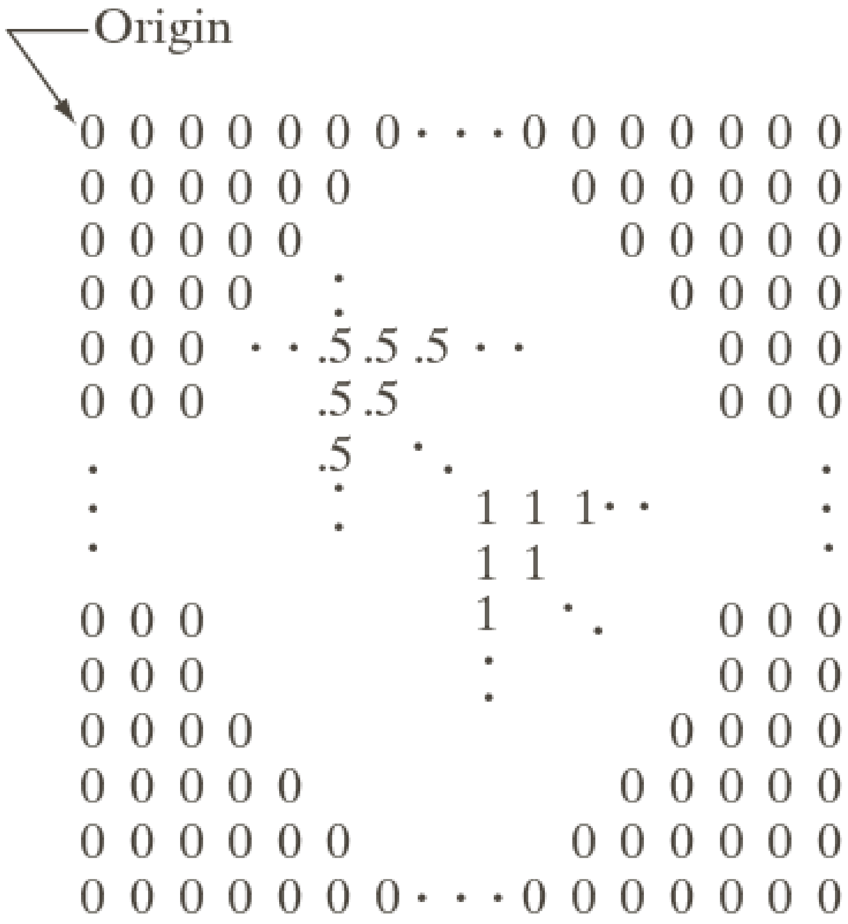
Image Representation



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Spatial Resolution

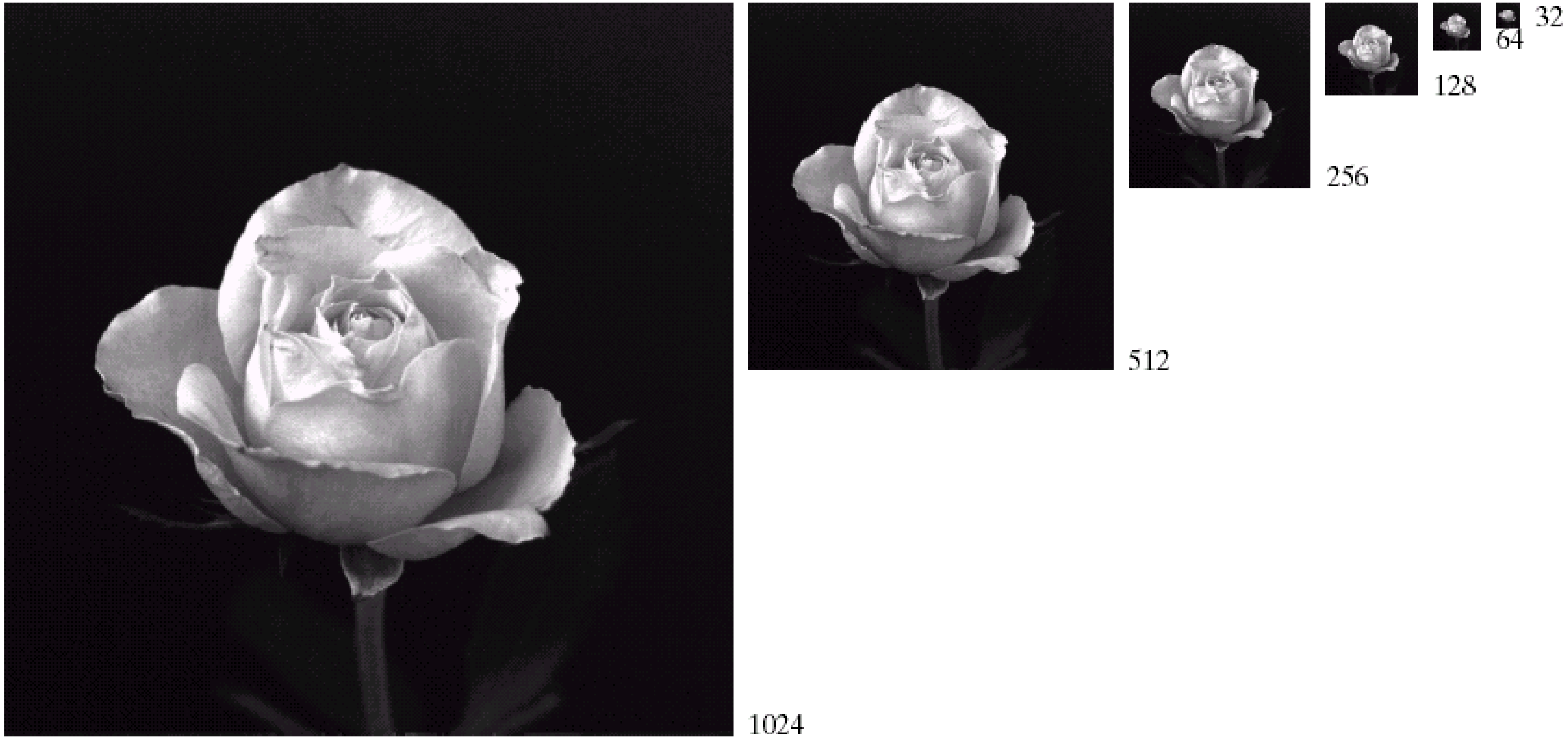
The spatial resolution of an image is determined by how sampling was carried out

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)

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Spatial Resolution (cont…)



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Spatial Resolution (cont…)

1024 * 1024 | 512 * 512 | 256 * 256

128 * 128 | 64 * 64 | 32 * 32

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Spatial Resolution (cont…)

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Intensity Level Resolution

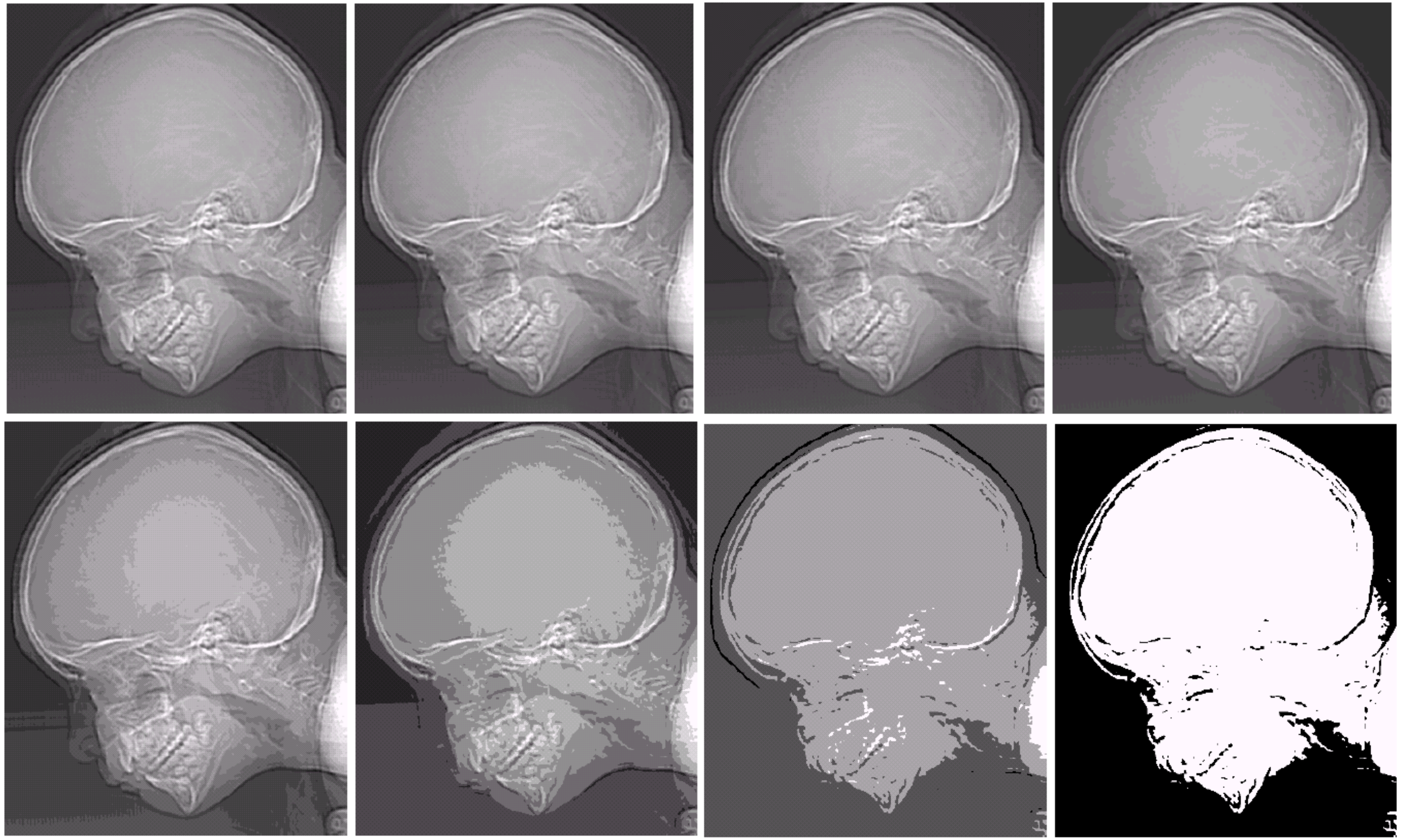
Intensity level resolution refers to the number of intensity levels used to represent the image

- 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…)

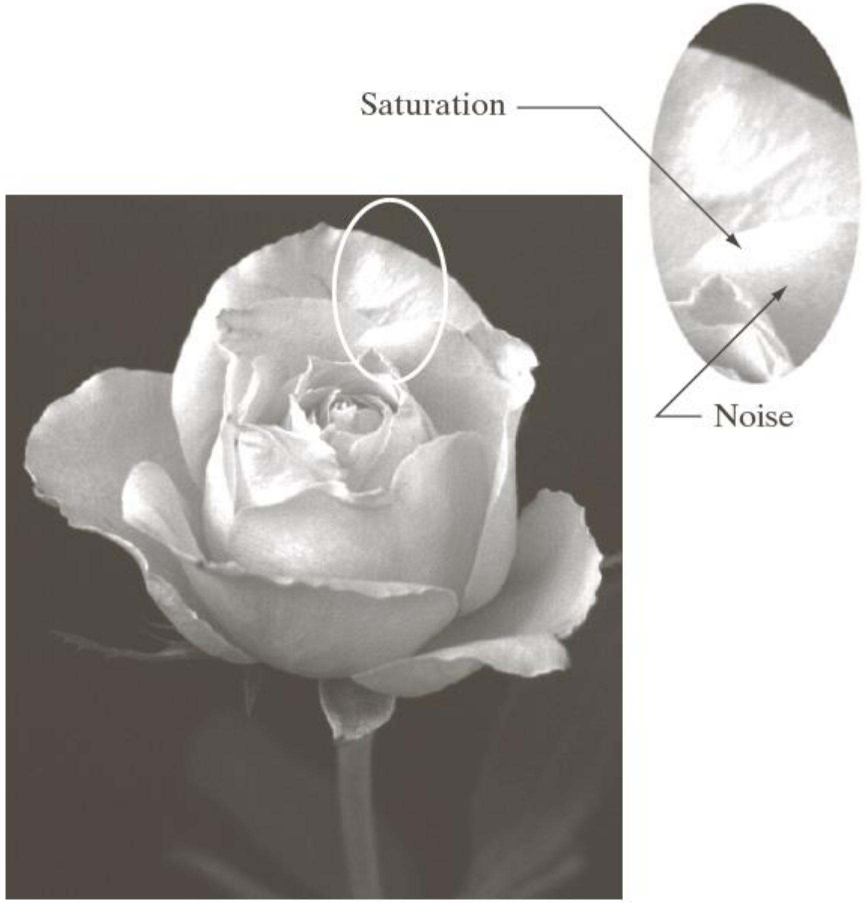
256 grey levels (8 bits per pixel) | 128 grey levels (7 bpp) | 64 grey levels (6 bpp) | 32 grey levels (5 bpp)



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

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Saturation & Noise



Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

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

Image credit: Google images

Intensity Level Resolution (cont…)

Low Detail

Medium Detail

High Detail

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Intensity Level Resolution (cont…)

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Intensity Level Resolution (cont…)

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Intensity Level Resolution (cont…)

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

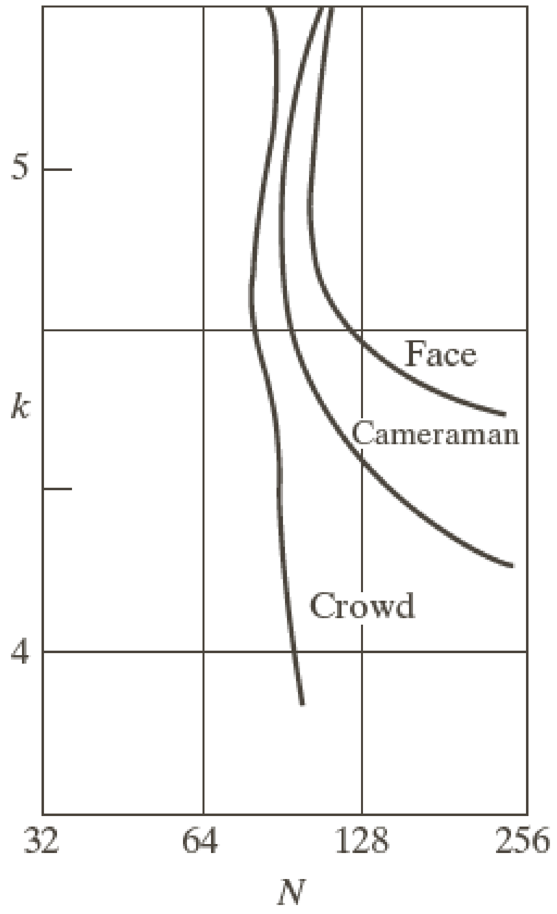
Intensity Level Resolution (cont…)

Isopreference curves.

Represent the dependence between intensity and spatial resolutions.

Points lying on a curve represent images of "equal" quality as described by observers.

They become more vertical as the degree of detail increases (a lot of detail need less intensity levels), e.g. in the *Crowd* image, for a given value of N, k is almost constant.



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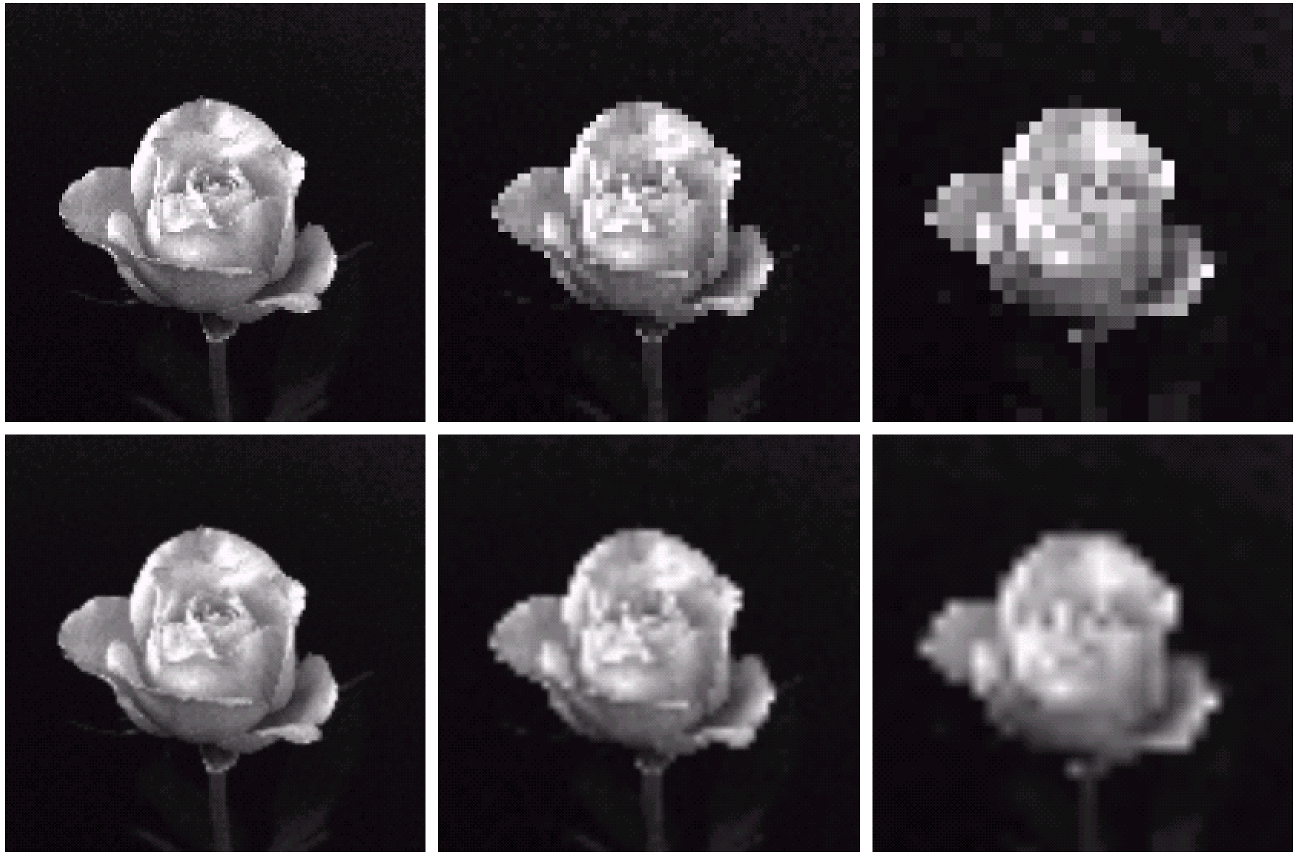
Interpolation (cont...)



a	b	c
d	e	f

FIGURE 2.25 Top row: images zoomed from 128 × 128, 64 × 64, and 32 × 32 pixels to 1024 × 1024 pixels, using nearest neighbor gray-level interpolation. Bottom row: same sequence, but using bilinear interpolation.

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Interpolation (cont...)

FIGURE 2.24 (a) Image reduced to 72 dpi and zoomed back to its original size (3692 × 2812 pixels) using nearest neighbor interpolation. This figure is the same as Fig. 2.20(d). (b) Image shrunk and zoomed using bilinear interpolation. (c) Same as (b) but using bicubic interpolation. (d)–(f) Same sequence, but shrinking down to 150 dpi instead of 72 dpi [Fig. 2.24(d) is the same as Fig. 2.20(c)]. Compare Figs. 2.24(e) and (f), especially the latter, with the original image in Fig. 2.20(a).

Adapted from Gonzalez, Rafael C. Digital image processing. Pearson education India, 2009.

Distances between pixels

For pixels $p(x,y)$, $q(s,t)$ and $z(v,w)$, D is a distance function or metric if:

$$a)\, D(p,q) \geq 0 \;\; (D(p,q) = 0 \;\; iff \;\; p = q),$$

$$b)\, D(p,q) = D(q,p),$$

$$c)\, D(p,z) \leq D(p,q) + D(q,z).$$

The Euclidean distance between p and q is defined as:

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

Distances between pixels

The city-block or D_4 distance between p and q is defined as:

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

Pixels having the city-block distance from a pixel (x,y) less than or equal to some value T form a diamond centered at (x,y). For example, for T=2:

		2		
	2	**1**	**2**	
2	**1**	**0**	**1**	**2**
	2	**1**	**2**	
		2		

Distances between pixels

The chessboard or D_8 distance between p and q is defined as:

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

Pixels having the city-block distance from a pixel (x,y) less than or equal to some value T form a square centered at (x,y). For example, for T=2:

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

Summary

We have looked at:

- Human visual system
- Light and the electromagnetic spectrum
- Image representation
- Image sensing and acquisition
- Sampling, quantisation and resolution
- Interpolation

Next time we start to look at techniques for image enhancement