Image Processing Fundamentals

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Contents

This lecture will cover:

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

Human Visual System

Human Visual System

- The best vision model we have!

- It can perform a number of image processing tasks in a manner vastly superior to anything we are presently able to do with computers.

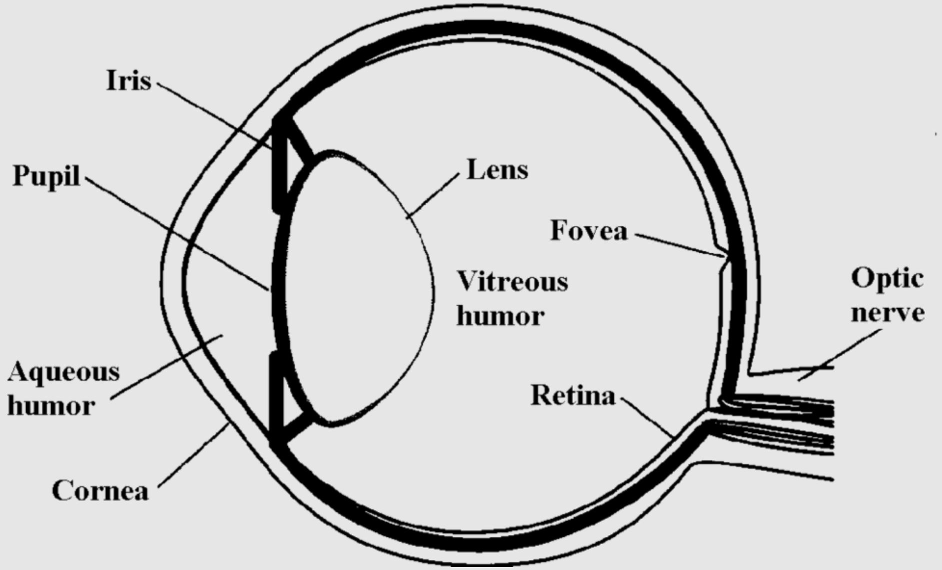
- Human visual system consists of two functional parts:
- **Eye**: biological equivalent of a camera
- **Brain**: performs all of the complex image processing.

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

Human Visual System: Human Eye

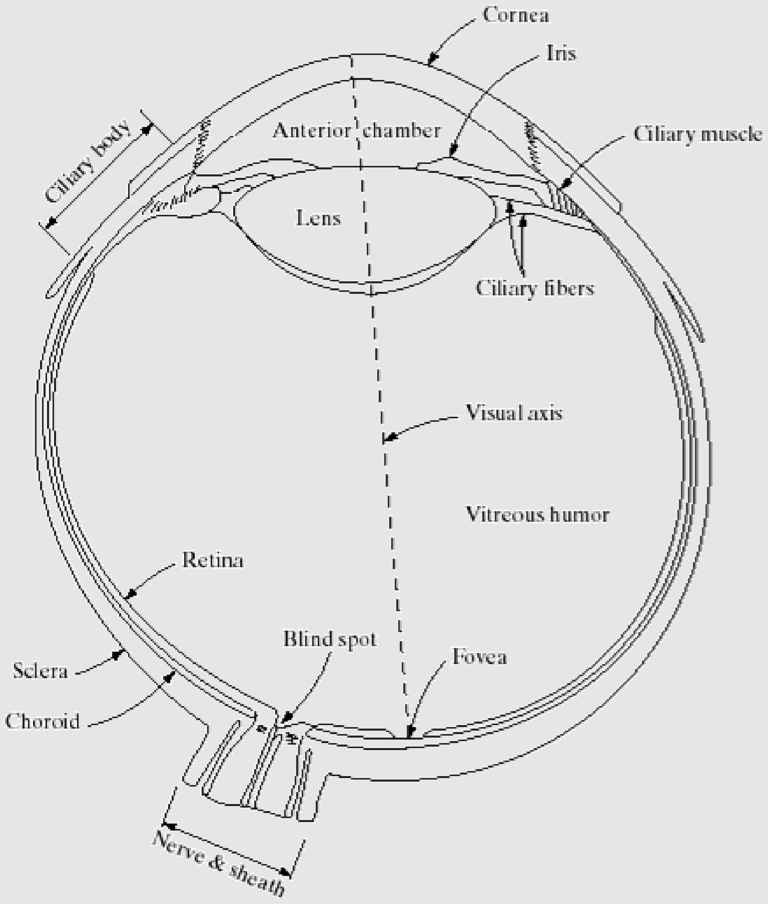
- Our eyes perceive of a scene through the light rays emitted or reflected.
- Healthy eye will react to such a ray by sending an electric signal to the brain through the optic nerve.

- Light ray path: cornea => aqueous humor => iris => lens => vitreous humor => retina.



Human Visual System: Human Eye

- The lens can vary its shape to focus the perceived image onto the retina;
- In the retina, the light rays are detected and converted to electrical signals by photoreceptors;
- The fovea is the area of the retina where our vision is sharpest;
- The retina is covered with photoreceptors called *cones* (6-7 million) and *rods* (75-150 million);



Human Visual System: Human Eye

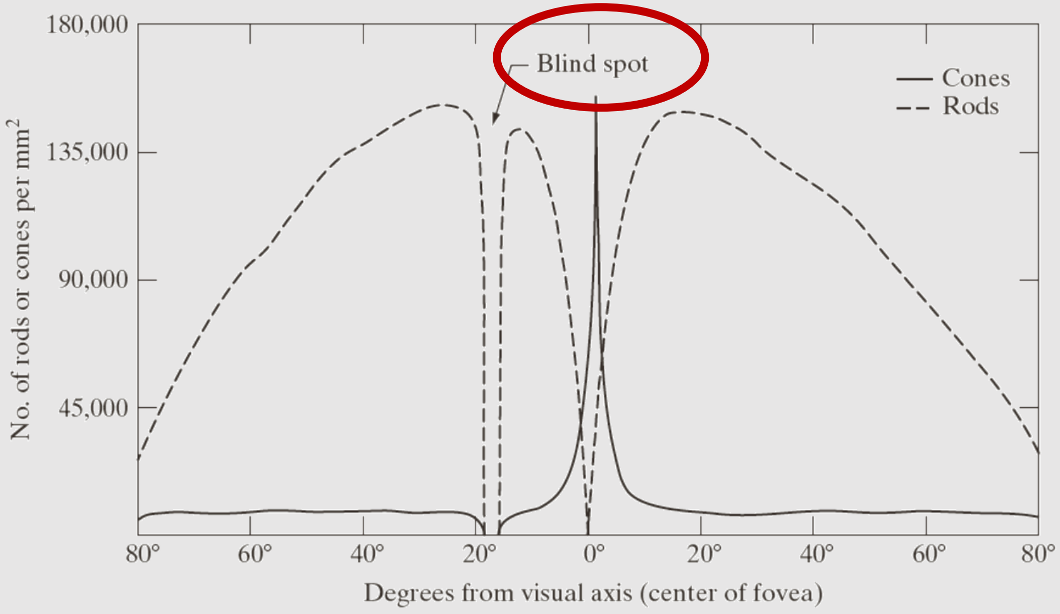
- Cones (concentrated around the fovea) are very sensitive to colour and details;
- Rods (more spread out) are sensitive to low levels of illumination;

3 types of vision

Scotopic or night vision: Under dark circumstances => rods are most active => we perceive only shades of grey.

Photopic or day vision: vision in very bright environments => cones are most active

Mesopic Vision: Vision in intermediate lighting environments => both cones and rods;



Human Visual System: *Blind spot Experience*

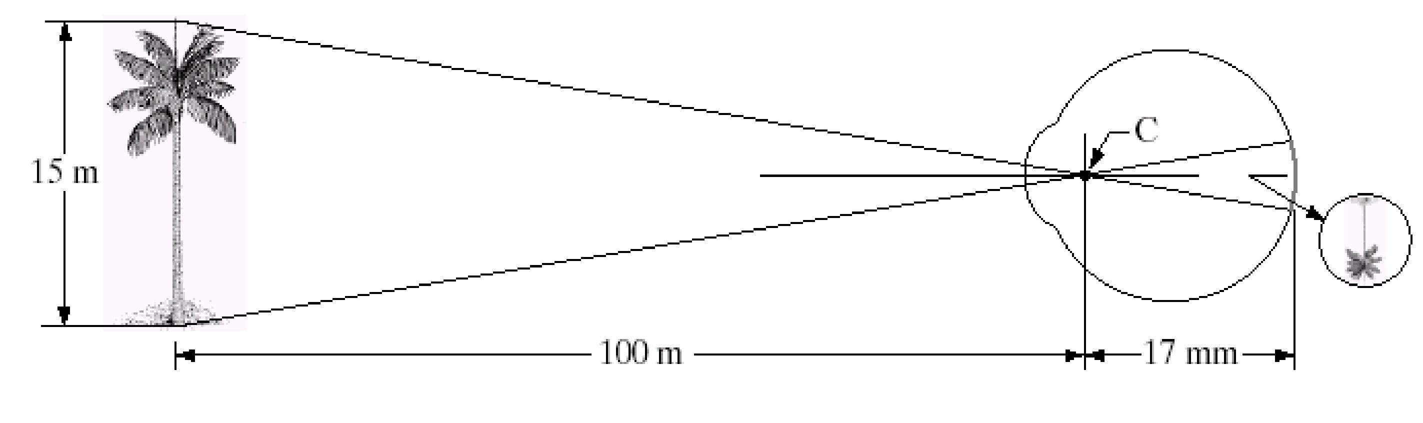
- Draw an image similar to that below on a piece of paper (the dot and cross are about 6 inches apart)

- 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!

No photoreceptors are found at the point where the optic nerve attaches to the eye (the so-called *blind spot*), so we cannot perceive anything there.

Human Visual System: Image Forming

- 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;
- Then, photoreceptors become excited and send signals to the brain.

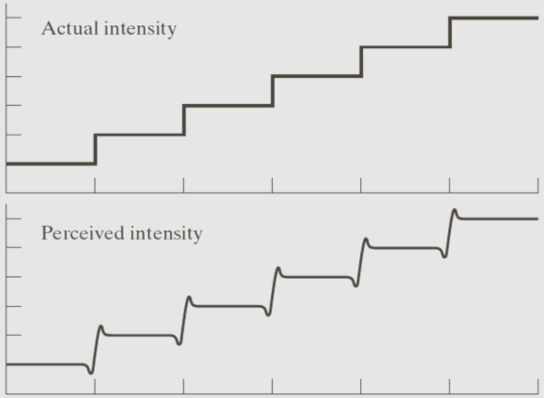


Human Visual System: Brightness Adaptation & Discrimination

- 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;
- The ability to detect a spot of light does not depend so much on the luminance of the spot itself as on the difference in luminance of spot and background, i.e., the contrast (higher the background luminance , the higher the contract to see);

Human Visual System: Brightness Adaptation & Discrimination

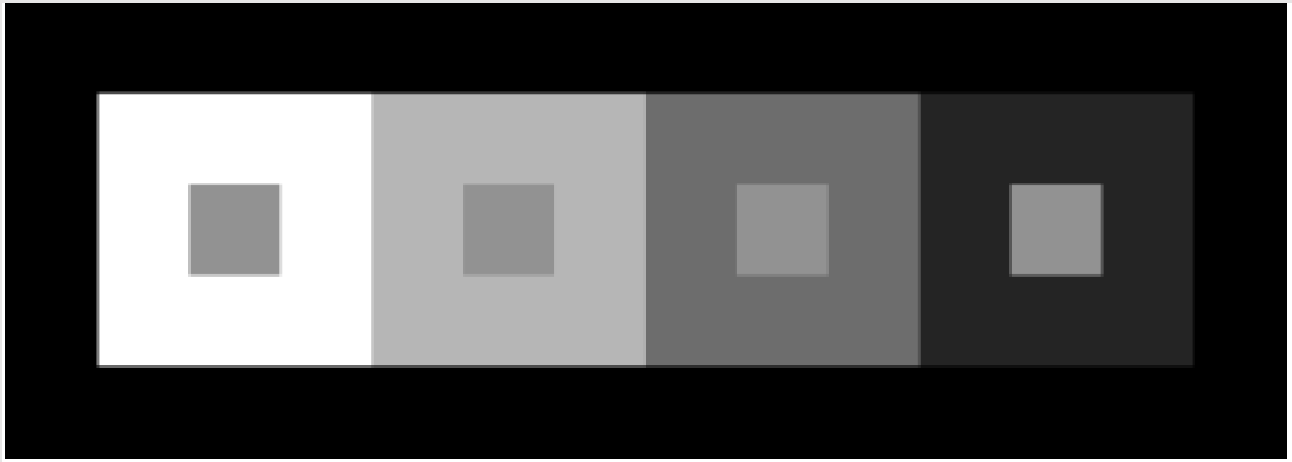
- There are a number of other contrast effects that influence the perceived brightness;
- Mach band effect: even though each bar is uniformly grey, our visual system enhances luminance changes. As the figure shows, overshoots and undershoots appear in the brightness graph.
- The Mach band effect shows us that our visual system sharpens the edges of the objects we perceive by adding a little contrast.



Mach band effect: each bar is uniformly grey, but our visual system enhances each contrast jump.
The graph at the right approximately shows the perceived brightness

Human Visual System: Brightness Adaptation & Discrimination

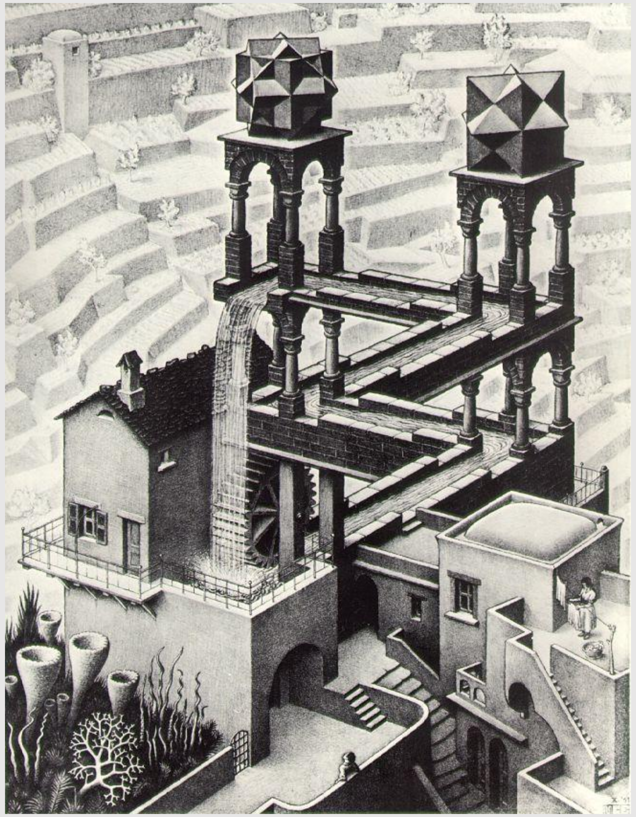
- The simultaneous contrast effect is another effect that shows us that the perceived brightness depends on the contrast, in this case (figure below) on the contrast with the local background.
- Even though the center squares are of equal luminance, they appear to be brighter if the background is darker. The one with the largest contrast to the background appears darkest.

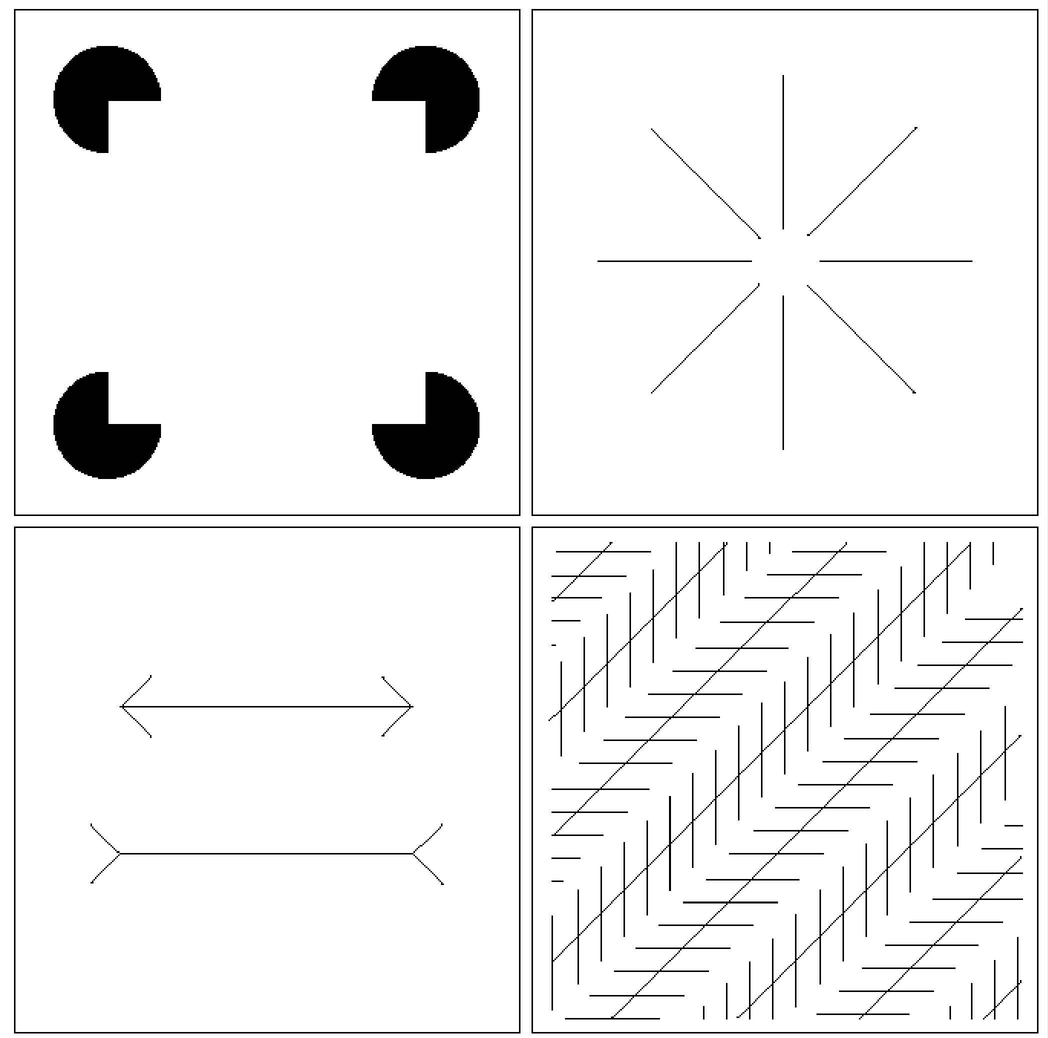


As the background gets darker, the perceived brightness of the squares increases.

Human Visual System: Optical Illusions

Our visual systems play lots of interesting tricks on us !!





The Electromagnetic Spectrum

- Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye => **Visible light**;
- The electromagnetic spectrum is split up according to the wavelengths of different forms of energy.

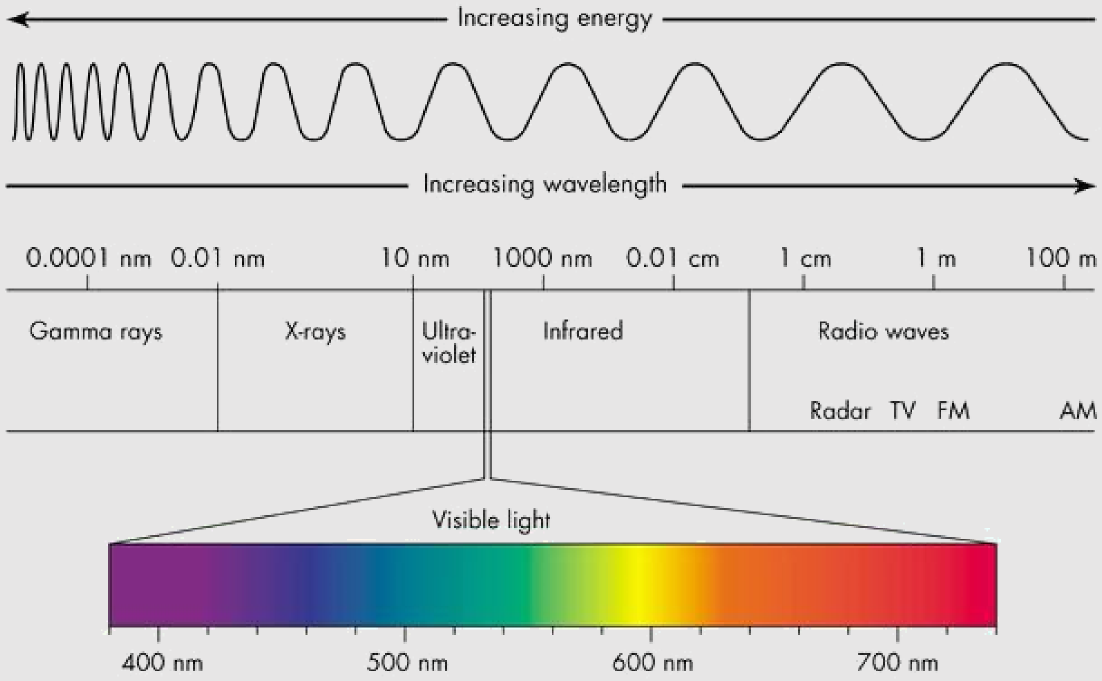
$$E = hf = \frac{hc}{\lambda}$$

$h = 6.63 \times 10^{-34}$ Js → Planck constant

f = frequency of photon/electromagnetic radiation

$c = 3 \times 10^{8}$ m/s → speed of light in a vacuum

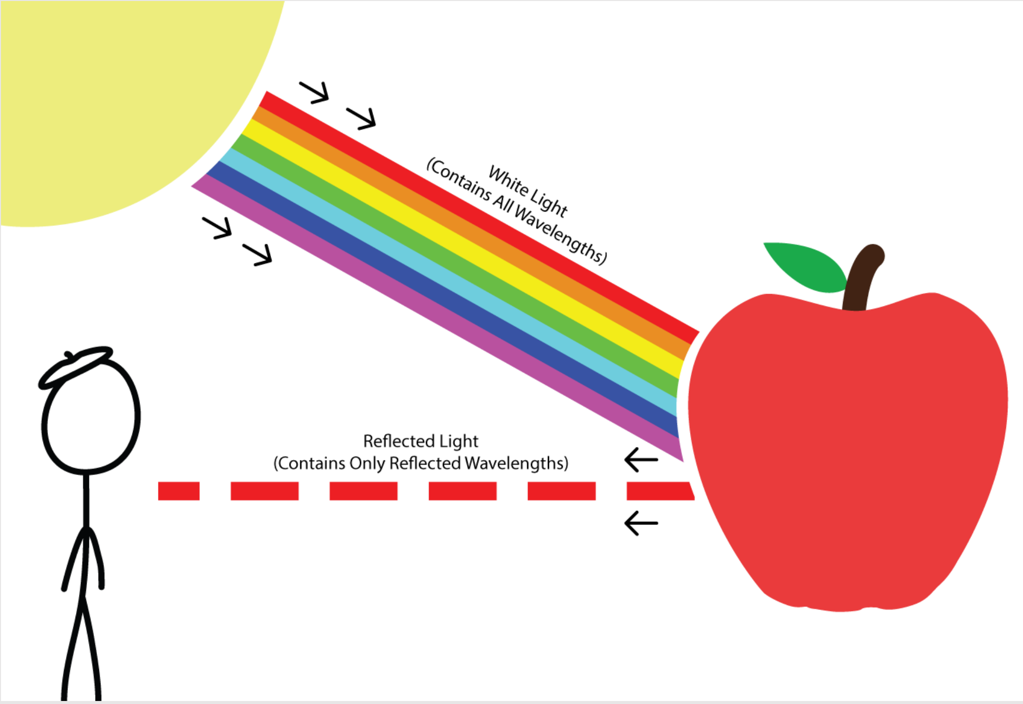
λ = wavelength of photon/electromagnetic radiation



Colour Perception

- 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 red object most wavelengths are absorbed, while the red light is reflected from the object and the subject sees the red colour.



Sampling, Quantisation and Resolution

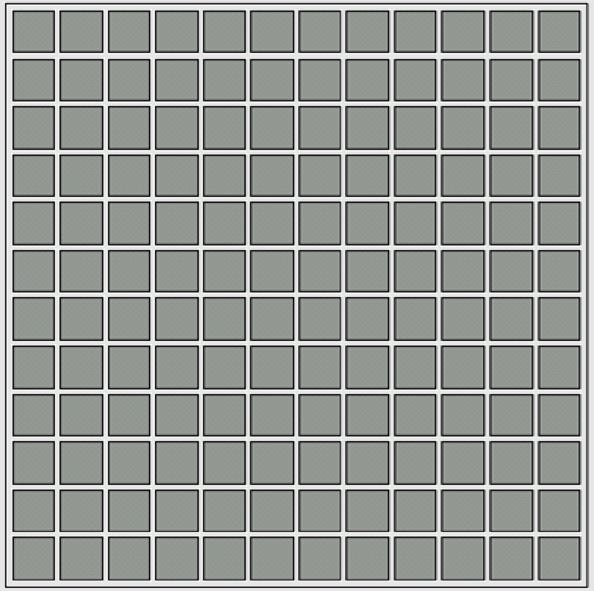
Phenomena involved in capturing a digital image of a real-world scene:

- Image sensing and representation
- Sampling and quantisation
- Resolution

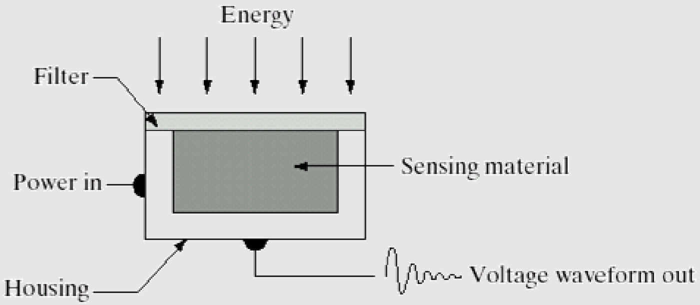
Image Sensing

- Incoming energy lands on a **sensor material responsive to that type of energy** and this generates a **voltage/ electric current**;
- **Photodiode** is a common photodetector that absorbs photons converting them in electric current; **CCD sensors** are used widely in digital cameras;
- Collections of sensors are arranged to capture images.

Array of Image Sensors



Imaging Sensor



Line of Image Sensors

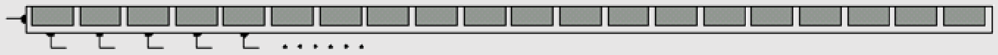
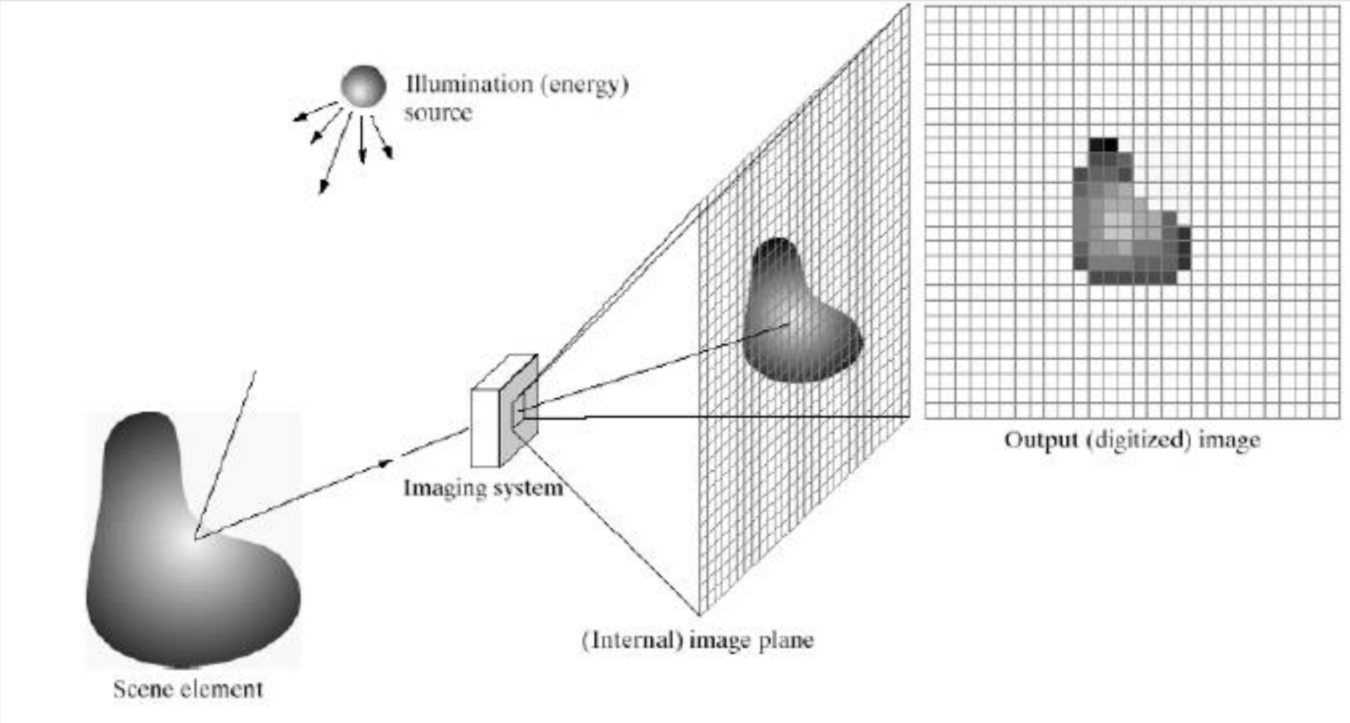


Image Acquisition

- 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
  - Electromicroscopic images of molecules

Image Sampling And Quantisation

- A **digital sensor** can only measure a **limited number of samples** at a **discrete** set of energy levels;
- Analog-digital conversion: an image function f(x,y) must be digitized both spatially (sampling) and in amplitude (quantization) by converting a continuous **analogue** signal into a **digital representation** of this signal;
- **Sampling:** refers to discretization of spatial coordinates (along x axis) => Sampling rate determines the **spatial resolution** of the digitized image;
- **Quantization:** refers to discretization of gray level values (amplitude (along y axis)) => Determines the **number of grey levels** in the digitized image.

Image Sampling And Quantisation

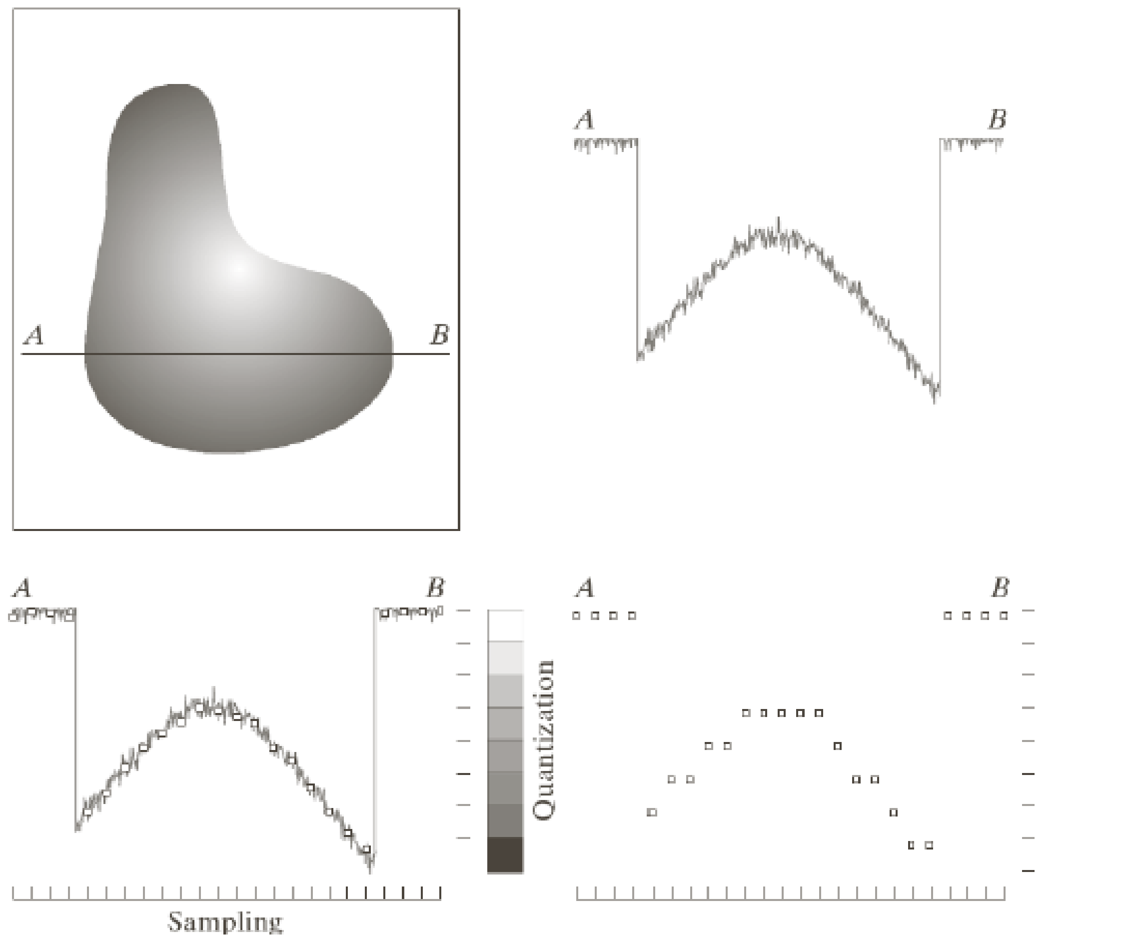


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

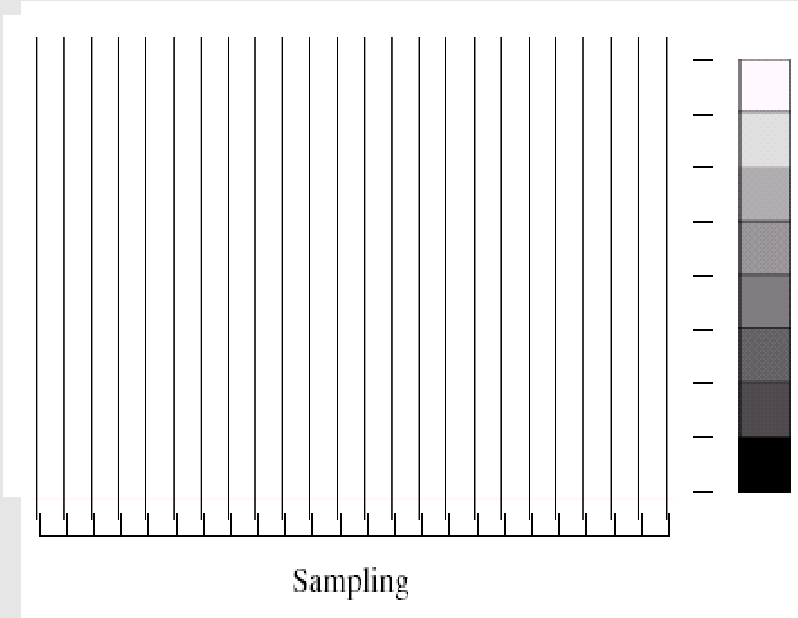


Image Sampling And Quantisation

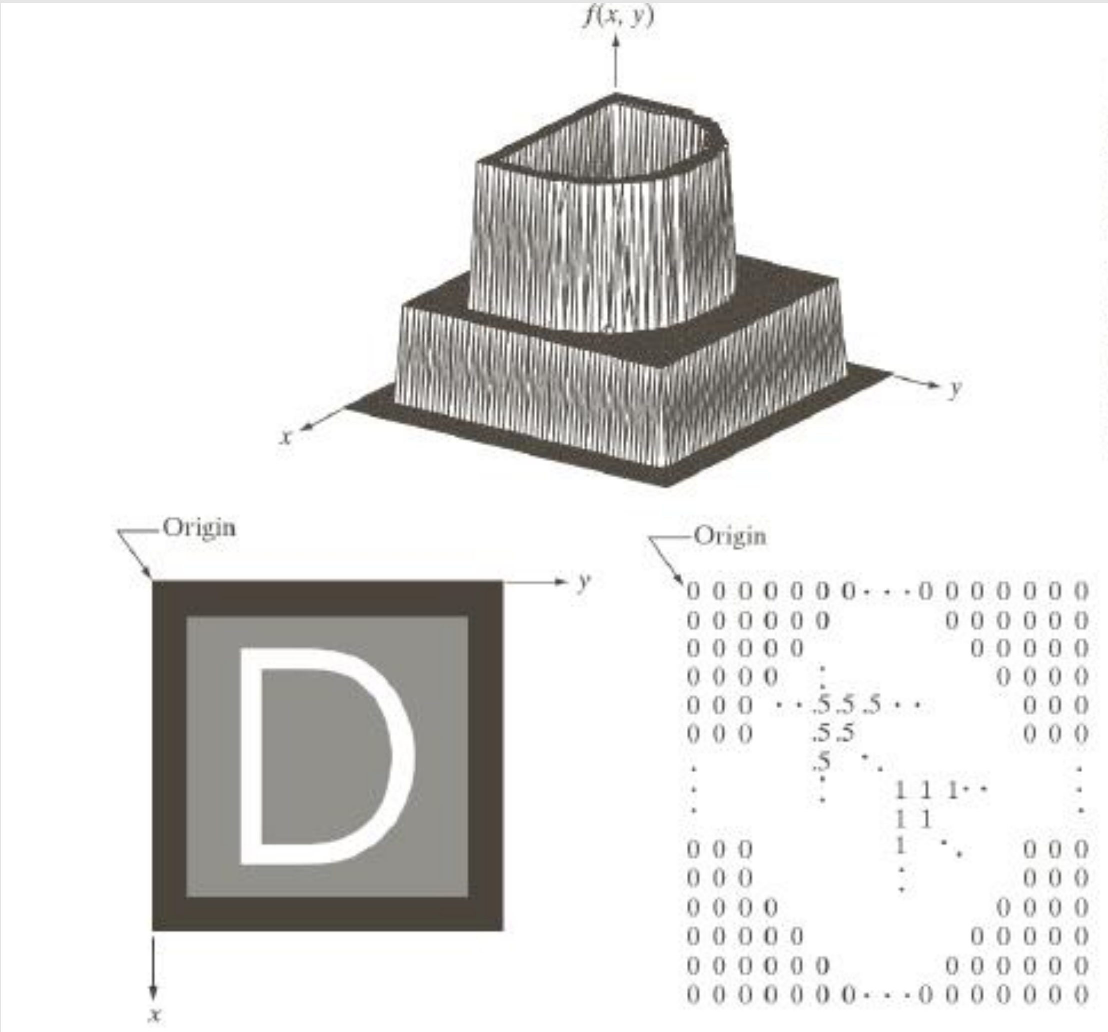


FIGURE 2.18 (a) Image plotted as a surface. (b) Image displayed as a visual intensity array. (c) Image shown as a 2-D numerical array (0, .5, and 1 represent black, gray, and white, respectively).

Image Sampling And Quantisation

- The number of **quantization levels** should be high **enough for human perception** of fine shading details in the **image**.
- The **occurrence of false contours** is the main problem in image which has been quantized with **insufficient brightness levels**.
- **Aliasing**: occurs when a signal is sampled at a less than twice the highest frequency present in the signal => **Nyquist Theorem is not ensured**

Signals at frequencies above half the sampling rate must be filtered out to avoid the creation of signals at frequencies not present in the original sound. Thus digital sound recording equipment contains low-pass filters that remove any signals above half the sampling frequency.

E.g. Fs=100 Hz => Fc < 50 Hz (low-pass filter)

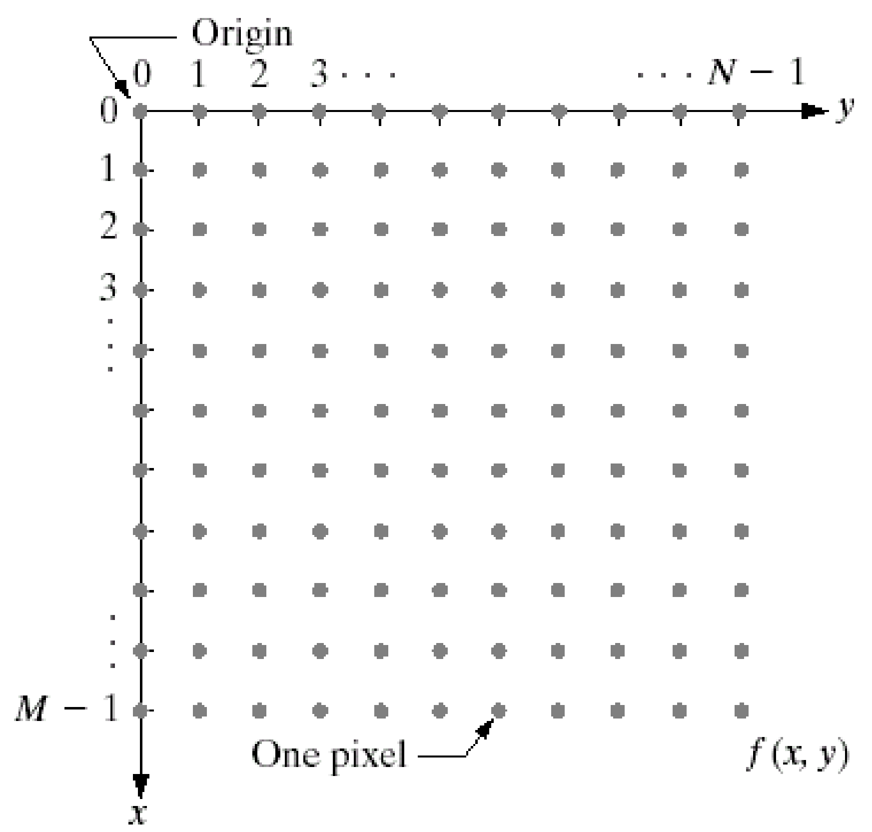
Image Representation

- A <u>digital image</u> may be defined as a <u>2D function f(x, y)</u>, where x and y are <u>spatial (plane) coordinates</u>, and the amplitude of “f” at any pair of coordinates (x, y) is called the <u>intensity or gray level</u> of the image.

- A <u>digital image</u> can be represented by a <u>compact matrix</u> composed of *M* rows and *N* columns of <u>pixels</u> each storing a value.

$$f(x, y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix}.$$

- Pixel values are most often grey levels in the range 0-255 (black-white).



Spatial Resolution

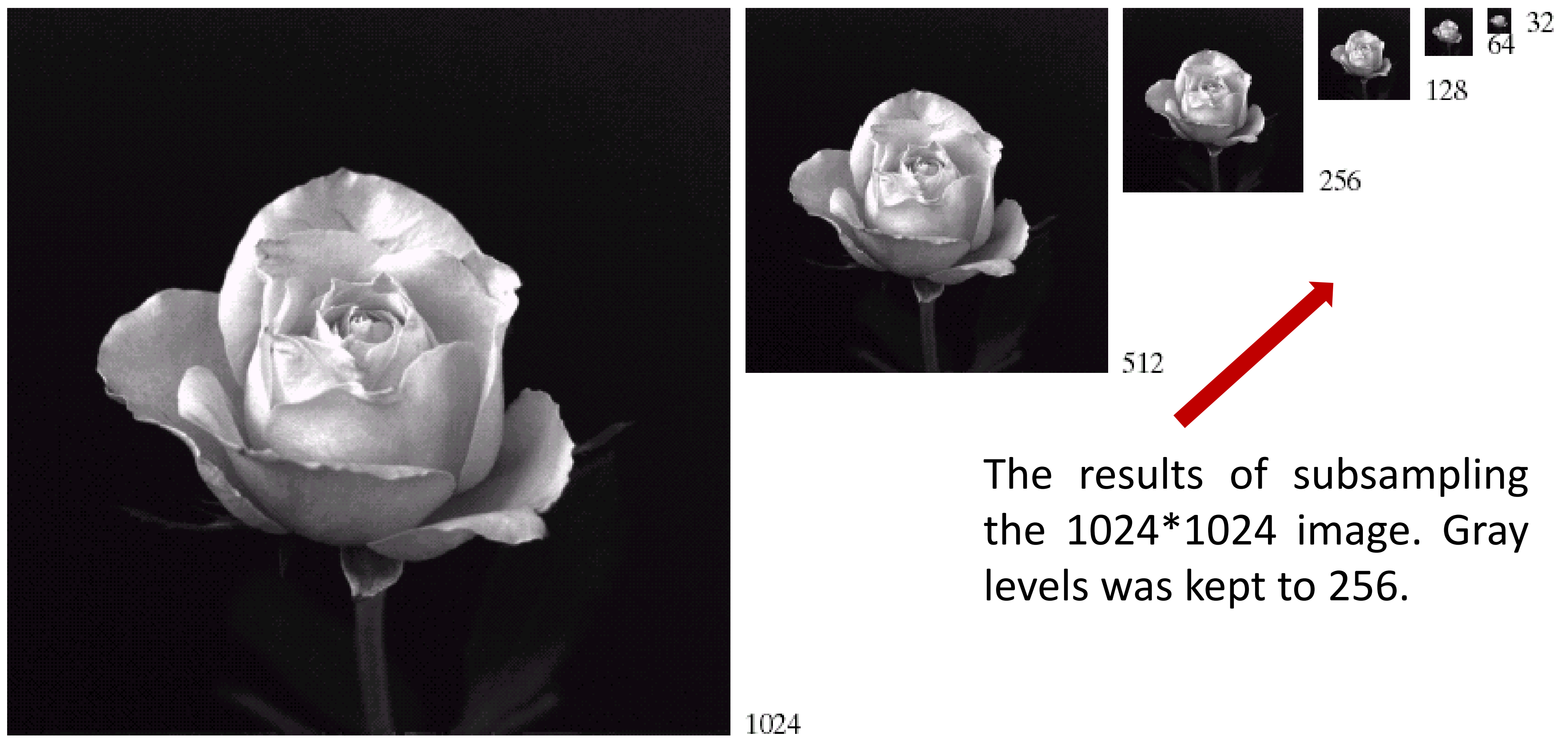
- Image resolution can be defined in many ways: pixel resolution & spatial resolution;
- Spatial resolution of an image refers to the smallest discernible detail in an image, i.e., the number of independent pixels values per inch to describe the image;
- Spatial resolution is determined by how sampling was carried out;
  - Vision specialists will often talk about pixel size;
  - Graphic designers will talk about dots per inch (DPI), i.e., number of discernible dots per inch.

Spatial Resolution

- Images having higher spatial resolution are composed with a greater number of pixels than those of lower spatial resolution;

Spatial Resolution

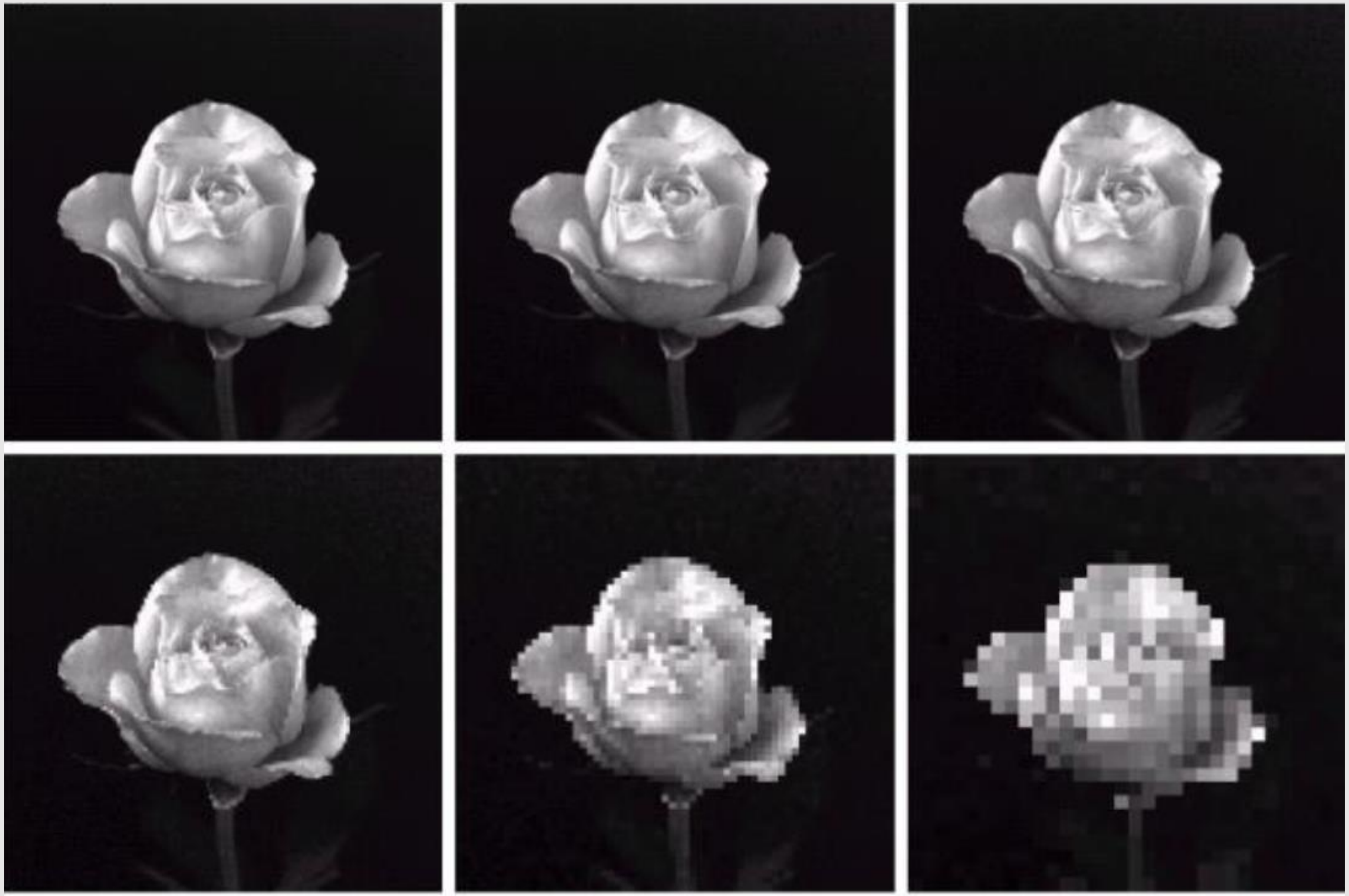
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



The results of subsampling the 1024*1024 image. Gray levels was kept to 256.

Image of size 1024*1024 pixels whose gray levels are represented by 8 bits = 256 gray levels .

Spatial Resolution



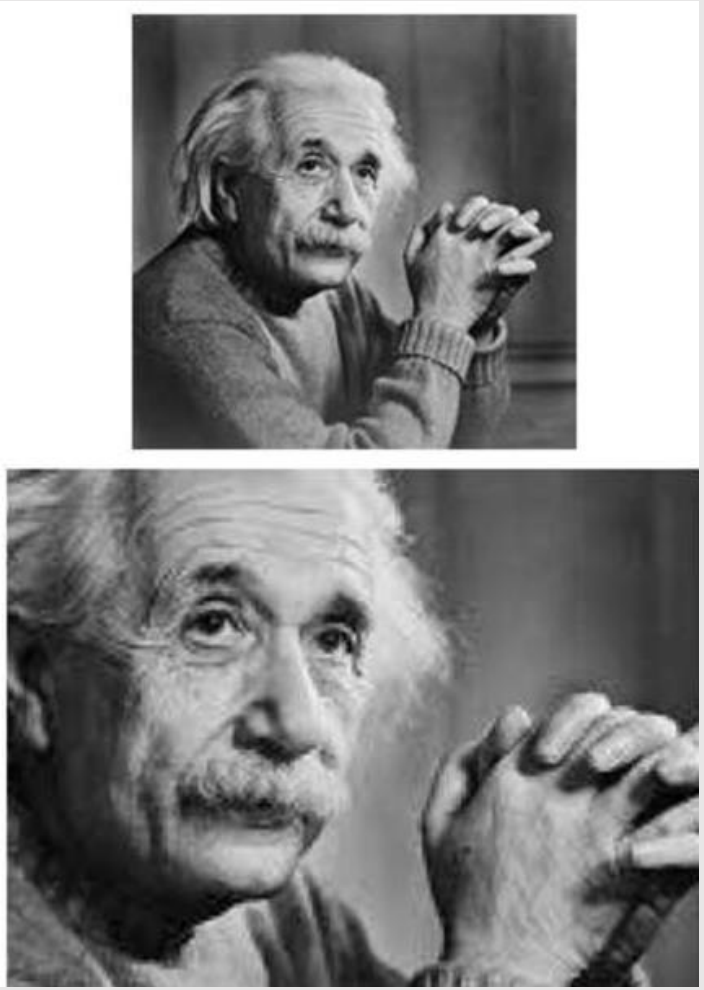
To compare the different spatial resolutions, we bring all the subsampled images up to size 1024 x 1024.

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

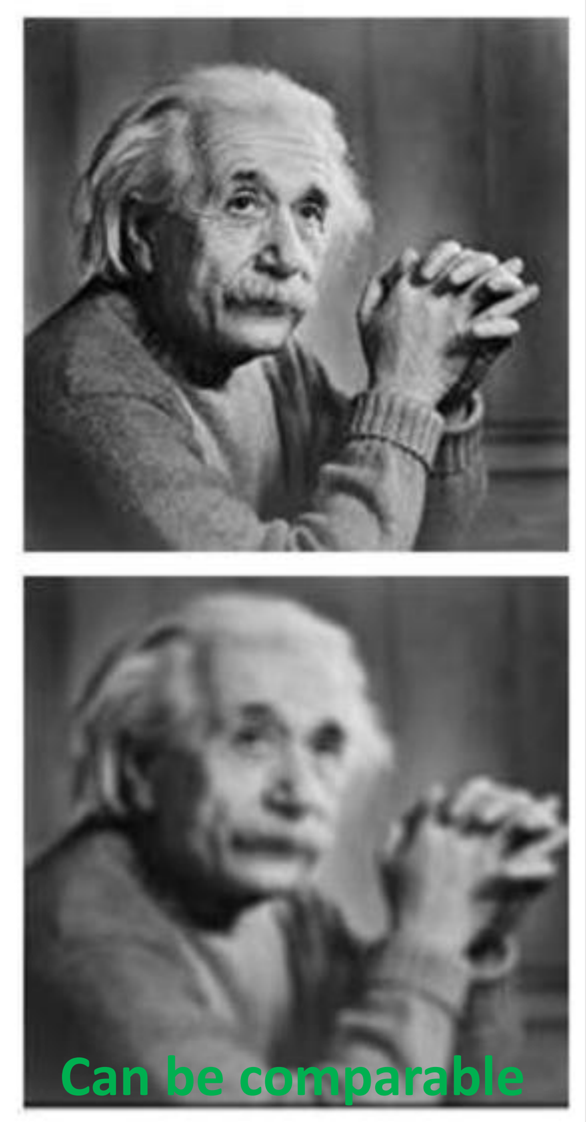
Spatial Resolution

Note

To compare the two images, to see which one is more clear or which has more spatial resolution, we have to compare two images of the same size.



Not comparable



Can be comparable

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 discernible 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	

Intensity Level Resolution

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

256 grey levels
(8 bits per pixel)

128 grey levels
(7 bpp)

64 grey levels
(6 bpp)

32 grey levels
(5 bpp)

Intensity Level Resolution

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

16 grey levels (4 bpp)

8 grey levels (3 bpp)

4 grey levels (2 bpp)

2 grey levels (1 bpp)

Intensity Level Resolution

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

Low Detail

Medium Detail

High Detail

Resolution: How much is enough?

The big question with resolution is always <u>how much is enough?</u>

- 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?

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

Saturation & Noise

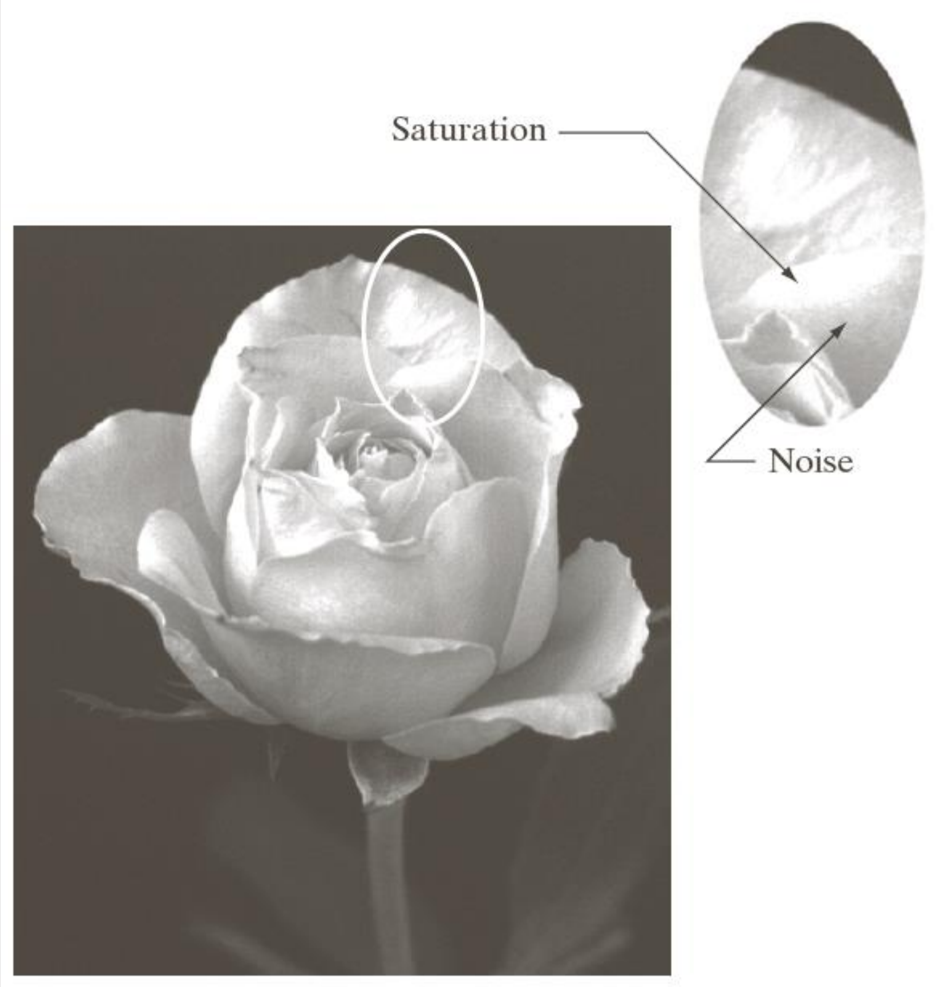
- <u>Saturation:</u> is used to describe the intensity of color in the image.
- The increment of saturation increases the separation between colors, i.e., the image becomes brighter
- Low saturation has the true color while saturation adds white color to the pure one. So highly saturated image will be too bright i.e. white
- A change in saturation normally has a <u>more noticeable effect on vibrant colors</u> and less on dull colors or colors that are almost neutral. This is because to change saturation, there must be some color saturation to work with in the first place.

Saturation & Noise

- Noise is the result of errors in the image acquisition process that result in pixel values that do not reflect the true intensities of the real scene.

- Digital images are prone to a variety of types of noise, depending on how the image is created:
  - If the image is scanned from a photograph made on film, the film grain is a source of noise. Noise can also be the result of damage to the film, or be introduced by the scanner itself;
  - If the image is acquired directly in a digital format, the mechanism for gathering the data (such as a CCD detector) can introduce noise;
  - Electronic transmission of image data can introduce noise.

Saturation & Noise



This image exhibits both noise and saturation.

- Saturation: the highest value beyond which all intensity levels are clipped (note how the entire statured area has a high contrast intensity level);

- Noise: especially in the darker regions of an image masks the lowest detectable true intensity level. In this image it is a grainy texture pattern;

Saturation & Noise

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