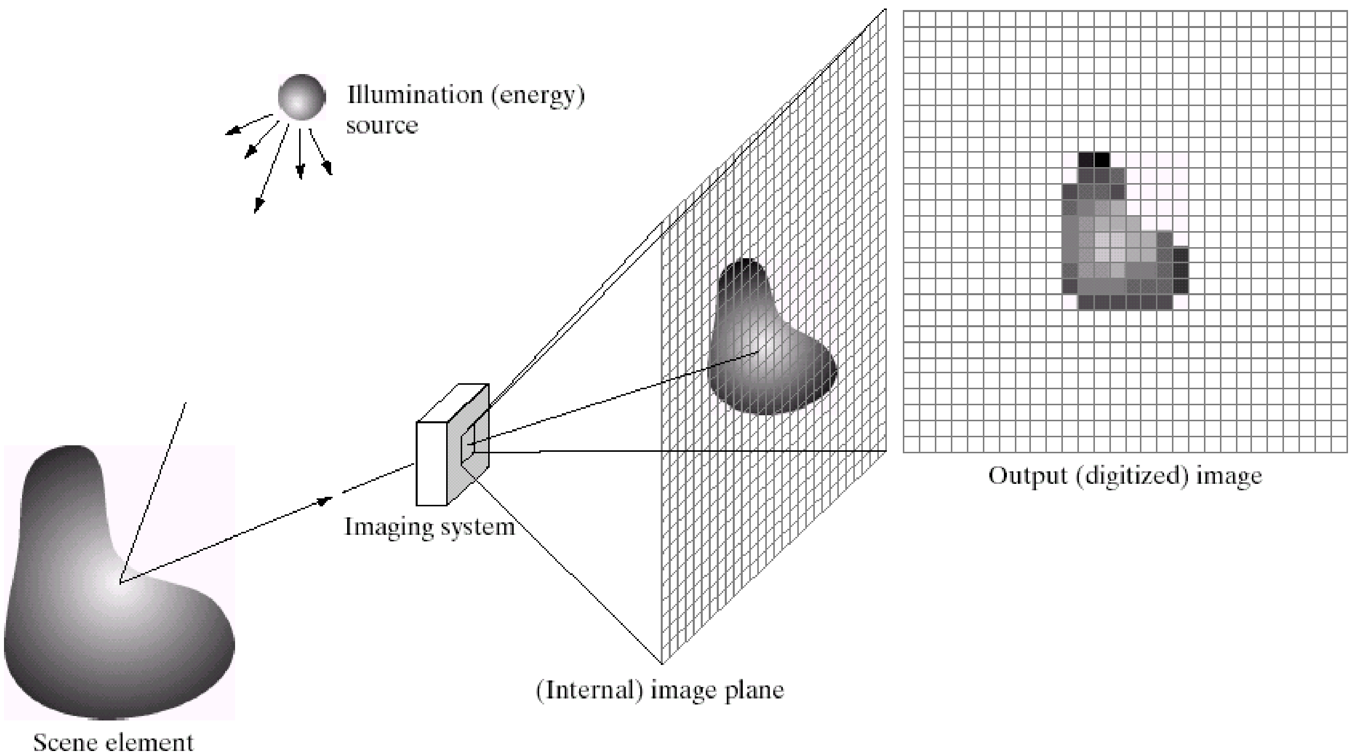
Fundamentals of Digital Image Processing

Partially adopted from Brian Mac Namee

Contents

Digital Image

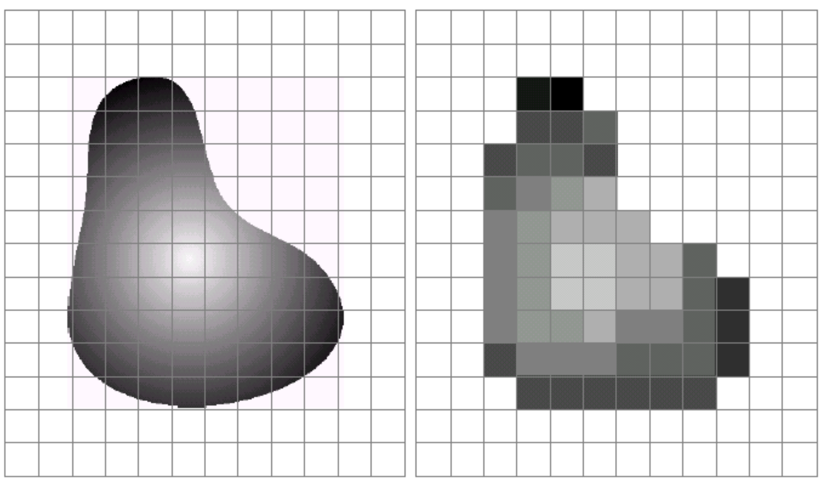
A **digital image** is a representation of a two-dimensional image as a finite set of digital values, called picture elements or pixels.

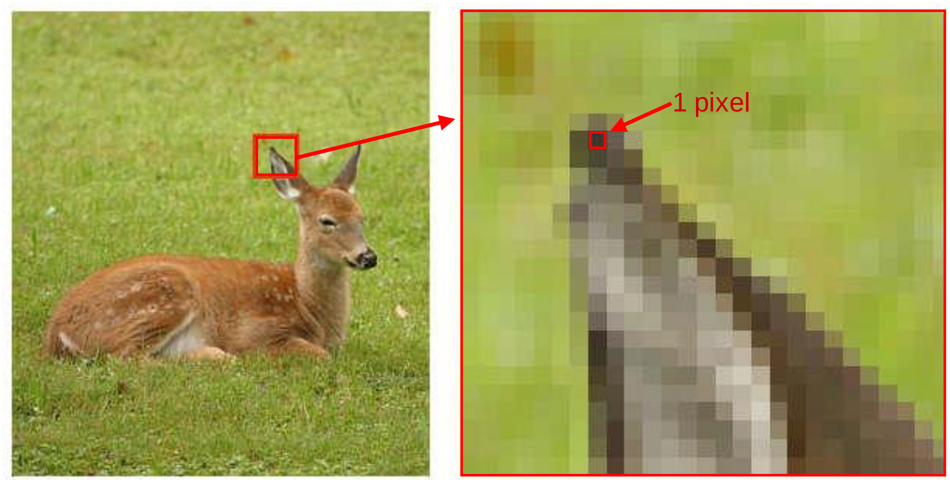


Digital Image

Pixel values typically represent gray levels, colours, heights, opacities, etc.

Digitization implies that a digital image is an *approximation* of a real scene.





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

Digital Image

Common image formats include:

1 sample per point (B&W or Grayscale)

3 samples per point (Red, Green, and Blue)

Digital Image Processing

Digital image processing focuses on two major tasks.

Improvement of pictorial information for human interpretation.

Processing of image data for storage, transmission and representation for autonomous machine perception.

Some argument about where image processing ends and fields such as image analysis and computer vision start.

Digital Image Processing

The continuum from image processing to computer vision can be broken up into low-, mid- and high-level processes.

Low Level Process	Mid Level Process	High Level Process
Input: Image **Output:** Image	**Input:** Image **Output:** Attributes	**Input:** Attributes **Output:** Understanding
Examples: Noise removal, image sharpening	**Examples:** Object segmentation, recognition	**Examples:** Scene understanding, autonomous navigation

History of Digital Image Processing

Early 1920s: One of the first applications of digital imaging was in the news-paper industry.

The Bartlane cable picture transmission system.

Early digital image used 5 gray levels

Images were transferred over submarine cable between London and New York.

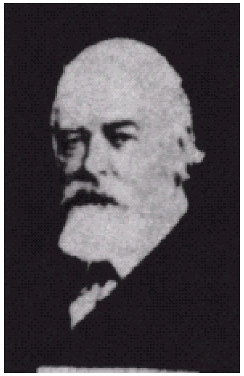
Pictures were coded for cable transfer and reconstructed at the receiving end on a telegraph printer.

History of Digital Image Processing

Mid to late 1920s: Improvements to the Bartlane system resulted in higher quality images.

New reproduction processes based on photographic techniques.

Increased number of tones in reproduced images.



Improved digital image

Early 15 tone digital image

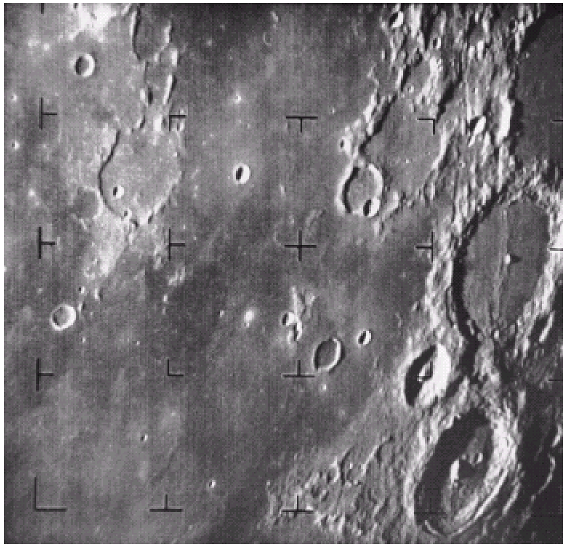
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

History of Digital Image Processing

1960s: Improvements in computing technology and the onset of the space race led to a surge of work in digital image processing.

1964: Computers used to improve the quality of images of the moon taken by the *Ranger 7* probe.

Such techniques were used in other space missions including the Apollo landings.



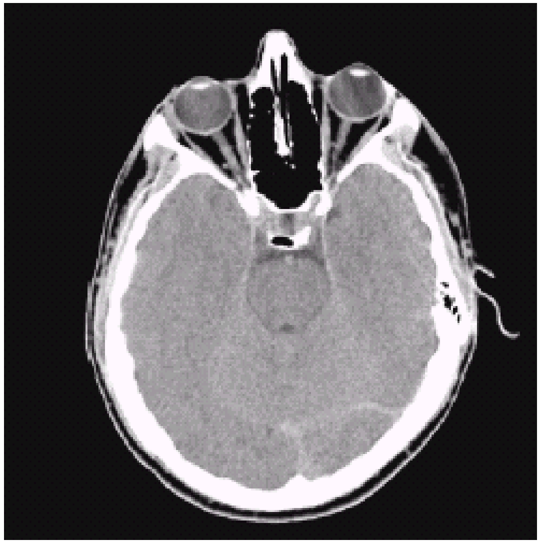
A picture of the moon taken by the Ranger 7 probe minutes before landing

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

History of Digital Image Processing

1970s: Digital image processing begins to be used in medical applications.

1979: Sir Godfrey N. Hounsfield & Prof. Allan M. Cormack share the Nobel Prize in medicine for the invention of tomography, the technology behind Computerised Axial Tomography (CAT) scans.



Typical head slice CAT image

History of Digital Image Processing

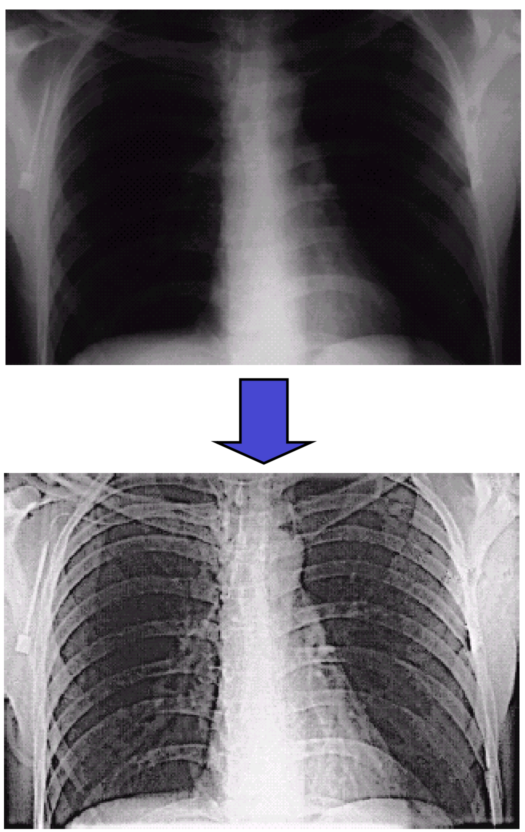
1980s - Today: The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas.

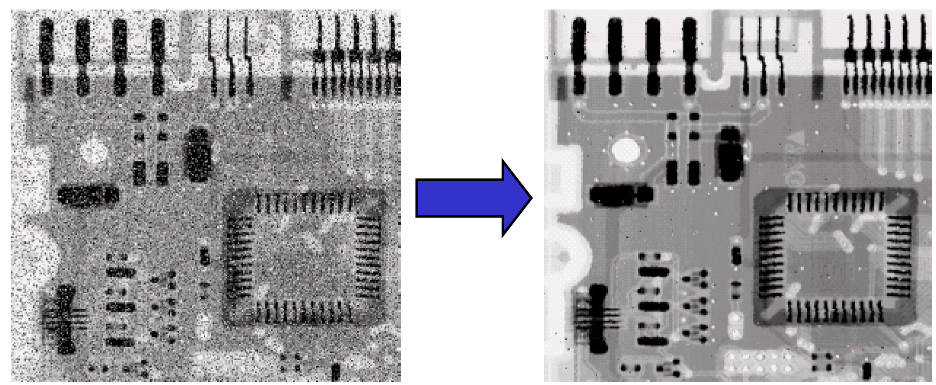
- ✓ Image enhancement/restoration
- ✓ Artistic effects
- ✓ Medical visualisation
- ✓ Industrial inspection
- ✓ Law enforcement
- ✓ Human computer interfaces

Examples: Image Enhancement

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

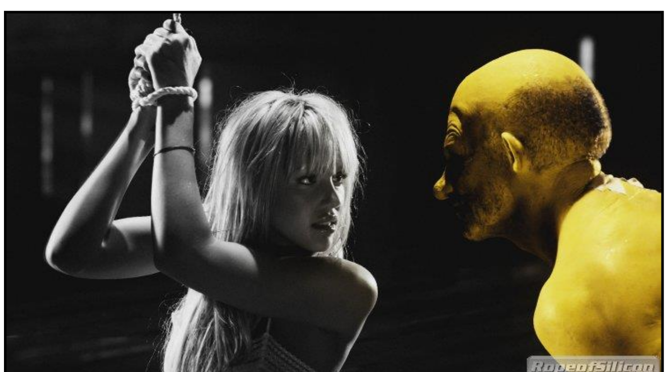
One of the most common uses of DIP techniques: improve quality, remove noise, etc.





Examples: Artistic Effects

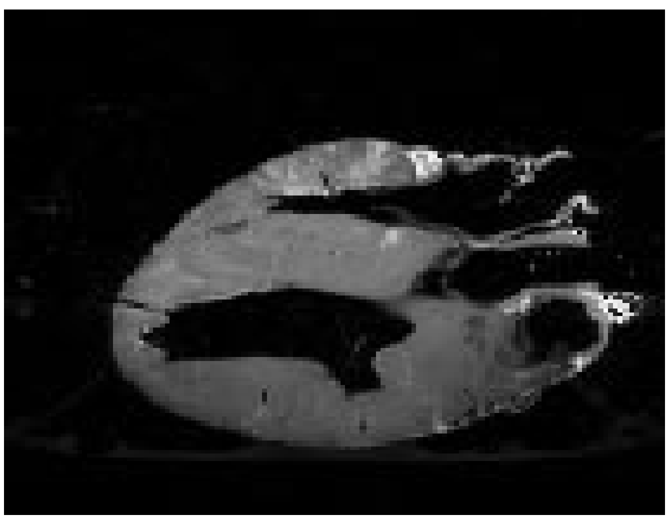
Artistic effects are used to make images more visually appealing, to add special effects and to make composite images.



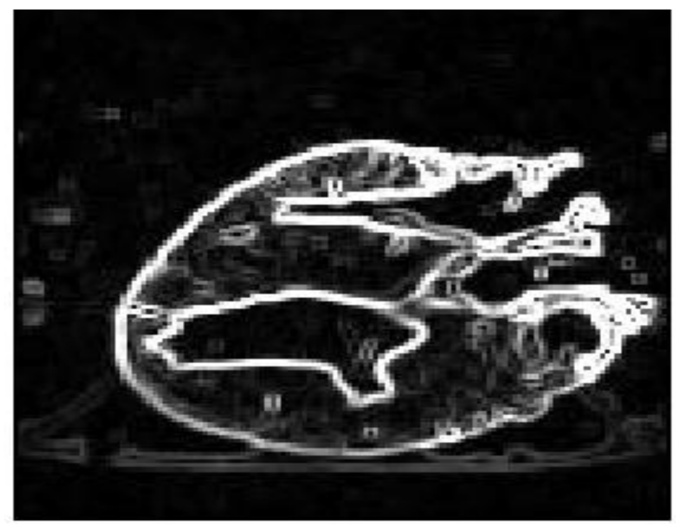
Examples: Medicine

Take slice from MRI scan of a dog heart and find boundaries between types of tissue.

Image with gray levels representing tissue density.



Original MRI Image of a Dog Heart



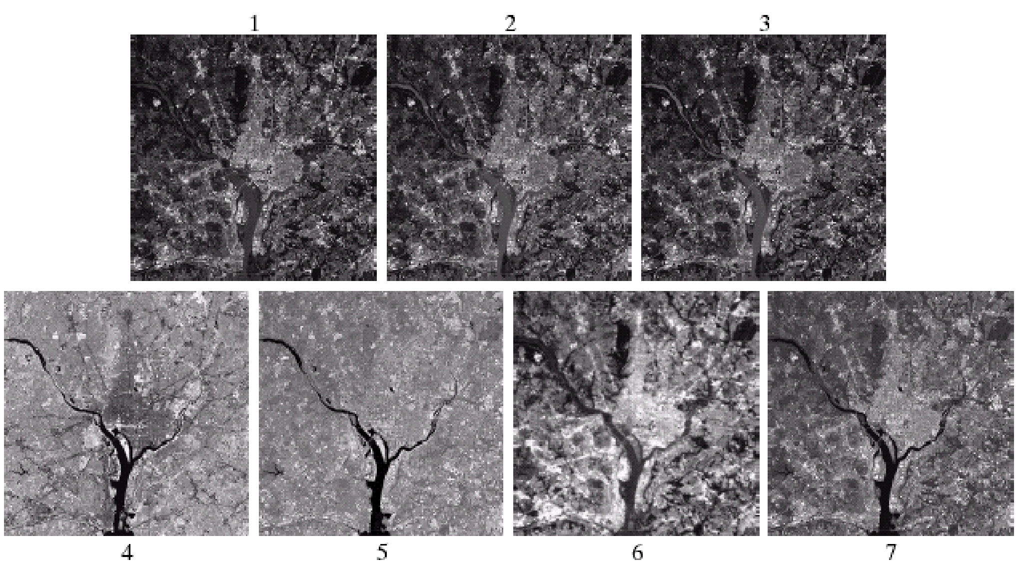
Edge Detection Image

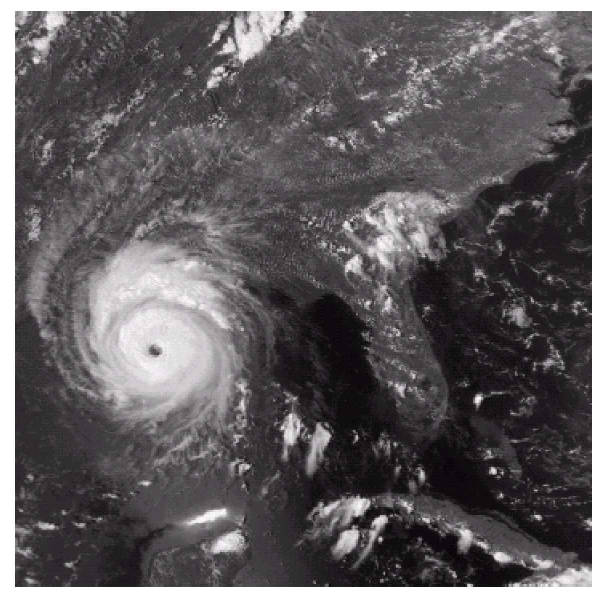
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Examples: GIS

Geographic Information Systems

Digital image processing techniques are used extensively to manipulate satellite imagery.





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

Examples: GIS

Night-Time Lights of the World data set.

- Global inventory of human settlement.

- Not hard to imagine the kind of analysis that might be done using this data.

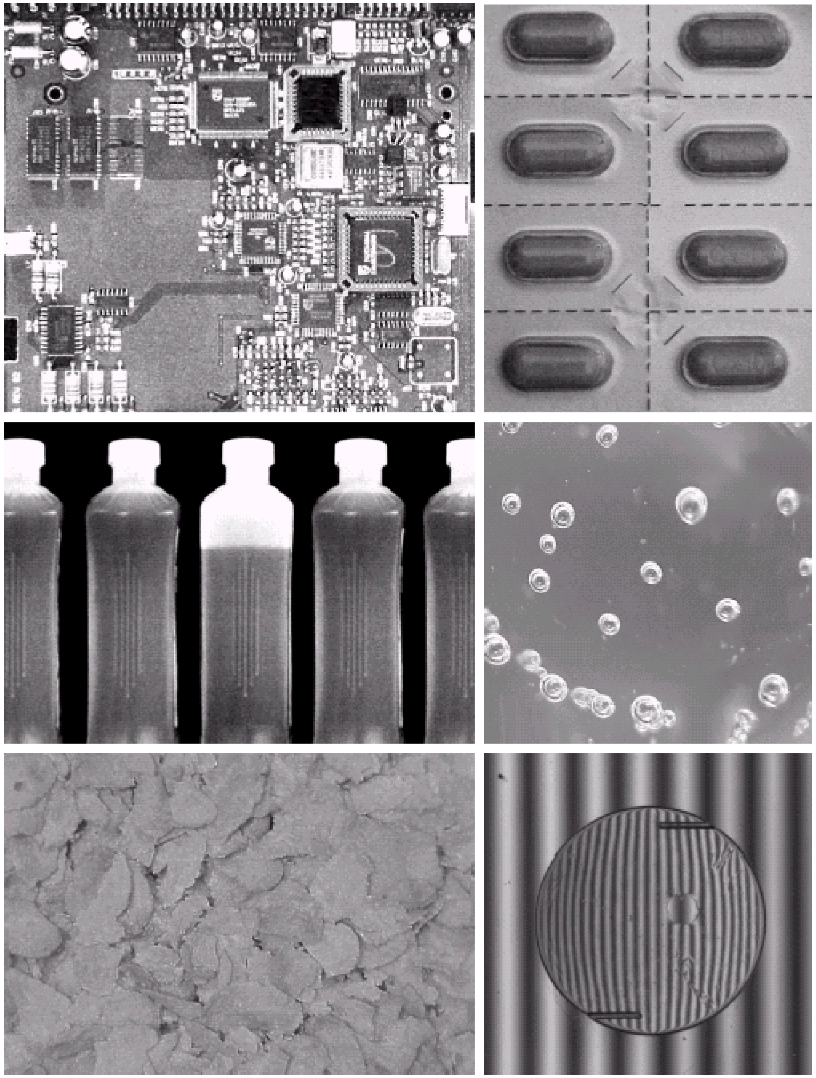
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Examples: Industrial Inspection

Human operators are expensive, slow and unreliable.

Make machines do the job instead.

Industrial vision systems are used in all kinds of industries.

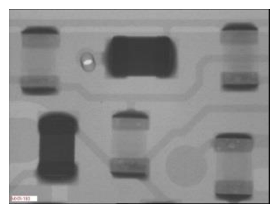


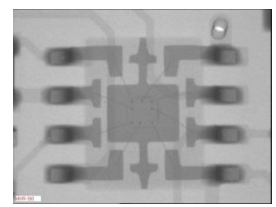
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

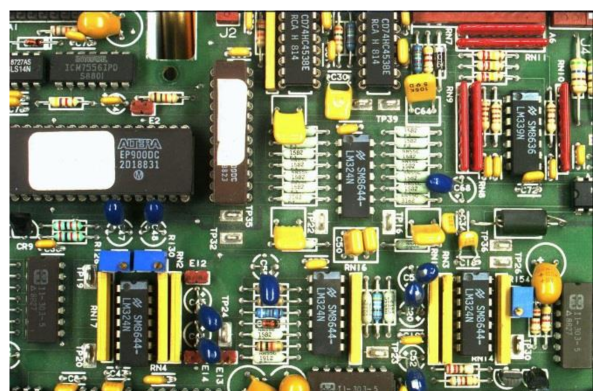
Examples: PCB Inspection

Printed Circuit Board (PCB) inspection

- Machine inspection is used to determine that all components are present and that all solder joints are acceptable.
- Both conventional imaging and x-ray imaging are used.





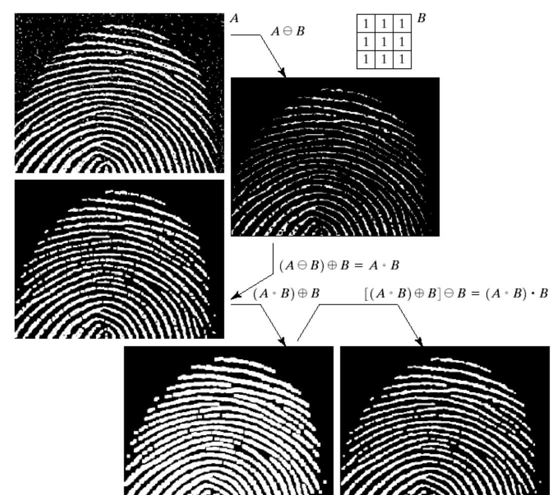


Examples: Law Enforcement

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

Image processing techniques are used extensively by law enforcers.

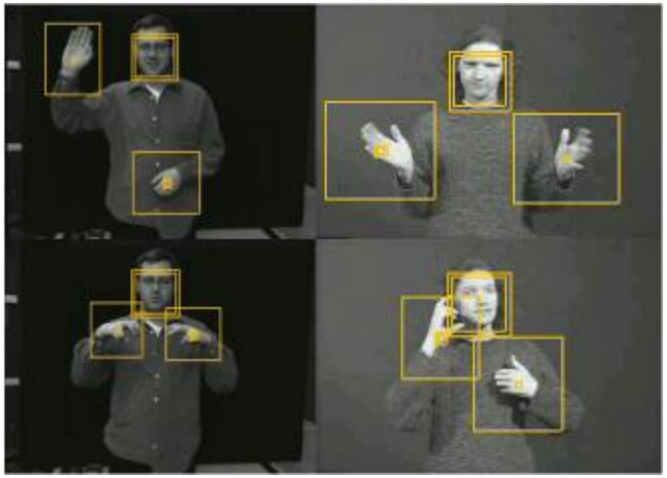
- Number plate recognition for speed cameras or automated toll systems
- Fingerprint recognition
- Enhancement of CCTV images

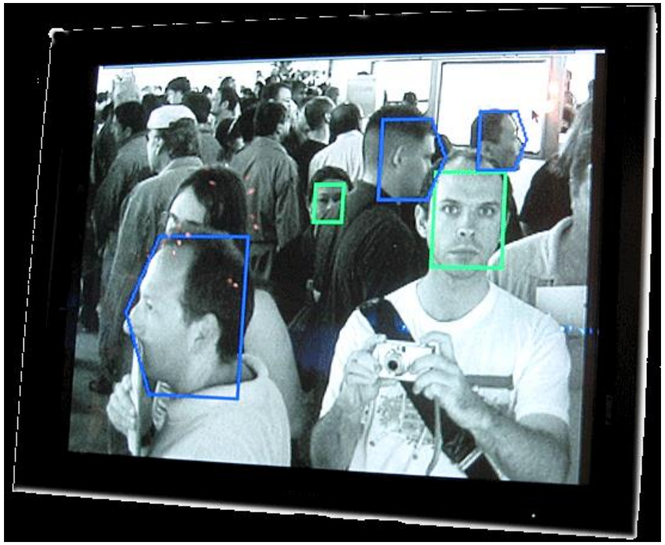


Examples: HCI

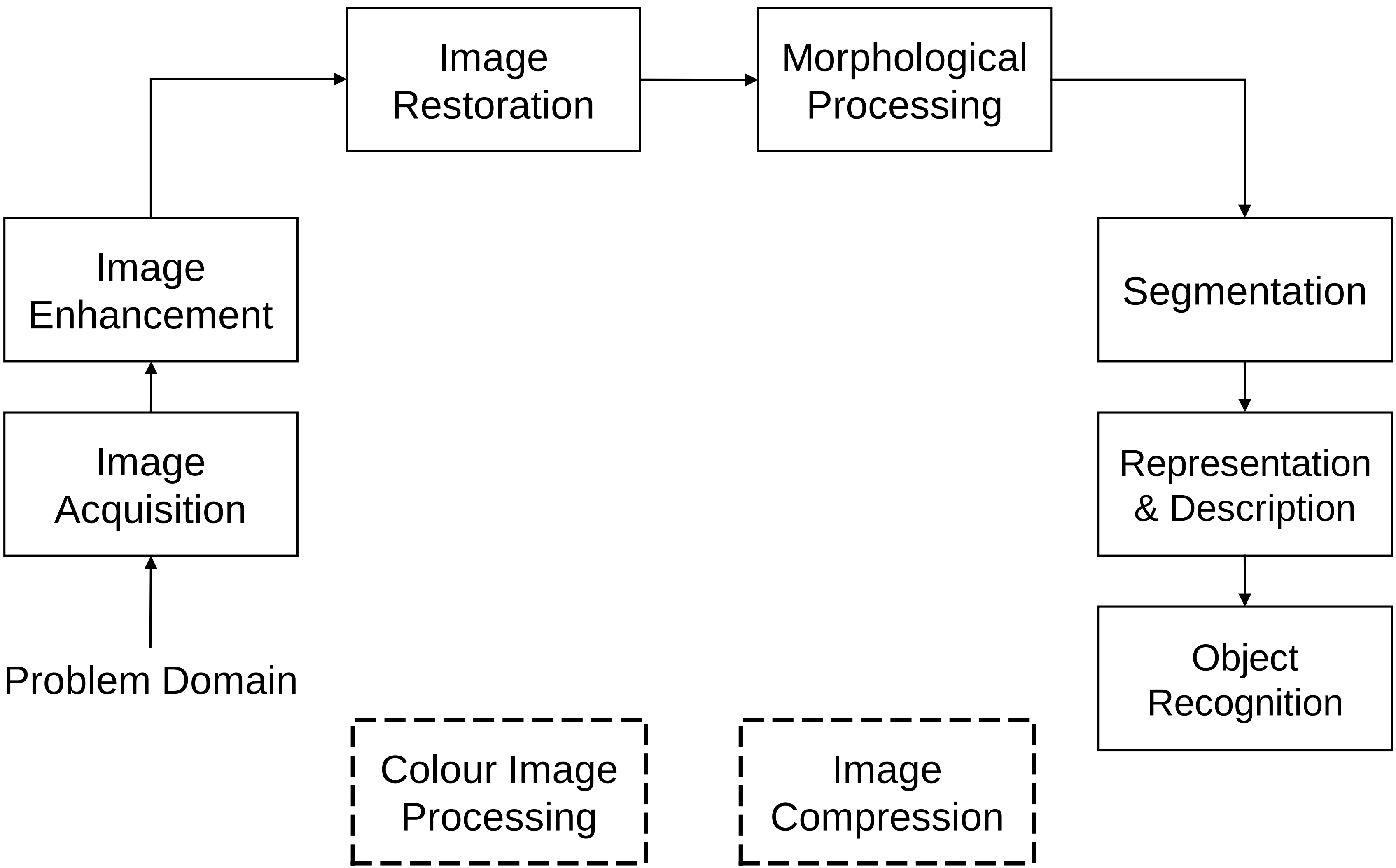
Try to make human computer interfaces more natural

- Face recognition
- Gesture recognition
- Handwriting recognition
- Optical character recognition (OCR)
- …

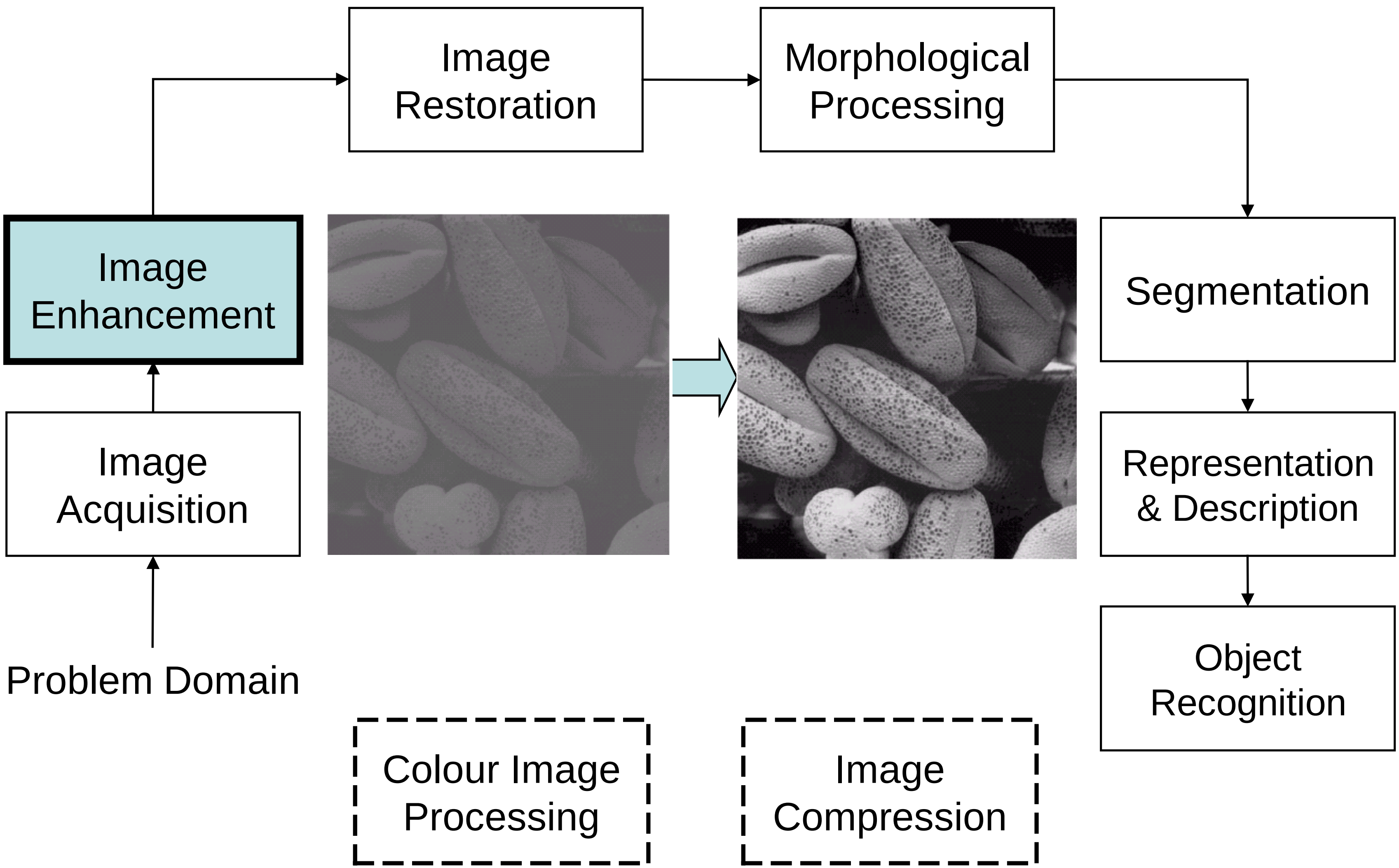




Phases of Digital Image Processing



Phases of Digital Image Processing : Image Enhancement



Phases of Digital Image Processing : Image Restoration

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

Image Restoration

Morphological Processing

Image Enhancement

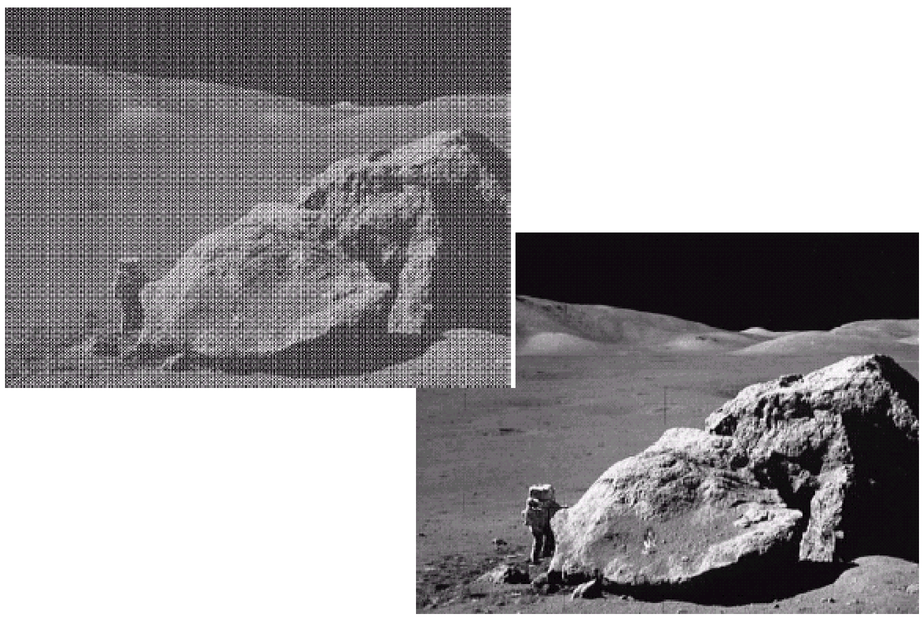
Segmentation

Image Acquisition

Representation & Description

Problem Domain

Object Recognition



Colour Image Processing

Image Compression

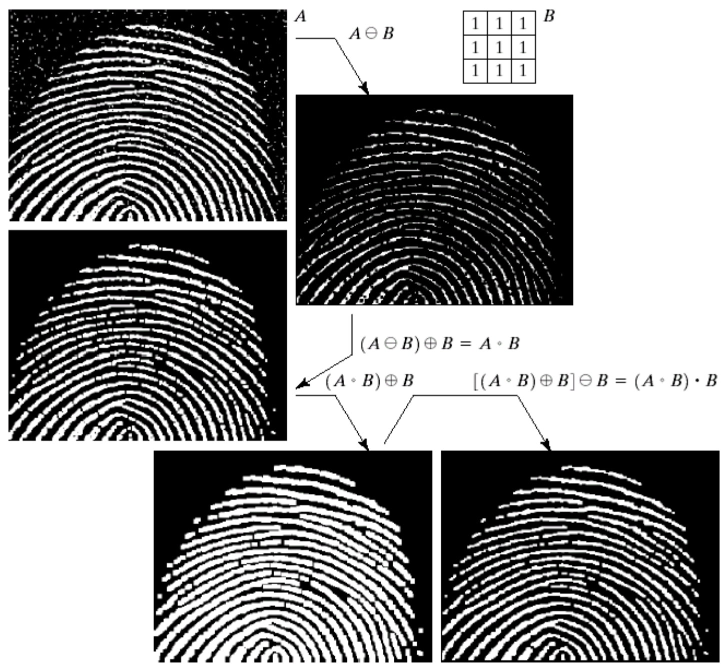
Phases of Digital Image Processing : Morphological Processing

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

Problem Domain → Image Acquisition → Image Enhancement → Image Restoration → **Morphological Processing** → Segmentation → Representation & Description → Object Recognition

Colour Image Processing

Image Compression



Phases of Digital Image Processing : Segmentation

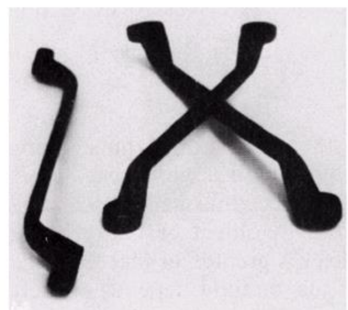
Image Enhancement

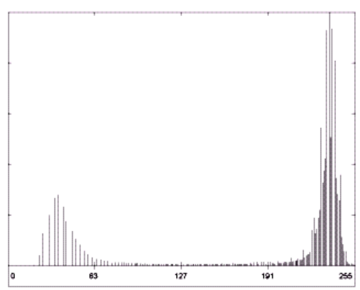
Image Acquisition

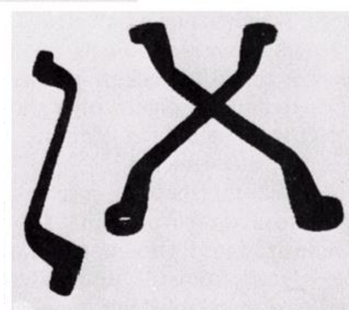
Problem Domain

Image Restoration

Morphological Processing







Colour Image Processing

Image Compression

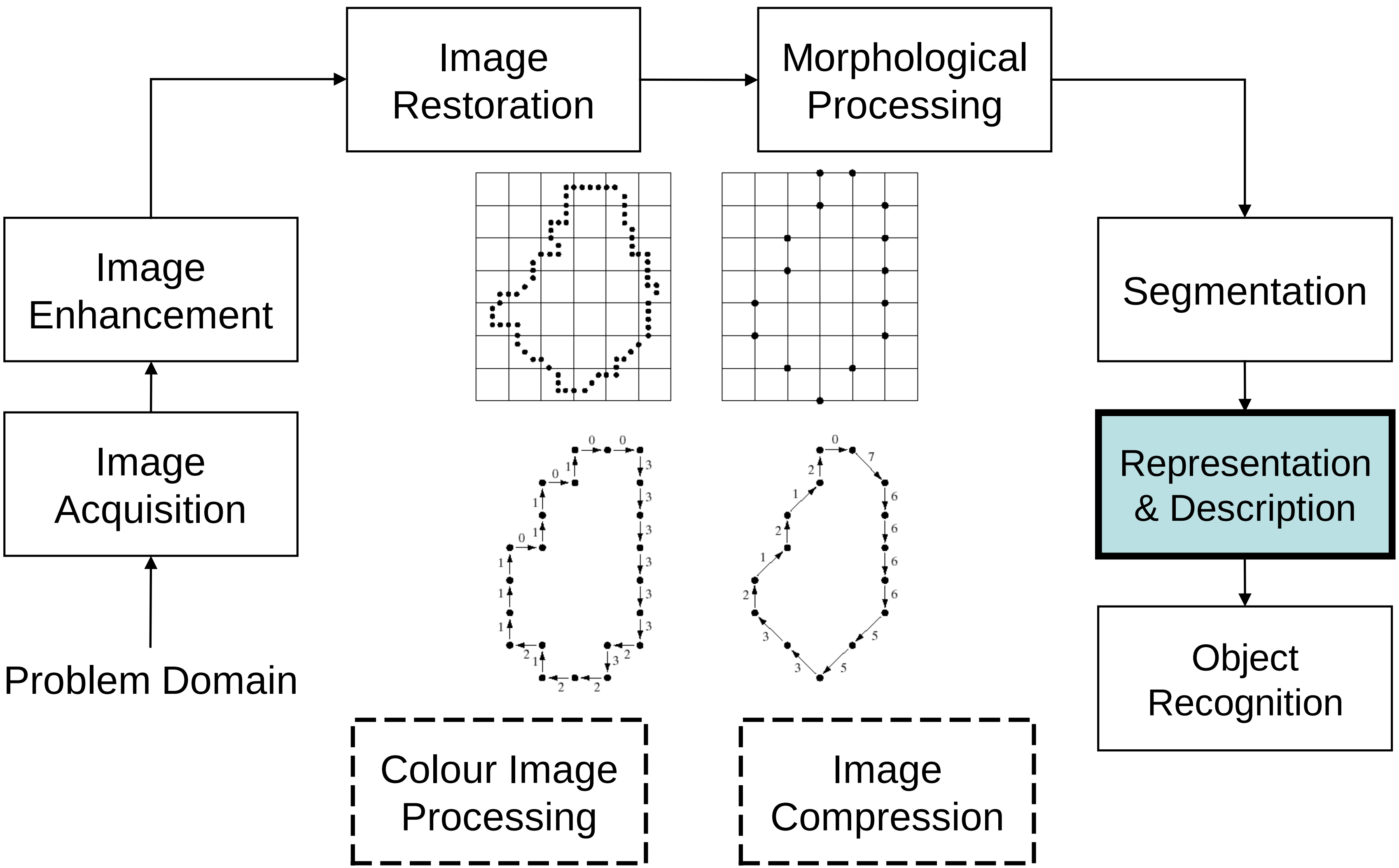
Segmentation

Representation & Description

Object Recognition

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

Phases of Digital Image Processing : Representation & Description



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

Phases of Digital Image Processing : Object Recognition

Problem Domain

Image Acquisition

Image Enhancement

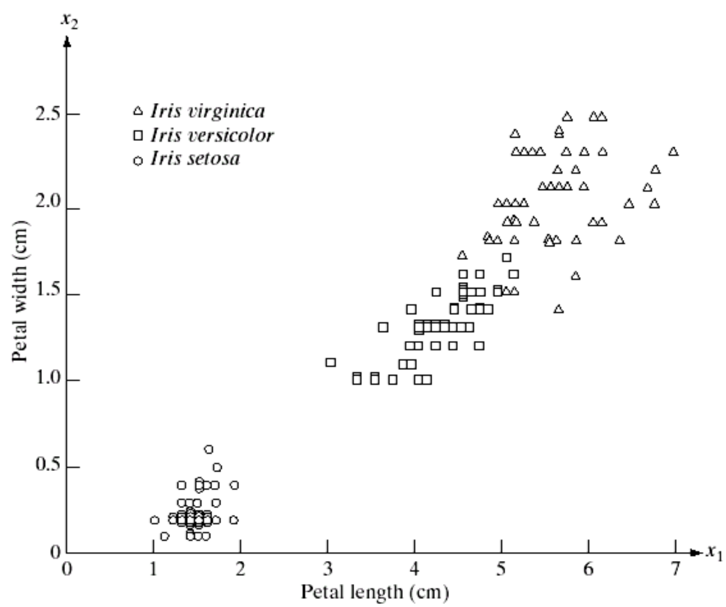
Image Restoration

Morphological Processing

Segmentation

Representation & Description

Object Recognition

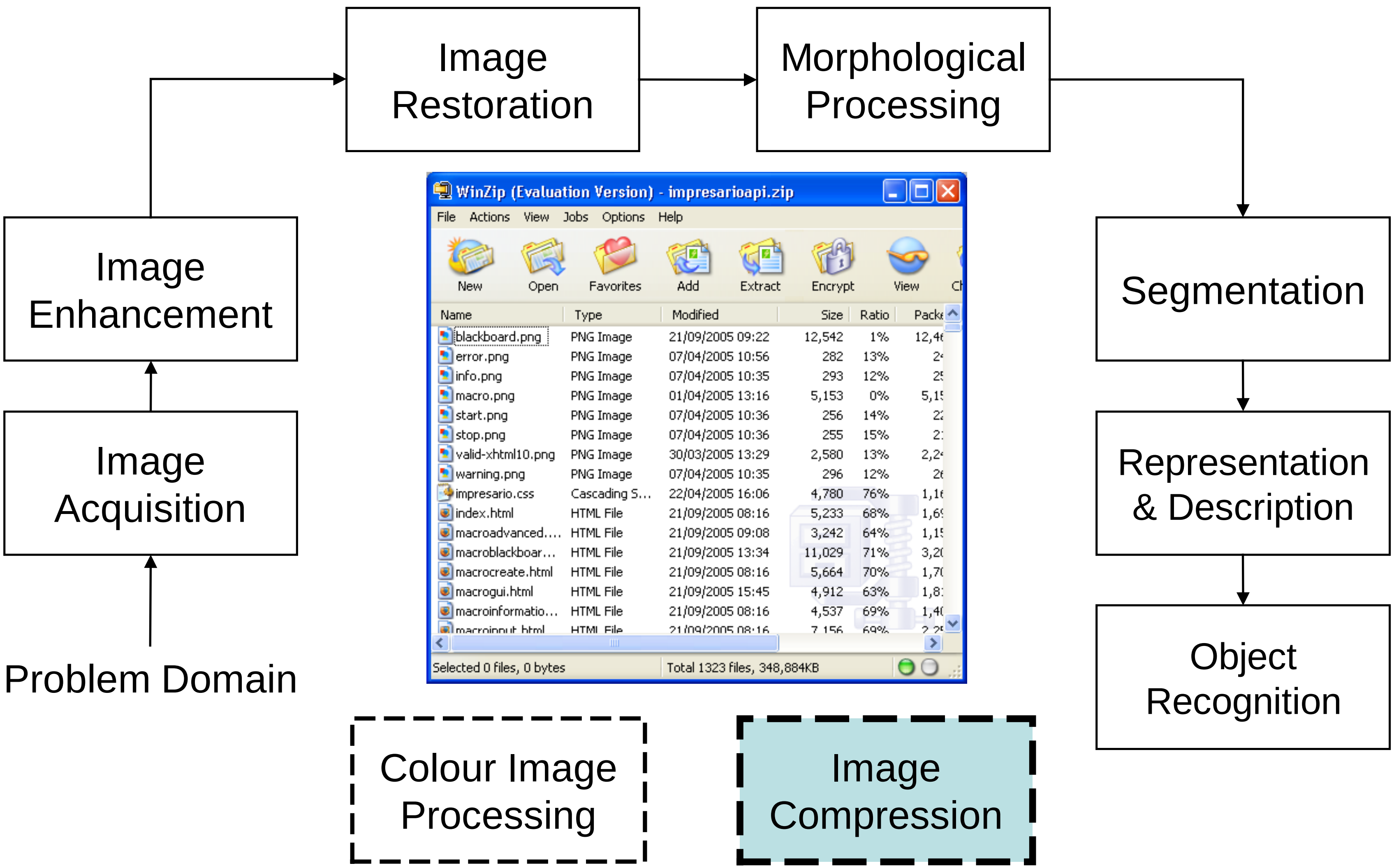


Colour Image Processing

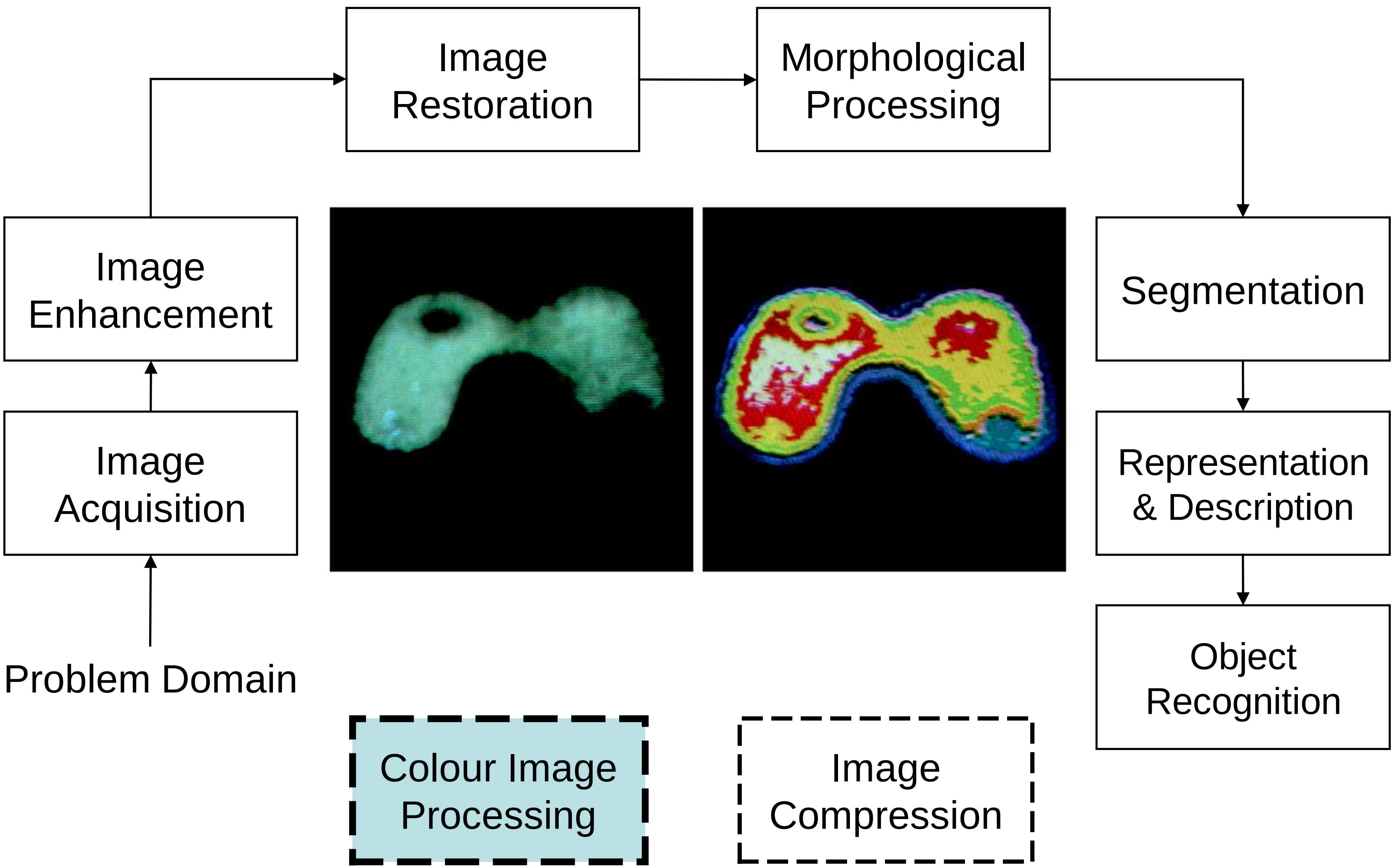
Image Compression

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

Phases of Digital Image Processing : Image Compression



Phases of Digital Image Processing : Colour Image Processing



Human Visual System

The best vision model we have!

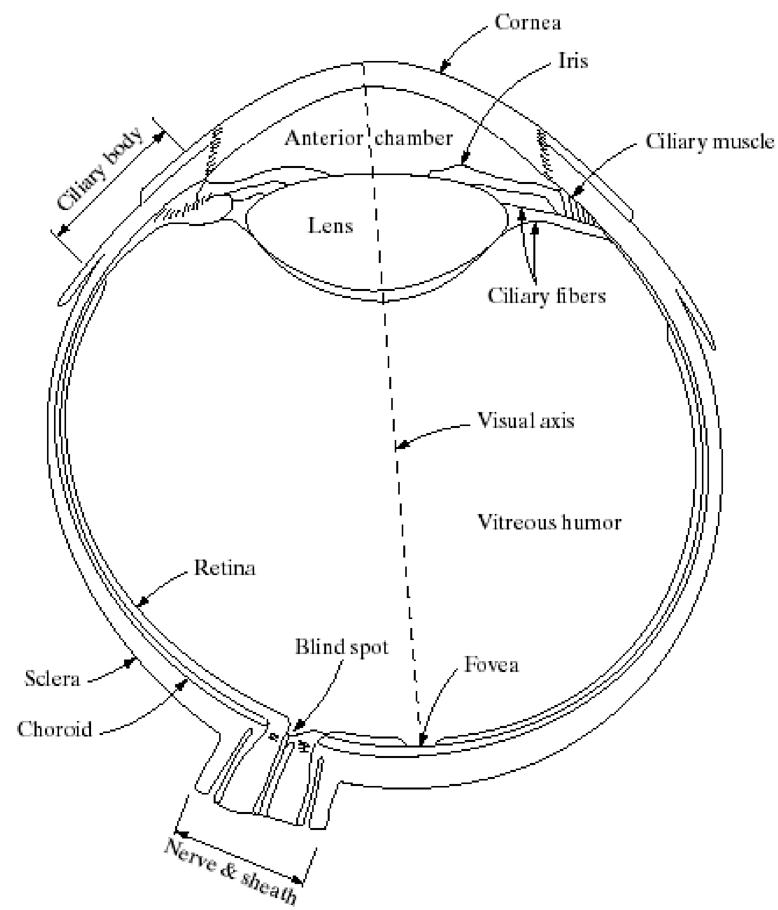
Knowledge of how images form in the eye can help us with processing digital images.

We will take just a rapid tour of the human visual system.

Structure of The Human Eye

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

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).

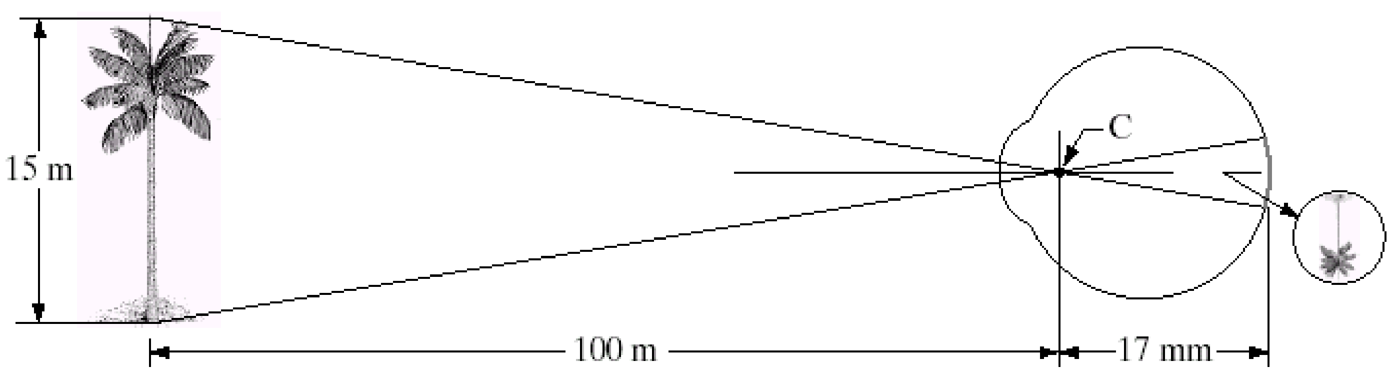
Cones are concentrated around the fovea and are very sensitive to colour.

Rods are more spread out and are sensitive to low levels of illumination.

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.



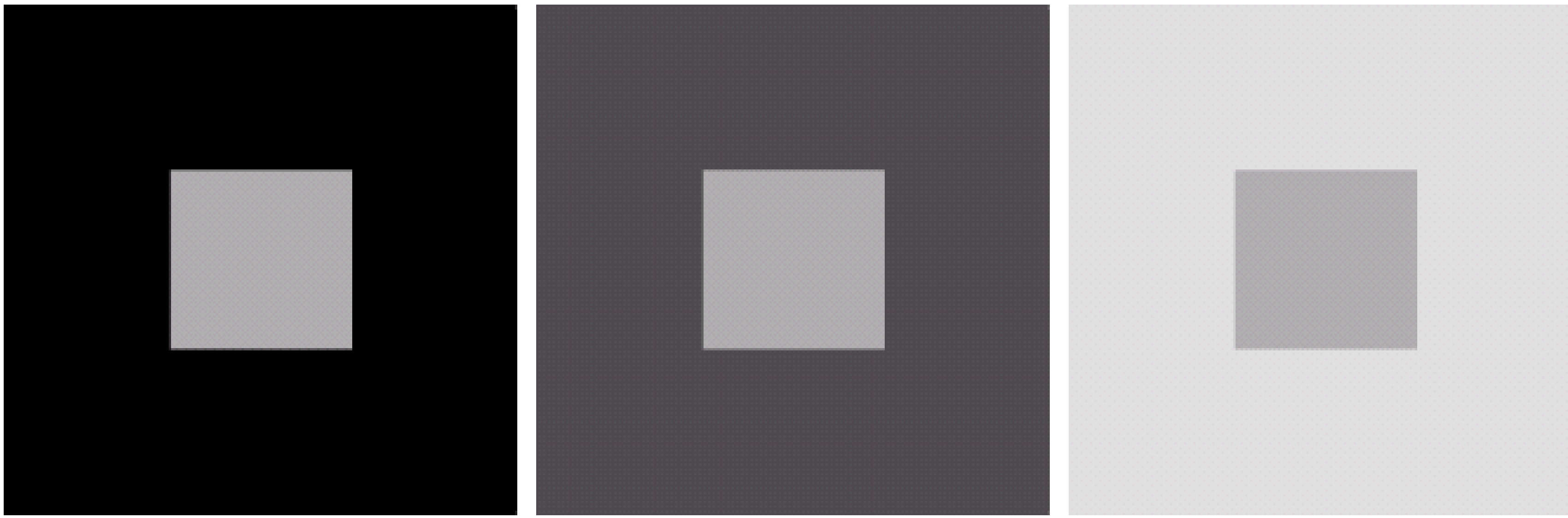
Brightness Adaptation & Discrimination

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



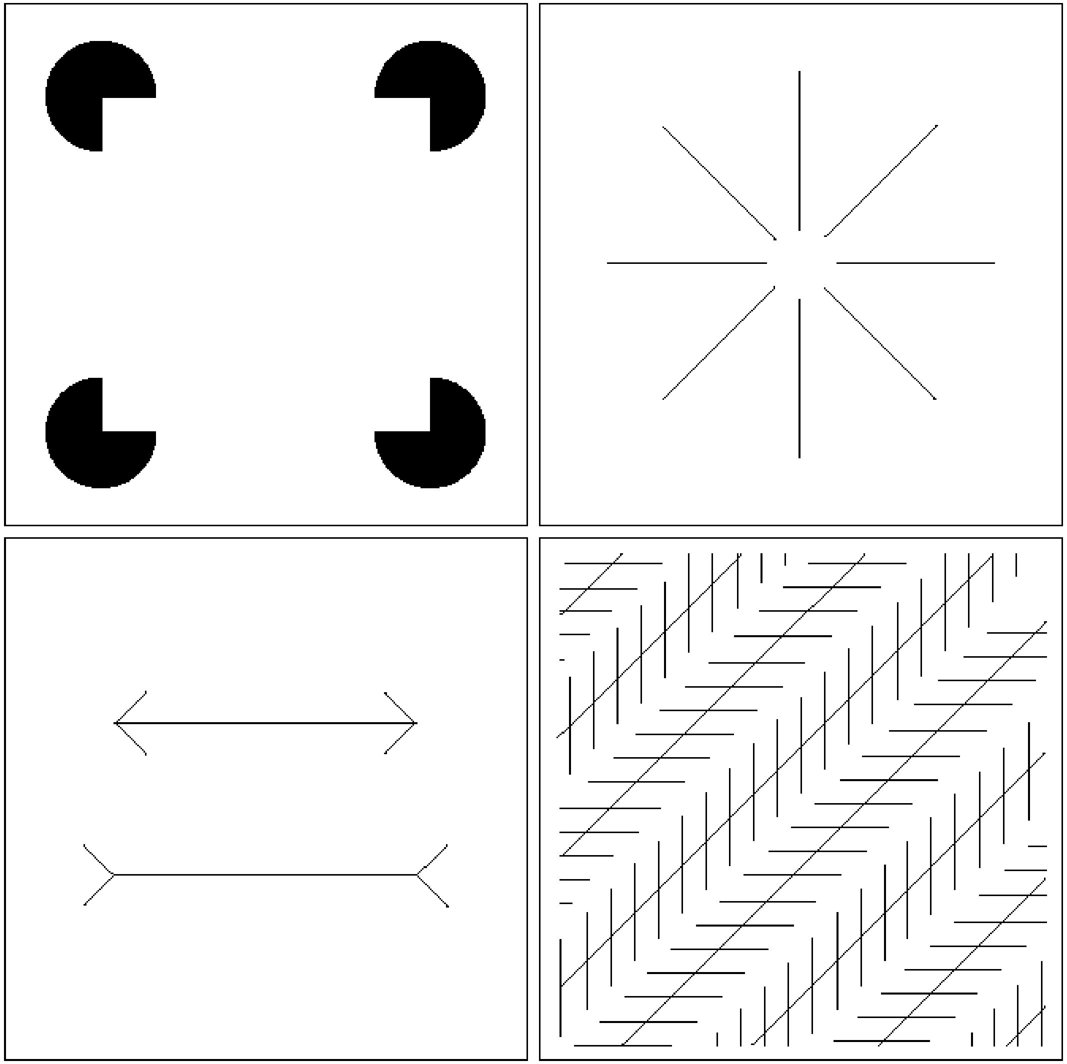
An example of *simultaneous contrast*

All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

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

Optical Illusions

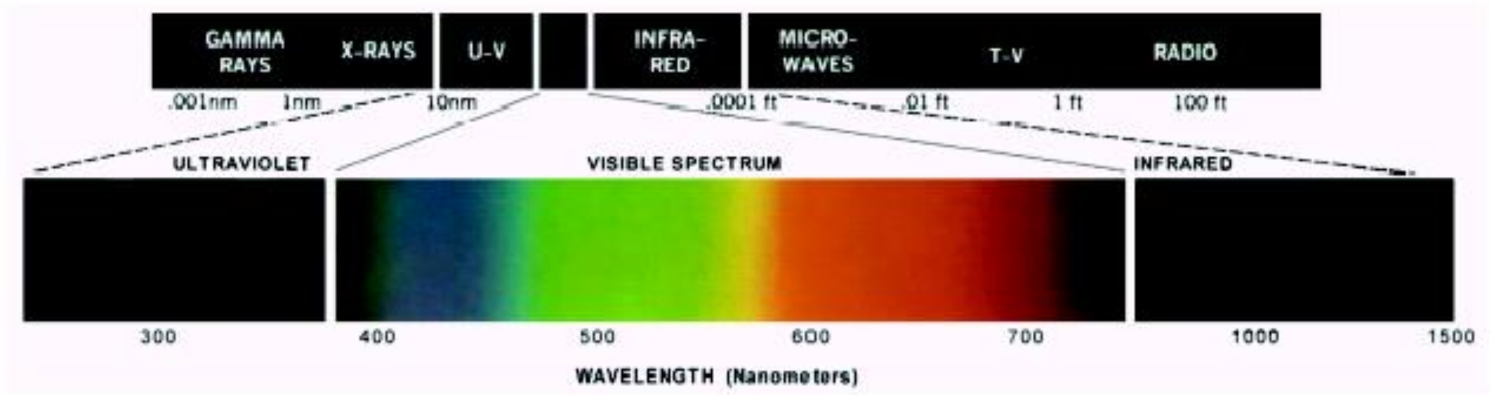
Our visual systems play lots of interesting tricks on us.



Light and 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.



Light and Electromagnetic Spectrum

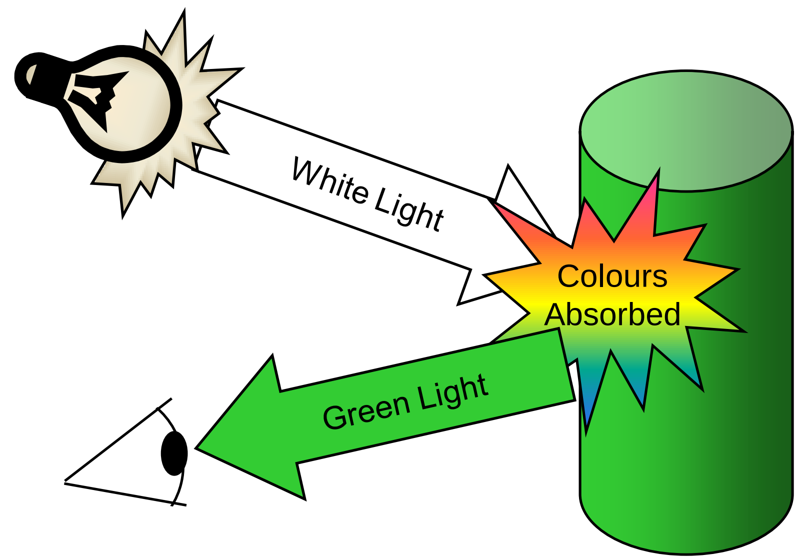
In 1666, Sir Isaac Newton discovered that light passed through a prism splits into a continuous spectrum of colours.

Many image applications use electromagnetic radiation that is far outside the visual spectrum – x-ray images, infra-red images. We generate images of these images by mapping them to the visual 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

We consider what is involved in capturing a digital image of a real-world scene.

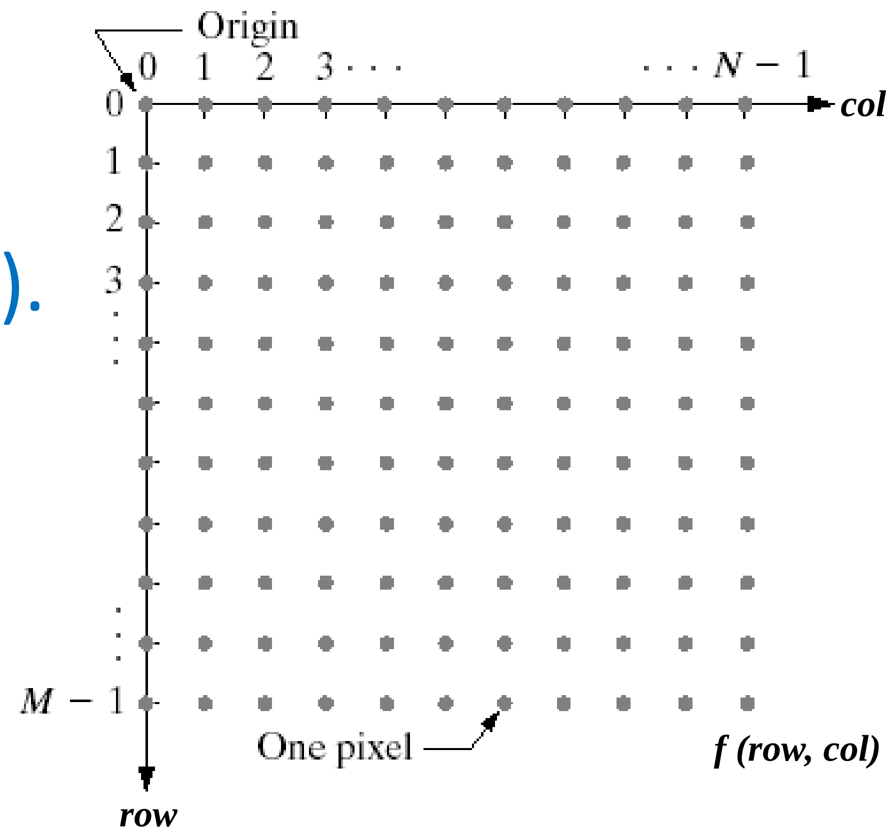
- ✓ Image Sensing and Representation
- ✓ Sampling and Quantisation
- ✓ Resolution

Image Representation

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).

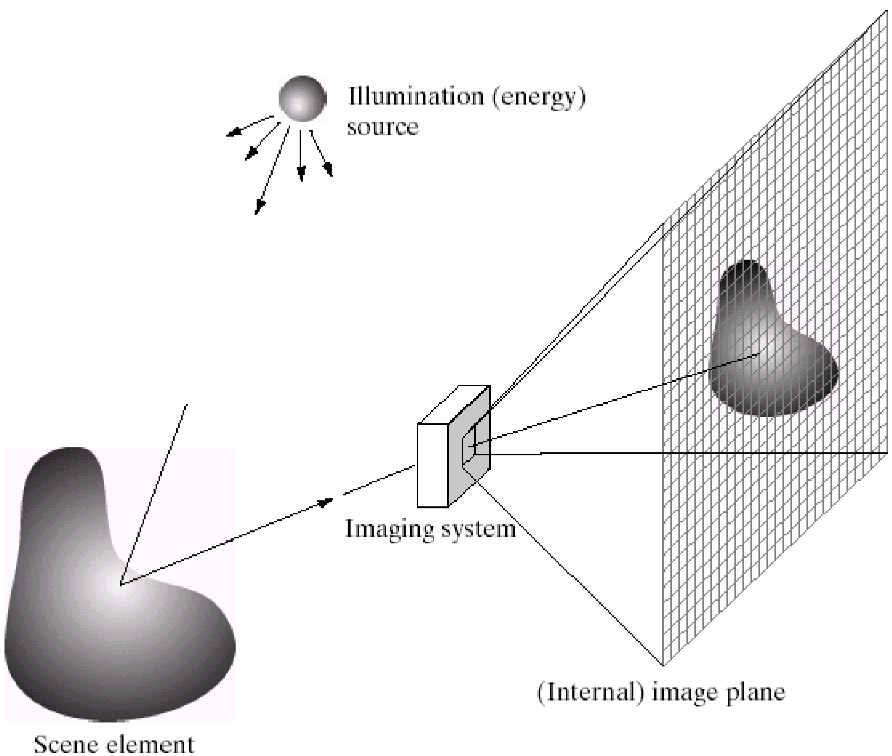
Images can easily be represented as matrices.



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.

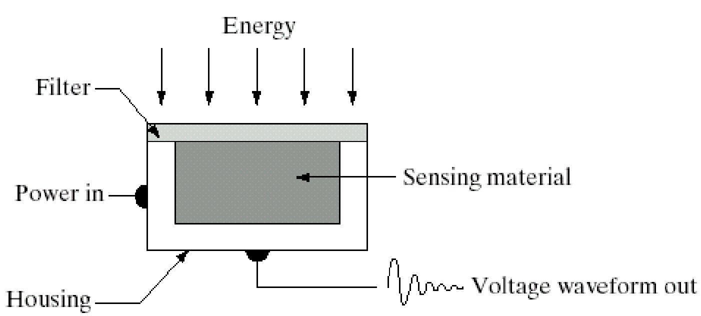


- Typical notions of illumination and scene can be way off:
  - X-rays of a skeleton
  - Ultrasound of an unborn baby
  - Electro-microscopic images of molecules

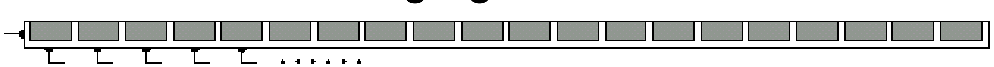
Image Sensing

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

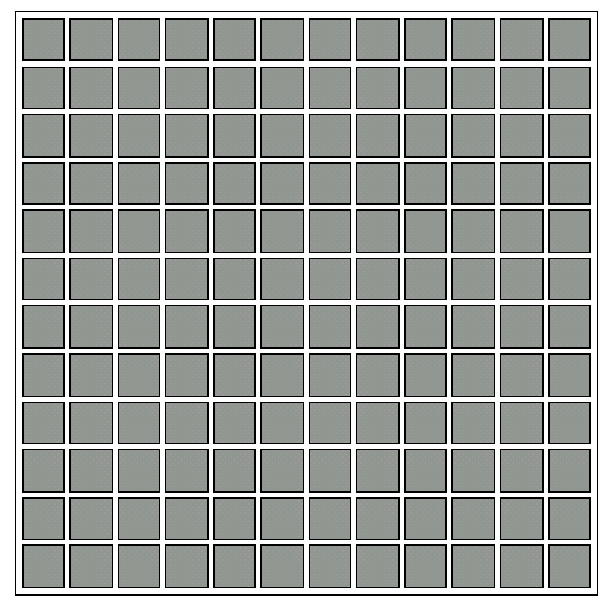
Collections of sensors are arranged to capture images.



Imaging Sensor



Line of Image Sensors



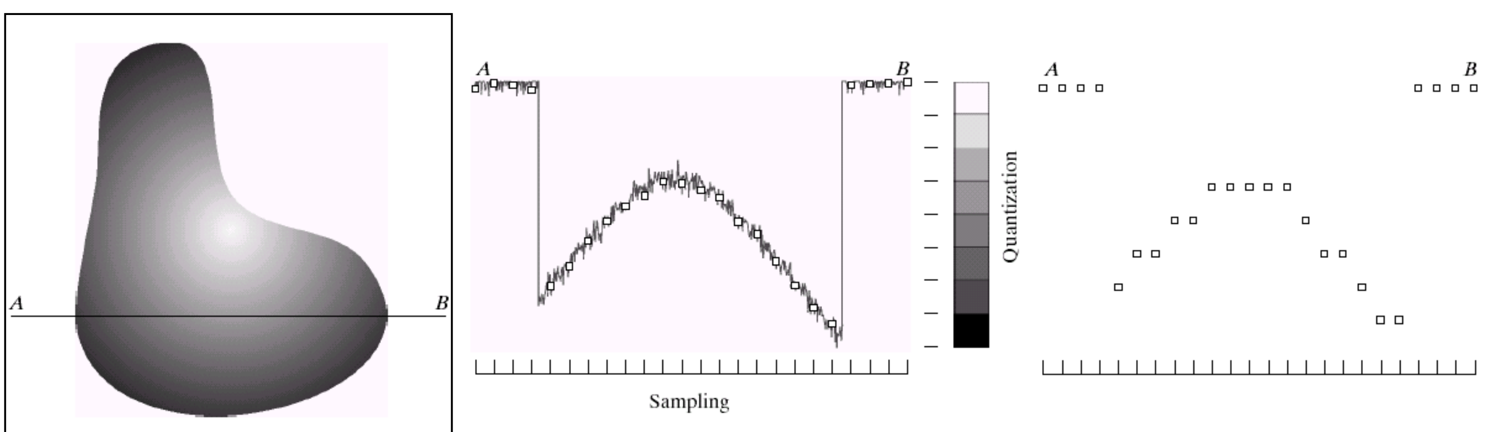
Array of Image Sensors

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

Image Sampling and Quantisation

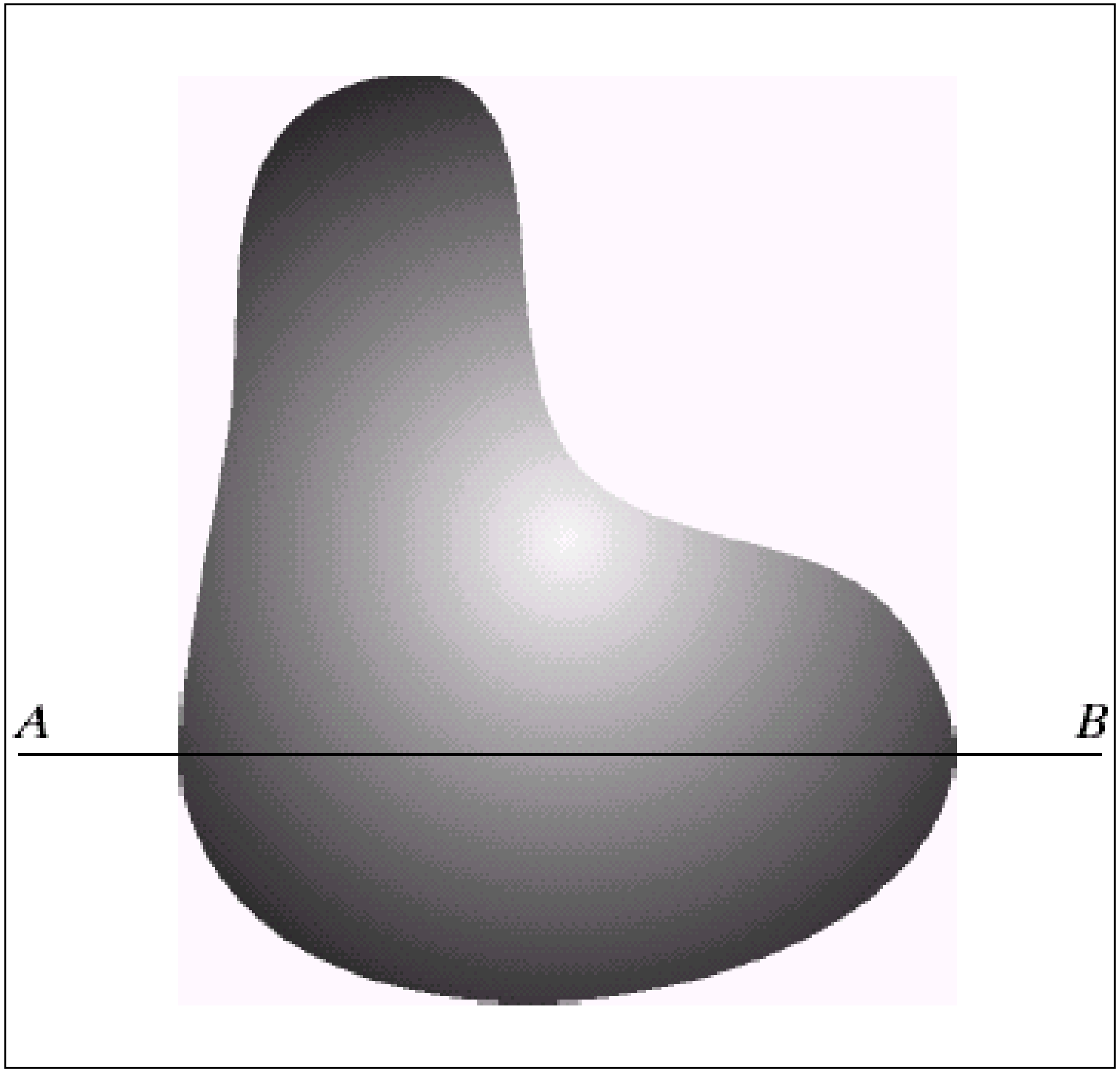
A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels.

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



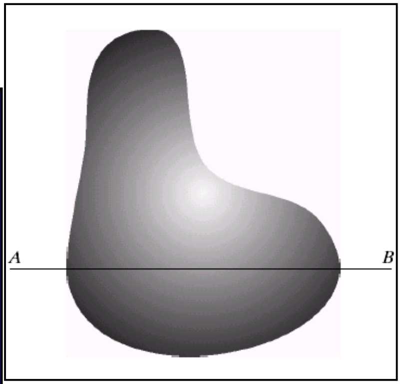
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

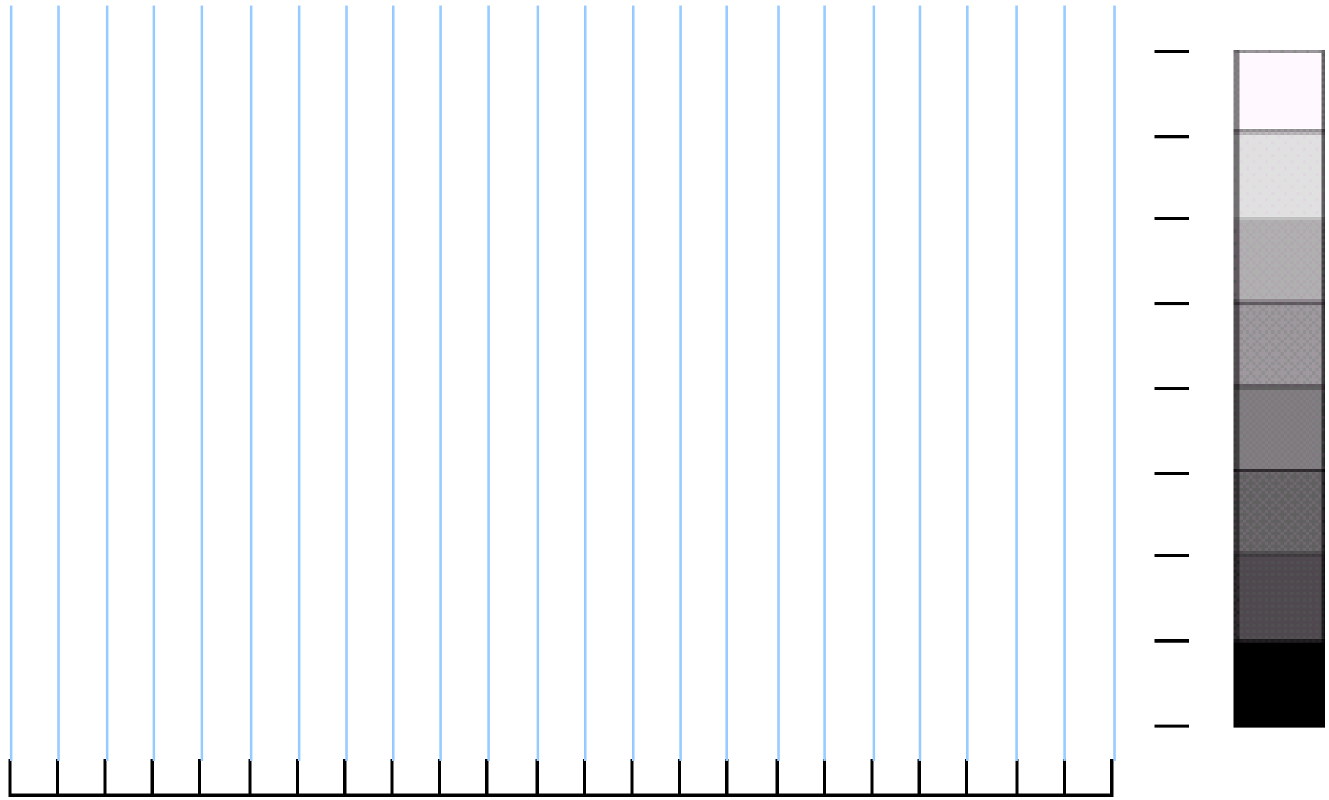
Image Sampling and Quantisation



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

Image Sampling and Quantisation





Sampling

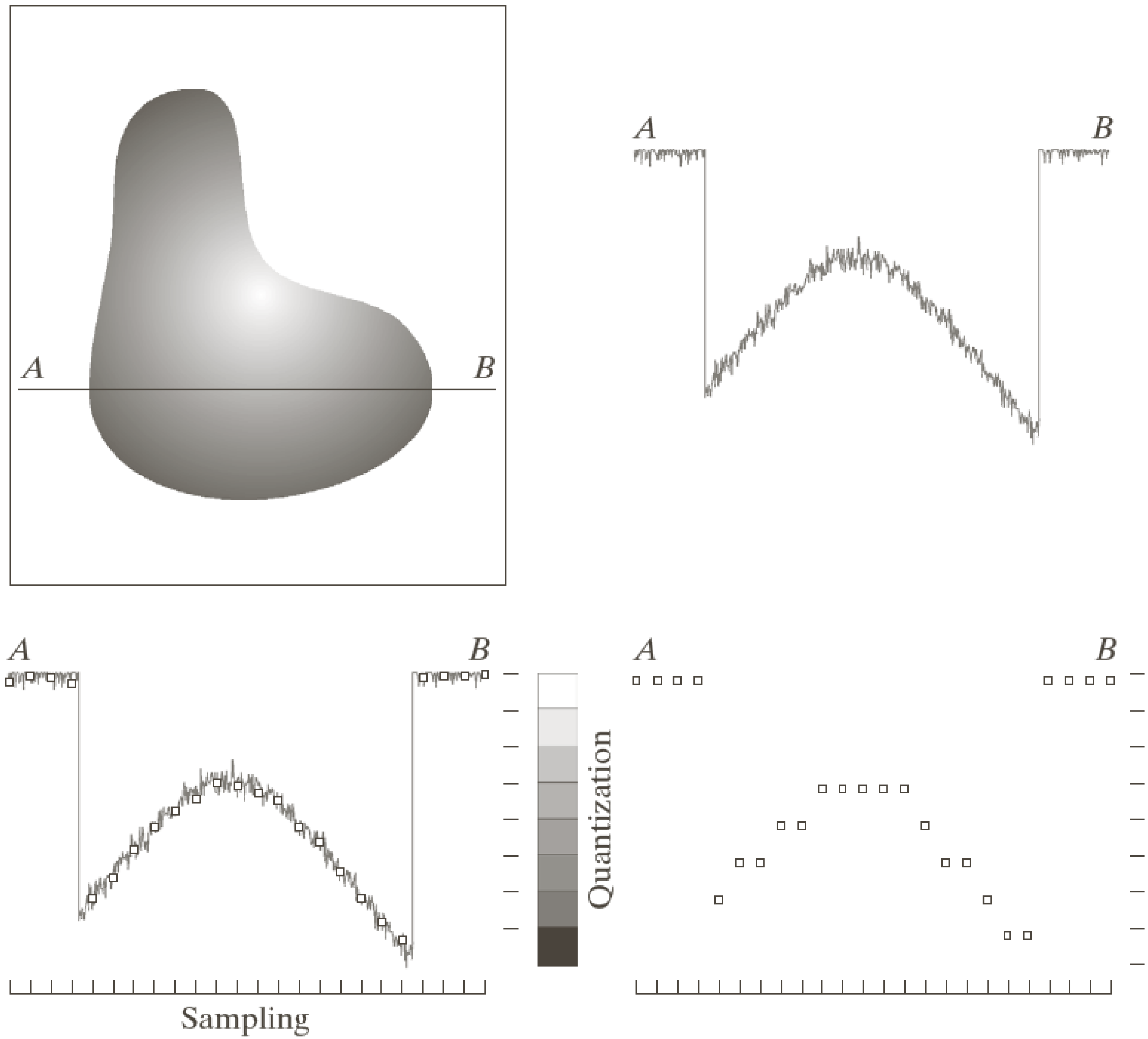

A
B
A
B
A
B
Quantization
Sampling
A
B

Image Sampling and Quantisation

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

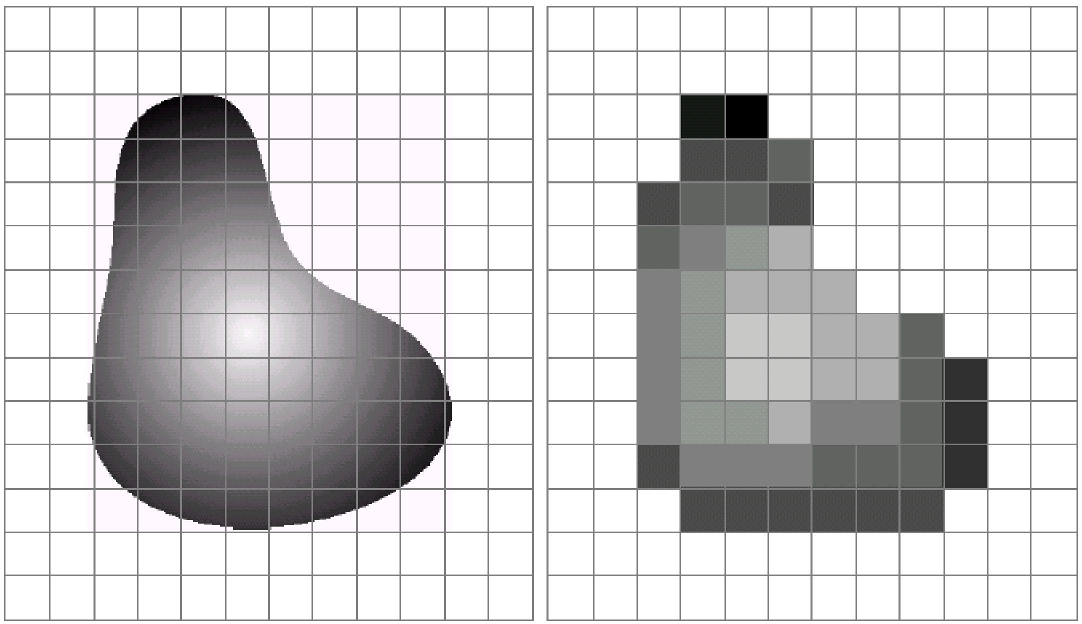
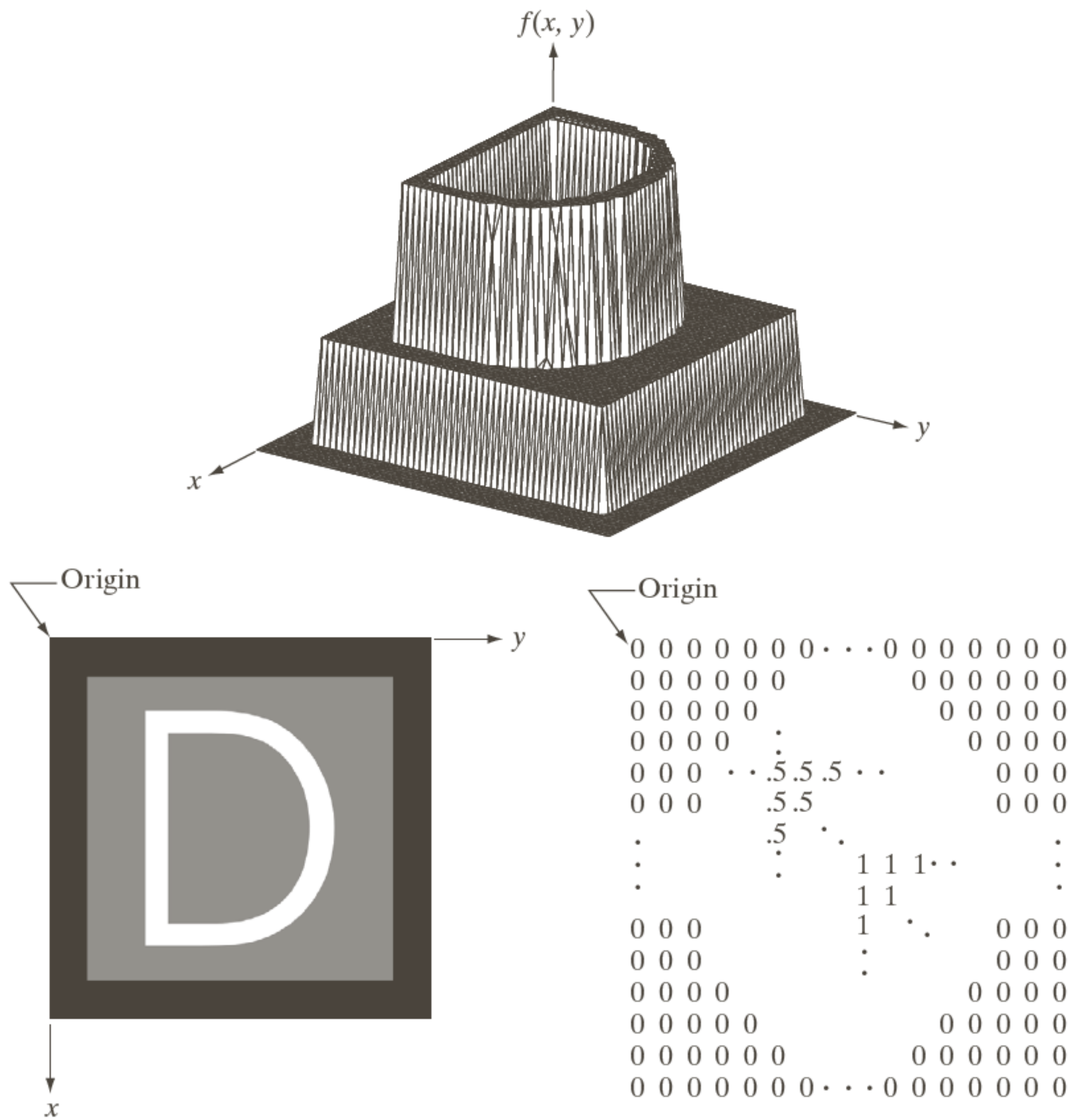
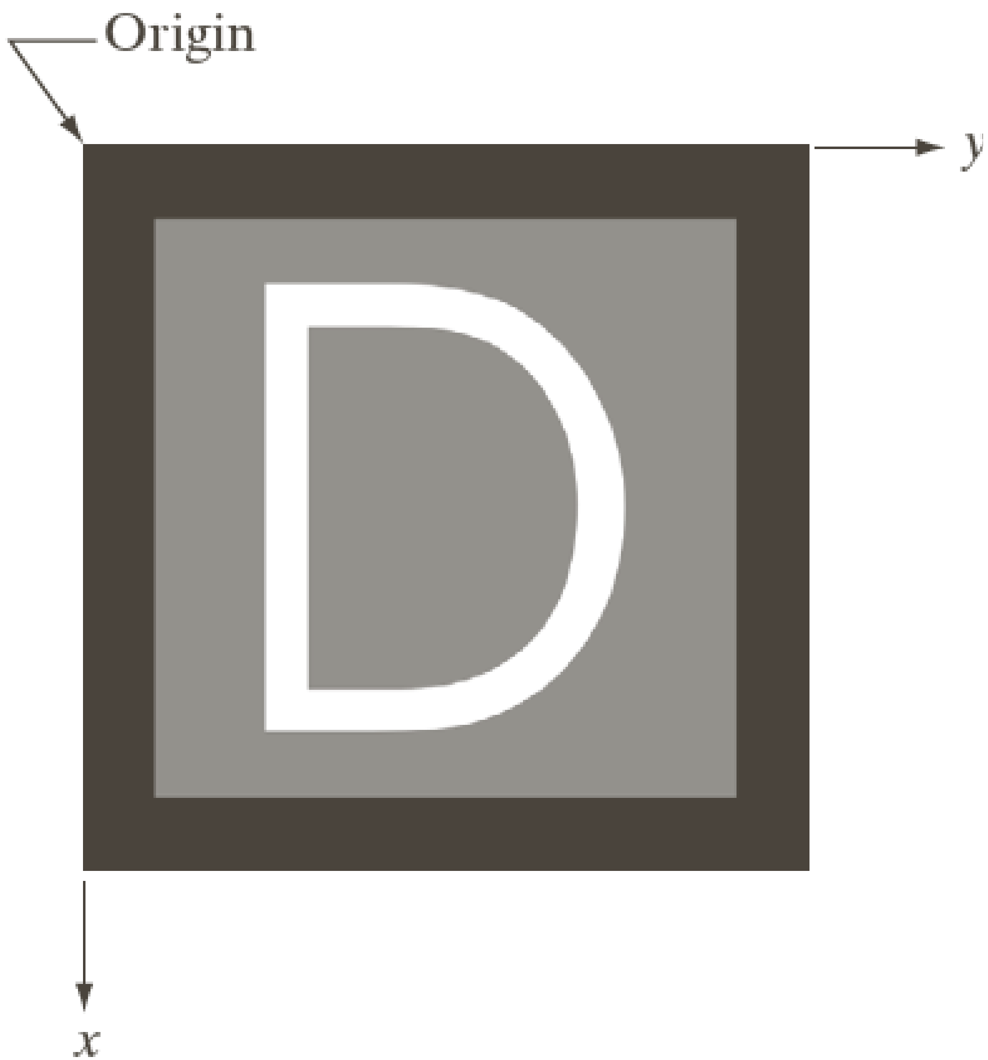


Image Representation



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

Image Representation



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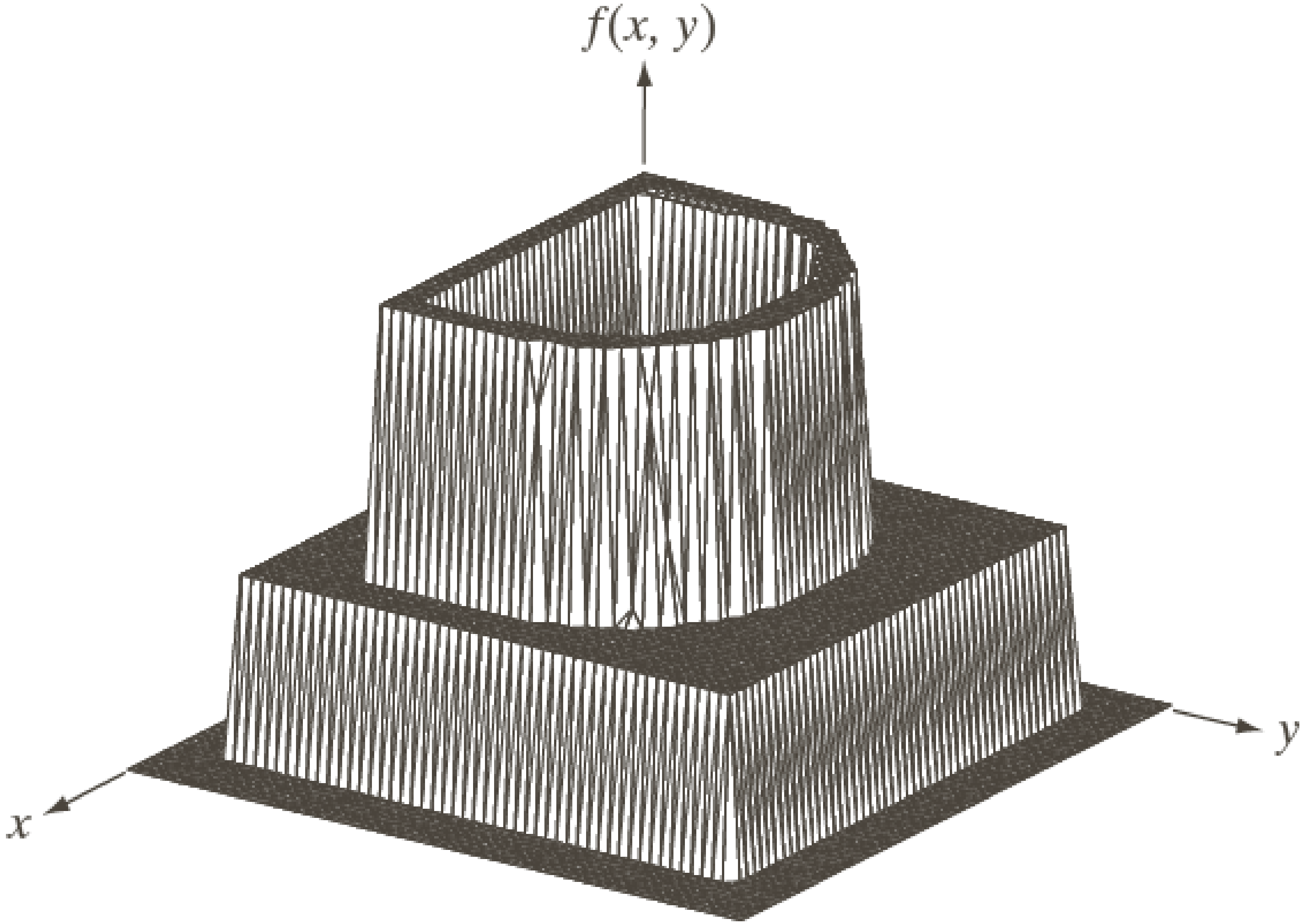

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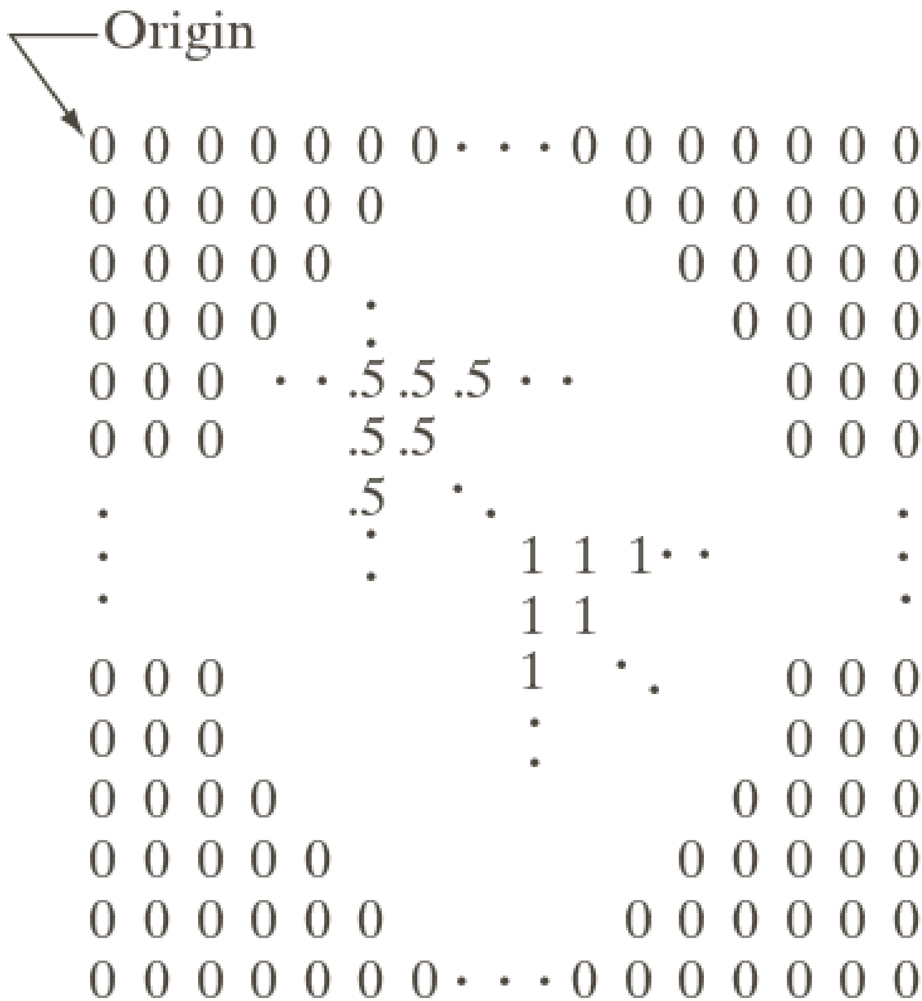


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Spatial Resolution

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

Spatial resolution simply refers to the smallest discernible detail in an image.

- Vision specialists will often talk about pixel size.
- Graphic designers will talk about *dots per inch* (DPI).

Spatial Resolution

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

512×512 image is generated by deleting every other row and column from the 1024×1024 image.

The original image is of size 1024×1024.

Other images are the results of subsampling the 1024×1024 image.

Subsampling is done by deleting appropriate number of rows and colouns from the original image.

Spatial Resolution

1024×1024

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

Spatial Resolution

Virtually impossible to point out difference comparing with previous image.

512×512

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

Spatial Resolution

<u>Very slight</u> fine checkerboard patterns in the border between flower petals and the black background.

256×256

Spatial Resolution

Checkerboard patterns are increasing in the border between flower petals and the black background.

128×128

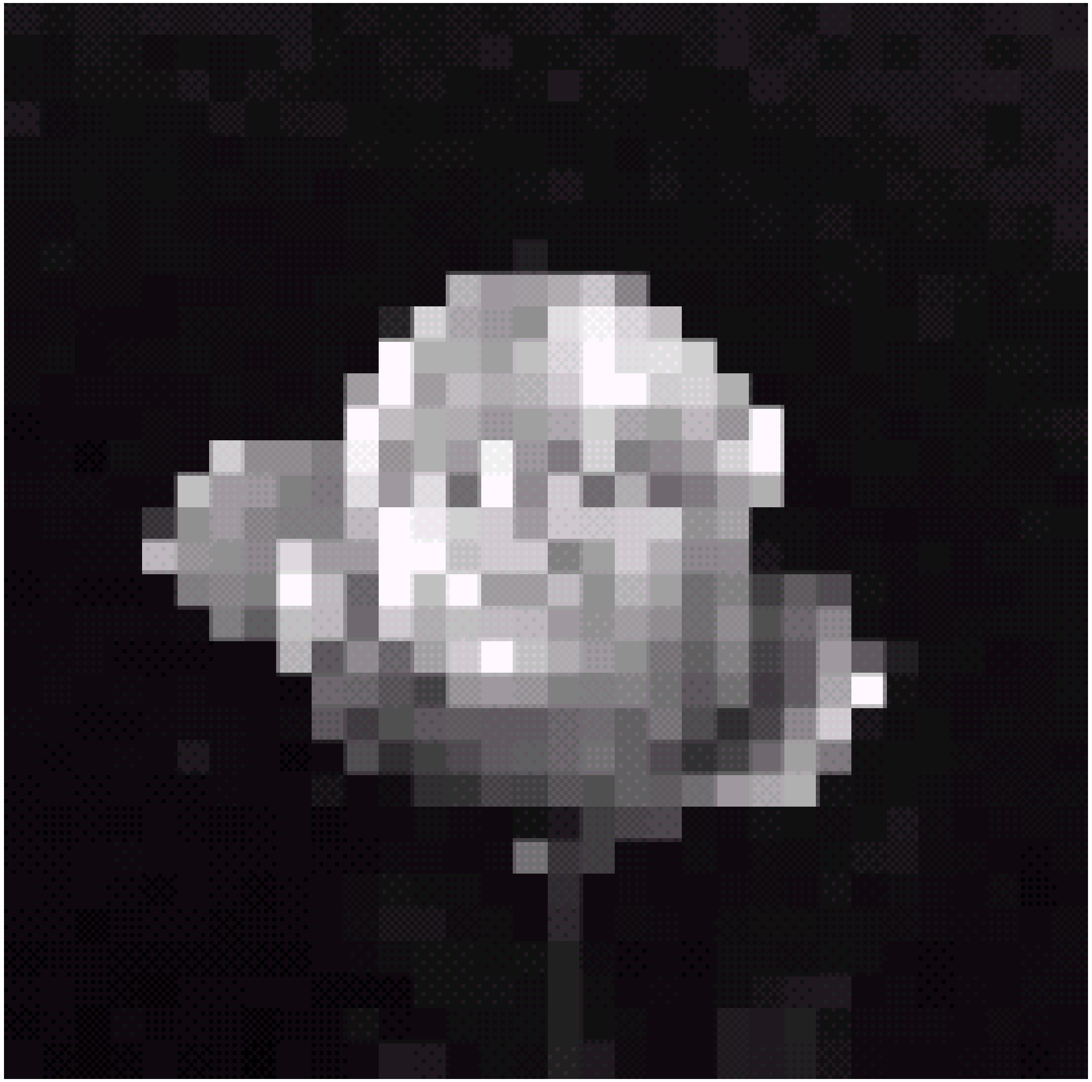
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Spatial Resolution

Prominent checkerboard patterns in the border between flower petals and the black background.

64 × 64

Spatial Resolution



Very prominent checkerboard patterns in the border between flower petals and the black background.

32×32

Intensity Level Resolution

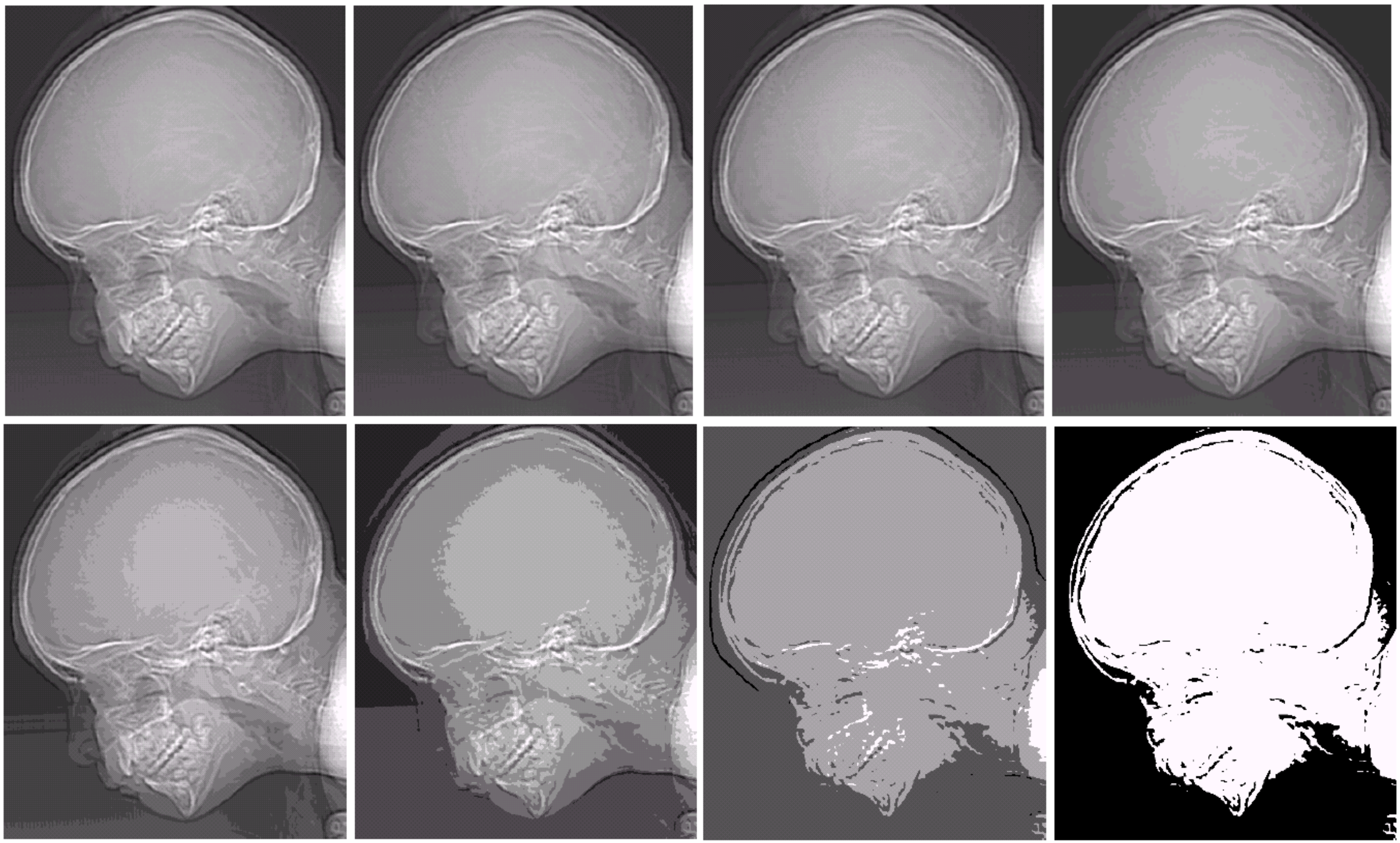
Intensity level resolution refers to the number of intensity levels used to represent the image.

- 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

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)

Intensity Level Resolution

Spatial resolution 452×374 is fixed for all the images.

8 bpp

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

Intensity Level Resolution

Virtually identical with previous image.

7 bpp

Intensity Level Resolution

Virtually identical with previous image.

6 bpp

Intensity Level Resolution

Suffering by false contouring effect.

This effect is caused by the use of an insufficient number of grey levels in smooth areas of a digital image (particularly in the skull).

5 bpp

Intensity Level Resolution

Suffering by false contouring effect.

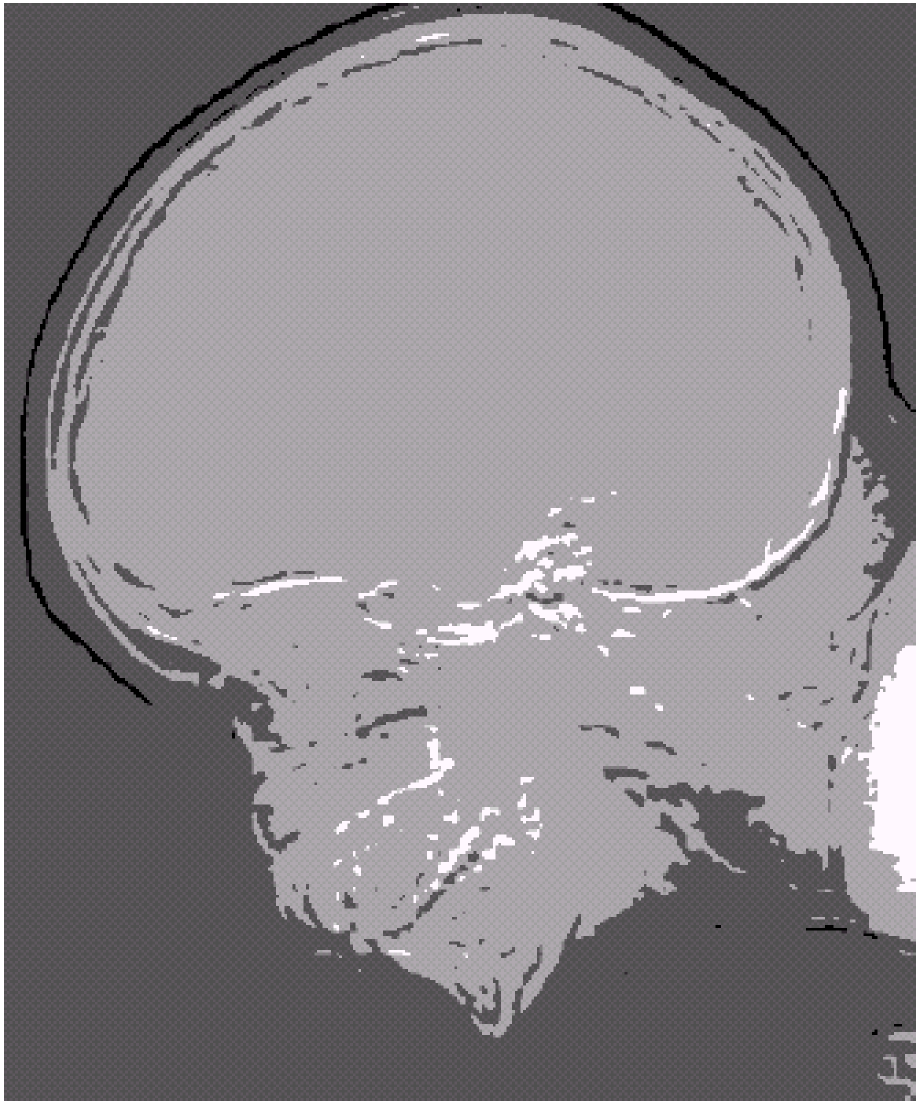
4 bpp

Intensity Level Resolution

Suffering by false contouring effect.

3 bpp

Intensity Level Resolution



Suffering by false contouring effect.

2 bpp

Intensity Level Resolution

Suffering by false contouring effect.

1 bpp

As a very rough rule of thumb, and assuming powers of 2 for convenience, images of size 256×256 pixels and 64 gray levels are about the smallest images, that can be expected to be reasonably free of objectionable sampling checker boards and false contouring.

Resolution: How Much is Enough?

The big question with resolution is always *how much is enough*?

- This depends on what is in the image and what you would like to do with it.

- Key questions include
  - 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.

Effect of Spatial and Intensity Level Resolutions Simultaneously

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

Image with a low level of detail

Image with a medium level of detail

Image with a relatively high level of detail

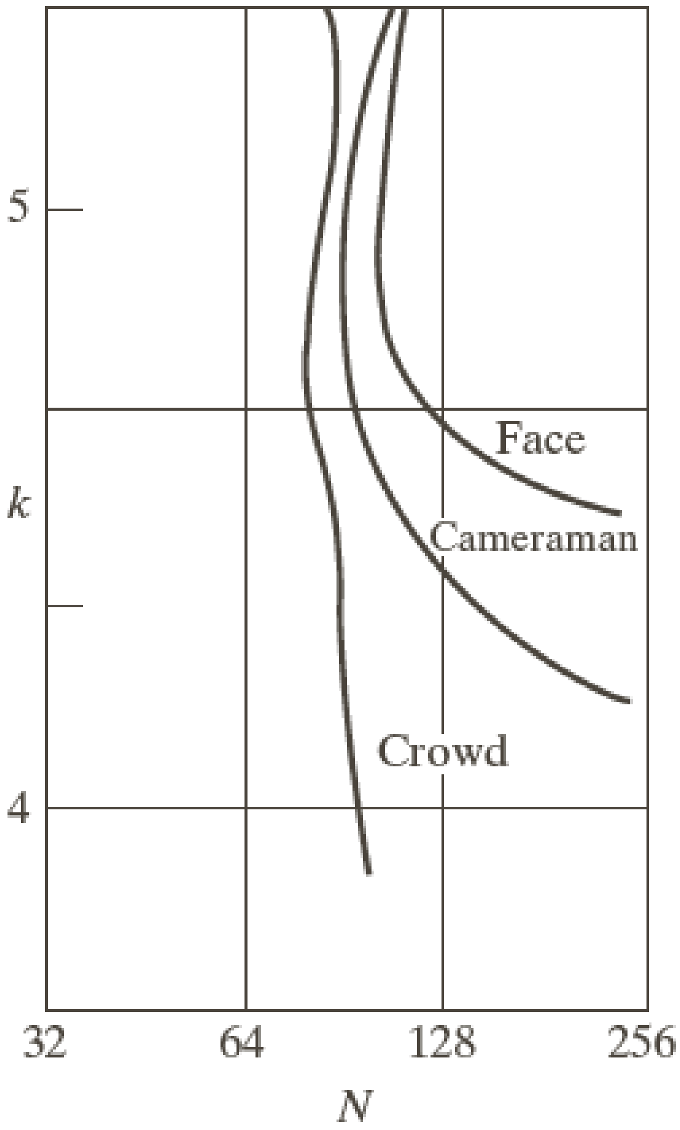
These three types of images were generated by varying spatial and intensity level resolutions.

Observers were then asked to rank them according to their subjective quality.

Effect of Spatial and Intensity Level Resolutions Simultaneously

Effect of Spatial and Intensity Level Resolutions Simultaneously

Effect of Spatial and Intensity Level Resolutions Simultaneously



Isopreference curves

The curve corresponding to the crowd is nearly vertical.

It indicates that for a fixed value of N, the perceived quality for this type of image is nearly independent of k.

The perceived quality in the other two image categories remained the same in some intervals in which the spatial resolution was increased, but the number of gray levels actually decreased.

The reason is that a decrease in k tends to increase the apparent contrast of an image, a visual effect that humans often perceive as improved quality in an image.