IE404

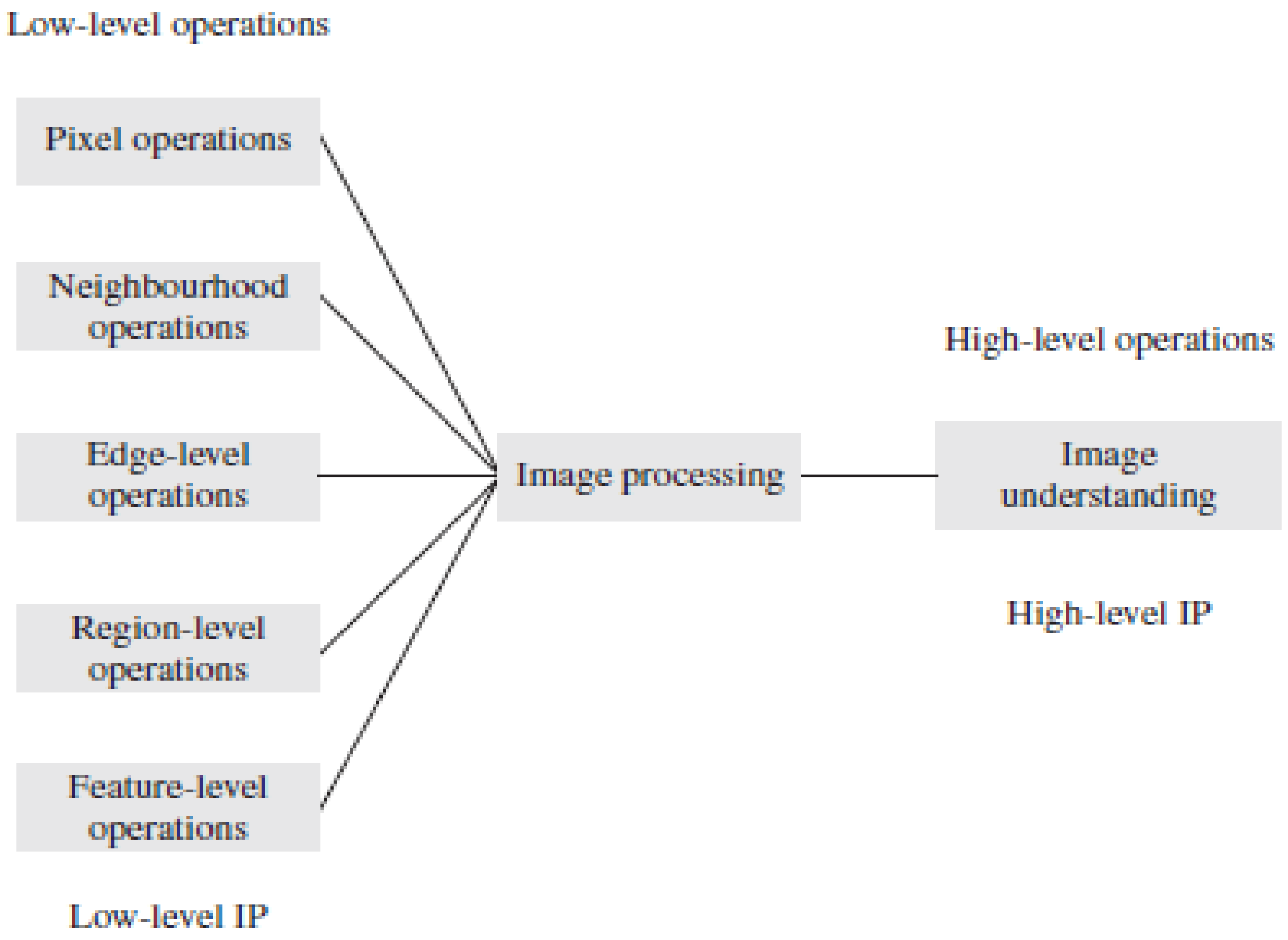
Digital Image Processing

Instructor: Manish Khare

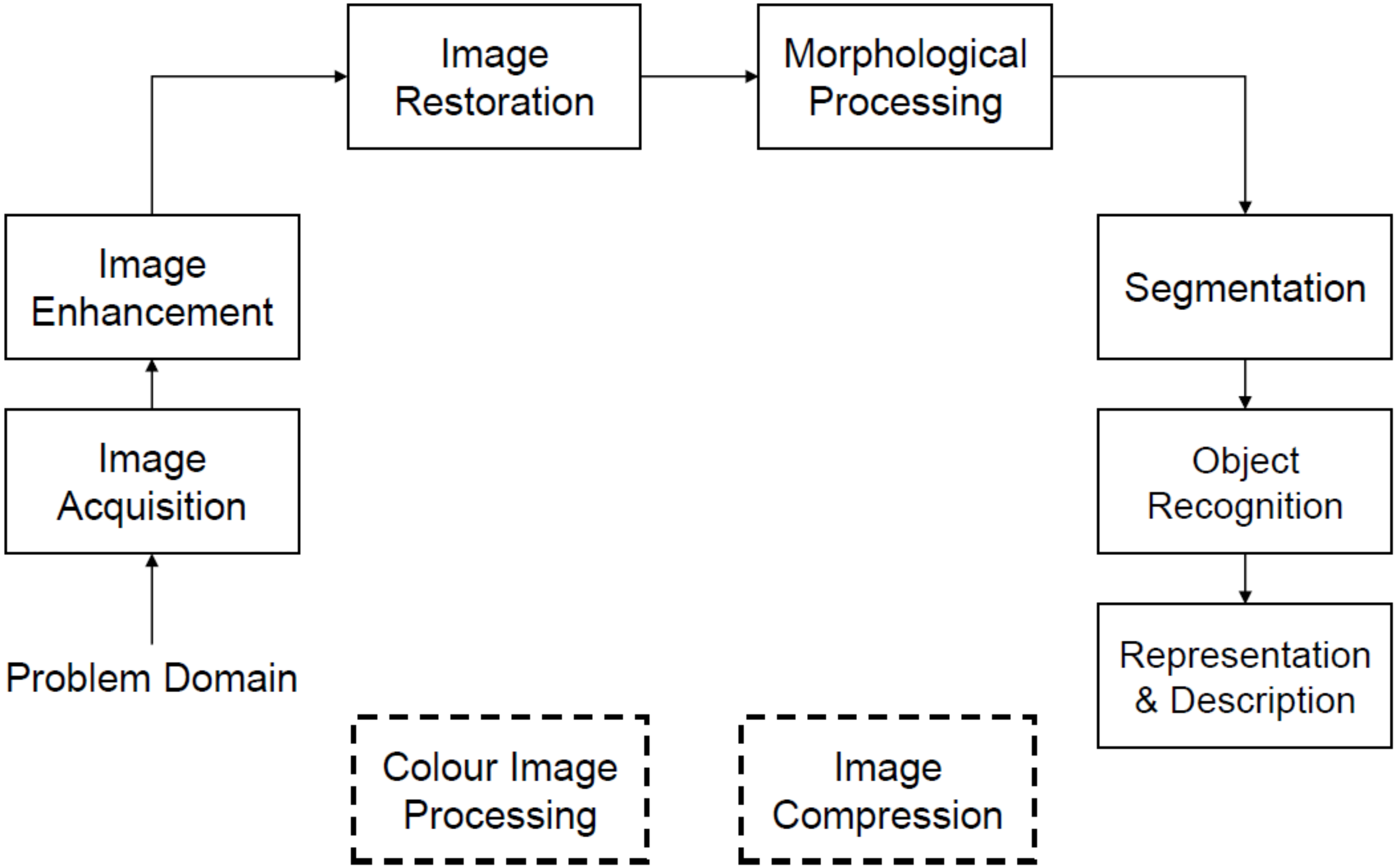
Lecture – 3,4,5

DIP Operations

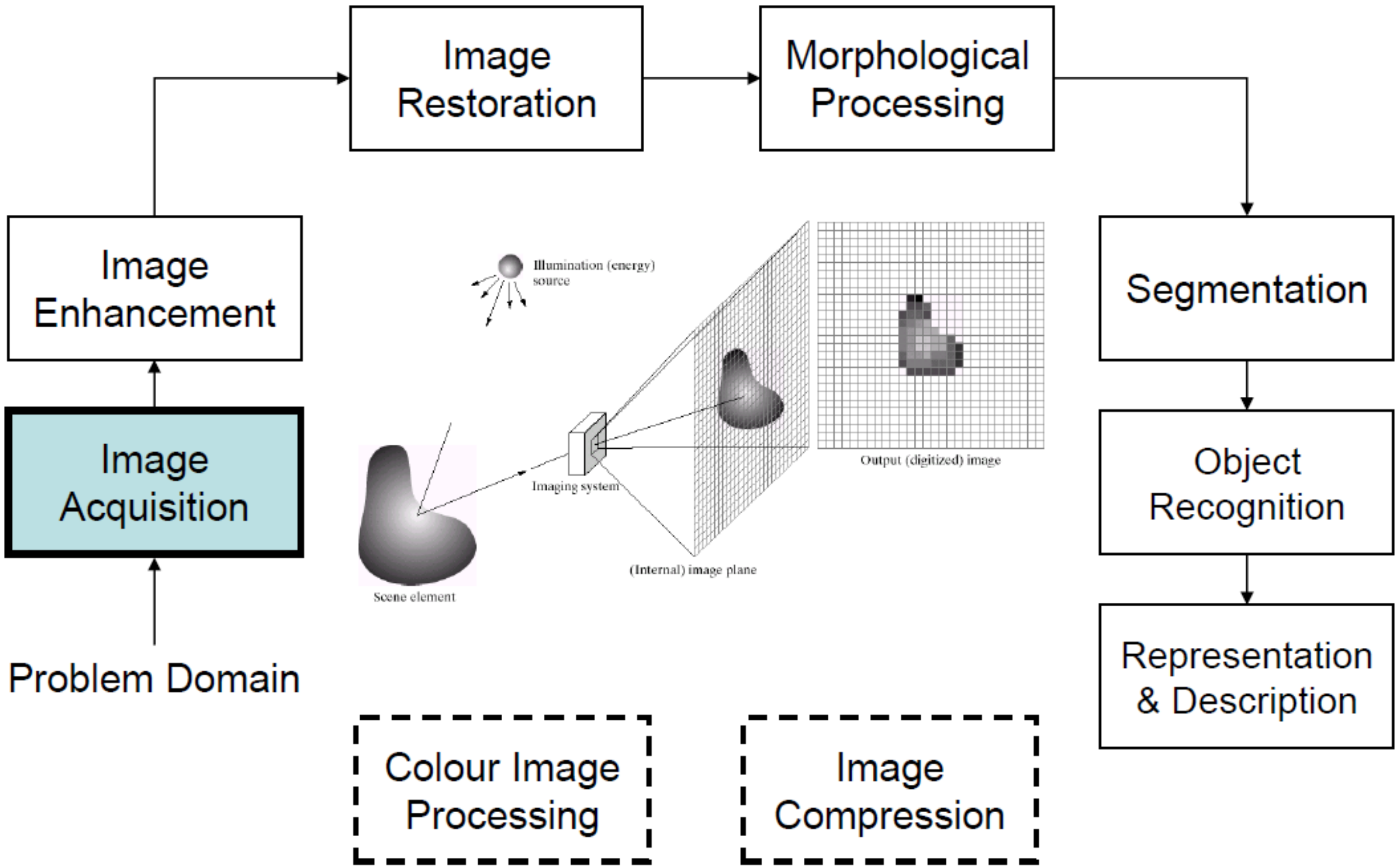
- Operation on images are: brightness, enhancement, contrast manipulation etc..


Low-level operations
Pixel operations
Neighbourhood operations
Edge-level operations
Region-level operations
Feature-level operations
Low-level IP
Image processing
High-level operations
Image understanding
High-level IP

Key Stages in Digital Image Processing



Key Stages in Digital Image Processing



- This step aims to obtain the digital image of the object.

Key Stages in Digital Image Processing

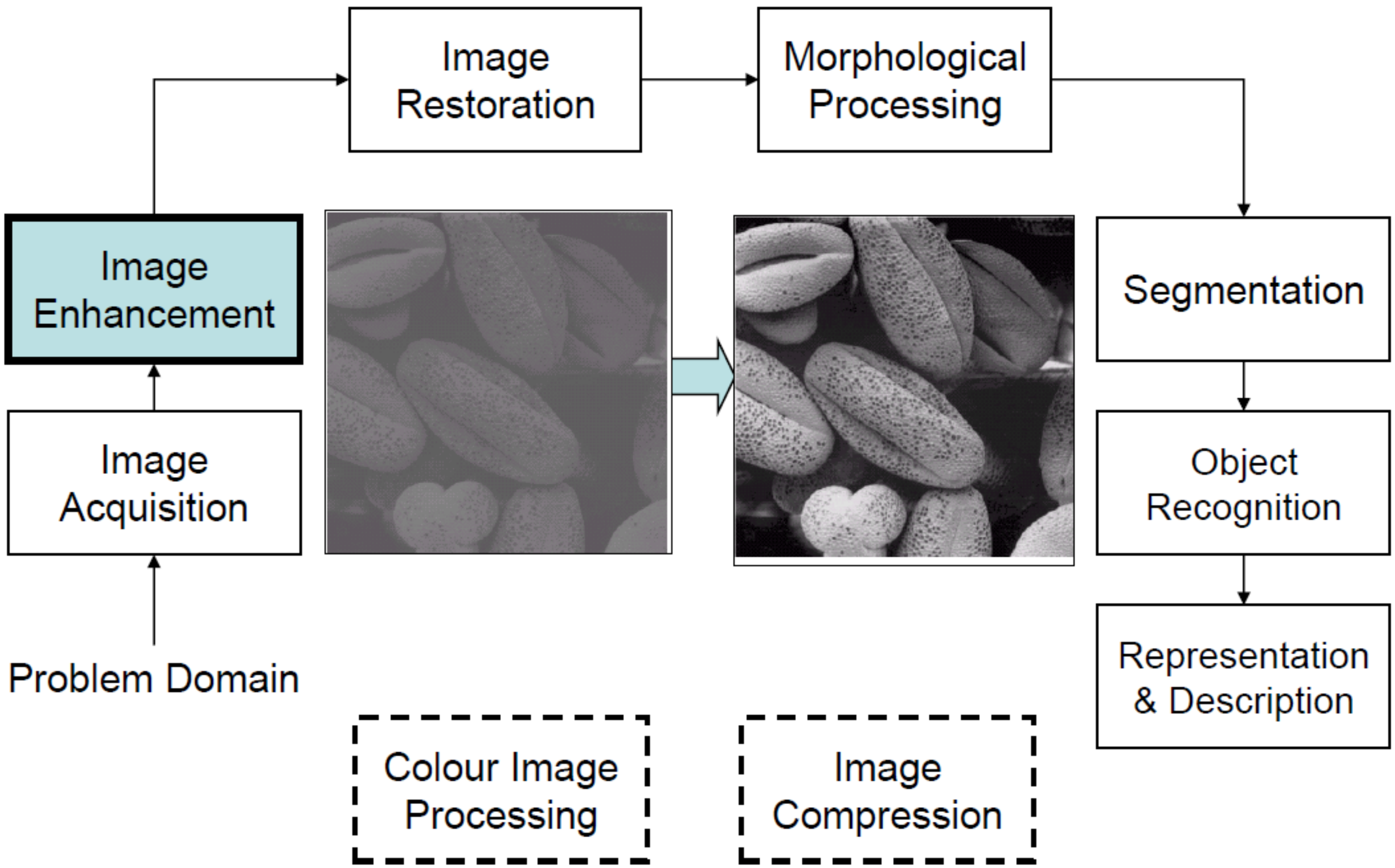


Image Enhancement

- Here objective is to accentuate certain image features for subsequent analysis or for image display.
- The principal objective of enhancement is to process an image so that the result is more suitable than the original image for a specific application.
- enhancement process itself does not increase the inherent information content in the data.
- It simply emphasizes certain specified image characteristics.
- Examples- contrast & edge enhancement, noise filtering, magnifying.

Key Stages in Digital Image Processing

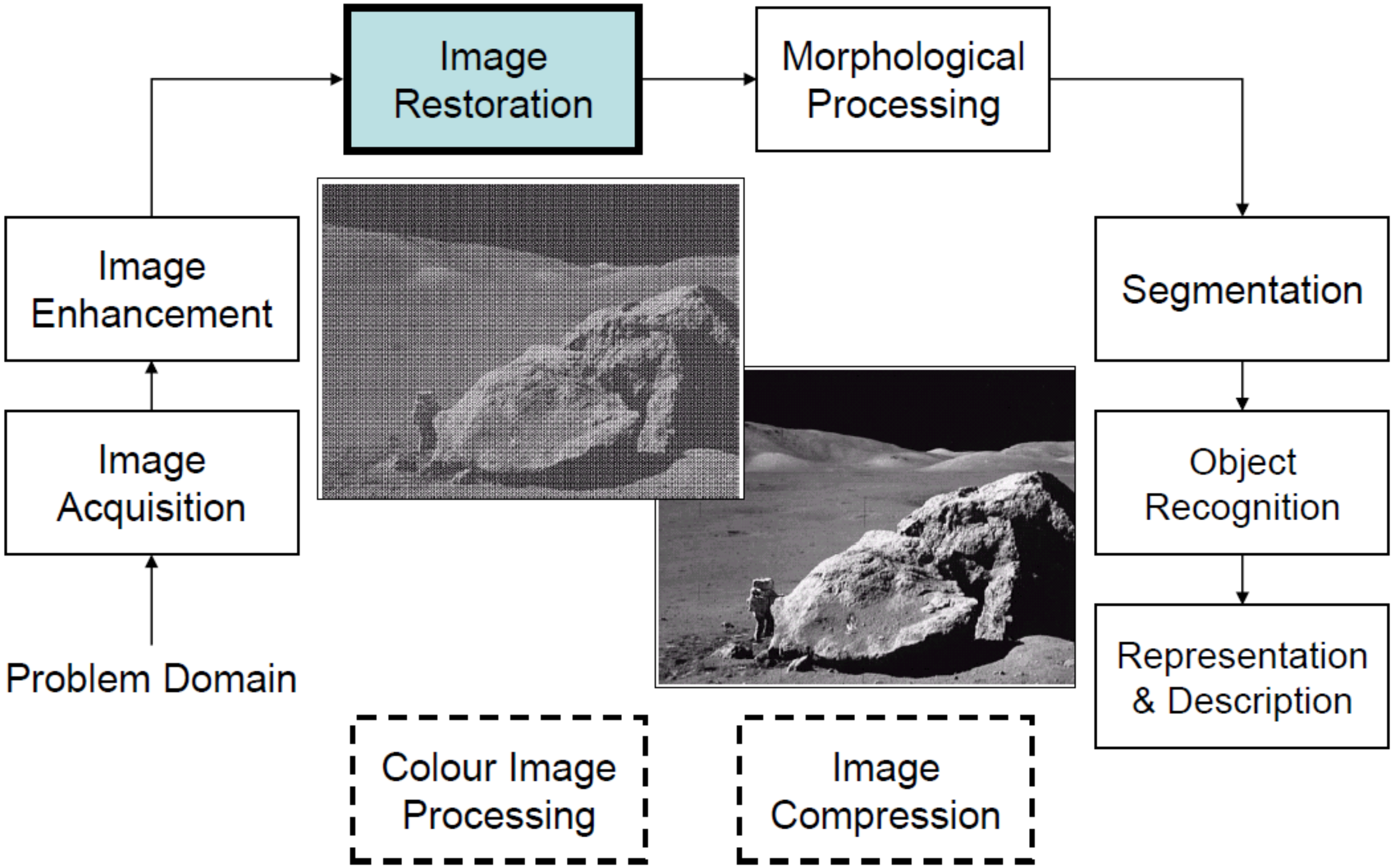


Image Restoration

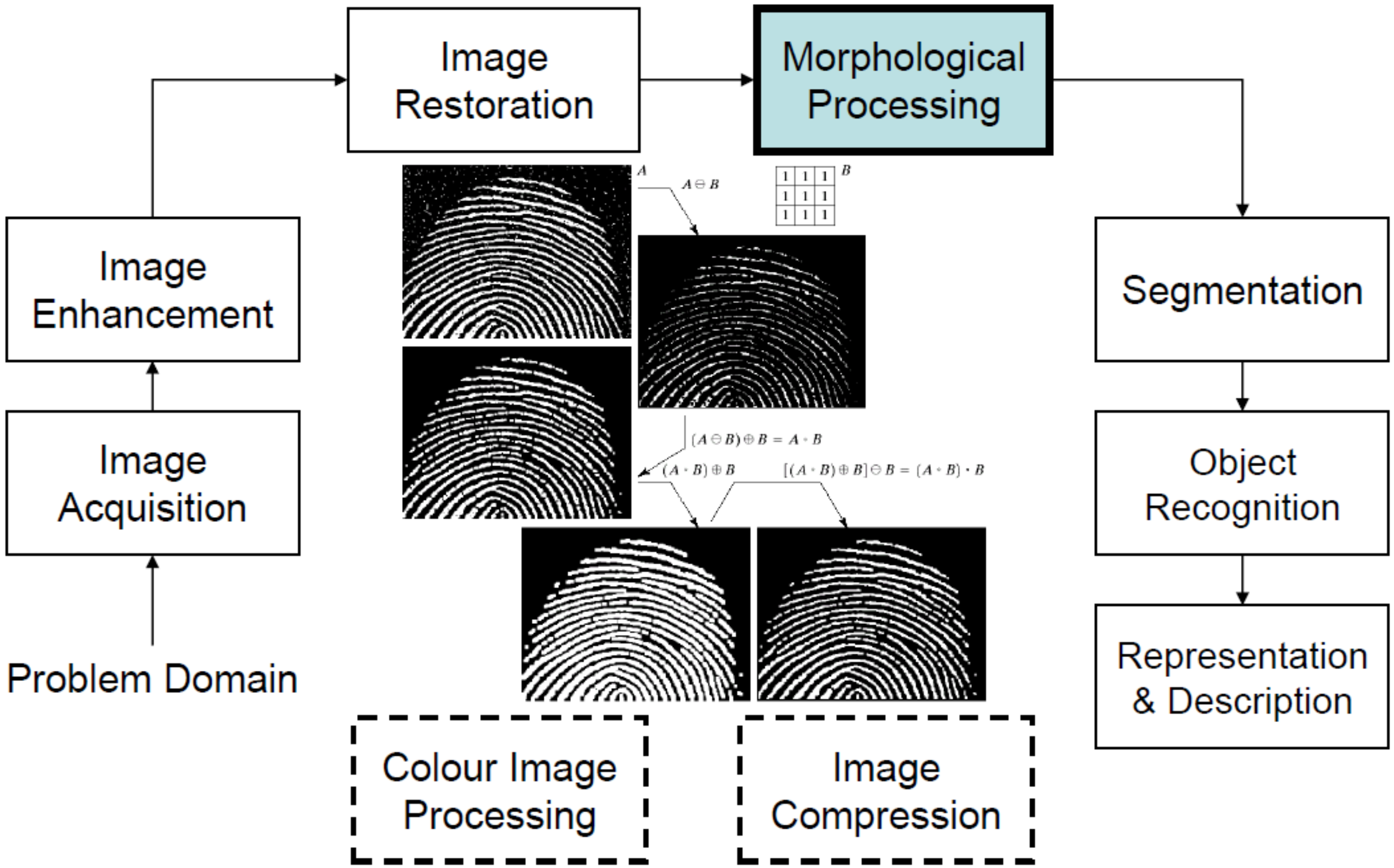
- It refers to removal or minimization of known degradations in an image.
- In other words it is concerned with filtering the observed image to minimize the effect of degradations.
- This includes deblurring of images degraded by the limitations of a sensor or its environment, noise filtering, and correction of geometric distortion or nonlinearities due to sensors.

Difference between image restoration and image enhancement

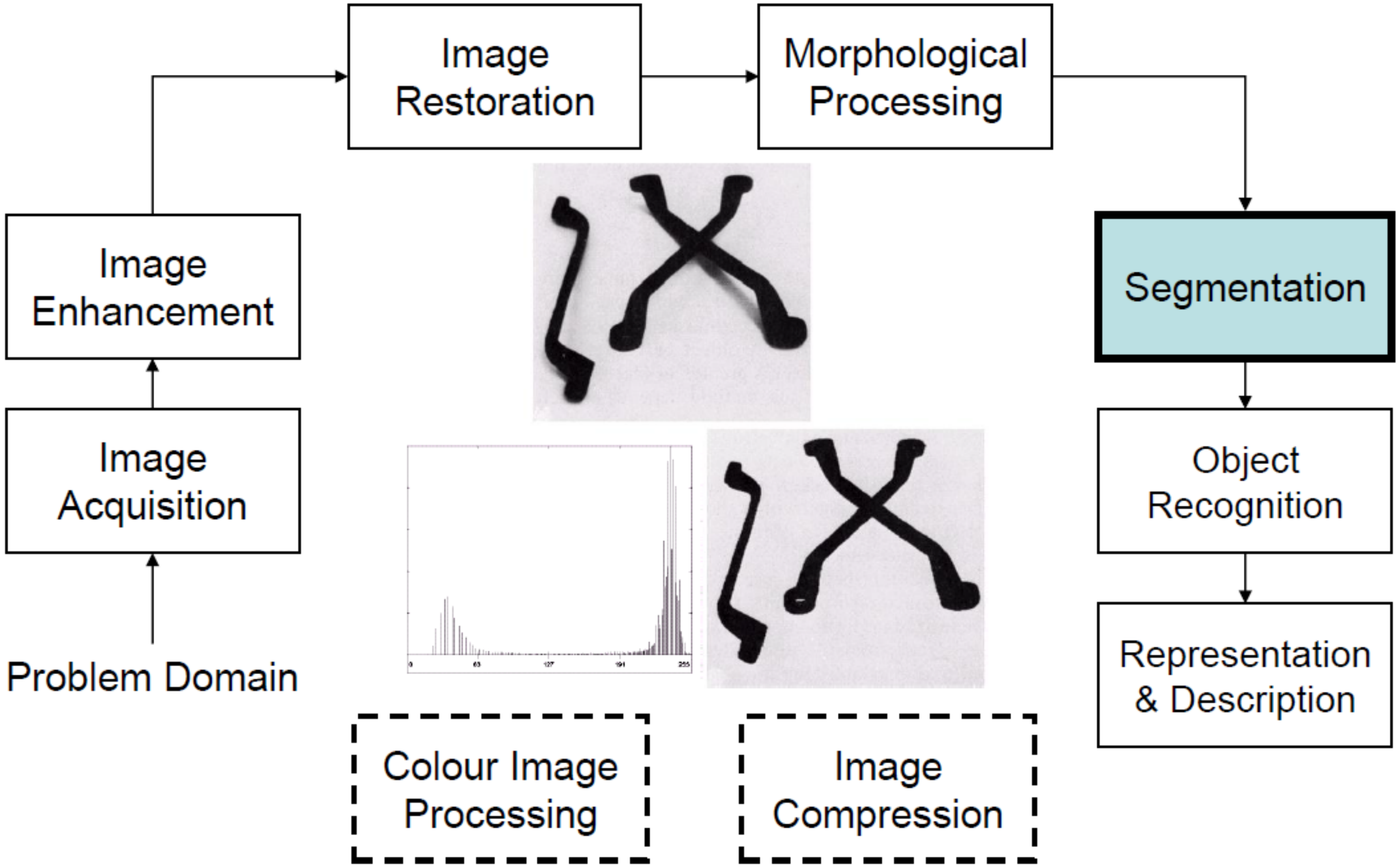
- Image enhancement process an image so that the result is more suitable than the original image.
- This criteria is difficult to represent mathematically.
- Enhancement techniques are much more image dependent.

- Image restoration is concerned with filtering the observed image to minimize the effect of degradations.
- Restoration problem can be quantified precisely.
- Restoration techniques often depend only on the class or ensemble properties of data set.

Key Stages in Digital Image Processing



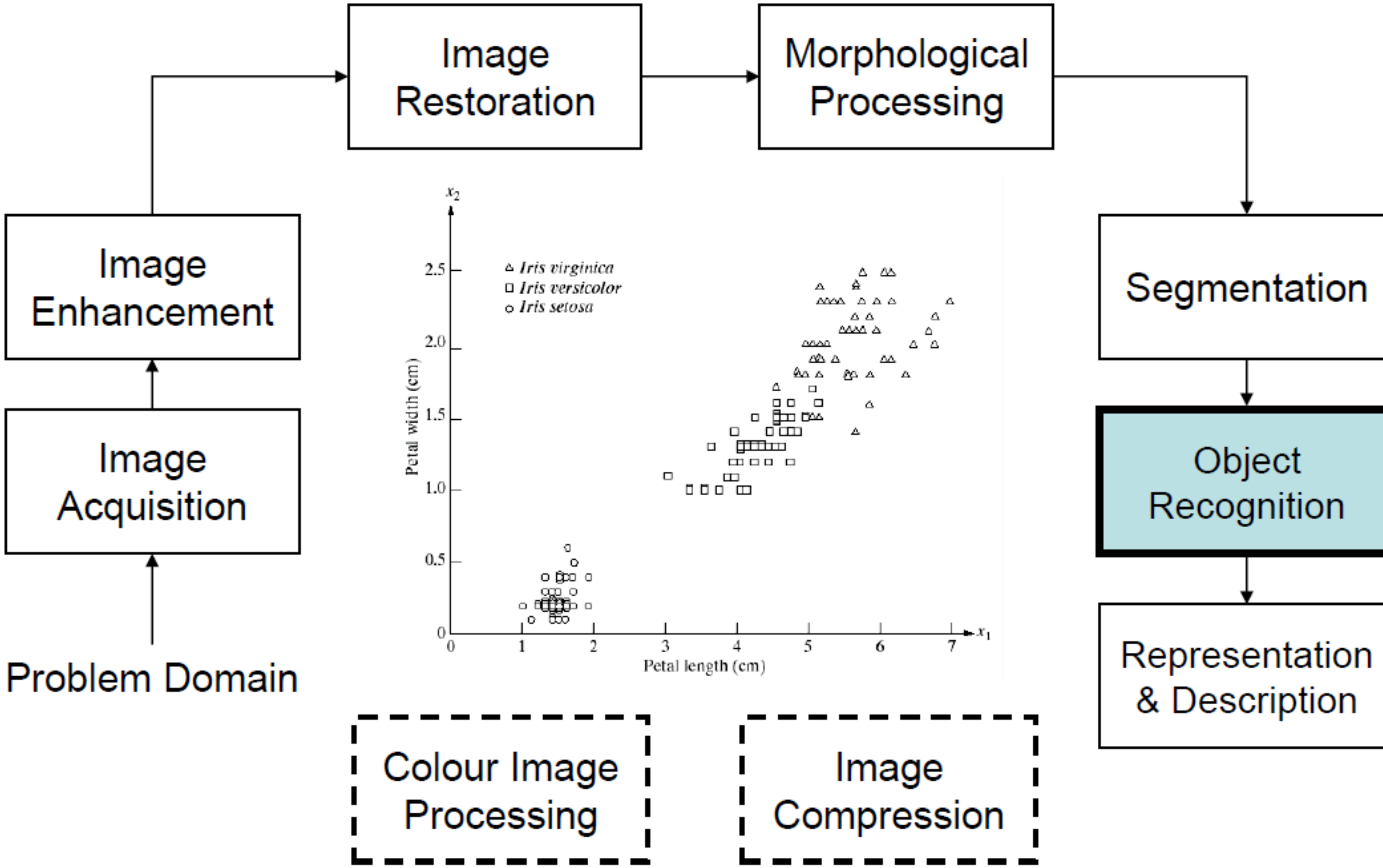
Key Stages in Digital Image Processing



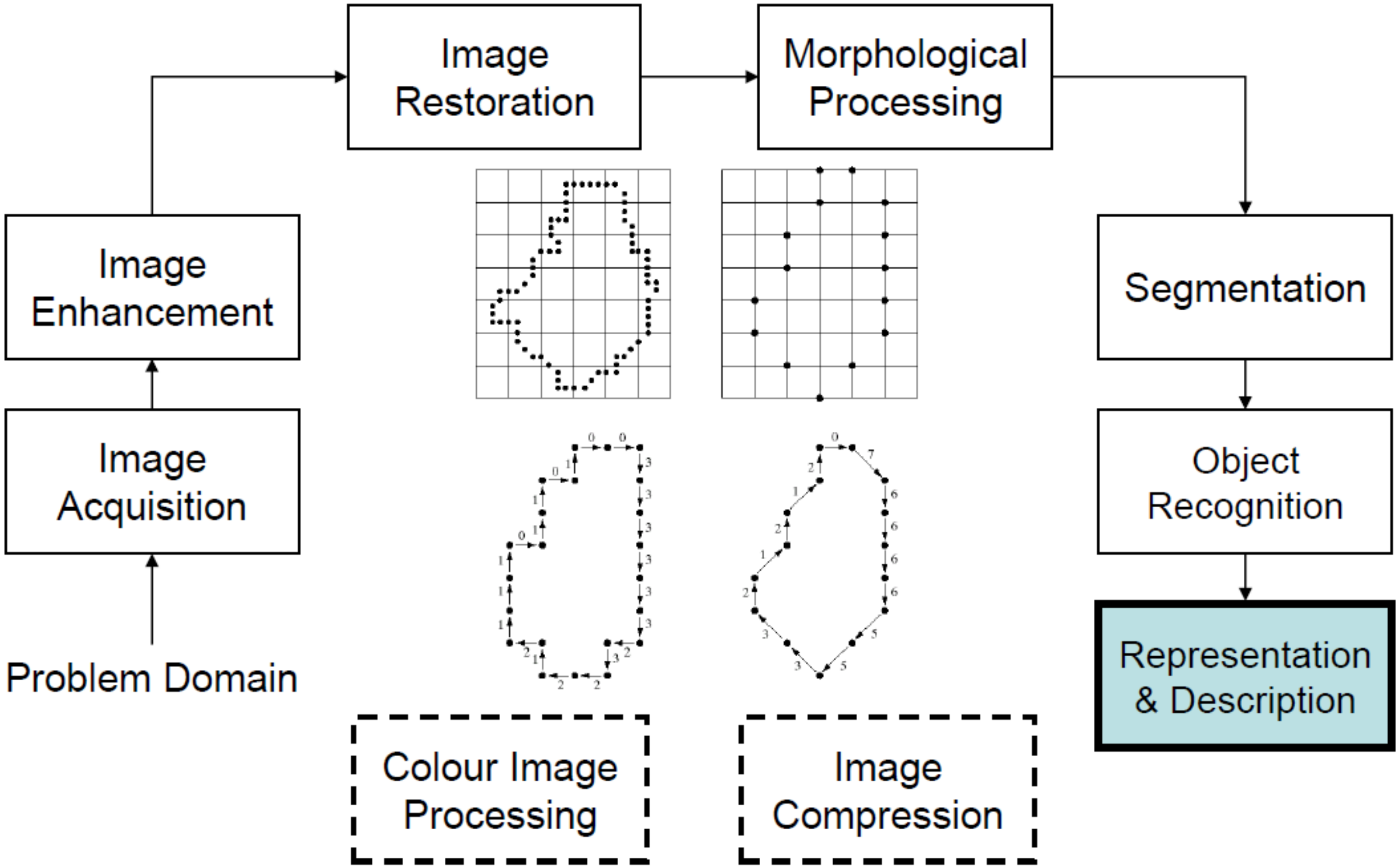
- This step divides the image into many sub-regions and extracts the regions that are necessary for further analysis.

- The portions of the image that are not necessary, such as image backgrounds (dictated by the image requirement), are discarded.

Key Stages in Digital Image Processing



Key Stages in Digital Image Processing



- Imaging applications use many routines for extraction of image features that are necessary for recognition. This is called image feature extraction step.

- This extracted object features are represented in meaningful data structures and the objects are described

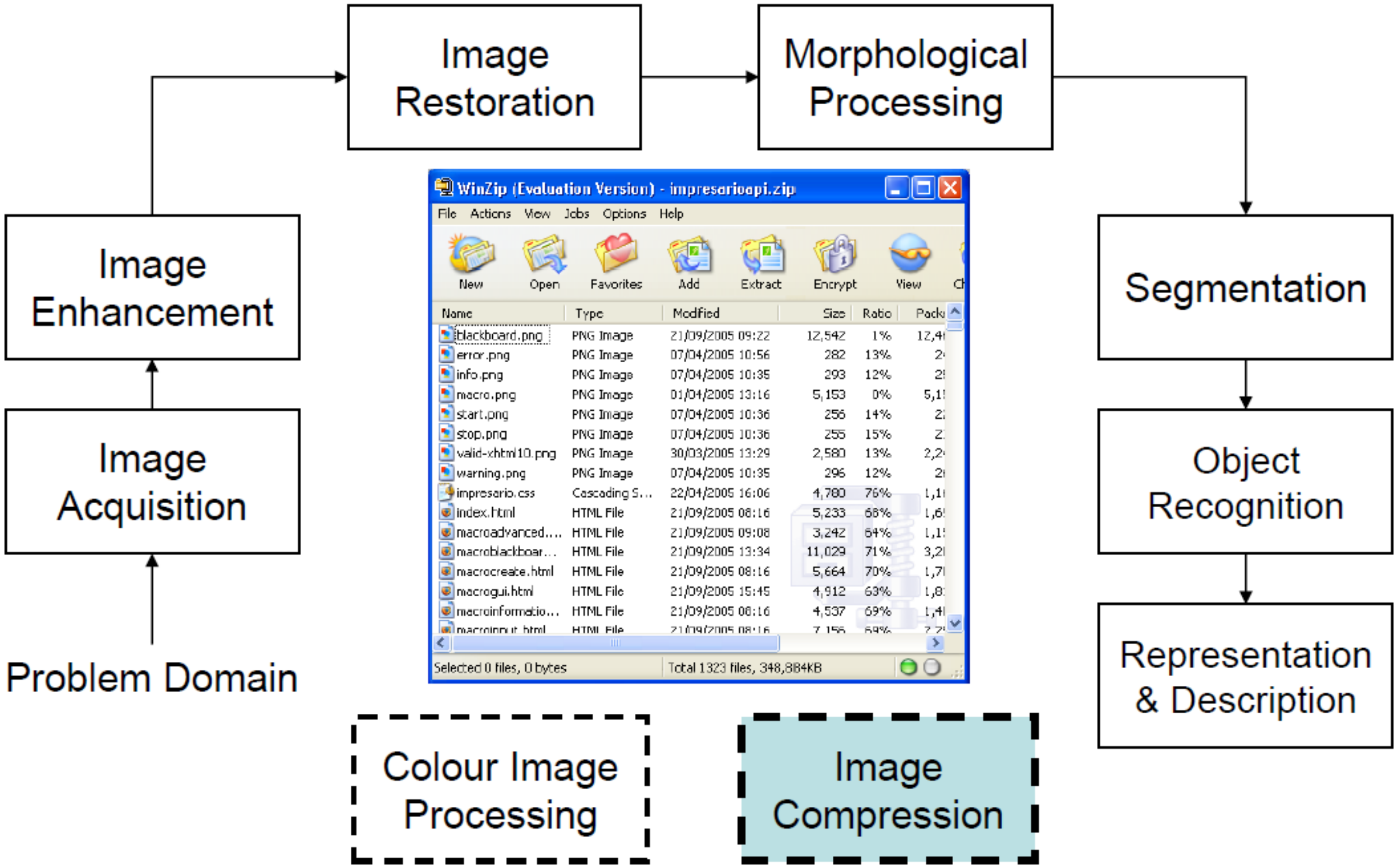


Image Acquisition
Problem Domain
Image Enhancement
Image Restoration
Morphological Processing
Segmentation
Object Recognition
Representation & Description
Colour Image Processing
Image Compression
WinZip (Evaluation Version) - impresarioapi.zip
File Actions View Jobs Options Help
New Open Favorites Add Extract Encrypt View
Name Type Modified Size Ratio
blackboard.png PNG Image 21/09/2005 09:22 12,542 1%
error.png PNG Image 07/04/2005 10:56 282 13%
info.png PNG Image 07/04/2005 10:35 293 12%
macro.png PNG Image 01/04/2005 13:16 5,153 0%
start.png PNG Image 07/04/2005 10:36 256 14%
stop.png PNG Image 07/04/2005 10:36 255 15%
valid-xhtml10.png PNG Image 30/03/2005 13:29 2,580 13%
warning.png PNG Image 07/04/2005 10:35 296 12%
impresario.css Cascading S... 22/04/2005 16:06 4,780 76%
index.html HTML File 21/09/2005 08:16 5,233 68%
macroadvanced.... HTML File 21/09/2005 09:08 3,242 64%
macroblackboar... HTML File 21/09/2005 13:34 11,029 71%
macrocreate.html HTML File 21/09/2005 08:16 5,664 70%
macrogui.html HTML File 21/09/2005 15:45 4,912 63%
macroinformatio... HTML File 21/09/2005 08:16 4,537 69%
Selected 0 files, 0 bytes
Total 1323 files, 348,884KB

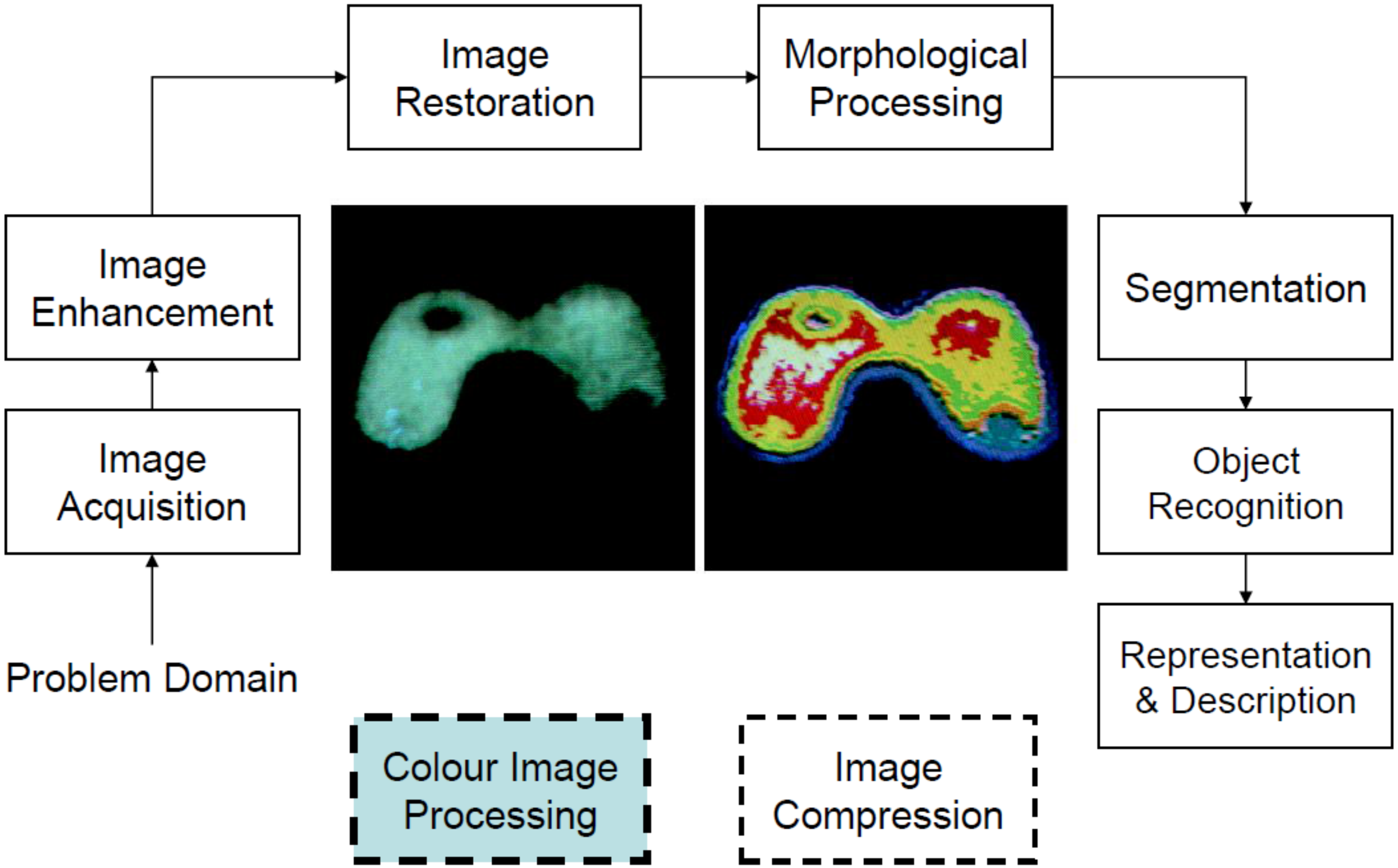


Image Restoration
Morphological Processing
Image Enhancement
Segmentation
Image Acquisition
Object Recognition
Representation & Description
Problem Domain
Colour Image Processing
Image Compression

Digital Imaging System

- A digital imaging system is a set of devices for acquiring, storing, manipulating, and transmitting digital images.

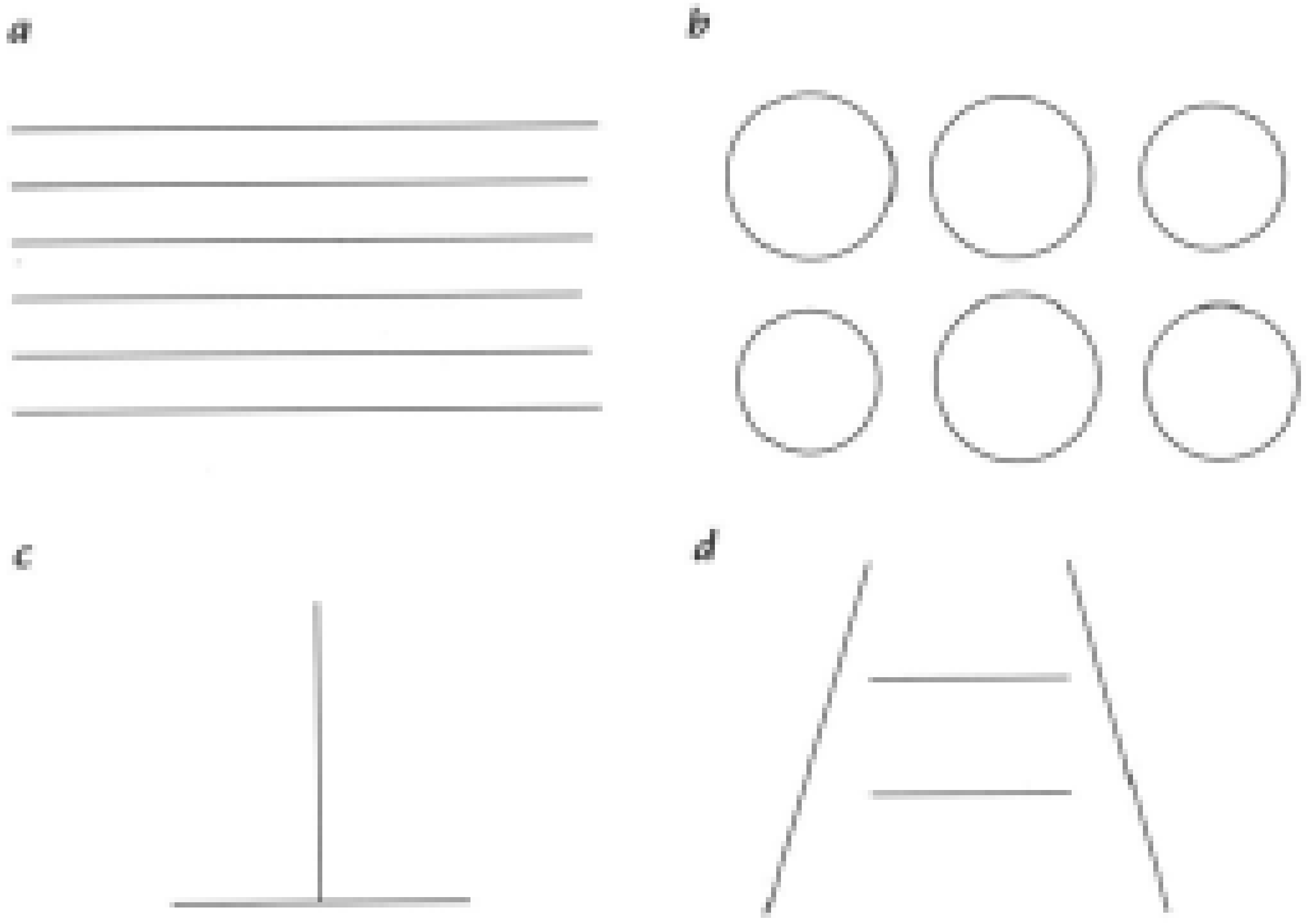
- We can’t think of image processing without considering the human vision system. We observe and evaluate the images that we process with our visual system.

- Without taking this elementary fact into consideration, we may be much misled in the interpretation of images.

Some Questions?

- What intensity differences can we distinguish?
- What is the spatial resolution of our eye?
- How accurately we estimate and compare distances and areas?
- How do we sense colors?
- By which features can we detect and distinguish objects?

Test Images



- Test images for distances and area estimation:
  - Parallel lines with up to 5% difference in length.
  - Circles with up to 10% difference in radius.
  - The vertical line appears longer but actually has the same length as the horizontal line.
  - Deception by perspective: the upper line appears longer than the lower one but actually have the same length.

Nature of Light

- Human beings perceive objects because of light. Light sources are of two types— primary and secondary. The sun and lamps are examples of primary light sources. While primary sources generate light, secondary light sources simply reflect or diffuse light from primary sources. The moon and clouds are examples of secondary sources of light.

- ***Wavelength -*** Wavelength is the distance between two successive wave crests or wave troughs in the direction of travel.

- ***Amplitude -*** Amplitude is the maximum distance the oscillation travels, away from its horizontal axis.

- ***Frequency -*** The frequency of vibration is the number of waves crossing at a point

- Relationship between wavelength (lambda) and frequency (f)

$$\lambda = c / f$$

Where c = speed of light = 299,792,458 m / s

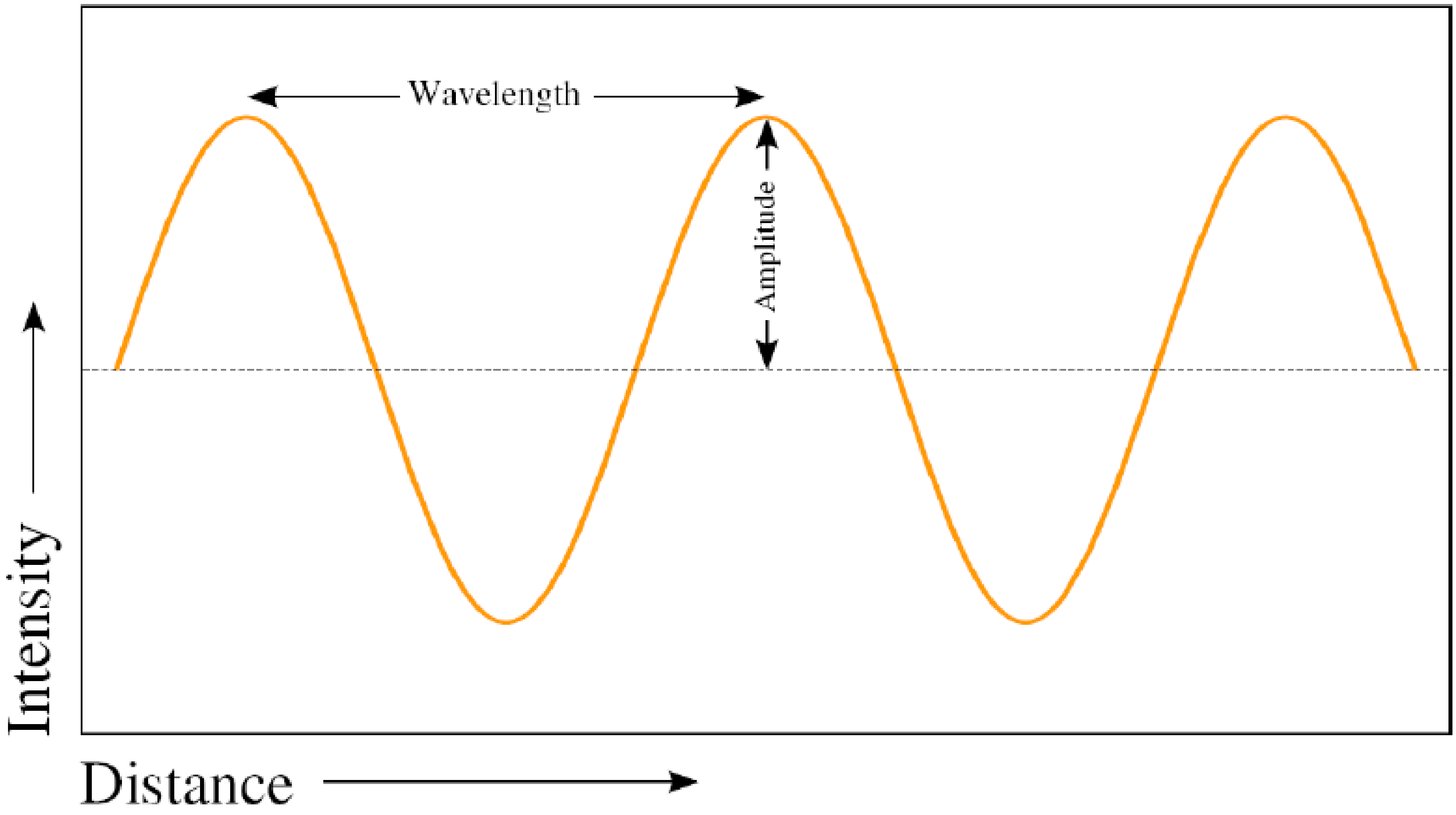
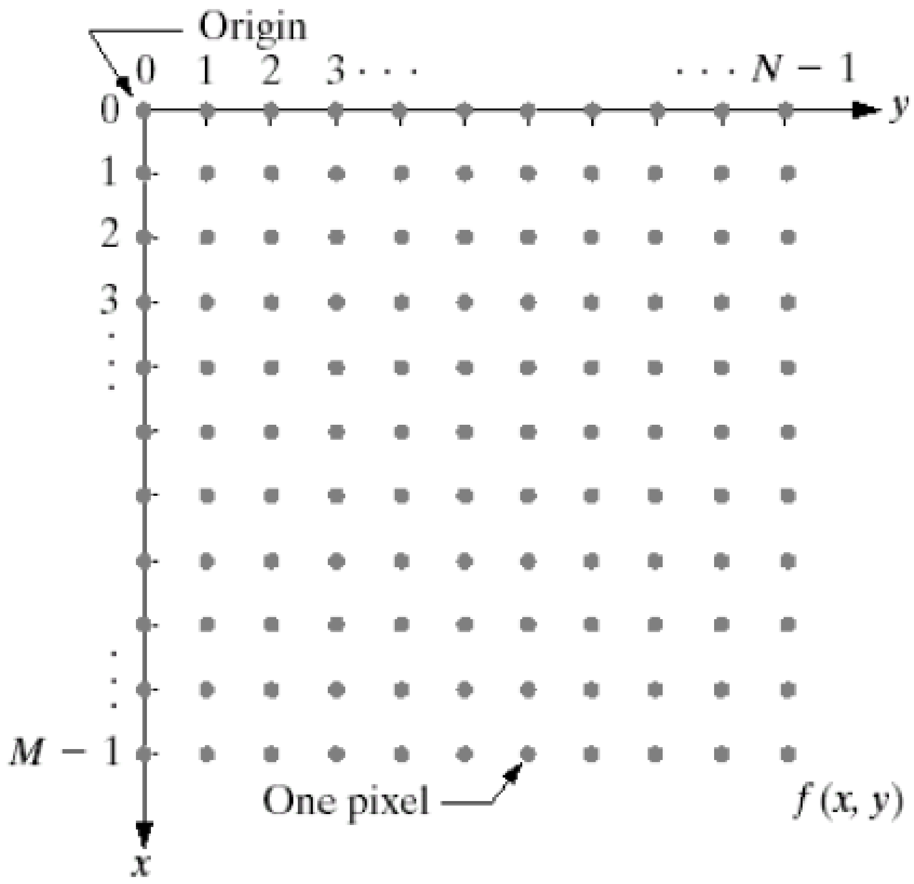
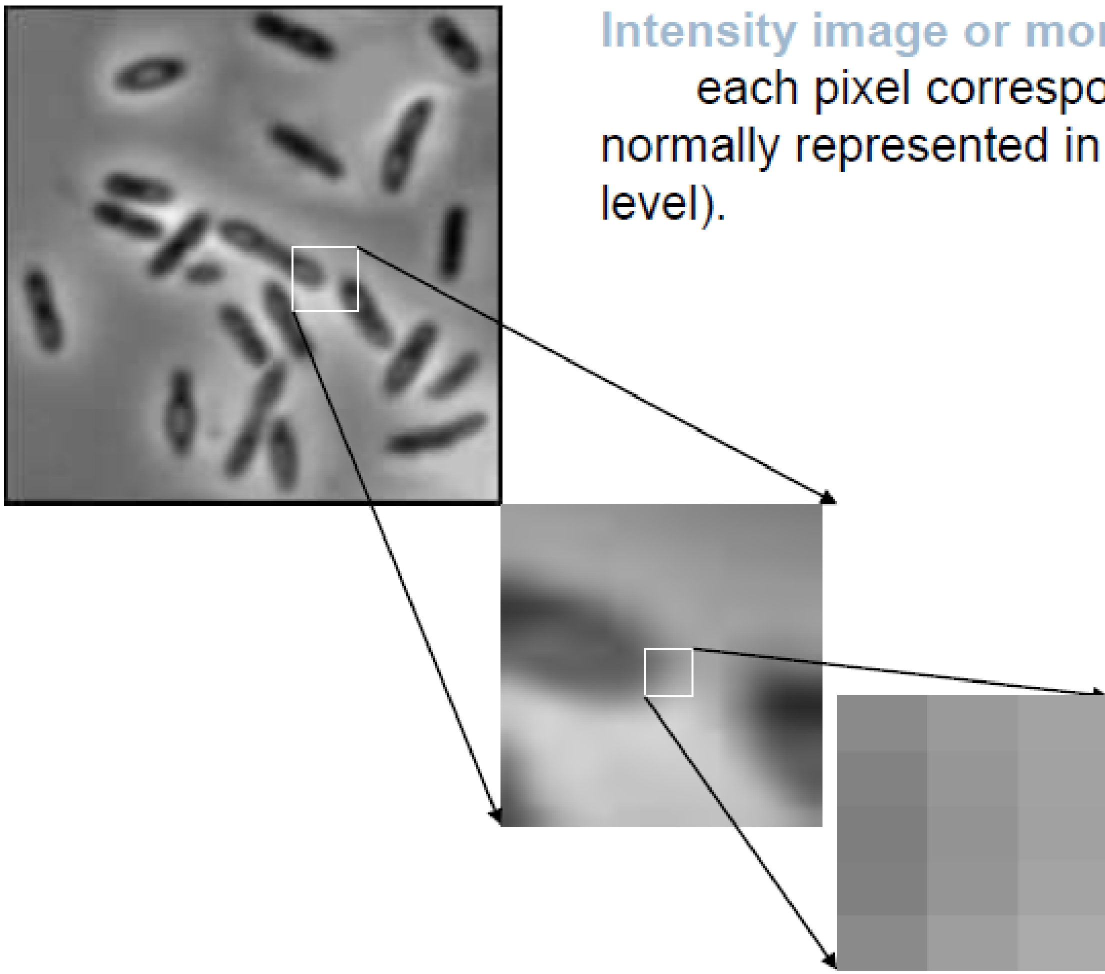


Diagram of a light wave.

Conventional Coordinate for Image Representation



Digital Image: Intensity Image



Intensity image or monochrome image

each pixel corresponds to light intensity normally represented in gray scale (gray level).

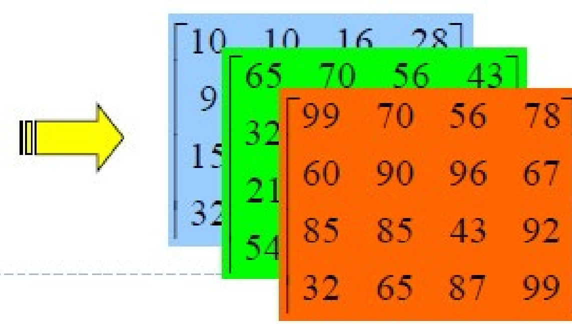
Gray scale values

$$\begin{bmatrix} 10 & 10 & 16 & 28 \\ 9 & 6 & 26 & 37 \\ 15 & 25 & 13 & 22 \\ 32 & 15 & 87 & 39 \end{bmatrix}$$

Digital Image: RGB Image

Color image or RGB image: each pixel contains a vector representing red, green and blue components.

RGB components



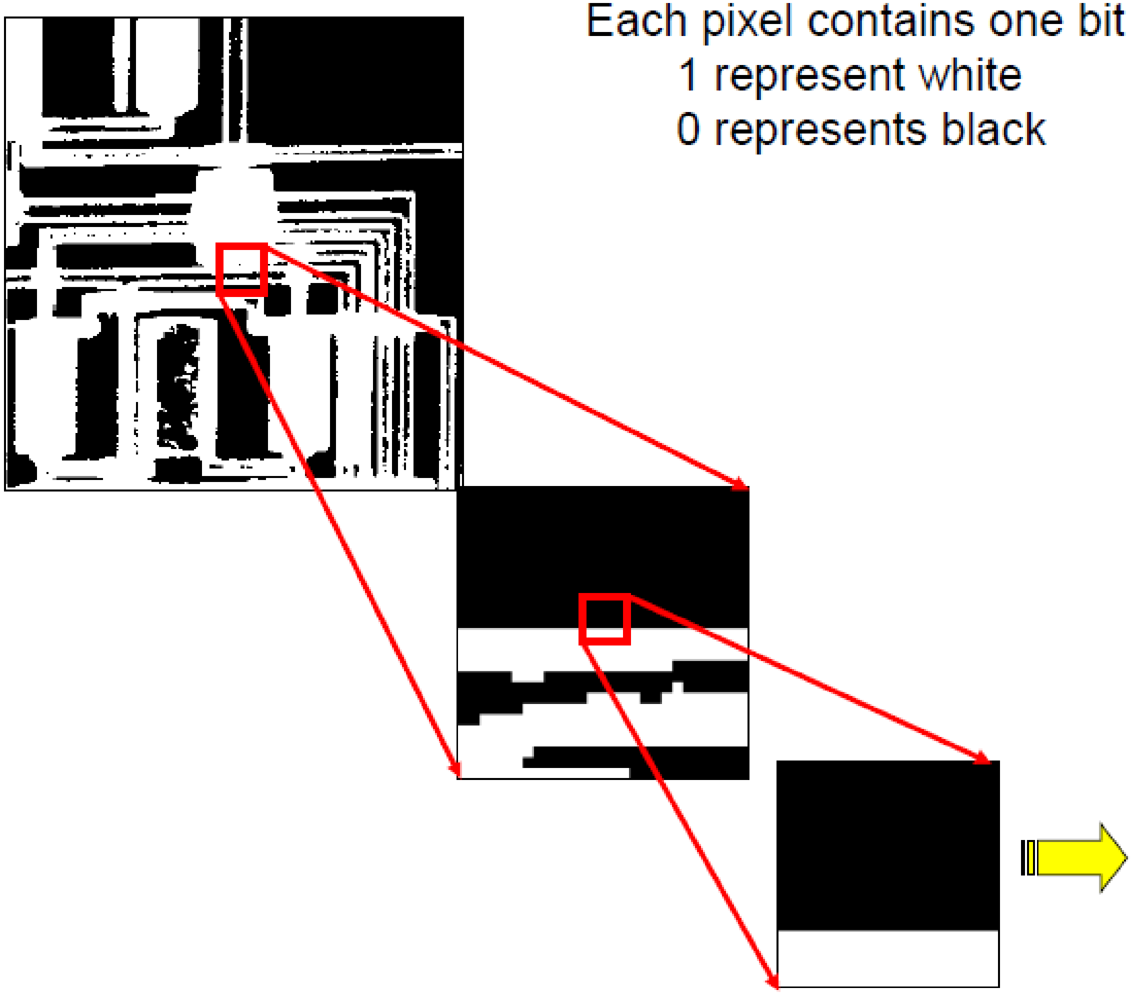
Digital Image: Binary Image

Binary image or black and white image

Each pixel contains one bit :

1 represent white

0 represents black



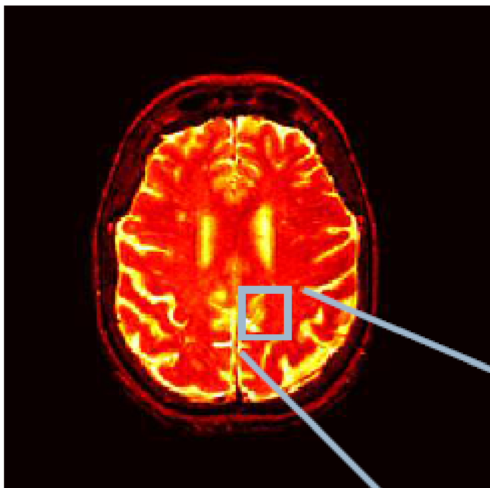
Binary data

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

Digital Image: Index Image

Index image

Each pixel contains index number pointing to a color in a color table

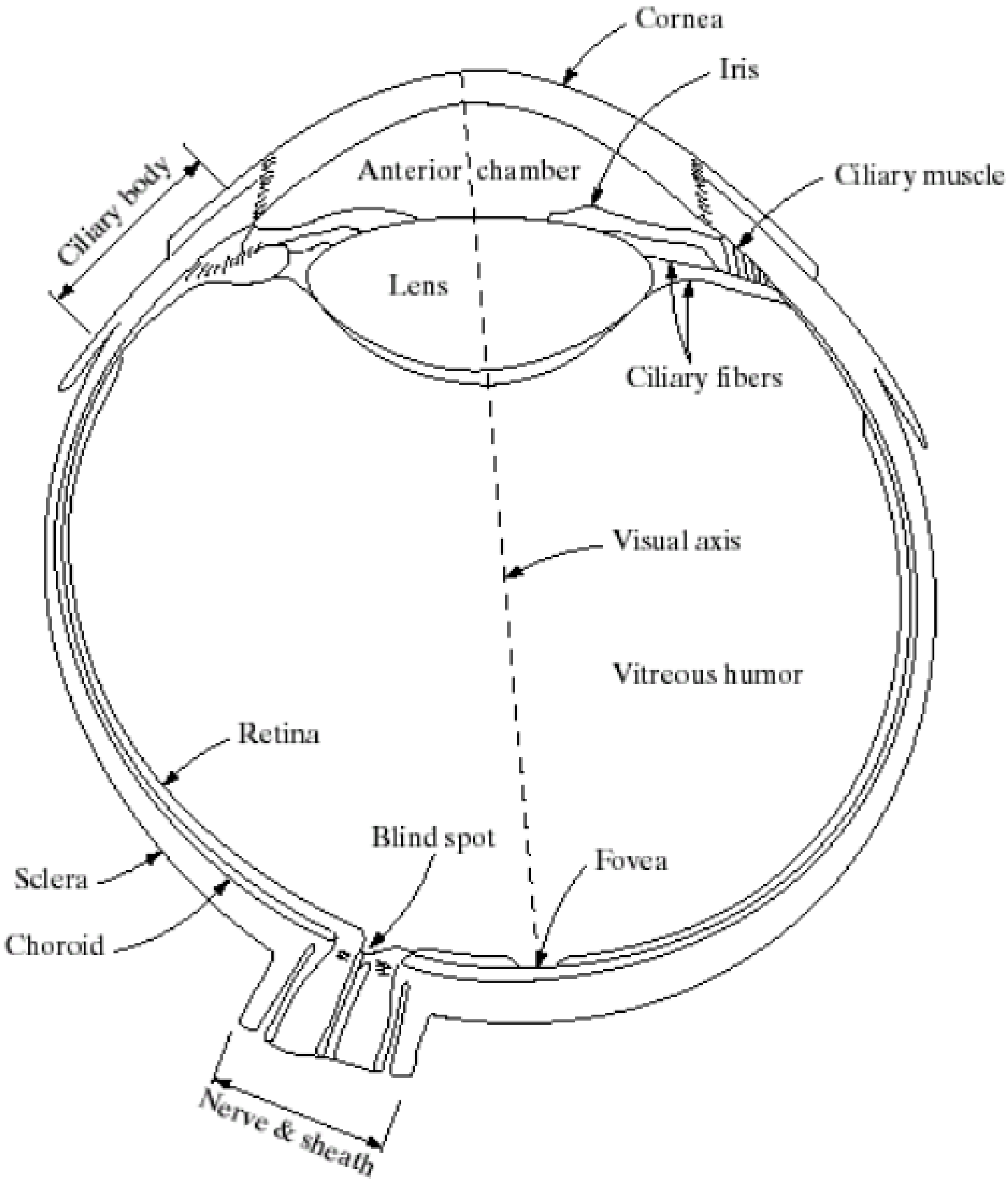


$$\begin{bmatrix} 1 & 4 & 9 \\ 6 & 4 & 7 \\ 6 & 5 & 2 \end{bmatrix}$$

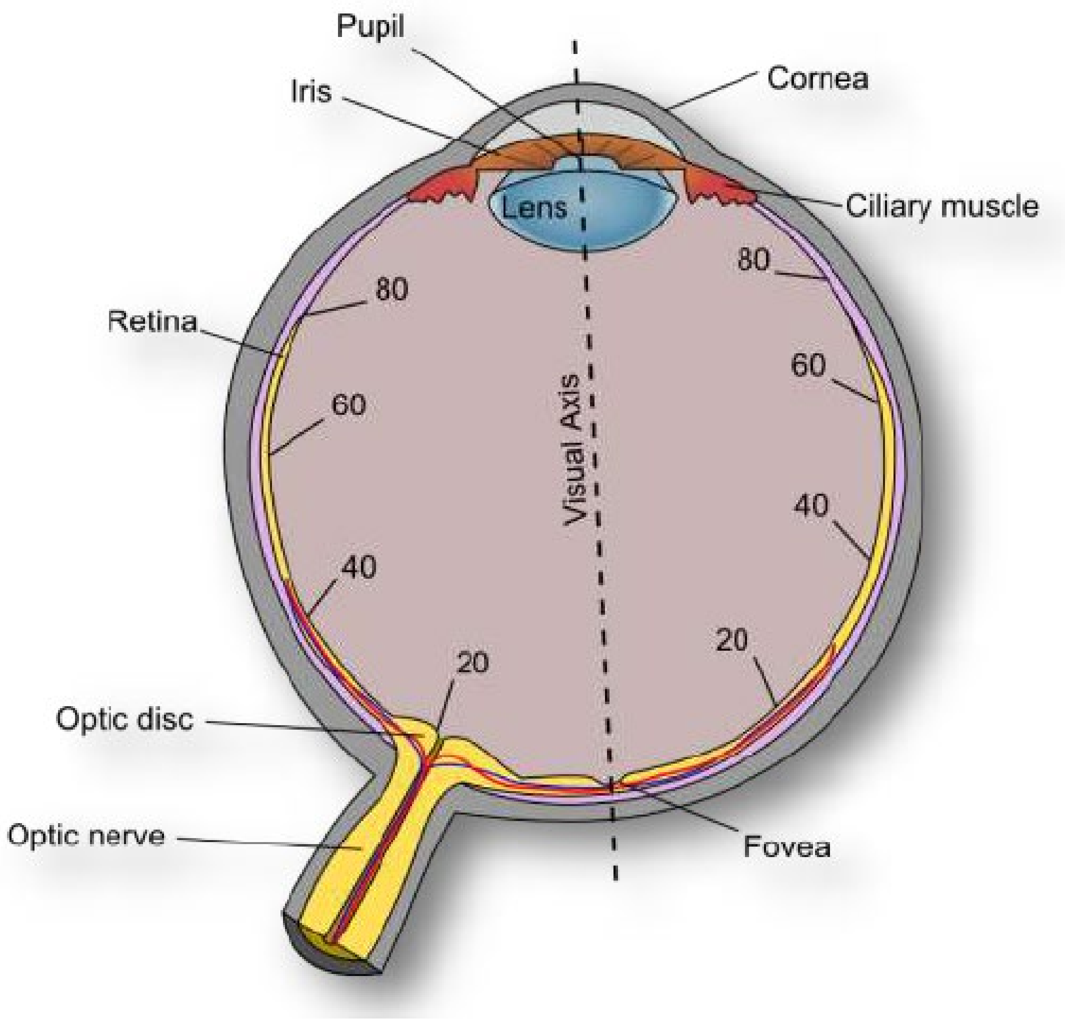
Index value

Color Table

Index No.	Red component	Green component	Blue component
1	0.1	0.5	0.3
2	1.0	0.0	0.0
3	0.0	1.0	0.0
4	0.5	0.5	0.5
5	0.2	0.8	0.9
…	…	…	…

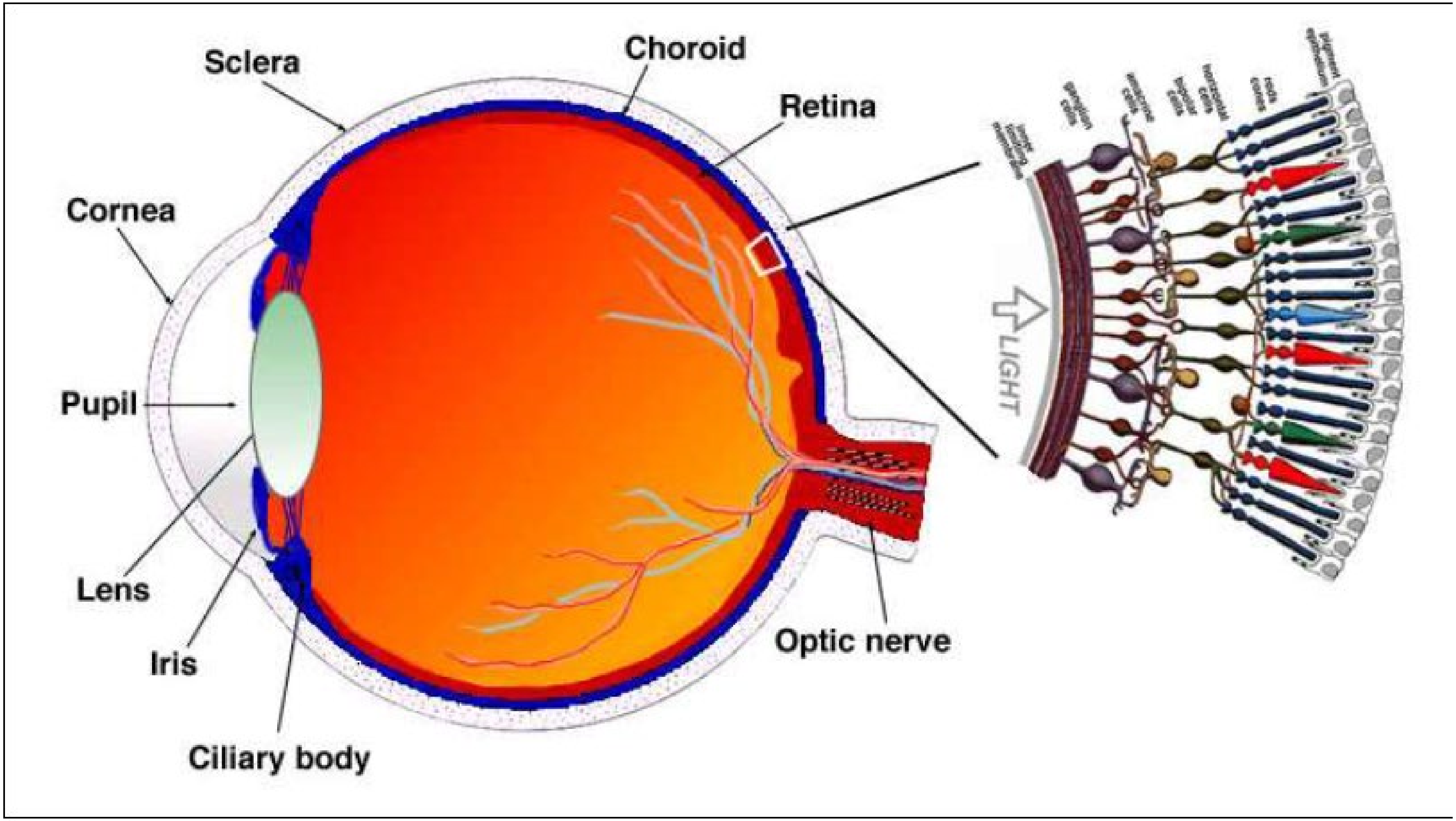

Cornea
Iris
Ciliary body
Anterior chamber
Ciliary muscle
Lens
Ciliary fibers
Visual axis
Vitreous humor
Retina
Blind spot
Fovea
Sclera
Choroid
Nerve & sheath

Human Eye



Pupil
Iris
Cornea
Lens
Ciliary muscle
Retina
80
60
40
20
Visual Axis
80
60
40
20
Optic disc
Optic nerve
Fovea

Anatomy of the Human Eye



Human Visual System

- Human vision
  - **Cornea** acts as a protective lens that roughly focuses incoming light
  - **Iris** controls the amount of light that enters the eye
  - The **lens** sharply focuses incoming light onto the retina
    - Absorbs both infra-red and ultra-violet light which can damage the lens
  - The **retina** is covered by **photoreceptors** (light sensors) which measure light

- **Lens**
  - both infrared and ultraviolet light are absorbed appreciably by proteins within the lens structure and, in excessive amounts, can cause damage to the eye.
- **Retina**
  - Innermost membrane of the eye which lines inside of the wall's entire posterior portion. When the eye is properly focused, light from an object outside the eye is imaged on the retina.

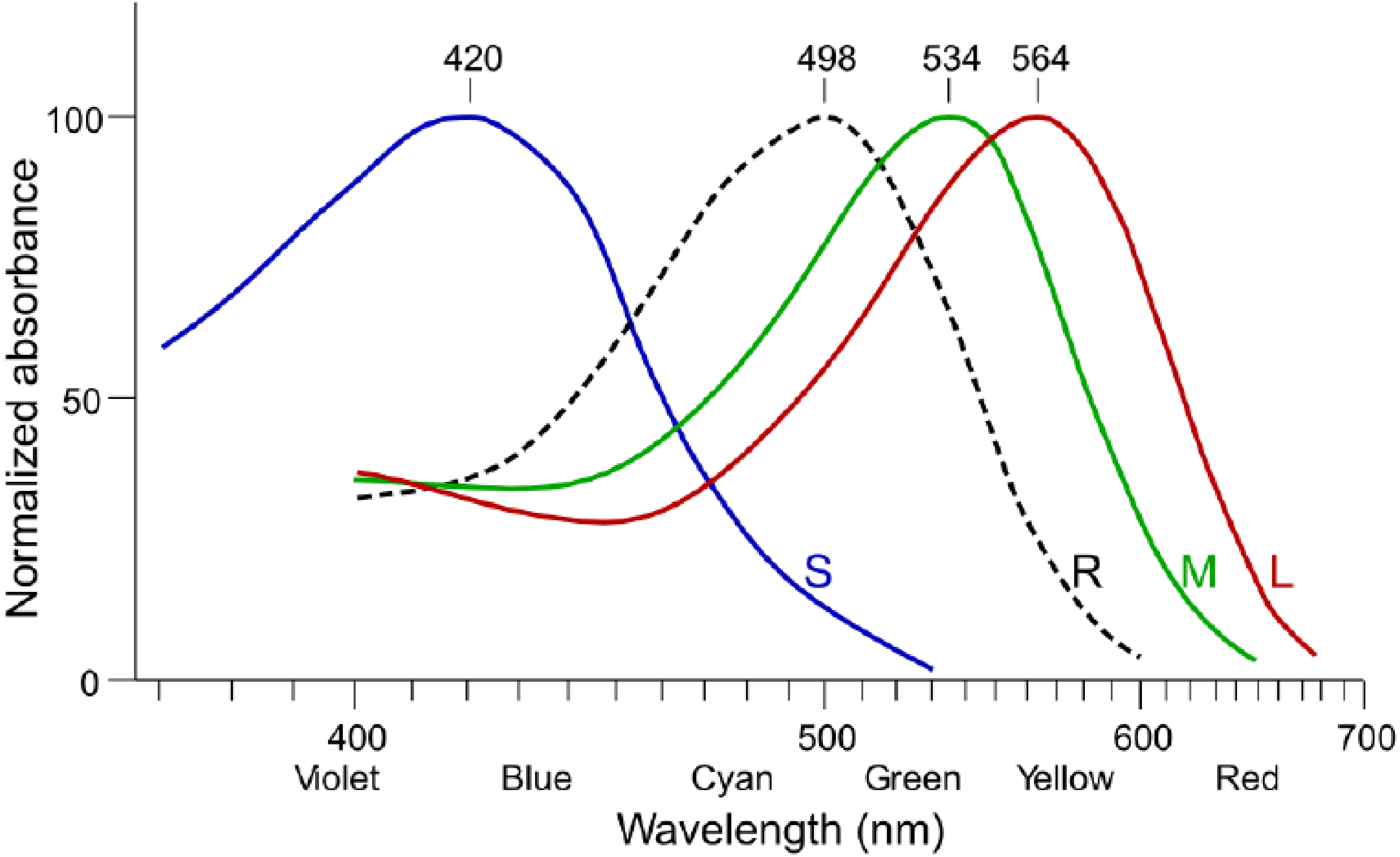
Photoreceptors

- **Rods**
  - Approximately 100-150 million rods, distributed over the retina surface.
  - Non-uniform distribution across the retina (Several rods are connected to a single nerve end reduce the amount of detail discernible)
  - Sensitive to low-light levels (scotopic vision)
  - Lower resolution

Cones

- Approximately 6-7 million cones, located in the central portion of the retina.
- Sensitive to higher-light levels (photopic vision)
- High resolution
- Detect color by the use of 3 different kinds of cones each of which is sensitive to red, green, or blue frequencies
  - Red (L cone) : 564-580 nm wavelengths (65% of all cones)
  - Green (M cone) : 534-545 nm wavelengths (30% of all cones)
  - Blue (S cone) : 420-440 nm wavelengths (5% of all cones)

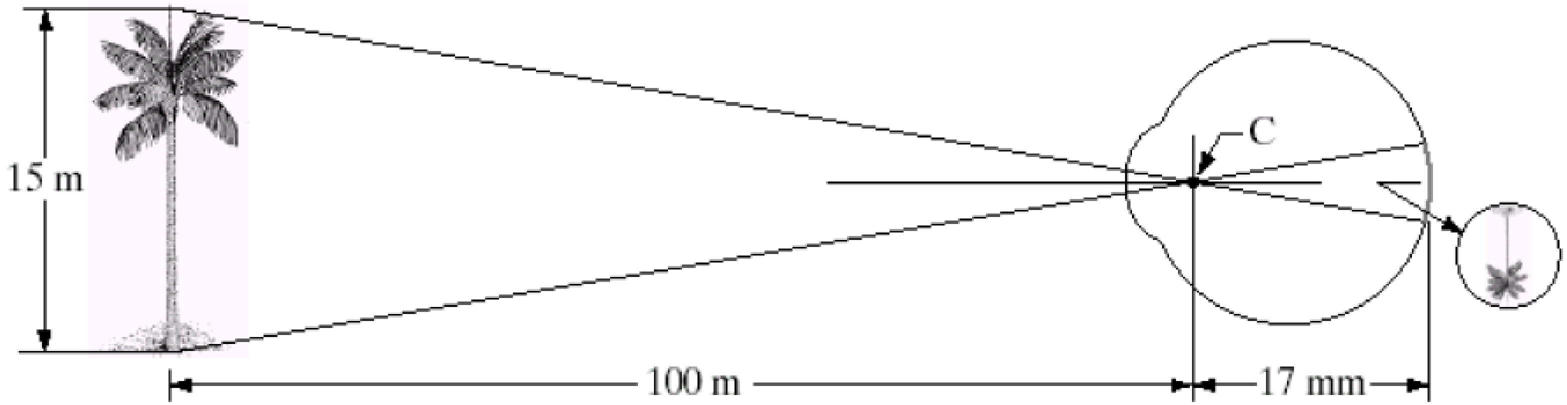
Cone (LMS) and Rod (R) responses



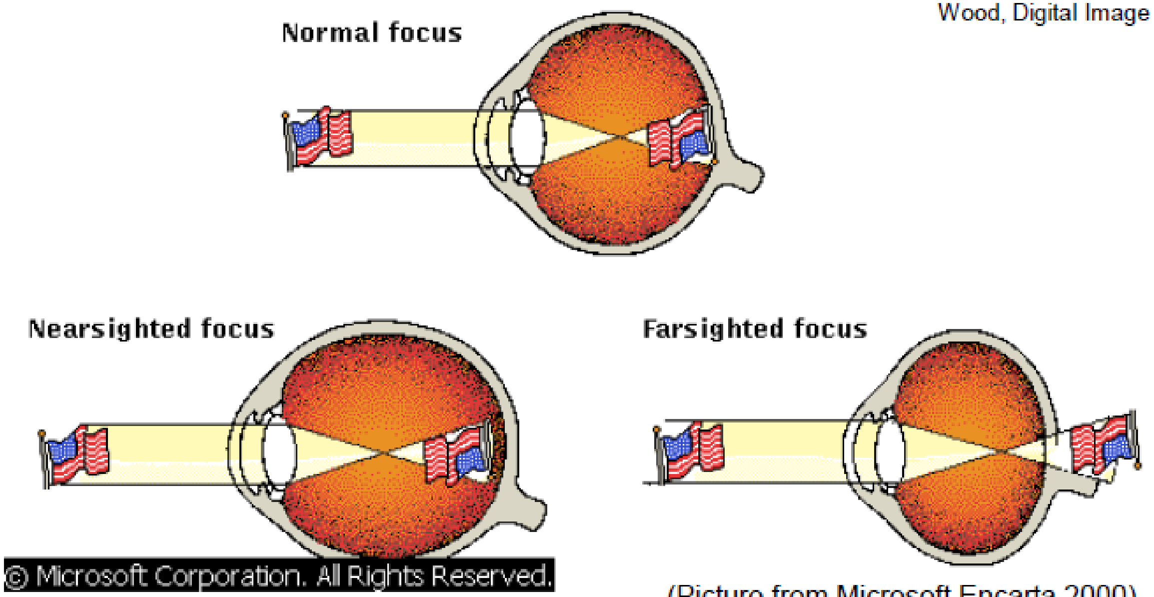
Comparison between rods and cones

Rods	Cones
Used for night vision	Used for day vision
Loss causes night blindness	Loss causes legal blindness
Low spatial resolution with higher noise	High spatial resolution with lower noise
Not present in fovea	Concentrated in fovea
Slower time response to light	Quicker time response to light
One type of photosensitive pigment	Three types of photosensitive pigment
Emphasis on motion detection	Emphasis on detecting fine detail

Image Formation in the Human Eye



(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.



(Picture from Microsoft Encarta 2000)

Human Visual Perception

- Light intensity:
  - The lowest (darkest) perceptible intensity is the scotopic threshold
  - The highest (brightest) perceptible intensity is the glare limit
  - The difference between these two levels is on the order of 10^{10}
  - We can't discriminate all these intensities at the same time! We adjust to an average value of light intensities and then discriminate around the average.

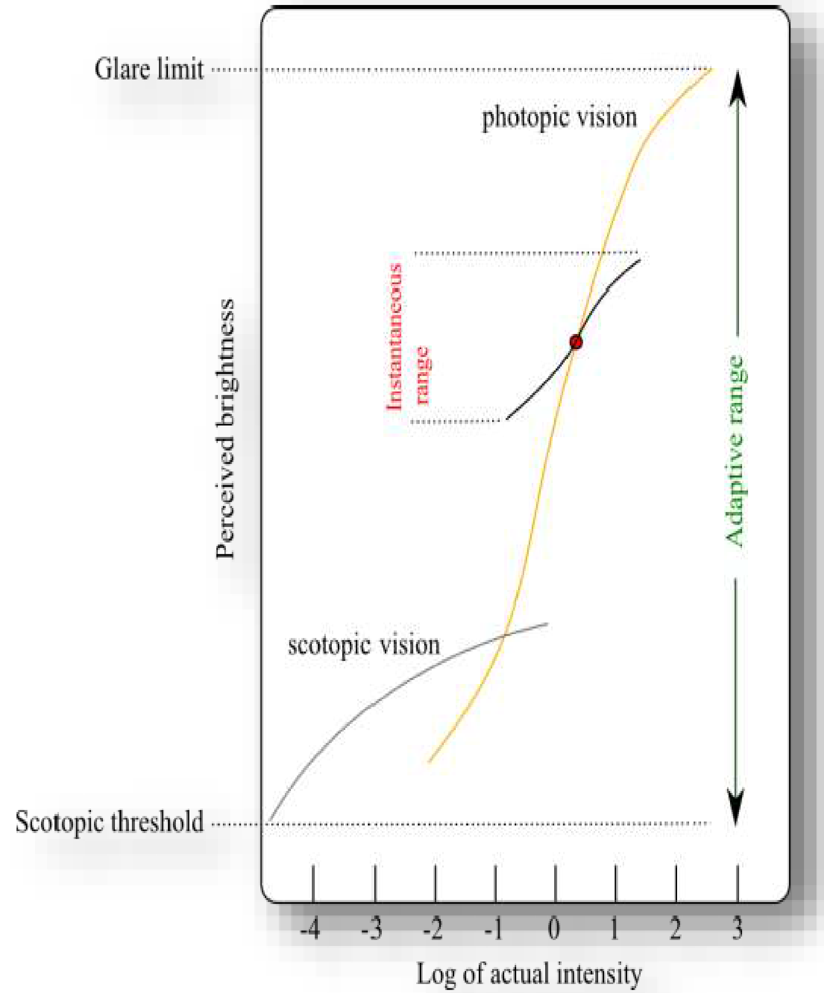
Human Visual Perception

Log compression.

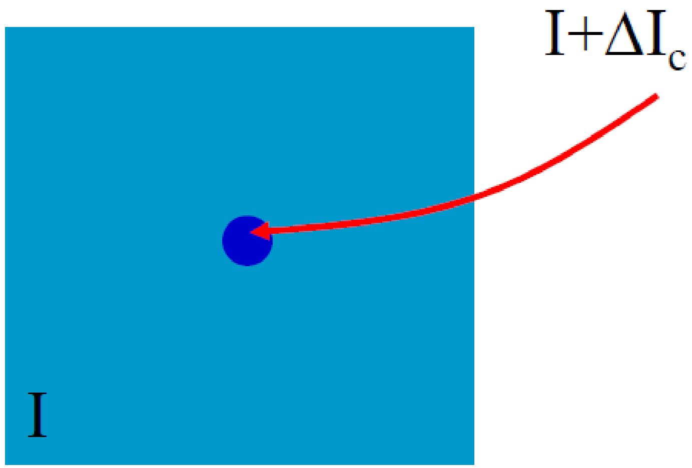
- Experimental results show that the relationship between the perceived amount of light and the actual amount of light in a scene are generally related logarithmically.
  - The human visual system perceives brightness as the logarithm of the actual light intensity and interprets the image accordingly.
  - Consider, for example, a bright light source that is approximately 6 times brighter than another. The eye will perceive the brighter light as approximately twice the brightness of the darker.

Brightness Adaption

- Actual light intensity is (basically) log-compressed for perception.
- Human vision can see light between the glare limit and scotopic threshold but not all levels at the same time.
- The eye adjusts to an average value (the red dot) and can simultaneously see all light in a smaller range surrounding the adaptation level.
- Light appears black at the bottom of the instantaneous range and white at the top of that range.



Contrast Sensitivity



Weber's ratio: $\Delta I_c/I$

Good brightness discrimination

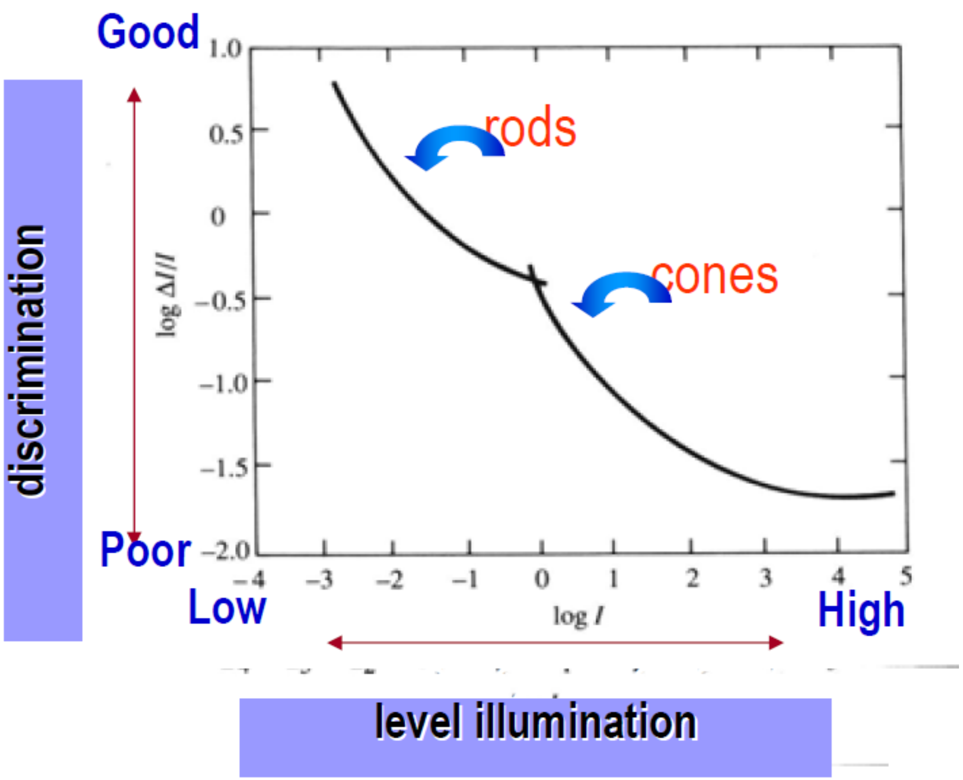
⇨ $\Delta I_c I$

Bad brightness discrimination

⇨ $\Delta I_c/I$ is large.

- The ability of the eye to discrimination b/w change in brightness at any specific adaptation level is of considerable interest.
- I is uniformly illumination on a flat area large enough to occupy the entire field of view.
- ΔIc is the change in the object brightness required to just distinguish the object from the background

Weber Ratio

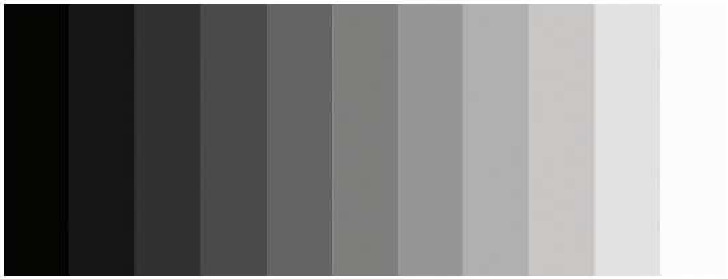


- Brightness discrimination is poor (the Weber ratio is large) at low levels of illumination and improves significantly (the ratio decreases) as background illumination increases.
- Hard to distinguish the discrimination when it is bright area but easier when the discrimination is on a dark area.

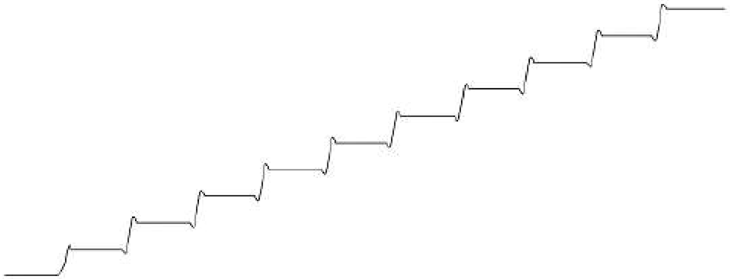
Brightness Adaptation and Mach Banding

- When viewing any scene:
  - The eye rapidly scans across the field of view while coming to momentary rest at each point of particular interest.
  - At each of these points the eye adapts to the average brightness of the local region surrounding the point of interest.
  - This phenomena is known as local brightness adaptation.
    - Mach banding is a visual effect that results, in part, from local brightness adaptation.
    - The eye over-shoots/under-shoots at edges where the brightness changes rapidly. This causes 'false perception' of the intensities

Brightness Adaptation and Mach Banding



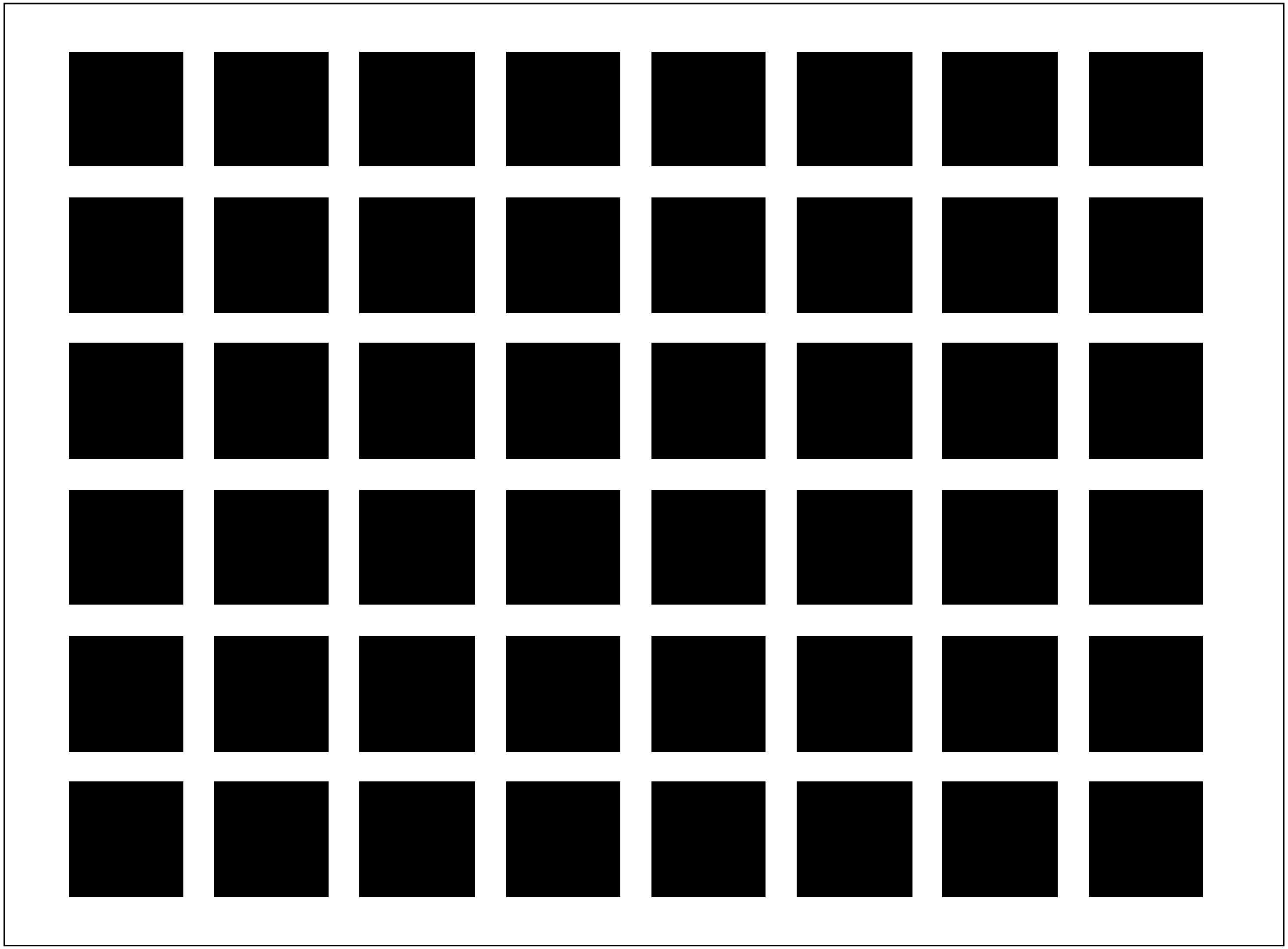
(a) Mach banding.

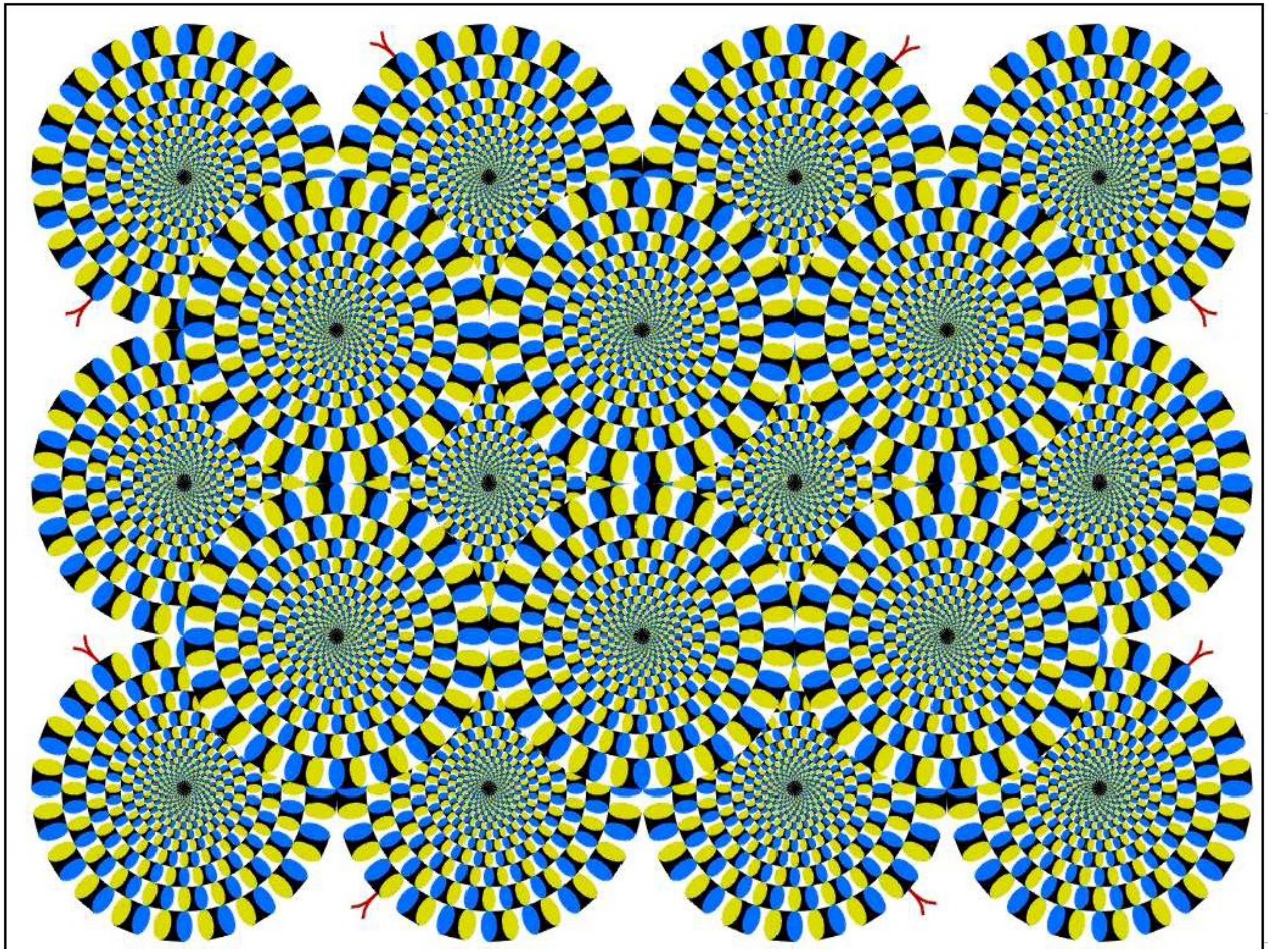


(b) Row profile of perceived brightness.

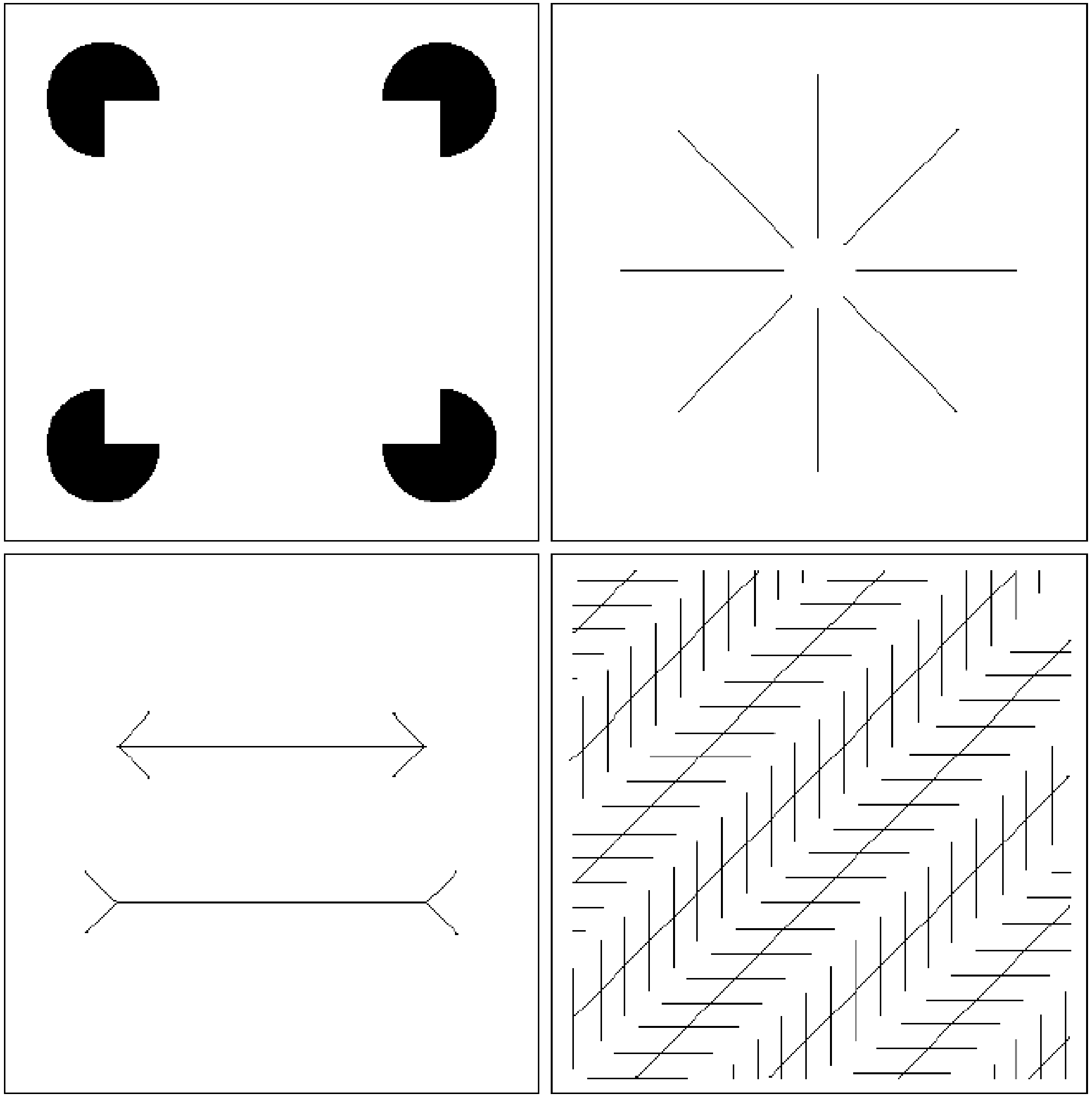
Figure 2.8. Mach banding effect.

Brightness Adaption (Hermann Grid)





Optical Illusion



Simultaneous Contrast

- Simultaneous contrast refers to the way in which two adjacent intensities (or colors) affect each other.
  - Example: Note that a blank sheet of paper may appear white when placed on a desktop but may appear black when used to shield the eyes against the sun.

- Below Figure is a common way of illustrating that the perceived intensity of a region is dependent upon the contrast of the region with its local background.
  - The four inner squares are of identical intensity but are contextualized by the four surrounding squares
  - The perceived intensity of the inner squares varies from bright on the left to dark on the right.

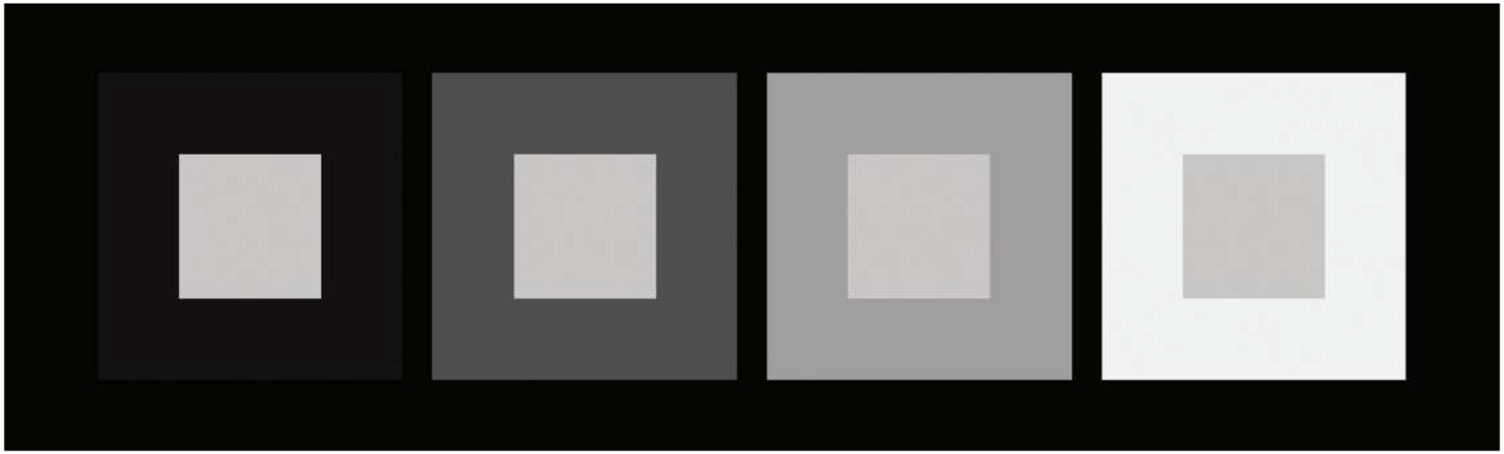
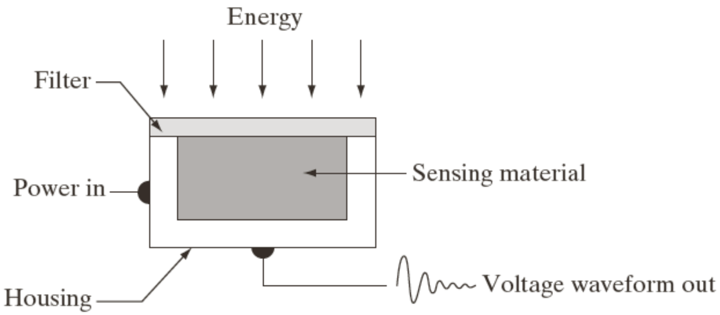
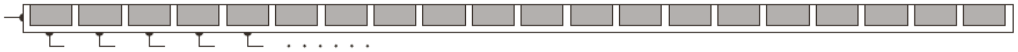


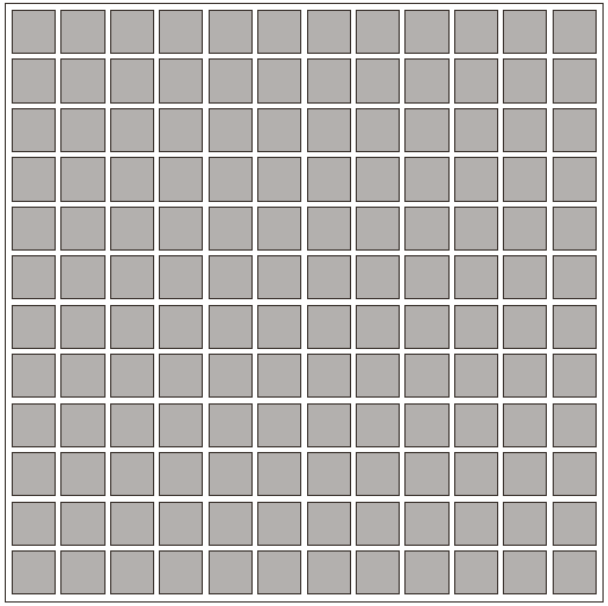
Image Sensing and Acquisition

- Most of the images in which we are interested are generated by the combination of an illumination source and the reflection or absorption of energy from that source by elements of the scene being imaged.

- Three 3 principal sensor arrangements (produce an electrical output proportional to light intensity) used to transform illumination energy into digital images.
  - Single Imaging Sensor
  - Line Sensor
  - Array Sensor







a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

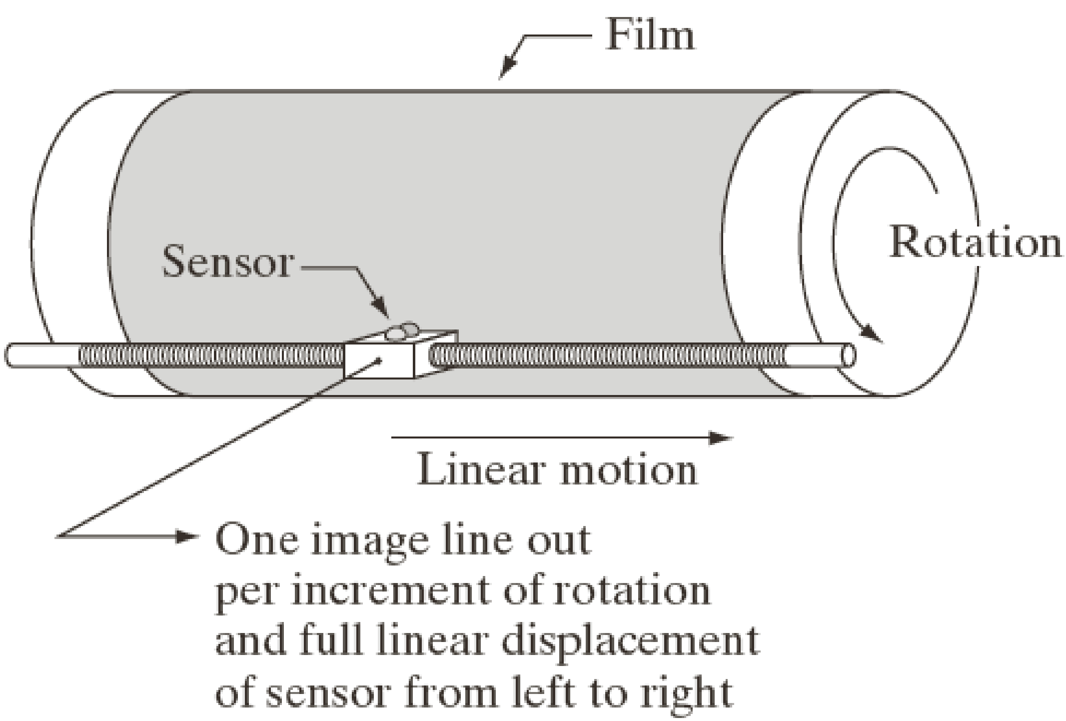
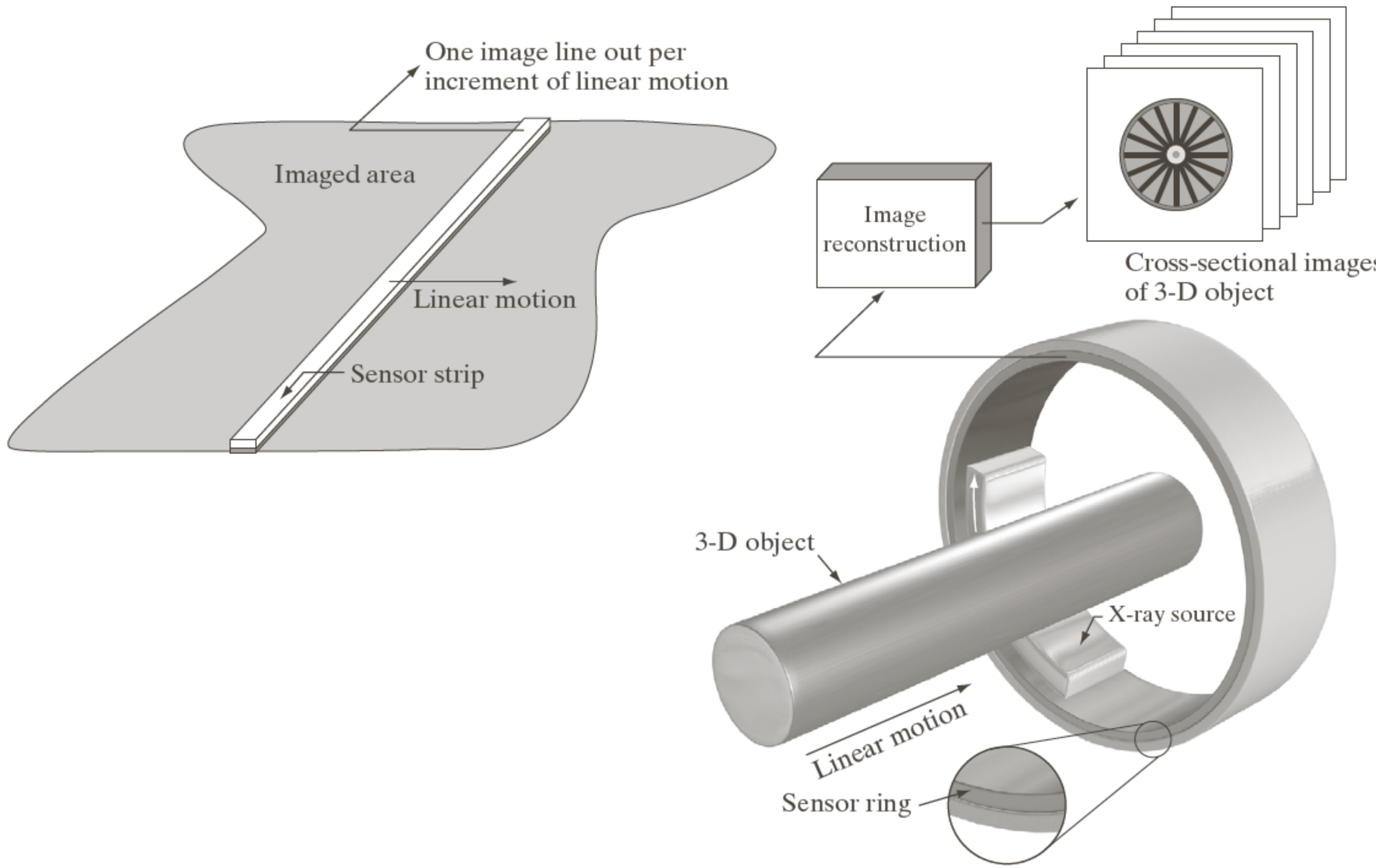


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

Image Acquisition Using Single Sensor

- The most common sensor of this type is the photodiode, which is made of silicon materials and whose output voltage waveform is proportional to light. The use of a filter in front of a sensor improves selectivity.

- 2D image generated by displacement in x- and y directions between the sensor and the area to be imaged.



a b

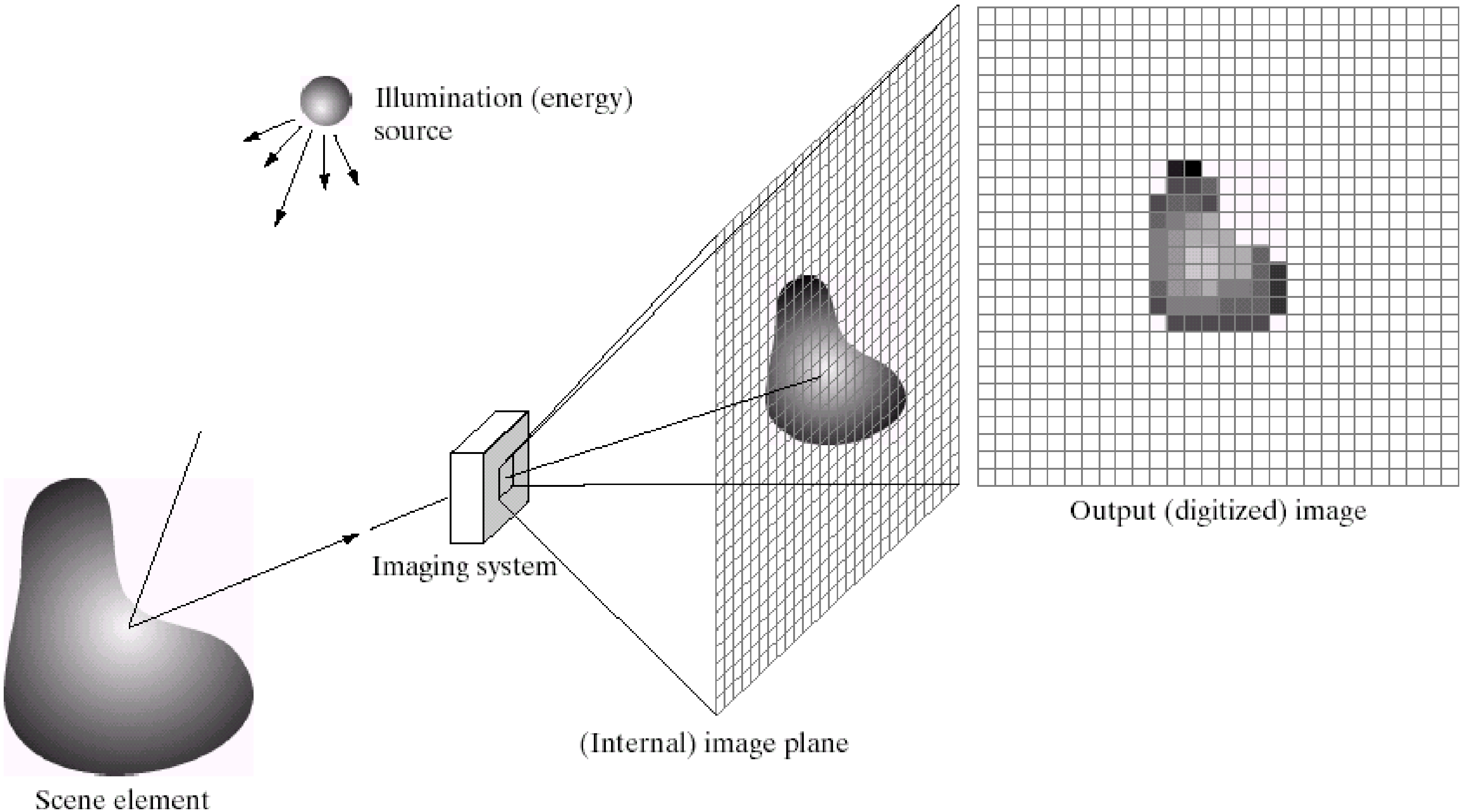
FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

- Sensing devices with 4000 or more in-line sensors are possible. In-line sensors are used routinely in airborne imaging applications, in which the imaging system is mounted on an aircraft that flies at a constant altitude and speed over the geographical area to be imaged.

- One-dimensional imaging sensor strips that respond to various bands of the electromagnetic spectrum are mounted perpendicular to the direction of flight. The imaging strip gives one line of an image at a time, and the motion of the strip completes the other dimension of a two-dimensional image.

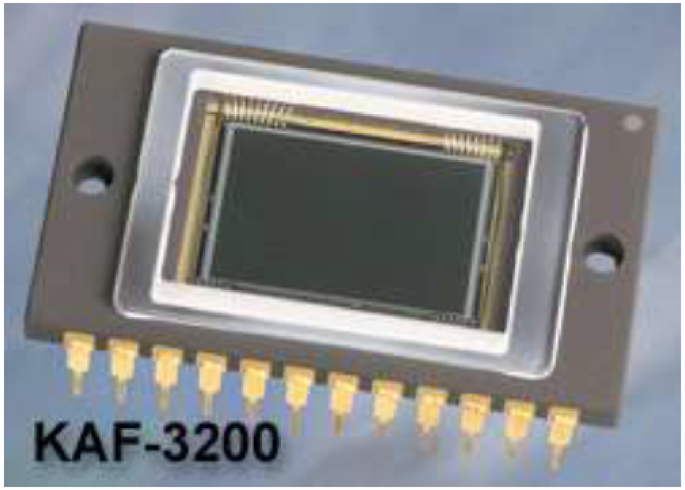
- Sensor strips mounted in a ring configuration are used in medical and industrial imaging to obtain cross sectional ("slice") images of 3-D objects.

- A rotating X-ray source provides illumination and the portion of the sensors opposite the source collect the X-ray energy that pass through the object. This is the basis for medical and industrial computerized axial tomography (CAT) imaging.



a
b
c d e

FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.



CCD KAF-3200E from Kodak.
(2184 x 1472 pixels,
Pixel size 6.8 microns^2)

- Used for convert a continuous image into a digital image
- Contains an array of light sensors
- Converts photon into electric charges accumulated in each sensor unit

Signal

- a signal is a function that carries information.
- Usually content of the signal changes over some set of spatiotemporal dimensions.

Vocabulary:

- **Spatio-temporal:** existing in both space and time.

Time-Varying Signals

- Some signals vary over time:

$$f(t)$$

- for example: audio signal

- may be thought at one level as a collection various tones of differing audible frequencies that vary over time.

Spatially-Varying Signals

- Signals can vary over space as well.
- An image can be thought of as being a function of 2 spatial dimensions:

$$f(x,y)$$

- for monochromatic images, the value of the function is the amount of light at that point.

- Medical CAT and MRI scanners produce images that are functions of 3 spatial dimensions:

$$f(x,y,z)$$

Spatiotemporal Signals

- What do you think a signal of this form is?

$$f(x,y,t)$$

x and y are spatial dimensions;

t is time.

Perhaps this is video signal/animation or other time-varying picture.

Types of Signals

- most naturally-occurring signals are functions having a continuous domain.

- However, signals in a computer have are discrete samples of the continuous domain.

- in other words, signals manipulated by computer have discrete domains.

Analog & Digital

- most naturally-occurring signals also have a real-valued range in which values occur with infinite precision.

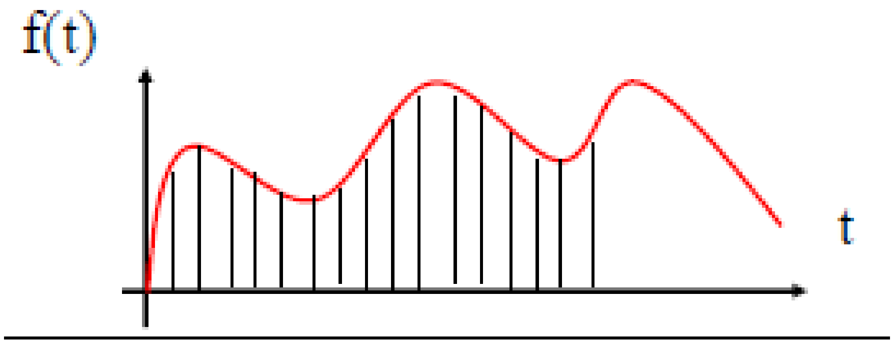
- to store and manipulate signals by computer we need to store these numbers with finite precision. thus, these signals have a discrete range.

signal has continuous domain and range = analog

signal has discrete domain and range = digital

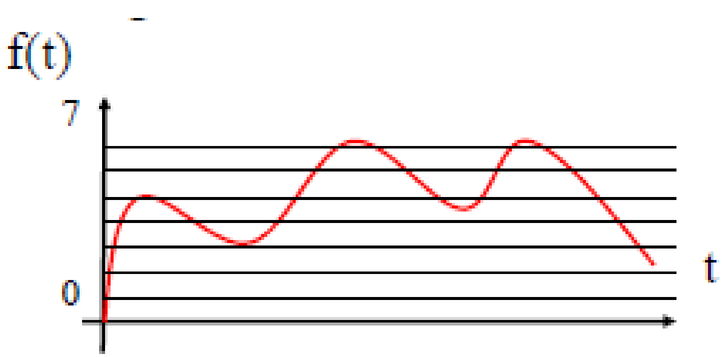
Sampling

- sampling = the spacing of discrete values in the domain of a signal.
- sampling-rate = how many samples are taken per unit of each dimension. e.g., samples per second, frames per second, etc.



Quantization

- Quantization = spacing of discrete values in the range of a signal.
- Usually thought of as the number of bits per sample of the signal. e.g., 1 bit per pixel (b/w images), 16-bit audio, 24-bit color images, etc.



- 8 levels = 2^3: uses 3 bits to represent the value of the function.

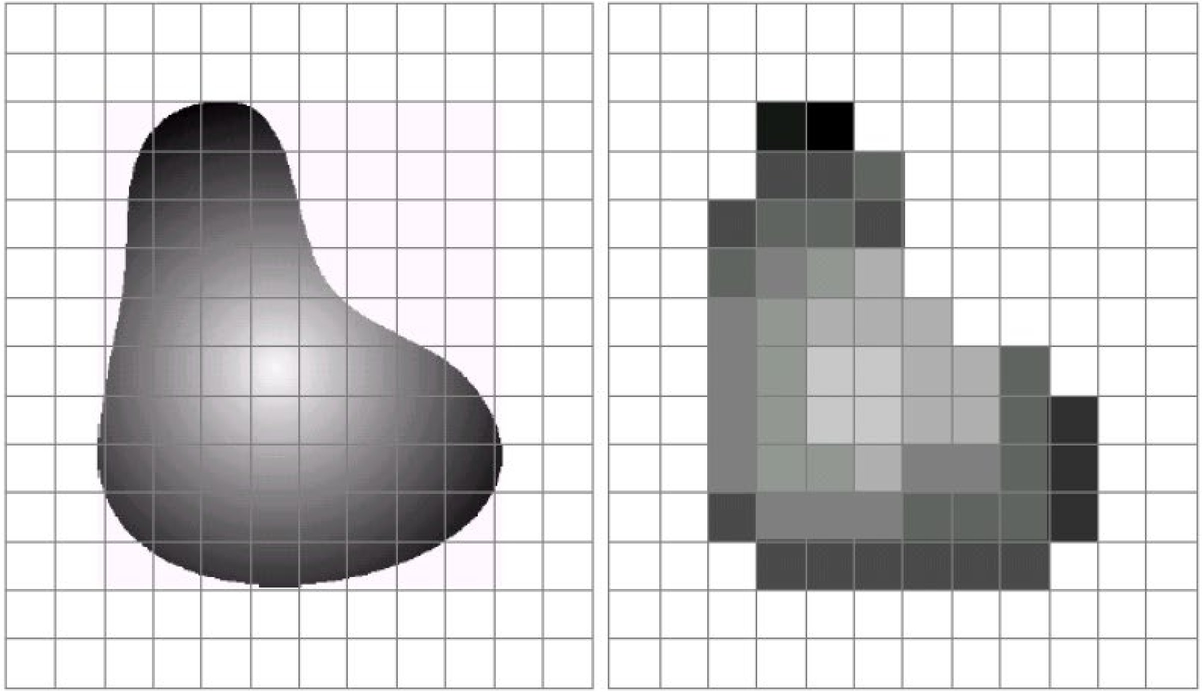


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Image sampling: discretize an image in the spatial domain

Spatial resolution / image resolution: pixel size or number of pixels

Digital Image Representation

- A digital image is an image ***f(x,y)*** that has been digitized both in spatial coordinates and brightness.

- the value of f at any point ***(x,y)*** is proportional to the brightness (or gray level) of the image at that point.

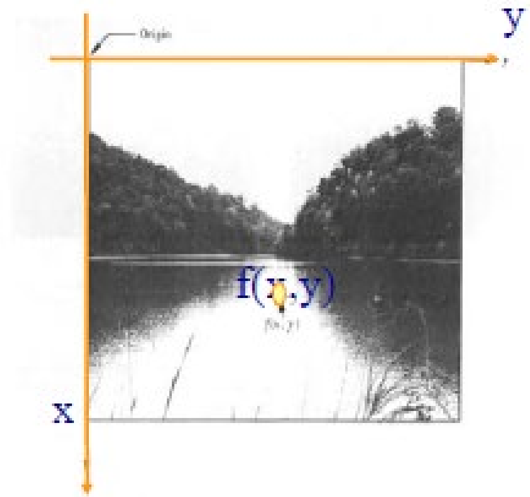


Figure 1.5 Axis convention used for digital image representation.

Light – Intensity Function

- Image refers to a 2-D light – intensity function ***f(x,y)*.**

- the amplitude of ***f*** at spatial coordinates ***(x,y)*** gives the intensity (brightness) of the image at that point.

- light is a form of energy thus ***f(x,y)*** must be nonzero and finite.

$$0 < f(x, y) < \infty$$

Illumination and Reflectance

- the basic nature of ***f(x,y)*** may be characterized by 2 components:
  - the amount of source light incident on the scene being viewed –

    Illumination, *i(x,y)*

  - the amount of light reflected by the objects in the scene

    Reflectance, *r(x,y)*

Illumination and Reflectance

$$f(x, y) = i(x, y)r(x, y)$$

$$0 < i(x, y) < \infty$$

Determined by the nature of the light source

$$0 < r(x, y) < 1$$

determined by the nature of the objects in a scene – bounded from total absorption to total reflectance

Gray Level

- we call the intensity of a monochrome image ***f*** at coordinate ***(x,y)*** the gray level ***(l)*** of the image at that point.

- thus, ***l*** lies in the range ***Lmin*** $\leq$ l $\leq$ ***Lmax***

- ***Lmin*** is positive and ***Lmax*** is finite.
- gray scale = [***Lmin***, ***Lmax***]
- common practice, shift the interval to [***0***, ***L***]
- ***0 = black , L = white***

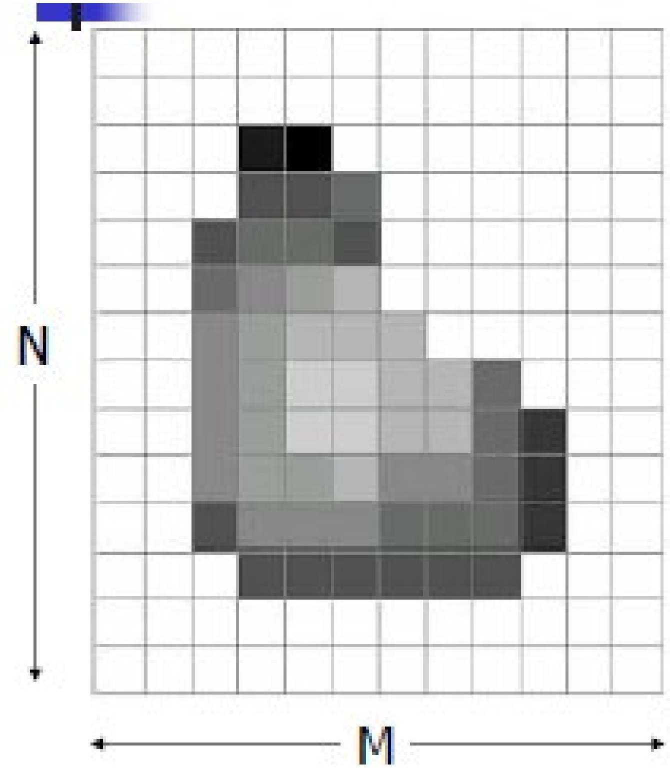
Number of bits

- The number of gray levels typically is an integer power of 2

$$L = 2^k$$

- Number of bits required to store a digitized image

$$b = M \times N \times k$$



Resolution

- The resolution can be defined in many ways. Such as pixel resolution, spatial resolution, temporal resolution, spectral resolution.

- Out of which we are going to discuss pixel resolution.

- In pixel resolution, the term resolution refers to the total number of count of pixels in an digital image. For example. If an image has M rows and N columns, then its resolution can be defined as M X N.

Resolution

- Resolution (how much you can see the detail of the image) depends on sampling and gray levels.
- the bigger the sampling rate (n) and the gray scale (g), the better the approximation of the digitized image from the original.
- the more the quantization scale becomes, the bigger the size of the digitized image.

Resolution - Megapixels

- We can calculate mega pixels of a camera using pixel resolution.
  - Column pixels (width) X row pixels (height) / 1 Million.
- The size of an image can be defined by its pixel resolution.
  - Size = pixel resolution X bpp (bits per pixel)

Calculating the mega pixels of the camera

- Lets say we have an image of dimension: 2500 X 3192.
- Its pixel resolution = 2500 * 3192 = 7982350 bytes.
- Dividing it by 1 million = 7.9 = 8 mega pixel (approximately).

Aspect Ratio

- Another important concept with the pixel resolution is aspect ratio.

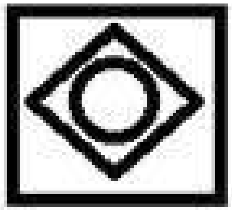
- Aspect ratio is the ratio between width of an image and the height of an image. It is commonly explained as two numbers separated by a colon (8:9). This ratio differs in different images, and in different screens. The common aspect ratios are:
  - 1.33:1, 1.37:1, 1.43:1, 1.50:1, 1.56:1, 1.66:1, 1.75:1, 1.78:1, 1.85:1, 2.00:1, e.t.c

Advantage of Aspect Ratio

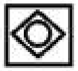
- Aspect ratio maintains a balance between the appearance of an image on the screen, means it maintains a ratio between horizontal and vertical pixels. It does not let the image to get distorted when aspect ratio is increased.

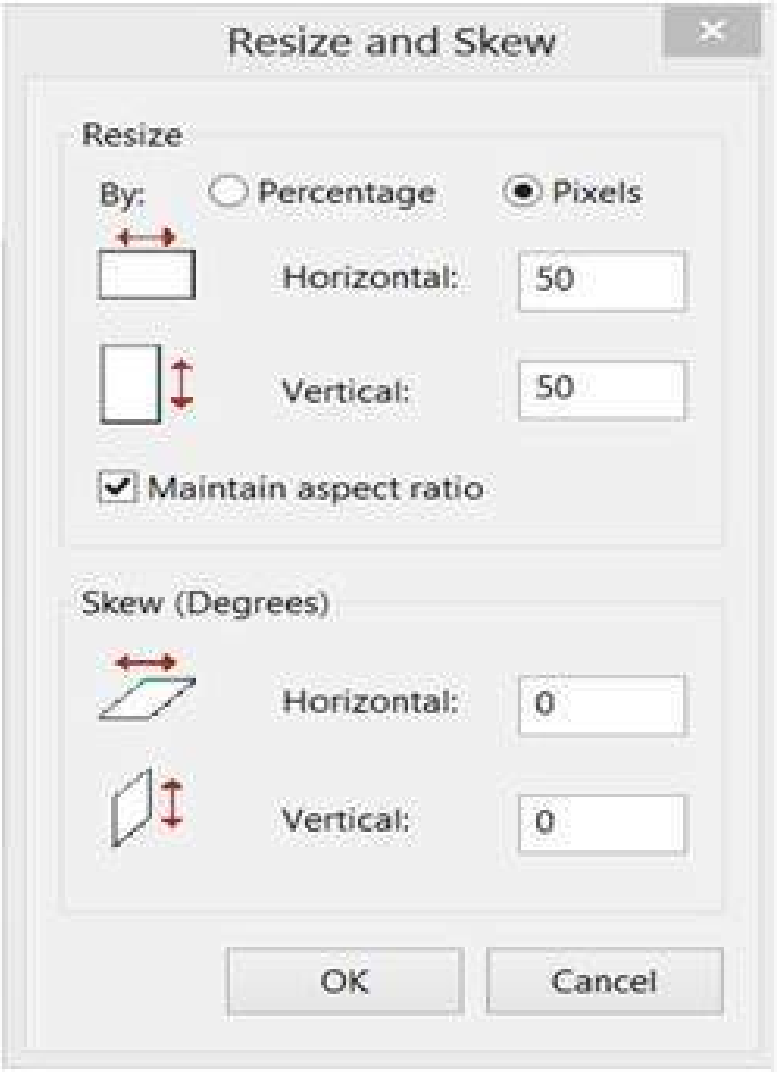
- For example
  - This is a sample image, which has 100 rows and 100 columns. If we wish to make is smaller, and the condition is that the quality remains the same or in other way the image does not get distorted, here how it happens.

Original image



Changing the rows and columns by maintain the aspect ratio in MS Paint





- If you are given an image with aspect ratio of 6:2 of an image of pixel resolution of 480000 pixels given the image is an gray scale image.

- And you are asked to calculate two things.
  - Resolve pixel resolution to calculate the dimensions of image
  - Calculate the size of the image

Solution:

Given:

Aspect ratio: c:r = 6:2

Pixel resolution: c * r = 480000

Bits per pixel: grayscale image = 8bpp

Find:

Number of rows = ?

Number of cols = ?

Equation 1. c:r = 6:2 → c = 6 r / 2

Equation 2. c = 480000/r

Comparing both equations → $\frac{6r}{2} = \frac{480000}{r}$

$$r^2 = \sqrt{\frac{480000*2}{6}}$$

That gives r = 400.

Put r in equation 1, we get → c = 1200.

So rows = 400 cols = 1200.

- Solving 2nd part:

Size = rows * cols * bpp

Size of image in bits = 400 * 1200 * 8 = 3840000 bits

Size of image in bytes = 480000 bytes

Size of image in kilo bytes = 48 kb (approx).