Unit 1

DIGITAL IMAGE FUNDAMENTALS

What Is Digital Image?

An image may be defined as a two-dimensional function, f(x, y), where x and y are *spatial* (plane) coordinates, and the amplitude of ‘f ’ at any pair of coordinates (x, y) is called the *intensity* or *gray level* of the image at that point.

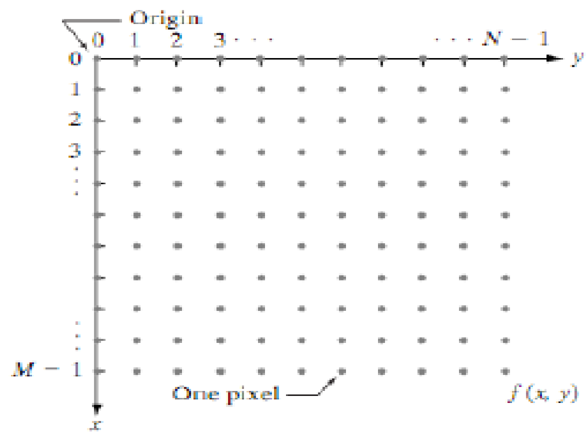


Fig: Coordinate convention used to represent digital images

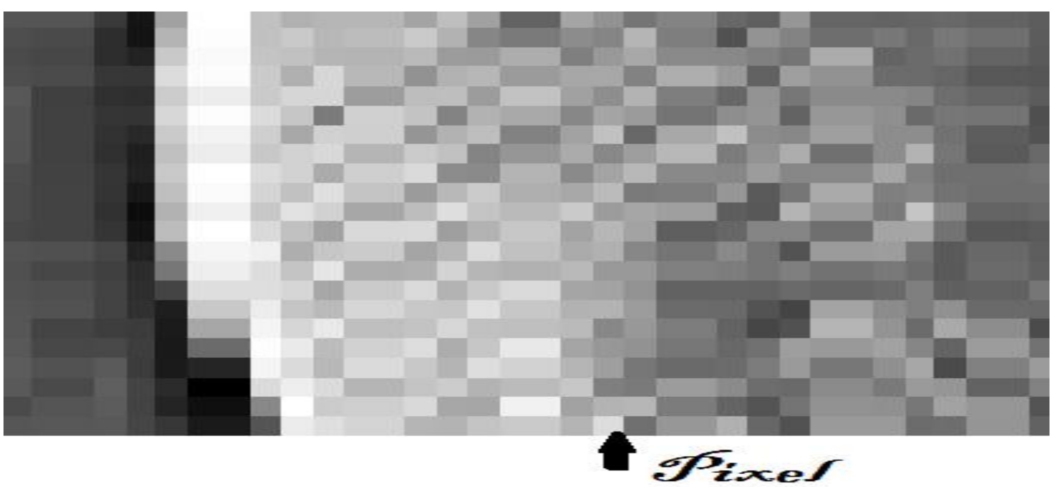


Fig: Zoomed image, where small white boxes inside the image represent pixels

Digital image is composed of a finite number of elements referred to as *picture elements*, *image elements*, *pels*, and *pixels*. *Pixel* is the term most widely used to denote the elements of a digital image.

We can represent M*N digital image as compact matrix as shown in fig below

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

When x, y, and the amplitude values of f are all finite, discrete quantities, we call the image a *digital image*. The field of *digital image processing* refers to processing digital images by means of a digital computer.

Advantages of Digital Images

The processing of images is faster and cost effective.

Digital images can be effectively stored and efficiently transmitted from one place to another.

Whenever the image is in digital format, the reproduction of the image is both faster and cheaper.

When shooting a digital image, one can immediately see if the image is good or not.

Drawbacks of digital Images

A digital file cannot be enlarged beyond a certain size without compromising on quality

The memory required to store and process good quality images is very high.

Fundamental Steps in Digital Image Processing

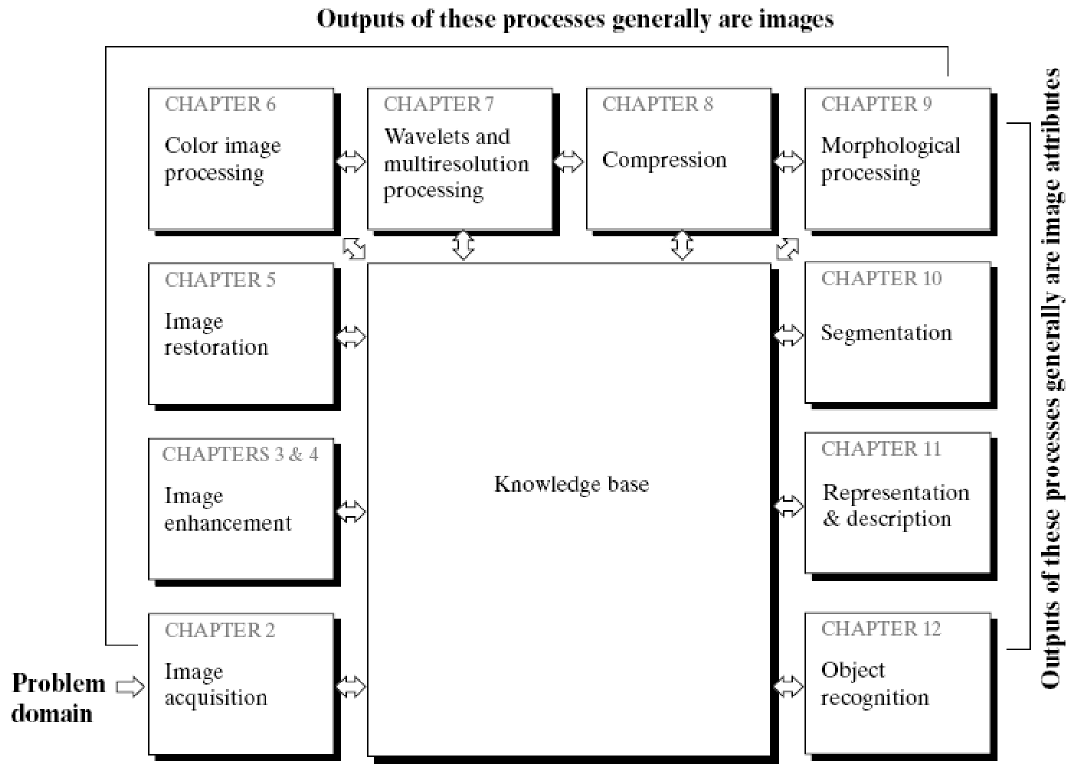
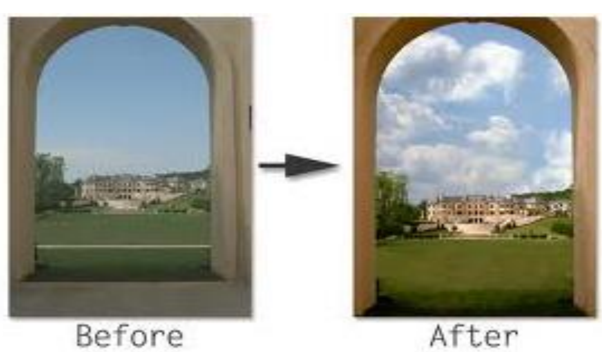


Fig 1.1: Steps involved in an Digital Image Processing

Image acquisition is the creation of digital images, typically from a physical scene. The most usual method is by digital photography with a digital camera. Generally, the image acquisition stage involves preprocessing, such as scaling.

Image enhancement: Basically, the idea behind enhancement techniques is to bring detail that is obscured(unclear), or simply to highlight certain features of interest in an image. A familiar example of enhancement is when we increase the contrast of an image because "it looks better." It is important to keep in mind that enhancement is a very subjective (Personal opinion) area of image processing.



<u>Image restoration</u> is an area that also deals with improving the appearance of an image. However, unlike enhancement, which is subjective, image restoration is objective, in the sense that restoration techniques tend to be based on mathematical or probabilistic models of image degradation. Enhancement, on the other hand, is based on human subjective preferences regarding what constitutes a "good" enhancement result.

Image restoration is the operation of taking a corrupted/noisy image and we to try to remove the noise content, such that output will be same as original image. In Image enhancement we are not dealing with noisy image. We take a low contrast image and try to enhance in order to make it look better.

<u>Color image processing</u> is an area that has been gaining in importance because of the significant increase in the use of digital images over the Internet.

<u>Wavelets</u> are the foundation for representing images in various degrees of resolution. In particular, this material is used in this book for image data compression and for pyramidal representation, in which images are subdivided successively into smaller regions.

<u>Compression</u> as the name implies, deals with techniques for reducing the storage required to save an image, or the bandwidth required to transmit it.

<u>Morphological processing</u> is useful for extracting image components that are useful in the representation and description of shape.

<u>Segmentation</u> procedures partition an image into its constituent parts or objects. In general, autonomous segmentation is one of the most difficult tasks in digital image processing. Image segmentation is typically used locate objects and boundaries (lines, curves etc) in image.

<u>Representation and description</u> there are two types of data representation. (i) Boundary representation (ii) Regional representation. Boundary representation is appropriate when the focus is on external shape characteristics, (eg) faces, corners. Regional representation is appropriate when the focus is on internal properties, such as texture or skeletal shape
Description, also called *feature selection*, deals with extracting attributes that result in some quantitative information of interest or are basic for differentiating one class of objects from another.

<u>Recognition</u> is the process that assigns a label (e.g., "vehicle") to an object based on its descriptors.

<u>Knowledge Base:</u> In addition to guiding the operation of each processing module, the knowledge base also controls the interaction between modules

Components of an Image Processing System

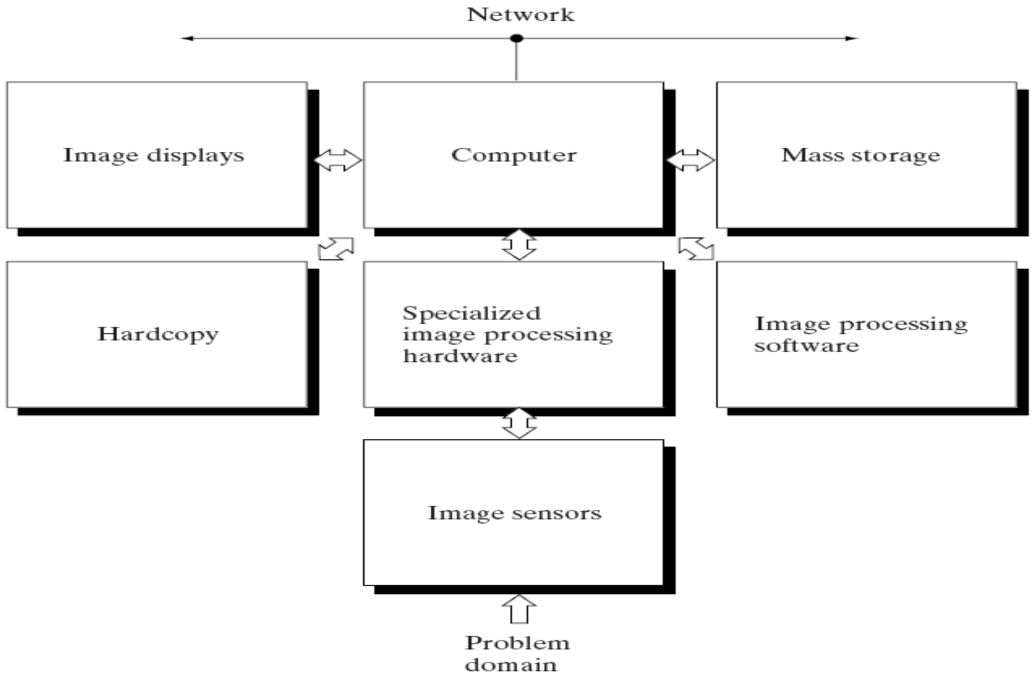


Fig 1.2: Components involved in IP

Sensors produce an electrical output proportional to light intensity.

With reference to ***sensing***, two elements are required to acquire digital images. The first is a physical device(sensor) that is sensitive to the energy radiated by the object we wish to image. The second, called a *digitizer*, is a device for converting the output of the physical sensing device into digital form. For instance, in a digital video camera, the sensors produce an electrical output proportional to light intensity. The digitizer converts these outputs to digital data.

Specialized image processing hardware usually consists of the digitizer, plus hardware that performs other primitive operations, such as an arithmetic logic unit (ALU). One example of how an ALU is used is in averaging images as quickly as they are digitized, for the purpose of noise reduction. This type of hardware sometimes is called a *front-end subsystem*.In other words, this unit performs functions that require fast data throughputs (e.g., digitizing and averaging video images at 30 frames/s) that the typical main computer cannot handle.

The ***computer*** in an image processing system is a general-purpose computer and can range from a PC to a supercomputer. In dedicated applications, sometimes specially designed computers are used to achieve a required level of performance, but our interest here is on general-purpose image processing systems. In these systems, almost any well-equipped PC-type machine is suitable for offline image processing tasks.

Software for image processing consists of specialized modules that perform specific tasks. A well-designed package also includes the capability for the user to write code.

Mass storage capability is a must in image processing applications. An image of size 1024*1024 pixels, in which the intensity of each pixel is an 8-bit quantity, requires one megabyte of storage space if the image is not compressed. Digital storage for image processing applications falls into three principal categories: (1) short term storage for use during processing, (2) on-line storage for relatively fast recall, and (3) archival storage, characterized by infrequent access. Storage is measured in bytes (eight bits), Kbytes (one thousand bytes), Mbytes (one million bytes), Gbytes (meaning giga, or one billion, bytes), and T bytes (meaning tera, or one trillion, bytes).
One method of providing short-term storage is computer memory. Another is by specialized boards, called *frame buffers*, that store one or more images and can be accessed rapidly, usually at video rates (e.g., at 30 complete images per second. Online storage generally takes the form of magnetic disks or optical-media storage.

Image displays in use today are mainly color (preferably flat screen) TV monitors

Hardcopy devices for recording images include laser printers, inkjet units. But paper is the obvious medium of choice for written material.

Networking means exchange of information or services (eg through internet) among individuals, groups, or institutions. Networking is almost a default function in any computer system in use today. Because of the large amount of data inherent in image processing applications, the key consideration in image transmission is bandwidth.

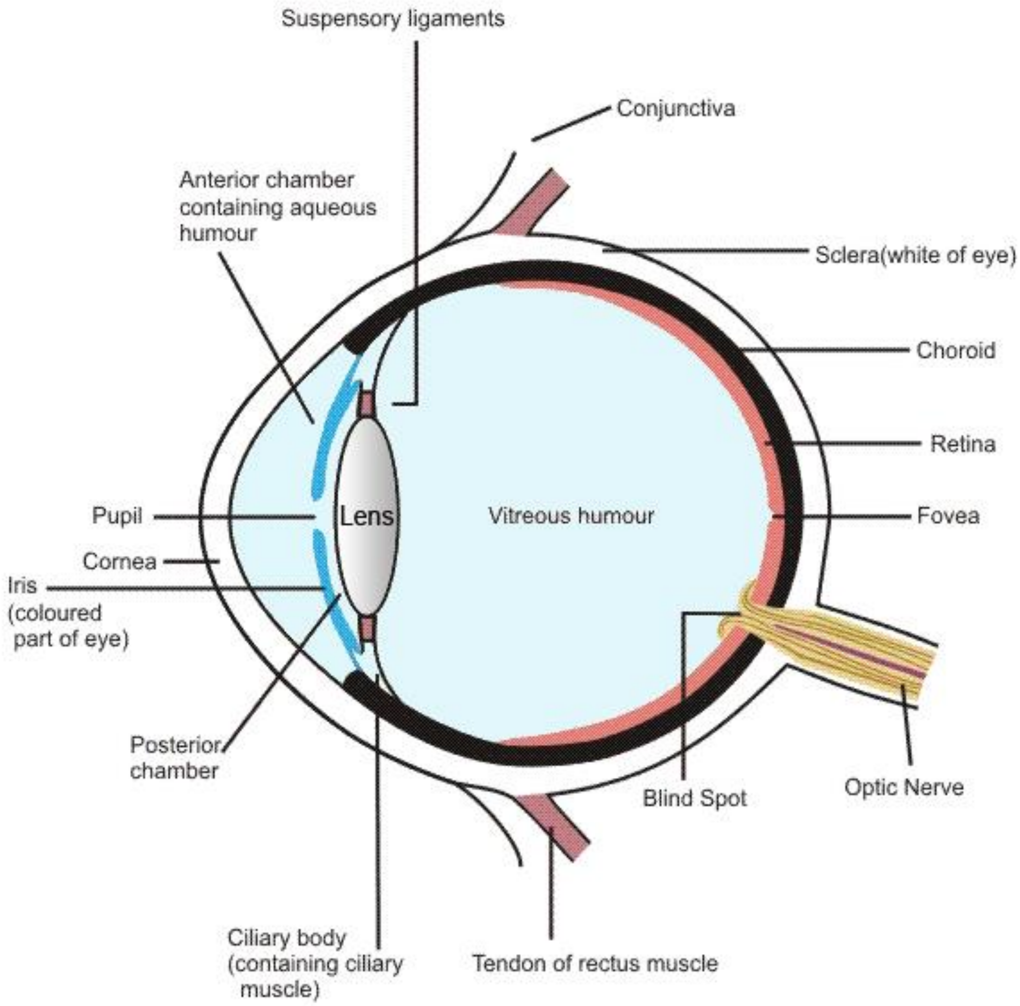


Figure 1: Cross section of a human eye

Human Eye

In Fig 1 is shown a cross-section of human eye. The main elements of the eye are as follows:

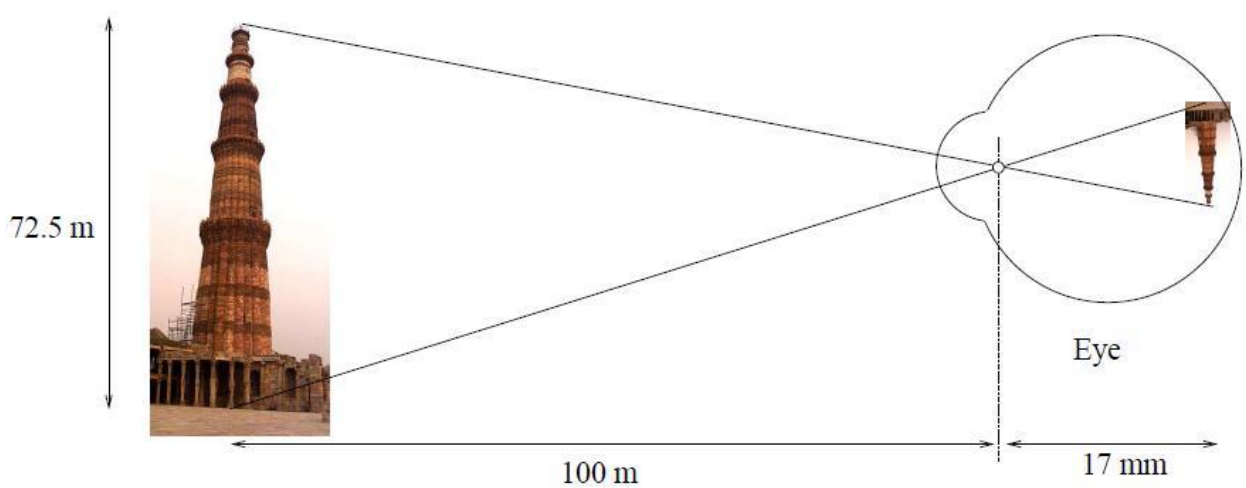
The eye ball	The eye ball is approximately spherical, with the vertical measure of it being approximately 24 mm, slightly lesser than the horizontal width. The field of view covers 1600(width) × 1350 height area. Anterior of the eye has the outer coating cornea while the posterior has the outer layer of sclera.

Cornea	The cornea is a transparent, curved, refractive window through which the light enters the eye. This segment (typically 8 mm in radius) is linked to the larger unit, the sclera, which extends and covers the posterior portion of the optic globe. The cornea and sclera are connected by a ring called the limbus.
Iris, pupil	The pupil is the opening at the center of the iris. It controls the amount of light entering the eye ball. Its diameter varies from 1 to 8 mm in response to illumination changes. In low light conditions it dilates to increase the amount of light reaching the retina. Behind the pupil is the lens of the eye.
Lens	The lens is suspended to the ciliary body by the suspensory ligament, made up of fine transparent fibers. The lens is transparent (has 70% water) and absorbs approximately 8% of the visible light spectrum. The protein in the lens absorbs the harmful infrared and ultraviolet light and prevents damage to the eye.
Choroid	Situated beneath the sclera this membrane contains blood vessels that nourish the cells in the eye. Like the iris, it is pigmented to prevent light from entering the eye from any other direction other than the pupil.
Retina	Beneath the choroid lies the retina, the innermost membrane of the eye where the light entering the eye is sensed by the receptor cells. The retina has 2 types of photoreceptor cells – rods and cones. These receptor cells respond to light in the 330 to 730 nm wavelength range.
Fovea	The central portion of the retina at the posterior part is the fovea. It is about 1.5 mm in diameter.
Rods	There about 100 million rods in the eye they help in dim-light (scotopic) vision. Their spatial distribution is radially symmetric about the fovea, but varies across the retina. They are distributed over a larger area in the retina. The rods are extremely sensitive and can respond even to a single photon.

	However they are not involved in color vision. They cannot resolve fine spatial detail despite high number because many rods are connected to a single nerve.
Cones	There are about 6 million cones in the eye. The cones help in the bright-light (photopic) vision. These are highly sensitive to color. They are located primarily in the fovea where the image is focused by the lens. Each cone cell is connected to its separate nerve ending. Hence they have the ability to resolve fine details.
Blind Spot	Though the photo-receptors are distributed in radially symmetric manner about the fovea, there is a region near the fovea where there are no receptors. This region is called as the blind spot. This is the region where the optic nerve emerges from the eye. Light falling on this region cannot be sensed.

<u>Image formation in the eye</u>

The focal length (distance between the center lens and the retina) of the lens varies between 14 mm and 17 mm. To focus on distant objects, the controlling muscles cause the lens to be relatively flattened. Similarly, these muscles allow the lens to become thicker in order to focus on objects near the eye. An inverted image of the object is formed on the fovea region of the retina.



In above figure the observer is looking at a tree 72.5 m high at a distance of 100m. If h is the height in mm of that object in the retinal image, it is easy to calculate the size of the retinal image of any object. 15/100=h/17 or h=2.55mm

Brightness Adaption and Discrimination

The human eye can adapt to a wide range ($\approx 10^{10}$) of intensity levels. The brightness that we perceive (subjective brightness) is not a simple function of the intensity. In fact the subjective brightness is a logarithmic function of the light intensity incident on the eye.

The HVS(Human Visual System) mechanisms adapt to different lighting conditions. The sensitivity level for a given lighting condition is called as the **brightness adaption level**. As the lighting condition changes, our visual sensory mechanism will adapt by changing its sensitivity. The human eye cannot respond to the entire range of intensity levels at a given level of sensitivity.

Example

If we stand in a brightly lit area we cannot discern details in a dark area since it will appear totally dark. Our photo-receptors cannot respond to the low level of intensity because the level of sensitivity has been adapted to the bright light. However a few minutes after moving into the dark room, our eyes would adapt to the required sensitivity level and we would be able to see in the dark area. This shows that though our visual system can respond to a wide dynamic range, it is possible only by adapting to different lighting conditions. At a given point of time our eye can respond well to only particular brightness levels. The response of the visual system can be characterized with respect to a particular brightness adaption level.

How many different intensities can we see at a given brightness adaption level?

At a given brightness adaption level, a typical human observer can discern between 1 to 2 dozen different intensity changes. If a person is looking at some point on a grayscale image (monochrome image), he would be able to discern about 1 to 2 dozen intensity levels. However, as the eyes are moved to look at some other point on the image, the brightness adaption level would change, and a different set of intensity levels will now become discernable. Hence at a given adaption level the eye cannot discriminate between too many intensity levels, but by varying the adaption level the eye is capable of discriminating a much broader range of intensity levels.

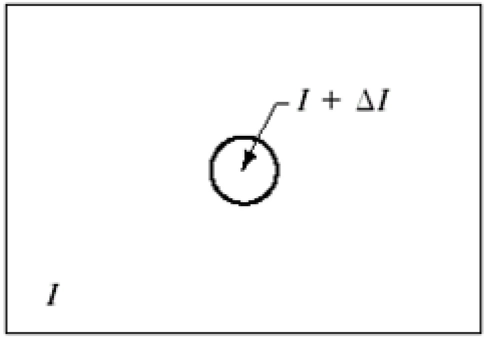


Fig: Basic experimental setup used to characterize brightness discrimination

Example (only for your understanding)

If you lift up and hold a weight of 2.0 kg, you will notice that it takes some effort. If you add to this weight another 0.05 kg and lift, you may not notice any difference between the apparent or subjective weight between the 2.0 kg and the 2.1 kg weights. If you keep adding weight, you may find that you will only notice the difference when the additional weight is equal to 0.2 kg. The increment threshold for detecting the difference from a 2.0 kg weight is 0.2 kg. The just noticeable difference is 0.2 kg. For the weight of magnitude, I, of 2.0 kg, the increment threshold for detecting a difference was a ΔI (pronounces, delta I) of 0.2 kg.

Example (which you have to write in exam):

Further, the discriminability of the eye also changes with the brightness adaption level. Consider a opaque glass, that is illuminated from behind by a light source whose intensity I, can be varied. To this field is added an increment of illumination ΔI, in the form of a short duration flash that appears as a circle at the center of the uniformly illuminated field. If ΔI is not bright enough, the subject says "no" indicating no perceivable change. As ΔI gets stronger, the subject may give a positive response of "yes" indicating a perceived change. The ratio $\frac{\Delta I}{I}$ is called as the weber ratio.

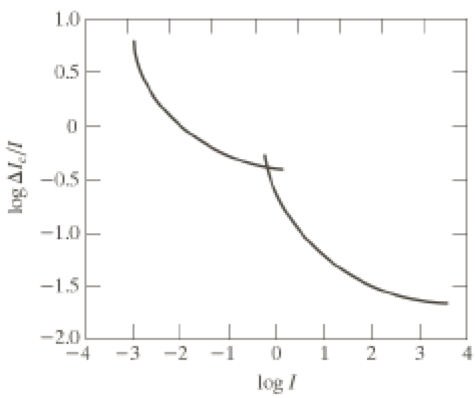


Fig: Typical weber ratio as a function of intensity

A plot of log $\frac{\Delta I}{I}$, as a function of log I has the general shape shown in above fig. This shows brightness discrimination is poor at low levels of illumination, and improves significantly as background illumination increases.

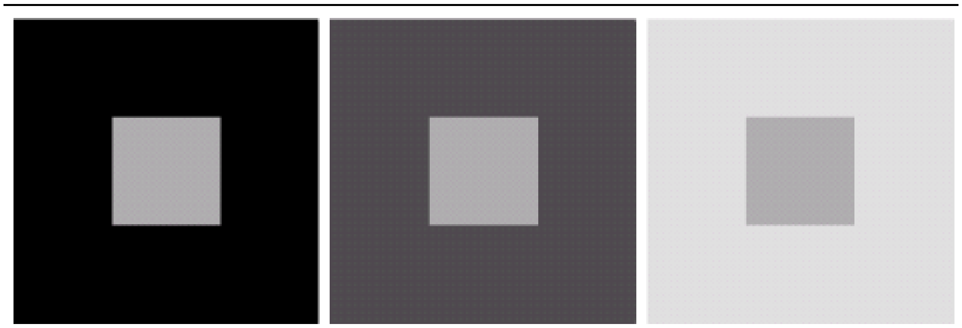
Mach-band effect

Figure 2: Mach Band effect

The Mach-band effect is an optical illusion as shown in Fig 2. The image shown consists of two regions one towards the left and one towards the right which are of uniform intensity. At the middle there is strip on which the intensity changes uniformly from the intensity level on the left side to the intensity level on the right side. If we observe carefully we notice a dark band immediately to the right of the middle strip and a light band immediately to the left of the middle strip. Actually the dark (or light) band has the same intensity level as the right (or left) part of the image, but still we perceive it darker than that. This is the **Mach-band illusion**. It happens because as we look at a boundary between two intensity levels, the eye changes its adaption level and so we perceive the same intensity differently.

Simultaneous contrast

The perceived brightness of a region does not depend on the intensity of the region, but on the context (background or surrounding's) on which it is seen. All the center squares have exactly same intensity. However, they appear to the eye to become darker as the background gets lighter.



An example of *simultaneous contrast*

3. Light

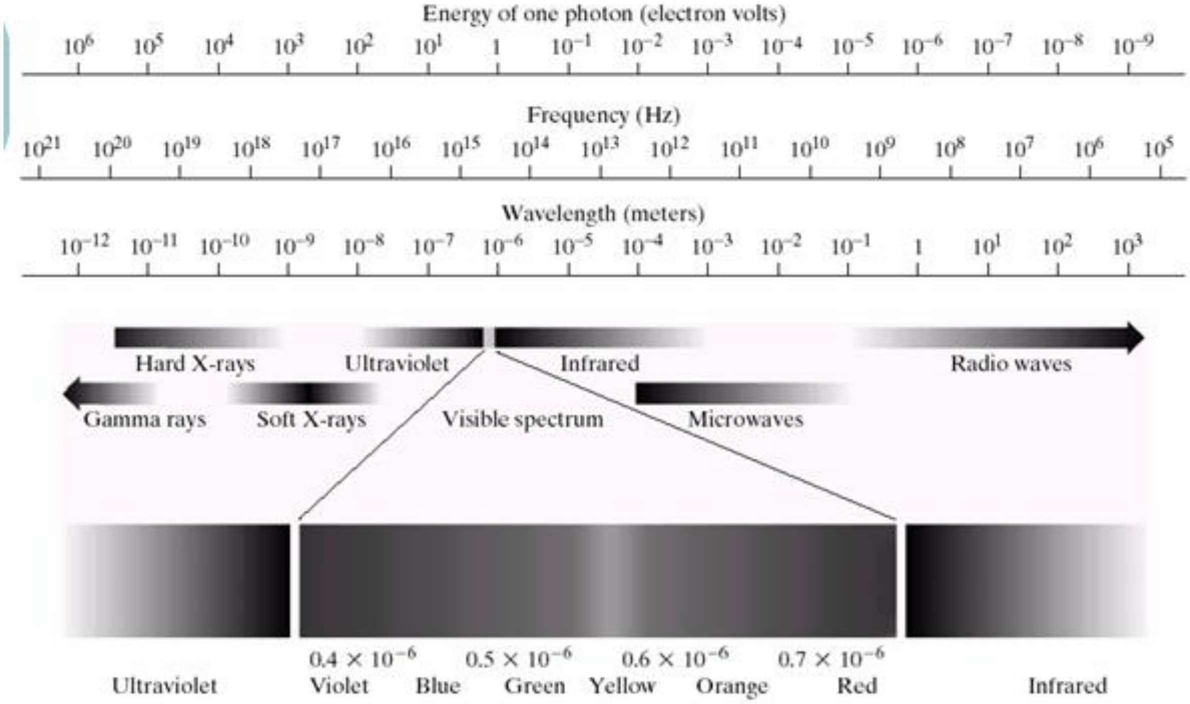


Fig: The electromagnetic spectrum.

The light as we see it illuminating the objects is a very small portion of the electromagnetic spectrum. This is the visible color spectrum which can be sensed by the human eye. Its wavelength spans between 0.43 mm for violet to 0.79 mm for red. The wavelengths outside this range correspond to radiations which cannot be sensed by human eye. For example, the ultra-violet rays, the X-rays and the Gamma rays have progressively shorter wavelengths, and on the other hand, infrared rays, microwaves, and radio waves have progressively larger wavelengths.

The color that we perceive for an object is basically that of the light reflected from the object. Light which gets perceived as gray shades from black to white is called as monochromatic or achromatic light (without color). Light which gets perceived as colored is called as chromatic light. Important terms which characterize a chromatic light source are:

Radiance	The total amount of energy that flows from the light source. Measured in watts.
Luminance	It measures the amount of energy an observer perceives from a light source. Measured in lumens.
Brightness	Indicates how a subject perceives the light in a sense similar to that of achromatic intensity.