DIGITAL IMAGE PROCESSING

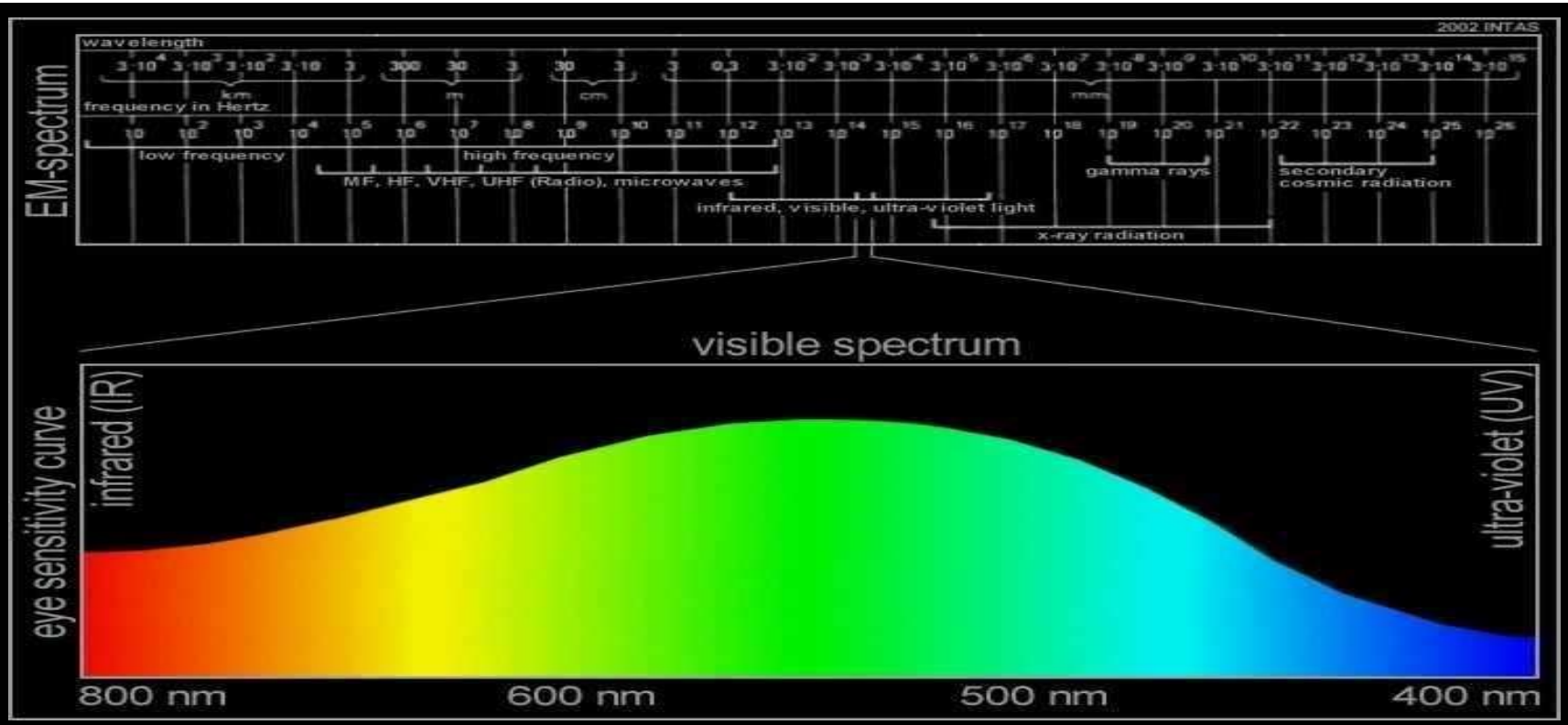
LECTURE # 4

DIGITAL IMAGE FUNDAMENTALS-I

Topics to Cover

- Light and EM Spectrum
- Visual Perception
- Structure Of Human Eyes
- Image Formation on the Eye
- Brightness Adaptation and Discrimination
- Image Acquisition
  - ✓ Image Acquisition using Point Sensor
  - ✓ Image Acquisition using Line Sensor
  - ✓ Image Acquisition using Array Sensor

Light and EM Spectrum



Light & EM Spectrum

- Light is a particular type of EM radiation that can be seen by human eye.
- EM waves are massless particles each traveling in a wavelike pattern and moving at a speed of light.
- We can specify waves through frequency and wavelength.
- The colors that human perceive in an object are determined by the nature of the light reflected from the object.
  - For example green objects reflect light with wavelengths primarily in the 500 to 570nm range while absorbing most of the energy at other wavelengths.

Light & EM Spectrum

- **Achromatic Light**

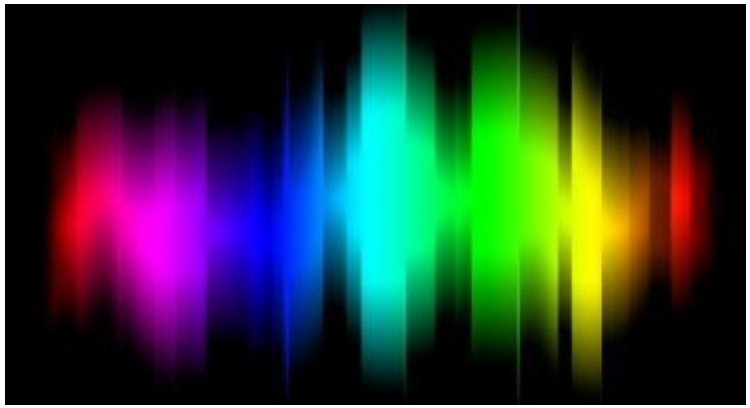
  - ✓ Light that is void of color is called achromatic or monochromatic light
  - ✓ The only attribute of such light is its intensity.
  - ✓ The term gray level generally is used to describe monochromatic intensity because it ranges from black to grays and finally to white

- **Chromatic light**

  - ✓ spans EM spectrum from 0.43 um (violet) to 0.79 um (red).

  - ✓ Three basic quantities are used to describe the quality of a chromatic light source

    1. **Radiance**
    2. **Luminance**
    3. **Brightness**



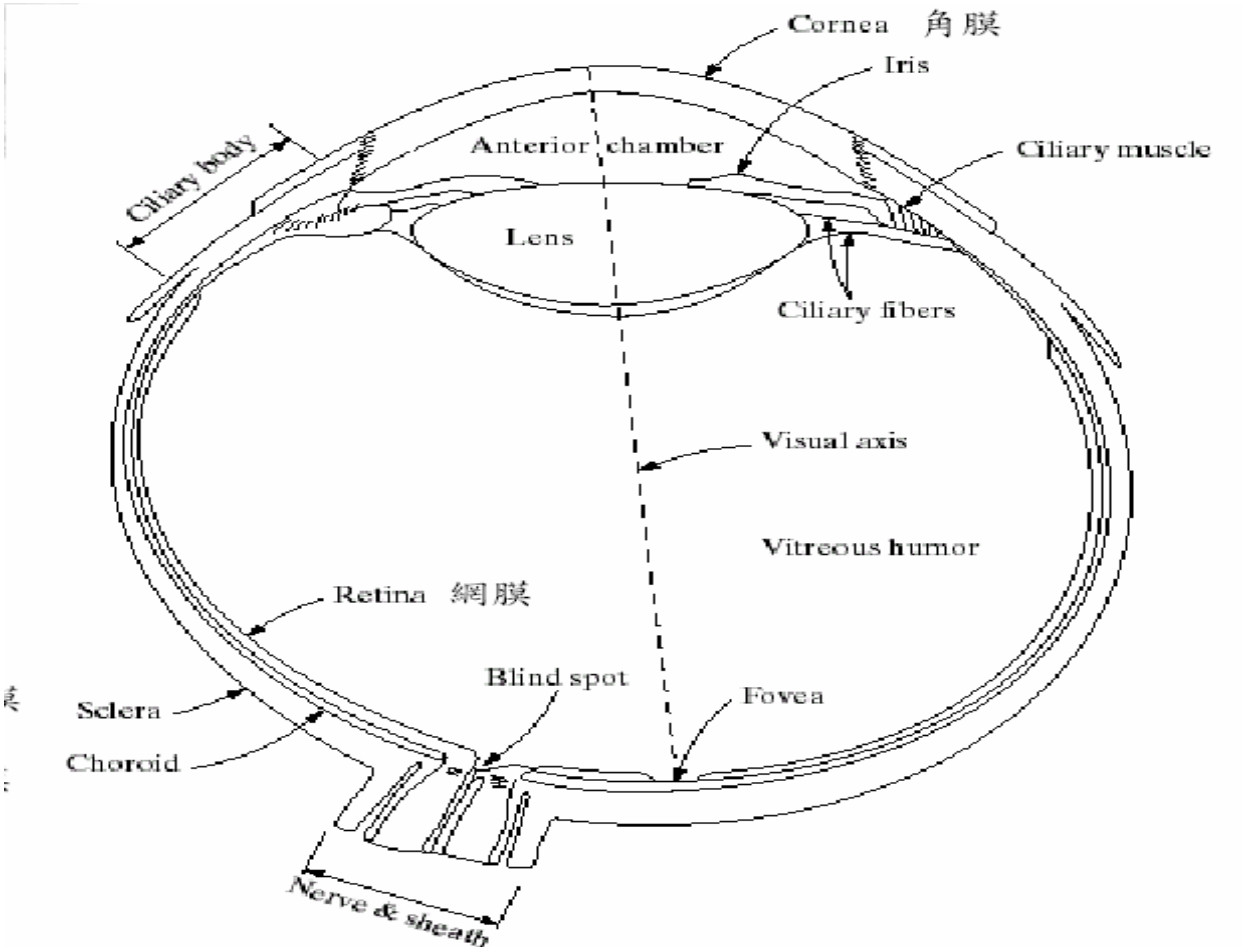
Light & EM Spectrum

- Radiance
  - ✓ The total amount of energy that flows from the light source
  - ✓ Measured in Watts(W)
- Luminance
  - ✓ Gives a measure of the amount of energy an observer perceives from the light source.
  - ✓ Measured in Lumens (lm) or Candela per square meter (cd/m2)
  - ✓ For example light emitted from a source operating in a far infrared region of the spectrum could have significant energy (radiance) but an observer would hardly perceive it; its luminance would be hardly zero
- Brightness
  - ✓ Subjective descriptor of light perception that is practically impossible to measure

Visual Perception

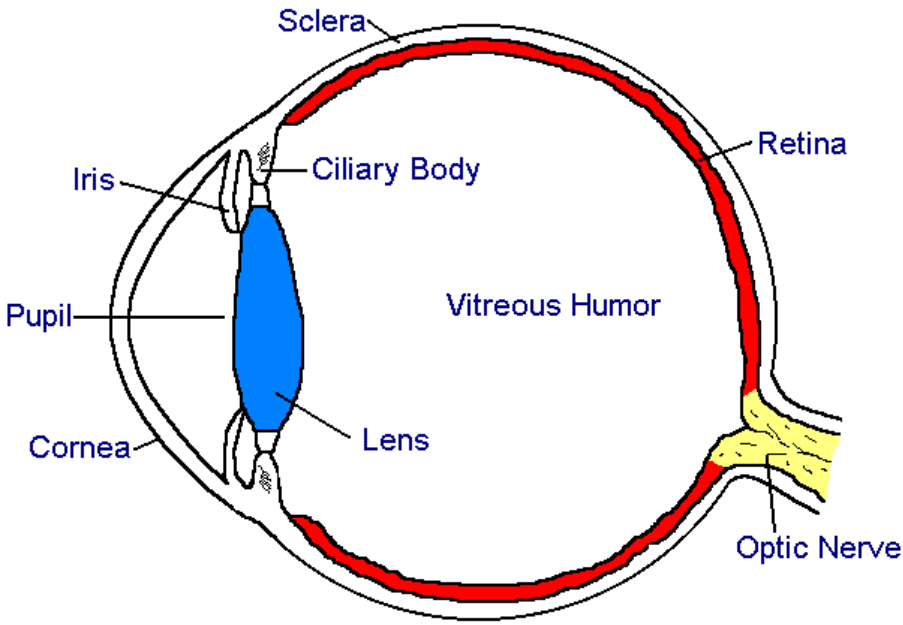
- How images are formed in the eye ?
- Eye's physical limitation ?
- Human visual interpretation of images ?

Structure of Human Eyes



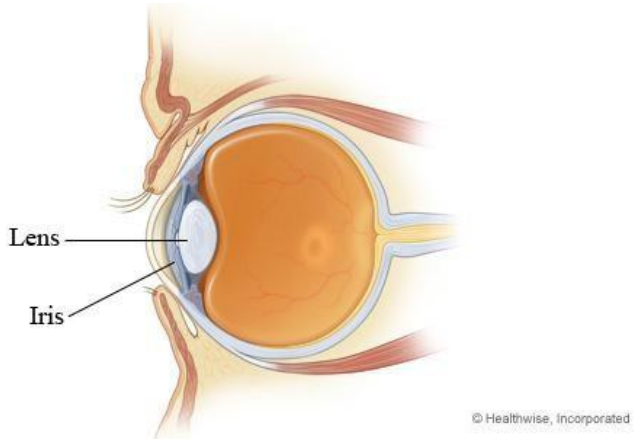
Structure of Human Eyes

- Three membranes enclose the eye:
- Cornea and sclera
  - ✓ Cornea is a tough, transparent tissue cover the anterior surface of the eye.
  - ✓ Sclera is a opaque membrane enclose the remainder of the optic globe.
- Choroid
  - ✓ A network of blood vessels for eye nutrition
  - ✓ At its anterior extreme, it is divided into the *ciliary body* and *iris diaphragm*.
  - ✓ The central opening (the *pupil*) varies in diameter from 2 to 8 mm.
- Retina
  - ✓ Retina lines the insides of the wall's interior portion with two classes of receptors:



Structure of Human Eyes

- Lens
  - ✓ Lens is made of concentric layer of fibrous cells and is suspended by fiber that attached to the ciliary body.
  - ✓ The lens absorbs approximately 8% of the visible light spectrum.
  - ✓ The lens contains 60-70% water and 6% fat and protein.



Structure of Human Eyes – Eye Sensors

- We see the scene with the sensors in the retina of the eye called rods and cones

Color Sensor

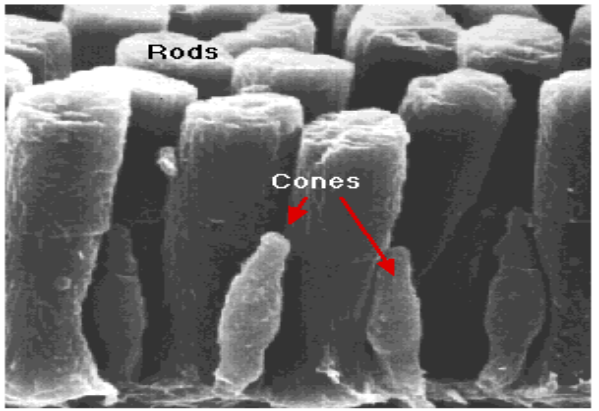
- Cones: (Red 65%, Green 33%,Blue 2%)
  - ✓ 6 – 7 millions located primarily in the central portion of the retina
  - ✓ Highly sensitive to color
  - ✓ Photopic or bright-light vision

Brightness Sensor

- Rods
  - ✓ 75- 150 millions distributed over the retinal surface.
  - ✓ Not involved in color vision and sensitive to low illumination
  - ✓ Scotopic or dim vision

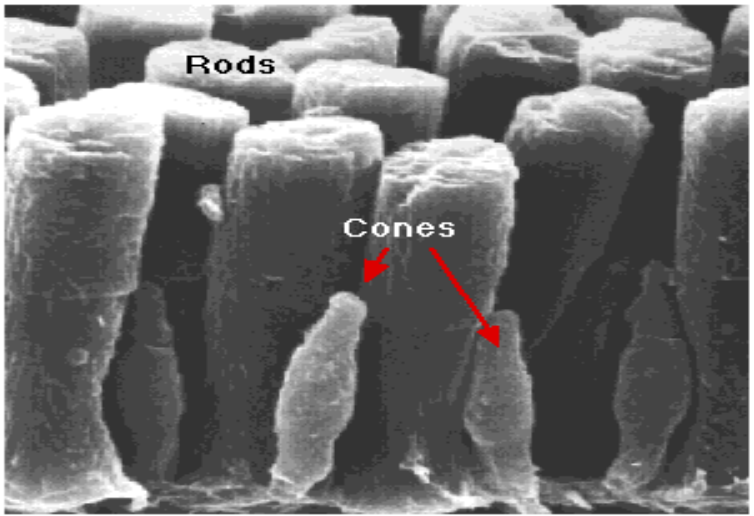
Structure of Human Eyes – Eye Sensors[Rods]

- Rods are more sensitive than the cones but they are not sensitive to color, they perceive images as black, white and different shades of grey.
- They work well in dim light as they contain a pigment, rhodopsin, which is sensitive at low light intensity, but saturates at higher (Photopic) intensities.
- More than one thousand times as sensitive, the rods respond better to blue but very little to red light
- Rods are distributed throughout the retina but there are none at the fovea and none at the blind spot. Rod density is greater in the peripheral retina than in the central retina.



Structure of Human Eyes – Eye Sensors[Cones]

- Each cone contains one of three pigments sensitive to either RED GREEN or BLUE
- Each pigment absorbs a particular wavelength of color. There are short wavelength cones that absorb blue light, middle wavelength cones that absorb green light, and long wavelength cones that absorb red light
- When we observe a color that has a wavelength between that of the primary colors red, green and blue, combinations of the cones are stimulated.
- An example could be that yellow light stimulates cones that are sensitive to red and to green light. The result is that we can detect light of all colors in the visible spectrum
- People who suffer color blindness have less numbers of particular cones than normal, so they get colors confused.



Structure of Human Eyes

- The cones are most dense in the center of retina.
- Density of cones in the area of fovea is 150,000 element/mm2
- The number of cones in fovea is 337,000 elements.

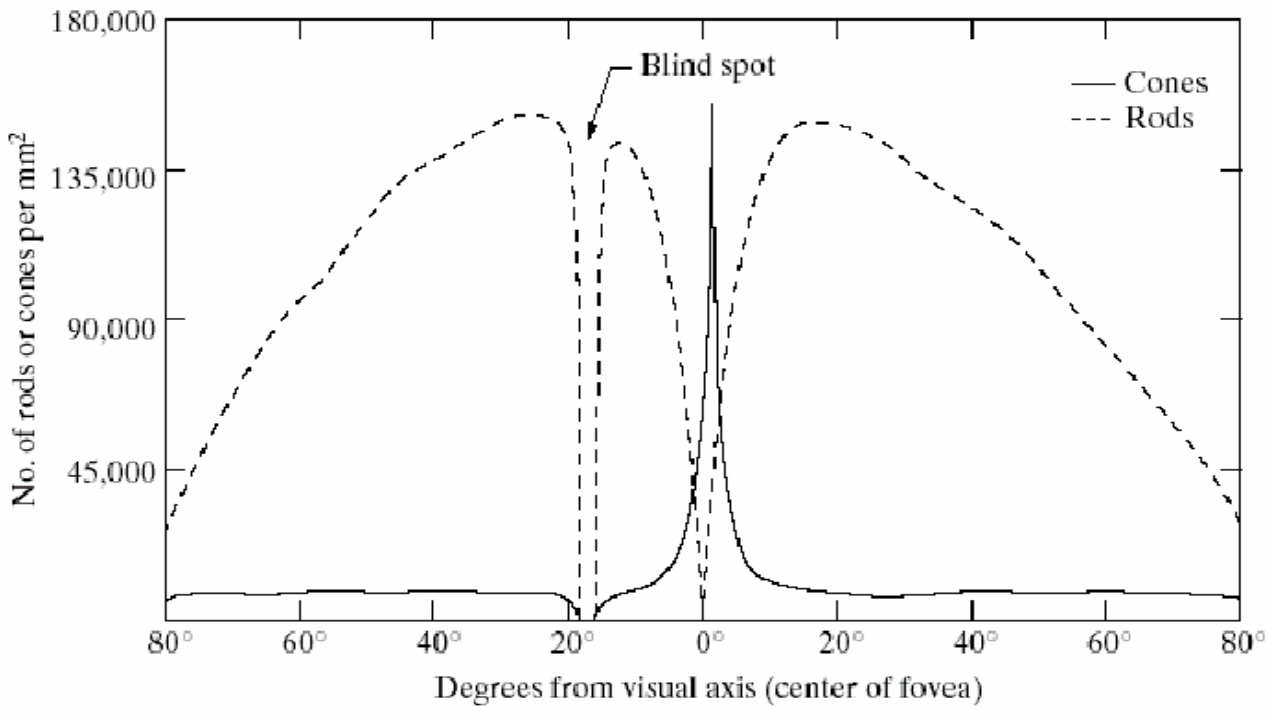


FIGURE 2.2
Distribution of rods and cones in the retina.

Structure of Human Eyes – Field of View [2]

- The **field of view** (also **field of vision,** abbreviated **FOV**) is the extent of the observable world that is seen at any given moment.
- Different animals have different fields of view, depending on the placement of the eyes.
- Humans have an almost 180-degree forward-facing horizontal field of view, while some birds have a complete or nearly-complete 360-degree field of view. In addition, the vertical range of the field of view in humans is typically around 100 degrees.

Field of View- Binocular vision[3]

- Binocular vision is vision in which both eyes are used together. The word binocular comes from two Latin roots, bini for double, and oculus for eye

- Having two eyes confers at least four advantages

  - ✓ First, it gives a creature a spare eye in case one is damaged.
  - ✓ Second, it gives a wider field of view. For example, humans have a maximum horizontal field of view of approximately 200 degrees with two eyes, approximately 120 degrees of which makes up the binocular field of view (seen by both eyes) flanked by two uniocular fields (seen by only one eye) of approximately 40 degrees
  - ✓ Third, it gives binocular summation in which the ability to detect faint objects is enhanced.
  - ✓ Fourth it can give stereopsis [4] in which parallax provided by the two eyes' different positions on the head give precise depth perception [5]

Depth perception is the visual ability to perceive the world in three dimensions (3D) and the distance of an object.

Stereopsis (from stereo- meaning "solid" or "three-dimensional", and opsis meaning appearance or sight) is the impression of depth that is perceived when a scene is viewed with both eyes by someone with normal binocular vision.

Field of View- Monocular vision[4]

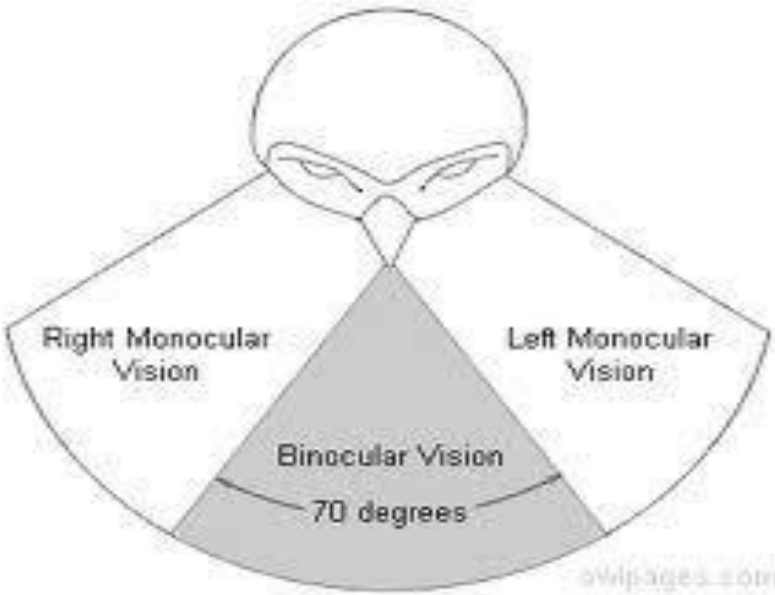
- **Monocular vision** is vision in which each eye is used separately. By using the eyes in this way, as opposed by binocular vision, the field of view is increased, while depth perception is limited.

- The eyes are usually positioned on opposite sides of the animal's head giving it the ability to see two objects at once. The word monocular comes from the Greek root, *mono* for one, and the Latin root, *oculus* for eye.

- Most birds and lizards (except chameleons) have monocular vision.

- Owls and other birds of prey are notable exceptions. Also many prey have monocular vision to see predators.

Field of View- Monocular vision & Binocular Vision



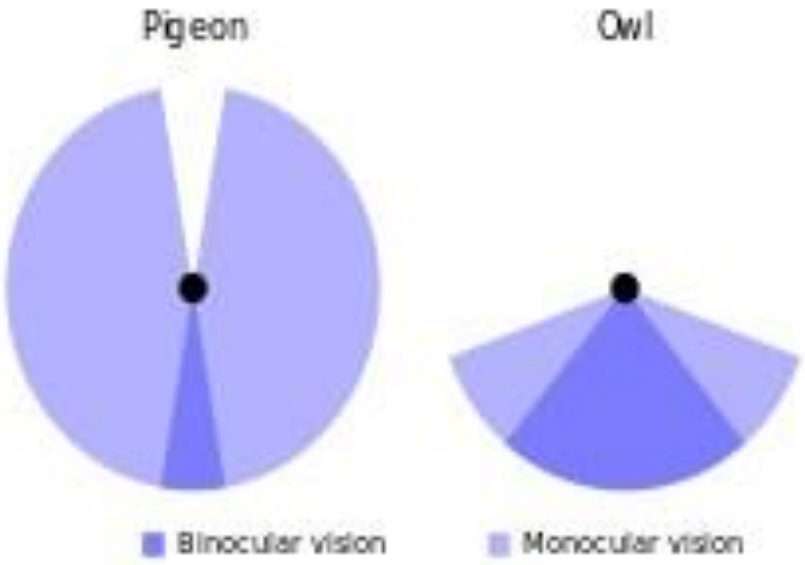
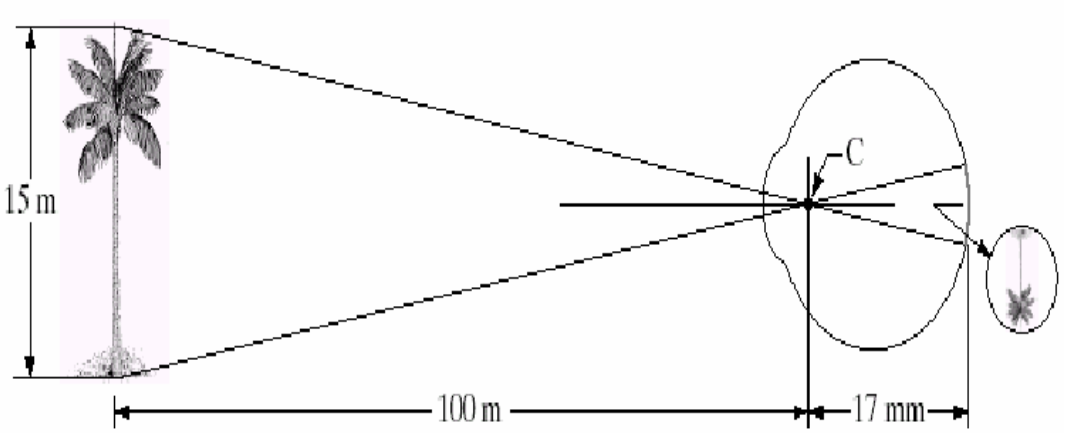


Image Formation in the Eyes

- The distance between the center of the lens and the retina (focal length) varies from 17mm to 14mm.
- The shape of lens is controlled by the tension of fibers of the ciliary body.
- The retinal image is reflected primarily in the area of fovea.
- Perception = excitation of light receptors, which transform radiant energy into electrical impulses that are ultimately decoded by the brain.

FIGURE 2.3
Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.



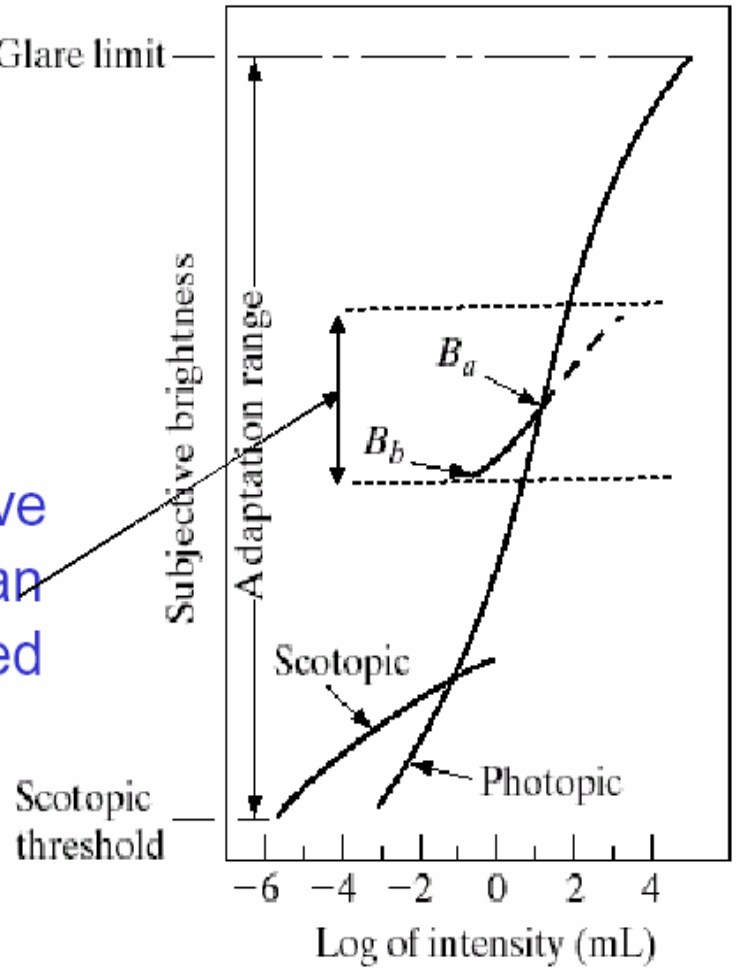
Brightness Adaptation & Discrimination

- The range of light intensity levels to which the human visual system can adapt is enormous – on the order of 10^10.
- The *subjective brightness* is a logarithmic function of light intensity incident on the eye.
- In photopic vision, the range is about 10^6.
- The current sensitivity level it can discriminate simultaneously is rather small compared with the total adaptation range
- *Brightness adaptation level*: the current sensitive level of the visual system.

Brightness Adaptation & Discrimination

FIGURE 2.4
Range of subjective brightness sensations showing a particular adaptation level.

The range of subjective brightness that eye can perceive when adapted to this level



Brightness Adaptation & Discrimination

Experiments: Apply a short–duration flash at a circle to see if ΔI is bright enough

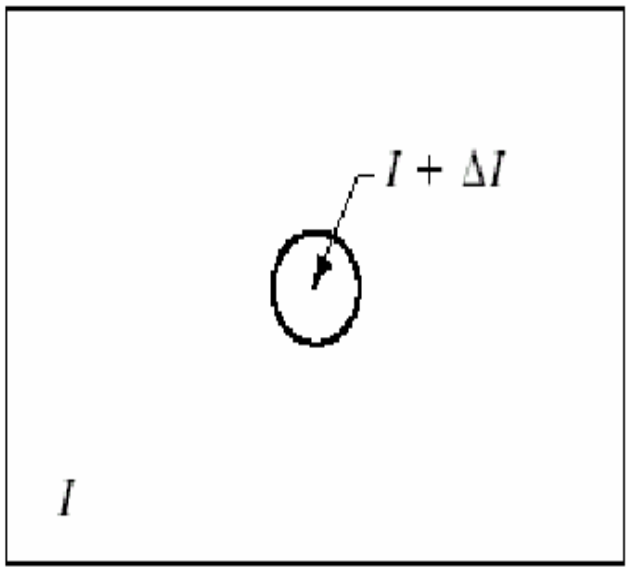
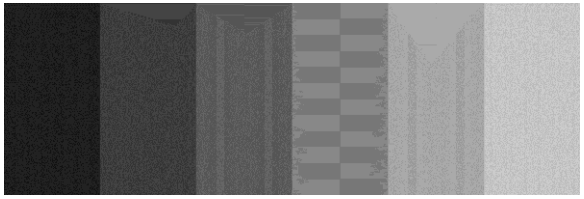


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

Brightness Adaptation & Discrimination

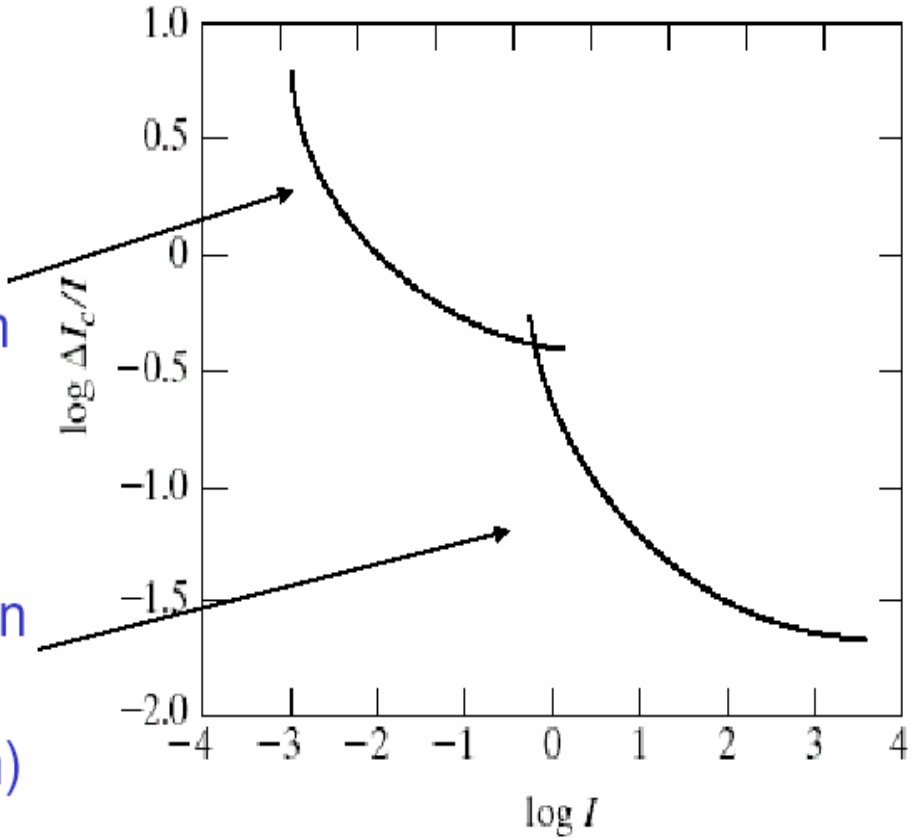
- The dIc is the increment of illumination discriminable 50% of the time with the background illumination I.
- The quantity dIc/I is called the Weber ratio.
- The *smaller* dIc/I means that a small percentage change in intensity is discriminable – *good brightness discrimination*
- If the background illumination is constant, the intensity of object is allowed to vary incrementally from never perceived to always being perceived.
- Typically the observer can discern a totally from one to two dozens different intensity changes.
  - ✓ The number of gray level for digital image
  - ✓ Contouring Effect: Not sufficient no. of gray levels



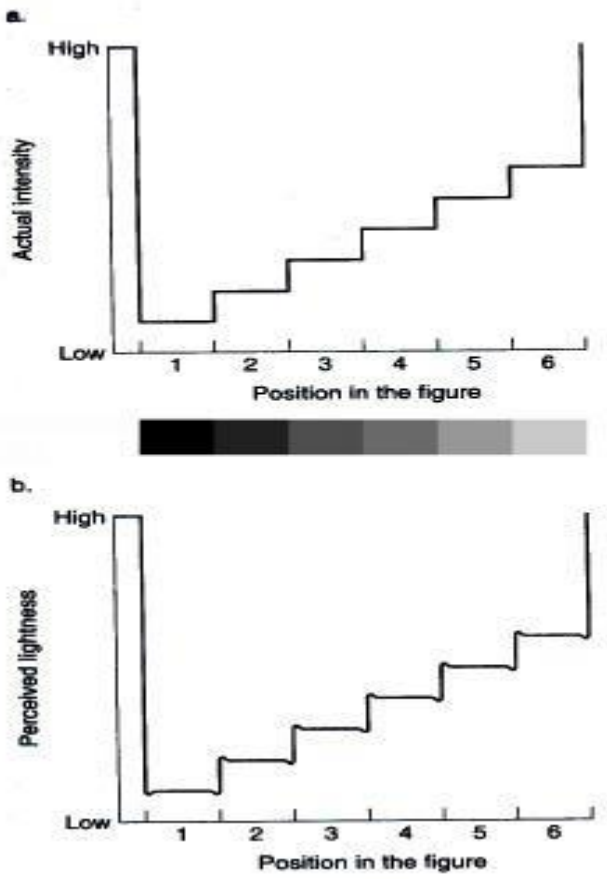
Brightness Adaptation & Discrimination

- *Perceived brightness* is not a simple function of *intensity, rather it is log of intensity*

FIGURE 2.6
Typical Weber ratio as a function of intensity.

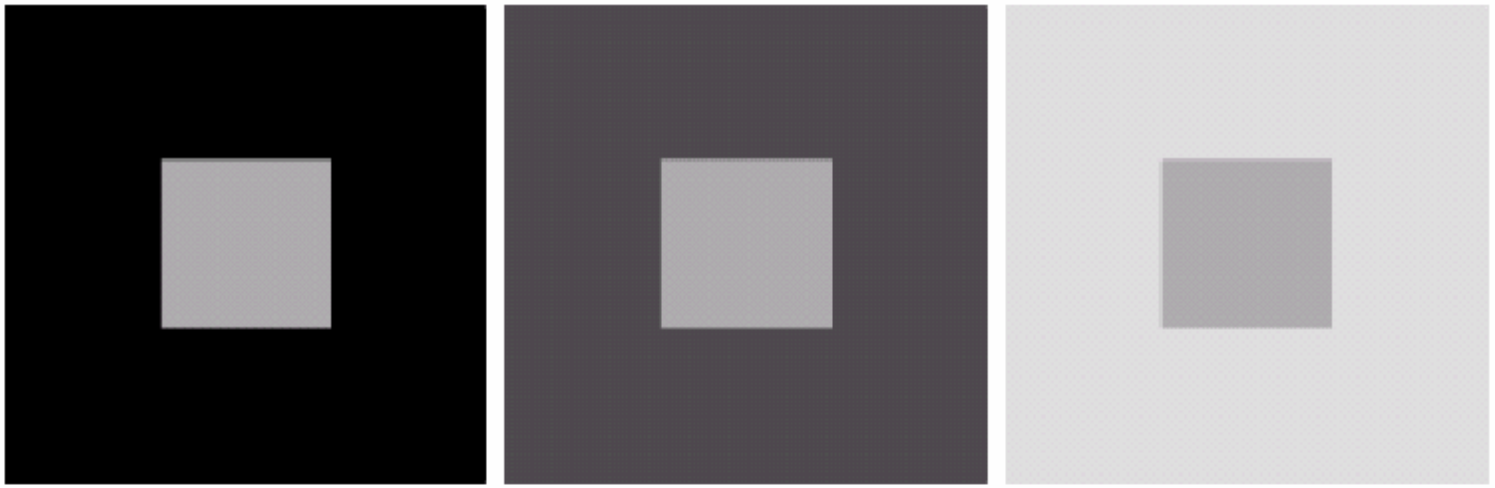


Mach Band Effect



Brightness Adaptation & Discrimination

- A region's perceived brightness does not simply depend on its intensity but also on the background – *Simultaneous contrast*.



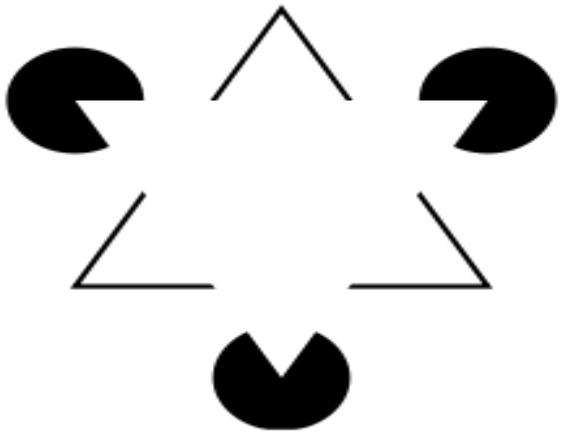
a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

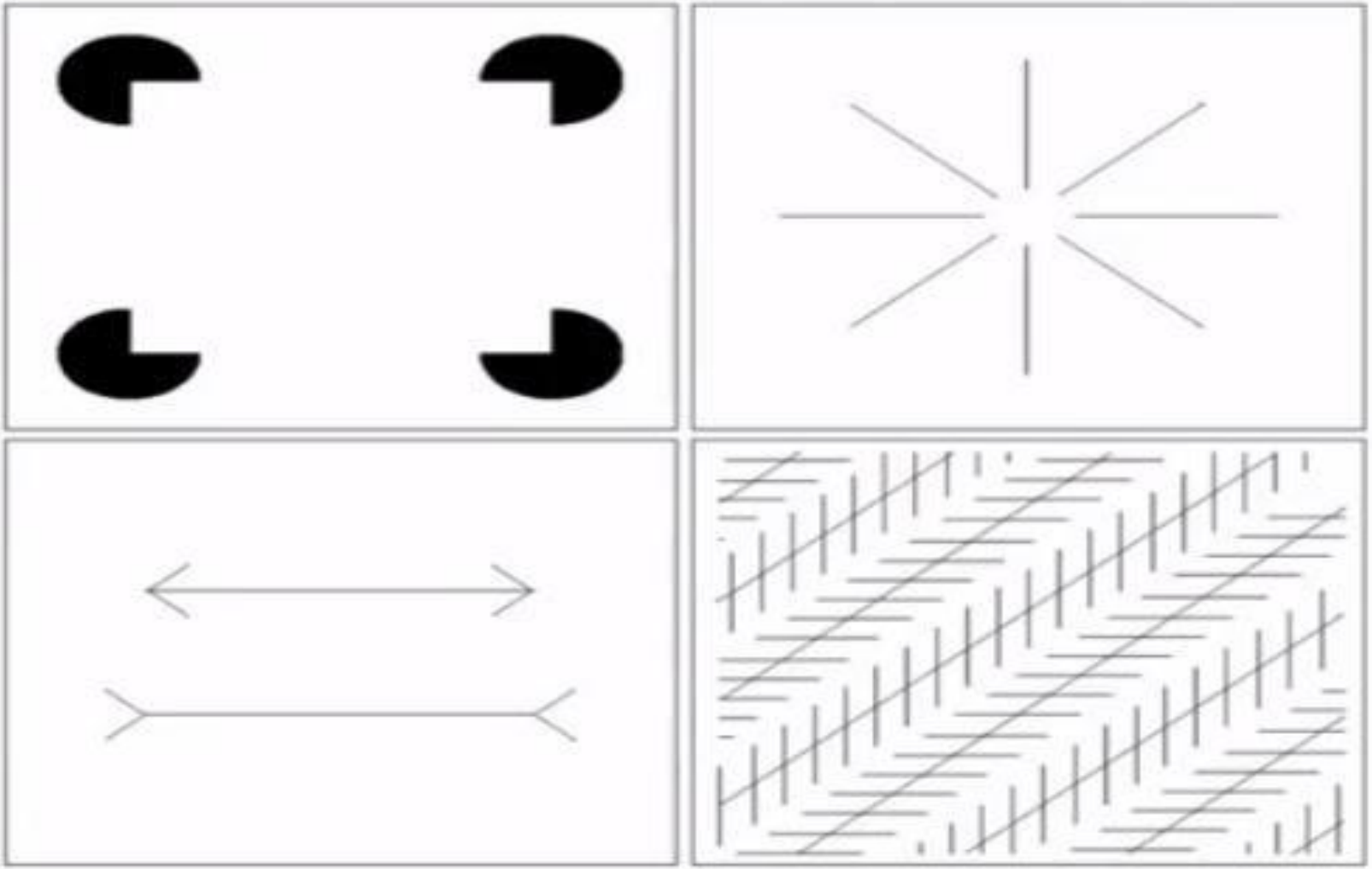
OPTICAL ILLUSION

Optical illusion [2]

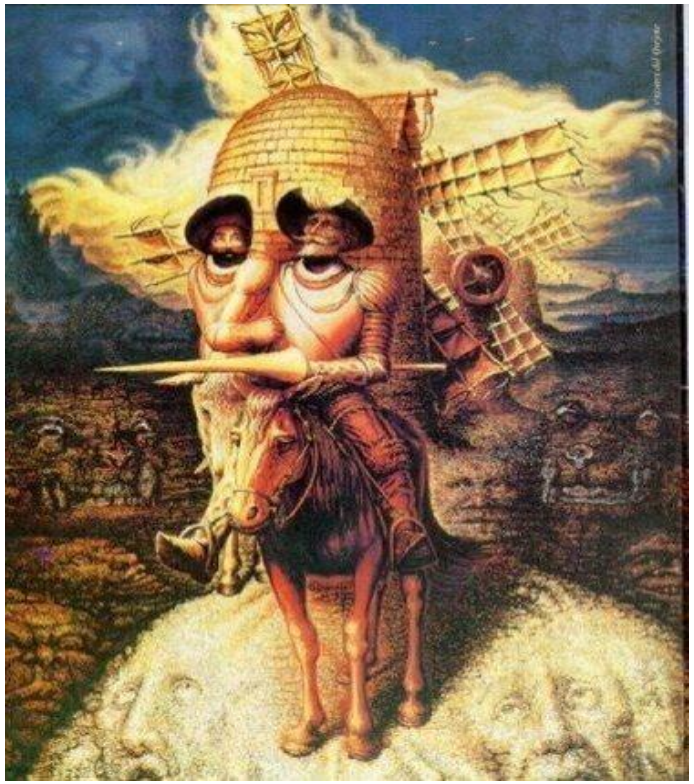
- An **optical illusion** (also called a **visual illusion**) is characterized by visually perceived images that differ from objective reality.
- The information gathered by the eye is processed in the brain to give a perception that does not tally with a physical measurement of the stimulus source.
- Optical illusion is a phenomena in which the eye fills in non existing information or wrongly perceives the geometrical properties of objects



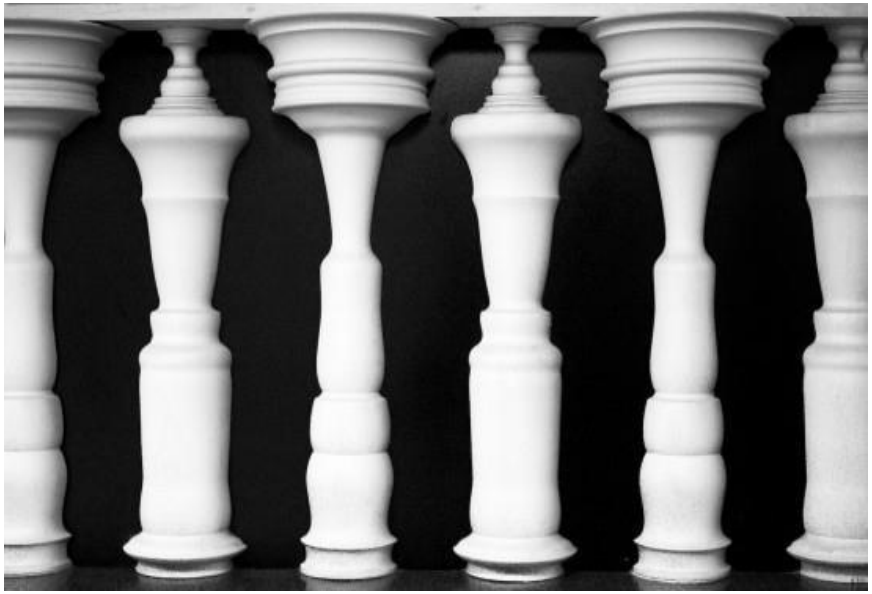
Optical illusion

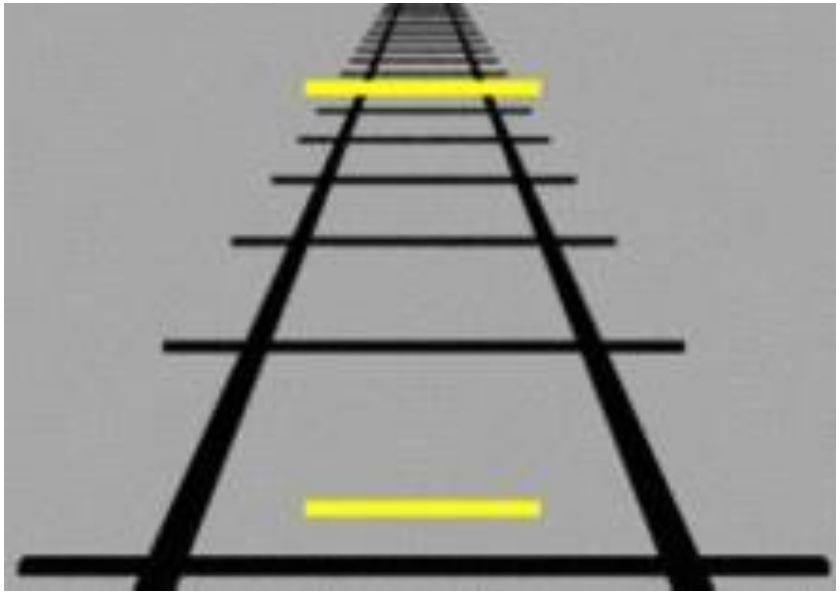


Optical illusion

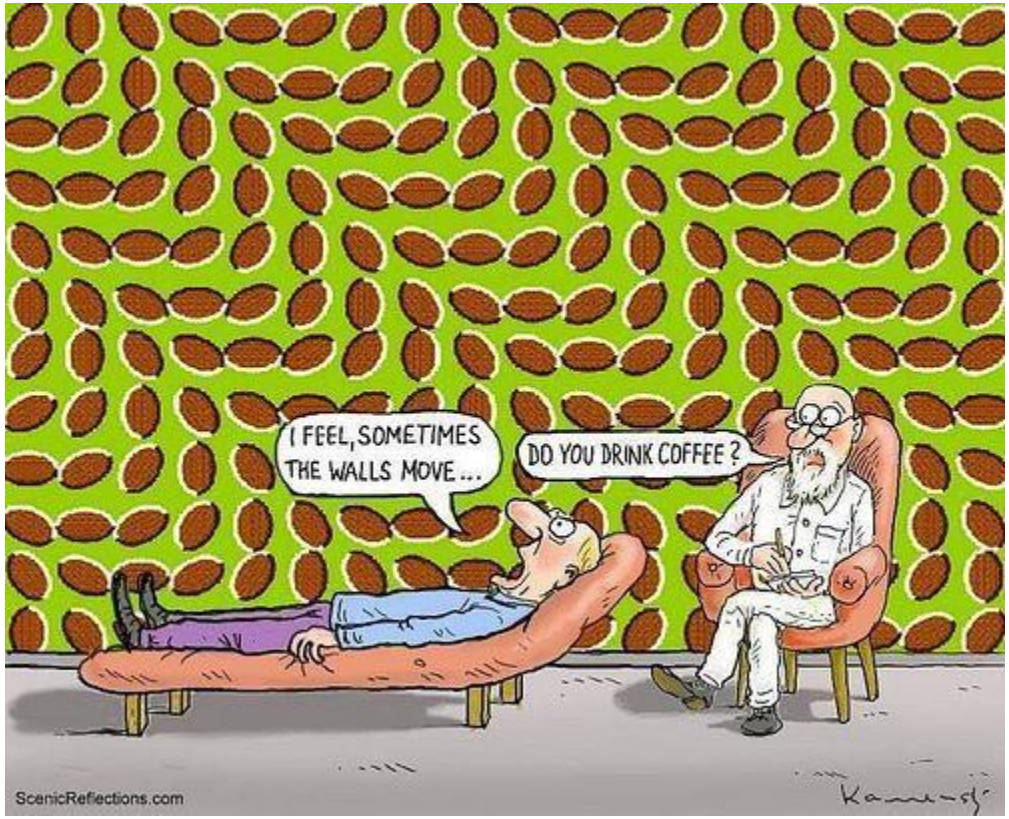


Optical illusion





Optical illusion



Optical illusion

Image Acquisition

Image Acquisition

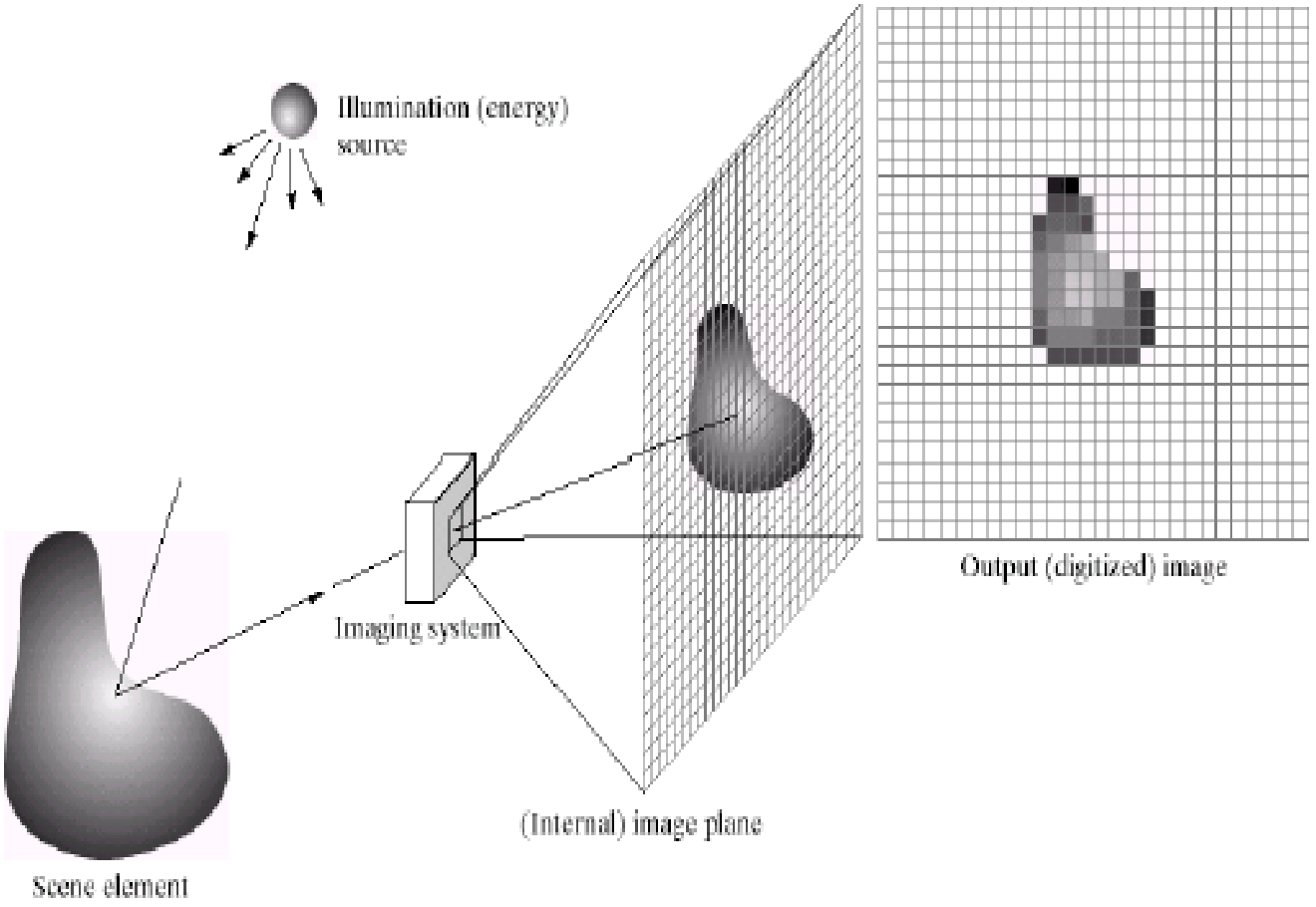


Image Acquisition using Point Sensor

- Specify the location of vertical and horizontal motors
- Sense the light reflection
- Voltage waveform will be received (Analog signal)
- Convert this analog signal into digital signal through sampling and quantization
  - ✓ Apply Sampling to digitize coordinate values
  - ✓ Apply Quantization to digitize amplitude values
- Store the digitized value in memory

Single imaging sensor

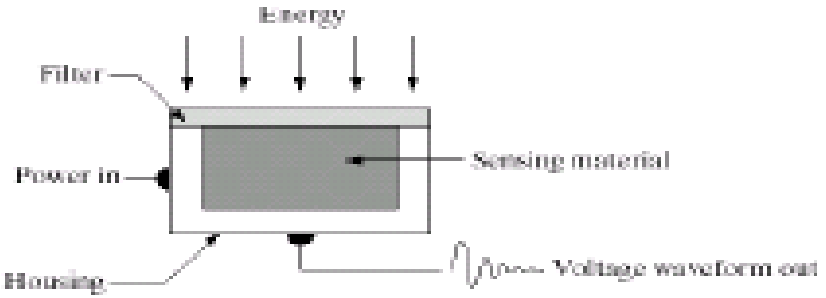


Image Acquisition using Point Sensor

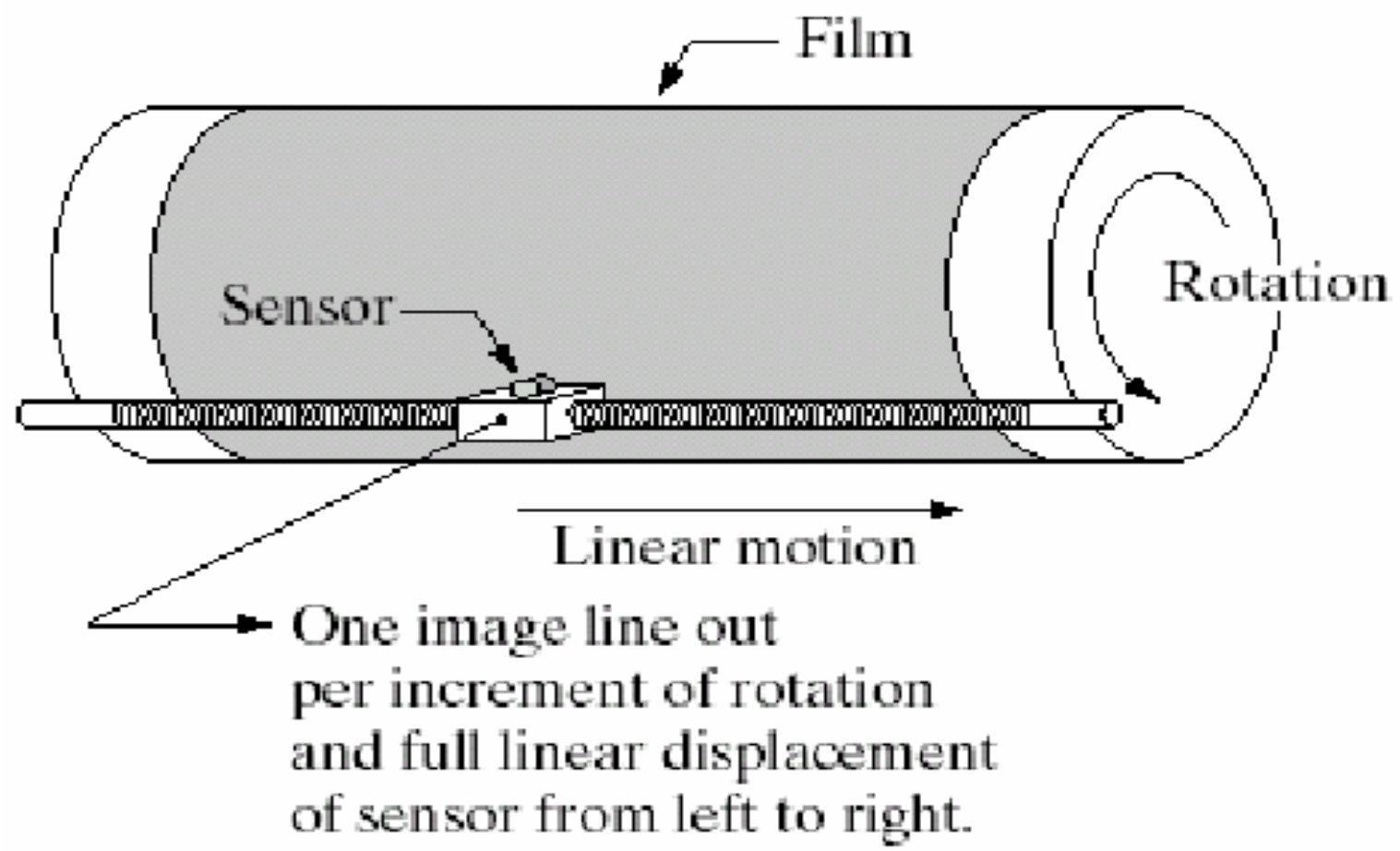


Image Acquisition using Line Sensor

- Specify the location of vertical motor
- Sense the light reflection
- Voltage waveform will be received (Analog signal)
- Convert this analog signal into digital signal through sampling and quantization
  - ✓ Apply Sampling to digitize coordinate values
  - ✓ Apply Quantization to digitize amplitude values
- Store the digitized value in memory

Line sensor

Image Acquisition using Line Sensor

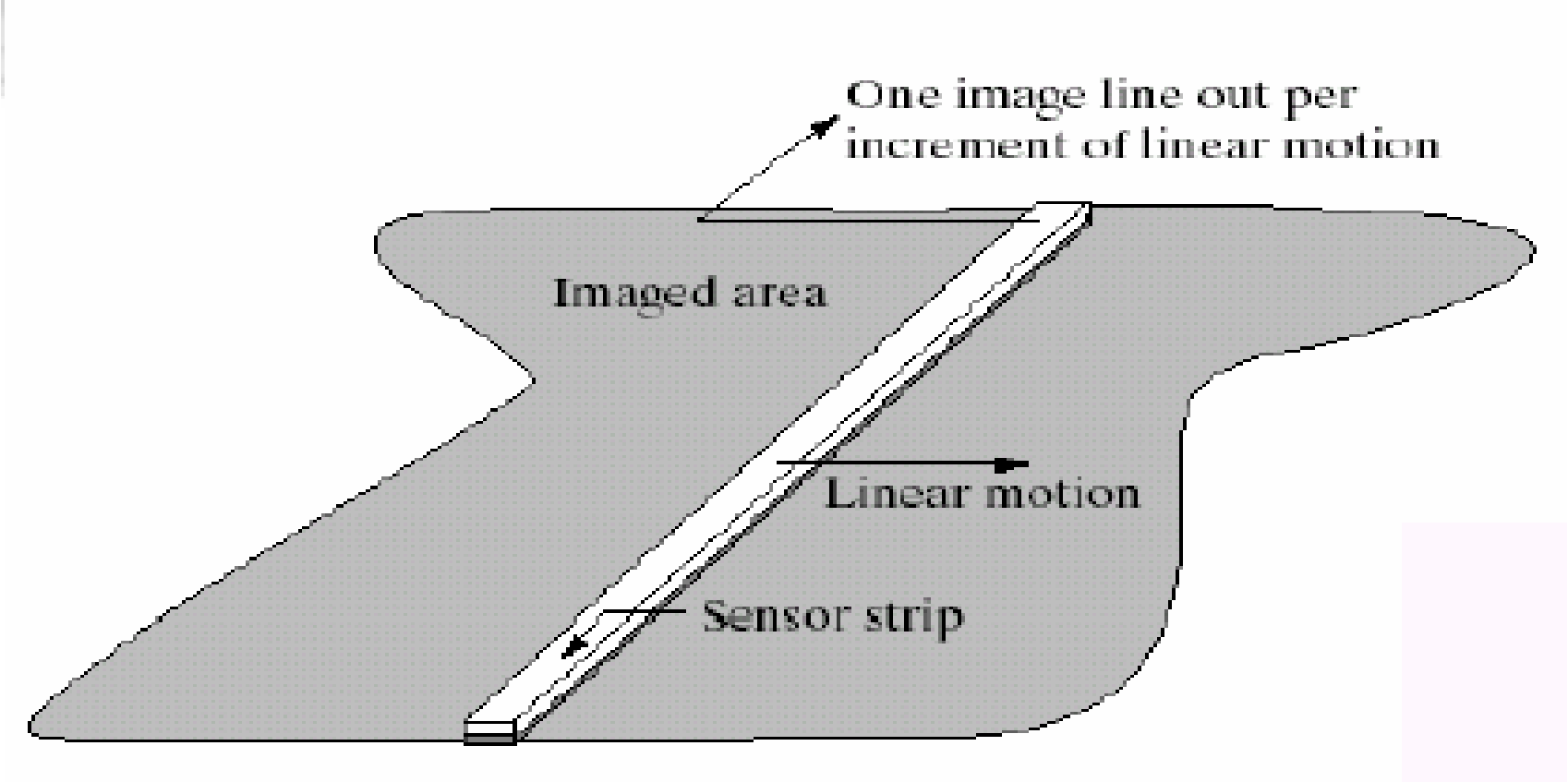


Image Acquisition using Array Sensor

- Figure shows individual sensors arranged in a form of 2-D array
- This arrangement exists in modern day digital cameras
- A typical sensors for these cameras is a CCD array, which can be manufactured with a broad range of sensing properties and can be packaged in arrays of 4000 x 4000 elements or more
- CCD sensors are used widely in digital cameras and other light sensing instruments
- The response of each sensor is proportional to the integral of the light energy projected on to the surface of the sensor

Array sensor

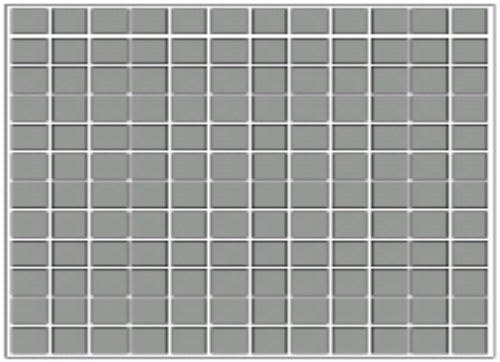


Image Acquisition using Array Sensor

- Sense the light reflection on the sensor (arranged in 2D form)
- Voltage waveform will be received (Analog signal)
- Convert this analog signal into digital signal through sampling and quantization
  - ✓ Apply Sampling to digitize coordinate values
  - ✓ Apply Quantization to digitize amplitude values
- Store the digitized value in memory

Array sensor

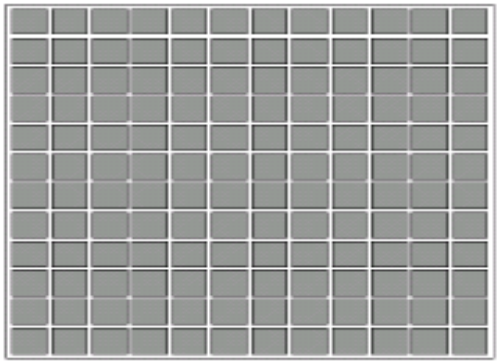


Image Formation Model

Image Formation Model

Object Visibility

- Object becomes visible when illuminating source strikes the objects and due to reflection our eyes can see the object because reflection reaches our eye after striking through object
- Scene Visibility = Reflection from the object , Light Source
- Image = reflectance , illumination

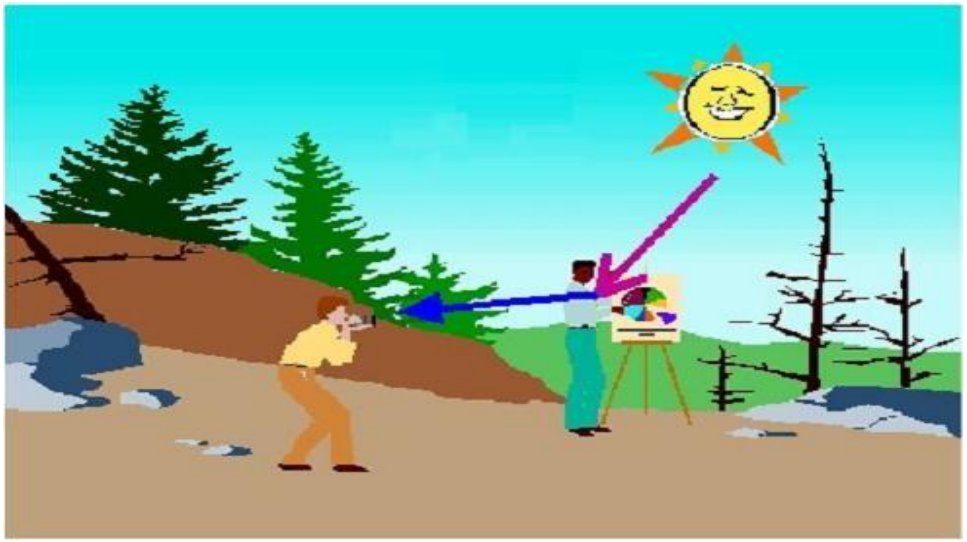


Image Formation Model

- For monochromatic image 2-D array: $f(x, y)$
- The $f(x, y)$ is characterized by two components:
  - The amount of source illumination incident on the scene, i.e., $i(x,y)$.
  - The amount of illumination reflected by the objects in the scene, *i.e.*, ***reflectivity*** $r(x, y)$.
- $f(x, y)=i(x, y)\ r(x, y)$
  where $0 < i(x, y) < \infty$ and $0 < r(x, y) < 1$
- Reflectivity function: $r(x, y)$
- For X-ray, ***transmissivity*** function
- The ***intensity*** of monochrome image is

$$L_{min} \le f(x,y) \le L_{max} \quad L_{min} = i_{min} r_{min} \text{ and } L_{max} = i_{max} r_{max}$$

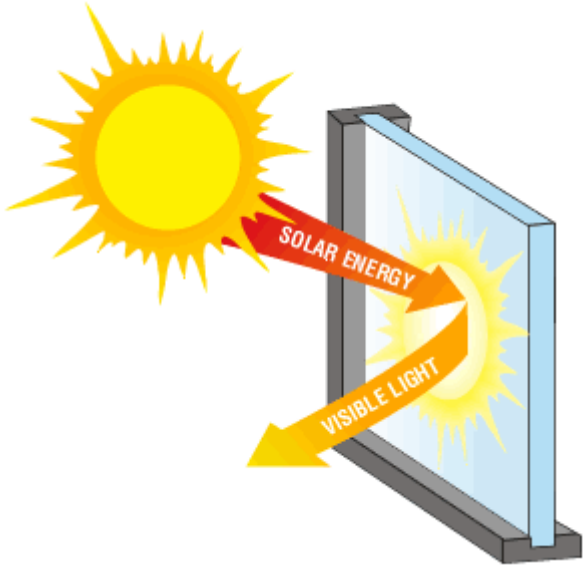
- The interval [Lmin, Lmax] is called the gray scale
- Common practice is to shift this interval to [0 to L-1], where I=0 is considered black and I=L-1 is considered white on the gray scale
- All intermediates are shades of gray varying from black to white

Some Typical illumination Ranges

- Illumination
  - ✓ Lumen — A unit of light flow
  - ✓ Lumen per square meter (lm/m^2) — The metric unit of measure for illuminance of a surface
  - ✓ On a clear day, the sun may produce in excess of 90,000 lm/m^2 of illumination on the surface of the Earth
  - ✓ On a cloudy day, the sun may produce less than 10,000 lm/m^2 of illumination on the surface of the Earth
  - ✓ On a clear evening, the moon yields about 0.1 lm/m^2 of illumination
  - ✓ The typical illumination level in a commercial office is about 1000 lm/m^2

Some Typical Reflectance Ranges

- Reflectance
  - ✓ 0.01 for black velvet
  - ✓ 0.65 for stainless steel
  - ✓ 0.80 for flat-white wall paint
  - ✓ 0.90 for silver-plated metal
  - ✓ 0.93 for snow



- **Note::**
  - ✓ **Value range of reflectance 0 to 1**
  - ✓ **0 means total absorption and 1 means total reflection**

References

1. DIP by Gonzalez
2. http://en.wikipedia.org/wiki/Field_of_view
3. http://en.wikipedia.org/wiki/Binocular_vision
4. http://en.wikipedia.org/wiki/Monocular_vision
5. http://en.wikipedia.org/wiki/Stereopsis
6. http://en.wikipedia.org/wiki/Depth perception
7. http://en.wikipedia.org/wiki/Optical_illusion