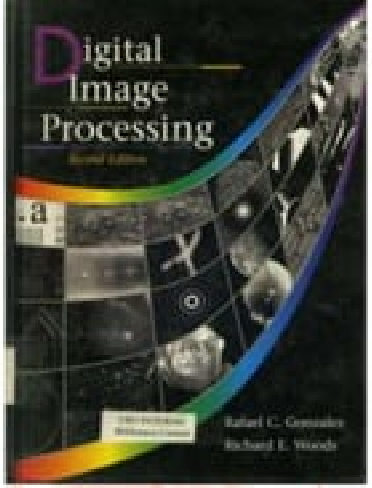

DIGITAL IMAGE PROCESSING

(2ND EDITION)

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Miscellanea

- **Lectures:** A
  - Monday 1:00 – 3:00
  - Tuesday 2:00 – 4:00
- **Lectures:** B
  - Monday 8:00 – 10:00
  - Wednesday 1:00 – 3:00
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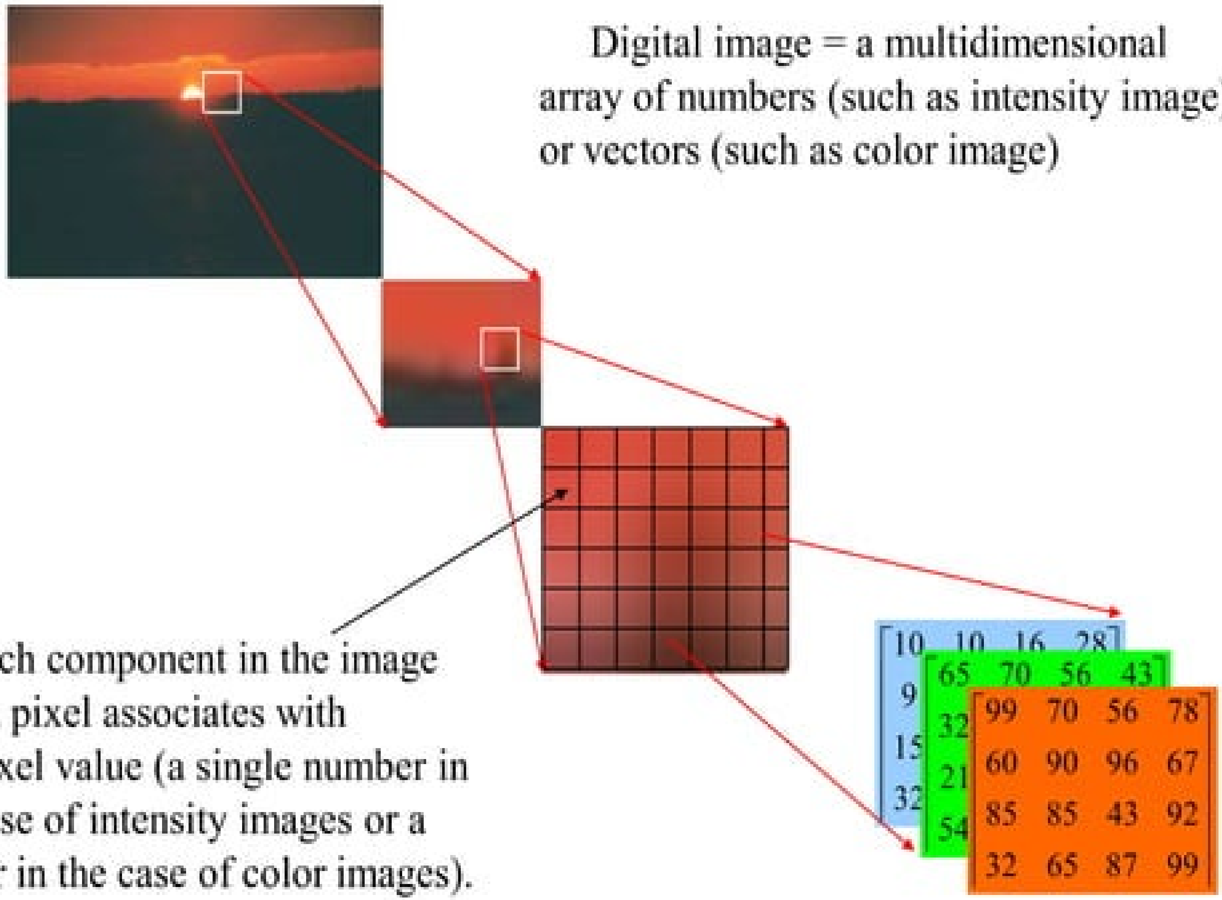
CONTENTS FOR CHAPTER 2

Digital Image

Digital image = a multidimensional array of numbers (such as intensity image) or vectors (such as color image)



Each component in the image called pixel associates with the pixel value (a single number in the case of intensity images or a vector in the case of color images).

In many image processing applications, the objective is to help a human observer perceive the visual information in an image. Therefore, it is important to understand the 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 whirlwind tour of the human visual system

2.1 Elements of Visual Perception

- Structure of the Human Eye
- Image Formation in the Eye
- Brightness Adaptation and Discrimination

STRUCTURE OF THE HUMAN EYE

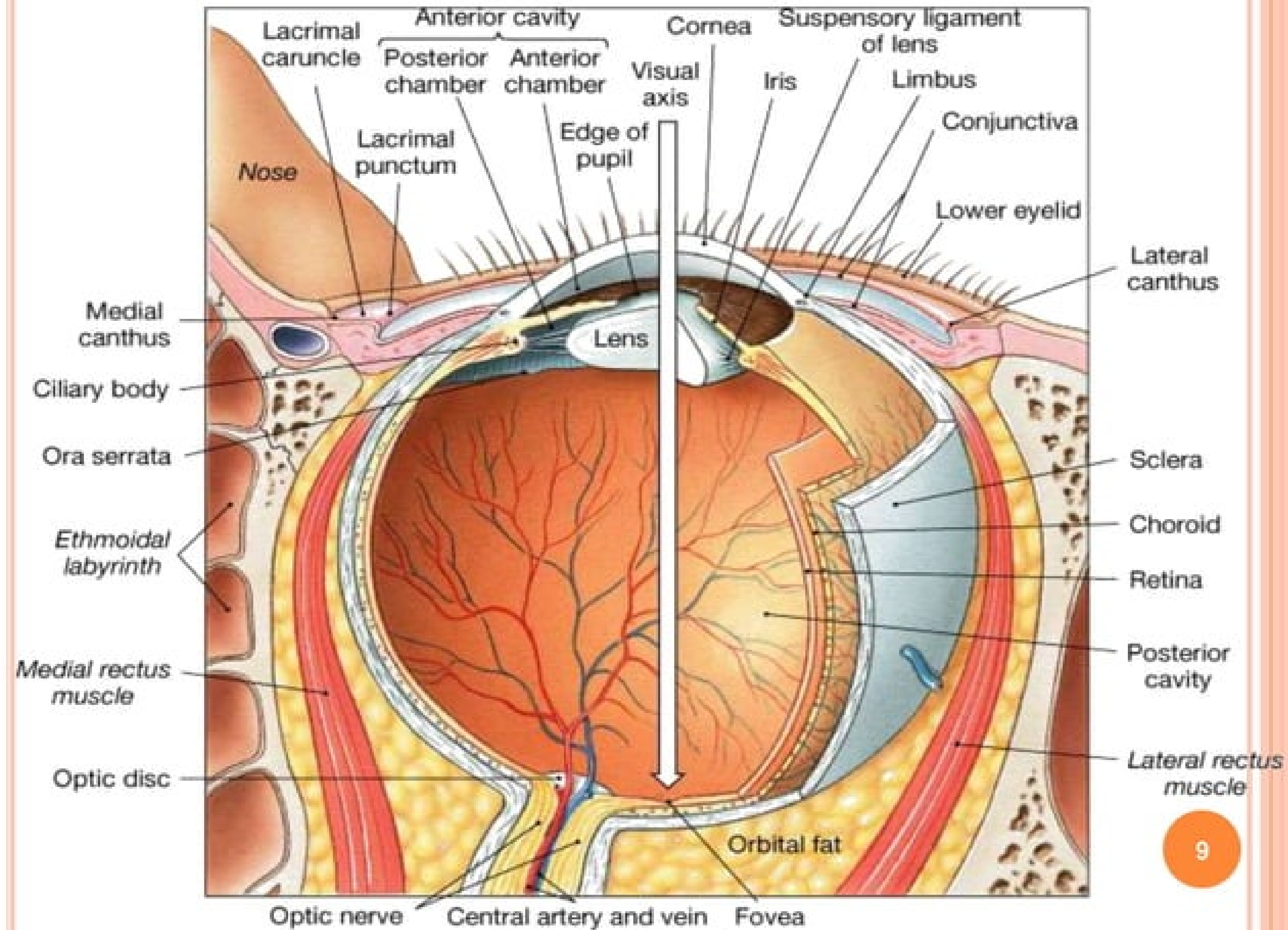
- Eye characteristics
  - nearly spherical
  - approximately 20 mm in diameter
  - three membranes
    - **cornea** (transparent) & **sclera** (opaque) outer cover
    - **choroid** contains a network of blood vessels, heavily pigmented to reduce amount of extraneous light entering the eye. Also contains the iris diaphragm (2-8 mm to allow variable amount of light into the eye)
    - **retina** is the inner most membrane, objects are imaged on the surface.

RETINAL SURFACE

- Retinal surface is covered in discrete light receptors
- Two classes
  - – **Cones**
    - 6-7 million located primarily near the center of the retina (the fovea)
    - highly sensitive to color
    - can resolve fine details because each is attached to a single nerve ending
    - Cone vision is called photopic or bright-light vision
  - – **Rods**
    - 75-150 million distributed over the retinal surface
    - multiple rods connected to a single nerve ending
    - give a general overall picture of the field of illumination
    - not color sensitive but are sensitive to low levels of illumination
    - Rod vision is called scotopic or dim-light vision

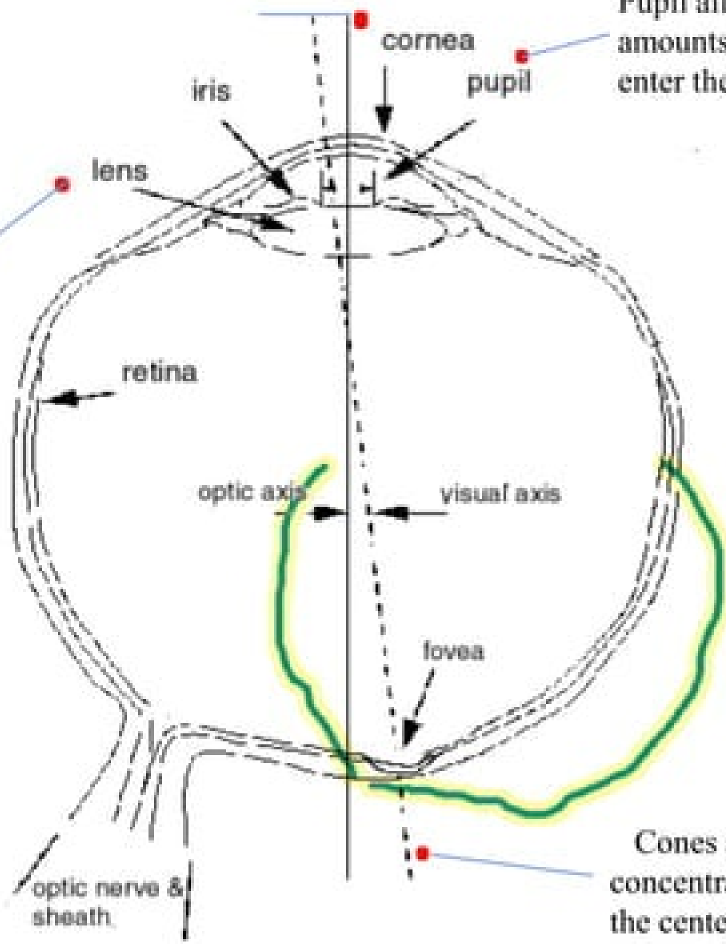
CONT'D…

- **Rods** are thin cells with slender rodlike projections that are the photoreceptors for:
  - Black and white vision
  - Vision in dim light
- **Cones** are the receptors for:
  - Color vision
  - Visual acuity
- There are **three types of cones**, each with a different visual pigment
  - One sensitive to green light
  - One sensitive to blue light
  - One sensitive to red light
- The perceived color of an object depends on the quantity and combination of cones that are stimulated
- In very dim light, cones do not function
- **Color blindness** occurs because there is an absence or deficiency of one or more of the visual pigments in the cones. So the person cannot distinguish certain colors.


Anterior cavity
Lacrimal caruncle
Posterior chamber
Anterior chamber
Cornea
Suspensory ligament of lens
Visual axis
Iris
Limbus
Conjunctiva
Edge of pupil
Lacrimal punctum
Nose
Lower eyelid
Lateral canthus
Medial canthus
Lens
Ciliary body
Ora serrata
Sclera
Choroid
Ethmoidal labyrinth
Retina
Posterior cavity
Medial rectus muscle
Optic disc
Lateral rectus muscle
Orbital fat
Optic nerve
Central artery and vein
Fovea

Cornea is a transparent structure that covers the iris and pupil

Pupil allows varying amounts of light to enter the eye.



Lens helps to focus light on the retina.

Retina includes

- Rods (94%) (light sensitive)
- Cones (6%) (color sensitive)

Cones are concentrated in the center of the retina - the fovea

CONT'D…

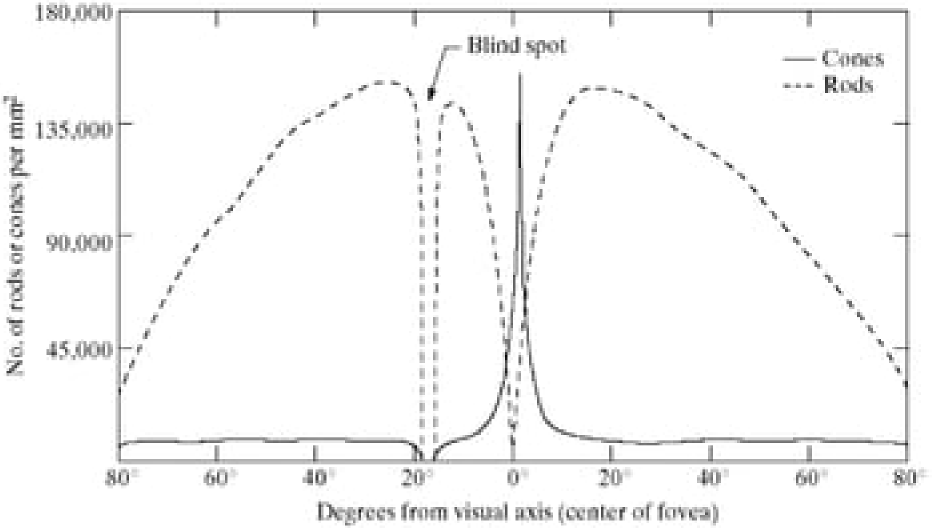
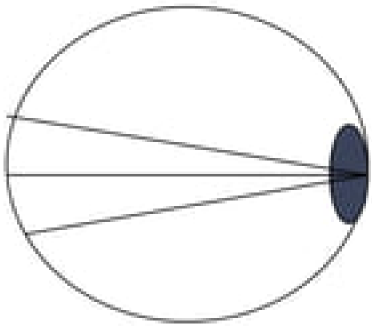


FIGURE 2.2 Distribution of rods and cones in the retina.



- Fovea size is 1.5 mm in diameter
- 1.5 mm × 1.5 mm square contain 337000 cones

5mm × 5mm CCD imaging chip

Image Formation in the Eye

- The principal difference between the lens of the eyee and an ordinary optical lens is that the former is flexible.
- The radius of curvature of the anterior surface of the lens is greater than the radius of its posterior or surface.
- The shape of the lens is controlled by tension in the fibers of the ciliary body.
- 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.
- The distance between the center of the lens and the retina (called the focal length) varies from approximately 17mm to about 14mm, as the refractive power of the lens increases from its minimum to its maximum.
- When the eye focuses on an object farther away than about 3m, the lens exhibits its lowest refractive power.
- When the eye focuses on a nearby object, the lens is most strongly refractive.
- This information makes it easy to calculate the size of the retinal image of any objects.

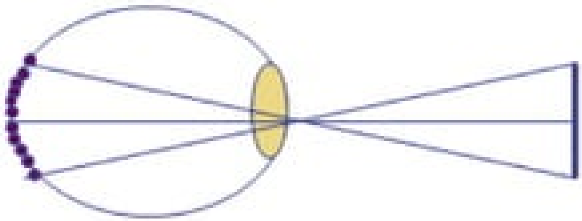
Blind-Spot Experiment

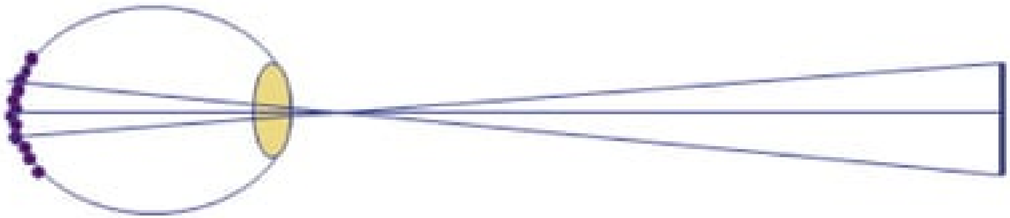
Draw an image similar to that below on a piece of paper (the dot and cross are about 6 inches apart)

Close your right eye and focus on the cross with your left eye

Hold the image about 20 inches away from your face and move it slowly towards you

The dot should disappear!





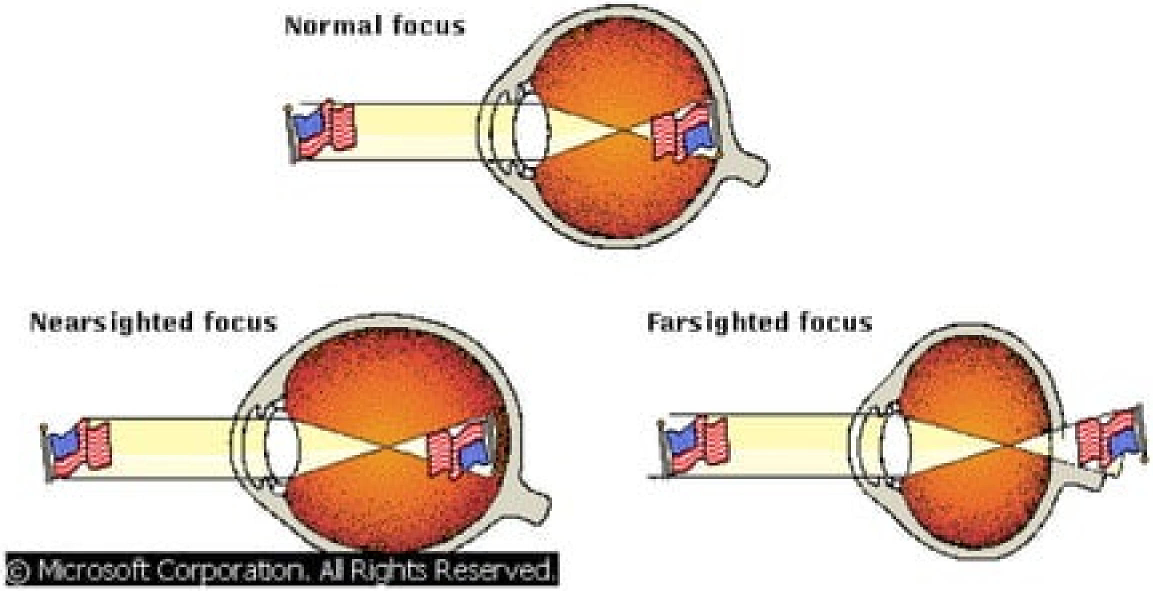

Normal focus
Nearsighted focus
Farsighted focus
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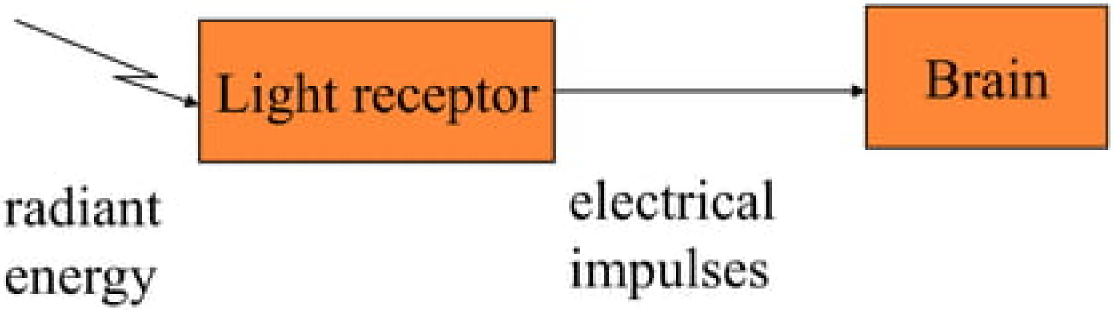
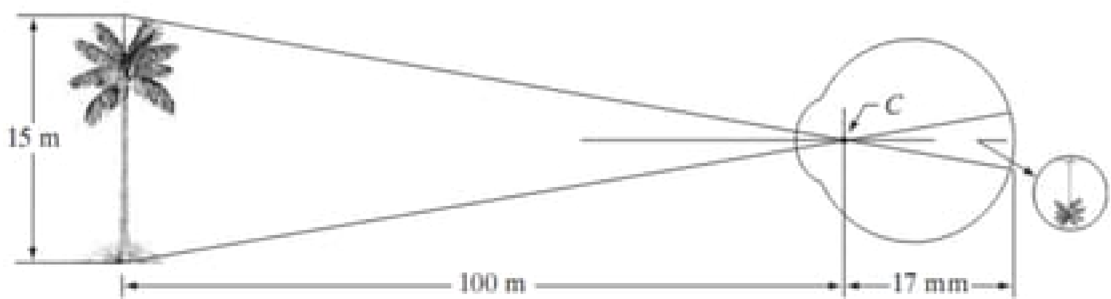
IMAGE FORMATION IN THE EYE

- 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



- Example:
  - Calculation of retinal image of an object



15/100=h/17 or h=2.55 mm

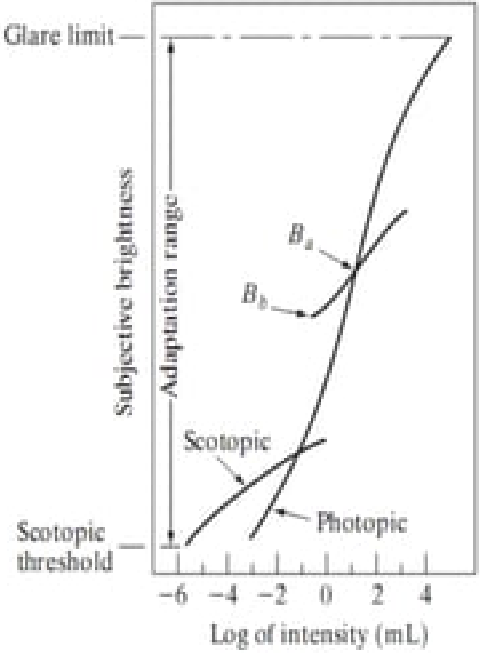
Brightness Adaptation and Discrimination

- Range of light intensity levels to which **HVS** (human visual system) can adapt: on the order of 10^{10} _ from the scotopic threshold to the glare limit.

- Subjective brightness (i.e. intensity as perceived by the HVS) is a **logarithmic function** of the light intensity incident on the eye.

- The visual system does not operate simultaneously over the 10^{10} range. It accomplishes this large variation by changes in its overall sensitivity, a phenomenon known as brightness adaptation.

- For any given set of conditions, the current sensitivity level of HVS is called the **brightness adaptation level**.



mL = millilambert

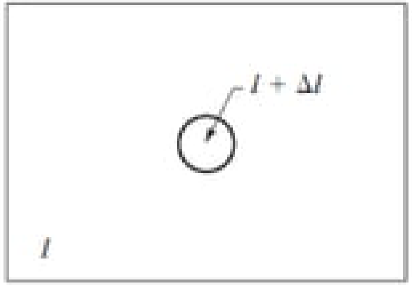
CONT'D

- Brightness discrimination is the ability of the eye to discriminate between changes in light intensity at any specific adaptation level.
- The quantity $\Delta I_c/I$, where ΔI_c is the increment of illumination discriminable 50% of the time with background illumination I, is called the Weber ratio. A small value of Weber ratio, means good brightness discrimination.

- The eye also discriminates between changes in brightness at any specific adaptation level.

$$\boxed{\frac{\Delta I_c}{I} \rightarrow \text{Weber ratio}}$$

Where: ΔI_c: the increment of illumination discriminable 50% of the time
I : background illumination

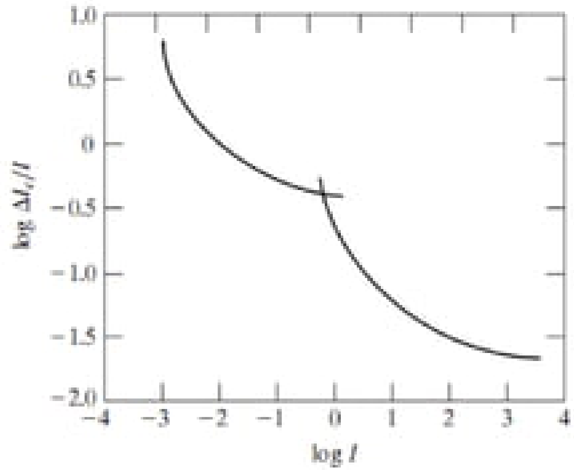


CONT'D

Weber ratio (the experiment) $\Delta I_c/I$

- I: the background illumination
- ΔI_c : the increment of illumination
- Small Weber ratio indicates good discrimination
- Larger Weber ratio indicates poor discrimination

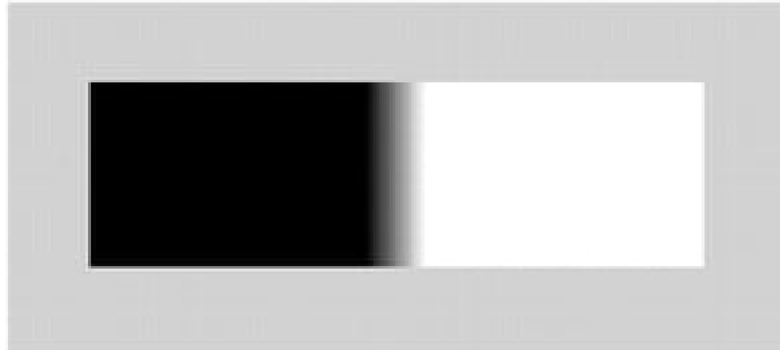
- Brightness discrimination is poor at low levels of illumination. The two branches in the curve indicate that at low levels of illumination vision is carried out by the rods, whereas at high level by the cones.

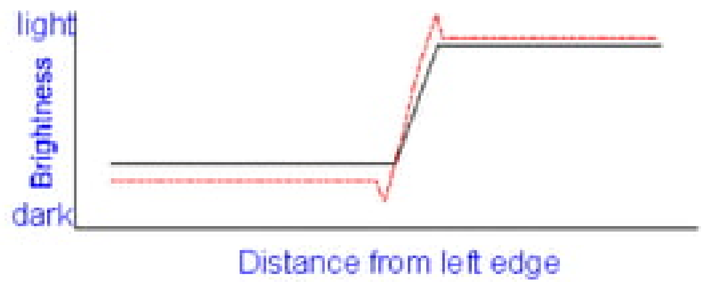


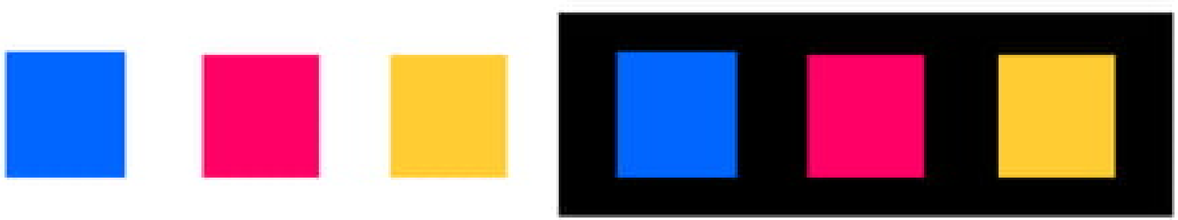
Typical Weber ratio as a function of intensity

Psychovisual effects

- The perceived brightness is not a simple function of intensity
  - Mach band pattern
  - Simultaneous contrast
  - And more… (see *link*)

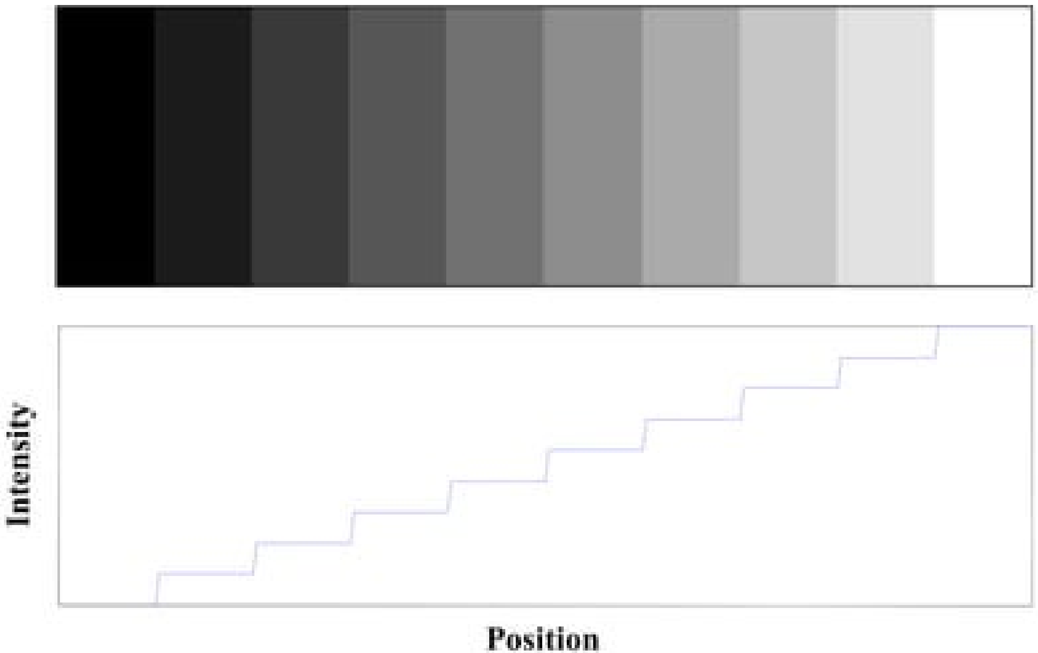




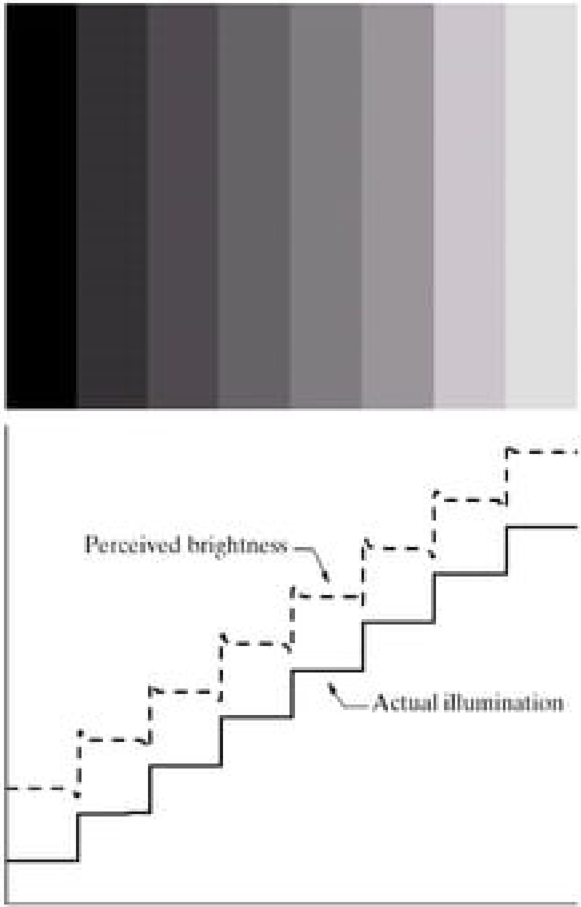


Perceived Brightness

Two phenomena clearly demonstrate that perceived brightness is not a simple function of intensity.



AN EXAMPLE OF MACH BAND



Intensities of surrounding points effect perceived brightness at each point.

In this image, edges between bars appear brighter on the right side and darker on the left side.

First Phenomena
Visual system tends to undershoot or overshoot around boundary of regions of different intensities.

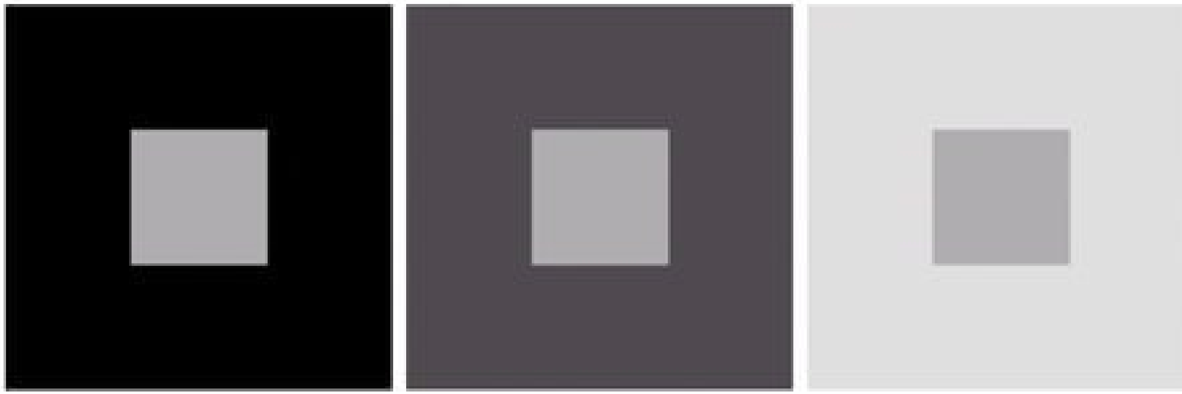
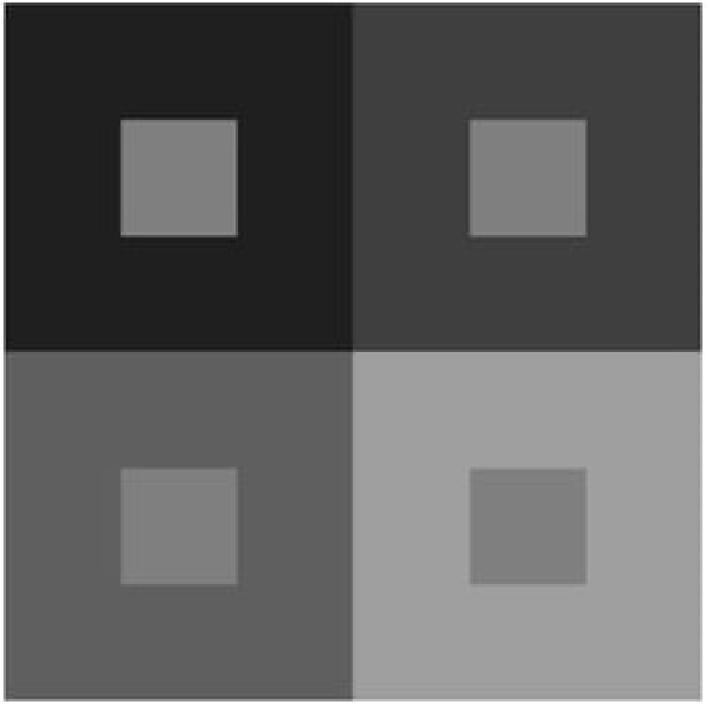


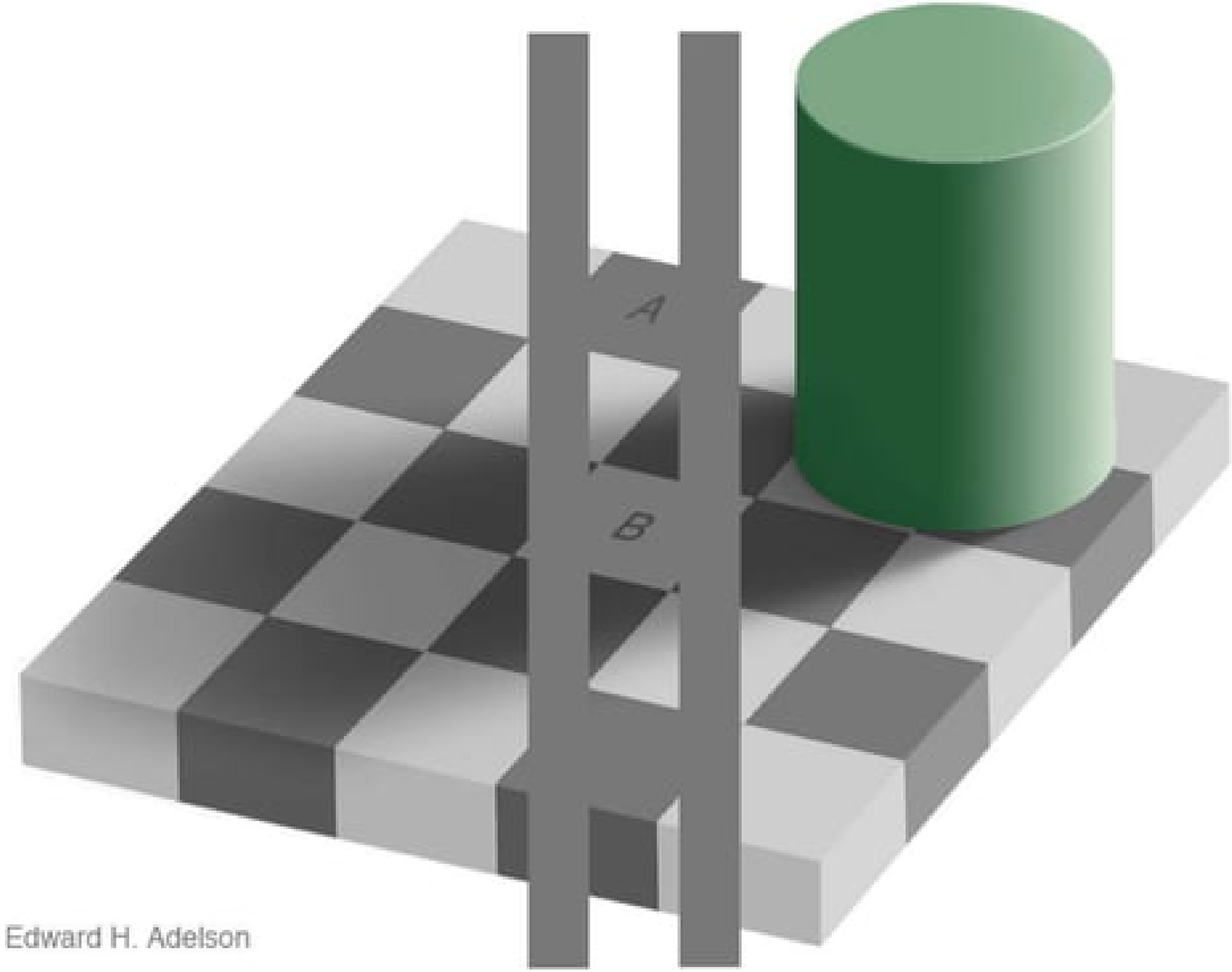
FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

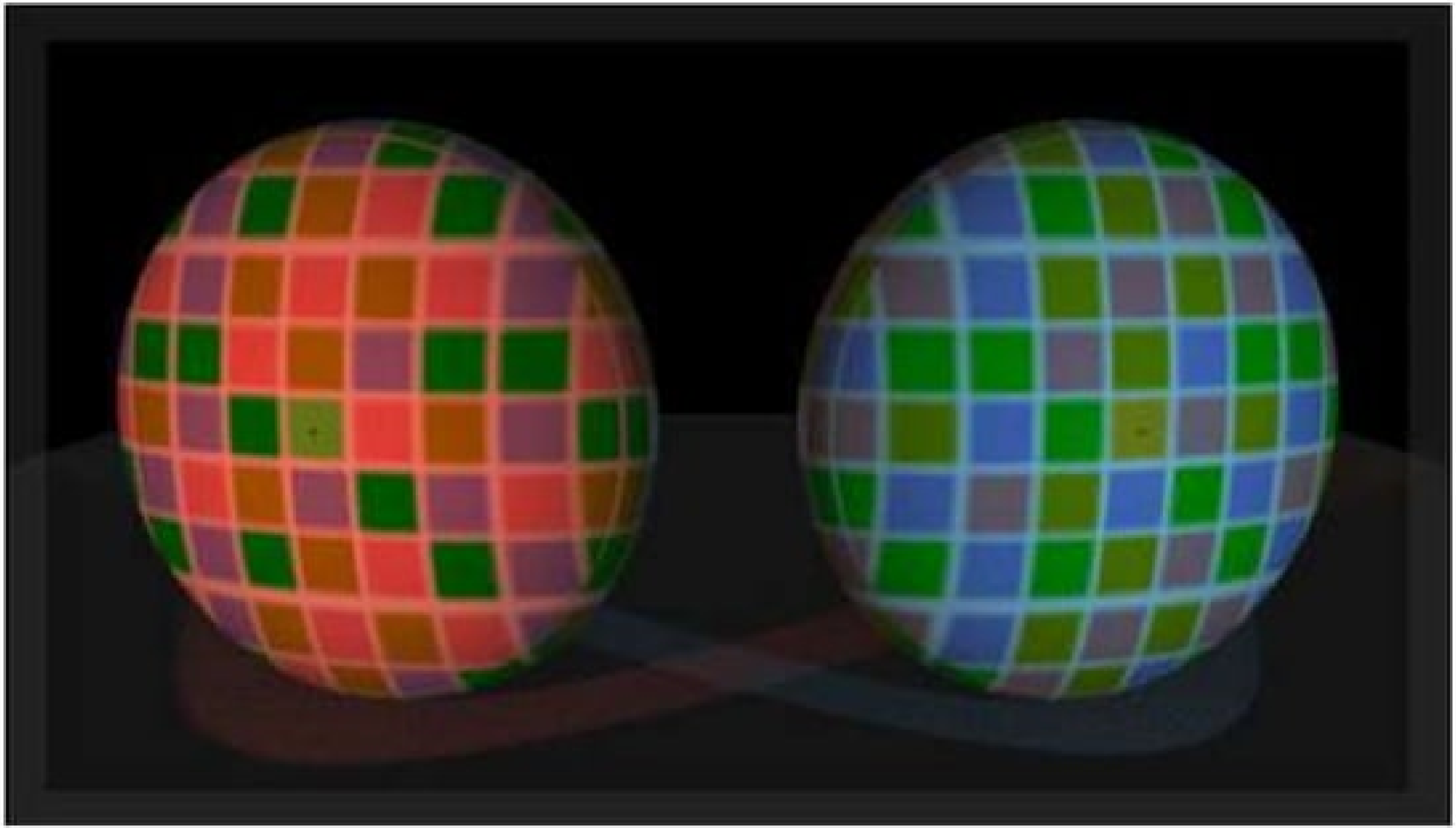
The second phenomena, called simultaneous contrast, a spot may appears to the eye to become darker as the background gets lighter.

Brightness Adaptation of Human Eye : Simultaneous Contrast



<u>Simultaneous contrast</u>. All small squares have exactly the same intensity but they appear progressively darker as background becomes lighter.


A
B
Edward H. Adelson

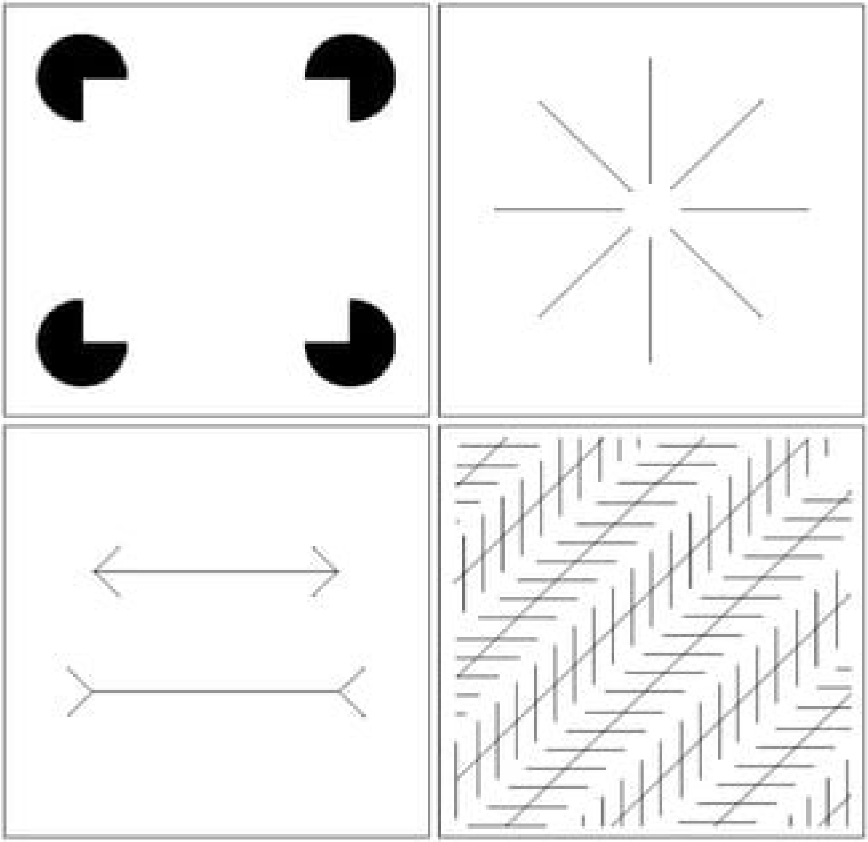


OPTICAL ILLUSIONS

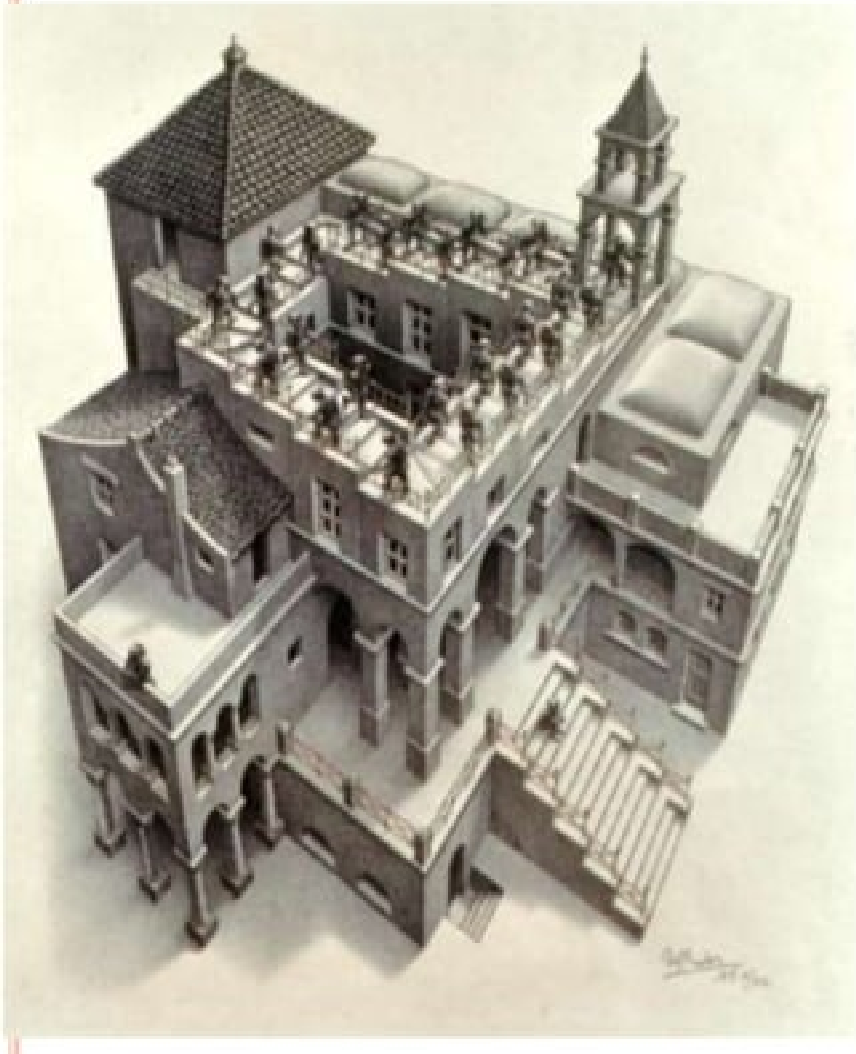
Optical illusions occurs when the eye fills in non-existing information or wrongly perceives geometrical properties of objects.

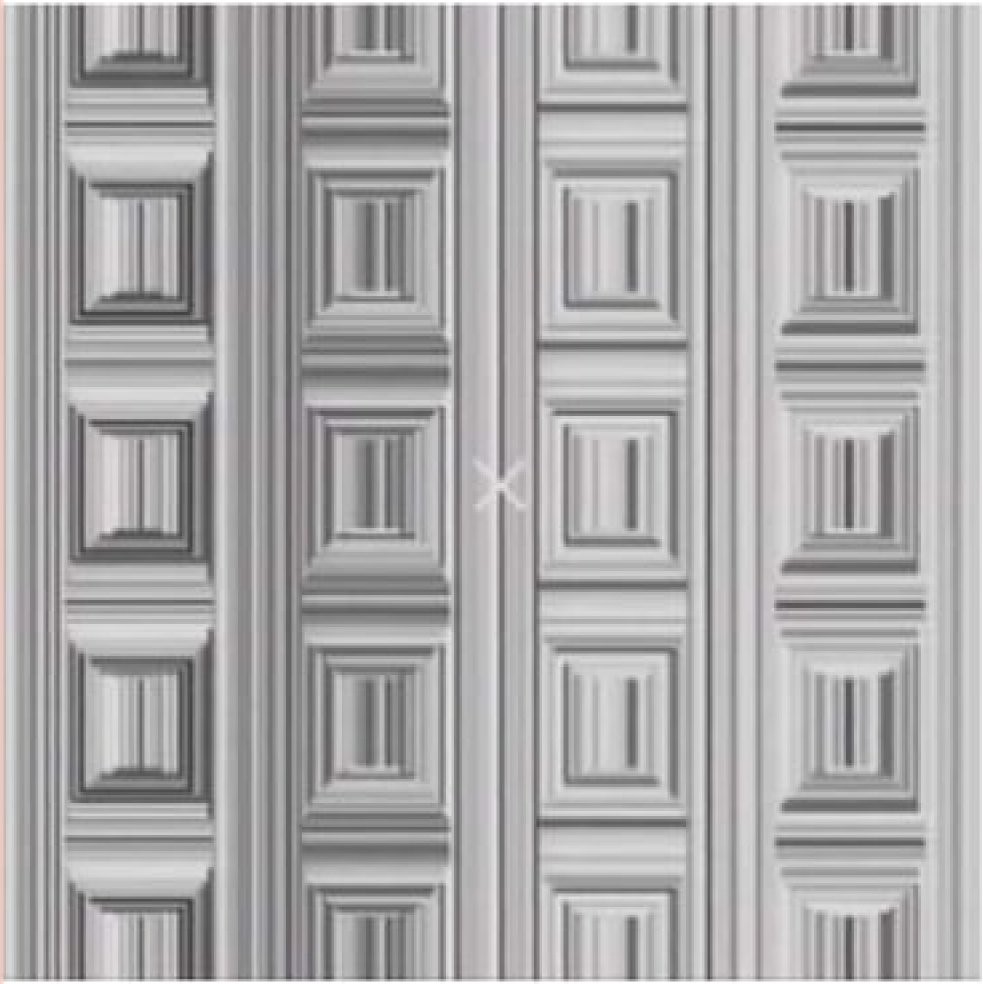
a	b
c	d

FIGURE 2.9 Some well-known optical illusions.



Optical Illusions (cont…)





Stare at the cross in the middle of the image and think circles

Mind Map Exercise: Mind Mapping For Note Taking

Beau Lotto: Optical Illusions Show How We See

http://www.ted.com/talks/lang/eng/beau_lotto_optical_illusions_show_how_we_see.html

2.2 Light and the Electromagnetic Spectrum

LIGHT AND THE ELECTROMAGNETIC SPECTRUM

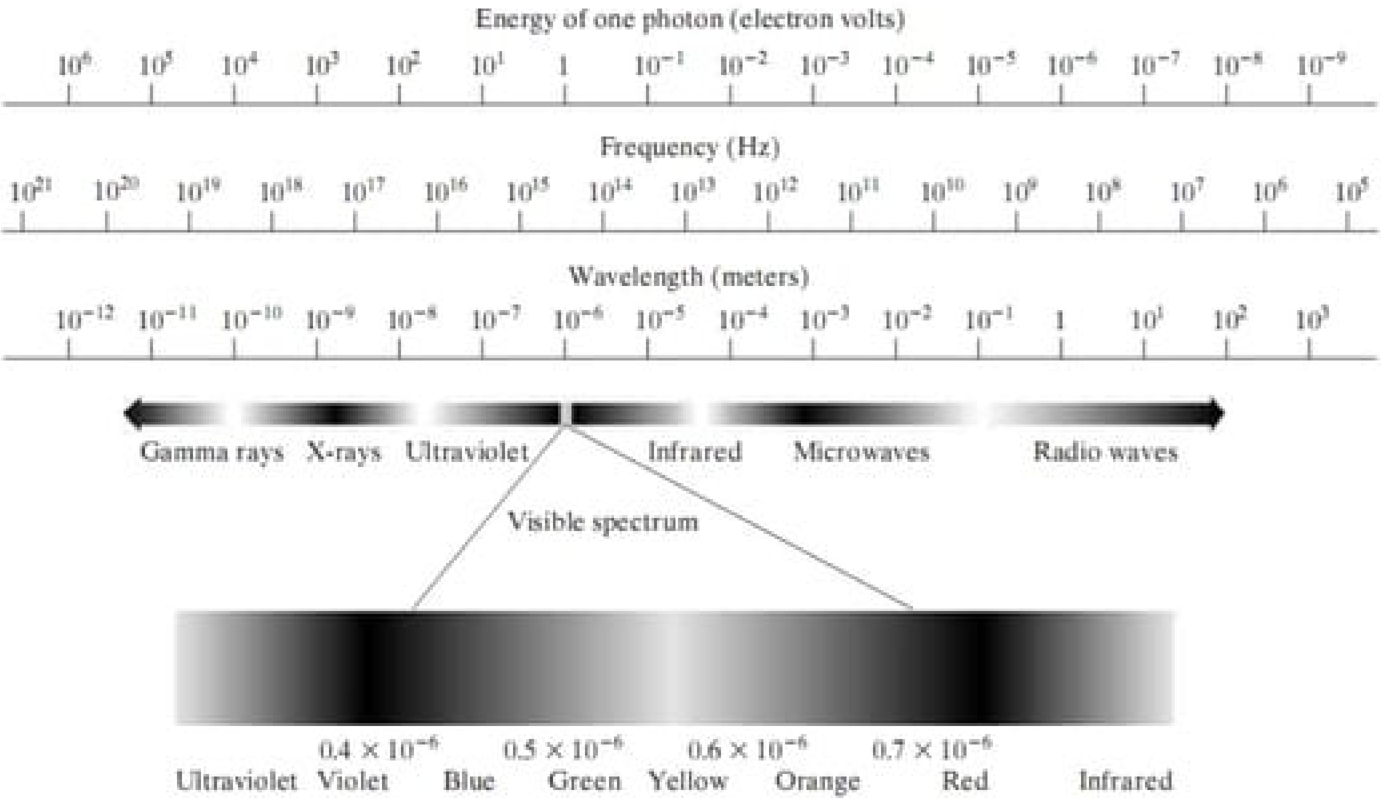
- In 1666, Sir Isaac Newton discovered that when a beam of sunlight is passed through a glass prism, the emerging beam of light is not white but consists instead of a **continuous spectrum of colors** ranging from **violet** at one end to **red** at the other.

- The range of colors we perceive in visible light represents a very small portion of the electromagnetic spectrum.

- On one end of the spectrum are **radio waves** with wavelengths billions of times longer than those of visible light.

- On the other end of the spectrum are **gamma rays** with wavelengths millions of times smaller than those of visible light.

CONT'D



The Wavelength of an Electromagnetic Wave Required to "SEE" an Object Must be of the Same Size as or Smaller Than the Object.

The 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

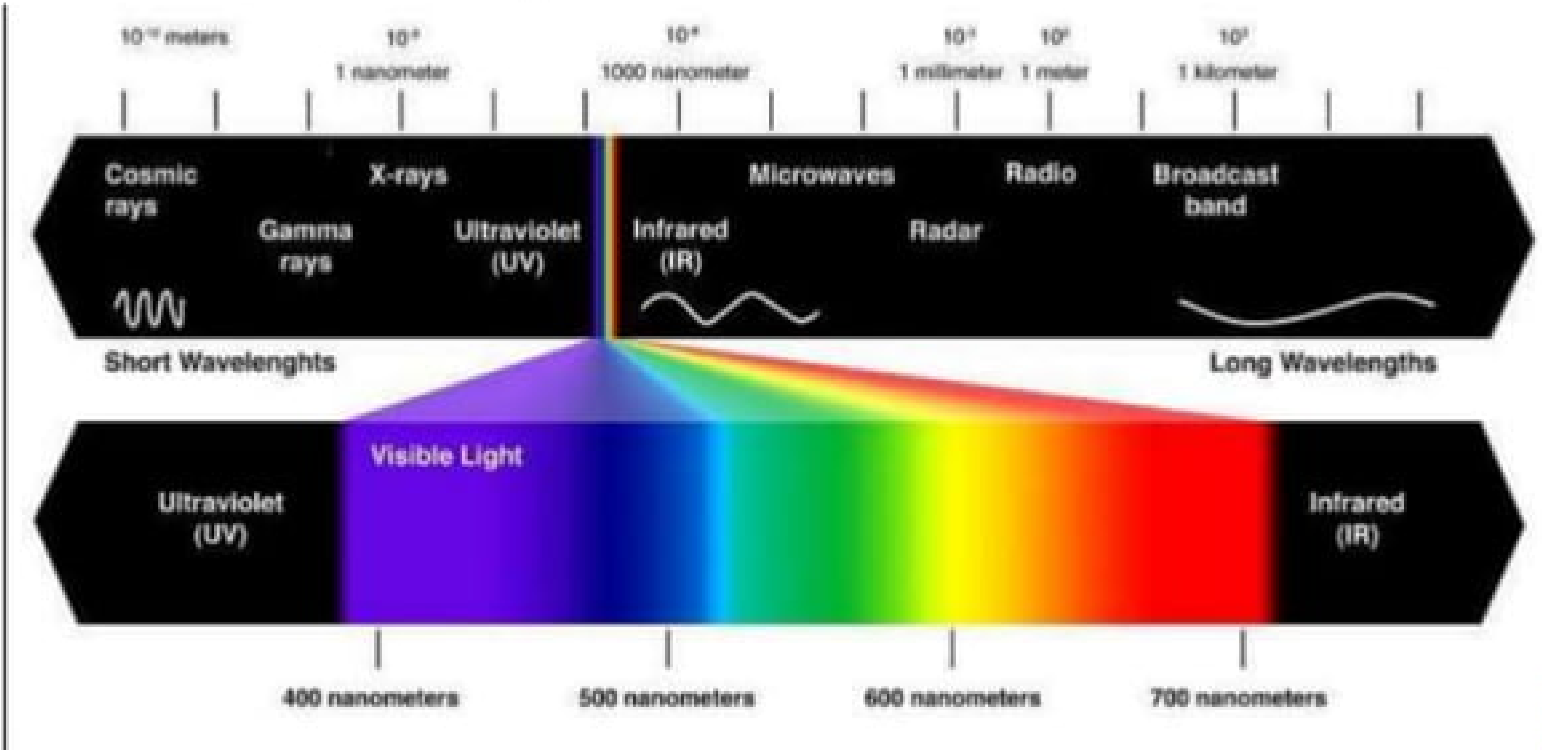
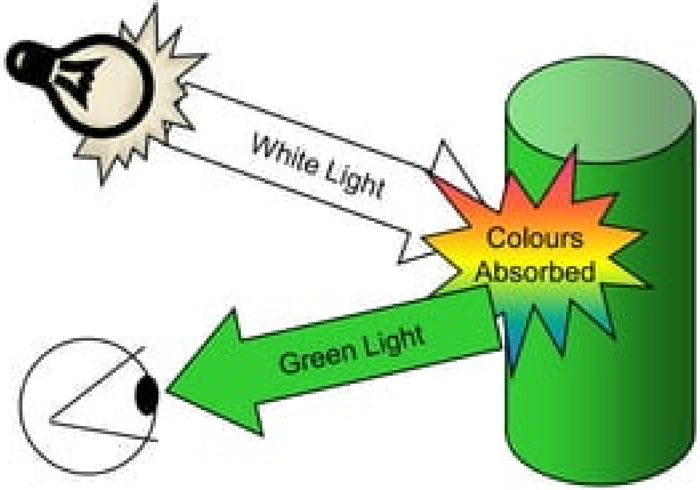


Fig. The electromagnetic spectrum arranged according to energy per photon

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.

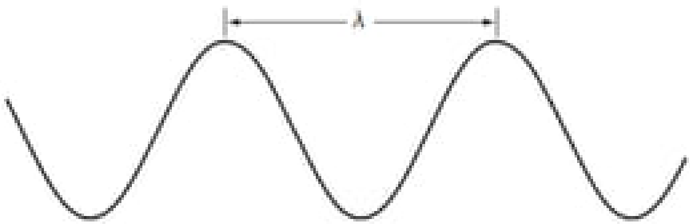


Light and the Electromagnetic Spectrum

- The colors that humans perceive in an object are determined by the nature of the light reflected from the object.
- Achromatic or monochromatic light is void of color, and is described by its intensity (gray level).
- Chromatic light spans the electromagnetic energy spectrum from 0.43 to 0.79 μm, and is described by
  - Radiance: Total amount of energy that flows from the light source, and measured in watts (W)
  - Luminance: Measured in lumens (lm), gives a measure of the amount of energy an observer perceives from a light source
  - Brightness: Subjective descriptor of light perception that is practically impossible to measure.

CONT'D

Wavelength (λ), frequency (ν), and energy (E) are related by the expressions



$$\lambda = \frac{c}{\nu} = 2.998 \times 10^{8}\ \mathrm{m/s}$$

$$E = h\nu$$

- The electromagnetic spectrum can be expressed in terms of wavelength (λ), frequency (ν), or energy (E).

  - ***h*** is Planck's constant.
  - The units of wavelength are meters, with the terms *microns* and *nanometers* being used just as frequently.
  - Frequency is measured in Hertz (Hz), with one Hertz being equal to one cycle of a sinusoidal wave per second.
  - unit of energy is the electron-volt.

CONT'D

- Electromagnetic waves can be visualized as propagating sinusoidal waves with wavelength, or they can be thought of as a stream of mass-less particles, each traveling in a wavelike pattern and moving at the speed of light. Each mass-less particle contains a certain amount (or bundle) of energy. Each bundle of energy is called a photon.

- Energy is proportional to frequency,
  - Higher-frequency (shorter wavelength) electromagnetic phenomena carry more energy per photon.

- Gamma rays are so dangerous to living organisms.

CONT'D

- Light is a particular type of electromagnetic radiation that can be seen and sensed by the human eye.

- The visible band of the electromagnetic spectrum spans the range from approximately 0.43 micro m (**violet**) to about 0.79 micro m (**red**).

- For convenience, the color spectrum is divided into six broad regions: **Violet**, **Blue**, **Green**, **Yellow**, **Orange**, and **Red**.

The Origins of Digital Image Processing (color)

- The colors that humans perceive in an object are determined by the nature of the light reflected from the object.

- A body that reflects light and is relatively balanced in all visible wavelengths appears white to the observer.

- A body that favors reflectance in a limited range of the visible spectrum exhibits some shades of color.
  - For example, green objects reflect light with wavelengths primarily in the 500 to 570 nm range while absorbing most of the energy at other wavelengths.

THE ORIGINS OF DIGITAL IMAGE PROCESSING (ACHROMATIC OR MONOCHROMATIC)

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

The Origins of Digital Image Processing (Chromatic light)

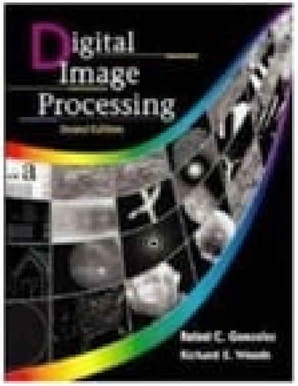
- **Radiance** is the total amount of energy that flows from the light source, and it is usually measured in watts (W).

- **Luminance**, measured in lumens (lm), gives a measure of the amount of energy an observer perceives from a light source.
  - For example, light emitted from a source operating in the far infrared region of the spectrum could have significant energy (radiance), but an observer would hardly perceive it; its luminance would be almost zero.

- **Brightness** is a subjective descriptor of light perception that is practically impossible to measure. It embodies the achromatic notion of intensity and is one of the key factors in describing color sensation.

REFERENCES

- "Digital Image Processing", 2/ E, Rafael C. Gonzalez & Richard E. Woods, www.prenhall.com/gonzalezwoods.



Questions?

Chapter 2 – Next Section (Coming Soon)