Human Eyes as an Image Sensor

(See diagram for the structure of eye at the end of this chapter.)

1. Photo sensors

Upper 7 decades of photo-reception (*"photopic vision"*) is achieved by retina cones, while lower 3 decades (*"scotopic vision"*) is achieved by retina rods. It is believed that the photopic vision is brought by photochemical reaction of red, green, and blue pigments, while scotopic vision is a product of rhodopsine.

2. Threshold photo-sensitivity

100 – 150 photons of 507 nm light entering the pupil (diameter 2 – 8 mm), equivalent to luminance of smaller than 10^{-6} cd/m^2.

3. Spectral sensitivity

Light-adapted eyes: 400 – 700 nm (peak at 555 nm: yellow light)
Dark-adapted eyes: 380 – 650 nm (peak at 507 nm: green light)

4. Contrast sensitivity

Human eye can distinguish about 50 discrete shades of gray, corresponding to 6- to 7-bit ***"gray values"*** in digitized image display.

More accurately, human eye's property can be modeled to a close proximity to the equation below (Rose, 1947).

$$B \times C^2 \times a^2 = \text{constant}$$

Where, B; luminance of the scene, C; threshold contrast, α; the angular size of the object.

In reasonably high luminance and a test object is fairly large, human eyes can detect 2% gray level differences (***DI/I***). However, at very low luminance, a contrast of 100% or more is needed to be distinguished. According to the Rose model, human eye is matched with that of ideal sensing device in the following properties.

Storage time: 0.2 seconds

Signal/noise (S/N) ratio: 5

Quantum efficiency[*)]: At low luminance = 5%
At high luminance = 0.5%

*) In this definition, 5% means that only 5 out of 100 photons is detected after entering into the iris. Modern image sensor (photocathode) has a much higher QE being as much as 30%, as well as very high S/N ratio. (See Chapter on Digital Imaging.)

5. Dynamic range

More than ten decades of *interscene* dynamic range, ranging between 10^{-6} and 10^{5} lumens/m^2 (Lux). This level of sensitivity requires adaptation of about 30 minutes (from photopic vision to scotopic vision). During the interval of time before full adaptation is acquired, the *intrascene* dynamic range is only about 4 decades.

6. Spatial resolution

In the center of retina (*"central fovea"*), the distance between adjacent cones is 1.5 to 2 μm. Taking the *Nyquist factor* of two, one needs 3 – 4 μm separation of the stimuli to be accurately resolved. In contrast, assuming the diameter of pupil of 2 mm, estimated radius of the first order diffraction pattern for 555 nm point light source formed at retina would be 4.6 μm.

7. Scanning property

The visual accuracy is closely related to the ability of involuntary rapid movement of eyes. Once scanned, the signal is processed by complex neuronal network. One would be amazed learning a similarity between human photo-reception and scanning imaging devices such as laser scanning confocal microscope.

8. Visual cortex and hallucinations

Though this is not in scope of this lecture, I found a Jan. 1, 2002 article in Chicago Tribune interesting and provocative. Article ***"Seeing more than meets eye"*** reports the study by Dr. Jack Cowan of Univ. Chicago finding that four patters which hallucinated individual sees ("tunnel shapes", "honeycombs", "cobwebs", "spirals") are in fact registered pattern cells of visual cortex. The individual "sees" these patterns regardless the actual test pattern is precisely registered lines or blocks.

(Excerpt) 'Normally, the 100 million neurons of the credit-card size visual cortex at the back of the head convert what our eyes see into edges, color, depth and other features, and then reassemble the pieces into recognizable scenes of the outside world. The process works fast. About 40 milliseconds after seeing an object, edge detectors are activated and in another 40 milliseconds the edges become pieced together into contours and the beginnings of surfaces. This information goes to other parts of the brain to be compared with stored memories." (For detail, archive at, http://www.chicagotribune.com/news/nationworld/.)

(Diagram: Human Eye)

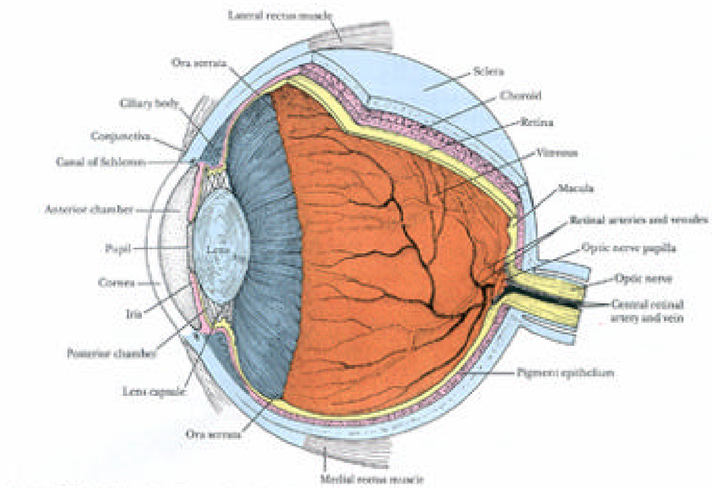

Figure 23.2. Schematic diagram illustrating the internal structures of the human eye. (Modified from *The Anatomy of the Eye*, from an original drawing by Paul Peck. Copyright, Lederle Laboratories Division of American Cyanamid Company. All rights reserved. Reprinted with permission.)

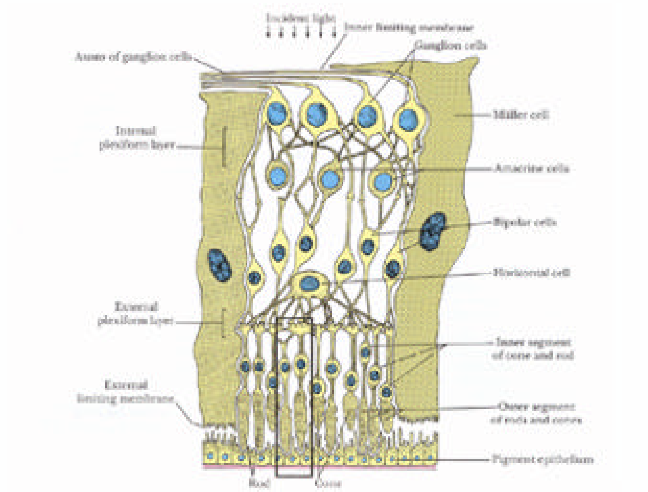

Figure 23.6. Schematic drawing of the layers of the retina. The interrelationship of the neurons is indicated. Light would enter the retina and pass through the internal layers of the retina before reaching the photoreceptors of the rods and cones that are closely associated with the pigment epithelium. The area in the rectangle is shown at higher magnification in Figure 23.7. (Modified from Dowling JE, Boycott BB: Organization of the primate retina: electron microscopy.)

"Histology" (Ross, Romrell, Kay, 1995)

(Hallucination: "Aliasing"?)