Photorealistic Rendering
Lesson I

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The physiological structure of the human eye is shown in figure 1. The most important structural elements of the optic path are the *cornea*, *iris*, *pupil*, *lens* and *retina*. The cornea is a clear coating over the eye. It serves as both a protective structure and a focusing element. It in fact is a stronger focusing than the lens. The iris is a colored annulus behind the cornea but before the lens. The pupil is formed by the open part of the pupil. Light passing through the pupil enters the trapsparent lens. The lens is surrounded by a set of muscles called the cilary body. When these muscles are relaxed the lens in a normal eye focuses to infinity. When these muscles are tensed the lens is compressed and the eye's focal point moves closer to the eye. The light falls on the retina which contains a thin layer of cells covering about 200^{o} on the back of the eye.

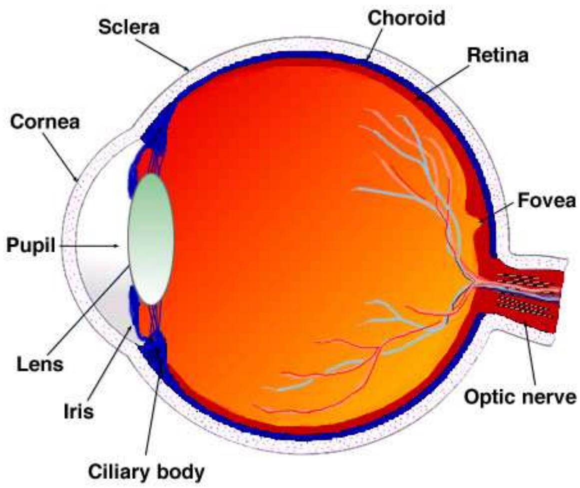

Figure 1.

The retina contains two type of photo-receptors *rods* and *cones*. Cones are primarily resposible for color perception. Rods are limited to intensity, though they are about ten time more sensitive to light than cones. The fovea, only about 1 or 2^{o}, of visual angle, is the area with the greates density of light receptors. The fovea only contains cones receptors and it has the densest collection, having about 147,00 cones per square millimeter. Figure 2 shows a picture of the rods and cones in the retina. Also shown are the neural connections that lead to the optic nerve. A fair amount of processing is done in the neural network even before the the signal is sent to the optic nerve. The eye contains about 120 million cones and 6 millions rods, while the optic nerve contains only about 1 million fibers, thus the data reduction in the optical signal is about two orders of magnitude.

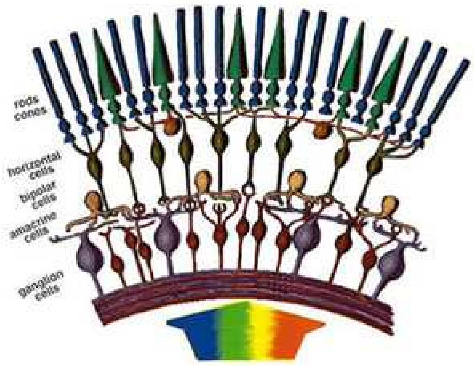

Figure 2.

Figure 3. shows the relative densities of the rods and cones in a cross section of the eye. Note the *optical disk,* frequently called the blind spot, that contains no receptors. This is the area that optic nerve enters the eye. The cones come in three varieties, *S*, *M* and *L* (also known as *B, G, R*). There frequency response is shown in figure 4. The fact the only three colors are actually sampled out of an infinite number of wavelengths gives rise to a infinite number of , *Metamers*, or spectrums that will give identical responses to the eye. The short wavelengths are roughly correspond to blue, the long wavelength red and the medium to green. This is the origin of the *trichromatic* theory of color Vision. The eye has actual receptors for the RGB colors. The fact that CRTs and LCD displays also are build on a RGB color model have to do with the trichromatic basis of human vision. If things were this simple vision would be a boring field.

Much evidence point to a much more complex human visual model. The *color opponency* theory, figure 5, seems to fit observed human vision better than the trichromatic model. In this model human vision is given by three channels that represent luminosity, red-green and blue-yellow.

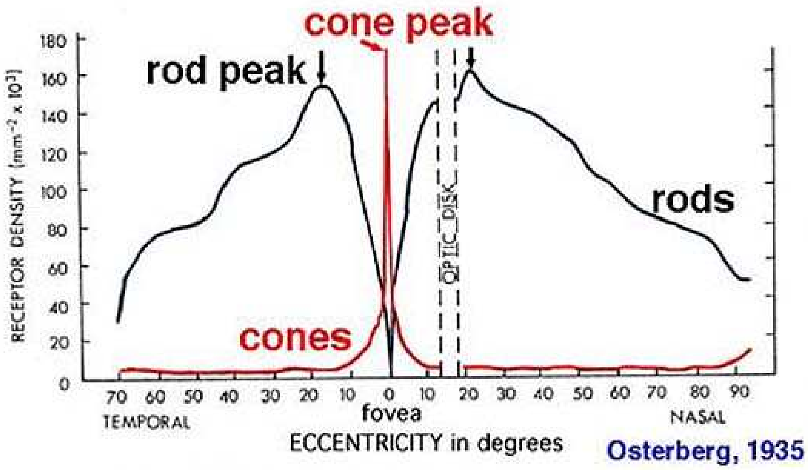

Figure 3.

The opponent colour theory was first proposed by Hering in 1872. At the time, this theory rivalled the well accepted trichromatic theory which explains the trichromasy of vision and predicts colour matches. Hering's opponent colour theory suggests that there are three channels: red-green, blue-yellow and black-white, with each responding in an antagonist way. That is, either red or green is perceived and never greenish-red.

This has led to the modern model of normal colour vision which incorporates both the trichromatic theory and the opponent colour theory into two stages. The first stage can be considered as the receptor stage which consists of the three photopigments (blue, green and red cones). The second is the neural processing stage where the colour opponency occurs. The second stage is at a post-receptoral level, and occurs as early as the horizontal cell level.

Human vision is actually more complicated as can be demonstrated by the optical phenomenon known as Mach bands, shown in figures 6 and 7. A possible explaination for this phenomenon is involves the *retinal ganglion cells*, figure 8. These cells act as weighted integrators of the intensity signal coming from the photoreceptors. This response allows us to accommodate to wide differences in contrast in an image.

The *contrast sensitivity* of the human eye is a function of the contrast and the spatial frequency as show in figure 9.

The temporal response of the photoreceptors gives rise to a smoothing at frequencies above the critical flicker frequency (CCF). The human eye can perceive flicker at frequencies lower than 60 Hz.

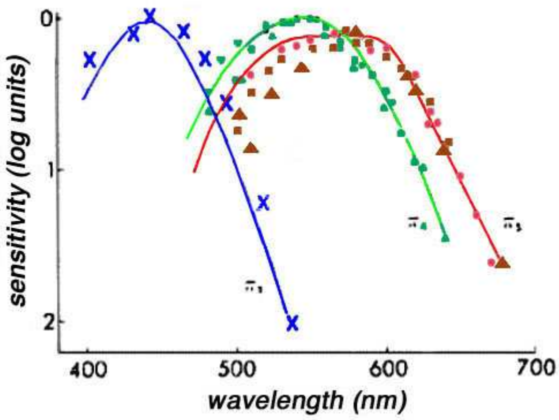

Figure 4.

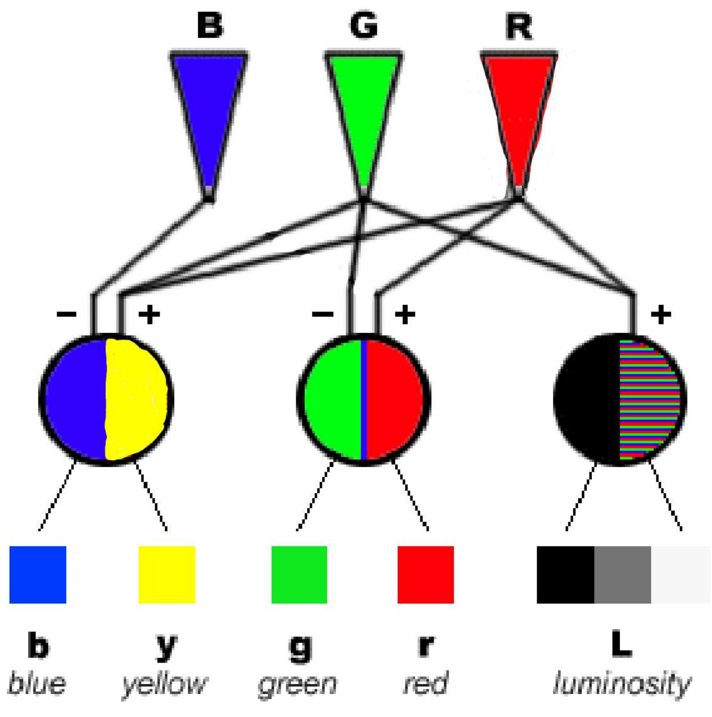

Figure 5.

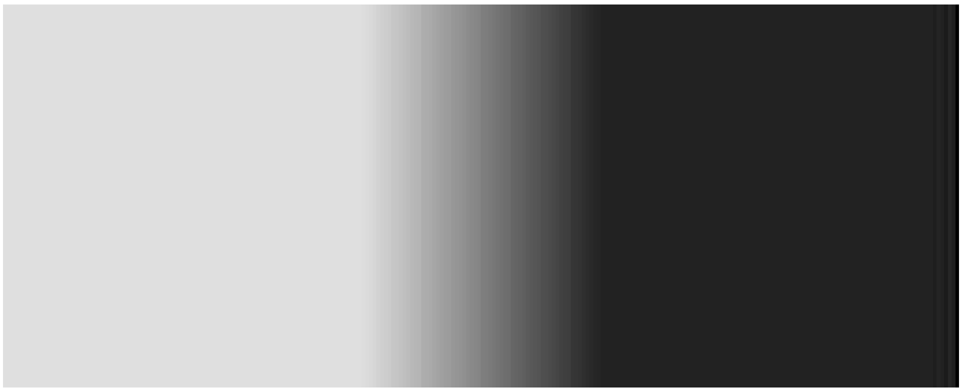

Figure 6.

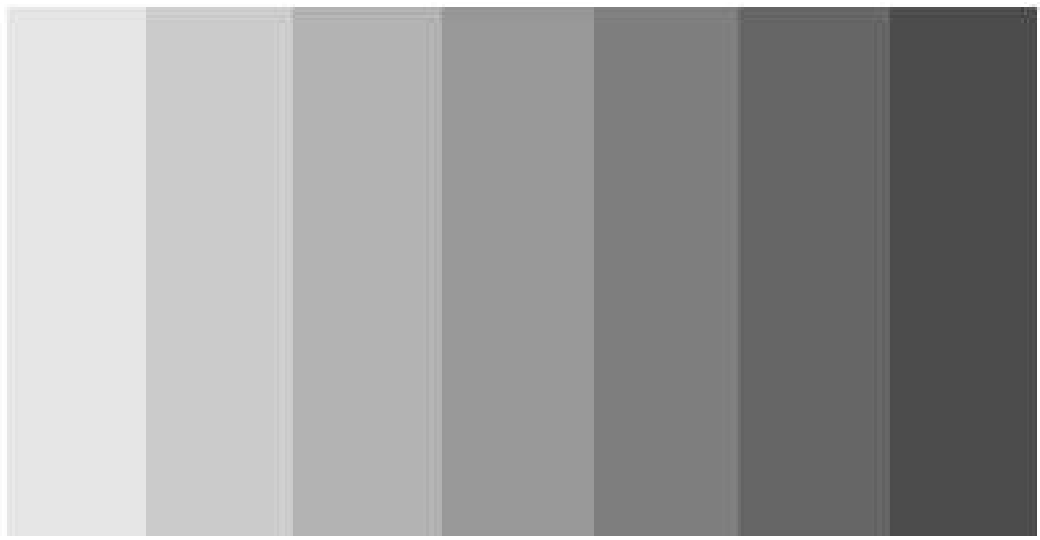

Figure 7.

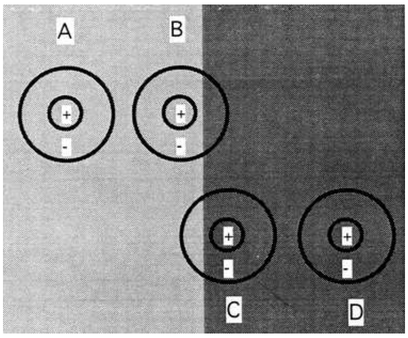

Figure 8.

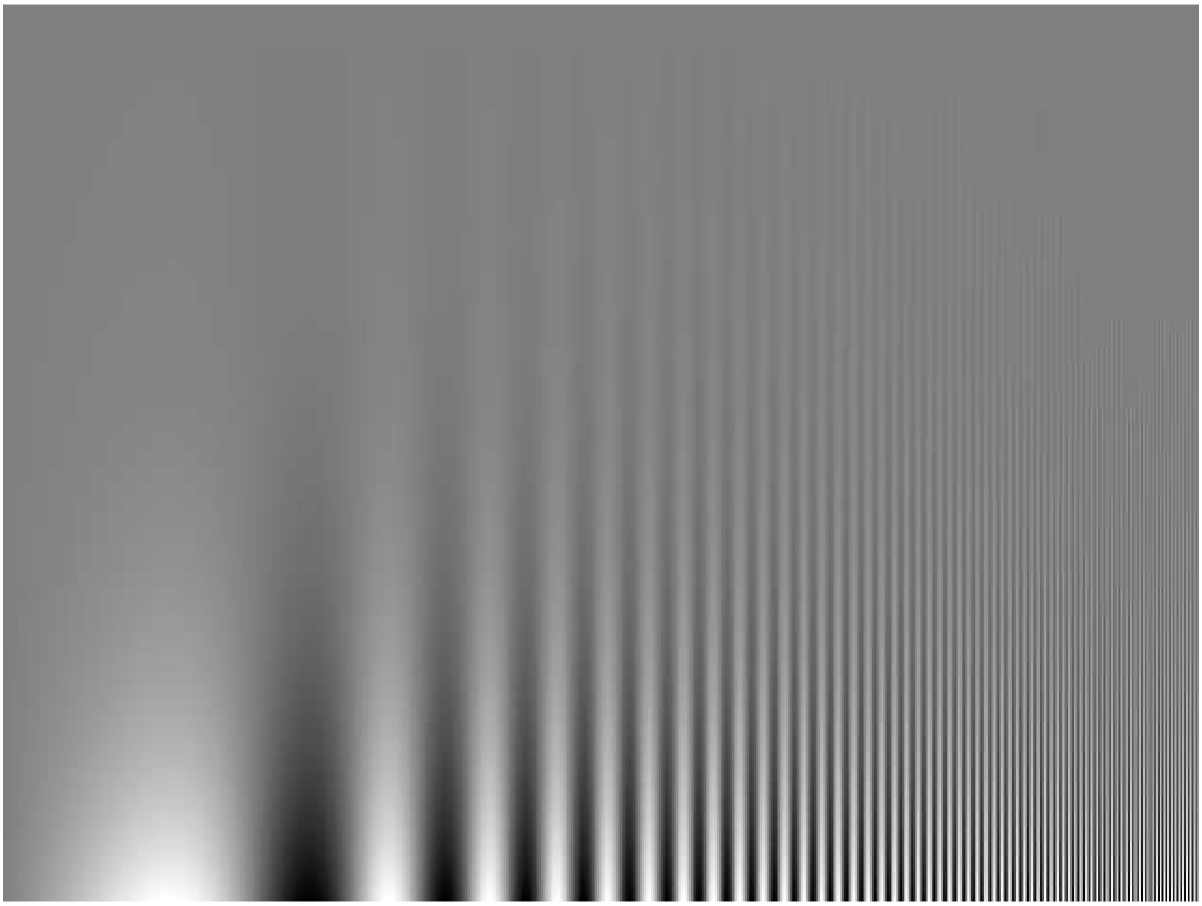

Figure 9.

A Normal Human Contrast Sensitivity Function

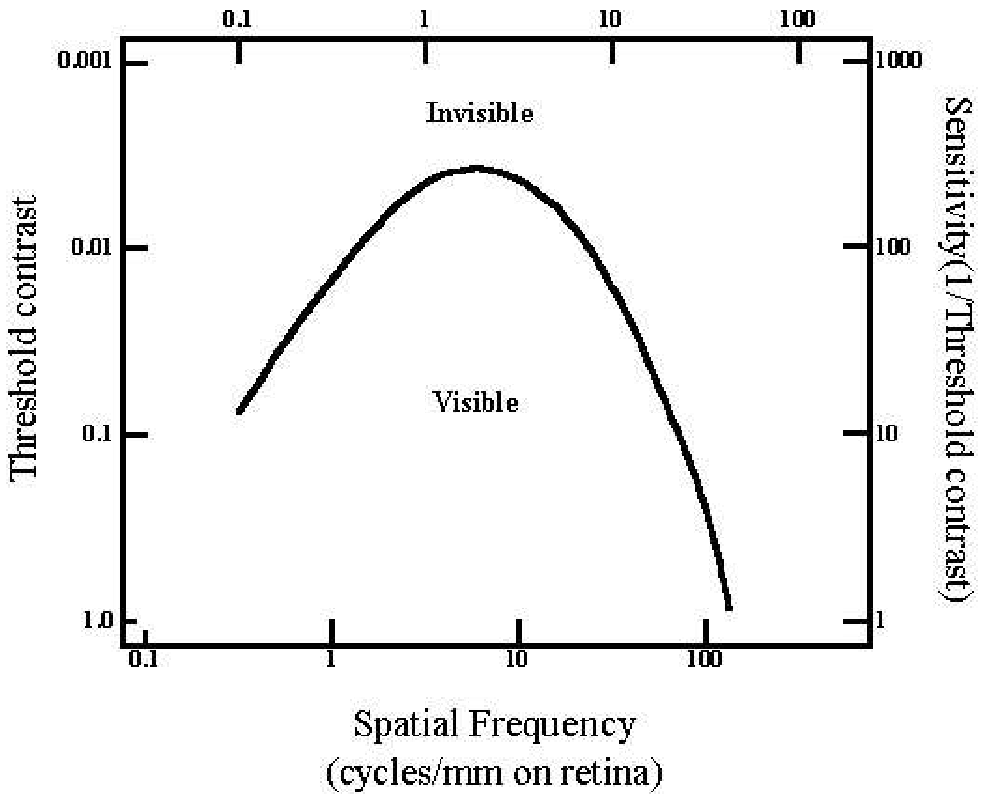

Figure 9.

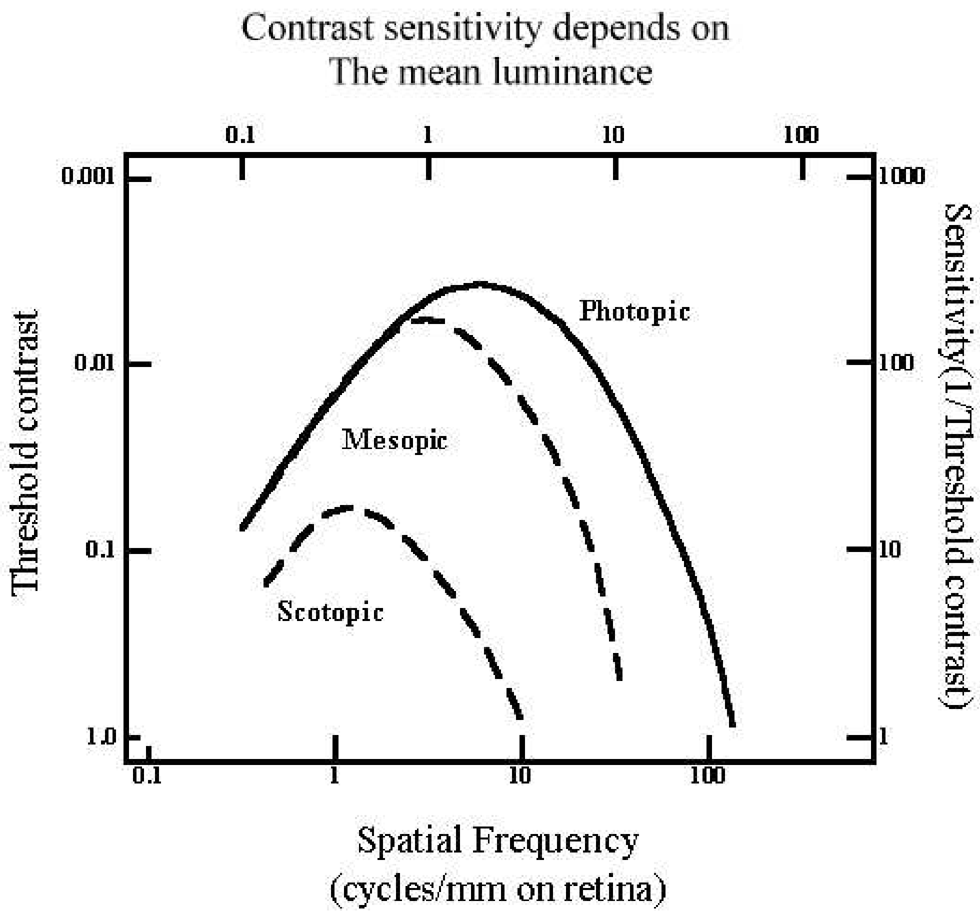
Contrast sensitivity depends on
The mean luminance
0.1
1
10
100
0.001
0.01
0.1
1.0
1000
100
10
1
Photopic
Mesopic
Scotopic
Threshold contrast
Sensitivity(1/Threshold contrast)
0.1
1
10
100
Spatial Frequency
(cycles/mm on retina)

Figure 9.