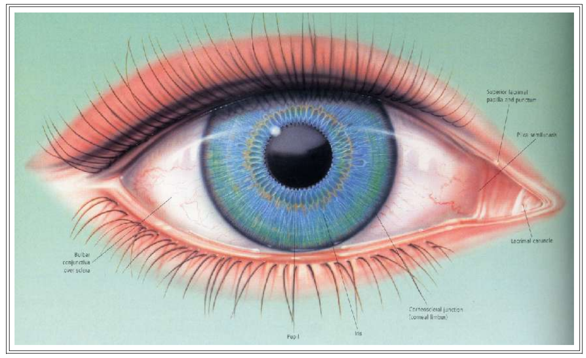
Vision: Seeing is believing



Our obvious sense of vision is the one we use and trust the most in interpreting the world around us from the genius of Michelangelo's Sistine Chapel ceiling to mist-filled vistas of a mountain range. Two-

thirds of all the information processed in the human brain comes in through the eyes. About one-fourth of the brain is involved in visual processing, more than for all other senses.

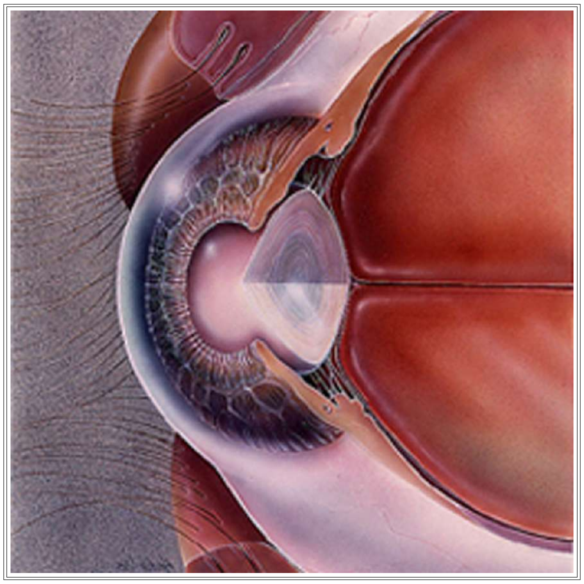
Anatomy of human eye

No larger than a Ping-Pong ball, weighing roughly only 7 gram, each of your eye is concerned with converting light of various wavelengths reflected from objects at varying distances and bringing the **visual field** to the photoreceptor cells situated in the innermost layer of eye, the **retina**. This is seen by optician or physician, using ophthalmoscope.

Each eyeball is composed of three concentric layers. The outer most **sclera** (or "white of the eye") is tough but elastic sheath of fibrous connective tissue containing collagen fibres, except for the coloured part at the front. It provides the attachment point for the muscles that move the eye. The coloured circle on your eye, a ring of muscle, is called the **iris** containing pigments which give its colour. At the centre is the transparent zone or **pupil** through which light enters the eye. The domed 1/6 th portion of sclera called **cornea** at the front, is transparent and more curved surface to act as a main structure reflecting light towards the retina. Just inside the sclera is a layer of darkly pigmented tissue the **choroid**, rich in blood vessels that prevent internally reflected light within the eye. These reflections reduce resolution, but increase sensitivity by sending the unabsorbed light back for another try. This mirror-like layer called tapetum accounts for the way's a cat's eyes seem to glow in the dark. Just behind the junction between the main part of the sclera and the cornea, the choroid becomes thicker and has smooth muscles embedded in it. This portion of the choroid is called **ciliary body** which joins with the iris. Tears secreted by the lachrymal glands lubricate the exposed surface of the eye, including the **conjunctiva**, the thin transparent stratified mucous membrane continuous with the inner surface of epithelium of eyelids which covers the cornea except in the centre. Embedded in each tarsal plate of the eyelids is a row of elongated modified sebaceous glands known as **Meiboian glands**. Their oily secretion helps keep the eyelids from adhering to each other. The iris also contains radial bands and a ring of circular smooth muscle. It is to control the amount of light that reaches the photosensors at the back of the eye just as the diaphragm of the camera controls the amount of light reaching the film. Control of radial muscles and relaxation of the circular muscles causes dilation of the pupil. A tiny circular area, about 6 mm in diameter in the retina is **yellow spot** or **macula lutea**, where your vision is sharpest. If we accidentally focus on intense light sources such as sun to limit the damage, this acts as filter over **fovea**, a tightly packed array of specialised photosensor-receptor cells in the centre of the circle. This is 2 or so mm above the **blind spot** from where the **optic nerve**, a smooth and round cord emerge.

The **lens** composed of crystalline protein is suspended behind the pupil by a **suspensory ligament** attached to the cilliary body. The lens and its suspensory ligament divide the cavity of the eye ball into two chambers. The chamber between the cornea and lens in filled with a gel, clear watery fluid, the **aqueous**

humor, that is finally drained into the blood through canal of Schlemm. The chamber behind the lens is filled with a clear semi-solid gelatinous material, the **vitreous humor** which helps to maintain the shape of the eye ball.

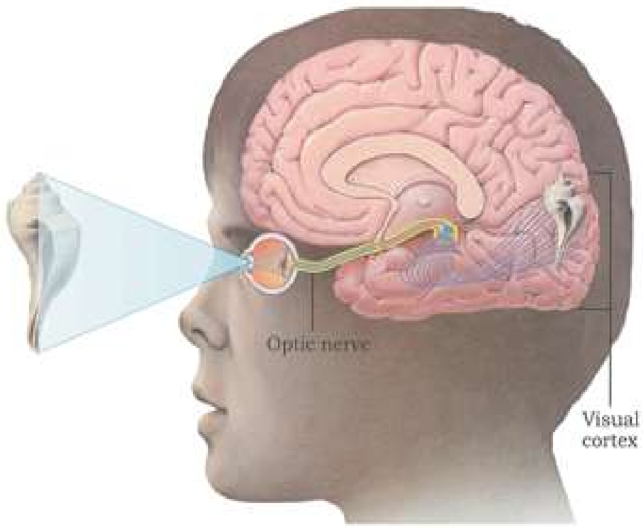


The retina which is not more than the size of a postal stamp and thinner than even that, is composed of several layers of cells each containing a characteristic type of the cell. First there is the photoreceptor layer containing the photosensitive cells, the **rods**, and **cones**, partially embedded in the microvilli of pigment epithelium cells of the choroid Next is the intermediate layer containing short sensory **bipolar neurons**. Bipolar cells in turn synapse with the **retinal ganglion cells** whose axons, bundle together as the optic nerve. The relationship of receptors to bipolar cells to ganglion cells is 1:1:1 within the fovea. Outside the fovea, however, processing of visual information can occur within the retina because often several receptor cells synapse with a single bipolar cell and several bipolar cells synapse with a single ganglion cell. Besides this convergence of information, **horizontal** and **amacrine cells** enable lateral transfer of information from pathway to pathway. Each horizontal cell receives synapses from many receptor cells and synapses onto many bipolar cells and other horizontal cells. Amacrine cells both receive synapses from and synapse onto bipolar cells. They also synapse onto many ganglion cells. This allows a certain amount of processing of visual information to occur before it leaves the retina, for instance, these cells are involved in lateral inhibition. This lateral flow of information sharpens the perception of contrast between light and dark patterns falling in the retina. Note that the retina is arranged anatomically in reverse order from what might be expected. The receptor cells are in the back of the retina, and light must pass through the nerve cells to reach them.

Accommodation: Focusing

Accommodation is the reflex mechanism by which light rays from objects at various location in the near visual field are brought to focus on the retina. To focus a camera on objects close at hand, you must adjust the distance between the lens and the film. Fishes, amphibians, and reptiles accommodate in a similar manner, moving the lens of their eyes closer to or farther from their retinas. Mammals and birds use a different method. They alter the shape of the lens. In bright light the circular muscle of the iris diaphragm contracts, the radial muscle relaxes, the pupil becomes smaller and less light enters the eye, preventing damage to the retina. In dim light the opposite muscular contractions and relaxations occur. In the dark of night your pupil may become up to 16 times bigger. The added advantage of reducing the pupil size is that it increases the depth of focus of the eye so that any displacement of the photosensors in the retina will not impair the focus.

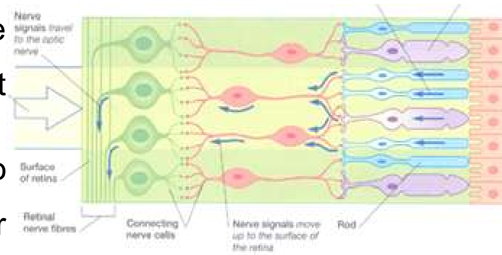
Light rays from distant objects (>6 metres) are parallel when they strike the eye. Light rays from near objects (< 6 metres) are diverging when they reach the eye. In both cases the light rays must be refracted or bent to focus on the retina and refraction must be greater for light from near objects. The closest point at which you can see an object clearly with full accommodation is called your **near point**. Normal value of it is 6” (9-50 cm). The **far point** is nearest point from which light rays come parallel and are clearly focused on the retina without accomodation. Normal value of it is 20” (6 m). The normal eye is able to accommodate light from objects from about 25 cm to almost infinity. With the involuntary cilliary muscles at rest the flatter lens has the correct optical properties to focus distant images on the retina but not close images. The state of contraction of the cilliary muscles changes the tension on surpensory ligaments. This acts on the natural elasticity of the lens which causes it to change its radius of curvature and thus the degree of refraction. As the radius of the curvature of the lens decreases it becomes thicker, round up and amount of refraction increases. It is the tension of the suspensory ligaments applied to the lens which determines the shape of the lens. When the circular cilliary muscles are relaxed and the suspensory ligament becomes taut. The lens is pulled into a flattened shape suitable for focusing distant objects decreasing the refraction. When the tension is decreased, the circular cilliary muscles are contracted and the suspensory ligament slack, consequently the lens becomes a more spherical shape suitable for focusing objects.



The image produced by the lens of eye on the retina is inverted and reversed. However, objects are perceived the right way up because of the way in which the brain interprets the images. One role of amacrine cells is to adjust the sensitivity of the eye according to the overall level of light falling on the retina. When light levels change, amacrine cell connections to the ganglion cells help the ganglion cells remain sensitive to temporal changes in the stimulation. Thus when with large changes in background illumination, the eyes are sensitive to smaller, more rapid changes in the pattern of light falling on the retina. The peripheral region of the retina does not transmit a point-to-point image, as does the fovea, but transmits instead a processed version of the visual input. It is with this portion of the eye, for example, that we detect movement and boundaries. It has been said that we use the periphery of the eye as a detector and the fovea as an inspector.

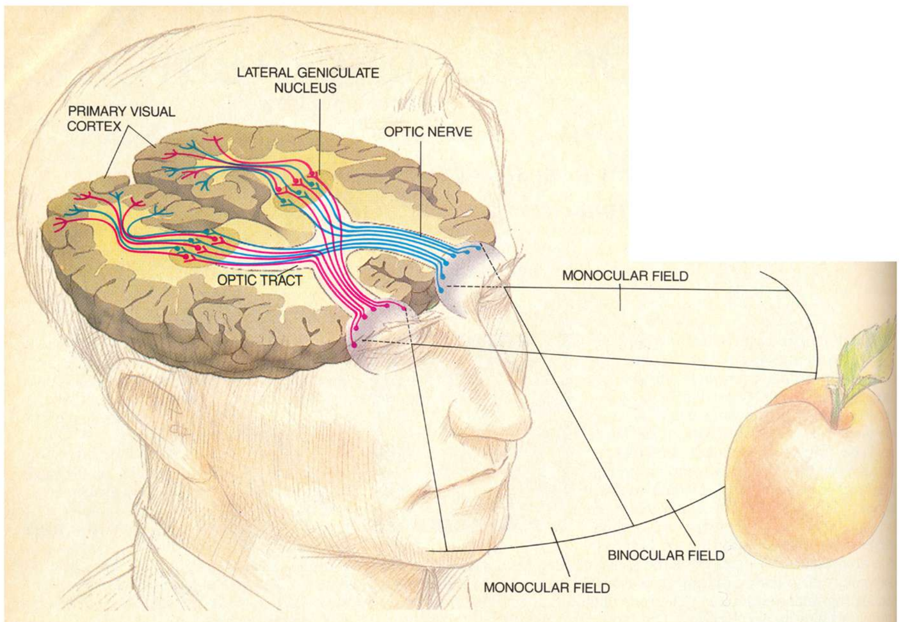
Photoreception

The transmission of nerve impulses to the brain in response to stimulation of photoreceptors in the retina by light is the function of the optic nerves. The density of photosensors in not the same across the entire retina. Light coming from the centre of the field of vision falls on an area of the retina called the **fovea** [L. pit], where the density of sensors is the highest. The human fovea has about 160,000 sensors per mm^2 . There are two major kinds of photosensors, both named for their shapes **rod cells** and **cone cells**. Rods and cones form an uneven mosaic within the retina, with rods generally outnumbering cones more than 10 to 1,that is, 100-125 millions rods as opposed to 5-7 millions cones. Even though, the thin elongate rods are distributed uniformly throughout the retina except at the fovea, our macula including fovea contain mostly shorter than rods, elongate, inverted ice-cream cone shaped cones. This is where your vision is sharpest. Rods are much more sensitive to light than cones and respond to lower light intensities, only shades of dim light and are unable to discriminate colour and so are principally responsible for black-and-white night vision because they contain one visual pigment. They also allow us to discriminate between different shades of dark and light and permit us to see shape and movement. Cones contain three visual pigments and so function in colour vision, enabling us to differentiate and discriminate colours. They are used principally in day light and are responsible for actual detail. In moonlight, we can not see colours because only the rods are functioning.



Seeing in colour

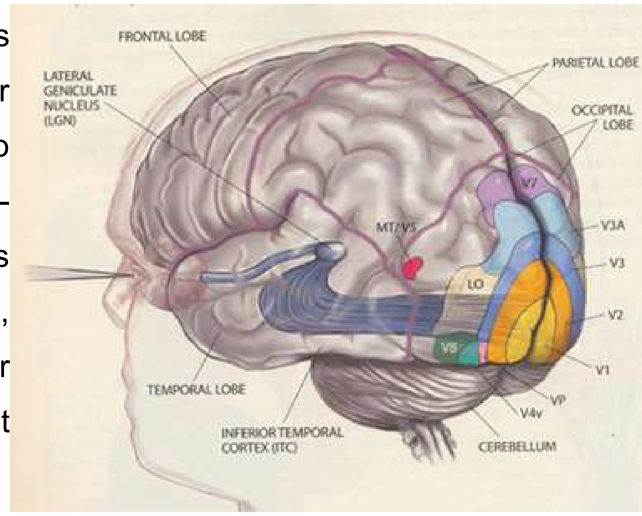
Seeing a colour involves making comparisions. The sensation of colour is triggered by the complex exchange between light and the relative responses of different classes of the cones in the retina. The mechanism of cone transduction is much more complex. There are three classes of cones, each possessing a different pigment sometimes called iodopsin having a different wave length sensitivity where initial discrimination of colours occurs. These opsin molecules differ slightly with a distinctive amino acid sequence and thus a different shape. All three cone pigments have retinal, a lipid as their prosthetic group, and these absorb light over a wide range of wave lengths. Short wave length-sensitive cones absorb maximally at 455 nm Medium wave length-sensitive cones absorb



maximally at 530 nm and Long wave length-sensitive cones absorb maximally at 625 nm.

Some times, they are referred to as blue, green and red cones respectively, but these are misnomers based on the colours in the spectrum. It may seem odd that we can distinguish colours so well when the absorption curves of three pigments overlap so much. For instance, Yellow light (580 nm) stimulates red cones about twice effectively as green cones. The same sensation can be obtained if two beams of light of yellow-green (560 nm) and orange (600 nm) are mixed. The human sensitivity ratio of blue : green : red is 0.11 : 0.59 : 0.30. So it is most sensitive to green if that of white light is 1. When we perceive some thing white, white light stimulates all the three classes of cones to signal equally or something back that we consider colourless is seen when all the three classes of cones signal inhibition equally. The initial discrimination of colours occur in the retina but the final perception of colour occurs in V_4 layer of the visual cortex.

Neurons, in this layer of visual cortex specialize in colour constancy. They compare and contrast the output of the ganglion cells in pairs to obtain fine colour distinction we perceive as colours. The key to colour constancy is our amazing ability to see colours as constant in an ever-changing world, that is, the colours of objects remains the same, whether we observe them under artificial light or under an overcast sky at noon or cloudless day.



Perception of distance and size:

The region of the environment from which each eye collects light is called the **visual field**. Since both our eyes are frontally placed, there is an overlap between the visual fields of each eye allowing us to discern distance and 3D-structure. This is called **binocular vision**. It has several advantages over monocular vision. Besides a larger visual field of 180^0, damage to one eye is compensated by the other, and cancels the effect of the blind spot. Most of the image perceived by the visual cortex in the brain results from the simultaneous integration of information from both eyes. Further more, a major source of information from each of the eye about the third which has a slightly different view of the same scene, what is called binocular disparity. Subtle differences appear between the images from the two eyes because each eye is looking at the environment from a slightly different position. This different degrees of disparity between the two image representing different distances is crucial to stereoscopic vision. Comparison of the two images in the visual cortex enables us to perceive the shapes, textures, distances and relative movements of objects. Frontally placed eyes and centrally situated foveas, producing good visual acuity are essential for good **stereoscopic vision**. So when you look at apple, you see more than its shape and colour, you see its thickness and how far away it is. This ability is called **depth perception**. You can appreciate the effect by closing your left eye. Hold one of your fingers vertically about 10 cm in front of your open right eye and line it up with some distant object such as the vertical part of a door frame. Now open your left eye at the same time close your right eye. Your finger and the distant object will now be misaligned. It is only significant for objects nearer than 70 meters. Perception of greater distance depends partly on memory. We are familiar with most of the objects around us. The smaller they appear, the more distant we assume they are and vice versa. Another effect is called the moving parallax. When we scan objects in the visual field, near objects move across the image to a greater extent than distant objects.

Integration of visual signals in the brain

The eye, by itself, can not see, unless the brain processes, sight is not possible.

What does the eye tell the brain? The tiny foot print of the photon is amplified thousands of times to alter by mere millivolts: the electrical signature of the photoreceptor. Thus, light energy is changed into electrical energy, the hard currency of neural exchange. The signal now enters the cellular network of the retina for relay. Then there are some million ganglion cells next to photoreceptors in the retina. Large, fast **"magno"** [L. magnus = large] **ganglion cells** seem to specialise in motion and outline features. For instance, most of inputs from a bird's outline and flying movements come from rods. Smaller, slower **"parvo"** [L. parvus = small] **ganglion cells** attend to colour and fine detail of form, in this case, bird's colour and structural details. And most of its input come from cones. So the two channels are independent within the system. So in order to actually see a bird on the wing, the little image is sent on faithfully like in cable TV. It is turned into electrical signals sent down cables to some sort of neural "TV screen". Our eyes funnel two million fibres into the straw-sized optic nerves. Some fibres from each optic nerve cross at a structure called the optic chiasma before entering into the base of the brain. Similarly impulses from the left side of each eye travel to the left side of the brain. The next stops are twin lateral geniculate bodies, a part of thalamus, deep in each brain hemisphere. They are visual sorting office, a relay station. Next to the lateral geniculate nucleus, the fibres lead up and back to your brain's complex cinema screen: the visual cortex, about the size of a credit card.

How long does this complicated process take? No longer than it takes to blink an eye. The signals transmitted at about 450 kilometres per hour take just a fraction of a second or 0.4 seconds to get here.

Visual processing:

How do all these systems produce the solid image you see? By extracting biologically relevant information at each stage and associating firing patterns with past experience. The mechanism of visual processing is complex and not well understood, but it is clear so far that the brain definitely does not work like a digital camera. The neurons in the visual cortex are arranged in six layers, each with a different hierarchical function in processing the visual information. The first layer recognises sloping lines, the second recognises complete shape, the third recognises moving lines and so on.

Primary visual cortex separates the image into distinct feature channels. Different groups of cells work collectively to extract each feature.

(i) Cells in the blobs extract colour.

(ii) Binocular cells compute the disparity from the two eyes and thus depth.

(iii) Simple and complex cell are activated by edges of particular orientation.

Region known as V_1 is the first place in the visual cortex, where visual information arrives. Object perception begins in V_1 which extracts simple features that are common to all images, e.g. line. The cells in this are a have thee smallest receptive fields and contain two kinds of neurons one sensitive to line orientation and other sensitive to wavelength. The wavelength-sensitive neurons have "opponent" properties. From V_1 information is sent to higher order visual areas first to V_2 and then to V_3. Retina is mirrored at the V_1 V_2 border and again at the V_2 V_3 border. V_2 region channelises neural information from V_1 to the more specialised sub area V_3 and V_{3A} there messages related to the dynamic form, especially the shapes of objects in motion, such as a flying butterfly are processed. From V_3, information diverges to over three dozen higher order visual areas. Each processes some special aspect of visual information. These visual areas are like a multi-screen cinema. The main difference is that each screen is showing a different attribute of the same movie. Neurons in V_4 region selectively specialise in colour constancy. For instance, the multi coloured butterfly appear to have the same colour even when the illumination varies. V_5 is the sub area where the motion of moving pattern, we perceive. For instance, the dancing movements of a chorus. It ends in the inferior temporal cortex where cells respond to a particular combination of complex features, for example, those that define a particular face. Medial temporal area analyzes visual motion. Functions of some areas of visual cortex are not known and being explored.