Vision
Morphology of the retina:
The retina consists of the following types of cells:
- Pigment epithelium
- Photoreceptors
- Bipolar cell
- Ganglion cell
- Horizontal cell
- Amacrine cell

There are many different synaptic transmitters.

The rods and cones, which are next to the choroid, synapse with bipolar cells, and the bipolar cells synapse with ganglion cells.

The axons of the ganglion cells converge and leave the eye as the optic nerve.

Horizontal cells connect receptor cells to the other receptor cells in the outer plexiform layer.

Amacrine cells connect ganglion cells to one another in the inner plexiform layer via processes of varying length and patterns.
Pigment epithelium:
It is a single sheet of melanin-containing epithelial cells, it has the following functions:

a. Light absorption: most of the light reaching the back of the eye is absorbed by the pigment epithelium so that light scattering does not degrade visual.

b. Phagocytosis: the membranous disks and other debris sloughed from the photoreceptors are phagocytosed by cells of the pigment epithelium.

c. Vitamin A (retinol) storage: the pigment epithelium serves as repository for vitamin A, which is needed for the synthesis of rhodopsin.

The eyes convert energy in the visible spectrum into action potentials in the optic nerve.

The wave-lengths of visible light range from approximately 397–723 nm. The images of objects in the environment are focused on the retina. The light rays striking the retina generate potentials in the rods and cones. Impulses initiated in the retina are conducted to the cerebral cortex, where they produce the sensation of vision.
### Photoreceptors:

<table>
<thead>
<tr>
<th>Rod</th>
<th>Cone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Morphology:</strong></td>
<td><strong>a. Inner segment:</strong></td>
</tr>
<tr>
<td>The major functional segments of either</td>
<td>Thin inner segment</td>
</tr>
<tr>
<td>a rod or cone are: (1) the outer segment</td>
<td>Thick inner segment</td>
</tr>
<tr>
<td>2. the inner segment</td>
<td>b. Outer segment</td>
</tr>
<tr>
<td>3. the nucleus</td>
<td>In the rods and cones contains large</td>
</tr>
<tr>
<td>4. the synaptic body</td>
<td>numbers of discs (as many as 1000 discs)</td>
</tr>
<tr>
<td>Both rod and cone contains nucleus,</td>
<td>in each rod or cone.</td>
</tr>
<tr>
<td>abundant mitochondria and synaptic</td>
<td>① Rod like appearance</td>
</tr>
<tr>
<td>vesicles</td>
<td>② the disks are separated from cell</td>
</tr>
<tr>
<td>a. Inner segment</td>
<td>membrane</td>
</tr>
<tr>
<td>thin inner segment</td>
<td>③ Rod outer segment being constantly</td>
</tr>
<tr>
<td>b. Outer segment</td>
<td>renewed by formation of new disks at the</td>
</tr>
<tr>
<td>In the rods and cones contains large</td>
<td>inner edge of the segment and Phagocytosis</td>
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<tr>
<td>numbers of discs (as many as 1000 discs)</td>
<td>of old disks and from the outer tip by</td>
</tr>
<tr>
<td>in each rod or cone.</td>
<td>cells of the pigment epithelium.</td>
</tr>
<tr>
<td>① Rod like appearance</td>
<td>② the saccules are formed in the outer</td>
</tr>
<tr>
<td>③ Rod outer segment being constantly</td>
<td>segment by infoldings of the cell membrane</td>
</tr>
<tr>
<td>renewed by formation of new disks at the</td>
<td>③ cone renewal is more diffuse process</td>
</tr>
<tr>
<td>inner edge of the segment and Phagocytosis</td>
<td>and appears to occur at multiple sites in</td>
</tr>
<tr>
<td>of old disks and from the outer tip by</td>
<td></td>
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<tr>
<td>cells of the pigment epithelium.</td>
<td>the outer segments</td>
</tr>
</tbody>
</table>
Photoreceptors:

**Rod**
1. Distribution:
   - mainly are extrafoveal
   - about 120 million in eye

**Cone**
1. Distribution:
   - mainly are intrafoveal
   - about 6 million in eye
Photoreceptors:

**Rod**

3. Photosensitive pigment:
   - It is called rhodopsin or visual purple.
   - Retinene1:
     - Synthesized from vitamin A;
     - light-absorbing;
     - bonded to membrane protein opsins
   - Retinene is into two forms all-trans retinal (active) and 11-cis retinal (inactive)

**Cone**

3. Photosensitive pigment:
   - It is called conesin.
   - Opsin is called photopsin:
     - Opsin moiety contains different aa sequences that determine wavelength of light absorb.
   - There are three types which gives 3 types of cones:
     a. cyan-opsin: maximally sensitive to blue (420)
     b. iod-opsin maximally sensitive to green (534nm)
     c. porphy-opsin: maximally sensitive to red (564nm)

Diagrammatic representation of the structure of rhodopsin, showing the position of retinene1 (R) in the rod disk membrane. Retinene1 is parallel to the surface of the membrane and is attached to a lysine residue at position 296 in the seventh transmembrane domain.
Photoreceptors:

**Rod**

4. **Functions**:
   - I. The rods, which are more sensitive to light than cones, are responsible for night vision (scotopic vision) because:
     - A. rods can absorb more light than cones.
     - B. rods contain more rhodopsin in their outer segment.
     - C. rods can detect light entering the eye from any direction.
   
   II. Rods produce a greater response for each photon of light absorbed. The scotopic visual apparatus is incapable of resolving the details and boundaries of objects (low visual acuity) or determining their color. They detect **white, black and shades of gray**.

III. Rods remain polarized for a longer time than cones. Therefore, the response produced by several photons of light can be added together to create a larger response in rods than in cones.

6. **Dark adaptation**:
   - Cones adapt first.

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**Cone**

I. The cones are responsible for **daylight vision**; vision in bright light (photopic vision). Cones can respond to light over a large range of intensities.

II. Cones achieve high visual acuity because:
   - a) they are concentrated in the fovea (where the images are formed) and have less sensitivity by 200 times than rods.
   - b) They respond only to light directly along their (visual axis).
   - c) They do not respond to scattered light.
   - d) Their response to light is brisk; the cones produce an image of high quality and sharp images.

III. The cones have three different photopigments. Color vision is achieved by combining the information contained in cones, which absorb light in the red, green or blue range of the visual spectrum.

6. **Light adaptation**:
   - Rods adapt first.
**Rhodopsin-retinal visual cycle and excitation of the rode:**

**Note:**
Rode and rhodopsin have been studied more deeply than cons so we believe what happen in rod could also happens in cons

**Rhodopsin and its decomposition by light energy:**

**A. Bleaching** (bleaching) is a rapid process (up to 5 minutes)

A light photon interacts with the retinal in a photoreceptor cell.

1. The retinal undergoes isomerization, changing from the 11-cis to all-trans configuration.
   - Retinal no longer fits into the opsin binding site.

2. Opsin therefore undergoes a conformational change to metarhodopsin II.

3. Metarhodopsin II is unstable and splits, yielding opsin and all-trans retinal.
   - Metarhodopsin II will create action potential in rode

**B. regeneration of rhodopsin is slow process takes minutes** (up to 30 min)

1. Metarhodopsin II will change to opsin (scotopsin) +

2. All-trans retinal is transported to the pigment epithelial cells to be reduced to all-trans retinol, the precursor to 11-cis retinal. This is then transported back to the rods. All-trans retinal cannot be synthesized by humans and must be supplied by vitamin A in the diet. **Deficiency of all-trans retinal can lead to night blindness** (as rods are part of night vision).

Formation of rhodopsin again after they combine with each other.
The rod receptor potential is hyperpolarizing, not depolarizing; why?

Activation of the receptor protein in rods (rhodopsin) by light (1 photon activate 1 rhodopsin)

1. The opsin (Metarhodopsin II) activates the regulatory protein transducing (heterotrimeric G protein, which in this case is called transducin or Gt1)
2. Transducin to dissociate from its bound GDP, and bind GTP
3. The alpha subunit of transducin dissociates from the beta and gamma subunits, with the GTP still bound to the alpha subunit.
4. The alpha subunit-GTP complex activates phosphor-di-esterase or PDE.
5. Phosphor-di-esterase breaks down cGMP to 5'-GMP
6. This lowers the concentration of cGMP
7. cGMP depended sodium channels to close.
8. cGMP depended sodium channels causes hyperpolarization of the cell due to the ongoing efflux of potassium ions.

a. Na-K ATPase pushes 3Na outside and 2K inside rode

b. Potassium "leak" channels pushes K to outside again and Na cannot return to rode due to closer of cGMP-dependent Na+ channels

c. Rod loses many positive charge ions ➤ hyperpolarization

9. Hyperpolarization of the cell causes voltage-gated calcium channels to close.

10. As the calcium level in the photoreceptor cell drops, the amount of the neurotransmitter glutamate that is released by the cell also drops. This is because calcium is required for the glutamate-containing vesicles to fuse with cell membrane and release their contents.

11. A decrease in the amount of glutamate released by the photoreceptors causes

① depolarization of On center bipolar cells (rod and cone On bipolar cells)

② hyperpolarization of off-center bipolar cells.

At dark the reverse will occur and there is depolarization and increase in neurotransmitter release
Dark and light adaptation:
Between the limits of maximal dark adaptation and maximal light adaptation, the eye can change its sensitivity to light as much as 500,000 to 1 million times, with the sensitivity automatically adjusting to changes in illumination.

Because registration of images by the retina requires detection of both dark and light spots in the image, it is essential that the sensitivity of the retina always be adjusted so that the receptors respond to the lighter areas but not to the darker areas.

There are 4 mechanisms underlying light/dark adaptation:
1. Optic adaptation (Pupil size)
   the pupil diameter only ranges from 1 or 2 mm to about 8 mm, for an increase in area (or total light entering the eye) of a factor of 16-64. Changes in pupillary size changes in the amount of light allowed through the pupillary opening
2. Receptor adaptation
   a. Switchover from rods to cones
   b. Bleaching/ regeneration of the photo-pigments
Neural adaptation, involving the neurons in the successive stages of the visual chain in the retina itself and in the brain. That is, when light intensity first increases, the signals transmitted by the bipolar cells, horizontal cells, amacrine cells, and ganglion cells are all intense. However, most of these signals decrease rapidly at different stages of transmission in the neural circuit.

**Neural adaptation**

1. Neural degree of adaptation is only a few fold rather than the many thousand fold that occurs during adaptation of the photochemical system.
2. Neural adaptation occurs in a fraction of a second, in contrast to the many minutes to hours required for full adaptation by the photo-chemicals.

**Dark adaptation**

During dark adaptation

First: pupillary size will increases (dilation of pupa); dilation will depend on degree of darkness

Second:

Receptor adaptation will includes

a. Switchover from cones to rods.

b. Bleaching/regeneration of the photo-pigments
Note we have to put in mind

1. that cones have lower sensitivity to light than rods and
2. that building of photosensitive process is slow process while destruction of it is a fast process

Rapid Cons adaptation (Phase one): When we transfer from light to dark the cones are still working so in the first minute the sensitivity is low but will decrease gradually due to destruction of photosensitive pigment; and because destruction process is fast this why it will not takes more than 5 minute for cons to adapt (reach Plateau)

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When we begins dark adaptation the photo-sensitive pigment in cones begins to destruct (so sensitivity decrease) while in rod will be build up (so sensitivity increase). After (7-10 minutes) the sensitivity will be equalizes this is called (Rod-cone Break Or alpha pointe)

Slow rods adaptation (Phase two): Because rod will build up photosensitive pigment slowly this is why it takes about 20 to 30 minutes for rod to adapt (reach Plateau). Occurs after 93% of rhodopsin has already regenerated

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At the end of dark adaptation, the eye is about 100,000 times (i.e., 5 log units) more sensitive than it was at the beginning of the test, a level called dark adapted sensitivity.

Radiologists, aircraft pilots, and others who need maximal visual sensitivity in dim light can avoid having to wait 20 minutes in the dark to become dark-adapted if they wear red goggles when in bright light. Light wavelengths in the red end of the spectrum stimulate the rods to only a slight degree while permitting the cones to function reasonably well. Therefore, a person wearing red glasses can see in bright light during the time it takes for the rods to become dark-adapted.
Light adaptation
This occurs when we move from the dark into bright light. The bright light momentarily dazzles us and all we see is white light because the sensitivity of the receptors is set to dim light.

Rods and cones are both stimulated

\[ \text{large amounts of the photo-pigment are broken down instantaneously,} \]

\[ \text{producing a flood of signals resulting in the glare.} \]

Within about one minute the cones are sufficiently excited by the bright light to take over.

Visual accuracy and color vision continue to improve over the next ten minutes.

Adaption occurs in 5 minutes and is due to

1. Constriction of pupa
2. The sensitivity of the retina decreases dramatically due to decrease of photo-sensitive pigment in rod and cones (as we said that degeneration is faster than regeneration)
3. Retinal neurons undergo rapid adaptation inhibiting rod function and favoring the cone system.

During light adaptation retinal sensitivity is lost
Retinal electrophysiology

The retina extends anteriorly almost to the ciliary body.

The different neuronal cell types in the retina are as follows:

1. The photoreceptors—the rods and cones—which transmit signals to the outer plexiform layer, where they synapse with bipolar cells and horizontal cells.

2. The horizontal cells, which transmit signals horizontally in the outer plexiform layer from the rods and cones to bipolar cells.

3. The bipolar cells, which transmit signals vertically from the rods, cones, and horizontal cells to the inner plexiform layer, where they synapse with ganglion cells and amacrine cells.

4. The amacrine cells, which transmit signals in two directions, either directly from bipolar cells to ganglion cells or horizontally within the inner plexiform layer from axons of the bipolar cells to dendrites of the ganglion cells or to other amacrine cells.

5. The ganglion cells, which transmit output signals from the retina through the optic nerve into the brain.
There are many different synaptic transmitters.

a. Both the rods and the cones release glutamate at their synapses with the bipolar cells in a graded fashion. More depolarized means more glutamate. More hyperpolarized means less glutamate.

b. Amacrine cells that secrete inhibitory transmitters including (GABA), glycine, dopamine, acetylcholine, and indolamine.

c. The transmitters of the bipolar, horizontal, and interplexiform cells are unclear.
The eye is unique in that the receptor potentials of the photoreceptors and the electrical responses of most of the other neural elements in the retina are local, graded potentials, and it is only in the ganglion cells that all-or-none action potentials transmitted over appreciable distances are generated.

The importance of electrotonic conduction is that it allows graded conduction of signal strength. Thus, for the rods and cones, the strength of the hyperpolarizing output signal is directly related to the intensity of illumination; the signal is not all or none, as would be the case for each action potential.

The responses of the rods, cones, and horizontal cells are hyperpolarizing

The responses of the horizontal cells are always inhibitory.

The responses of the amacrine cells produce depolarizing potentials and spikes that may act as generator potentials for the propagated spikes produced in the ganglion cells.

The cone receptor potential has a sharp onset and offset,

The rod receptor potential has a sharp onset and slow offset.
The major differences between the peripheral retina (extra-foveal) and the central retina (foveal) are:

First:

In the center (central fovea)

a. there are only slender cones (about 35,000 of them) and no rods.

b. the number of optic nerve fibers leading from this part of the retina is almost exactly equal to the number of cones. The (cones: bipolar cells: ganglion cells) (1:1:1)

This phenomenon explains the high degree of visual acuity in the central retina in comparison with the much poorer acuity peripherally.
Second: peripheral retina (extra-foveal)

there are much greater sensitivity of the peripheral retina to weak light, which occurs

a. partly because rods are 30 to 300 times more sensitive to light than cones are

b. as many as 200 rods converge on a single optic nerve fiber in the more peripheral portions of the retina

Thus signals from the rods summate to give even more intense stimulation of the peripheral ganglion cells and their optic nerve fibers.

Because there are approximately 6 million cones and 120 million rods in each human eye but only 1.2 million nerve fibers in each optic nerve, the overall convergence of receptors through bipolar cells on ganglion cells is about 105:1.
Retinal receptive field:
The position of the spot of light was systematically varied across the retinal surface, and while they did this the response of the ganglion cell was continuously monitored.

For most positions on the surface of the retina, flashing a spot of light has absolutely no effect on the cell's response (that is, it continues responding at its spontaneous firing rate). Within a particular region, called the *receptive field*, flashing the spot affects the ganglion cell's response.

Retinal receptive field is the region of the visual space that makes a retinal ganglion cell change its firing under the presence of a certain visual stimulus.
center-surround organization
(On-center, Off-center retinal ganglion cell):

On-center retinal ganglion cell

1. no stimulus was presented: Spontaneous firing rate of a few spikes/sec
2. Flashing small bright spot in the center sub-region increases the cell’s response
3. Flashing a bright annulus in the surround sub-region inhibits the cell’s response
4. There is little or no response to a large (full field) spot of light that covers both the center and the surround because excitation in the center cancels the inhibition from the surround, called lateral inhibition. This is because 2 and 3 cancel each other

Off-center retinal ganglion cell

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Electrophysiology explanation of on-center off-center retinal ganglion cell action potential:

1. On-center retinal ganglion cell
   The receptive field of a bipolar cell consists of two parts:
   a. Center receptive field:
      Light on the receptive field center, which provides a direct input from the photoreceptors (hyperpolarization) \(\rightarrow\) to the bipolar cells (depolarization) \(\rightarrow\) ganglion cell (depolarization)
   b. Peripheral receptive field:
      i. Light on the receptive field periphery: light on photoreceptors \(\rightarrow\) stimulate horizontal cell (inhibitory) \(\rightarrow\) Bipolar cell (inhibited) \(\rightarrow\) ganglion cell (inhibited)
      ii. Dark on the receptive field periphery the horizontal cell will not stimulate so nothing will happen

2. Off-center retinal ganglion cell
   Off-center cells respond in exactly the same way to dark spots as on-center cells respond to bright spots.
   The mechanism for producing the center of a bipolar cell's receptive field is well known: direct innervation of the photoreceptors above it,
   ① (ON) bipolar cell:
      a metabotropic activate which is (G-proteins, which modulate ion channels directly or indirectly through enzymes and second messengers)
   ② OFF bipolar cell:
      inotropic which is (ligand-gated ion channels)
The combination of ON-center and OFF-center ganglion cells is another example of a parallel pathway. ON-center and OFF-center ganglion cells are physiologically distinct (as just described above). ON-center and OFF-center ganglion cells are anatomically distinct:

1. The ganglion cells' dendrites branch out in separate sub-layers of the retina.
2. Ganglion cells' dendrites branch receive synaptic inputs from different subclasses of bipolar cells.

There is complete coverage: ON-center and OFF-center receptive fields each completely cover the visual field.

The neural signals originating in the ON- and OFF-center retinal ganglion cells remain segregated in the retina and the LGN, then merge completely in the complex cells in primary visual cortex (V1).
What is the benefit of on-center off-center?

The center-surround organization of receptive fields is an application of lateral inhibition seen in sensory system which makes retinal bipolar cells and ganglion cells very sensitive to contrast.

For example, the response of a given cell to light will be stronger if the light portion of the visual field is adjacent to a dark portion. As a result, the retinal mechanisms for contrast enhancement make our visual systems very sensitive to edges or borders or shapes and allow us to perceive even weak contrasts.
## Types of Retinal Ganglion Cells

<table>
<thead>
<tr>
<th></th>
<th>Magnocellular: large (M) or alpha or parasol cells (10%)</th>
<th>Parvocellular: small (P) beta cells or midget ganglion cells (80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receptive Field</strong></td>
<td>1. large and smaller in number</td>
<td>1. small and more numerous</td>
</tr>
<tr>
<td><strong>Axons Conduct Impulse</strong></td>
<td>2. slow</td>
<td>2. fast</td>
</tr>
<tr>
<td><strong>Responses to Stimuli</strong></td>
<td>3. sustained</td>
<td>3. transient</td>
</tr>
<tr>
<td><strong>Sensitivity to the Color</strong></td>
<td>4. sensitive to black and white stimuli Monitor rods</td>
<td>4. sensitive to the color monitor cones</td>
</tr>
<tr>
<td><strong>Main Function</strong></td>
<td>5. Highly sensitive</td>
<td>5. highly sensitive</td>
</tr>
<tr>
<td></td>
<td>① to low-contrast stimuli</td>
<td>① to visual signals that relate to fine details (texture, and shape)</td>
</tr>
<tr>
<td></td>
<td>② to rapid movement visual signals</td>
<td>② to different colors</td>
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<td></td>
<td>③ to stereopsis</td>
<td></td>
</tr>
<tr>
<td><strong>End to on LGN</strong></td>
<td>Magnocellular lamina of LGN</td>
<td>Parvocellular lamina of LGN</td>
</tr>
</tbody>
</table>

![Diagram of retinal ganglion cells](https://via.placeholder.com/150)
Central Neurophysiology of Vision

Visual pathways

Retinas ➔ optic nerves ➔ optic chiasm ➔ optic tracts ➔ dorsal lateral geniculate nucleus of the thalamus ➔ geniculocalcarine fibers pass by way of the optic radiation (also called the geniculocalcarine tract) to the primary visual cortex in the medial occipital lobe.
Visual fibers pass to several older areas of the brain

(1) from the optic tracts to the suprachiasmatic nucleus of the hypothalamus, presumably to control circadian rhythms that synchronize various physiological changes of the body with night and day;

(2) into the pretectal nuclei in the midbrain,
   a. to elicit reflex movements of the eyes to focus on objects of importance and
   b. to activate the pupillary light reflex;

(3) into the superior colliculus, to control rapid directional movements of the two eyes and head

(4) into the ventral lateral geniculate nucleus of the thalamus and surrounding basal regions of the brain, presumably to help control some of the body’s behavioral functions.
Lateral geniculate body of the thalamus functions:
1. It relays visual information (so accurate that there is exact point-to-point transmission) from the optic tract to the visual cortex.
   Layers II, III, and V (from ventral to dorsal) receive signals from the lateral half of the ipsilateral retina
   layers I, IV, and VI receive signals from the medial half of the retina of the opposite eye.
2. To “gate” the transmission of signals to the visual cortex—that is, to control how much of the signal is allowed to pass to the cortex.
   The nucleus receives gating control signals from two major sources:
   (1) corticofugal fibers
   (2) reticular areas of the mesencephalon.
From the lateral geniculate nucleus, a magnocellular pathway and a parvocellular pathway project to the visual cortex.
   a. The magnocellular pathway, from layers 1 and 2, carries signals for movement, depth, and flicker, black and white information, point-to-point transmission is poor
   b. The parvocellular pathway, from layers 3 to 6, carries signals for color vision, texture, shape, and fine detail point-to-point spatial information is accurate
Organization and function of visual cortex:

Brodmann’s area 17, V1, visual area I (Primary Visual Cortex) or the striate cortex:
The retina is fully represented in primary visual cortex where the macula represented by the largest area.

Secondary Visual Areas of the Cortex/visual association areas:
Brodmann’s area 18, V2, Visual area II,
Brodmann’s area 19 V3, V4, V5)
The layers of primary visual cortex:
Like almost all other portions of the cerebral cortex, the primary visual cortex has six distinct layers. The axons from the lateral geniculate nucleus that form the magnocellular pathway end in layer 4, specifically in its deepest part, layer 4Cα. Many of the axons that form the parvocellular pathway end in layer 4Cβ and 4A.

The layers of the cortex differ not only in their inputs and their local interconnections but also in the more distant structures to which they project.

Efferent pathway from cortex:
① All layers except 4A, and 4C send fibers out of the cortex.
② Layers 2 and 3 and layer 4B project mainly to other cortical regions,
③ Layer 5 projects to the superior colliculus in the midbrain
④ Layer 6 projects mainly back to the lateral geniculate body
Columnar architecture of primary visual cortex

Vertical neuronal columns in the visual cortex.

Primary visual cortex is organized into a two-dimensional array of vertical columns.

Vertical columns extend from the cortical surface to underlying white matter (مصفّرة کانونها قطعة صمون لوف).

Vertical columns are several million.

Vertical columns having a thickness of 30 to 50 micrometers.

Vertical columns represent a functional unit.

Vertical columns has perhaps 1000 or more neurons.

Vertical columns processes a characteristic (contrast, color, orientation, movements etc.) of different part of visual field.
Vertical columns have two dimensions:

a. **Ocular dominance columns** which receive preference from either the **contralateral** or the **ipsilateral** eye (or right and left eye); which is important for **binocular interaction and depth perception**

**Binocular interaction:** is interaction of visual signals from the two separate eyes.

The visual signals from the two separate eyes remain separated. These signals remain separated from each other but when they arrive in **layer IV** of the primary visual cortex; the signals from one eye enter the columns of every other stripe, alternating with signals from the second eye so that they will fuse with each other. The result, when viewed from above, is a **vivid pattern** of stripes that covers much of the visual cortex. The information observed about the degree of register of images from the two eyes also allows a person to distinguish the distance of objects by the **mechanism of stereopsis (depth perception)**. 

Columnar architecture: As one moves an electrode vertically through the thickness of the cortex, one finds that most neurons have the same selectivity (e.g., the same orientation preference and eye dominance).

**Ocular dominance columns:** As one moves an electrode tangentially through the cortex, one first finds cells that respond to left eye input, then binocular (responsive to both/either eye), then right eye, then binocular, then left again, etc.

**Orientation columns:** As one moves the electrode tangentially in the orthogonal direction, one first finds cells selective for vertical, then diagonal, then horizontal, etc.
b. Orientation توجيه columns

The orientation preferences of neighboring columns differ in a systematic way; as one moves from column to column across the cortex, sequential changes occur in orientation preference of 5–10 degrees. Thus, it seems likely that for each ganglion cell receptive field in the visual field, there is a collection of columns in a small area of visual cortex representing the possible preferred orientations at small intervals throughout the full 360 degrees.

Orientation columns are important in perceiving form and movements. ادراك الشكل والحركة
Cortical Modules: وحدات:
Cortical module is a basic unit processing visual stimuli in visual cortex
Cortical module 2mm X 2mm dimensions
Cortical module is a cortical image of point in space
Cortical modules consists of:
a. 2 ocular dominance column
b. 2 hyper-columns
Hyper-columns is a set of columns that are responsive to line of all orientation from a particular region in the visual cortex and view by two ocular dominance columns, one from each
c. 16 blobs
Bolb: Layers 2 and 3 of the cortex contain clusters of cells about 0.2 mm in diameter that, unlike the neighboring cells, contain a high concentration of the mitochondrial enzyme cytochrome oxidase.
Bolbs are arranged in a mosaic in the visual cortex and are concerned with color vision
“Color Blobs” in the Visual Cortex.

Color Blobs Interspersed among the primary visual columns and some of the secondary visual areas.

Color Blobs receive lateral signals from adjacent visual columns and are activated specifically by color signals.

Color Blobs are presumably the primary areas for deciphering color. رموز
Feature Detection Model of Form Perception

The feature detector model of form perception is based on the fact that neurons farther and farther into the visual system become more and more selective in what they respond to.

Retinal neurons respond to spots of light.

Neurons in primary visual cortex respond to bars of light.

Neurons in the first stages of the visual association cortex respond only to moving bars of light.

Neurons in the later stages of the visual association cortex respond to complex patterns, including hand-shaped and face-shaped patterns.

The simple and complex cells have been called feature detectors because they respond to and analyze certain features of the stimulus.
Simple cells

Simple cells are found mainly in layer IV of the primary visual cortex.

Simple cells are monocular.

Simple cells respond to bars of light, lines, or edges, with following criteria:

a. Simple cells respond only when they have a particular orientation (orientation selectivity) (e.g., vertical) but not to the orthogonal orientation (e.g., horizontal). When, for example, a bar of light is rotated as little as 10 degrees from the preferred orientation, the firing rate of the simple cell is usually decreased, and if the stimulus is rotated much more, the response disappears.

orientation selectivity

[Graph showing orientation selectivity]
b. Simple cells have separate ON and OFF sub-regions
Simple cells which fire high frequency of Action potentials only when a bar of light is at the center of its receptive field and in a particular orientation; the areas of the receptive field which cause the high frequency of Action potential is called the ON sub-region and the areas of the receptive field that do not trigger high frequency of Action potential is called the OFF sub-region.

c. Simple cells respond best to elongated bars or edges

d. Simple cells perform length summation (they have bigger responses with increasing bar length up to some limit, at which point the response reaches a plateau)

e. Simple cells receptive fields are non-concentric and linear. Thus, a response is elicited by stationary linear stimuli
Complex cells

a. Complex cells are orientation selective.

Complex cells are nearly all binocular.

d. Complex cells perform length summation.
Hyper-complex cell (currently called an end-stopped cell)

a. Hyper Complex cells respond to lines that are oriented in the same direction motion (not position specific). Length (property of end-stopping) which means if the bar is too short or too long, it will not be able to excite hyper-complex cell.

b. hypercomplex cells can provide a means for corners and curves in the environment by identifying the ends of a given stimulus.

Hypercomplex cells were originally characterized as the superordinate class of visual processing cells above simple and complex cell because

a. Hyper-complex cells respond to complex stimuli such as hand and face.

b. if complex cell respond to line with particular orientation such as, then Hyper complex respond to combination of features such as (A).

In the human visual system, simple cells become active when they are subjected to stimuli such as edges. Complex cells then combine the information of several simple cells and detect the position and orientation of a structure. Hyper-complex cells then detect endpoints and crossing lines from this position and orientation information, which is then used in the brain's secondary cortex for information association.
<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Selectivity</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>orientation, position</td>
<td>Brodmann area 17</td>
</tr>
<tr>
<td>Complex</td>
<td>orientation, motion, direction</td>
<td>Brodmann area 17 and 18</td>
</tr>
<tr>
<td>Hypercomplex</td>
<td>orientation, motion, direction, length</td>
<td>Brodmann areas 18 and 19</td>
</tr>
</tbody>
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