Note: The majority of the Lecture material based on CH9 and Dr. Johnson’s slides.
*Significant importance clinically
- Within the brain, it has long distance projections from the retina to the occipital cortex
- Vulnerable to:
  - Tumors
  - Pressure
  - White matter diseases (e.g., MS)
  - Hemorrhage
  - Head trauma
basics: it is a special somatic afferent nerve. a central track.

1. optic nerve

this is not a peripheral nerve. what is the evidence for this?

1. myelinated by oligodendrocytes (not schwann cells)
2. ms is a white matter ( oligod ) disease & optic nerve is affected
3. does not regenerate -
   peripheral nerves will regenerate b/c of schwann cells
4. optic nerve - embryologically it is an "out pocketing" of the diencephalon

note optic nerve has duo mater + arachnoid mater & subarachnoid space w/ csf around it vs pia covering

peripheral nerves are covered with a contiguous covering called epineurium
Retina details

development

optic vesicle out pouch from the diencephalon

1

2

lens pushes up against it
Differentiation of the Forebrain

The next important developments occur in the forebrain, where secondary vesicles sprout off on both sides of the prosencephalon. The secondary vesicles are the optic vesicles and the telencephalic vesicles. The central structure that remains after the secondary vesicles have sprouted off is called the diencephalon, or “between brain” (Figure 7.12). Thus, the forebrain at this stage consists of the two optic vesicles, the two telencephalic vesicles, and the diencephalon.

The optic vesicles grow and invaginate (fold in) to form the optic stalks and the optic cups, which will ultimately become the optic nerves and the two retinas in the adult (Figure 7.13). The important point is that the retina at the back of the eye, and the optic nerve containing the axons that connect the eye to the diencephalon and midbrain, are part of the brain, not the PNS.
**Optic Cup Development**

- **Lens Pouch**: The lens pouch is pulled up against it.
- **Optic Stalk**: The optic stalk is formed.
- **Optic Cup**: The outer part of the cup will form the choroid.
- **Retina**: The retina will be formed from the inner part of the cup.
Fundus detail

Optic disc - slightly medial (3.5mm from center)

- Disease
  - Disc margins are not clearly demarcated
  - Blood vessels are not clear
  - Physiological cup that is not too deep

Macula = "spot"

Lentil = "yellow"

Optic disc

Avascular area - just capillaries
Recognize that the optic disc is the head of the optic nerve. All of the fibers (axons) from the retinal ganglion cells are converging onto the optic disk.

Notice: the optic disc does not have any rods or cones. Implication: no light receptors in the visual field at that spot. There is a blind spot.
**FIGURE 9.5**  
*The retina, viewed through an ophthalmoscope.* The dotted line through the fovea represents the demarcation between the side of the eye nearer the nose (nasal retina) and the side of the eye nearer the ear (temporal retina). The imaginary line crosses through the macula, which is in the center of the retina (it appears slightly to one side here because the photograph was taken to include the optic disk off to the nasal side of the retina).

**FIGURE 9.6**  
*The eye in cross section.* Structures at the front of the eye regulate the amount of light allowed in and refract light onto the retina, which wraps around the inside of the eye.
Layers of the retina

- Vitreous body
- Retina
- Cornea
- Lens
- Iris
- Ciliary body
- Choroid
- Sclera
- Optic nerve
Note the outer & inner references are from the middle of the eye ball.
Note the outer & inner references are from the middle of the eye ball.

- Inner side
- Outer side
- Expanded View
- Choroid
- Retina
- Vitreous
- Image falls on this part of retina
- Object
- Inner side of retina next to vitreous
- Outer side next to choroid
Light must pass through the retina to stimulate photoreceptors. The vitreous humor body is on the outer side of the retina. Photoreceptors are found in the choroid layer, which is transparent. Rods and cones are photoreceptors. Bipolar cells and retinal ganglion cells are located on the inner side of the retina.
sclera
cornea
pigment cell layer
PHOTORECEPTORS (RODS/CONES)

BIPOLAR

RETINAL GANGLION CELLS

light
The Retina

Outer Segments of Receptors, respond to light

Receptors
Mostly bipolar cells
Ganglion cells
Axons from ganglion cells

NOTE:
Not a particularly "intelligent design"!

Slide from Dr. Christine Johnson
The Retina

Visual Receptors
Rods & Cones

Slide from Dr. Christine Johnson
### Comparing Rods and Cones:

<table>
<thead>
<tr>
<th></th>
<th>Rods</th>
<th>Cones</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape?</strong></td>
<td>Outer Segment rod-like</td>
<td>Outer Segment cone-like</td>
</tr>
<tr>
<td><strong>Outer Segment</strong></td>
<td>Discs with embedded visual pigment molecules</td>
<td>Folded Sheet w/embedded visual pigment molecules</td>
</tr>
<tr>
<td><strong>Contents?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Size?</strong></td>
<td>Larger (more vis pigment)</td>
<td>Smaller (less vis. pigment)</td>
</tr>
<tr>
<td><strong># ?</strong></td>
<td>~ 120 million/eye</td>
<td>~ 6.5 million/eye</td>
</tr>
<tr>
<td><strong>Distribution?</strong></td>
<td>None in fovea, High conc in periphery</td>
<td>High conc. in fovea, Dispersed in periphery</td>
</tr>
<tr>
<td><strong>Code Color?</strong></td>
<td>No (Grays only)</td>
<td>Yes (Per proportions of Red, Green, Blue)</td>
</tr>
<tr>
<td><strong>Detect Motion?</strong></td>
<td>Excellent</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Acuity?</strong></td>
<td>Low</td>
<td>High (esp. in fovea)</td>
</tr>
<tr>
<td><strong>Light Sensitivity?</strong></td>
<td>High (can operate in dim light)</td>
<td>Not as good (require brighter light)</td>
</tr>
<tr>
<td><strong>Connectivity?</strong></td>
<td>High Convergence (many rods:1 ganglion)</td>
<td>Low Convergence (1 or few cones:1 ganglion)</td>
</tr>
</tbody>
</table>
Visual Receptors: 
Rods & Cones

Rods, being larger, have MORE Photo-pigment

Also differ in #:
Rods ~120 million/eye
Cones ~6 million/eye

Slide from Dr. Christine Johnson
Sensation - Vision

1. Physical Stimulus -> Light
2. Receptor <-> Photoreceptors

- Sun electromagnetic waves
- Gamma waves
- AM/FM radio
- Violet 400 nm
- Red 700 nm
**FIGURE 9.2**

The electromagnetic spectrum. Only electromagnetic radiation with wavelengths of 400–700 nm is visible to the human eye. Within this visible spectrum, different wavelengths appear as different colors.
**FIGURE 9.14**

**Rods and cones.** (a) Rods contain more disks and make vision possible in low light; cones enable us to see in daylight. (b) Scanning electron micrograph of rods and cones. (Source: Courtesy of J. Franks and W. Halfter.)

Visual Receptors: Rods & Cones

**SIMILARITIES**

- Molecules of photopigment embedded in outer segments
- Outer segments embedded in "Pigment epithelium"
- Graded Potentials
- Release Inhibitory NT
Visual Receptors: Rods & Cones

**RODS**

- 1 kind of photopigment
- Do not code color
- Excellent for **motion** detection
- Poor acuity
- High sensitivity (operate in dim light)
- Mainly **Dorsal** Path

**CONES**

- 3 kinds of photopigment (1 type per cone)
- Do code **color**
- Poor for motion detection
- Excellent **acuity** (detail discrimination)
- Low sensitivity (require bright light)
- Mainly **Ventral** Path

Slide from Dr. Christine Johnson
TRANSDUCTION → FROM LIGHT TO ELECTRICAL POTENTIALS

Recall

$E_{Na} \approx +65 \text{ mV}$

resting potential $\approx -65 \text{ mV}$

$E_K \approx -80 \text{ mV}$

$t (\text{ms})$

the reason the resting membrane potential is so close to $E_K$ is because of the $K^+$ leak channels.
Consider the photoreceptors:

- Rod
- Cone

Diagram:
- Outer segment
- Inner segment
- Cell bodies
- Terminal
In complete darkness, rhodopsin is open. This results in a resting membrane potential of approximately -30 mV. The dark current is a key aspect of this process.
In the dark, the cGMP Na⁺ channel is activated.
Visual Receptors

Typical distribution of ions in inactive cell:

- K+ concentrated inside,
- Na+ & Ca++ outside

Outer Segment, w/molecules of Photo-Pigment ("Visual Purple")

Cell Body

Ion Gates: Closed in inactive cell

Vesicles of Neurotransmitter
In the **Dark**, cGMP holds **Na⁺** gates open...

Slide from Dr. Christine Johnson
The
"Dark Current"

In the **Dark**, cGMP holds **Na⁺** gates open...
The "Dark Current"

As Na+ accumulates in cell, the change in polarity opens Ca++ gate...

In the Dark, cGMP holds Na+ gates open...

...Na+ enters
As **Na⁺** accumulates in cell, the change in polarity opens **Ca²⁺** gate...

In the **Dark**, cGMP holds **Na⁺** gates open...

...**Ca²⁺** enters

...**Na⁺** enters  

Slide from Dr. Christine Johnson
In the Dark, cGMP holds Na+ gates open...

As Na+ accumulates in cell, the change in polarity opens Ca++ gate...

...Ca++ enters

...Na+ enters

Visual Receptors fire in the dark!
The "Dark Current"

As positive charges accumulate in cell, Na⁺ exits, via Electrostatic Pressure.

Slide from Dr. Christine Johnson
The "Dark Current"

As positive charges accumulate in cell, Na⁺ exits, via Electrostatic Pressure.

Ca++ Pump ejects Ca++ (requires energy)
The "Dark Current"

As positive charges accumulate in cell, Na+ exits, via Electrostatic Pressure.

Ca++ Pump ejects Ca++ (requires energy)
The "Dark Current"

Ca++ Pump ejects Ca++ (requires energy)

Na+ enters

Ejection of Ca++ should end NT release, but whole cycle begins again . . .
Ejection of Ca++ should end NT release, but whole cycle begins again . . .
The "Dark Current"

Ca++ enters

Na+ enters

Na+ enters

NT is repeatedly released...

... as long as there is no light.

Slide from Dr. Christine Johnson
Isomerization

A molecule of photo-pigment

11-cis Retinal

Opsin

"Visual Purple" . . .
A molecule of photo-pigment

11-cis Retinal

"Visual Purple" . . .

In the Light

Photo-pigment absorbs light, gets "Bleached"

All trans Retinal

. . . turns pink

Slide from Dr. Christine Johnson
Isomerization initiates a metabolic chain reaction...
Isomerization initiates a metabolic chain reaction...

...that changes cGMP into 5'GMP, which will not hold Na+ gates open.
Isomerization initiates a metabolic chain reaction...

With no influx of Na+, Ca++ gates remain shut.

No NT is released

...that changes cGMP into 5'GMP, which will not hold Na+ gates open.

So, in the Light, the “Dark Current” is shut down

Slide from Dr. Christine Johnson
Recall — Receptors mediate signaling

Categories of cellular receptors
channel-linked receptor

XMTR

ions

(ionotropic-ligand gated)
G-PROTEIN-COUPLED RECEPTORS

regulate intracellular reactions using G-proteins

(metabotropic receptors)
many G-protein-linked receptors

e.g. β-adrenergic receptor
muscarinic (ACH) receptor
metabotropic glutamate receptor
Rhodopsin is another G-protein coupled/linked receptor.
G-protein coupled receptors

- Ligand receptor
- Extracellular
- Membrane
- Intracellular

Region that interacts with G-protein
G-protein coupled receptors

- ligand receptor
- extracellular region
- region that interacts with G-protein

Interaction site
inactive state
1. When ligand is bound to the receptor, the cytosolic tail interacts and changes the conformation of a G-protein.
2. The α-subunit loses the GDP and binds GTP instead.
3. G-protein breaks up into 
\[
\alpha\text{-GTP} \quad \text{and} \quad \beta\delta \text{ parts}
\]

4. The two components can then act on other targets. → open ion chan. &/or regulate enz. acty.
INACTIVE  \[\alpha\beta\delta\]

Active

Starting Condition

\[\text{GTP} \rightarrow \text{GDP}\]

\[\text{GDP} \rightarrow \text{GTP}\]

*\text{*\alpha* subunit can hydrolyze GTP \rightarrow GDP to inactivate*}

GDP is exchanged for GTP

Return to BOUND STATE
When there is light

Na⁺ channel closes (no more cGMP)

membrane potential hyperpolarizes

Graph showing voltage changes in dark and light conditions:
- Dark: Voltage changes from -40 mV to -30 mV
- Light: Voltage changes to more negative values

$E_{Na^+}$ and $E_{K^+}$ indicators on the graph.
When there is light

- Na+ channel closes (no more cGMP)
- Membrane potential hyperpolarizes

Graph:
- Dim light
- Medium light
- Bright light
- Light flash

Diagram:
- Dark
- Light
- Membrane potential change
- Voltage levels (mV)
- V_{Na+}, V_{K+}
Rhodopsin is a 2nd messenger G-protein coupled.
Rhodopsin is a 2nd messenger/G-protein coupled protein that activates Na+ channel (+Ca++). It consists of opsins, 11-cis retinal, and a PDE (phosphodiesterase) enzyme.
What happens with light:

- Light

Rhodopsin changes configuration when it absorbs different wavelengths of light.

PDE activates an enzyme.

- CGMP levels close Na⁺ channel.

- CGMP closes gated Na⁺ (and Ca²⁺) channel.
Rhodopsin has two components: retinal and opsin. In the 11-cis configuration, opsin is embedded in the membrane.
Rhodopsin has two components:
- Retinal
- Opsin

Both are embedded in the 11-cis configuration membrane.

When a photon of light hits the retinal, its conformation changes from CIS to TRANS.
Rhodopsin has two components: retinal and opsin, embedded in the cis configuration membrane.

1. When a photon of light hits the retinal, its conformation changes from CIS to TRANS.

2. When retinal is in the trans-state, it activates opsin into metarhodopsin II.
Metarhodopsin II diffuses in the membrane & associates with transducin.
TRANSDUCIN

2

TRANS

METARHODOPSIN II

3

METARHODOPSIN II

GDP

GTP

a

βγ
PDE (PHOSPHODIESTERASE)
5. Ca^2+ and Na^+ closes no more cGMP to keep it open
membrane potential hyperpolarized
When there is light:

- **Nal channel closes** (no more cGMP)
- Membrane potential hyperpolarizes

Graph showing graded potential:
- Dim light
- Medium light
- Bright light

- Light flash

Graph showing dark state:
- E_{Na^+}
- E_{K^+}

Graph showing light state:
- 0 mV
- 20 mV
Isomerization & Re-Generation of Photo-Pigment

After a photon of light has Isomerized a molecule of photo-pigment... ...it will soon regenerate into its original form, so it is ready to respond to the next photon.

- **We are "Light Adapted"** when much of our photo-pigment has been isomerized
  - Come inside on a sunny day, at first the indoor light seems very dim
  - In the snowy arctic, so much bright light at once can temporarily BLIND you, if ALL your photopigment is isomerized at once
  - Eventually, you can see well again, because, in time, your photopigment will regenerate

- **We are "Dark Adapted"** after spending time in the dark
  - At first, when you turn out the light, you cannot see anything
  - But in time, as your photo-pigment regenerates, you can see faint shapes etc in the dark
The light provides enough energy to change conformation.

This also causes rhodopsin molecule to change shape.

When rhodopsin II associates with transducin, activated cGMP binds to PDE.
The Retina

Slide from Dr. Christine Johnson
Distribution of cone/rod in the retina.

- Most of the 5 million cones are in the fovea.
Retina is transparent

RODS & CONES
PHOTORECEPTORS

BIPOLAR CELLS

RETINAL GANGLION CELLS

light
vitreous humor body
inner side of retina

light must pass through the retina to stimulate photoreceptors

outer side of retina

choroid
Laminar organization of the retina

Layers
1. Pigment epithelium
2. Layer of rods and cones
3. Photoreceptor layer
4. Outer limiting layer
5. Outer nuclear layer
6. Outer plexiform layer
7. Horizontal cells
8. Inner nuclear layer
9. Amacrine cells
10. Inner plexiform layer
11. Ganglion cell layer
12. Nerve fiber layer
13. Inner limiting layer

Outer side of retina
- Platform = network of connections

Inner side of retina
- Vitreous humor body
- Light

To optic disk
COMPLEXITY IN RETINAL SIGNALING

photo receptors
have simple
graded responses

hyperpolarize  depolarize
**Bipolar Cells in the Light**
- Bipolar ON Cells → depolarize when light hits PRC
- Bipolar OFF Cells → hyperpolarize when light hits PRC

**Bipolar Cells in the Dark**
- Bipolar ON Cells → hyperpolarize in the dark
- Bipolar OFF Cells → depolarize in the dark
The Retina - Five Layers of Neurons

- Receptors (Rods & Cones)
- Bipolars
- Horizontal Inter-Neurons (Lateral Inhibitors)
- Amacrines
- Ganglions

Visual Pathway
RECALL:
Whether a neurotransmitter (like Glutamate) is “Excitatory” or “Inhibitory” depends on what effect it has on Post-Synaptic Cell.

At junction of Receptors & Bipolars, Glutamate has an **Inhibitory Effect** (letting Cl- into next cell)

At junction of Bipolars & Ganglions, Glutamate has an **Excitatory Effect** (letting Na+ into next cell)

---

*Fig. 13. The types of neurons in the vertebrate retina that use glutamate as a neurotransmitter (red).*

Slide from Dr. Christine Johnson
The Retina

Visual Pathway

Spontaneous, Graded, & Inhibitory

Spontaneous, Graded, & Excitatory

Action Potentials & Excitatory

Rod and cone receptors (R)

Bipolar cells (B)

Amacrine cells (A)

Ganglion cells (G)

Horizontal cell (H)

Light rays
The Retina

Visual Pathway

Inter-Neurons

Spontaneous, Graded, & Inhibitory

Spontaneous, Graded, & Inhibitory

Graded & Inhibitory

Spontaneous, Graded, & Excitatory

Action Potentials & Excitatory

MNEMONIC
Once you get to the Ganglion Firing is All-or-None

Slide from Dr. Christine Johnson
Strange But True – Receptors are turned OFF by light

If Receptor cells are turned OFF by light
really, turned down – reducing their release of NT
(i.e. If Dark Current is reduced by incoming light)
how do they signal that light is present..???

**ANSWER:**
What matters is NOT what one cell does,
but how they are CONNECTED!
By convention, when we draw neural circuits . . .

Cell Body
Axon

Excitatory

Inhibitory
Strange But True – Receptors are turned OFF by light

To the Brain (No Light)

Receptor

“Do Not Fire!”

Bipolar

(Silence)

Ganglion

In the Dark

Slide from Dr. Christine Johnson
Strange But True – Receptors are turned OFF by light

To the Brain
(No Light)

In the Dark

Receptor

Bipolar

Ganglion

“Do Not Fire!” (Silence)

“Light!”

(Silence)

“YEEHAH!”

In the Light

Slide from Dr. Christine Johnson
Strange But True – Receptors are turned OFF by light

In Dim Light
Receptor Bipolar Ganglion
"Do Not Fire!" (Silence)

In Dark (No Light)
"YEEHAH!"

In Light!
"Shhh!" "Psst"

Slide from Dr. Christine Johnson
Strange But True – Receptors are turned OFF by light

**In the Dark**

- Receptor
- Bipolar
- Ganglion

"Do Not Fire!" (Silence)

To the Brain (No Light)

**In the Light**

- Receptor
- Bipolar
- Ganglion

"Light!" (Silence)

"YEEHAH!"

**In Dim Light**

- Receptor
- Bipolar
- Ganglion

"Dim Light" (Silence)

"Shhh!" "Psst"
Microscopic Anatomy of the Retina

• Direct (vertical) pathway
  – Ganglion cells
  – Bipolar cells
  – Photoreceptors
Visual Processing - Retina

Direct Pathway:
- Photo receptors
- Bipolar cells
- Retinal ganglion cells

Bipolar Cell Response to Light:
- When light shines on photo receptor, the bipolar cell hyperpolarizes.
- When light turns off, the bipolar cell turns on.

Light Shines on Photoreceptor Cell, Bipolar Cell Depolarizes.
Light Turns Them On.

Hyperpolarized → Depolarized
Two types of bipolar cells:

- They are classified by how they respond to light.
ON Bipolar depolarized in light

OFF Bipolar hyperpolarized in light

RESET

Light On

Light Off

Light source

LIGHT IS ON

https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html
The Receptive Field

Move pin to map the region of skin that causes spiking in the sensory axon.

Receptive field on skin

Recording from sensory axon en route to spinal cord

Receptive field of the sensory neuron

DRG
The Receptive Field

- Area of retina where light changes neuron’s firing rate
- Fields change in shape and stimulus specificity.
ON BIPOLAR CELL RESP.

LIGHT PULSE

Light on

Light off

Light in receptive field center

Photoreceptor hyperpolarized

Less glutamate released

ON Bipolar cell depolarized

0 mV

-60 mV

-80 mV

ON

OFF

LIGHT

https://nba.uth.tmc.edu/neuroscience/s2/chapter14.html
Microscopic Anatomy of the Retina—(cont.)

- Retinal processing also influenced by lateral connections
  - Horizontal cells
    - Receive input from photoreceptors and project to other photoreceptors and bipolar cells
  - Amacrine cells
    - Receive input from bipolar cells and project to ganglion cells, bipolar cells, and other amacrine cells
Bipolar cells have concentric receptive fields.

When the receptors surrounding the center receptors of the on bipolar receptive field are illuminated ("Light On") and the center receptors kept in the dark, the On-Bipolar cell is hyperpolarized.
Bipolar Cell Receptive Fields

- Receptive field: ON and OFF bipolar cells
  - Receptive field: Stimulation in a small part of the visual field changes a cell’s membrane potential.
  - Antagonistic center-surround receptive fields
Bipolar Cell Receptive Fields—(cont.)

- ON-center bipolar cell
  - Depolarized by light in receptive field center
  - Hyperpolarized by light in receptive field surround
Laminar Organization of the Retina

- Seemingly inside-out layers
- Light passes through ganglion cells and bipolar cells before reaching photoreceptors.
Connectivity Patterns

play a critical role in information-transmission functions

e.g. Acuity in Cones

e.g. Sensitivity in Rods

e.g. Receptive Fields

e.g. Simultaneous Contrast
Regional Differences in Retinal Structure

• Structure varies from fovea to retinal periphery.

• Peripheral retina
  – Higher ratio of rods to cones
  – Higher ratio of photoreceptors to ganglion cells
  – More sensitive to low light
Regional Differences in Retinal Structure—(cont.)

- Cross section of fovea: pit in retina where outer layers are pushed aside
  - Maximizes visual acuity
- Central fovea: all cones (no rods)
  - Area of highest visual acuity
Convergence

Cone Convergence:
Cones show LOW convergence

Rods Convergence:
Rods show HIGH convergence

**Cone**
1:1 or Few:1
(Cones per Ganglion, on average across retina, 6:1)

**Rods**
Many:1
(Rods per Ganglion, on average across retina, 120:1)
Due to connectivity pattern, details are preserved.

Connectivity Matters

CONES
1:1
Cone: Ganglion

High Acuity
Connectivity Matters

Due to Connectivity pattern, details are lost

RODS
Many:1
Cone:Ganglion

Poor Acuity

Slide from Dr. Christine Johnson
Light not perceived

Each cone reacts slightly...

...but not enough activity from each Bipolar to cross the threshold for Ganglion to fire

CONES
1:1
Cone:Ganglion

Low Sensitivity
Connectivity Matters

...and activity of Bipolars **summates**, sufficient to cross the threshold for Ganglion to fire

**RODS**
Many:1
Cone:Ganglion

Light perceived

Each rod reacts slightly...

High Sensitivity

Slide from Dr. Christine Johnson
Although note...

- Yes, Rod connectivity accounts, to a large extent, for the SENSITIVITY of the Rod system . . .

- But, also, Rods are LARGER and have MORE PHOTO-PIGMENT than Cones do, & this also contributes to sensitivity

- That is, there is a better chance that a given photon of light will hit a Rod than a Cone, so in low light, Rods are more likely to be the receptors to respond

**MNEMONIC**
More and bigger rods, Better the odds!
Receptive Field

= Set of Receptors whose activity influences the activity of a “Target” cell
VISION IS A CROSSED SENSATION

* LEFT VISUAL FIELD \rightarrow RIGHT V1

[Diagram showing visual processing with text annotations]
Ipsilateral fibers: layers 2, 3, 5

Layers of LGN

Contralateral fibers: layers 1, 4, 6
Feature Detection

Parallel Processing:

1. Color Info.
   - Cones
     - Red: 60%
     - Green: 30%
     - Blue: 10%

2. Form Info
   - What are the Boundaries of Object?

P-Pathway (Parvo Cellular Pathway)

P-Cell

- Very good spatial resolution
- High level of detailed information
- Poor temporal resolution (motion)
- Used for stationary objects
- Color information - cones
MOTION

* Magno (MAGNOCellular Pathway)

* M-CELL

* motion tracking
* high temporal resolution
* "blurry image"
* no color information
* has high contrast sensitivity
Recall:

- Photo receptors
- Bipolar cells
- Retinal ganglion cells

**Note:** The M- & P-pathways respond to different stimuli.
**THE DIFFERENCE BETWEEN**

**M-Ganglion cells**
- transient response
- larger cell body ("parasol")
- project to layers 1 & 2
- in LGN (co-rich layers)
- project (4ca) V1
- V2 -> THICK STRIPES

**P-Ganglion cells**

**MAGNO (M) PATHWAY**
- small cell body (nudget)
- sustained response
- project to layers 3-6 in LGN
- P ALERT TO V1: [4A u 4B]
- both co-rich & non co-rich layers
- co-rich layer in V1
- P-pathway is further diluted into streams

**P-I PATHWAY**
- co-blobs V1 V2
- non co inter blobs V1
- thin stripes V2
- inter stripes of V2