COGS17 Neurobiology of Cognition

# Lecture 4.1: Vision

**Visual Receptors** (Rods & Cones) – Contain Photopigment molecules that react to light ("Isomerize") >> alters release of NT

See ***Supplement* to Vision Lecture** on LECTURES page of class website

**Isomerization** = Converting light into a neural signal
- Outer Segment of Receptors composed of lamellae w/embedded **Photopigment** molecules that react to light, made of …
  -1) **Opsin**: long protein chain (150 X as large as…) -2) **Retinal**: short lipid segment, synthesized from Vitamin A
- *11-Cis* Retinal absorbs photon of light, changes shape (straightens, now called *All-trans* Retinal) and detaches from Opsin
  - Opsin changes color from reddish-purple to pale yellow ("bleached")
  - This activates Second Messengers in Receptor that lead to ion gates closing, modifying graded release of NT
  - Each Rod has ~10 mil photopigment molecules, called Rhodopsin; Cones have less photopigment, their own variants
- Photopigment **Regeneration** (recombination of Retinal & Opsin), using enzymes from Pigment Epithelium, Requires time
  - e.g. Hard to see indoors at first after bright sunlight (since "Light Adapted") but as regenerate, sensitivity restored
  - e.g. Hard to see just after turn off lights, but soon, as more regenerate, sensitivity increased (become "Dark Adapted")

**The Retina** – Composed of Neurons (except Pigment Epithelium), multi-layered, covering rear, inner wall of eyeball
- **Receptors** - Rods & Cones – rearmost layer of retina
  - **Rods**: larger, in periphery, ~120 million/eye - **Cones**: smaller, dispersed throughout retina, ~6 million/eye
  - **Fovea** - small central area of high concentration of Cones only; for high detail resolution
- **Bipolars** - Postsynaptic to Receptors, show Spontaneous firing, Graded Potentials, release Excitatory NT
- **Ganglions** - Postsynaptic to Bipolars, Show Action Potentials; Axons of the Ganglion Cells form the **Optic Nerve** => brain
  - **Blind Spot** or "Optic Disk" - where Optic Nerve leaves eye & blood vessels enter/leave; No Receptors there
- **Interneurons** - perpendicular to pathway, influence interactions between the above neurons:
  - **Horizontals** – Graded Potentials, mostly Inhibitory NT, modify interface of Receptors and Bipolars
  - **Amacrines** – Graded Potentials, mostly Inhibitory NT, modify interface of Bipolars and Ganglions; Many kinds
- Pigment Epithelium - rearmost layer of (Non-Neural) cells; feeds & recycles from receptors; helps reflect/maximize light

**STRANGE BUT TRUE**: *Light* turns Receptor cells OFF (down), *Darkness* turns them ON (up) !
- Recall that Receptors show **Spontaneous** firing, Graded Potentials, release Inhibitory NT
  - i.e. In the *absence* of stimulation, Receptor's Na+ gates open, Na+ flows in & out = **Dark Current**
    - Ca++ gates also open, causing continuing release of NT, Ca++ actively pumped out so cycle can repeat
  - As photopigments are isomerized, Na+ & Ca+ gates close, increasing Receptor's polarity, decreasing NT release
- *So*, in the dark, Receptors release enough inhibitory NT to prevent Bipolars from triggering Ganglions
  So Ganglions, by not firing, in effect, report to brain: "No light"
  - In bright light, Receptors are shut down, do not inhibit Bipolars, so Bipolars spontaneously release enough excitatory NT to pass Ganglion's threshold for firing, so Ganglion sends message: "Bright Light!"
  - In dim light, Receptors' spontaneous release of NT is decreased (a graded reaction, more light, less NT) so Bipolars only somewhat inhibited & release enough excitatory NT to sometimes trigger Ganglions

**Connectivity Patterns** play a critical role in information-transmission functions…

**Convergence**: Receptors converge (via their Bipolars) onto Ganglion cells; Rods: High Convergence, avg. 120:1 Ganglion
Cones: Low Convergence, avg. 6:1 Ganglion; In **Fovea**: Very Low**,** Cones often only **1:1** Midget Ganglion
- **Acuity**: Convergence helps to account for Acuity (detail resolution) differences between Rods & Cones
  - Rods: light from 3 environmental points falls on 3 Rods, but if all 3 Rods converge (via Bipolar) on 1 Ganglion
    ==> that 1 Ganglion can only send the message: "Something out there"
  - Cones: light from 3 environmental points falls on 3 Cones, each communicates (via Bipolars) with just 1 Ganglion
    ==> those 3 Ganglions send message: "3 things out there" = High Acuity

- **Sensitivity** Convergence also helps account for Sensitivity differences between Rods and Cones
  - Consider what happens in dim light (i.e. very little light reaching Photopigments in Receptors)…
    - Cones => little change in inhibitory NT released from each Cone => little excitatory NT released from each Bipolar
      => may be insufficient to trigger AP from each Ganglion - So, no info sent to brain (i.e. no light detected)
    - Rods => little change in inhibitory NT released from each Rod => little excitatory NT released from each Bipolar
      => BUT since many converge on one ganglion, **sum** of NT is sufficient to trigger AP from Ganglion
        - So, info sent to brain (i.e. even dim light detected - So see dim star best by NOT looking directly at it!)

**Receptive Field** (RF) = Set of Receptors whose activity influences the activity of a "Target" cell (i.e. any downstream cell)
- Size and type of a Target's RF is determined by patterns of Convergence and Lateral influences
- e.g. Ganglion (target) along path from converging Rods has large RF, while Ganglion along path from Cones has small RF
- Thus, as described above, cells with small receptive fields are often involved in high acuity perception

- e.g. Some Ganglions, LGN, and V1 cells have **Center-Surround RFs** per pattern of Excitation, Inhibition and Convergence
  - For example, if a Ganglion Cell has an Excitatory Center-Inhibitory Surround RF…
    - Light > the Center of its RF results in that Ganglion being excited (by activity of Bipolars from that area)
    - Light > the Surround of its RF results in that Ganglion being inhibited (by activity of Amacrines from that area)
    - Light > more Center than Surround results in Ganglion being more likely to reach threshold or to fire at higher rate
    - Light > more Surround than Center results in Ganglion being less likely to reach threshold or to fire at lower rate

**Lateral Inhibition** - Another important connectivity pattern, seen throughout brain (e.g. Help create Center-Surround RFs)
- Functions mainly to **exaggerate differences** (e.g. between areas of dark/light, serving to highlight edges of objects)
- e.g. Amacrine, excited by its Bipolar, sends Lateral Inhibition to Ganglions nearby
  - Amacrine's response is graded, so the more excitation from the Bipolar the more inhibition sent to the neighbors
- e.g. Responsible, in part, for "illusions" like **Simultaneous Contrast** (See schematic of circuit on ***Supplement***)
  - e.g. Given a stimulus in which a wide, *light* gray border surrounds a *medium* gray patch ("Medium 1") vs. one in which a different wide, *dark* gray border surrounds a patch of the SAME gray ("Medium 2")
  - Even tho Medium 1 is physically the same as Medium 2, Medium 1 appears darker than Medium 2.
  - This is because Bipolars are more excited by the light gray border than by the dark gray border, so their Amacrines, near the light border, send more Lateral Inhibition to the center region, than Amacrines from the dark border do
- e.g. **Direction-Sensitive** Cells (Motion Detectors) involve **Uni**-Directional Lateral Inhibition (See next lecture)