



# **Biological Psychology**

**M5X00908 Brain, Behaviour, and Cognition (BBC)**

## **Lecture 3: The Visual System**

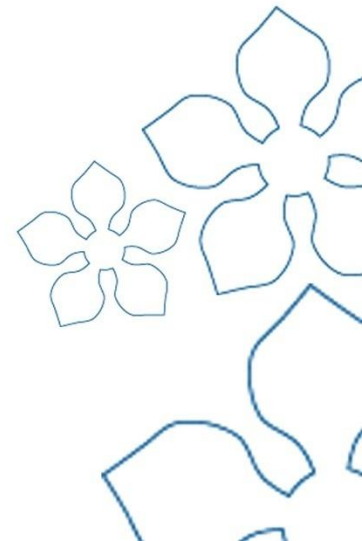
**Dr Kate Williams**



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PRIFYSGOL CYMRU  
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UNIVERSITY OF WALES  
**Trinity Saint David**

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# What Do We See?

**When information enters our eyes its projected to an area at the back of the eye called the retina.**

**But this projected image is not an accurate internal copy of the external world.**

**Somehow a distorted & upside-down 2D retinal image is transformed into the 3D world we perceive**

**Two types of research needed to study vision**

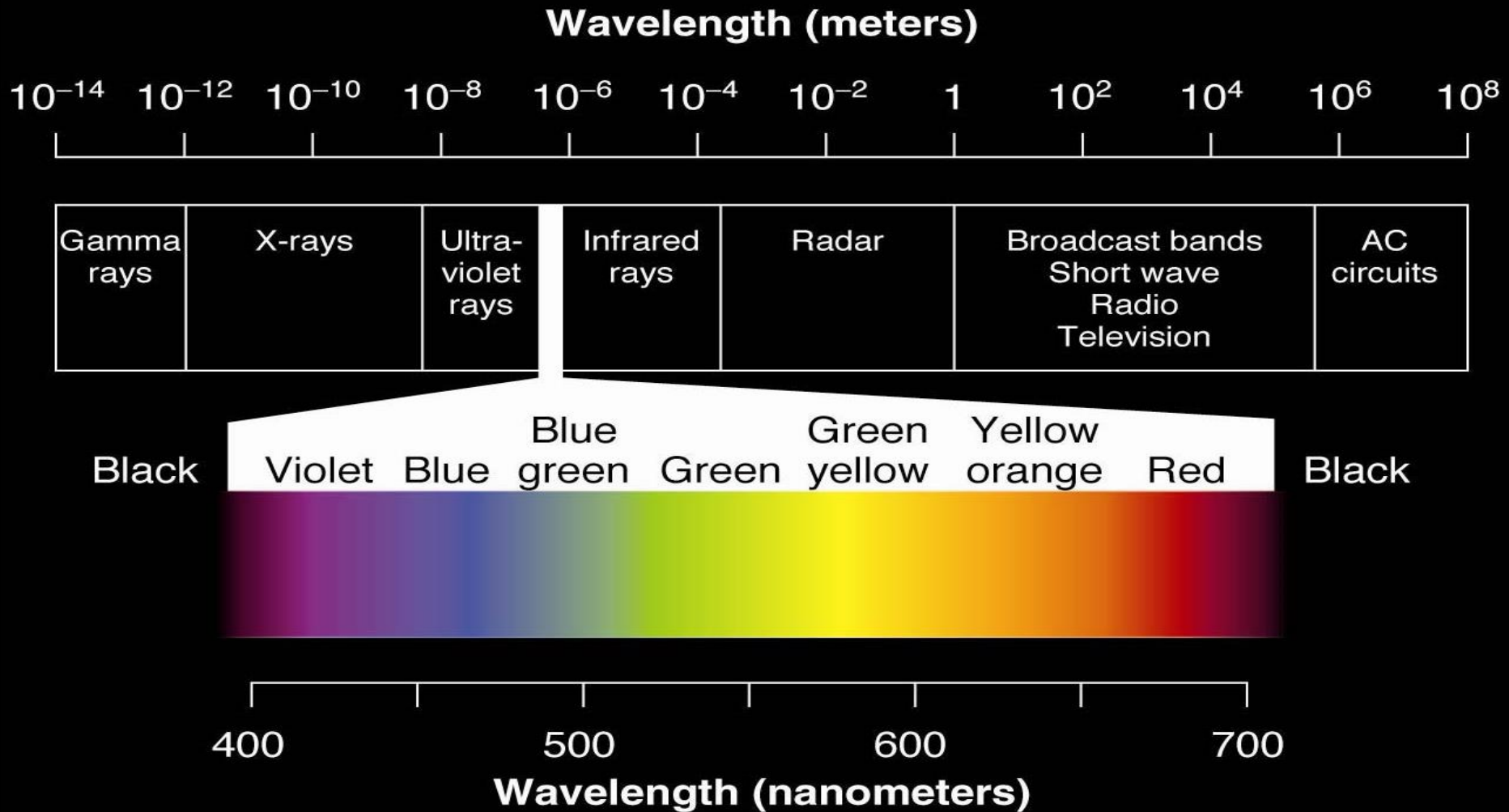
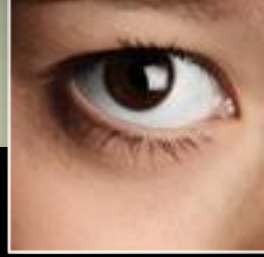
- 1. Research probing the components of the visual system**
- 2. Research assessing what we see**



# **We can see because light bounces off objects and that light enters the eye**

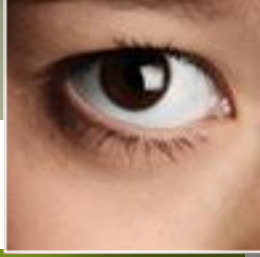
- Some species can see when there is little light
- Light can be thought of in 2 ways:
  1. Particles of energy (photons)
  2. Waves of electromagnetic radiation (energy)
- Humans see light between 380-760 nanometers

# The Electromagnetic Spectrum



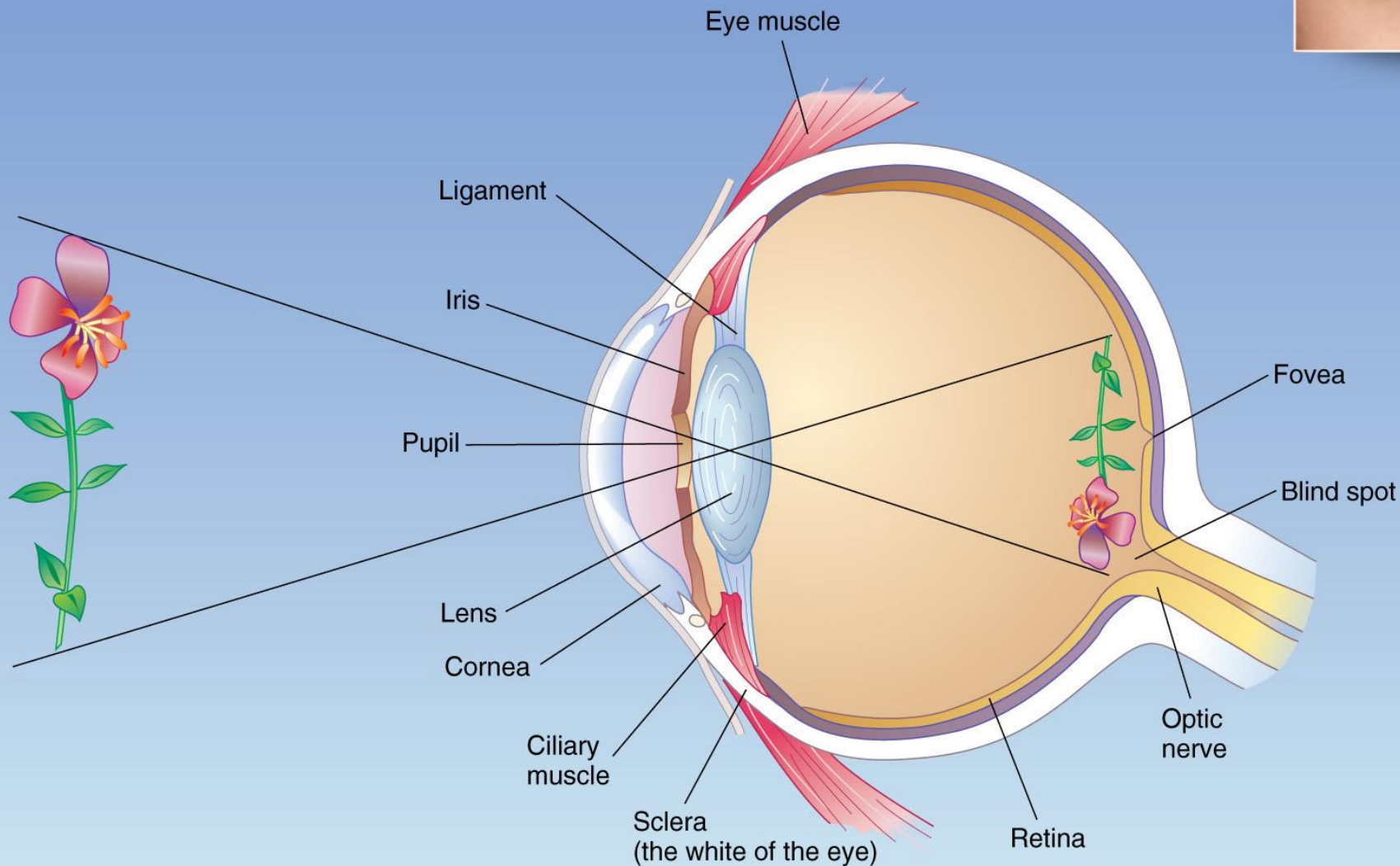
Some animals see other wavelengths, e.g., rattlesnakes thought to see infrared rays, which allows them to see warm-blooded prey in darkness.

# The Pupil and the Lens



- Amount of light reaching retina is controlled by the **iris** (gives our eyes their colour).
- Light enters through the **pupil** (size changes in response to changes in illumination).
- This comes from compromise between:
  - **Sensitivity of eye** – ability to see when light is dim, and
  - **Acuity of eye** – ability to see details of objects.
- Behind pupil is the **Lens** – focuses light on the **retina**
- **Ciliary muscles** alter the shape of the lens as needed
  - This increases ability of the lens to bend (refract) light and brings close objects in to sharp focus. When we focus on the distance the lens is flattened.
  - This process is called **accommodation**.

# The Pupil and the Lens



## The Human Eye

# Eye Position and Binocular Disparity

- We have 2 eyes – so why do we not end up seeing 2 of everything?
  - Movement of our eyes are coordinated so each point in the world is projected to corresponding points on the both retinas.
- To do this our eyes **Converge**: turn slightly inward when objects are close.
- But the position of images on the 2 retinas are never going to be the same because our eyes do not view the world from exactly the same position.
- This results in: **Binocular disparity** – difference in position of same image on the two retinas
- The visual system uses this to construct & provide the brain with a 3-D image and distance information



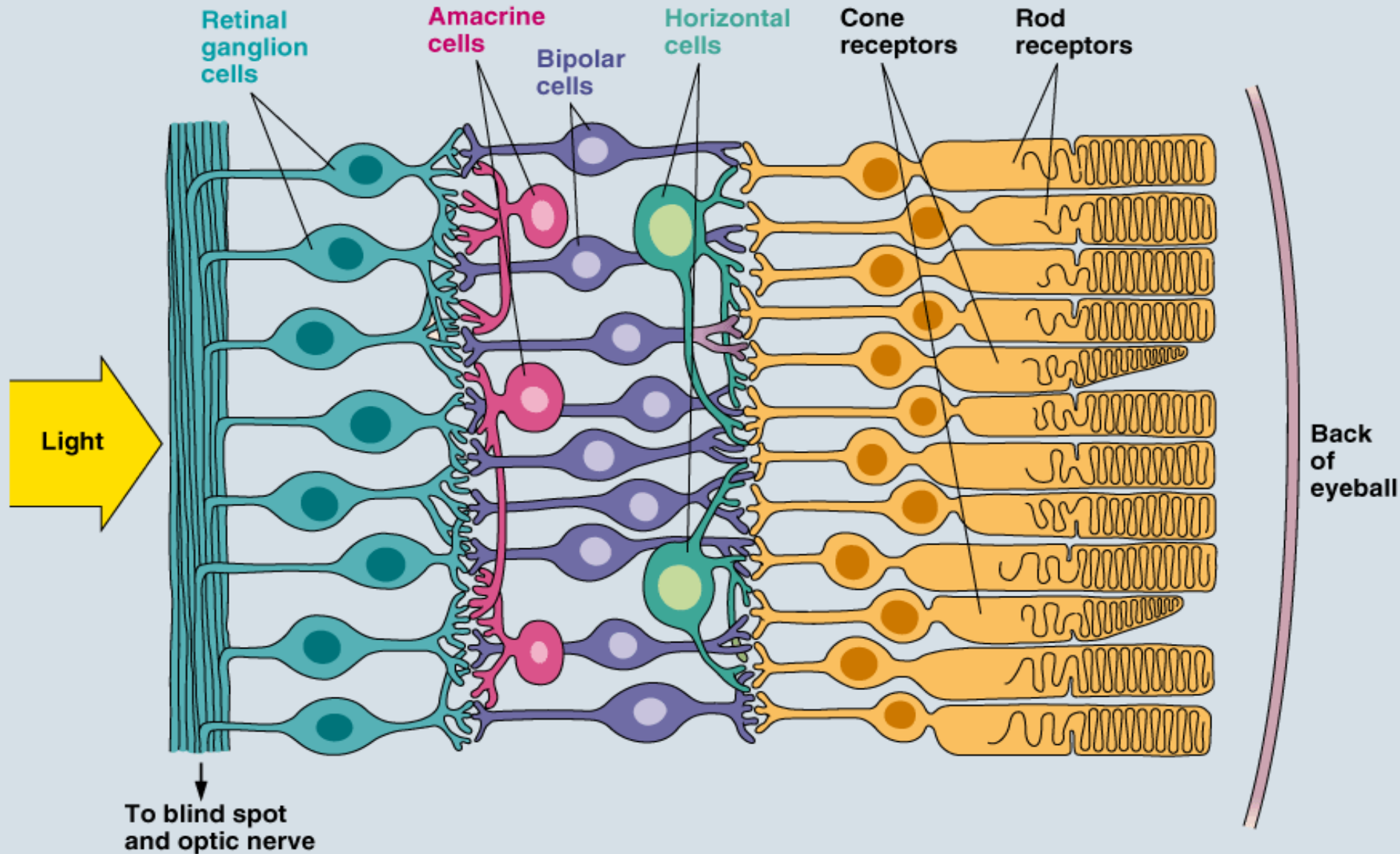
# The Retina and Translation of Light into Neural Signals

- Once light has passed through pupil and lens, it lands on the retina, which converts light to neural signals and conducts them to the CNS.
- The retina is in a sense “inside-out”
  - Light passes through several cell layers before reaching its receptors
- The retina is composed of 5 layers of different types of neurons: receptors, horizontal cells, bipolar cells, amacrine cells, and retinal ganglion cells.
- Vertical pathway – receptors > bipolar cells > retinal ganglion cells
- Lateral communication - Horizontal cells & Amacrine cells



# The Retina and Translation of Light into Neural Signals

## Cellular Structure of the Mammalian Retina

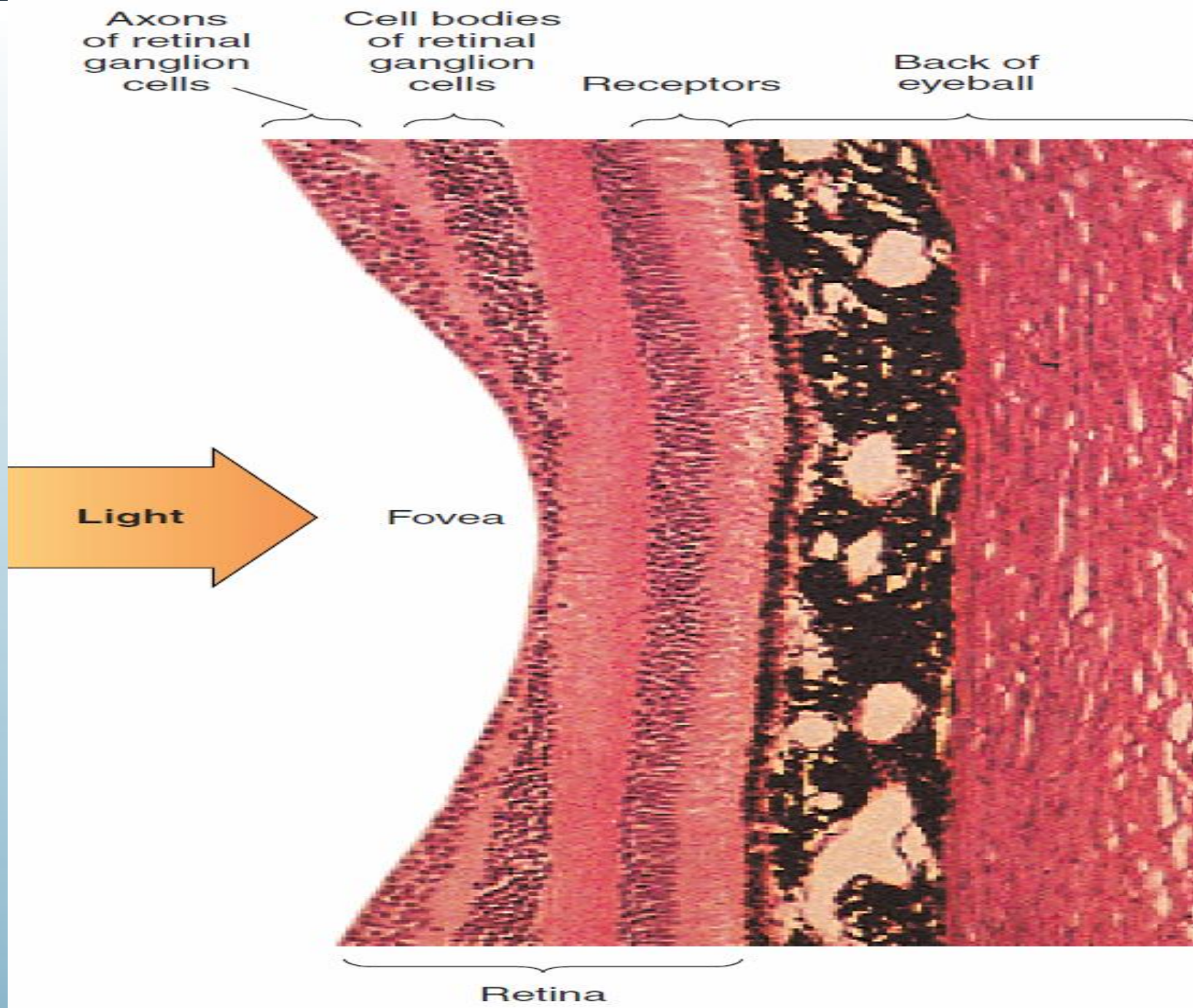


# The Retina and Translation of Light into Neural Signals

- Inside-out arrangement creates 2 visual problems:
  1. Incoming light is distorted by retinal tissue through which it must pass before reaching the receptors.
    - Dealt with by the fovea: indentation about 0.33 cm in diameter at the centre of the retina.
    - Area of the retina specialized for high-acuity vision (fine details).
    - Thinning of the retinal ganglion cell layer at the fovea reduces the distortion of the incoming light.
  2. For the bundle of retinal ganglion cell axons to leave the eye there is a gap in the receptor layer - **blind spot**.
    - Section where there are no receptors so anything that falls on the area is not picked up.
    - To deal with this, the system uses information by receptors around the blind spot to fill in gaps in the retinal image.
    - Referred to as **completion** and suggests the visual system does more than just create a copy of the external world.

# The Retina and Translation of Light into Neural Signals

A section  
of the  
retina





# Cone and Rod Vision

**Duplexity theory of vision** – cones and rods mediate different kinds of vision

## **Cones:**

### **Photopic (daytime) vision**

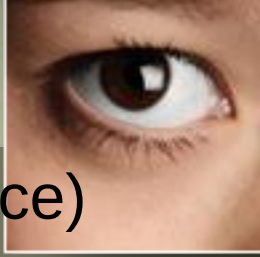
- High-acuity color information in good lighting
- Only cones are found at the fovea

## **Rods:**

### **Scotopic (nighttime vision)**

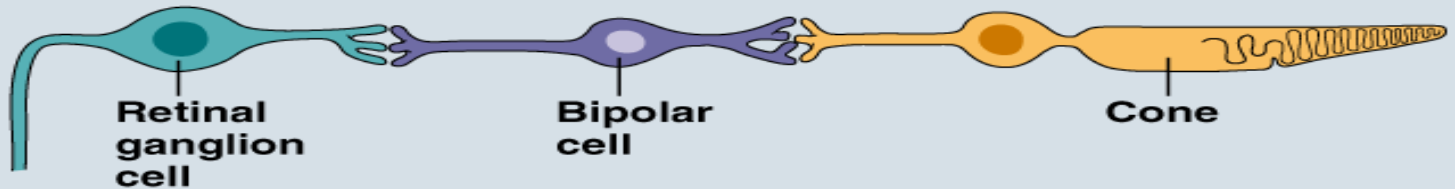
- High-sensitivity, allowing for low-acuity vision in dim light, but lacks detail and color information
- More convergence than cone system, increase sensitivity, decrease acuity

# Cone and Rod Vision

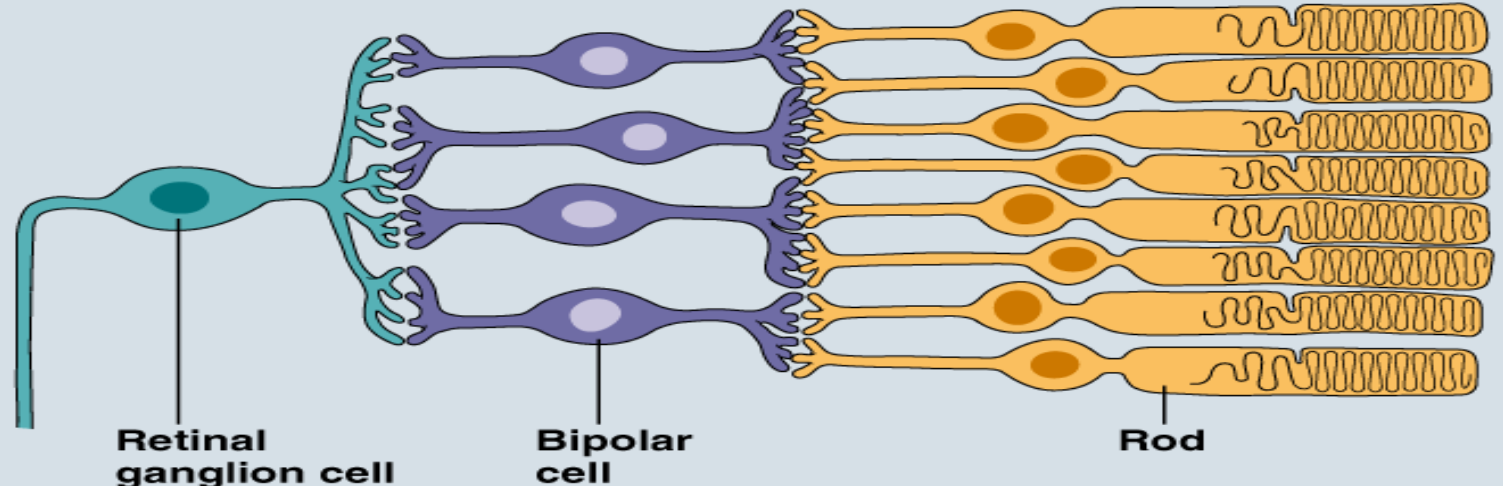


Difference comes from the way they are wired (convergence)  
Photopic system has few cones converging on each RGC  
Scotopic has several hundred rods converge on single RGC

**Low Convergence in Cone-Fed Circuits**

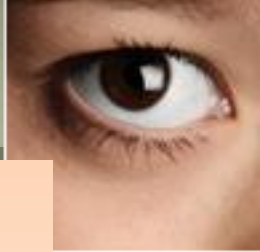


**High Convergence in Rod-Fed Circuits**

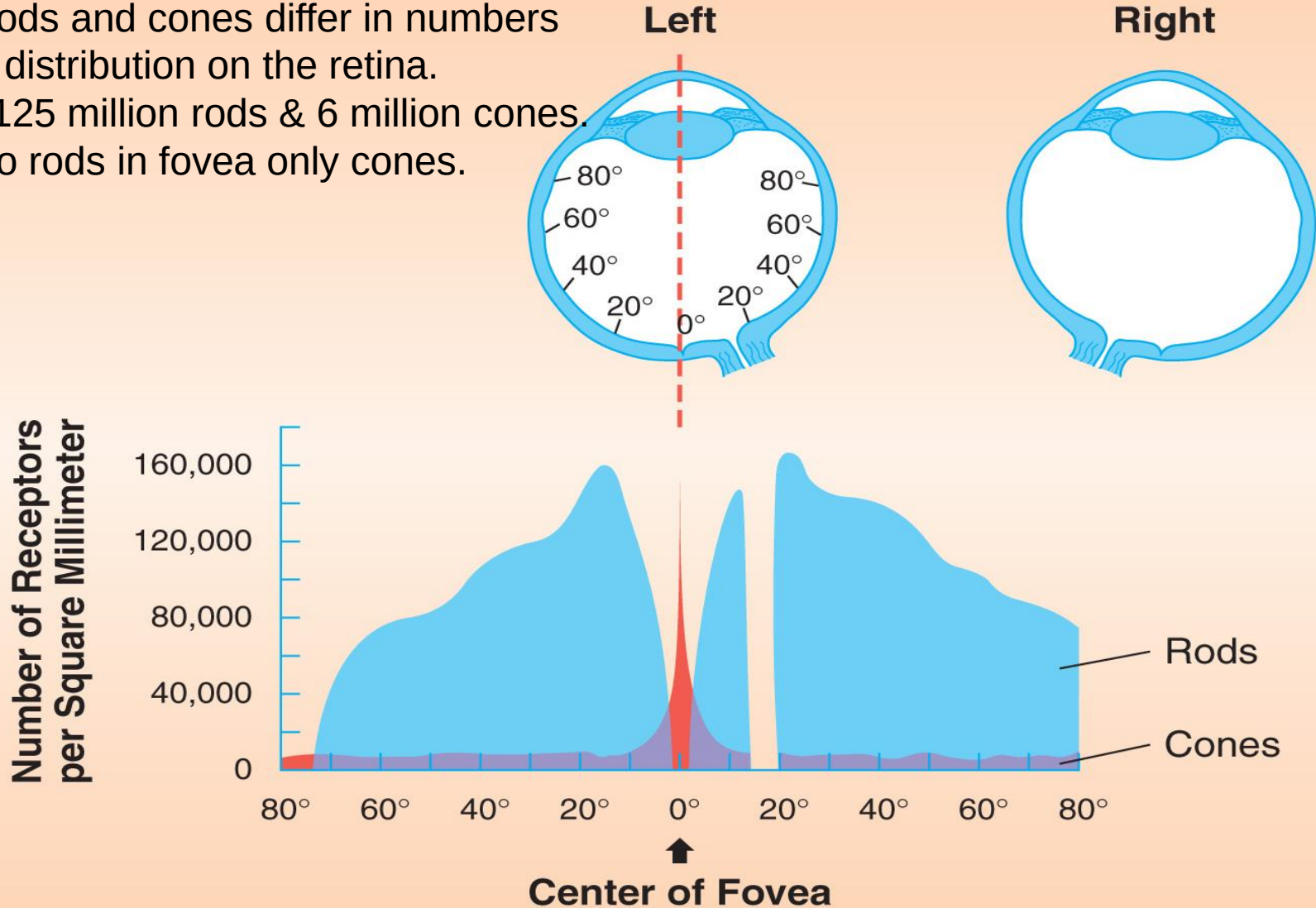


A schematic representation of the convergence of cones and rods on retinal ganglion cells.

# Cone and Rod Vision



- Rods and cones differ in numbers & distribution on the retina.
- ~125 million rods & 6 million cones.
- No rods in fovea only cones.



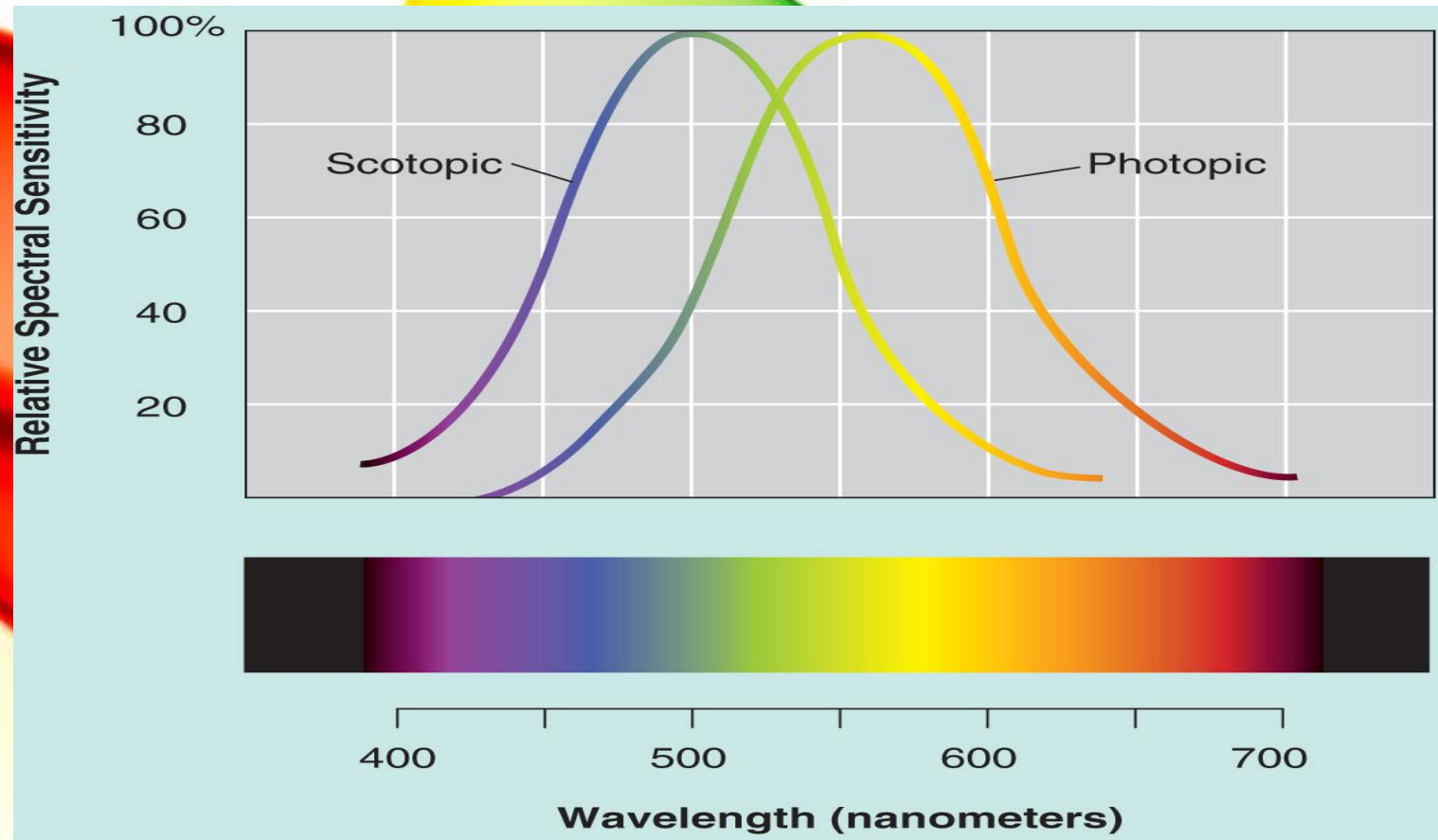
The distribution of cones and rods over the human retina. (Adapted from Lindsay & Norman, 1977.)

# Spectral Sensitivity

- Lights of the same intensity but different wavelengths may not all look as bright
- A **spectral sensitivity curve** shows the relationship between wavelength and brightness
- There are different spectral sensitivity curves for photopic (cone) vision and scotopic (rod) vision

# Spectral Sensitivity

Human photopic (cone) and scotopic (rod) spectral sensitivity curves.



- Under photopic conditions, the visual system is maximally sensitive to wavelengths of ~560 nanometers so a light at 500 nanometers would have to be more intense than one at 560 to be seen as equally bright.
- Under scotopic conditions the visual system is maximally sensitive to wavelengths of ~500 nanometers so a light of 560 nanometers would have to be more intense than one at 500 to be seen as equally bright.

# Eye Movement



- Cones are responsible for mediating high-acuity colour vision under photopic conditions – but how do they do this when so many of them are crammed in to the fovea?
- Our eyes continually scan the visual field.
- So, our visual perception at any one time is the summation of recent visual information.
- This is why the world remains there even when we blink.
- Even when we fix our eyes on one object our eyes constantly move – and these involuntary fixational eye movements are of 3 types: tremor, drift, and saccades.



# Visual Transduction: The Conversion of Light to Neural Signals

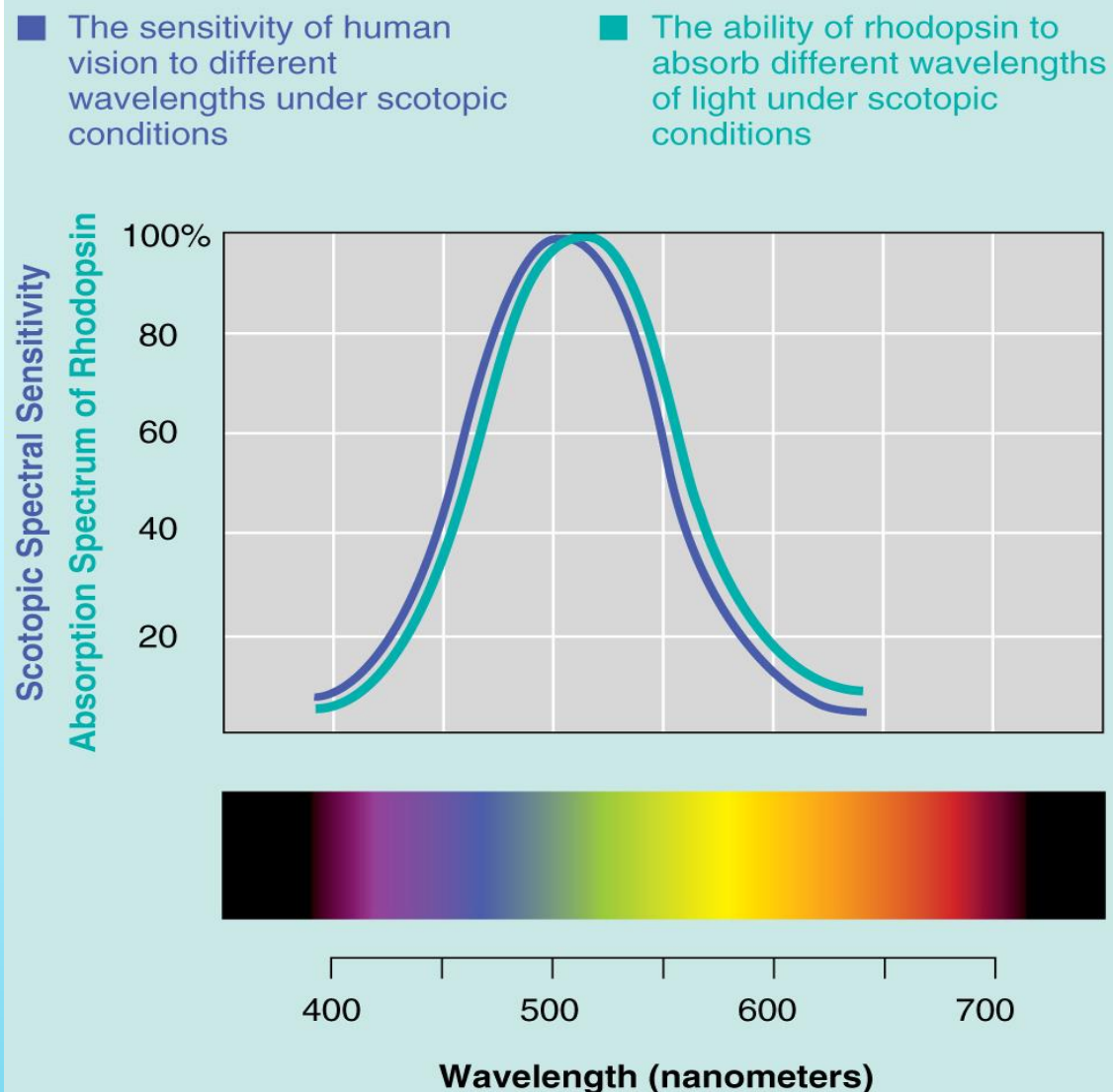


- **How does light turn to neural signals?**
- **Transduction:** conversion of 1 form of energy to another
- **Visual transduction:** conversion of light to neural signals by rods & cones.
- They contain chemicals called photopigments that absorb light and transduce it to neural activity.
- Red pigment (pigment is any substance that absorbs light) called rhodopsin was extracted from rods in 1876.
- When exposed to a continuous intense light it was bleached (lost its colour and its ability to absorb light)
- When put back in darkness, red colour & light-absorbing capability returned.

# Visual Transduction: The Conversion of Light to Neural Signals

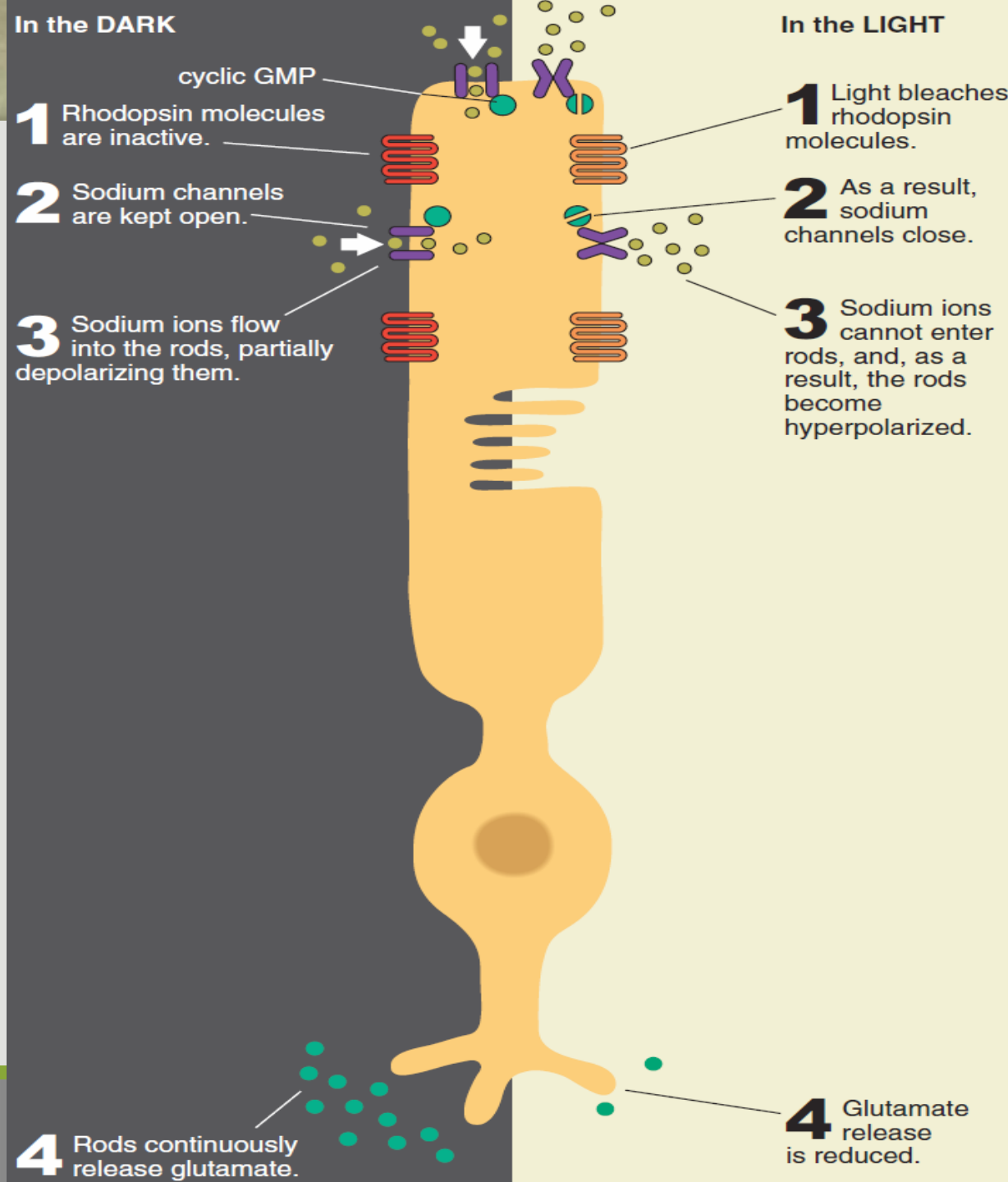


- Figure shows relationship between absorption spectrum of rhodopsin (green) & human scotopic spectral sensitivity curve (blue).
- The fact that they are so close shows that in dim light our sensitivity to various wavelengths is a direct consequence of rhodopsin's ability to absorb them.

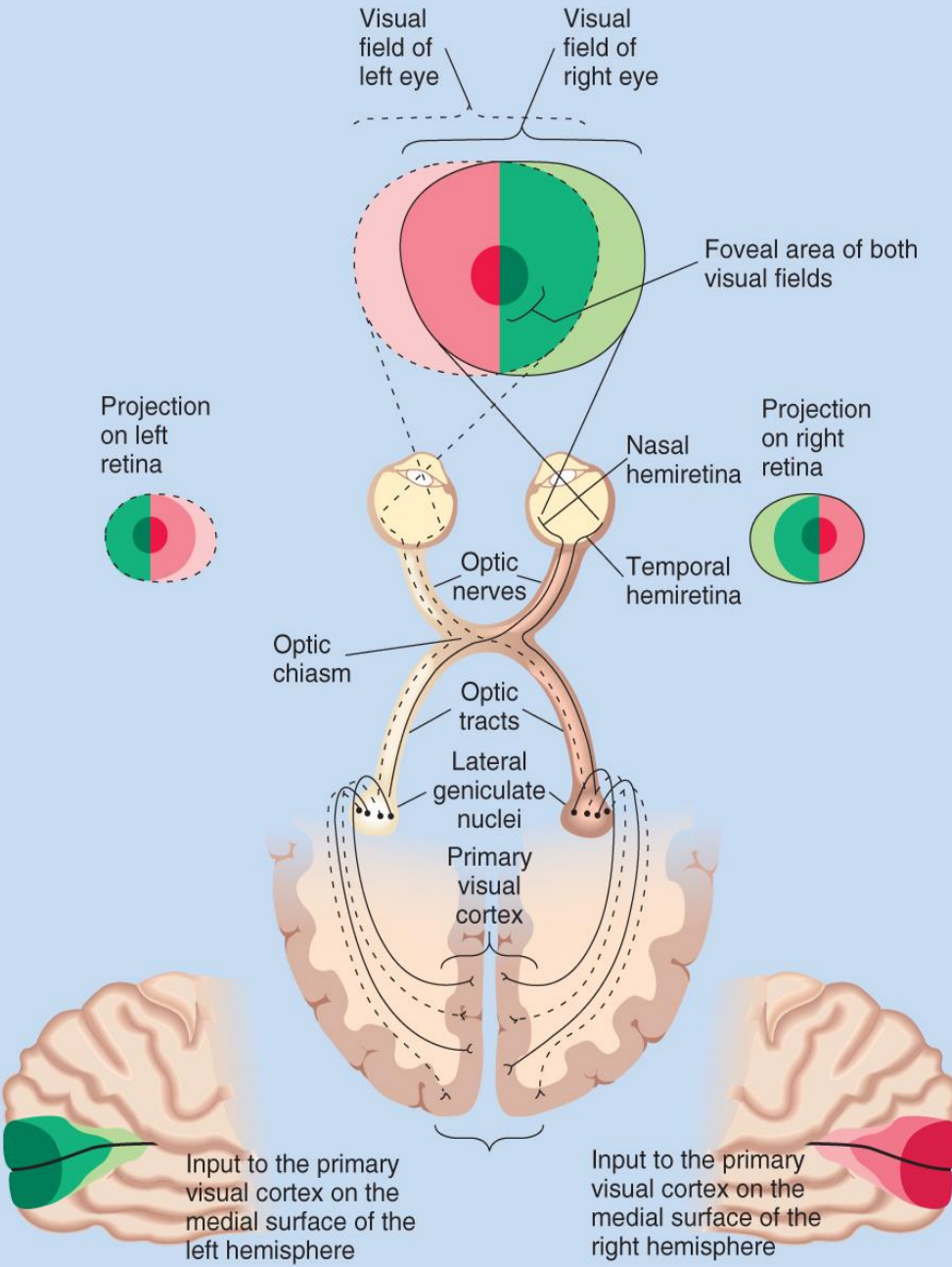


# Visual Transduction

## The inhibitory response of rods to light



# From Retina to Primary Visual Cortex



- The retinal-geniculate-striate pathways are about 90% of axons of retinal ganglion cells
- The left hemiretina of each eye (right visual field) connects to the right lateral geniculate nucleus (LGN); the right hemiretina (left visual field) connects to the left LGN of the thalamus.
- Most LGN neurons that project to primary visual cortex (V1) terminate in the lower part of cortical layer IV

# Retinotopic Organization



- Information received at adjacent portions of the retina remains adjacent in the striate cortex (**retinotopic**)
- This means that 2 stimuli presented to adjacent areas of the retina excite adjacent neurons at all levels of the system.
- More cortex is devoted to areas of high acuity – like the disproportionate representation of sensitive body parts in somatosensory cortex
- About 25% of primary visual cortex is dedicated to input from the fovea

# The M and P channels of communication that flow through each LGN.



## Magnocellular layers

- Big cell bodies, bottom two layers of LGN
- Particularly responsive to movement
- Input primarily from rods

# M

## Parvocellular layers

- Small cell bodies, top four layers of LGN
- Color, detail, and still or slow objects
- Input primarily from cones

# P

# Seeing Edges



- Edges are informative because they define the extent and position of all objects in the world.
- An edge is where 2 different areas of a visual image meet.
- Perception of an edge is perception of contrast between 2 adjacent areas in the visual field.
- To enhance these contrasts our visual system creates nonexistent stripes called:
  - **Mach bands** for contrast enhancement
    - Makes edges easier to see
    - A consequence of lateral inhibition

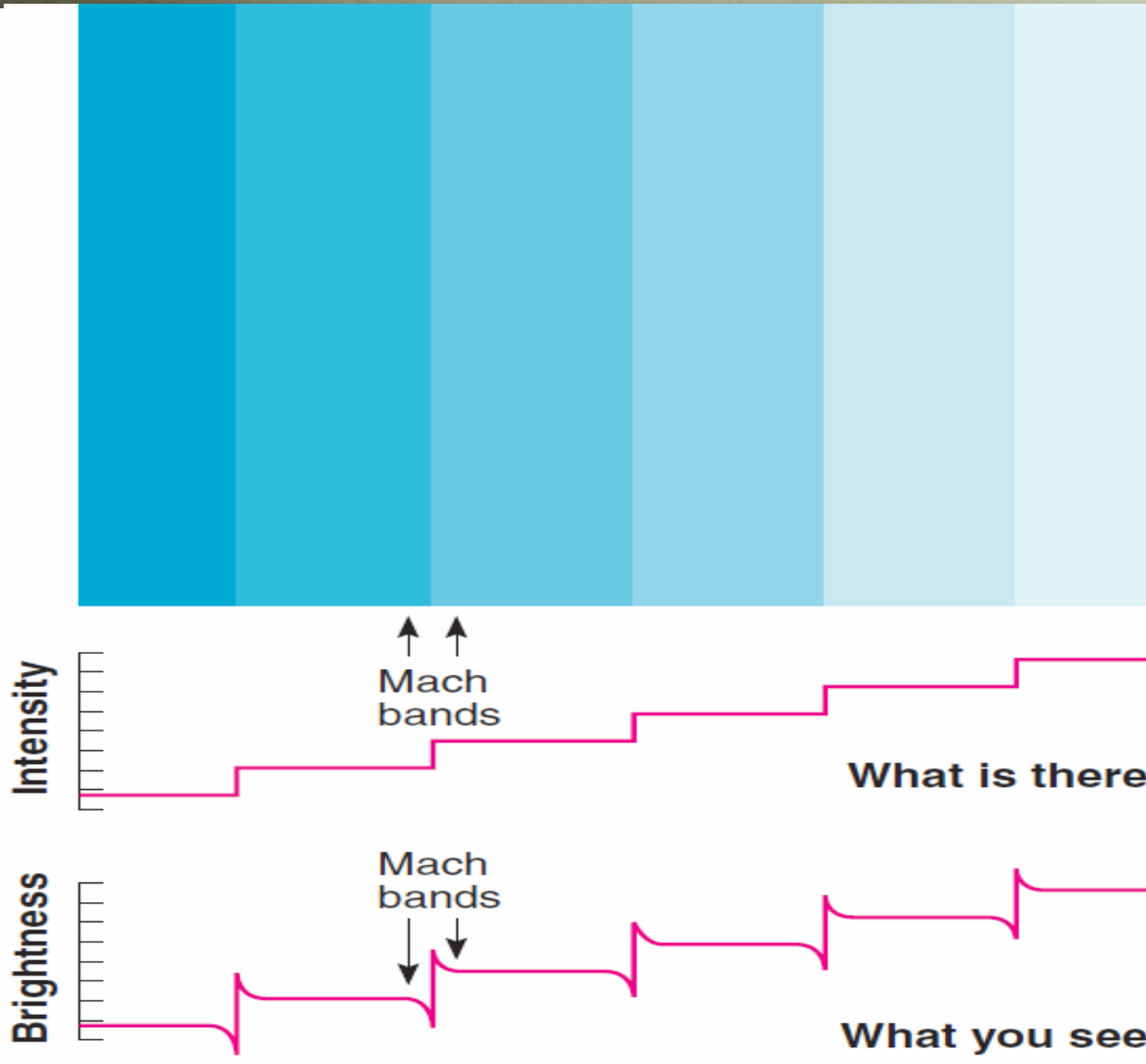


# Lateral Inhibition and Contrast Enhancement

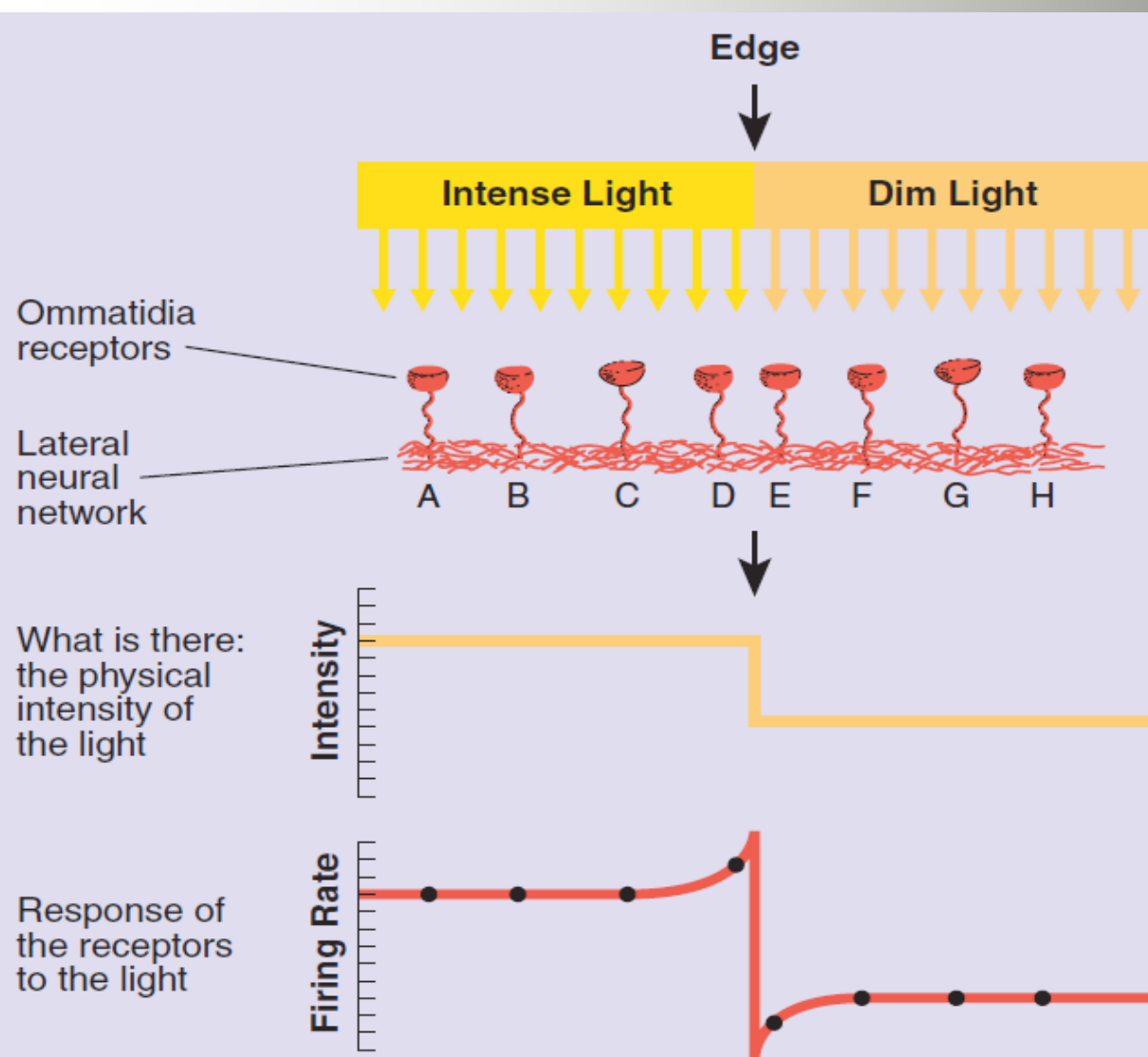


## The illusory Mach bands

- Intensity graph shows what is actually there:
- a series of stripes of differing intensities.
- But what we see is the brightness changing from darker to lighter.
- Next to each edge the brighter stripe looks brighter than it actually is and the darker stripe looks darker.
- Mach bands enhance the contrast at each edge enabling us to see the edge easier.



# Lateral Inhibition and Contrast Enhancement



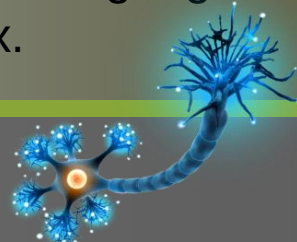
How lateral inhibition produces contrast enhancement (Adapted from Ratliff, 1972)

- When receptor is illuminated by light, it fires & inhibits other receptors around it from firing.
- Contrast enhancement is firing rate of receptors on each side of edge
- E.g., receptor D fires more than others that are intensely illuminated (A,B,C) because it's next to the edge between intense & dim light.
- While receptor E fires less than others (F,G,H) because it's next to the edge between 2 types of lighting but on the dim side.

# Receptive Fields of Visual Neurons



- Hubel & Wiesel examined brightness contrast - won Nobel prize for research on neural mechanism of vision.
- Work involved paralyzing eye muscles of animal to place tip of microelectrode near a single neuron in the visual system.
  - Animal shown image on screen to identify receptive field of the neuron
  - Receptive field = area of the visual field within which it is possible for a visual stimulus to influence the firing of that neuron.
- Response of neurons to different stimuli within its receptive field is recorded to characterize the types of stimuli that influences that neurons activity the most.
- Microelectrode pushed further & process repeated for another neuron.
- Recordings taken for 3 levels of the retina-geniculate-striate system: retinal ganglion cells, the lateral geniculate nucleus, & lower layer 4 of the striate cortex.



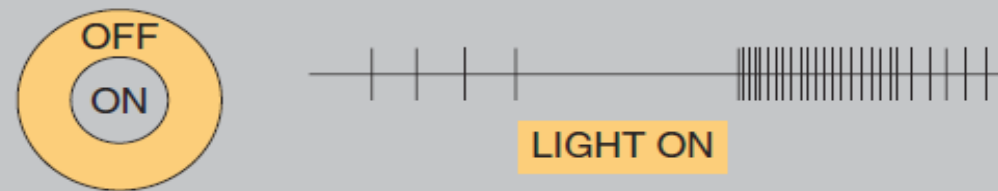
# Receptive Fields: Neurons of the Retina-Geniculate-Striate System



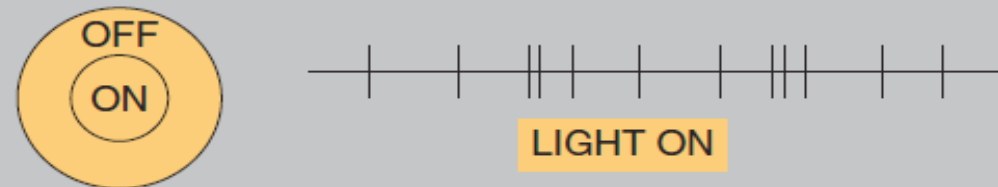
## Similarities seen at all three levels:

- Receptive fields of foveal areas are smaller than those in the periphery
- Neurons' receptive fields are circular in shape
- Neurons are monocular (each neuron had a receptive field in one eye but not the other).
- Many neurons at each level had receptive fields with excitatory and inhibitory area that were separated by a circular boundary.

# Receptive Fields: Neurons of the Retina-Geniculate-Striate System



The most effective way of maximizing the firing of an on-center or off-center cell is to completely illuminate either the “on area” or the “off area” of its receptive field.



If both areas of a cell's receptive field are illuminated together, there is little reaction from the cell.

- Many cells have receptive fields with a center-surround organization: excitatory and inhibitory regions separated by a circular boundary
- Some cells are “on-center” and some are “off-center”

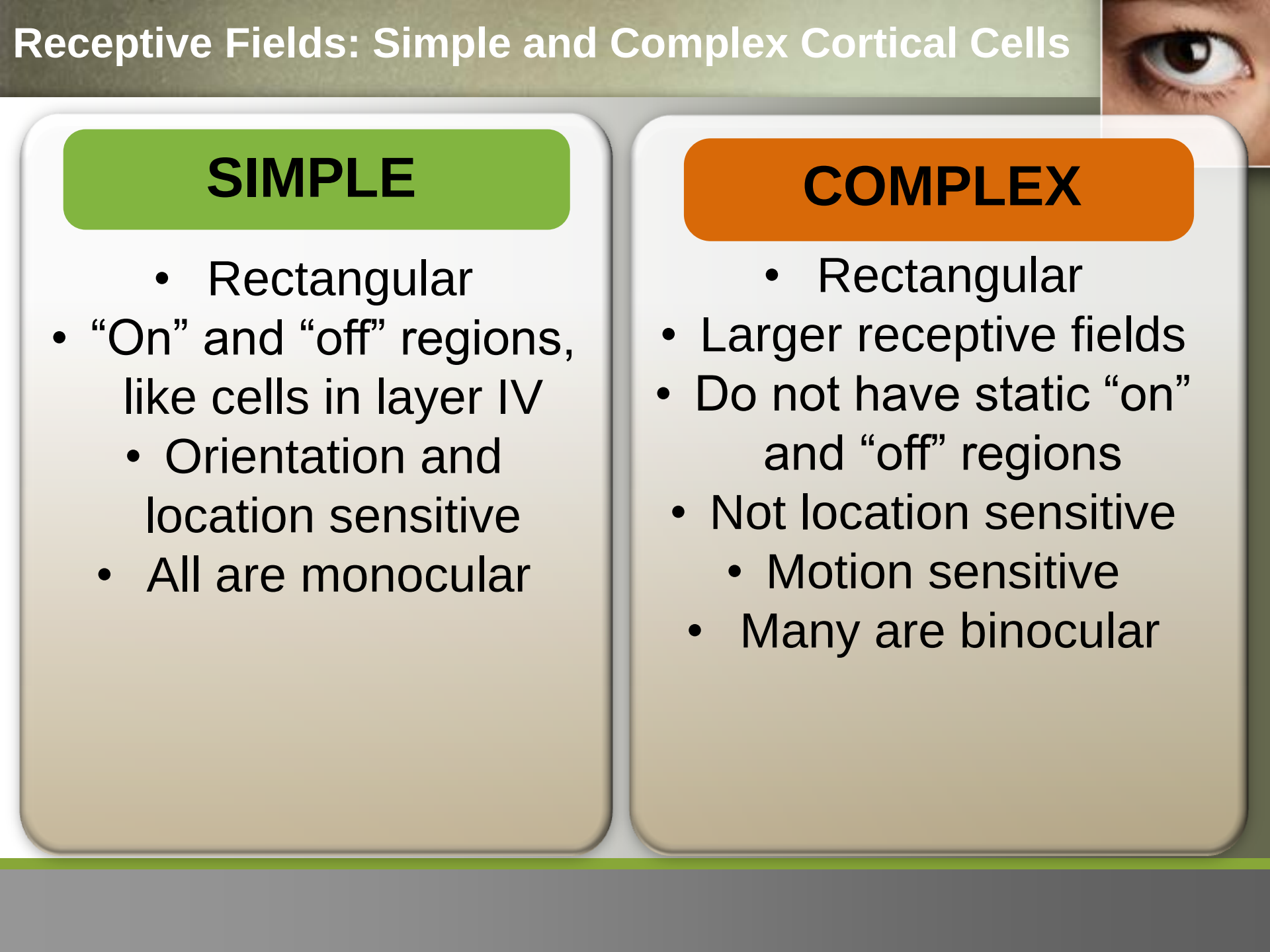
## The responses of an on-center cell to contrast

# Receptive Fields: Simple and Complex Cortical Cells



- In lower layer IV (4) of the striate cortex, neurons with circular receptive fields (as in retinal ganglion cells and LGN) are rare.
- Most neurons in V1 are either:
  - Simple – receptive fields are rectangular with “on” and “off” regions and respond best to bars of light, or
  - Complex – also rectangular, larger receptive fields, respond best to a particular stimulus anywhere in its receptive field

Figure 6.18 in Pinel book shows an example



# Receptive Fields: Simple and Complex Cortical Cells

## SIMPLE

- Rectangular
- “On” and “off” regions, like cells in layer IV
  - Orientation and location sensitive
- All are monocular

## COMPLEX

- Rectangular
- Larger receptive fields
- Do not have static “on” and “off” regions
- Not location sensitive
  - Motion sensitive
- Many are binocular

# Columnar Organization of Primary Visual Cortex



- Cells with simpler receptive fields send information on to cells with more complex receptive fields
- Primary visual cortex neurons are grouped in functional vertical columns such that all cells in a column have the same receptive field and ocular dominance:
  - Ocular dominance columns – as electrode moves horizontally, the dominance of the columns changes through areas of left-eye dominance and then right-eye dominance
  - Retinotopic organization is maintained

See Figures 6.19 & 6.20 in Pinel

# Plasticity of Receptive Fields of Neurons in the Visual Cortex



- **Plasticity is a fundamental property of visual cortex function**
- **Studies examining reactions to simple & individual stimuli (e.g., bars or spots of light) do not provide full understanding of how the visual system works.**
- **Receptive field properties need to be examined within a scene because we do not see things in isolation in the world.**



# Seeing Color: Component and Opponent Processing



## Component theory (trichromatic theory)

**Proposed by Young (1802),  
refined by Helmholtz (1852)**

- Three types of colour cone receptors in the eye, each with a different spectral sensitivity.
- Colour of stimulus encoded by the ratio of activity in the 3 receptors.
- Derived from observation that any colour in the visible spectrum can be matched by mixing together 3 different wavelengths of light in different proportions

## Opponent-process theory

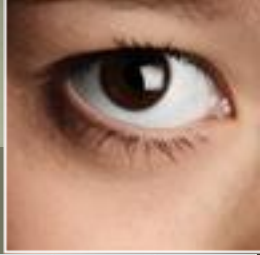
**Proposed by Hering (1878)**

- Two different classes of cells encoding color and another class encoding brightness.
- Each encodes two complementary color perceptions.
  - One class for red & green
  - Another class for blue and yellow
- Accounts for color afterimages and colors that cannot appear together (reddish green or bluish yellow)

**Both theories are correct:** coding of color by cones seems to operate on a purely component basis, opponent processing of color is seen at all subsequent levels.

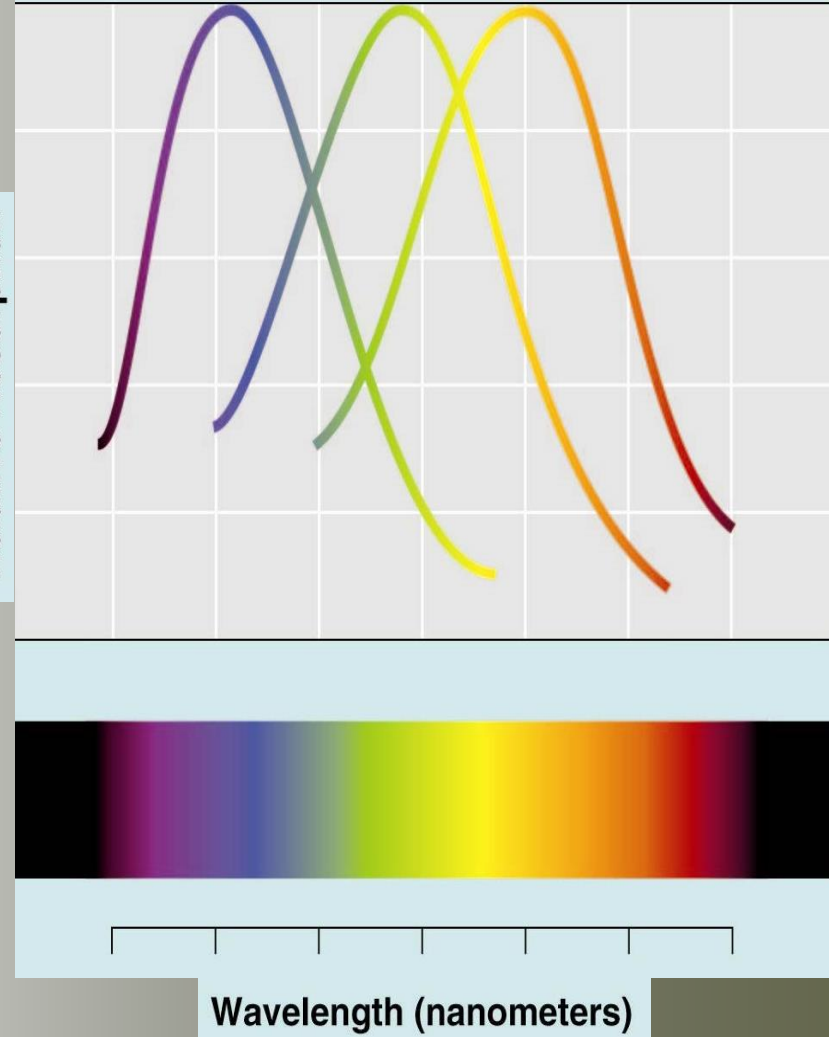
# Seeing Color

## The absorption spectra of the three classes of cones

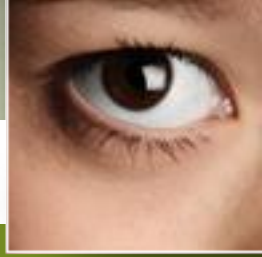


- 1960s: technique to measure absorption spectrum of photopigment contained in single cone developed & confirmed Young's findings.
- 3 different types of cones in the retina & each has different photopigment with its own characteristic absorption spectrum.
- Diagram shows some cones are more sensitive to short wavelengths, some to medium and some to long.
- 3 cones are red, green, & blue.

Relative Absorption

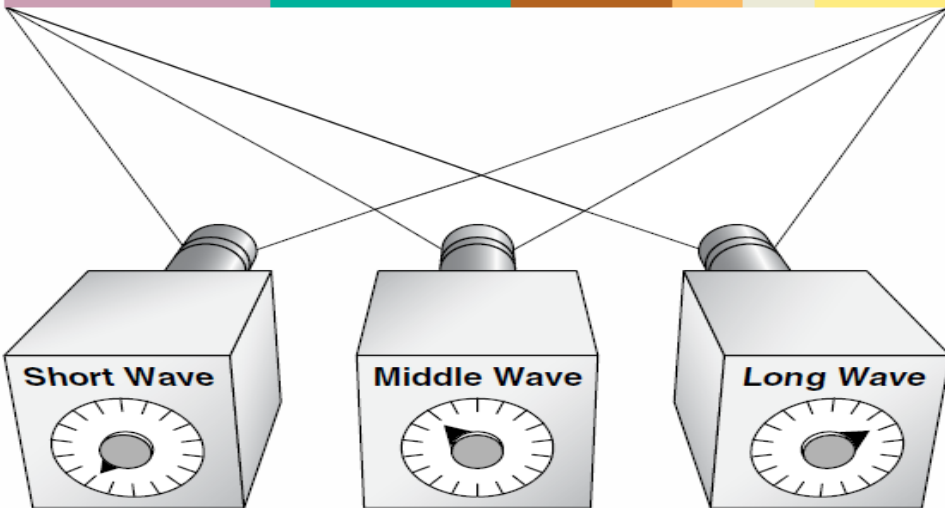
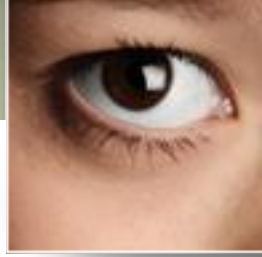


# Color Constancy & the Retinex Theory



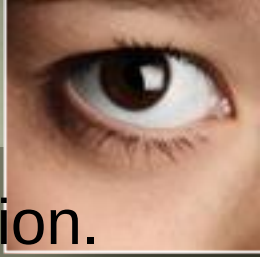
- One aspect the theories could not account for was **Color constancy**: colour perception is not altered by varying reflected wavelengths.
- **Retinex theory** (Land): color determined by proportion of light of different wavelengths that surface reflects
  - Although wavelengths of light reflected by surface change with changes in illumination, efficiency which a surface absorbs wavelength & reflects unabsorbed portion does not change
- Relative wavelengths are constant, so perception is constant
  - Dual-opponent colour cells are sensitive to colour contrast
  - Found in cortical “blobs”, the peg-like dual-opponent colour columns in the primary visual cortex

# Color Constancy and the Retinex Theory

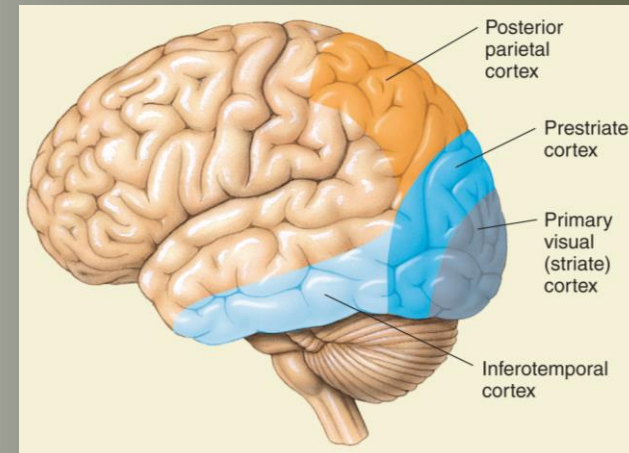


- **Method of Land's (1977) color-vision experiments:**
- **Ps viewed Mondrians illuminated by various proportions of three different wavelengths from projectors:**
  - short wavelength,
  - middle wavelength, and
  - long wavelength.
- **Adjusting amount of light emitted from each projector (therefore adjusting amount of light of each wavelength) had no effect on the perception of the colours on the Mondrian display.**

# Cortical Mechanisms of Vision and Conscious Awareness



- Occipital & areas of temporal cortex also involved in vision.
- Visual cortex is of 3 different types:
  1. Primary visual cortex (striate): receives input from visual relay nuclei of thalamus & located in posterior region of occipital lobe,
  2. Secondary visual cortex: receives input from primary visual cortex & located in pre-striate & inferotemporal cortex,
  3. Association cortex: receives input from secondary visual cortex & located in several parts of cerebral cortex but mainly in posterior parietal cortex.
- As information flows up visual hierarchy the neurons have larger receptive fields and the stimuli to which neurons respond are more specific and complex.



**The visual areas of the human cerebral cortex.**

# Damage to Primary Visual Cortex



## Scotomas

- Areas of blindness in contralateral visual field due to damage to primary visual cortex
- Detected by perimetry test

## Completion

- Patients may be unaware of scotoma – missing details supplied by “completion”



Lashley's scotoma



What Lashley saw

The completion of a migraine-induced scotoma as described by Karl Lashley (1941).

# Damage to Primary Visual Cortex



**Blindsight:** Another phenomenon displayed by patients with scotomas from damage to the primary visual cortex

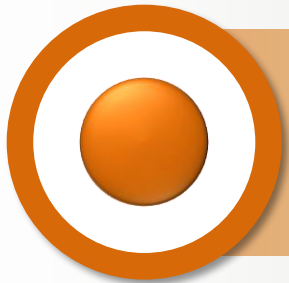
- Respond to visual stimuli but not consciously aware of “seeing”.
- Two neurological interpretations:
  1. Striate cortex not completely destroyed & remaining islands of functional cells capable of mediating visual abilities in the absence of conscious awareness.
  2. Visual pathways that ascend directly to secondary visual cortex from subcortical visual structures without passing through primary visual cortex are capable of maintaining some visual ability in the absence of cognitive awareness.
- Evidence for both but not enough conclusive evidence for one over other & perhaps a mechanism that involves both.

# Functional Areas of Secondary and Association Visual Cortex



Neurons in each area respond to different visual cues, such as color, movement, or shape

Lesions of each area results in specific deficits

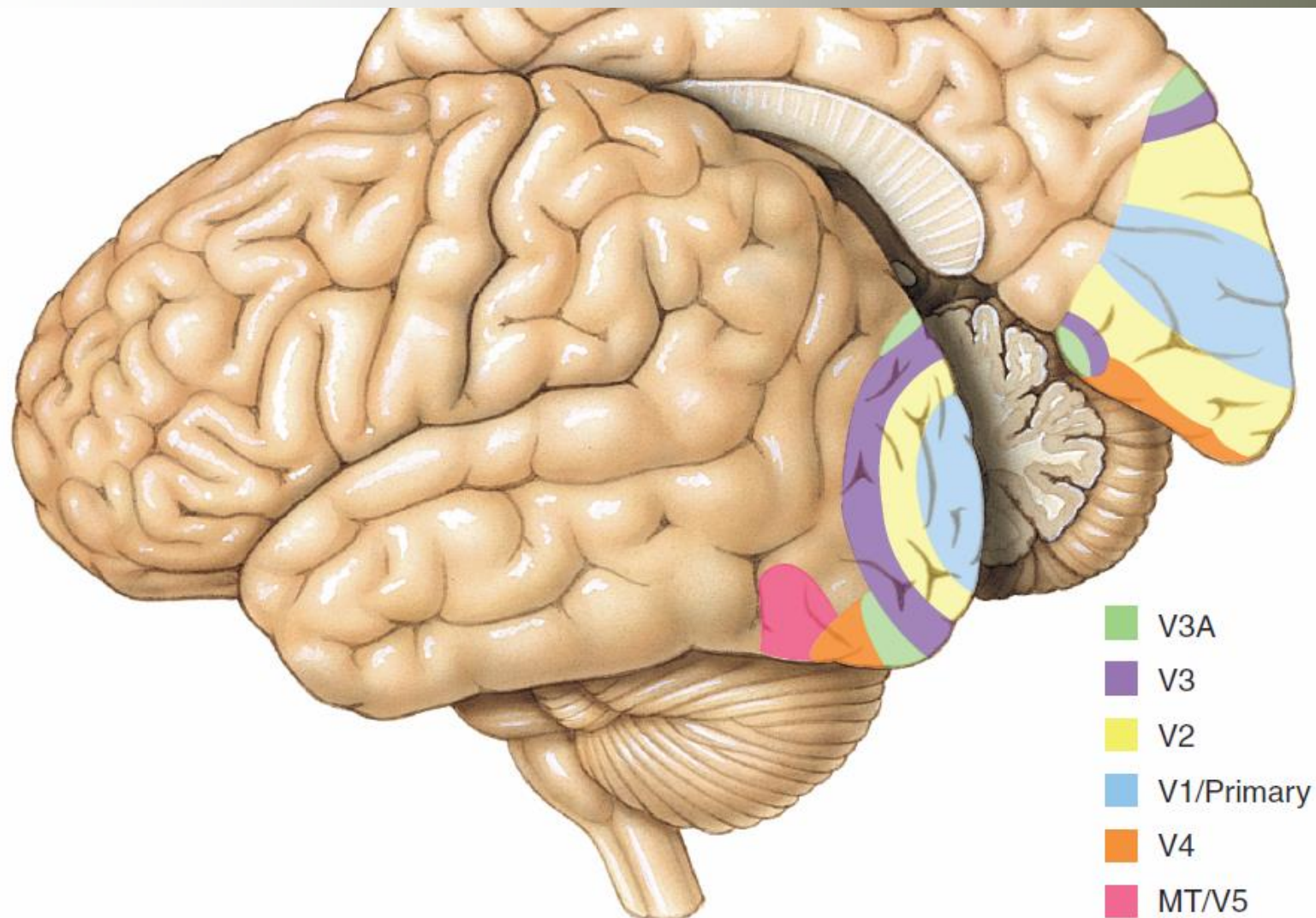


Anatomically distinct (about 12 functionally distinct areas identified so far)

Retinotopically organized



# Functional Areas of Secondary and Association Visual Cortex



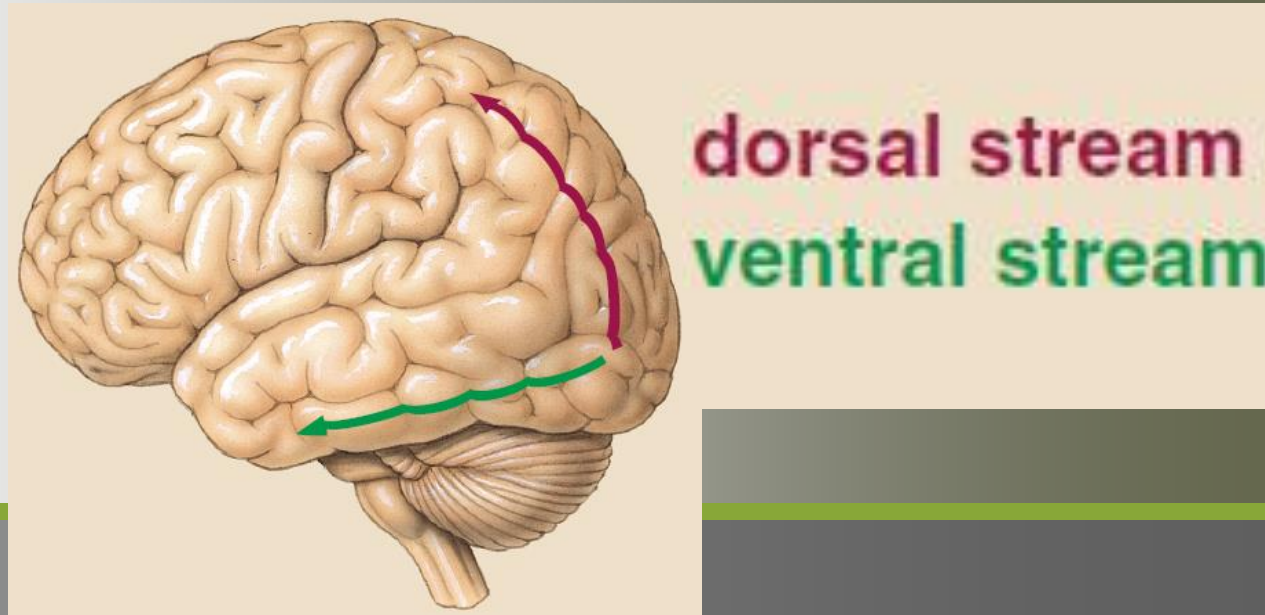
Some of the visual areas that have been identified in the human brain.

# Dorsal and Ventral Streams

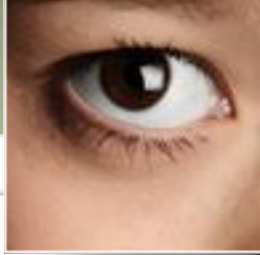


- Most visual info enters V1 via lateral geniculate nuclei: LGN
- Info from the two LGNs is received in V1 combined.
- Then separated to various functional areas of secondary & association cortex (See Horton & Sincich, 2004).

- Dorsal stream
- Ventral stream



# Dorsal and Ventral Streams



## **Dorsal Stream:**

pathway from primary visual cortex to the dorsal prestriate cortex & posterior parietal cortex.

- The “where” pathway (location and movement),  
or
- The pathway for control of behavior (e.g., reaching)

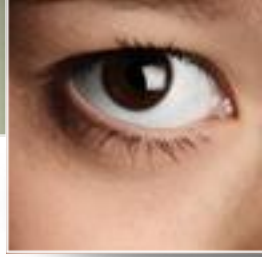
## **Ventral Stream:**

pathway from primary visual cortex to ventral prestriate cortex & inferotemporal cortex

- The “what” pathway (color and shape),  
or
- The pathway for conscious perception of objects

**“Where” vs. “What” Theory – Ungerleider and Mishkin (1982)**

# Dorsal and Ventral Streams



## Evidence for “Where” vs. “What” theory...

- Damage to some areas of cortex may abolish certain aspects of vision while leaving others unaffected.
- Patients with damage to posterior parietal cortex have difficulty accurately reaching for objects but are able to describe them well.
- Patients with damage to inferotemporal cortex have no difficulty reaching for objects but cannot describe them.
- See Ungerleider and Haxby (1994)

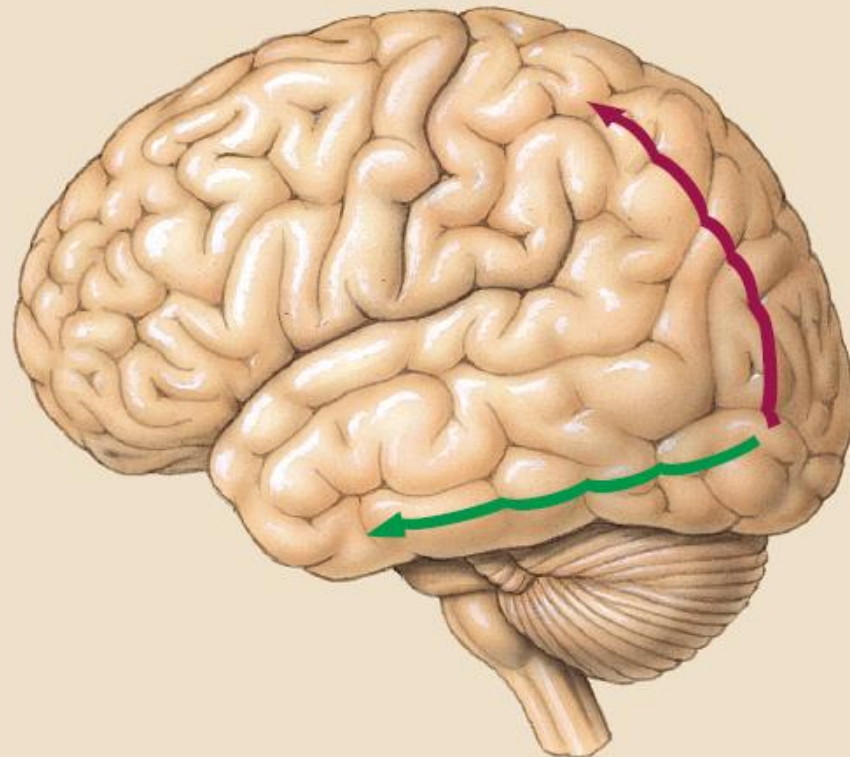
“Where” vs. “What” Theory – Ungerleider and Mishkin (1982)

# Dorsal and Ventral Streams



- Instead of seeing these as “where” & “what” pathways,
- Goodale & Milner (1992): difference is not in the kinds of info they carry but in the use that the information is put to.
- Dorsal function: direct behaviour interactions with object
- Ventral function: mediate conscious perception of objects
- “Control of behavior” vs. “conscious perception” theory.

## Dorsal and Ventral Streams: Two Theories and What They Predict



### “Where” vs. “What” Theory

**Dorsal stream** specializes in visual spatial perception

**Ventral stream** specializes in visual pattern recognition

#### *Predicts*

- Damage to **dorsal stream** disrupts visual spatial perception
- Damage to **ventral stream** disrupts visual pattern recognition

### “Control of Behavior” vs. “Conscious Perception” Theory

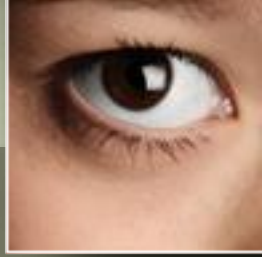
**Dorsal stream** specializes in visually guided behavior

**Ventral stream** specializes in conscious visual perception

#### *Predicts*

- Damage to **dorsal stream** disrupts visually guided behavior but not conscious visual perception
- Damage to **ventral stream** disrupts conscious visual perception but not visually guided behavior

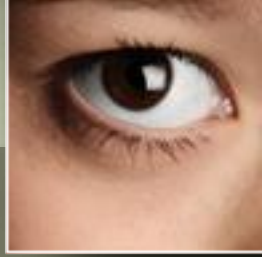
# Dorsal and Ventral Streams



**The “Control of behavior” vs. “conscious perception” theory can explain two major neuropsychological findings that are the foundation of the “What” vs. “Where” theory.....**

- 1. Patients with dorsal stream damage may do poorly on tests of location and movement because these tests involve performance measures.**
- 2. Patients with ventral stream damage do poorly on tests of visual recognition because they involve verbal, and thus conscious awareness.**

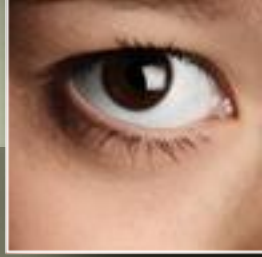
# Dorsal and Ventral Streams



## Evidence for “Control of behavior” vs. “conscious perception” theory....

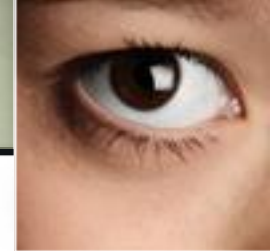
1. Some patients with bilateral lesions to the ventral stream have no conscious experience of seeing but are able to interact with objects.
  2. Some patients with bilateral lesions to the dorsal stream can consciously see objects but cannot interact with them.
- Goodale (2004): suggests an evolutionary implication
    - The conscious awareness mediated by the ventral stream is what distinguishes humans from evolutionary ancestors.

# Dorsal and Ventral Streams



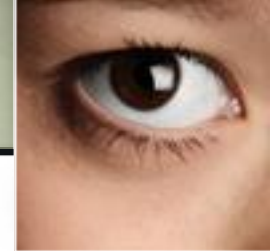
## Evaluation:

- **More research is needed to characterize the functions of the streams.**
- **Also, some suggest that the two streams do not function in isolation from one another (Konen & Kastner, 2008; Nassi & Calloway, 2009).**
- **Thus, future research could focus on how they interact.**



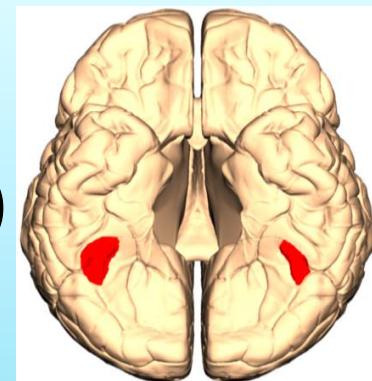
## Prosopagnosia

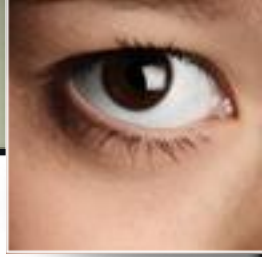
- Inability to distinguish faces – an agnosia for faces.
  - They recognize a face as a face but cannot recognize who it is.
  - They report seeing a jumble of facial parts never fused in a recognizable whole
    - See Stephan & Caine (2009)
- In some cases they cannot recognize themselves.
  - However, some have a general problem recognizing specific objects, not just faces (Behrmann et al., 2005).



## Prosopagnosia

- Associated with damage to the ventral stream between the occipital and temporal lobes:
  - Fusiform face area (FFA).
- Can be caused by brain damage (acquired)
- Or without brain damage (developmental)
- Parts of FFA are selectively activated by human faces (Kanwisher, 2006).
  - However, parts also respond to other visual stimuli.





## Prosopagnosia

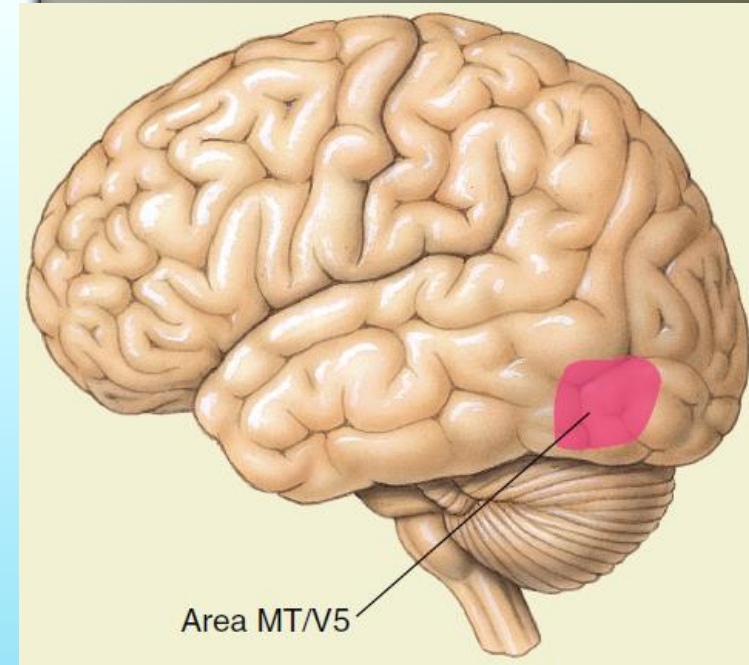
- May recognize faces without conscious awareness
  - Why? Because dorsal-stream function is intact.
- **Tranel & Damasio (1985):**
  - Presented patients with familiar and unfamiliar faces.
  - Patients claimed not to recognize any of the faces.
  - However, they exhibited large skin conductance response when familiar faces presented compared to unfamiliar faces.
  - Suggests faces were being unconsciously recognized by undamaged parts of the brain.
  - See Simon et al. (2011) for similar study on activity levels in FFA for familiar vs. unfamiliar faces.

# Neuropsychological disorders of vision



## Akinetopsia

- Deficiency in the ability to see movement progress in a normal smooth fashion
- Can be induced by a high dose of certain antidepressants
- Associated with damage to the middle temporal (MT) area of the cortex
- MT is also called V5 or MT/V5 because researchers studying the brain in different species use different terminology



# Next Week....



Mechanisms of Perception: Hearing, Touch, Smell, Taste, and Attention.

**Essential Reading...**

Pinel, J.P.J – *Biopsychology*: **Chapter 7**