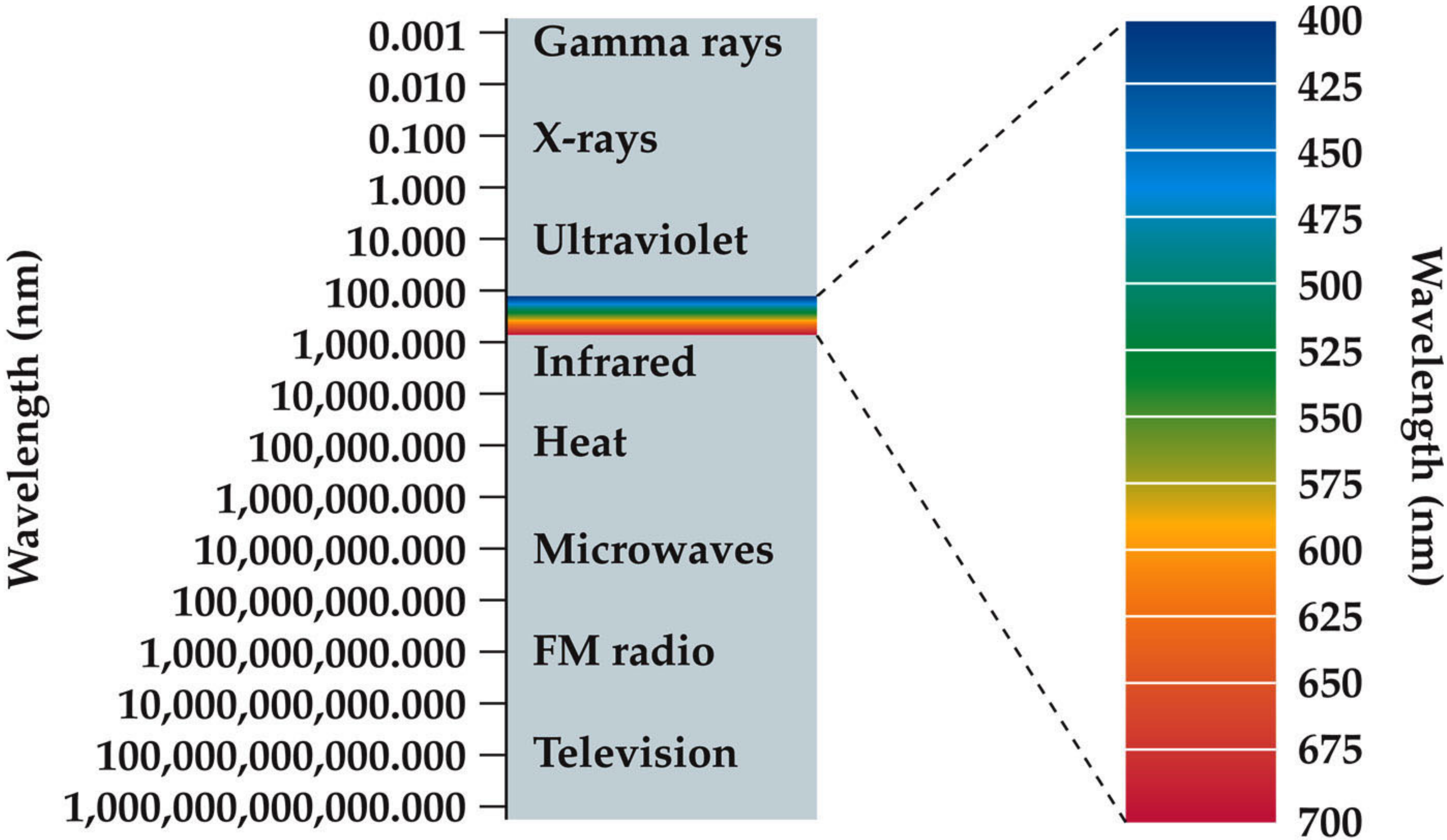
The First Steps in Vision

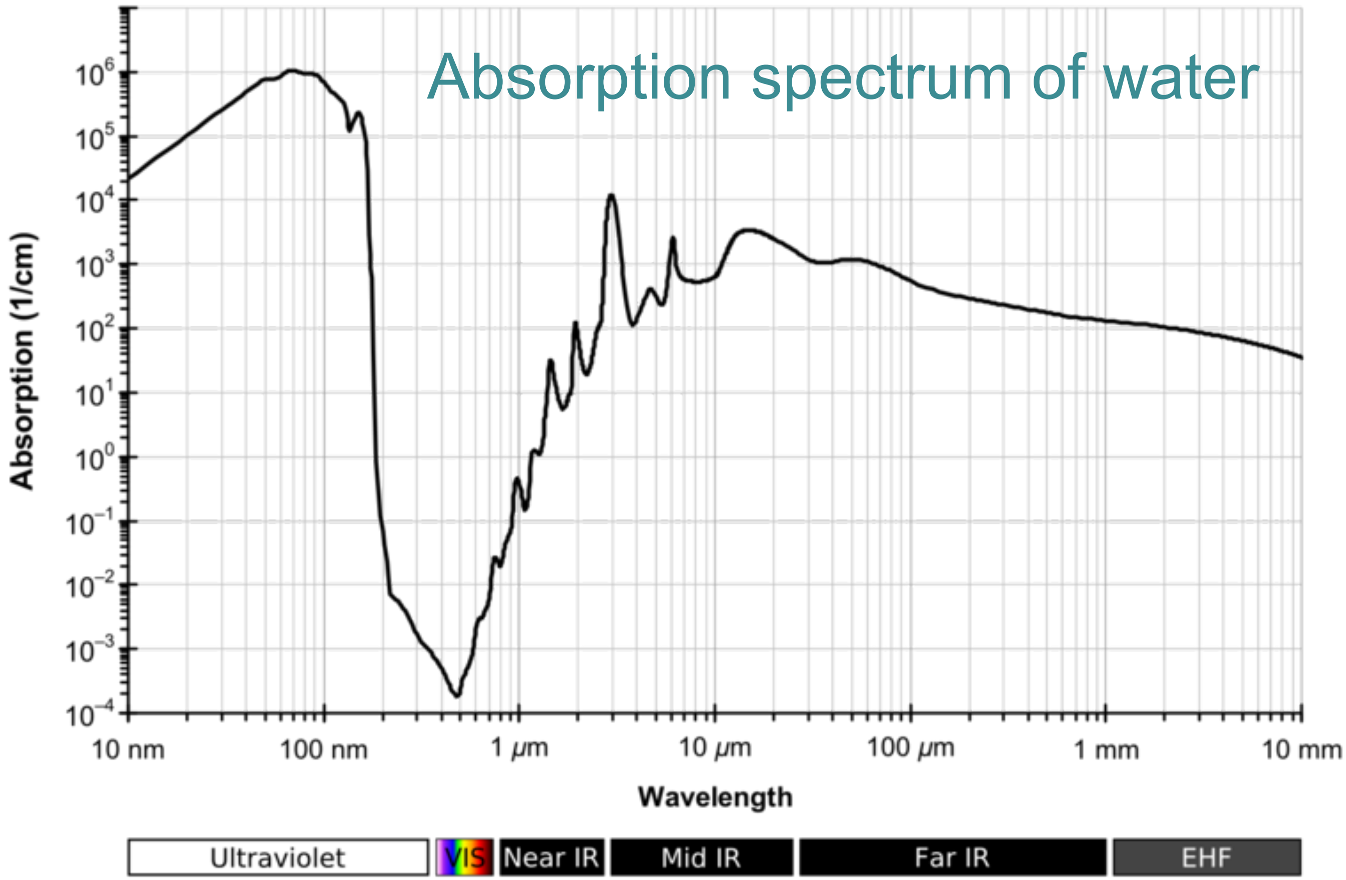
Visible Light: A narrow band of electromagnetic radiation

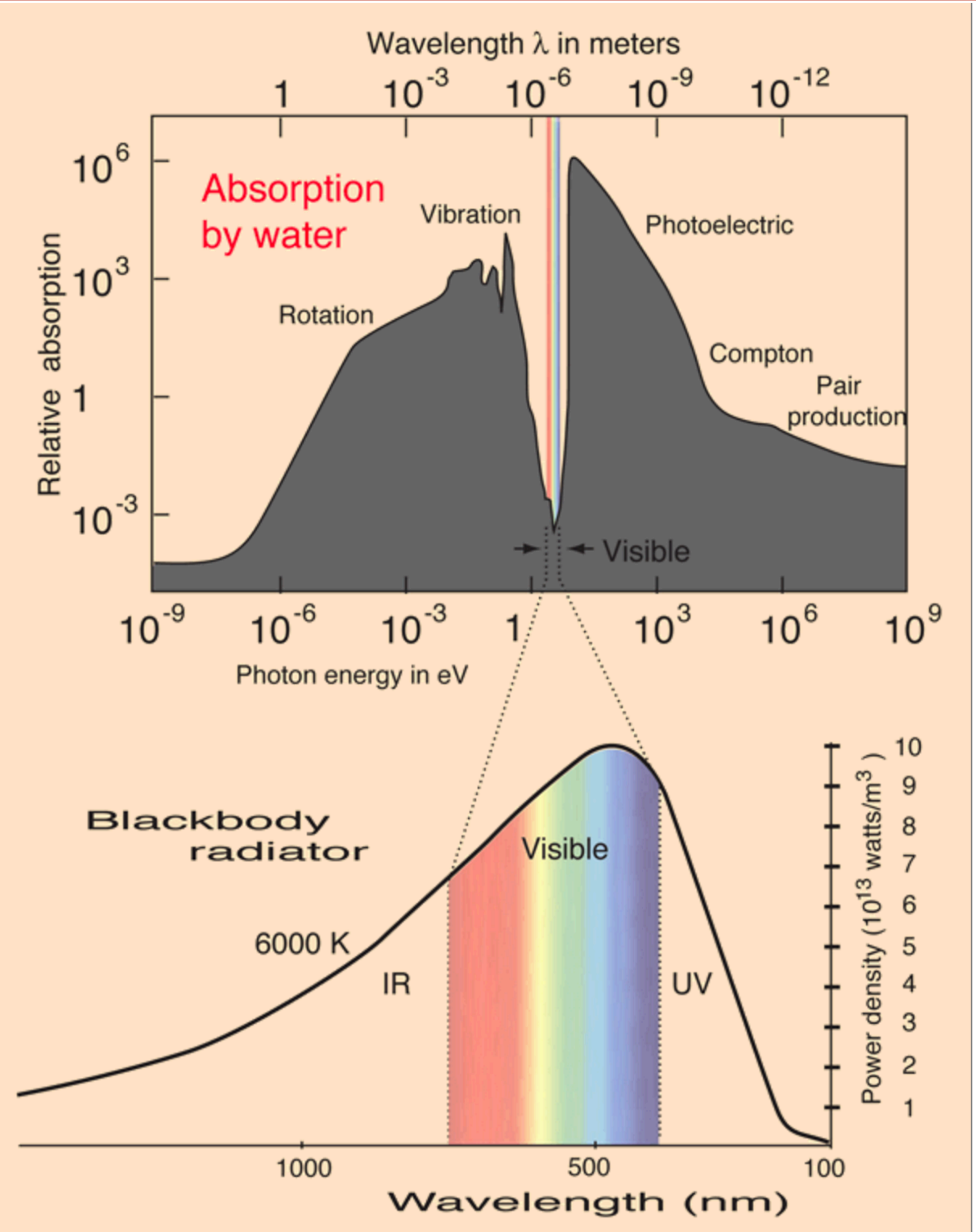


SENSATION & PERCEPTION 3e, Figure 2.1

The spectrum of electromagnetic energy, with the visible spectrum expanded at right

Availability





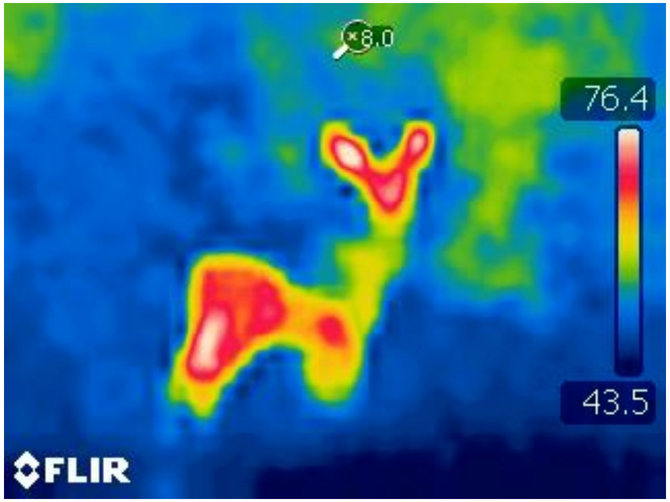
Wavelength λ in meters
1
10^{-3}
10^{-6}
10^{-9}
10^{-12}
Relative absorption
10^{6}
10^{3}
1
10^{-3}
Absorption by water
Vibration
Photoelectric
Rotation
Compton
Pair production
Visible
10^{-9}
10^{-6}
10^{-3}
1
10^{3}
10^{6}
10^{9}
Photon energy in eV
Blackbody radiator
Visible
6000 K
IR
UV
Power density (10^{13} watts/m^3)
10
9
8
7
6
5
4
3
2
1
1000
500
100
Wavelength (nm)

Biosafety

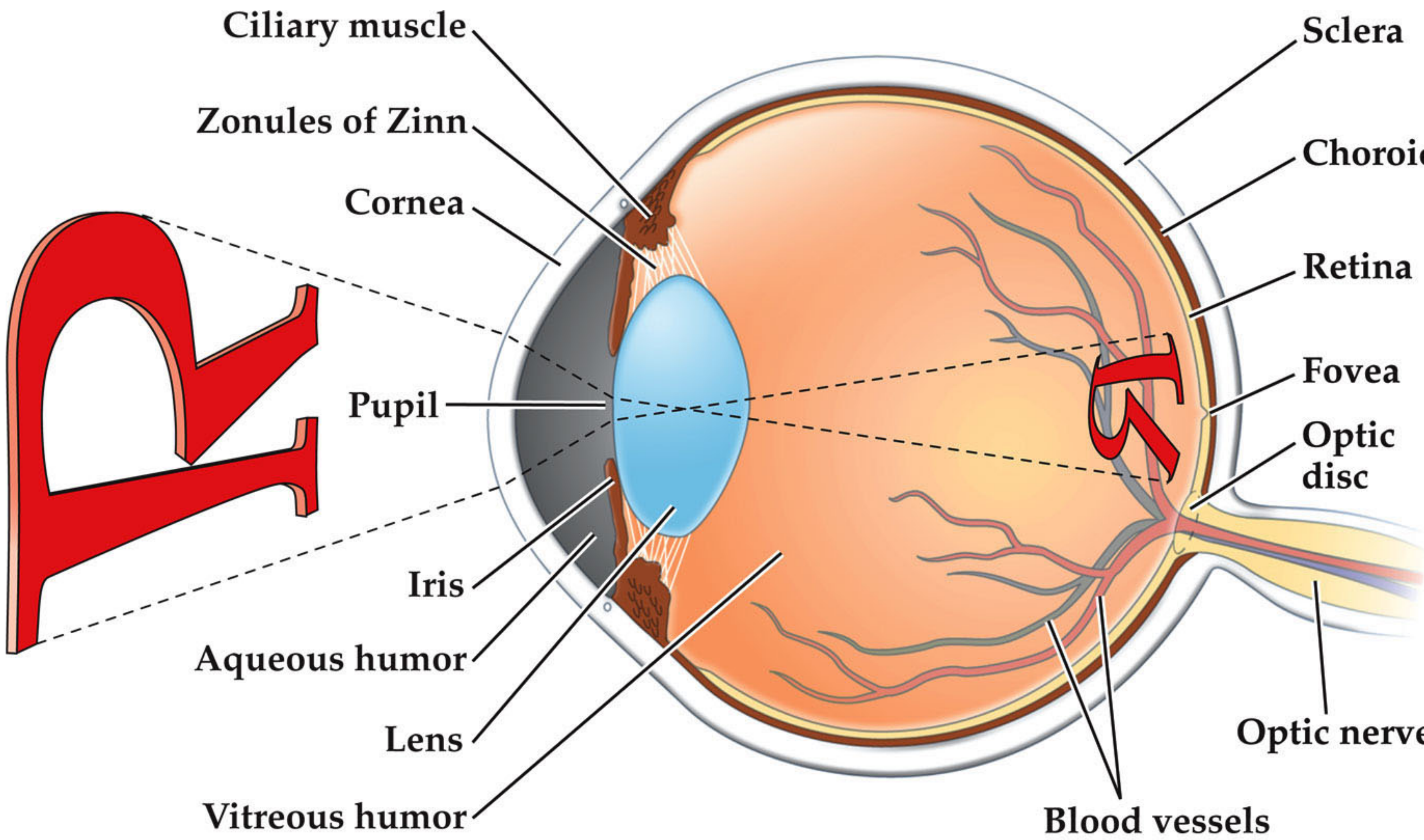
Short-wavelength radiation (X-rays, UV) and some microwaves are harmful for biological tissues.

Resolution

Opting for much longer wavelength radiations would have reduced the resolving power of our visual system

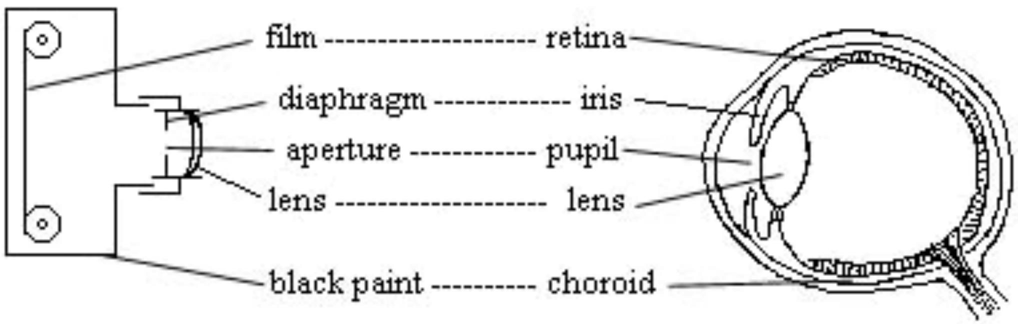


The human right eye in cross section (viewed from above)

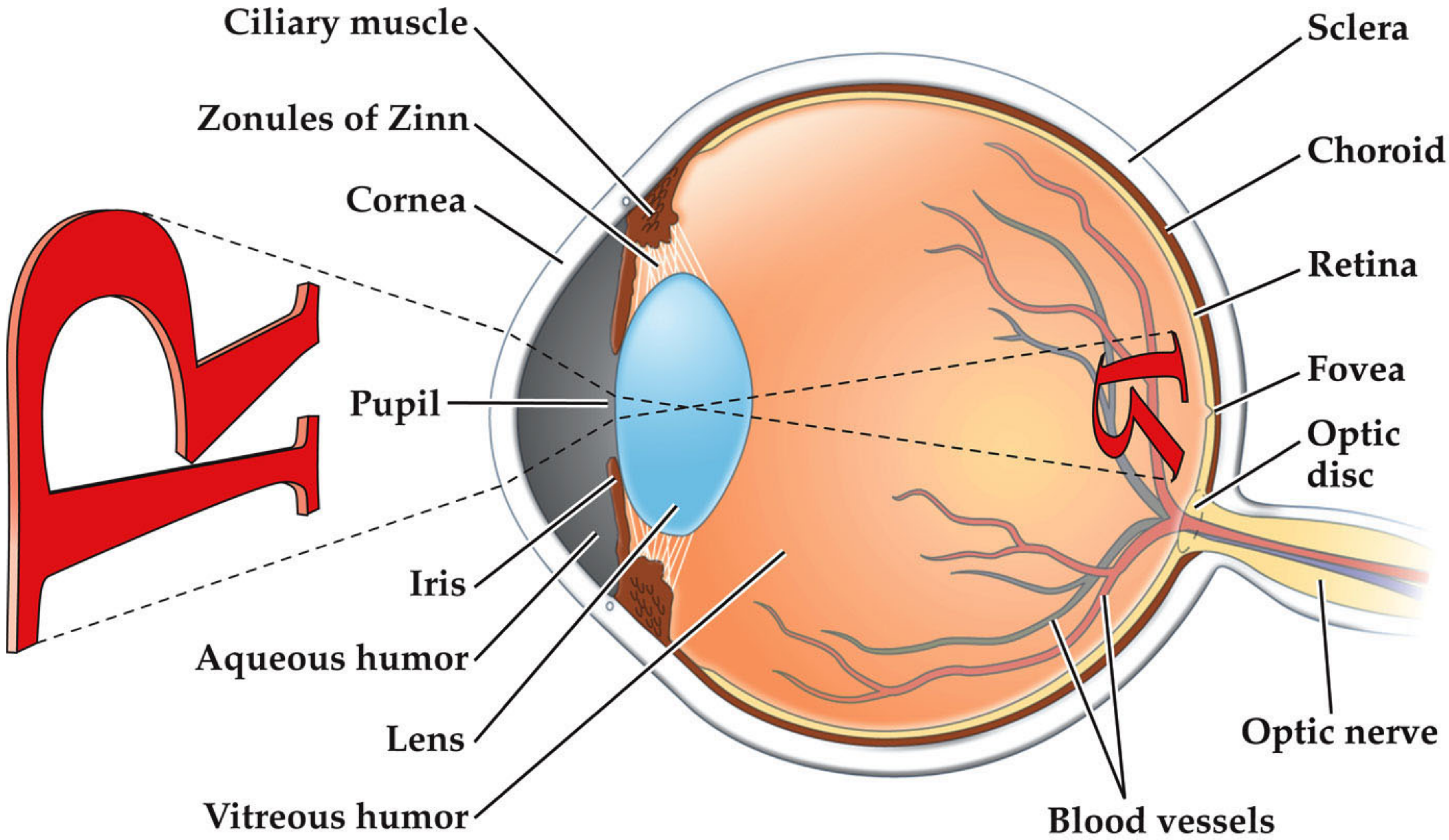


Eyes That See Light

- Camera analogy for the eye
  - F-stop: Iris/pupil. Regulates the amount of light coming into the eye
  - Focus: Lens. Creates image on retina
  - Film: Retina. Records the image

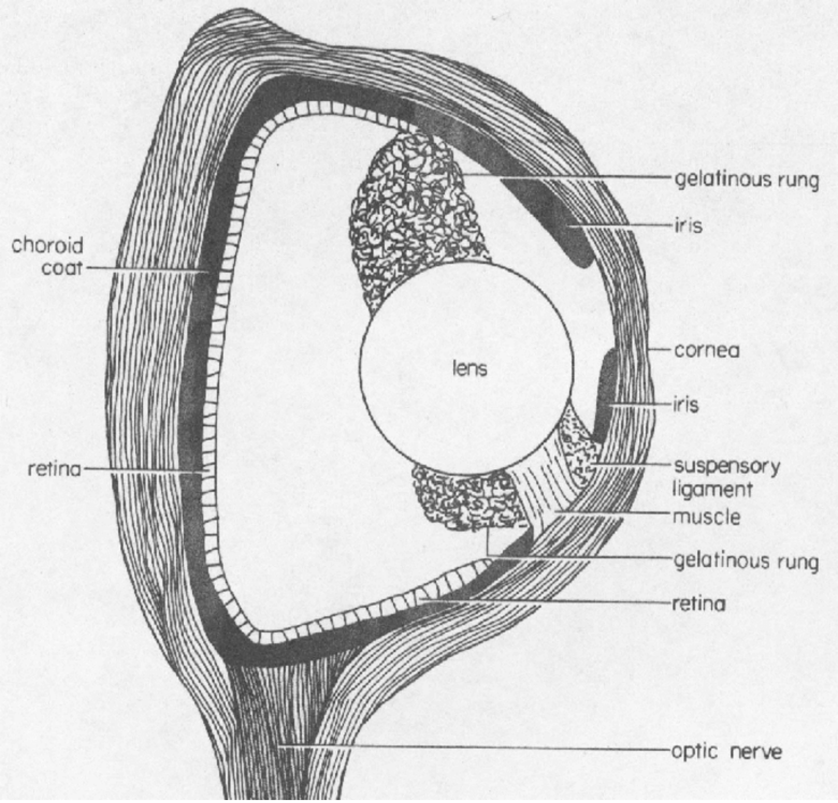


The human right eye in cross section (viewed from above)



Which component of the eye is most responsible for creating an image on the retina?

Why do we have a lens? Why couldn't the cornea have sufficed?



Having a lens is important for a fish.

Why do humans have one?

The lens is the only adjustable refractive element of the human eye.
Accommodation: The process in which the lens changes its shape, thus altering its refractive power

Refractive states of the eye

In the ideal condition, all the refractive elements of the eye create an image right on the retina. This is called emmetropia. Sometimes, however, refractive errors occur…

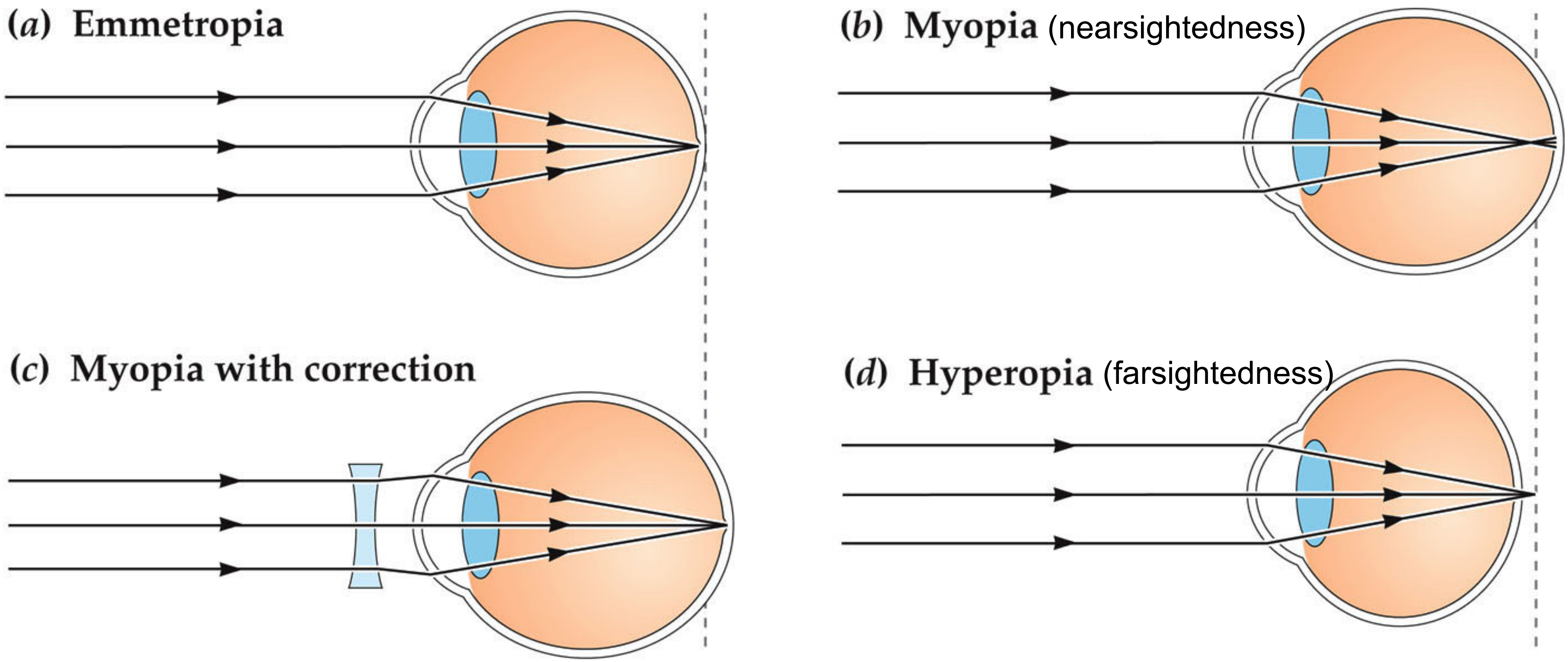
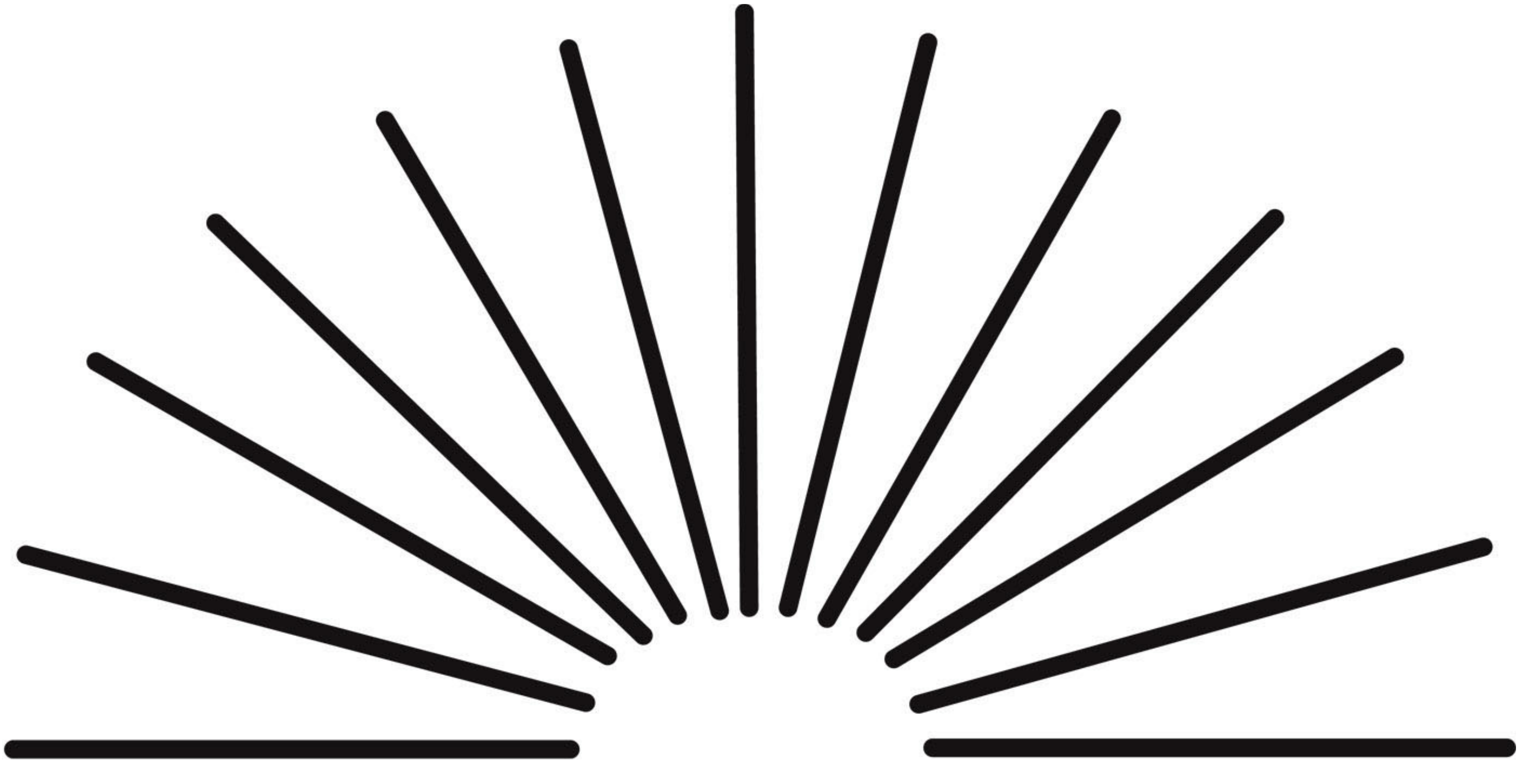


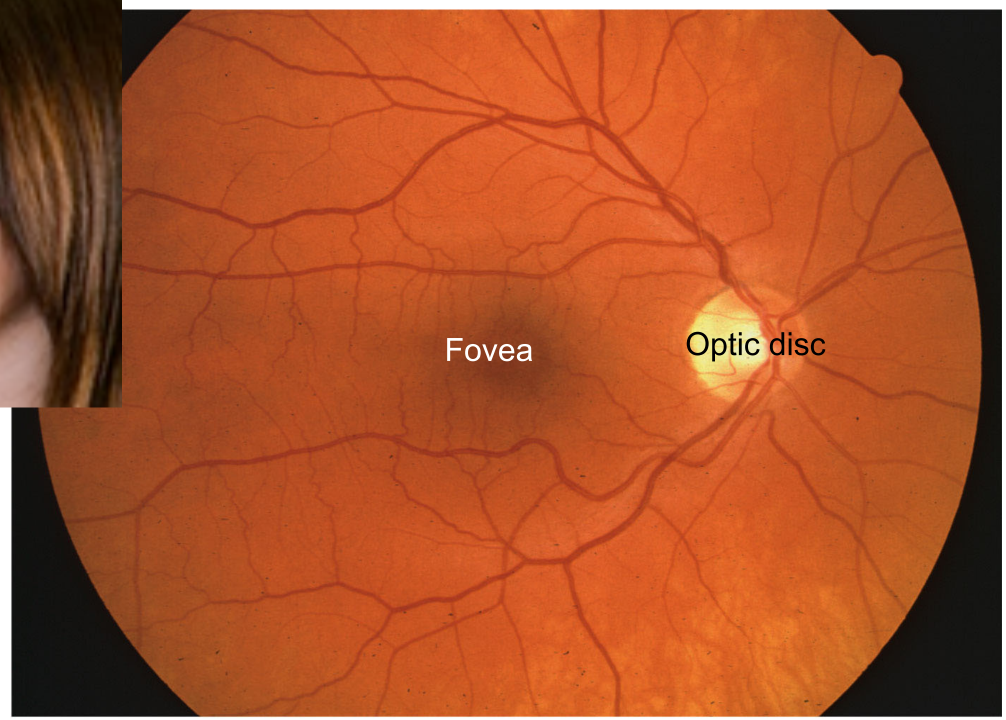
Figure 2.4 Fan chart for astigmatism

Astigmatism: A visual defect caused by the unequal curving of one or more of the refractive surfaces of the eye, usually the cornea



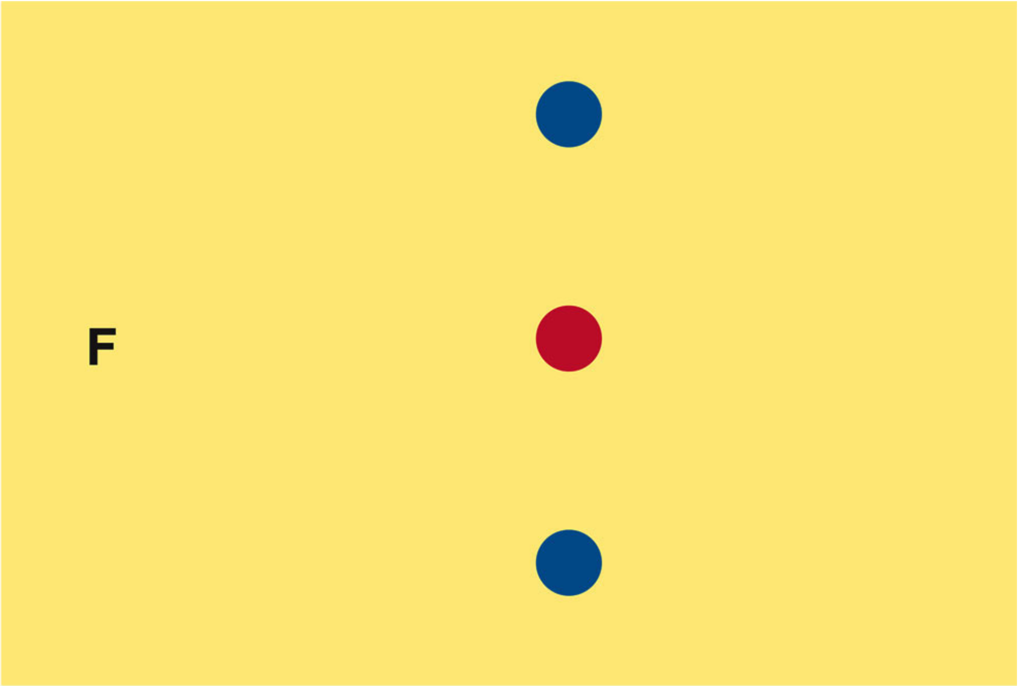
Eye structure

- Using the ophthalmoscope, doctors can view the back surface of patients' eyes, called the *fundus*



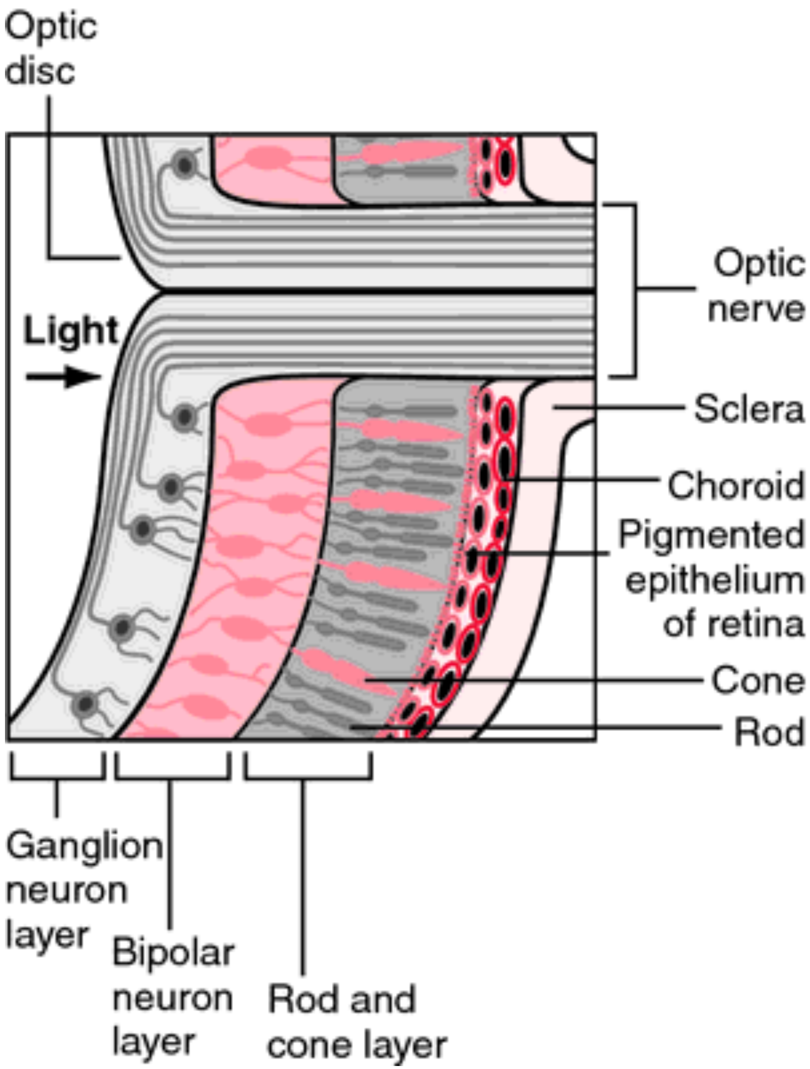
- Blind spot demo

(a)



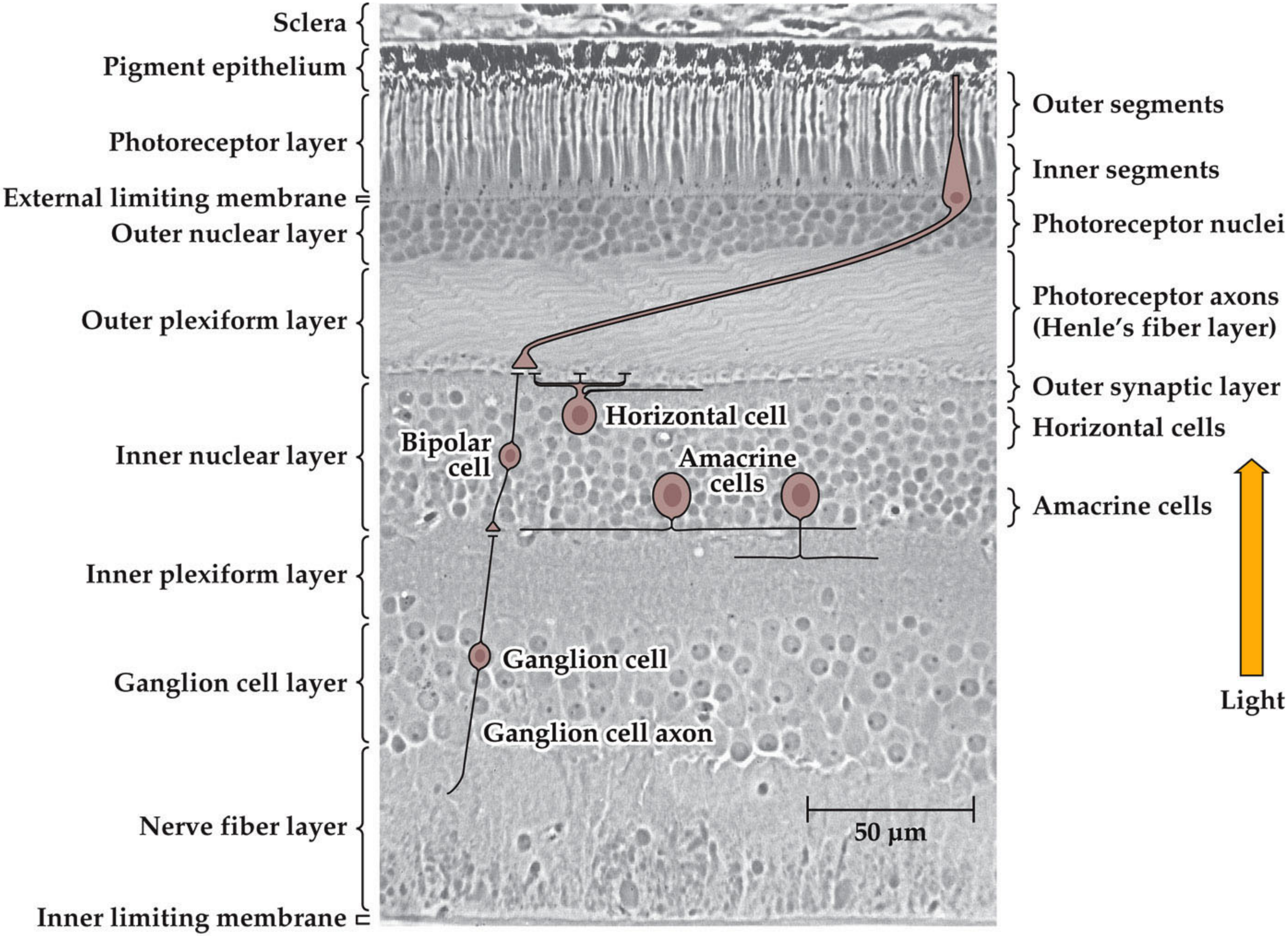
(b)

Retinal Information Processing



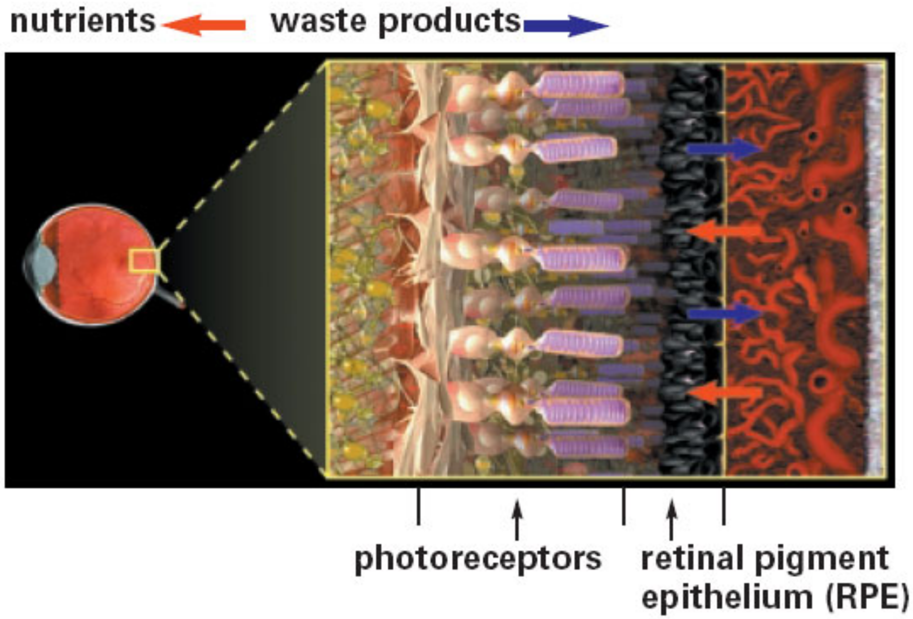
- Light passes through several layers of cells before reaching the rods and cones
  - Light activates a photoreceptor, which then signals the horizontal and bipolar cells that synapse with it
  - Bipolar cells are connected to amacrine and ganglion cells
  - Ganglion cells have axons that leave the retina through the optic disc (blind spot)

Figure 2.7 Photomicrograph of the retina



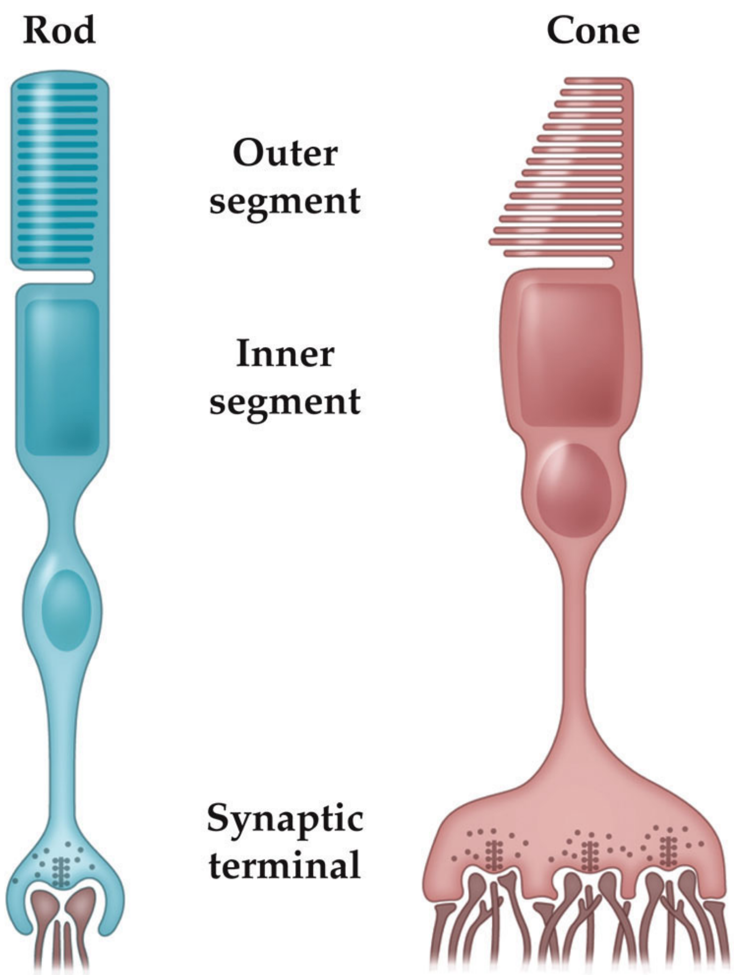
SENSATION & PERCEPTION 3e, Figure 2.7

Retinal Information Processing



- Photoreceptors: Cells in the retina that initially transduce light energy into neural energy
  - Rods: Photoreceptors that are specialized for night vision
    - Respond well in low luminance conditions
    - Do not process color
  - Cones: Photoreceptors that are specialized for daylight vision, fine visual acuity and color
    - Respond best in high luminance conditions

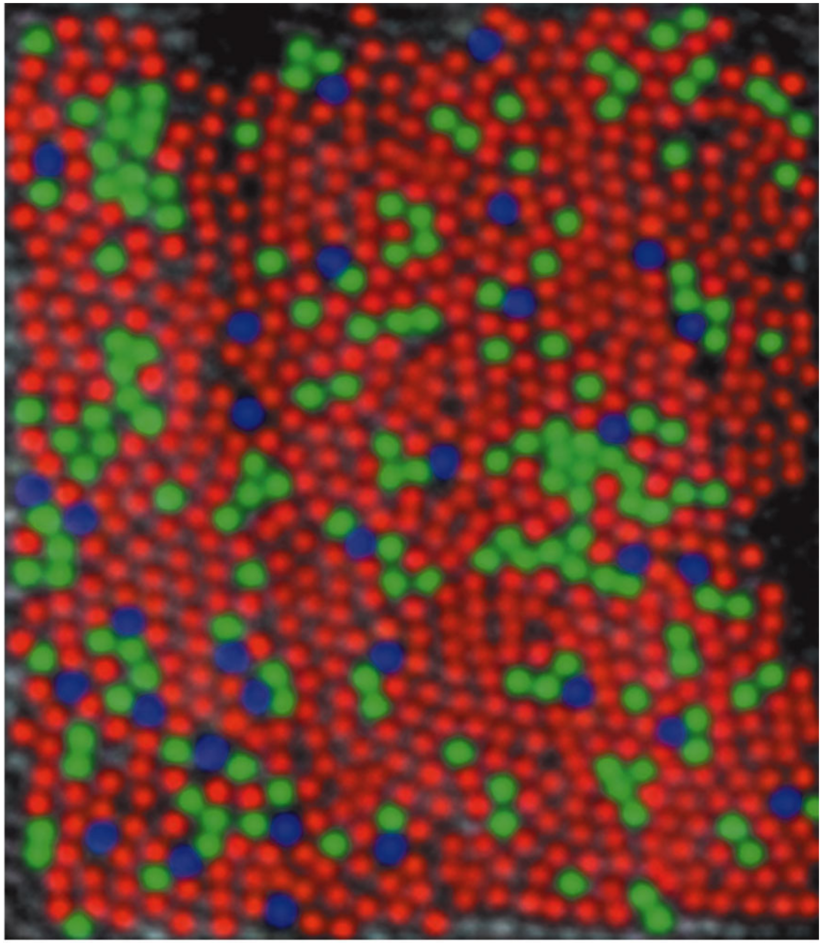
Retinal Information Processing



SENSATION & PERCEPTION 3e, Figure 2.8

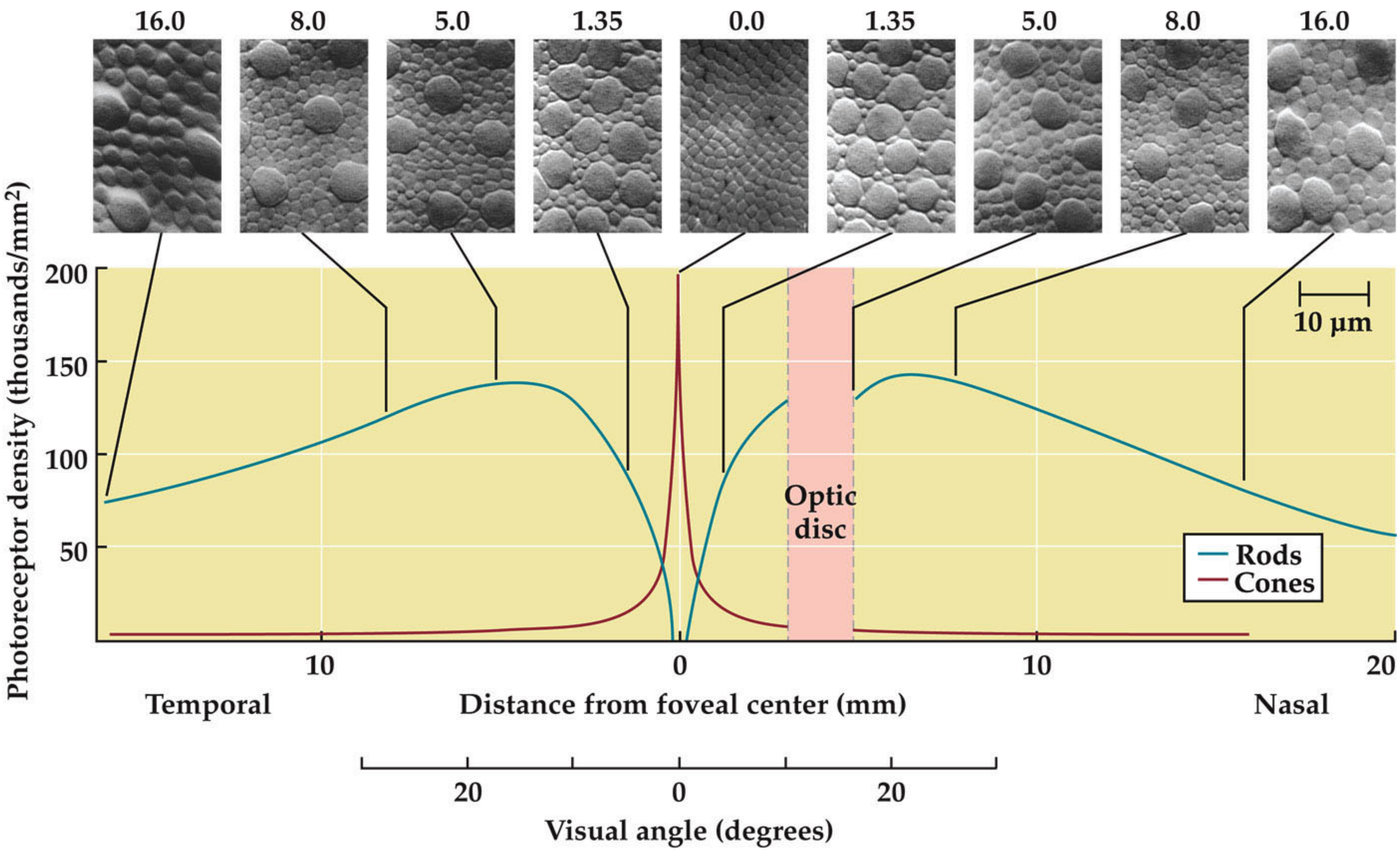
- Rods and cones are so named because of their respective shapes
- Capturing a photon: When light hits a photoreceptor, the process of photoactivation begins
  - Photoreceptors contain an outer segment (adjacent to the pigment epithelium), an inner segment, and a synaptic terminal
  - Visual pigments are manufactured in the inner segment and then stored in the outer segment
  - Pigments contain a protein, called an *opsin*, whose structure determines the wavelength of light to which the photoreceptor responds. Cones come in three ‘flavors’.

Blue, green, and red represent the S-, M-, and L-cones, respectively, of a living human being in a patch of retina at 1 degree from the fovea



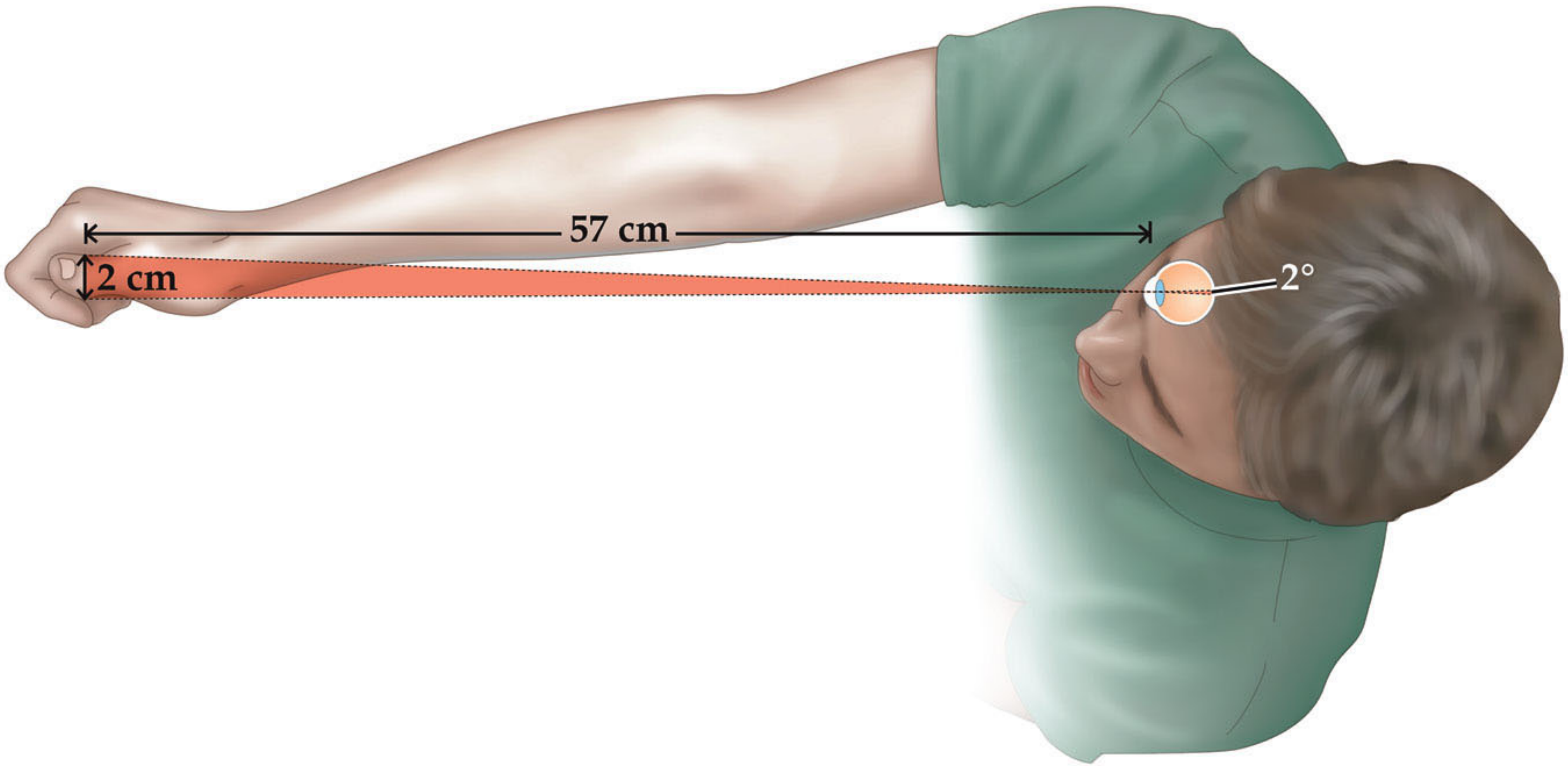
Not all patches of retina look like this. Photoreceptor distribution across the retina is very inhomogeneous

Photoreceptor distribution across the retina is very inhomogeneous



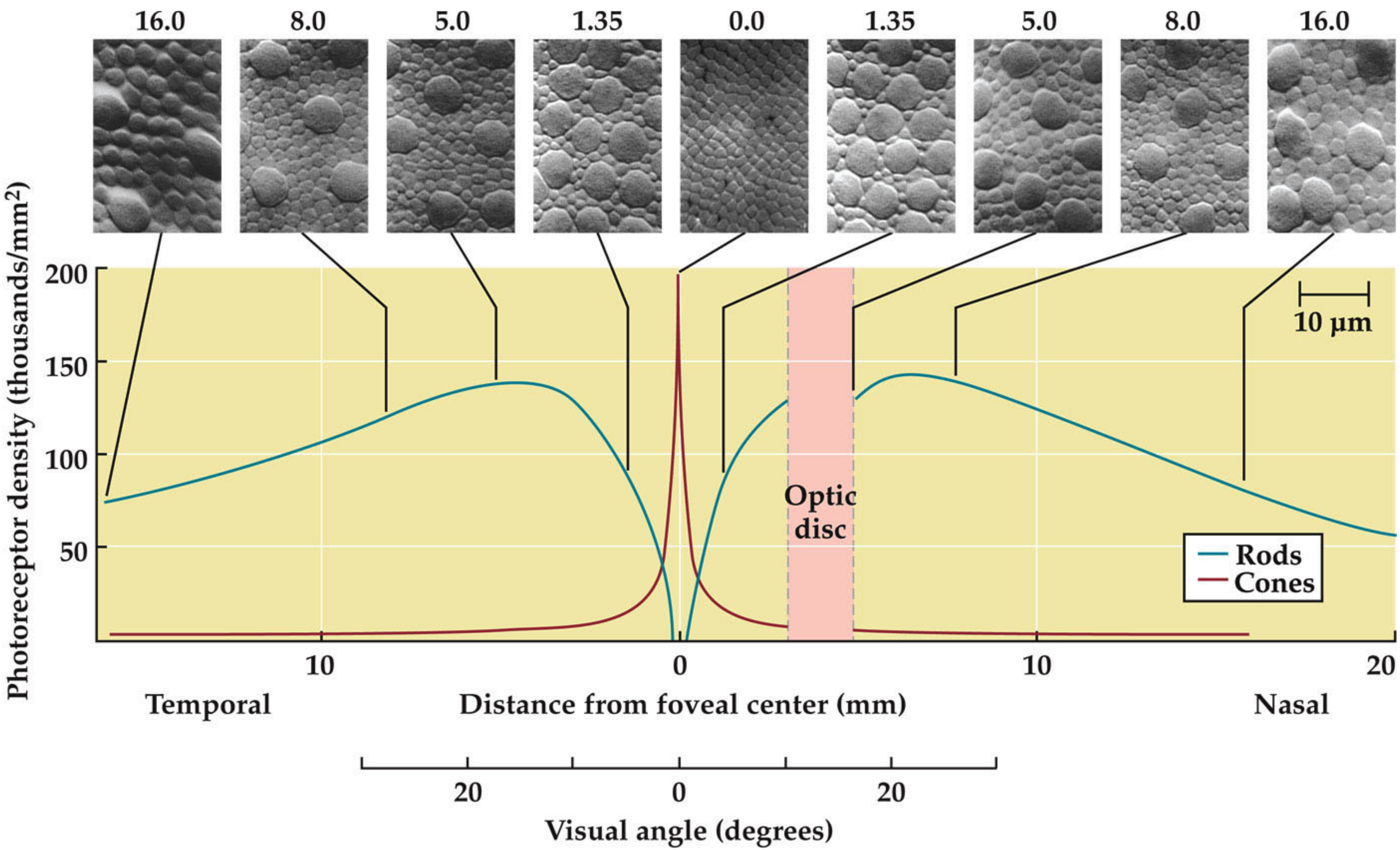
How big is the foveal (cone only) zone?

The “rule of thumb”



If you hold your thumb out at arms length, the width of your thumbnail is about 2 degrees of visual angle. This is the extent of the fovea.

Photoreceptor distribution across the retina is very inhomogeneous



How do we have the percept of ‘pan-field’ color?

Spectral sensitivity of the human eye

The relative efficiency of detection of light or other signal, as a function of the frequency or wavelength of the signal

Two types of retinal photo-receptors exist - cones and rods. Spectral sensitivity of eye is influenced by light intensity. Sensitivity to individual colors, in other words, wavelengths of the light spectrum, is explained by the RGB (red-green-blue) theory

Retinal photo-receptors

Cones cell

Cone-like shape at one end where a pigment filters incoming light

These cells concentrated in the center of the retina

Responding to bright-light condition (Photopic vision)

Responsible for perception of color

There are 3 cone types.

Long-wavelengths sensitive (L) - pigment erythrolabe. maximum sensitivity for red (max 564 nm)

Mid-wavelengths sensitive (M) - pigment chlorolabe. maximum sensitivity for green (max 533 nm)

Short-wavelengths sensitive (S) - pigment cyanolabe. maximum sensitivity for blue (max 437 nm)

Spectral sensitivity of the human eye

Rod cell

Narrower, characteristic shape

Sensitive enough to respond to a single photon of light (about 100 times more sensitive to a single photon than cones)

Responding to low-intensity light condition (Scotopic vision)

Visible spectrum

Visible spectrum means sensitivity of cones & rods. It varies with the wavelength. Wavelength ranges between 380 nm and 800 nm.

Spectral sensitivity of eye

Spectral sensitivity of eye is influenced by light intensity. And the light intensity determines the level of activity of cones cell and rod cell. And it can be determine the main characteristic of human vision.

Sensitivity to individual colors, in other words, wavelengths of the light spectrum, is explained by the RGB (red-green-blue) theory. This theory assumed that there are three kinds of cones. It's selectively sensitive to red (700-630 nm), green (560-500 nm), and blue (490-450 nm) light. And their mutual interaction allow to perceive all colors of the spectrum.

Sensitivity of human eye

Sensitivity of human eyes to light increase with the decrease in light intensity.

In day-light condition, the cones cell is responding to this condition. And the eye is most sensitive at 555 nm.

In darkness condition, the rod cell is responding to this condition. And the eye is most sensitive at 507 nm.

As light intensity decreases, cone function changes more effective way. And when decrease the light intensity, it prompt to accumulation of rhodopsin. Furthermore, in activates rods, it allow to respond to stimuli of light in much lower intensity.

Tangent 1: Explaining pan-field color

VISUAL COGNITION, 2007, 15 (7), 765–778

Psychology Press
Taylor & Francis Group

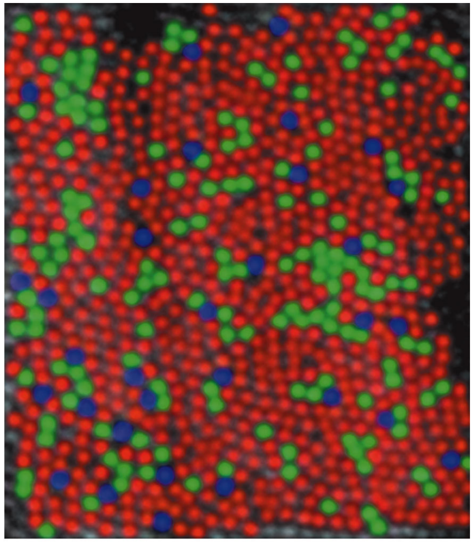
"Filling-in" colour in natural scenes

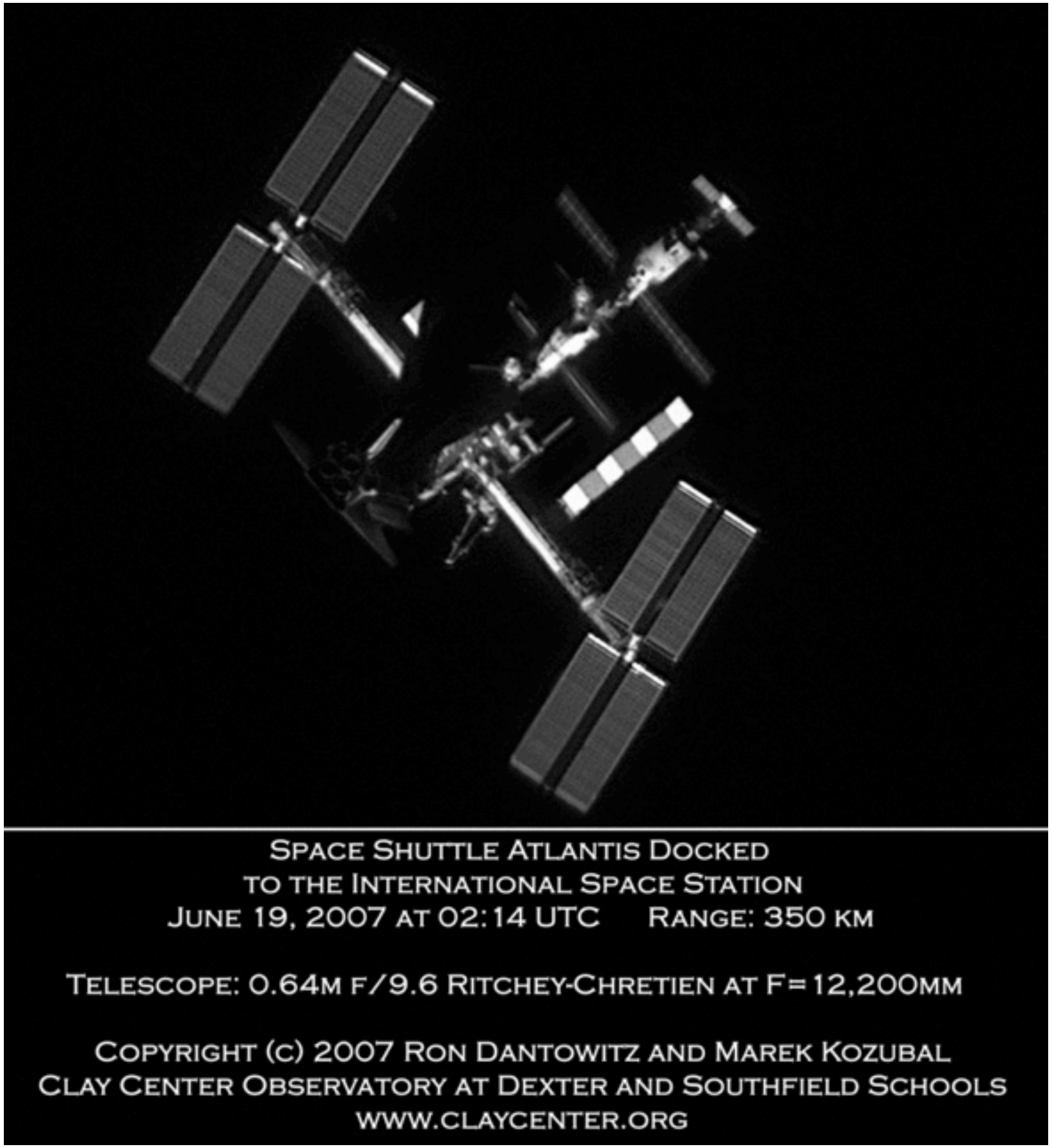
Benjamin Balas and Pawan Sinha

Department of Brain and Cognitive Sciences, MIT, Cambridge, MA, USA

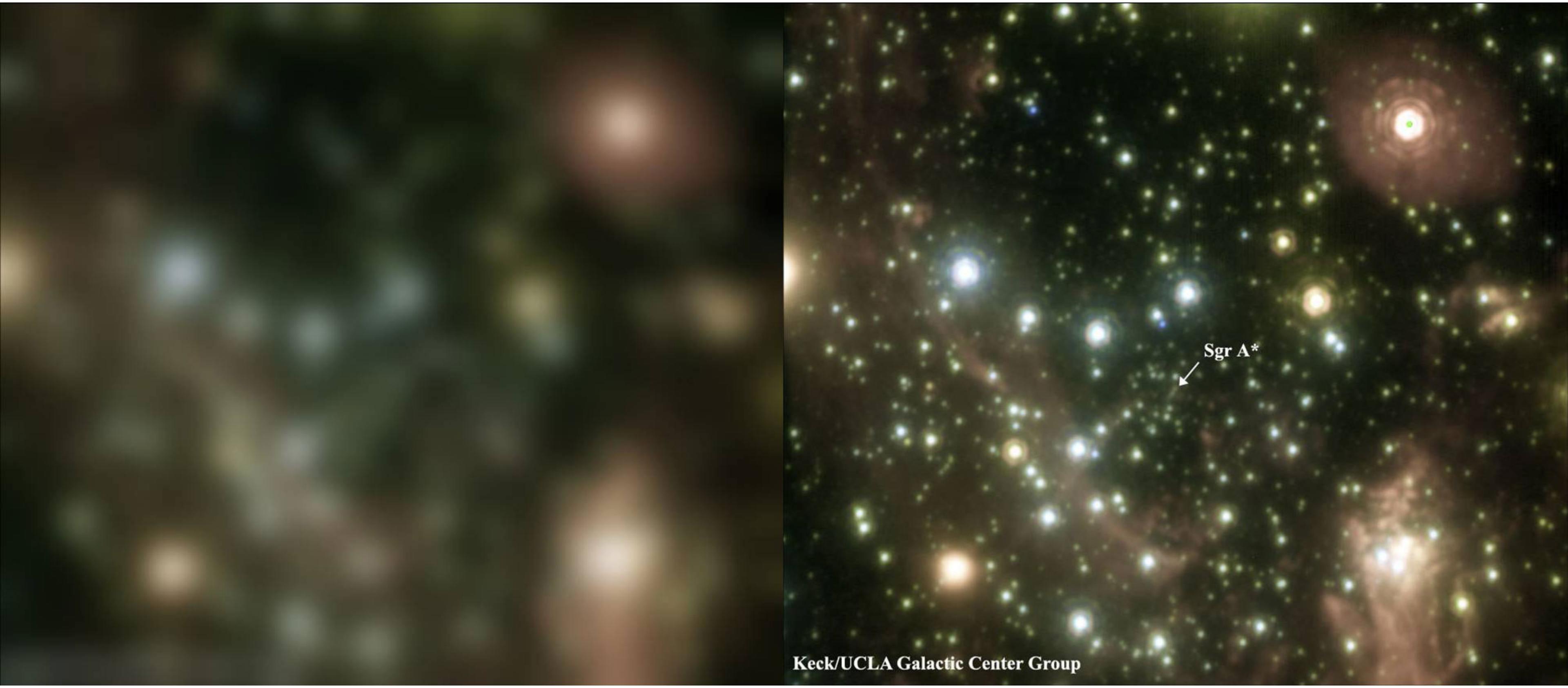
Our subjective experience of the world as being in full colour across the entire visual field is at odds with the highly fovea-biased distribution of cones in the retina. It is unclear how this percept of "pan-field colour" comes about. We use novel stimuli—"colour chimeras"—to demonstrate a related visual phenomenon in which observers perceive rich colour throughout images with large achromatic regions. This percept appears to critically depend on natural scene statistics. By separately manipulating chromatic and structural content in such images, we demonstrate that both the spatial distribution of colour and the presence of recognizable scene structure contribute to the experience of pan-field colour in these stimuli. Our results suggest that this percept is unlikely to be due to a low-level colour spreading process. Instead, we suggest that mechanisms dependent on natural scenes' chromatic and luminance statistics provide the basis for the phenomenon.

Tangent 2: How are these retinal images captured?





The miracle of adaptive optics



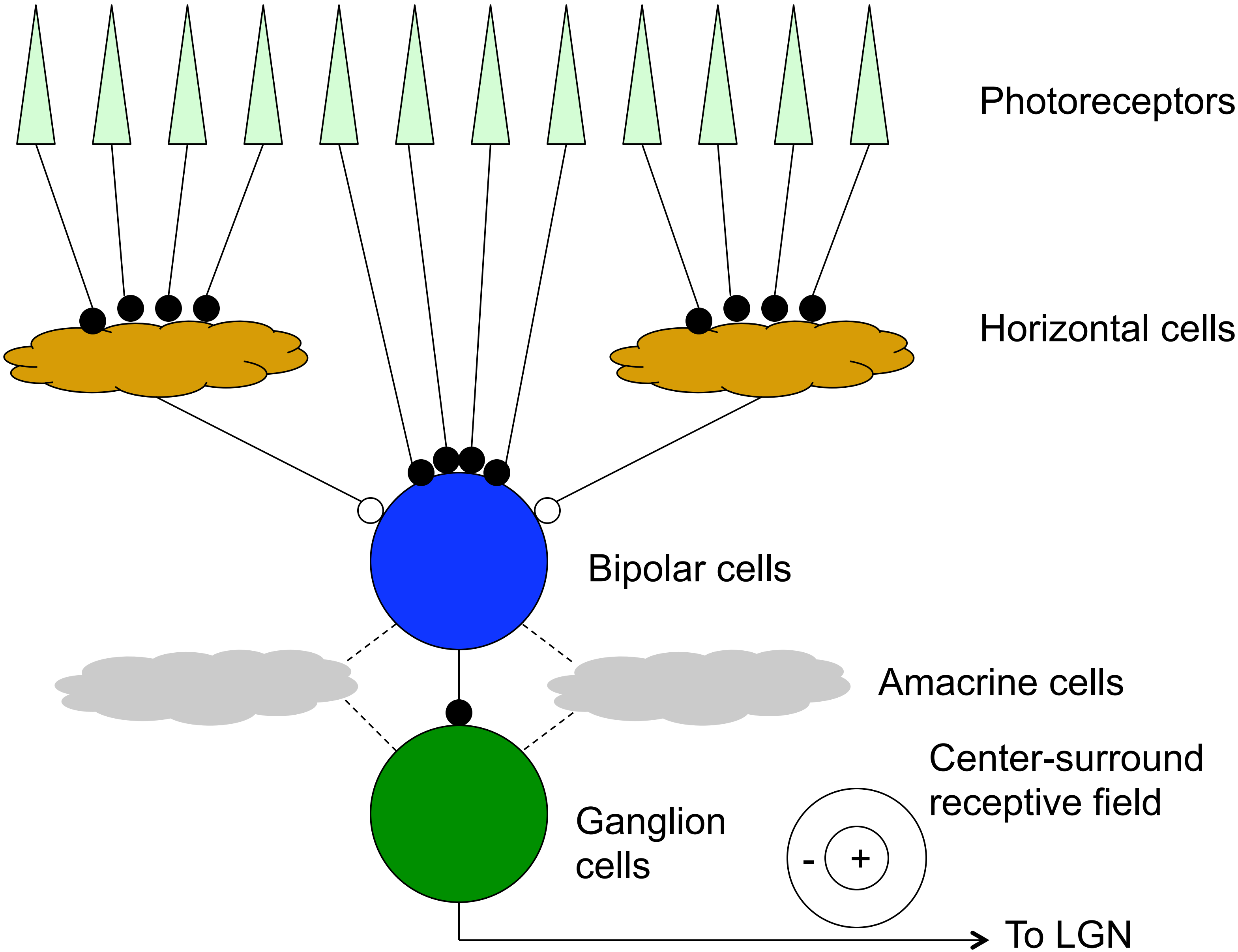
Tangent 3: Recent developments

- A third type of photoreceptor?

Intrinsically photosensitive retinal ganglion cells (ipRGCs)

Clyde Keeler

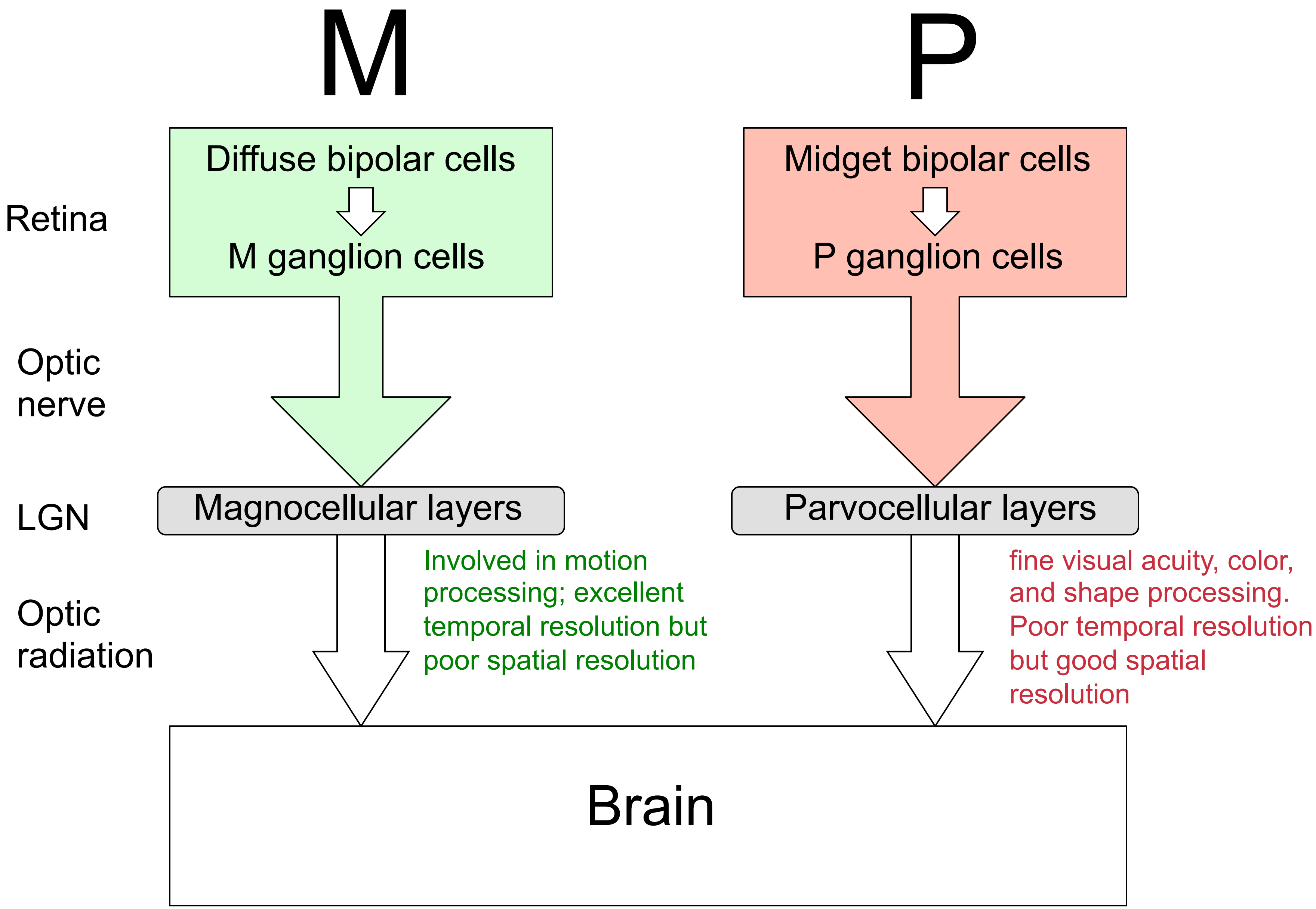
Retinal processing: Beyond the photoreceptors



Retinal processing: Beyond the photoreceptors

- The retina's vertical pathway: Photoreceptors, bipolar cells, and ganglion cells
  - Bipolar cell: A retinal cell that synapses with one or more rods or cones (not both) and with horizontal cells, and then passes the signals on to ganglion cells
    - Diffuse bipolar cell: A bipolar cell that receives input from multiple photoreceptors; connects to M ganglion cells
    - Midget bipolar cell: A small bipolar cell that receives input from a single cone; Connects to P ganglion cells

M and P pathways:

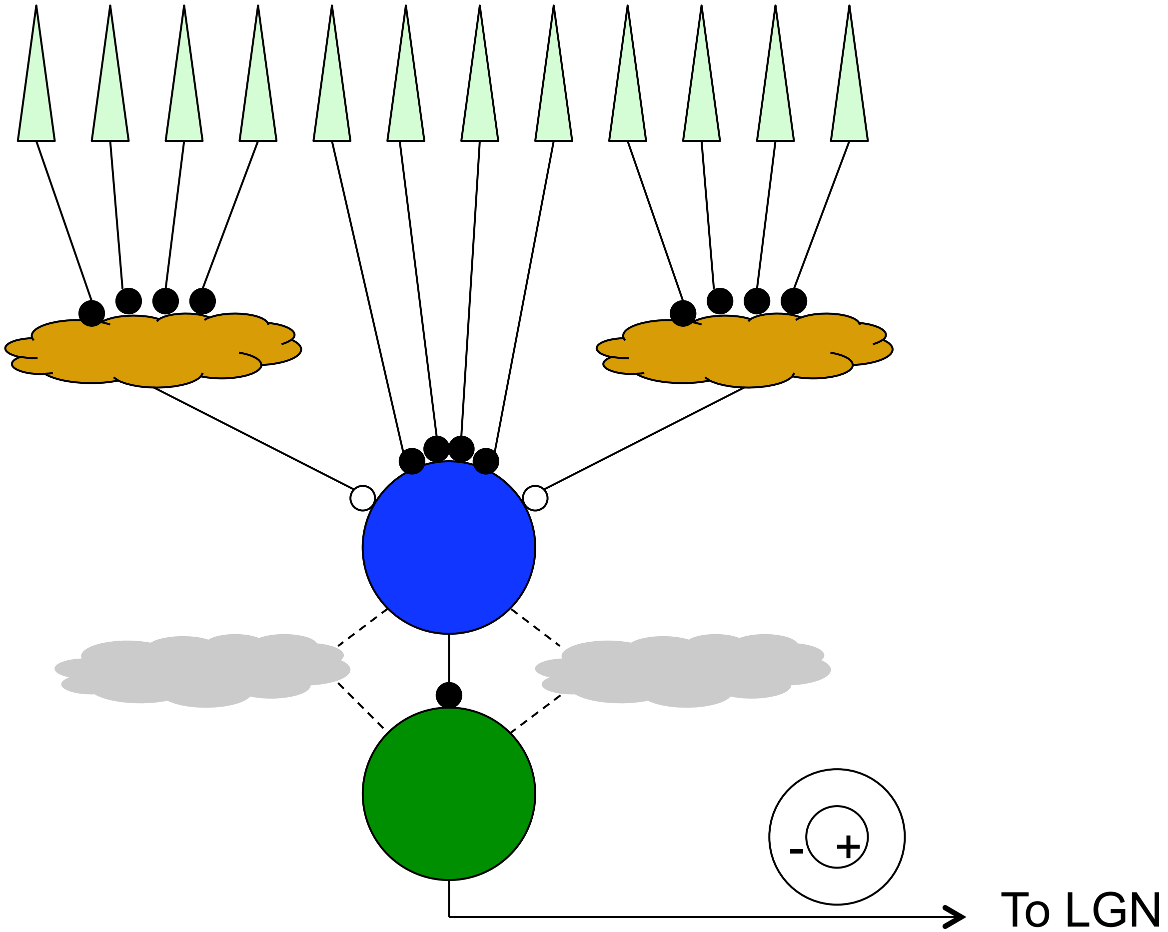


Retinal processing: Beyond the photoreceptors

- The retina's horizontal pathway: Horizontal and amacrine cells
  - Horizontal cells: Specialized retinal cells that run perpendicular to the photoreceptors and make contact with photoreceptors and bipolar cells
    - Responsible for lateral inhibition, which creates the center–surround receptive field structure of retinal ganglion cells
  - Amacrine cells: These cells synapse horizontally between bipolar cells and retinal ganglion cells
    - Have been implicated in contrast enhancement and temporal sensitivity (detecting light patterns that change over time)

Response properties of ganglion cells

Receptive field: The region on the retina in which stimuli influence a neuron's firing rate

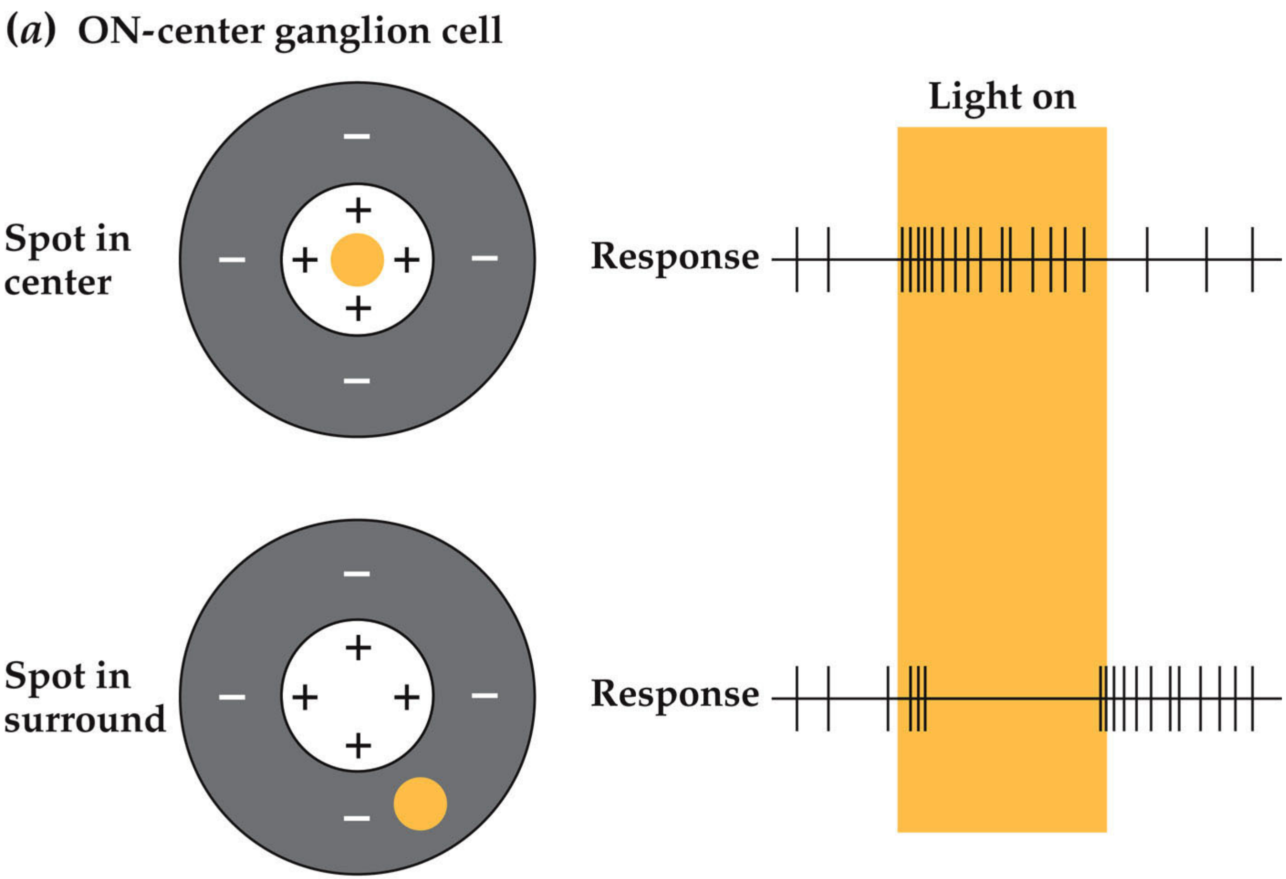


Response properties of ganglion cells

Stephen W. Kuffler
1913-1980

- Kuffler mapped out the receptive fields of individual retinal ganglion cells in the cat and found two kinds of cells
- ON-center ganglion cells
- OFF-center ganglion cells

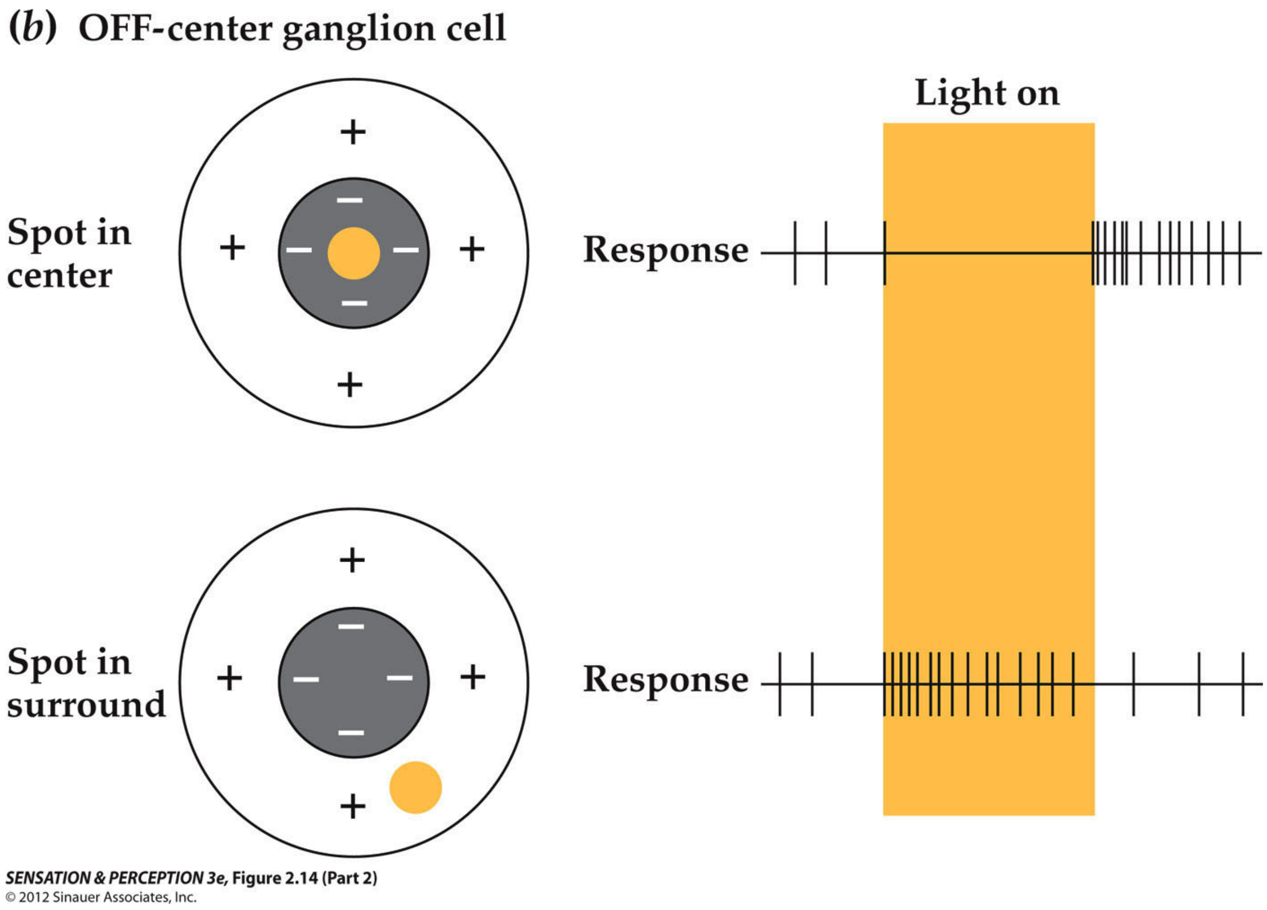
Retinal ganglion cell receptive fields (Part 1)



SENSATION & PERCEPTION 3e, Figure 2.14 (Part 1)

Excited by light falling on center, inhibited by light falling surround

Retinal ganglion cell receptive fields (Part 2)

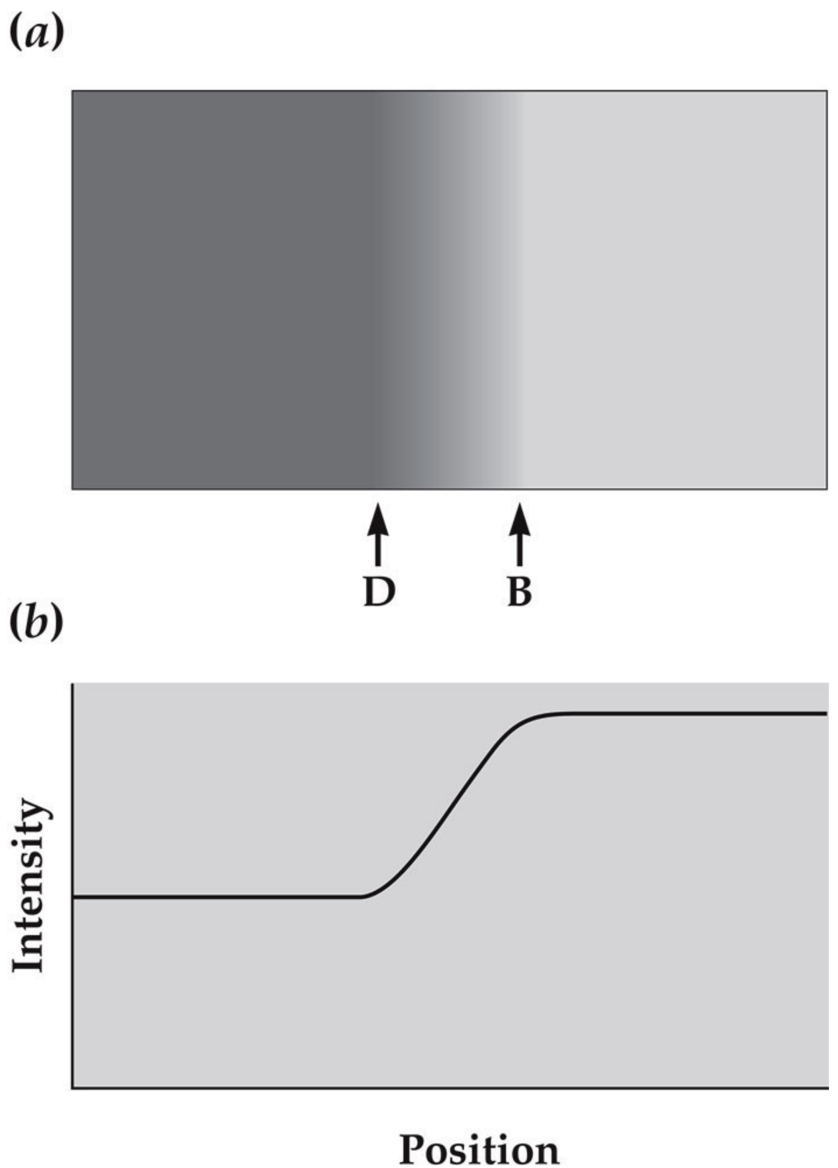


Inhibited by light falling on center, excited by light falling on surround

Why center-surround receptive fields?

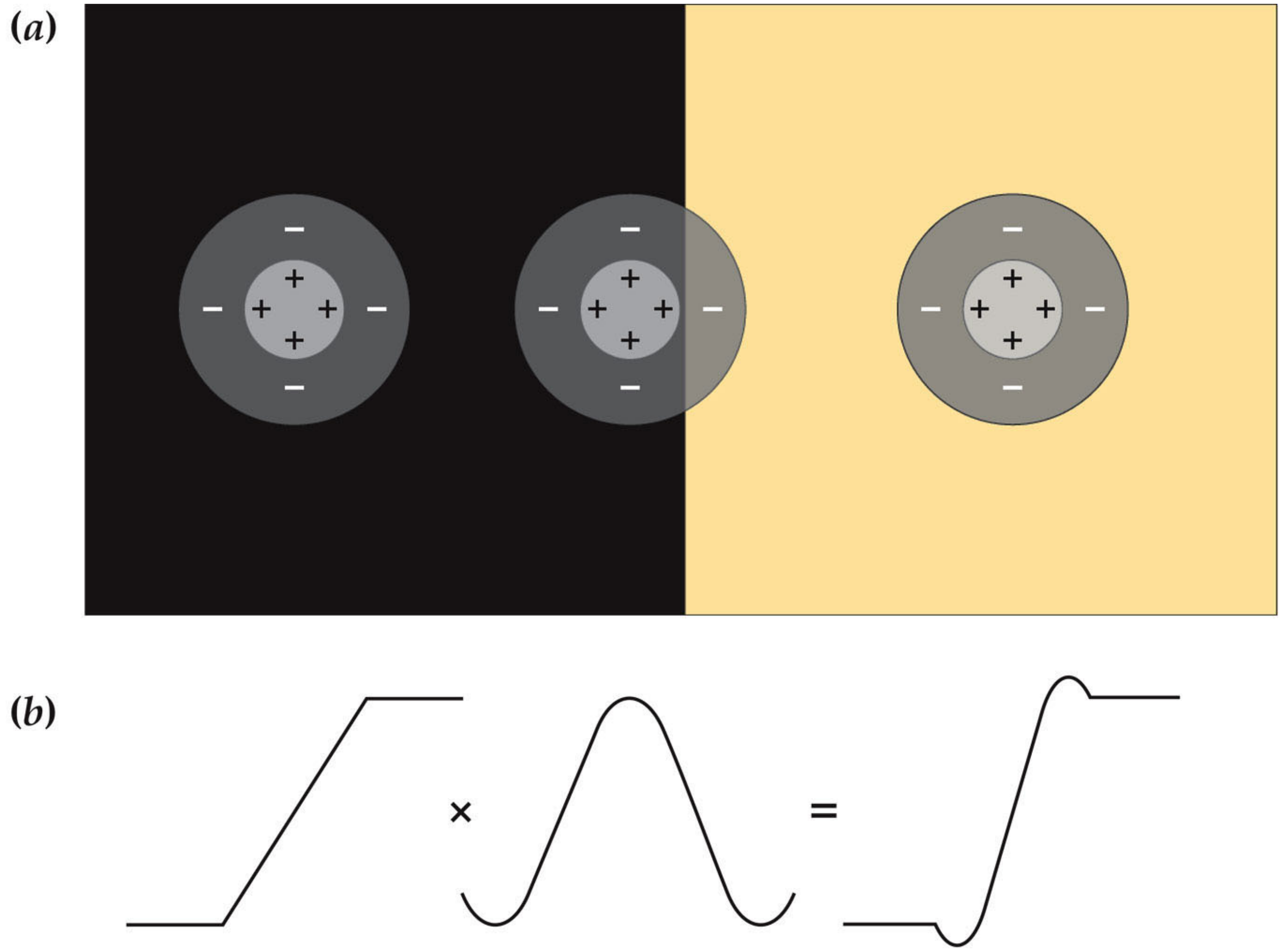
- Retinal ganglion cells are most sensitive to *differences* in the intensity of light between center and surround and are relatively unaffected by the average intensity
  - Luminance variations tend to be smooth within objects and sharp between objects
  - Thus, center-surround receptive fields help to emphasize object boundaries

Understanding Mach bands: Exercise for recitation



SENSATION & PERCEPTION 3e, **Figure 2.15**

Figure 2.16 Neuronal explanation for Mach bands



SENSATION & PERCEPTION 3e, Figure 2.16

Summary: Retinal fovea versus periphery

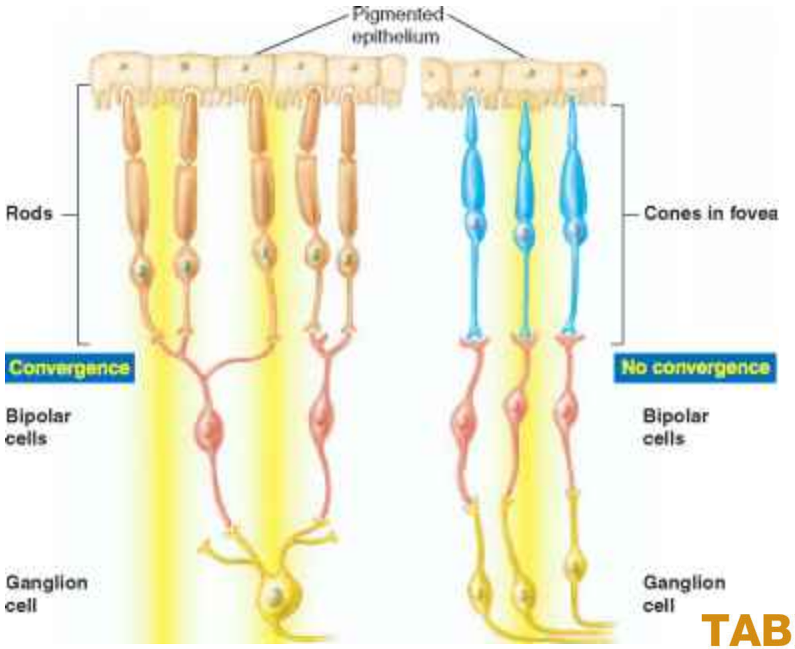


TABLE 2.1 ***Properties of the fovea and periphery in human vision***

Property	Fovea	Periphery
Photoreceptor type	Mostly cones	Mostly rods
Bipolar cell type	Midget	Diffuse
Convergence	Low	High
Receptive-field size	Small	Large
Acuity (detail)	High	Low
Light sensitivity	Low	High

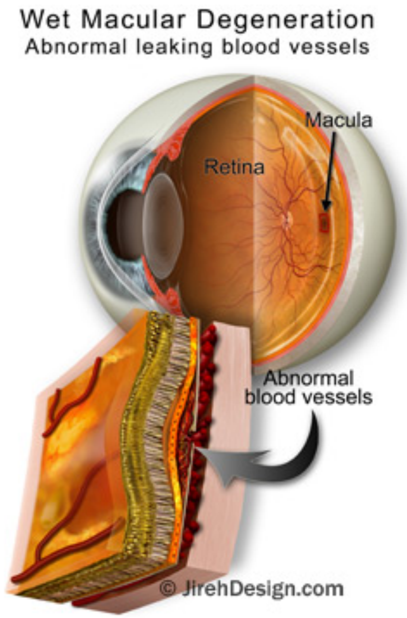
Degeneration of the fovea would lead to a loss of high-acuity vision…

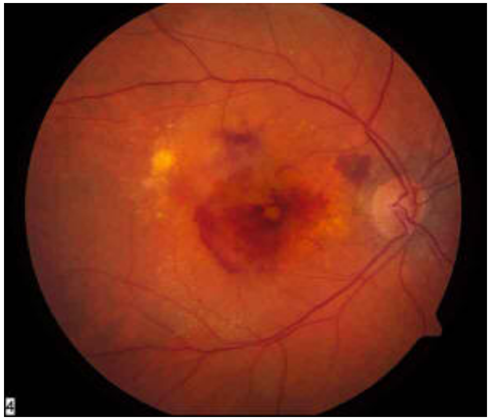
The Man Who Could Not Read

- Age-related macular degeneration (AMD): A disease associated with aging that affects the macula. AMD gradually destroys sharp central vision
  - Macula: The central part of the retina containing the fovea
- AMD causes central vision loss, resulting in a blind spot in the visual field called a scotoma. It impairs reading, driving and face recognition.

***SENSATION & PERCEPTION* 3e, Figure 2.12**

The Man Who Could Not Read





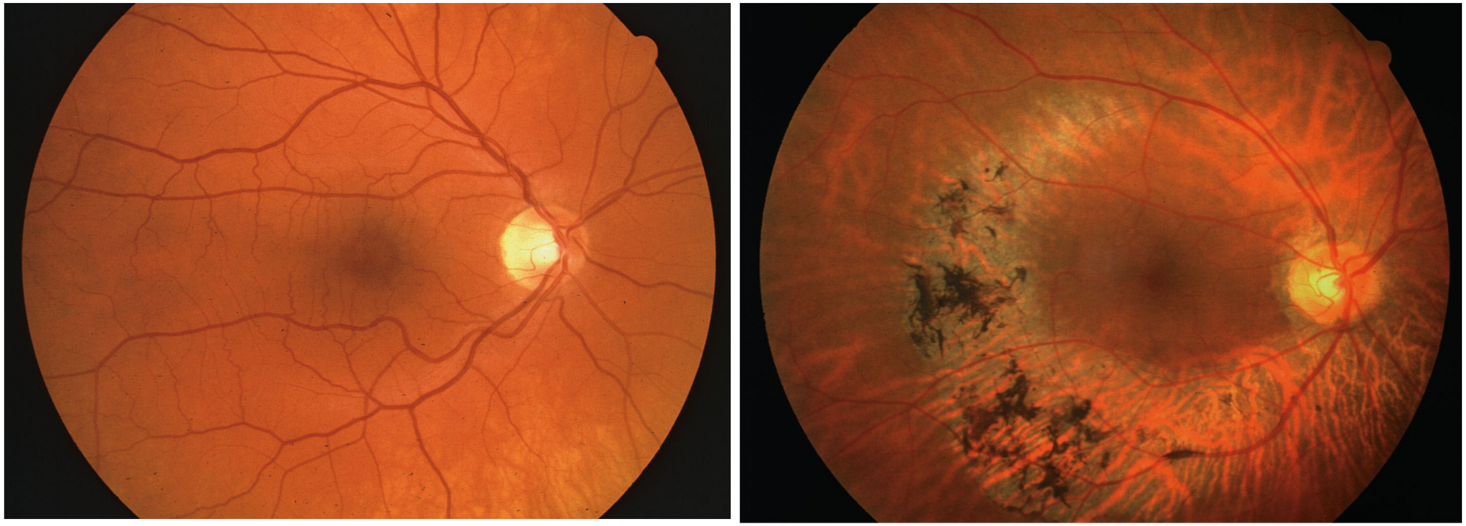
- Age-related macular degeneration (AMD)
  - Two varieties:
    - Wet AMD: Abnormal blood vessels grow under the macula and can leak blood and fluid, raising the macula and impairing central vision. As the macula is displaced, straight lines may look wavy
    - Dry AMD: More common. Occurs when macula cones degenerate. Sometimes dry AMD turns into wet AMD. Once dry AMD is advanced, no treatment can reverse the loss of vision

The Man Who Could Not Read

- Some treatments can delay and possibly prevent AMD from progressing
  - Studies show taking high-dose anti-oxidants and zinc significantly reduces risk of advanced AMD and associated vision loss

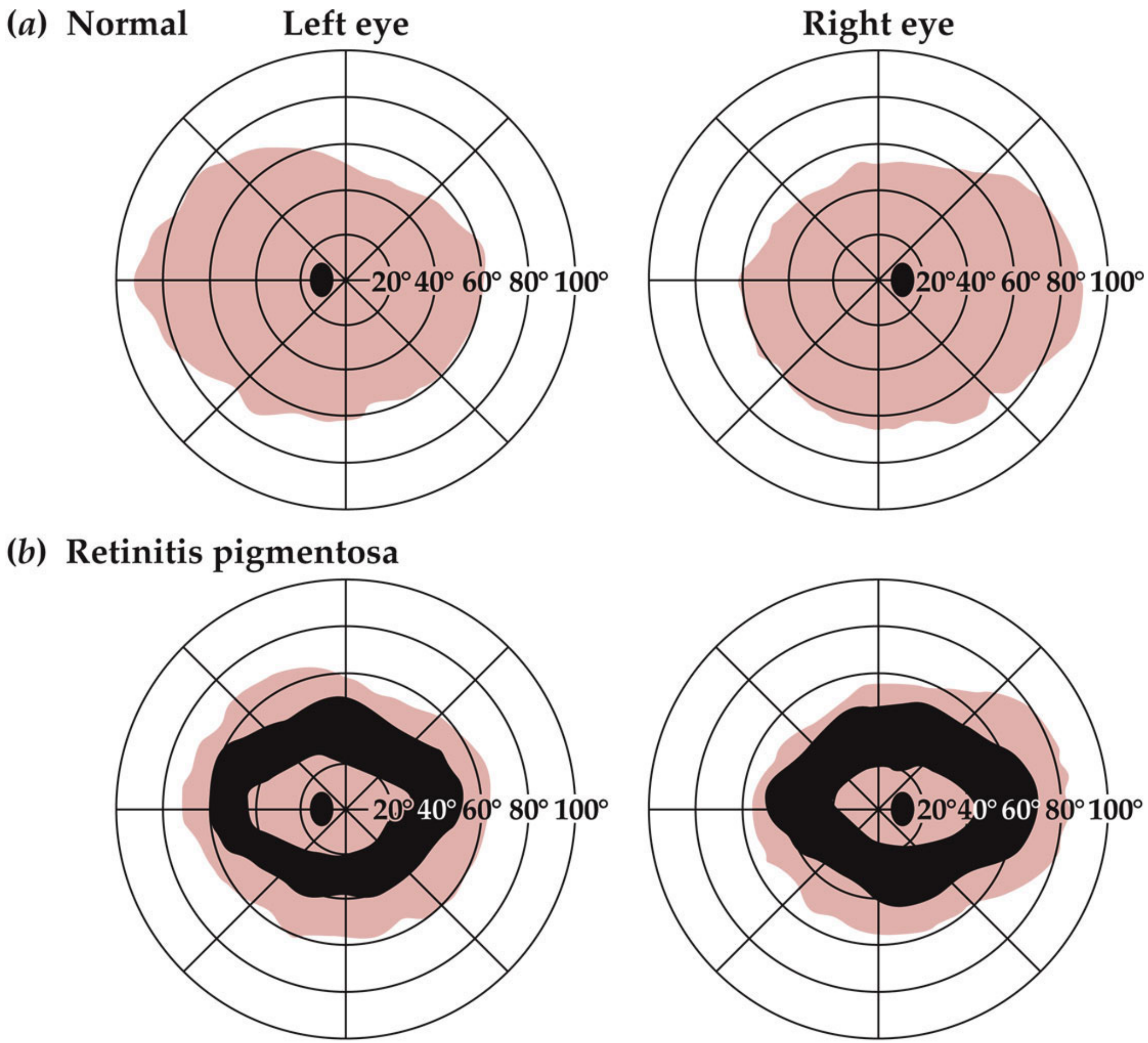
A ‘complementary’ visual problem…

- Retinitis pigmentosa (RP): Family of hereditary diseases involving the progressive death of photoreceptors and degeneration of the pigment epithelium



Many people may not notice the onset of retinitis pigmentosa at first because it primarily affects peripheral vision.

Visual fields in (a) normal individuals and (b) people with RP



SENSATION & PERCEPTION 3e, Figure 2.20

RP: Treatments?

There is no effective treatment for this condition. Wearing sunglasses to protect the retina from ultraviolet light may help preserve vision.

Some studies have suggested that treatment with antioxidants (such as high doses of vitamin A) may slow the disease. However, taking high doses of vitamin A can cause serious liver problems.

Summary of lecture

- The visible spectrum
- Overall structure of eyeball
- Refractive problems
- Retina: structure and function
- Retinal pathologies: AMD and RP

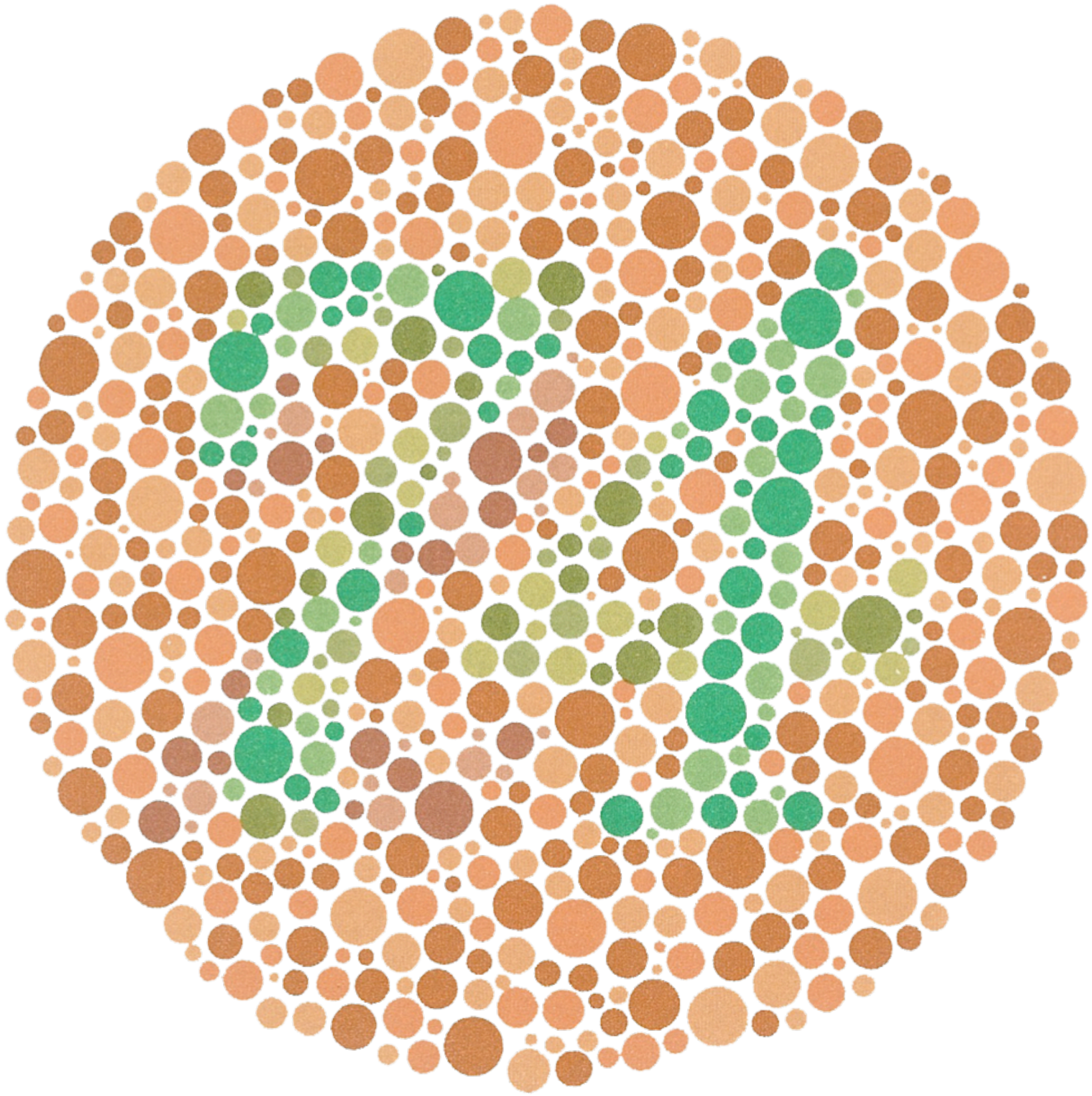
- Computational Neuroscience:
  How Artificial Intelligence Learns from Biological Intelligence

- http://www.youtube.com/watch?v=eRgXrJ-Kiig

Whistling in the Dark: Dark and Light Adaptation

- One of the most remarkable things about the human visual system is the incredible range of luminance levels we can adjust to
- Two mechanisms for dark and light adaptation:
  - Pupil dilation
  - Photoreceptors and their response properties

To be covered in recitation



Normal sight

Deuteranopia sight

Tritanopia sight

Monochromacy sight