Color Theory

- Chapter 3a **Perceiving Color**

- The eye
- Rods
- Cones
- After-images
- Color Constancy

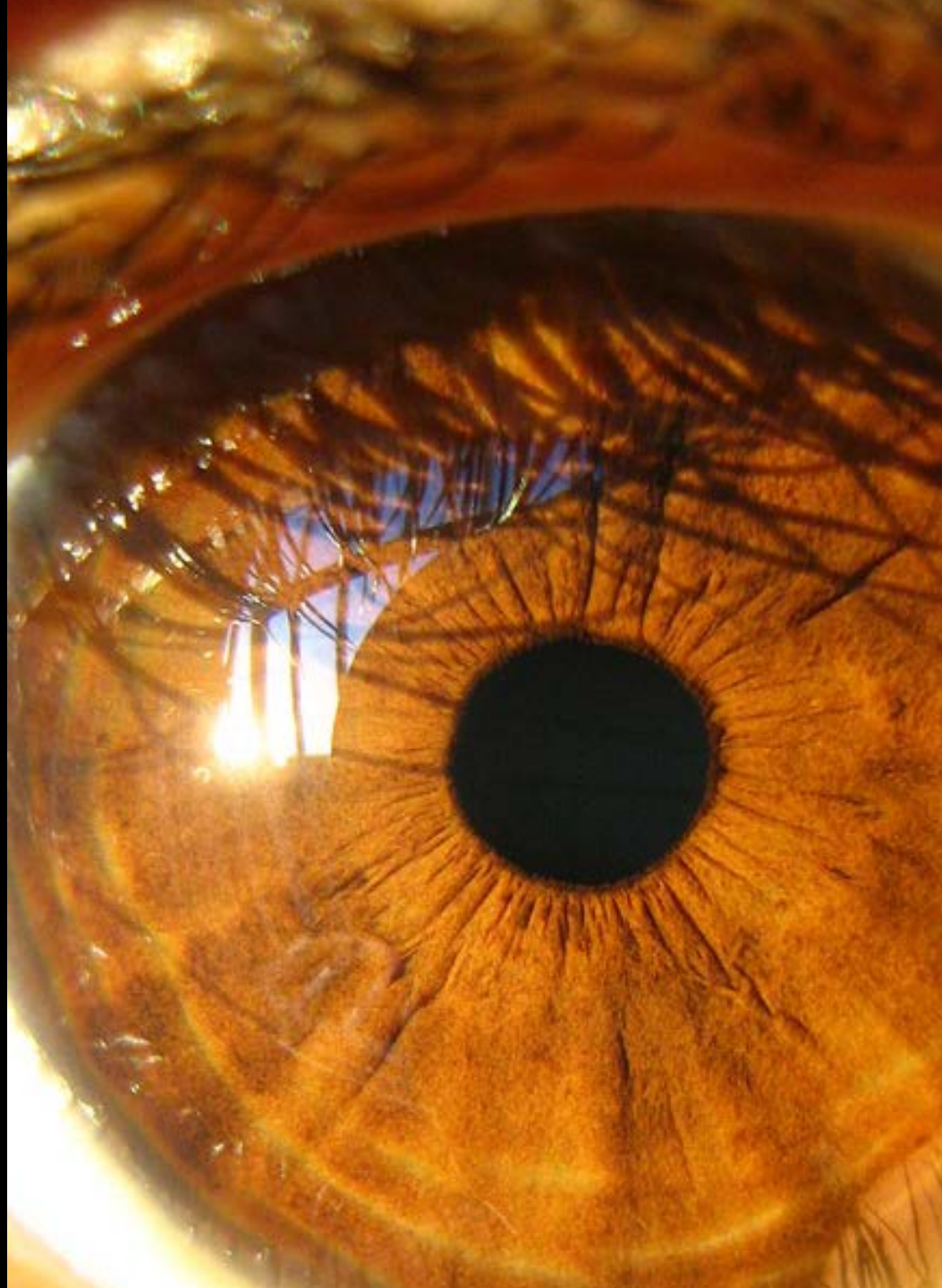
Color Theory

- **I know who you are…**
- ***…by your eyes.***
- Today security systems exist that identify people solely by their eyes.

Either by their *retinas*, or their *irises*.

Iris Recognition

- “Iris recognition technology looks at the unique characteristics of the iris, the colored area surrounding the pupil.
- While most biometrics have 13 to 60 distinct characteristics, ***the iris is said to have 266 unique spots***.
- Each eye is believed to be unique and remain stable over time and across environments .”
- http://www.globalsecurity.org/security/systems/biometrics-eye_scan.htm



Iris Recognition

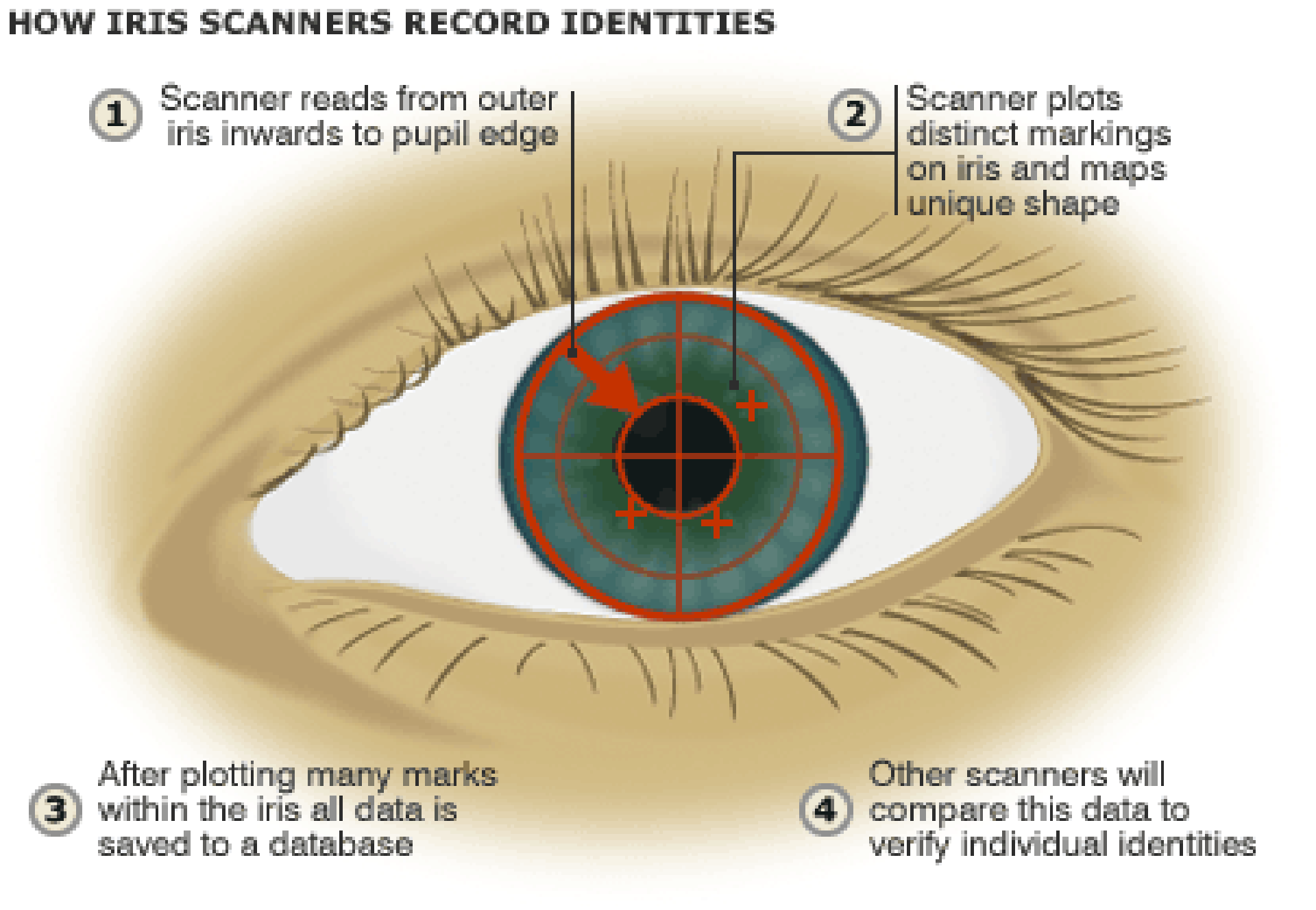
- “Iris recognition systems use small, high-quality cameras to capture a black and white high-resolution photograph of the iris.

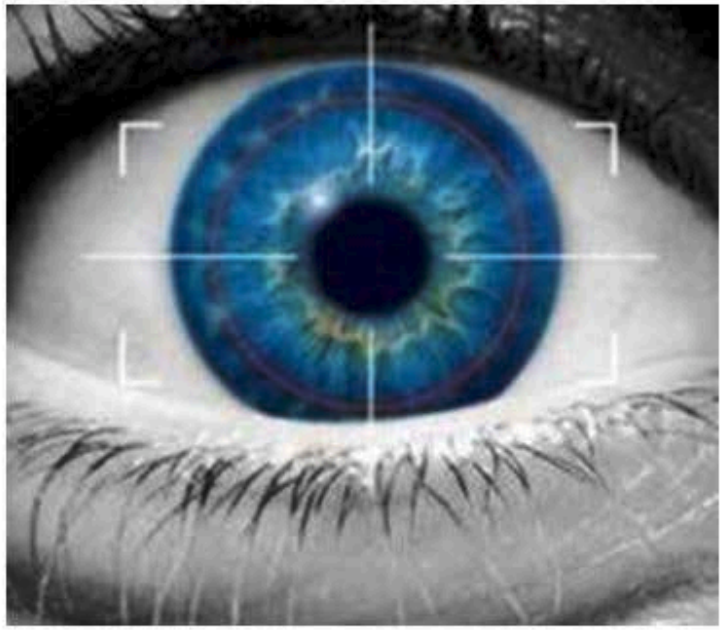
- Once the image is captured, **the iris' elastic connective tissue-called the trabecular meshwork-is analyzed, processed into an optical "fingerprint,"** and translated into a digital form….

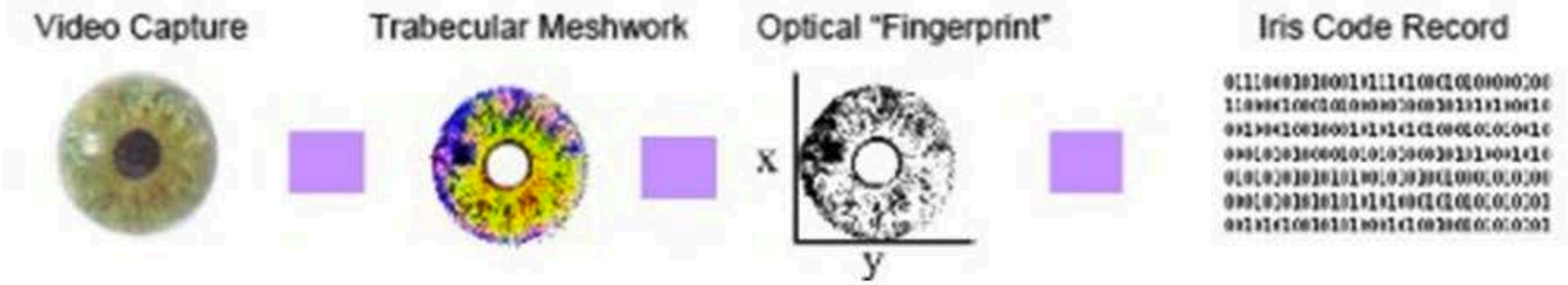
- this technology is considered to be one of the safest, fastest, and most accurate, noninvasive biometric technologies.”

  - www.globalsecurity.org/security/systems/biometrics-eye_scan.htm

Iris Recognition





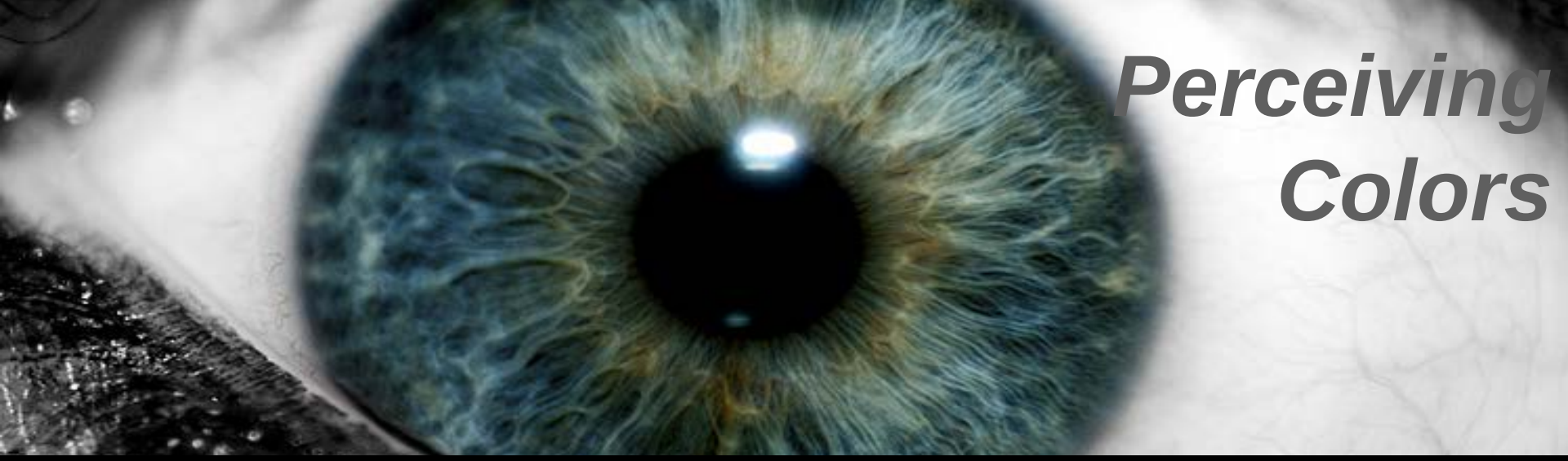


Take an image of the eye.

Process the image based on color and contrast traits

Process patterns and identify key features

Store those features in digital database



Perceiving Colors

- The Physics of light and color — wavelengths and selective absorption — are only some of the significant factors in what we see.
- The physiology of our eyes and nervous system is another factor.
- Eye's form and features are important in explaining some visual phenomena that designers need to be able to anticipate.
- However, we (our scientists) ***don't yet fully understand how we perceive color***.

From the eye to the brain

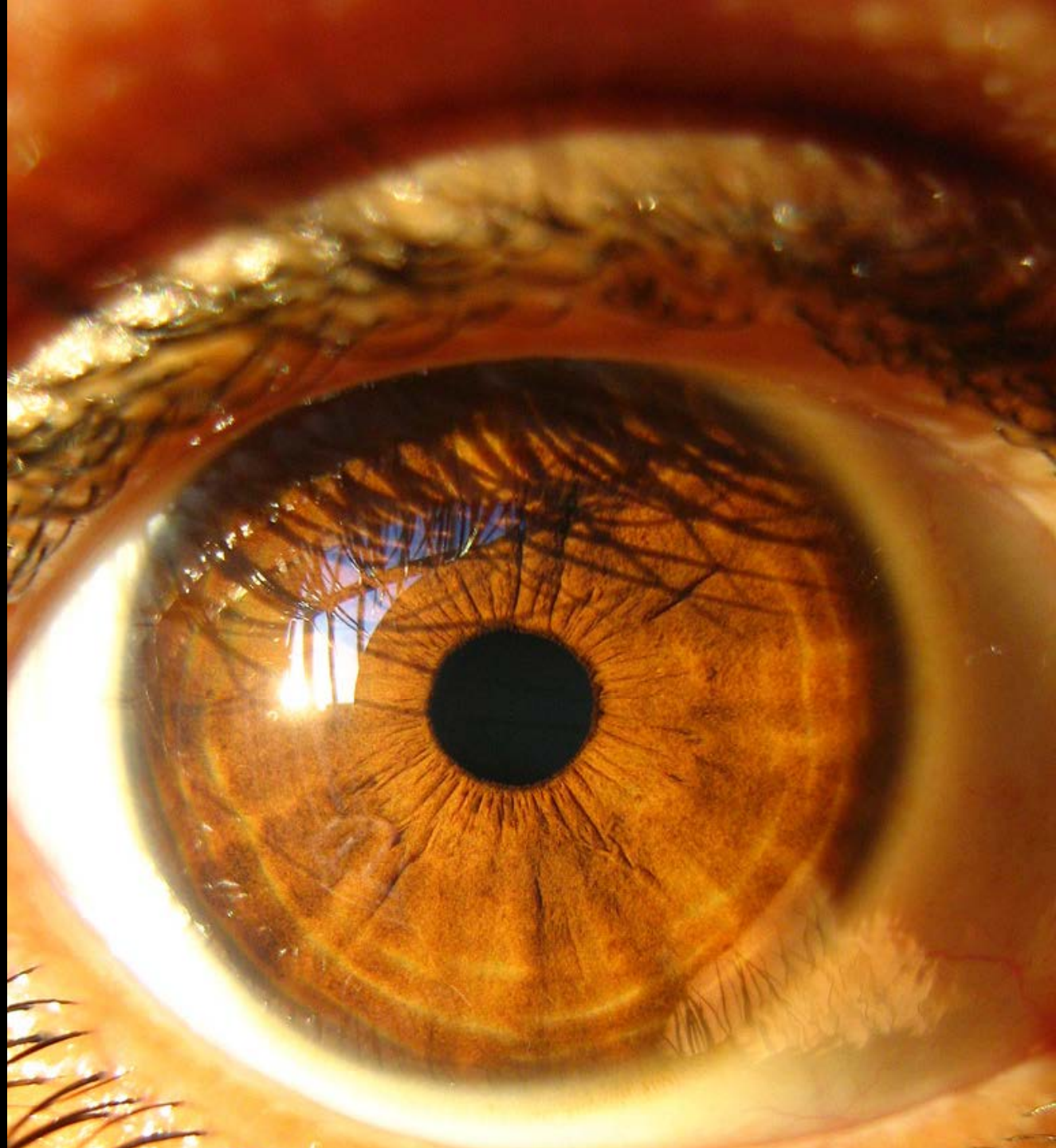
- One of the great mysteries is how the millions of nervous impulses are then **organized** into a meaningful image, and then into a conception of the "world out there."

- — **We don't "see" colors** — our mind interprets light waves *AS* colors.
  — **We don't "see" objects** — our mind interprets colors and organizes a conception of the world "out there." Gestalt psychology, particularly, studies how we convert patterns of color into conceptions of objects and space.

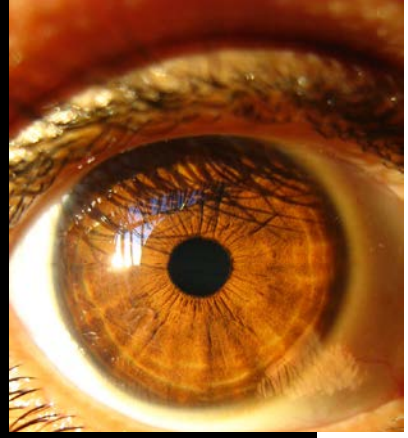
From Light to Image — serious processing

However light becomes an image of concrete, recognizable object, it apparently is **a demanding process**.

Almost **1/3** of your brain is dedicated to converting light into meaningful imagery.



From Light to Image — the eye as brain



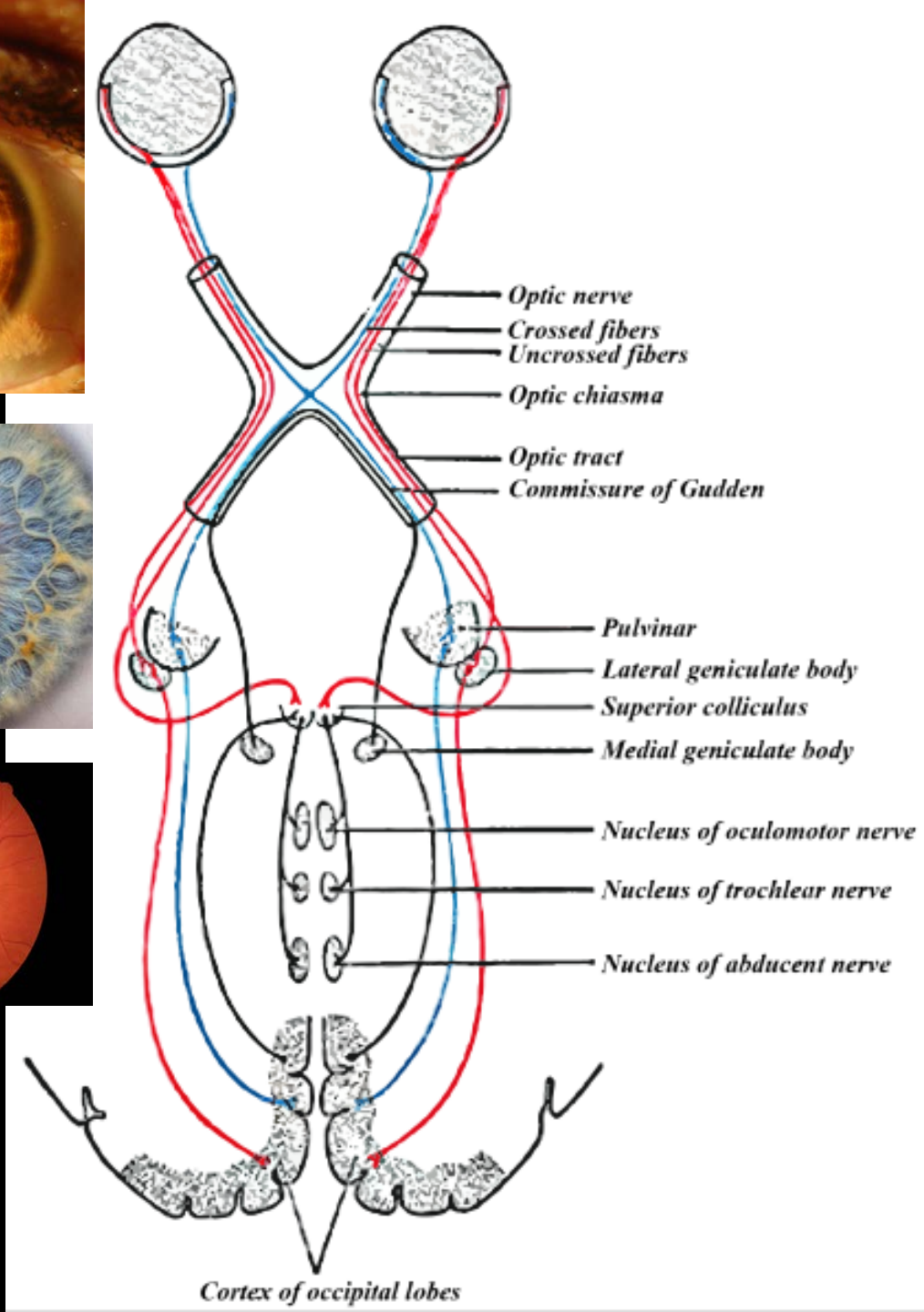
"Vision occurs neither in the eyes nor in the brain, but emerges from the collaboration of the eyes and the rest of the brain….

The retina is a thin sheet of brain tissue in the eyes.

It is the place where the brain first encounters light.

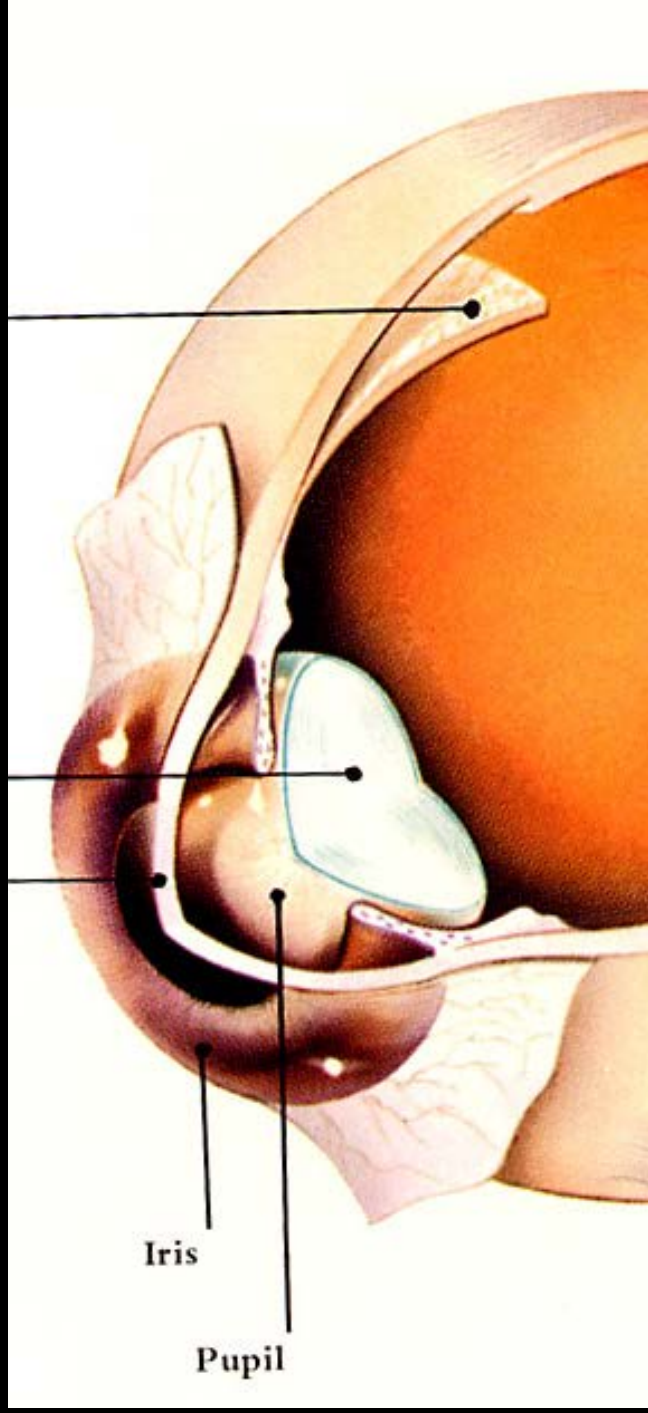
Signals travel back-and-forth between the eyes and the rest of the brain."

American Optometric Association
http://www.aoa.org/x5417.xml

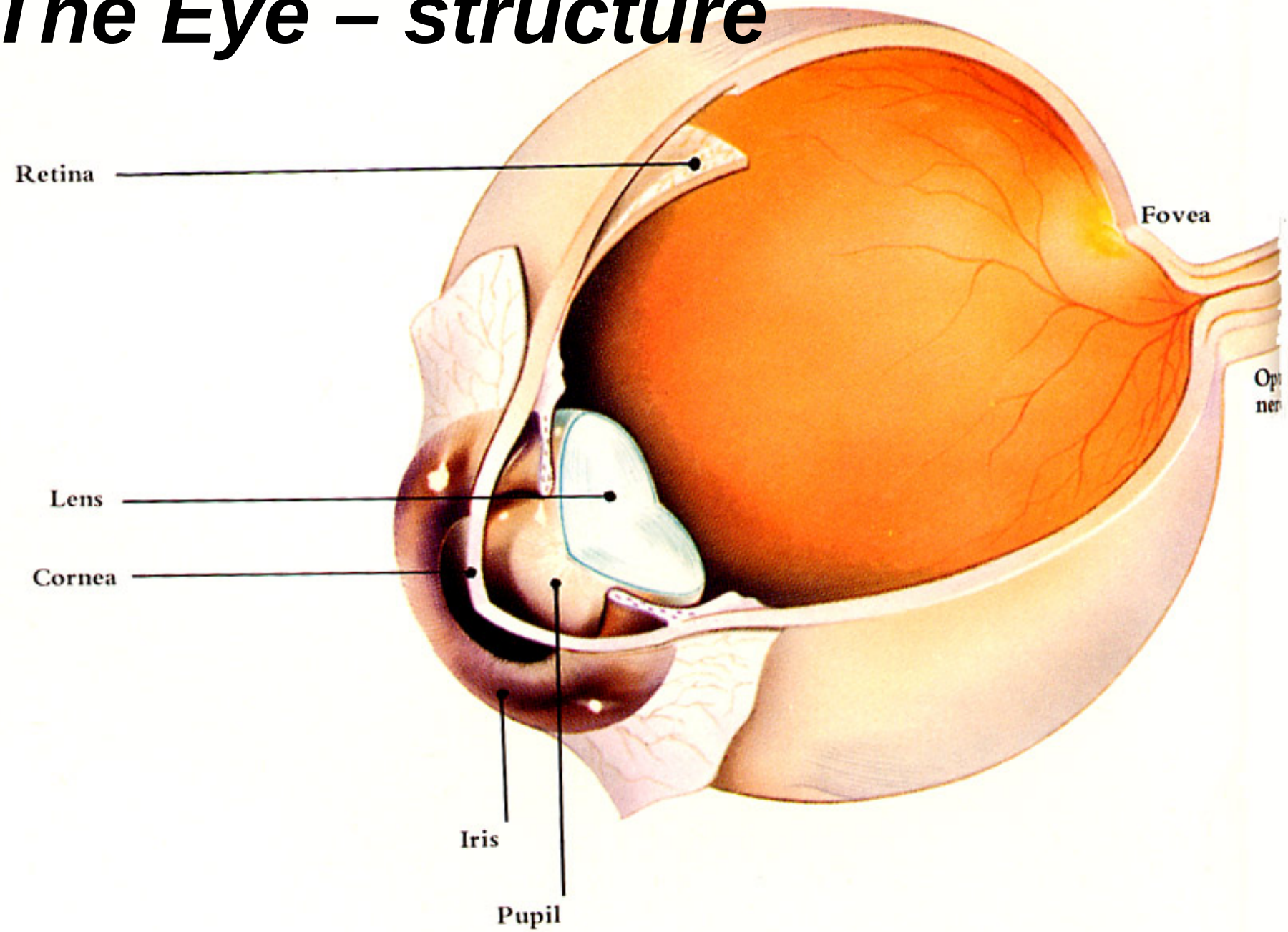


The Eye –structures in Front

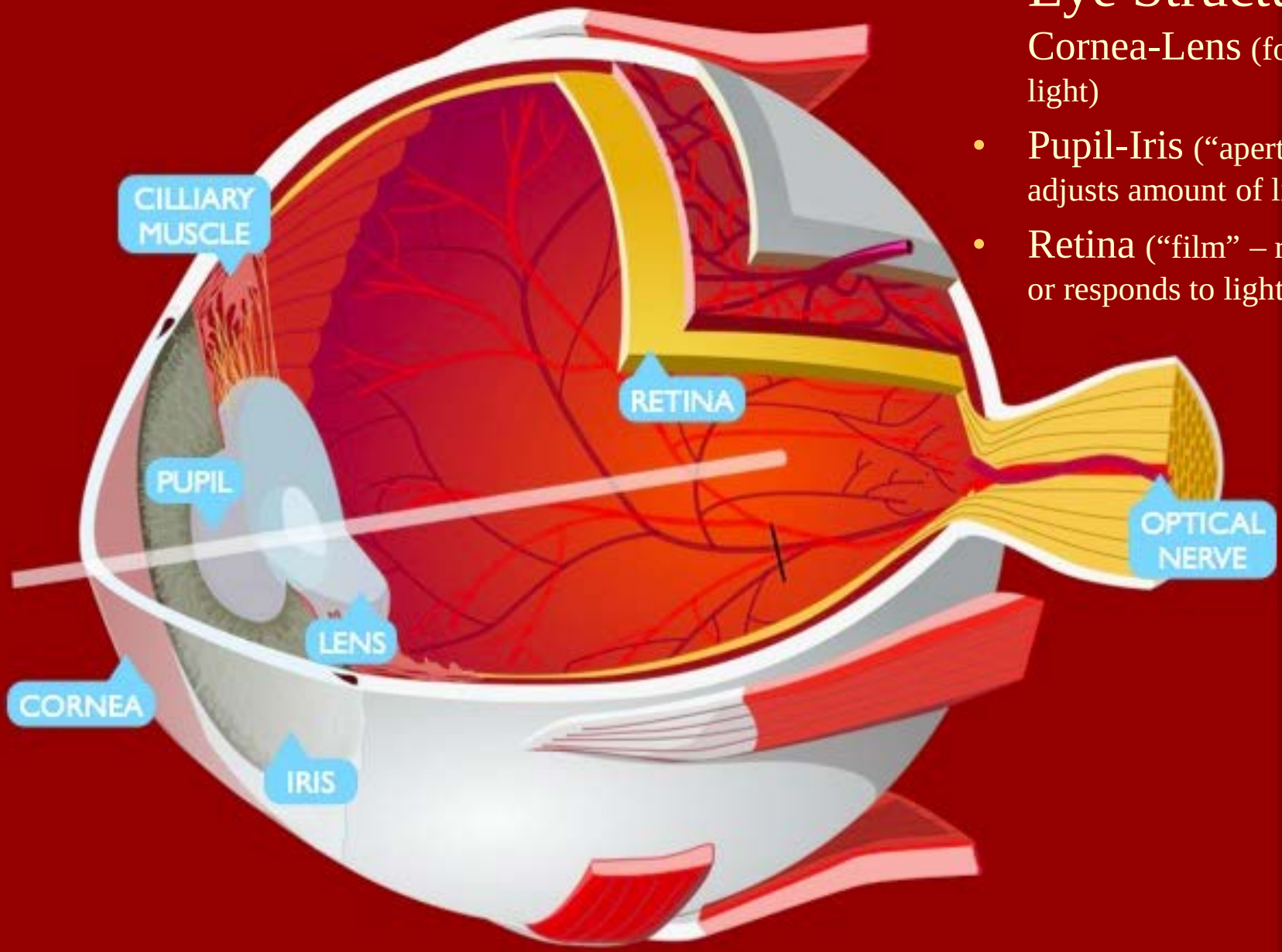
- The **front** of the eye is mainly concerned with:
- a) **focusing** light correctly on the back wall of the eye and
- b) increasing or decreasing the **amount of light that enters**.
- So, the functions of the lens, iris, pupil, and cornea are ***not*** of direct concern to color perception.



The Eye – structure



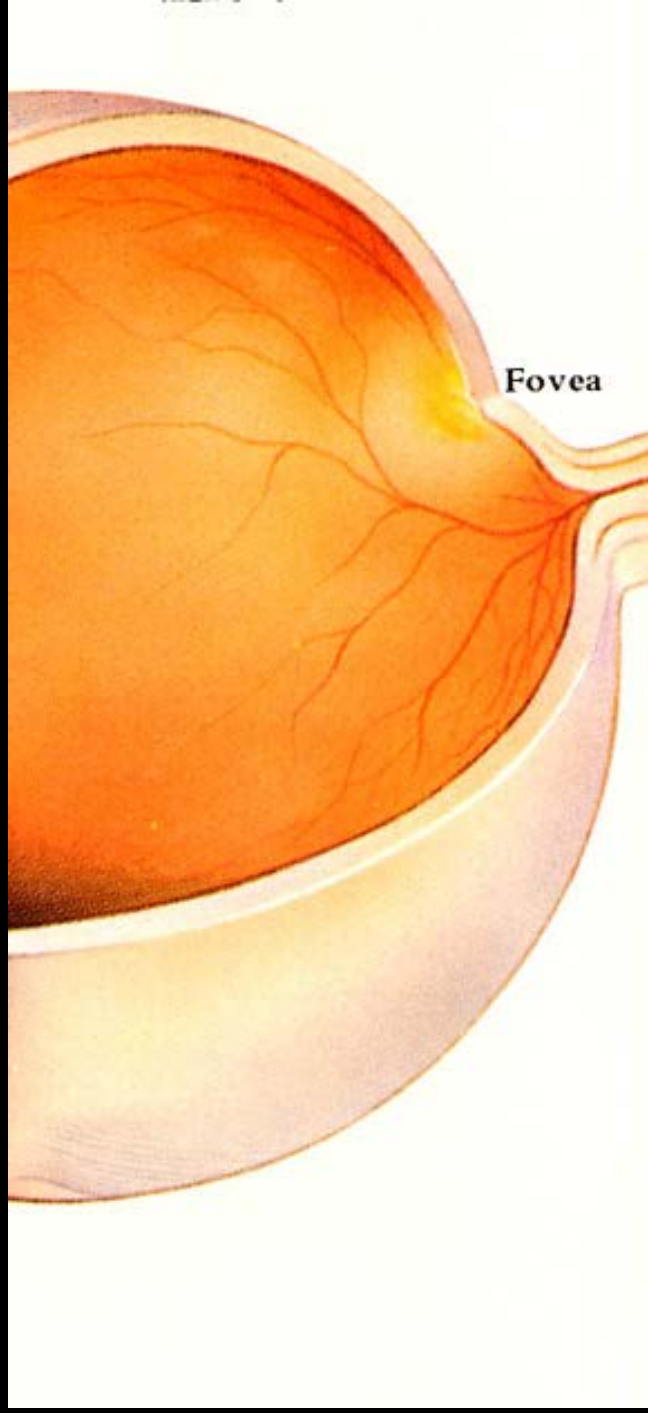
- Eye Structure:
  Cornea-Lens (focuses light)
- Pupil-Iris (“aperture” – adjusts amount of light)
- Retina (“film” – records or responds to light “sees”)

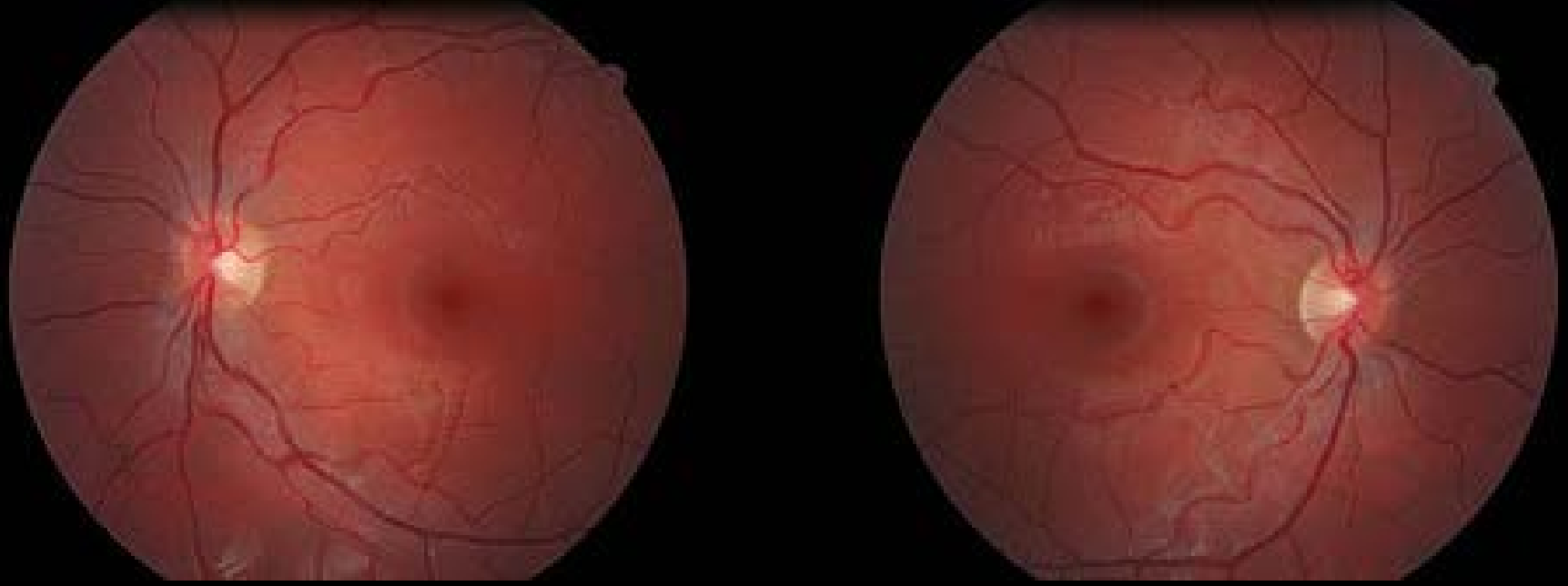


http://www.pixiq.com/article/eyes-vs-cameras

The Eye – photoreceptors in back

- The back of the eye is where light perception begins because that is where photosensitive nerves– they respond to light.
- The retina lines the back, inner wall of the eye.
- The retina has several layers of specialized cells.
- The layer that actually “sees” light is filled with two types of cells – the **rods and cones**.





A photo taken with a Canon Digital Retinal camera of the eyes' insides — the back wall.
The red wiggly lines are the blood vessels, the white spot is where the optic nerve joins the back of the eye and the dark spot is the macula.

"The macula is located roughly in the center of the retina, temporal to the optic nerve. It is a small and highly sensitive part of the retina responsible for detailed central vision. The fovea is the very center of the macula. The macula allows us to appreciate detail and perform tasks that require central vision such reading."

http://www.stlukeseye.com/Anatomy/Macula.asp

Unique retinal blood vessel pattern

Retinal photo.

Note that the pattern of blood vessels through your retina are unique — as are your fingerprints. Security systems sometimes include retinal scans that
a) photograph your retina and then
b) match the pattern of blood vessels to your personal records — thus confirming who you are (or aren‘t).

Retinal pattern and medical diagnosis

•August 31, 2005

•Scientists at MD Biotech in Morgantown, West Virginia, created an Optical Scanning Instrument (OSI) that can reveal a whole host of medical problems.

• In the prototype, what looks like an oversized pair of binoculars scans your eye as you look through the "wrong" end. The OSI takes snapshots of the inside of your eye. Then, the snapshots are analyzed using algorithms developed from healthy and unhealthy eyes.

•Each algorithm evaluates small variations in eye movements, pupil size, retinal blood vessels, infections, and corneal abnormalities to determine a match to a particular illness.

•Algorithms for exposure to toxins used in chemical warfare have already been developed. In the civilian world, those same algorithms could be used for exposure to toxic waste. Other algorithms that could be used right away include those for head trauma, carbon monoxide, cyanide, high blood pressure, diabetic retinopathy, and some neurological disorders.

Retinal pattern and medical diagnosis

•August 31, 2005

•Many health problems show up in your eyes, potentially creating non-invasive tests for everything from cocaine to sickle cell anemia.

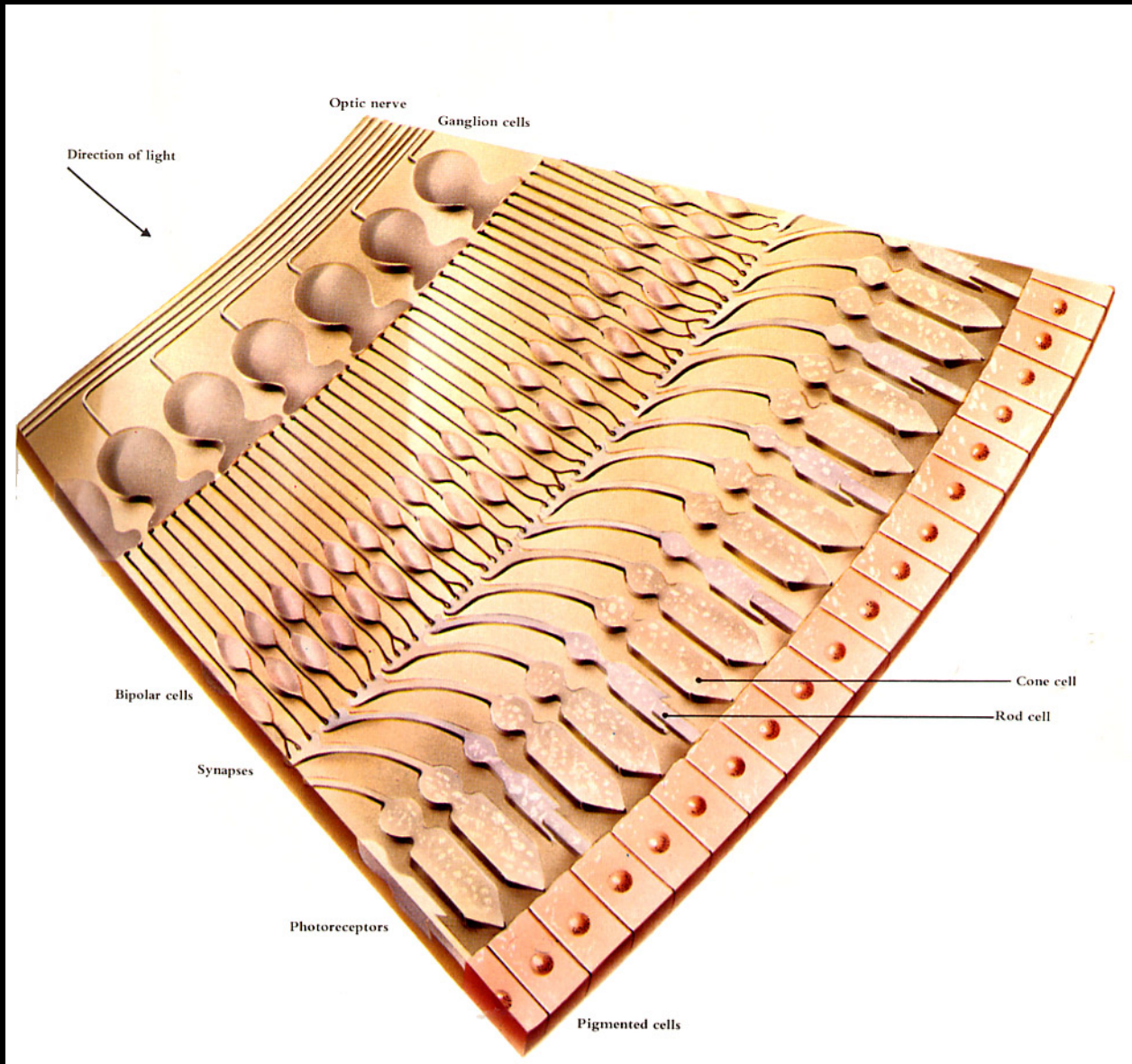
•Cocaine, alcohol, and other drugs can make the OSI a non-invasive drug test. Infectious diseases such as malaria, AIDS, syphilis, Lyme disease, and chicken pox all show up in your eyes.

•Interestingly enough, so does pregnancy – no more pink lines. Later on, premature births and malnutrition show up in the eyes. Even genetic diseases like leukemia, lymphoma, Stevens-Johnson syndrome, and sickle cell anemia affect the eyes.

•In addition, your eyes show signs of chronic health conditions like bleeding or clotting disorders, congestive heart failure, arthrosclerosis, and high and low cholesterol. Other poisons like botulism manifest themselves in the eyes, too.

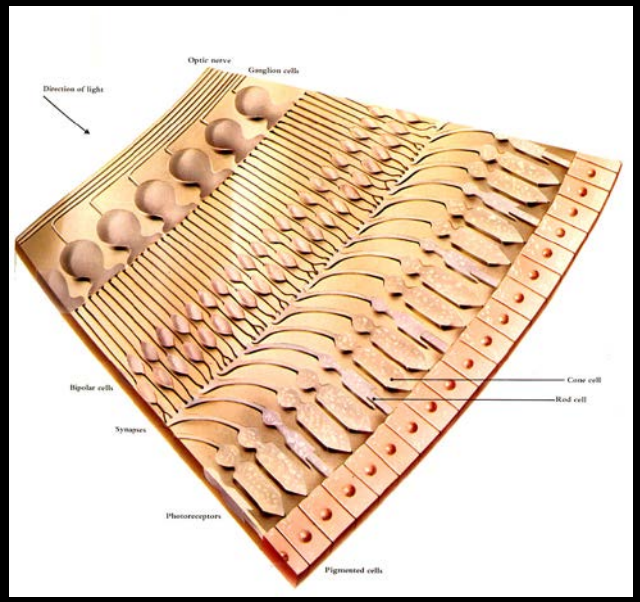
The Eye – retina

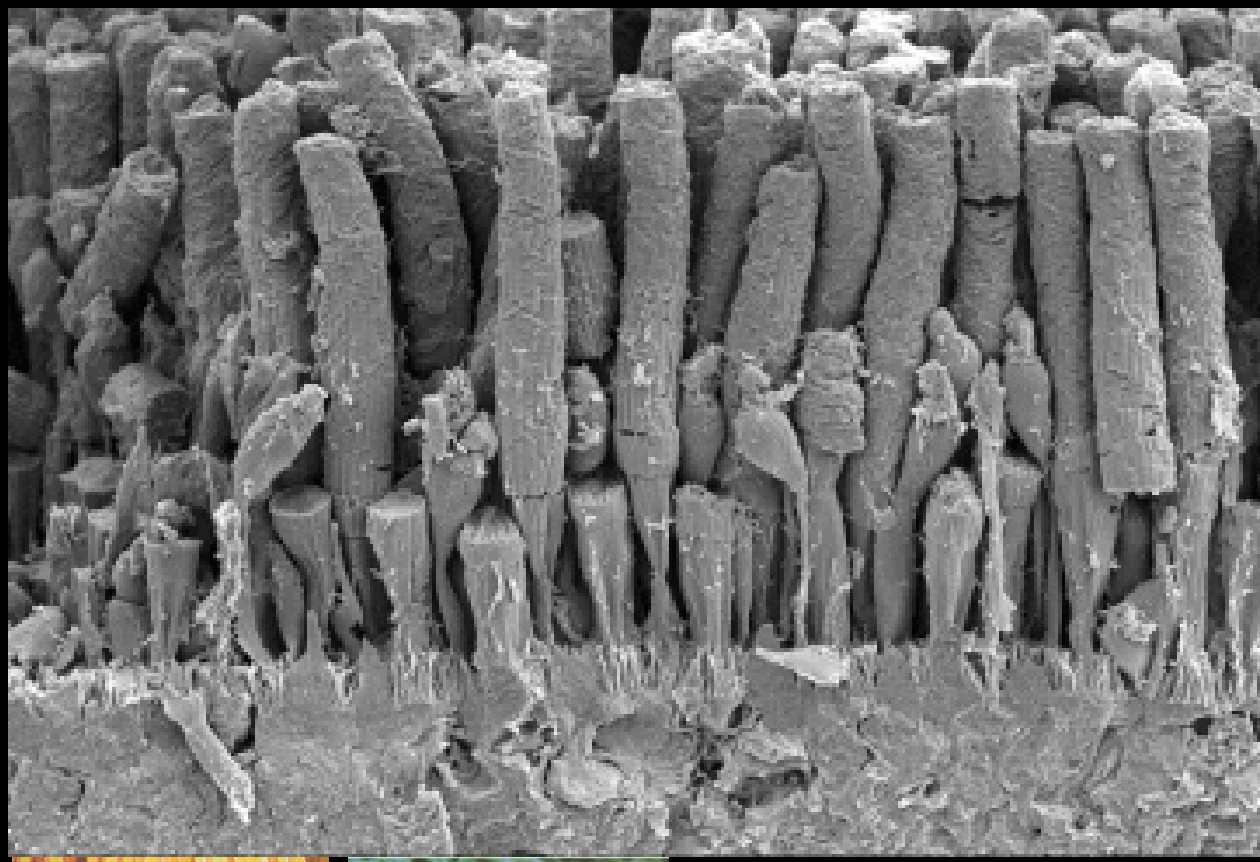
- The retina has several layers of specialized cells.
- The layer that actually “sees” light is filled with two types of cells – the **rods** and **cones**.

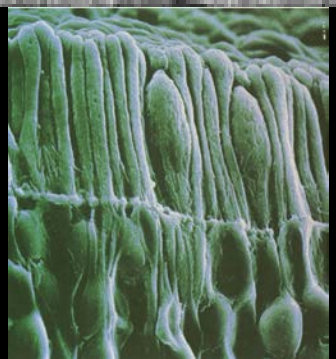


The Eye – retina

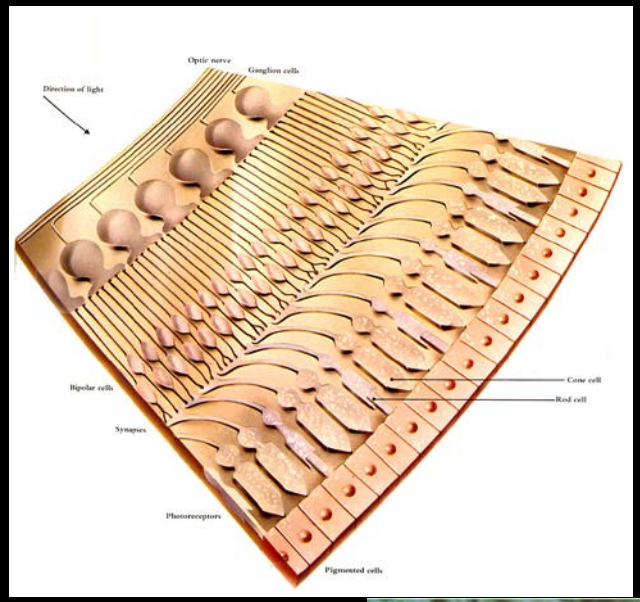
- Scanning Electron Microscope image of Rods and Cones

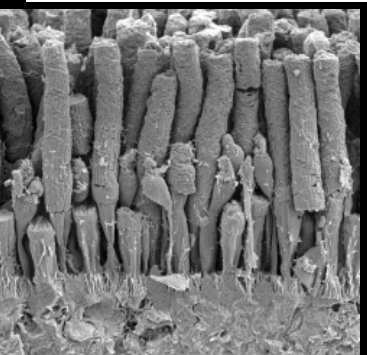


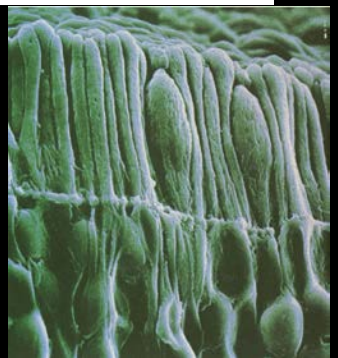




- Scanning Electron Microscope image of Rods and Cones







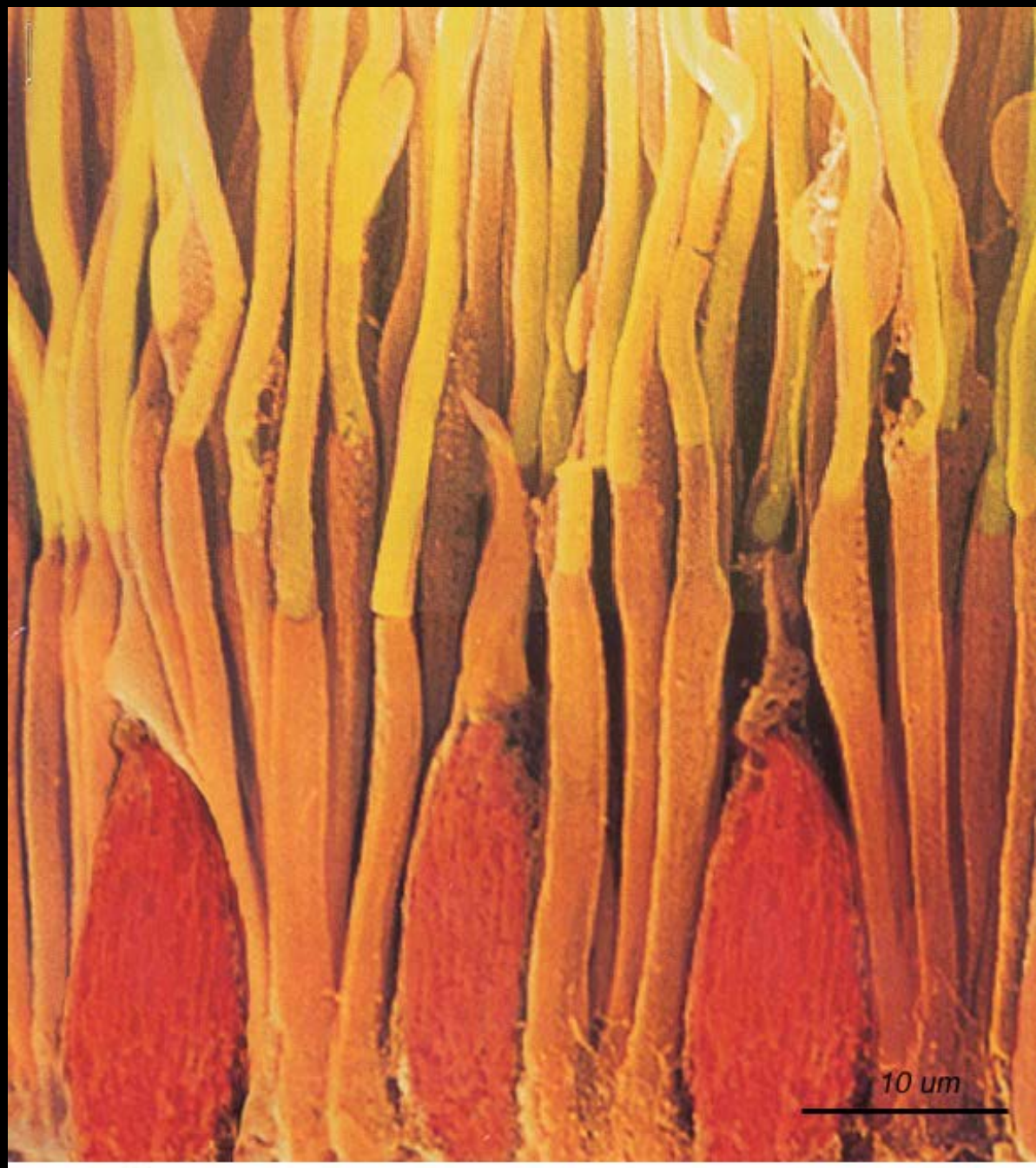
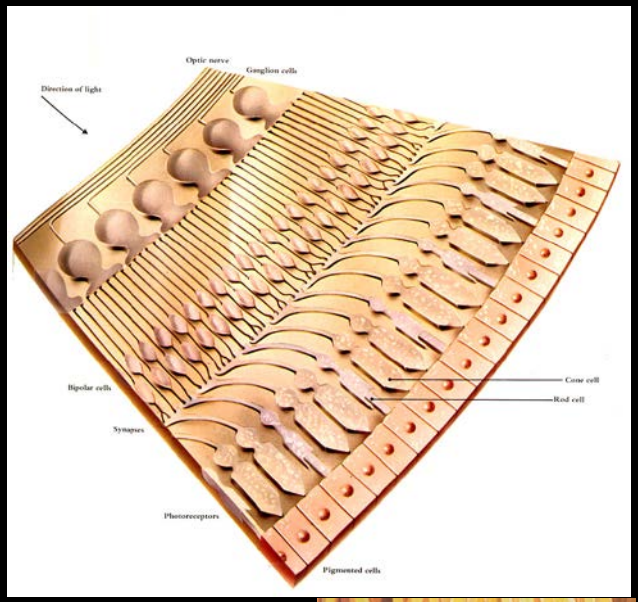
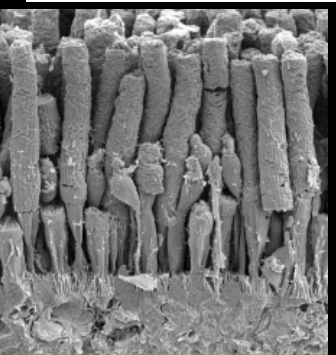
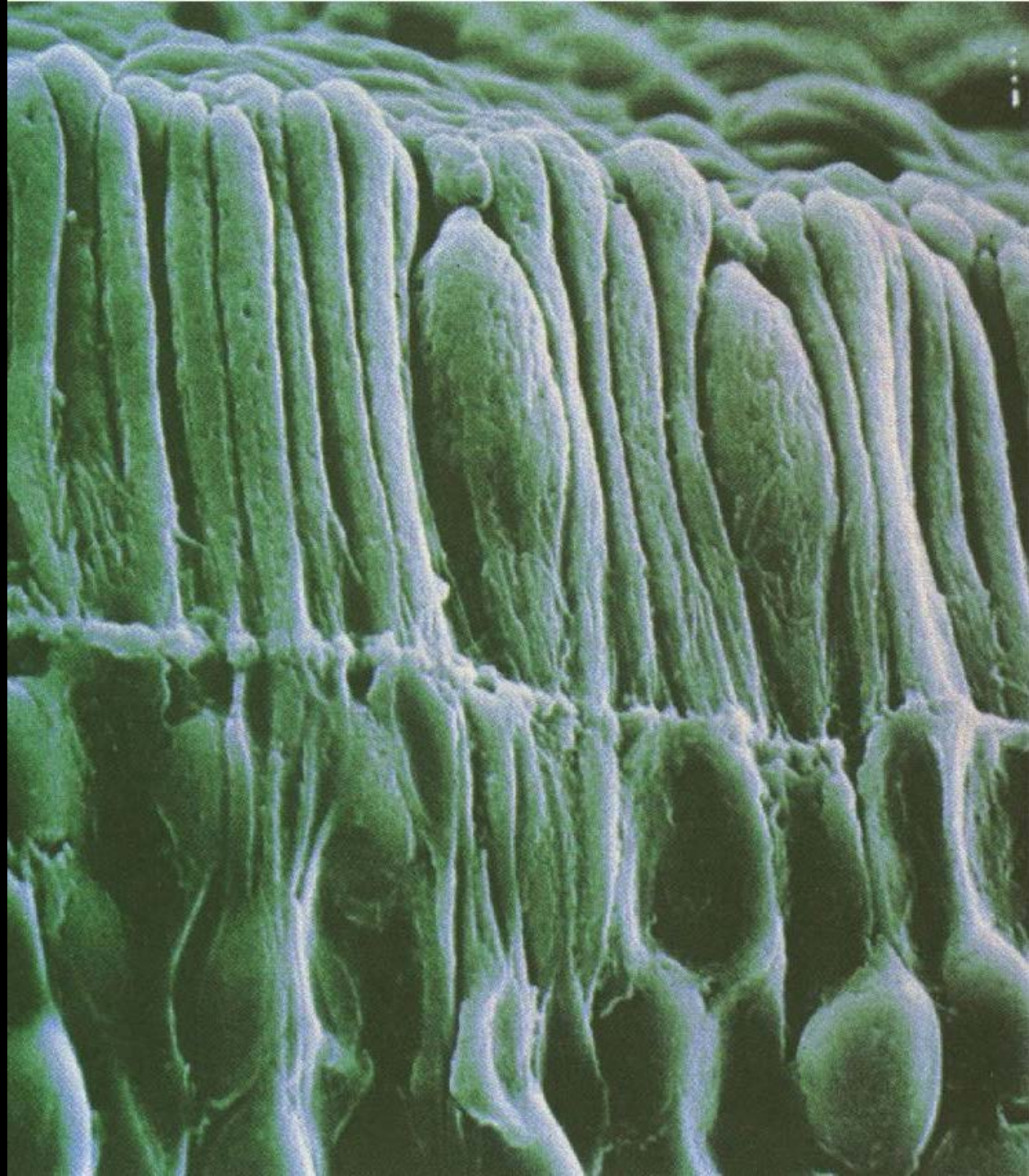


Fig1b. Scanning electron micrograph of the rods and cones of the primate retina. Image adapted from one by Ralph C. Eagle/Photo Researchers, Inc.

- Scanning Electron Microscope image of Rods and Cones



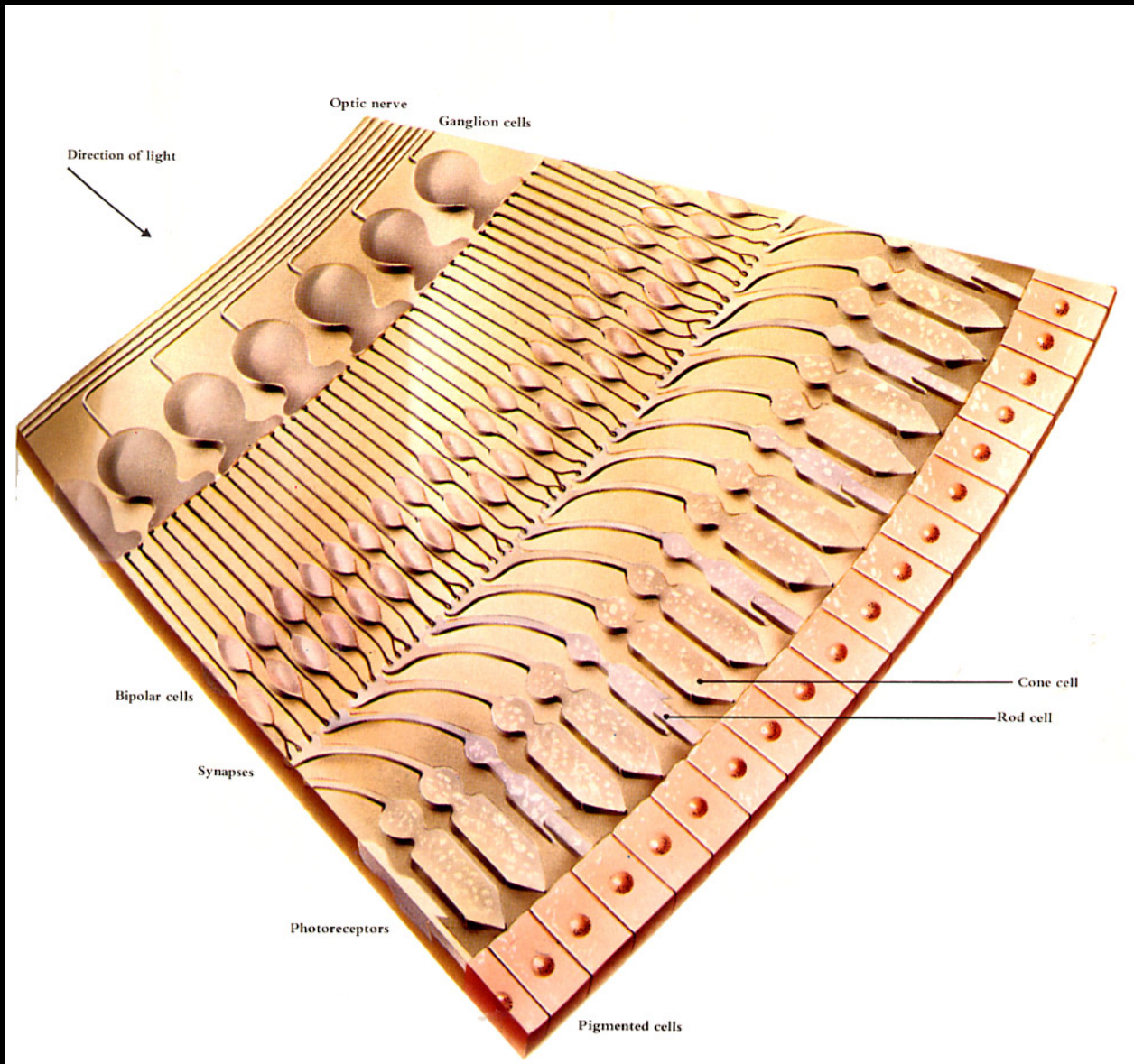


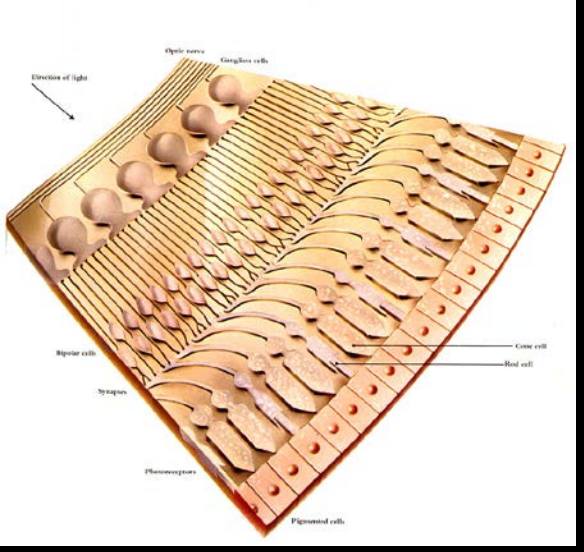


The Eye – retina

- Critics of creationism have used the design of the eye and retina as an example of "bad design"
  — why ***are*** the photo-sensitive cells *in back?*

- However, this arrangement
  a) is necessary and
  b) does not diminish vision at all.





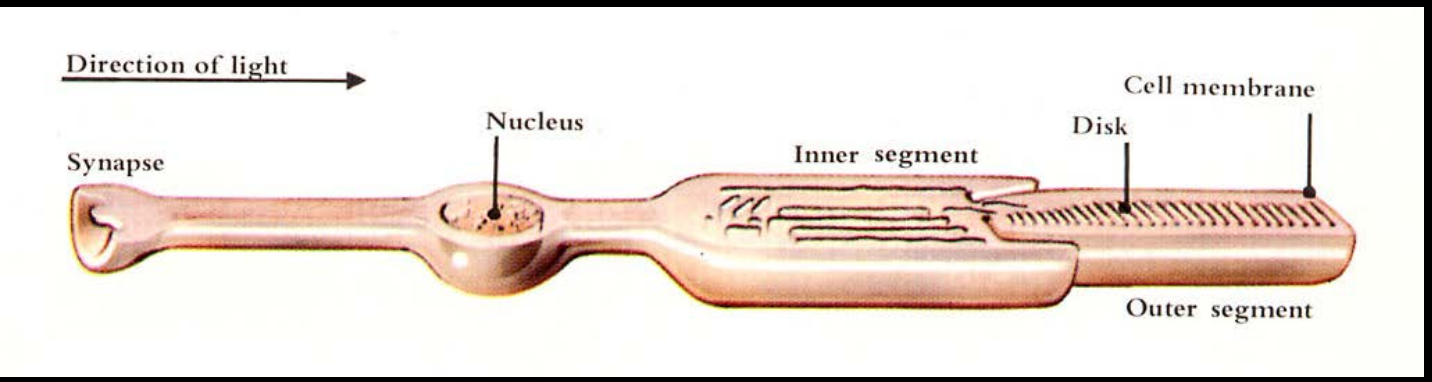
The Eye – wisdom of a backwards retina

"Ophthalmologist Dr George Marshall, says:

The idea that the eye is wired backward comes from a lack of knowledge of eye function and anatomy.

He explained that the nerves could not go behind the eye, because that space is reserved for the *choroid*, which provides the rich blood supply needed for the very metabolically active retinal pigment epithelium (RPE). This is necessary to regenerate the photoreceptors, and to absorb excess heat. So it is necessary for the nerves to go in front instead. The claim …that (nerves) interfere with the image is blatantly false, because the nerves are virtually transparent because of their small size and also having about the same refractive index as the surrounding vitreous humor."

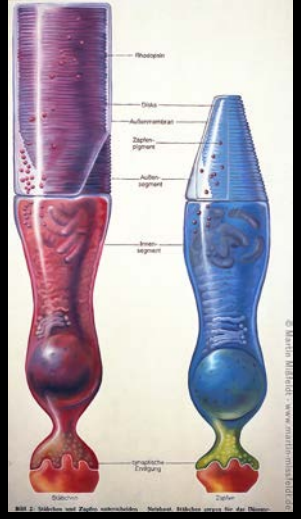
http://www.answersingenesis.org/home/area/re2/chapter7.asp



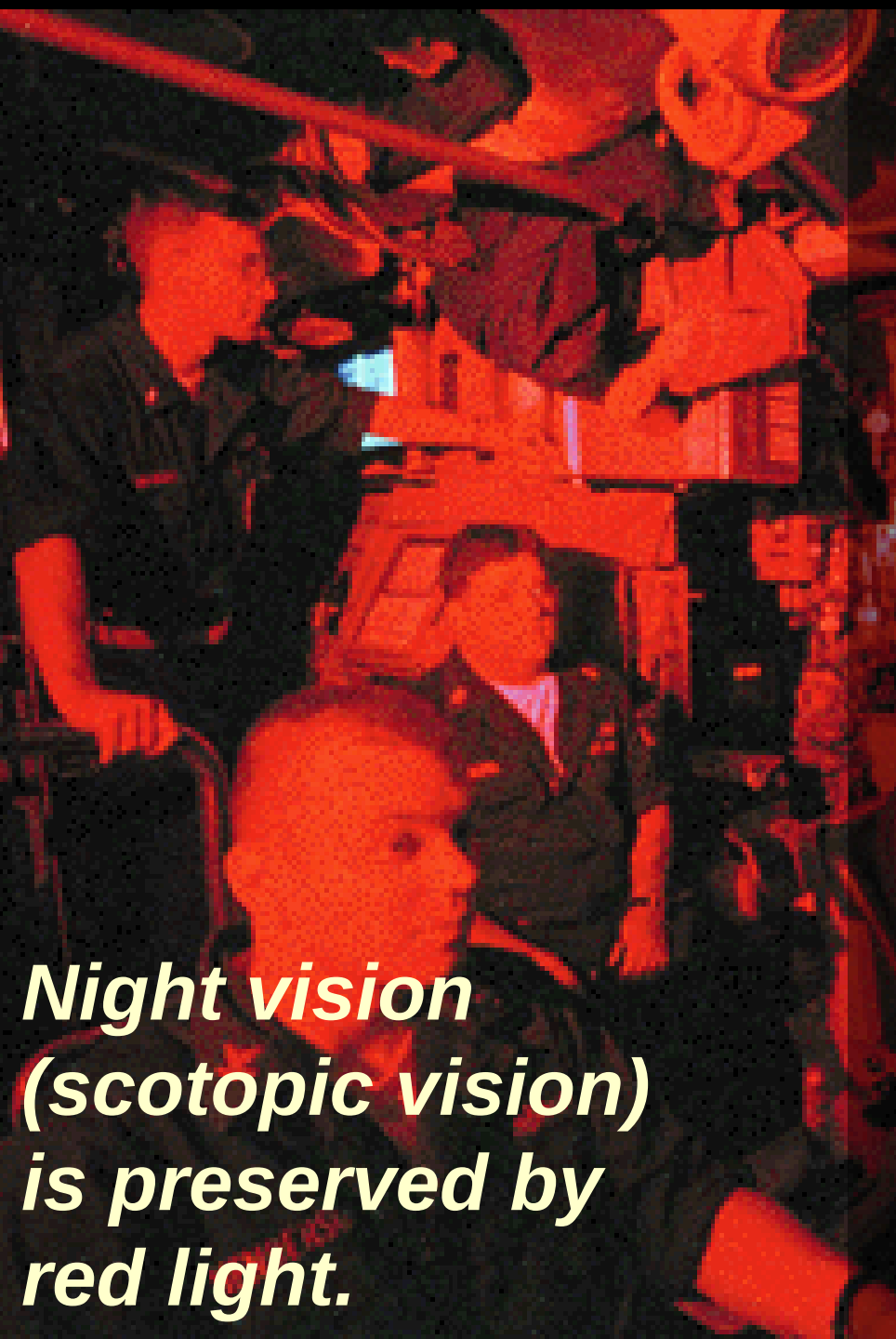
Rods

- Photosensitive cells .
- Shaped somewhat long and thin (compared to the cone-tipped cone cells).
- Function well **in dim light**.
- Our **night vision** depends on rods.
- Do **not** interpret color/hue **--** value only.
- (consequently, we do not see color well in low light)
- roughly **100 million** per eye

…Rods



- Rods contain **Rhodopsin** – “as light strikes this pigment, it bleaches, reducing electrical signals”
- This basically means that Rods get quickly “burned out” in daylight - or bright light - and so do not provide much information to the brain.
- However, at night, rods are roughly ***1000X more sensitive to low light than cones***.



Night vision (scotopic vision) is preserved by red light.

Military submarines always use red light during night time, when it's dark outside.

Why?
The sub crew has to keep both photopic vision (in order to be able to read all the control panels) and scotopic vision (in case if they have to look into a periscope during night time).

Red light is also used during nighttime by pilots, tank crew members, old-school astronomers and some lab-workers, who experiment with photosensitive materials.

...Rods don't see Red

Cockpit lighting of a B-52 set for night operations.

Reference
Hecht, 2nd Ed.
Sec. 5.7

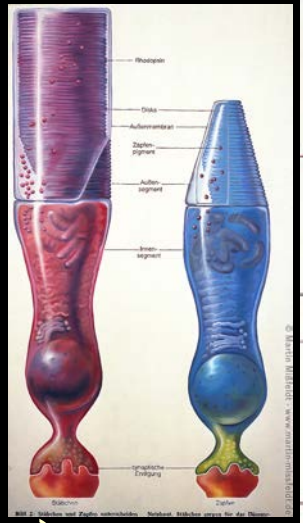
...Rods don't see Red

"The light response of the rods peaks sharply in the **blue**; they **respond very little to red light**. This leads to some interesting phenomena:

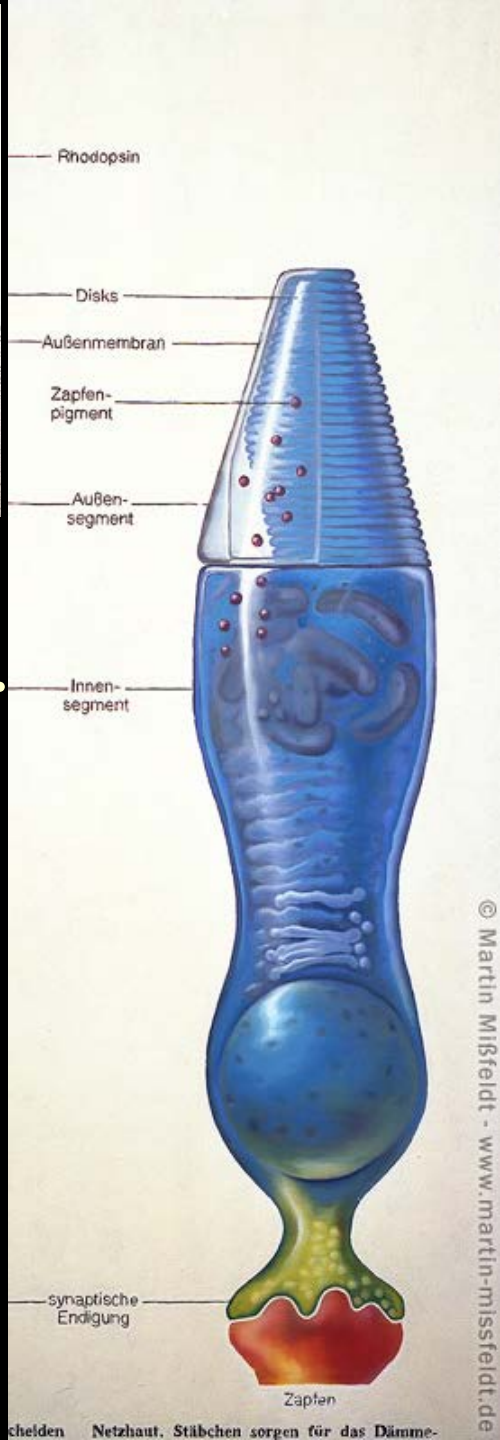
"The ship captain has red instrument lights. Since the rods do not respond to red, the captain can gain full dark-adapted vision with the rods with which to watch for icebergs and other obstacles outside.
It would be undesirable to examine anything with white light even for a moment, because the attainment of optimum night-vision may take up to a half-hour. Red lights do not spoil it."

Reference
Hecht, 2nd Ed.
Sec. 5.7

Cones

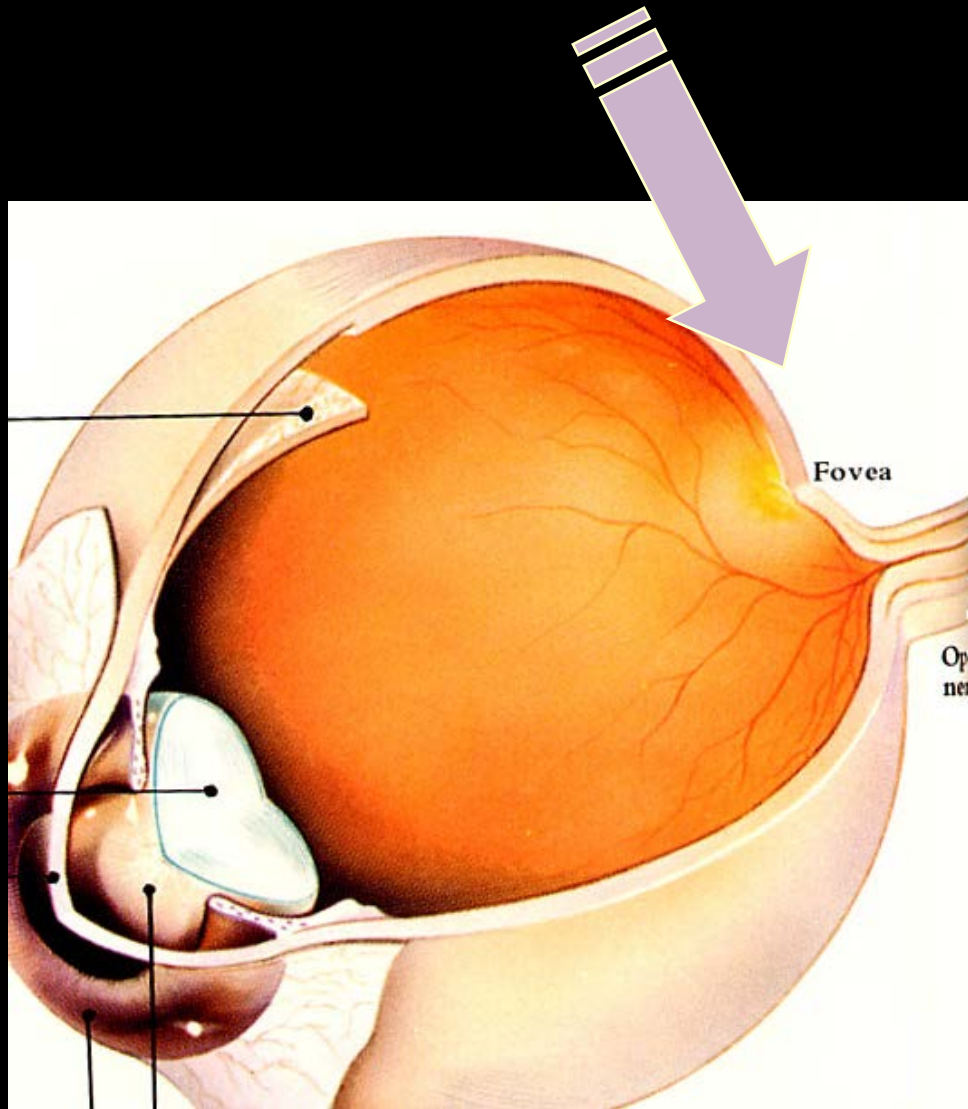


- Photosensitive cells (Iodopsin).
- Tips are shaped somewhat like cones.
- Function in **bright** light.
- Our **color/hue vision** depends on cones.
- There are ***three types of cones*** – each sensitive to red, green, **or** blue light.
- Roughly **6 million** per eye.



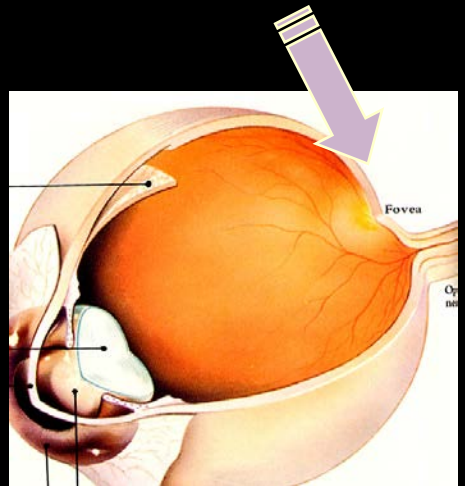
Fovea - hyper-sensitive color vision

- A tiny (1mm) area on the retina is covered with a dense collection of cones.
- This region is where we **see color distinctions best**.

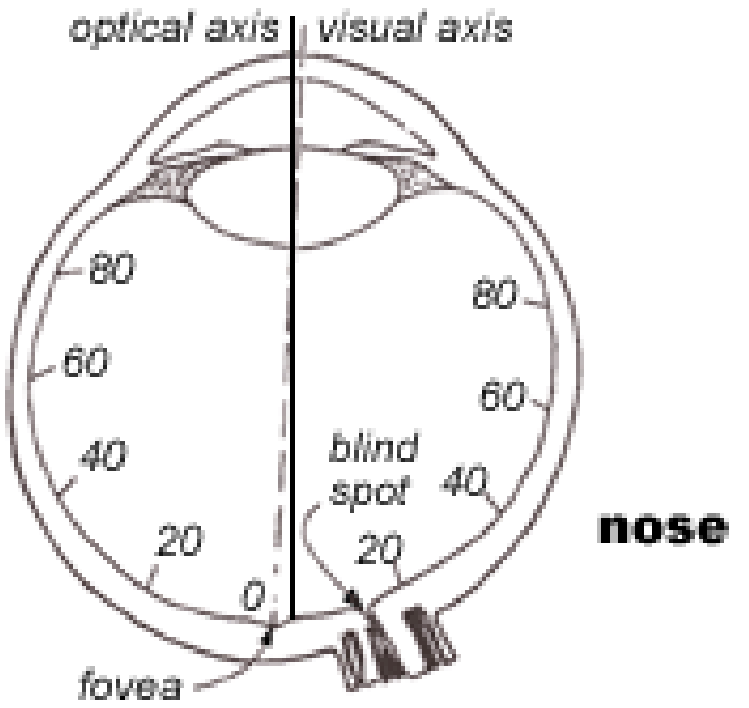


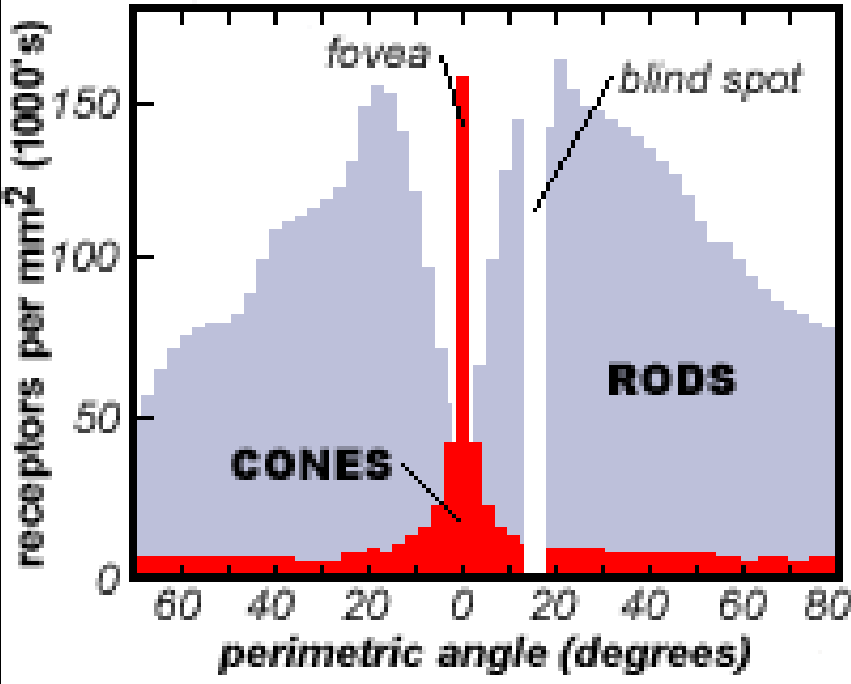
Varied Density of Rods & Cones

- **distribution of receptors**
- **across the retina**
- *left eye shown; the cones are concentrated in the fovea, which is ringed by a dense concentration of rods.*



http://
www.handprint.com
/HP/WCL/color1.html

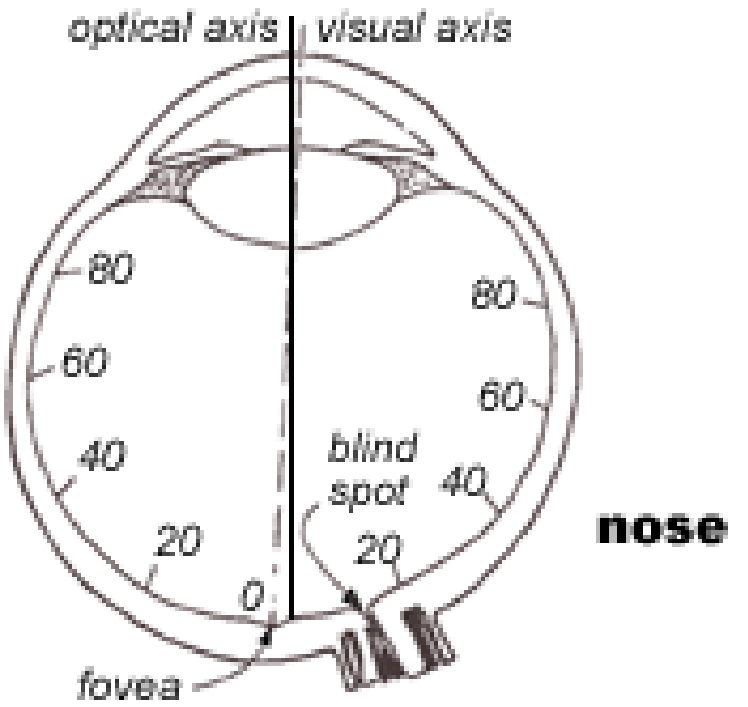


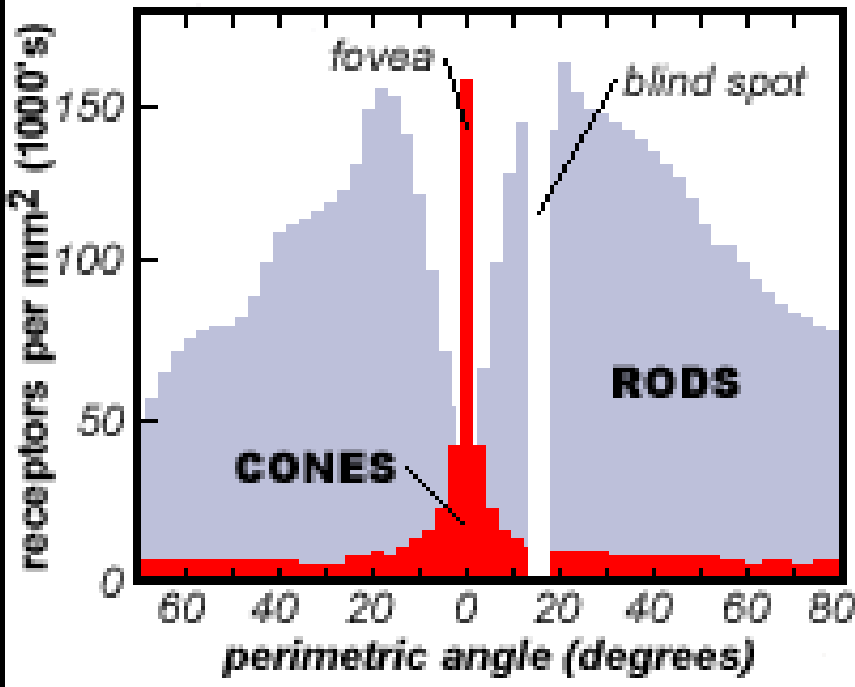


Varied Density
Cones along the fovea

- "**160,000 to 250,000** cones per square millimeter in the central fovea…
- …about **50,000** cones per square millimeter at the foveal border
- …about **5,000** cones per square millimeter in the retinal periphery."

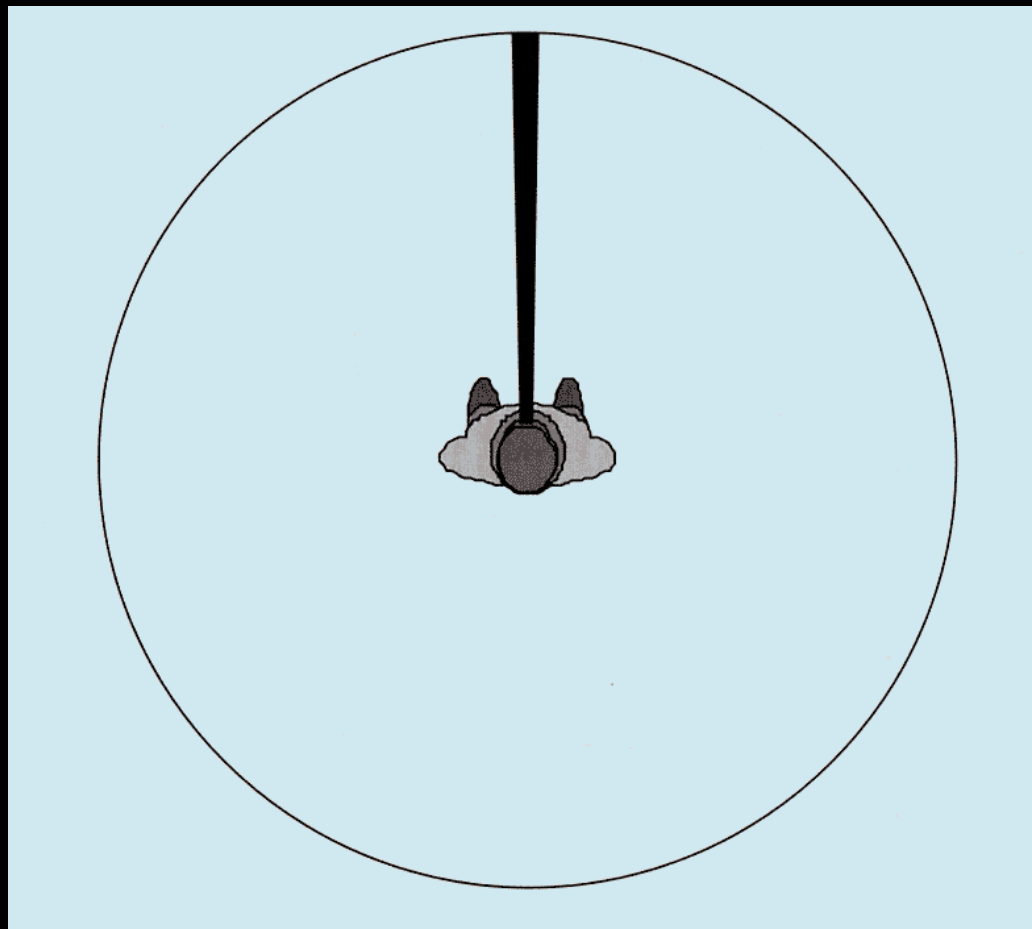
http://handprint.com/HP/WCL/color1.html#designeye





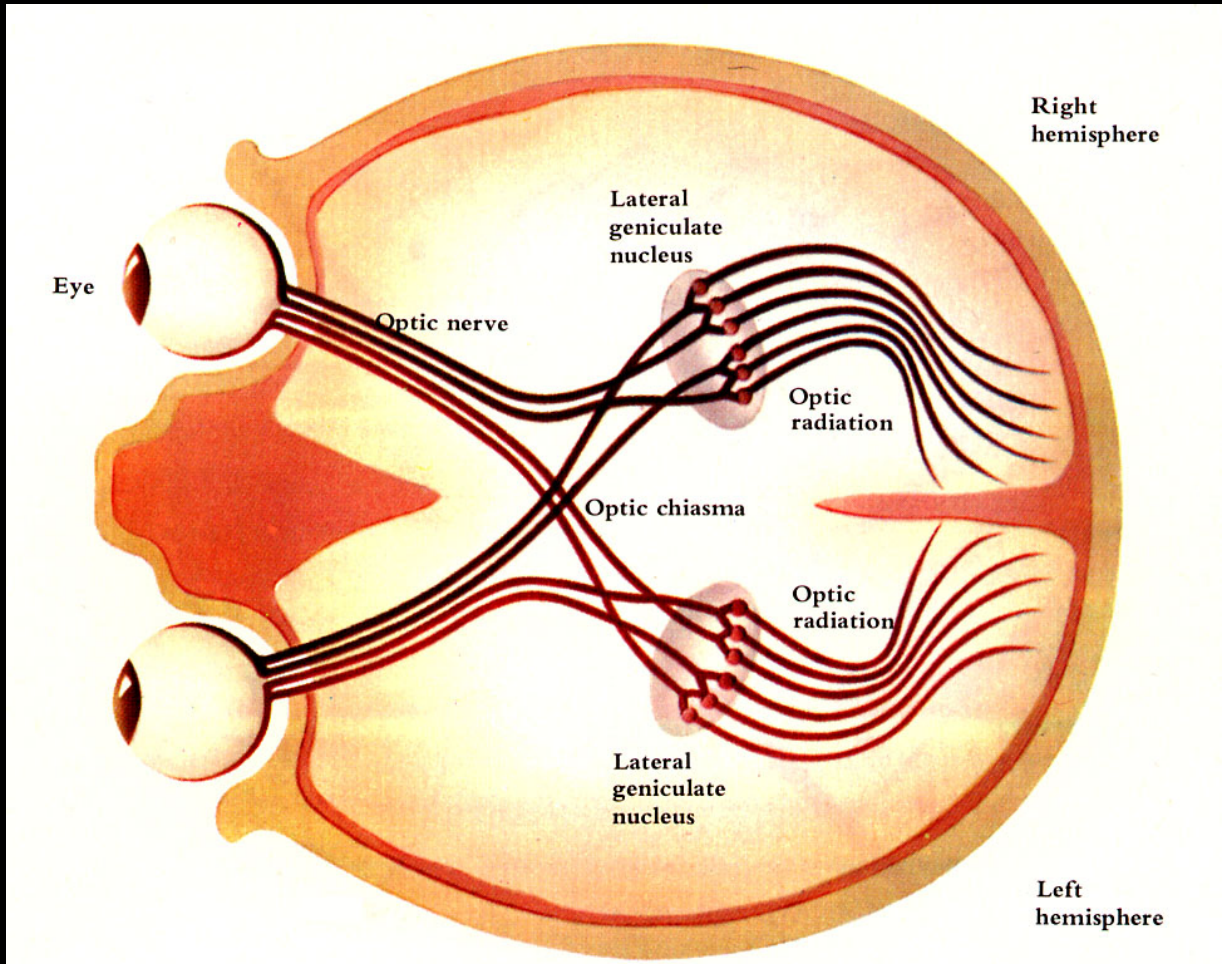
Fovea gives hyper-sensitive color vision

- Only a **2-degree region** of our visual field has this heightened color perception.
- We habitually redirect our eyes so that sharpest color vision is used.



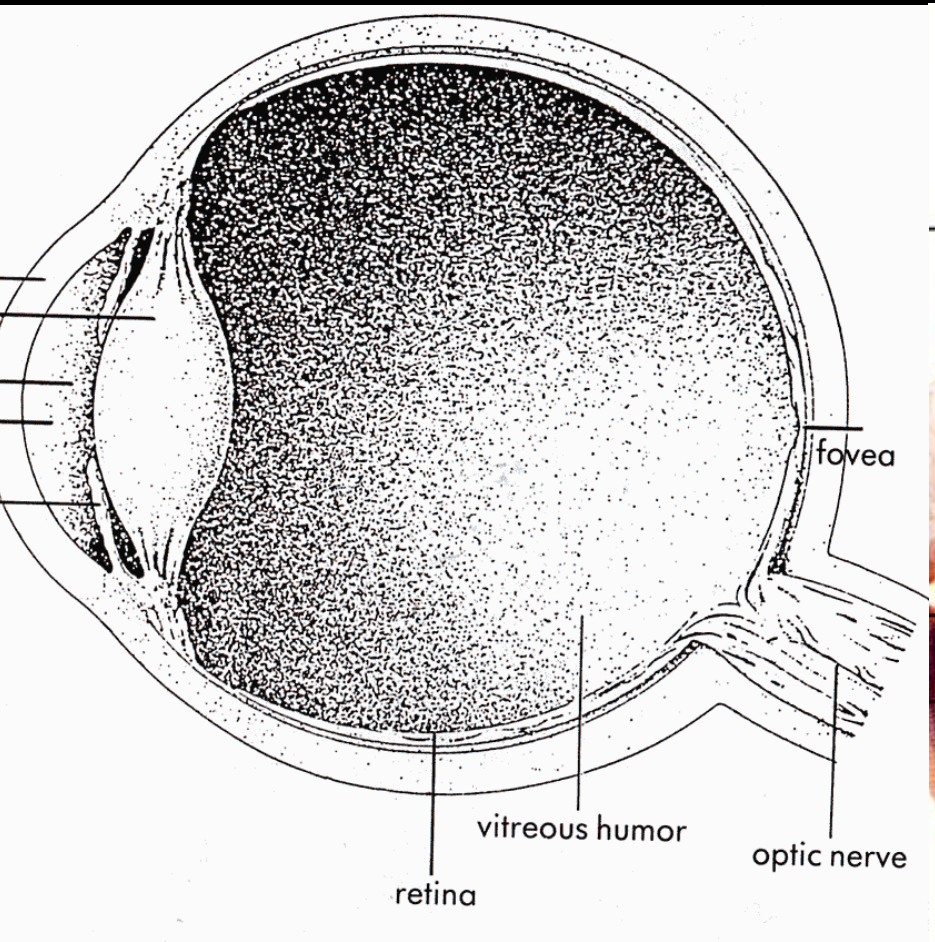
From the eye to the brain

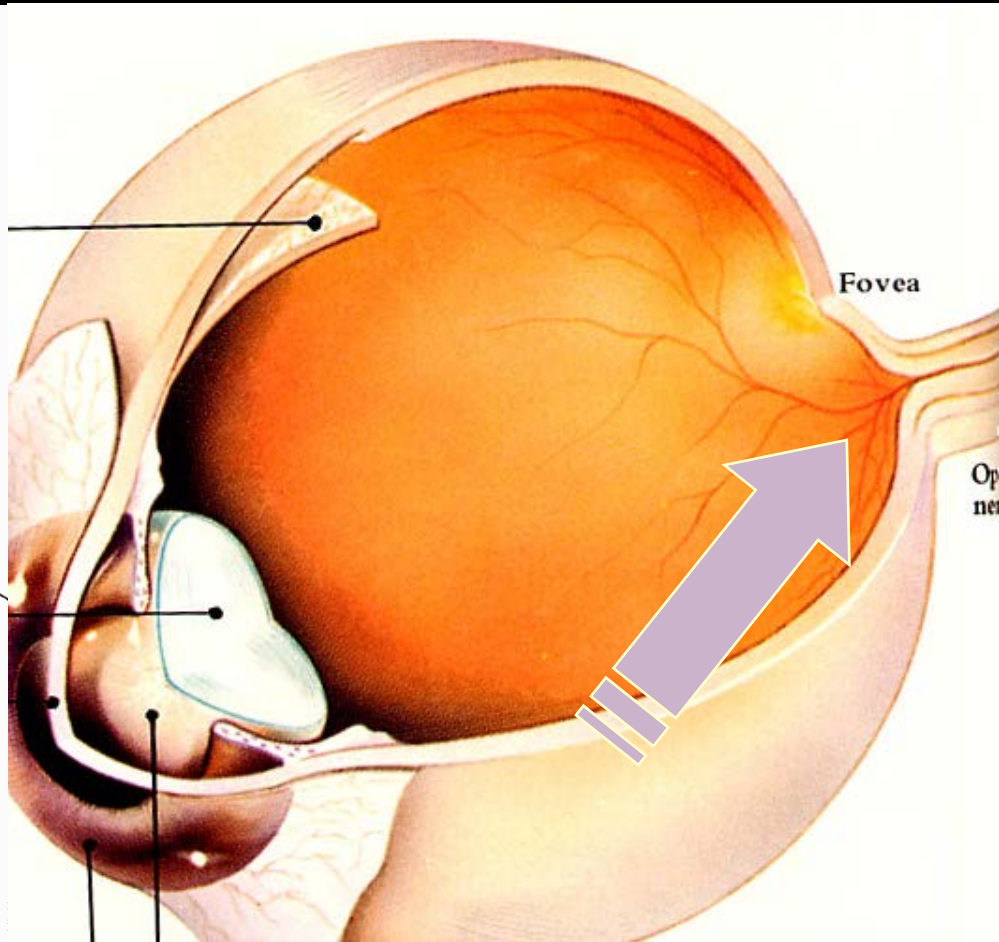
- The **optic nerve**, and its various parts, transfers nerve impulses from the rods and cones to the brain.



Blind spot at Optic Nerve

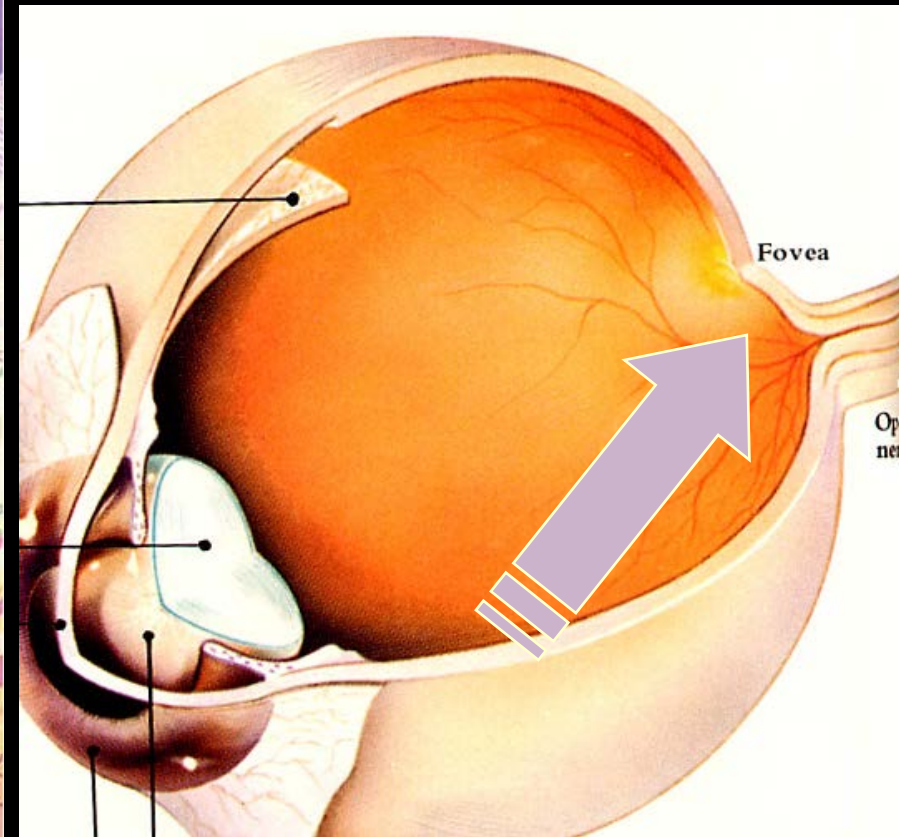
- Each eye has a blind spot where the optic nerve passes through the retina.





Blind spot at Optic Nerve

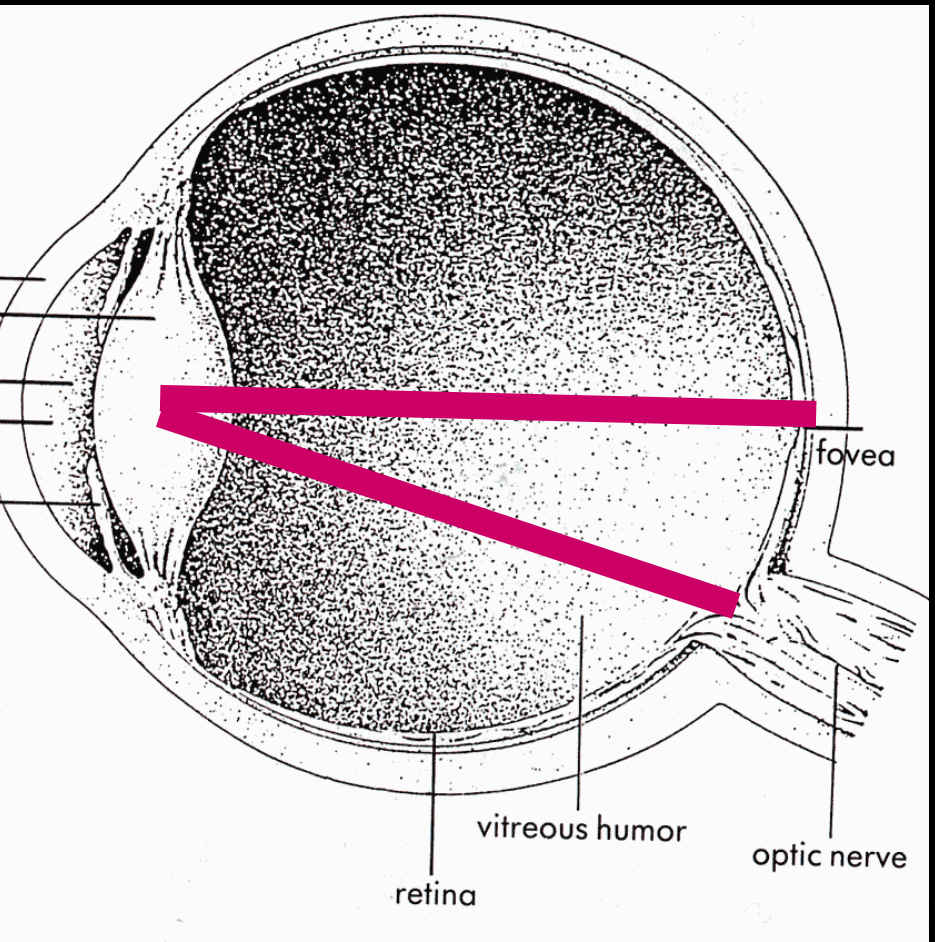
- Each eye has a blind spot where the optic nerve passes through the retina.



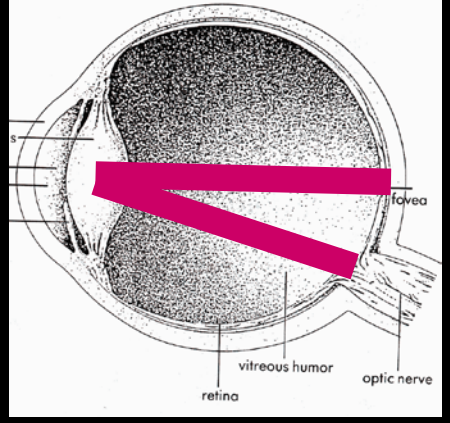
Blind spot

Close right eye. Focus on hand moving to the right….until the yellow dot disappears.

Blind spot at Optic Nerve



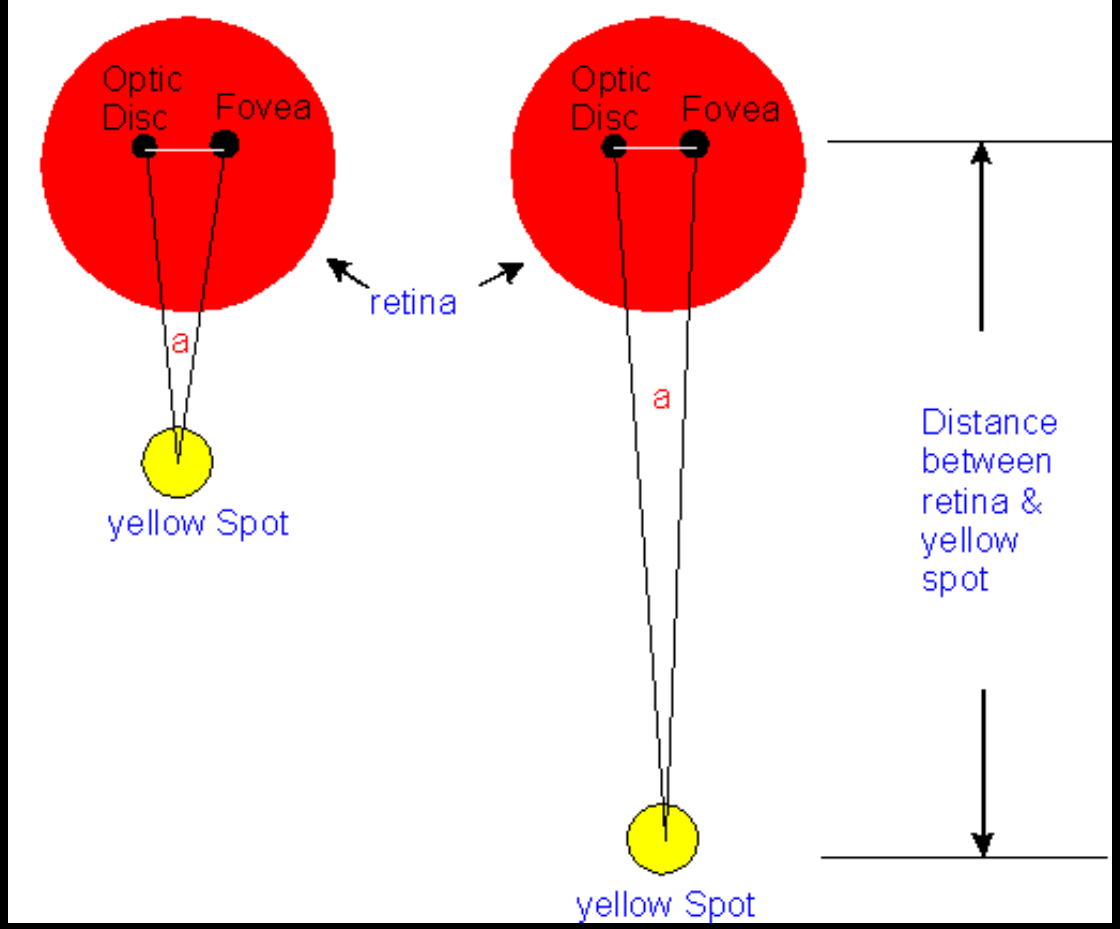
- Each eye has a blind spot where the optic nerve passes through the retina.
- The distance between the hand and the (invisible) dot, is related to the distance between you fovea and optic nerve.

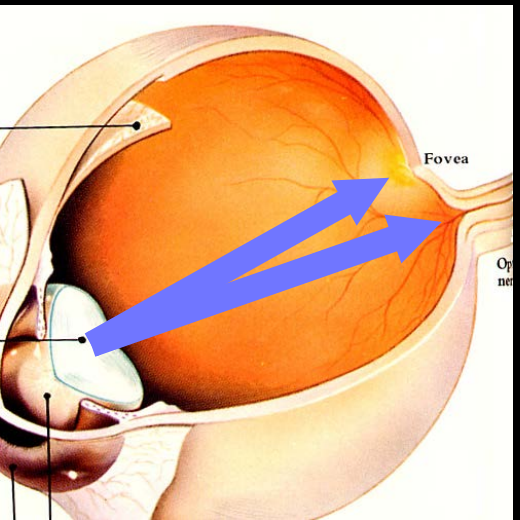


Impact of the Blind spot

- "…the blind spot occupies only 0.25% of the visual field, and…
  is far (15˚) from the visual axis so that the visual acuity of the region is only about 15% of the foveola, the most sensitive area of the retina right on the visual axis.
  So the alleged defect is only theoretical, not practical. The blind spot is not considered handicap enough to stop a one-eyed person from driving a private motor vehicle. The main problem with only one eye is the lack of stereoscopic vision."
- http://www.answersingenesis.org/home/area/re2/chapter7.asp

Angle/ distance between optic disk and fovea

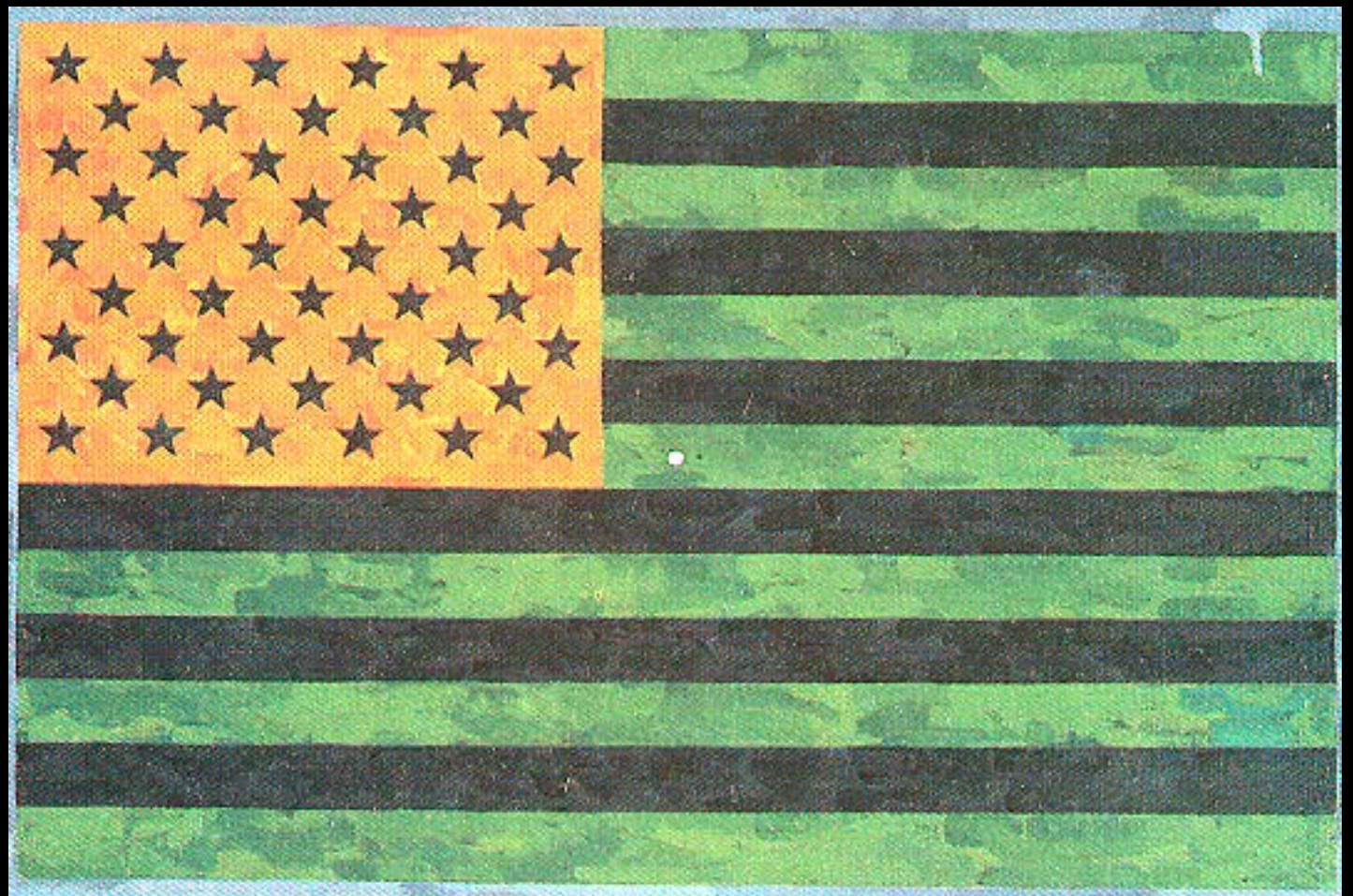




- **Form a triangle using the distance between the optic disc and the fovea as one side. You can see that as the distance between the spot and the retina changes the angle (a) changes. It gets larger as the distance gets shorter.**
- **Consequently, the closer you are to the screen the nearer you need to fix to the dot in order to make it disappear.**

Next time…
Seeing what isn't

- Wiping out those cones…
  …Color Afterimage.



Online color-discrimination challenge

- Check out, complete, and email me your result from the color-sorting challenge at:

- http://www.xrite.com/custom_page.aspx?PageID=77

- (linked directly from our course calendar)

- Color After Image is ALSO called *Successive Contrast*.
  (not to be confused with *Simultaneous Contrast* – which we meet soon)

Color Constancy

- Next class…
- … why does a white building look white in orange light?

- Read the rest of Chapter 3