NYU

CS-GY 6313 B: Information Visualization

9/19/2024

Logistics

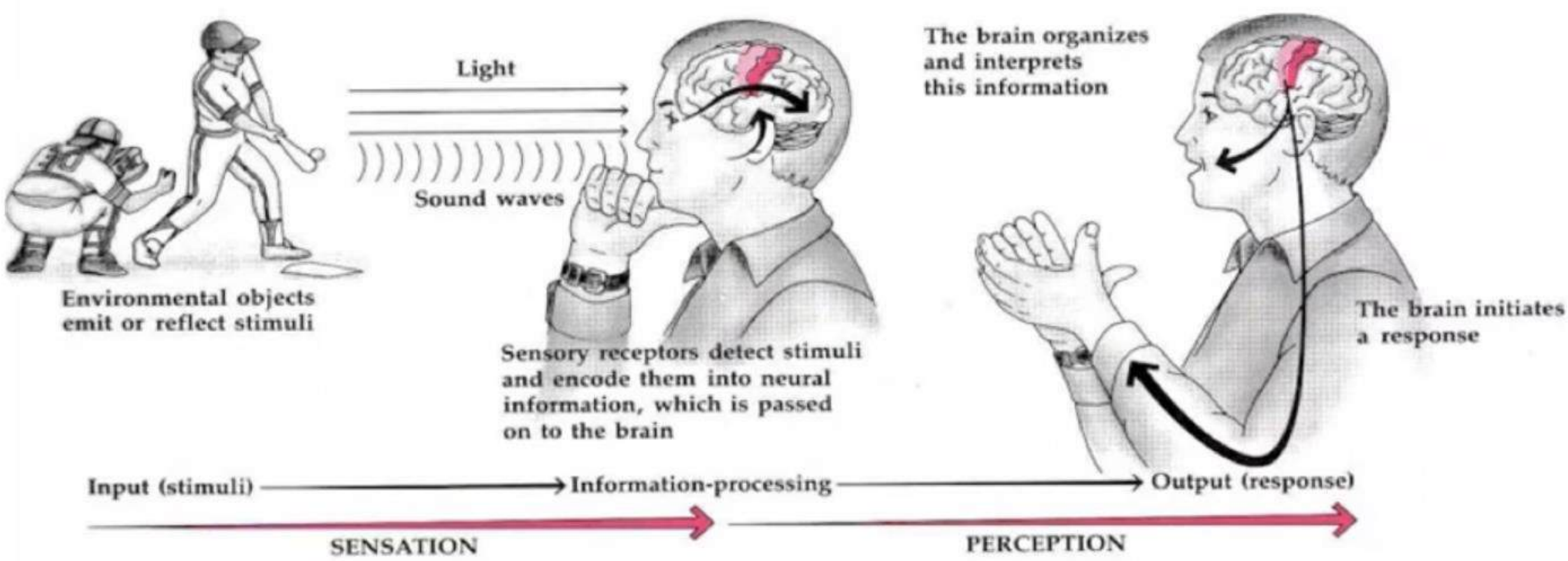
- Assignment 1 today
- Join the class Slack: Link on syllabus
- LaTeX tip: *If homebrew is installed, instead of the massive 6gb install of all tex stuff, brew has this cask: https://formulae.brew.sh/cask/basictex that installs the basic features that regular users need.*

Visual Perception

The Perceptual Process

- **Sensation:** physical stimulation
- **Perception:** interpretation of the sensory information

The Perceptual Process



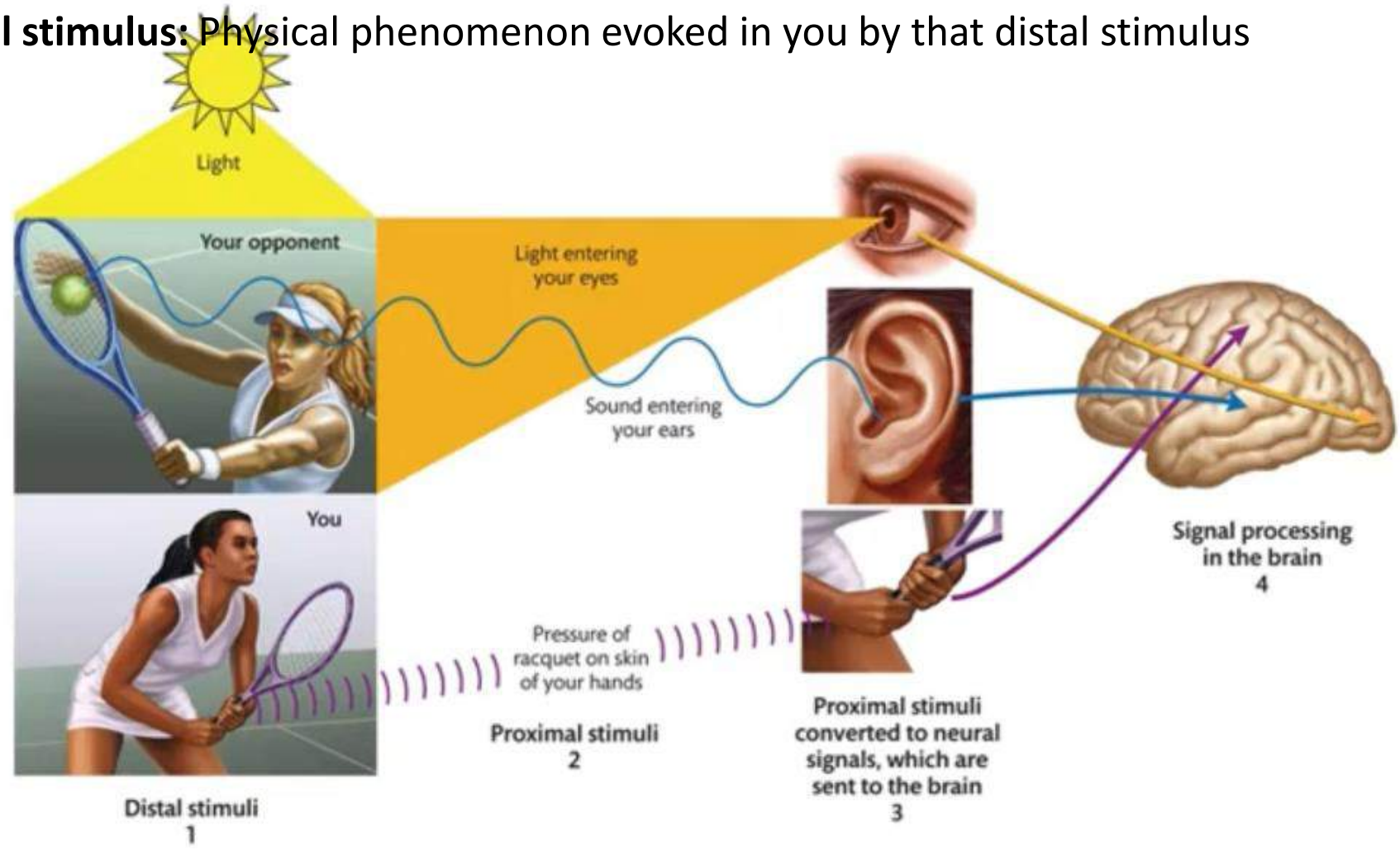
Sensation vs perception

- ***SENSATION:*** initial steps in the perceptual process, whereby **physical features of the environment** are converted into electrochemical signals that **are sent to the brain for processing**
  - ***SENSES:*** Physiological functions for converting particular environmental features into electrochemical signals

- ***PERCEPTION:*** Later steps in the perceptual process, whereby the initial sensory signals are used to **represent objects and events so they can be identified, stored in memory, and used in thought and action**
  - ***REPRESENTATION:*** information in the mind and brain used to identify objects and events, to store them in memory, and to support thought and action

Stimuli

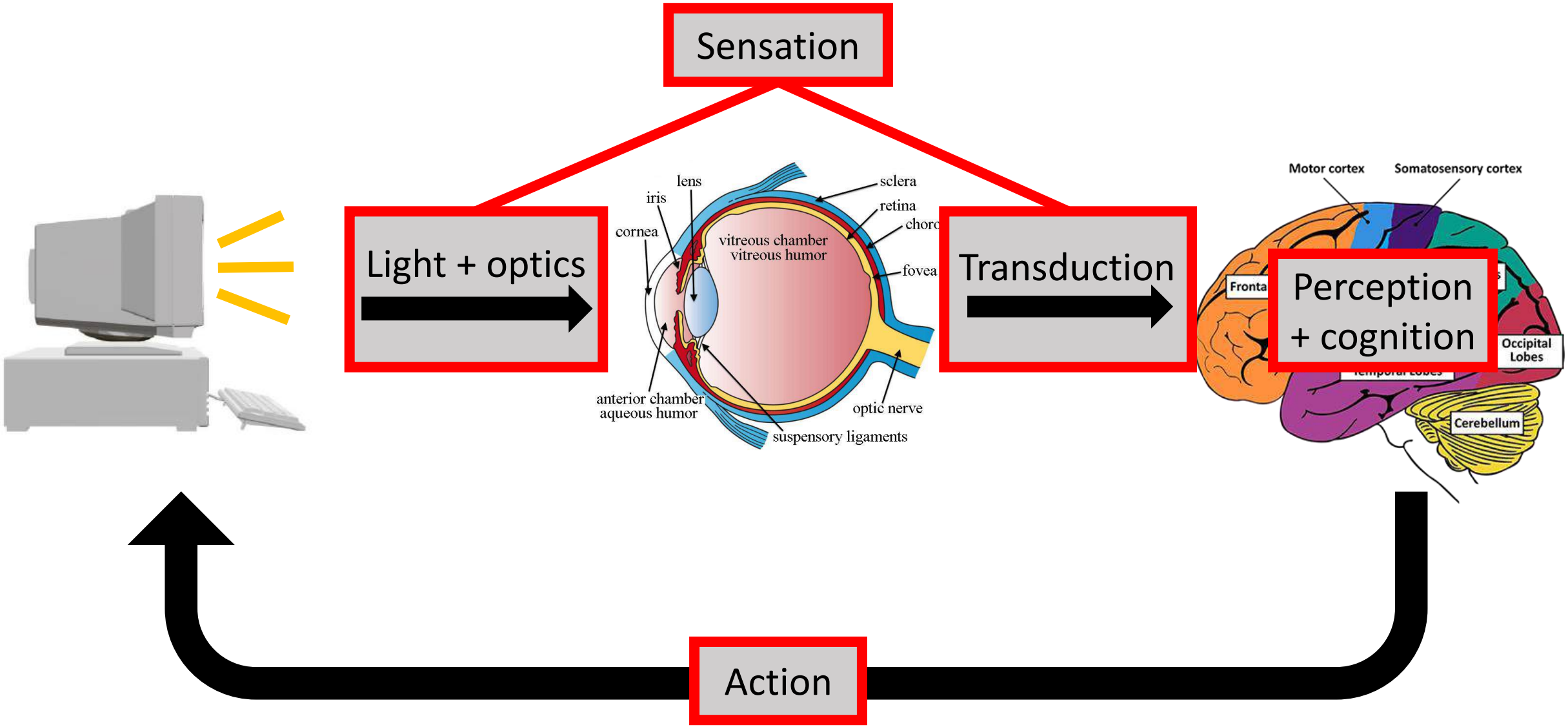
- **Stimuli:** Objects and events that are perceived (distal stimuli) and the physical phenomena they produce
  - **Distal stimulus:** Perceived object or event in the world
  - **Proximal stimulus:** Physical phenomenon evoked in you by that distal stimulus



Principles of perception

- **Bottom-up processing:** Information contained in neural signals from receptors
- **Top-down processing:** Observer's knowledge, expectations, and goals affect their perception of stimuli
  - An idea from 1866 (von Helmholtz)
  - Helps us explain things like optical illusions
  - https://www.youtube.com/watch?v=bgTbvyKyPCE
  - https://youtu.be/2k8fHR9jKVM?t=4

Perception-action loop



Light & Optics

- Electromagnetic Spectrum: Entire range of wavelengths of electromagnetic radiation

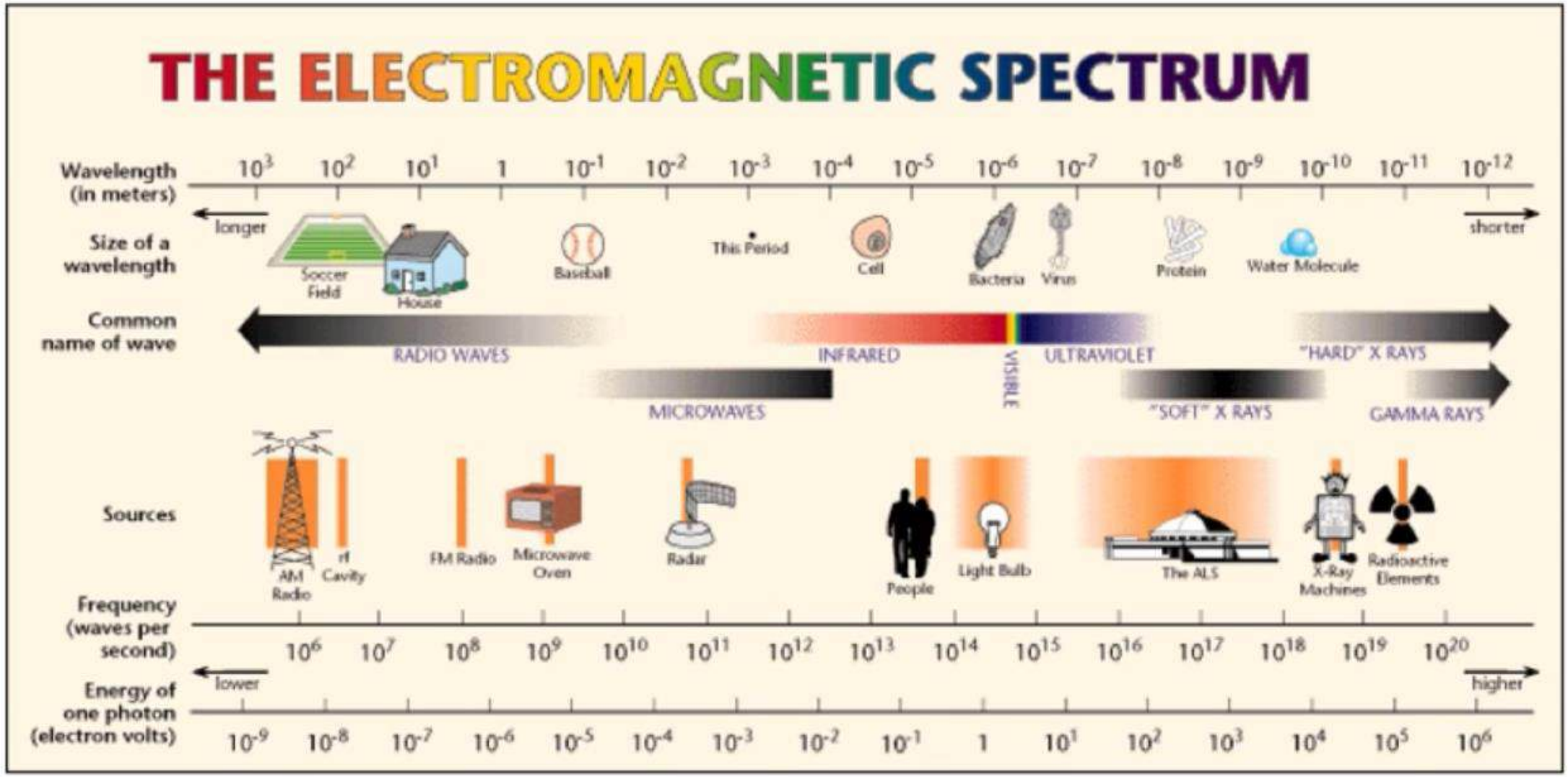
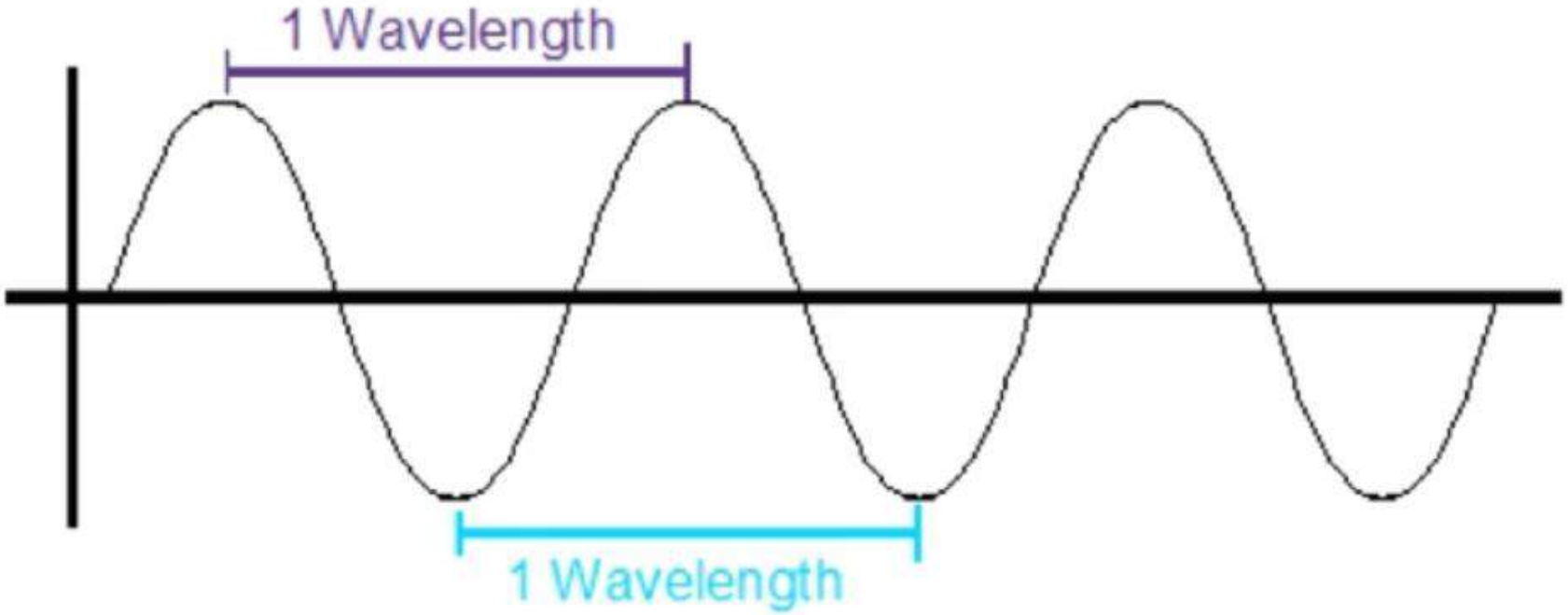


image source: http://www2.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html

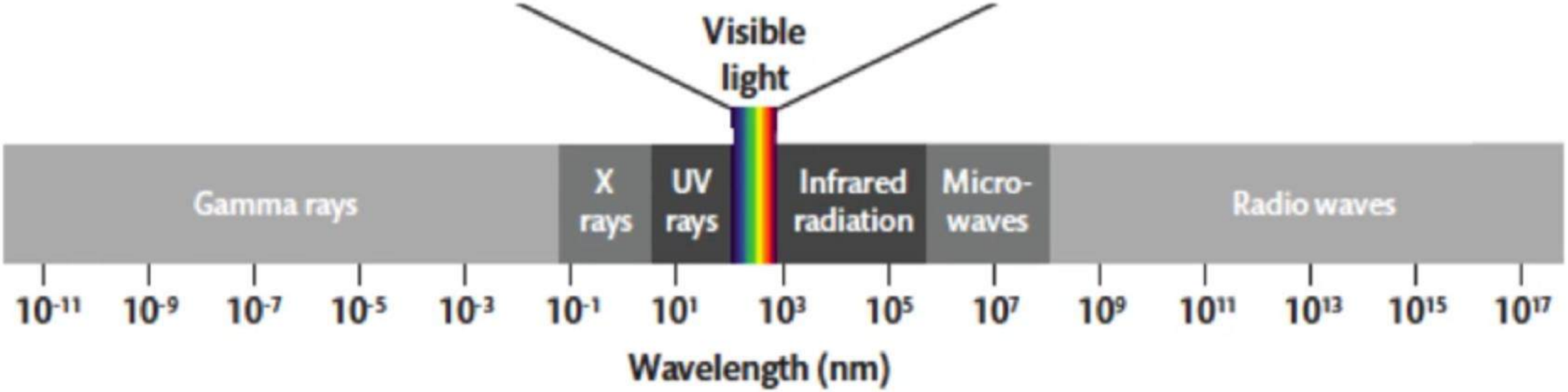
What is light?

- Both a wave and a particle
  - We care mostly about the wave properties
- Wavelength is a property of electromagnetic radiation
  - Distance between two successive peaks of waves
  - Different types of electromagnetic radiation are defined by their differences in wavelengths



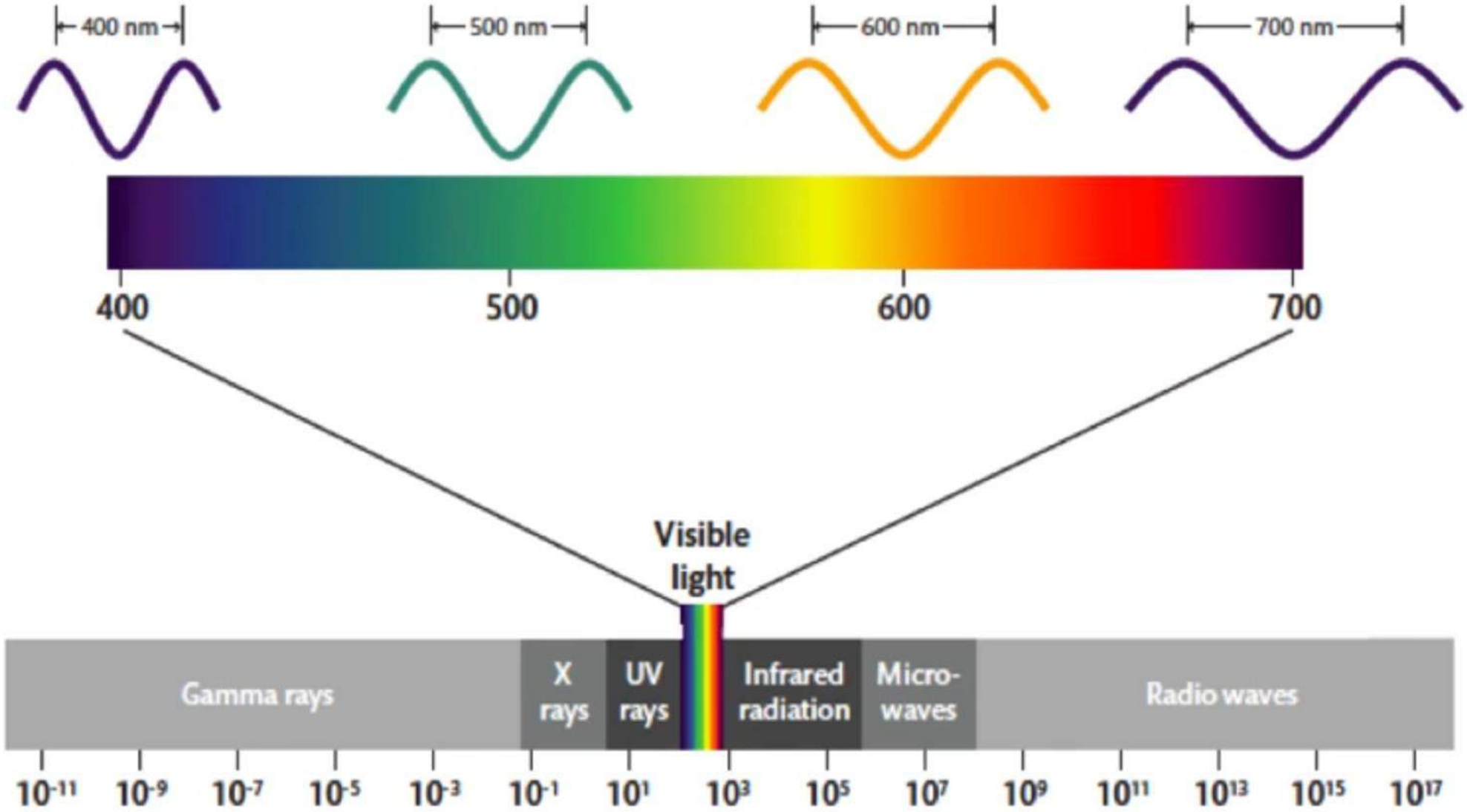
What is light?

- **Light** is the small slice of wavelengths in the middle of the spectrum (370 nm to ~730 nm)
  - In this range, differences in wavelength are perceived as differences in color

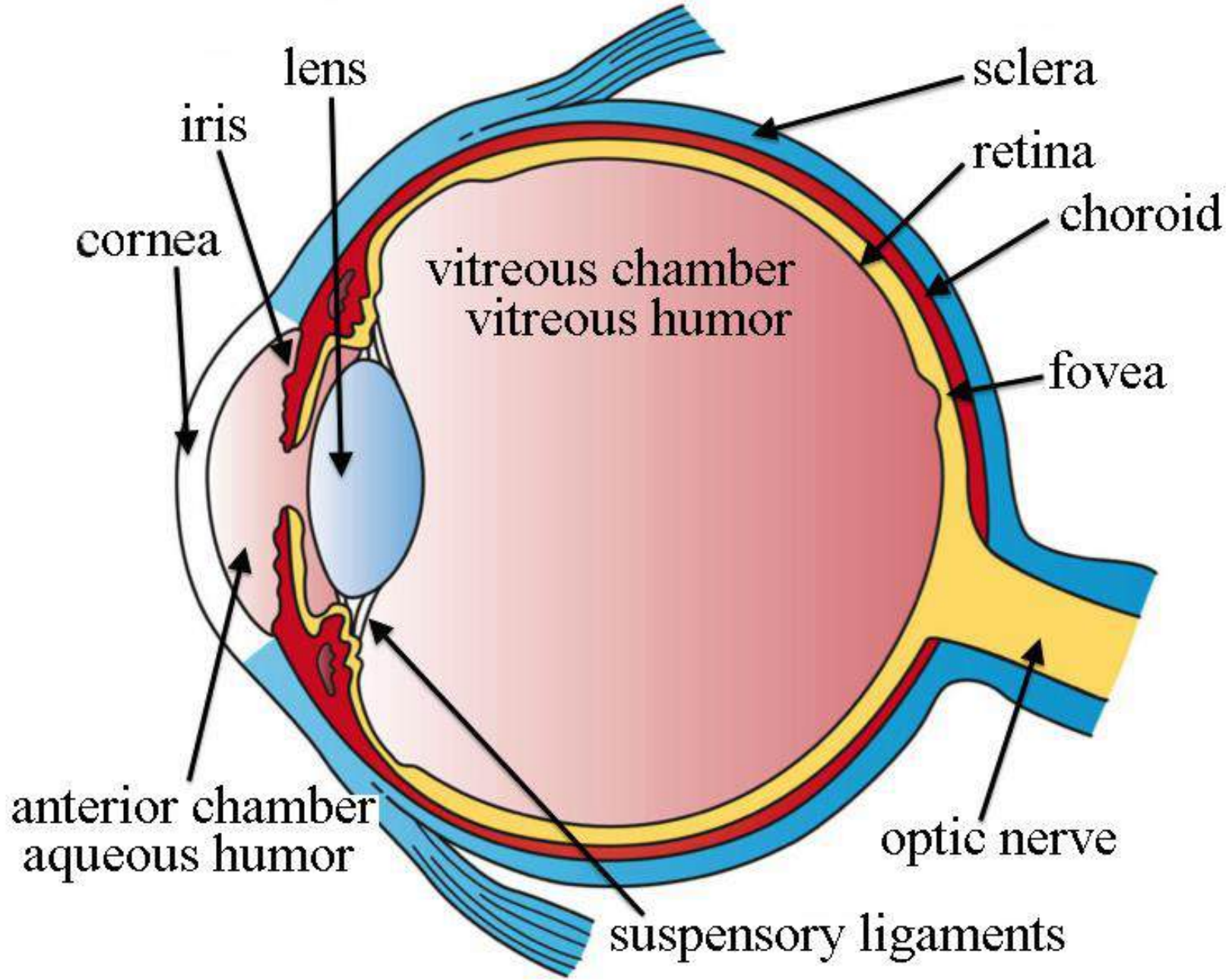


What is light?

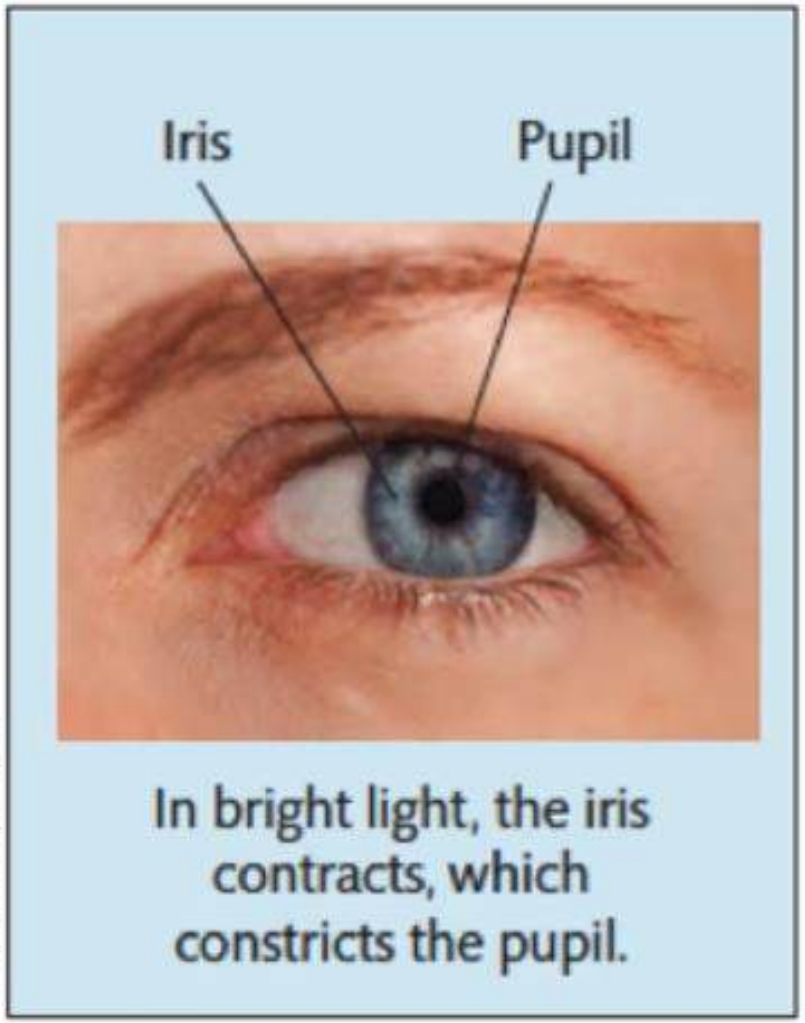
- **Color** of an object is the wavelengths of light that are reflected to the observer

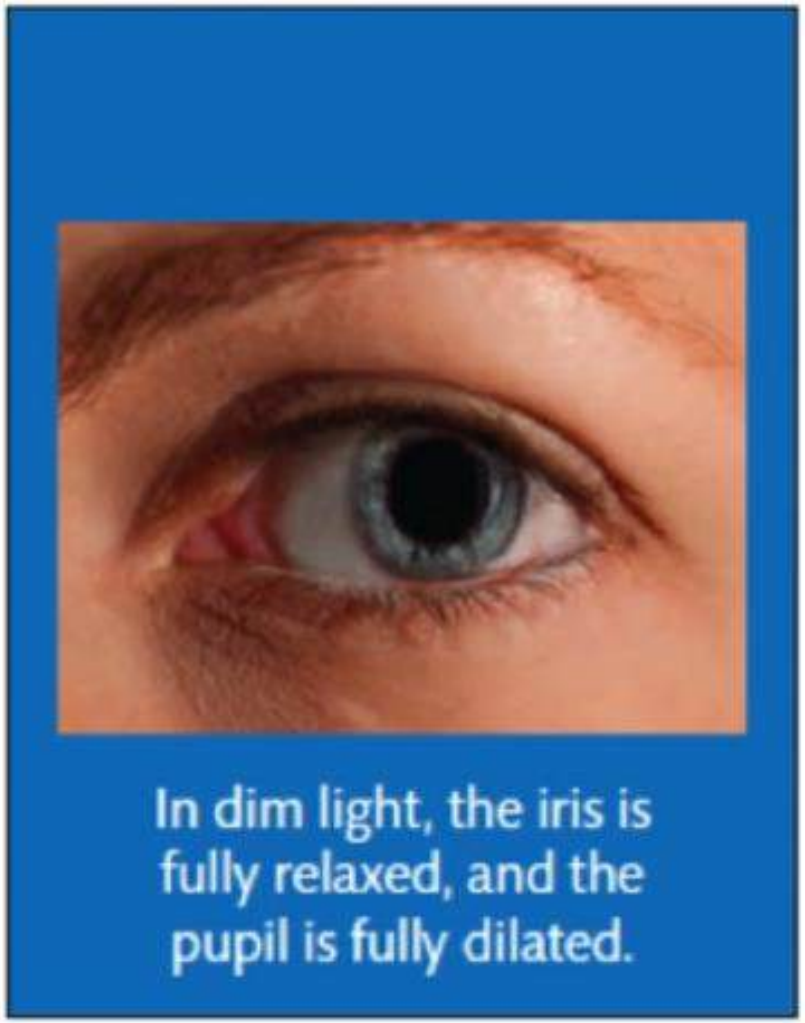


The Eye


lens
iris
cornea
sclera
retina
choroid
vitreous chamber
vitreous humor
fovea
anterior chamber
aqueous humor
optic nerve
suspensory ligaments

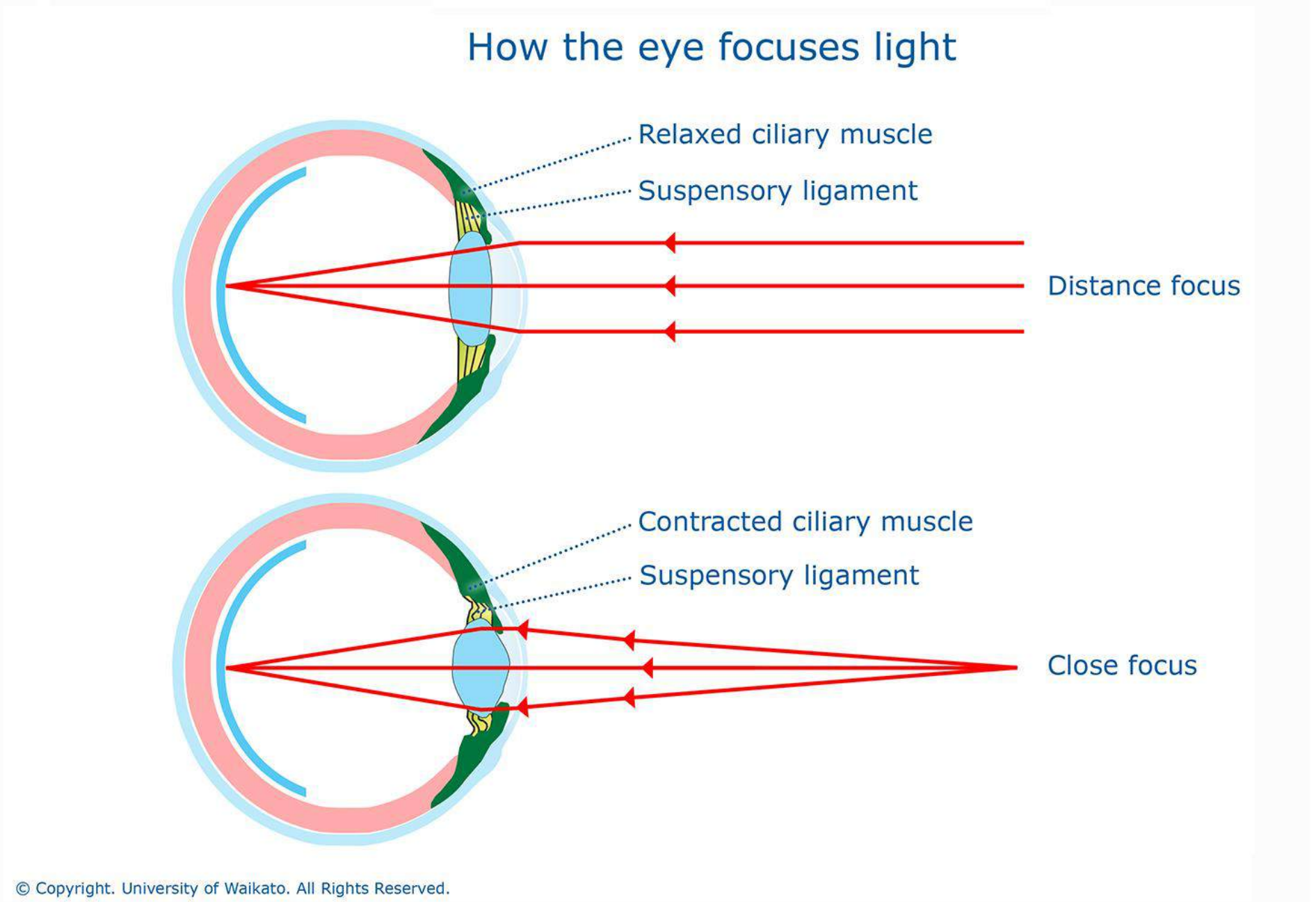
Iris and pupil





Ram.n Rivera-Moret

Lens


How the eye focuses light
Relaxed ciliary muscle
Suspensory ligament
Distance focus
Contracted ciliary muscle
Suspensory ligament
Close focus
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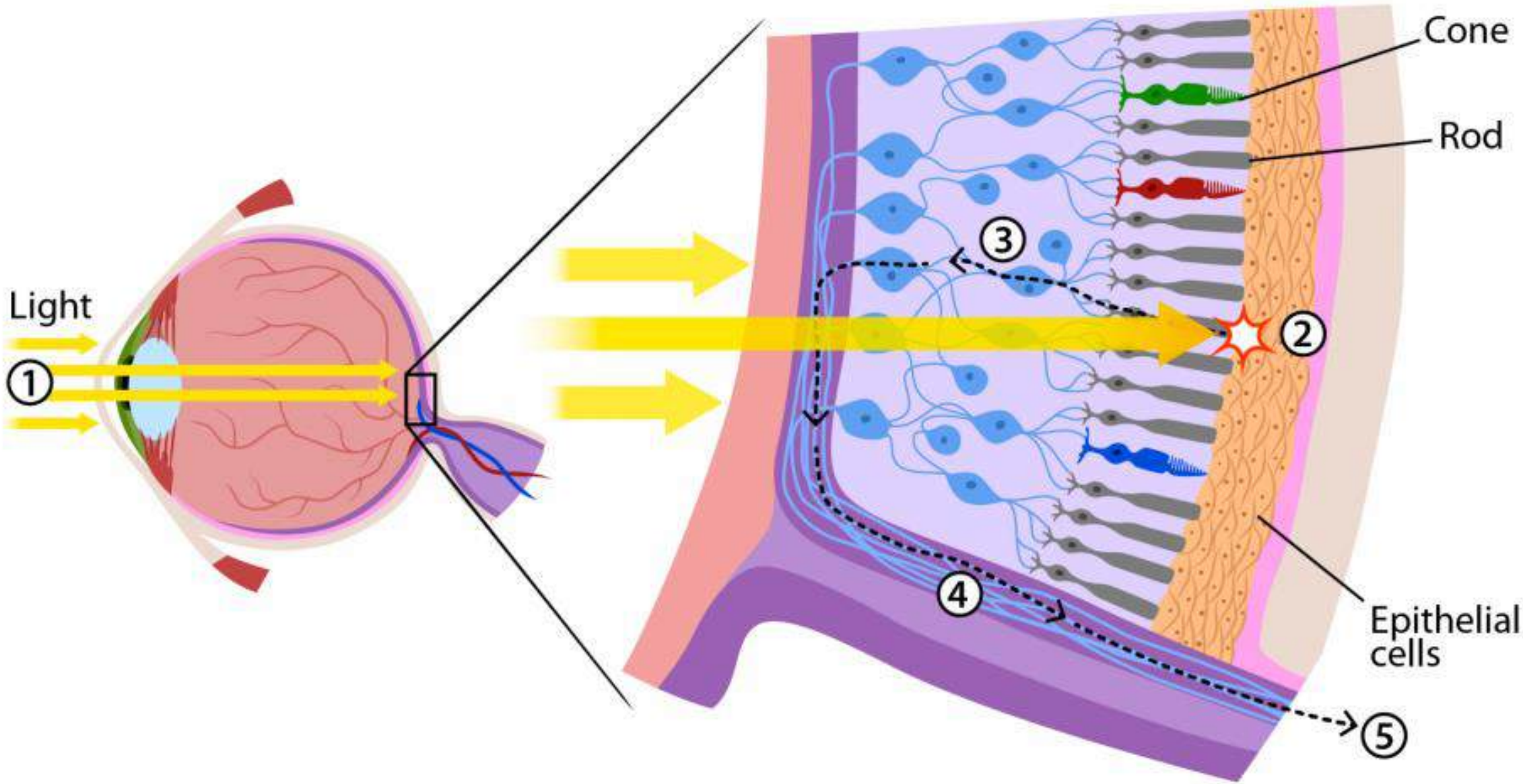
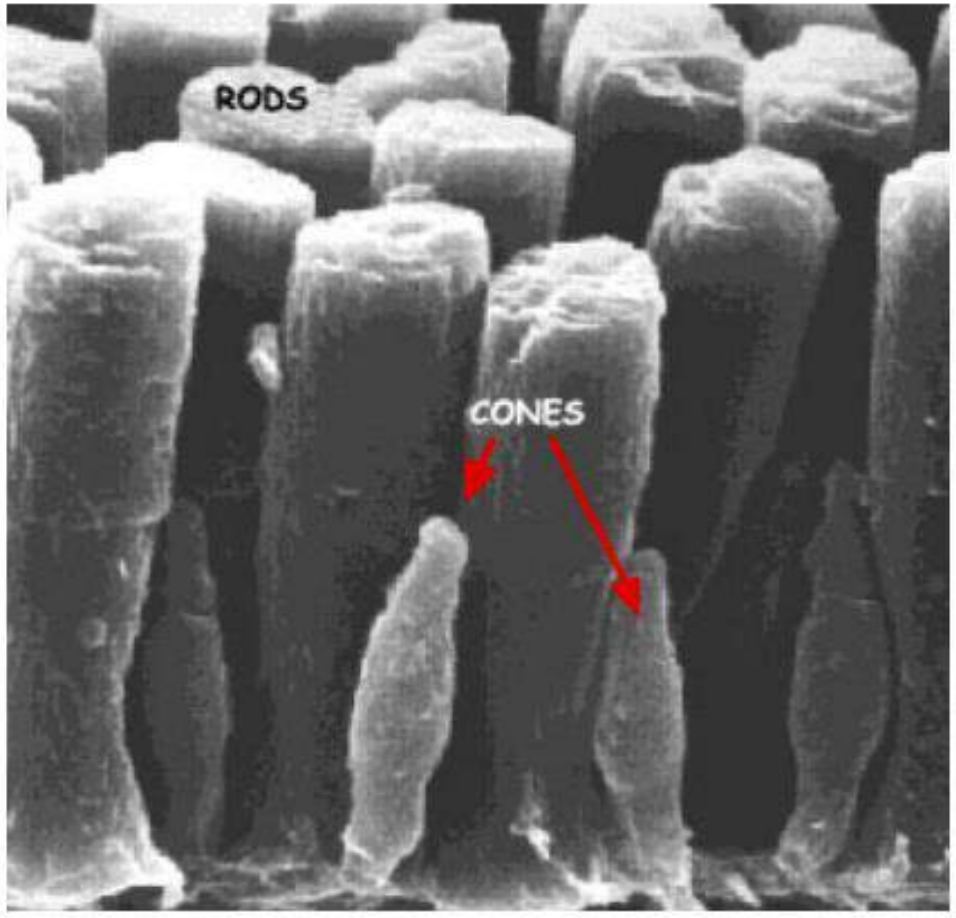
Retina



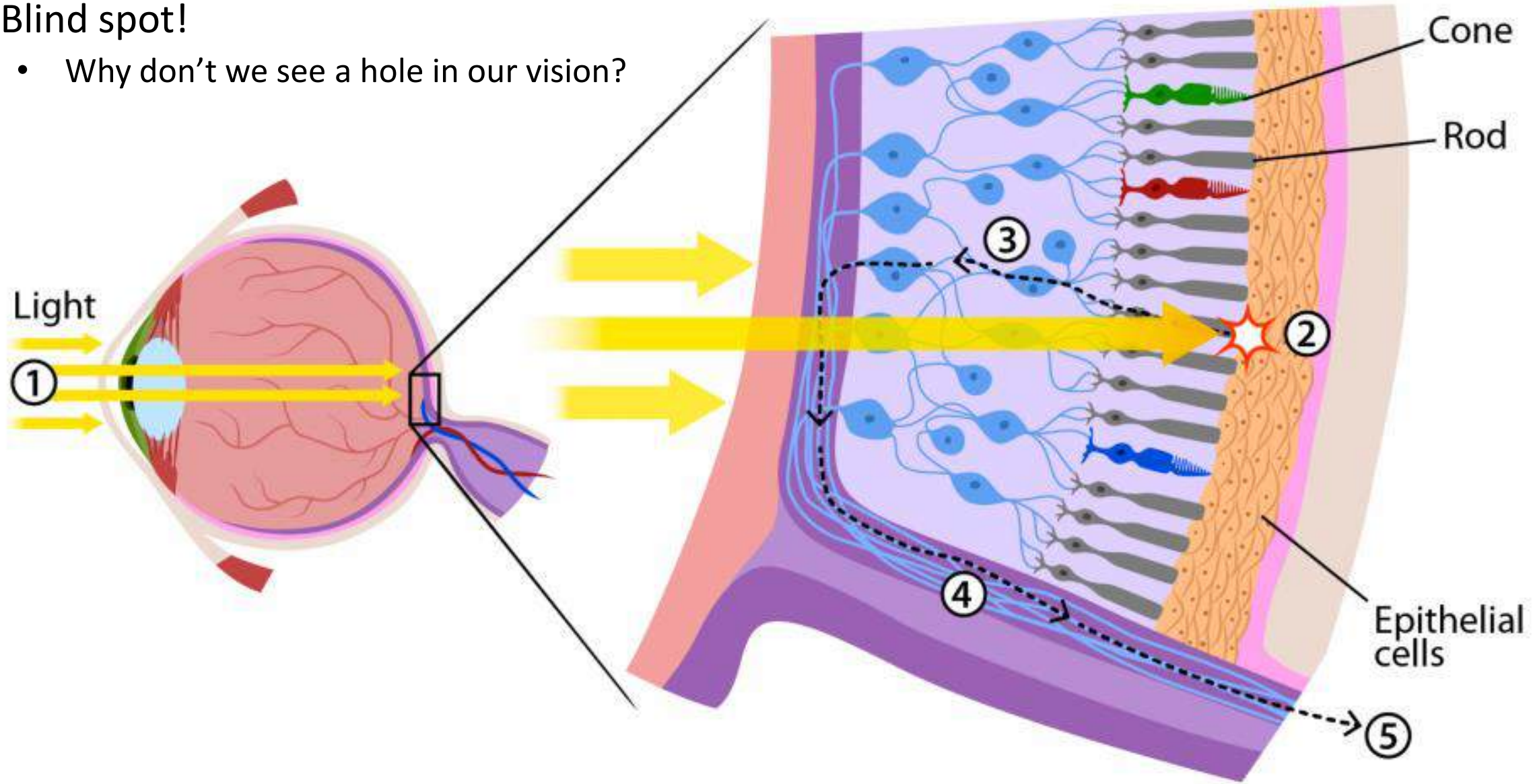
Retina: photoreceptors

- **Rods:** Sensitive to light levels, good for low light vision, can't see color
  - 120 million
  - Only one type
- **Cones:** Only activate at high light levels, responsible for color vision and fine details
  - 5-6 million
  - 3 types of cones:
    - ~60% L(ong)
    - ~30% M(edium)
    - ~10% S(hort)



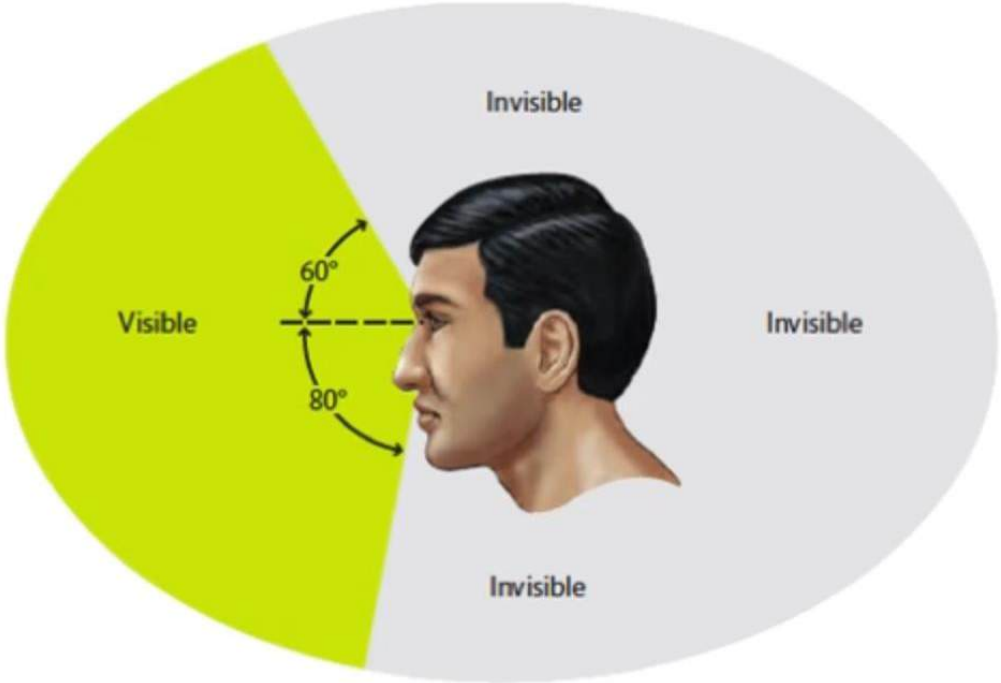
Retina: optic nerve

- Blind spot!
  - Why don't we see a hole in our vision?

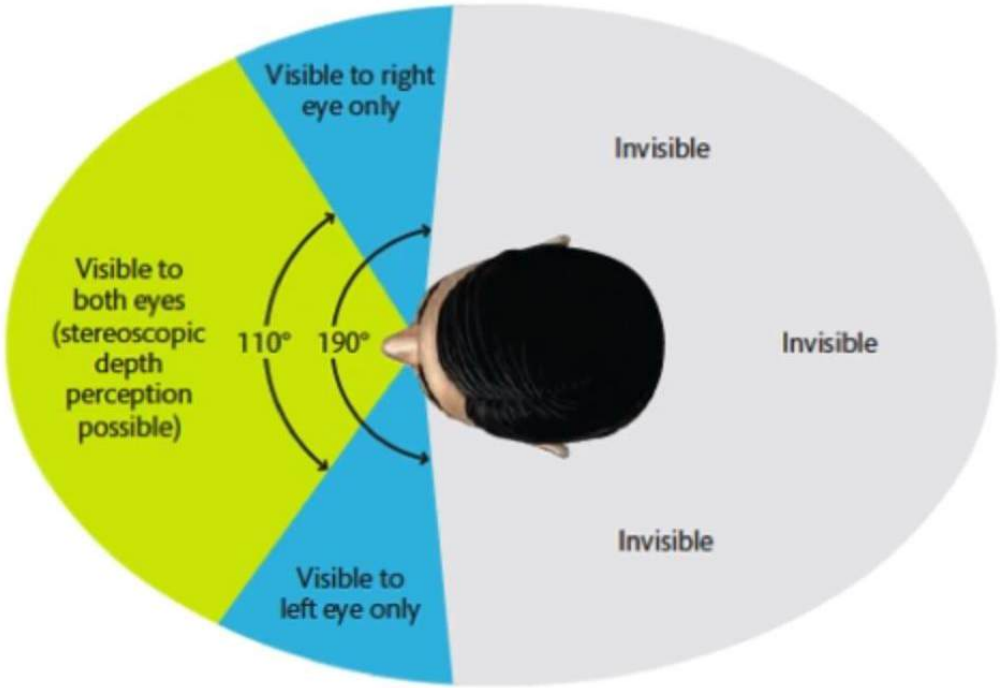


Field of view (FoV)

- The range of space around you that you can see
- Depends on the position of eyes
- Humans: eyes in front of head
  - Good for navigating
  - Good for depth perception (overlapping FoV)
  - Guides the movement of our hands and fingers

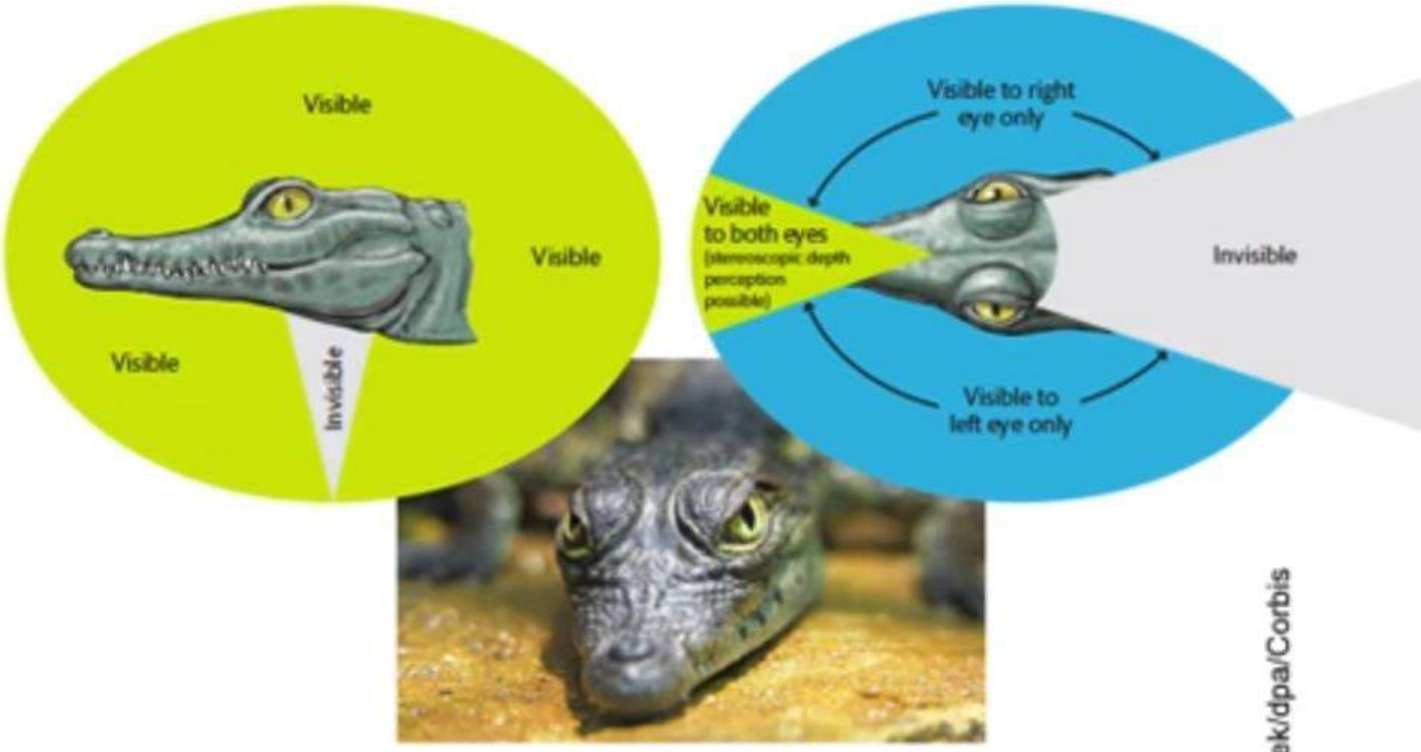


Your Field of View



Field of view (FoV)

- Crocodiles: eyes on side of head
  - Good for finding food
- Most predators' eyes are on the front of their head → good depth perception
  - Crocodiles are ambush predators!
- Most preys' eyes are placed laterally on head → easier to see nearby predators

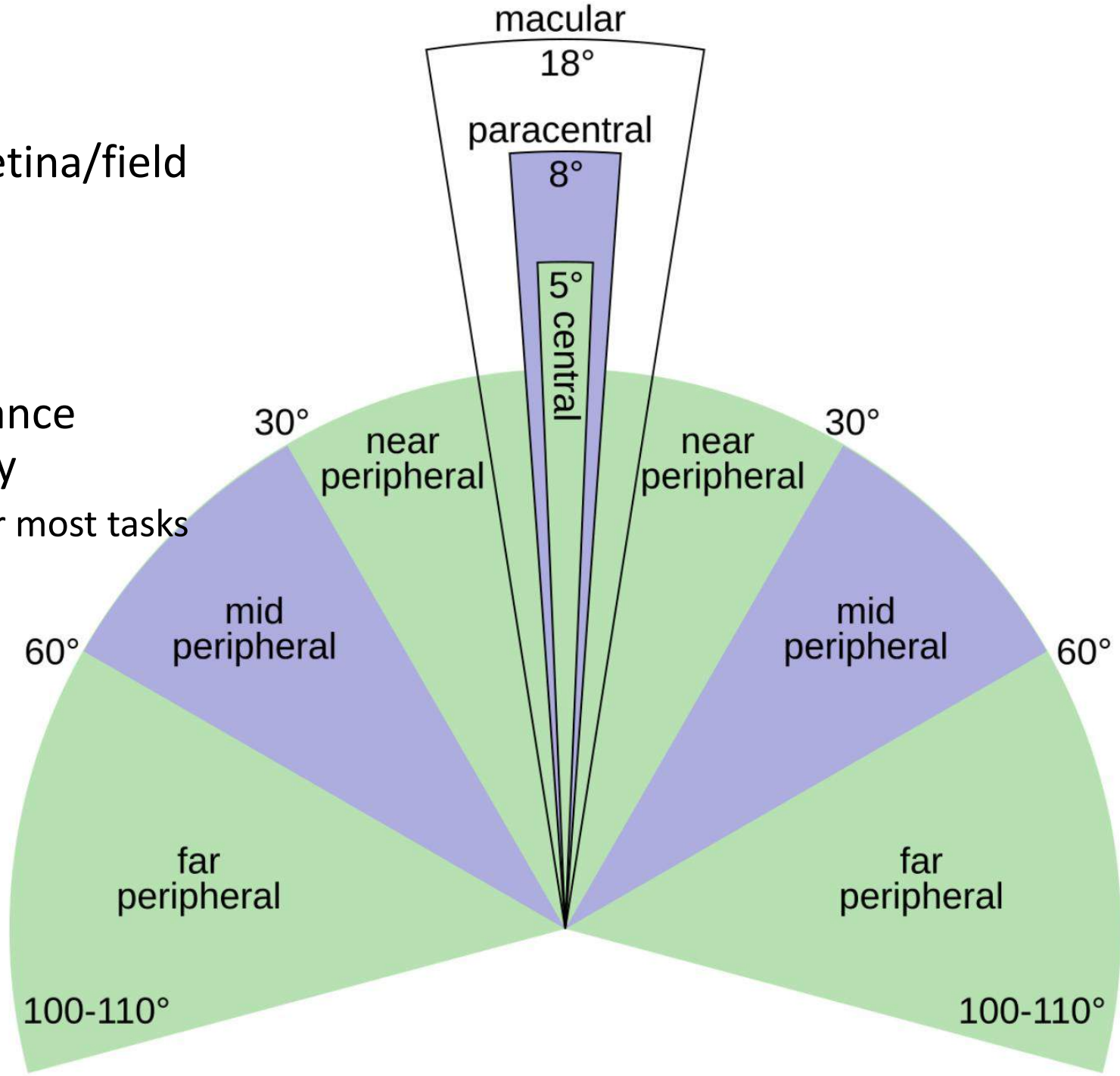


A Crocodile's Field of View

Ronald Wittek/dpa/Corbis

Field of view (FoV)

- Foveal vision = the center of your retina/field of view
  - Very high visual acuity
- Peripheral vision = not foveal vision
- Generally speaking, visual performance changes as a function of eccentricity
  - Peripheral vision is usually “worse” for most tasks



Peripheral vision: crowding

+

Peripheral vision: crowding

+ XVX

Peripheral vision: crowding

+ V

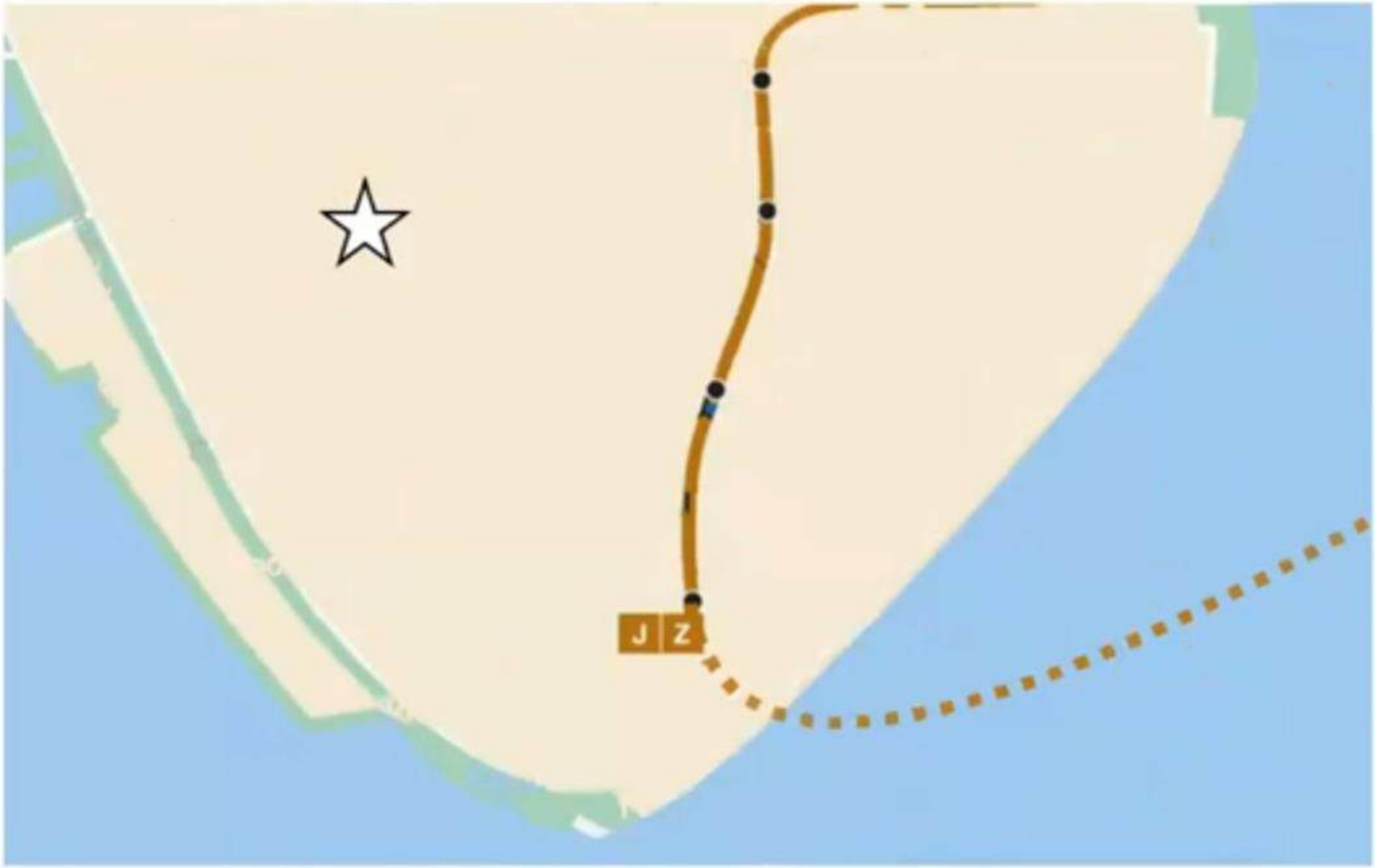
Peripheral vision: crowding

X V X + V

+ XVX

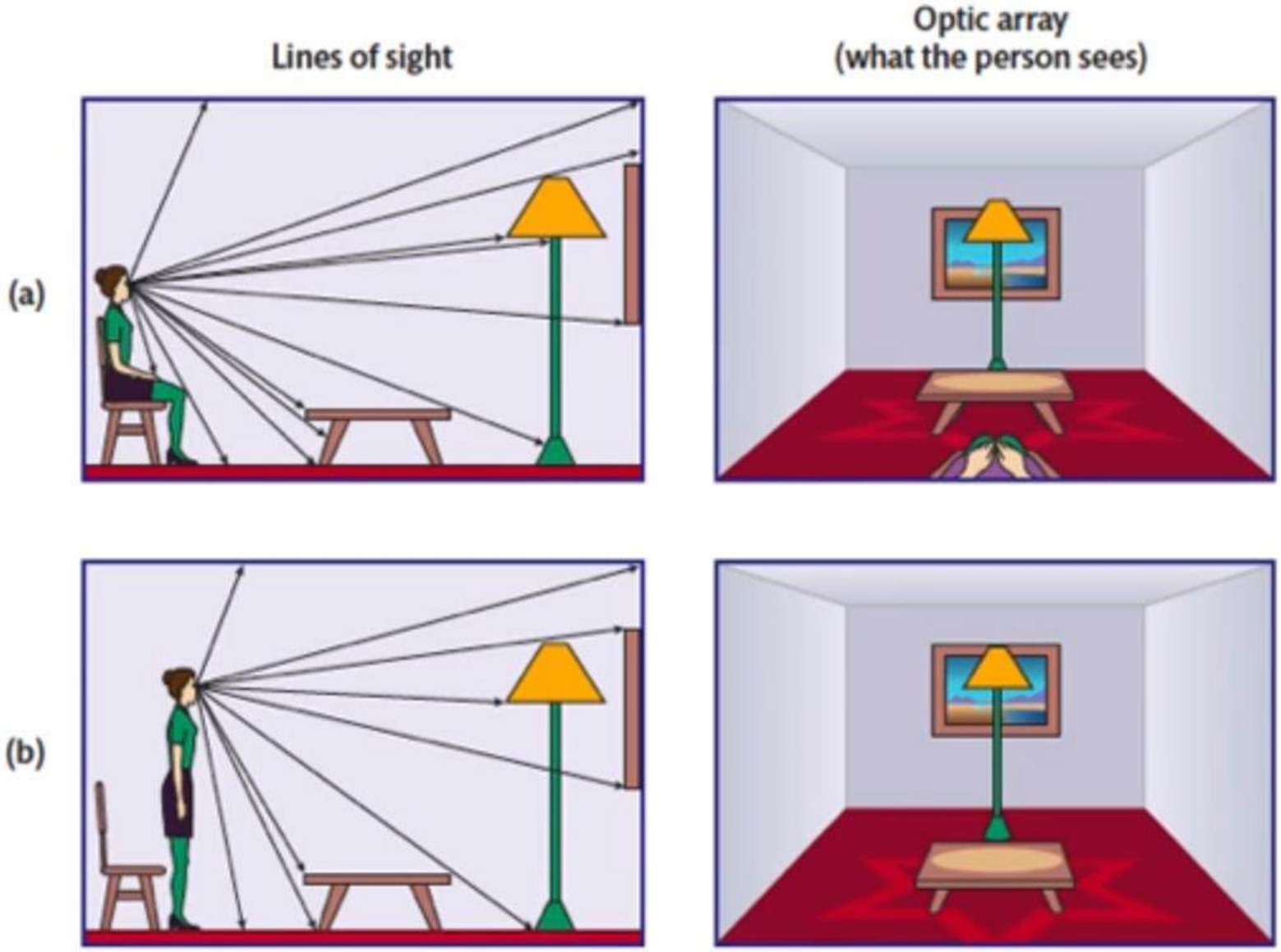
Peripheral vision: crowding

Peripheral vision: crowding



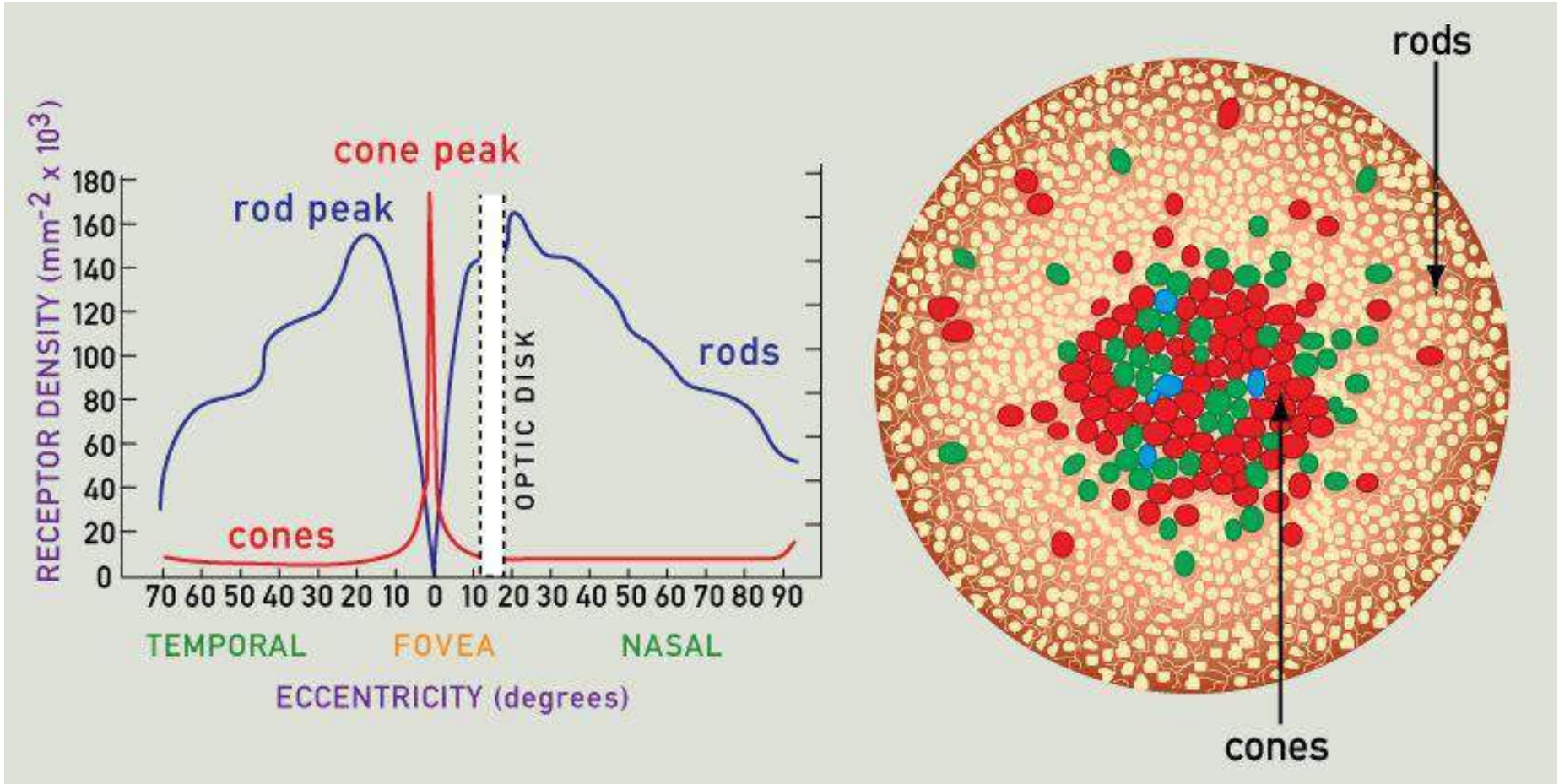
Optic array

- Pattern of light on the retina



Density of photoreceptors

- Density of cones in the fovea is very high
  - Falls off sharply
- Not many rods in the fovea
  - More rods outside of the fovea, still falls off



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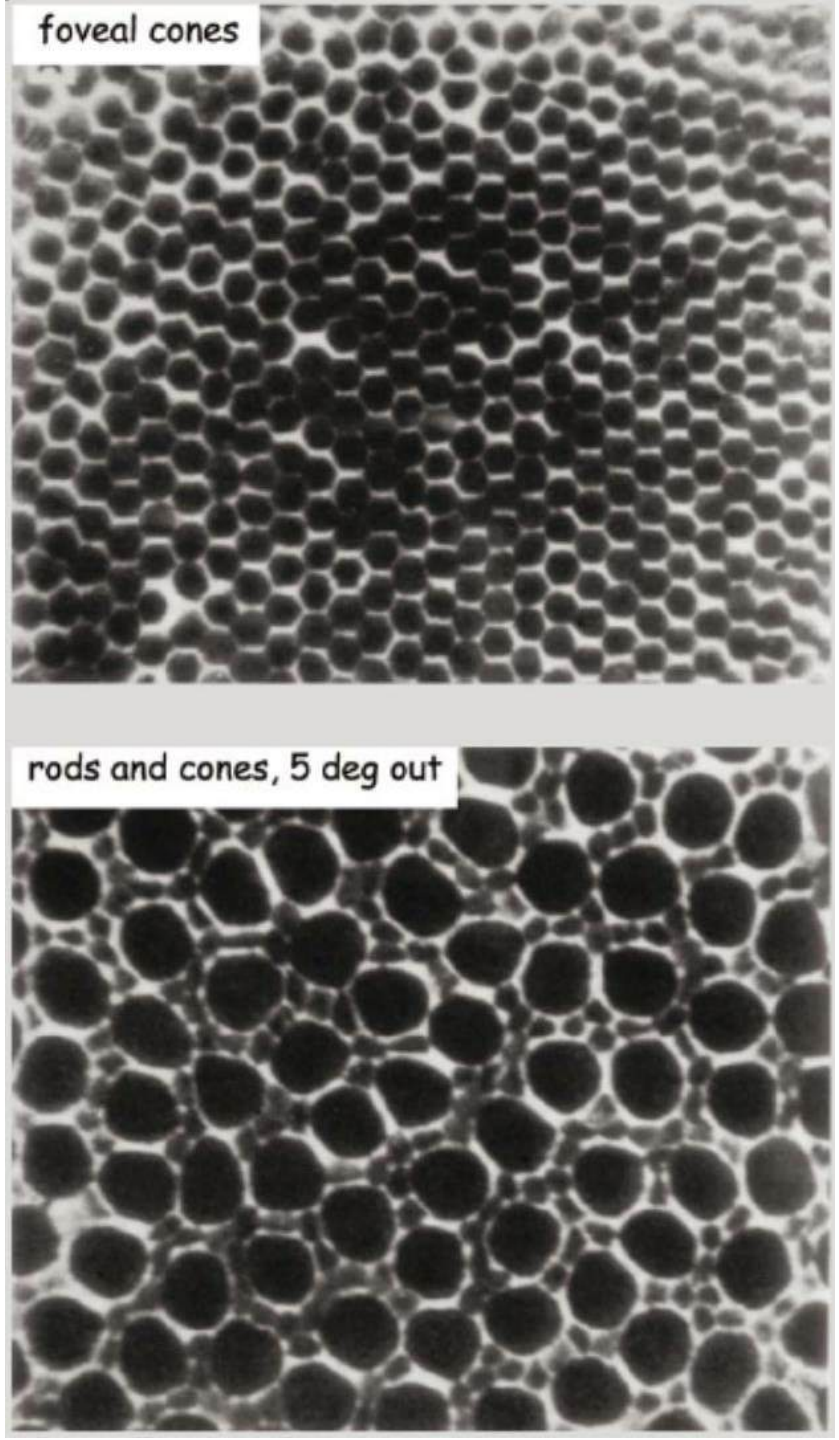
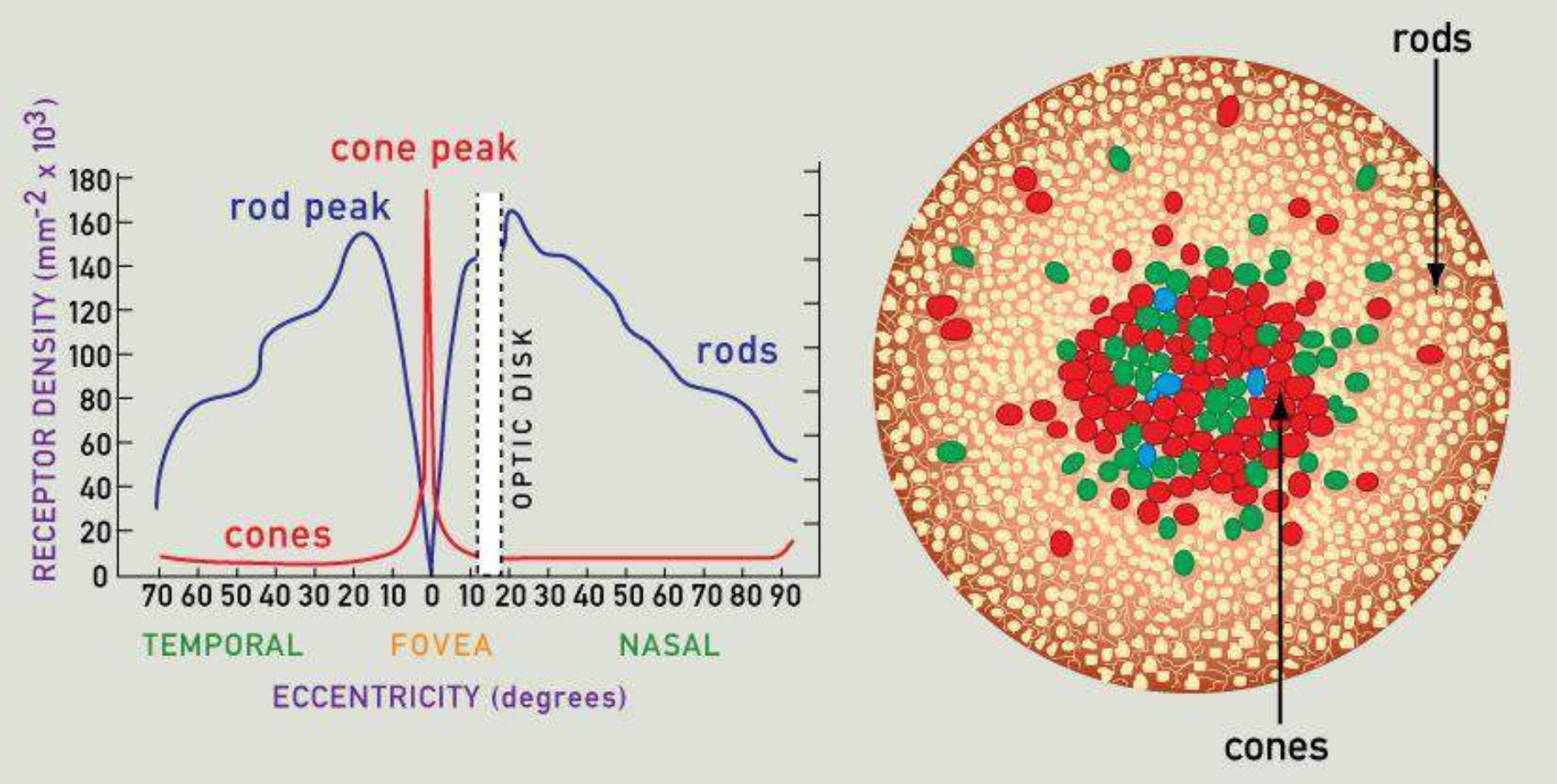


Density of photoreceptors

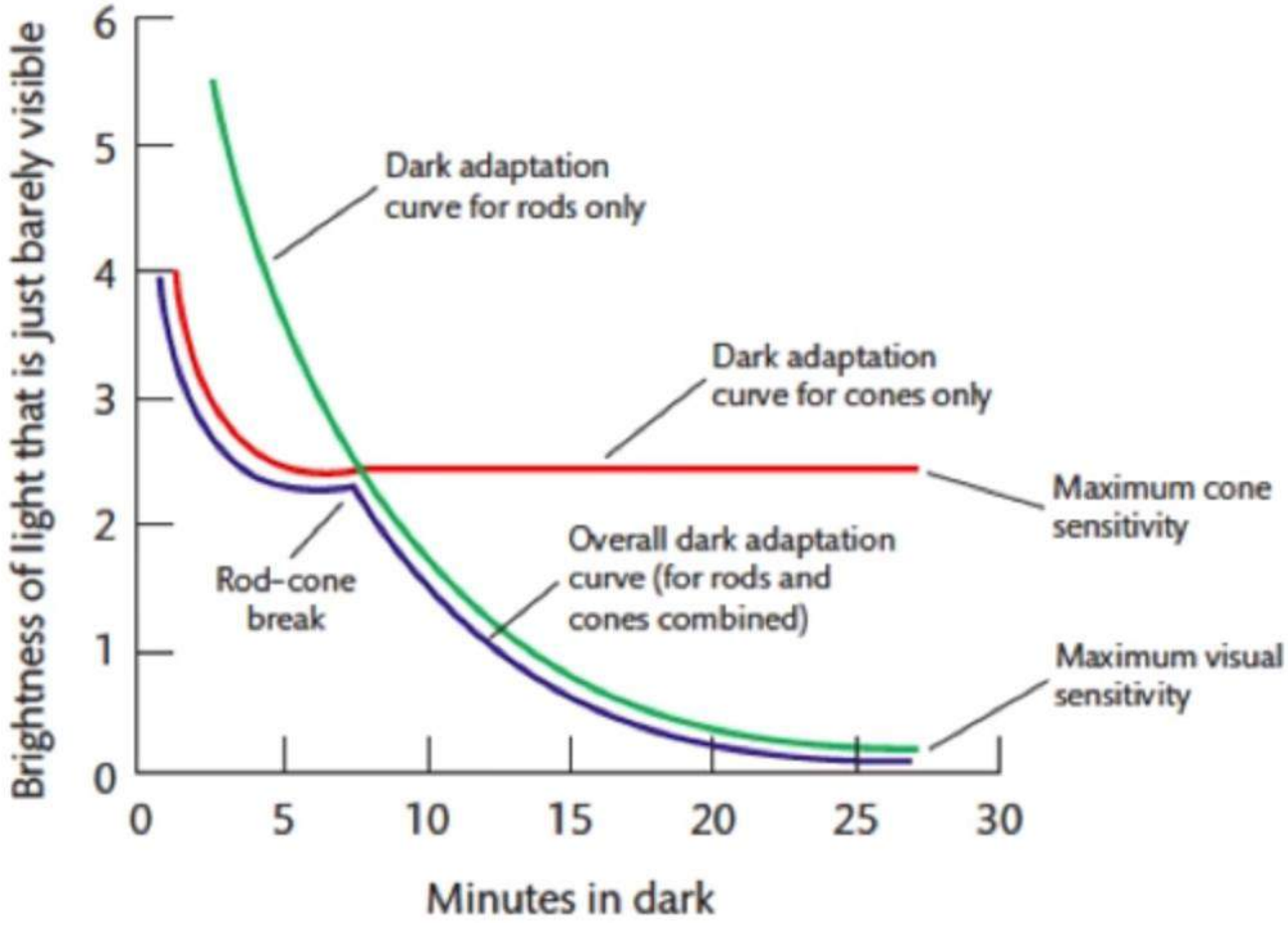
- Rods are still useful!
  - Comprise the vast majority of your retina → basically always in use
  - Good for night vision and motion perception



Dark adaptation

- Light adaptation (dark to light):
  - One minute of adaptation → doing pretty well
  - Whole process takes about 10 minutes to become fully light-adapted

- Dark adaptation (light to dark):
  - Much slower process
  - Whole process takes up to 30 minutes to become fully dark-adapted



Color

- Objects don’t have color themselves
  - Color is the perception of reflected light
- Different organisms do not necessarily see objects as the same color

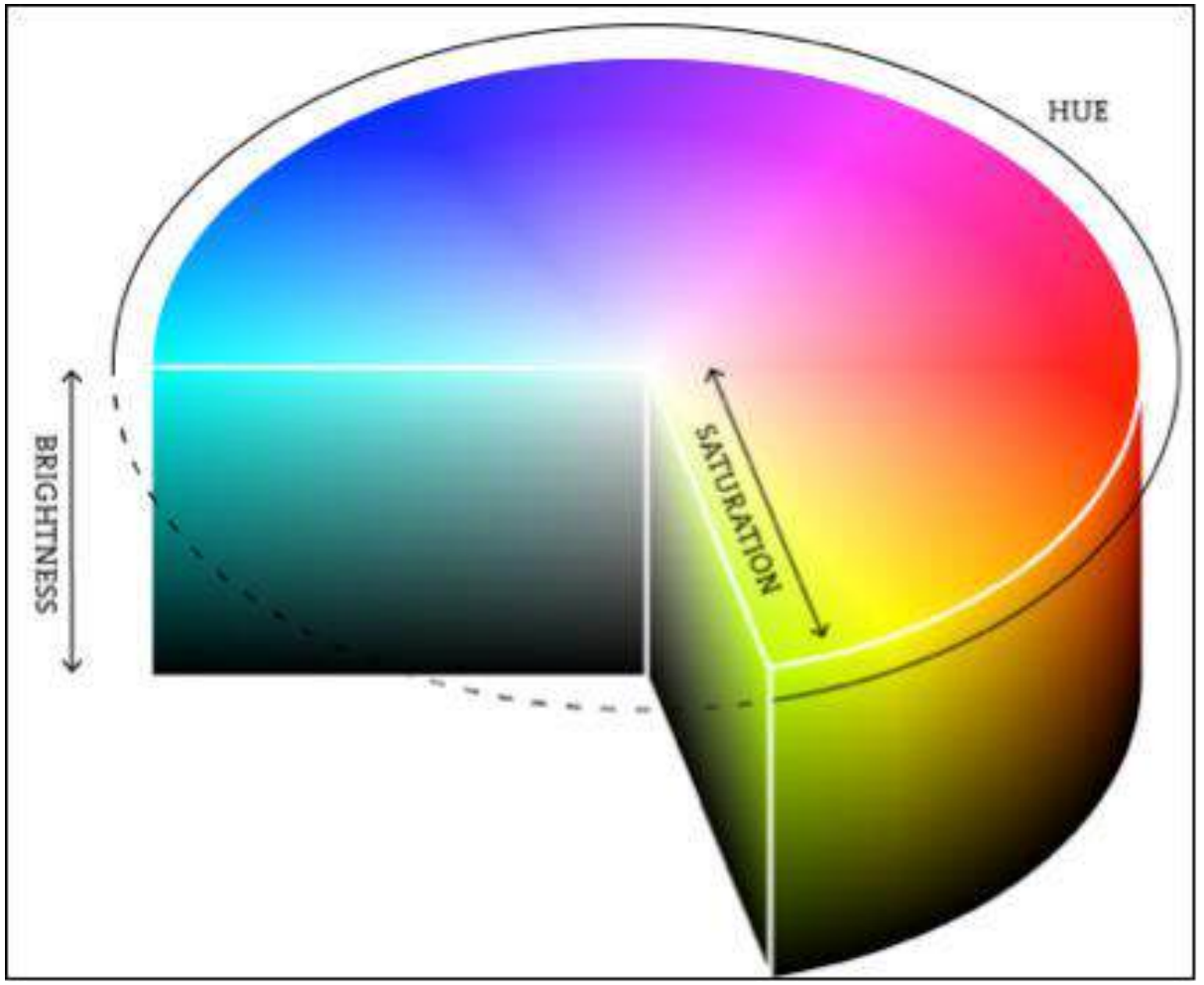
Color

- Different colors = different wavelengths of light
- Heterochromatic vs monochromatic light
  - Heterochromatic: wide range of different wavelengths (e.g. sunlight)
  - Monochromatic: single wavelengths (e.g. incandescent bulb)

- Different objects have different reflectances
  - Black paper reflects <10% of light, white paper reflects >80% of light

Color: Hue, Saturation, and Brightness

- **Physical components** of light and surfaces determine the wavelength of light that enters the eye → produces a **subjective** experience of color
- **Hue:** usually referred to as “color”; perceptual characteristic most closely associated with the wavelength
- **Saturation:** vividness/richness of a hue
- **Brightness:** amount of light



Color mixing

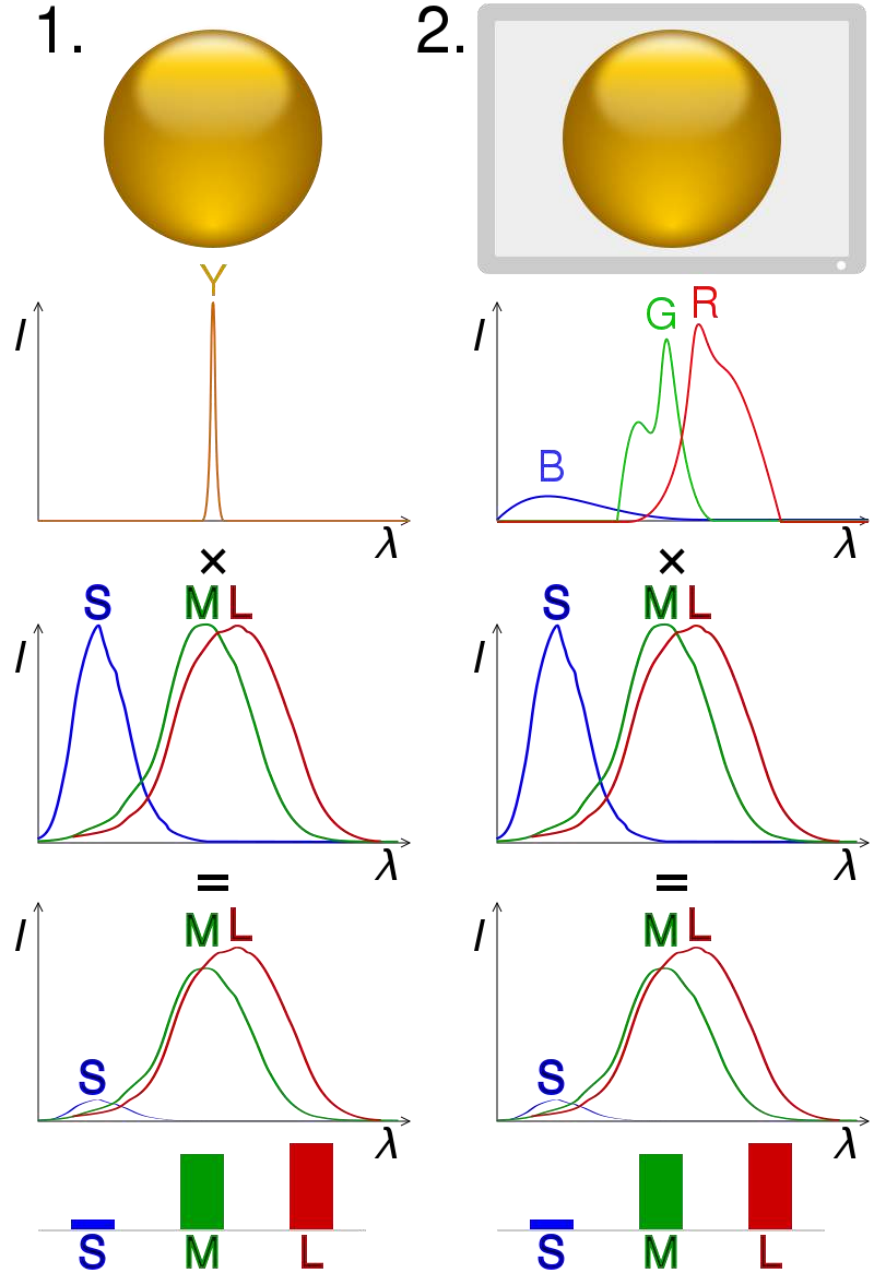
- **Additive color mixture:** mixture of different-colored **lights**. The perceived color is the result of adding together all wavelengths in all the lights in the mixture
  - Primary colors: red, green, blue
- **Subtractive color mixture:** mixture of different colored **substances**. The perceived color is due to the mixed substances absorbing different wavelengths of light, changing the final reflected light
  - Primary colors: red, yellow, blue
  - Cyan, magenta, yellow for printing
- **Complementary colors:** pairs of colors that produce grey when combined in equal proportions. Opposites in the hue space
- **Primary colors:** any 3 colors that can be combined in different proportions to produce a range of other colors. Not a single unique set

Color representation

- Two main theories on how color is represented:
  - Trichromatic color representation
  - Opponent color representation

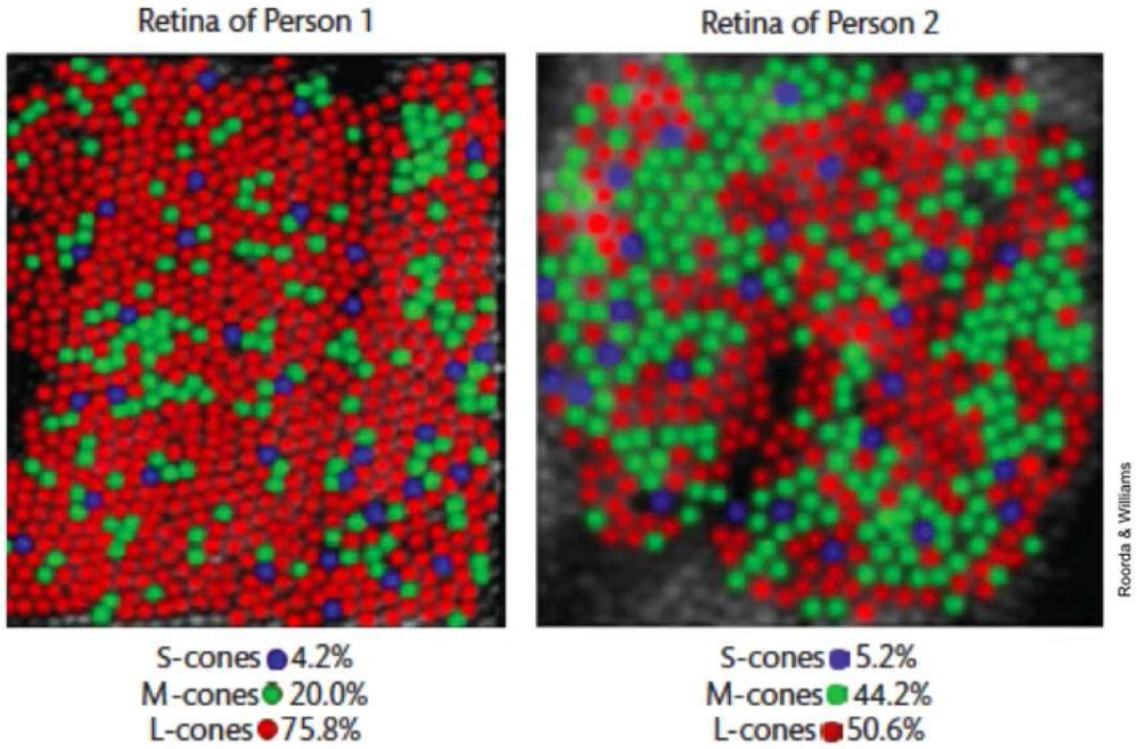
Trichromatic color representation

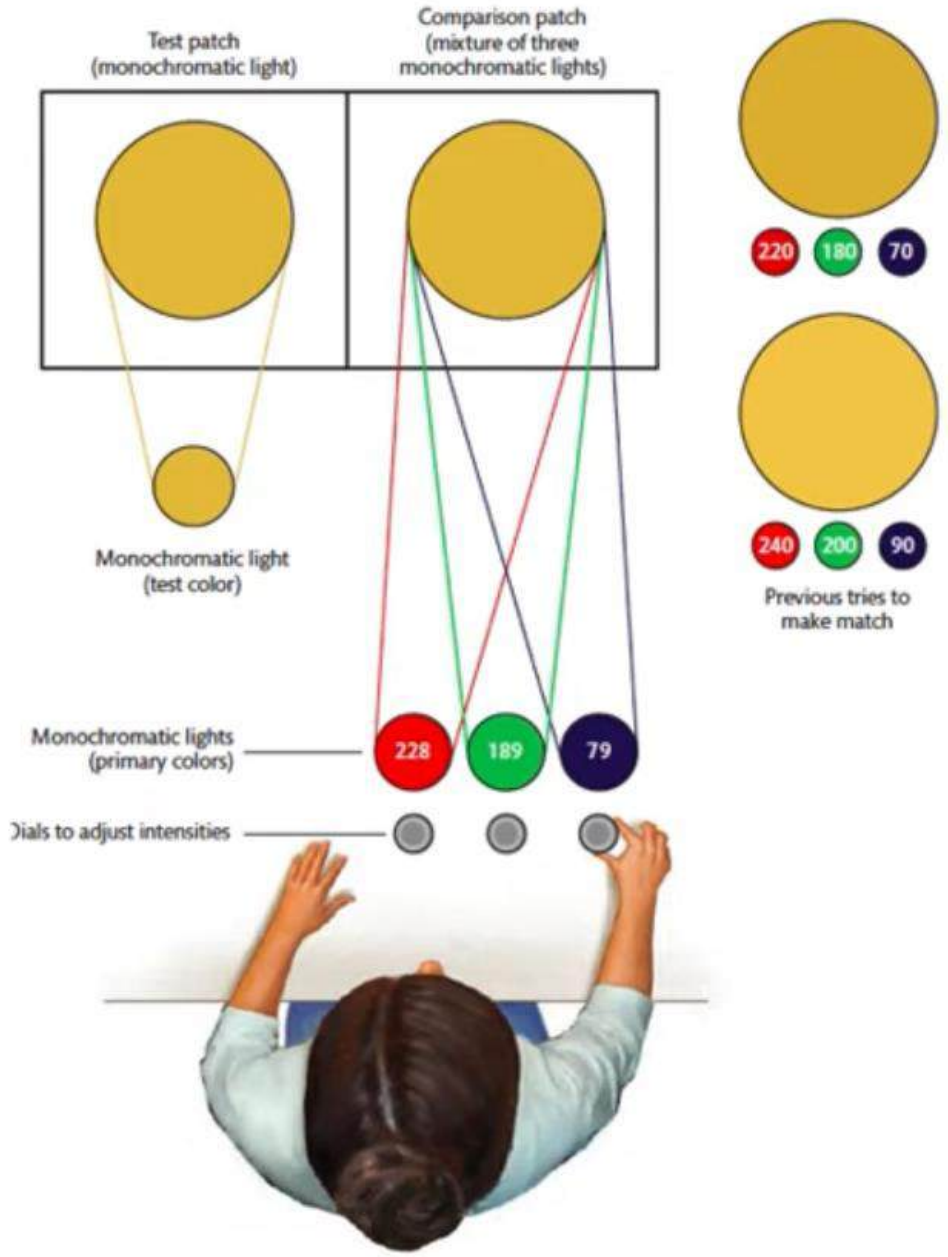
- Three types of color photoreceptors
- Metameric matching suggests 3 types of color receptors
  - Metamer: different objects (in our case, lights) that look the same but are made of different components



Trichromatic color representation

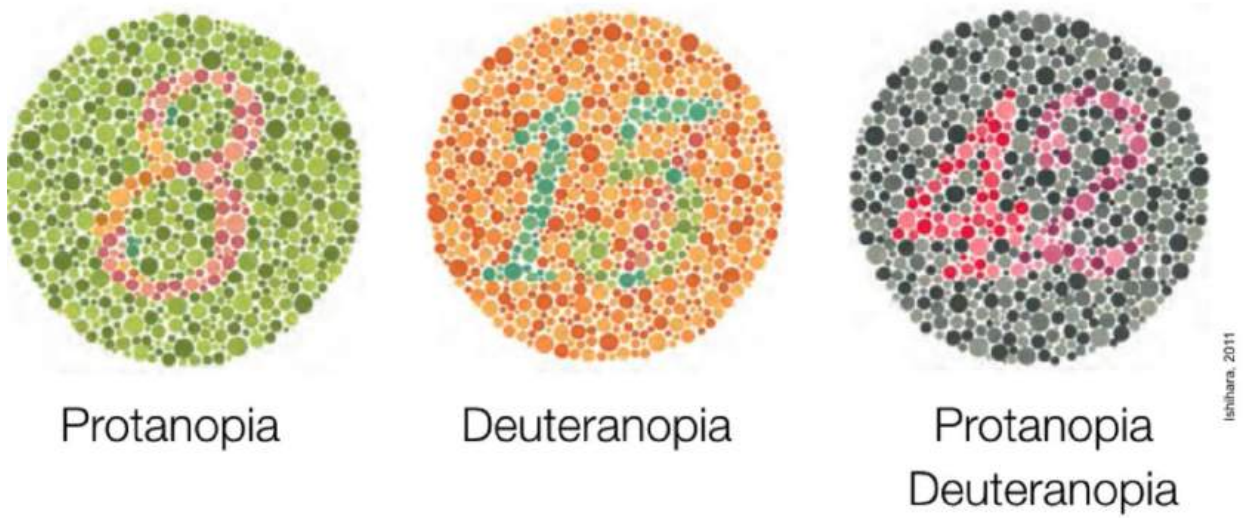
- Participants adjusted intensities of 3 monochromatic lights until their mixture matched a given test patch
- Showed support of the 3 types of cones before we were able to image the retina!
- Try it yourself: https://elvers.us/perception/metamers/





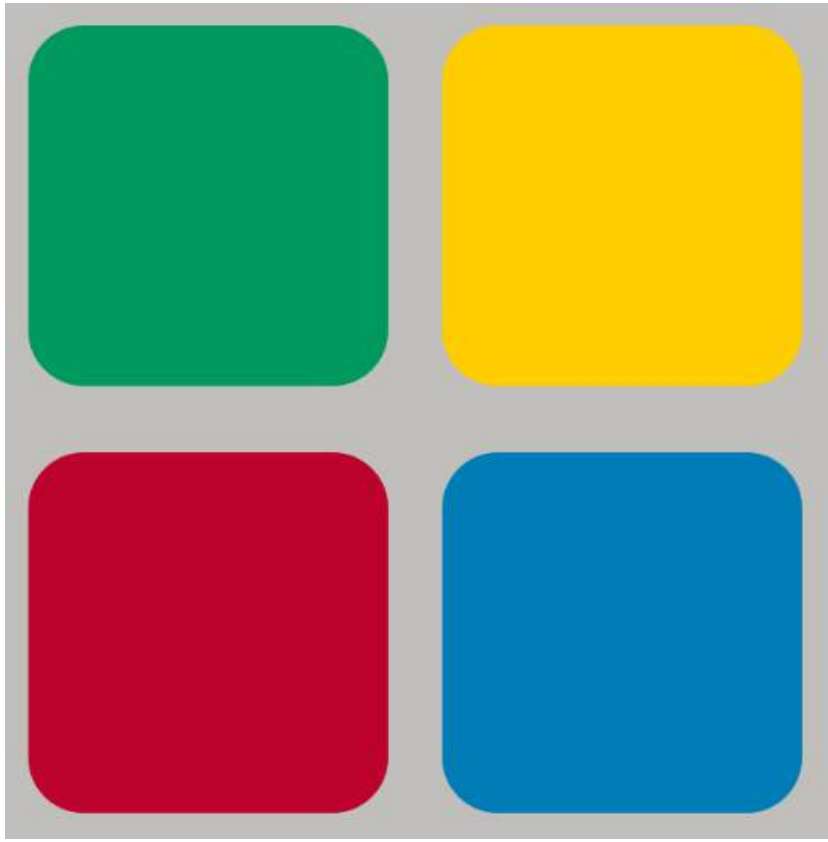
Color vision deficiencies

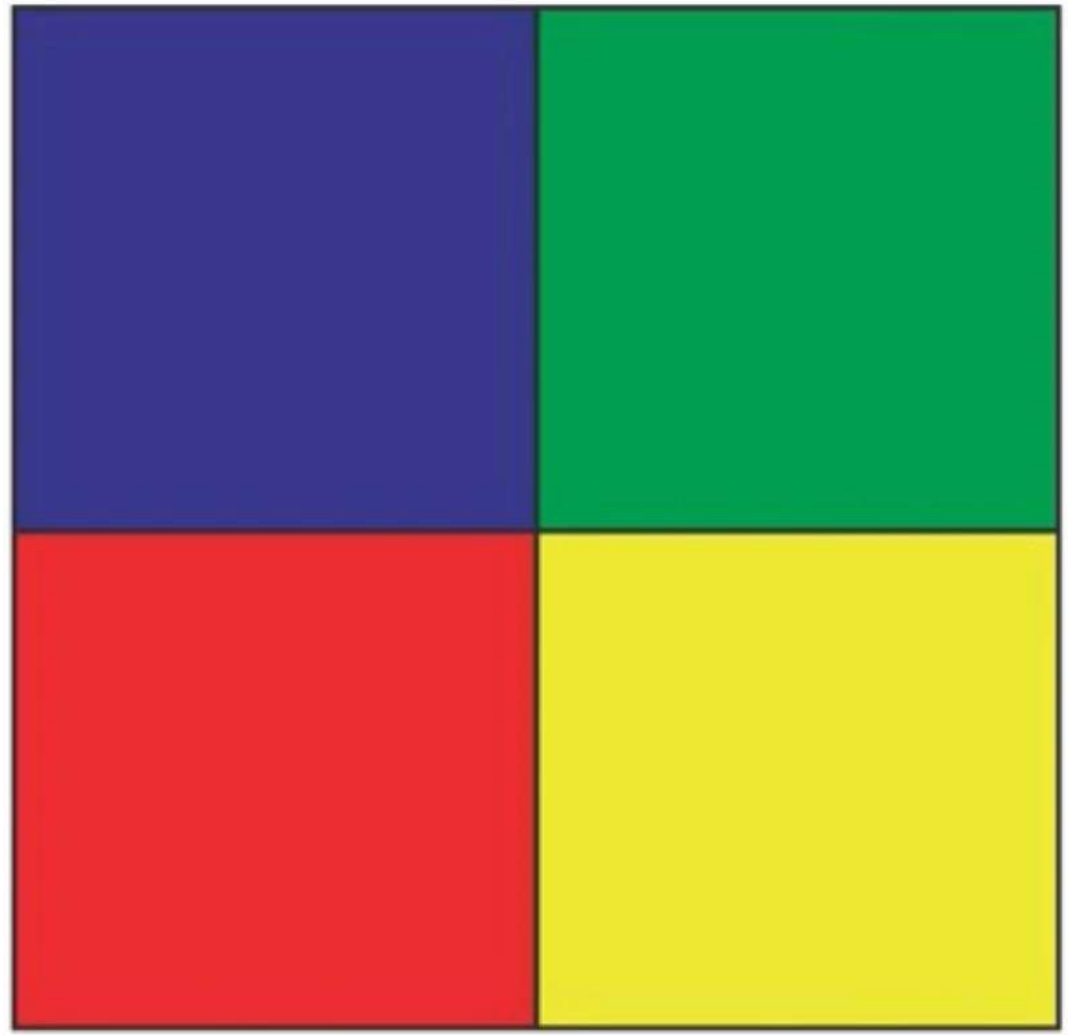
- Most people with color vision deficiencies are not completely blind to certain wavelengths, just less sensitivity
- Monochromacy: person only has rods or only rods + 1 type of cone
  - Totally color blind, sees everything as shades of gray
- Dichromacy:
  - Protanopia: person has M- and S-cones, but lacks L-cones. 1% of males, 0.02% of females
  - Deuteranopia: person has L- and S-cones, but lacks M-cones. 1% of males, 0.01% of females
  - Tritanopia: person has L- and M-cones, but lacks S-cones. 0.002 % of males and females
  - Simulate them: https://www.color-blindness.com/coblis-color-blindness-simulator/

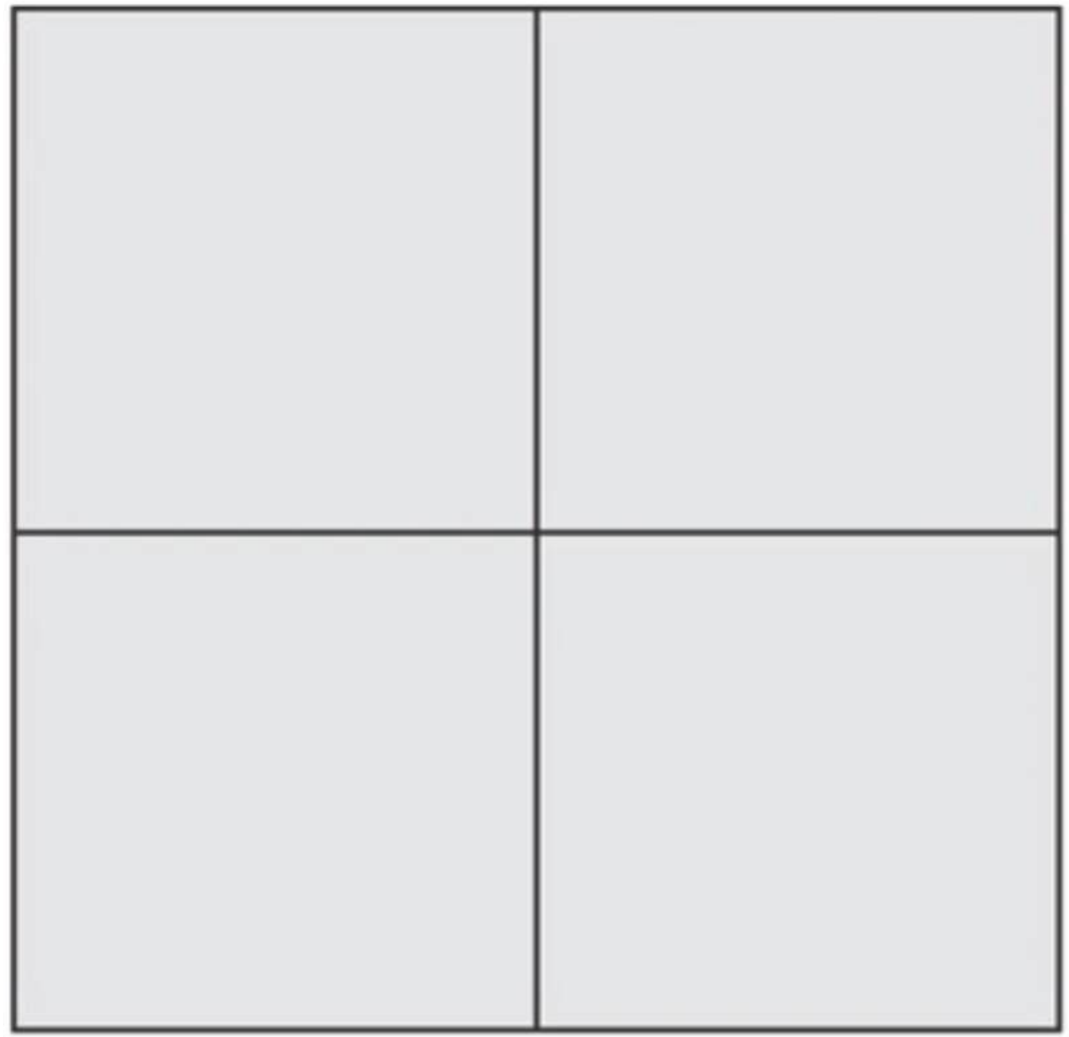


Opponent color representation

- Most humans have 3 (some have 4) types of cones for red, green, and blue wavelengths
- Humans act as if there are 4 primaries
- Evidence: color sorting tasks, after images, hue cancellation tasks, neuroscience







Opponent color representation

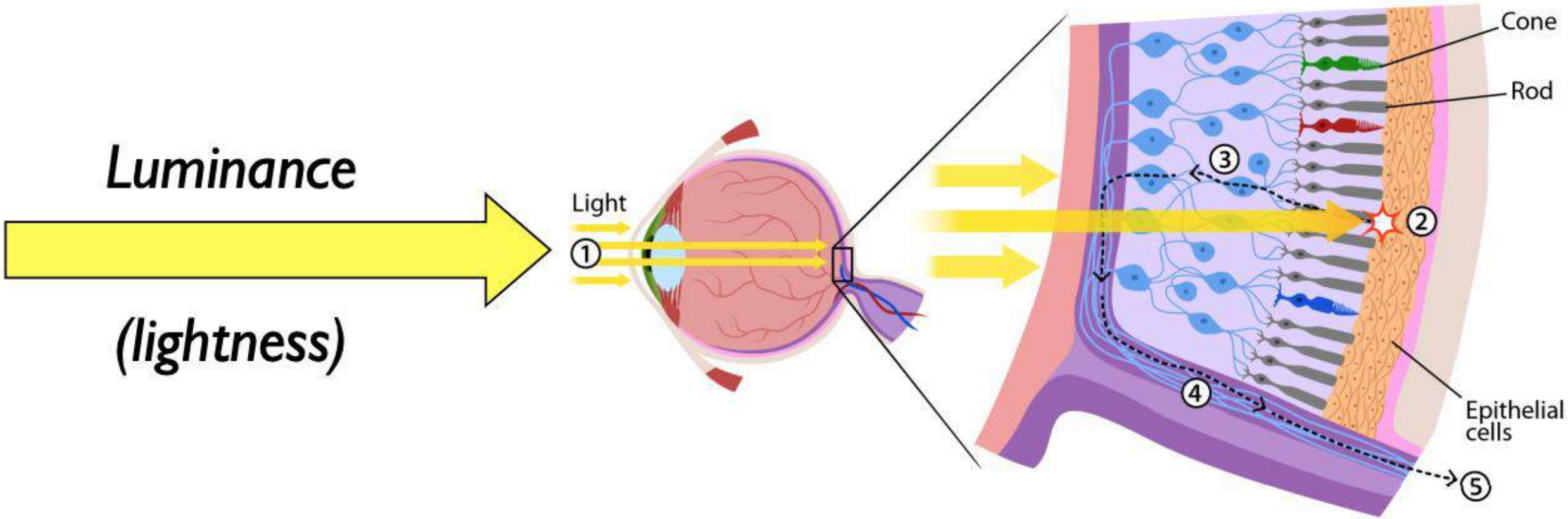
- Color afterimages: a result of photopigment bleaching, known as **chromatic adaptation**

- **Hue cancellation:** you can eliminate the perception of a color in a light by adding light of the complementary color

Color constancy

- Color is perceived as consistent under different types of light as long as enough wavelengths are available
  - Visual system estimates amount of each wavelength reflected from all surfaces on average
  - Tends to operate via the same concept of color adaptation
- Color constancy can fail!
  - Fails if the illuminating light consists of only a narrow range of wavelengths
  - Fails if just one surface is seen against a black/empty background

Luminance



Lightness = the perceived intensity of reflected light (reflectance) from a surface

Brightness = the perceived intensity of emitted light

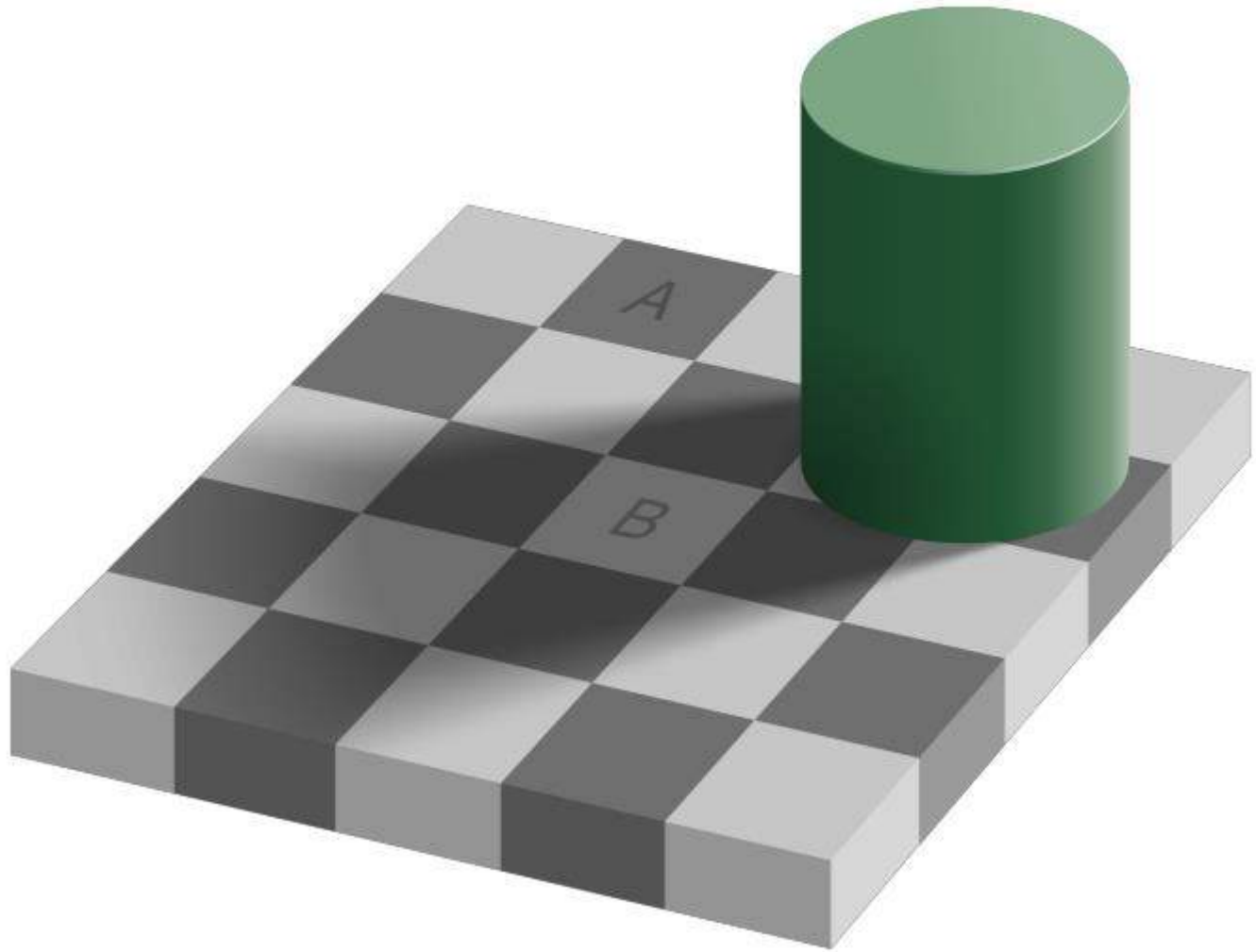
Credit: Prof. Michelle Borkin

Color: lightness constancy

- Lightness constancy refers to our ability to perceive the relative reflectance of objects despite changes in illumination.

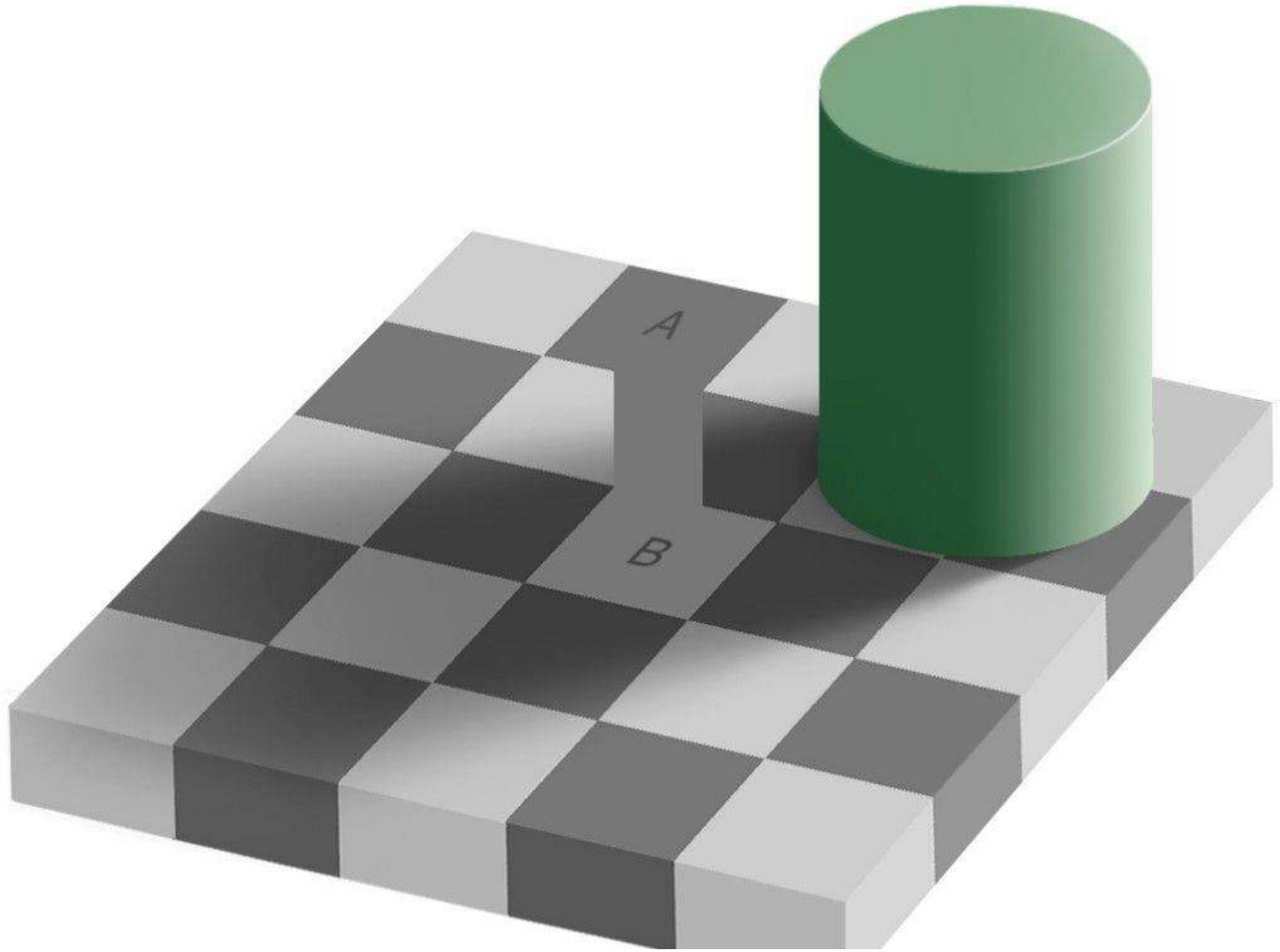
Credit: Prof. Michelle Borkin

Color: lightness constancy



Color: lightness constancy

Color: lightness constancy



Color: lightness constancy

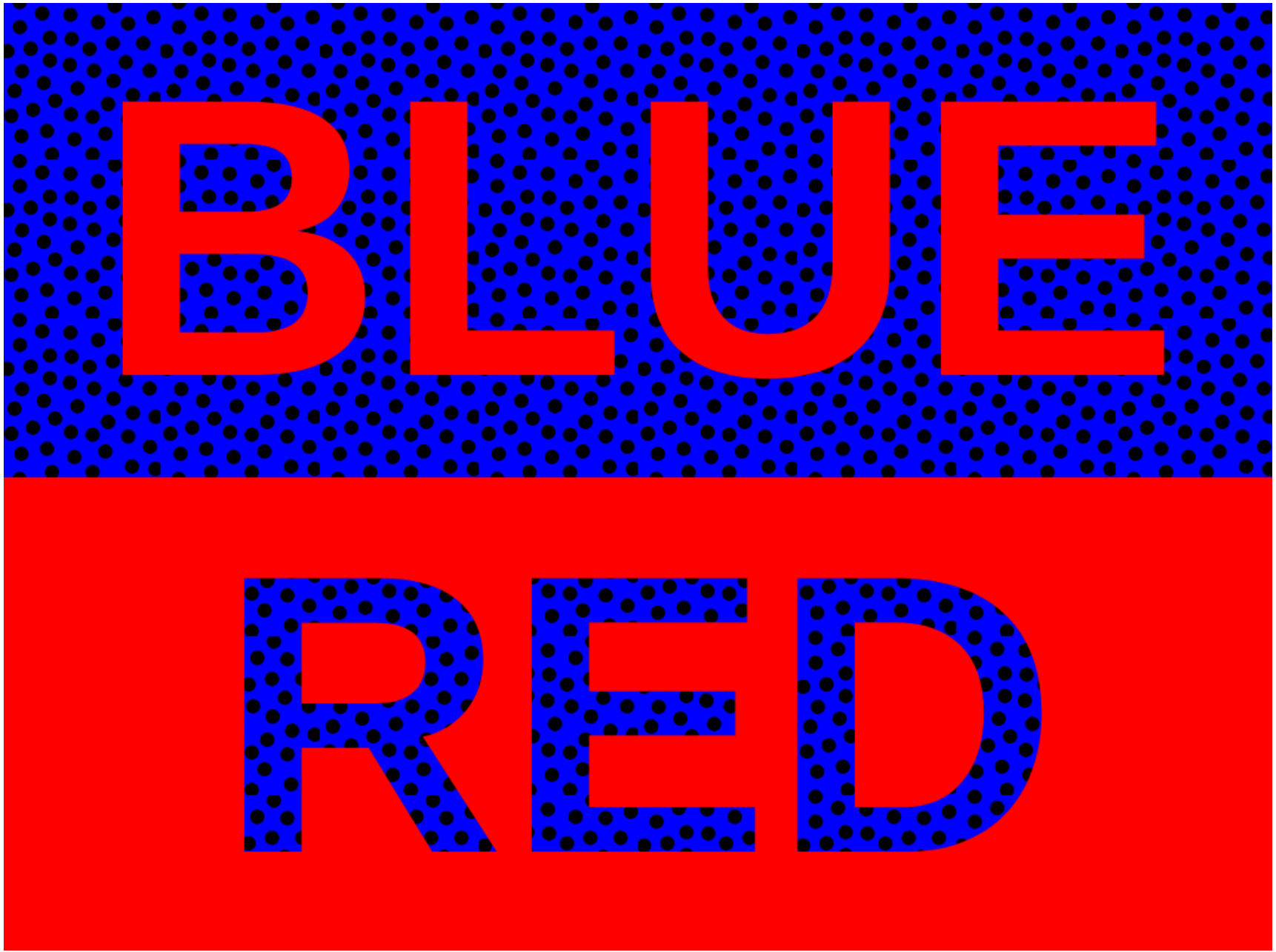
- Ratio principle with a two-part anchoring rule:
  - In any given scene, the part that reflects the most light is perceived as white, and every other region is perceived in relation to that anchor point
  - If the scene has different regions under different amounts of illumination, the visual system applies the anchoring rule separately in each illumination zone

- https://www.youtube.com/watch?v=TVUrHf2kcUM

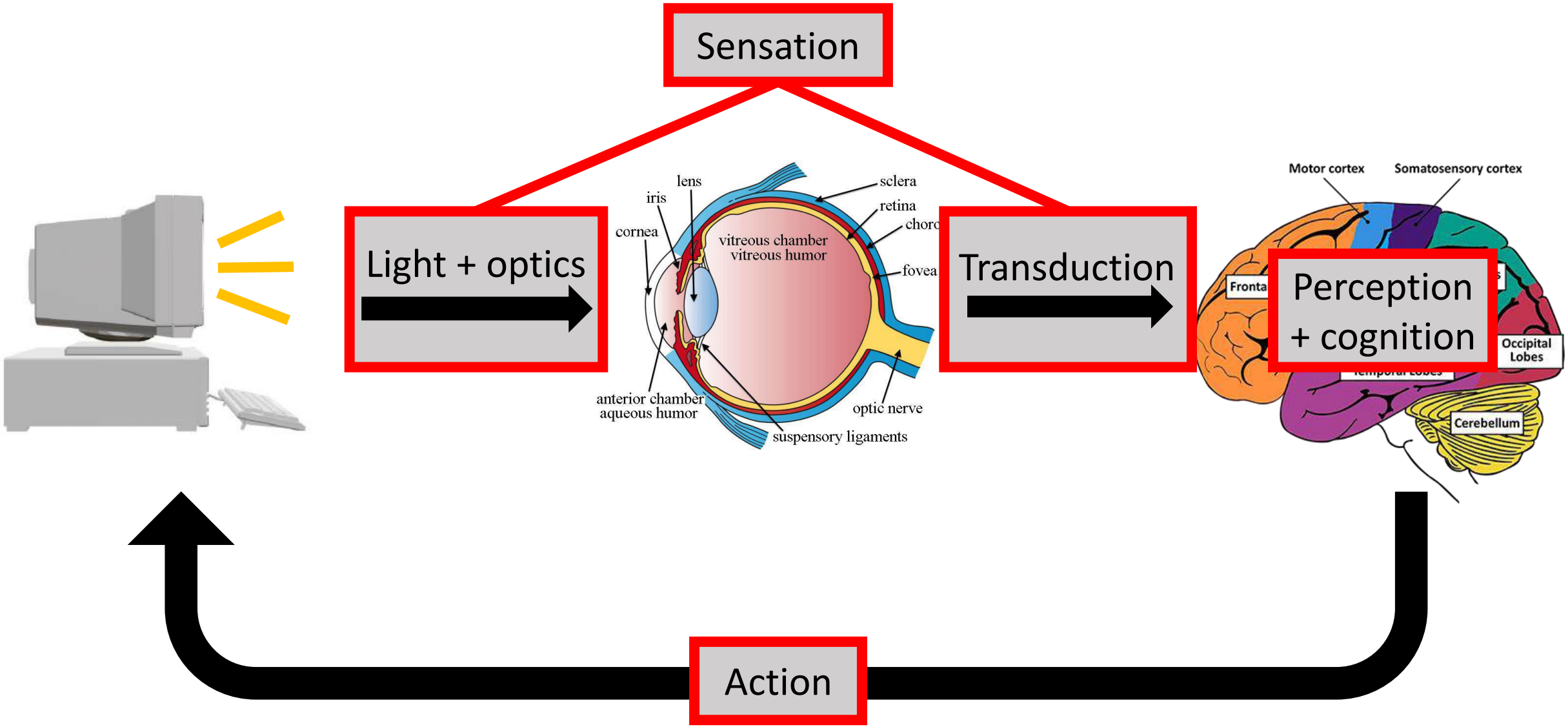
Color: lightness constancy

Color: lightness constancy

Chromostereopsis



Perception-action loop

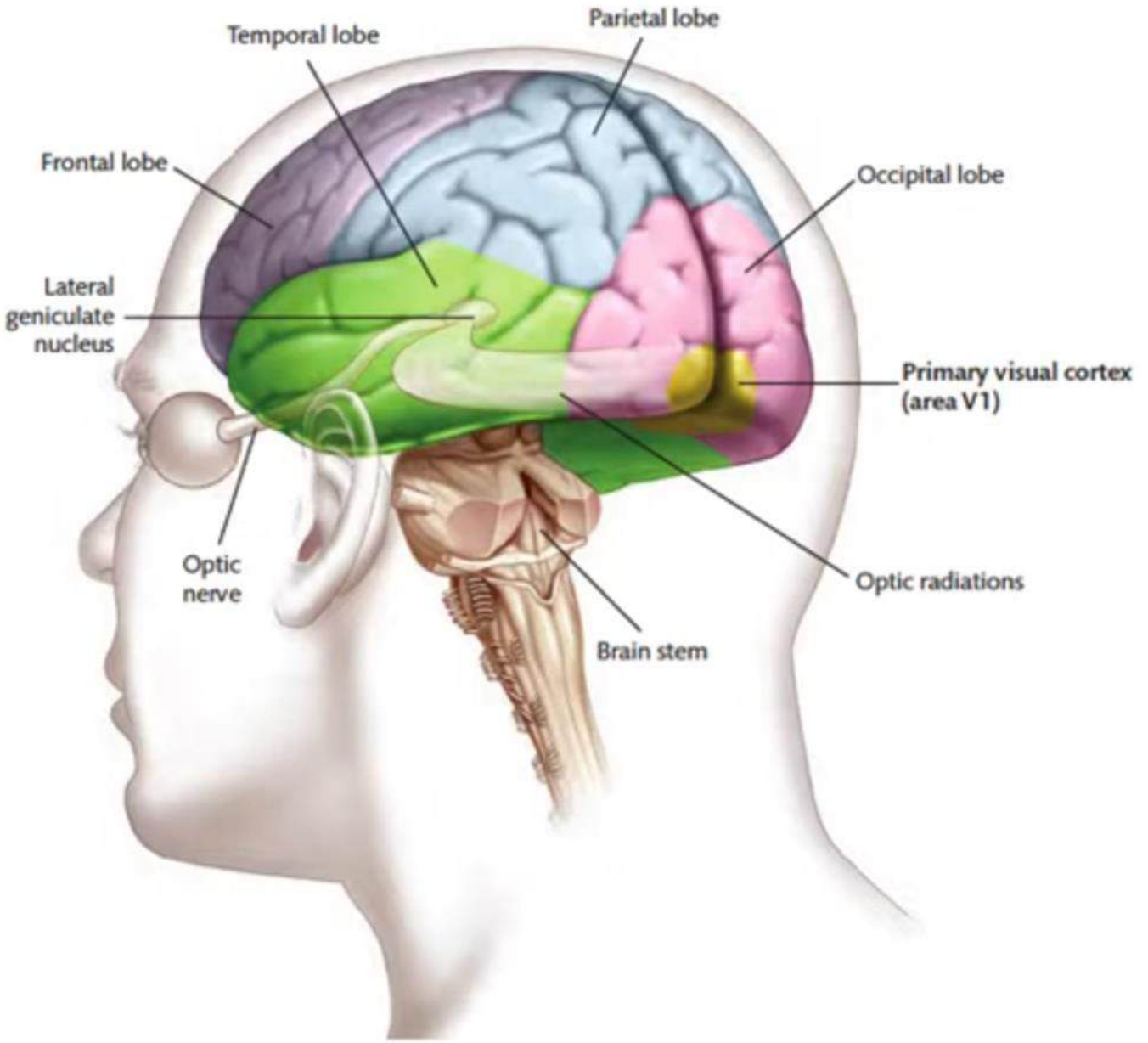


Perception and cognition

- Once the light reaches our brain, how do we interpret it?
- Answer: Lots of specialized cells and pathways in the brain!

Primary visual cortex (area V1)

- First stop for visual information
  - Further along in the brain, the more complex the information becomes
- Highly organized
  - Rentinotopic mapping: areas of the retina map onto specific regions of V1
  - Cortical magnification: more important regions of the retina (fovea) take up more space in V1
- Cells in V1 are stimulated by bars/edges within a narrow range of orientations
  - Specialized cells!
  - We have cats to thank: https://www.youtube.com/watch?v=IOHayh06LJ4



Functional areas and pathways

- Functional pathways in the brain that are specialized for processing specific types of information
- Neurons along different pathways are tuned to fire in response to different stimulus properties
- Dorsal pathway:
  - Motion, location, guide actions
- Ventral pathway:
  - Color, shape (curvature of edges)

- Feature detectors (more cats): https://www.youtube.com/watch?v=RSNofraG8ZE

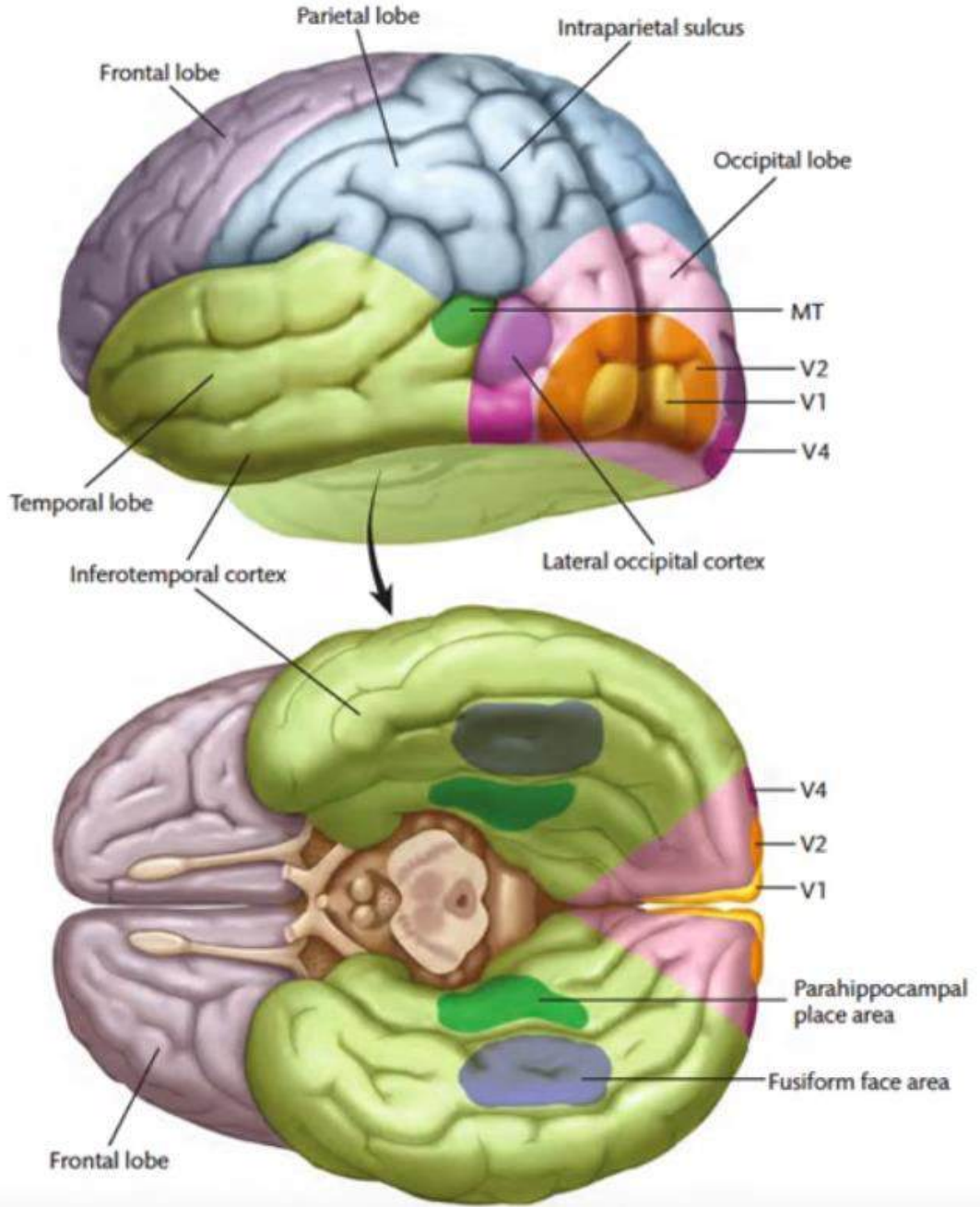
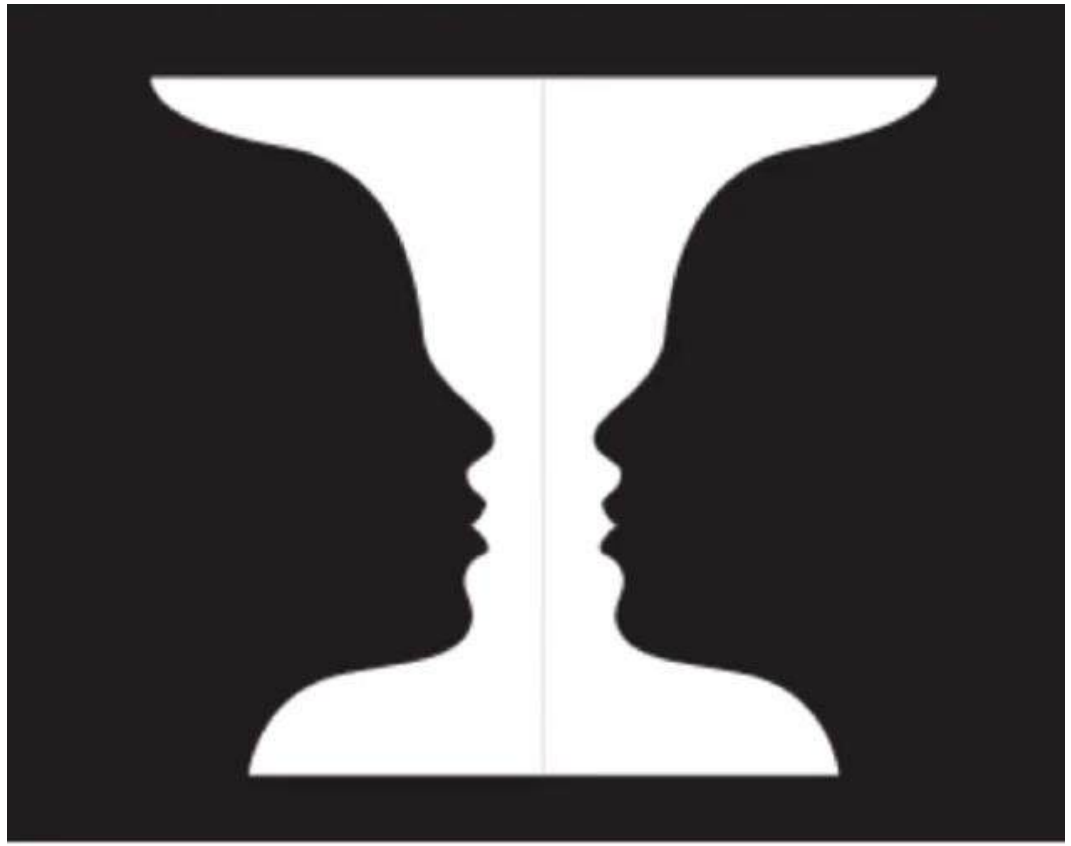


Figure-ground organization: border ownership

- Which border belongs to the object we are looking at vs the background of the object?
  - Accomplished using edge extraction
  - Usually it's clear which object 'owns' the border, but if it isn't, you get an ambiguous figure



Ambiguous Border Ownership

Figure-ground organization: border ownership

- What do you see?

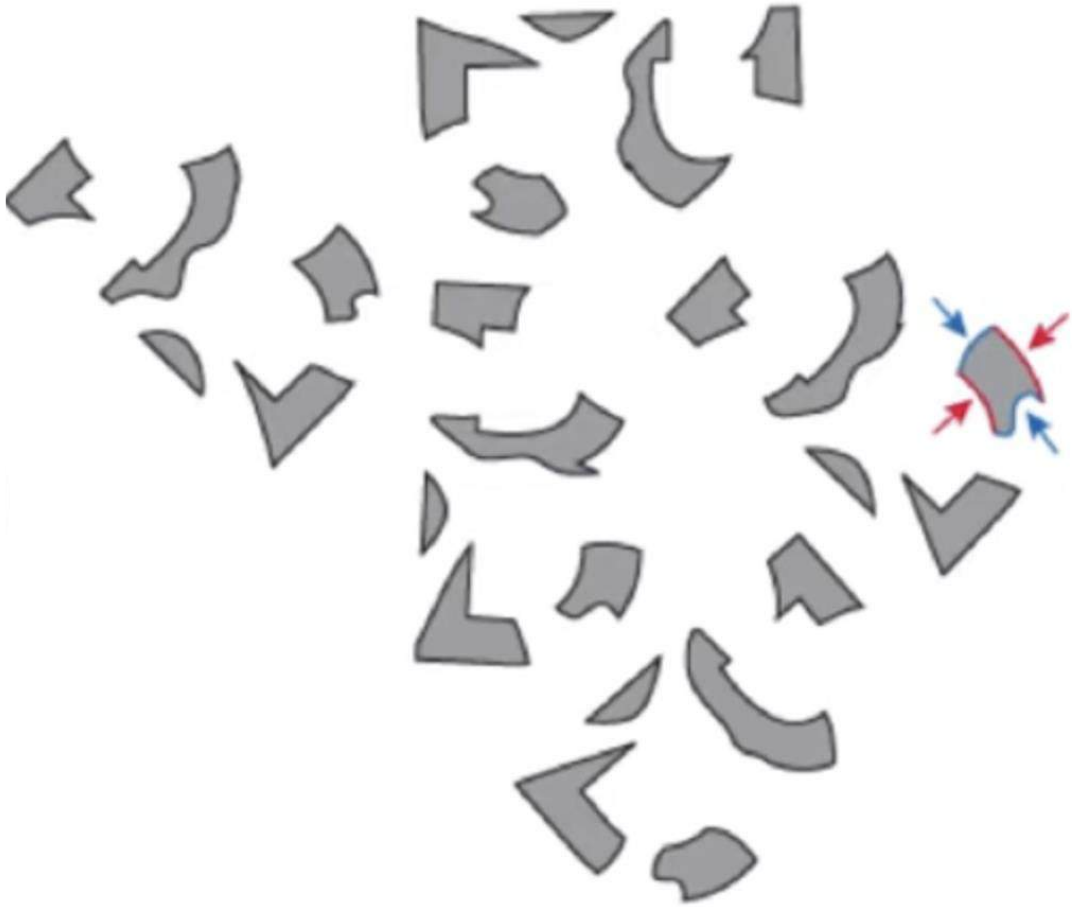


Figure-ground organization: border ownership

- Principles:
  - Depth
  - Surroundedness
  - Symmetry
  - Convexity
  - Meaningfulness
  - Simplicity

Figure-ground organization: border ownership

- Principles: Depth

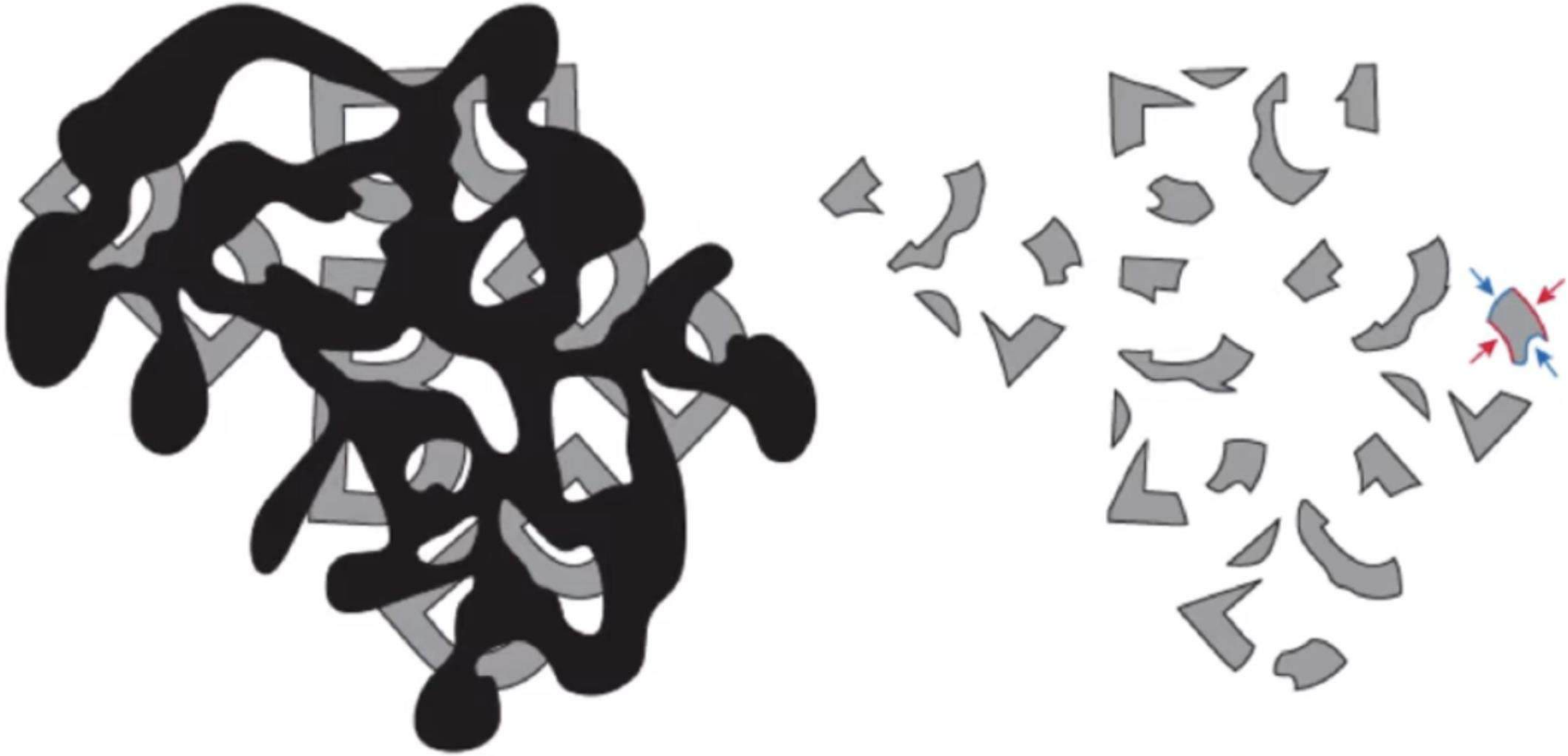


Figure-ground organization: border ownership

- Principles: Surroundedness
- Grey on black?
  - Border belongs to the grey region
- Black on grey?
  - Border belongs to the black region

Figure-ground organization: border ownership

- Principles: Symmetry
- Regions with symmetry are more likely to be seen as a figure than nonsymmetric regions

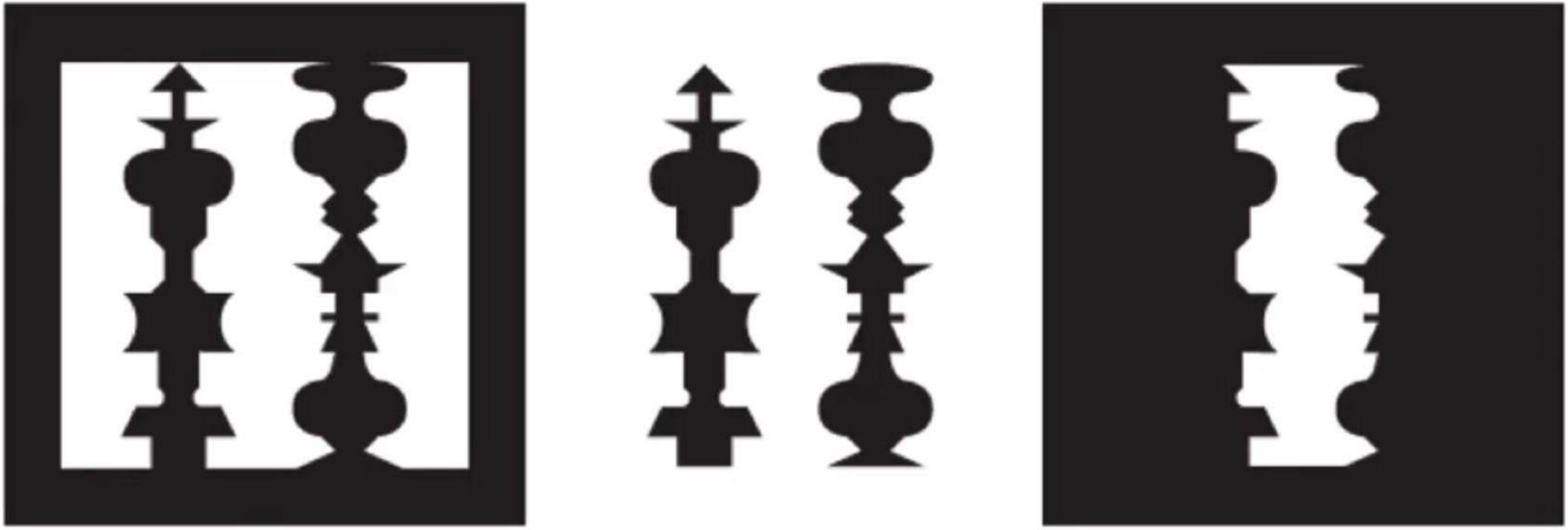
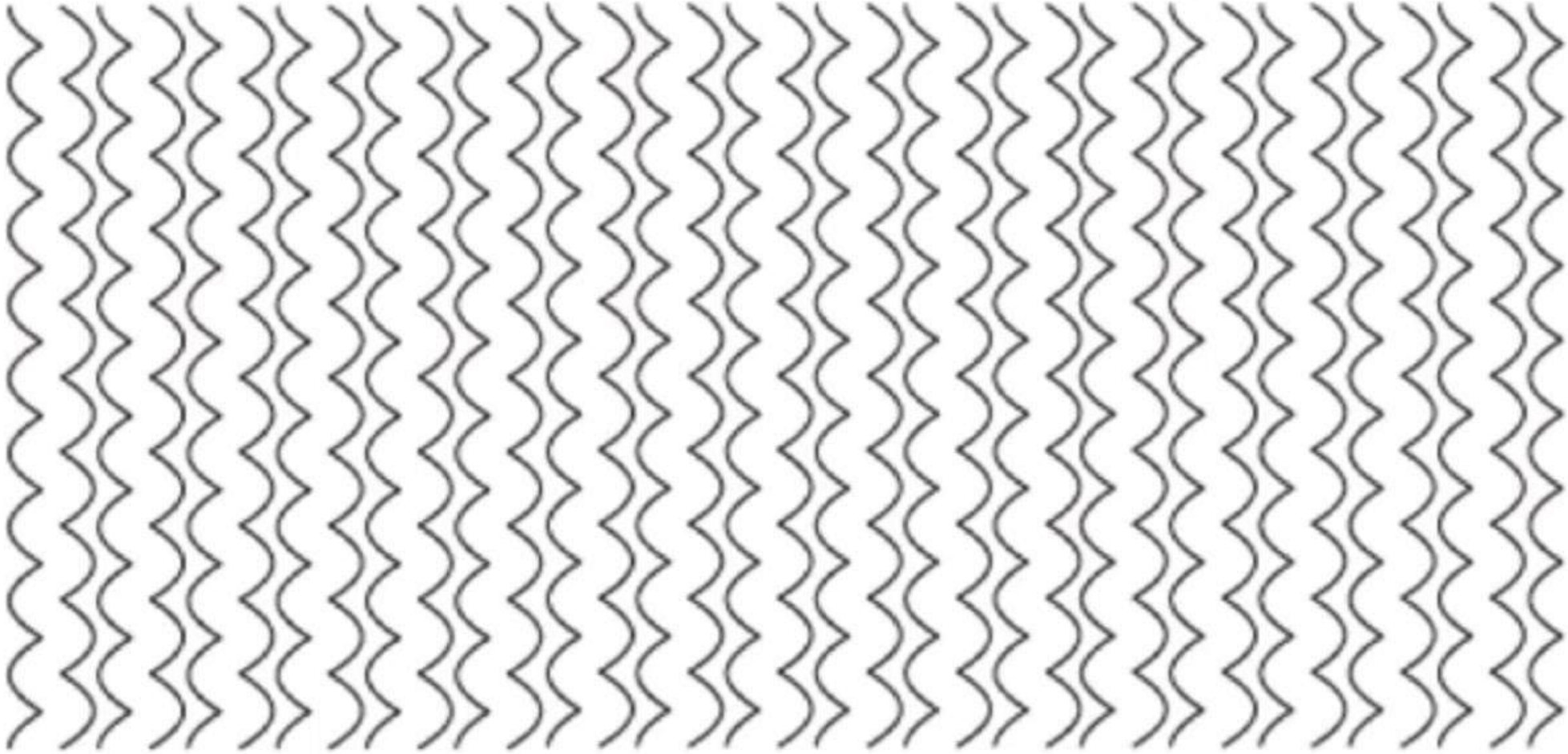


Figure-ground organization: border ownership

- Principles: Convexity
- Regions with convex borders are more likely to be seen as a figure than concave borders



Source: (Adapted from Stevens & Brookes, 1988, Figure 4.)

Figure-ground organization: border ownership

- Principles: Meaningfulness
- Sometimes the semantic meaning of shapes influences border assignment

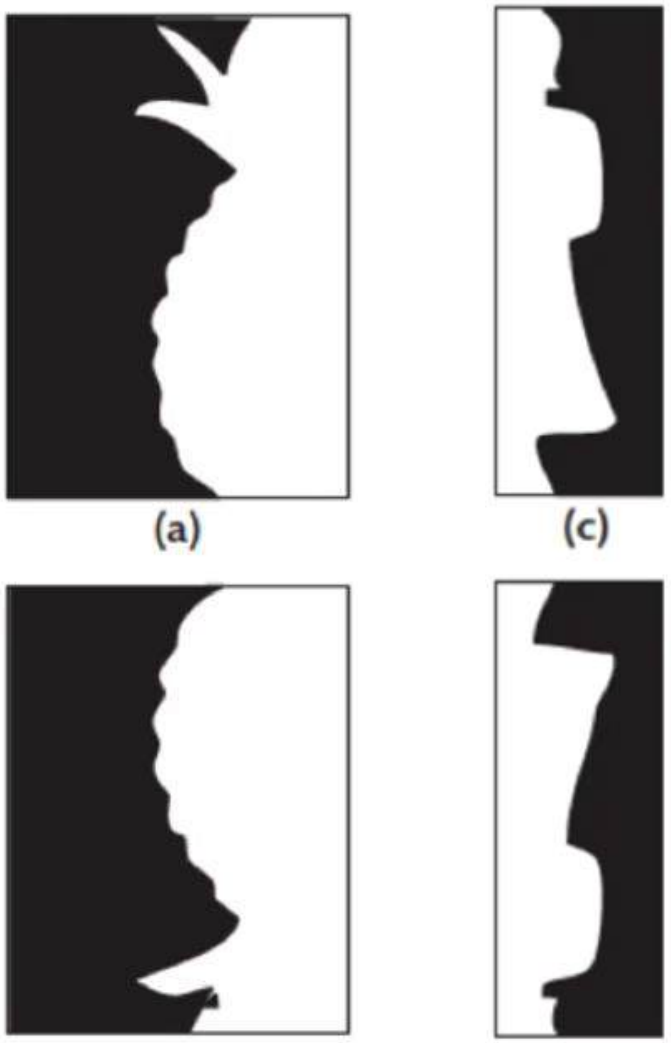
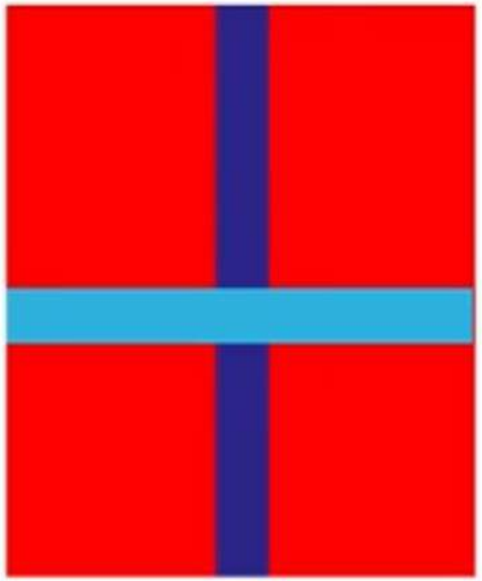


Figure-ground organization: border ownership

- Principles: Simplicity
- Biased towards the simplest explanation of what you see

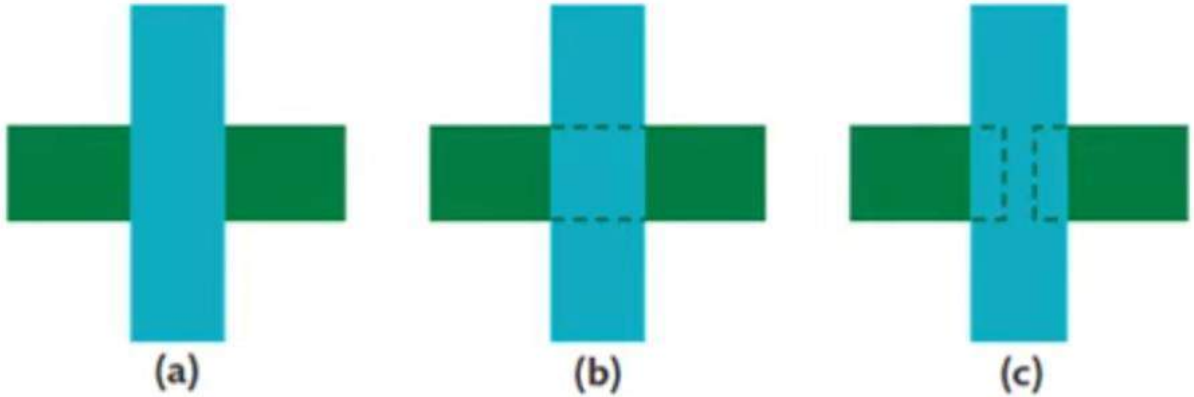


(a)

Perceptual grouping

- Gestalt laws:
  - **Proximity:** nearby elements are grouped more easily than far-apart elements
  - **Similarity:** similar elements are grouped together more often
  - **Common motion:** elements that move together are likely to be perceptually grouped
  - **Symmetry and parallelism:** elements that are symmetrical or parallel tend to group together
  - **Continuity:** edges that would meet if extended are perceived as a single edge

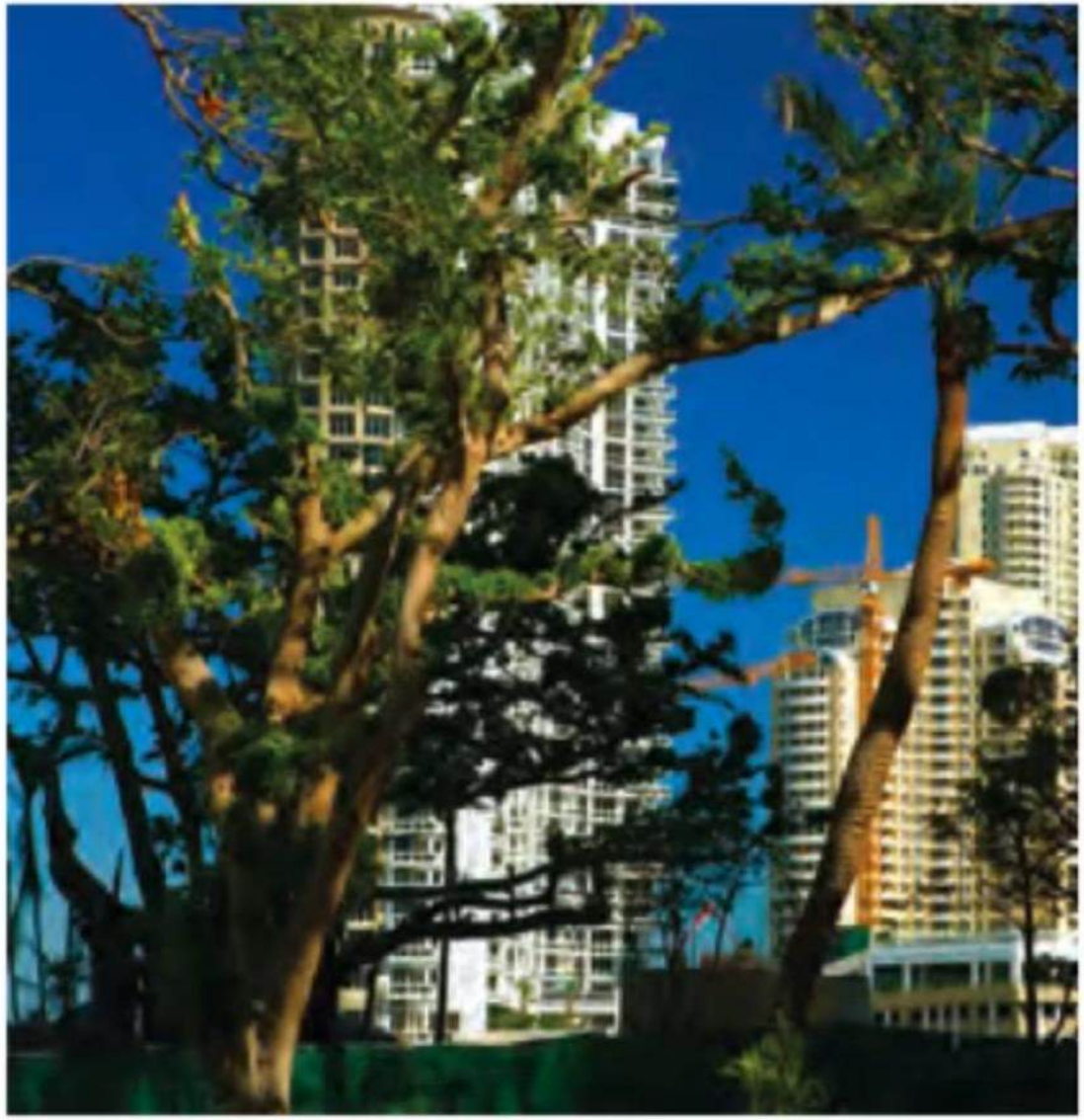
Perceptual grouping: continuity



Perceptual grouping: interpolation

Vibe Images/Alamy

(a)



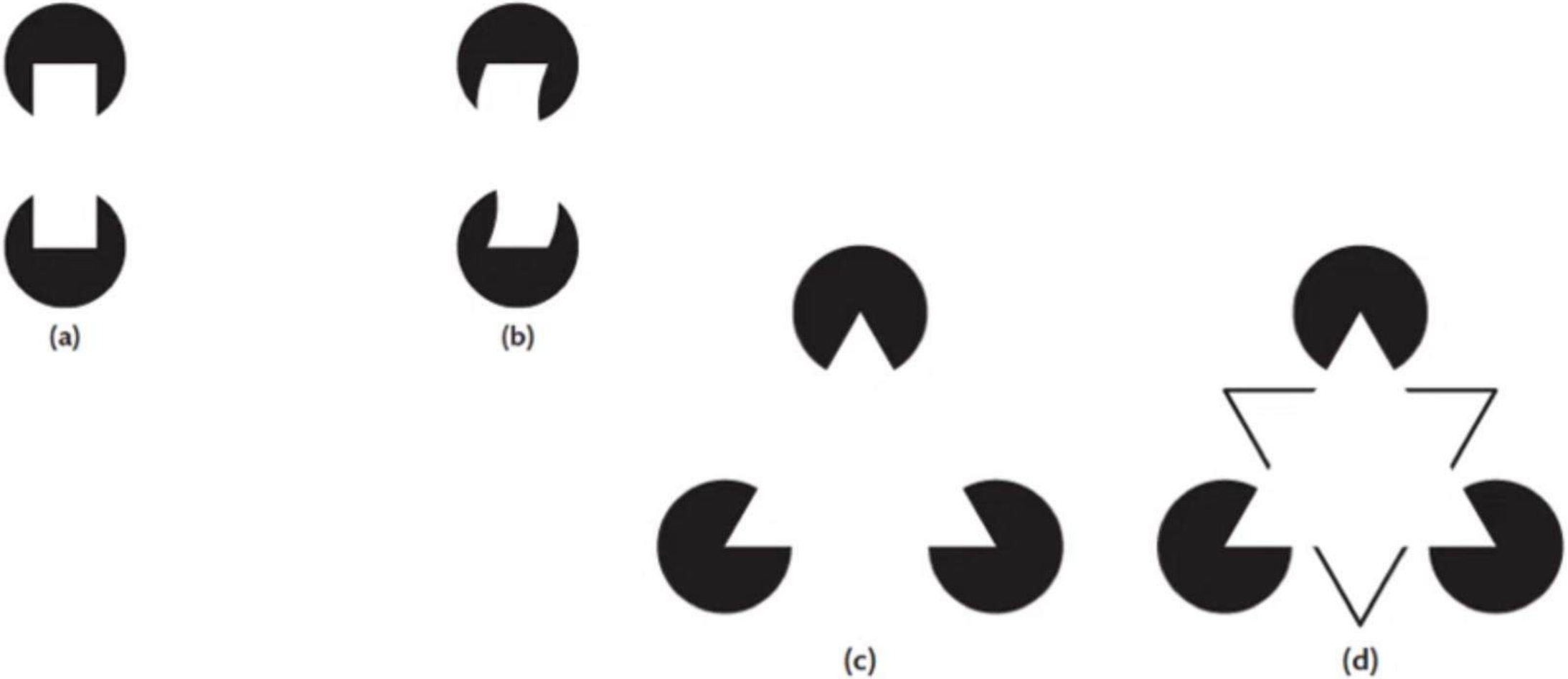
(b)

Glowimages/Getty Images]

Perceptual grouping: interpolation

Perceptual grouping: interpolation

- Two mechanisms at play:
  - Finding edges
  - Completing surfaces



Perceptual grouping: interpolation

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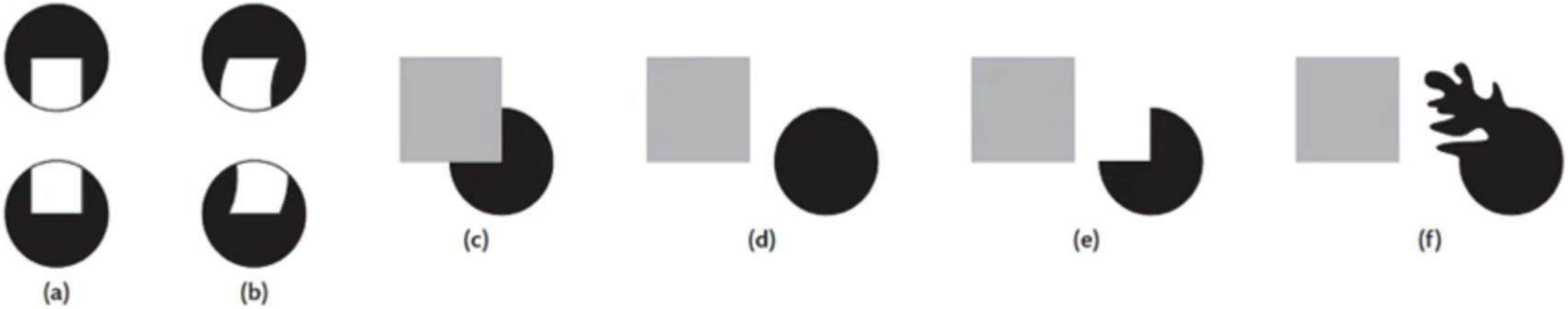

Perceptual grouping: interpolation

- Cats do it too??

If I fits I sits: A citizen science investigation into illusory contour susceptibility in domestic cats (*Felis silvestris catus*)

Gabriella E. Smith [a,b,*], Philippe A. Chouinard [c], Sarah-Elizabeth Byosiere [a,b]

[a] *Animal Behavior and Conservation Program, Department of Psychology, Hunter College, City University of New York, United States*
[b] *Thinking Dog Center, Department of Psychology, Hunter College, City University of New York, United States*
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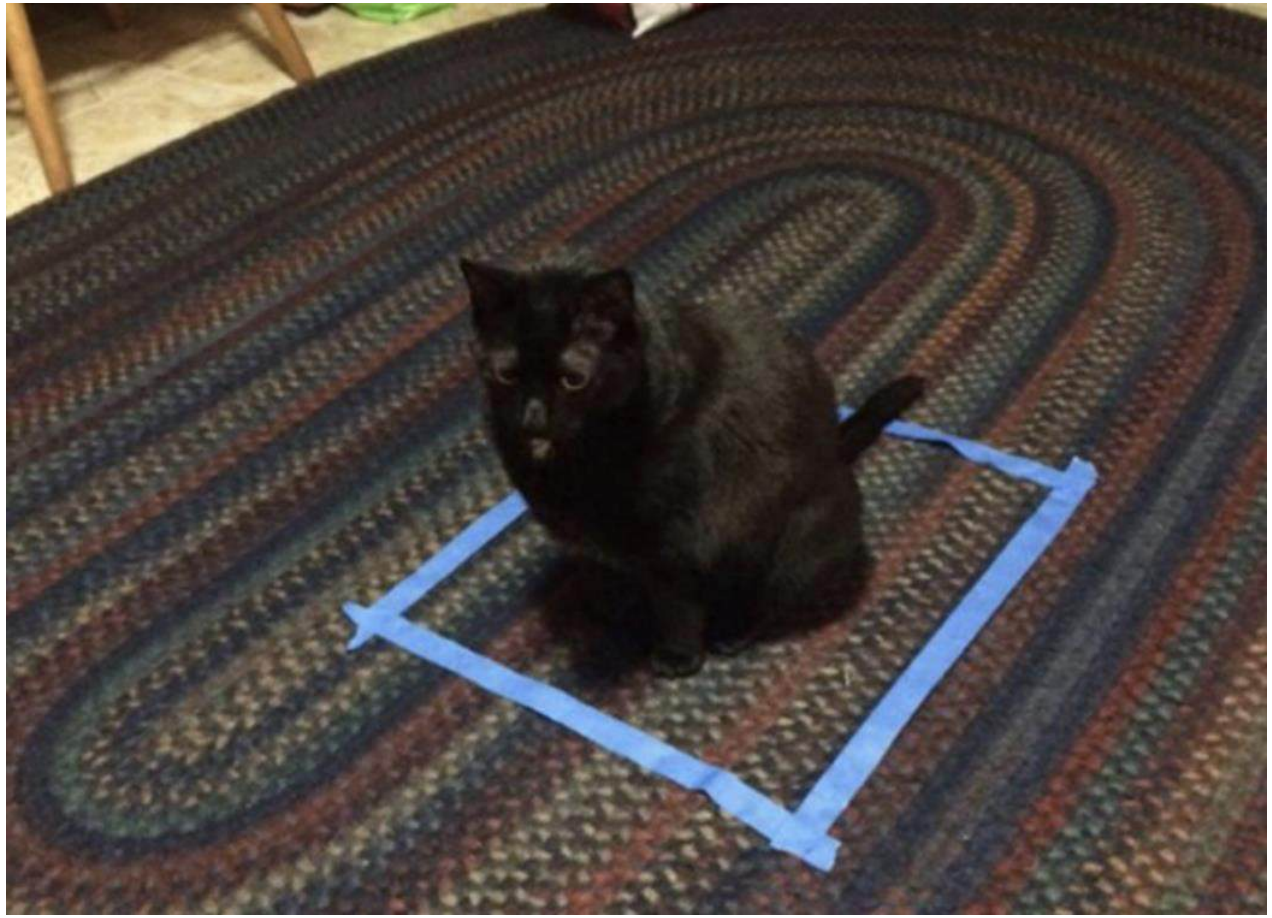

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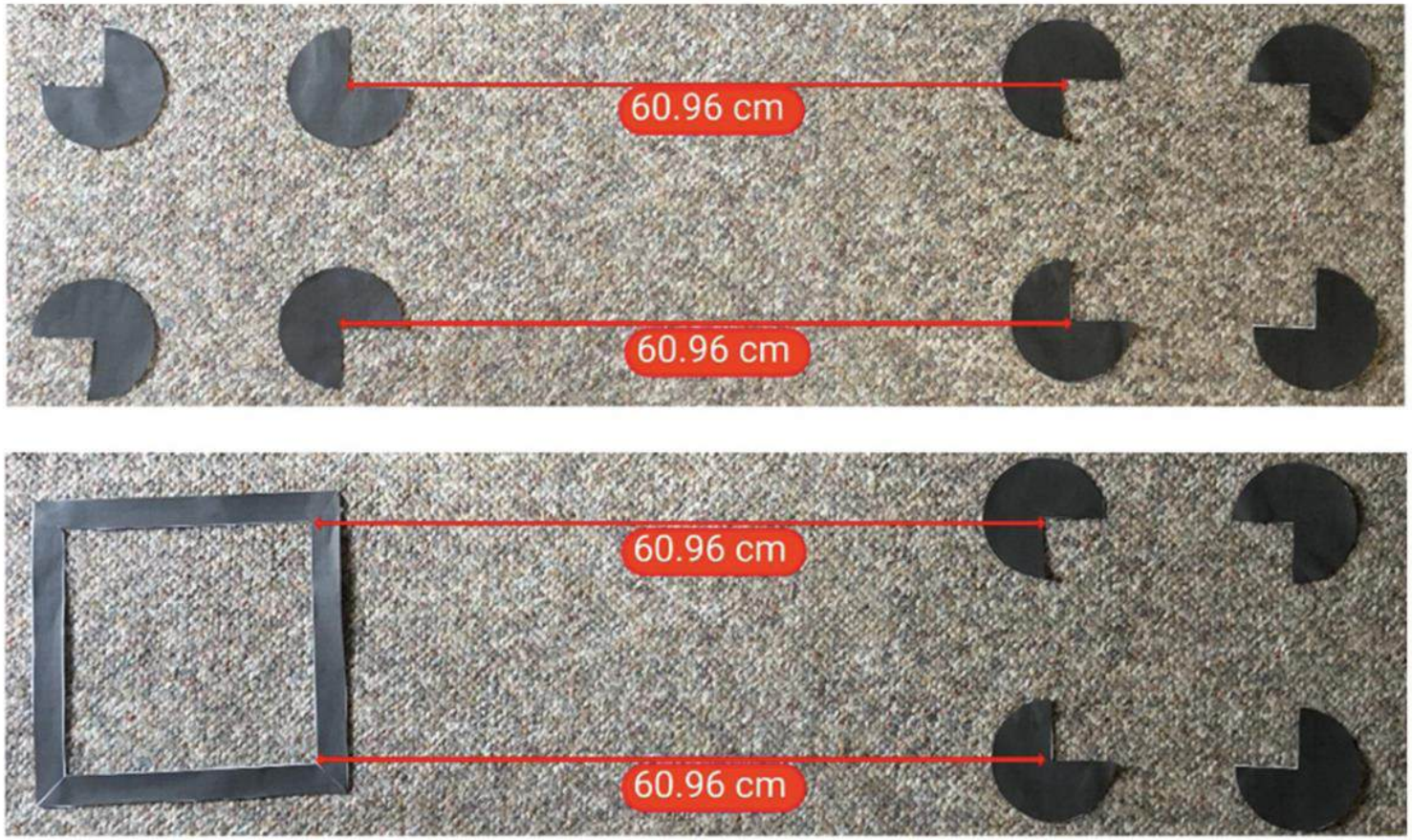

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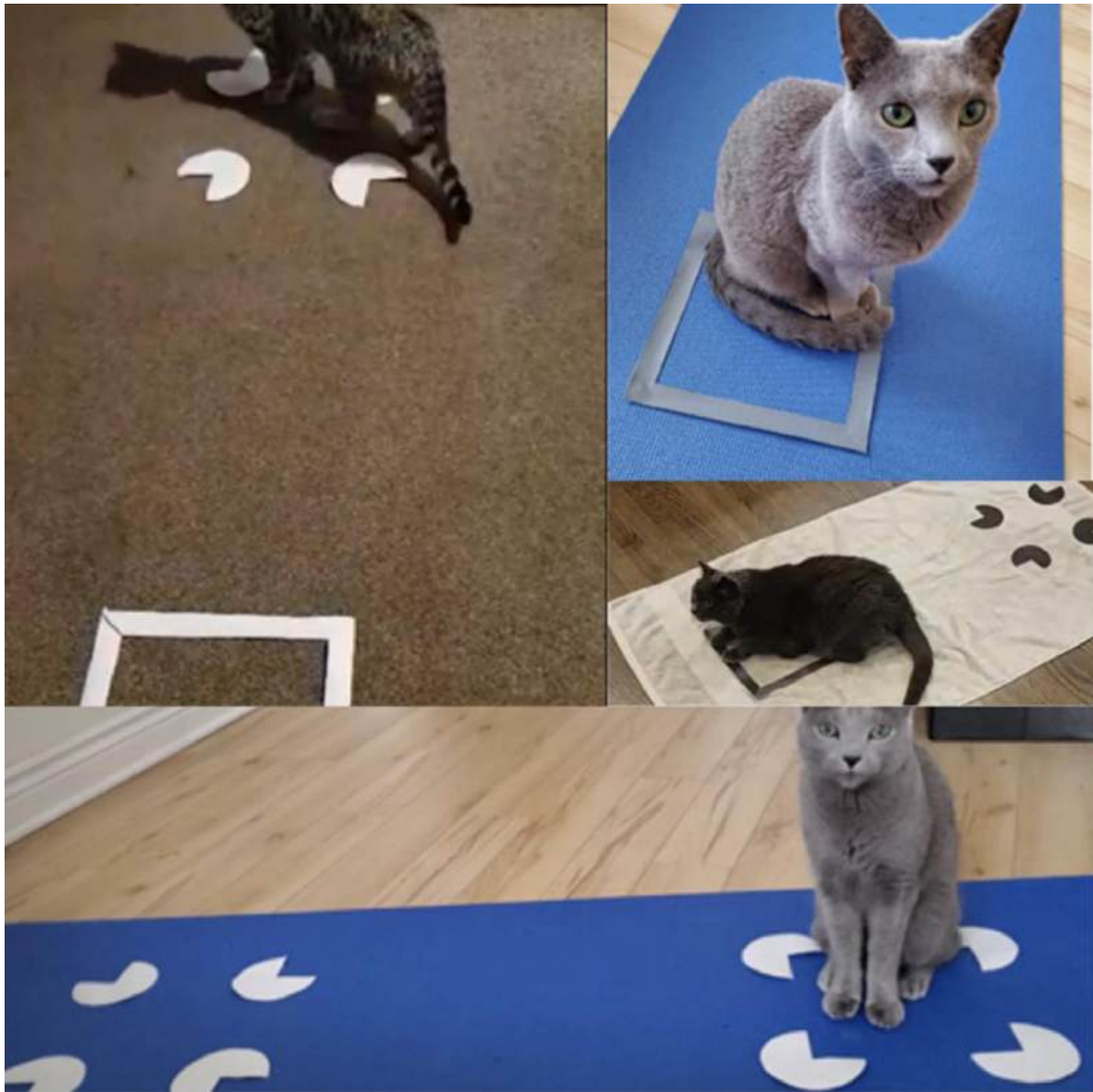

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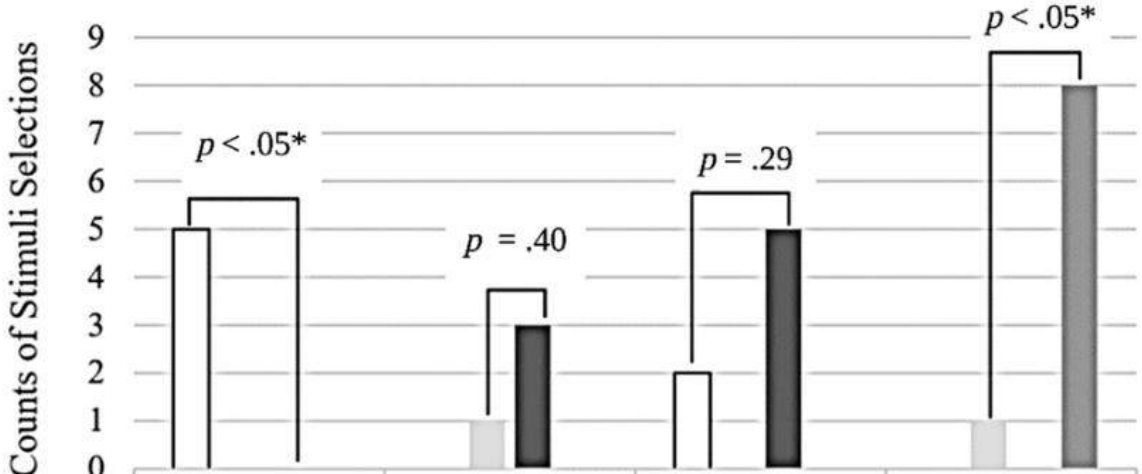


	Kanizsa vs. Control*	Control vs. Square	Kanizsa vs. Square	Control vs. Kanizsa/Square *
Kanizsa	5		2	
Control	0	1		1
Square		3	5	
Kanizsa/Square				8

Perceptual grouping: why?

- Natural statistics and constraints of the real world
  - If we can see our surroundings optimally, we have higher chances of survival
- Perceptual grouping tends to work poorly for man-made stimuli
  - Magic tricks!
- Illusions in the natural world are less common

(a)

(b)

Perceptual grouping: why?

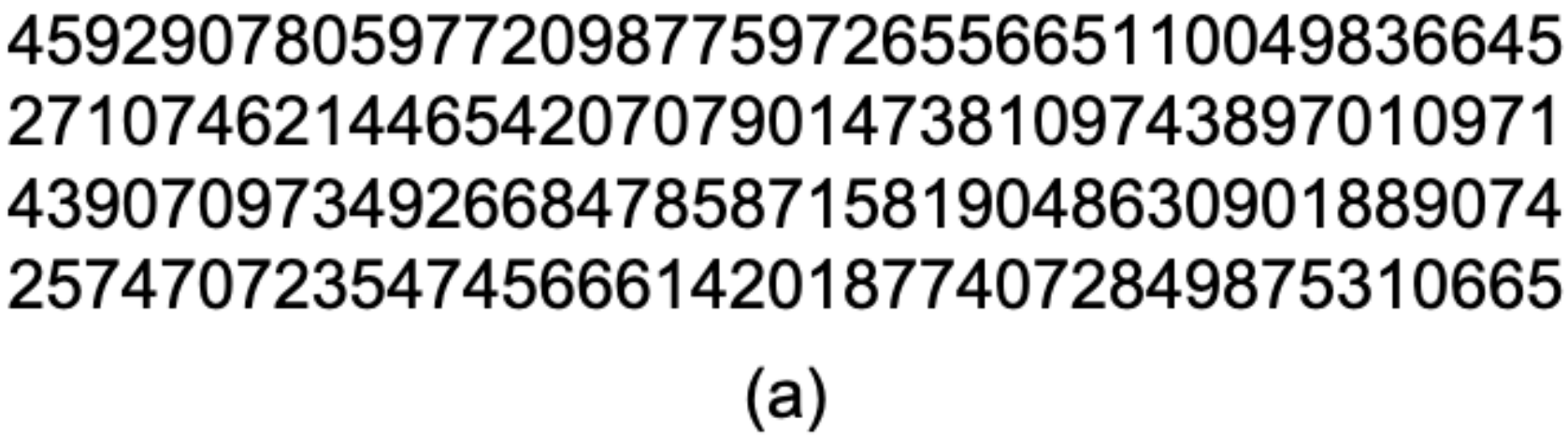
- Natural statistics and constraints of the real world
  - If we can see our surroundings optimally, we have higher chances of survival
- Perceptual grouping tends to work poorly for man-made stimuli
  - Magic tricks!
- Illusions in the natural world are less common
- Implication: cultural background matters for your visualizations!

Saliency, attention, and perception for action

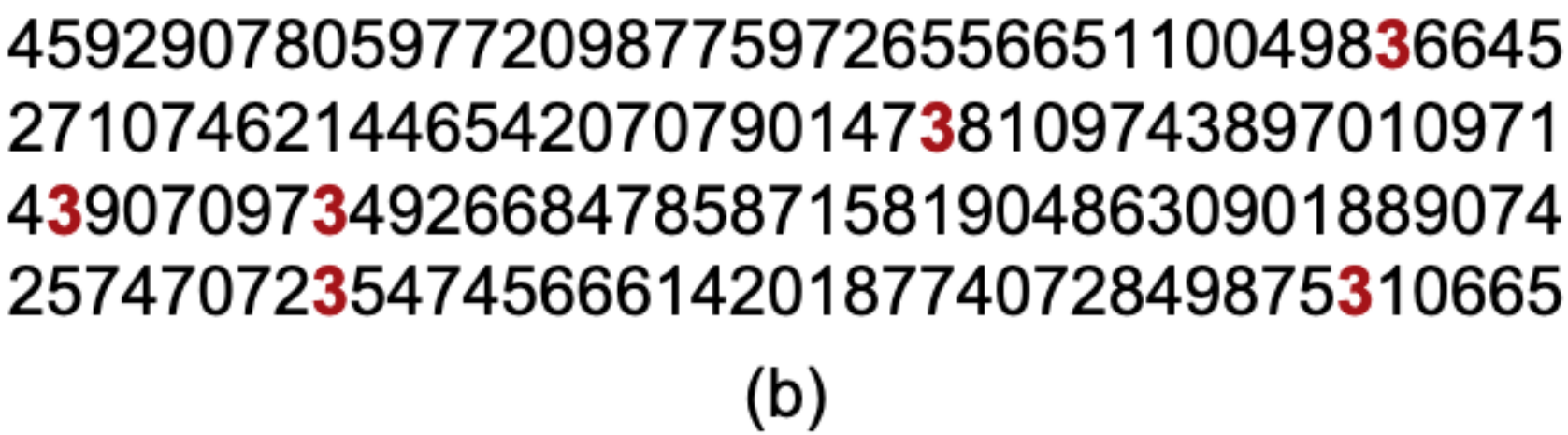
- Once the brain processes the stimuli and assigns it meaning, we need to do some action in response to this perception
  - For this class, that mostly involves visually scanning or manipulating (interacting with) the visualization for new information
- Our actions depend on which things we perceived
  - What did we pay attention to? What was most salient?

Preattentive processing

- Some visual features make some elements/objects more easily seen



(a)



(b)

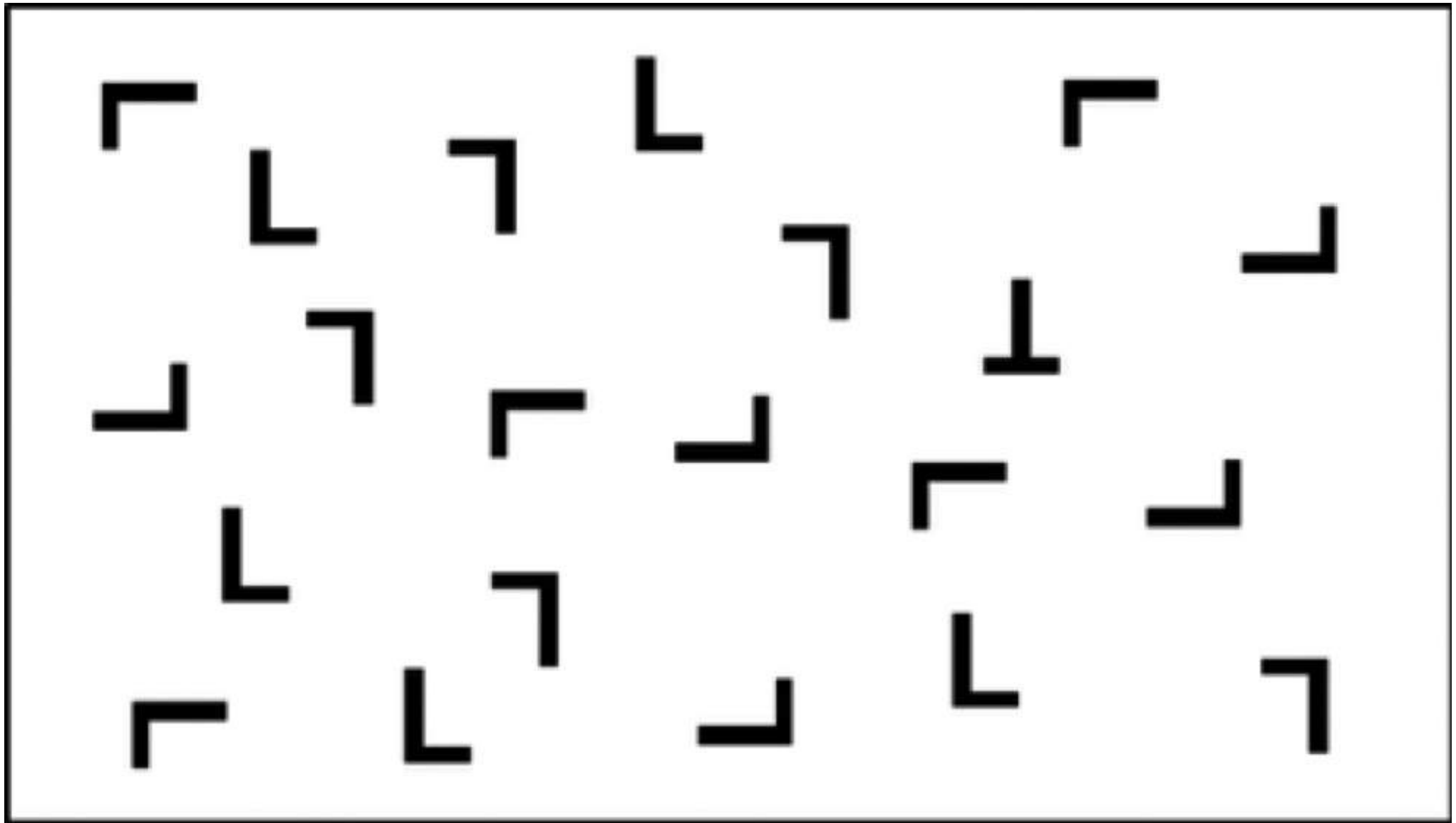
Preattentive processing

- Some visual features make some elements/objects more easily seen

Find the ‘T’ symbol

Preattentive processing

- Some visual features make some elements/objects more easily seen



Preattentive processing

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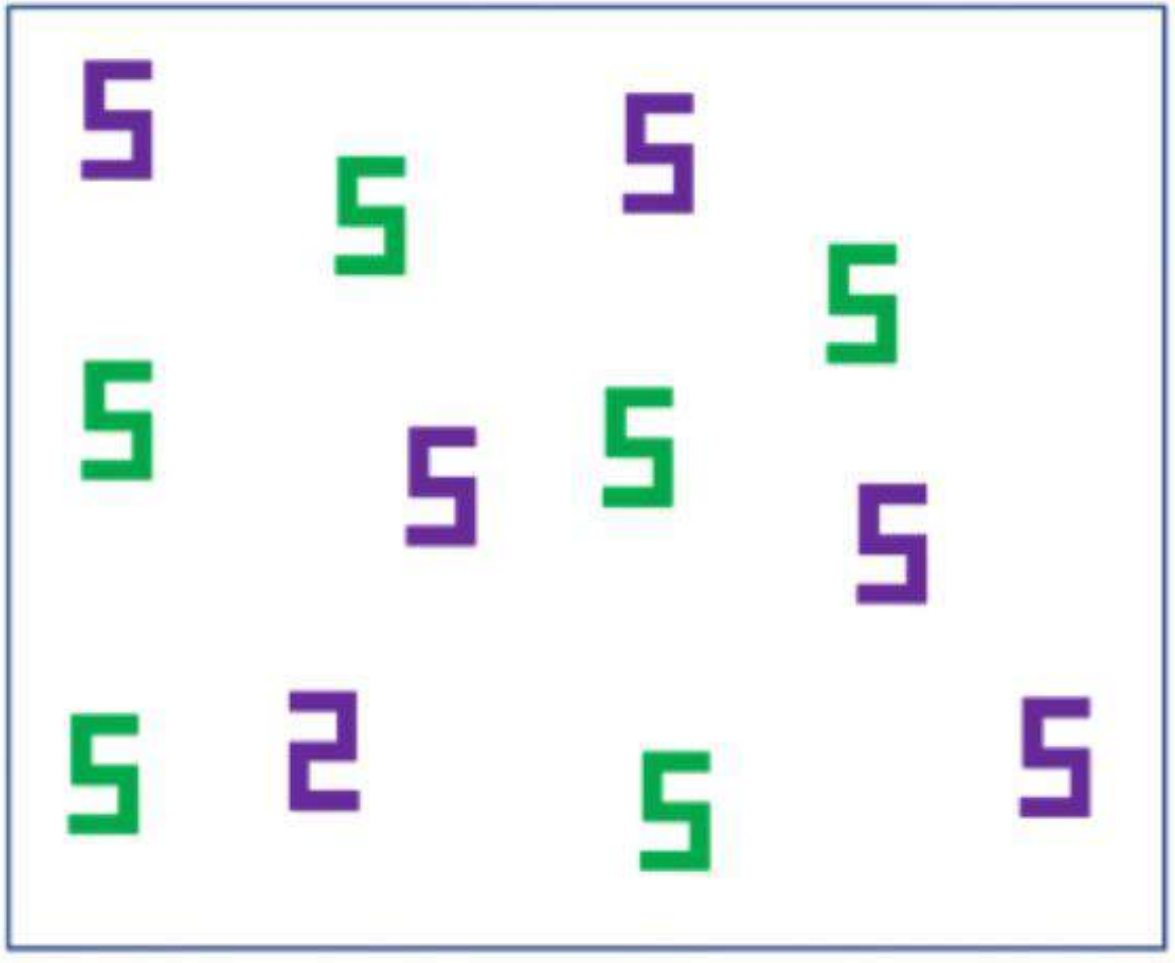

Find the 2

Preattentive processing

- Some features are more easily seen than others
  - Very complicated topic, no concrete explanation yet
- Low-level features seem to be processed first
  - Color: hue, brightness, saturation, etc.
  - Edges, contours, angles, etc.
  - Contrast
  - Orientation
  - Motion
  - Spatial frequency
- Put simply, these features contribute to the saliency of a visual element
- **Rule of thumb:** salient elements are usually *statistical outliers* compared to nearby elements

Actions

- Visual features have been processed, now we need to do something
  - Scan for new information
  - Manipulate (interact with) the visualization for new views

Actions: eye movements

- Three types of eye movements:
  - **Saccades:** rapid, ballistic eye movements
  - **Smooth pursuits:** slow, smooth eye movements that allow us to maintain focus on a moving object
  - **Vergence movements:** allow the eyes to maintain their focus on objects at different distances from the observer
    - https://www.youtube.com/watch?v=u4U3ms8kmAY

- Users will do these eye movements to gather new information in your visualizations

Attention and awareness

- Just because something is in the field of view does not mean the observer is aware of it
- Some things are very easy to perceive quickly, and some things are not

Scene gist

- https://youtu.be/v4qx2OqfosU?t=160
- 80% accuracy with only 36 milliseconds of viewing

Scene gist

Attention blindness

- https://www.youtube.com/watch?v=vJG698U2Mvo

Change blindness

- https://www.youtube.com/watch?v=FWSxSQsspiQ

You're about to see the waiting room of a science laboratory.

See if you can spot the items in the room that are a little "out of place."