Sensation: basic, primitive mental state corresponding to energies in env't; **experience** of world

Perception: mental state corresponding to properties of objects and events in env't; **knowledge** of world

Doctrine of Specific Nerve Energies
(Johannes Müller, 1826)

quality of sensation (visual, auditory, touch, etc.) depends on which nerve fibers are stimulated - NOT on the stimulus itself

fibers of optic nerve are normally stimulated by light
- may also be stimulated by pressure, electric current, and so on
- any stimulation will yield experience of light

any sensory experience must have corresponding set of nerve fibers: experiences of brightness, color, loudness, pitch, etc.

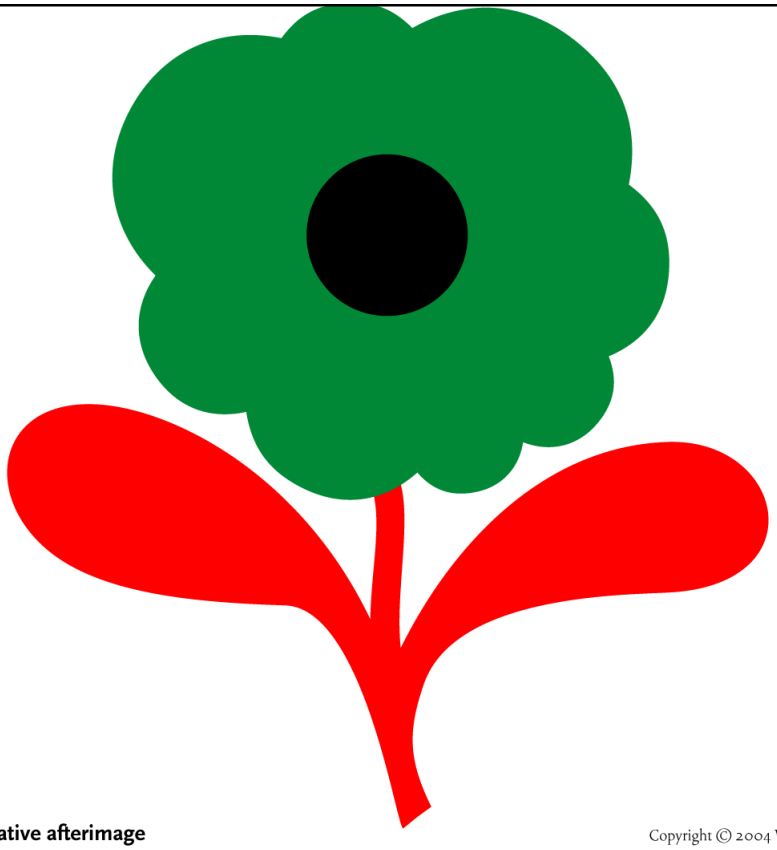


Figure 5.28: Negative afterimage

Light = electromagnetic radiation

electromagnetic spectrum from shortest to longest wavelength:

gamma rays, X-rays, ultraviolet, **color**, infrared, microwaves, radar, FM, TV, AM

intensity -> brightness
wavelength -> color (short = blue, medium = green, long = red)

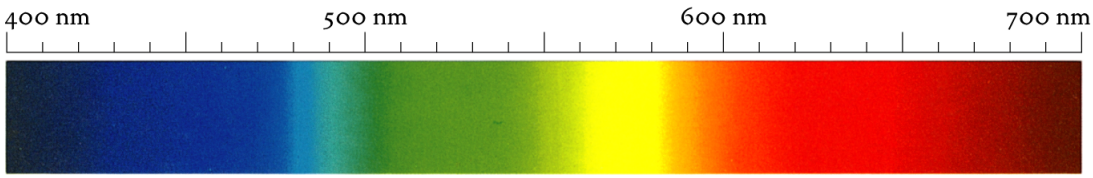


Figure 5.19: The visible spectrum and the four unique hues

Structure of the Eye

- retina consists of receptors (rods, cones), bipolar cells, ganglion cells, some others

- light enters pupil, then passes through eyeball to retina: through ganglia, bipolars, etc, then finally strikes receptors

-optic nerve: bundle of axons of ganglion cells, leading out back of eye to brain (leaving blind spot)

close left eye and look at X, then scan right until O disappears:

X . . . . O

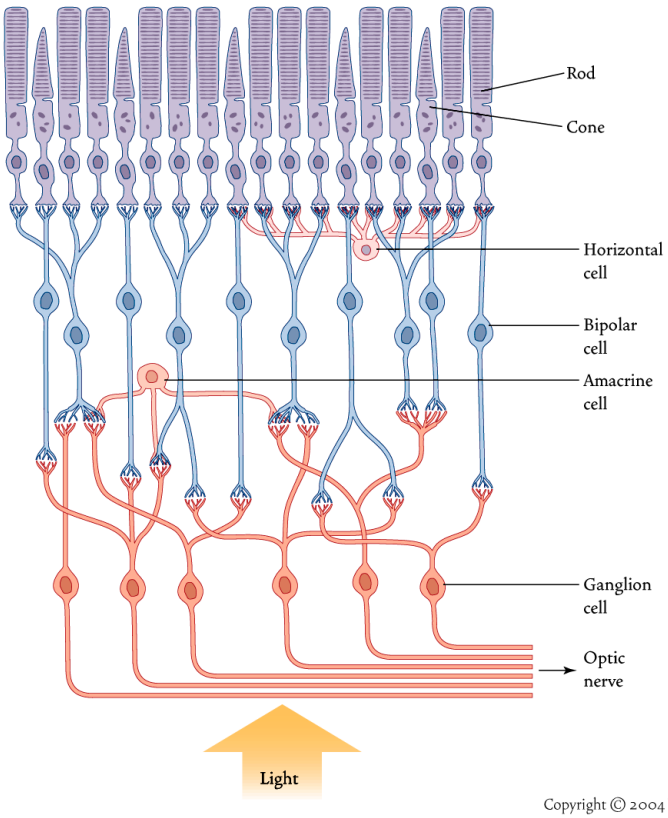


Figure 5.10: The retina

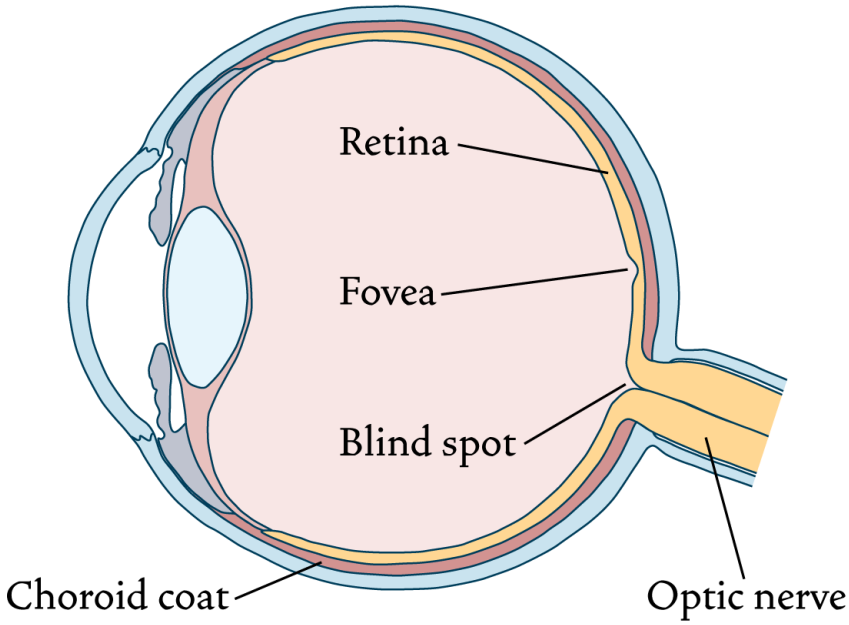


Figure 5.11: Fovea and blind spot

Structure of the Eye (cont'd)

- fovea: central depression in retina where cones are most densely packed - most acute vision

- rods: very sensitive; black/white (achromatic); night vision; mostly in periphery; 120,000,000

- cones: less sensitive; color (chromatic); daytime vision; mostly in fovea; 6,000,000

PHOTORECEPTORS: light-sensitive neurons in the retina of the eye that produce action potentials when stimulated by light
2 types of photoreceptor cells:
- rods (low light conditions like nighttime; black /white only)
- **CONES** (bright light conditions like daytime; COLOR vision)

3 types of **CONE** cells sensitive to different wavelengths of light
- short-wavelength – most sensitive to blue-ish light
- medium-wavelength – most sensitive to green-ish light
- long-wavelength – most sensitive to red-ish light

these send action potentials to **OPPONENT PROCESS CELLS**
- "opponent processes" are excitation and inhibition

3 types of **OPPONENT PROCESS CELLS** in the visual system (maybe in retinal ganglion cells, or in thalamus, or in cortex):
- black/white – excited, you see white; inhibited, you see black
- red/green – excited, you see red; inhibited, you see green
- blue/yellow– excited, you see blue; inhibited, you see yellow

How do we see colors?

first guess: trichromatic theory (Young-Helmholtz theory)

- all colors would be mixtures of blue, green, red based on response of those cone types

- but what about 1) afterimages, and 2) yellow?

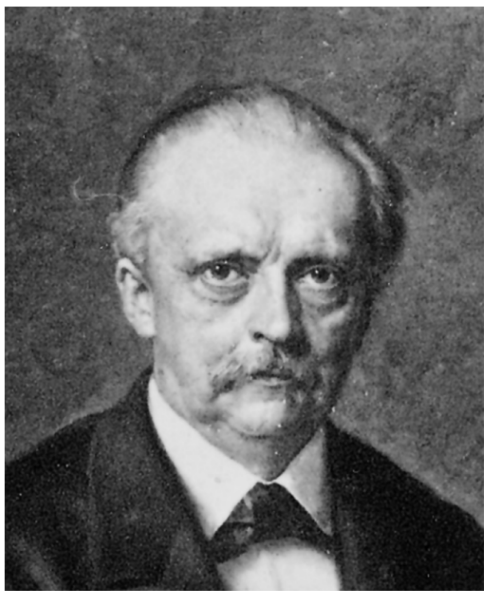
Thomas Young
(1773-1829)

- introduced the modern conception of energy
- first to measure astigmatism in vision
- revived wave theory of light and demonstrated wave interference phenomena (making possible Einstein's and Bohr's quantum insights)
- described mechanism of tides
- explained capillary action
- decoded 86 words of the Rosetta stone, noting that hieroglyphics employed both alphabetic and non-alphabetic characters (1814)
- introduced trichromatic theory of color vision (1801)

Thomas Young
(1773-1829)

Hermann von Helmholtz
(1829-1894)

- physicist - produced mathematical formulation of conservation of energy
  - made advances in thermodynamics, fluid dynamics, and electrodynamics
  - suggested the idea that enabled Heinrich Hertz to discover radio waves predicted by Maxwell's equations
- physician - wrote a monograph on hay fever
- physiologist - first to measure speed of nerve impulse
  - in optics, invented the opthalmoscope
  - in acoustics, developed the receptor resonance theory
- mathematician - helped with advances in geometry which eventually made possible Einstein's general theory of relativity
- philosopher - expounded empiricism in the field of epistemology
- psychologist - proposed unconscious inference as mechanism for perception (still the basis of computer vision)



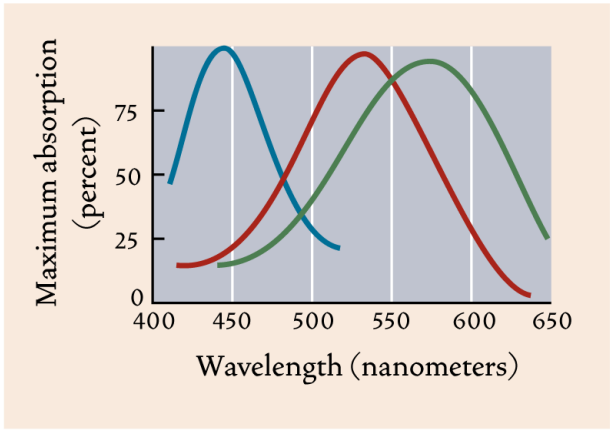
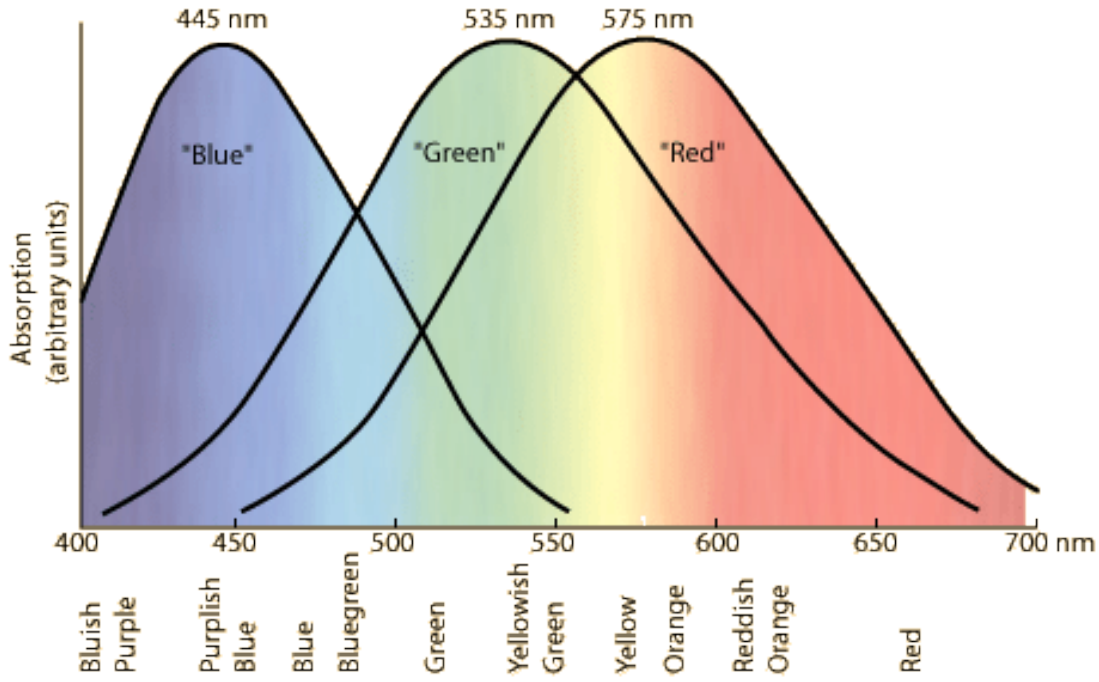
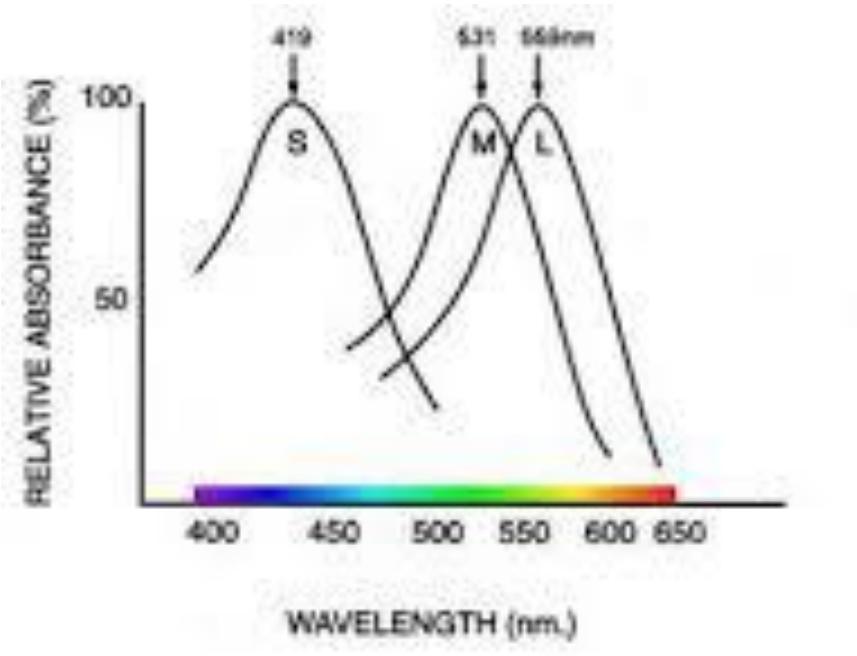


Figure 5.25: Sensitivity curves of three different cones in the primate retina





current theory: Opponent-Process theory

there ARE three cone types, but they're NOT blue, green and red! (they're more like violet, green, and yellow) - just call them short, medium, and long wavelength cones

- each responds to many wavelengths, but peak responses are at:
  Short=440 nm, Medium=530 nm, Long=560 nm

colors come in opponent pairs:
  black & white; red & green; blue & yellow

- activation of short, medium and long wavelength cones may excite or inhibit Opponent Process cells (which may be ganglion cells or cells in the thalamus or cortex)

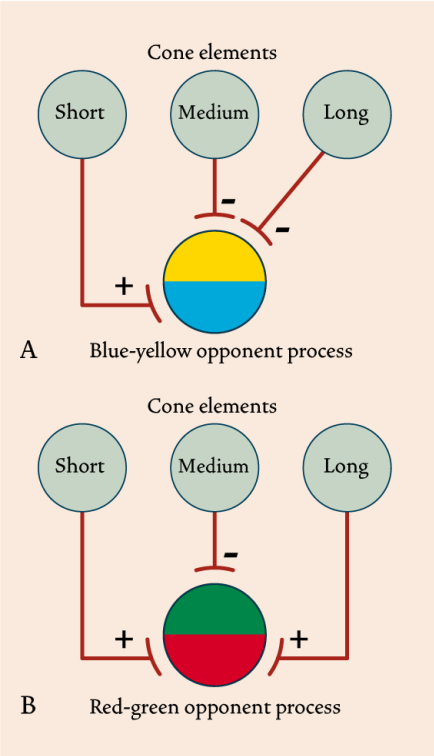
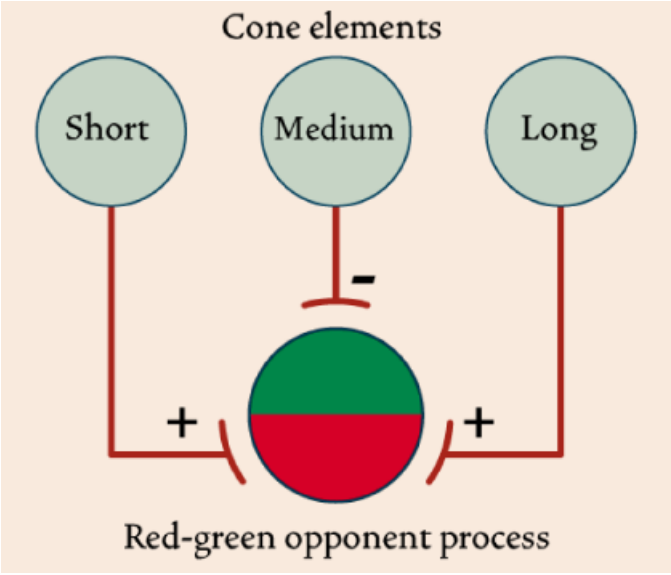
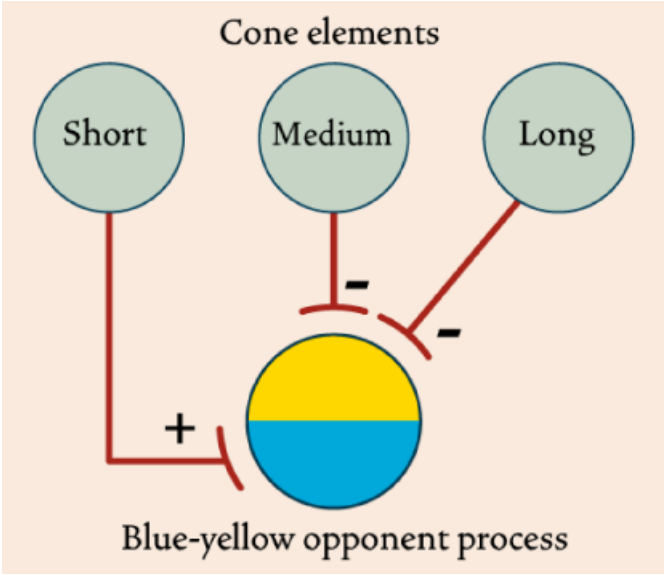


Figure 5.29: From receptors to opponent-process pairs





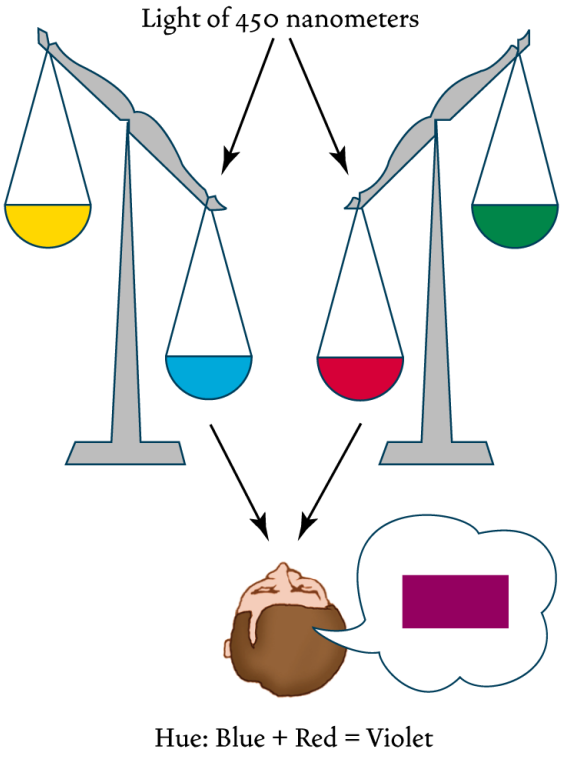


Figure 5.30: The opponent-process hue systems

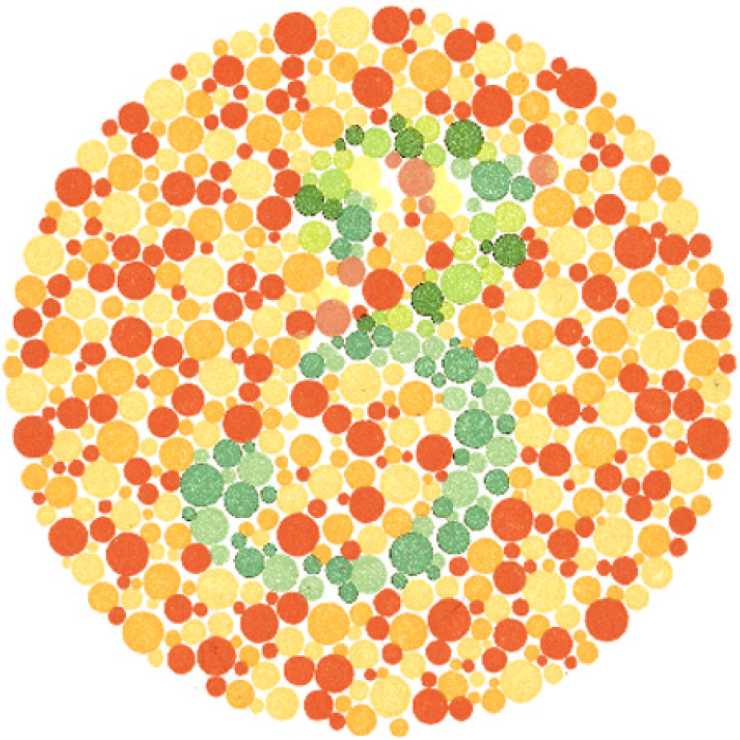


Figure 5.32: Testing for color blindness

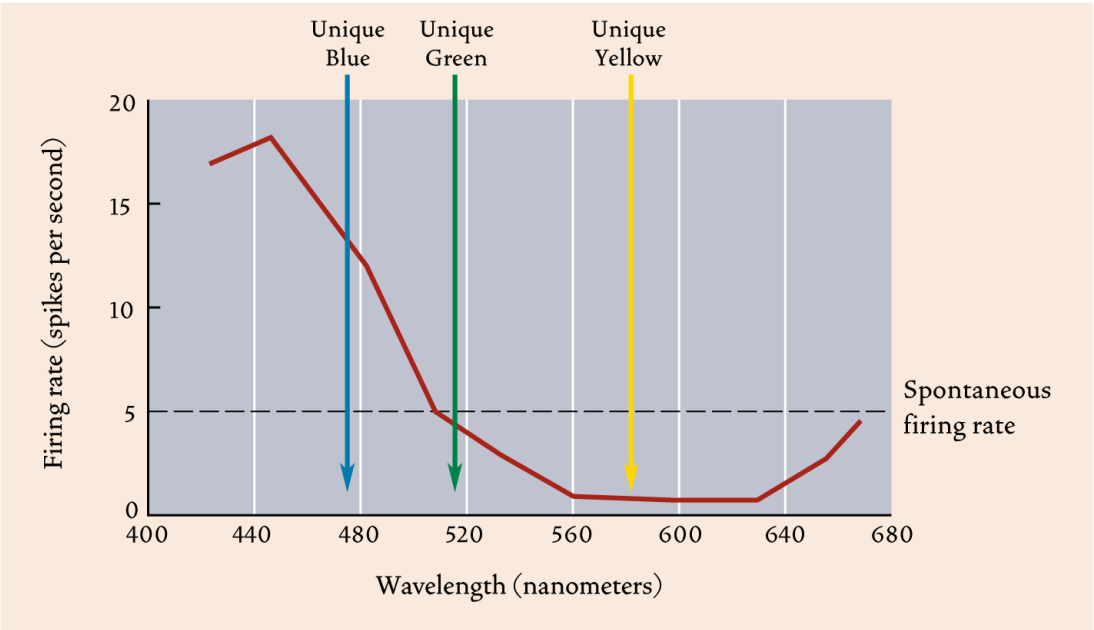


Figure 5.31: Opponent-process cells in the visual system of a monkey

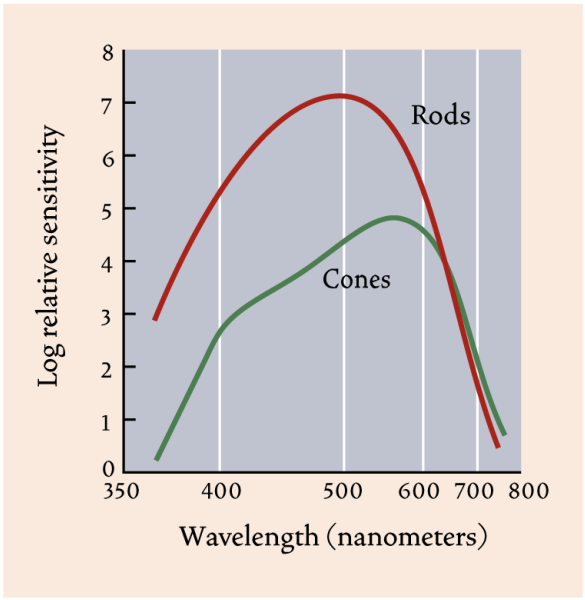
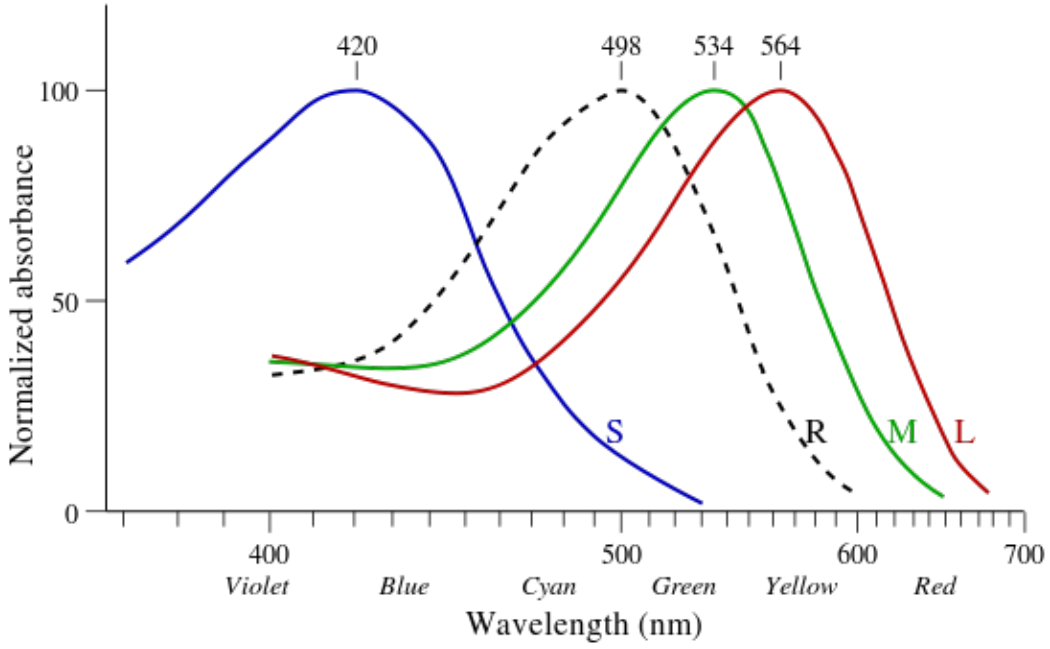


Figure 5.12: Sensitivity of rods and cones to light of different wavelengths



Lateral Inhibition and Brightness Contrast

- neighboring receptor cells tend to inhibit each other (using inhibitory interneurons to connect them)

- result is exaggeration of contrasts: dark looks darker, light looks lighter

-example:
brightness contrast - neighboring regions of different brightness have their boundaries sharpened as their brightness/darkness difference is increased

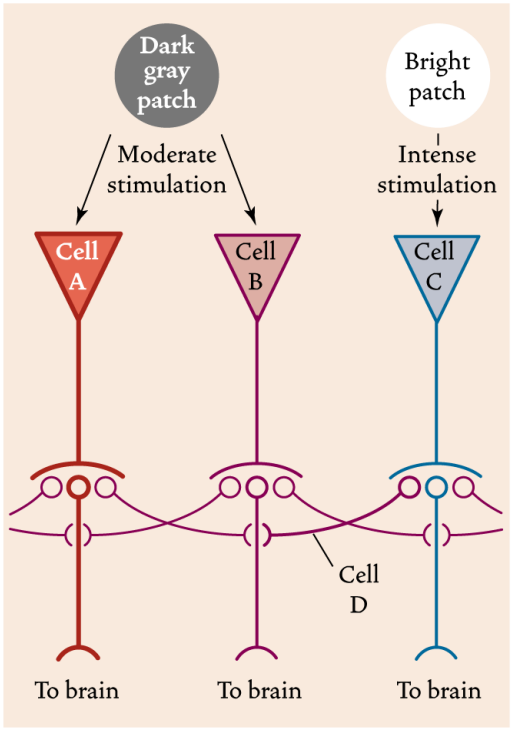


Figure 5.18: Lateral inhibition and contrast

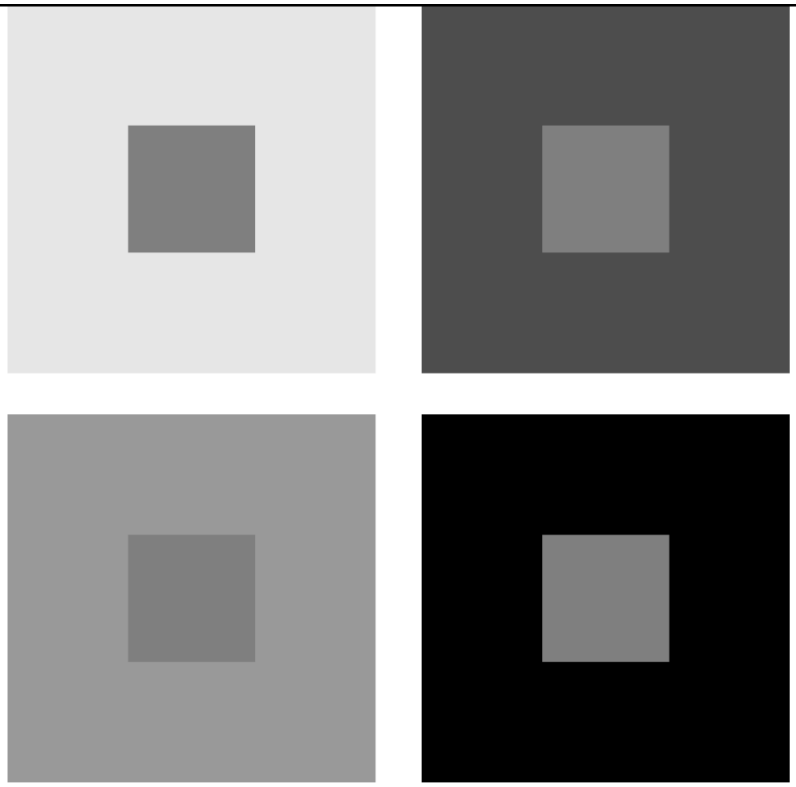


Figure 5.14: Brightness contrast

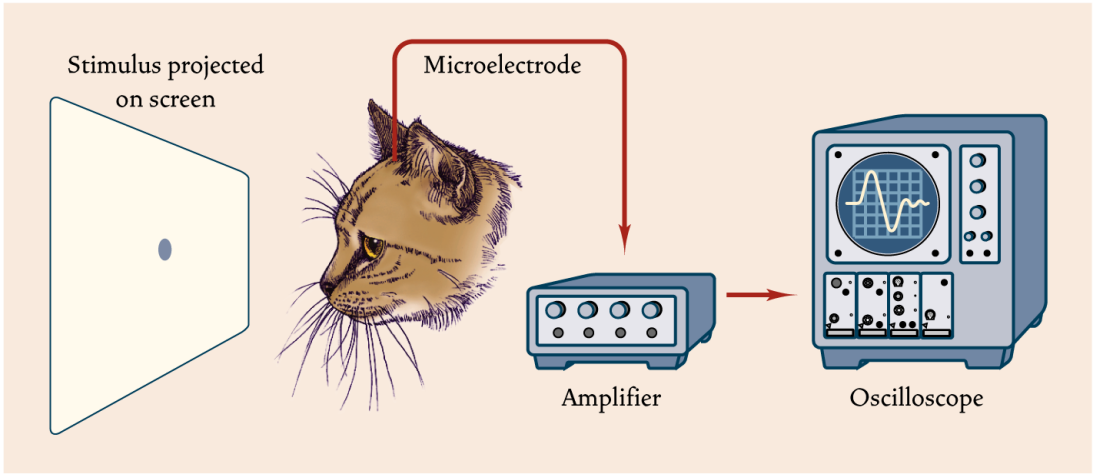


Figure 5.33: Recording from the visual system of a cat

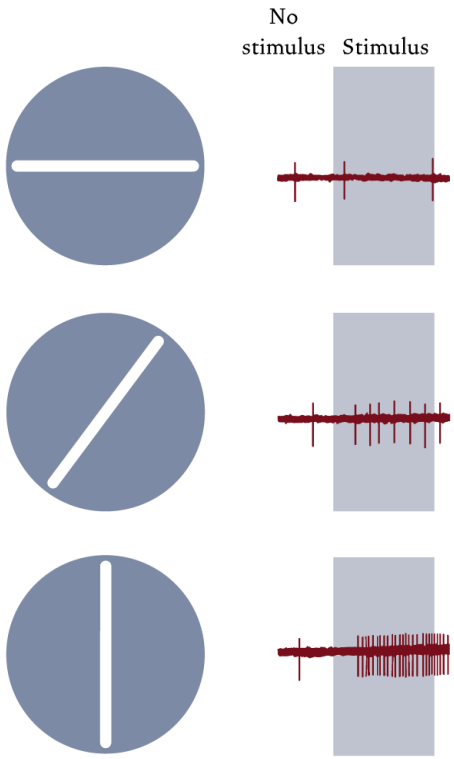


Figure 5.35: Feature detectors in the visual system of the cat

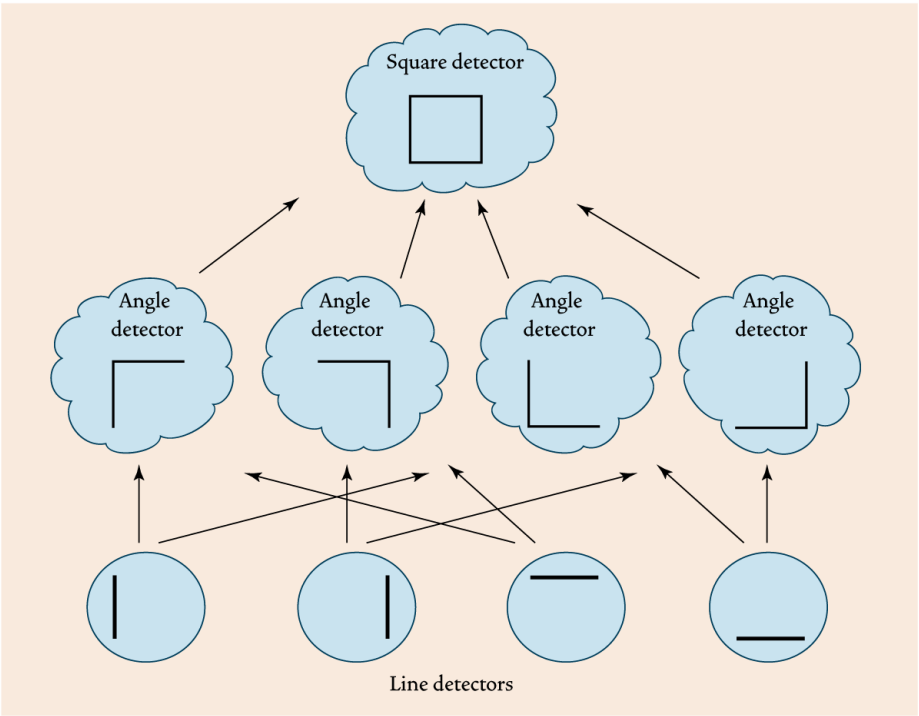


Figure 6.28: A feature net

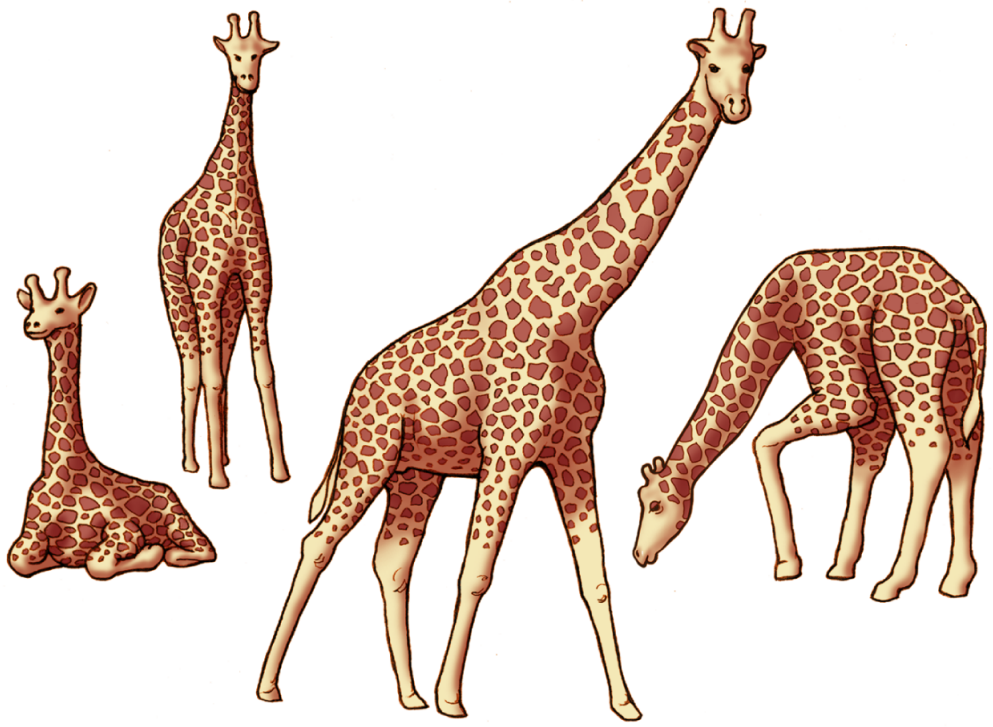


Figure 6.13: The variability of stimuli we recognize

DISTAL STIMULUS (thing in world)	reflected light ---------->	PROXIMAL STIMULUS (retinal image)

Retinal Image: stimulation of receptors produces sensations of brightnesses and colors

- then light sensations must be **interpreted** as objects

Perception is knowledge of world - experience of objects and events, **based** on sensations

Problem: POVERTY OF THE STIMULUS

- proximal stimulus (retinal image) is inadequate for knowing about distal stimulus

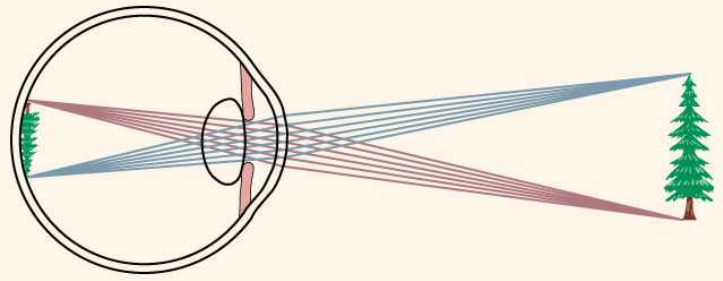
1) inverted - image of object is upside-down on retina

2) ambiguous - size and distance trade off:

- close-up small object has same image size as far-off large object

3) two-dimensional - image is flattened (and then curved, too!), but objects are three-dimensional solids

Conclusion: Perception doesn't happen in the EYE - it happens in the BRAIN!



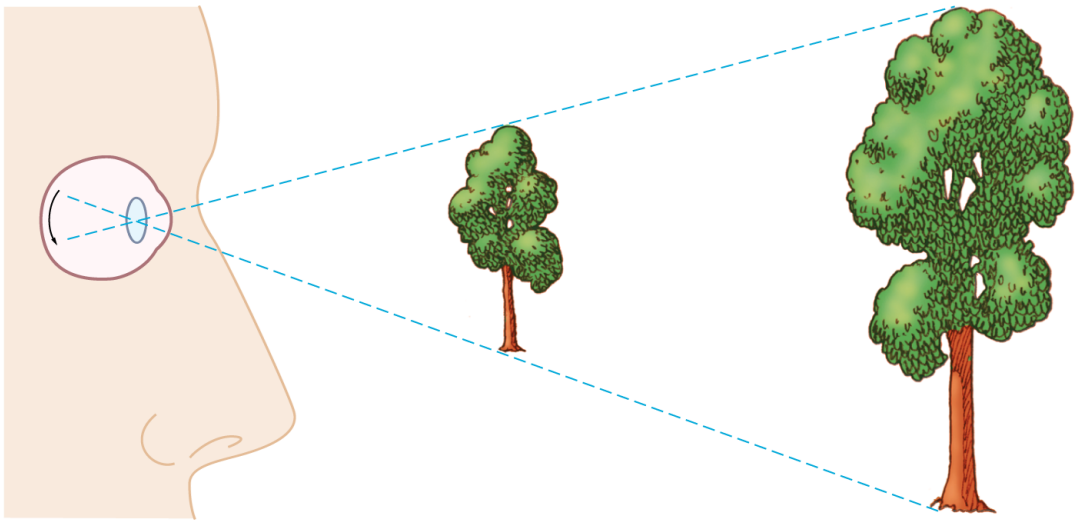


Figure 5.1: Distal and proximal stimuli

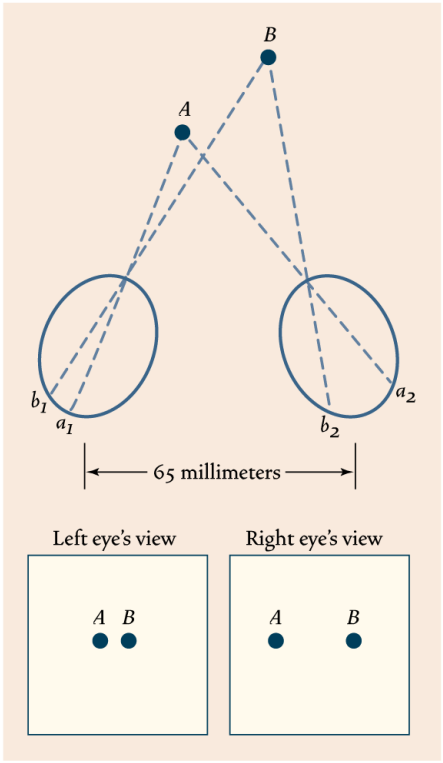


Figure 6.1: Retinal disparity

DEPTH PERCEPTION: an Empiricist view

- how far away is an object?

Hermann von Helmholtz (1821-1894)

retinal image
+
CUES along with
KNOWLEDGE STRUCTURES / INFERENCES
learned from **experience**

--> percept

HELMHOLTZIAN PROGRAM

monocular depth cues (only one eye needed):

- linear perspective - convergence point is far away
- interposition - nearer objects will occlude (block) farther objects
- relative size - nearer objects cast larger retinal images than farther objects (of same size)

"unconscious inference"

- best guess at what DISTAL stimulus PROBABLY caused the PROXIMAL stimulus (the retinal image)
- perception is always in the direction of the best inference ("maximum likelihood")

Figure 6.4: Linear perspective as a cue for depth

Figure 6.3: Interposition with simple displays

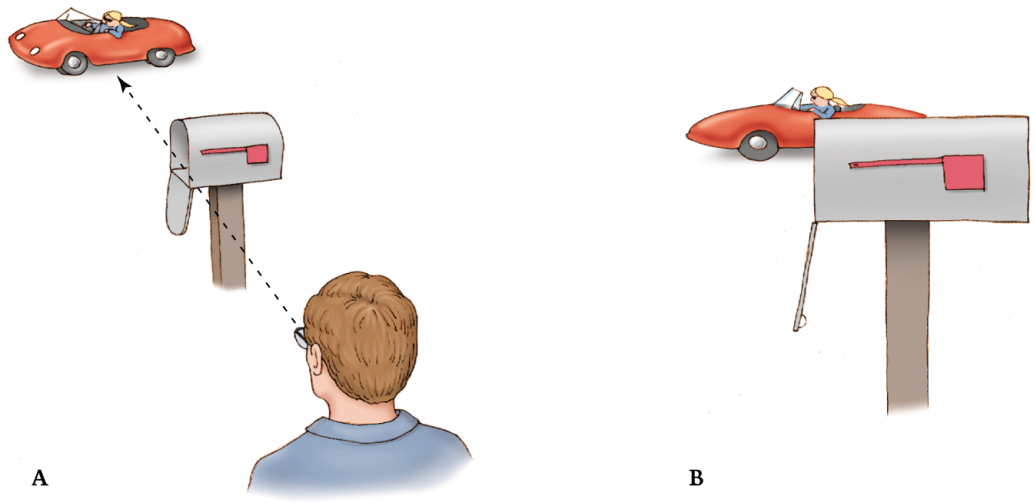


Figure 6.2: Pictoral cues

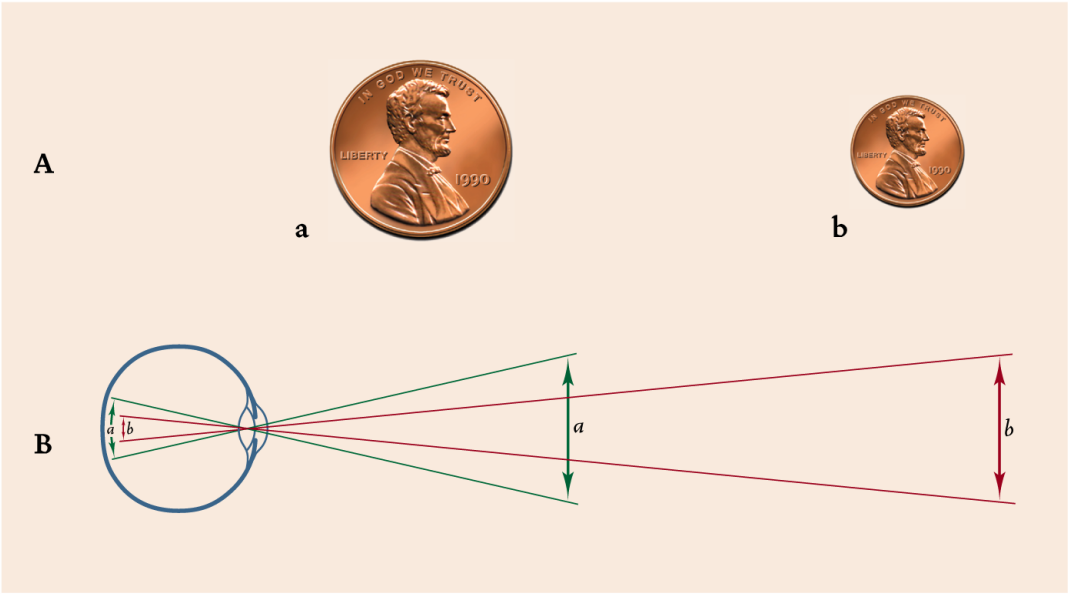


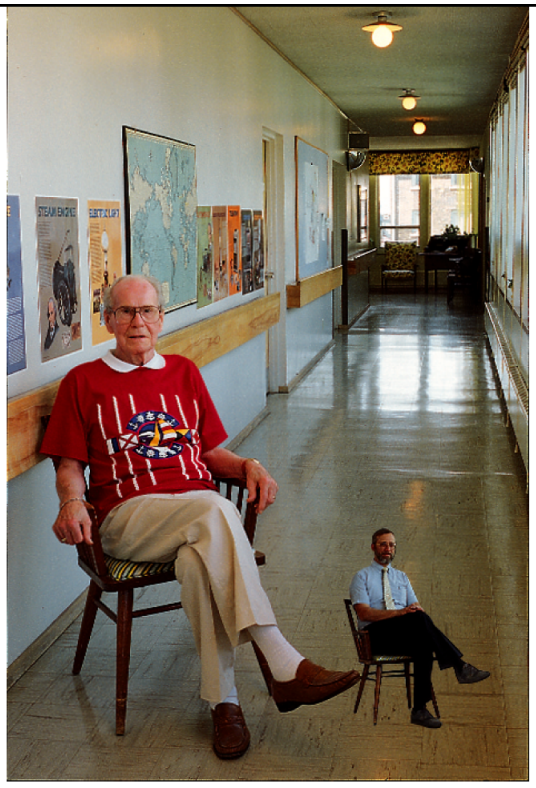
Figure 6.5: Relative size

infer distance of object:

- learned: points nearer to where lines converge are farther away
- retinal image: object appears near to where lines converge (linear convergence cue)
- infer: DISTAL object must be far away

use this inference to get SIZE information:

- learned: far off objects produce smaller retinal images
- retinal image: two objects appear to have SAME retinal image size (relative size cue)
- infer: the farther-away DISTAL object must be LARGER



Page 235: Perceived size and distance

FORM PERCEPTION: a Nativist view

- how do we organize the retinal image into a collection of objects?

Gestalt Psychologists (early 1900's in Germany, then U.S. in 1940's)

retinal image
+
INNATE LAWS of ORGANIZATION

--> percept

Figure 6.17: Perceptual segregation

Principles of perceptual organization

1) grouping by proximity

2) grouping by similarity

3) good continuation

4) closure

Apparent Motion: the phi-phenomenon

- stimulus present in two locations within short time interval is seen as one moving stimulus
- no moving stimulus though! (i.e., no sensations of movement)

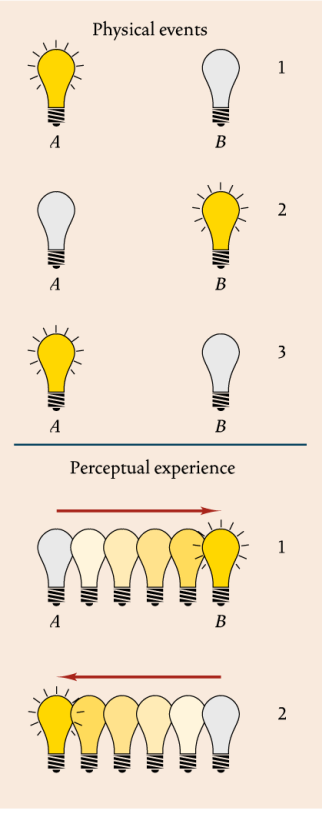
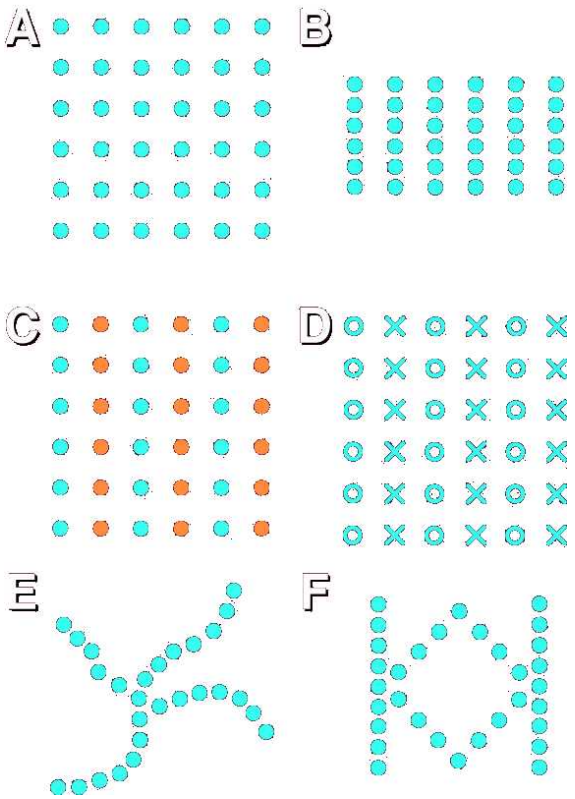


Figure 6.10: Apparent movement



GESTALT PROGRAM

1) Perception is always in the direction of the simplest, most economical configuration

- (based on equilibrium in supposed brain states!)
- ex.: in reversible figure-ground pictures, neither is simpler so both are seen

2) The WHOLE is different from the sum of the parts

- perception of form different from the collection of sensations that make it up
- ex.: subjective contours are perceived w/o sensations

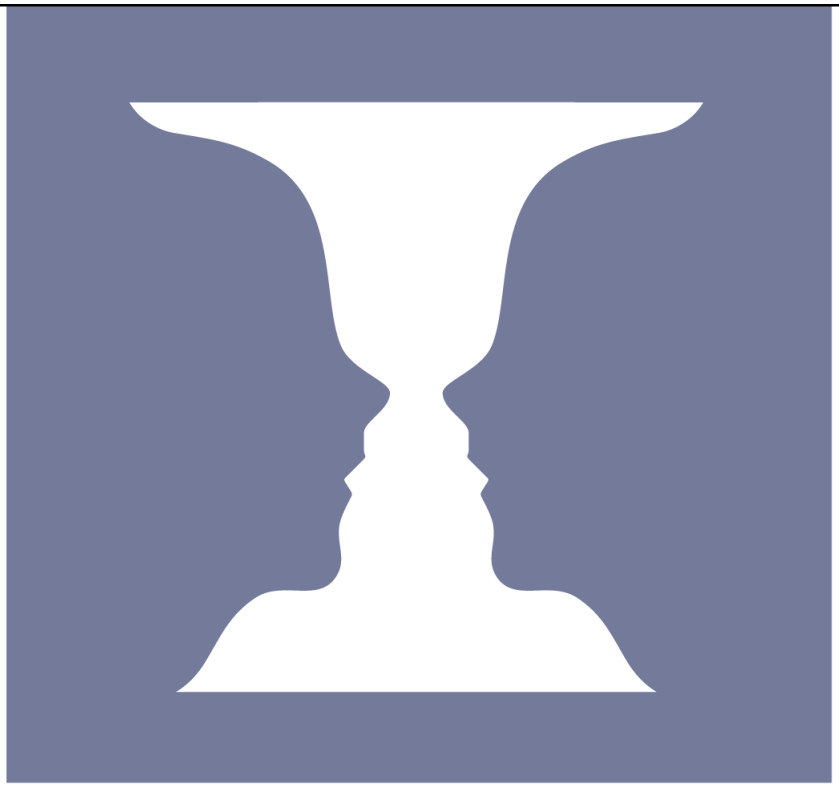


Figure 6.20: Reversible figure-ground pattern

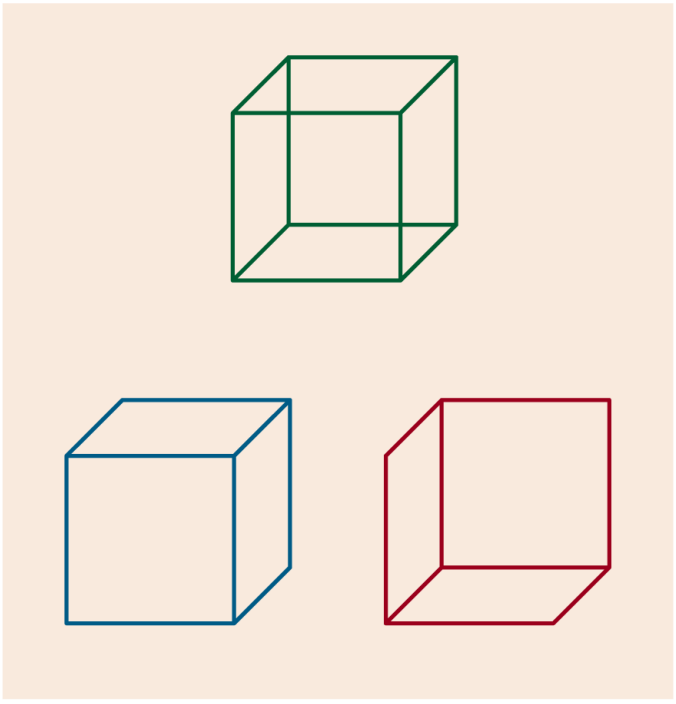


Figure 6.33: The Necker cube

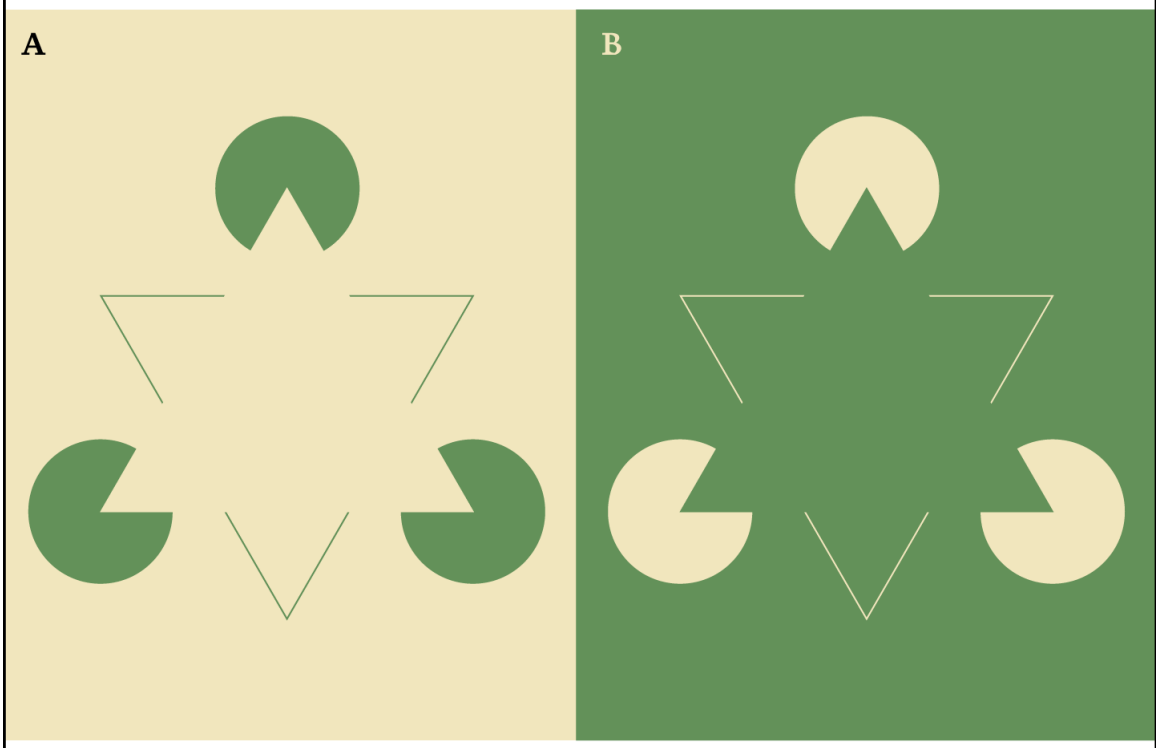


Figure 6.27: Subjective contours

EMPIRICISM: emphasis on role of learning from **experience** in world

- sensation + memory of experiences = perception
  ex.: How do we see the 3D world, based on a 2D retinal image?
- the (individual's) brain has learned regularities relating flat images to solid objects, and uses them to draw correct conclusions from the retinal image

NATIVISM: emphasis on role of **innate** (inborn) knowledge endowments

- sensation + inborn knowledge & rules = perception
  ex.: How do we see the 3D world, based on a 2D retinal image?
- the (species's) brain has evolved to know about the 3rd dimension, and uses that information to interpret the 2D retinal image

ASSUMPTIONS of BOTH Helmholtzian empiricist and Gestaltist (pseudo-)nativist programs:

1) proximal stimulus is inadequate, impoverished
- retinal image: info about size, shape, distance is lost

2) brain processes restore information lost from image
- Helmoltzian unconscious inference
- Gestalt lawful principles of organization (embodied in electrical brain fields)

There are no pure Empiricists and Nativists...

Helmholtz used cues in retinal image and memories of **experience** -- but had to assume an **innate** inference-making ability

Gestalt Psychologists believed generic physical processes were at work -- not specific to a species or even to living things: electrical field dynamics!

- other nativists (Plato, 387 BC; Chomsky, 1965) require **experience** to draw out the **innate** knowledge people have

PSYCHOPHYSICS: relation of physical variables of environment to sensations in our experience

- How is intensity of light related to our experience of "brightness"?

- to be detected, intensity must exceed the absolute threshold

- for a change to be detected, intensity must increase by the difference threshold

"just noticeable difference" (j.n.d.):

light of intensity I	increased by ΔI	notice?
300	1	NO
300	2	NO
300	3	NO
300	4	NO
300	5	YES!

Weber's Law (1834): $\Delta I / I$ is constant

$\Delta I / I$ = change in intensity relative to original intensity

- for $I = 60$, $\Delta I = 1$
- for $I = 120$, $\Delta I = 2$
- for $I = 180$, $\Delta I = 3$

so for vision, $\Delta I / I = 1/60$: "Weber fraction"

- smaller Weber fraction means greater sensitivity
- hearing is less sensitive: $\Delta I / I = 1/10$

TABLE 5.1 REPRESENTATIVE (MIDDLE-RANGE) VALUES FOR THE WEBER FRACTION FOR THE DIFFERENT SENSES

Sensory Modality	Weber Fraction ($\Delta I/I$)
Vision (brightness, white light)	1/60
Kinesthesis (lifted weights)	1/50
Pain (thermally aroused on skin)	1/30
Audition (tone of middle pitch and moderate loudness)	1/10
Pressure (cutaneous pressure "spot")	1/7
Smell (odor of India rubber)	1/4
Taste (table salt)	1/3

SOURCE: Geldard, 1962.

Table 5.1: Representative (middle-range) values for the Weber fraction for the different senses