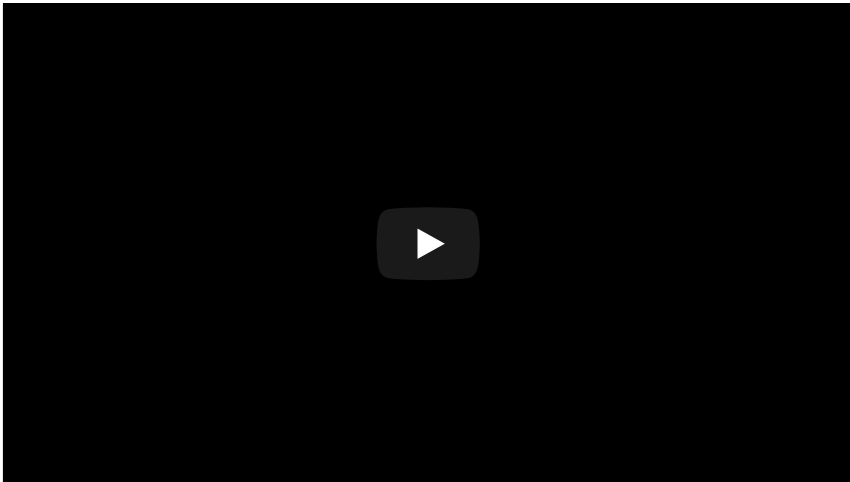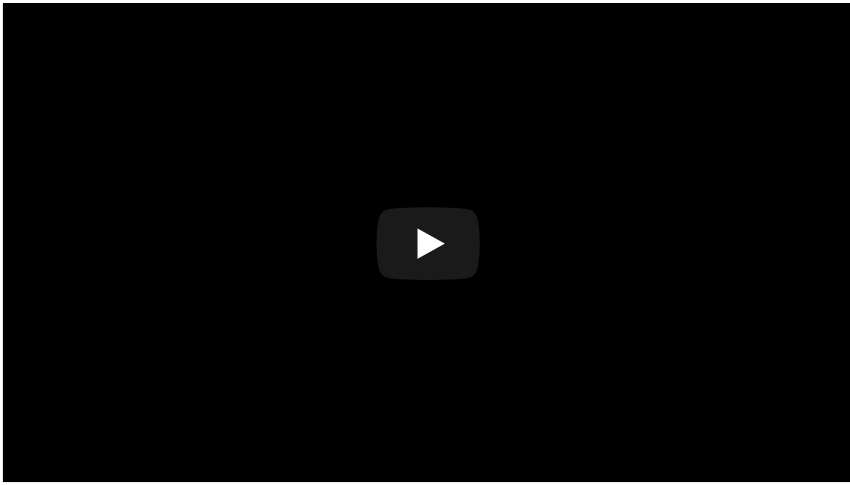# 511-perception

Rick Gilmore

2021-10-20 14:28:09

- Fun
- Principles of sensation & perception
  - Senses as (perception/action) systems
    - Smartphone as metaphor
  - Perception/action system dimensions
    - Questions for interoception
    - Questions for exteroception
    - Questions for action
  - From world to brain
    - Properties of the world
    - More than 5 sensory channels
    - Vision
    - Audition
    - Chemosensation
    - Somatosensation
    - Interoception
  - Features of sensory signals
    - Change across time
    - Detect repeating signals
      - Vision: Spatial frequency/contrast sensitivity
      - Audition: Frequencies in sound
    - Compare (>1) sensors located in different parts of the body
    - "Receptive fields"
      - Tactile
      - Visual
    - Topographic maps
      - Auditory: Tonotopic maps
      - Visual: Retinotopic maps
      - Somatosensory: Somatotopic maps in S1 & M1
    - Sensivity non-uniform
      - Two-point touch thresholds
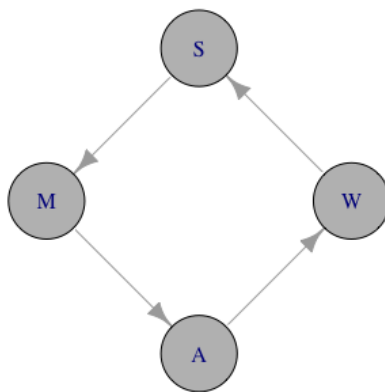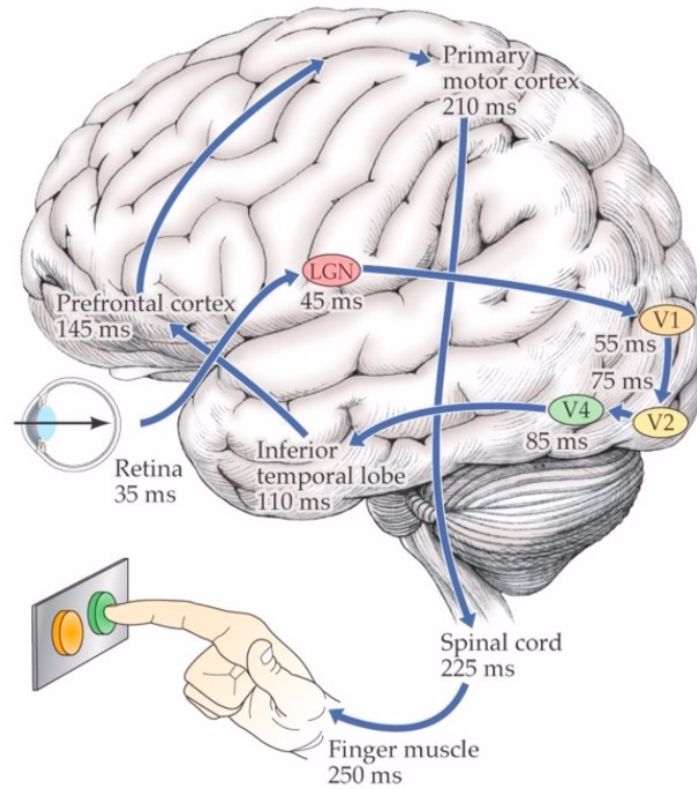   - Somatosensory homunculus

Fun

Principles of sensation & perception

Senses as (perception/action) systems

The Senses Considered as Perceptual Systems

James J. Gibson / *Cornell University*

Source: Amazon

Primary
motor cortex
210 ms

LGN
45 ms

Prefrontal cortex
145 ms

V1
55 ms
75 ms

V4
85 ms

V2

Retina
35 ms

Inferior
temporal lobe
110 ms

Spinal cord
225 ms

Finger muscle
250 ms

© 2001 Sinauer Associates, Inc.

Cerebral cortex₅

Striatum

Pallidum

Thalamus
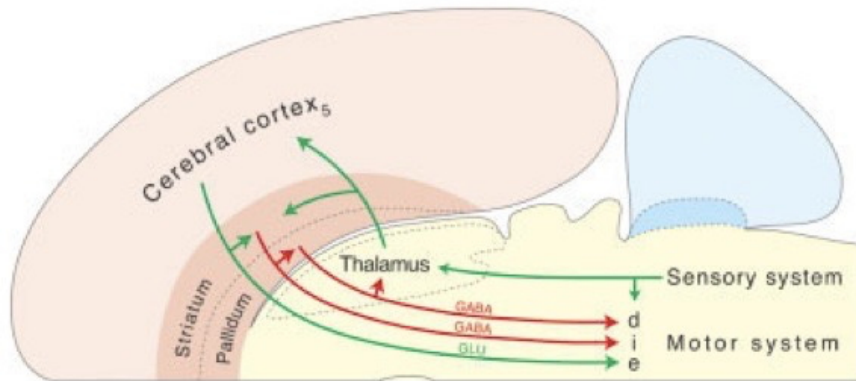
GABA
GABA
GLU

Sensory system

d
i
e

Motor system

Fig. 2. A model of the elementary or minimal circuit element characteristic of almost all parts of the cerebral hemispheres (pink). It consists of a triple descending projection to the motor system of the brainstem and spinal cord (see Fig. 1B), with feedback to cerebral hemisphere via thalamus. The model predicts that the cerebral hemisphere provides a direct excitatory input (e) to motor system via glutamatergic (GLU), layer 5 (for isocortex), cortical pyramidal neurons that generate a collateral in the striatum (lateral cerebral nuclei), which sends an inhibitory input (i) to motor system via GABAergic (GABA) medium spiny stellate neurons providing a collateral to pallidum (medial cerebral nuclei). The latter then sends a disinhibitory (d), GABAergic projection to motor system, with collaterals to dorsal thalamus, which then projects back to cortex via glutamatergic neurons (and of course receives various classes of sensory input). Many thalamic nuclei also project to striatum (Smith et al., 2004). This minimal circuit element is topographically organized and differentially elaborated regionally.
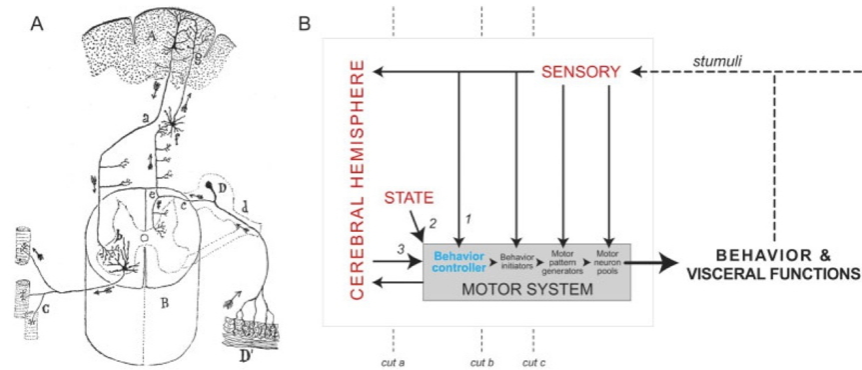
Source: Swanson

Fig. 1. **A:** Perhaps the first diagram illustrating the cellular organization of a vertebrate spinal reflex, based on the neuron doctrine and law of functional polarity, published by Cajal in 1890 (see Cajal, 1894). Note that he emphasized two interconnected sources of motor neuron (b) control: dorsal root ganglion cells (D) and cerebral cortical pyramidal (or psychomotor) neurons (A). For clarity, he showed sensory input to the right side of the spinal cord, and motor output from the left side. **B:** A modern version of the basic plan of nervous system organization, adding behavioral state inputs (2) to sensory or voluntary (1) and cerebral hemisphere/cognitive or voluntary (3) inputs to the motor system hierarchy; see text for details (adapted from Swanson, 2000a).

Source: Swanson, 2005

Smartphone as metaphor

- Accelerometer
- Gyroscope
- Magnetometer
- Proximity sensor
- Ambient light sensor
- Barometer
- Thermometer
- Mic
- Camera
- Radios (Bluetooth, wifi, cellular, GPS)

http://www.phonearena.com/news/Did-you-know-how-many-different-kinds-of-sensors-go-inside-a-smartphone_id57885 (http://www.phonearena.com/news/Did-you-know-how-many-different-kinds-of-sensors-go-inside-a-smartphone_id57885)

Perception/action system dimensions

- Interoceptive
    - Body position, movement, posture
    - Internal status: hunger, thirst, arousal, discomfort/pain, etc.
- Exteroceptive
    - Layout of environment, contents

Questions for interoception

- Tired or rested?
- Well or ill?

- Hungry or thirsty or sated?
- Stressed vs. coping?
- Emotional state?

Questions for exteroception

- Who/What is out there?
- Animate/inanimate?
    - Conspecific (same species)/non?
    - Threat/non?
    - Familiar/un?
    - Mate/non? or Friend/not?
    - Food source/non
- Where is it?
    - Distance
        - Proximal
        - Distal
    - Elevation, azimuth
    - Coordinate frames
        - Self/ego (left of me)
        - Object (top of object)
        - Allo/world (North of College)
- Where moving?

Questions for action

- What kind of response?
    - External
        - Move body
            - Approach/avoid/freeze
            - Signal/remain silent
            - Manipulate
    - Internal
        - Change physiological state
- Speed, quality, direction of response

From world to brain
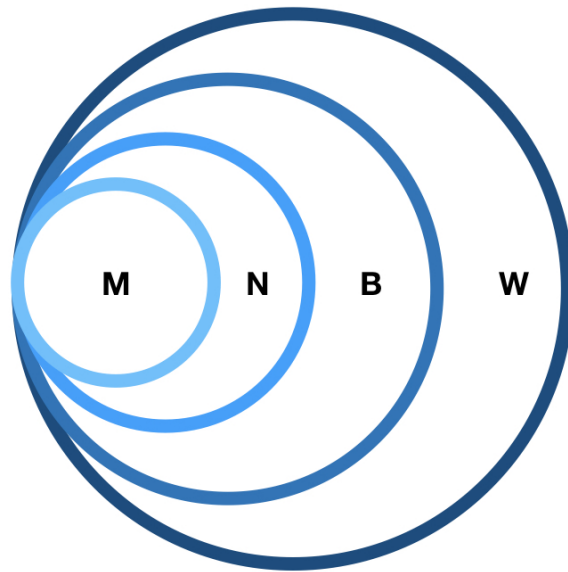
Realm	Domain
W	The world
B	The body
N	The nervous system
M	The mind

Properties of the world

- Behaviorally relevant conditions, events, and entities…
- Generate patterns…
  - Chemical
  - Photic/electromagnetic
  - Mechanical/acoustic
- That specialized sensors detect
- Neural circuitry processes

More than 5 sensory channels

TABLE 8.1 *Classification of Sensory Systems*

Type of sensory system	Modality	Adequate stimuli
Mechanical	Touch	Contact with or deformation of body surface
	Hearing	Sound vibrations in air or water
	Vestibular	Head movement and orientation
	Joint	Position and movement
	Muscle	Tension
Photic	Seeing	Visible radiant energy
Thermal	Cold	Decrement of skin temperature
	Warmth	Increment of skin temperature
Chemical	Smell	Odorous substances dissolved in air or water in the nasal cavity
	Taste	Substances in contact with the tongue or other taste receptor
	Common chemical	Changes in CO_2, pH, osmotic pressure
	Vomeronasal	Pheromones in air or water
Electrical	Electroreception	Differences in density of electrical currents

- What is the energy/chemical channel?
- Different energy/chemical channels carry different types of information
  - What is out there
  - Where it's located
- Different energy/chemical channels convey information at different rates
- Information about behaviorally relevant dimensions often signaled by multiple sources

Vision

- Source: Electromagnetic radiation
  - Reflected from surfaces
- What is it?
  - Shape, size, surface properties (color, texture, reflectance, etc.)
  - Wavelength/frequency, intensity
- Where is it?
  - Position: Left/right; up/down on retina
  - Near/far: retinal disparity, interposition, height above horizon…
  - Orientation, motion

Audition

- Source: Mechanical vibrations in air or water
- What is it?
  - Pattern of frequencies, amplitudes, durations
- Where is it?

- ○ Left/right or up/down: Interaural time/phase, intensity differences, pinnae filtering
  - ○ Motion: Frequency shifts via Doppler effect

Chemosensation

- Source: Chemicals in mouth, nasal cavity
- What is it?
  - ○ Mixtures of chemicals
- Where is it?
  - ○ Left/right; up/down; near/far via intensity gradients

Somatosensation

- Source: Thermal or mechanical stimulation (vibration/pressure) of skin
- What is it?
  - ○ Shape, size, smoothness, mass, temperature, deformability: Pattern of stimulation
- Where it it?
  - ○ Pattern of cutaneous receptors on skin

Interoception

- Hunger/thirst
  - ○ Receptors for nutrient, fluid levels
- Energy levels
  - ○ Receptors for hormones, NTs
  - ○ ANS responses
- Temperature
  - ○ Receptors in skin, viscera
- Mating interest
  - ○ Receptors for hormones, NTs
  - ○ ANS responses
- Body position & movement (proprioception)
  - ○ Receptors in muscles, joints, skin

Features of sensory signals

Change across time

- Tonic (sustained) vs. phasic (transient) responses
- Adaptation

- Decline in sensitivity with sustained stimulation
- Most sensory systems attuned to change

(a) Slowly adapting receptors

(b) Rapidly adapting receptors
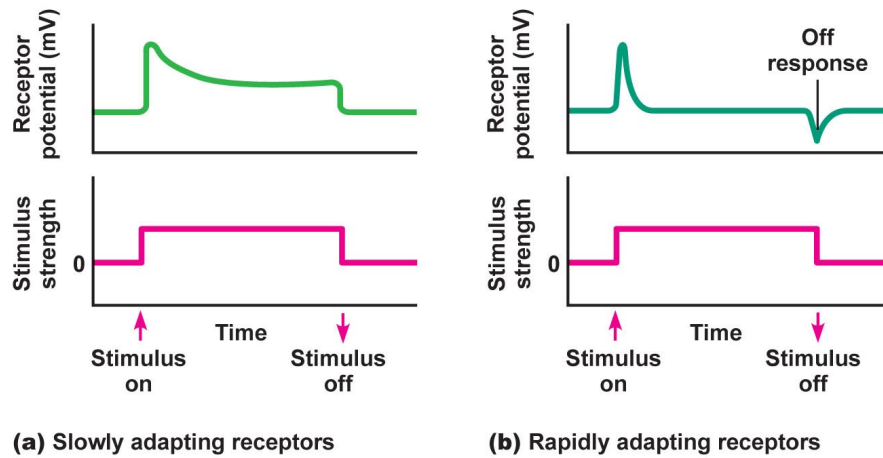
© 2011 Pearson Education, Inc.

- Information propagates at different speeds
  - Bigger diameter: Faster
  - Denser myelin: Faster

WIKIPEDIA

Nerve conduction velocity

Nerve conduction velocity (**CV**) is an important aspect of nerve conduction studies. It is the speed at which an electrochemical impulse propagates down a neural pathway. Conduction velocities are affected by a wide array of factors, which include; age, sex, and various medical conditions. Studies allow for better diagnoses of various neuropathies, especially demyelinating diseases as these conditions result in reduced or non-existent conduction velocities.

Contents
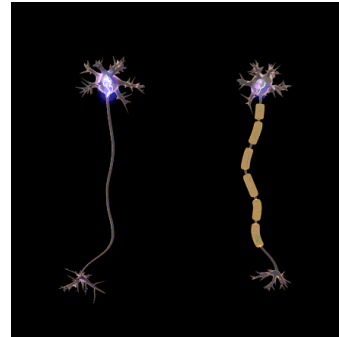
Saltatory conduction

Normal conduction velocities

Detect repeating signals

- In space (textures)
- In time

Vision: Spatial frequency/contrast sensitivity
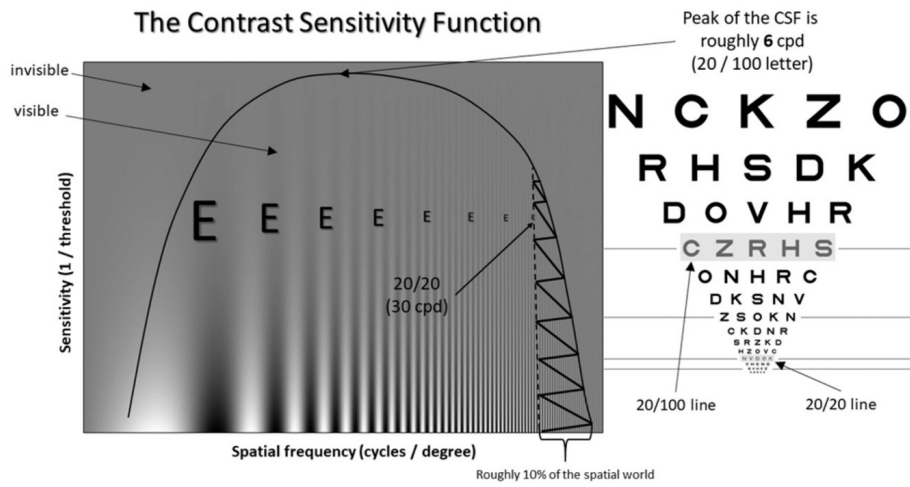
The Contrast Sensitivity Function

(Roark & Stringham, 2019) (http://dx.doi.org/10.1002/mnfr.201801053)

Audition: Frequencies in sound
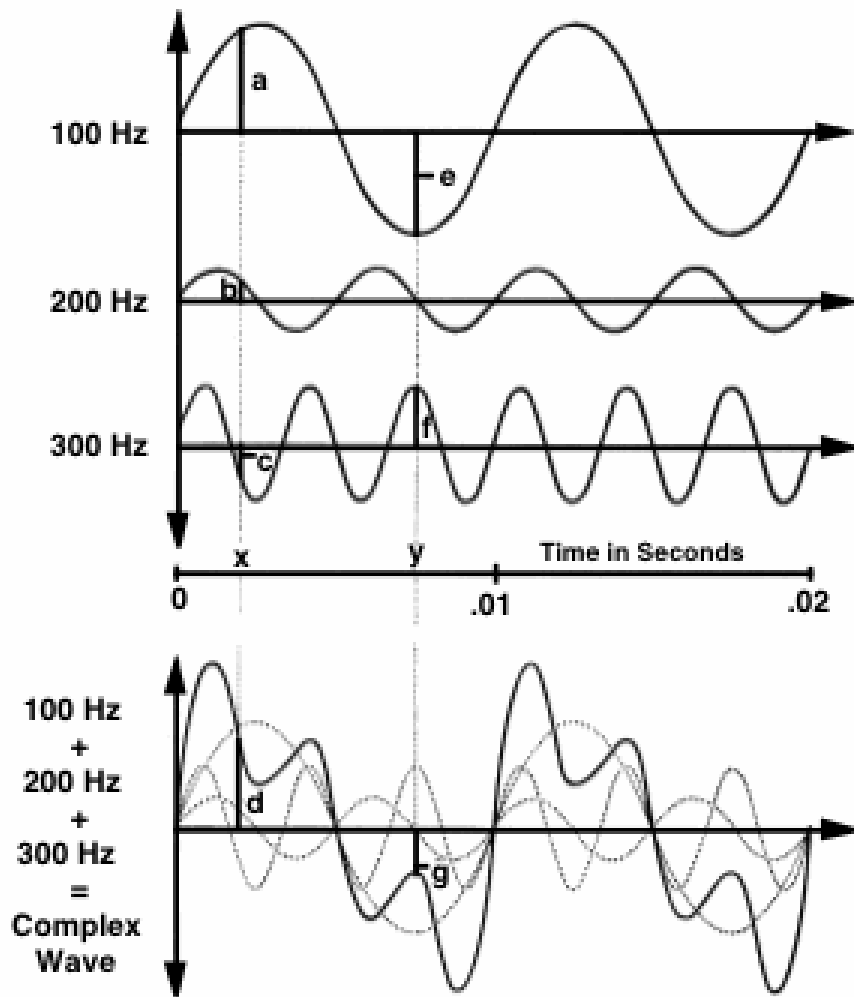
Compare (>1) sensors located in different parts of the body

- Eyes
- Ears
- Skin surface

- Nostrils
- Tongue

"Receptive fields" (https://en.wikipedia.org/wiki/Receptive_field)

- Area on sensory surface (e.g., retina, skin) that when stimulated changes neuron's firing

Tactile

(a) Experimental setup

Amplifier A   Amplifier B

Receptive field for cortical neuron A   Receptive field for cortical neuron B

(b) Cortical cell with receptive field on forelimb

Period of stimulation

Forelimb   Cortical neuron A

(c) Cortical cell with receptive field on tail

Period of stimulation

Tail   Cortical neuron B
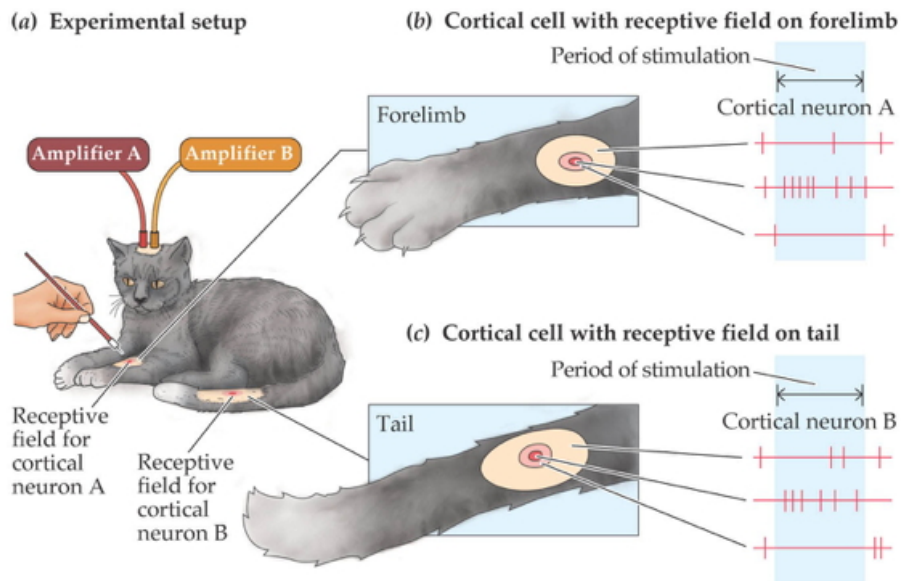
BIOLOGICAL PSYCHOLOGY, Fourth Edition, Figure 8.9 © 2004 Sinauer Associates, Inc.

Visual

Figure 1

on-center   off-center
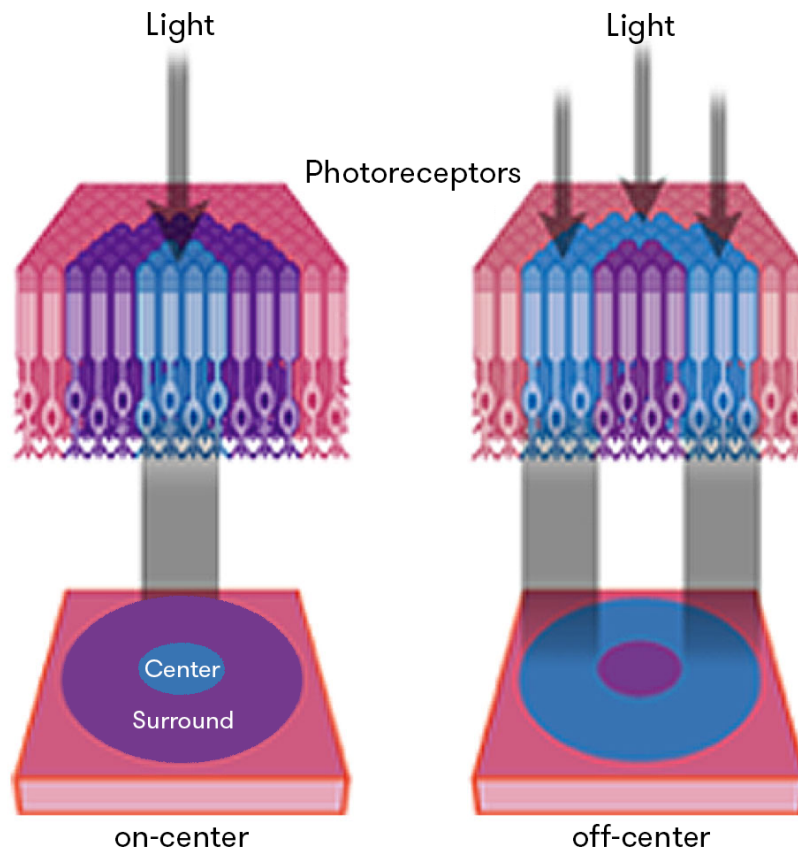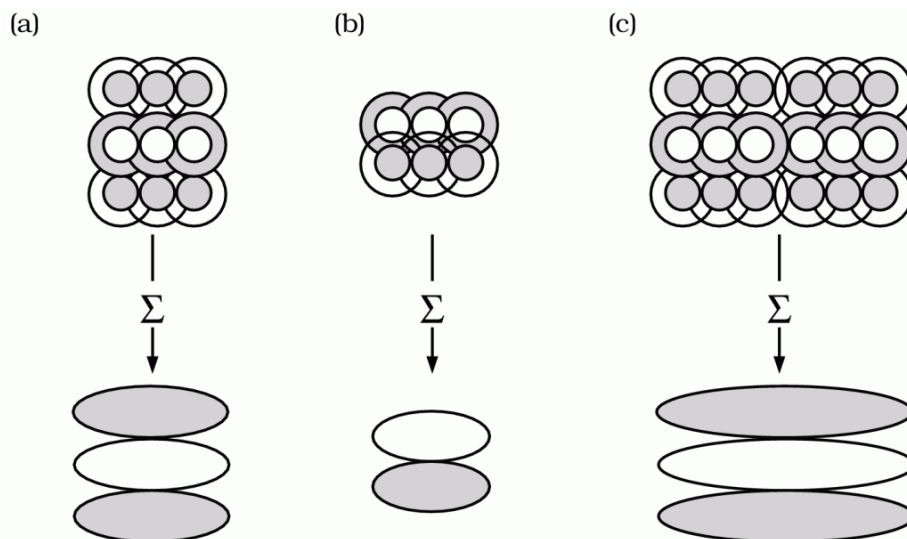
Topographic maps

Auditory: Tonotopic maps

Tonotopic Map Has Columnar Organization
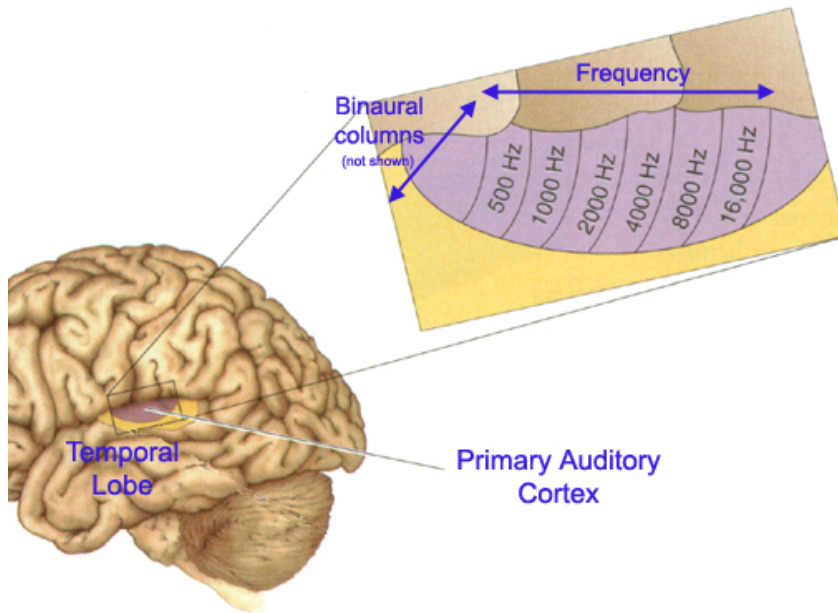
Visual: Retinotopic maps
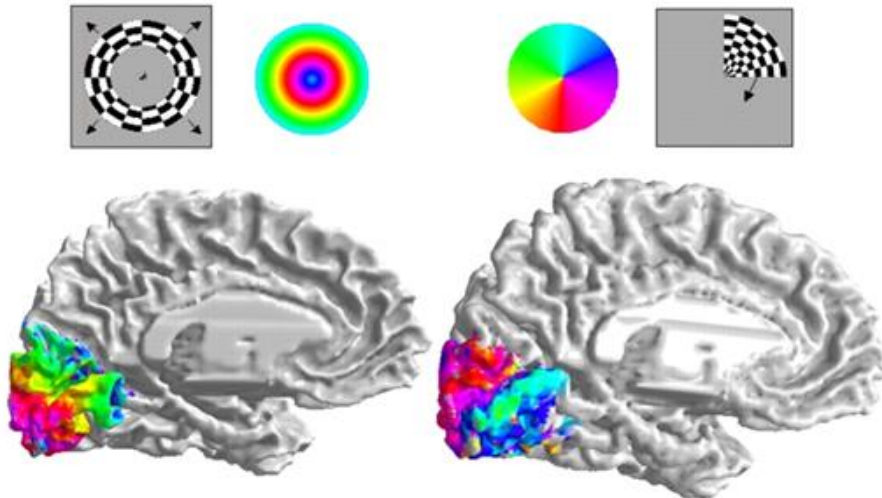
(Dougherty et al., 2003) (https://doi.org/10.1167/3.10.1)

Somatosensory: Somatotopic maps in S1 & M1
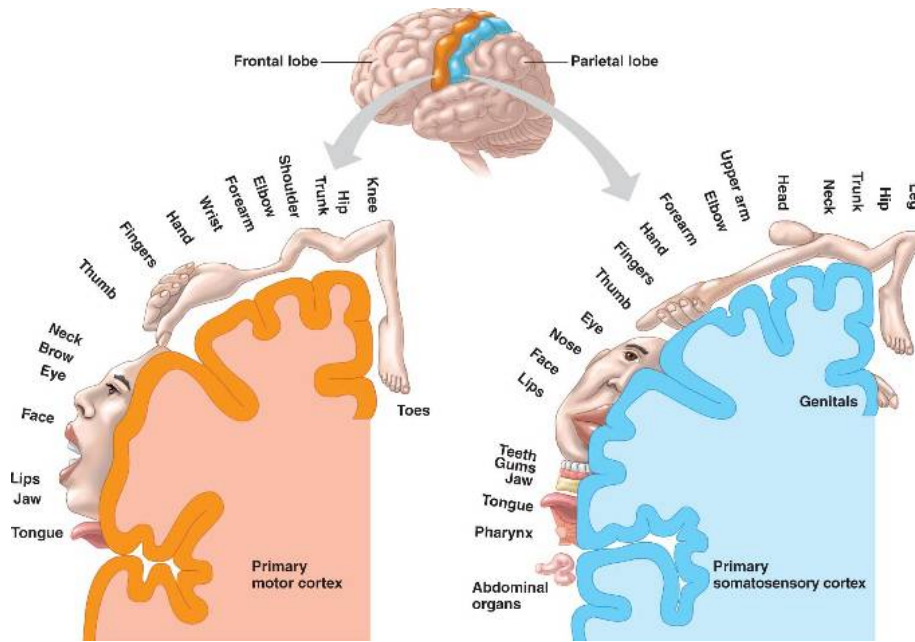
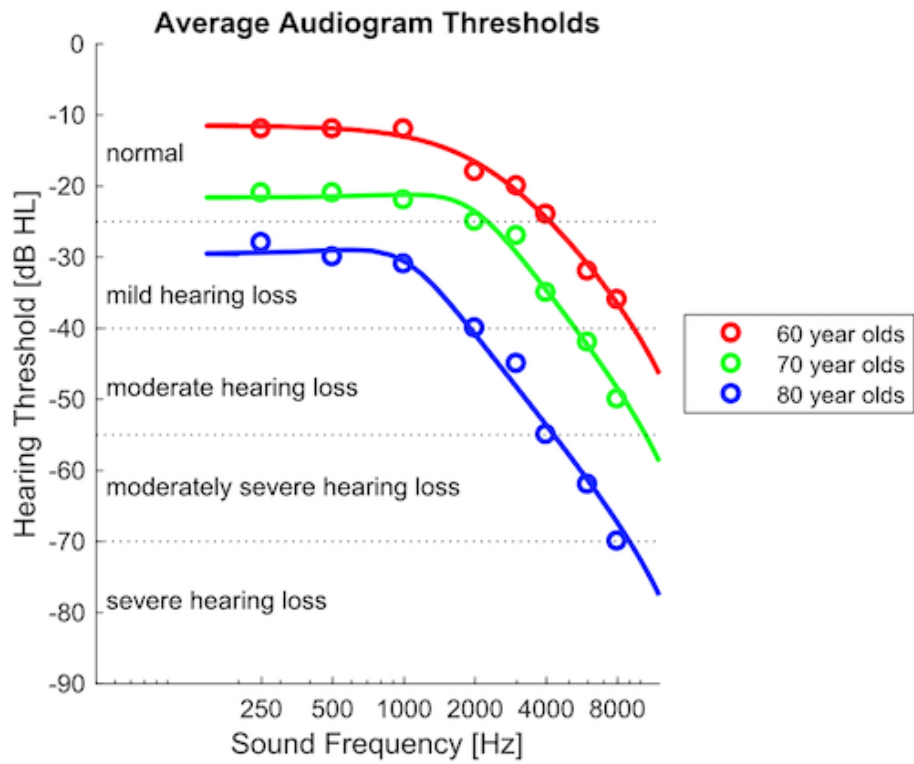Sensivity non-uniform

Two-point touch thresholds
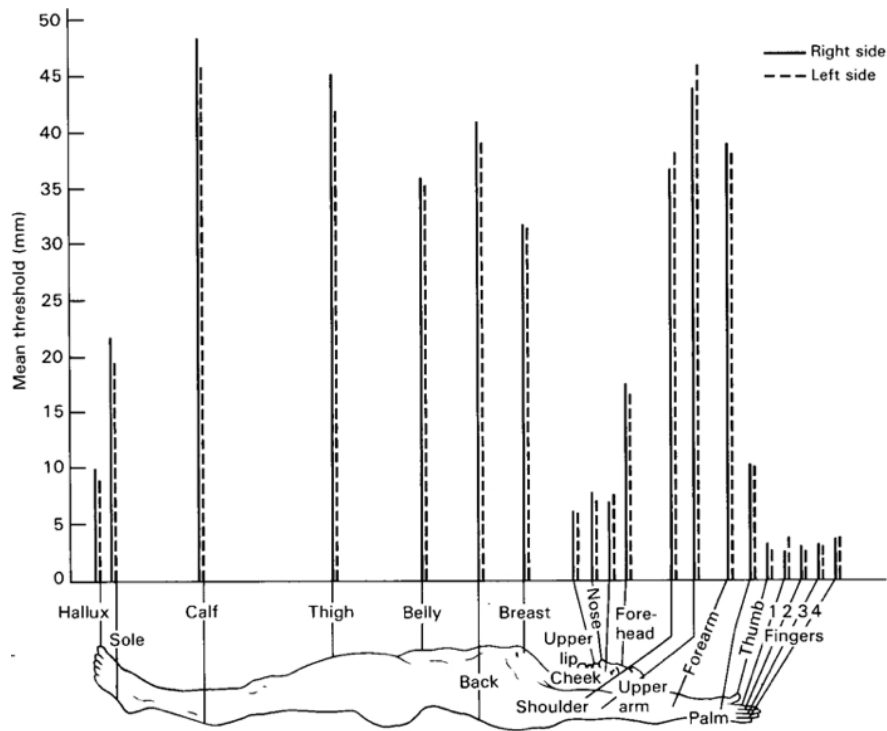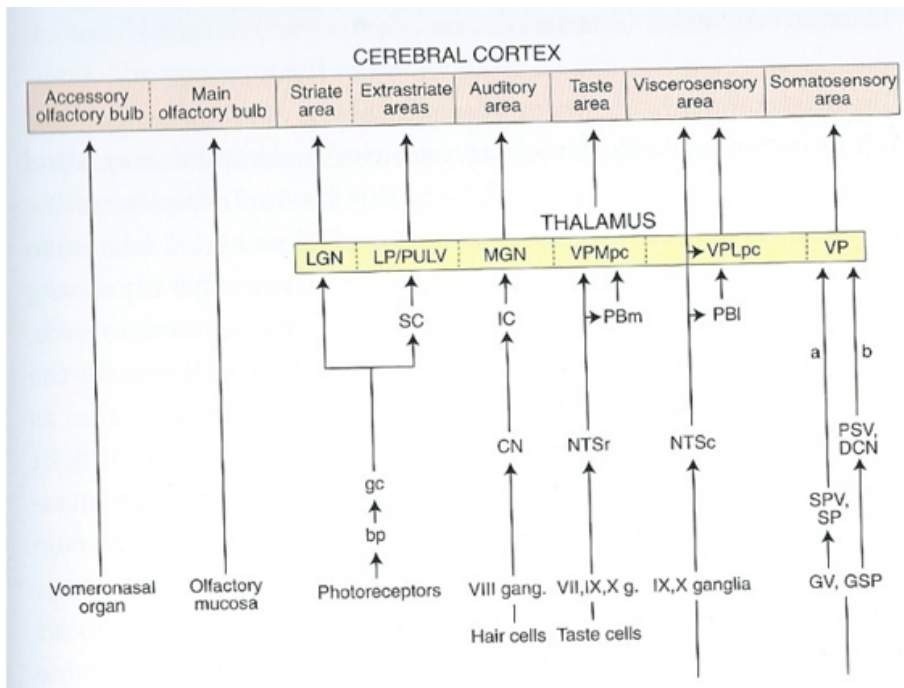

Somatosensory homunculus

Visual acuity non-uniform

https://upload.wikimedia.org/wikipedia/commons/thumb/2/27/AcuityHumanEye.svg/270px-
AcuityHumanEye.svg.png
(https://upload.wikimedia.org/wikipedia/commons/thumb/2/27/AcuityHumanEye.svg/270px-
AcuityHumanEye.svg.png)
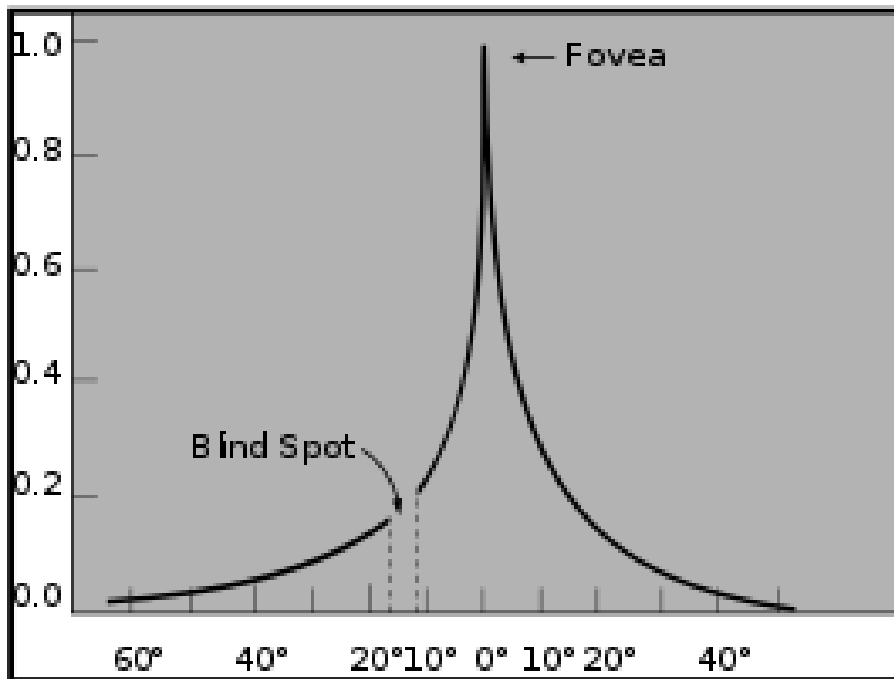
Hearing thresholds non-uniform

Average Audiogram Thresholds

http://auditoryneuroscience.com/ (http://auditoryneuroscience.com/)

Processing hierarchical/sequential AND parallel

Nonprimary sensory cortical areas — Primary sensory cortical areas — Nonprimary sensory cortical areas

Thalamus

Midbrain

Brainstem

Receptors Sensory cranial nerves

Spinal cord

Receptors Sensory peripheral nerves
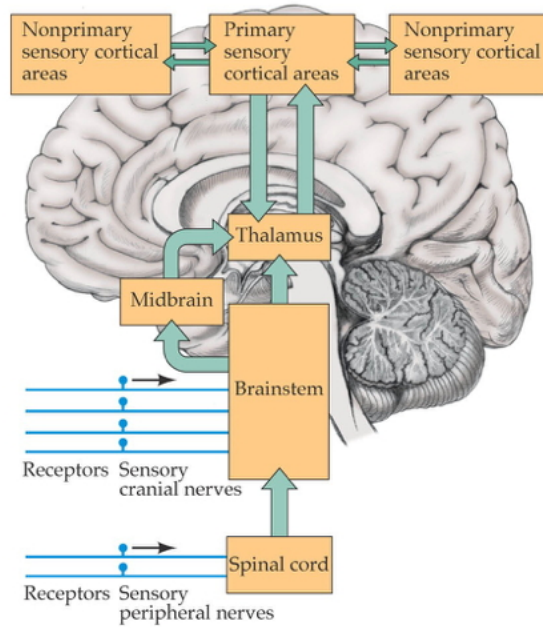
BIOLOGICAL PSYCHOLOGY, Fourth Edition, Figure 8.8 © 2004 Sinauer Associates, Inc.

Pain   Touch

Vibration   Stretch
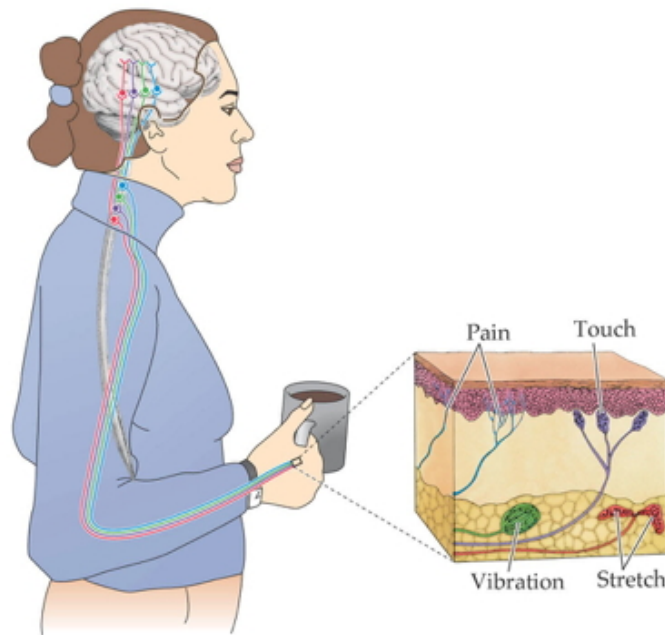
BIOLOGICAL PSYCHOLOGY, Fourth Edition, Figure 8.3 © 2004 Sinauer Associates, Inc.

Case study: Vision

Properties of Electromagnetic (EM) radiation
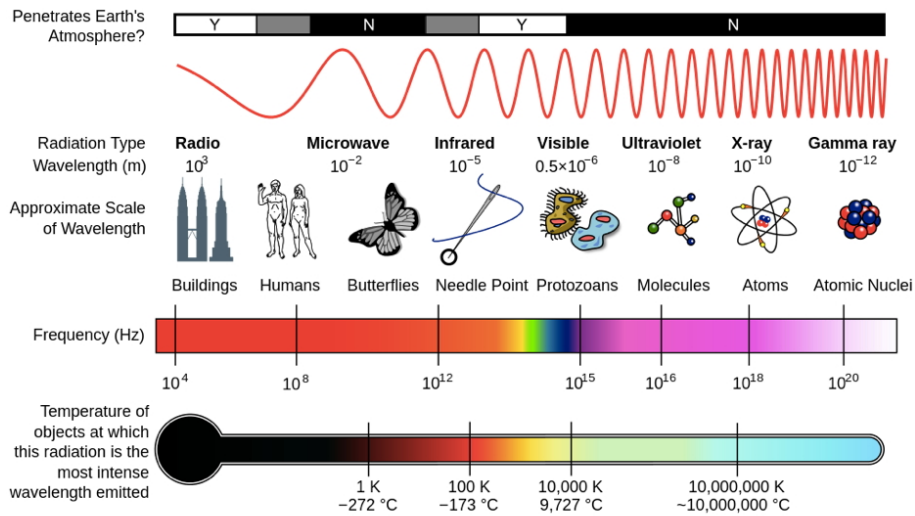
- Wavelength/frequency
- Intensity
- Location/position of source
- Reflects off some materials
- Refracted (bent) moving through other materials
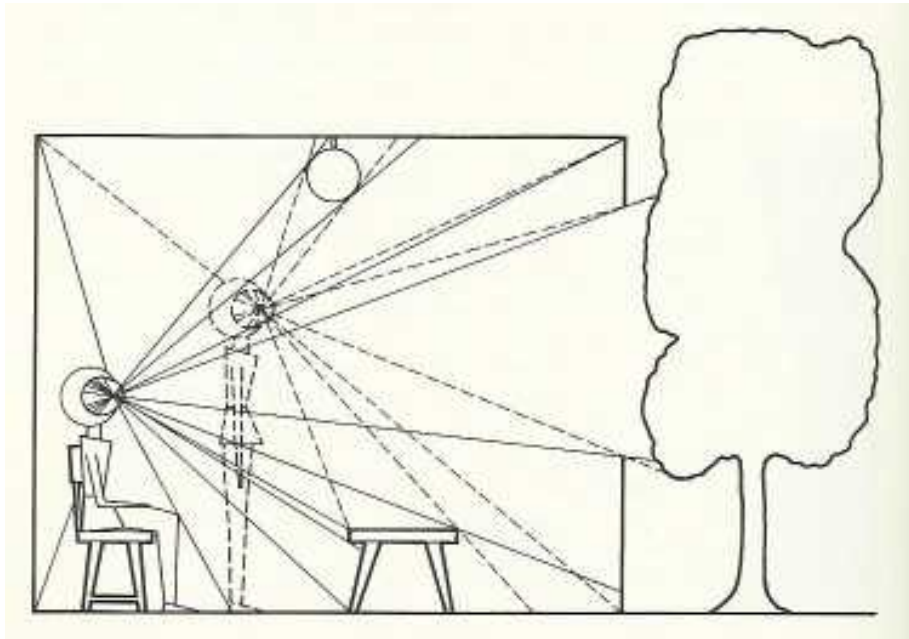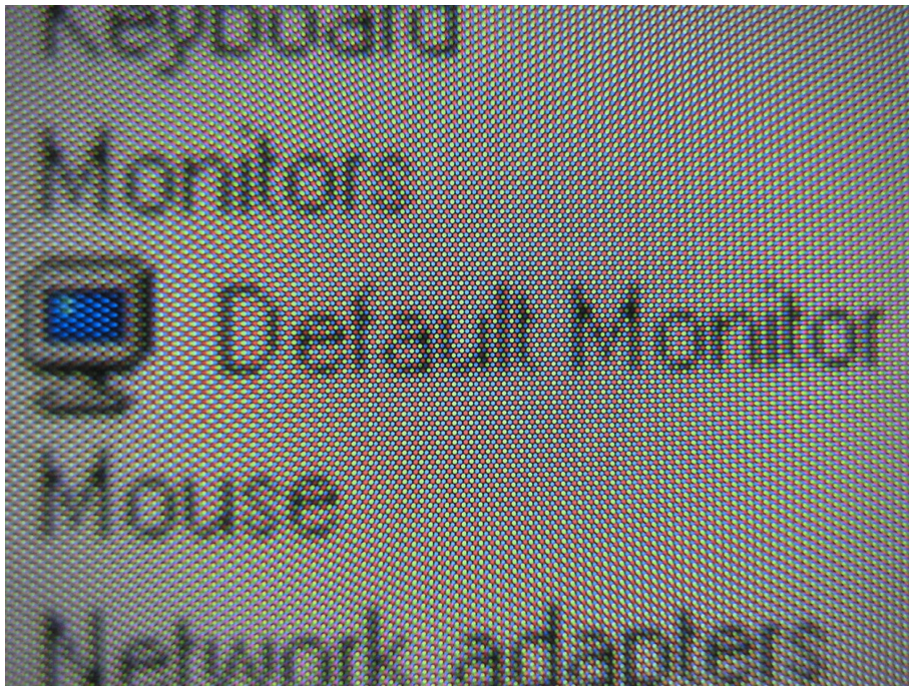- Information across space (and time)
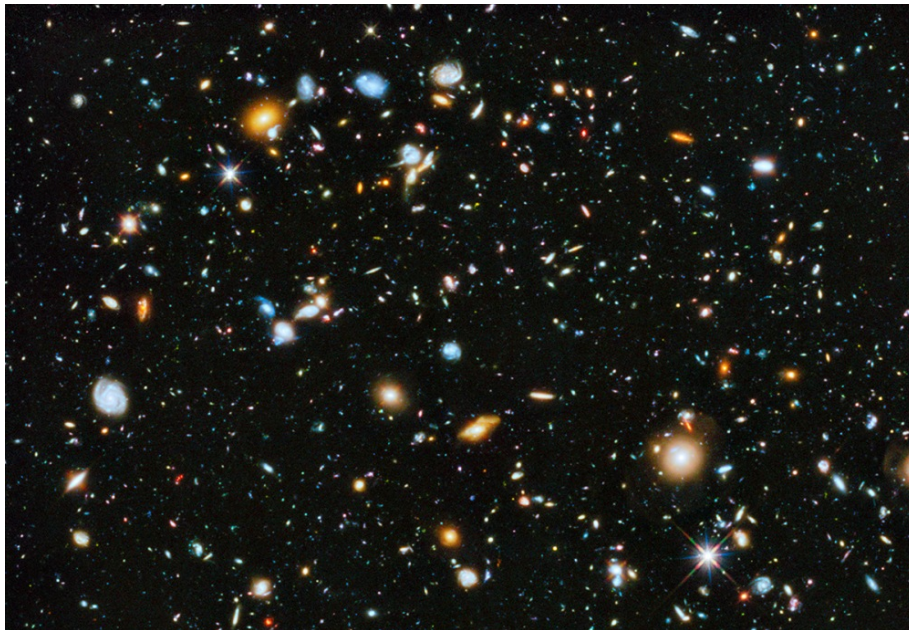
Reflectance spectra differ by surface
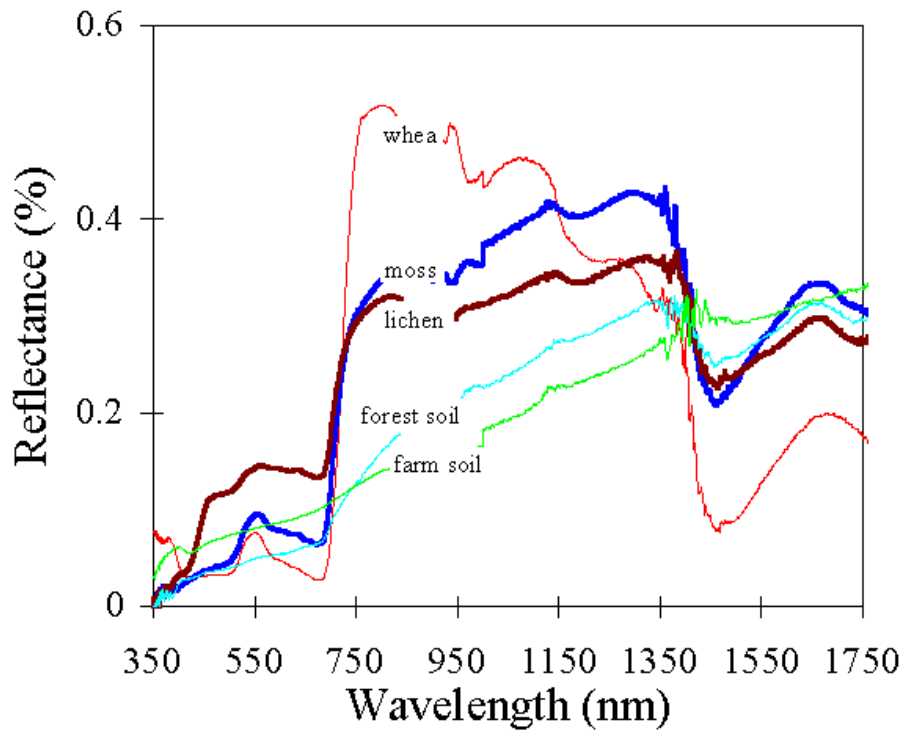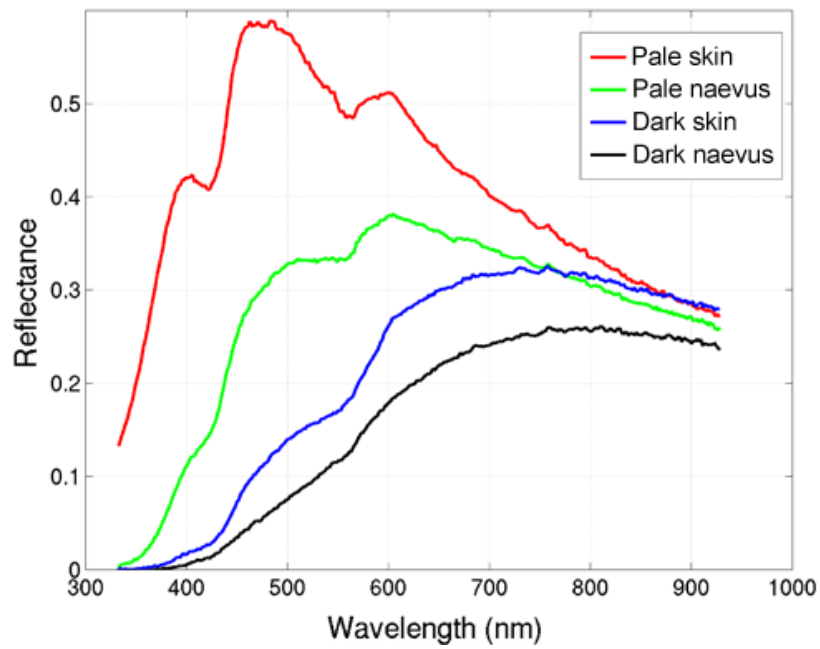
http://http://www.vgt.vito.be/userguide/book_1/4/42/ie42bd.gif
(http://http://www.vgt.vito.be/userguide/book_1/4/42/ie42bd.gif)

Optic array (https://en.wikipedia.org/wiki/Ambient_optic_array)
specifies geometry of environment

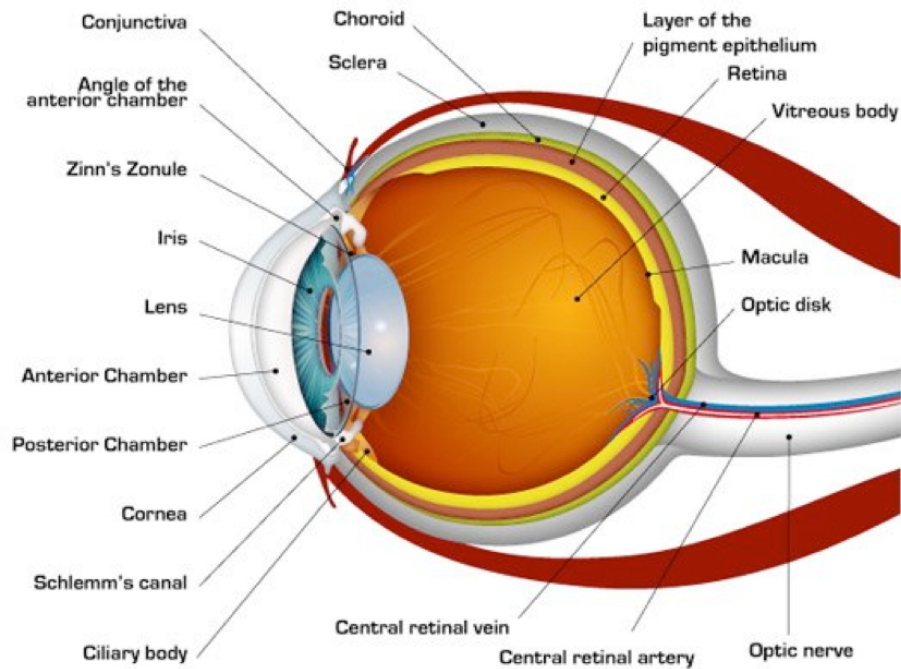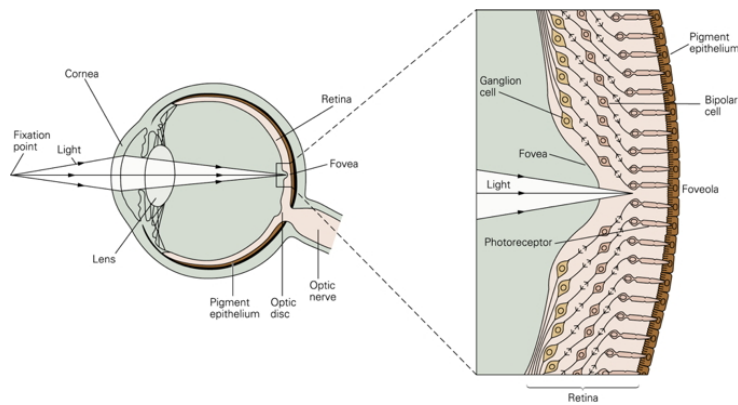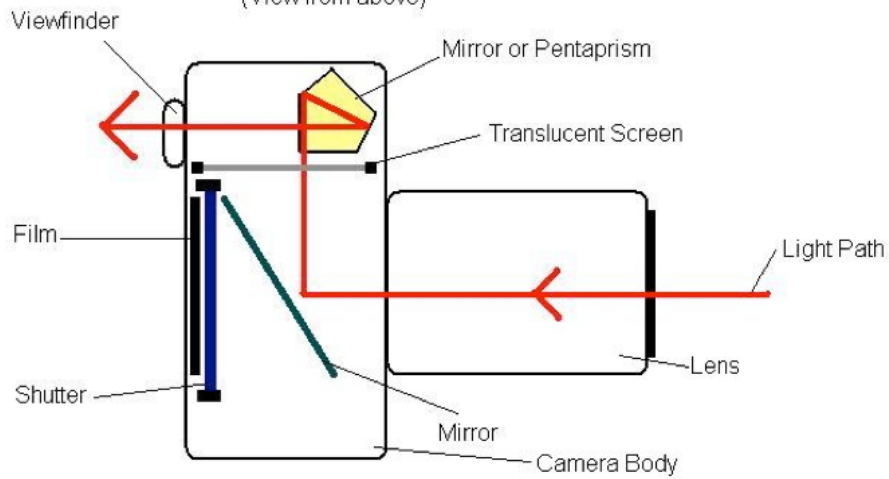## Categories of wavelength specify perception of color

- Eyes categorize wavelength into relative intensities within wavelength bands
- RGB ~ **R**ed, **G**reen, **B**lue
  - Long, medium, short wavelengths
- *Color is a neural/psychological construct*

The biological camera

How a Camera Works
(View from above)

Viewfinder

Mirror or Pentaprism

Translucent Screen

Film

Light Path

Lens

Shutter

Mirror

Camera Body

Cornea

Retina

Fixation point

Light

Fovea

Lens

Pigment epithelium

Optic disc

Optic nerve

Ganglion cell

Bipolar cell

Fovea

Light

Foveola

Photoreceptor

Retina

Conjunctiva

Choroid

Layer of the pigment epithelium

Sclera

Retina

Angle of the anterior chamber

Vitreous body

Zinn's Zonule

Iris

Lens

Macula

Anterior Chamber

Optic disk

Posterior Chamber

Cornea

Schlemm's canal

Central retinal vein

Ciliary body

Central retinal artery

Optic nerve

Parts of the eye
- *Cornea* - refraction (2/3 of total)

- *Pupil* - light intensity; diameter regulated by Iris.
- *Lens* - refraction (remaining 1/3; focus)
- *Retina* - light detection
  - ~ skin or organ of Corti in inner ear
- *Pigment epithelium* - regenerate photopigment
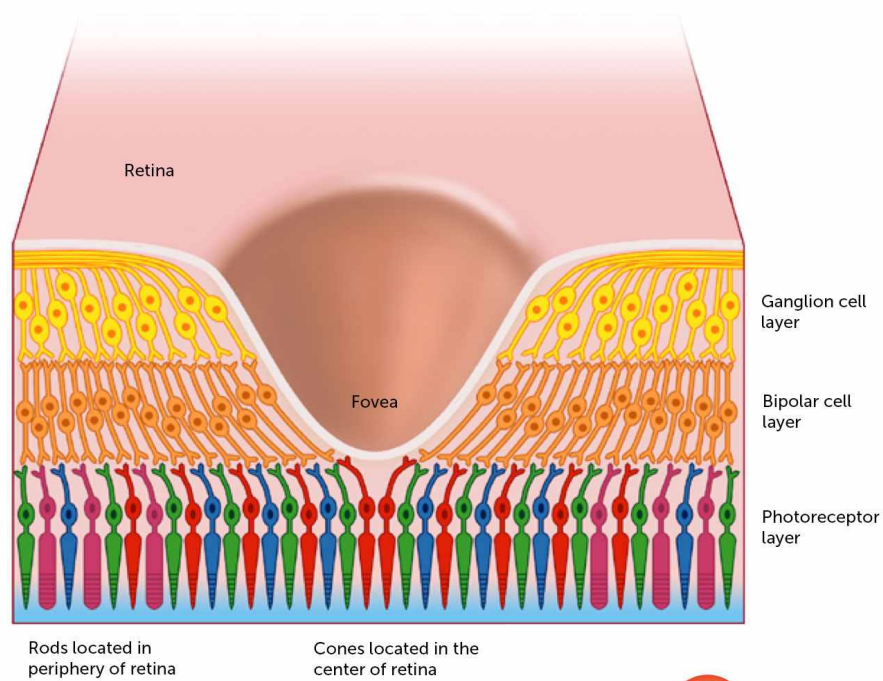- *Muscles* - move eye, reshape lens, change pupil diameter

Geometry of retinal image

- Image inverted (up/down)
- Image reversed (left/right)
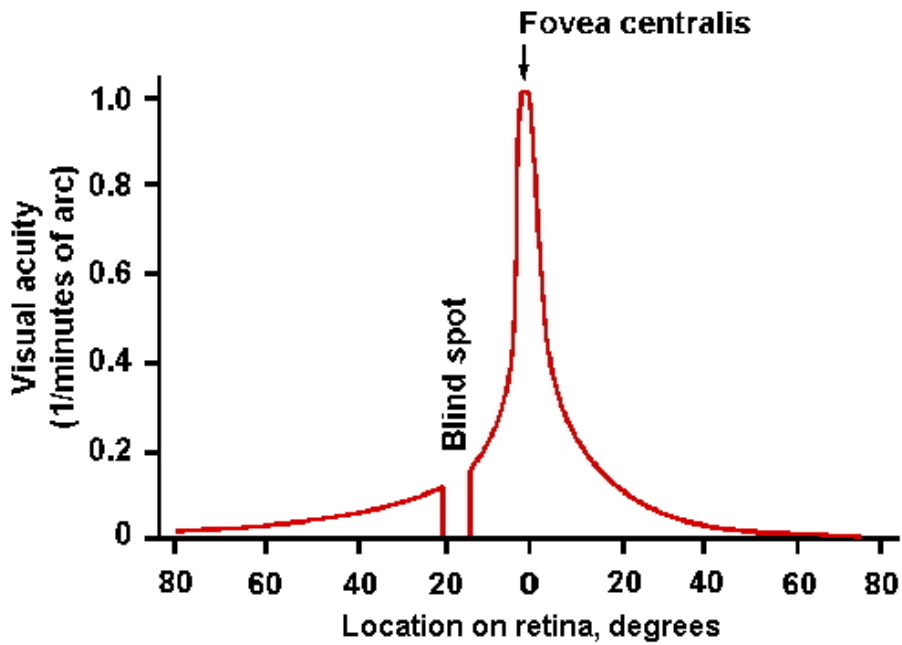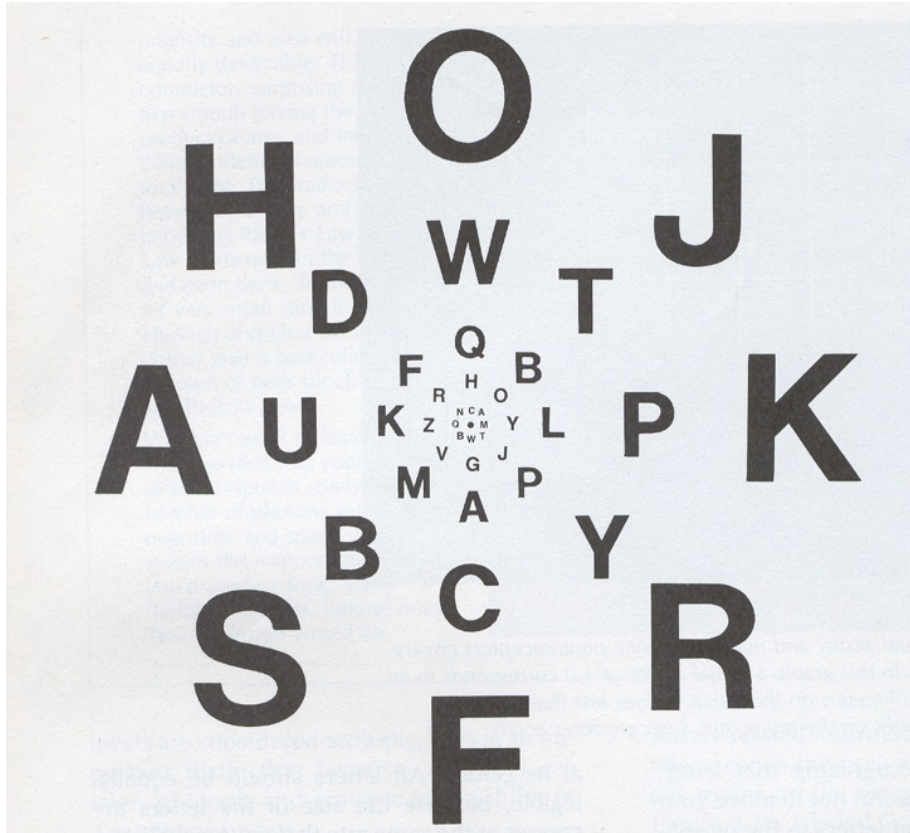- Point-to-point map (*retinotopic*)
- Binocular and monocular zones
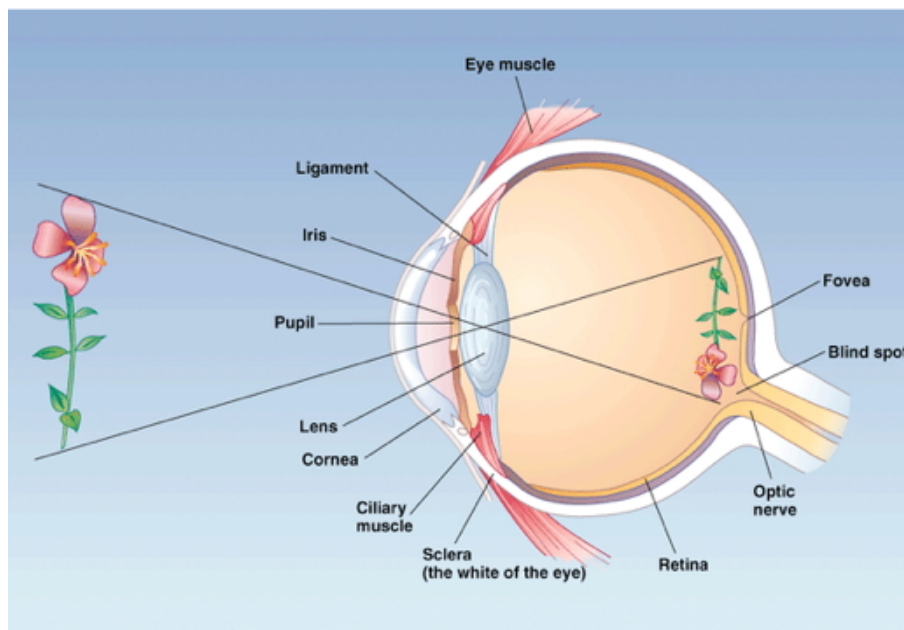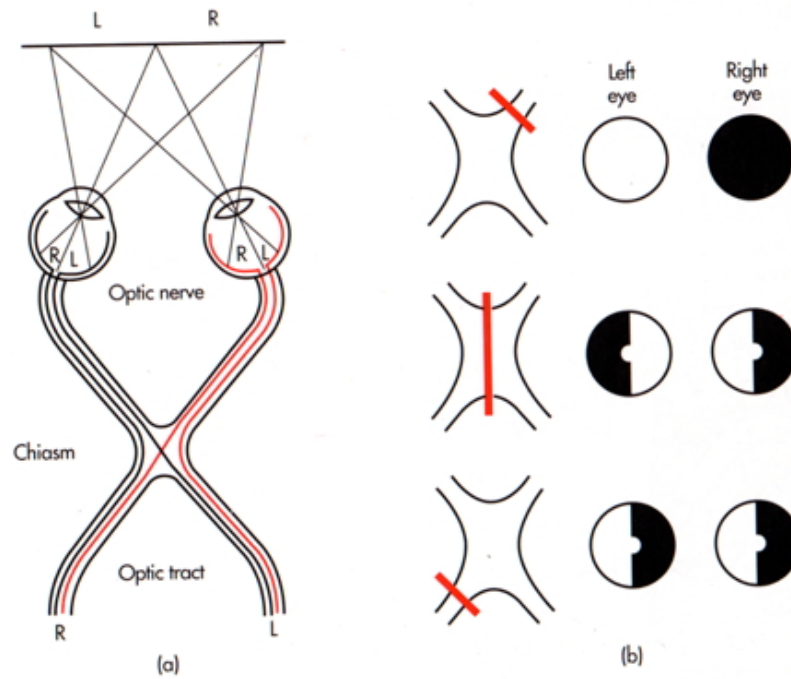
The *fovea*

http://www.brainhq.com/sites/default/files/fovea.jpg
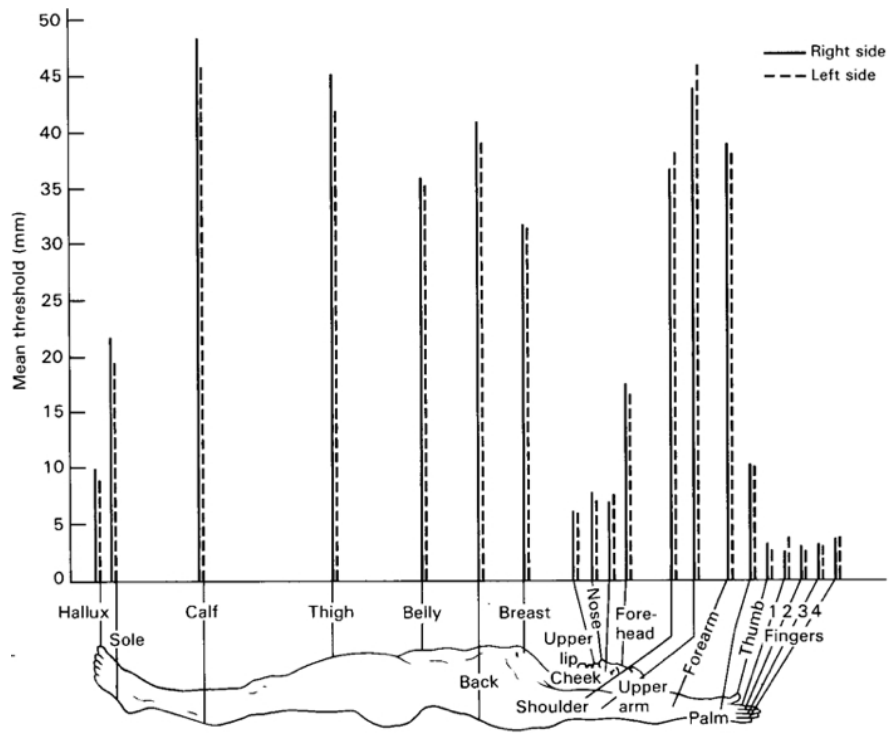(http://www.brainhq.com/sites/default/files/fovea.jpg)

- Central 1-2 deg of visual field
- Aligned with visual axis
- *Retinal ganglion cells* pushed aside

- Highest *acuity* vision == best for details
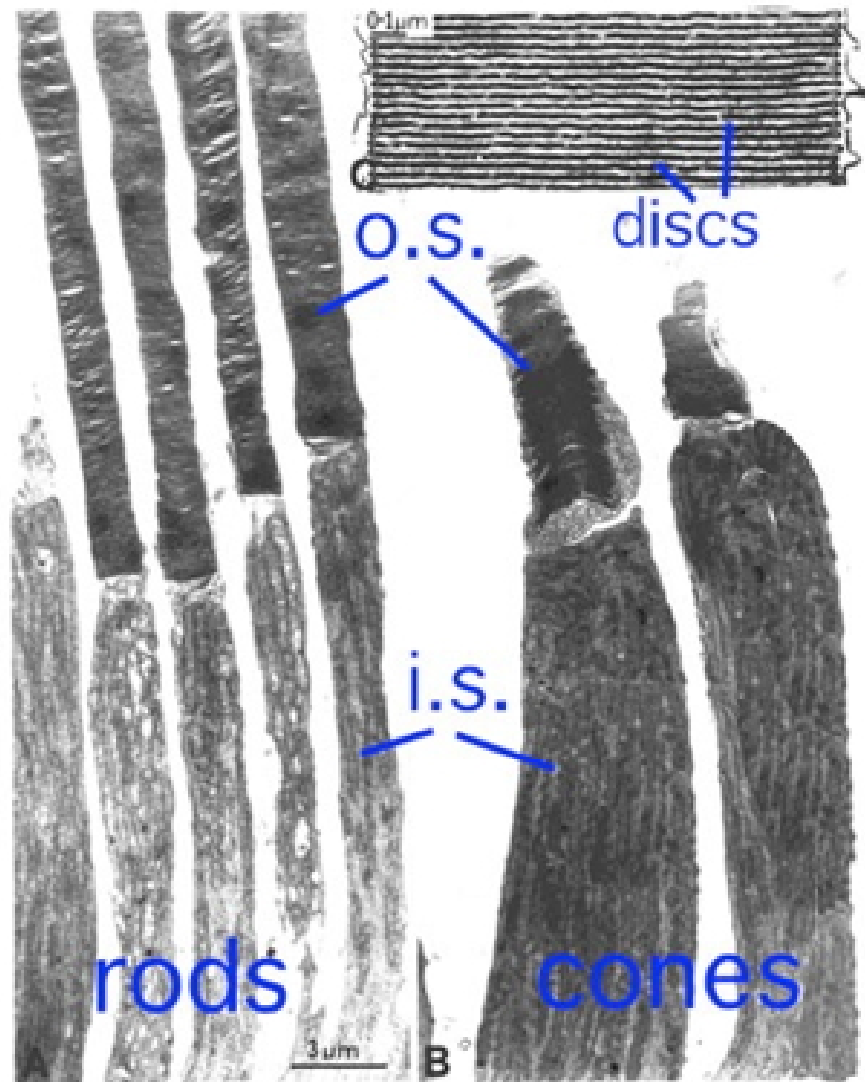- Acuity varies from center to periphery
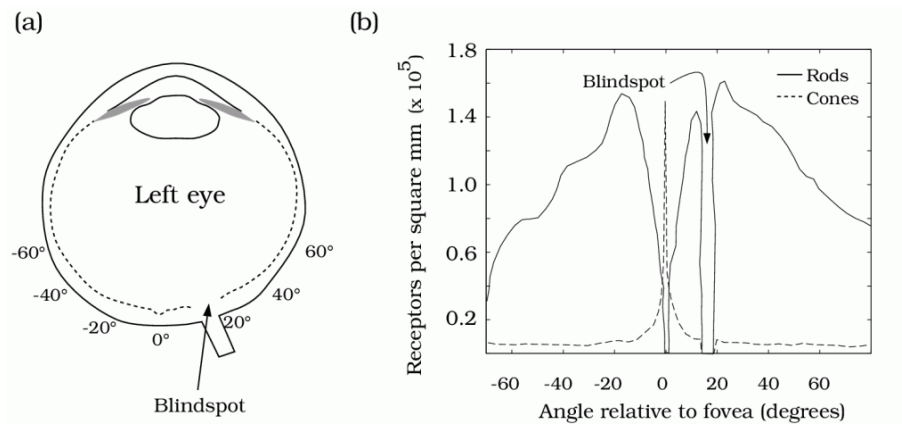

Fovea centralis

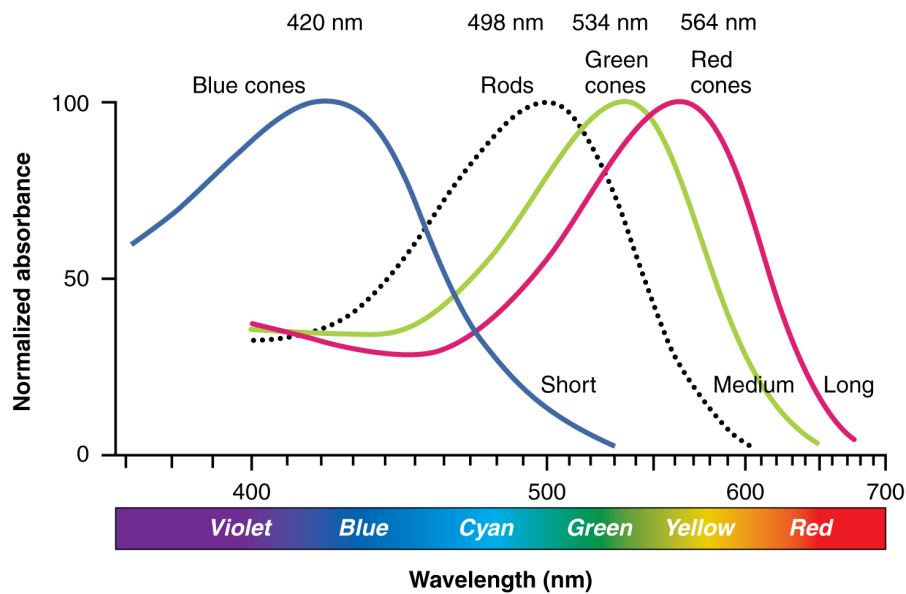What part of the skin is like the fovea?

Photoreceptors in retina detect light

- *Rods*
  - ~120 M/eye
  - Mostly in periphery
  - Active in low light conditions
  - One wavelength range
- *Cones*
  - ~5 M/eye
  - Mostly in center
  - 3 wavelength ranges

Photoreceptor physiology

- Outer segment
  - Membrane disks
  - *Photopigments*
    - Sense light, trigger chemical cascade
- Inner segment
  - Synaptic terminal
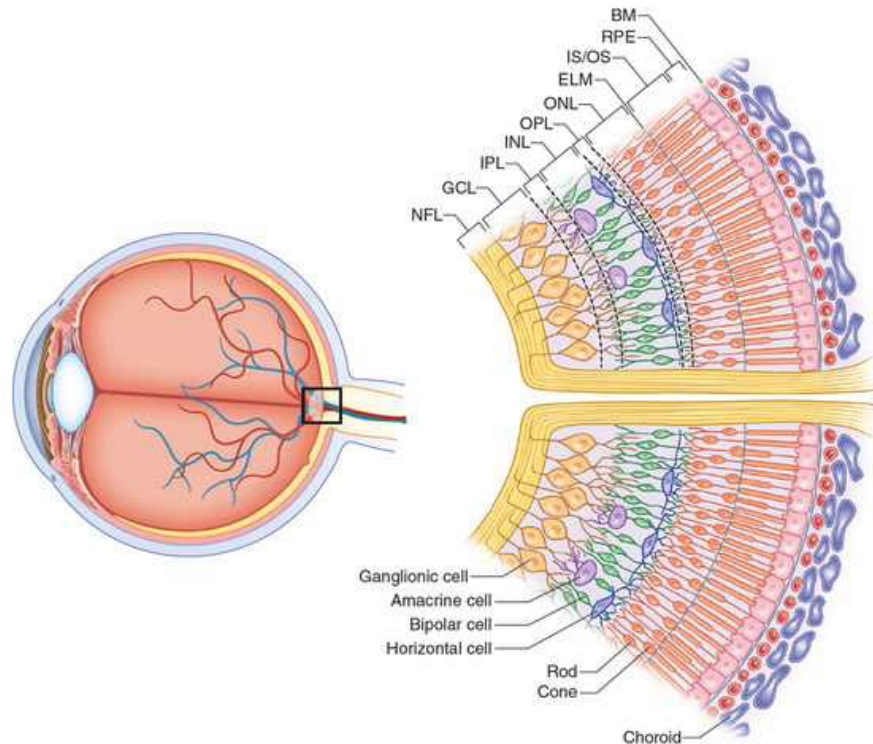- Light *hyperpolarizes* photoreceptor!
  - The *dark current*

Retina

- Physiologically *backwards*
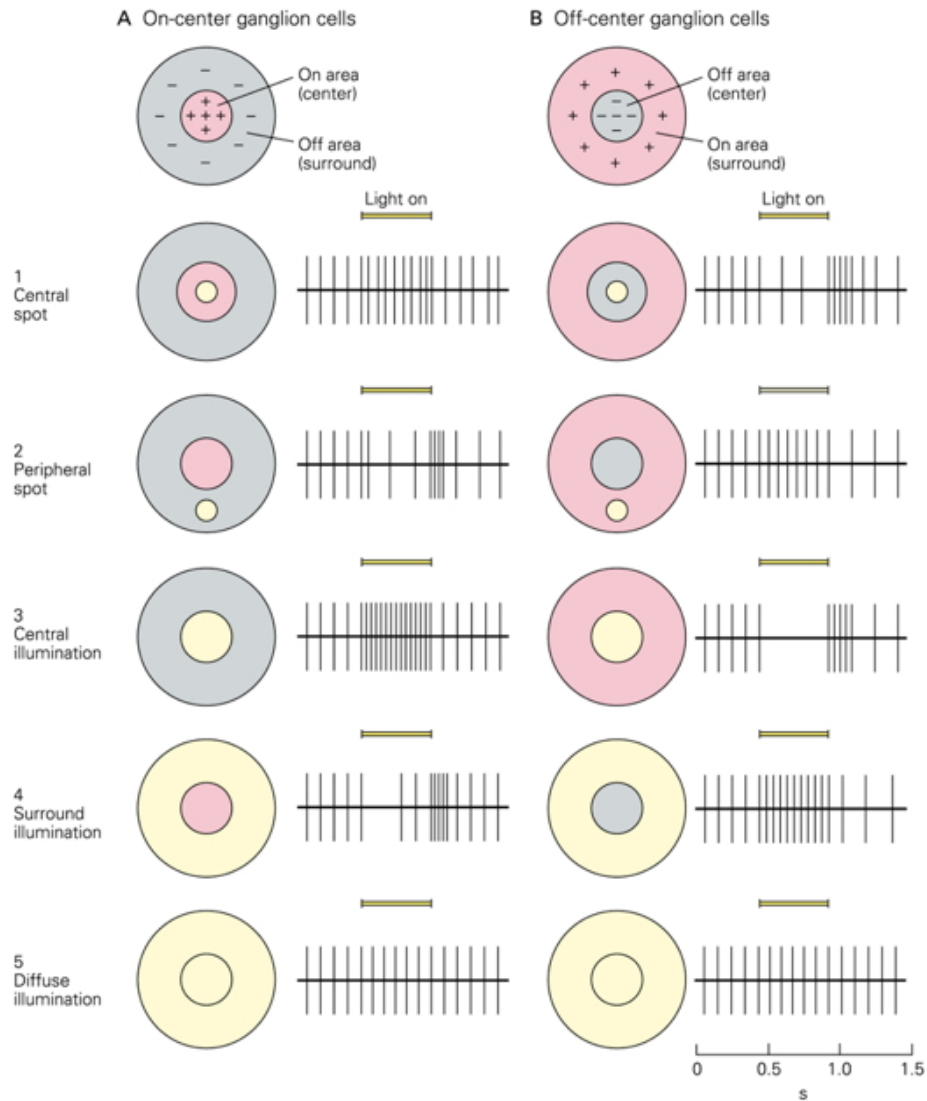 - How?
- Anatomically *inside-out*

- ○ How?

Retina

- Physiologically *backwards*
  - ○ Dark current
- Anatomically *inside-out*
  - ○ Photoreceptors at back of eye

http://www.retinareference.com/anatomy/ (http://www.retinareference.com/anatomy/)

- Information flows…
  - ○ From photoreceptors…
  - ○ To *Bipolar cells*
    - ■ <-> and *Horizontal cells*
  - ○ To *Retinal ganglion cells*
    - ■ <-> and *Amacrine cells*
 - ○ To cerebral cortex

Center-surround receptive fields

A On-center ganglion cells

B Off-center ganglion cells

- On area (center)
- Off area (surround)
- Off area (center)
- On area (surround)

Light on

1 Central spot

2 Peripheral spot

3 Central illumination

4 Surround illumination

5 Diffuse illumination

0   0.5   1.0   1.5
s

- Center region
  - Excites (or inhibits)
- Surround region
  - Does the opposite
- Bipolar cells & Retinal Ganglion cells ->
- Most activated by "donuts" of light/dark
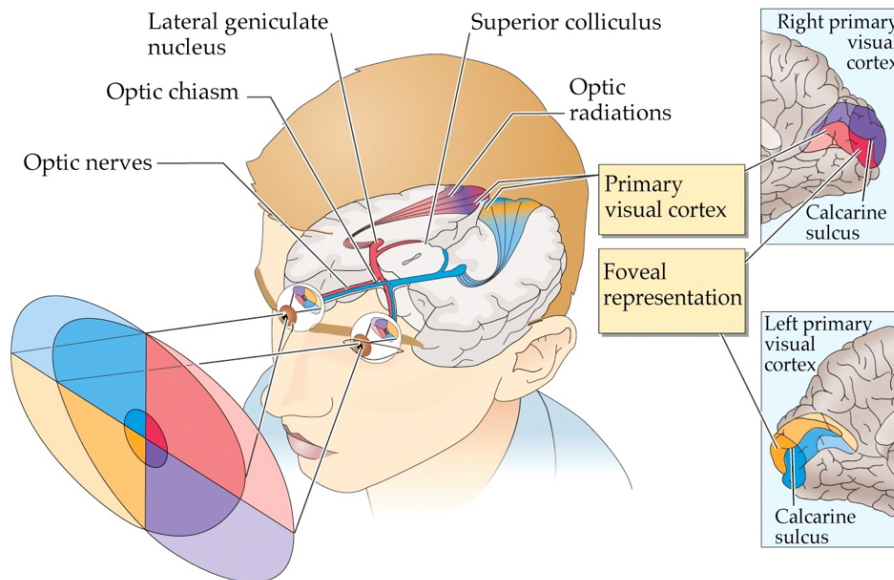 - Local contrast (light/dark differences)

Opponent processing
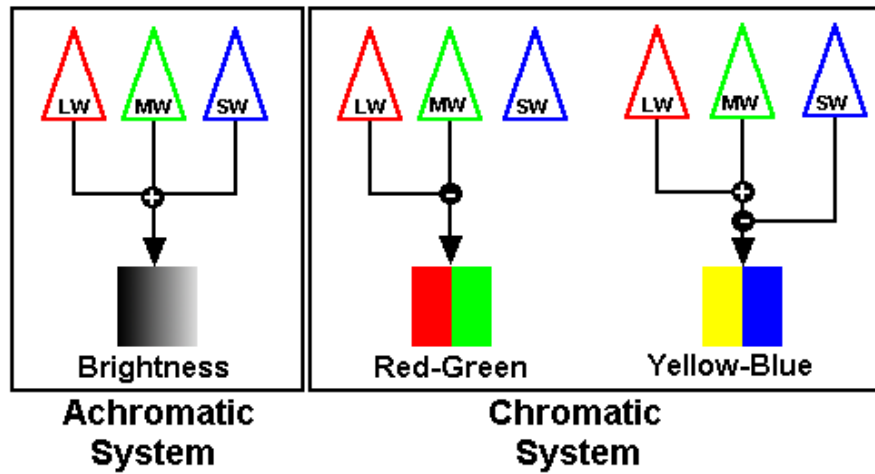
- Black vs. white (achromatic)
- Long (red) vs. Medium (green) wavelength cones
- (Long + Medium) vs. Short cones
- Can't really see reddish-green or bluish-yellow
 - "Oppose" one another at cellular/circuit level

From eye to brain

- Retinal ganglion cells
- 2nd/II cranial (optic) nerve
  - Optic chiasm (χ - asm): Partial crossing of fibers
  - Nasal hemiretina (lateral/peripheral visual field) cross
  - Left visual field (from L & R retinae) -> right hemisphere & vice versa
- *Lateral Geniculate Nucleus (LGN)* of thalamus (receives 90% of retinal projections)
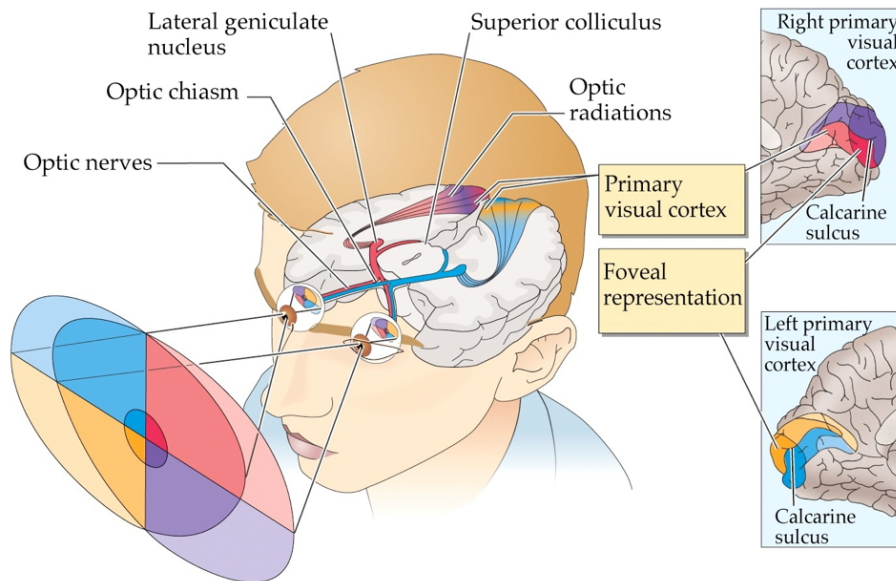
- Hypothalamus
  - *Suprachiasmatic nucleus* (superior to the optic chiasm): Synchronizes day/night cycle with circadian rhythms
- Superior colliculus & brainstem

LGN
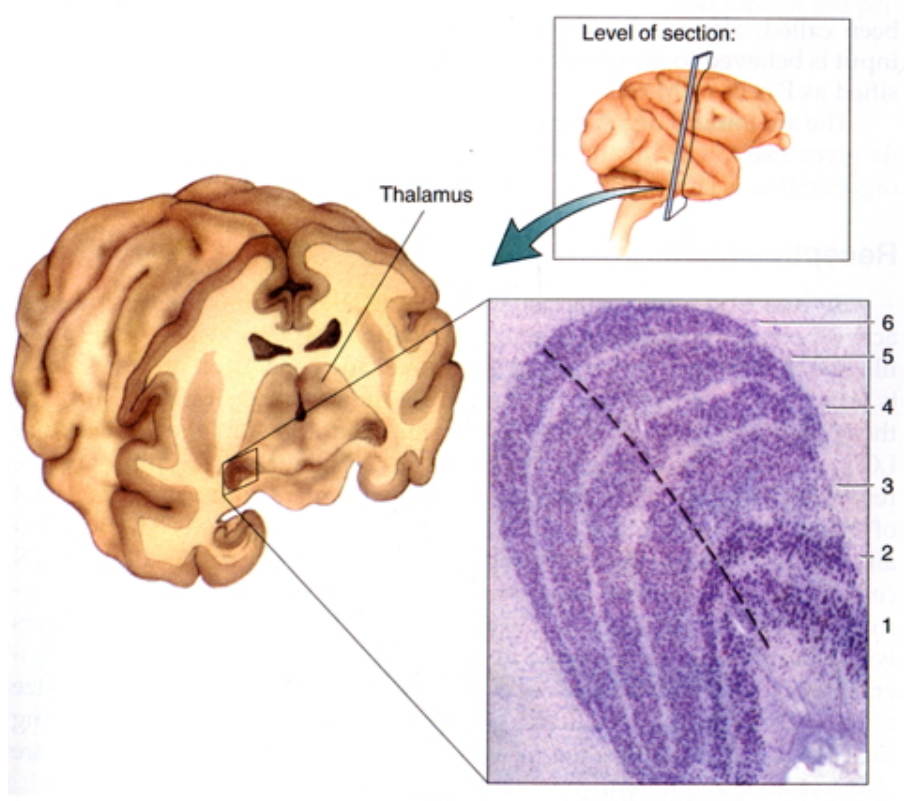
- 6 layers + intralaminar zone
  - Parvocellular (small cells): chromatic
  - Magnocellular (big cells): achromatic
  - Koniocellular (chromatic - short wavelength?)
- Retinotopic map of opposite visual field

From LGN to V1

Lateral geniculate nucleus — Superior colliculus — Optic chiasm — Optic radiations — Optic nerves — Primary visual cortex — Foveal representation — Right primary visual cortex — Calcarine sulcus — Left primary visual cortex — Calcarine sulcus

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- Via *optic radiations*
- *Primary visual cortex (V1) (http://www.scholarpedia.org/article/Area_V1)* in occipital lobe
- Create "stria of Gennari" (visible stripe in layer 4)
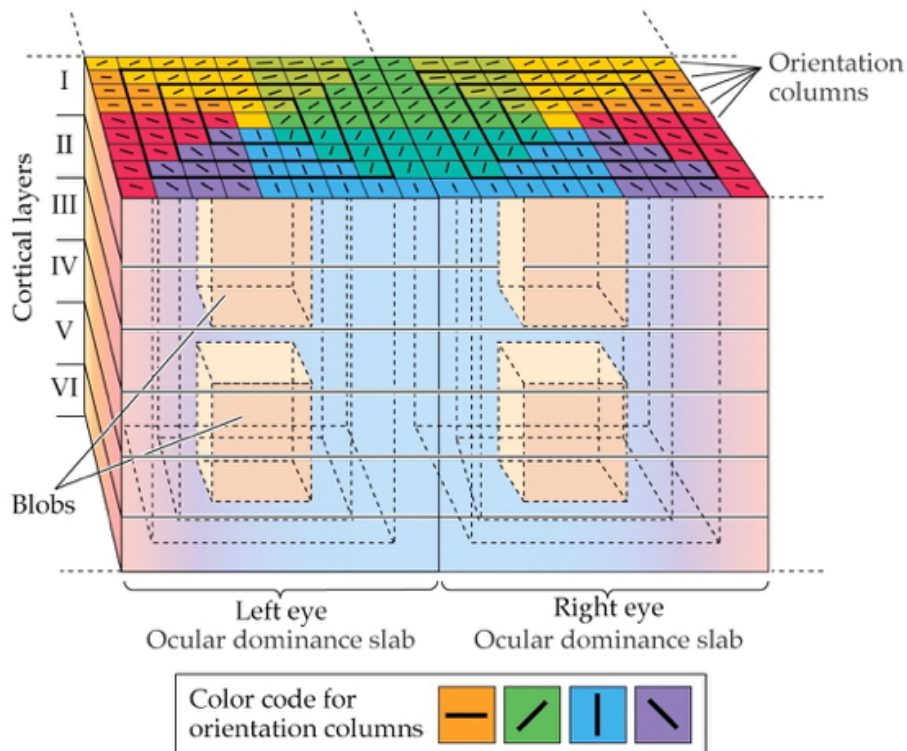- Calcarine fissure (medial occiptal lobe) divides lower/upper visual field

Human V1

(Dougherty et al., 2003) (http://dx.doi.org/10.1167/3.10.1)
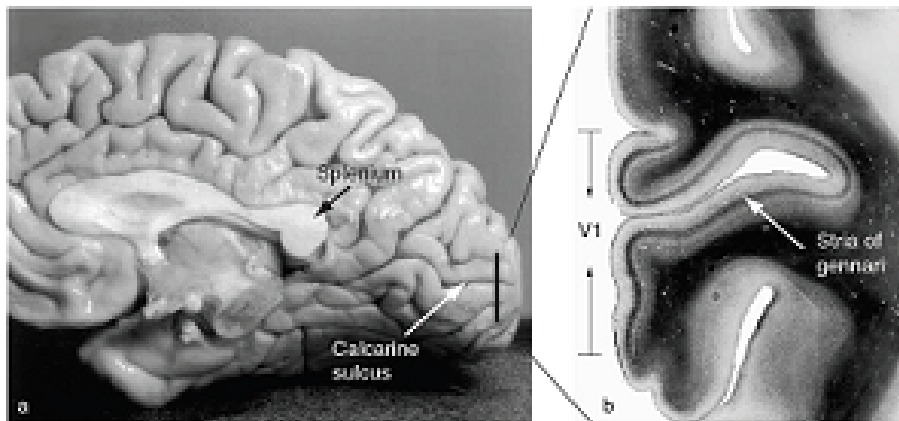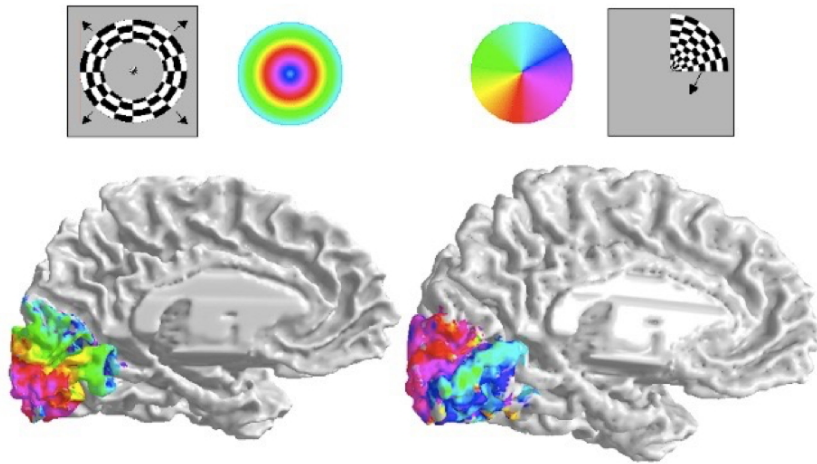
- Fovea overrepresented
  - Analogous to somatosensation
  - High acuity in fovea vs. lower outside it
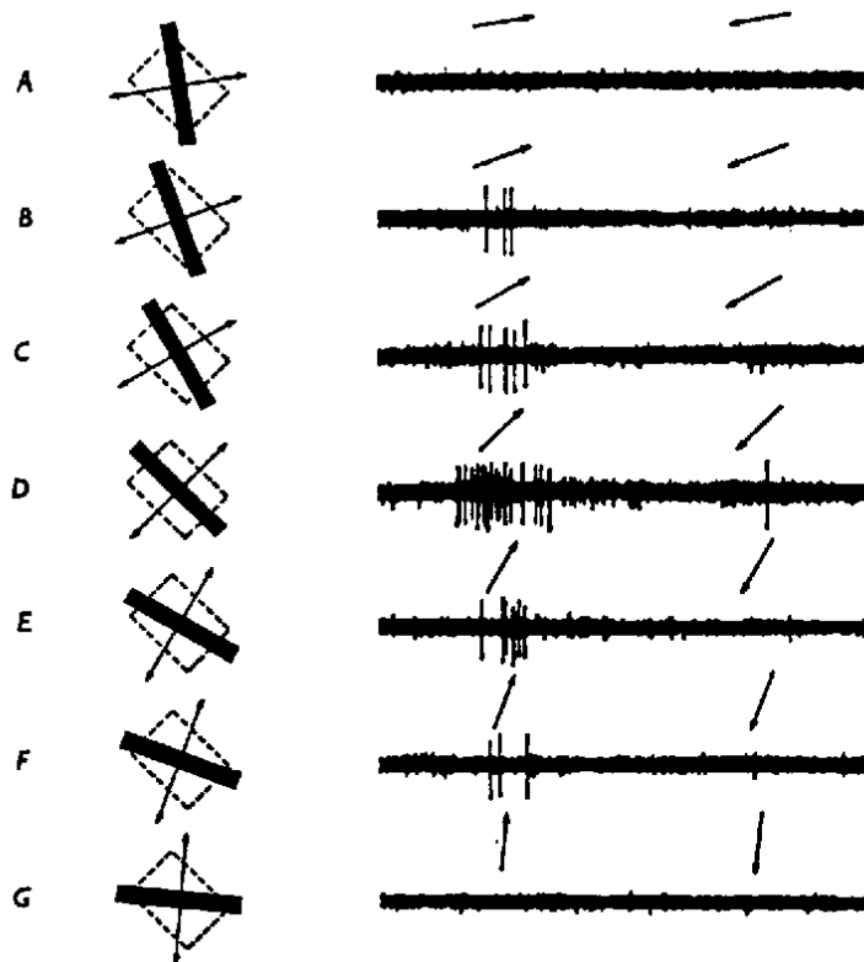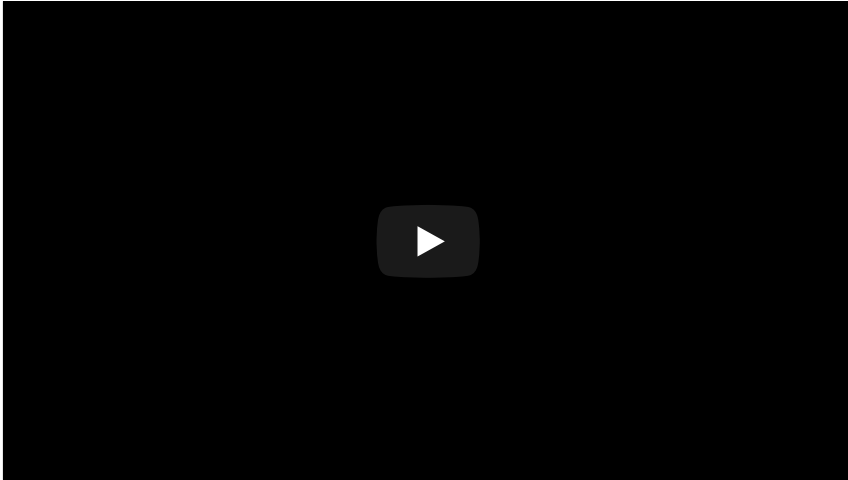- Upper visual field/lower (ventral) V1 and *vice versa*

Laminar, columnar organization
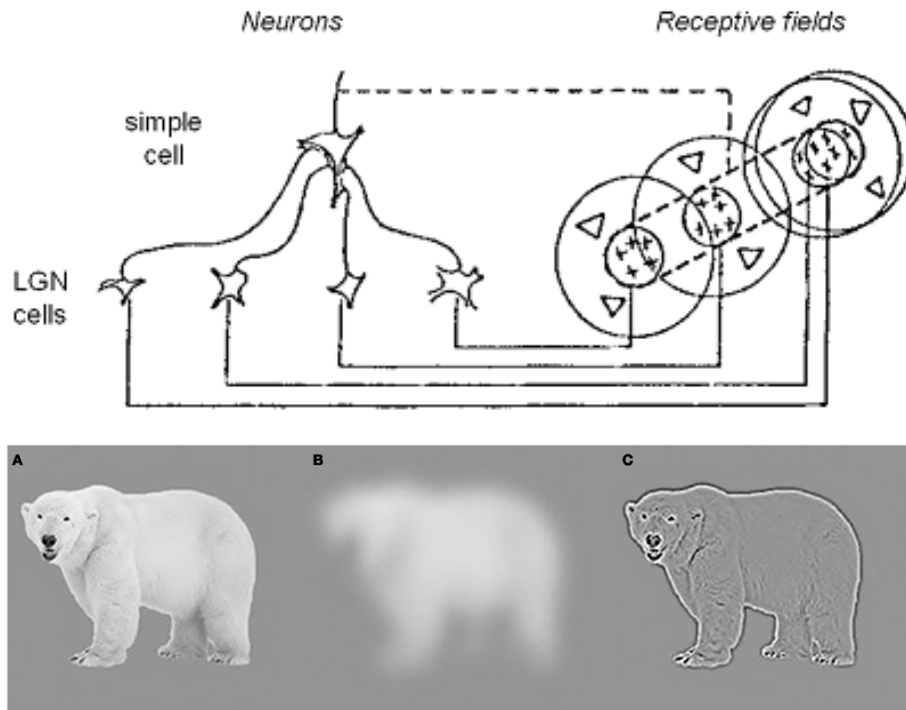

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- 6 laminae (layers)
  - Input: Layer 4 (remember stria of Gennari?)
  - Output: Layers 2-3 (to cortex), 5 (to brainstem), 6 (to LGN)
- Columns

- Orientation/angle
- Spatial frequency
- Color/wavelength
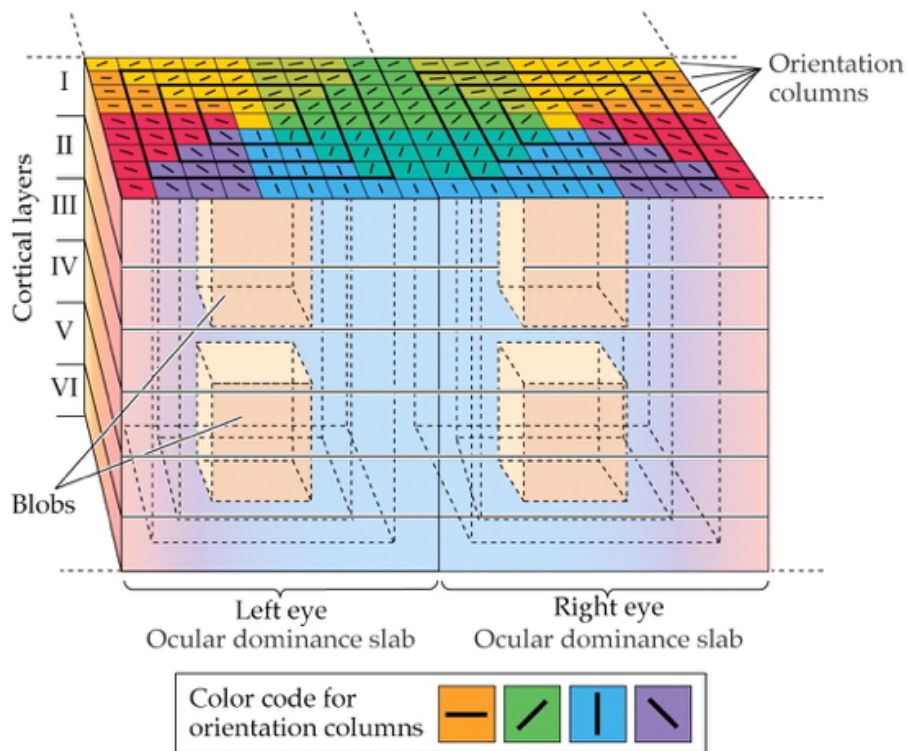- Eye of origin, *ocular dominance*

From center-surround receptive fields to line detection

Neurons — simple cell — LGN cells — Receptive fields

(Panichello, Cheung, & Bar, 2013) (http://dx.doi.org/10.3389/fpsyg.2012.00620)

Ocular dominance columns

http://www.scholarpedia.org/w/images/9/99/11-Hubel-Wiesel-model.png
(http://www.scholarpedia.org/w/images/9/99/11-Hubel-Wiesel-model.png)

Beyond V1

| Color | Motion | Stereopsis | Form | Specific form |
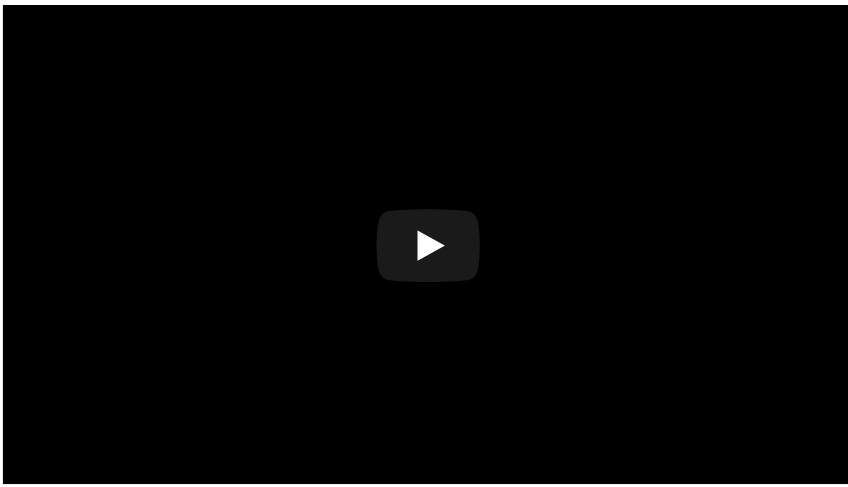
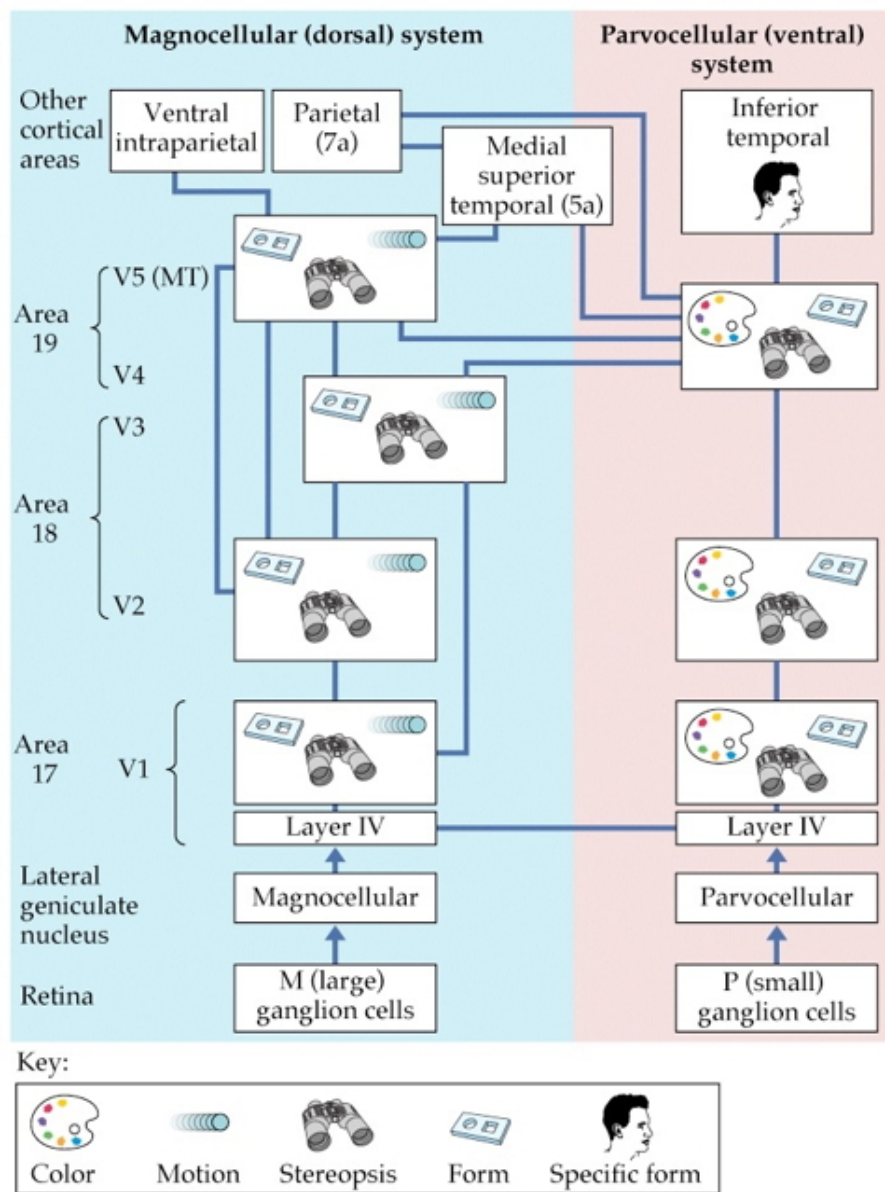© 2001 Sinauer Associates, Inc.

- Larger, more complex receptive fields

- *Dorsal stream* (where/how)
  - Toward parietal lobe
- *Ventral stream* (what)

What is vision for?

- What is it? (form perception)
- Where is it? (space perception)
- How do I get from here to there (action control)
- What time (or time of year) is it?

References

Dougherty, R. F., Koch, V. M., Brewer, A. A., Fischer, B., Modersitzki, J., & Wandell, B. A. (2003). Visual field representations and locations of visual areas V1/2/3 in human visual cortex. *Journal of Vision*, *3*(10), 1–1. https://doi.org/10.1167/3.10.1 (https://doi.org/10.1167/3.10.1)

Panichello, M. F., Cheung, O. S., & Bar, M. (2013). Predictive feedback and conscious visual experience. *Perception Science*, *3*, 620. https://doi.org/10.3389/fpsyg.2012.00620 (https://doi.org/10.3389/fpsyg.2012.00620)

Roark, M. W., & Stringham, J. M. (2019). Visual performance in the "real world": Contrast sensitivity, visual acuity, and effects of macular carotenoids. *Molecular Nutrition & Food Research*, *63*(15), e1801053. https://doi.org/10.1002/mnfr.201801053 (https://doi.org/10.1002/mnfr.201801053)