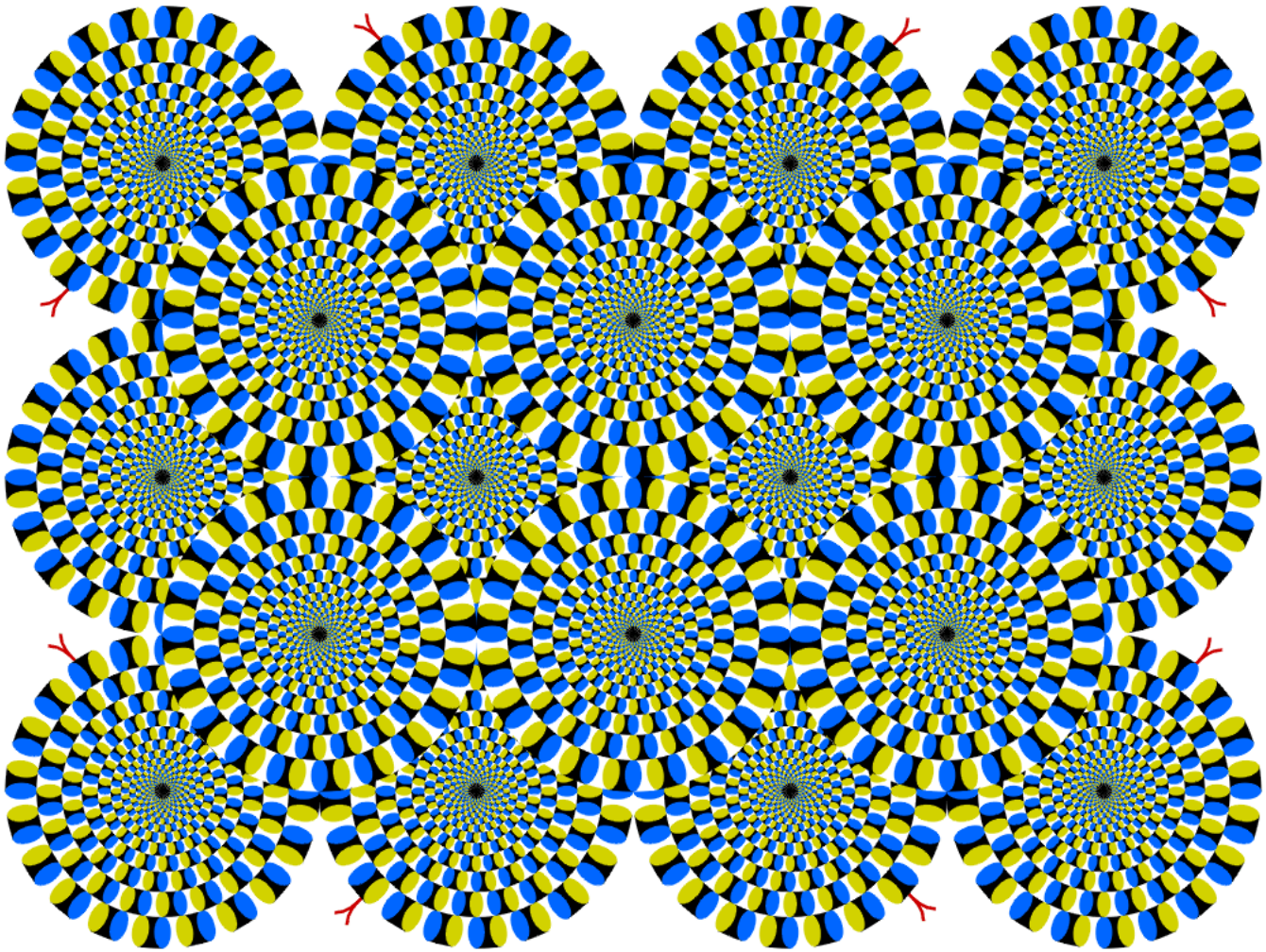
Lecture 8

Human Vision



A.Kitaoka 2003

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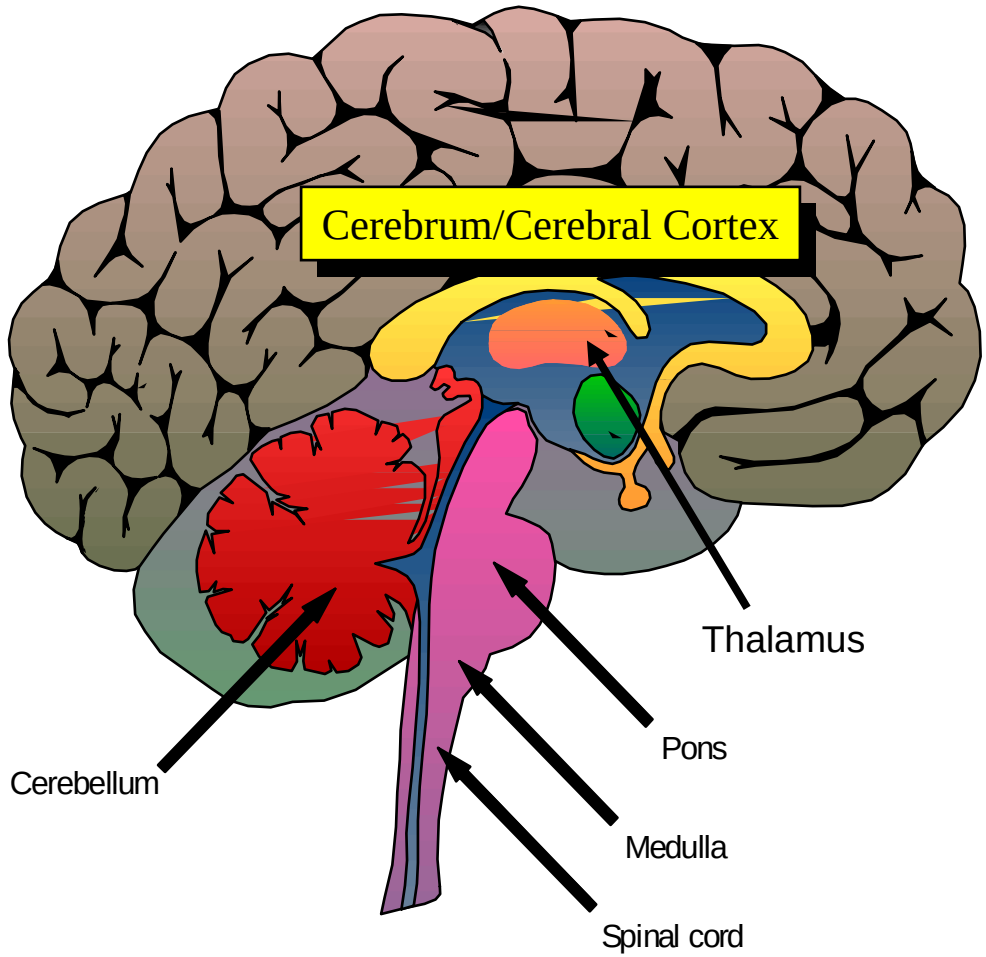
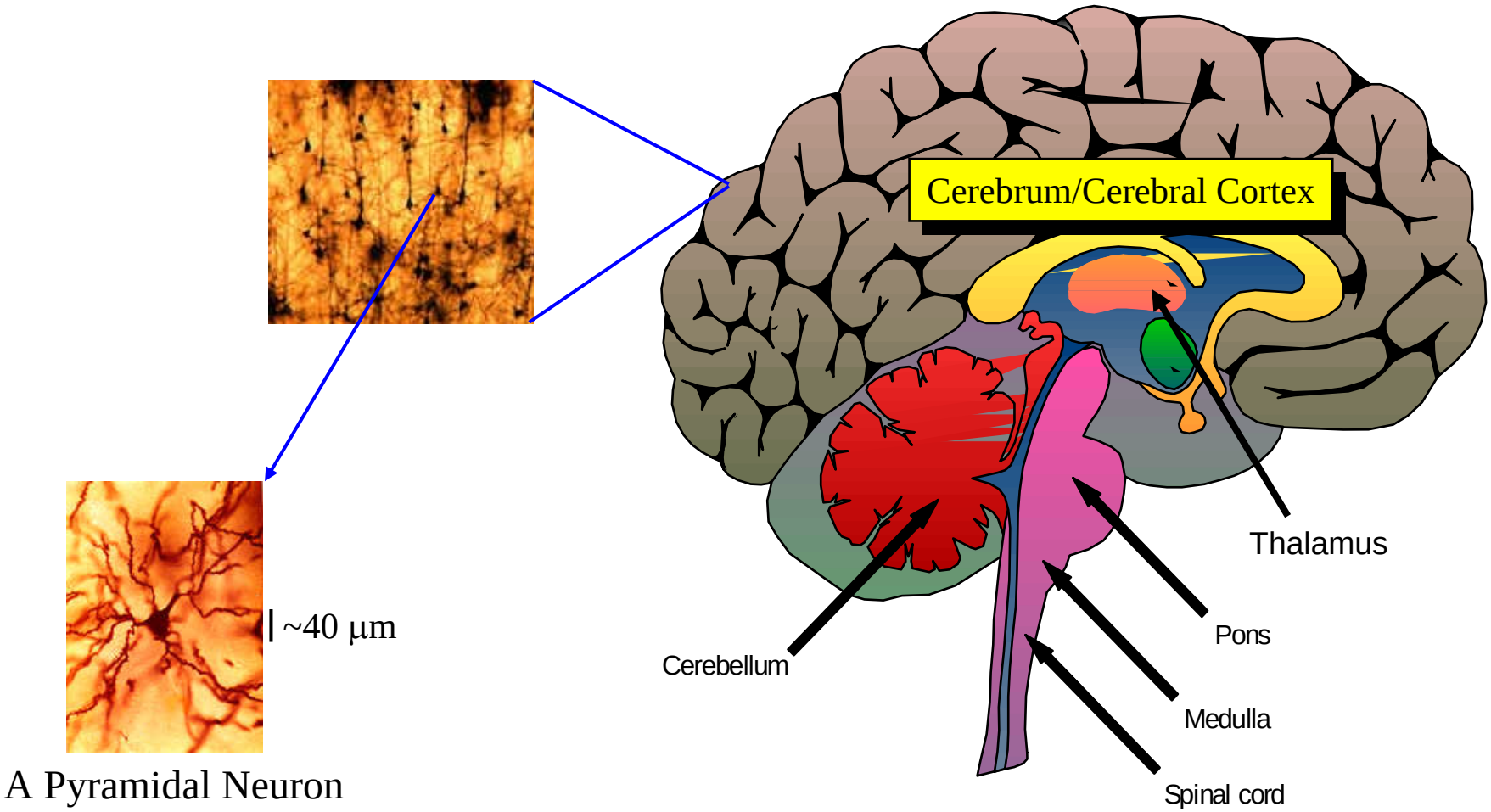
Our 3-pound Universe

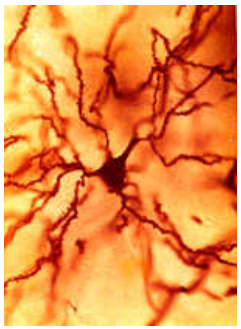


Enter…the neuron (“brain cell”)

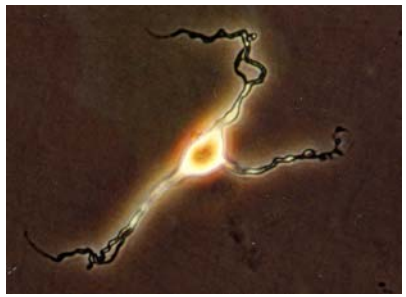


A Pyramidal Neuron

The Neuron Doctrine/Dogma



Cerebral Cortex Neuron

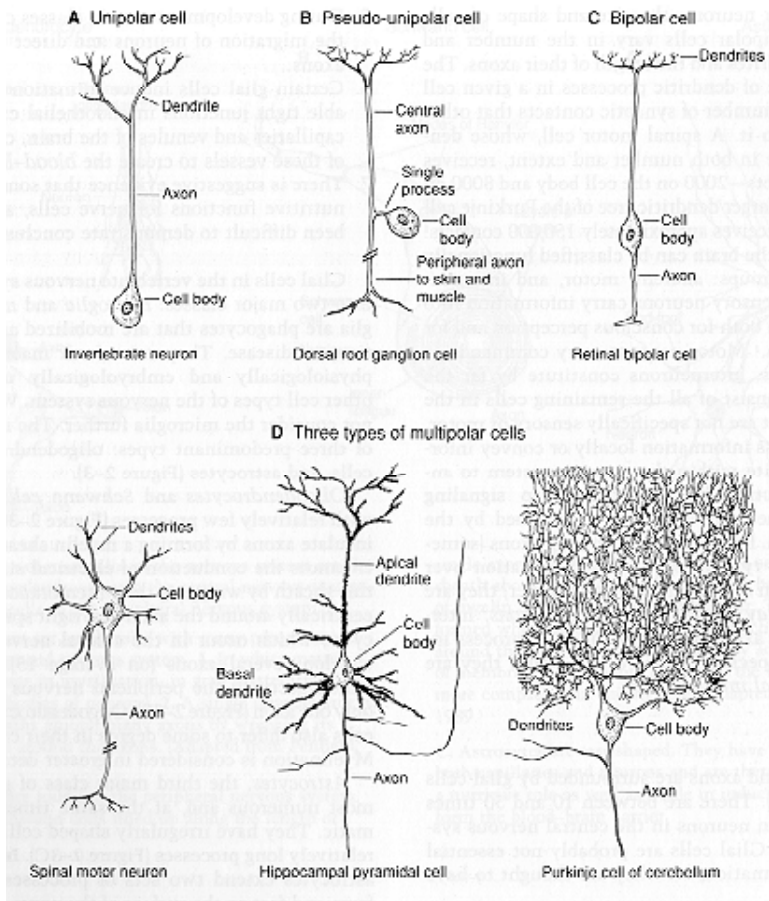


Neuron from the Thalamus

Neuron from the Cerebellum

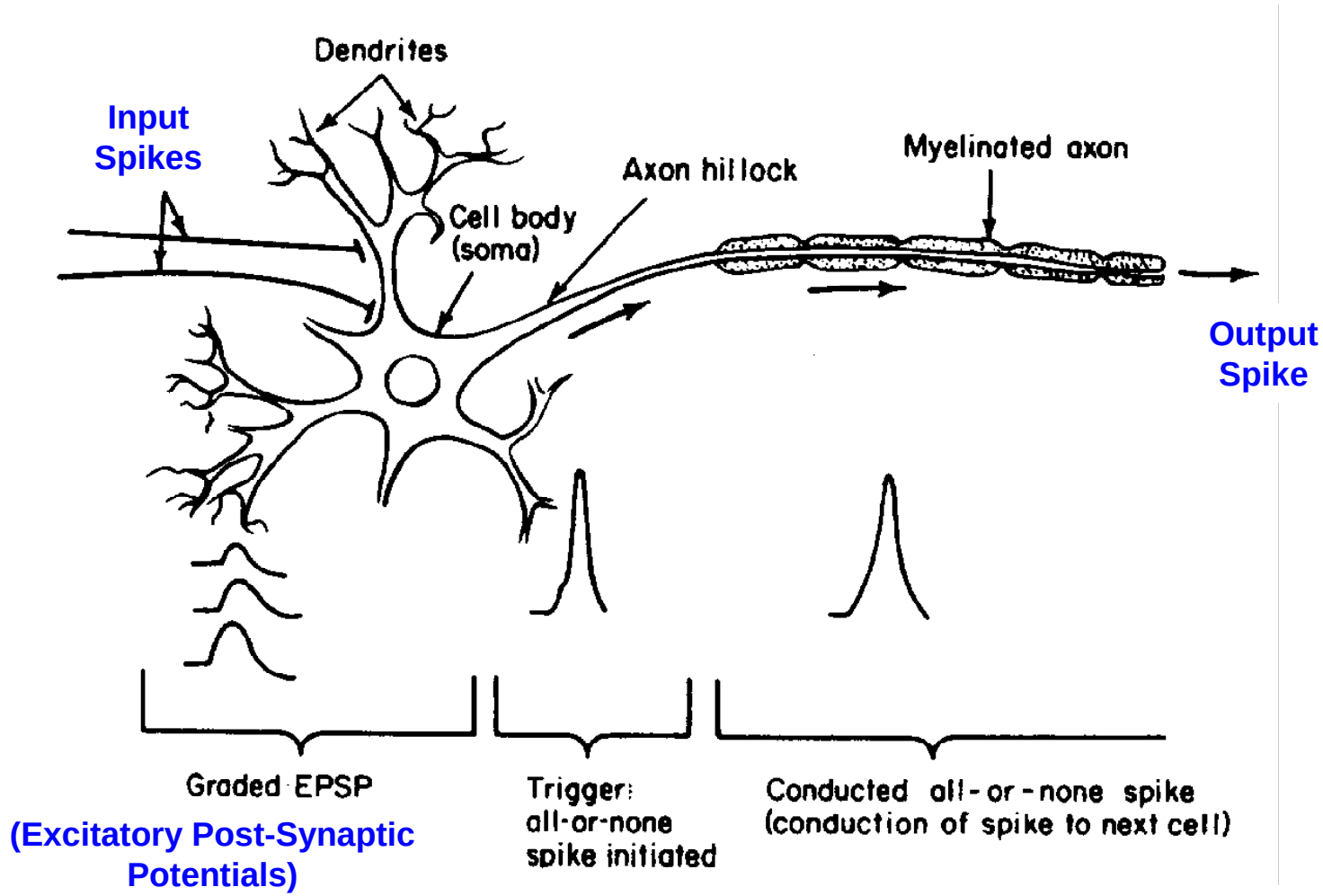
[Neuron Doctrine]: "The neuron is the appropriate basis for understanding the computational and functional properties of the brain"

First suggested in 1891 by Waldeyer

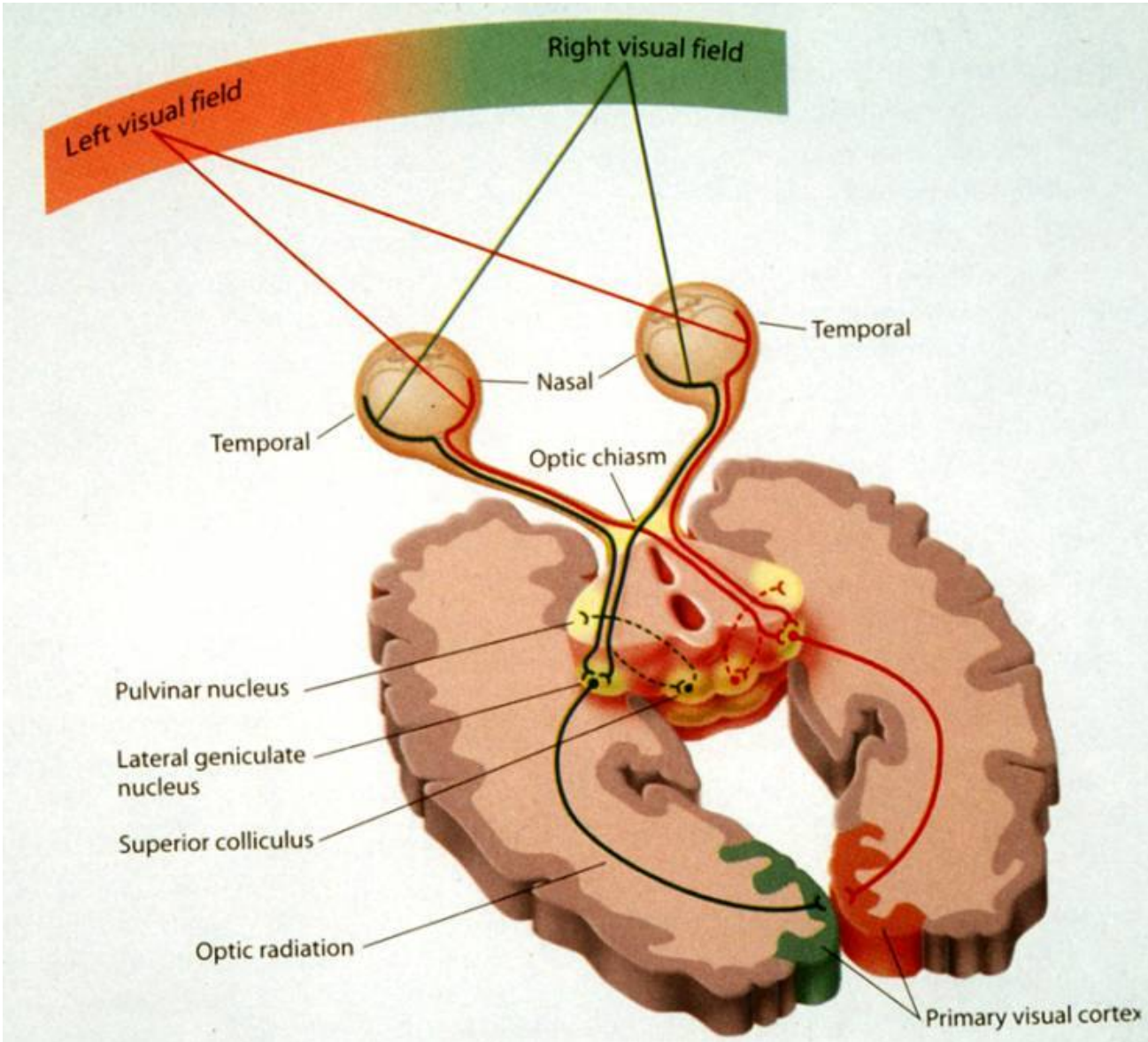


From Kandel, Schwartz, Jessel, Principles of Neural Science, 3rd edn., 1991, pg. 21

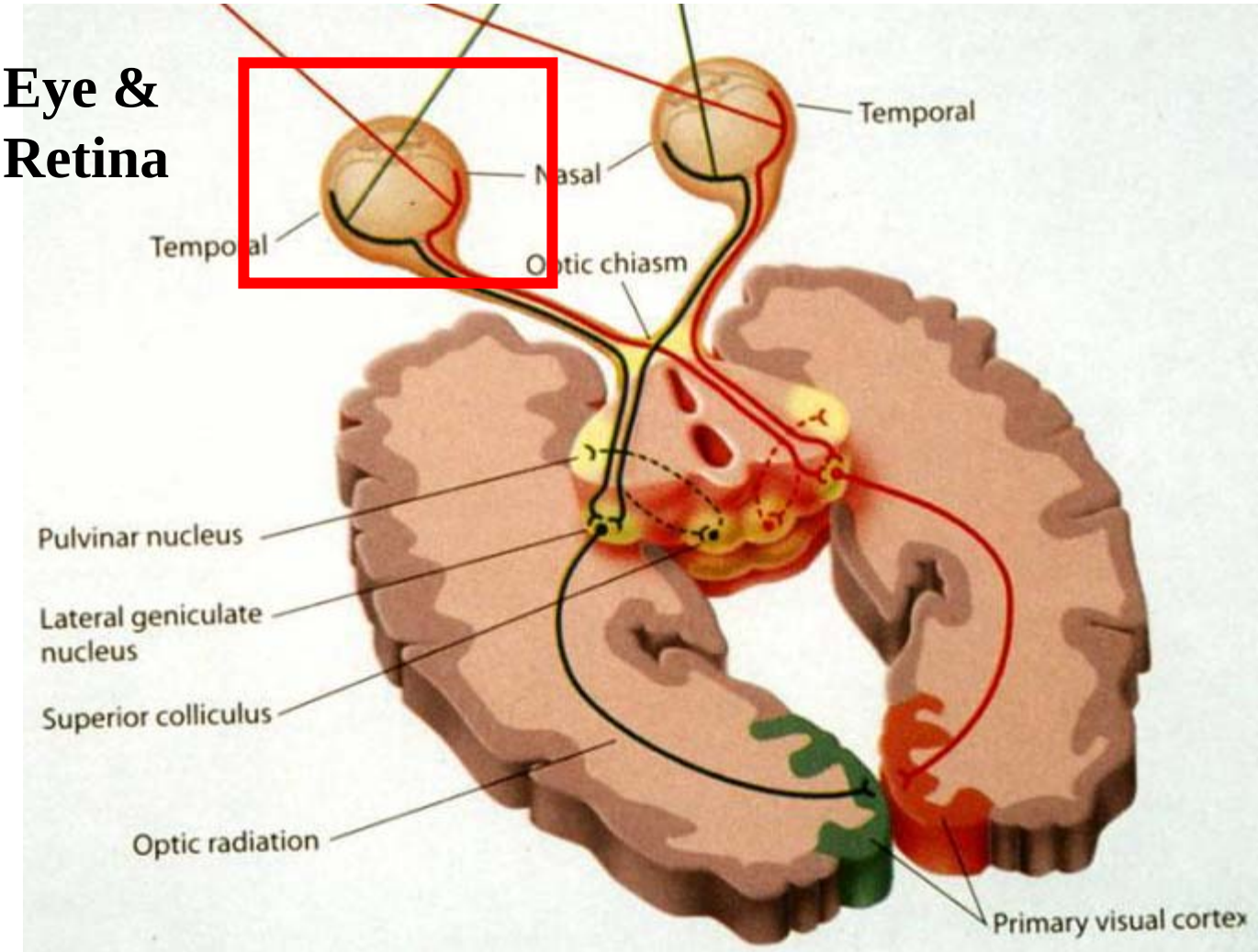
The Idealized Neuron



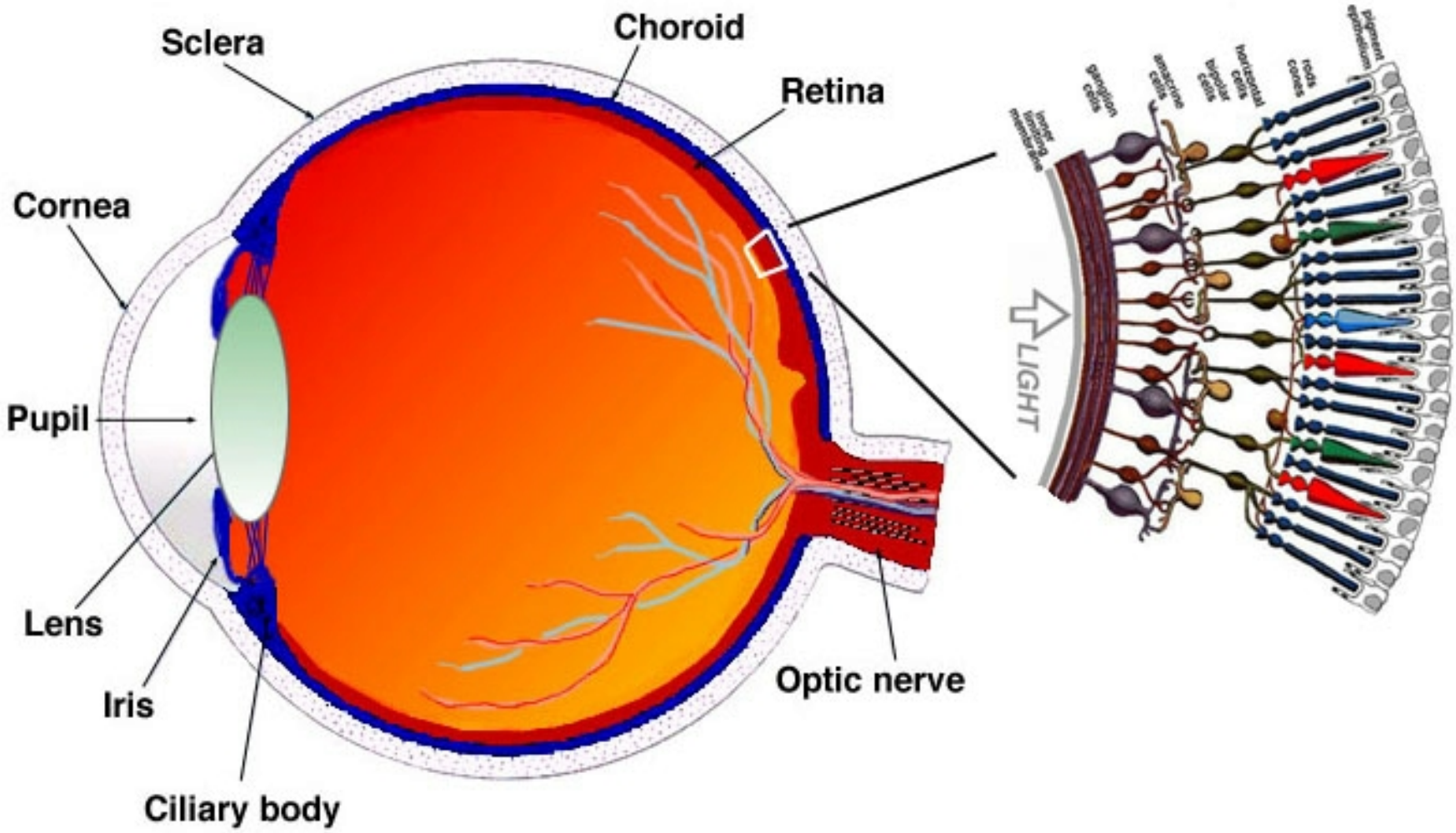
The Human Visual System



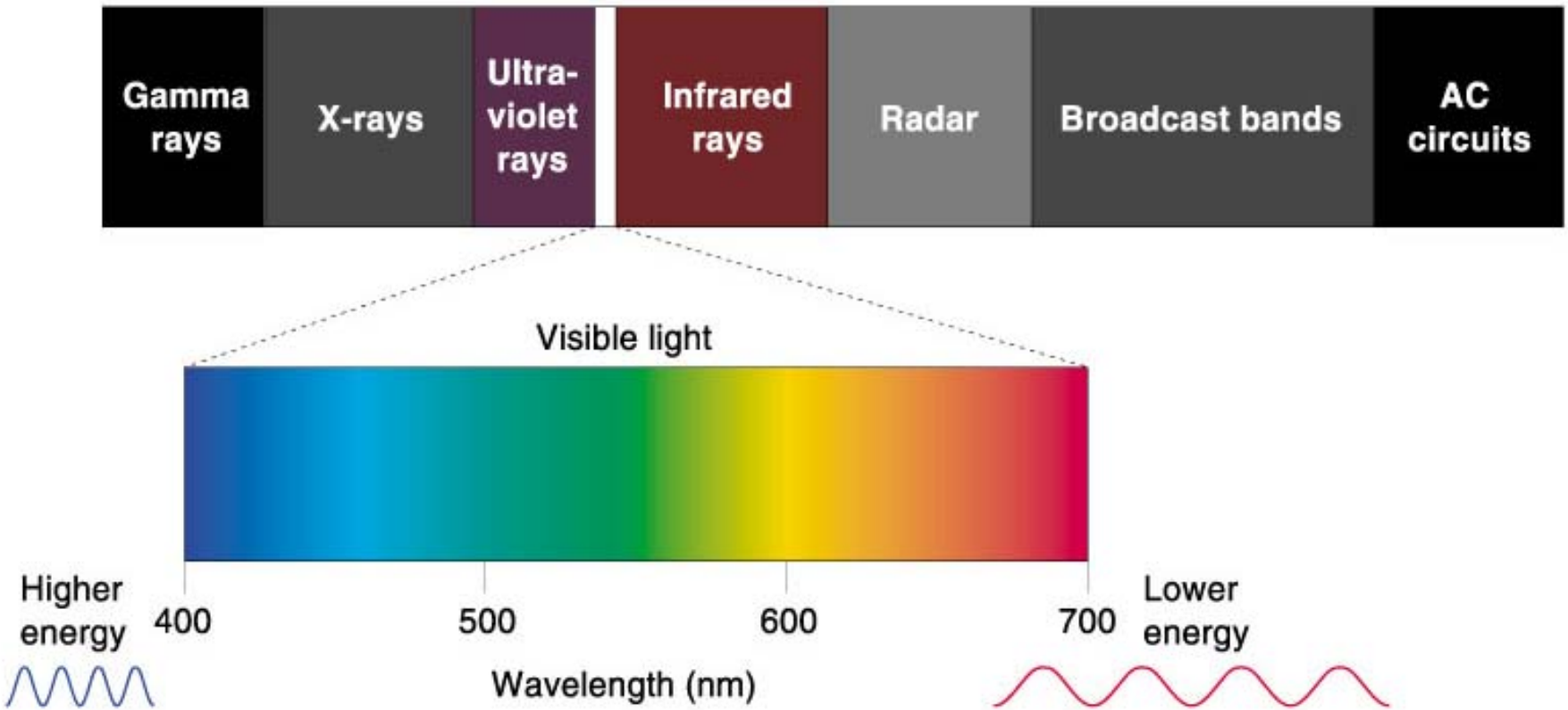
The Visual Pathway



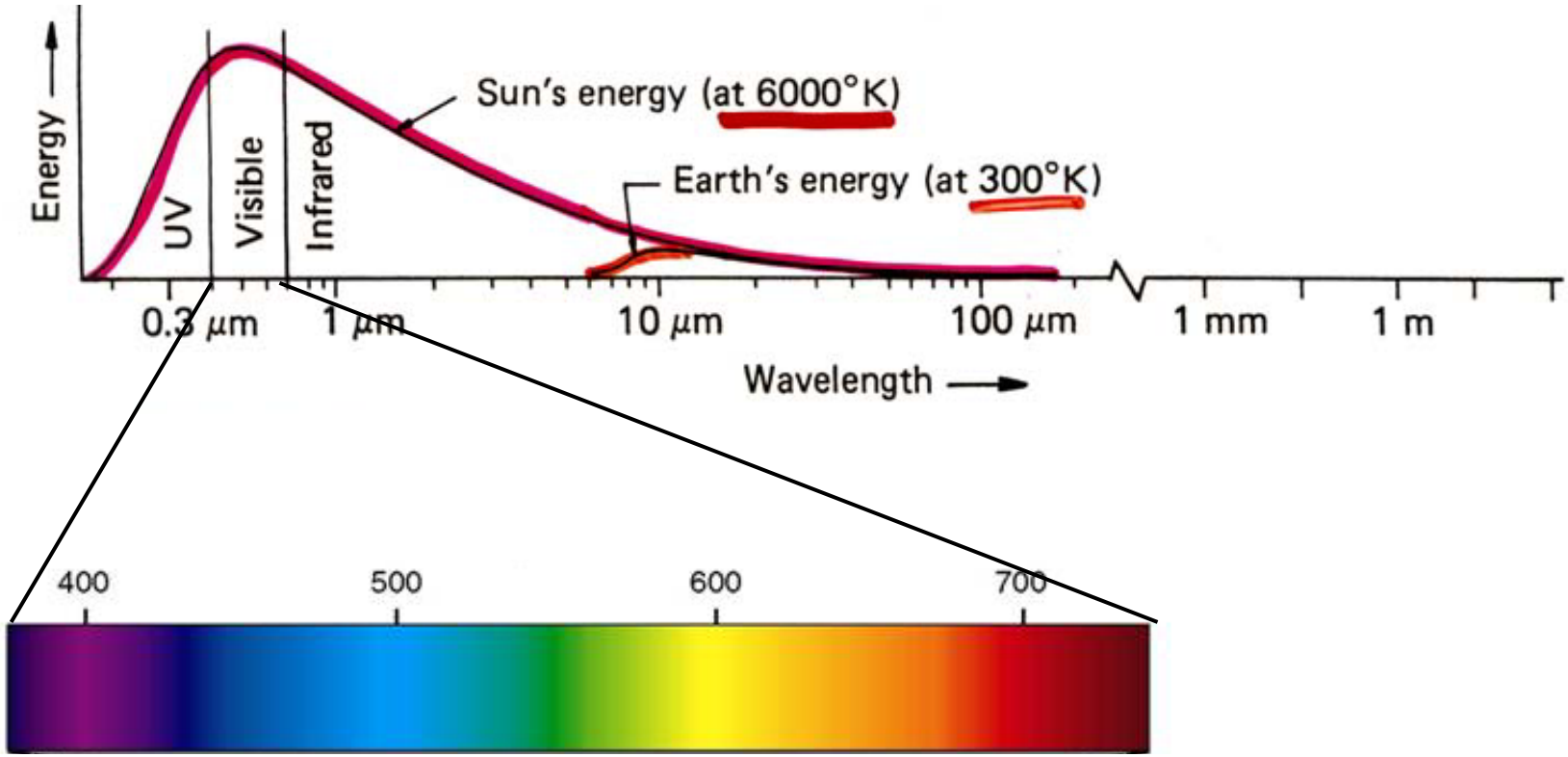
Human Eye and Retina



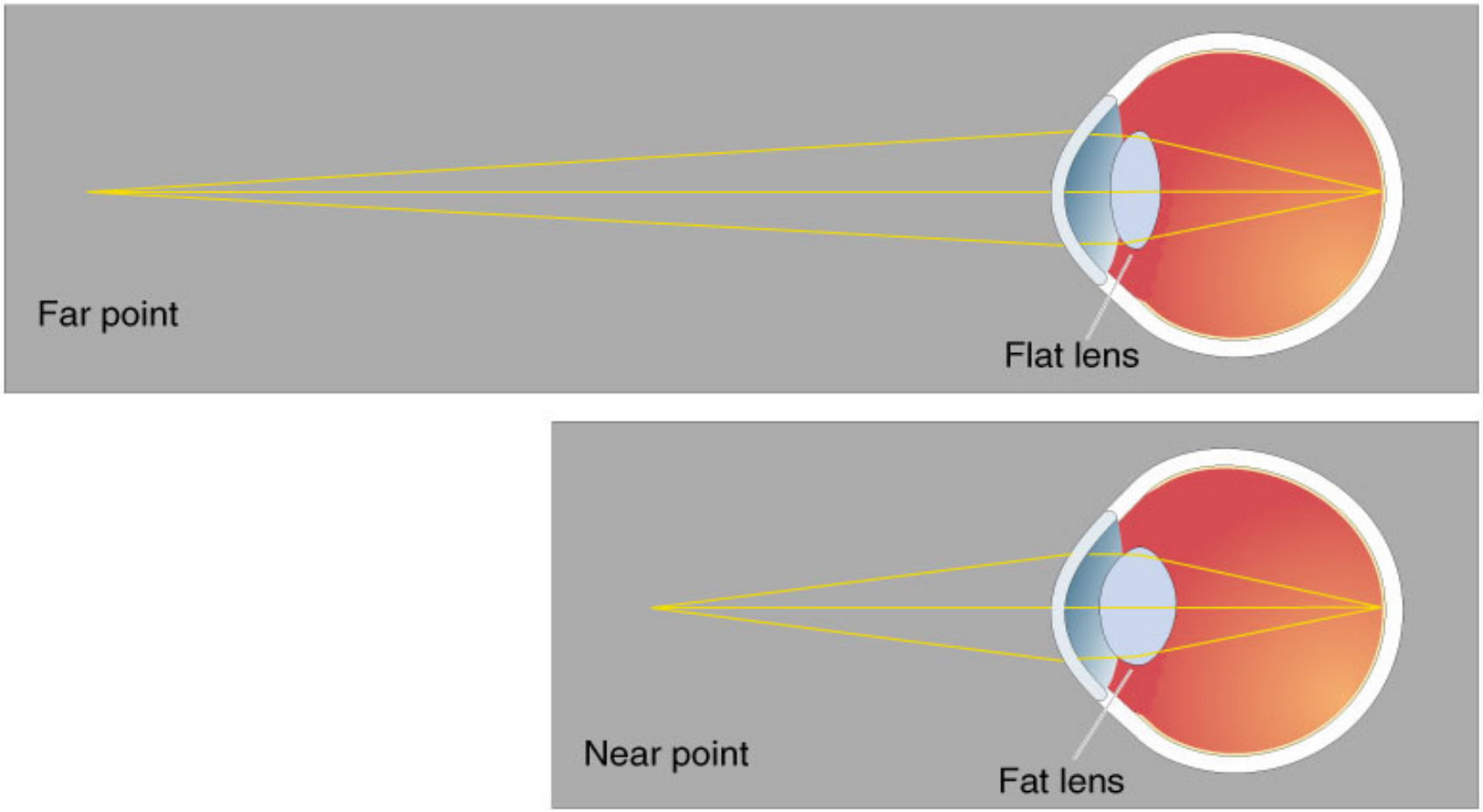
Light visible to the human eye



Our vision appears to be optimized for receiving the most abundant spectral radiance our star emits



The Eye: Accommodation by the Lens



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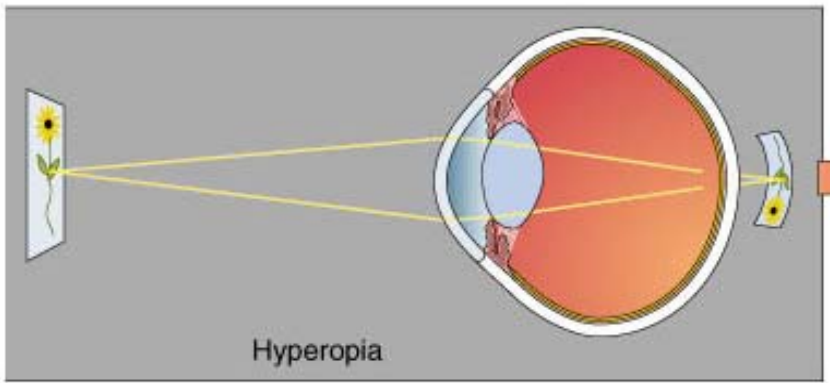
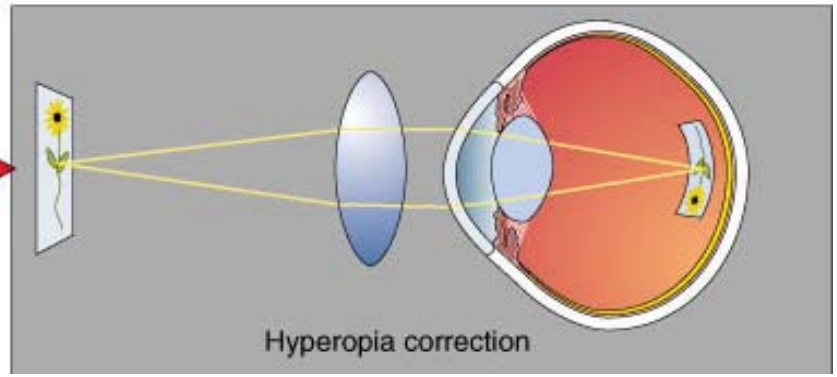
Eye Glasses: Why some of us need ‘em

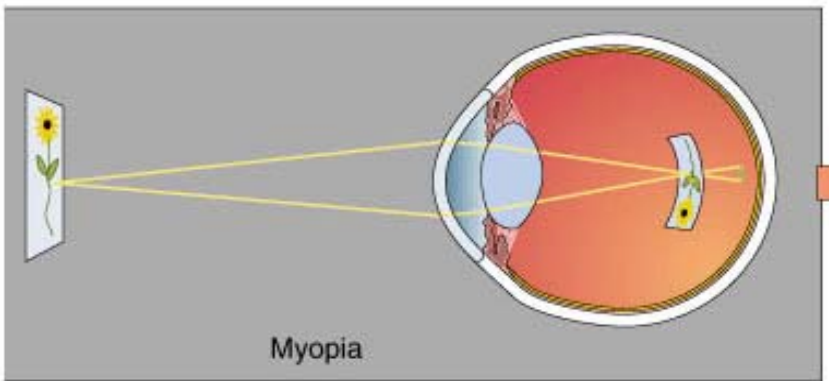
Farsightedness



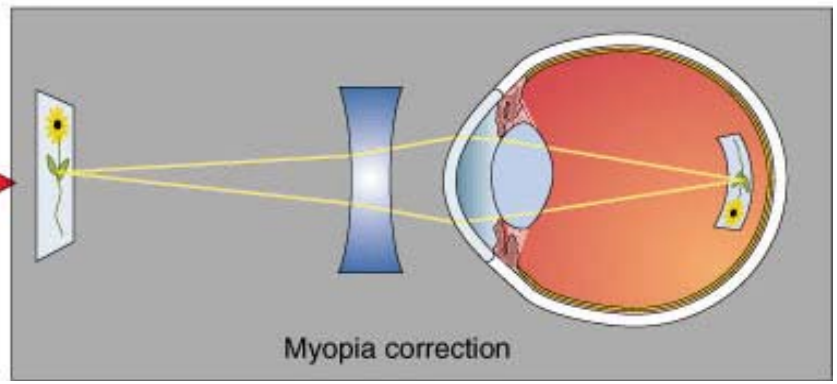
Corrected by artificial lens



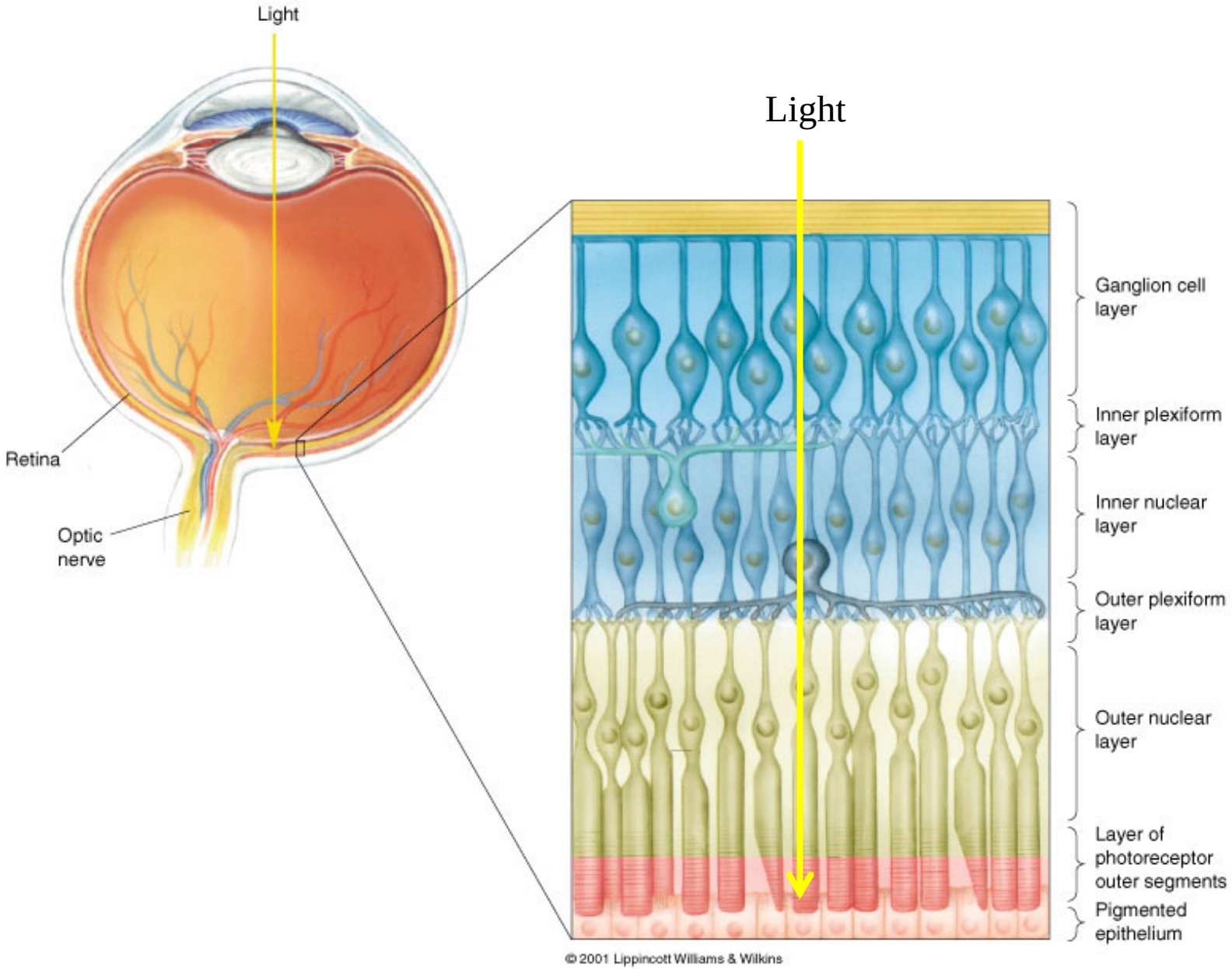
Nearsightedness



Corrected by artificial lens



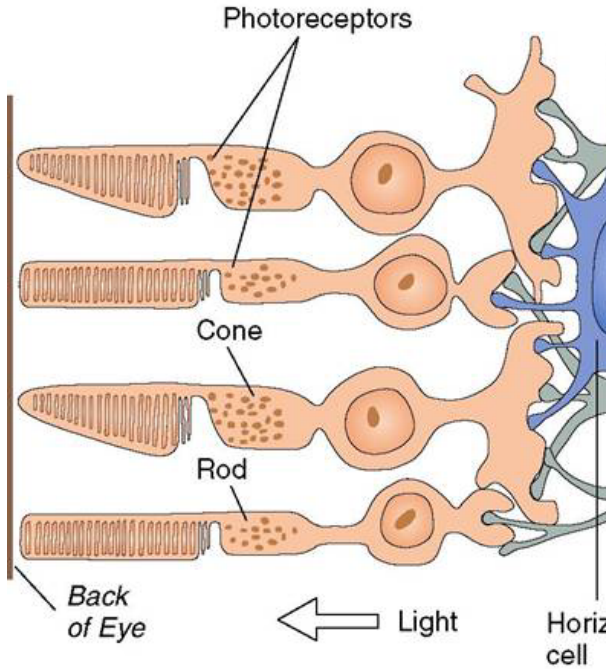
The Retina = Photoreceptors + Image Filtering

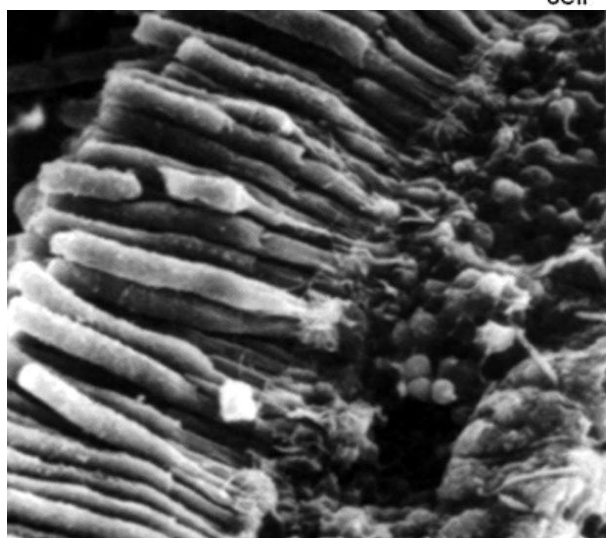


Photoreceptors in the Retina

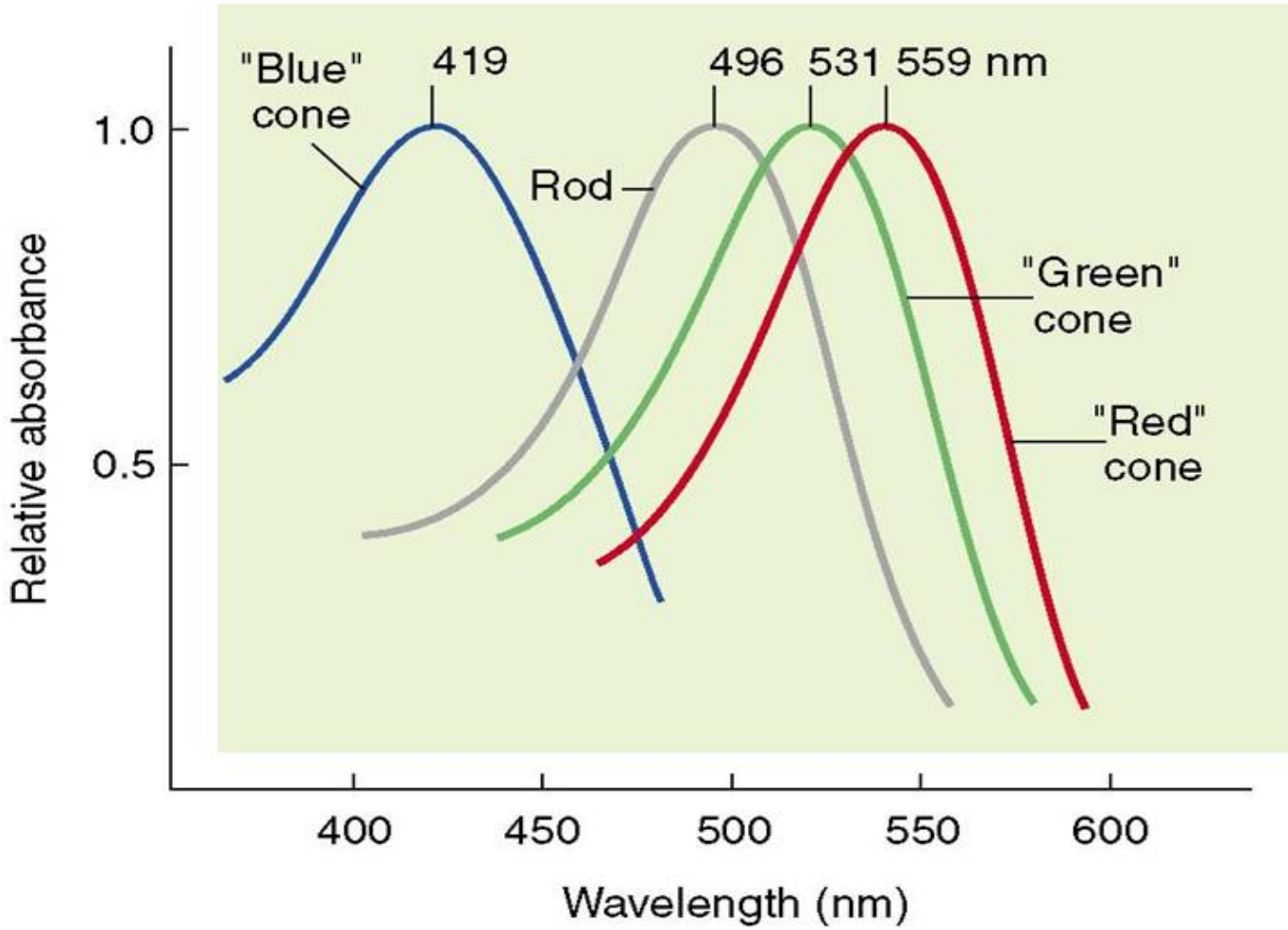
Two Types:

- Rods: Sensitive to intensity, but not color; form blurred images
- Cones: Color sensitive, form sharp images, require many photons. Three types, each maximally sensitive to one of three different wavelengths

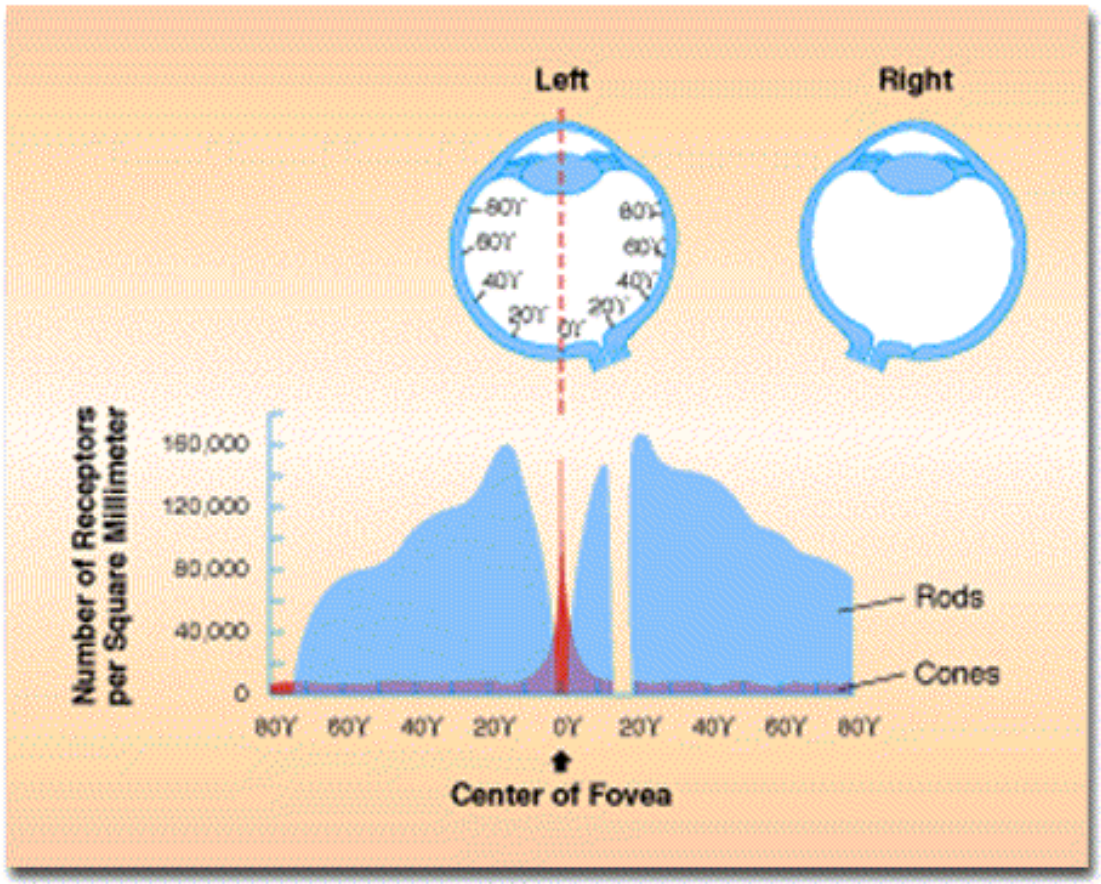




Coding of Light by Rods and Cones



Greater Density of Cones at the Center (Fovea)
More Rods in Periphery



Source: Adapted from Lidsay & Norman, 1977.

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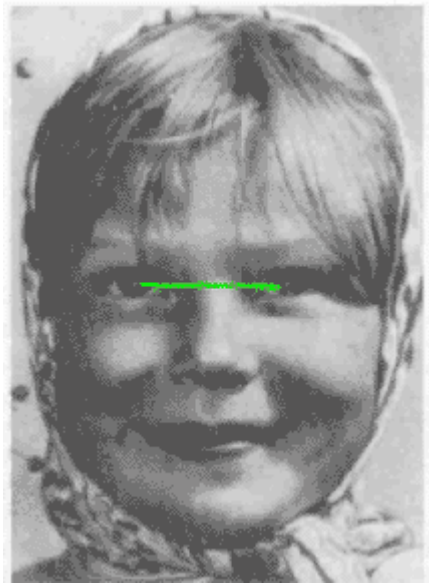
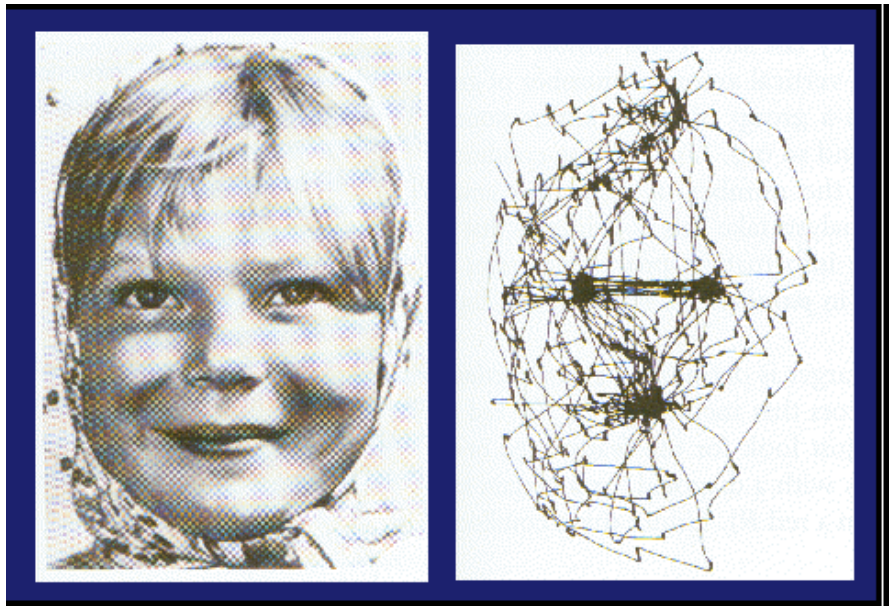
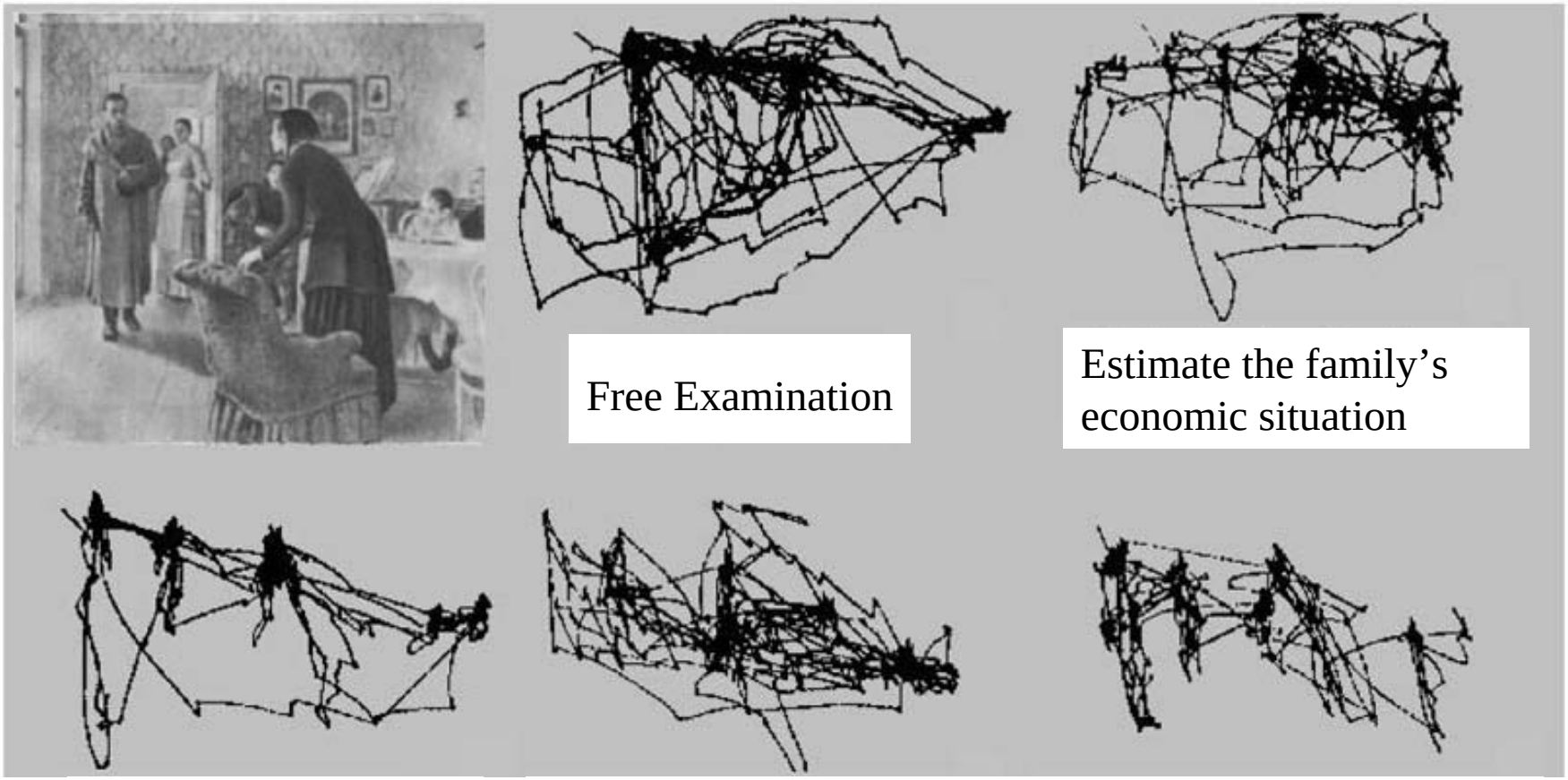
Eye movements used to bring interesting image regions into the fovea





(Yarbus, 1967)

Eye movements are usually determined by task goals



Free Examination

Estimate the family's economic situation

Estimate the ages of the people

What was the family doing before the arrival of the unexpected visitor?

Remember the clothes worn by the people

(Yarbus, 1967)

The Retina: Image Filtering

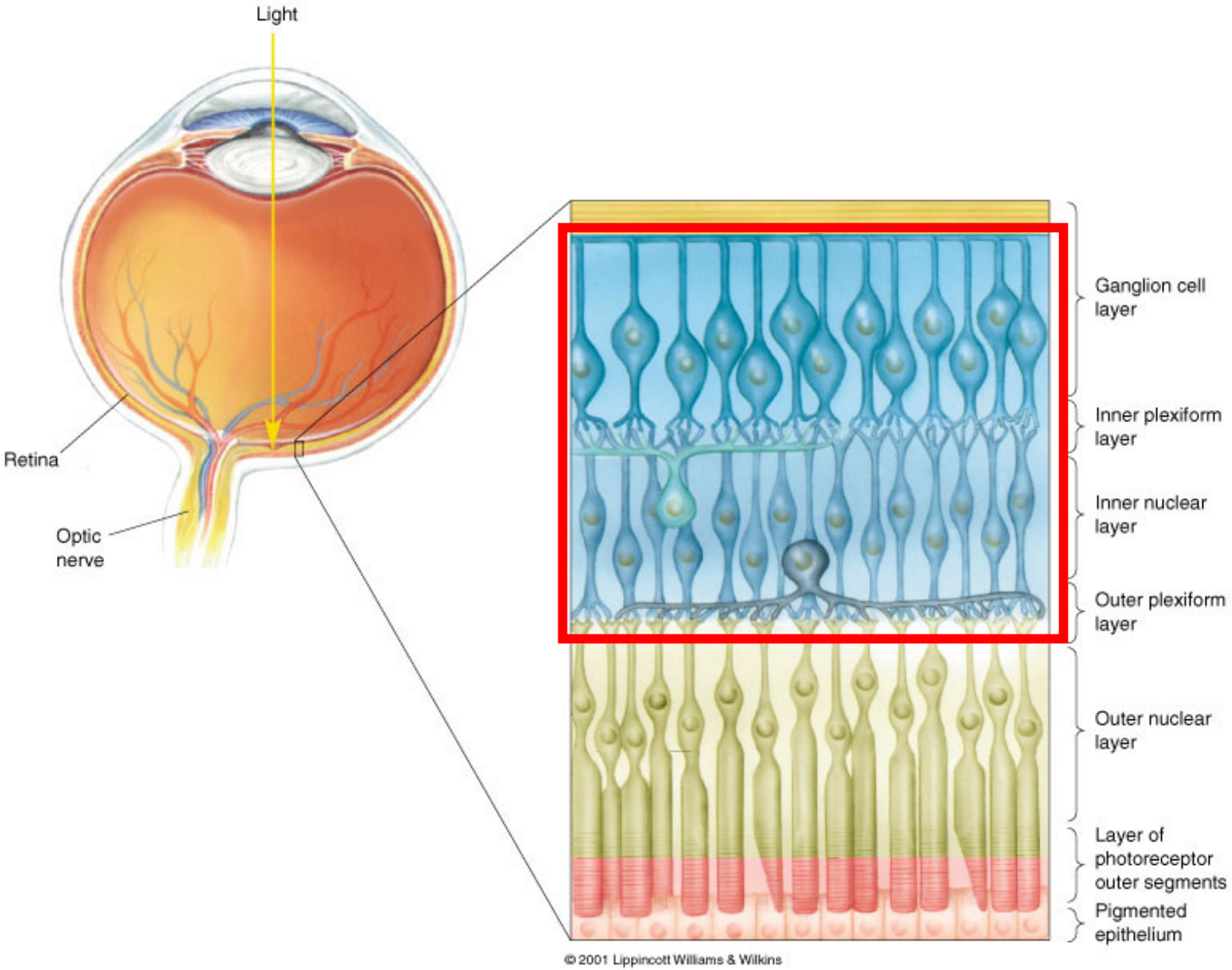
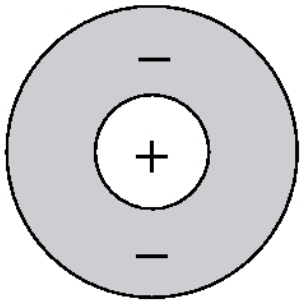
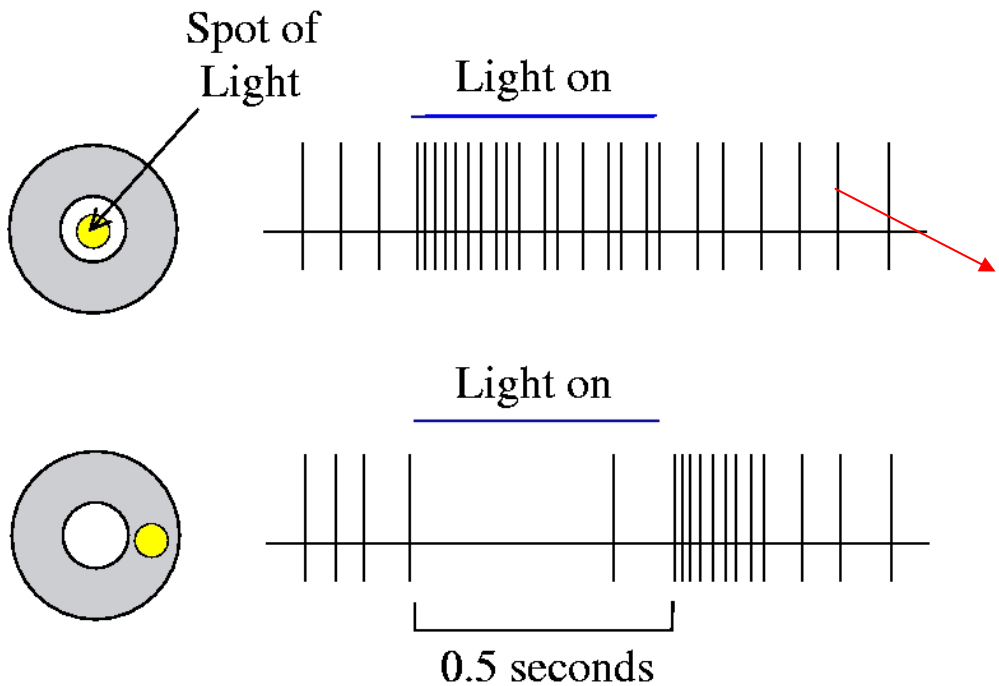


Image filtering in space and time in the retina

On center, Off surround cell



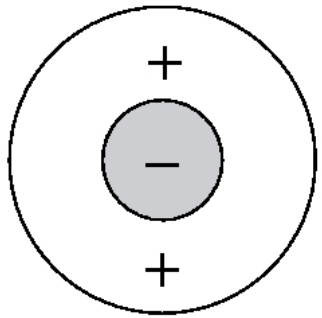
This space-time filter is also called the cell's "receptive field"

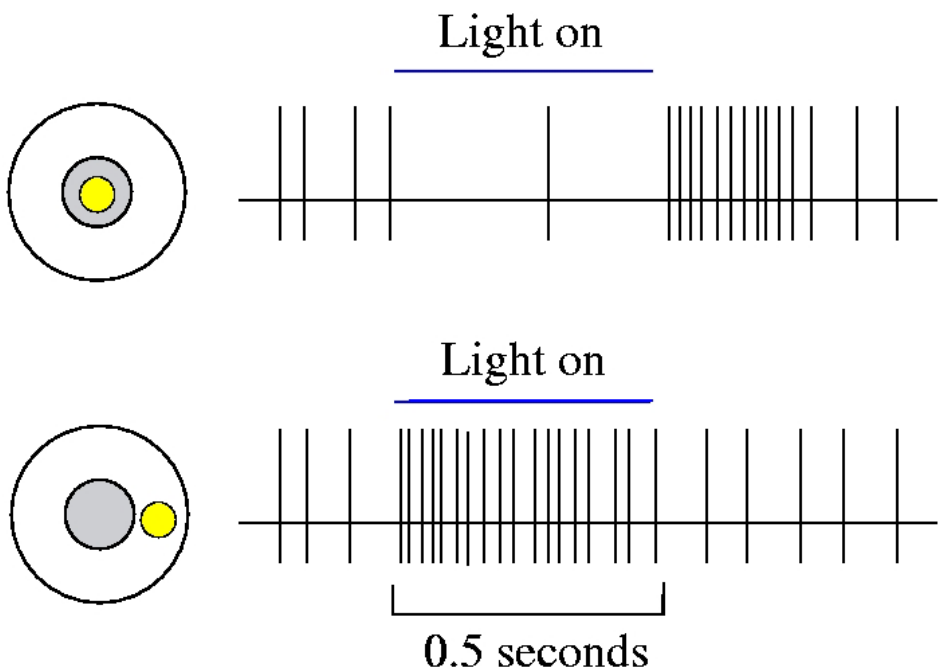


Neuron responds with electrical pulses known as Spikes or Action Potentials

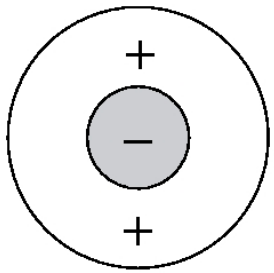
Image filtering in space and time in the retina

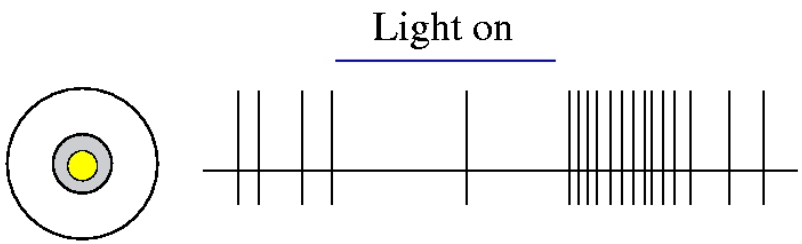
Off center,
On surround
cell

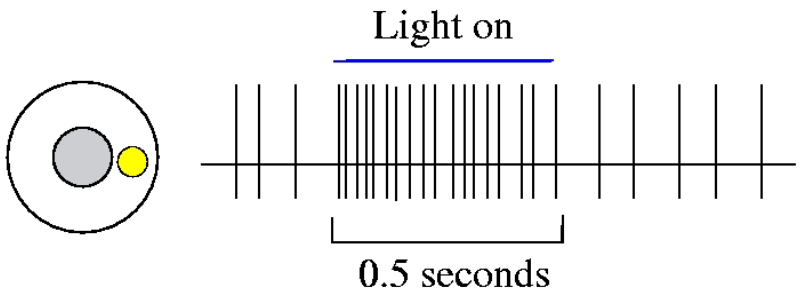




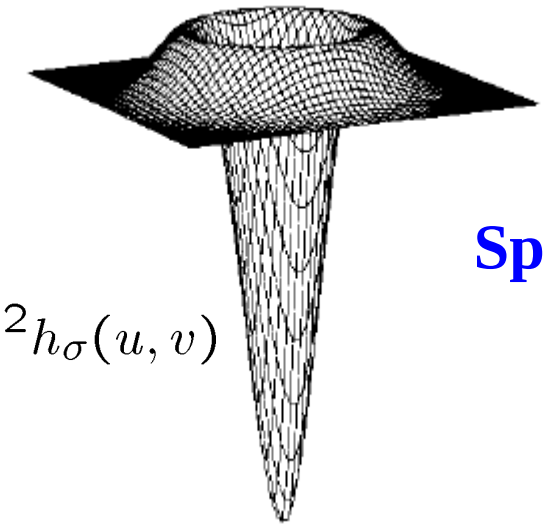
Retina takes spatial and temporal derivatives





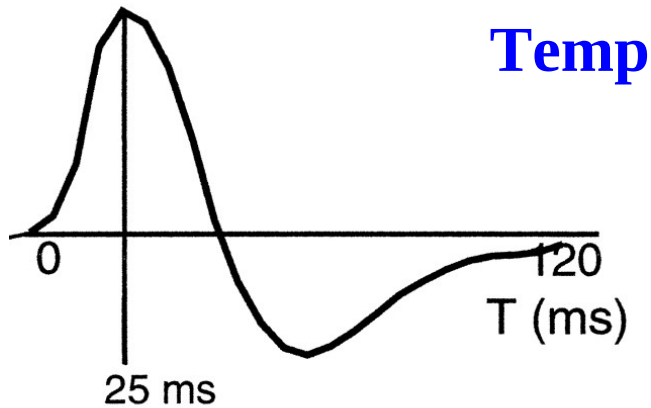


Laplacian of Gaussian



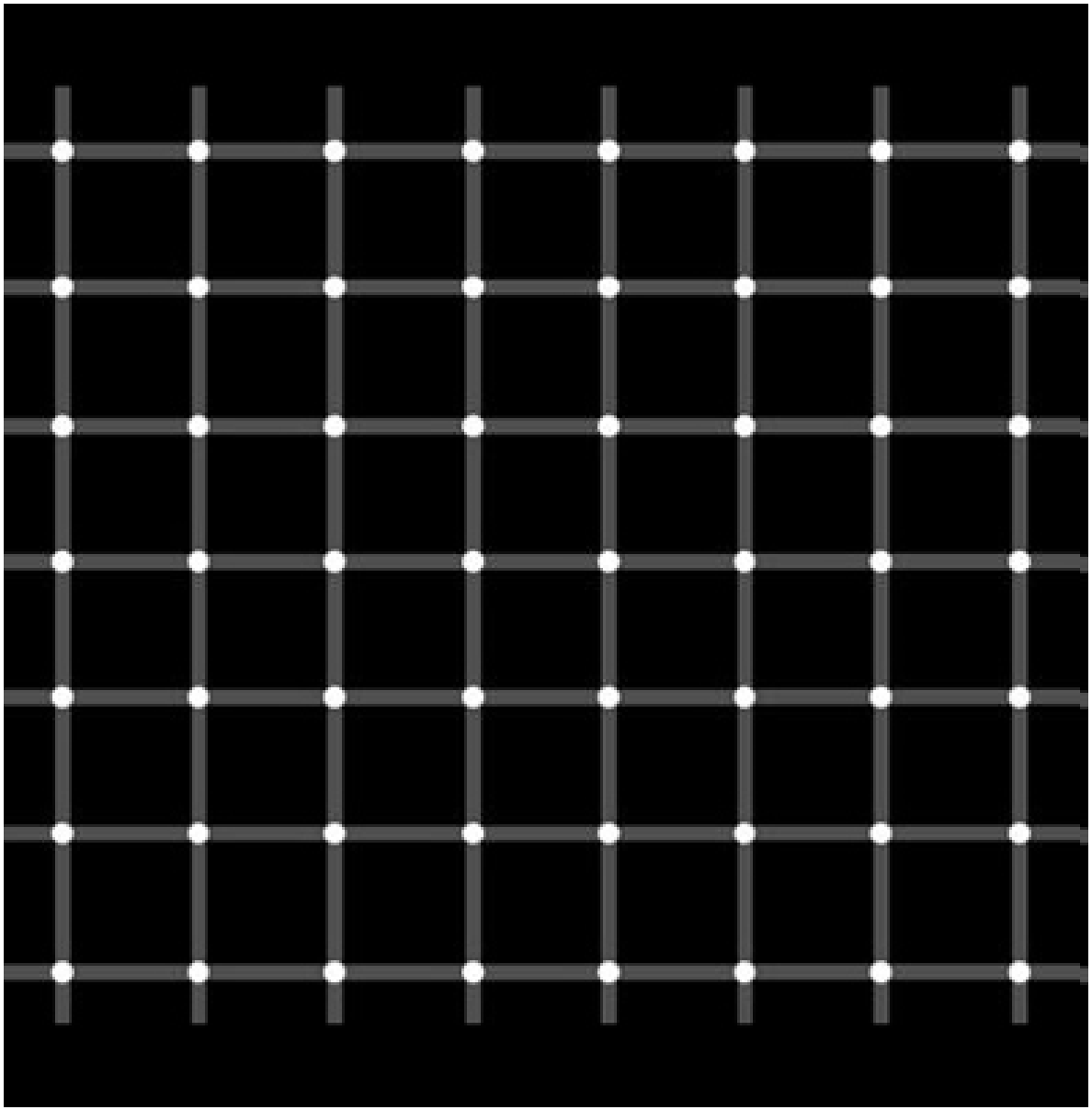
$\nabla^2 h_\sigma(u,v)$

Spatial



Temporal

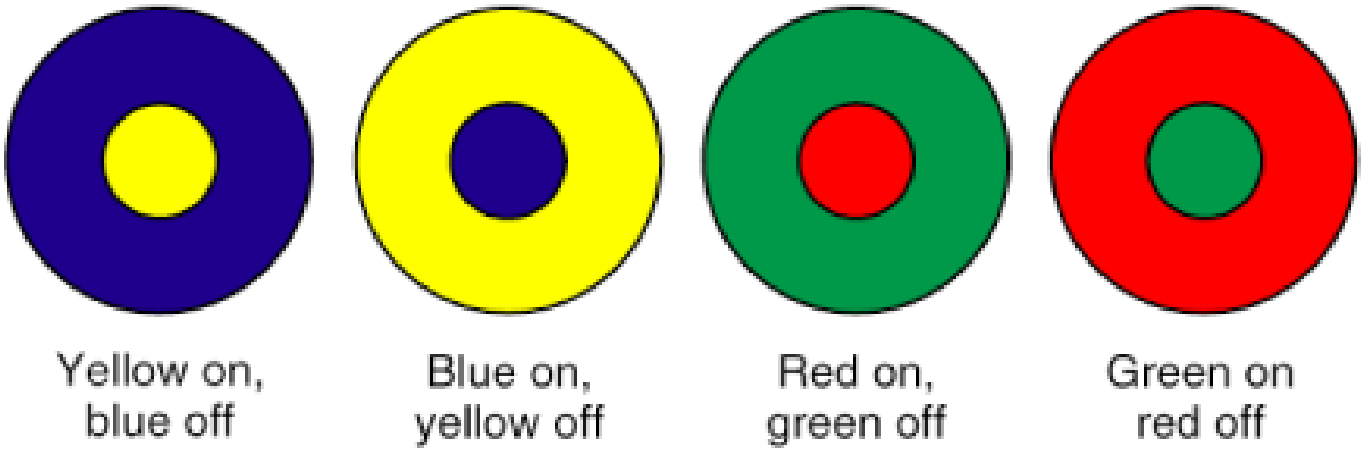
Your retinal filters at work



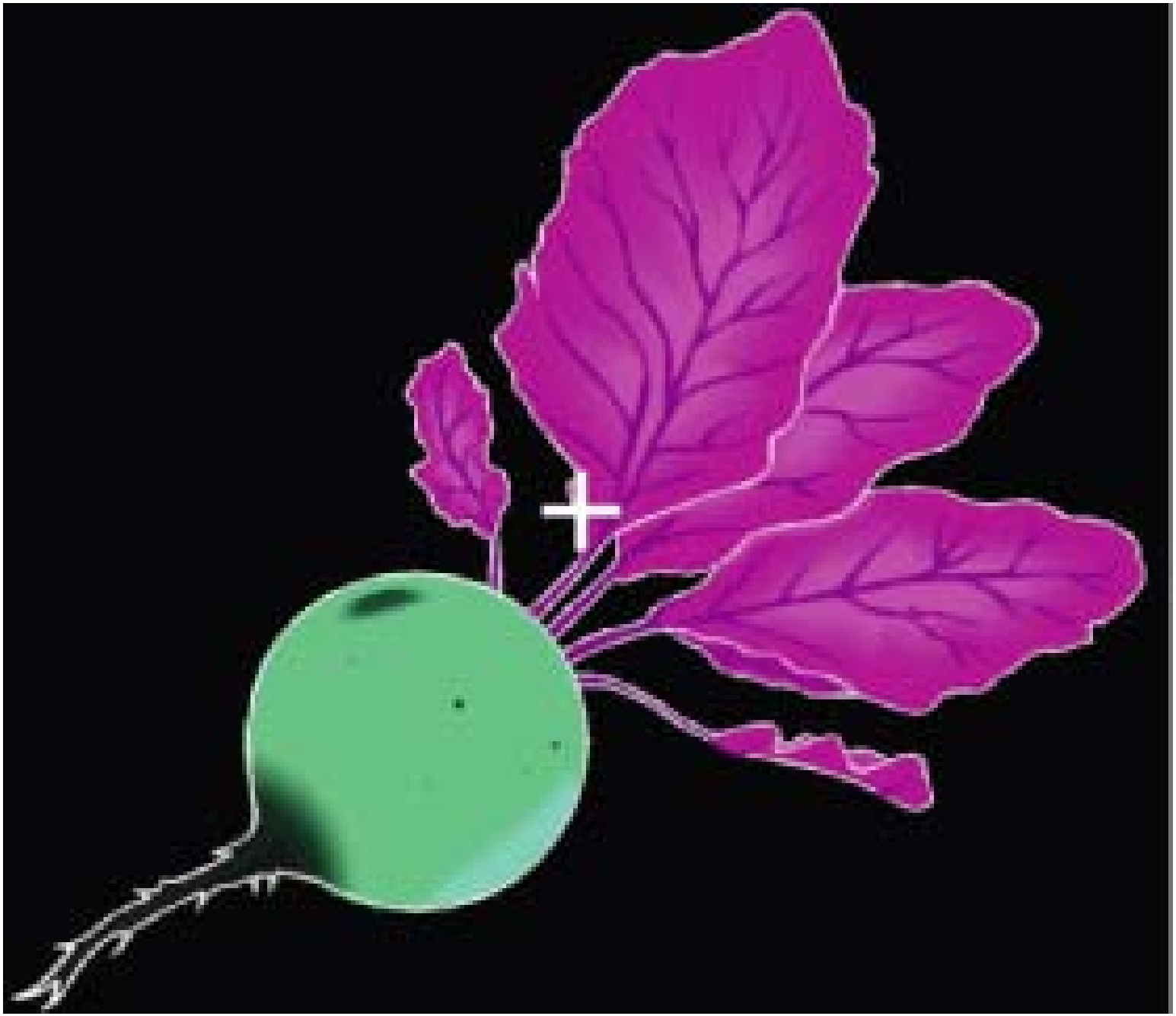
Black dots or white dots?

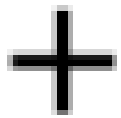
Retina also takes derivatives in color space!

"Color-opponent" processing

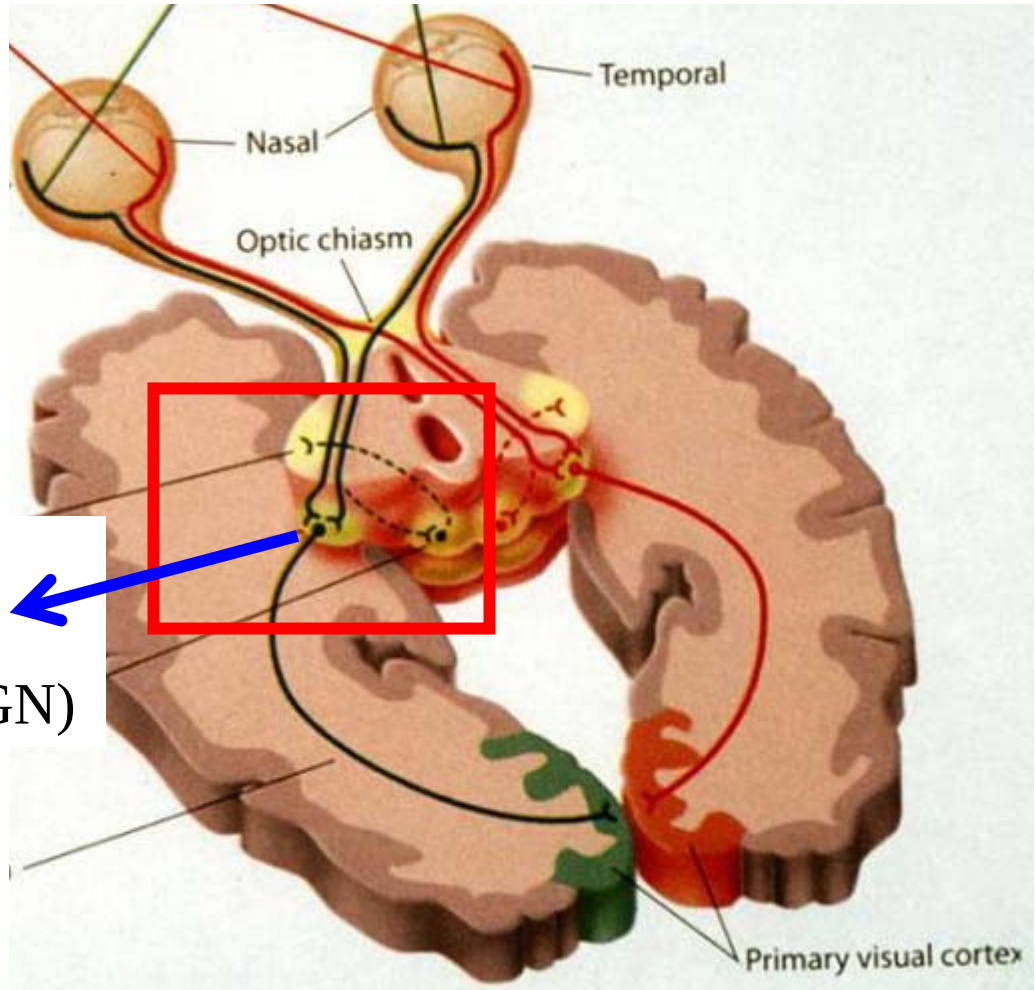


A visual consequence of this:
Negative afterimage: An image is seen after a portion of the retina is exposed to an intense visual stimulus (colors complimentary to those of stimulus)





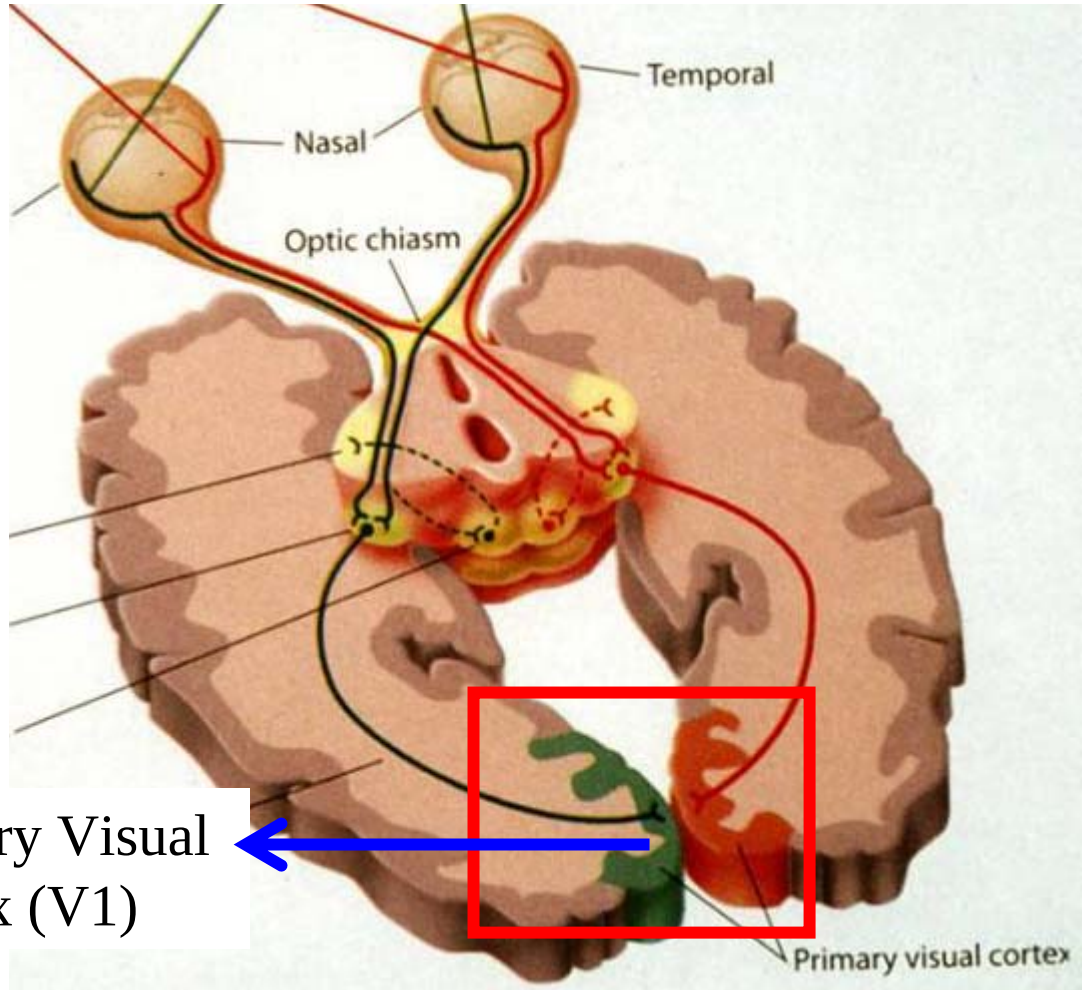
The Visual Pathway: LGN



Lateral
Geniculate
Nucleus (LGN)

LGN receptive fields similar to retinal (center-surround, on-off)
Thought to be a relay but receives massive feedback from cortex

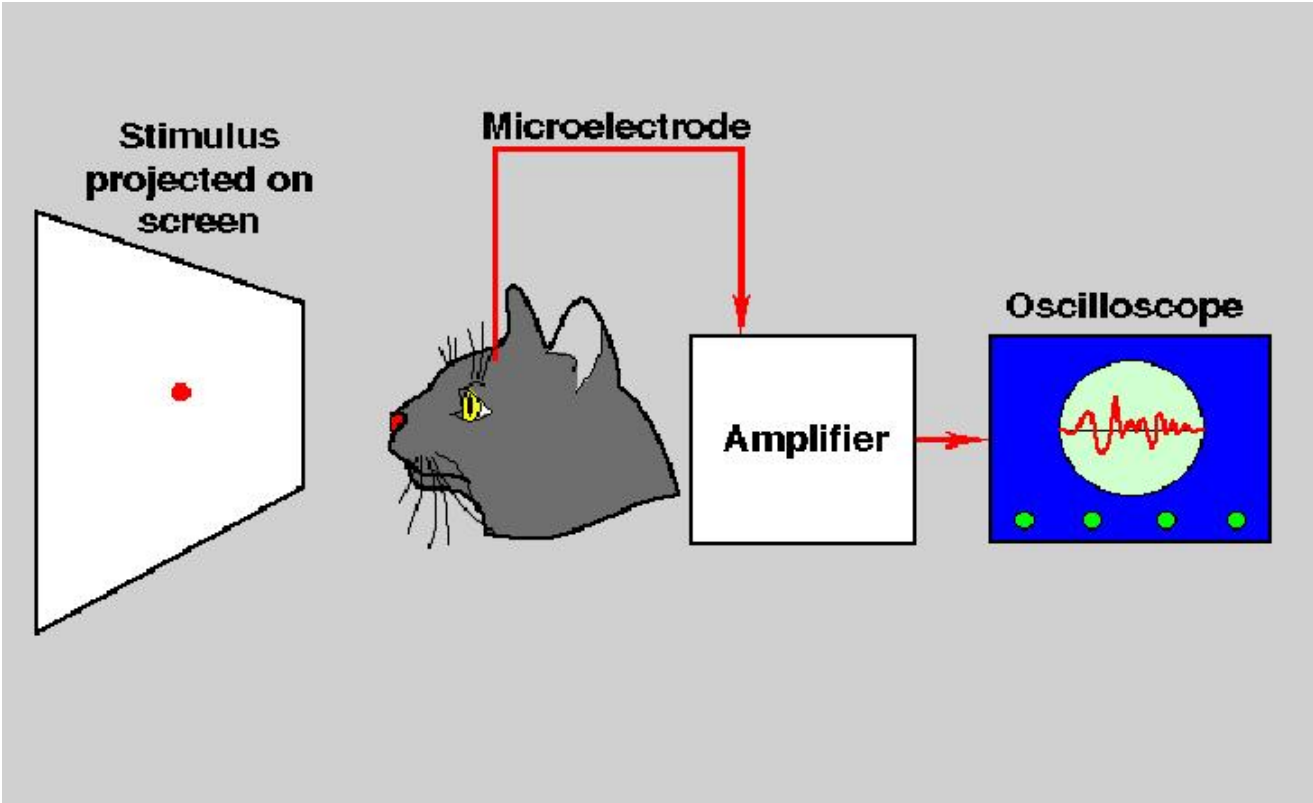
The Visual Pathway: V1



Primary Visual Cortex (V1)

A tale of two receptive fields

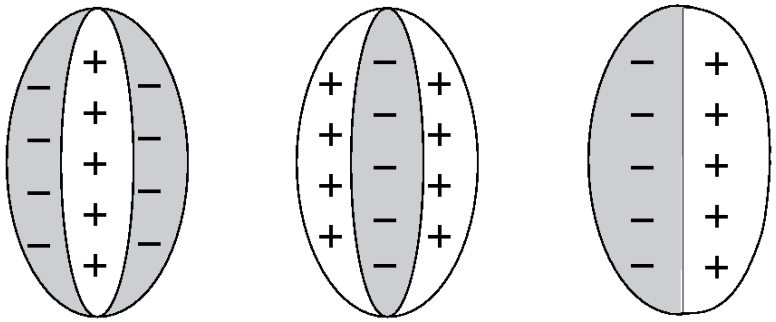
David Hubel and Torsten Wiesel were the first to characterize V1 receptive fields by recording from a cat viewing stimuli on a screen



In 1981, they received a Nobel prize in physiology and medicine for their work

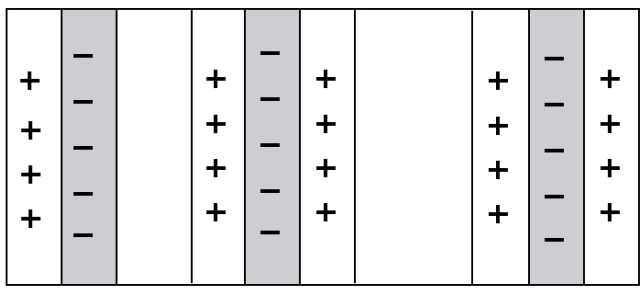
Simple and Complex Cell Receptive Fields

Receptive fields



"Bar" detectors "Edge" detector

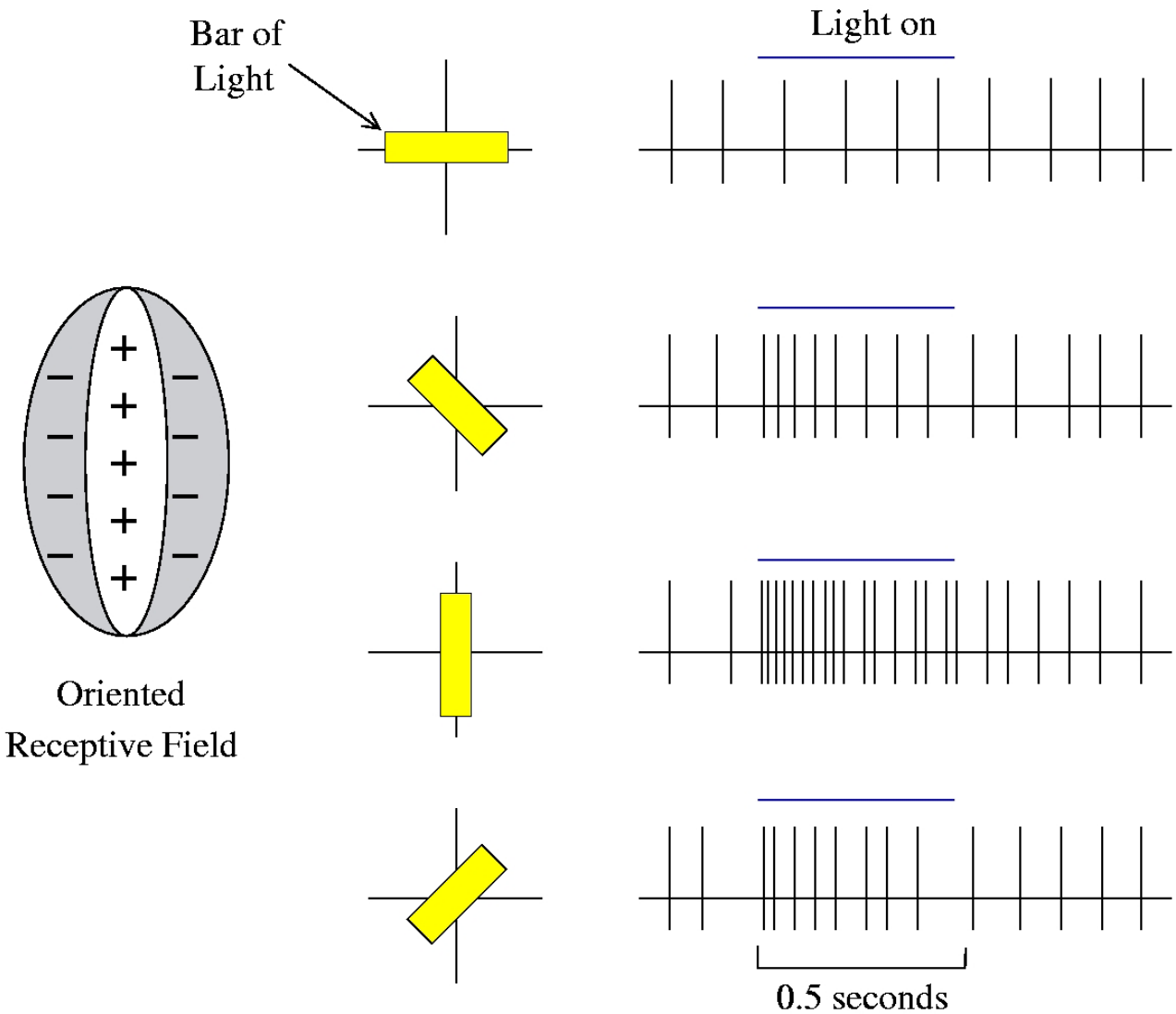
Simple cells:
Detect oriented bars and edges at a specific location



Position-invariant "bar" detector

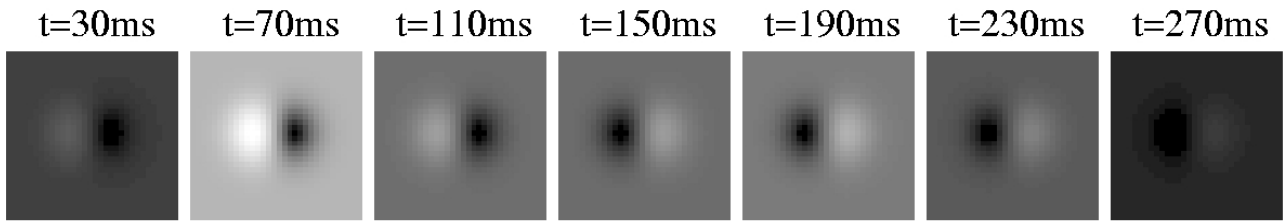
Complex cells:
Sensitive to orientation but invariant to position

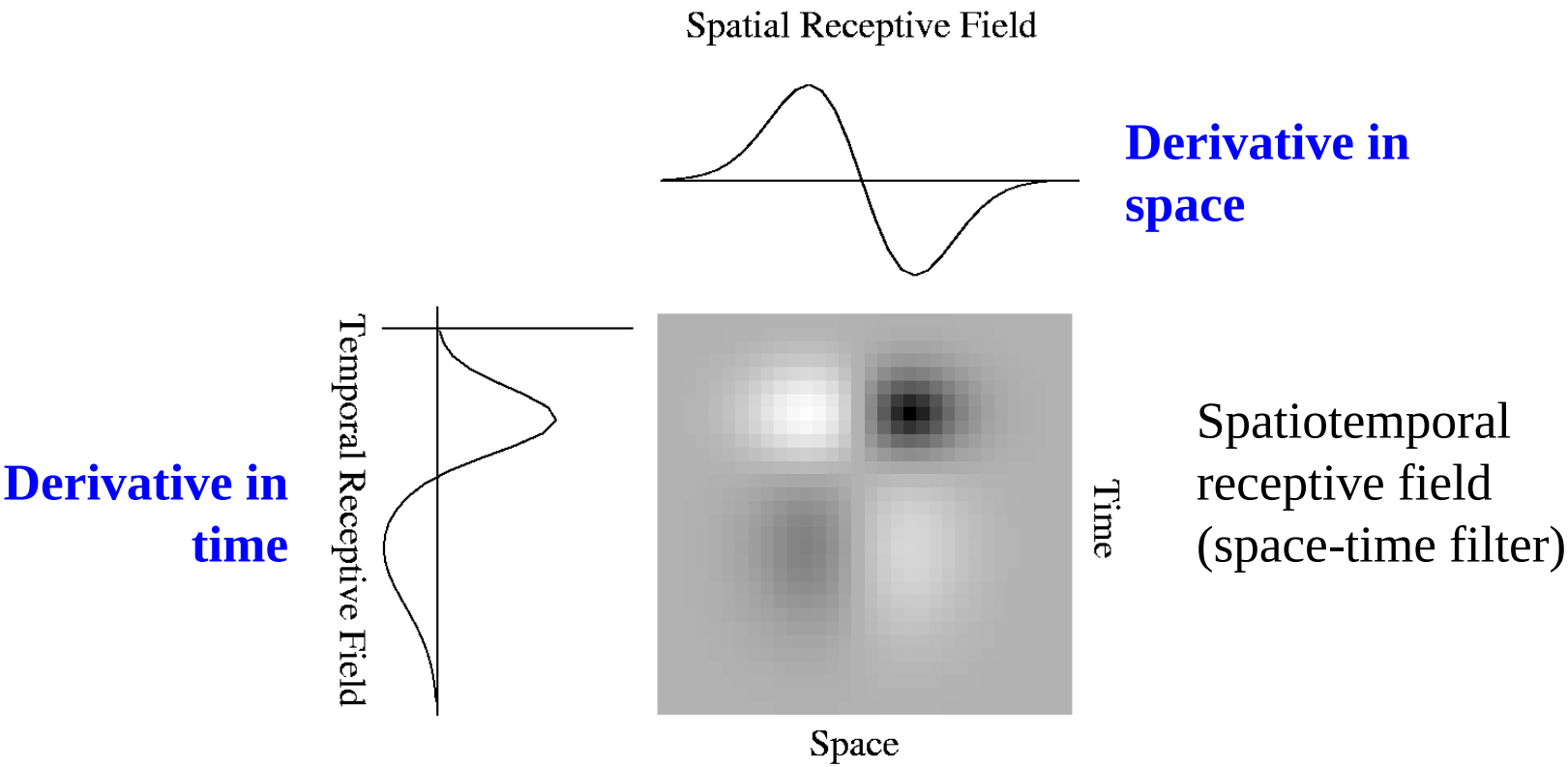
Orientation selectivity of a simple cell



Cortical cells compute derivatives too!
(but spatial derivative is orientation-sensitive)

Edge-detecting simple cell response over time

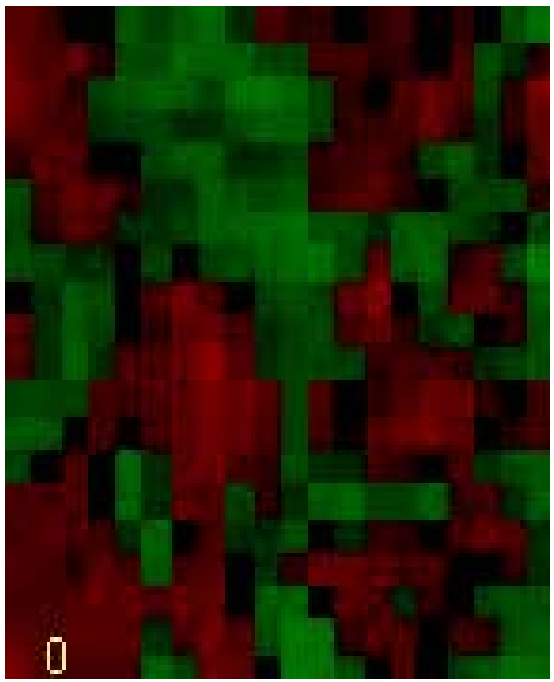




Spatiotemporal receptive field (space-time filter)

Direction selectivity of some cortical cells

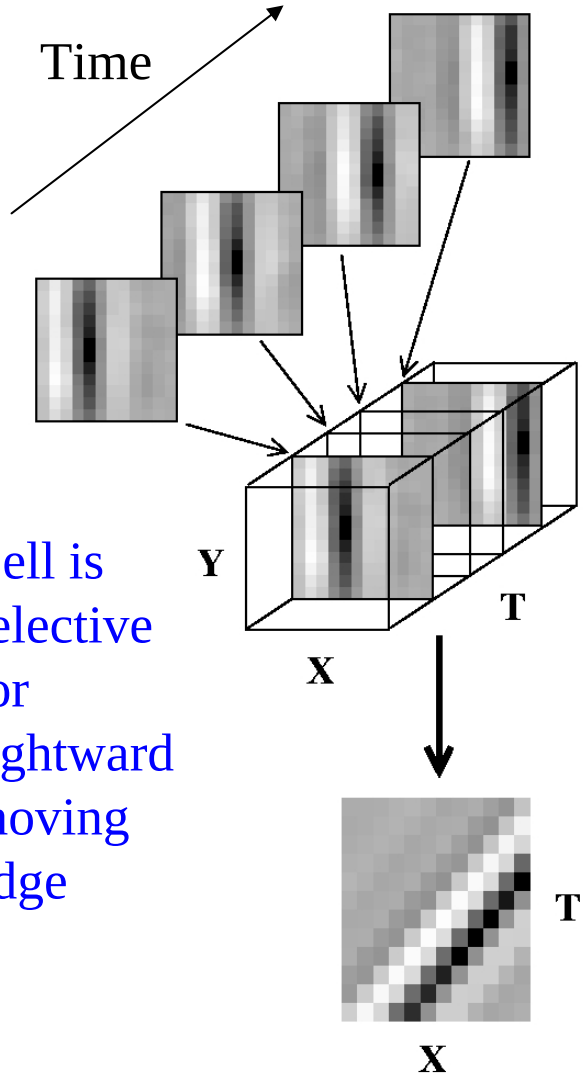
Spatial Receptive
Field for T = 0-300 ms



Space (Y)

Space (X)

(Copyright 1995, Izumi Ohzawa)



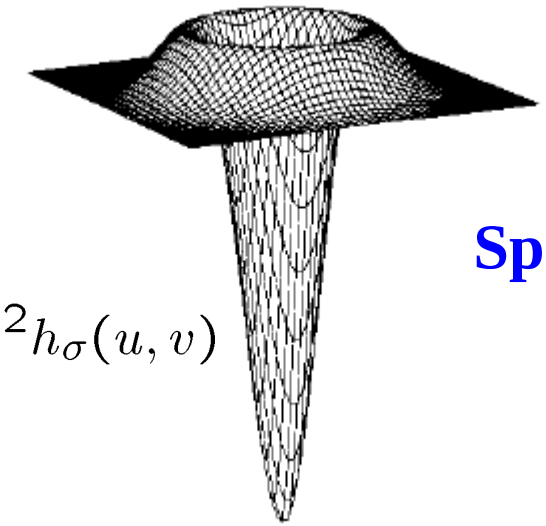
Cell is selective for rightward moving edge

(Oriented derivative in X-T space!)

Why derivatives: Predictive coding hypothesis

- Derivatives implement predictive coding in space, time,…
- **Predictive coding in space**: Use neighboring pixels to predict center pixel, signal only the error
- **Predictive coding in time**: Use past pixel values to predict next pixel value, signal only the error
- Reduces redundancy, allows efficient coding

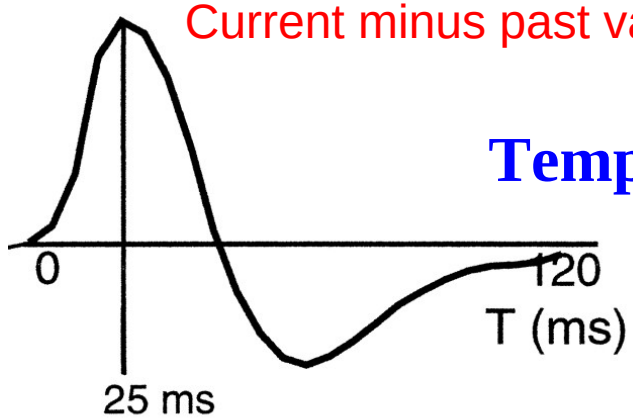
Surrounding pixels minus center



$\nabla^2 h_\sigma(u,v)$

Spatial

Current minus past values

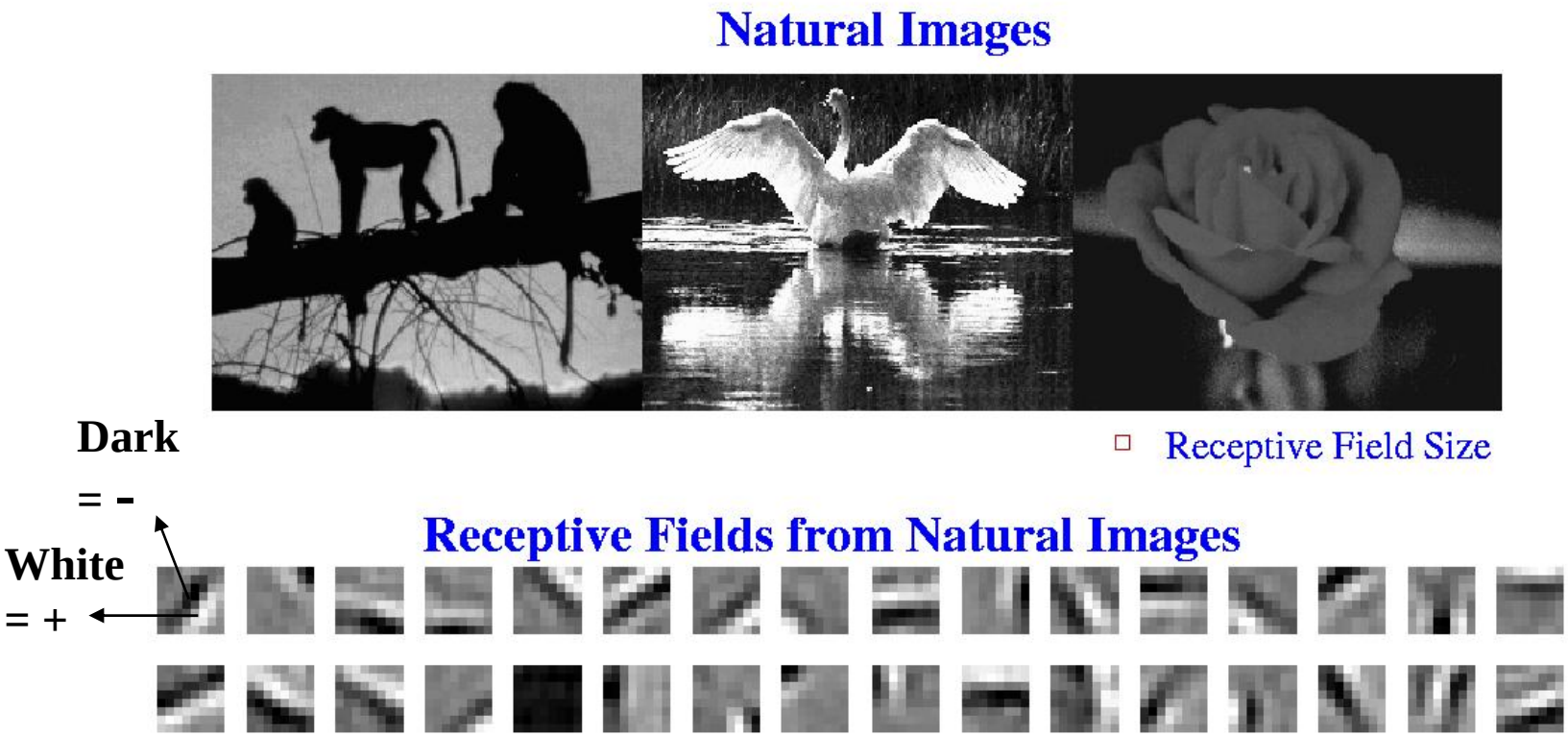


Temporal

See (Rao & Ballard, 1999a; 1999b) for more details

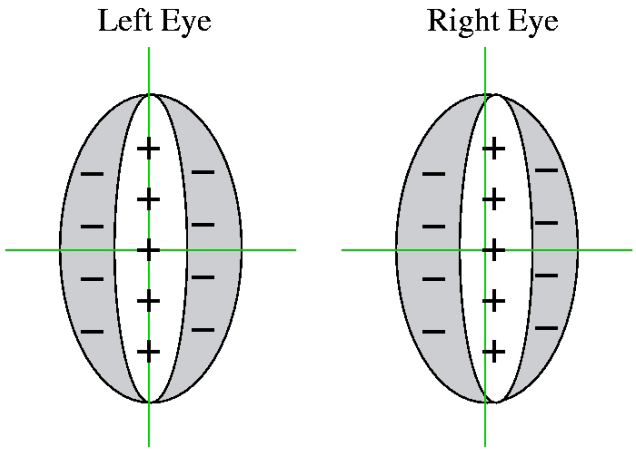
Why oriented filters?

- Hypothesis: Efficient coding of natural images
  - Goal: Learn a set of independent filters whose linear combination best represents natural images
  - Can show that the optimal set of such filters are oriented and localized to specific regions of the image

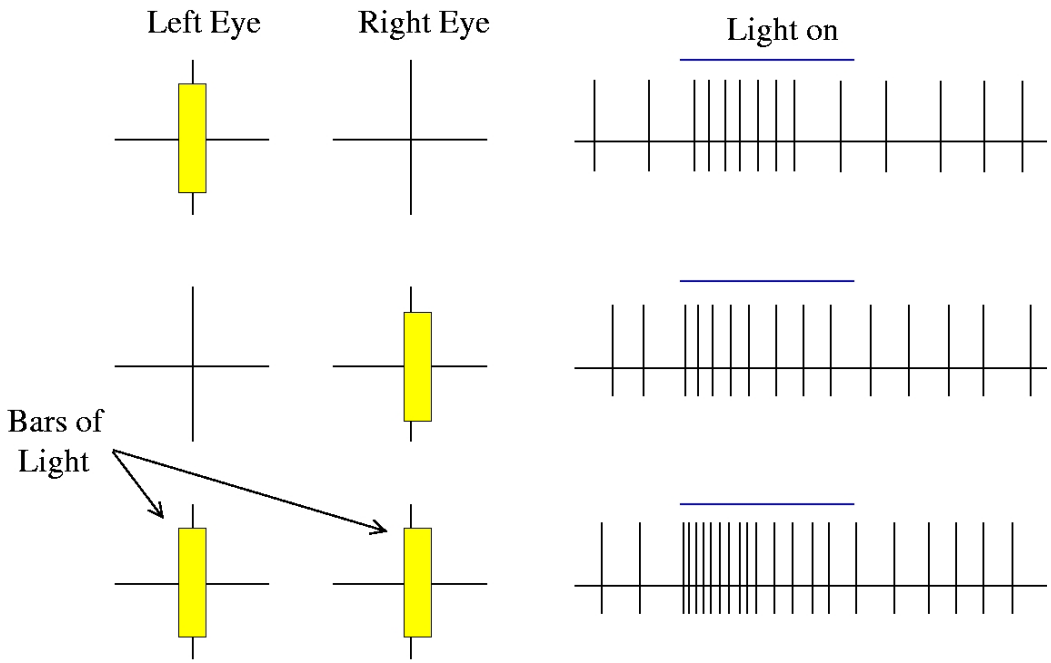


See (Olshausen & Field, 1996; Rao & Ballard, 1999) for more details

Depth selective cells in V1

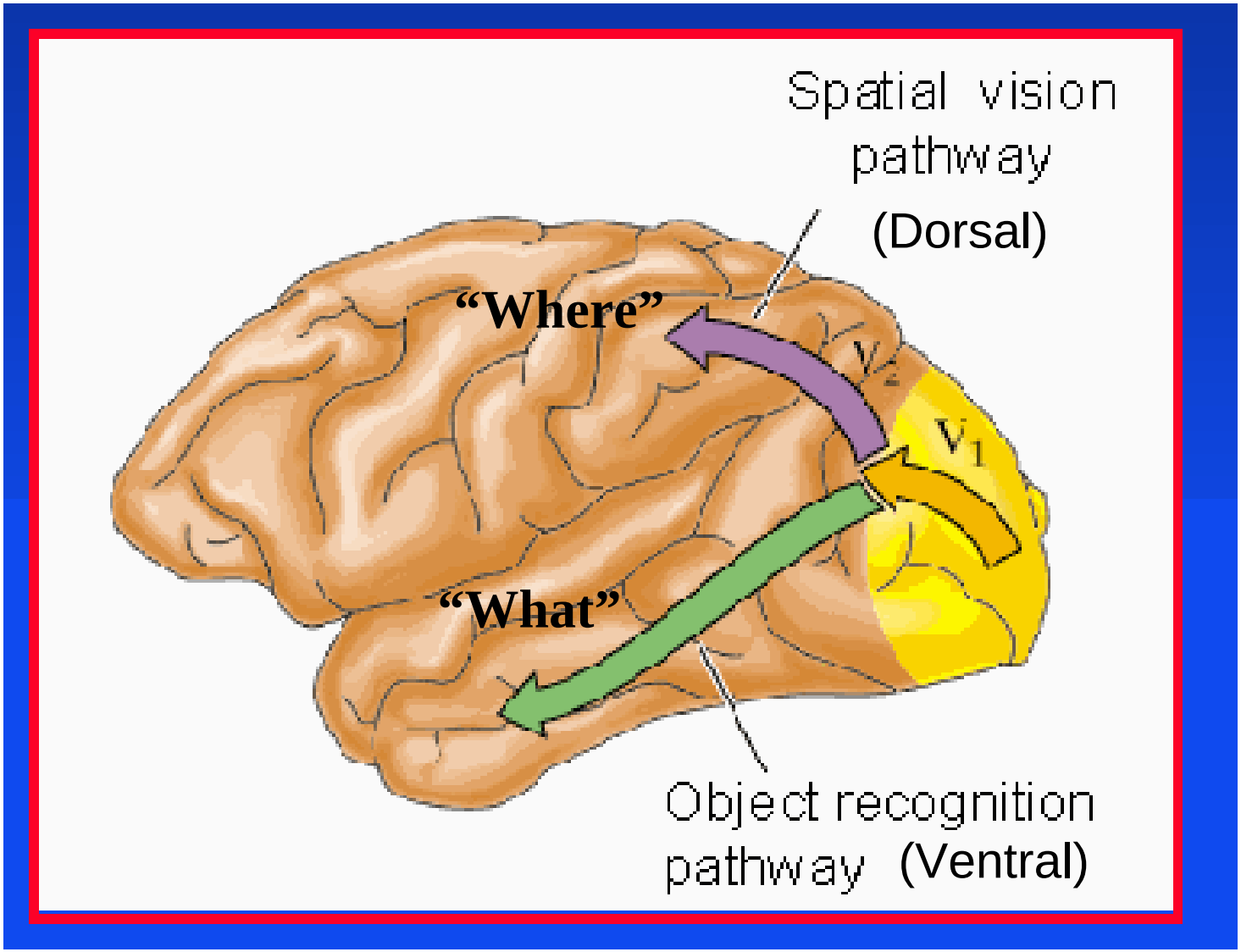


Binocular receptive fields: RF for right eye is slightly shifted to the right relative to left eye

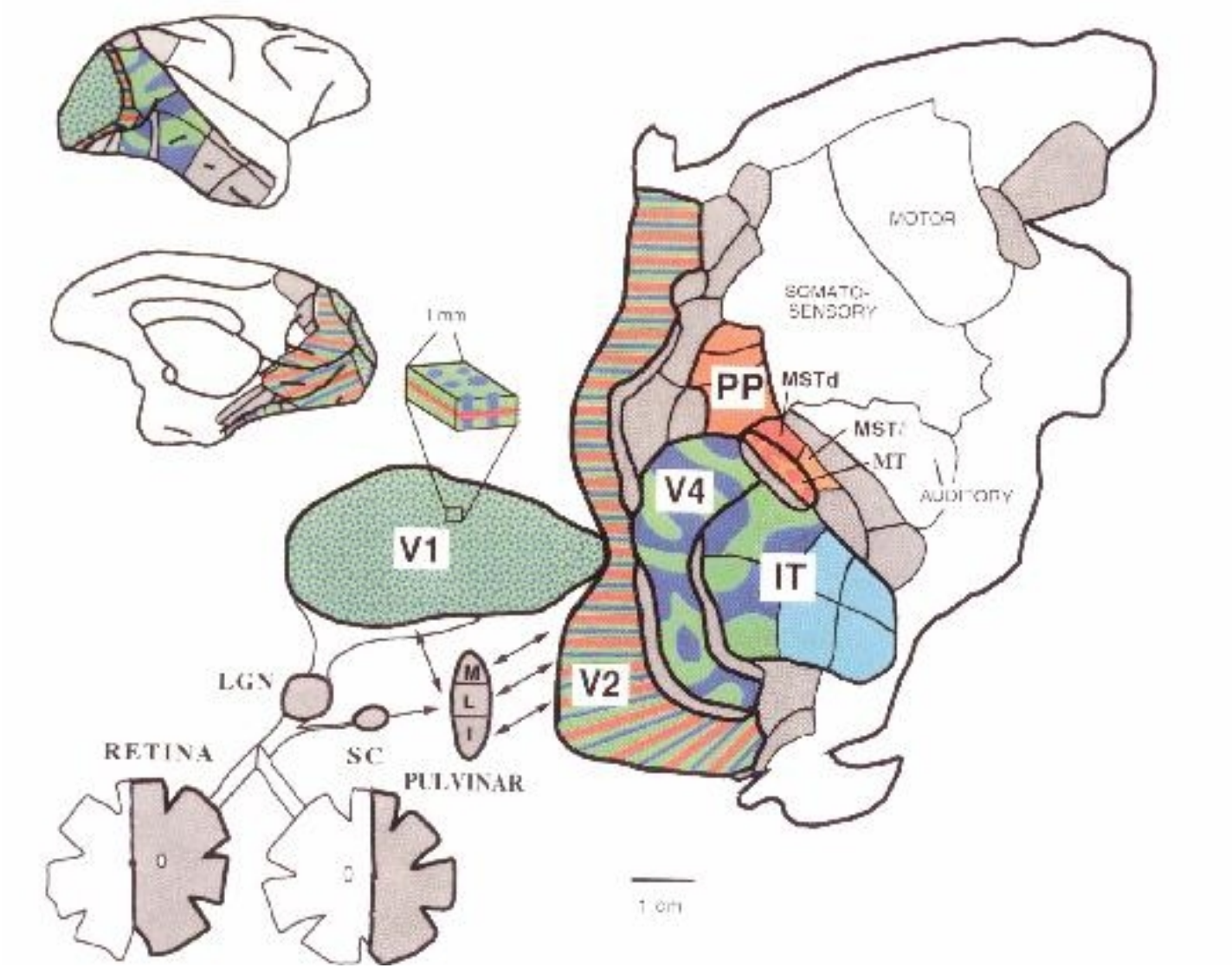


Cell is selective for vertical bars **at a particular depth** in the visual field

Dorsal and Ventral Pathways in the Visual Cortex



Visual Cortical Areas

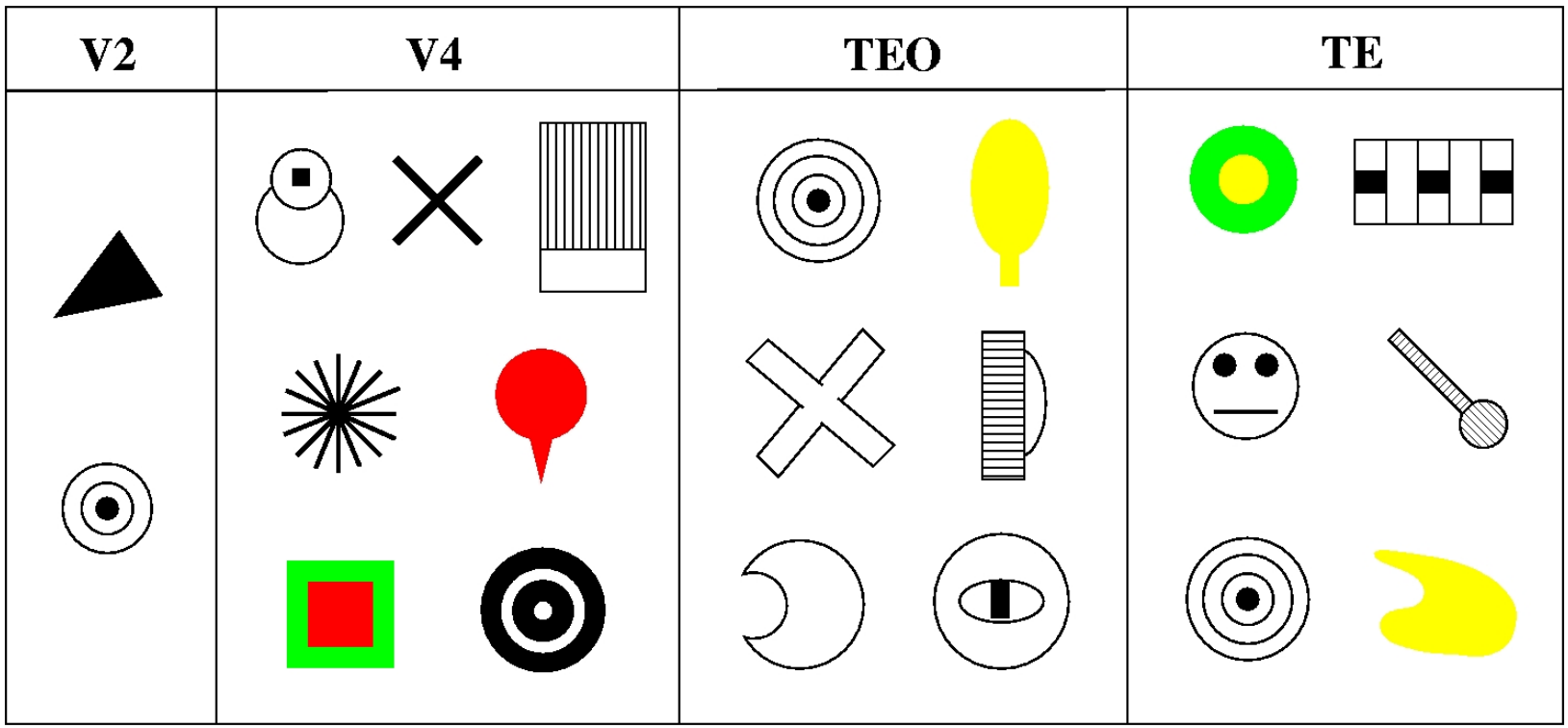


The Visual Cortex is Hierarchically Organized

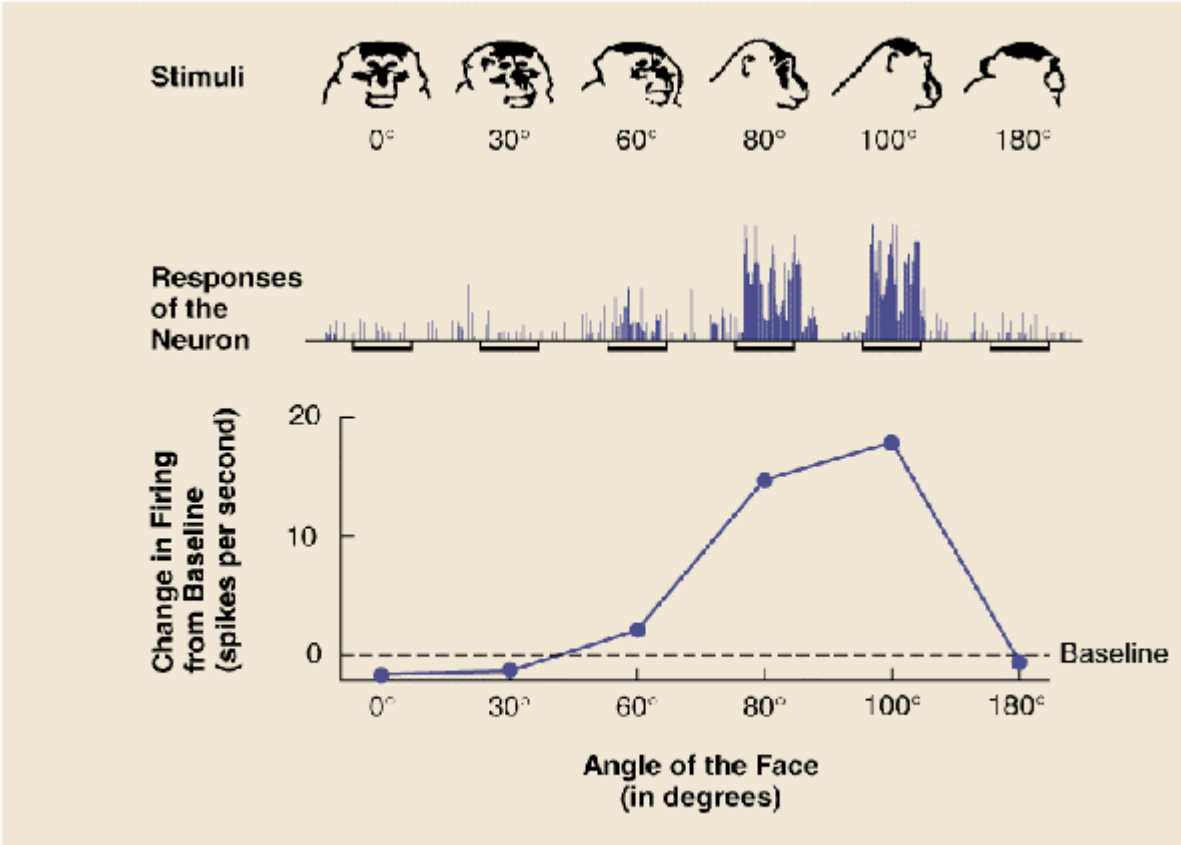
"Object" Pathway: V1 → V2 → V4 → TEO → TE

Cells respond to more and more complex stimuli as we go higher up

Example Receptive Fields



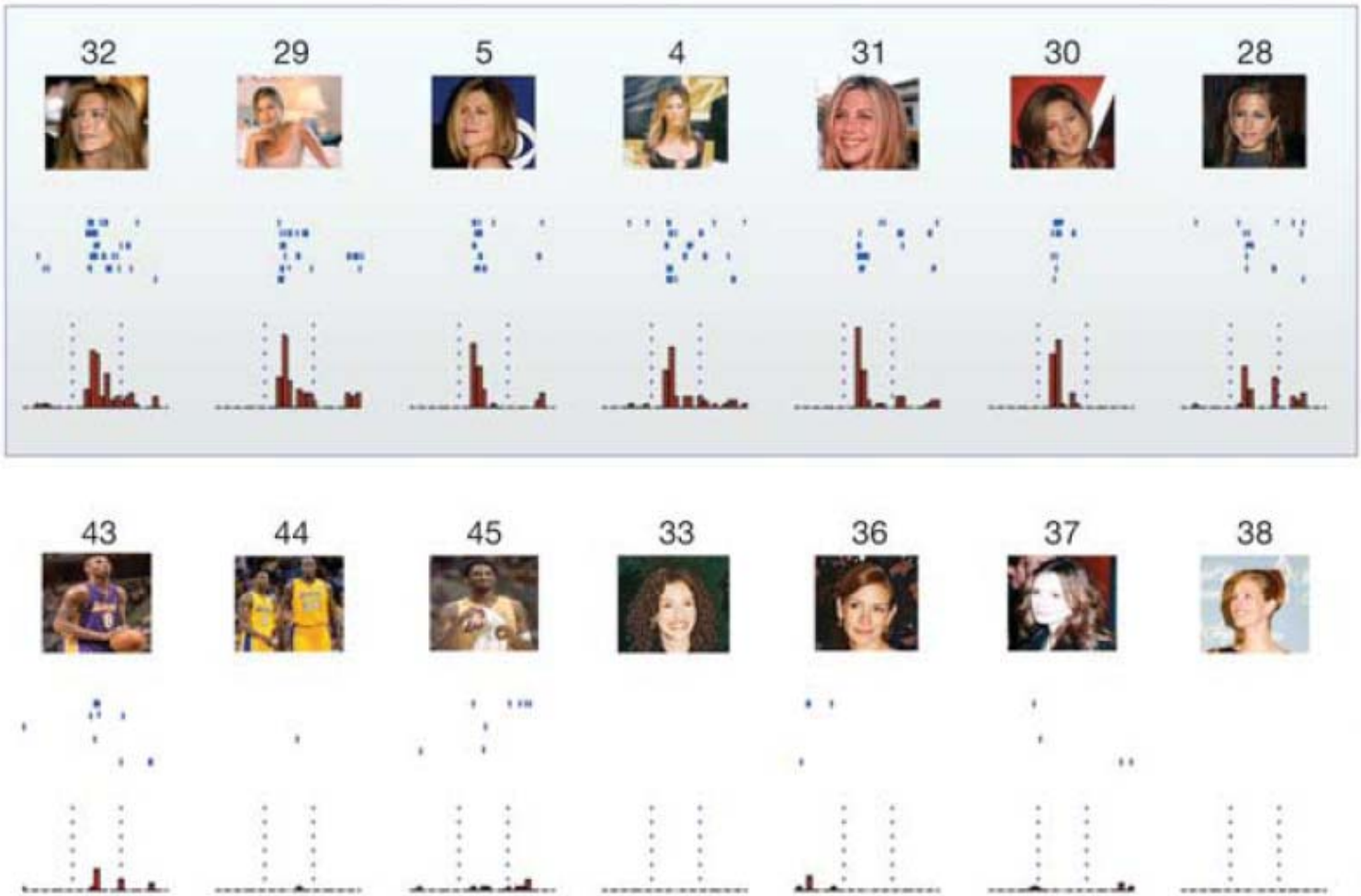
Example: Face selective cell in a monkey



Cell in area IT responds to profiles of monkey faces (some invariance to view changes)

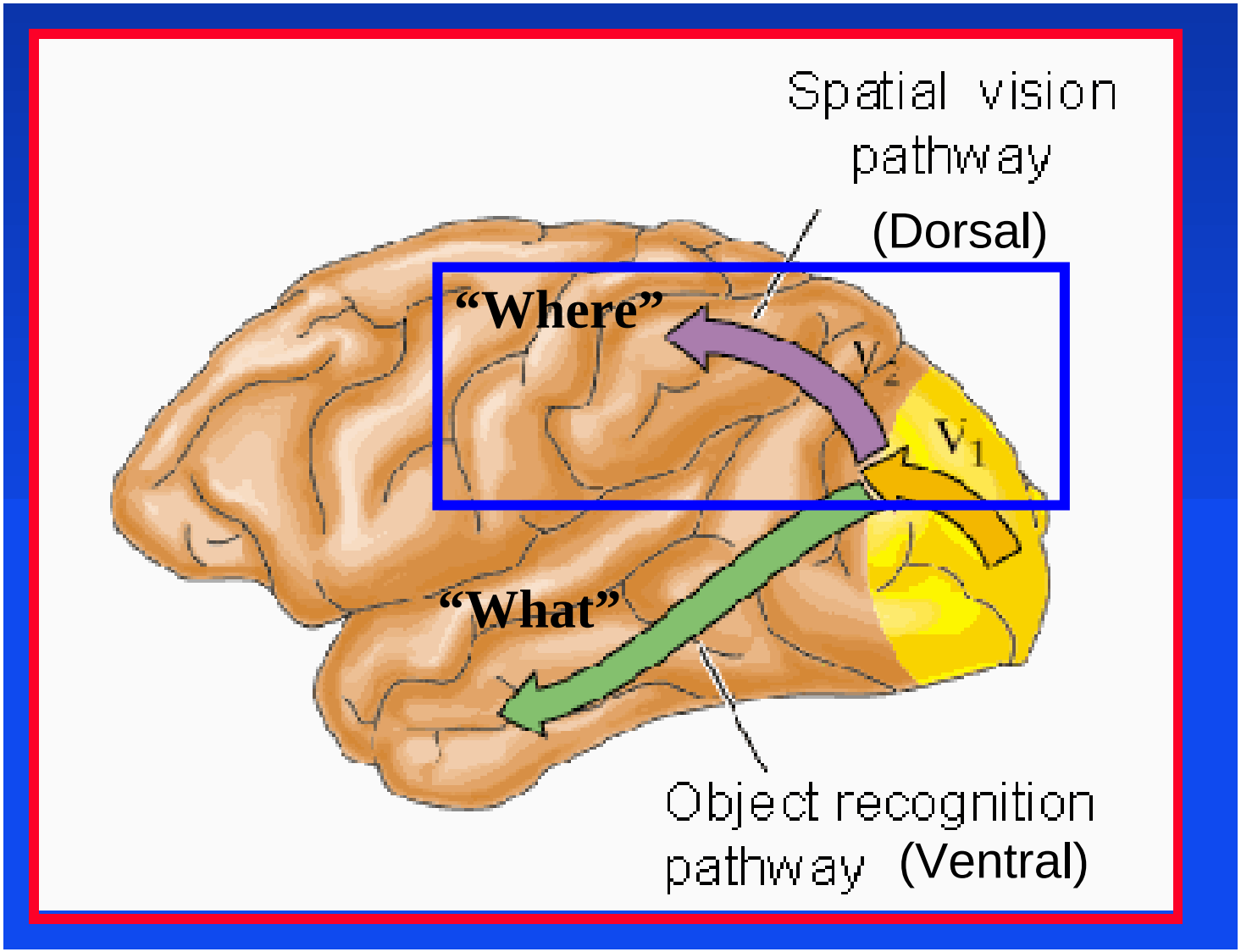
Source: Adapted from Gross et al., *Pattern Recognition Mechanisms*, p. 179-201. Berlin: Springer-Verlag 1985.

Example: “Jennifer Aniston cell” in a human



Cell in medial temporal lobe responded selectively to different images of JA
Other cells were found that responded to Bill Clinton, Halle Berry…
(Quiroga et al., 2005)

Dorsal and Ventral Pathways in the Visual Cortex



The "Where" Pathway

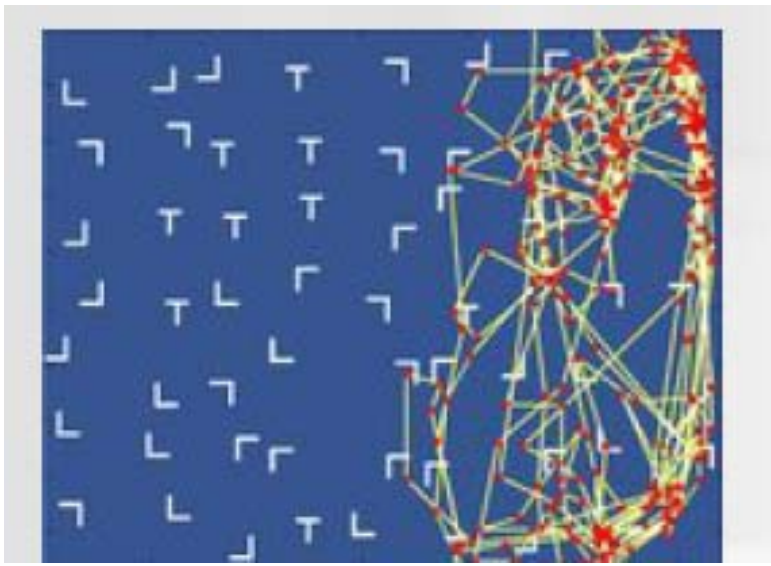
V1 → V2 →MT → MST → Posterior Parietal cortex

Cells respond to more and more complex forms of motion and spatial relationships

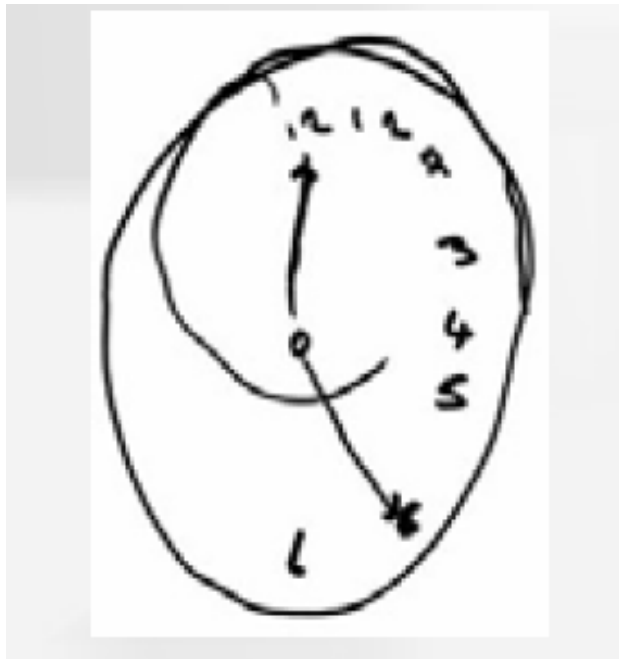
Damage to right parietal cortex may result in spatial hemi-neglect

Patient behaves as if the left part of the visual world doesn't exist

Eye movements only to right part of the screen

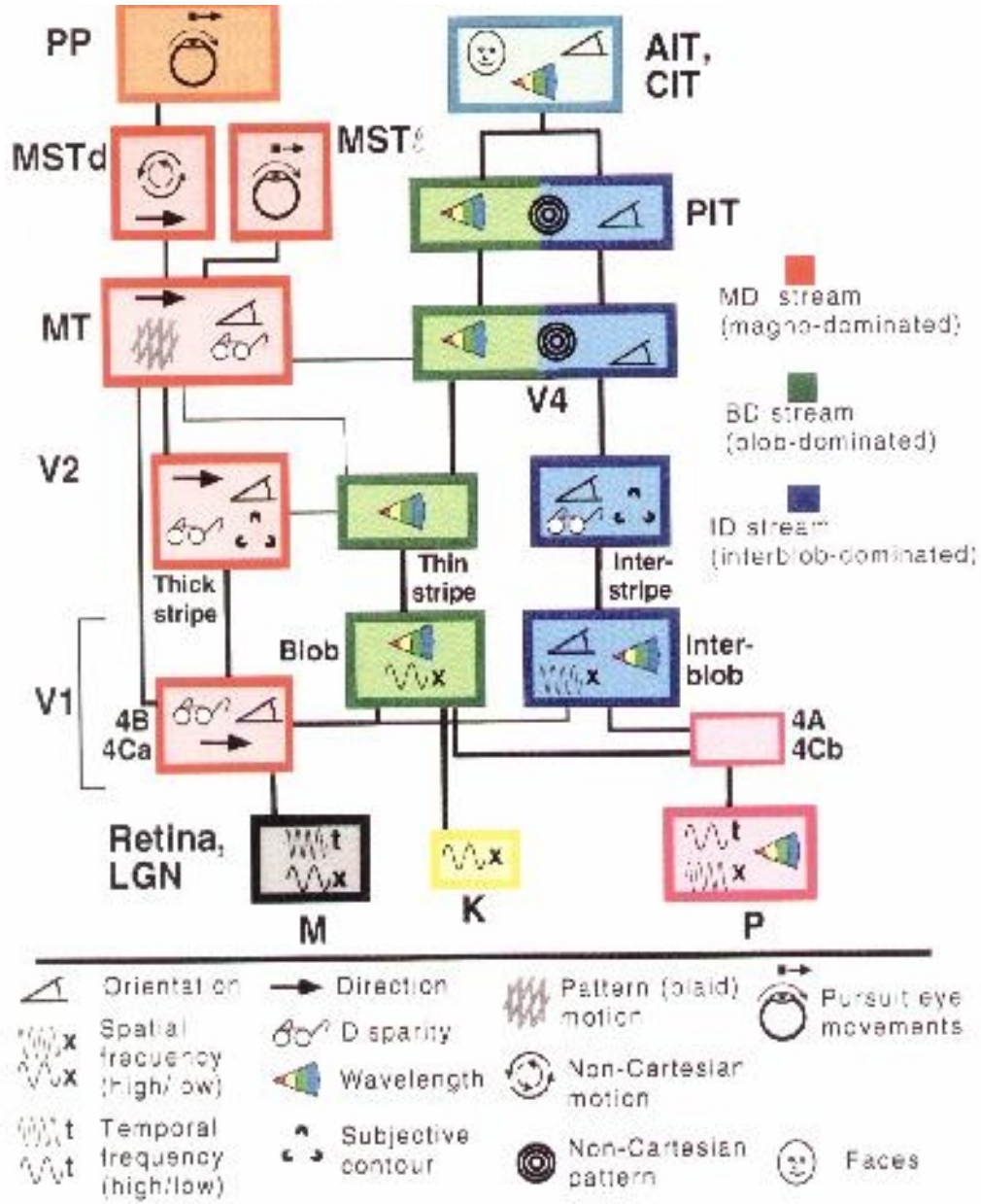


Only right side of clock drawn

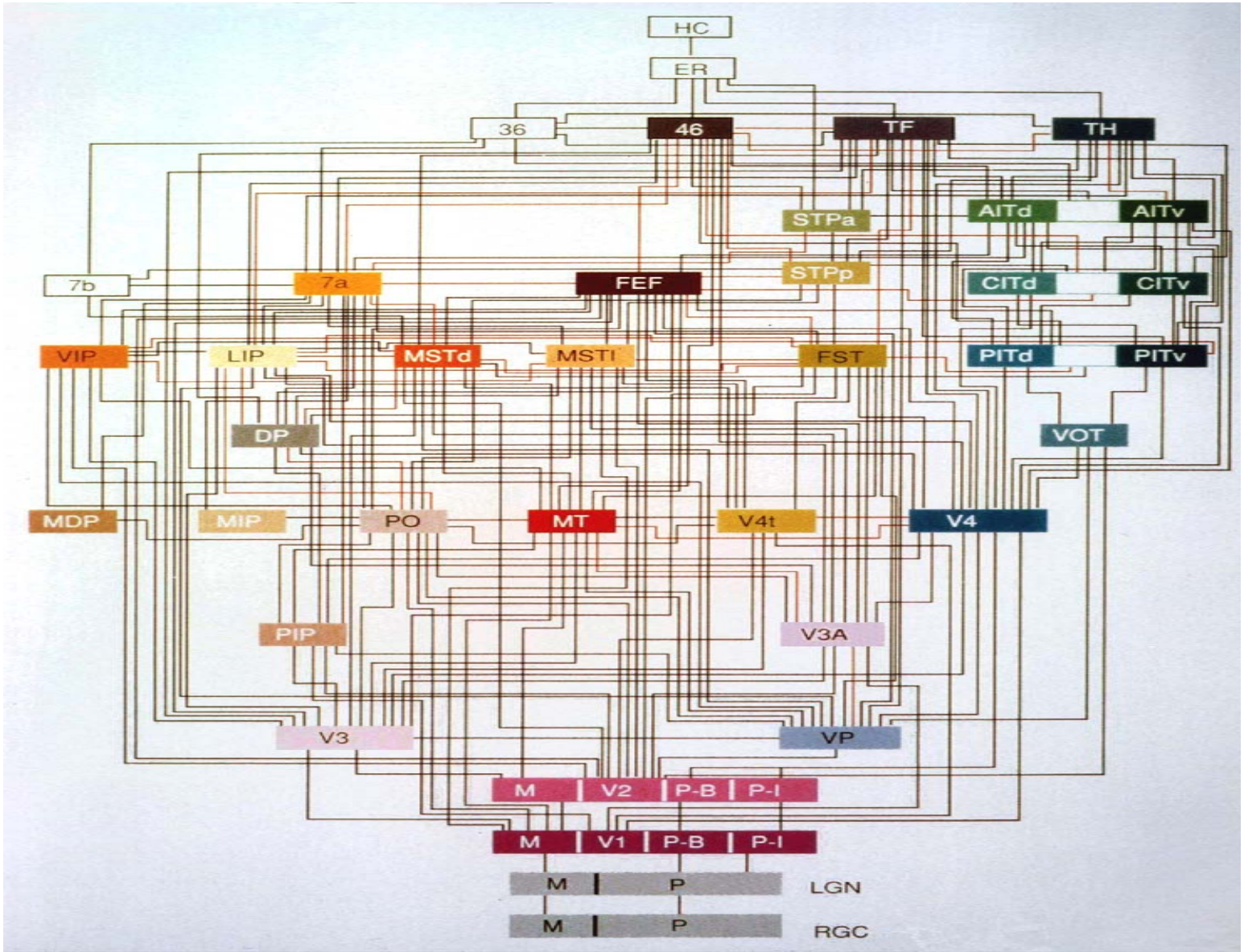


The Visual Processing Hierarchy

Where (motion, spatial relations) **What** (object properties, color)



The Real Connectivity Diagram

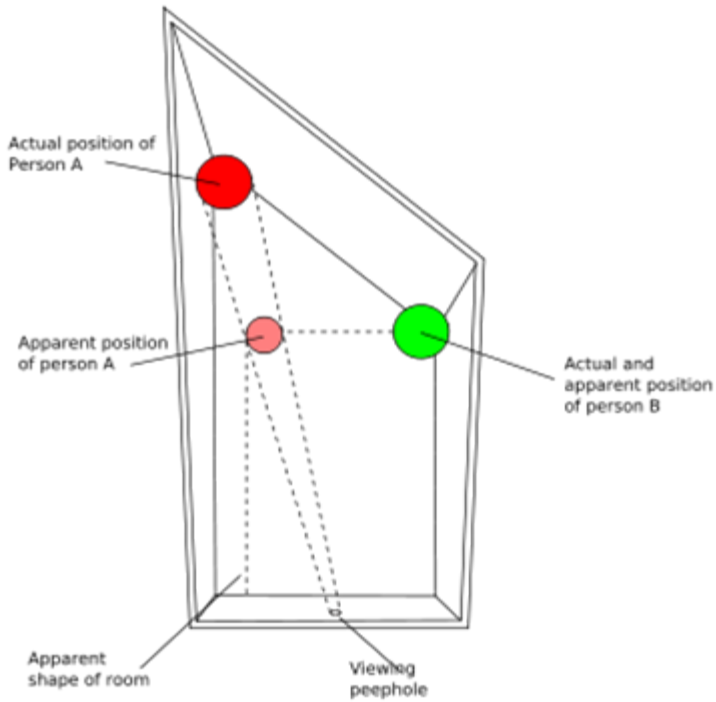


The visual system is optimized to process natural images (through evolution)

- Artificial, impoverished stimuli can lead to “illusions”
- Illusions can provide insights into the brain’s assumptions

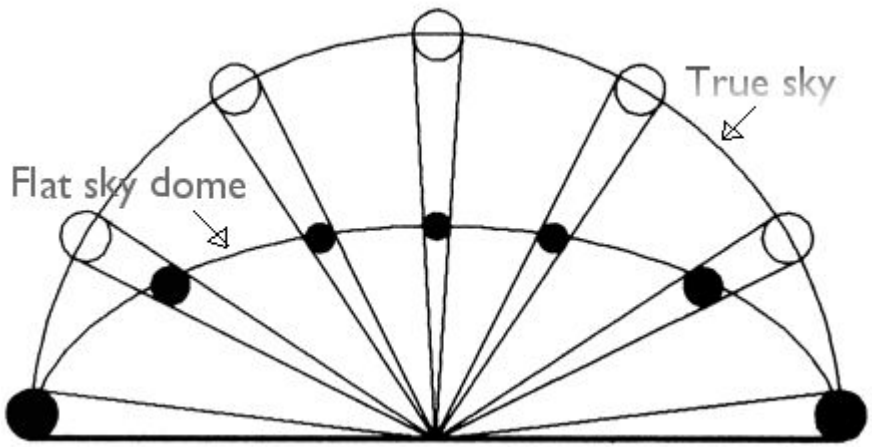
Perspective evidence about depth dominates knowledge of size

Ames room illusion



http://www.youtube.com/watch?v=Ttd0YjXF0no

Another Example: The moon illusion



Relative depth information from ground terrain near horizon overrides size constancy

Role of “Top-Down” Bias (Attention)

What is this image depicting?

Change Blindness

Something big is changing in this scene – what is it?

http://www.psych.ubc.ca/~rensink/flicker/download/

Attention is needed to perceive changes in scenes

Let’s do another one!

http://www.cogsci.uci.edu/~ddhoff/cbvenice.html

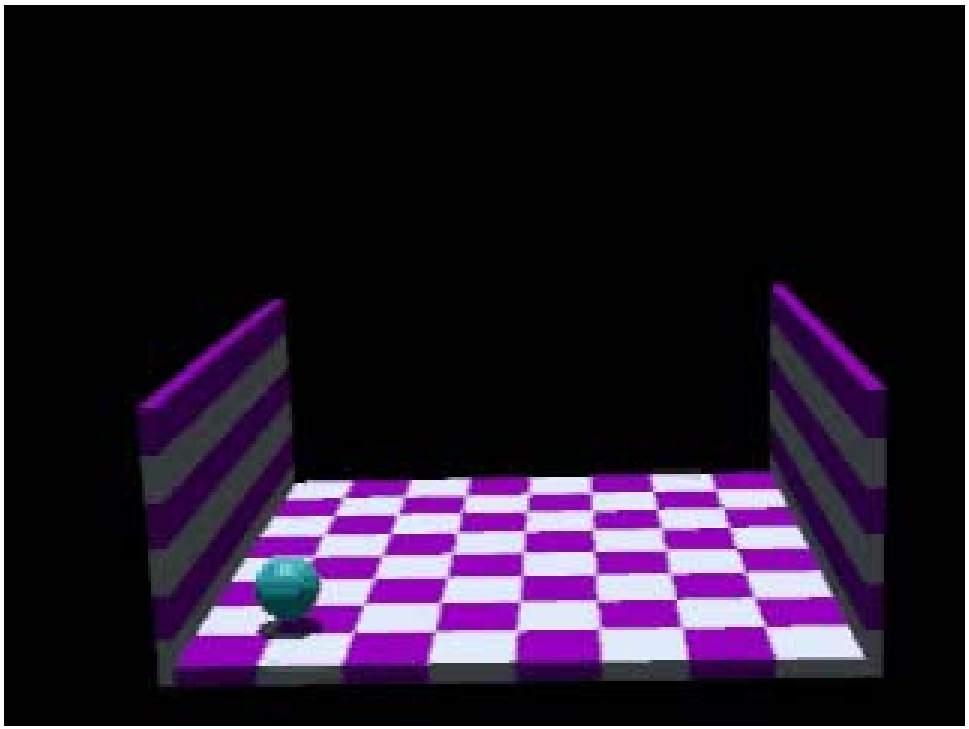
Human vision relies heavily on context

Sinha and Poggio, *Nature*, 1996

Human vision relies heavily on context

Sinha and Poggio, *Nature*, 1996

The role of shadows in scene interpretation



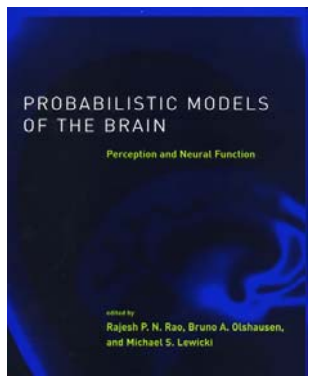
Trajectory of shadow influences interpretation of motion

(Kersten et al., 1996; 1997)

http://www.sandlotscience.com/Distortions/Ball_and_Shadow.htm

Summary and Recent Models

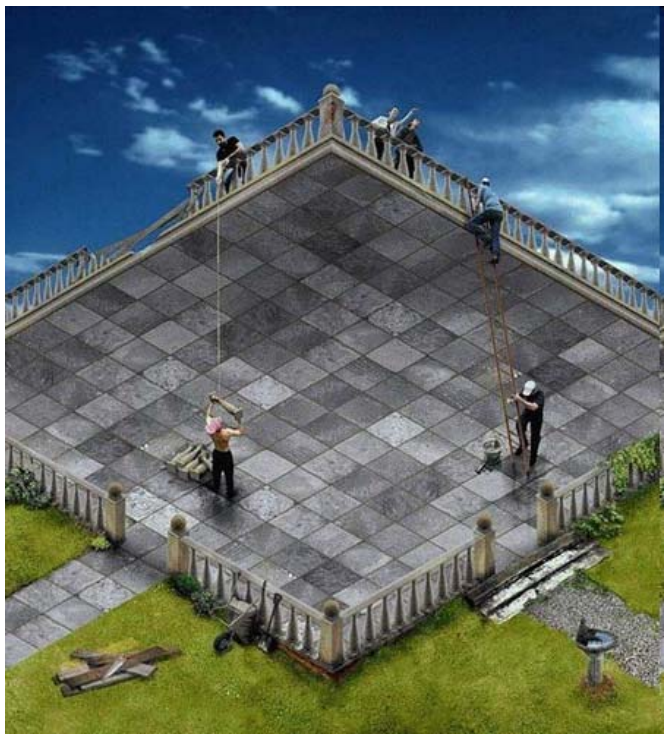
- The human visual system is faced with an ill-posed problem:
  - Ambiguity due to projection from 3D to 2D image
  - Uncertainty due to incomplete knowledge of the environment
  - Uncertainty due to noise in photoreceptors and neurons
- The visual system relies on a set of assumptions to solve this ill-posed problem
  - Assumptions presumably learned via evolution
  - Assumptions tailored for the natural visual world
  - Assumptions cause illusions/failures under impoverished conditions
- Recent models of visual perception rely on Bayesian principles
  - Perception as Bayesian inference
  - Uncertainty/ambiguity taken into account
  - Assumptions encoded as prior distributions
  - More details in recent books
    - Rao et al, 2002; Doya et al., 2007



Next Time: Pattern Recognition & Learning

Things to do:

- Work on Project 2
  - Sign up for panorama camera kit
- Vote on Project 1 Artifacts
- Read Chap. 4



http://www.blogiseverything.com/files/pics/optical_illusion1_small.jpg

("All is vanity" by C.A. Gilbert, 1892)