Human Visual System

Computer Vision I

CSE 252A

Lecture 18

Announcements

- Assignment 4 is due today, 11:59 PM
- Final exam is Dec 14, 7:00 PM-9:59 PM
- Please complete TA and course evaluations

Why should we study Biological Vision in a Computer Vision Course?

- Computer vision systems mostly operate under the same environmental constraints as biological systems
- Both systems exploit the same cues for interpreting scenes
- There is immense diversity in biological vision systems which can serve as models for machine systems
- It is easier to copy (or be inspired by) a working system than invent it from scratch

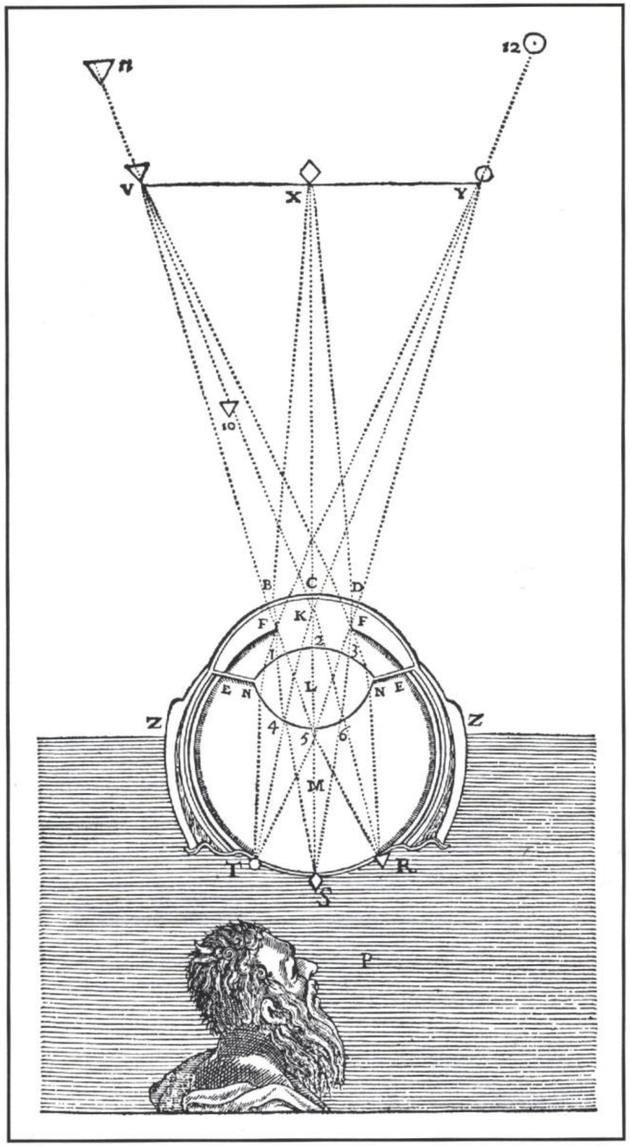


Figure 2.1 Image formation on the retina, according to Descartes. Descartes removed the eye of an ox, scraped its back to make it transparent, and then observed on it from a darkened room "not perhaps without wonder and pleasure" the inverted image of a scene (see [Pirenne 1967]). Such an experiment was performed originally by Scheiner, first with the eyes of sheep and oxen, and then, in 1625, with a human eye; the formation of an inverted retinal image was proposed by Kepler in 1604 (see [Polyak 1957]). (From Descartes's *La Dioptrique*, 1637.)

Kepler

Kepler, 1604

Eye as an optical instrument

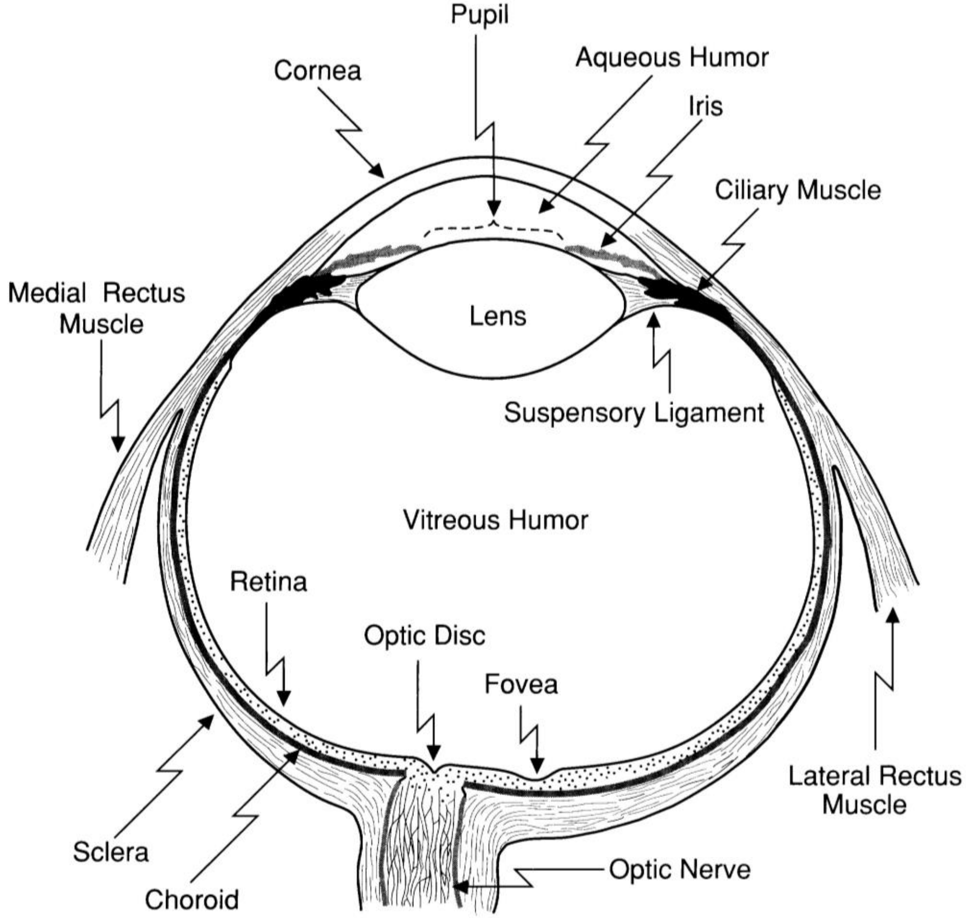
Image is inverted on retina

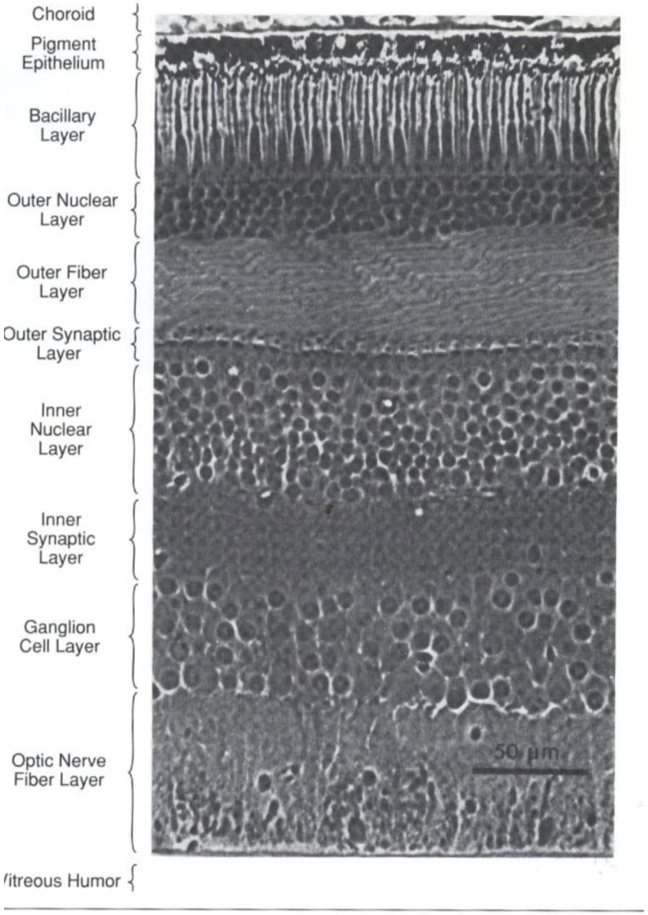
First such experiment by Scheiner, 1625

Ways to study human vision

1. Physiological
2. Phenomenological/Psychophysical
3. Cellular recordings
4. Functional MRI
5. Computational modeling

Physiological level





Ways to study human vision

1. Physiologically
2. Phenomenological/Psychophysical
3. Cellular recordings
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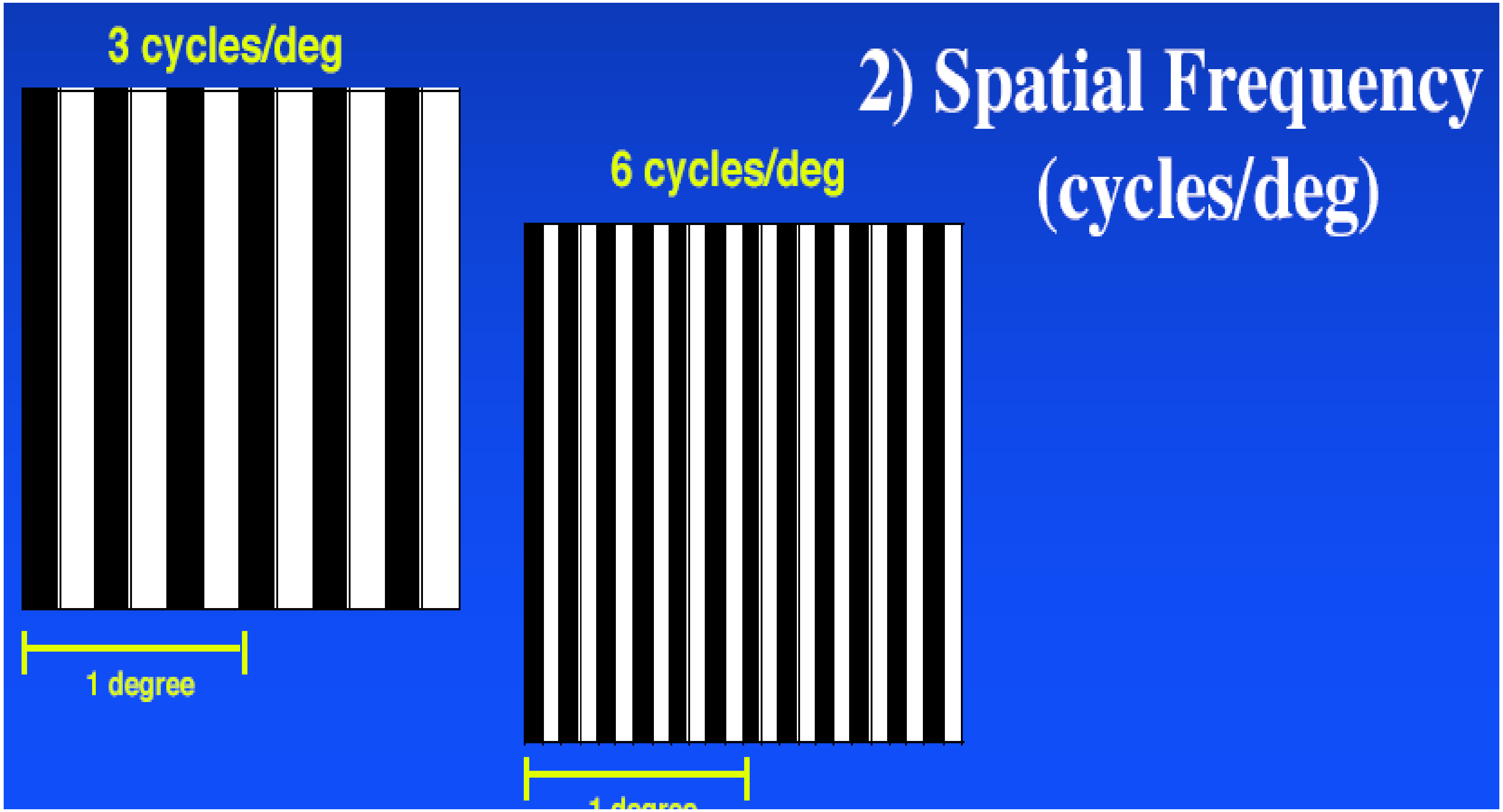
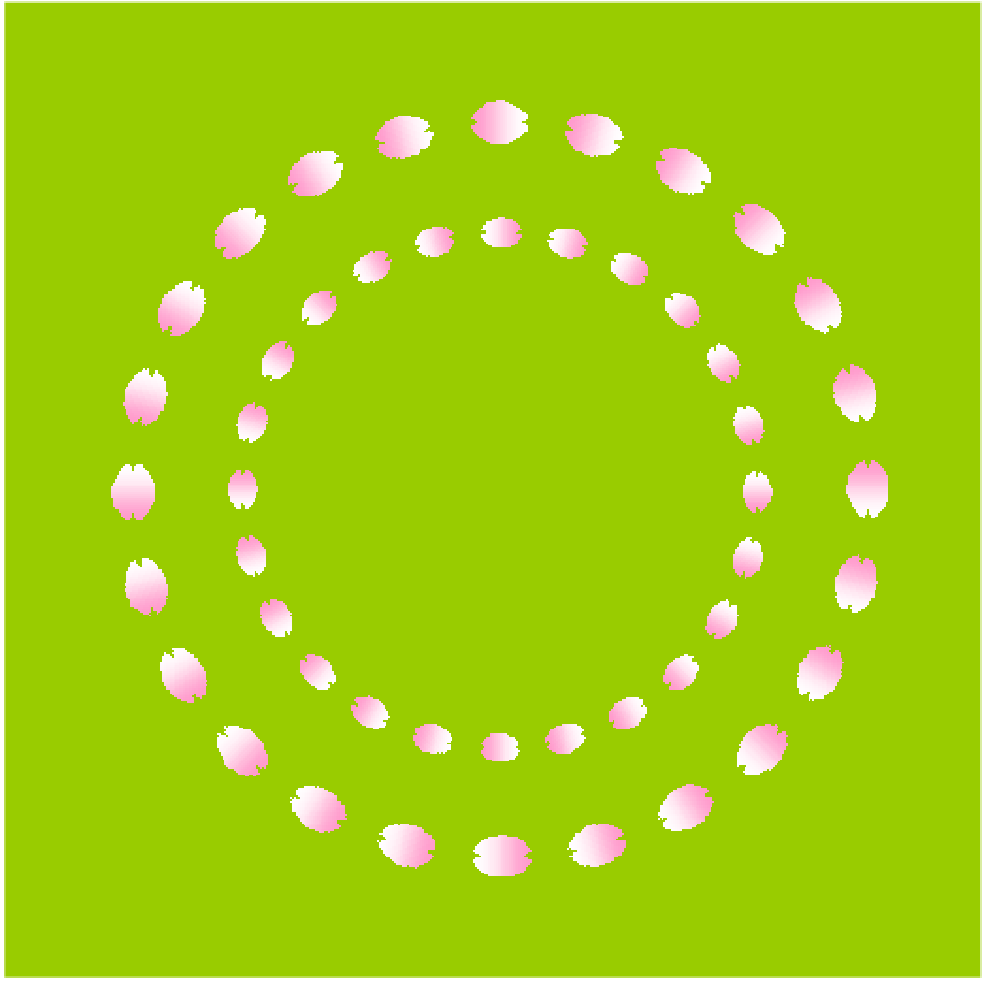
Psychophysical Testing of Subjects

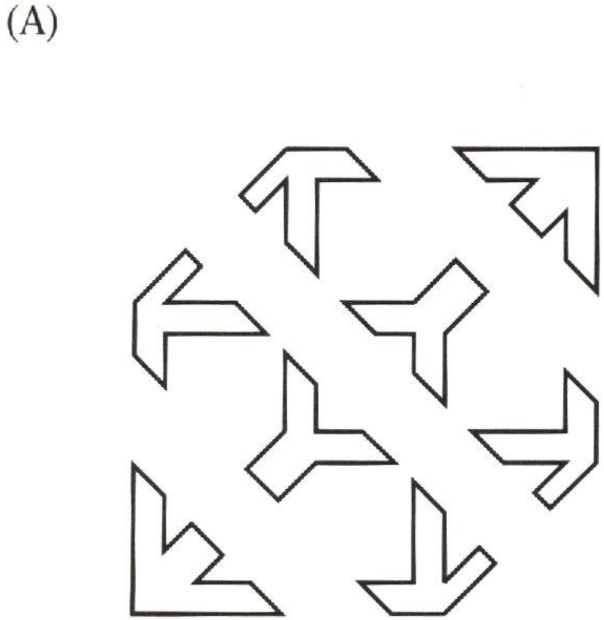
Example:
Show gratings with different spatial frequencies



Gradients/Motion



Perceptual Organization



Occlusion provides a different organization

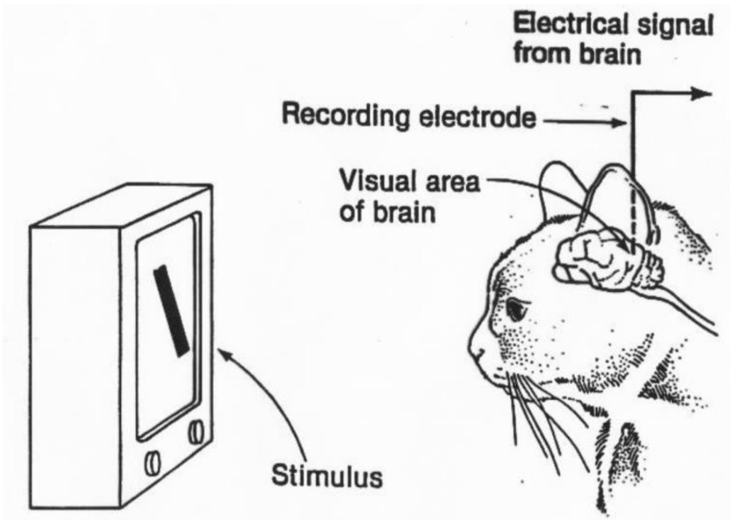
Perceptual Organization

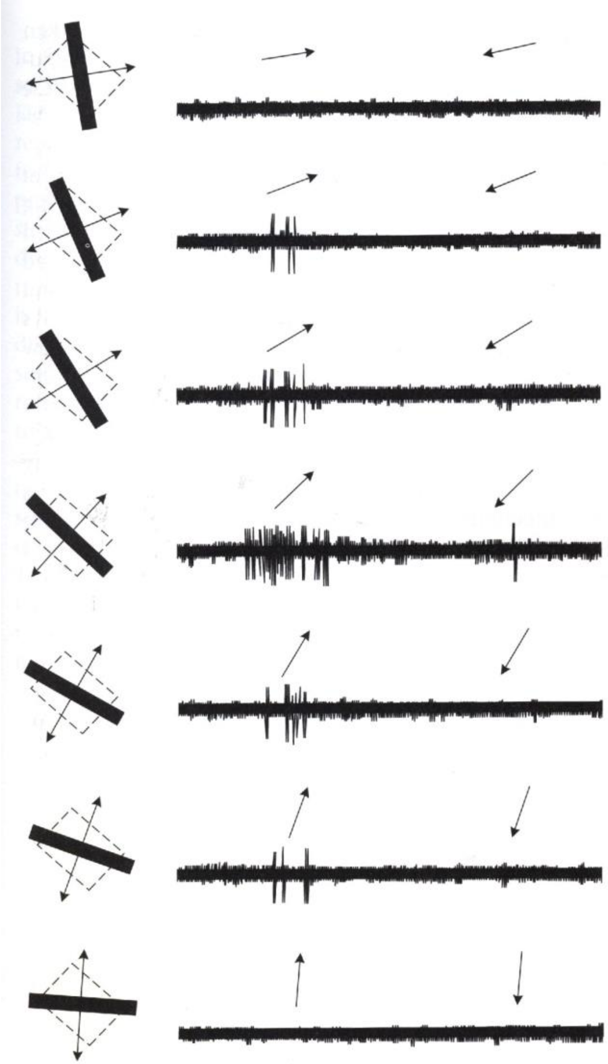
(B)

Ways to study human vision

1. Physiologically
2. Phenomenological/Psychophysical
3. Cellular recordings
4. Functional MRI
5. Computational modeling

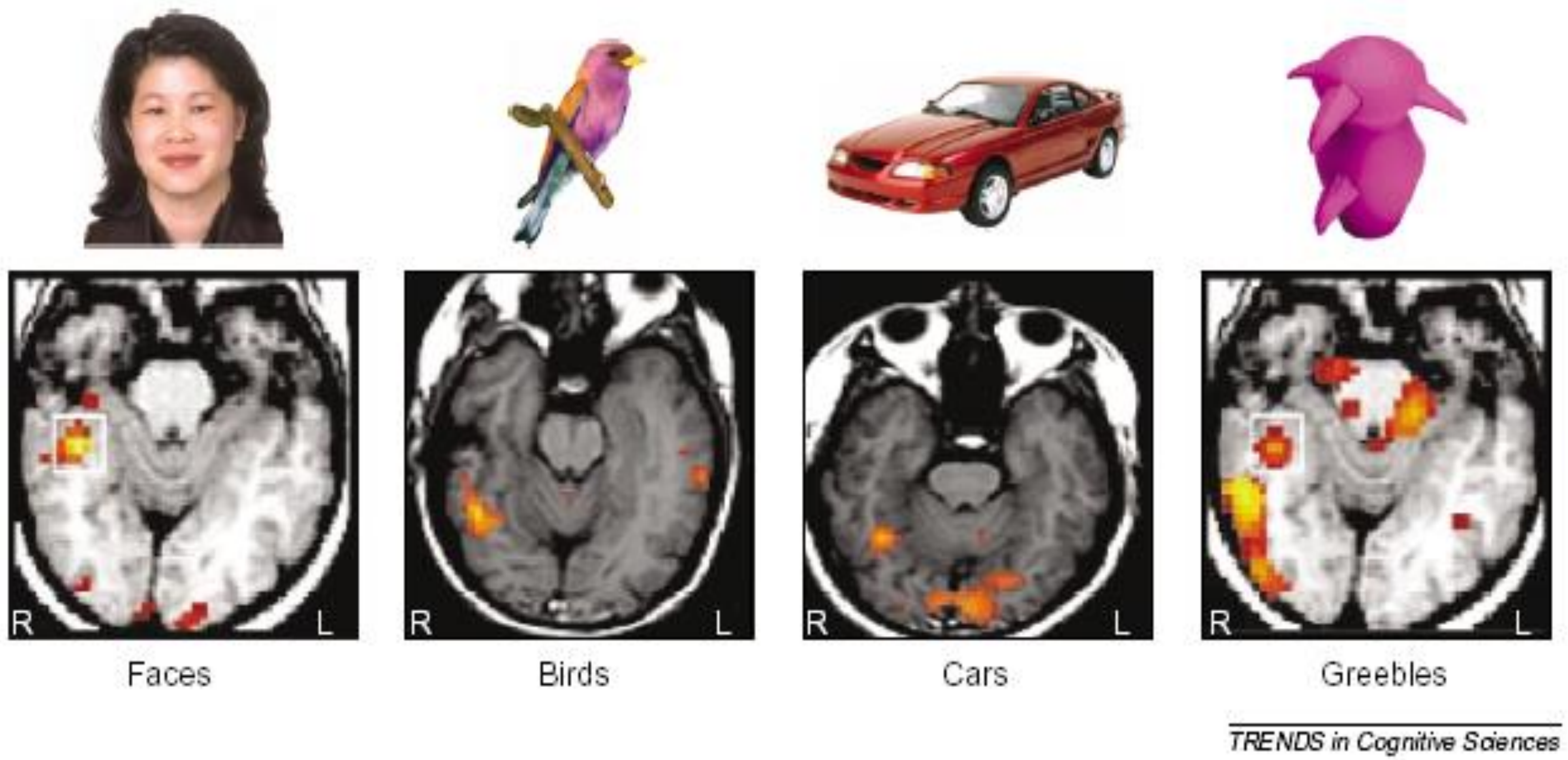
Single Cell Recordings





6.12 DIRECTION SELECTIVITY of a cortical neuron's response. The left-hand portion of each panel shows the receptive-field location, the orientation of the line stimulus, and the two motion directions. The action potentials shown on the right are the neuron's response to motion in each of the two opposite directions. The neuron's response depends upon the direction of motion and the orientation of the line. After Hubel and Wiesel, 1968.

fMRI

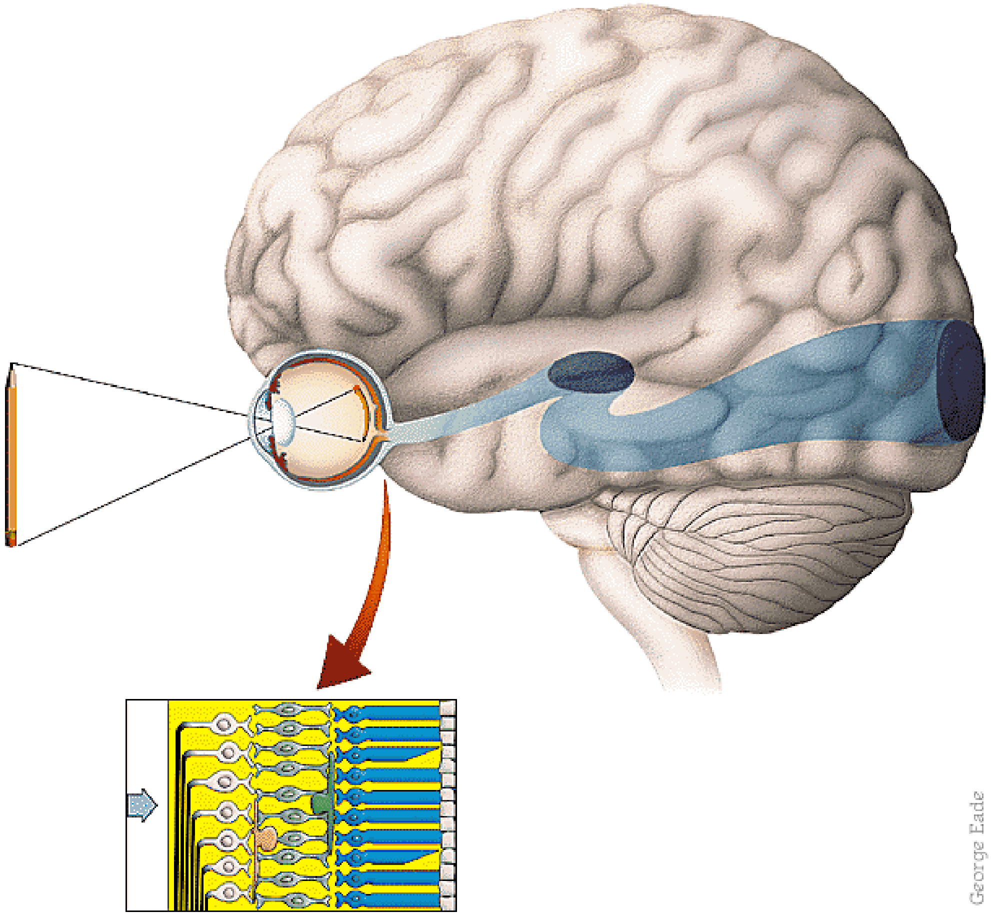


Activation in the right fusiform gyrus.
[Tarr, Cheng 2003]

Ways to study human vision

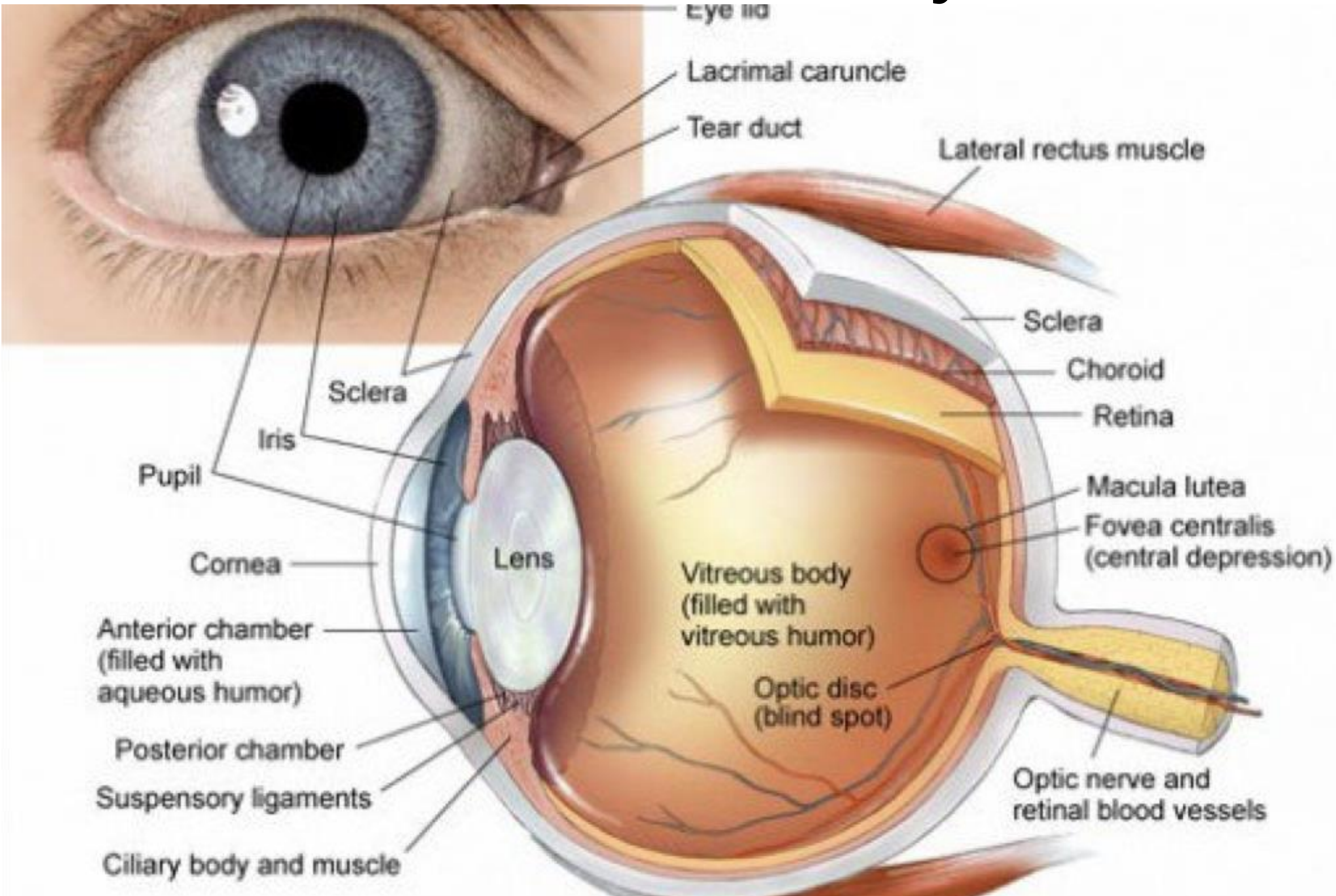
1. Physiologically
2. Phenomenological/Psychophysical
3. Cellular recordings
4. Functional MRI
5. Computational modeling

Computational Modeling

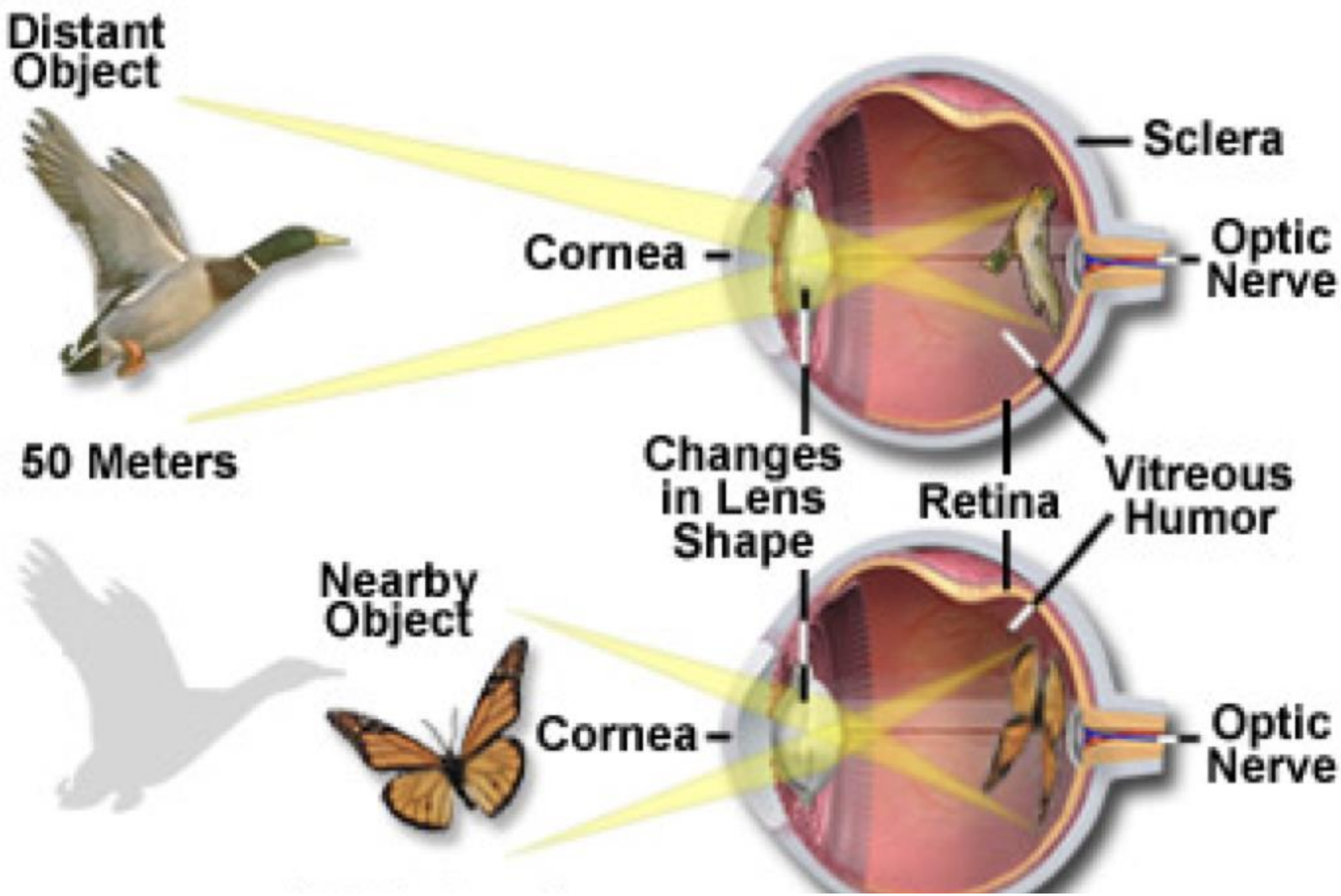


What is being computed and why?

Structure of the eye

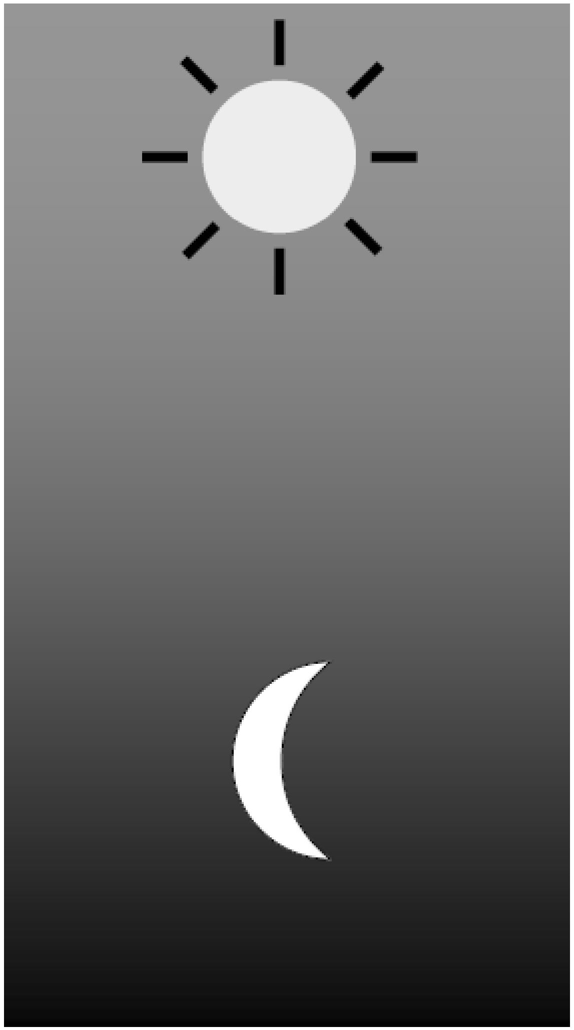


Focus



Distant Object
Sclera
Cornea
Optic Nerve
50 Meters
Changes in Lens Shape
Retina
Vitreous Humor
Nearby Object
Cornea
Optic Nerve

The range of lighting



Direct sun	100‘000 Lux
Sunny day	50‘000 Lux
Cloudy day	5‘000 Lux
Office	400 Lux
Home lighting	10 Lux
Street lamps	1 Lux
Full moon	0.1 Lux
Quarter moon	0.01 Lux
Clear moonless night	0.001 Lux
Cloudy moonless night	0.0001 Lux

Total lighting range

Electronic imagers

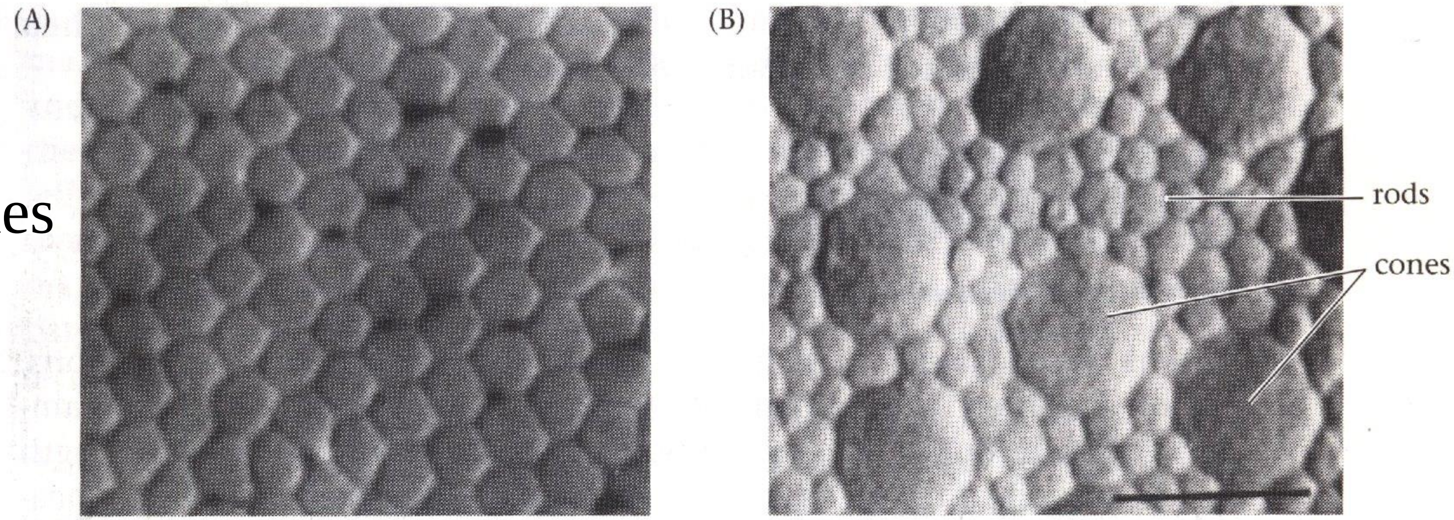
1 lux = 1 lumin/m^2

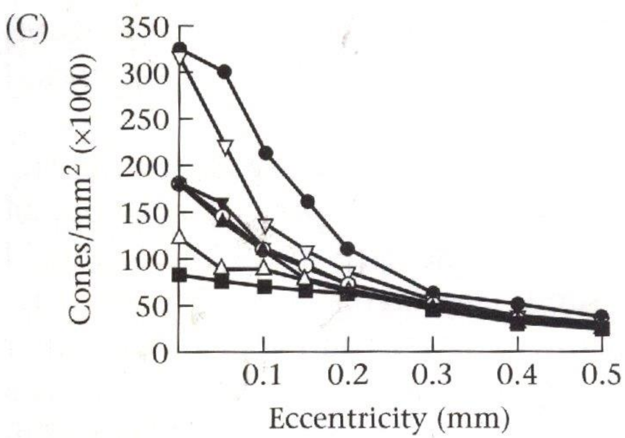
Rods and cones

Fovea

Periphery

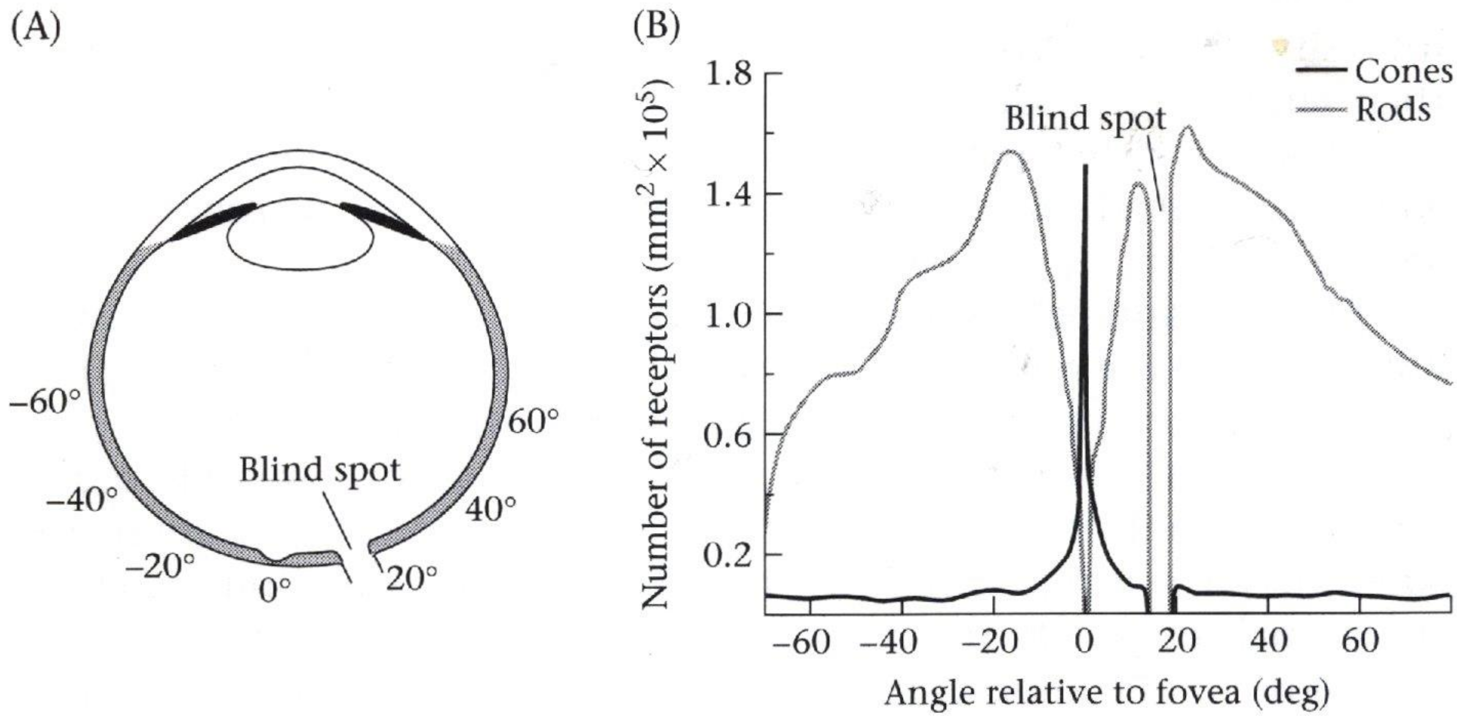
cones





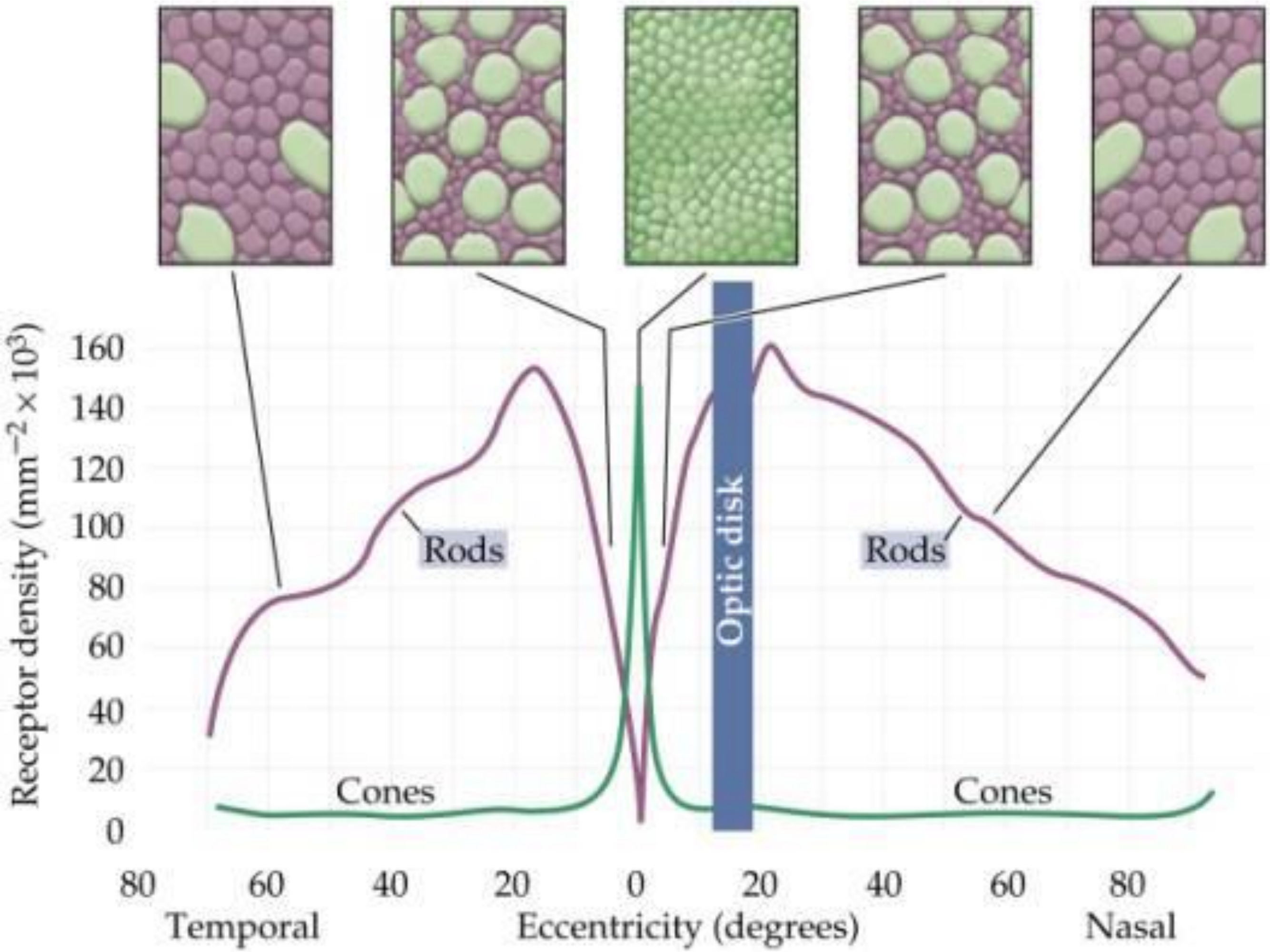
3.4 THE SPATIAL MOSAIC OF THE HUMAN CONES. Cross sections of the human retina at the level of the inner segments showing (A) cones in the fovea, and (B) cones in the periphery. Note the size difference (scale bar = 10 μm), and that, as the separation between cones grows, the rod receptors fill in the spaces. (C) Cone density plotted as a function of distance from the center of the fovea for seven human retinas; cone density decreases with distance from the fovea. Source: Curcio et al., 1990.

Distribution of Rods & Cones



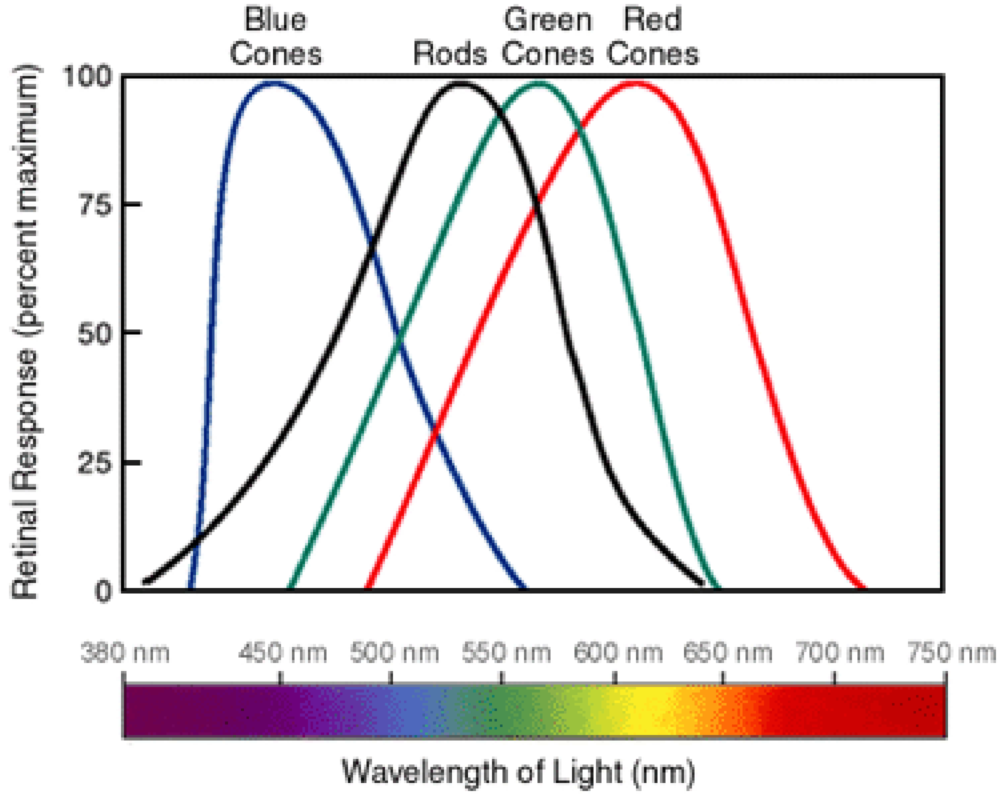
3.1 THE DISTRIBUTION OF ROD AND CONE PHOTORECEPTORS across the human retina. (A) Degrees of visual angle relative to the position of the fovea for the left eye; the position of the blind spot is also shown. (B) The cone receptors are concentrated in the fovea. The rod photoreceptors are absent from the fovea and reach their highest density between 10 and 20 degrees peripheral to the fovea. No photoreceptors are present in the blind spot.

Distribution of Rods & Cones



Three types of cones: R,G,B

Response of kth cone = $\int \rho_k(\lambda)E(\lambda)d\lambda$

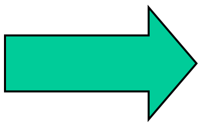


There are three types of cones

S: Short wave lengths (Blue)

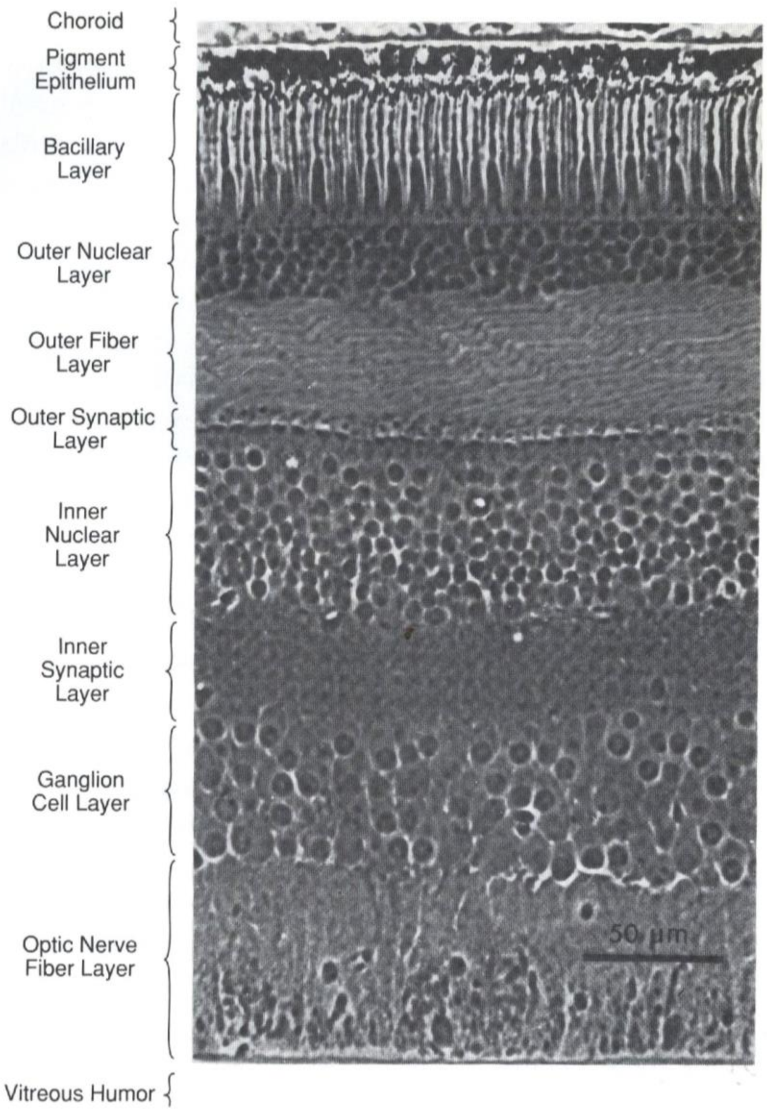
M: Mid wave lengths (Green)

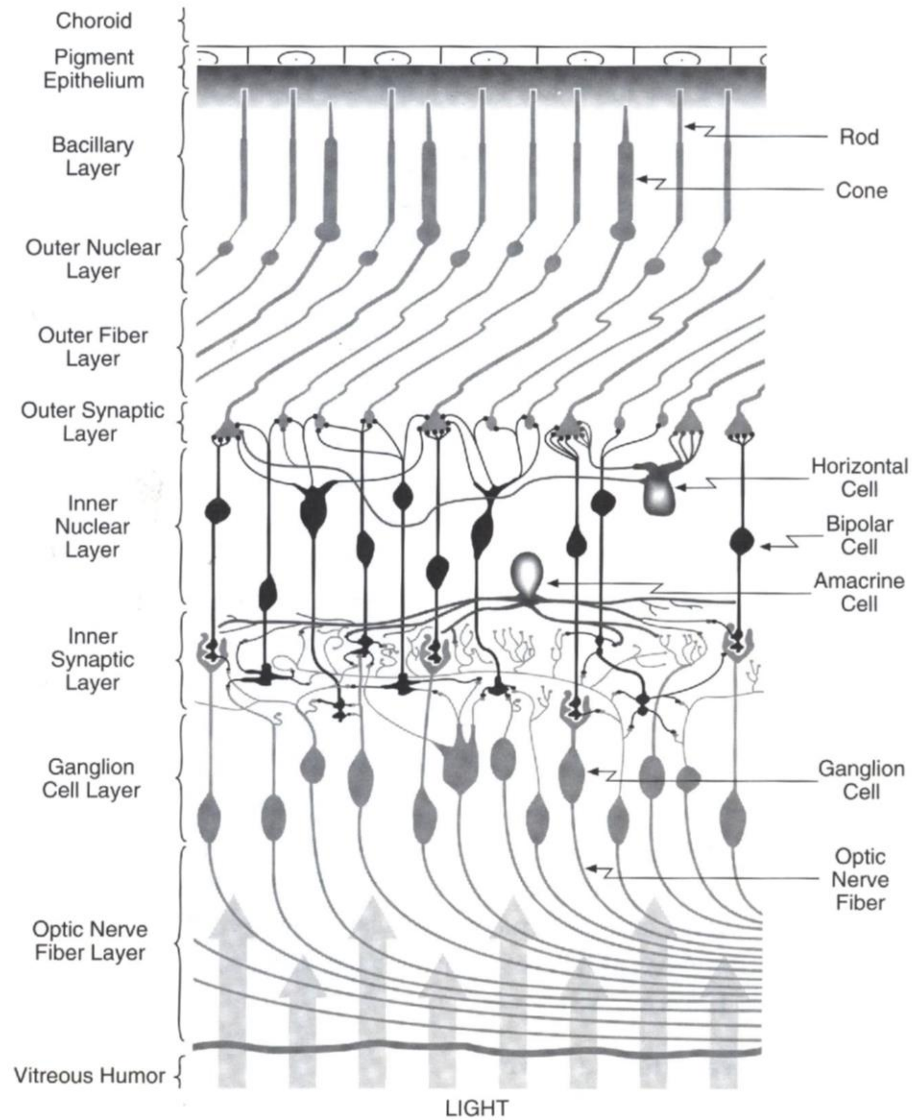
L: Long wave lengths (Red)



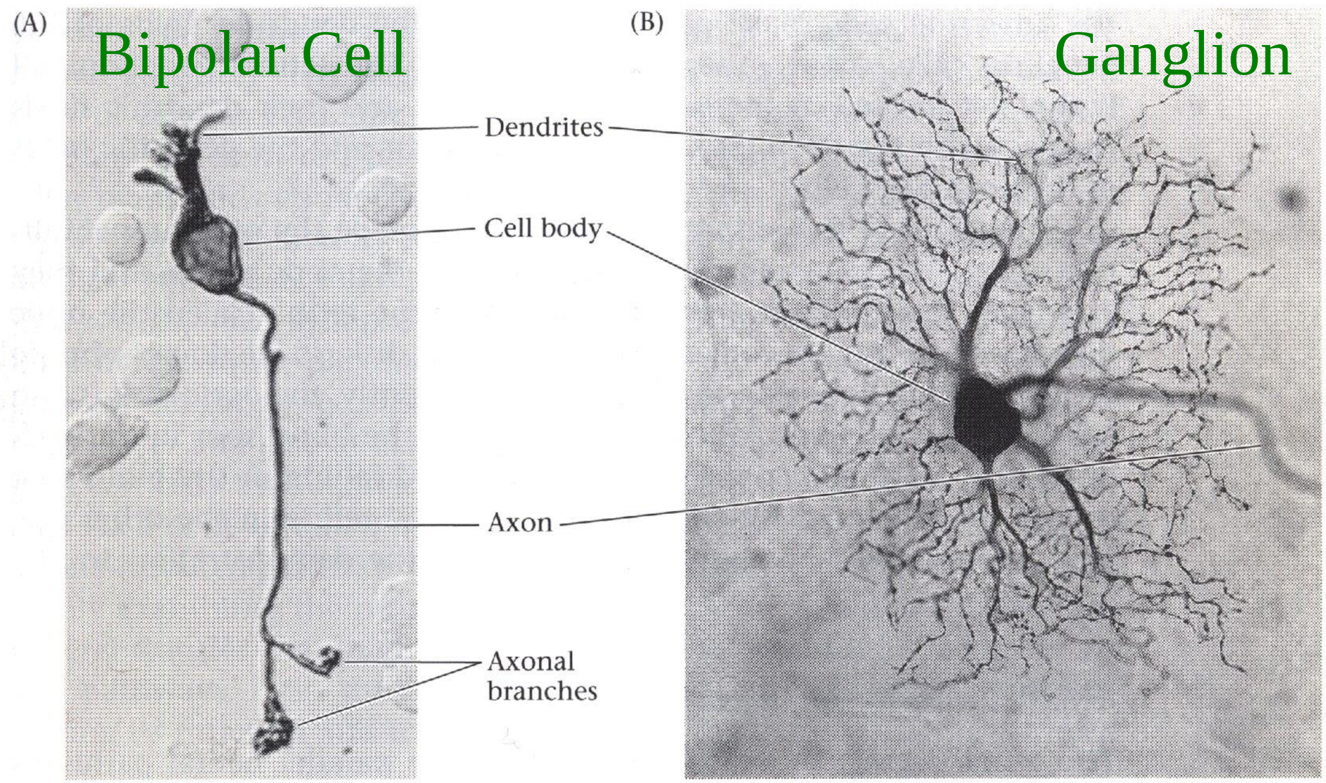
- Three attributes to a color
- Three numbers to describe a color

Retina edge on



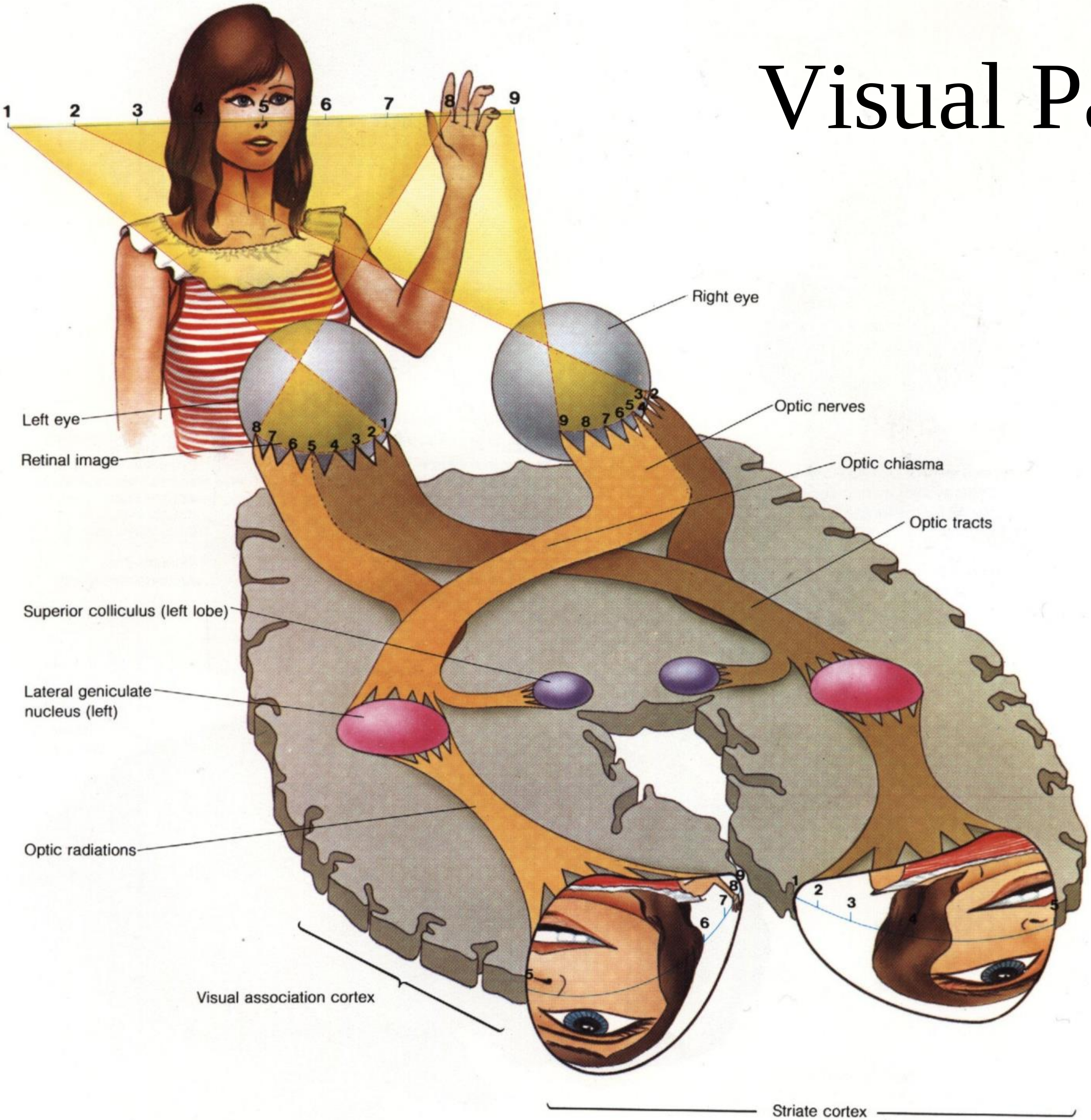


Retinal Neuron

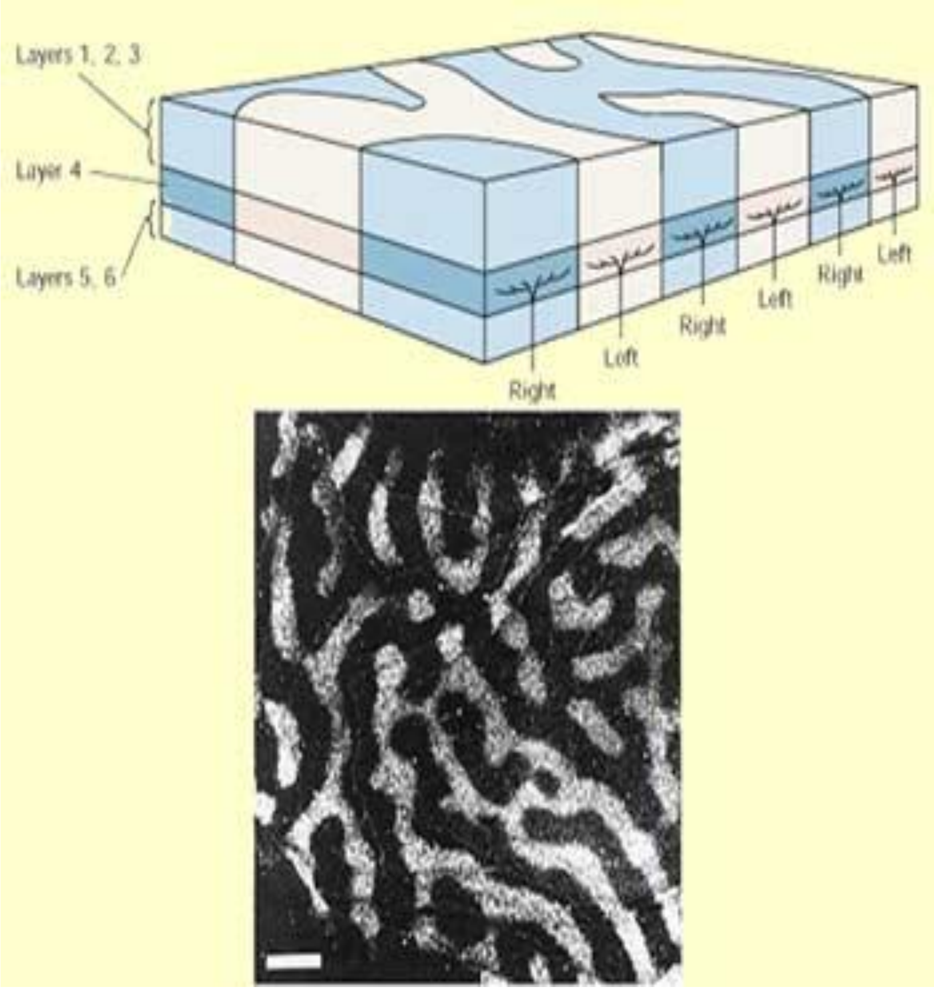


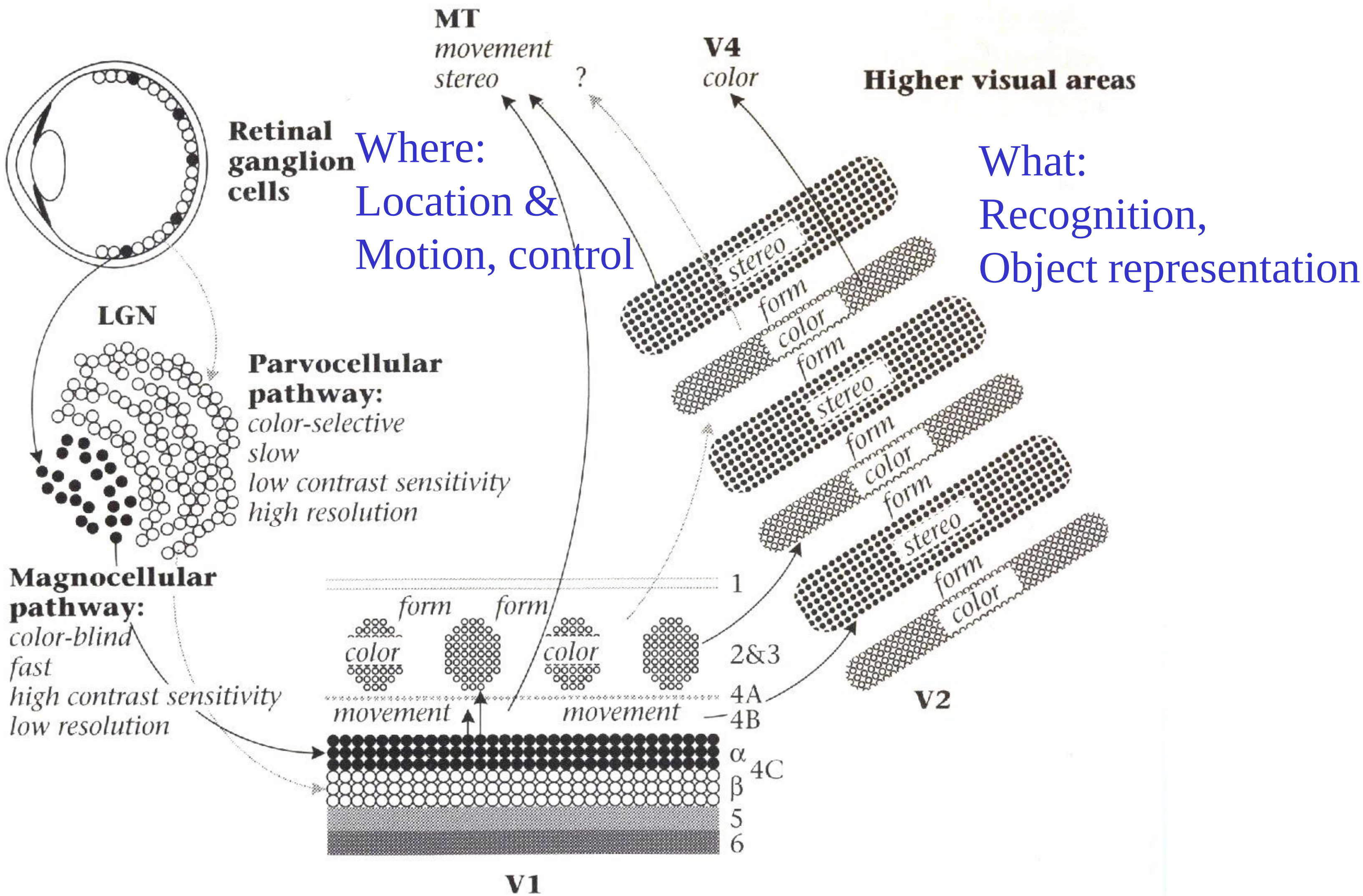
5.2 RETINAL NEURONS have many different shapes and sizes. (A) The cell body of a bipolar cell resides in the outer nuclear layer. Its dendrites make contact with the photoreceptors and horizontal cells and its axon carries the output of the bipolar cell to the inner plexiform layer (see Figure 5.1), where it contacts the dendritic field of a ganglion cell. (B) The retinal ganglion cell bodies reside in the ganglion cell layer of the retina (see Figure 5.1). The axons of the retinal ganglion cells comprise the optic nerve. Several types of retinal ganglion cells can be distinguished based on the properties of their dendritic fields, their interconnections, and their cell bodies. The cell shown here was called a parasol cell by Stephen Polyak (1941, 1957). Sources: A from Yamashita and Wässle, 1991; B from Dacey and Petersen, 1992.

Visual Pathways



Ocular Dominance Columns





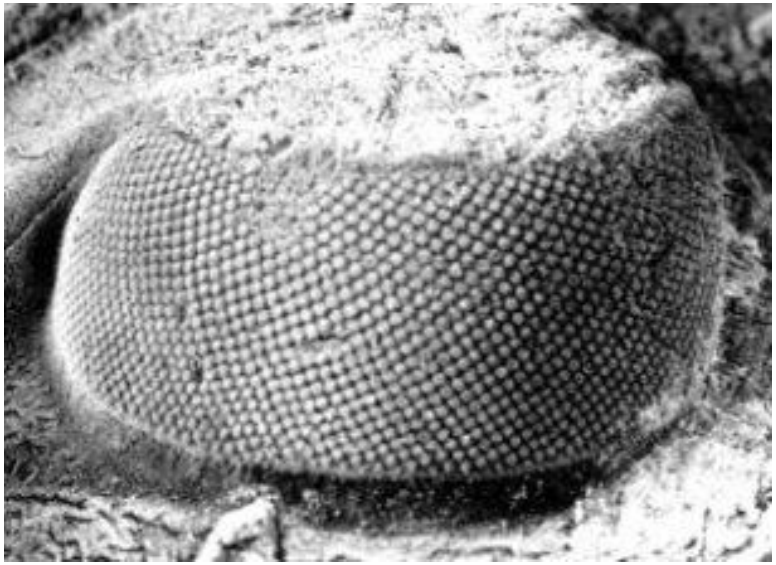
6.23 AN ANATOMICAL/PERCEPTUAL MODEL OF THE VISUAL CORTEX. In this speculative model, visual streams within the cortex are identified with specific perceptual features. The anatomical streams are identified using anatomical markers; the perceptual properties are associated with the streams by applying the neuron doctrine. Source: Livingstone and Hubel (1988).

Other Eyes

Trilobite Visual System

- Most ancient known visual system.
- Compound eye with single crystal for each lens.

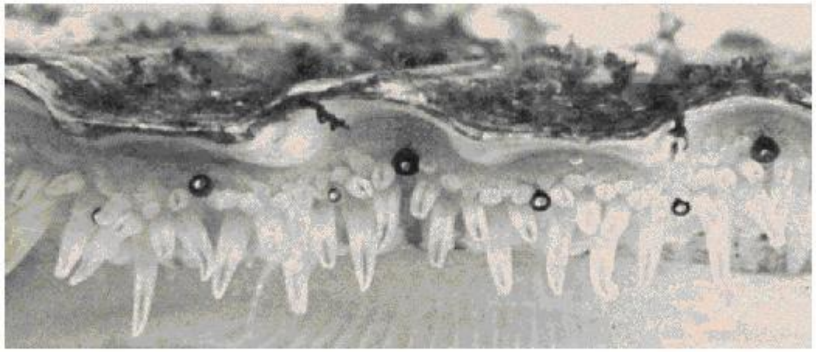
Electron Micrograph of
Holochroal eye

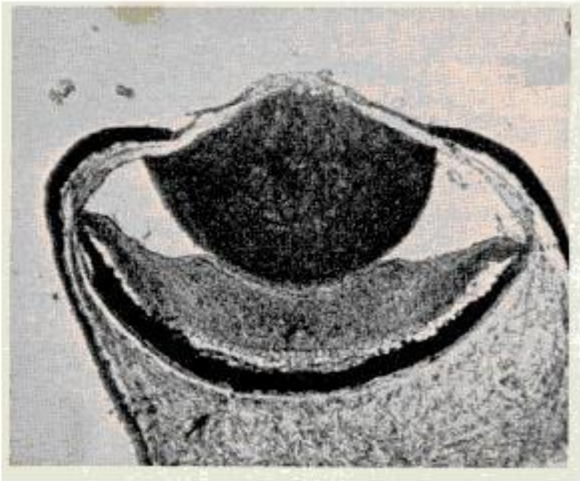


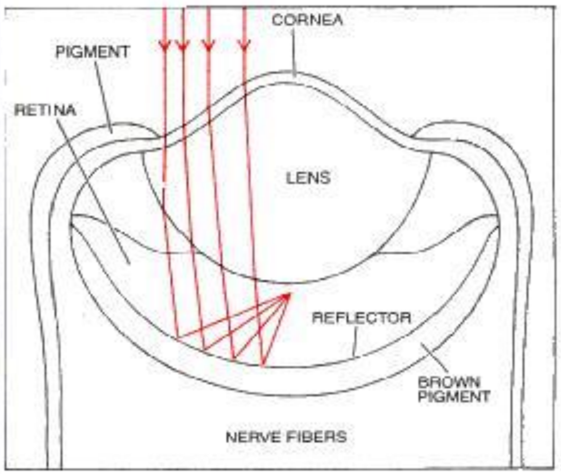
Good trilobite eye info at: http://www.aloha.net/~smgon/eyes.htm

Scallop eyes

- Hundreds of primitive eyes, mirror in back
- Changes in light and motion and very rough images are registered on the retinas of the mollusk.
- Nice material at: http://soma.npa.uiuc.edu/courses/bio303/Ch11b.html







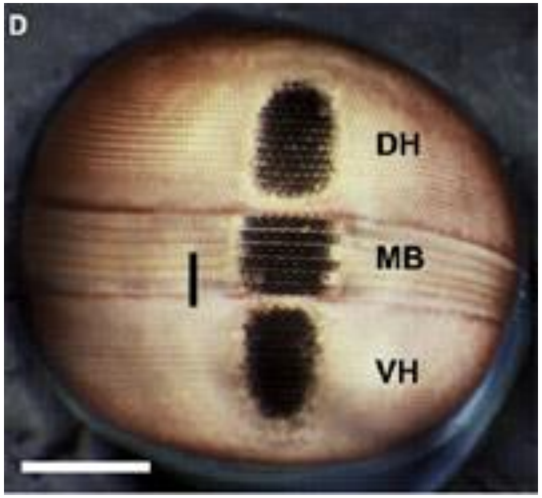
Stomatopod eyes

- Dumb bell shaped, compound eyes (next slide)
- Stereo vision with just one eye;
- Each eye is up on a stalk, with a wide range of motion;
- Stomatopods have up to 16 visual pigments
  - stomatopods can see ultra-violet and infra-red light
  - some can see polarized light
- See http://www.ucmp.berkeley.edu/aquarius/

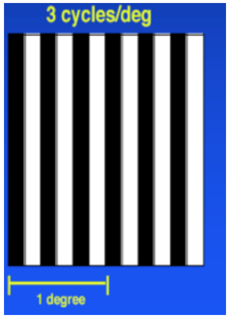
Larva Mantis Shrimp

Adult Mantis Shrimp

Mantis Shrimp



Trinocular vision

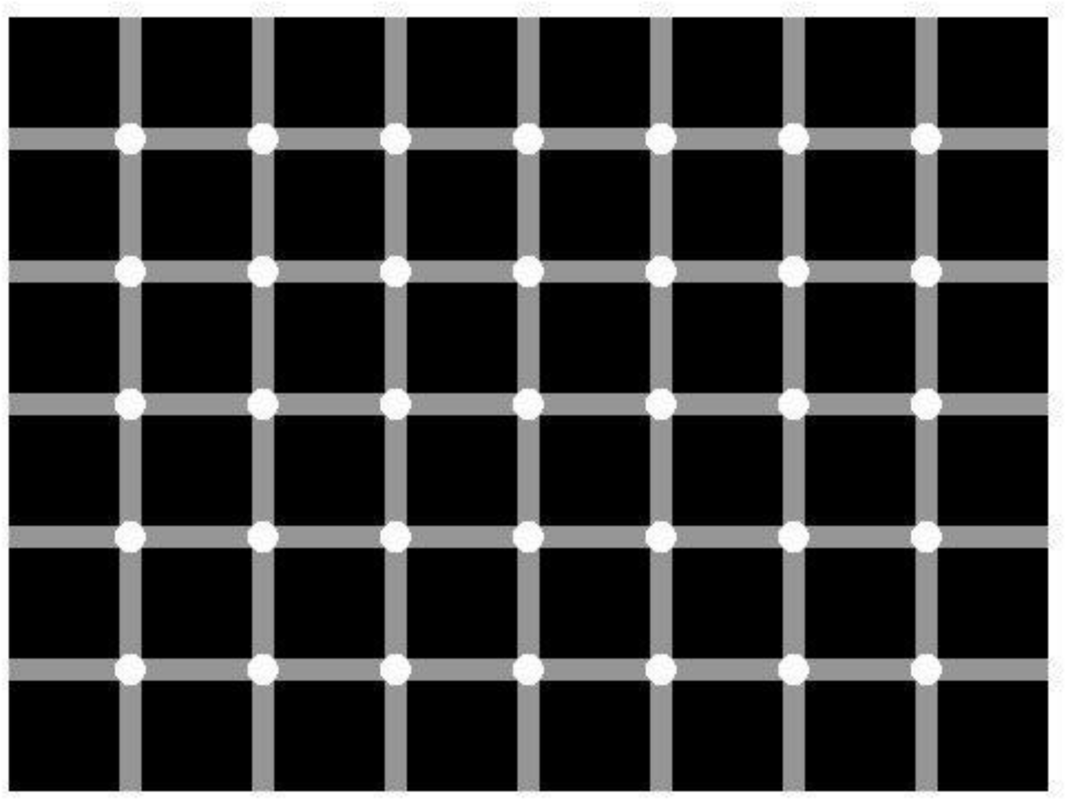


Note: Visual resolution of human eye is 60 cycles per deg whereas Wedge-Tailed Eagle is 140 cycles per deg

"Visual Acuity and the Evolution of Signals," Eleanor M. Caves et al., Trends in Ecology & Evolution, May 2018.

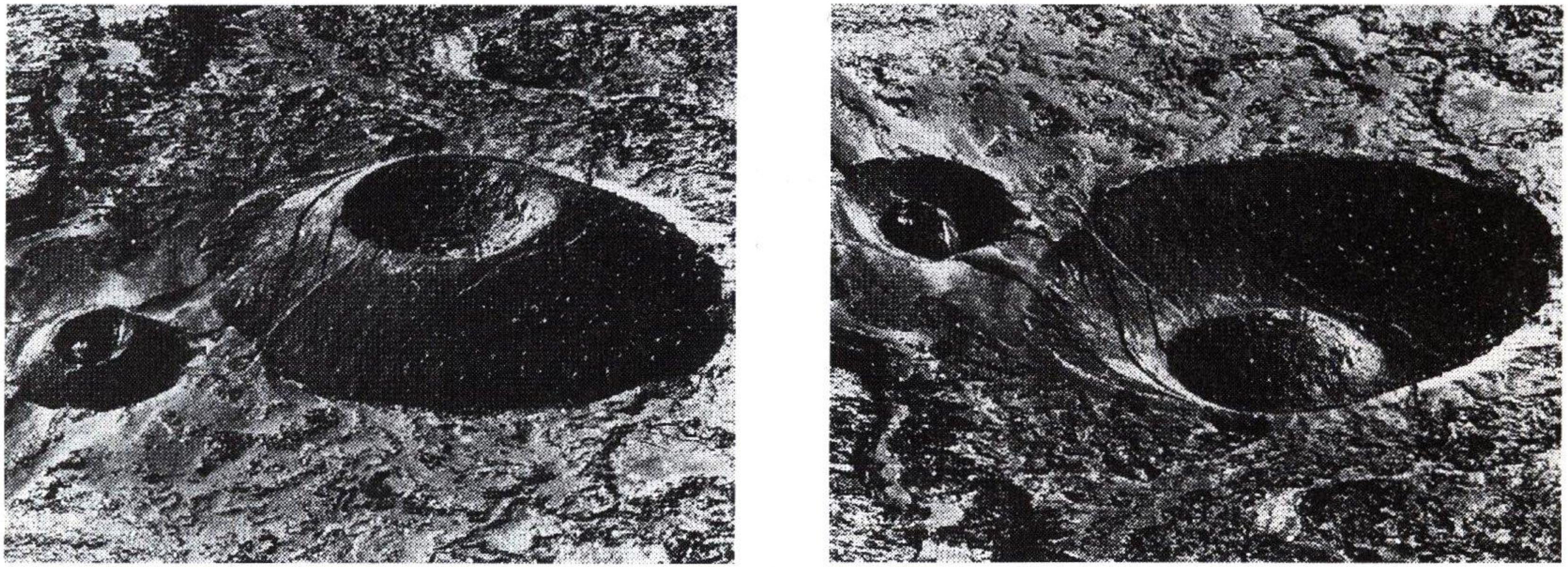
Cues

Fixate at center
What color are the dots?

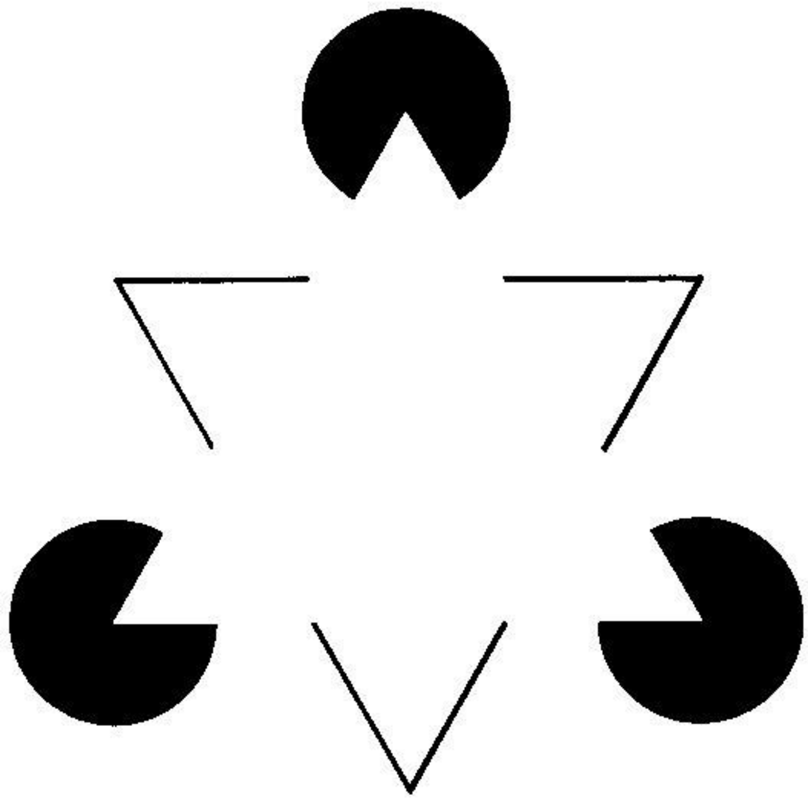


Shading Cues

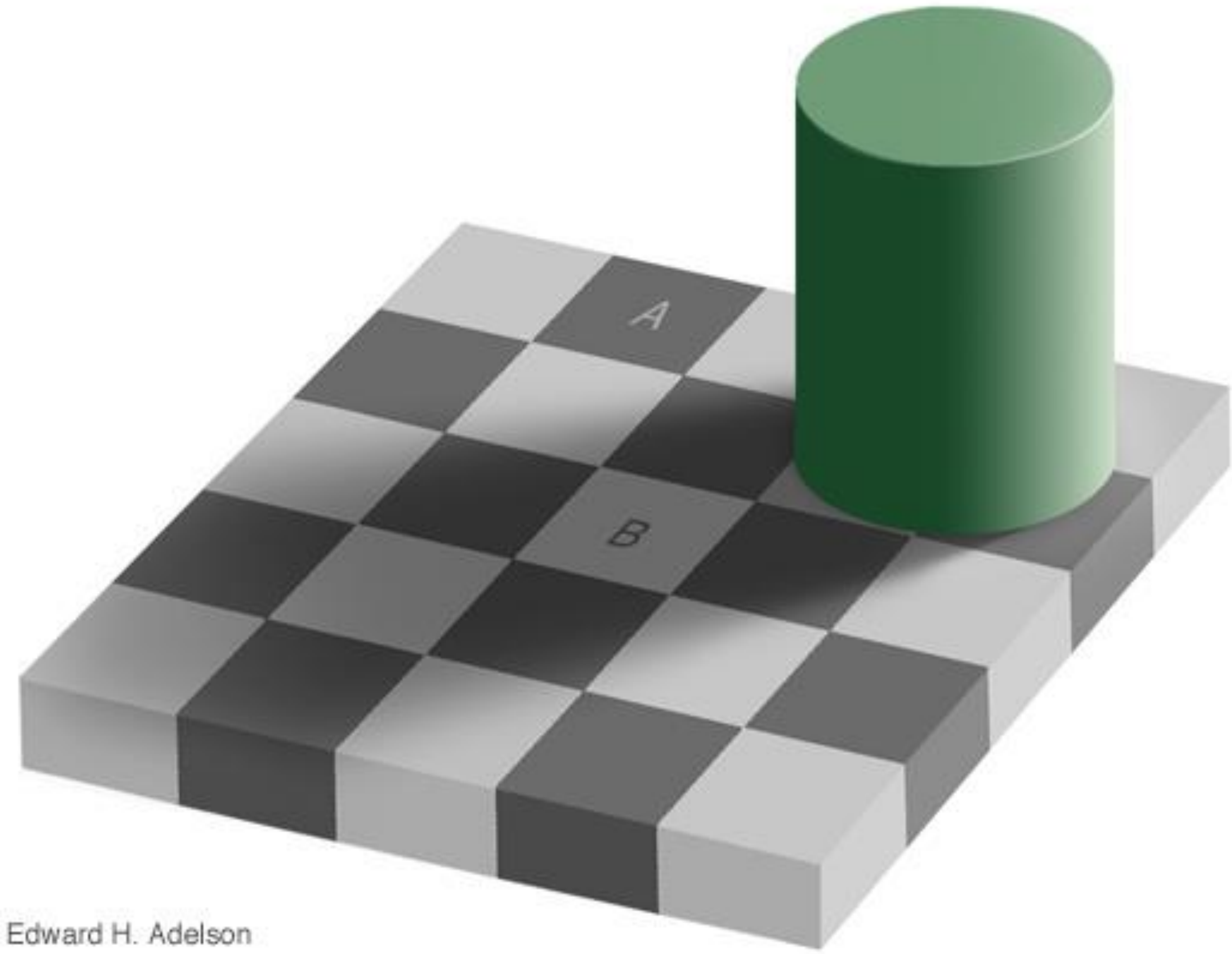
(A) (B)



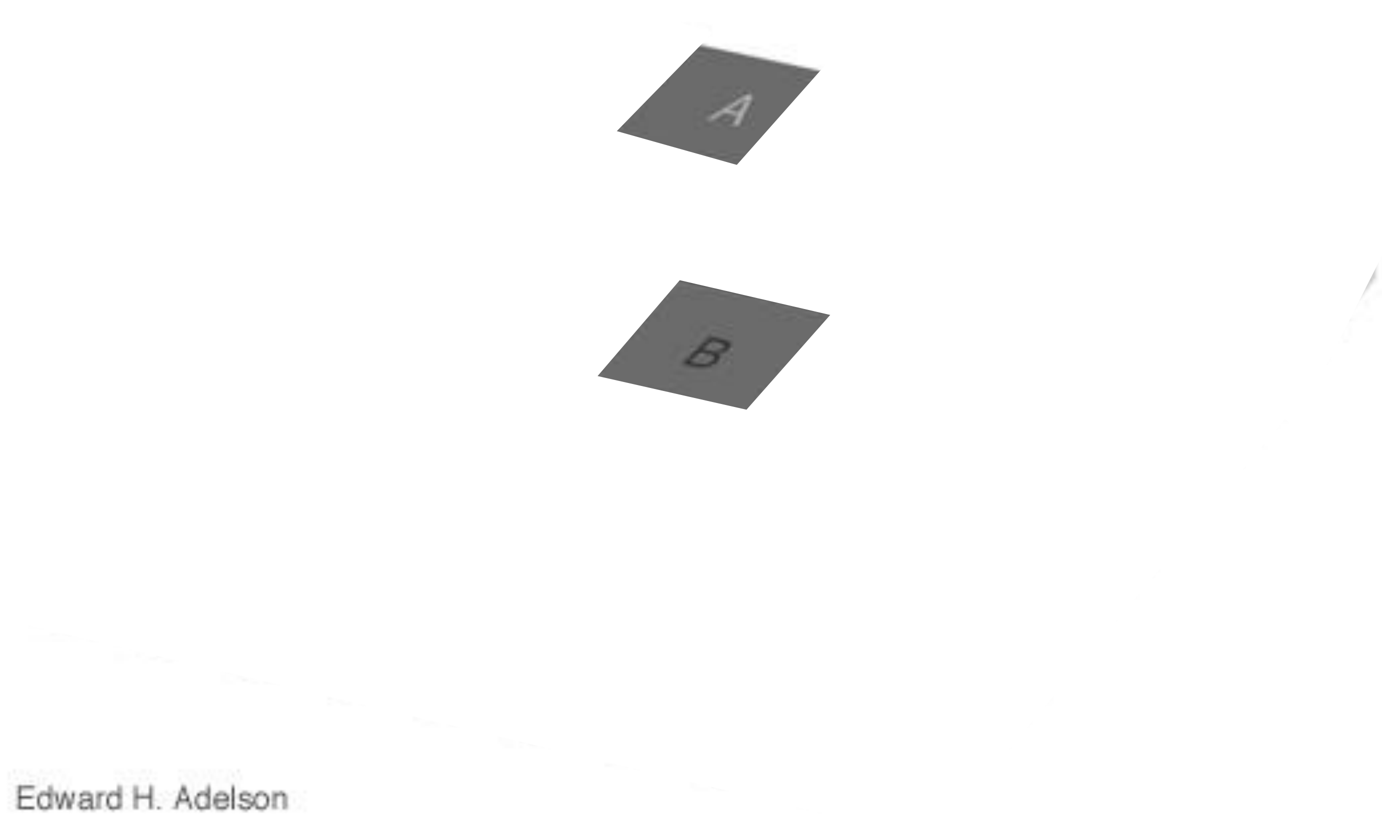
Subjective Contours
Kanizsa's Triangle



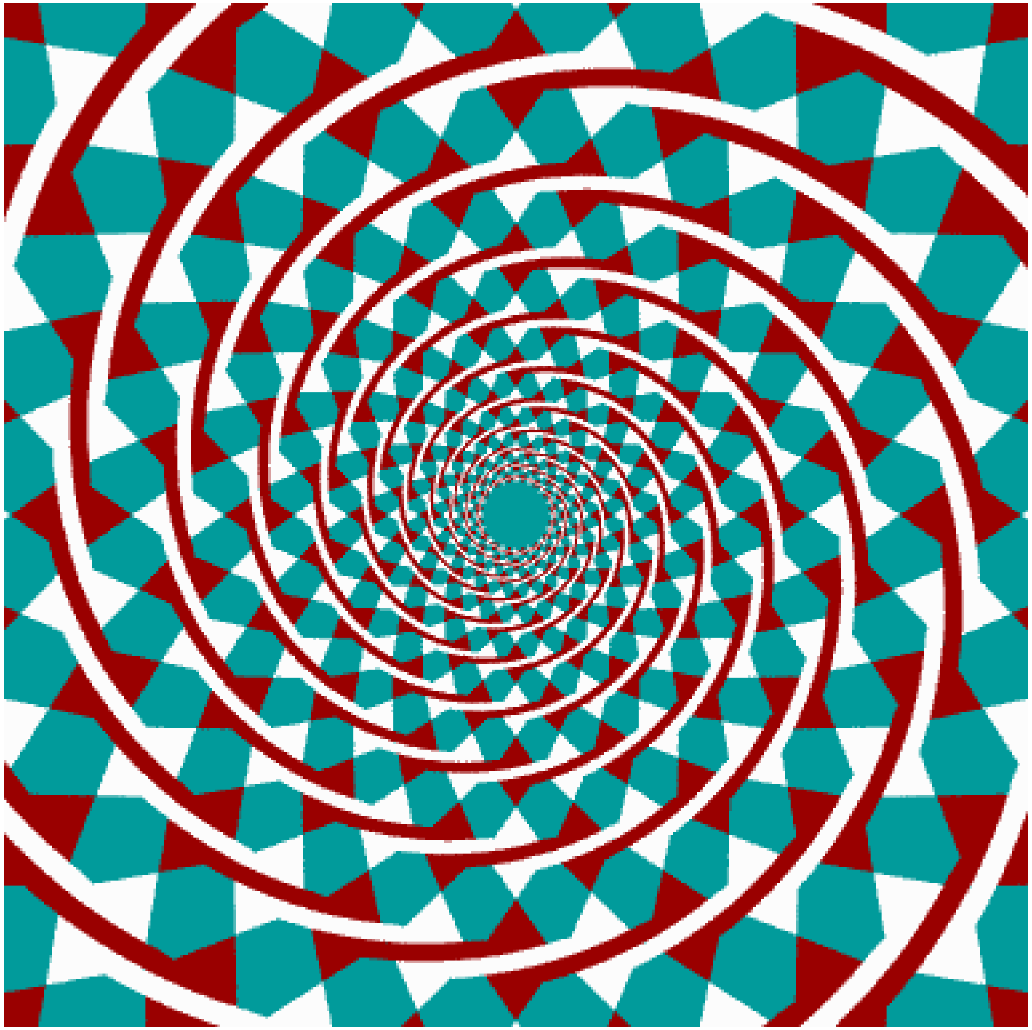
Which square is darker?



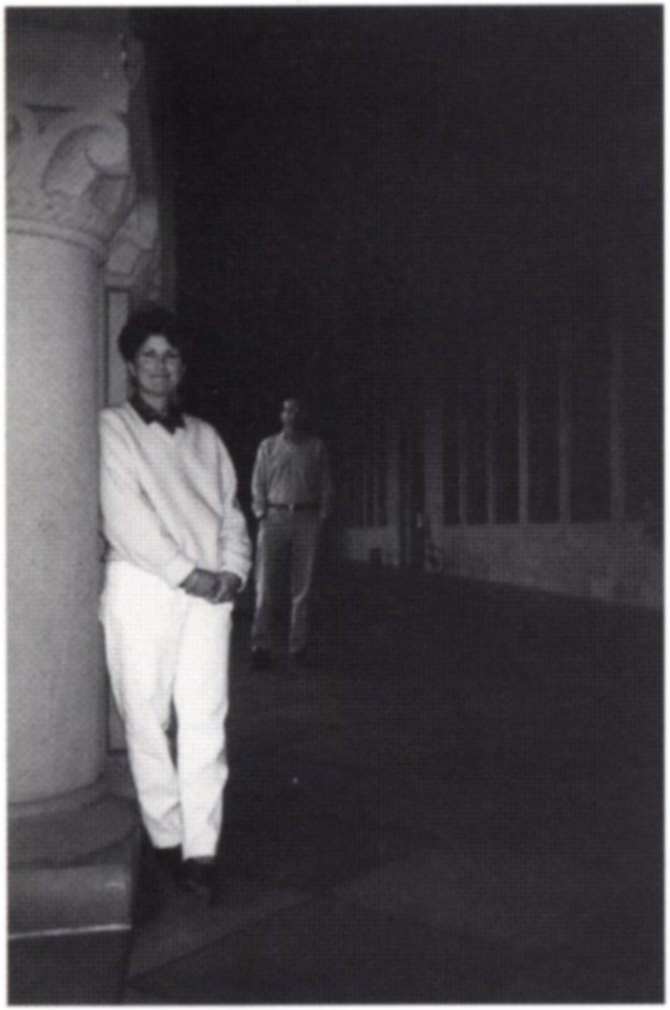
Which square is darker?



Global vs. Local information: Fraser's Spiral



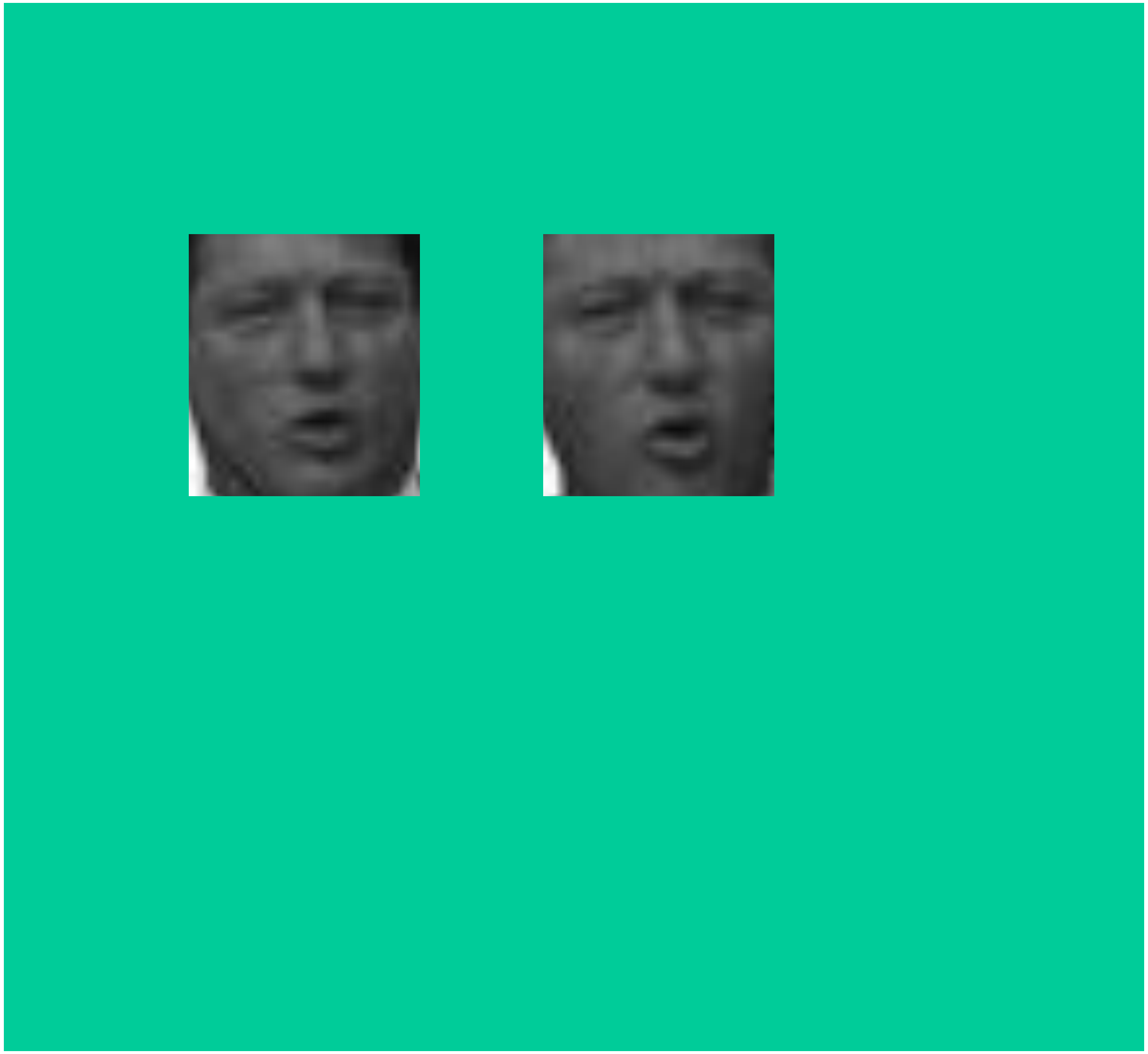
Context



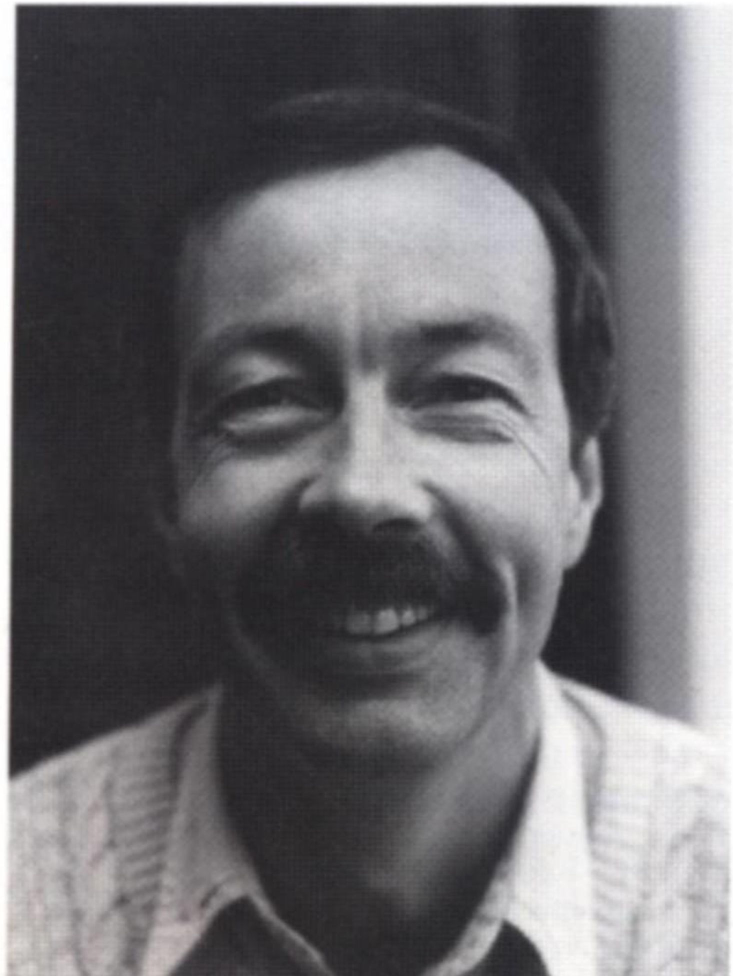
Who is taller?

Who is taller?

Context: Whose faces do you see?



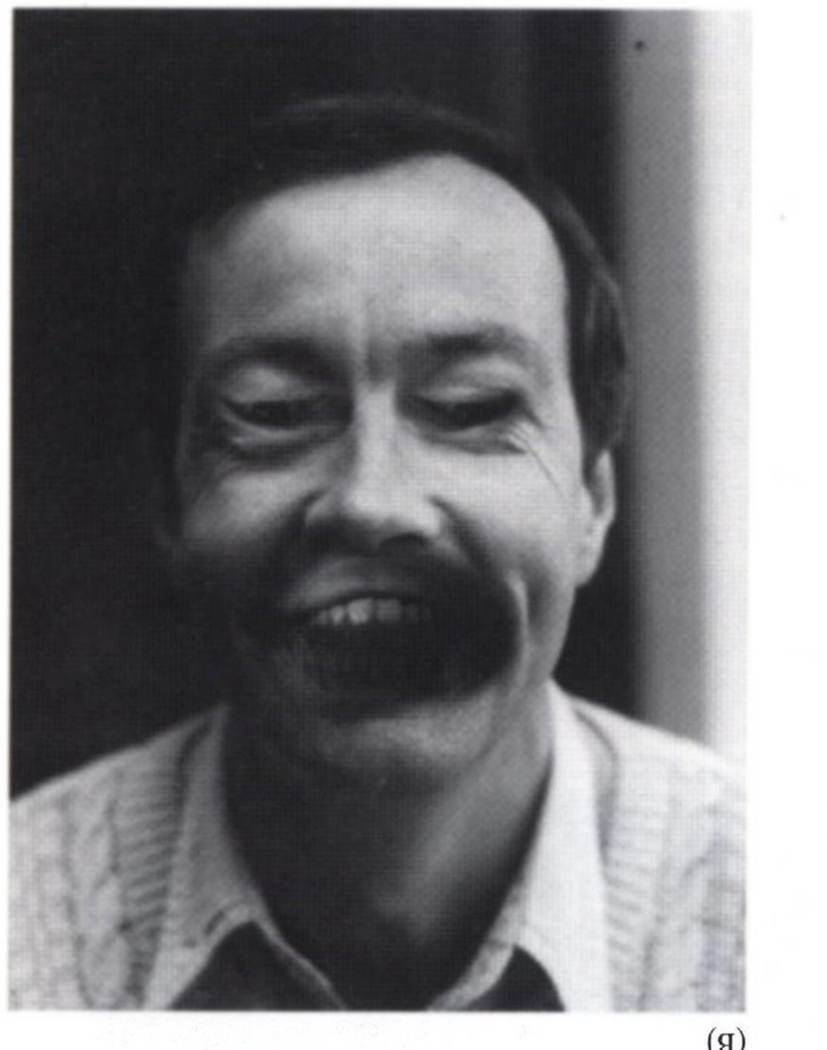
A picture of a man



In this shot, what is his facial expression?

(B)

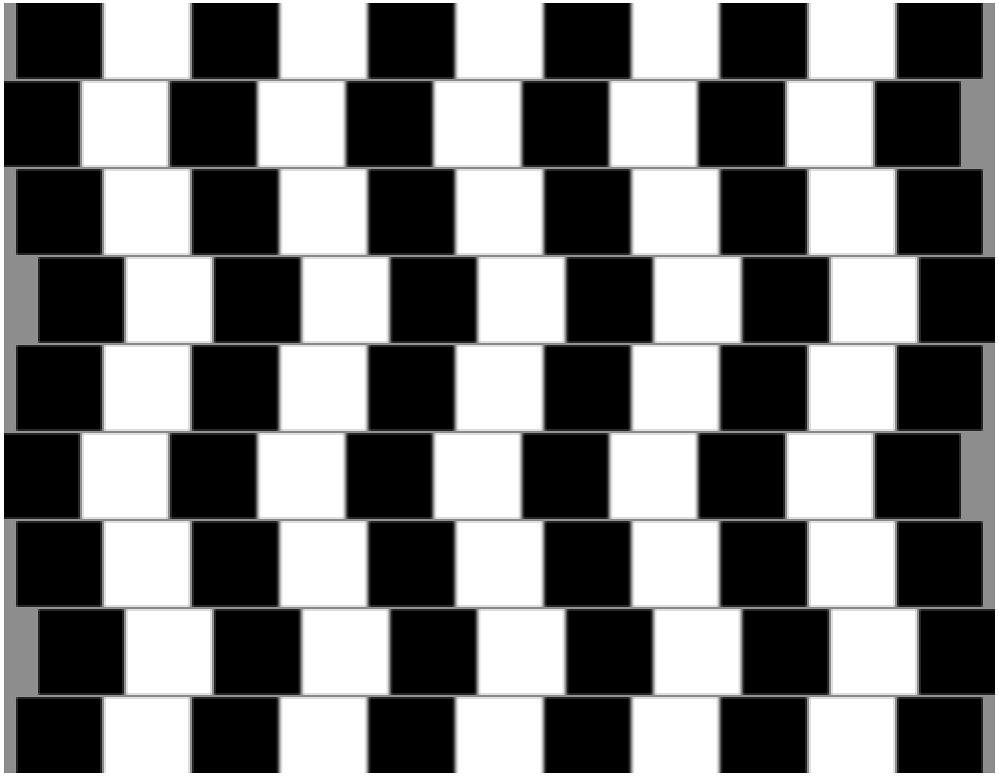
In this shot, what is his facial expression?



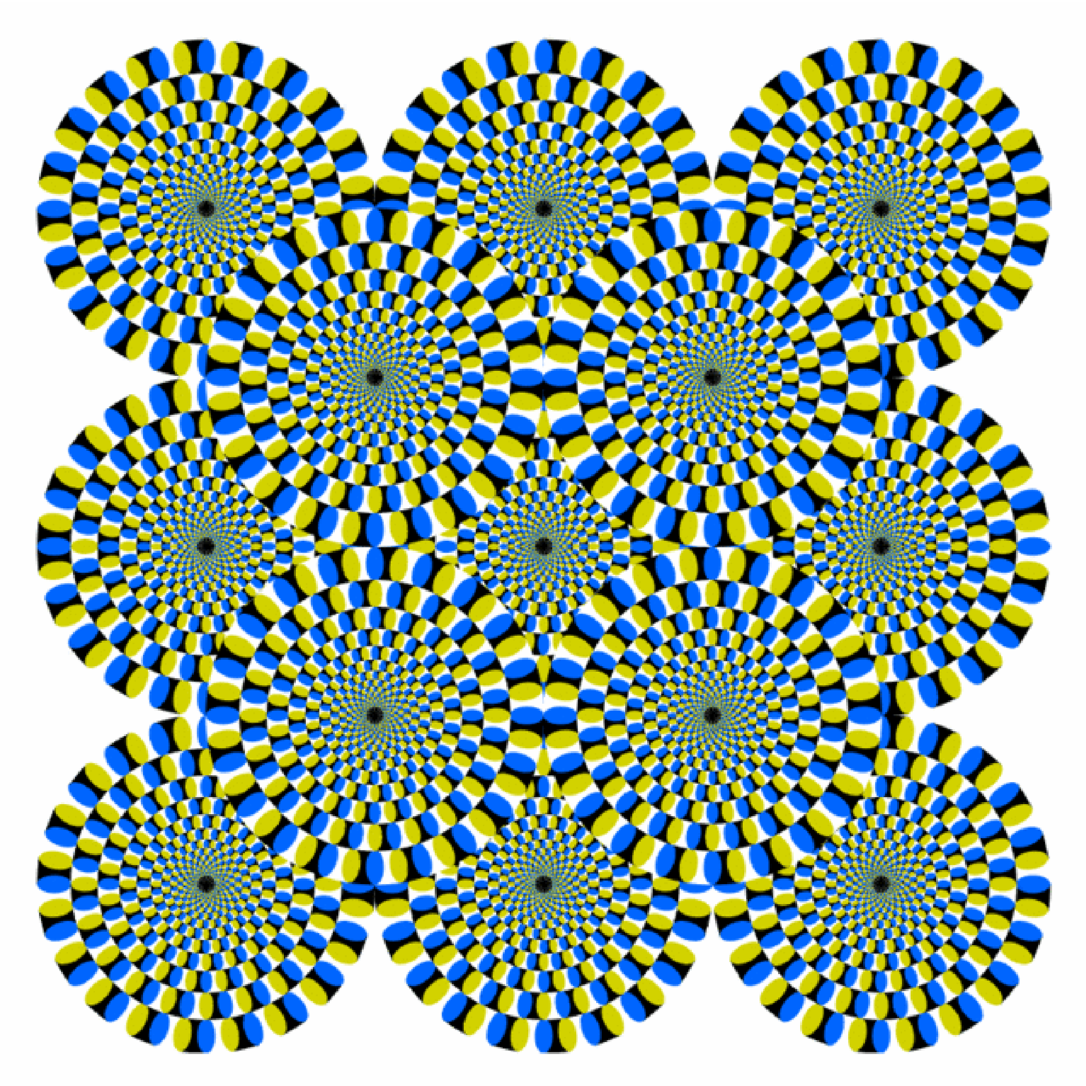
Thatcher illusion

Hidden Human Face

Horizontal Lines are Parallel



Static Image



Summary of CSE 252A

- Geometric image formation
- Photometric image formation
- Photometric stereo
- Image filtering
- Edge detection and corner detection
- Calibrated stereo
- Feature matching
- Uncalibrated stereo
- Feature extraction
- Structure from motion
- Robust model fitting
- Optical flow and motion
- Recognition, detection, and classification
- Neural networks
- Convolutional neural networks
- Color
- Perception