CS 530 - Visualization

Human Vision

Slides courtesy of Penny Rheingans (UMBC)

January 28, 2013

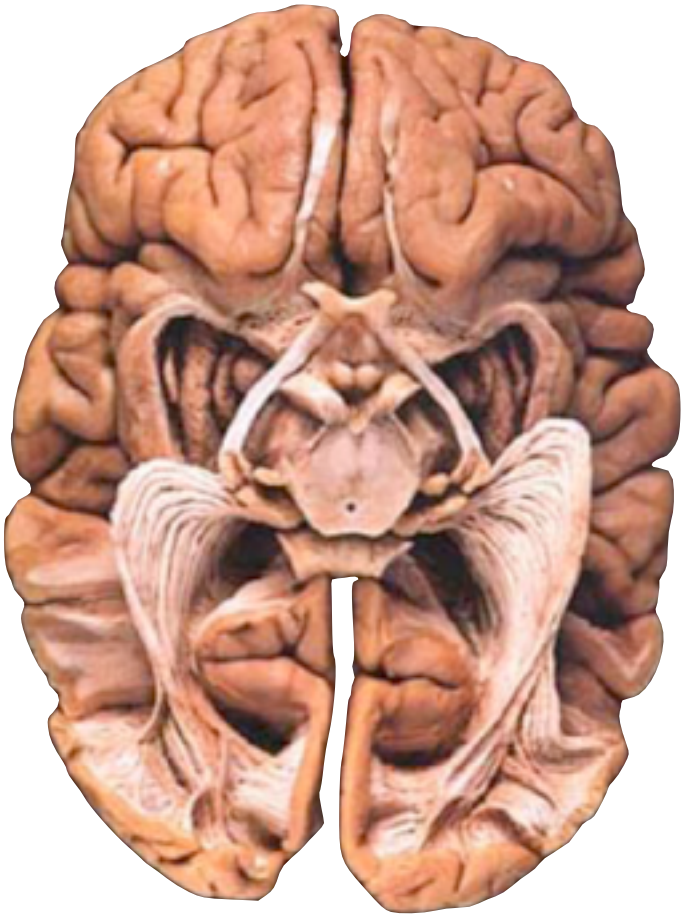
Studying Human Vision is Difficult

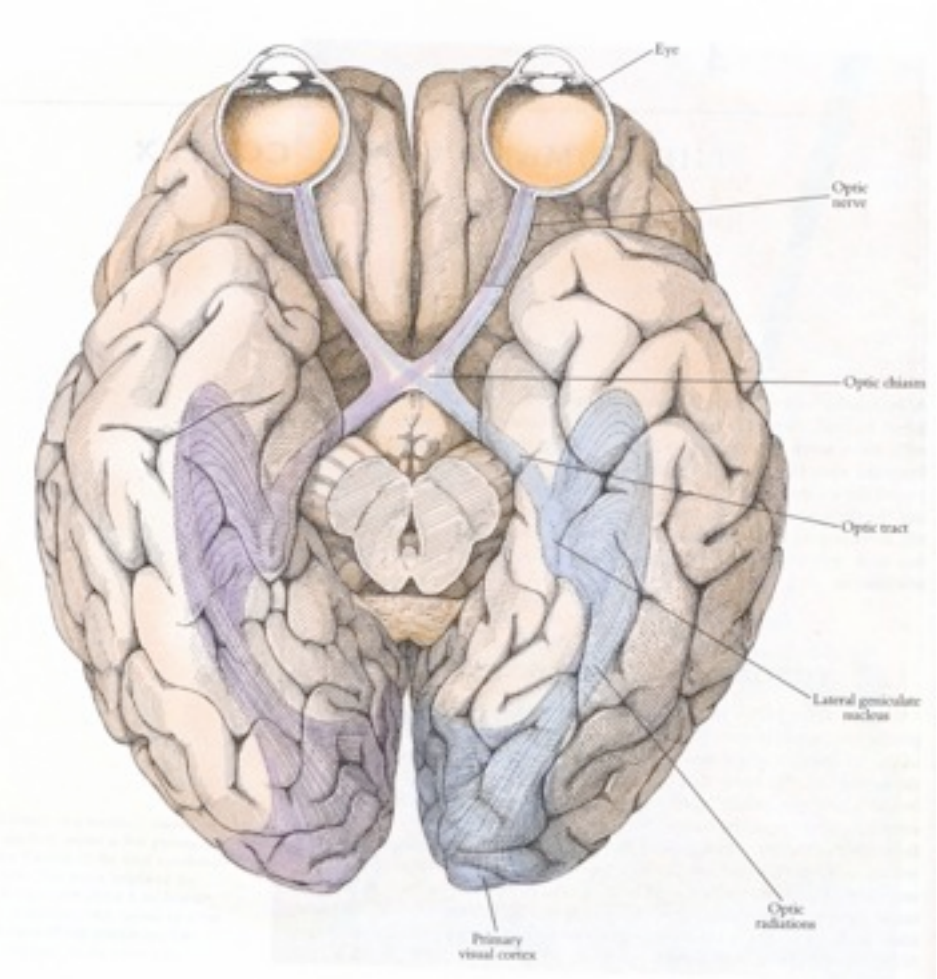
- Brain is complicated
  - 100×10^9 neurons, 60×10^{12} synapses
  - Vision: ~50% of brain associated with seeing
- Interactions
  - Adaptation (time, conditions)
  - Context dependent
  - Active
  - High-level knowledge

Methods for Studying Human Vision

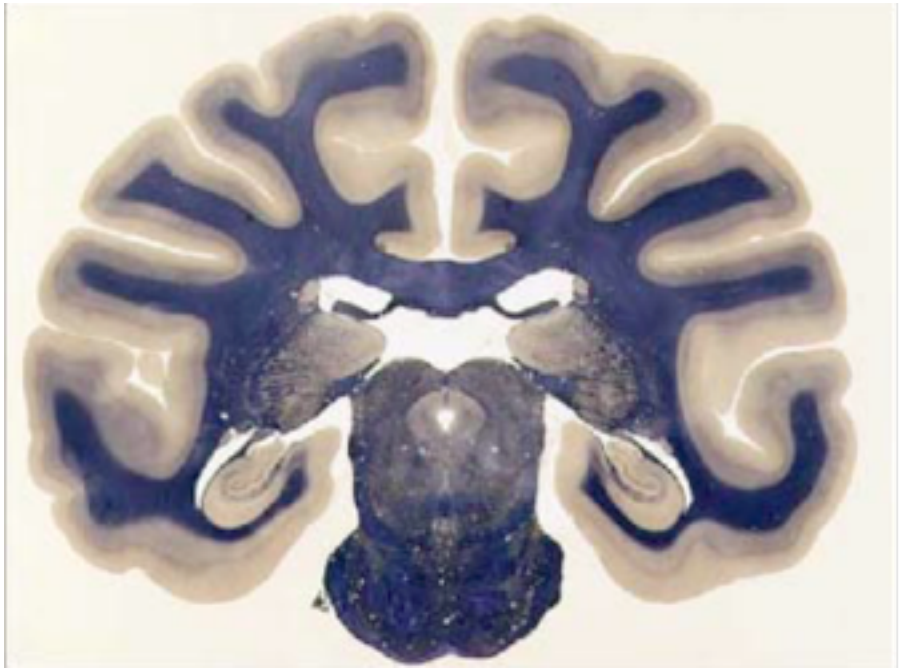
- Dissection and Histology
- Animal measurements
- Structural and functional brain imaging
- Modeling
- Human (subjective) experiments

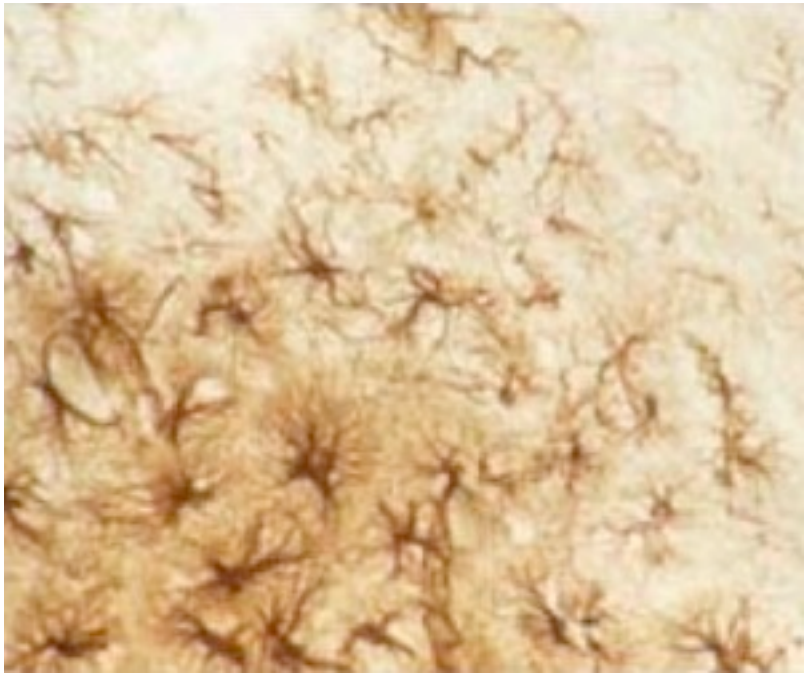
Dissection



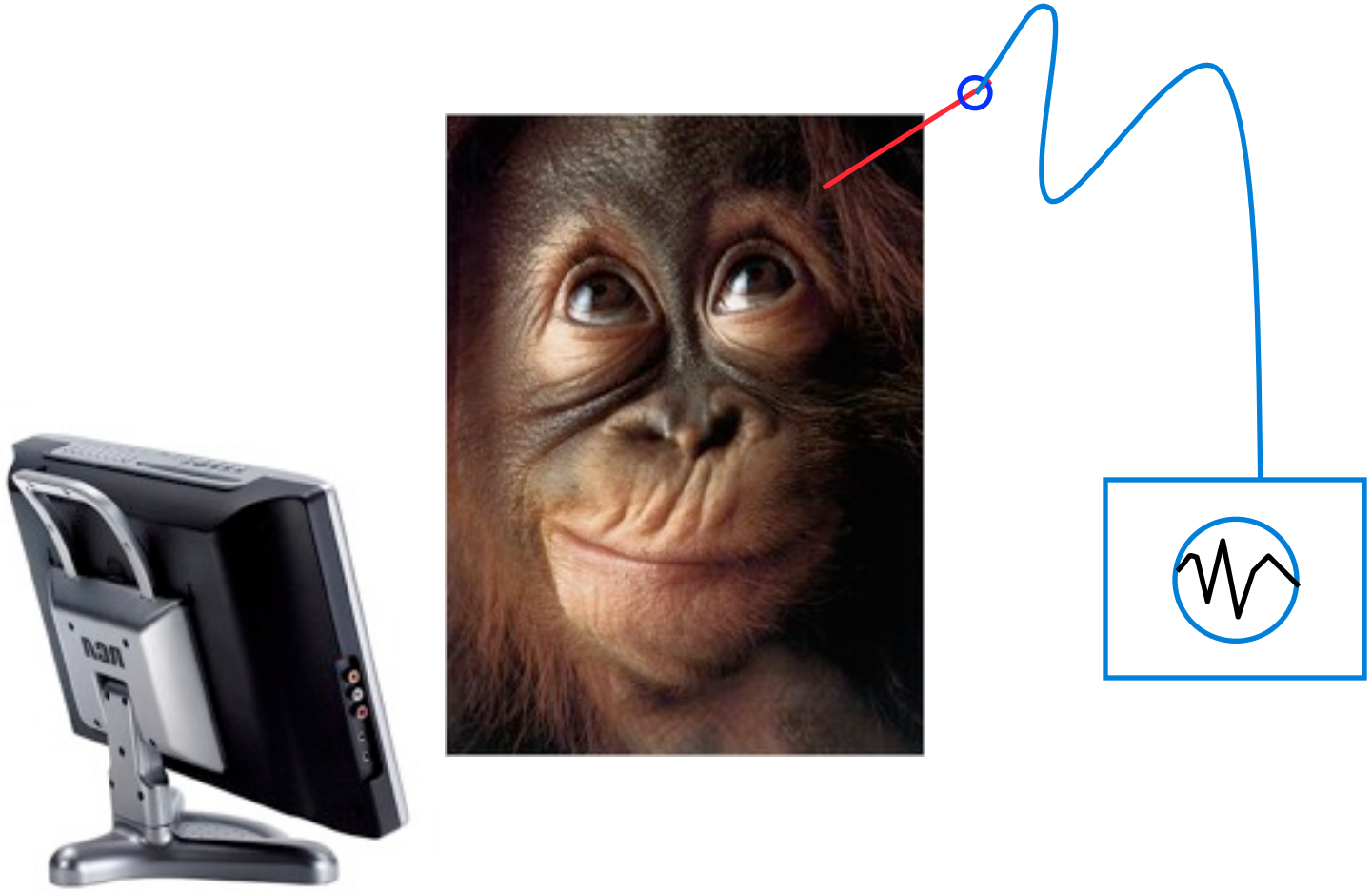

Eye
Optic nerve
Optic chiasm
Optic tract
Lateral geniculate nucleus
Optic radiations
Primary visual cortex

Histology

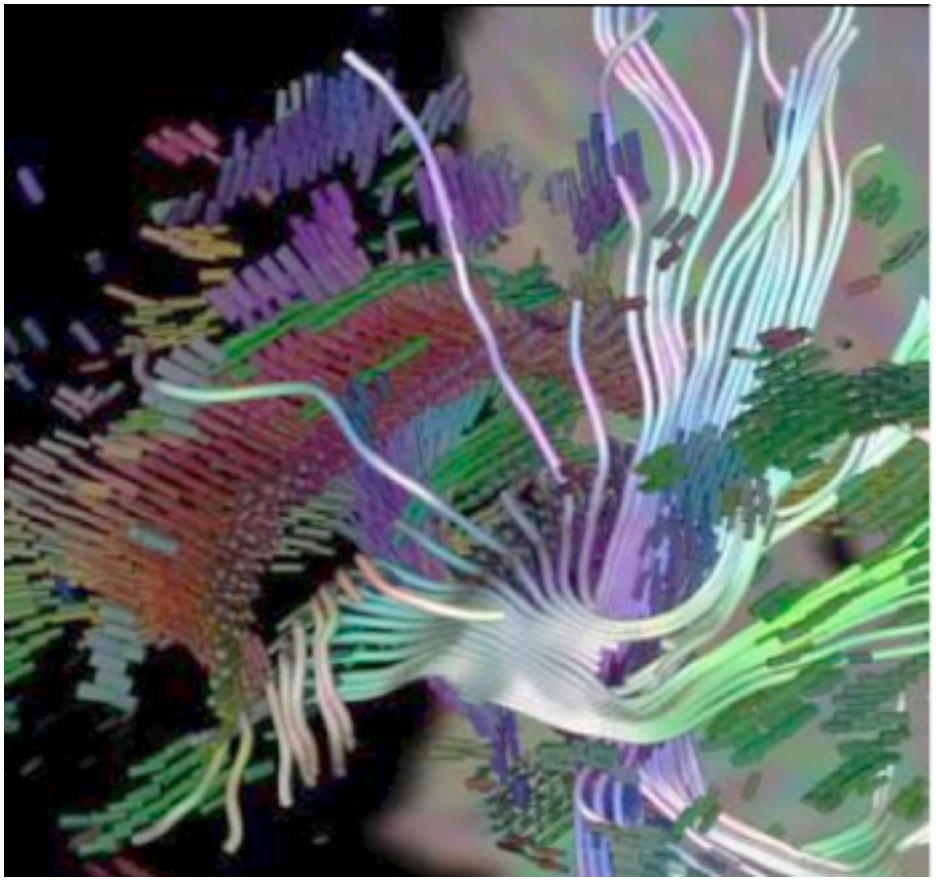




Animal Studies

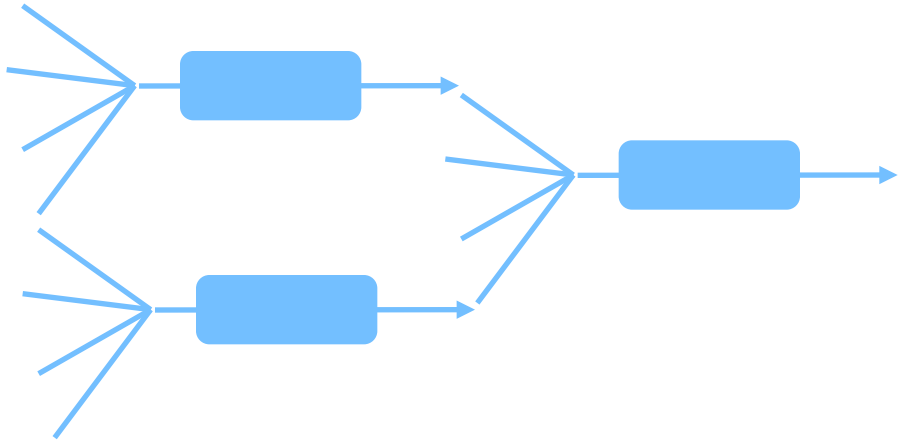


Functional / Structural Brain Imaging



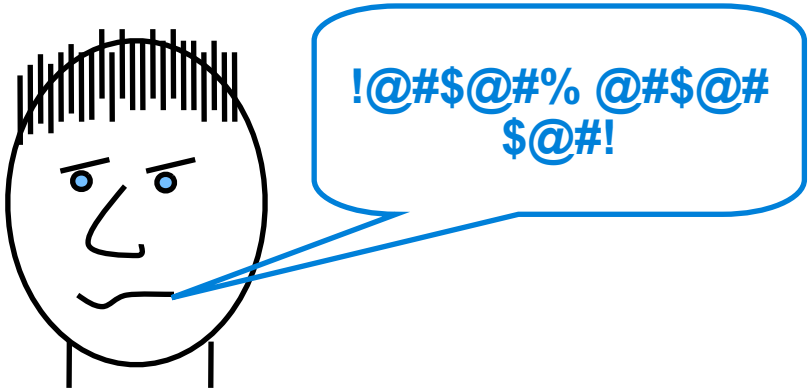
Modeling

- Try to predict particular aspects of vision via computer models
  - Neurons
  - Functional elements
- Build artificial systems that mimic behavior of real ones



Human Subjects: Psychophysics

- Subjects respond to stimuli and task
  - Verbal
  - Mechanical (e.g. button)



Various Approaches

- System – neurosciences
- Subjective experiences – psychophysics
- Illusions
- Evolutionary (role of vision for human survival)
- Pathways

Functions of Human Vision

- Shape/size
- Depth
- Motion
- Recognition

Properties of Vision

- Accurate relative to other senses
  - Location, size, and identification at a distance
- Limitations
  - Veridical perception is limited
  - Absolute judgments are often poor
  - Lack of quantification
- Good at
  - Relative judgments
    - *Time and space*
  - Identification

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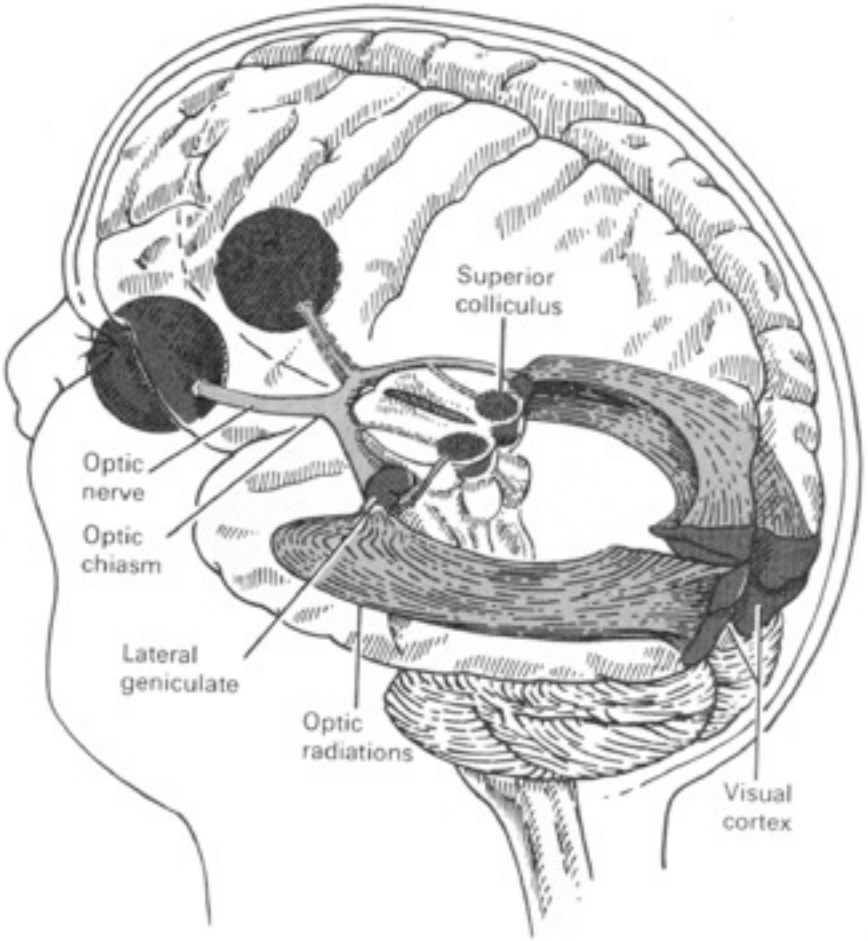
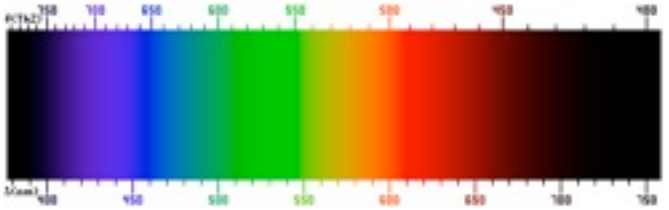
Human Vision Aspects

- Spatial Vision
- Depth
- Motion
- Color

System View

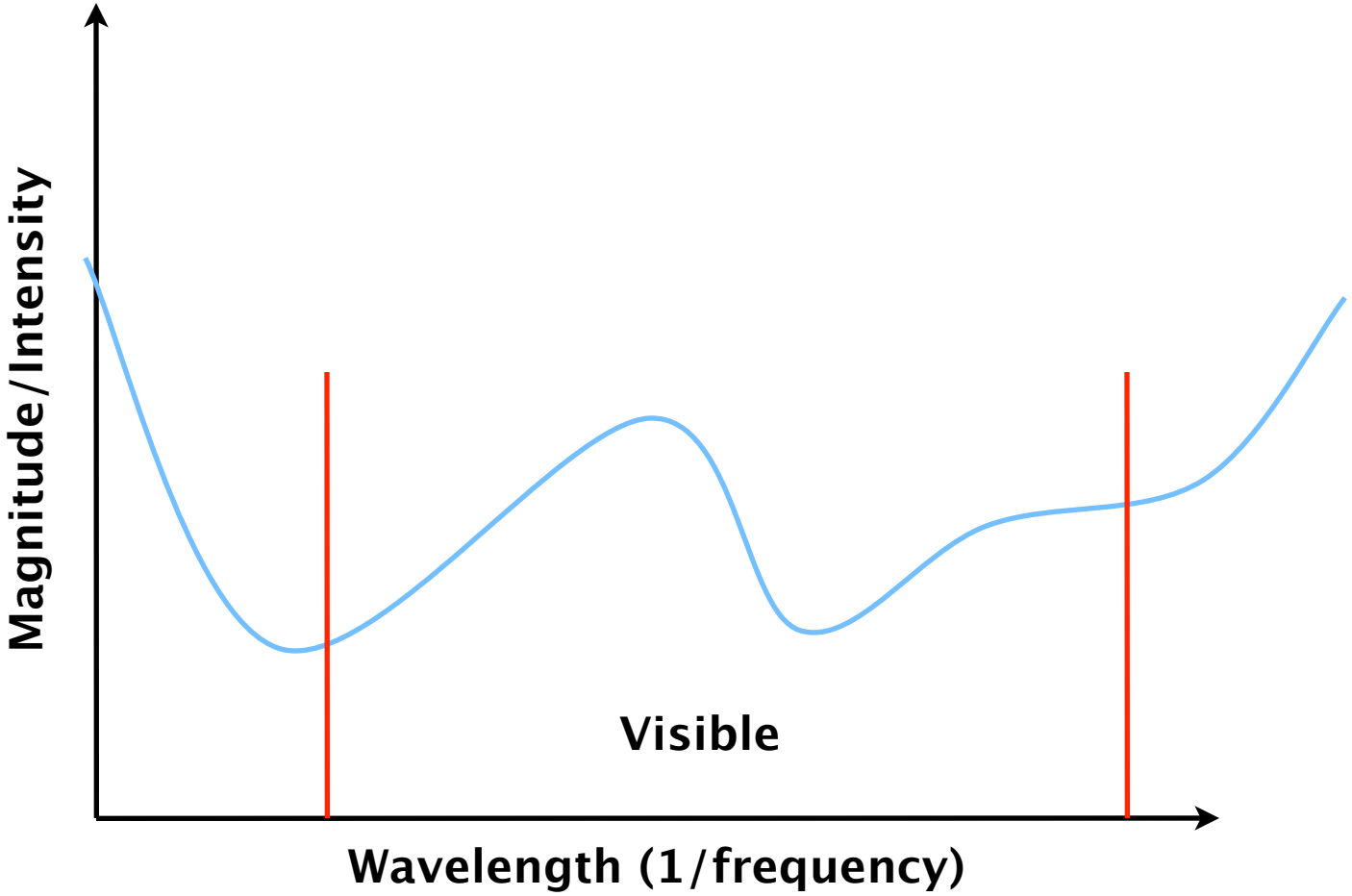

Superior colliculus
Optic nerve
Optic chiasm
Lateral geniculate
Optic radiations
Visual cortex

Light

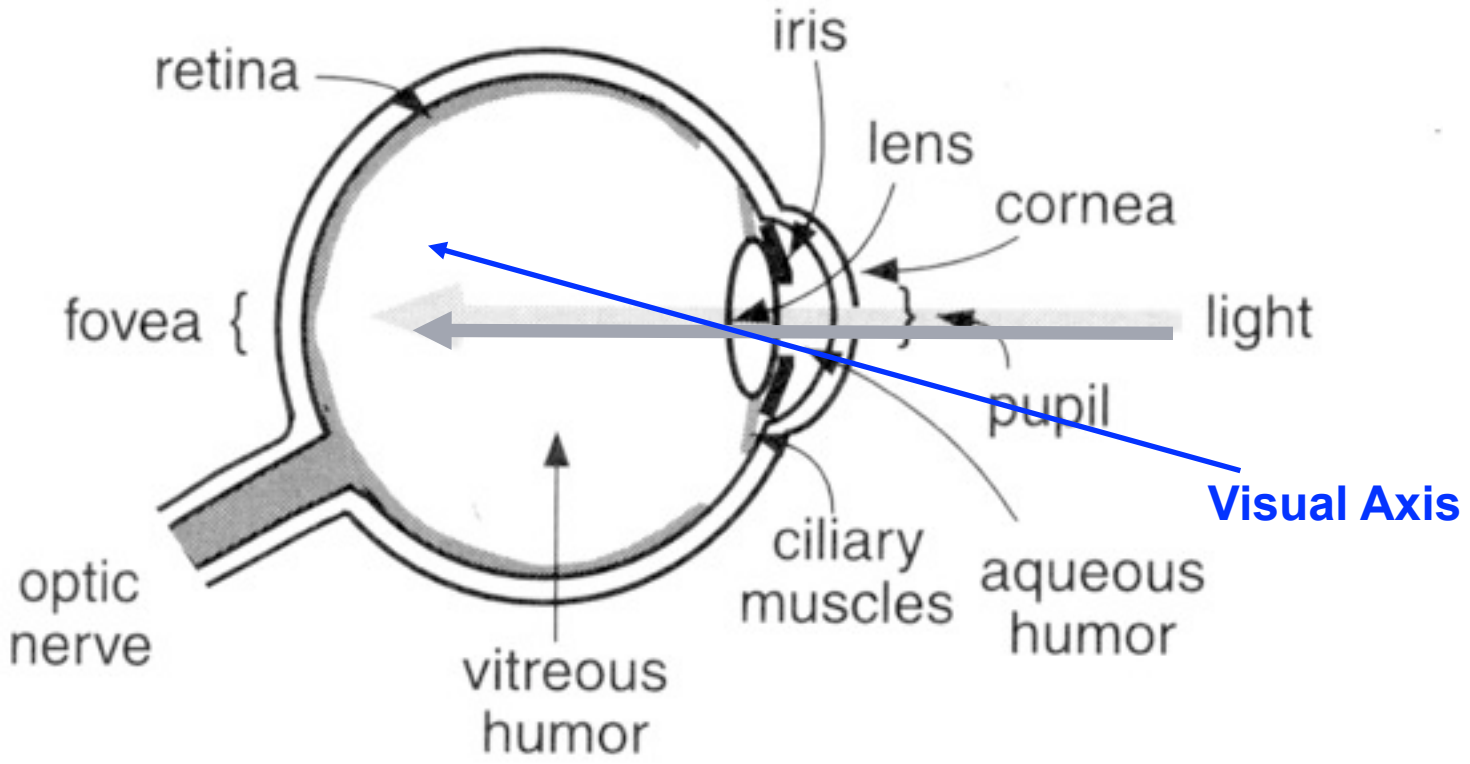


- Visible range: 390-700nm
- Luminance has a large dynamic range:
  - 0.00003 -- Moonless overcast night sky
  - 30 -- Sky on overcast day
  - 3000 -- Sky on clear day
  - 16,000 -- Snowy ground in full sunlight
- Colors result from spectral curves
  - dominant wavelength, hue
  - brightness, lightness
  - purity, saturation

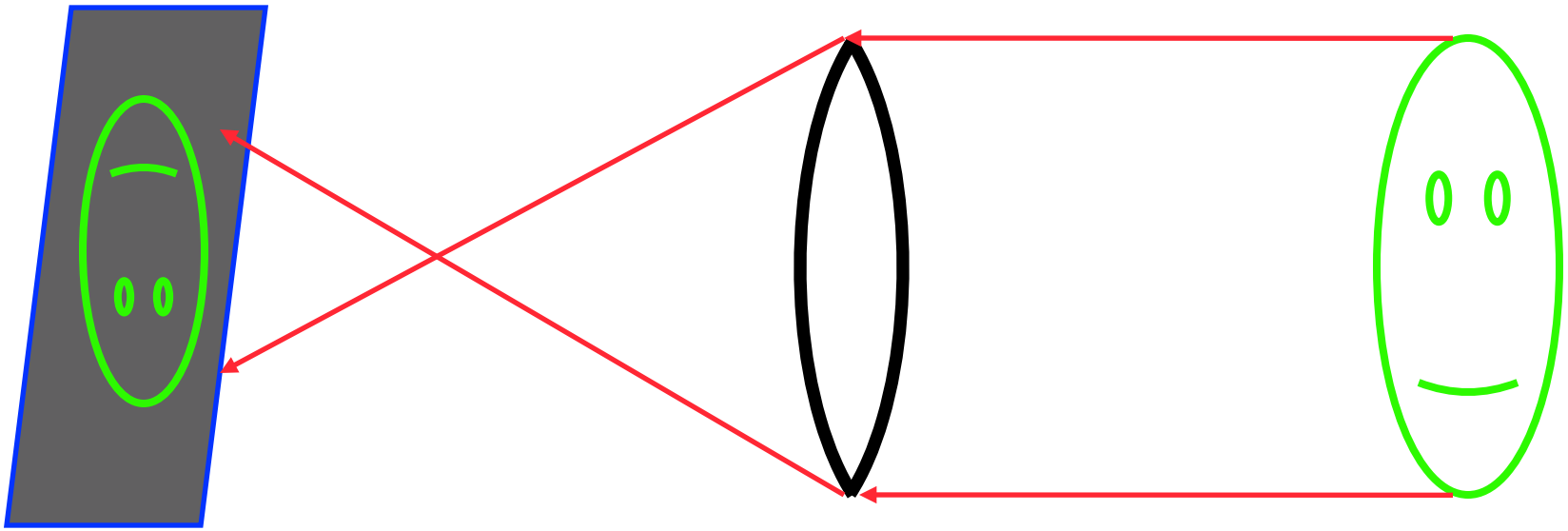
Spectral Curve (of incoming radiation)



Physiology: Eye



Perspective Projection and Image Formation



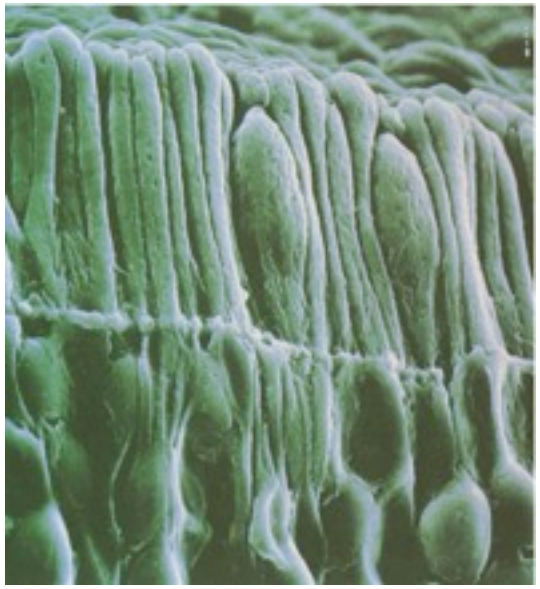
Physiology: Photoreceptors

Discrete sensors that measure energy

- Adaptation

Rods

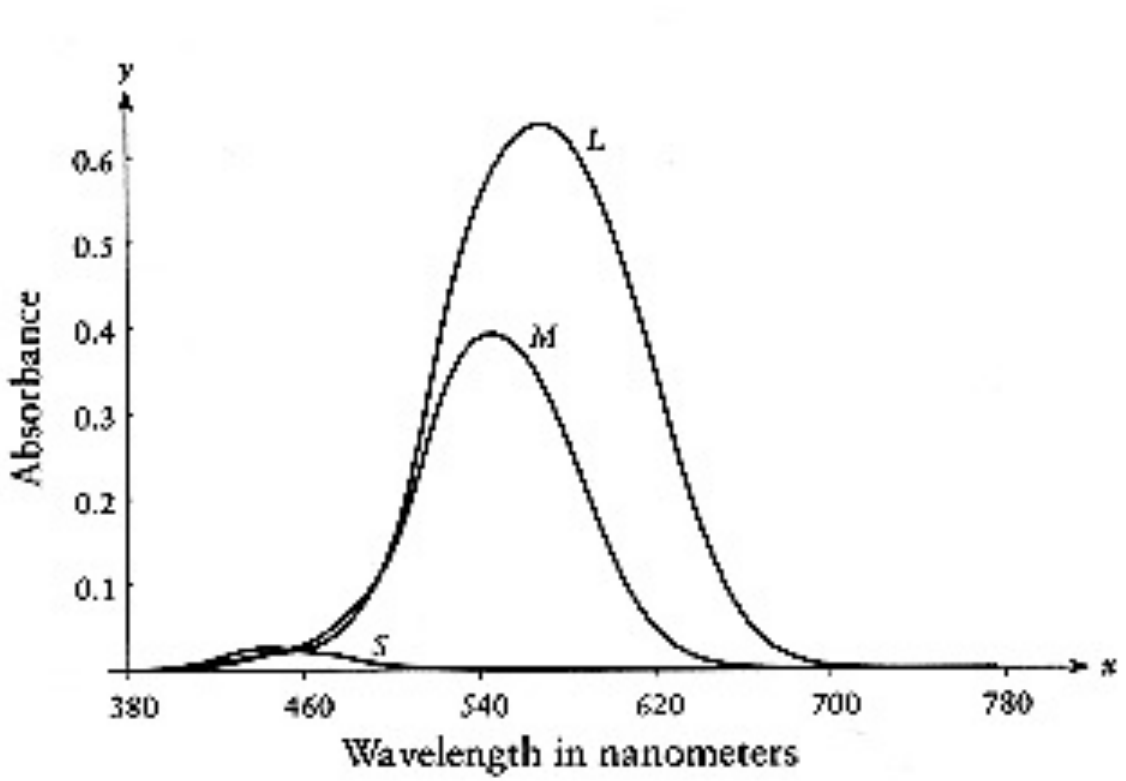
- active at low light levels (scotopic vision)
- only one wavelength-sensitivity function



Cones

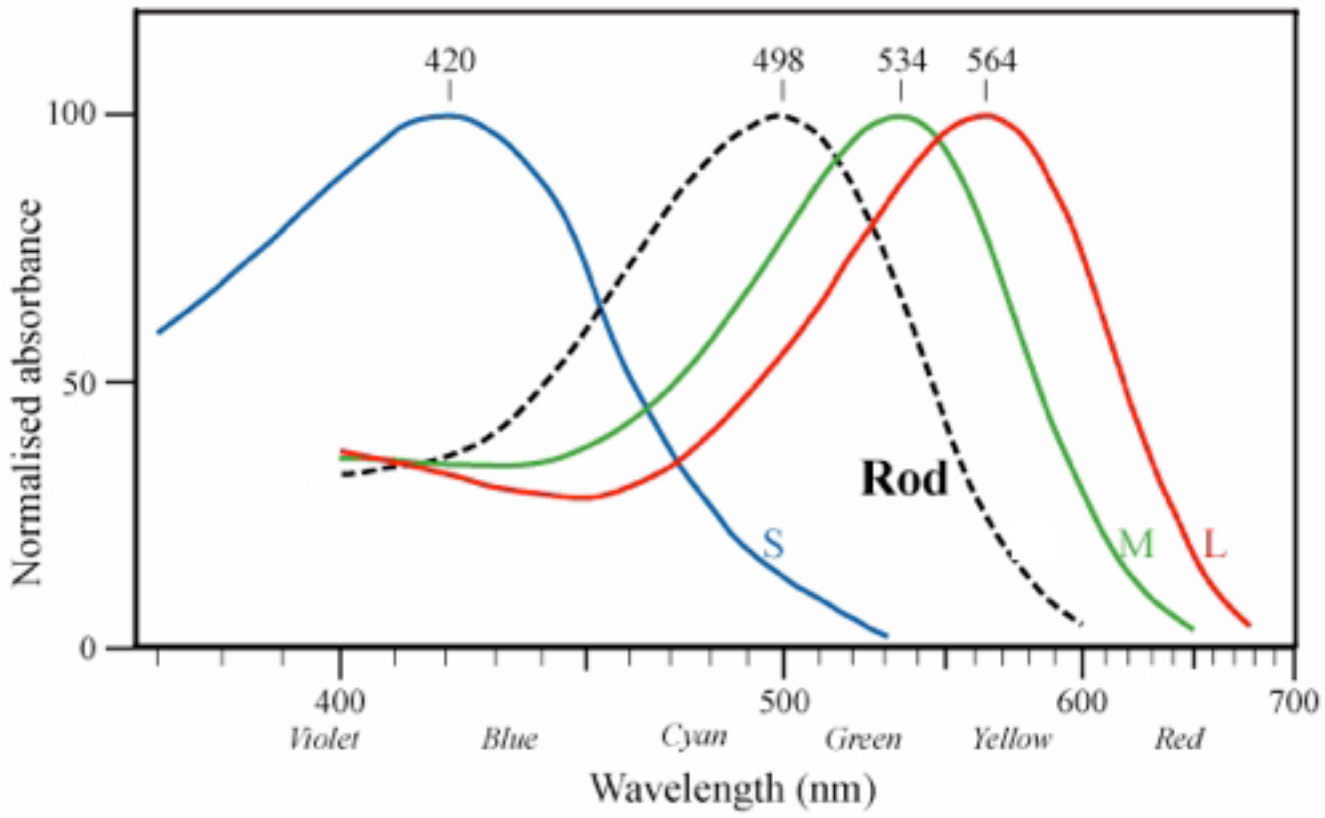
- active at normal light levels (photoptic)
- three types: sensitivity functions with different peaks

Cone Sensitivity Functions

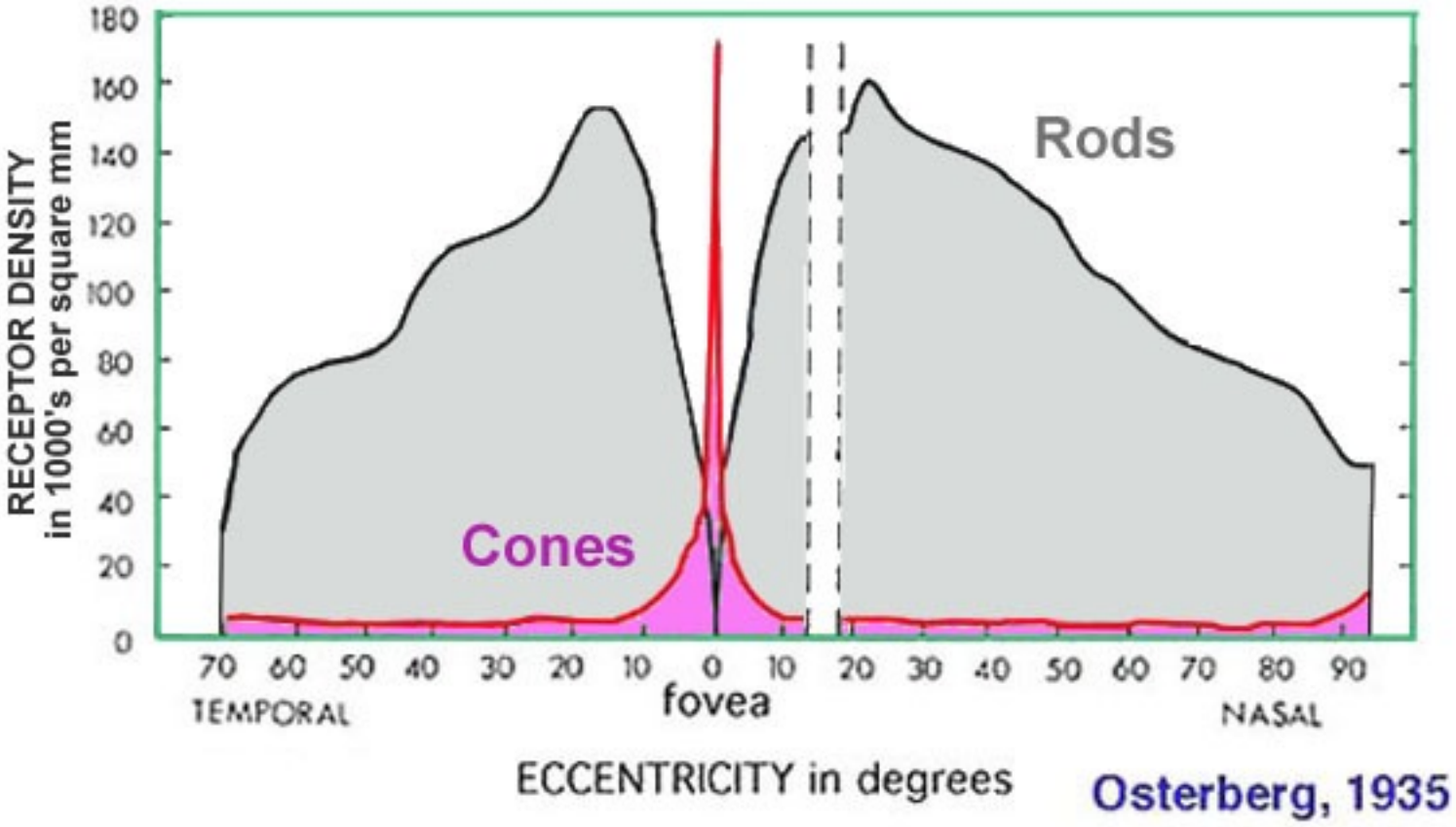


Glassner '95, p. 16.

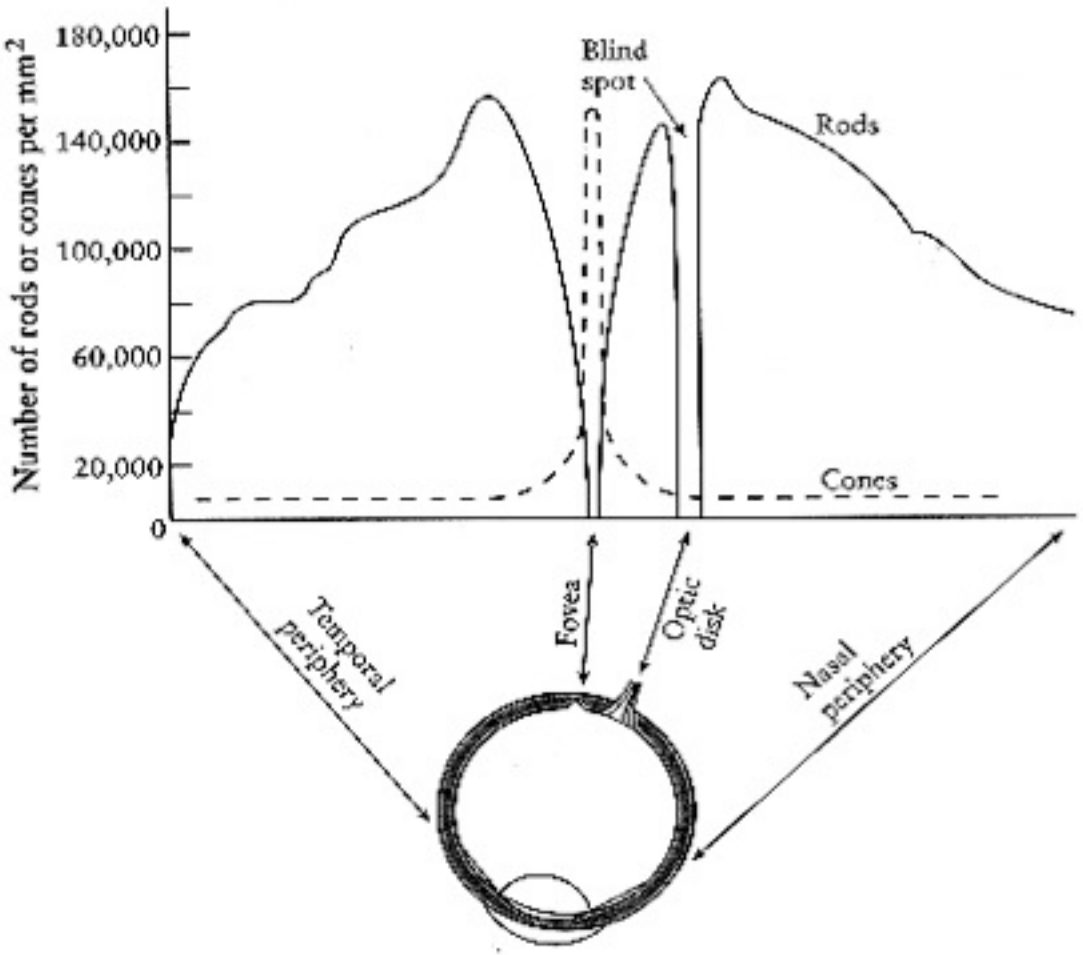
Cone Sensitivity Functions



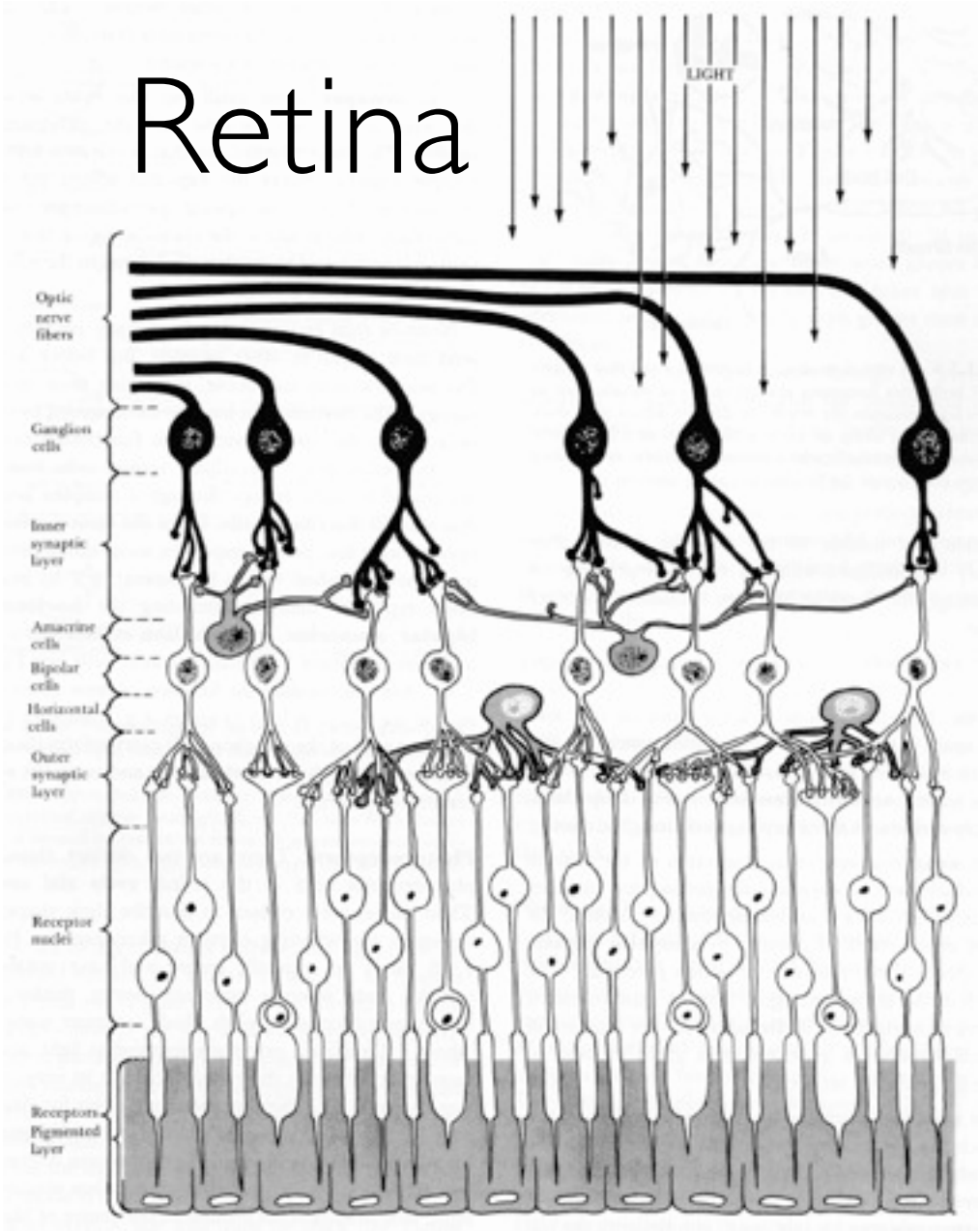
Rod Sensitivity Function



Rod Sensitivity Functions



Retina


LIGHT
Optic nerve fibers
Ganglion cells
Inner synaptic layer
Amacrine cells
Bipolar cells
Horizontal cells
Outer synaptic layer
Receptor nuclei
Receptors
Pigmented layer

Physiology: Ganglia

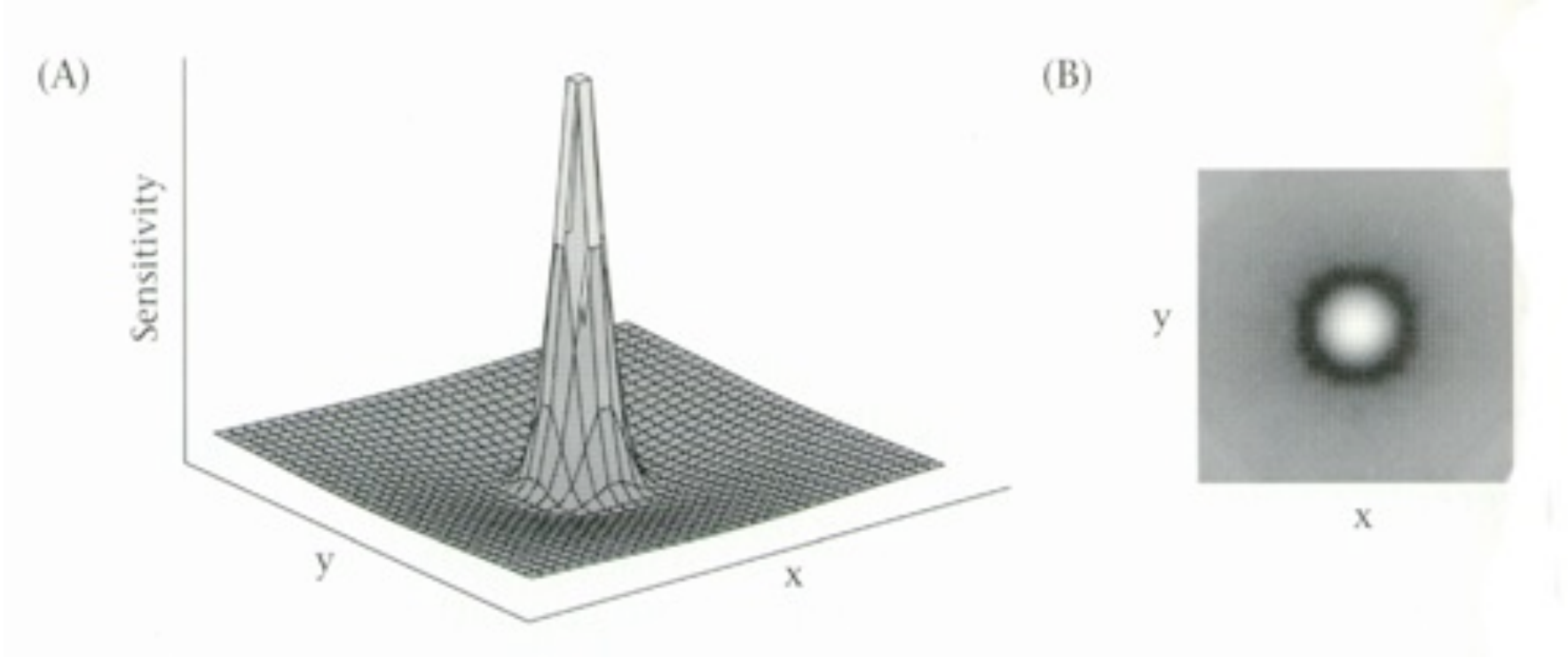
Transform incoming SML into opponent color responses

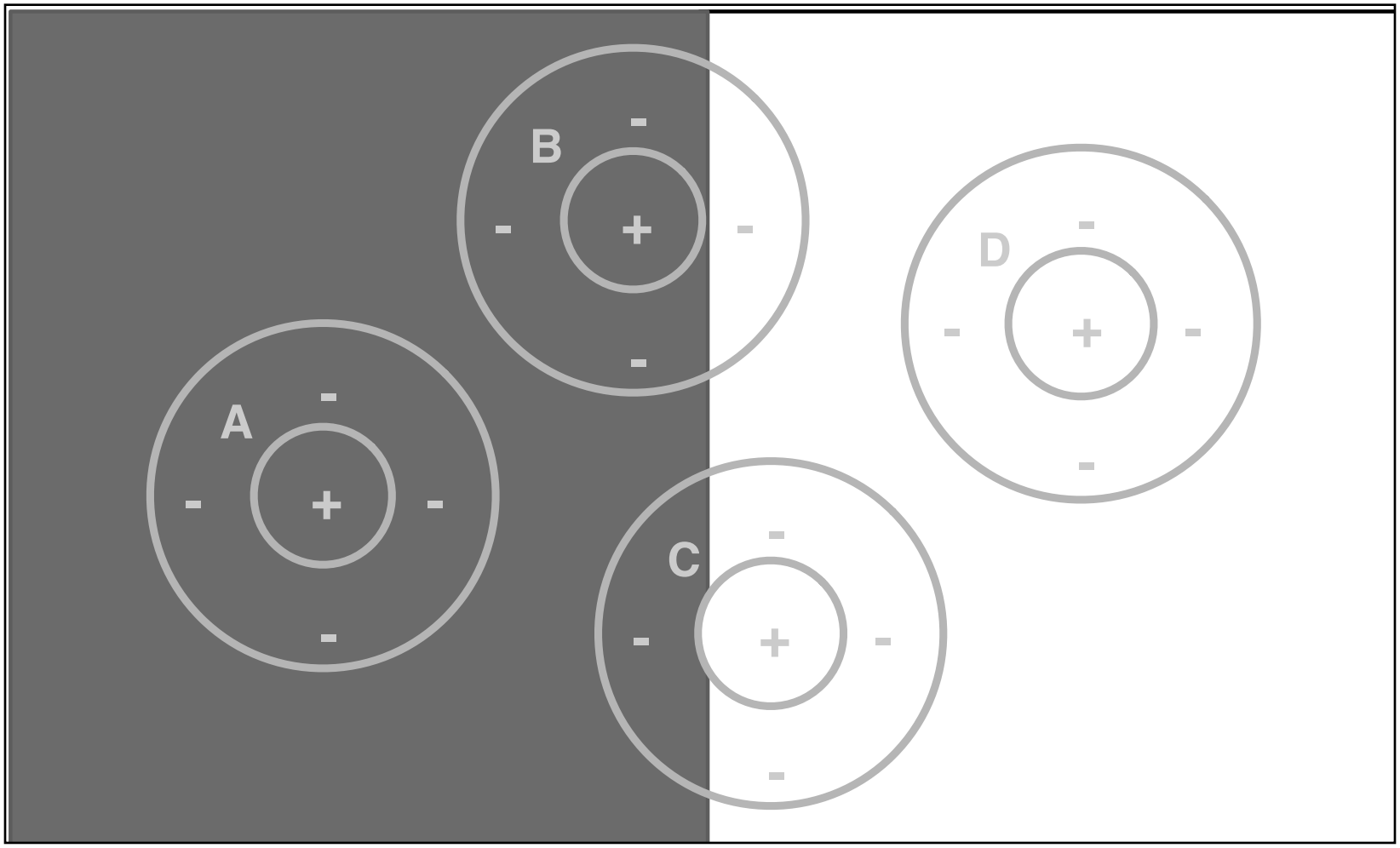
- G - R
- Y - B (Y = R+G)
- W (W ≅ R+G)

Characteristics

- concentric receptive fields
- logarithmic response of receptors
- adaptation

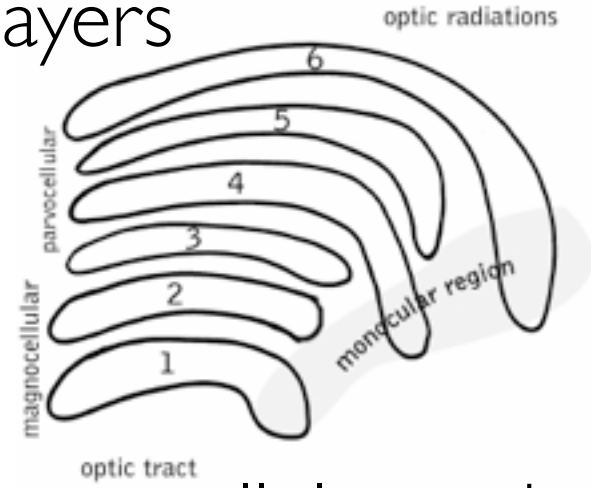
Center-surround Receptive Fields




A
B
C
D
+
-

Physiology: Brain Lateral Geniculate Nuclei (LGN)

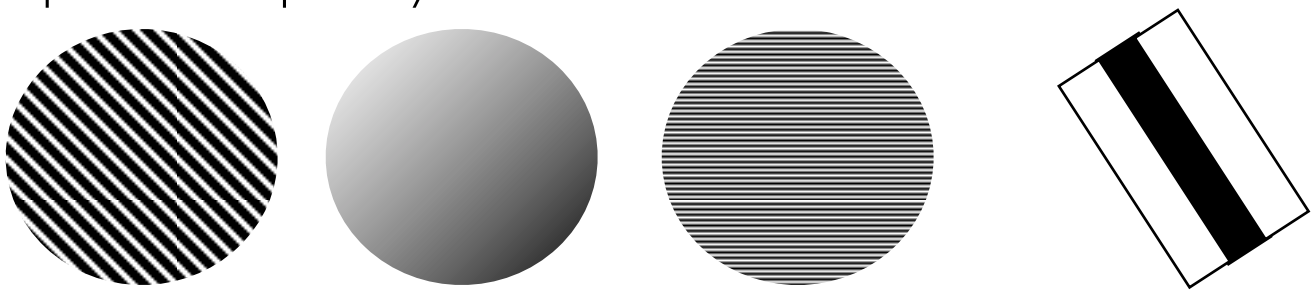
- Assemble data for single side of visual field
- sheets of neurons arranged in layers
- Retinotopic mapping



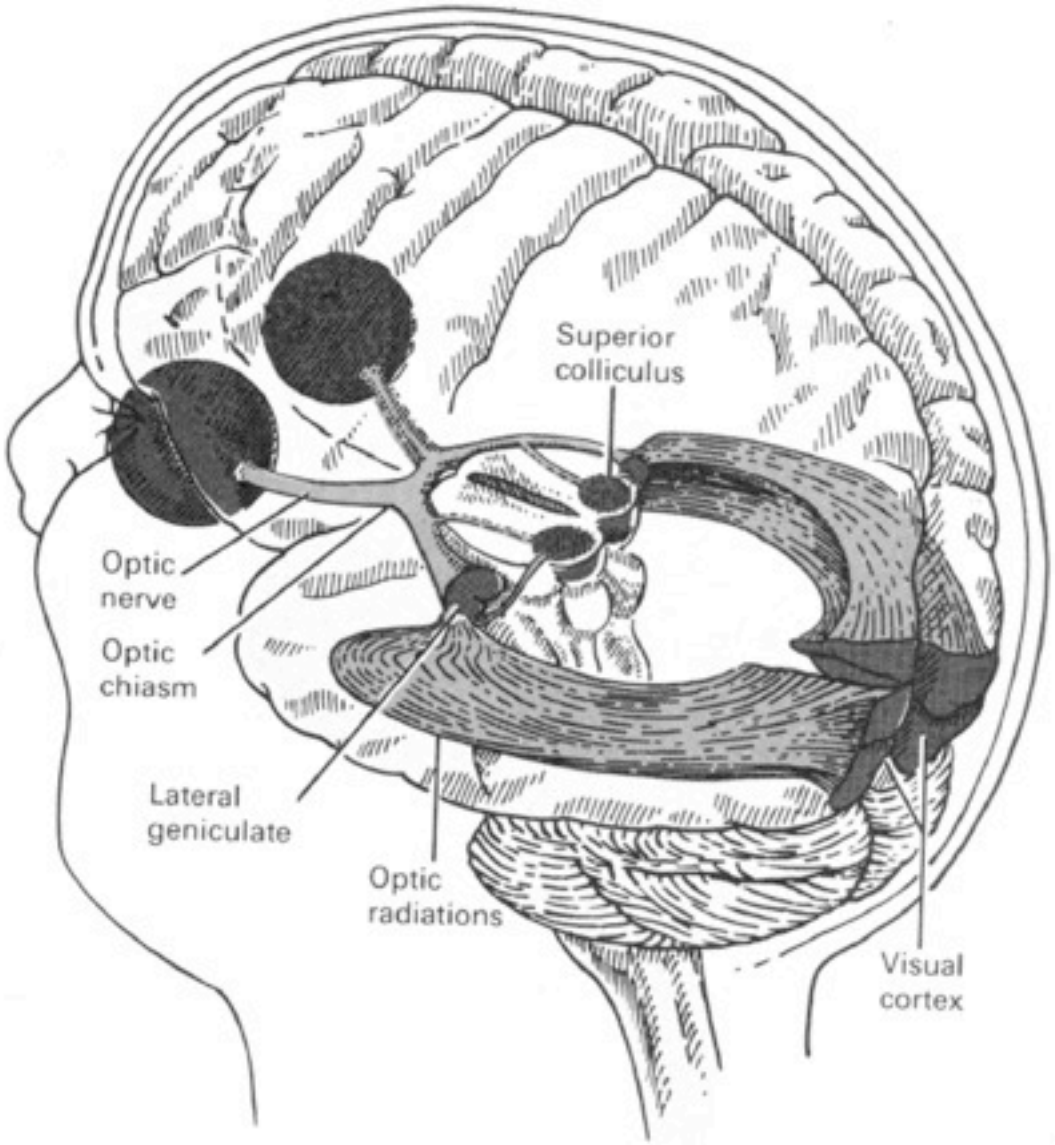
- 2 monochromatic layers => magnocellular path
- 4 chromatic layers => parvocellular path

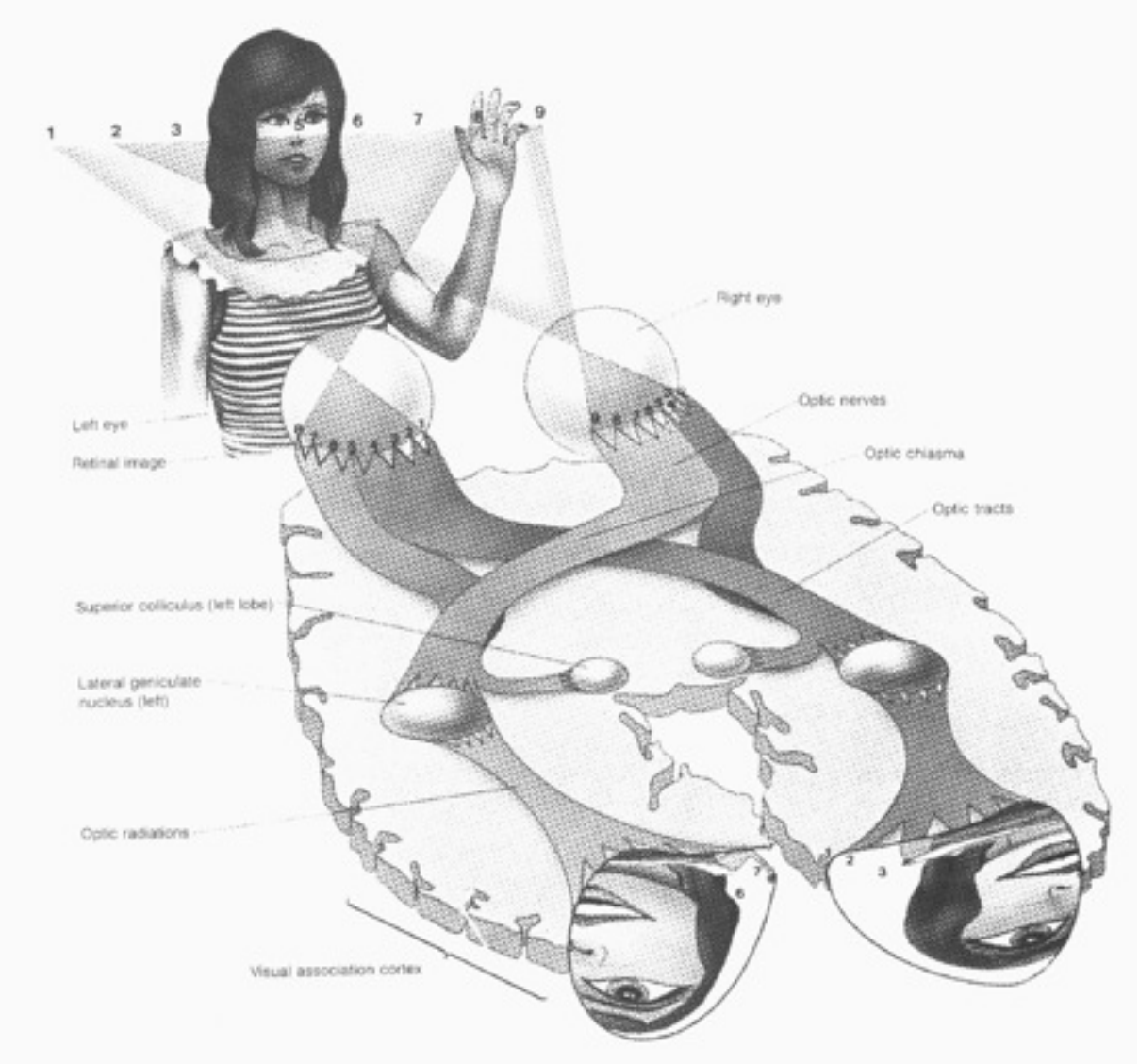
Physiology: Brain

- Visual cortex
  - orientation
  - simple vs. end-stopped cells (length specific)
  - binocular w/ocular dominance
  - spatial frequency



- Feedback from cognitive levels to earlier stages


Superior
colliculus
Optic
nerve
Optic
chiasm
Lateral
geniculate
Optic
radiations
Visual
cortex


1
2
3
6
7
9
Right eye
Optic nerves
Optic chiasma
Optic tracts
Left eye
Retinal image
Superior colliculus (left lobe)
Lateral geniculate nucleus (left)
Optic radiations
Visual association cortex

Magnocellular Division

- Role in vision
  - identify objects and boundaries
  - depth perception
  - motion perception
- Characteristics
  - color: achromatic
  - acuity: large RF centers
  - speed: fast, transient response

Parvocellular Division

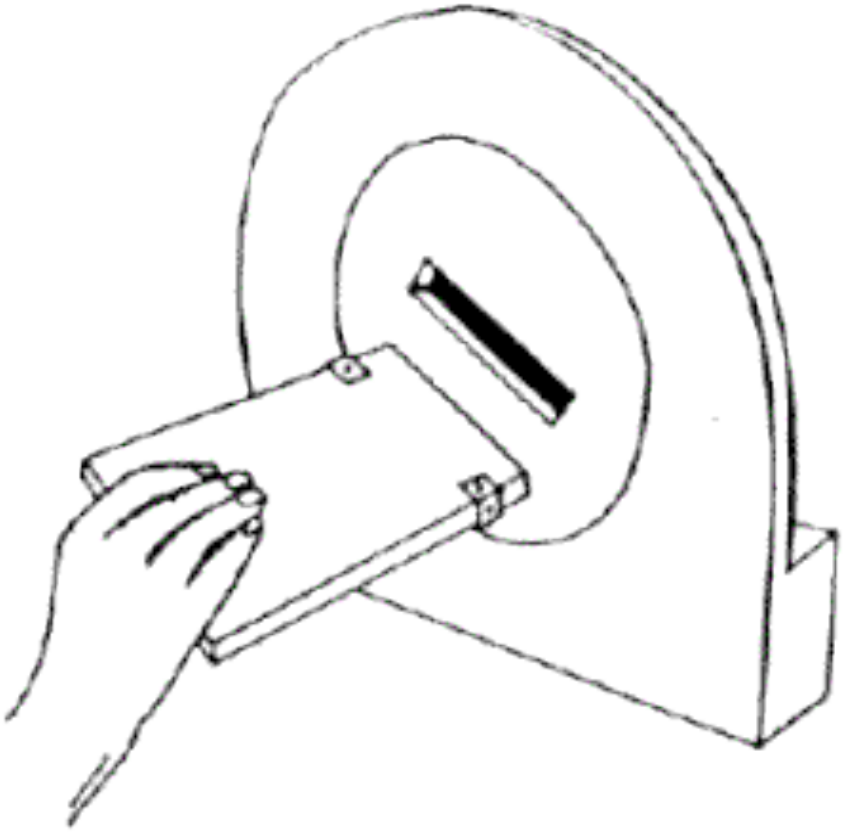
- Role in vision
  - discrimination of fine detail
  - color
- Characteristics
  - color: sensitive to wavelength variations
  - acuity: small RF centers
  - speed: relatively slow response (static)

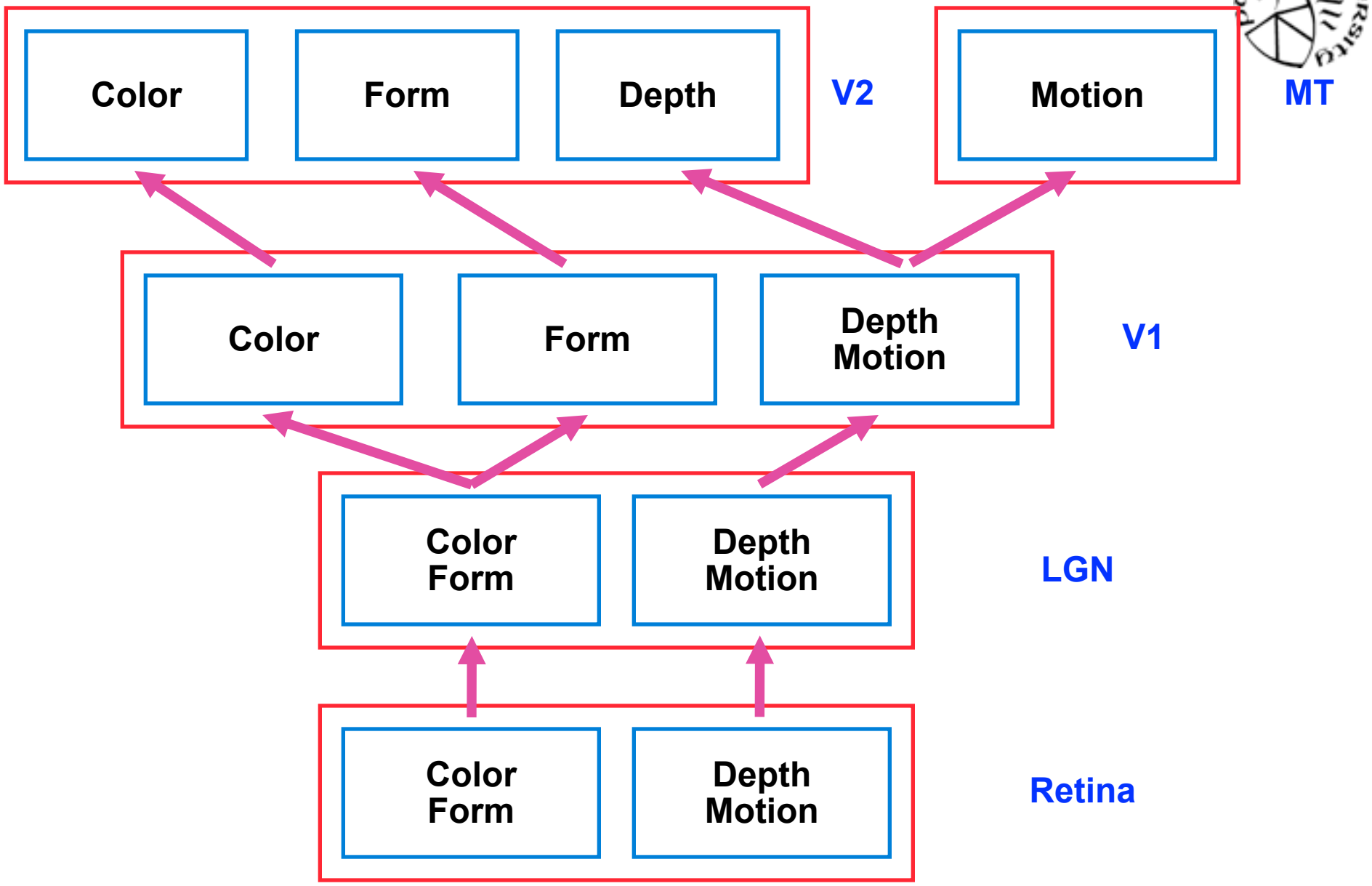
Visual Pathways: A Theory/Model

- Pathways process information differently
- Information gets combined as needed
- Different levels of distinction (granularity)

	"What" pathway	"Where" pathway
Information	Object Vision: color, shape, texture	Spatial Vision: depth, motion, location
Color	Uses/carries color info	Brightness only
Contrast	Requires large contrast differences	Sensitive to small differences in brightness
Speed	Slower	Faster, more transient
Duration	Longer	Shorter
Acuity (res.)	Higher	Lower (factor of 2-3)
Visual Field	Only central (fovea)	Central & perirpheral
Age (evol.)	Younger	Older
Other senses	Only visual info	Combined with auditory & other info

Where: Link of visual and motor skills




Color
Form
Depth
V2
Motion
MT
Color
Form
Depth
Motion
V1
Color
Form
Depth
Motion
LGN
Color
Form
Depth
Motion
Retina

System Characteristics

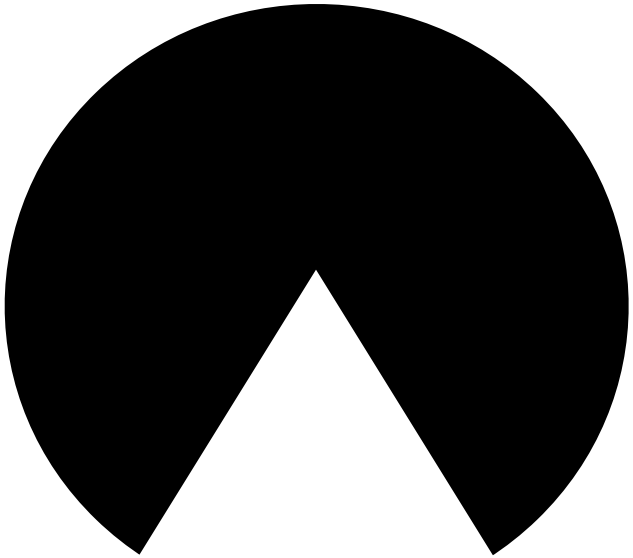
- Contrast sensitivity influenced by spatial frequency
- Adaptation
- Communication between neighboring receptors
- Illusions

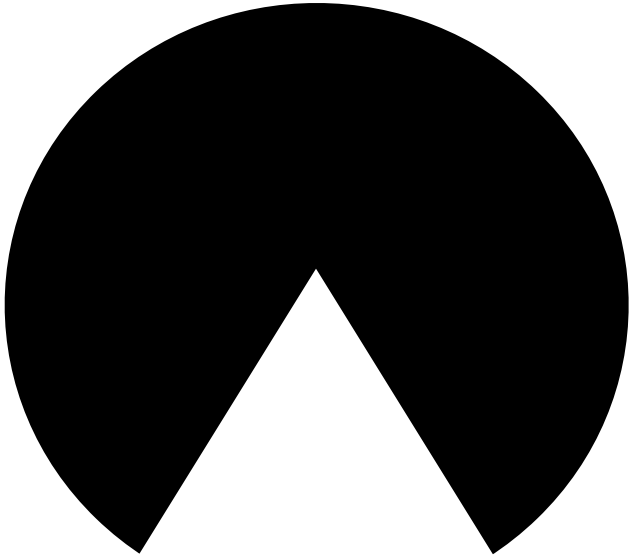
Communication between Receptors

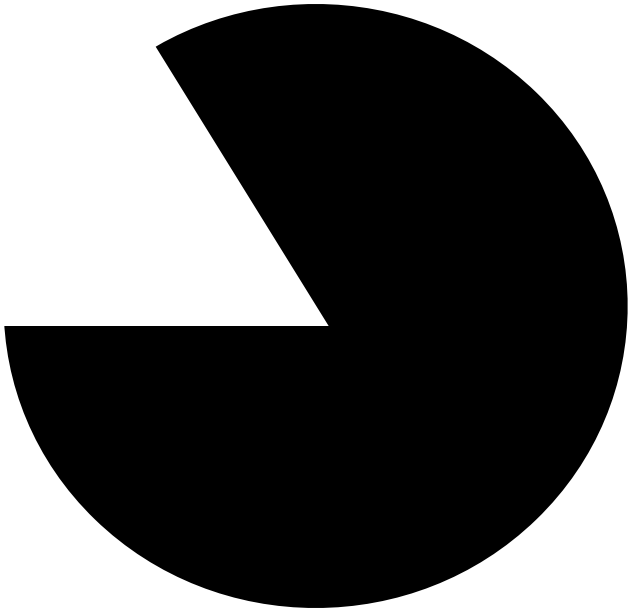
- Edge completion: subjective contours
- Relative judgments
  - intensity
  - size
  - slope
- Constancy
  - lightness
  - simultaneous contrast
- Tolerance of noise

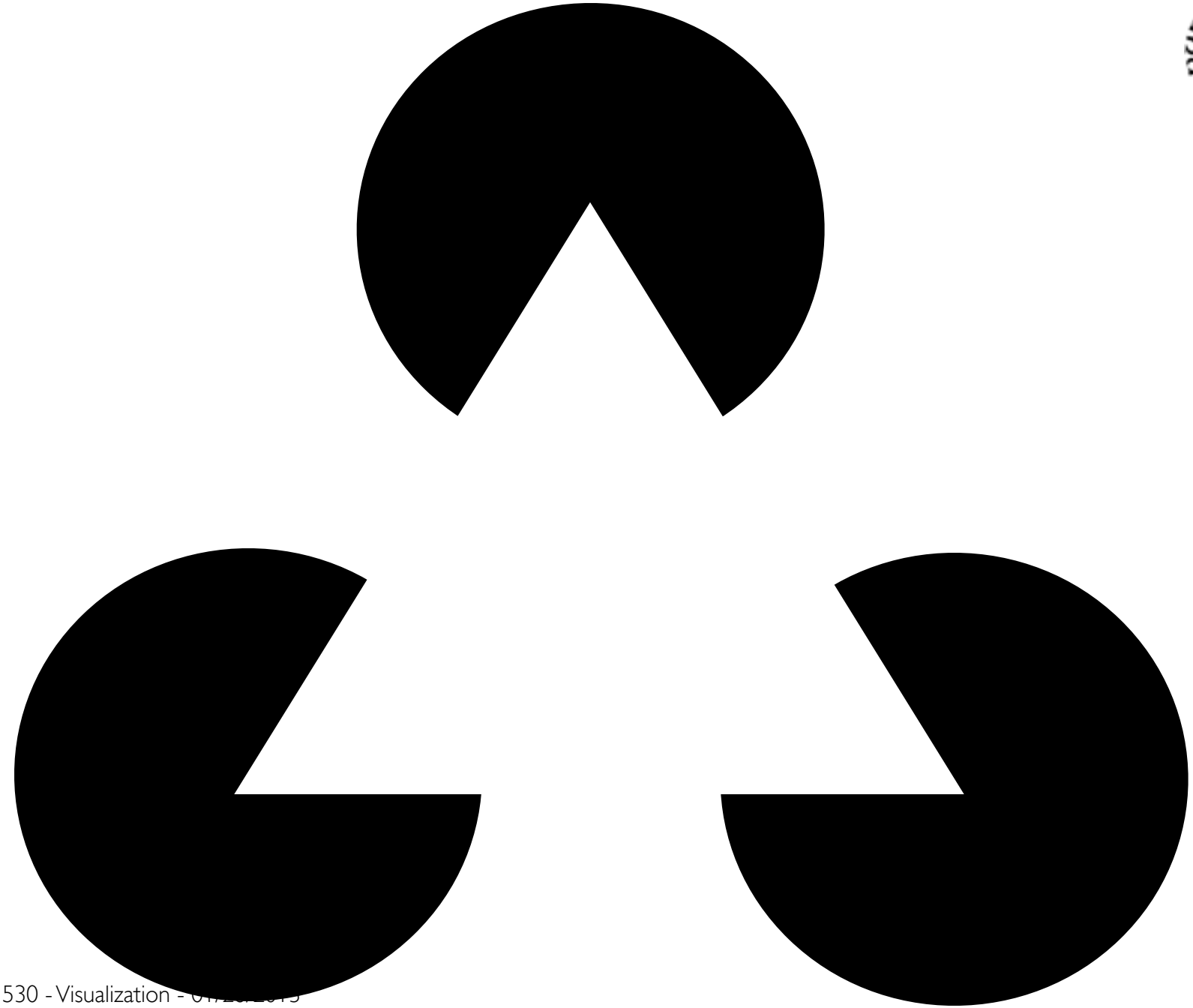
Constancy

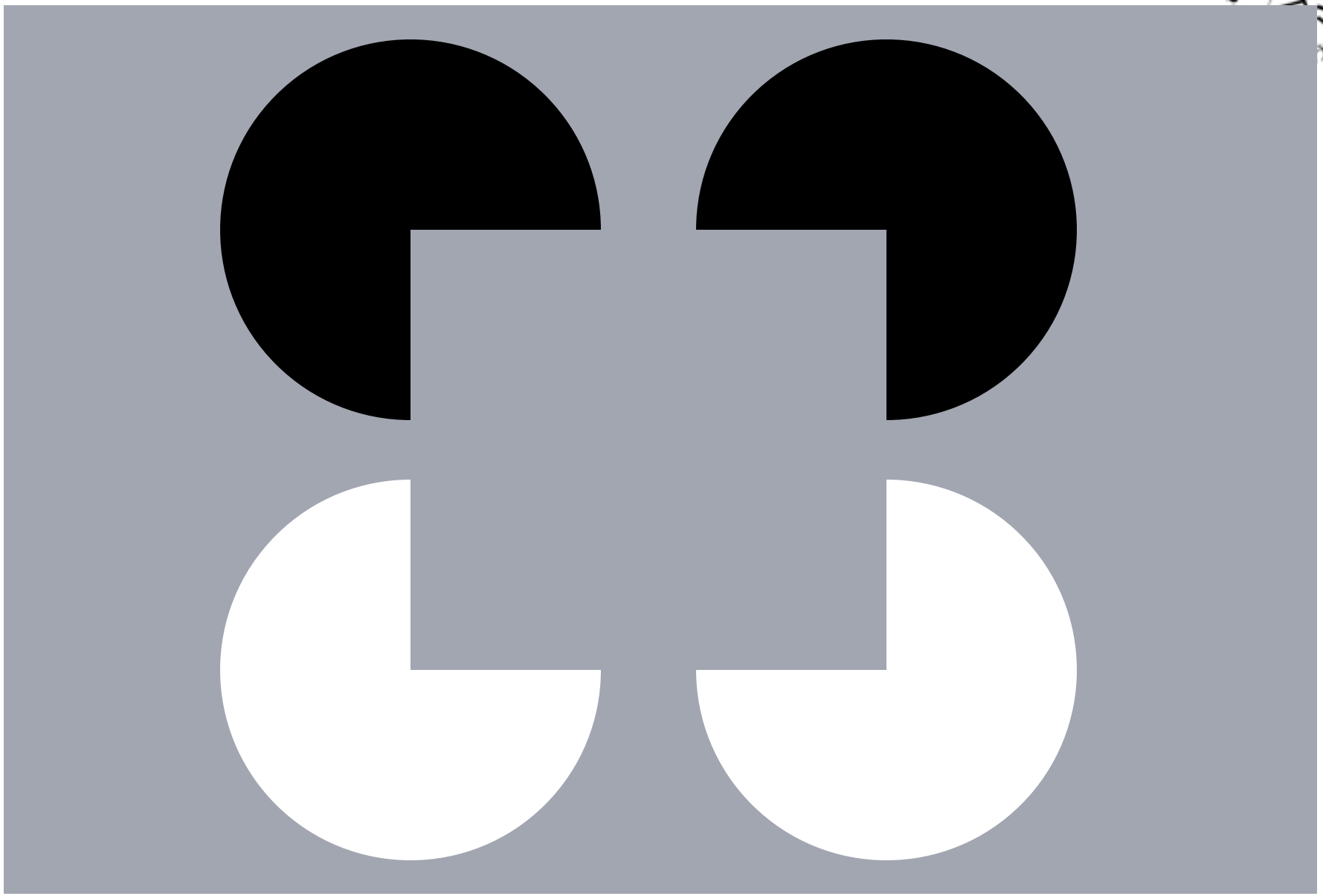
- Distal stimulus - objects in the 3D world
- Proximal stimulus - pattern on the retina
- Constancy - tendency to perceive the unchanging properties of the distal stimulus rather than the transient properties of the proximal stimulus
- Invariants - quantities that do not change under a set of transformations

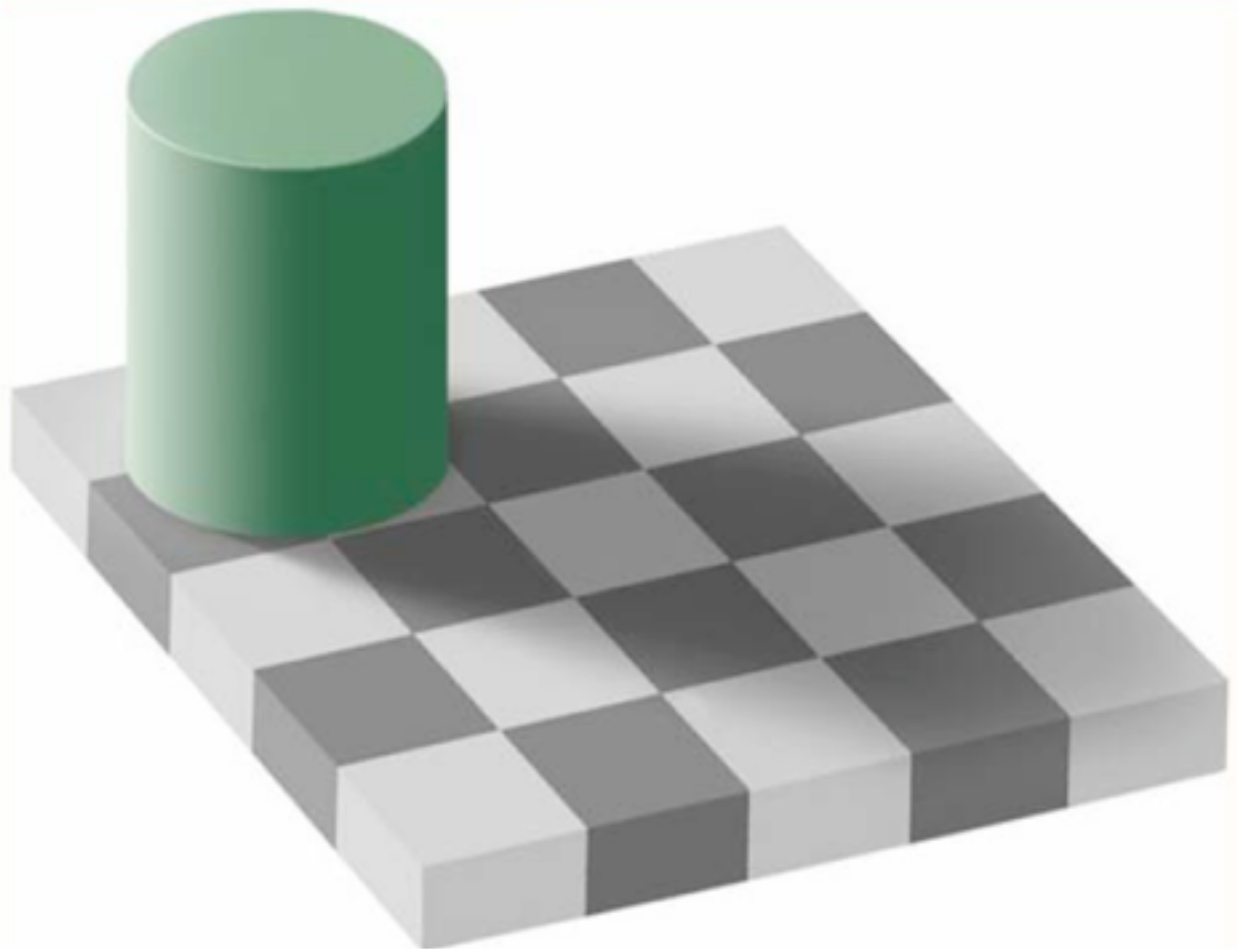


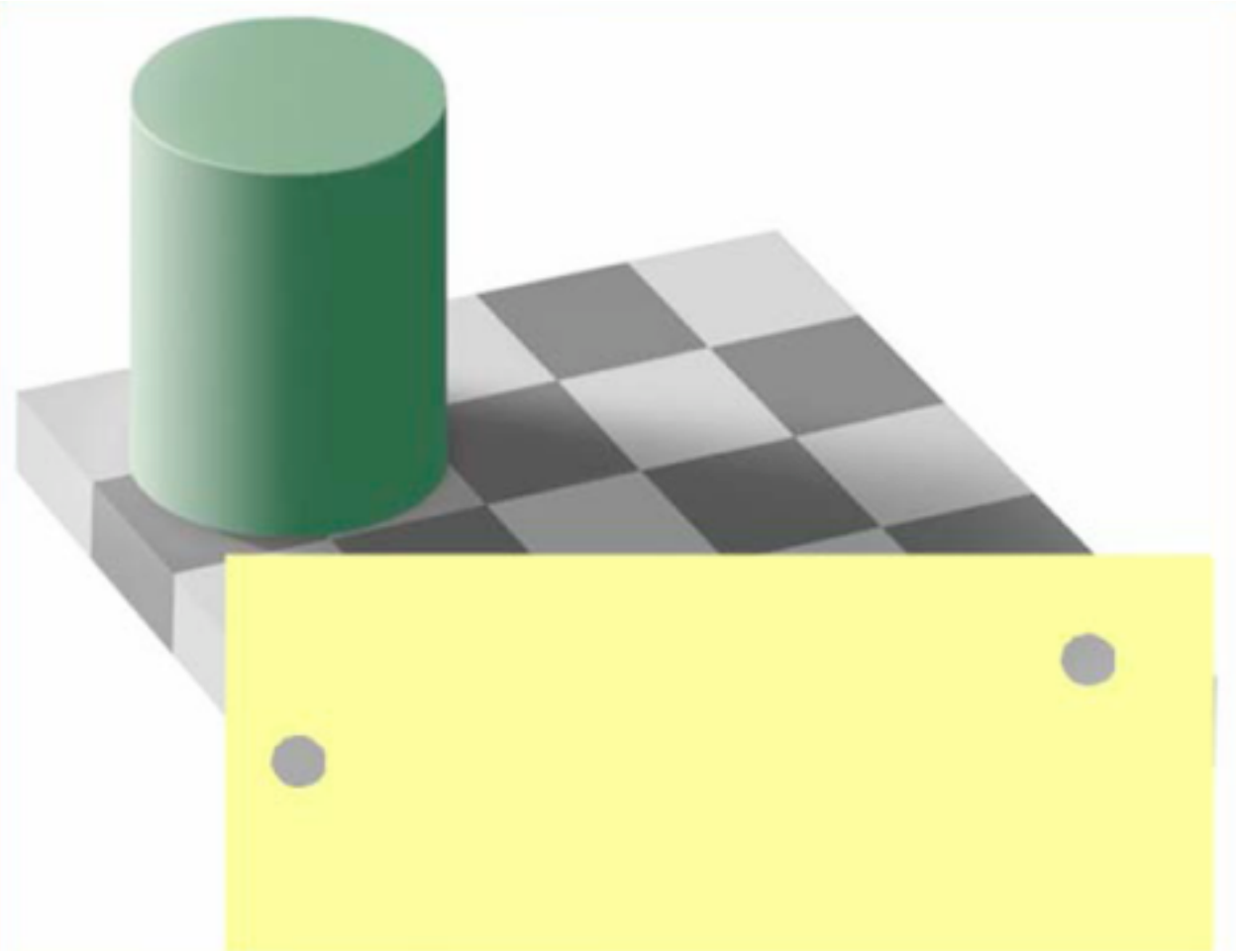


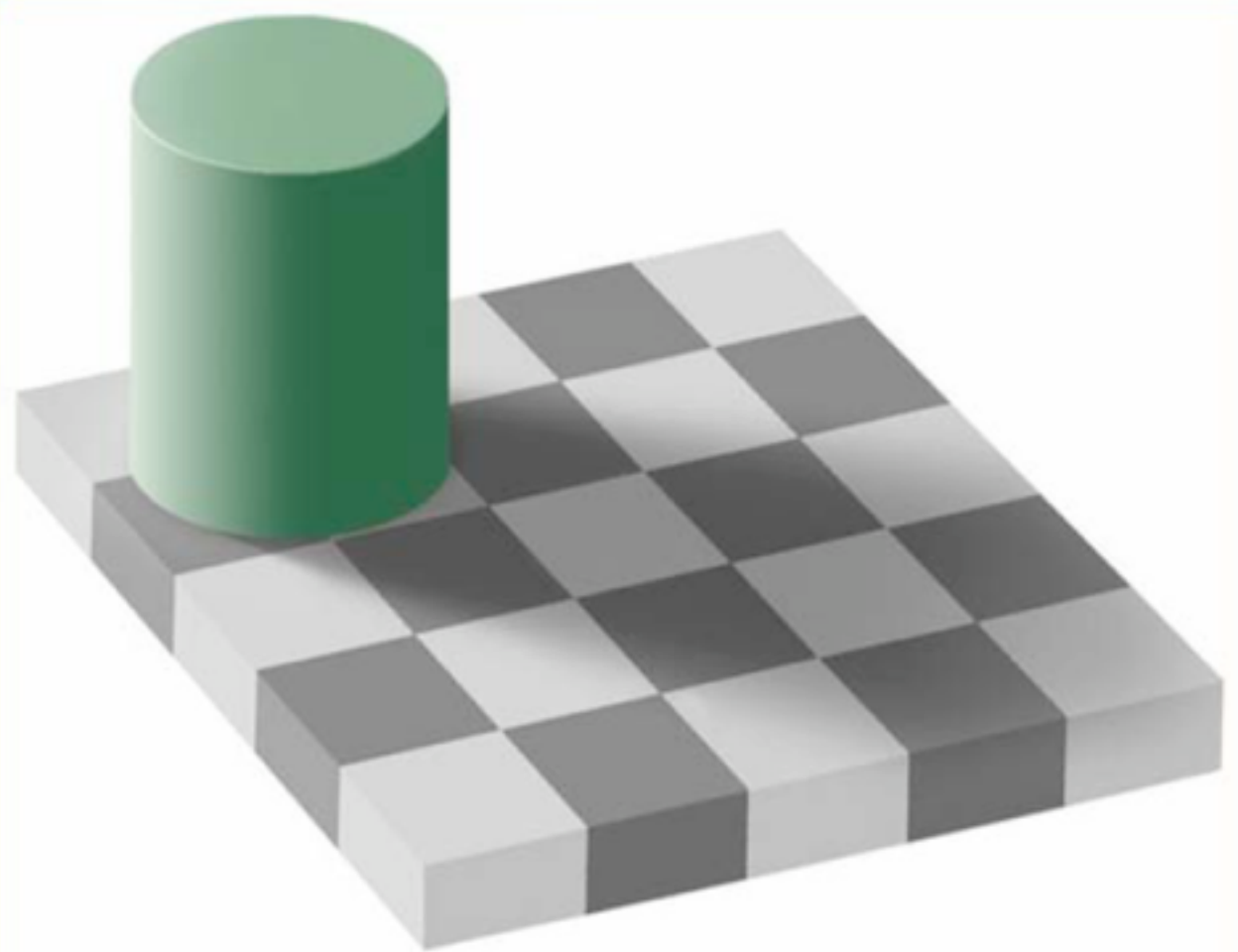


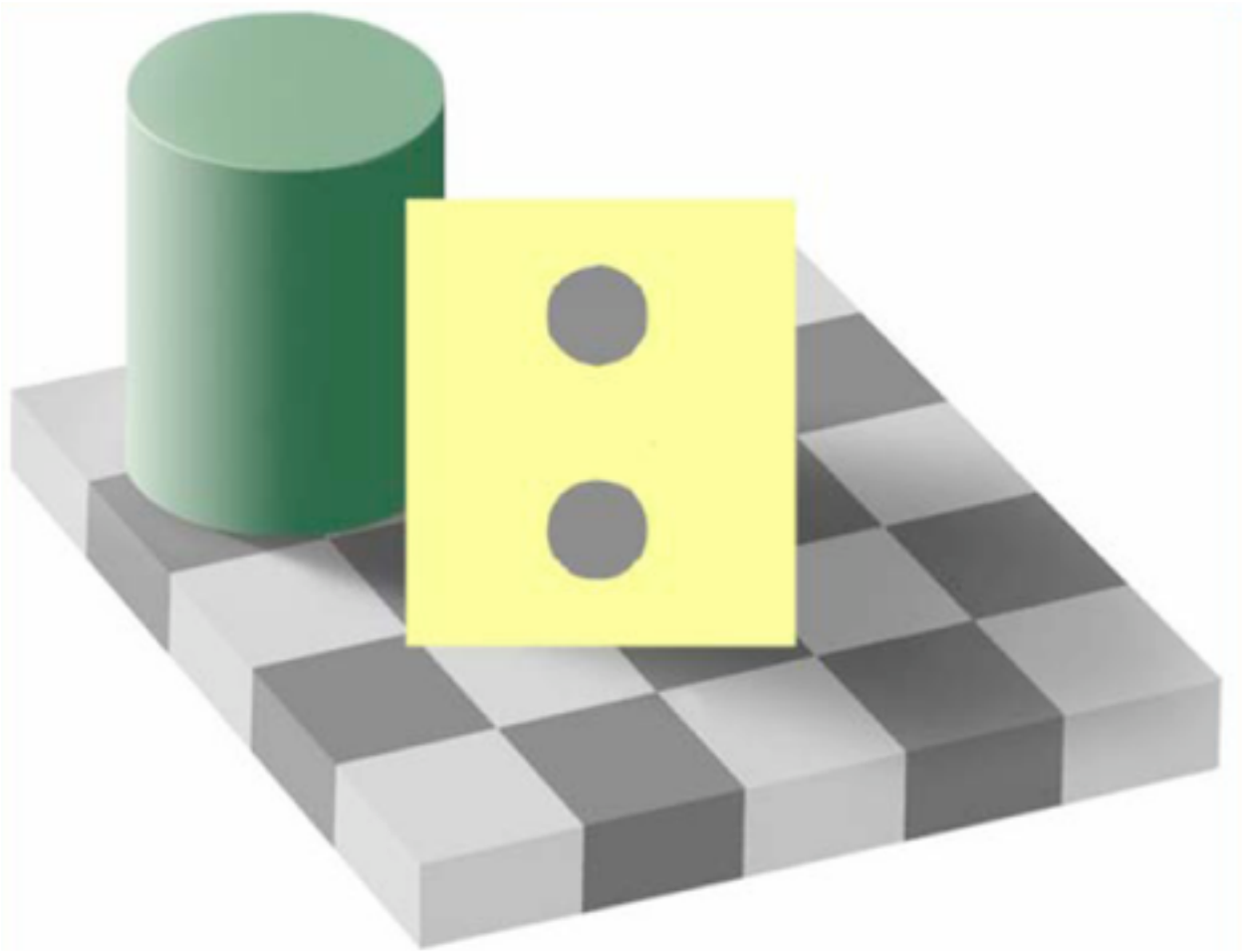


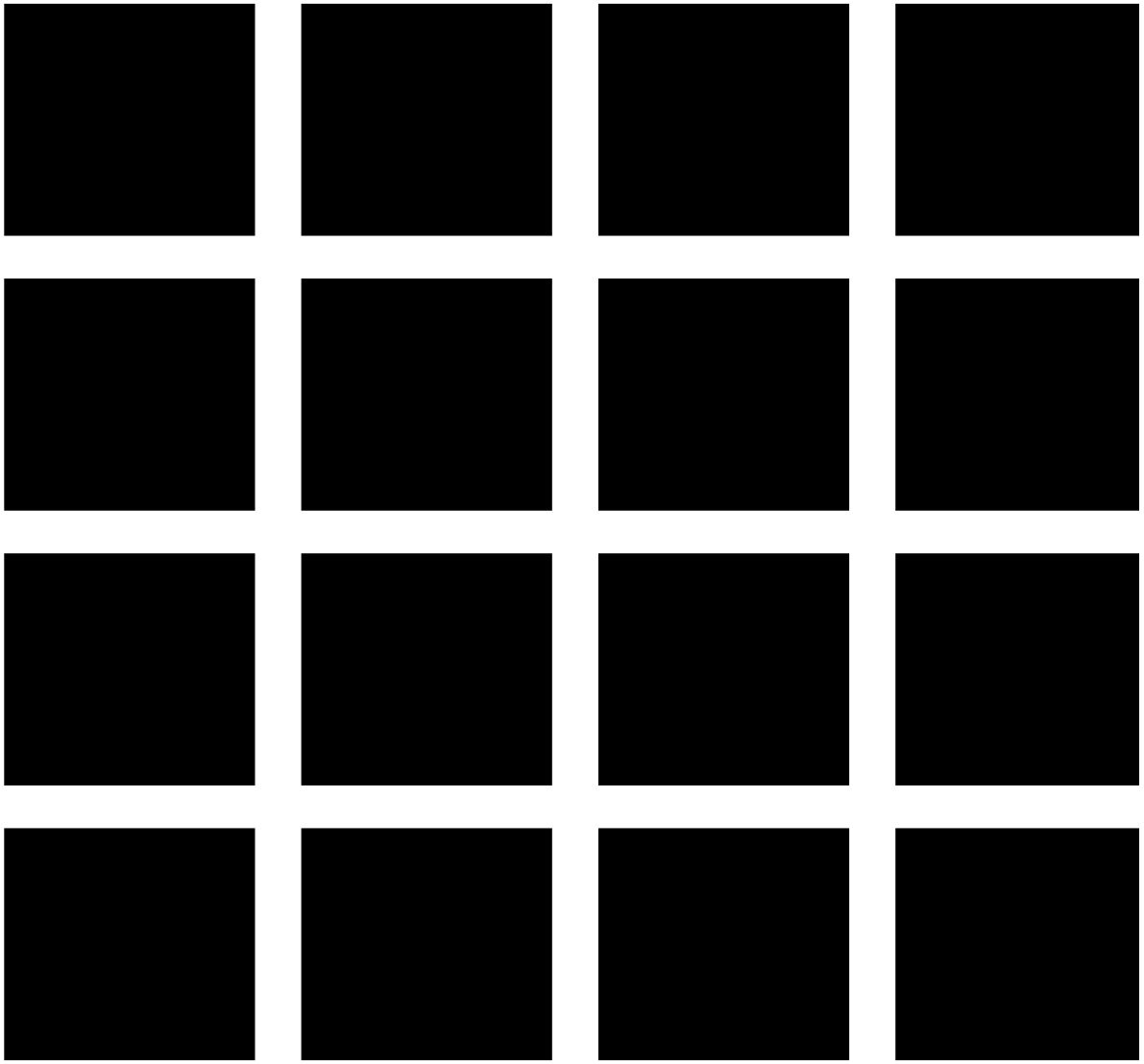


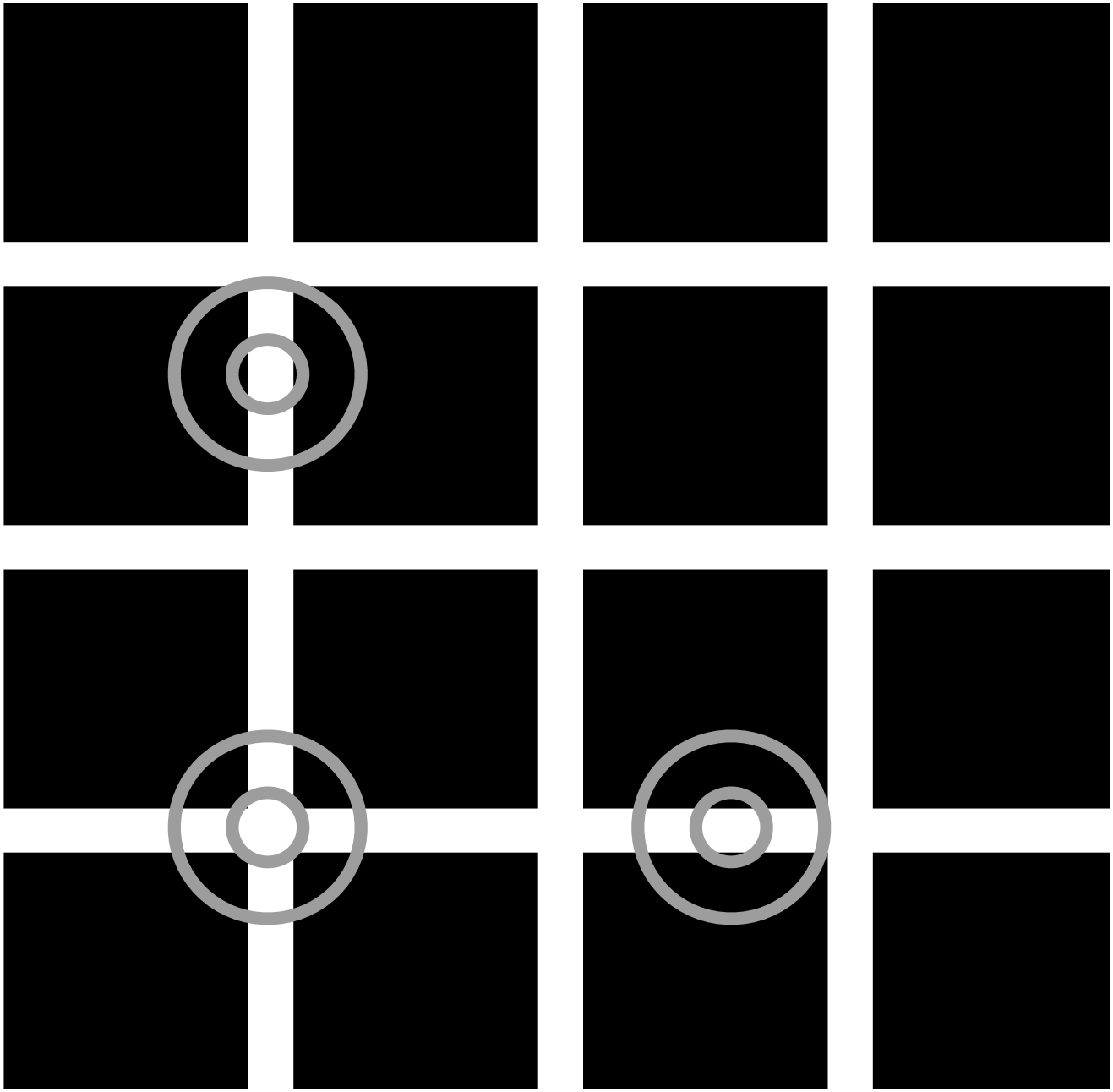




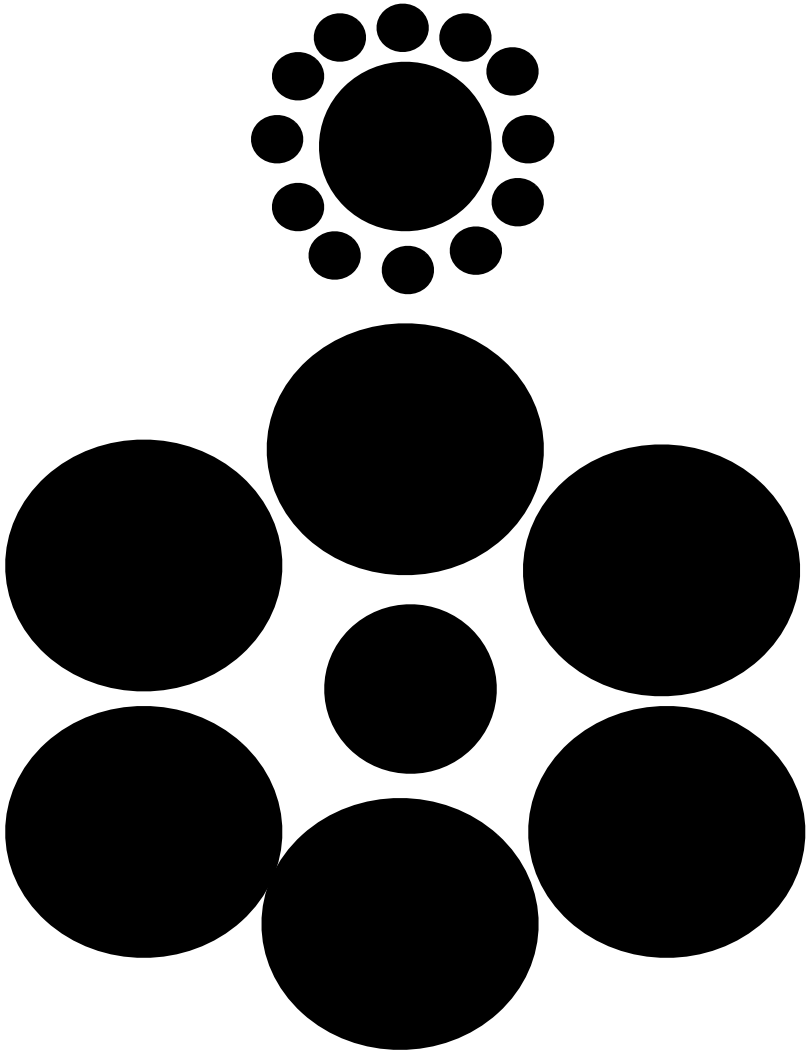




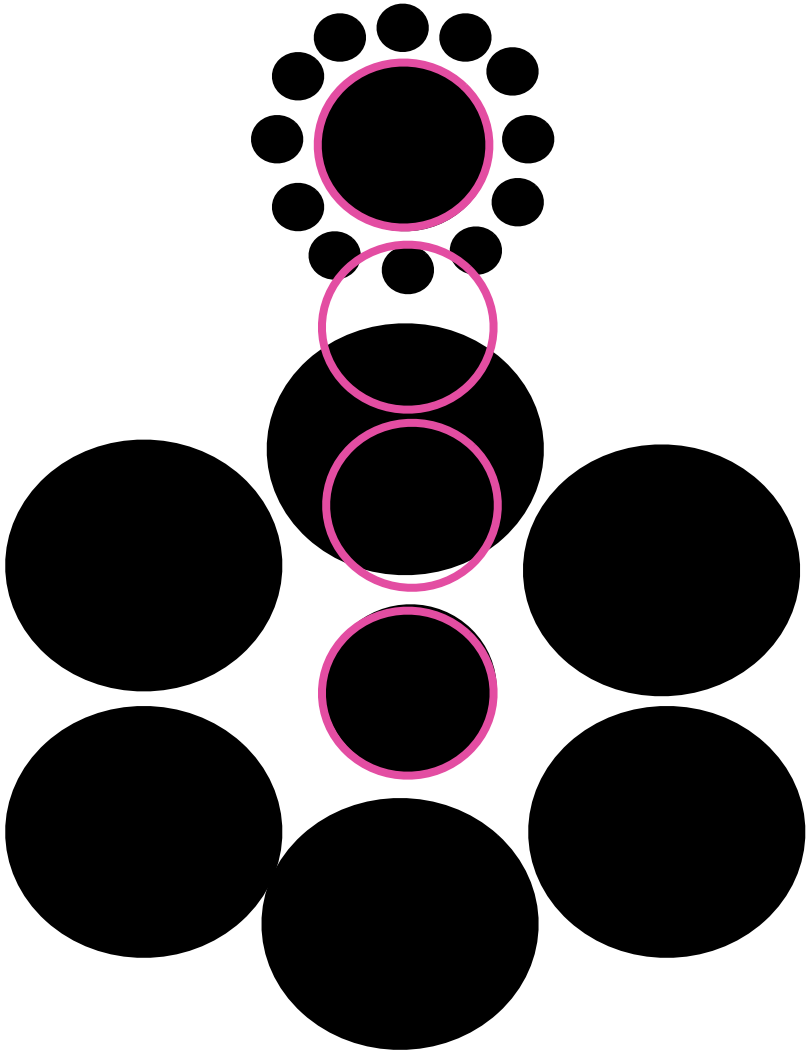


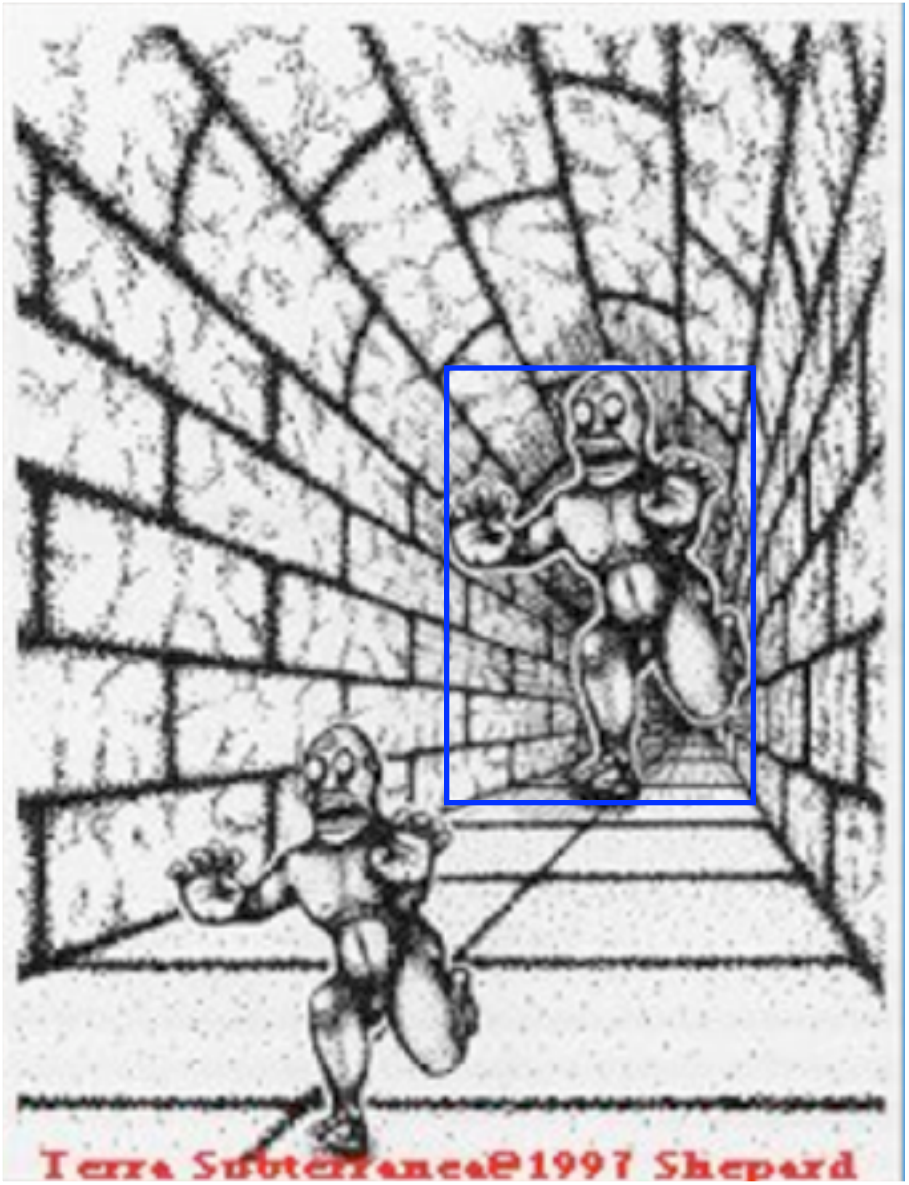


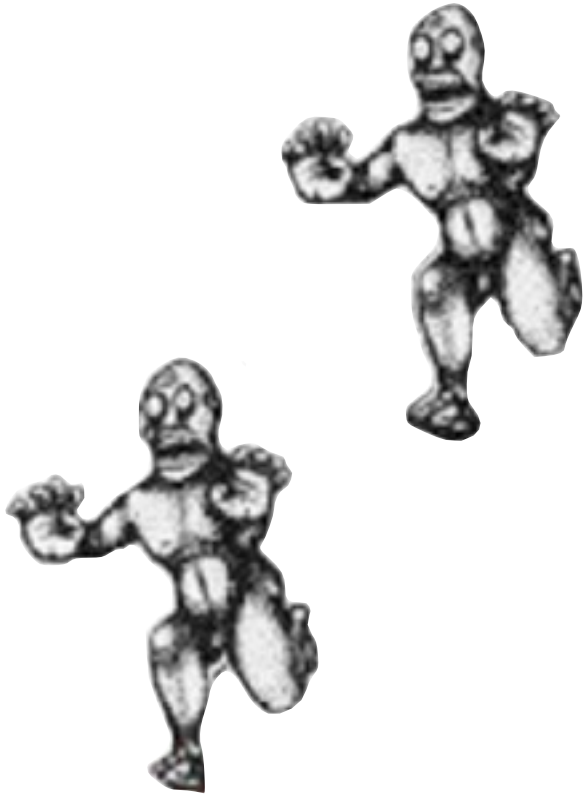
Perceived Sizes are Relative

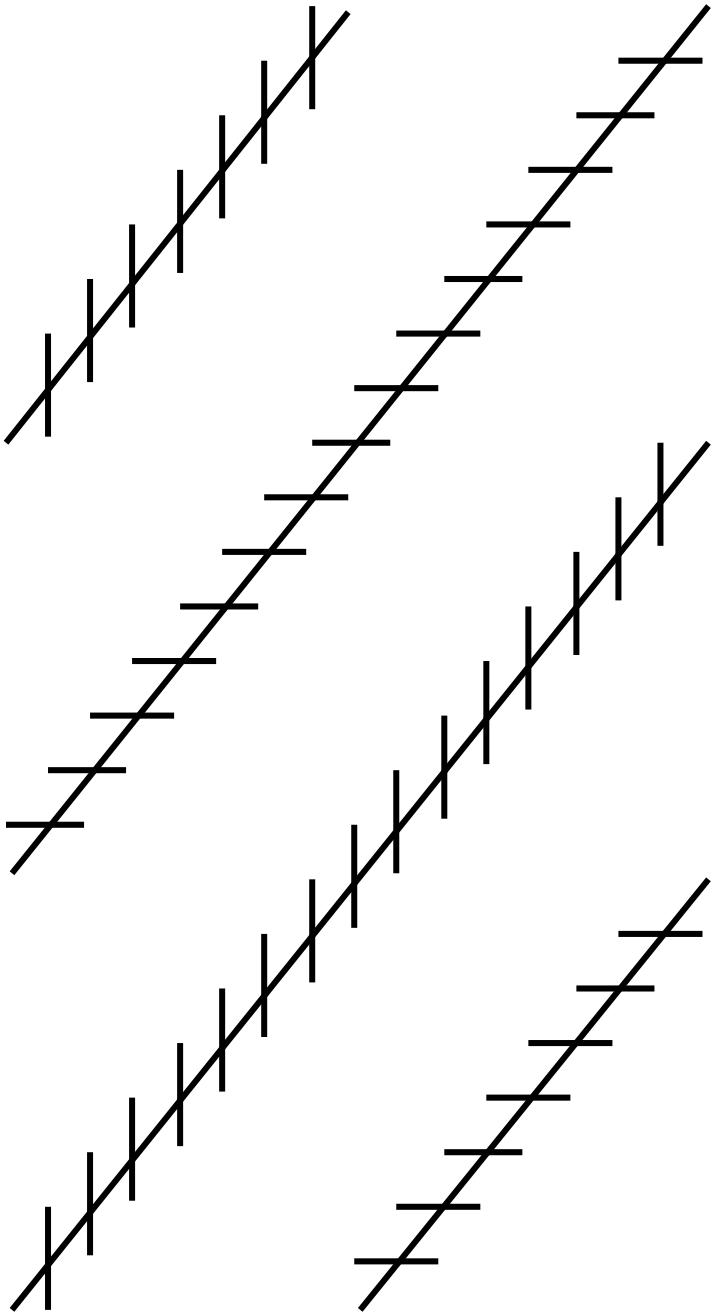


Perceived Sizes are Relative

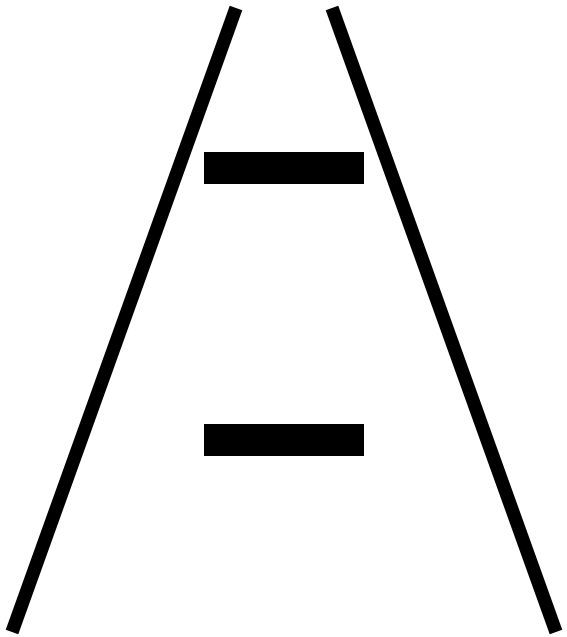



Terra Subterranea©1997 Shepard

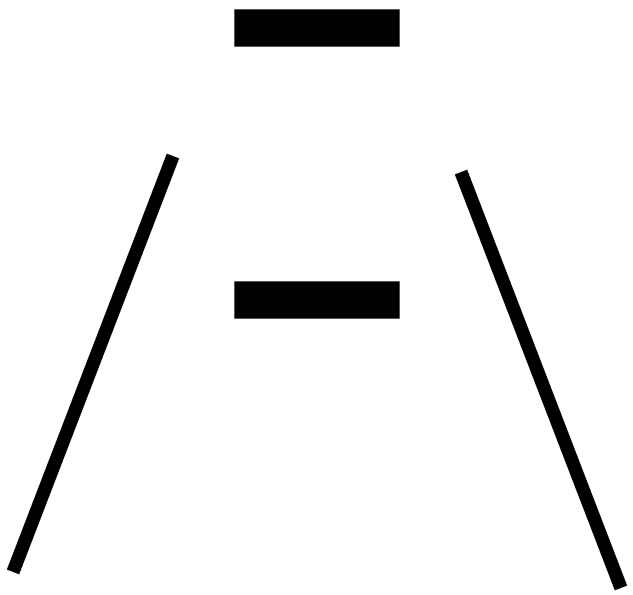


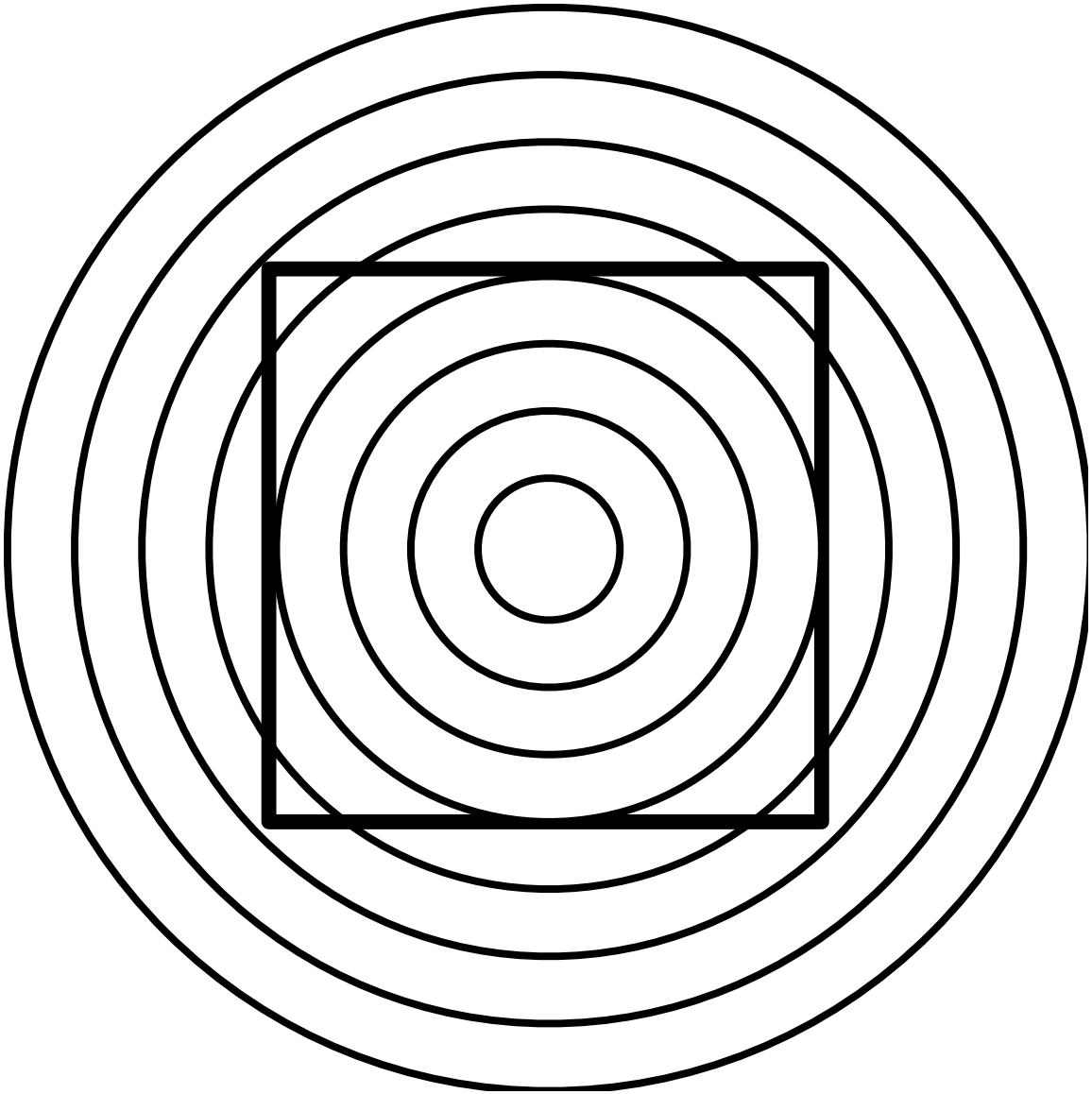


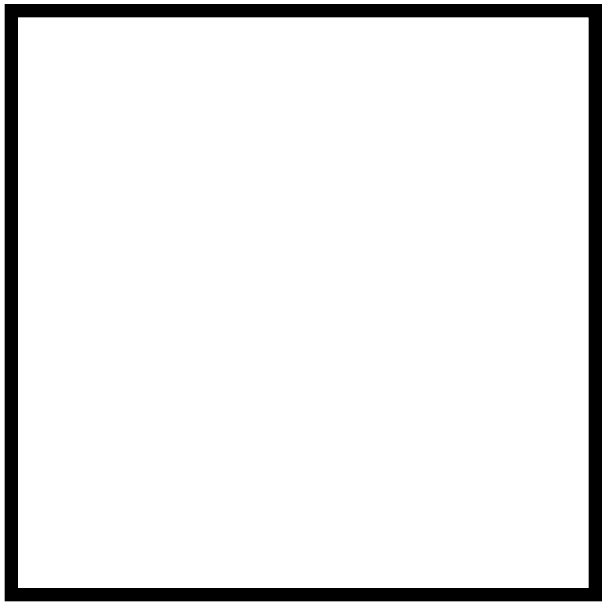
Ponzo Illusion



Ponzo Illusion







Illusions: Why?

- Violate some set of underlying assumptions
- Feedback from higher visual processes
- 3D interpretation of 2D drawings
- Expectations from experience

Human Vision
What Can We Learn?

- Subjective observations relative (differences)
  - Brightness
  - Color
  - Size
  - Orientation
- Interactions between inputs
  - Local and nonlocal
- What are people good at?
  - Recognition vs analysis
  - Qualitative vs quantitative

Depth

Magnocellular Division

Discriminates objects from one another

Characteristics (relative to parvocellular path)

- color : insensitive to wavelength variations
- acuity : larger RF centers
- speed : faster and more transient response
- contrast : more sensitive to low contrast stimuli

Observed characteristics of motion perception

- color-blind: impaired at equiluminance
- quickness
- high contrast sensitivity
- low acuity : impaired at high spatial frequencies

Depth Pathway

Red and green cones

Type A retinal ganglion cells

Magnocellular layers in LGN

Primary visual cortex

- disparity tuned neurons (thick stripes in V2)

Middle Temporal Lobe (MT)

Motor Cues

- Vergence
  - Angles of the eye
- Accomodation
  - Change of lens shape
  - Focus

Binocular Cues

- Depth cues resulting from two views (one from each eye)
- Include:
  - retinal disparity (stronger for close objects)
  - neurons sensitive to particular disparities

Monocular Cues

- Depth cues available in single eye image
- Include:
  - Occlusion
  - Size
  - Perspective
  - Focus
  - Head-motion parallax
  - Kinetic depth effect (object-motion parallax)

Motion and Interaction

Roles of Motion Processing

Required for Pattern Vision

Driving Eye Movements

Time to Collision

Exproprioceptive Information

Perception of Moving Objects

Depth from Motion

Encoding 3D Shape

Image Segmentation

Characteristics of Motion Perception

Fundamental, independent visual process

- motion aftereffects
- motion blindness

Based primarily on brightness

Ability to interpret structure degrades in periphery

Spatio-temporal interactions

Motion Pathway

- Red and green cones
- Type A retinal ganglion cells
- Magnocellular layers in LGN
- Area 4B in primary visual cortex
  - direction selectivity
  - velocity selectivity
  - expansion/contraction of visual field
  - global rotation
- Middle temporal lobe

Apparent Motion

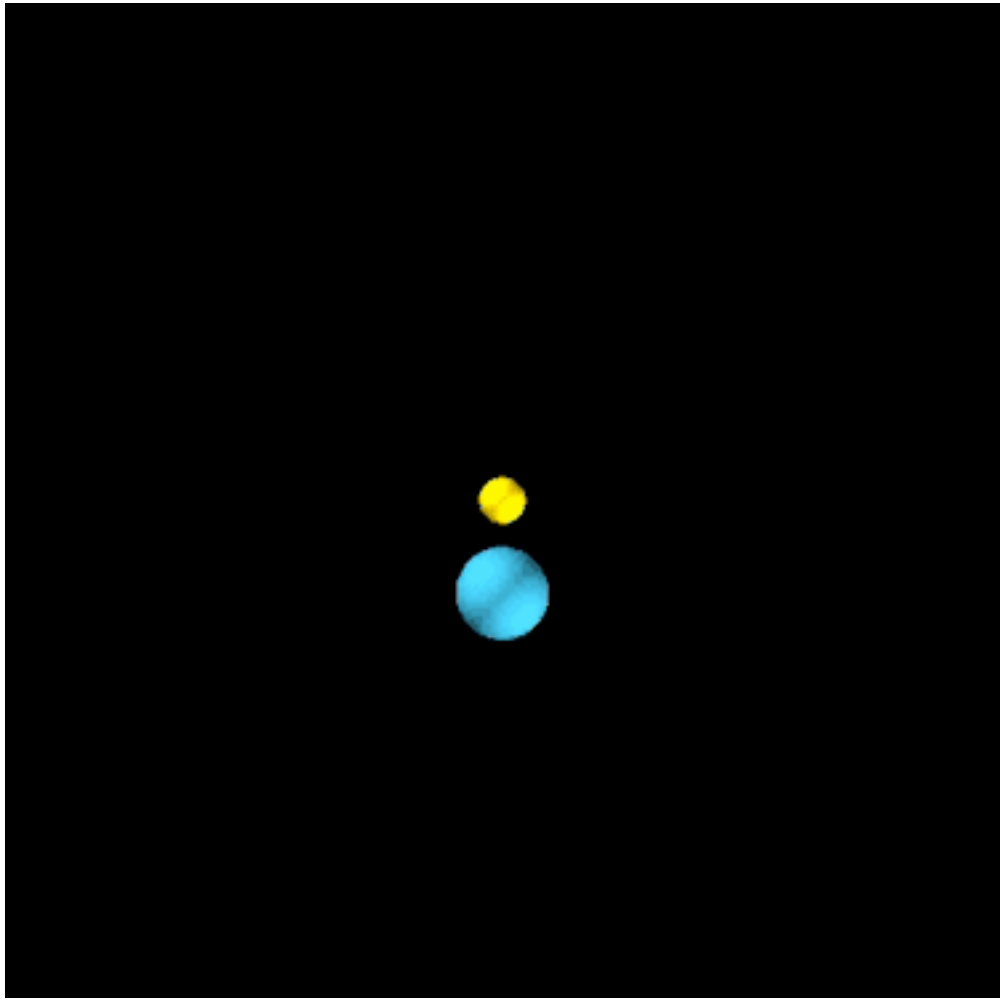
Definition: perception of motion without stimulus continuity (stroboscopic and cine)

Influences

- spatial frequency characteristics
- global field effects
- number of frames
- expectations from reality

Limitations

- maximum of 300 msec interstimulus interval
- decreased size constancy (max ~8 Hz)
- decreased sense of observer motion



Depth from Motion

Motion depth cues

- head motion parallax
- kinetic depth effect
- magnitude of motion indicates relative depth

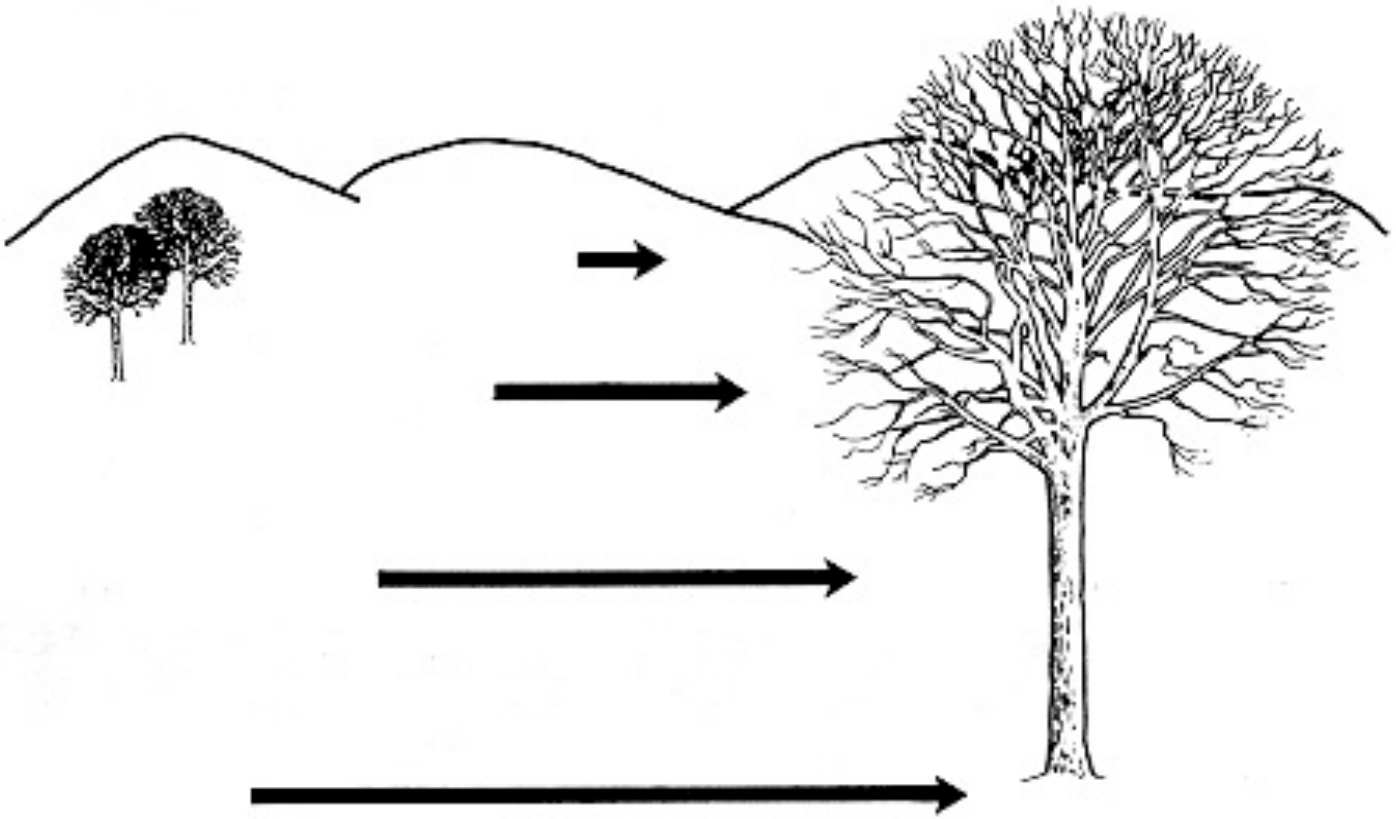
Applications

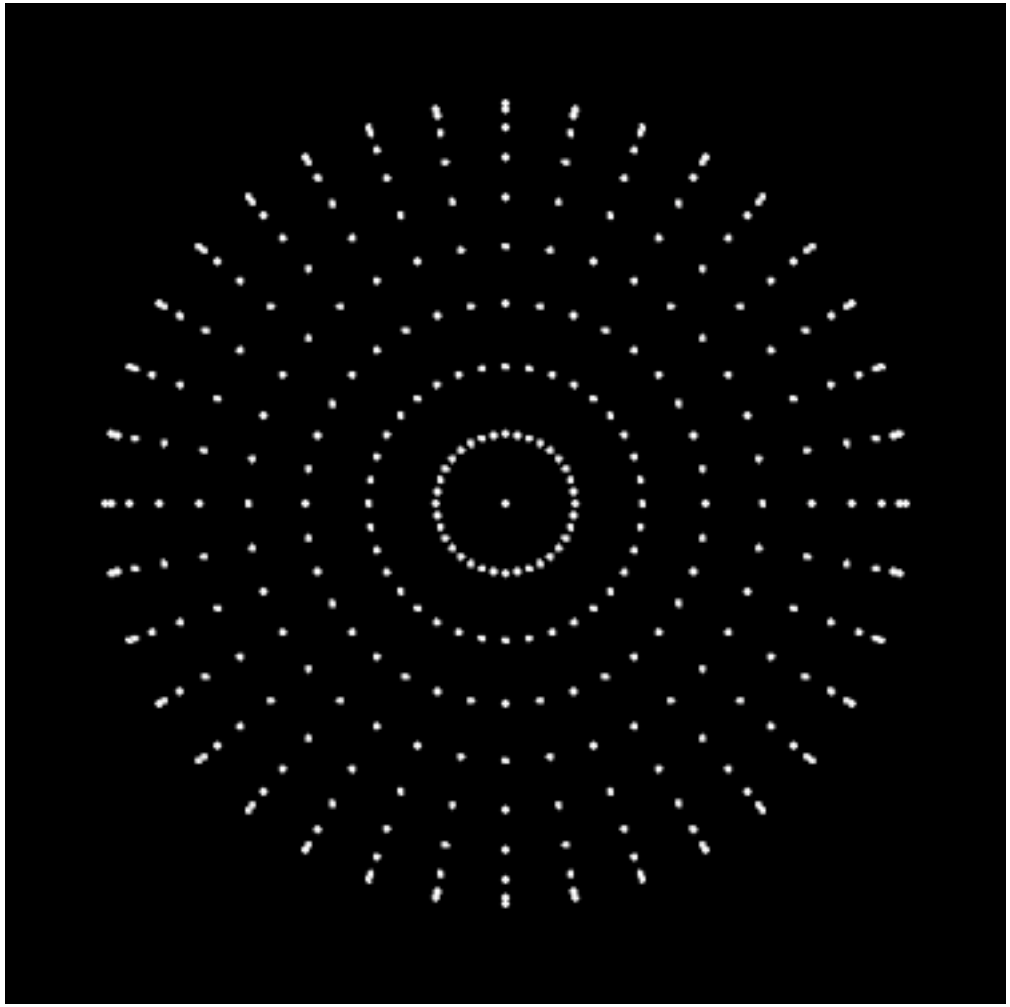
- indicating relative object positions
- compensating for lack of other depth cues

Limits

- relative, not absolute depth
- perceived size, perceived depth related

Head Motion Parallax





3D Structure from Motion

Relative motion conveys info about 3D shape

Rigidity assumption

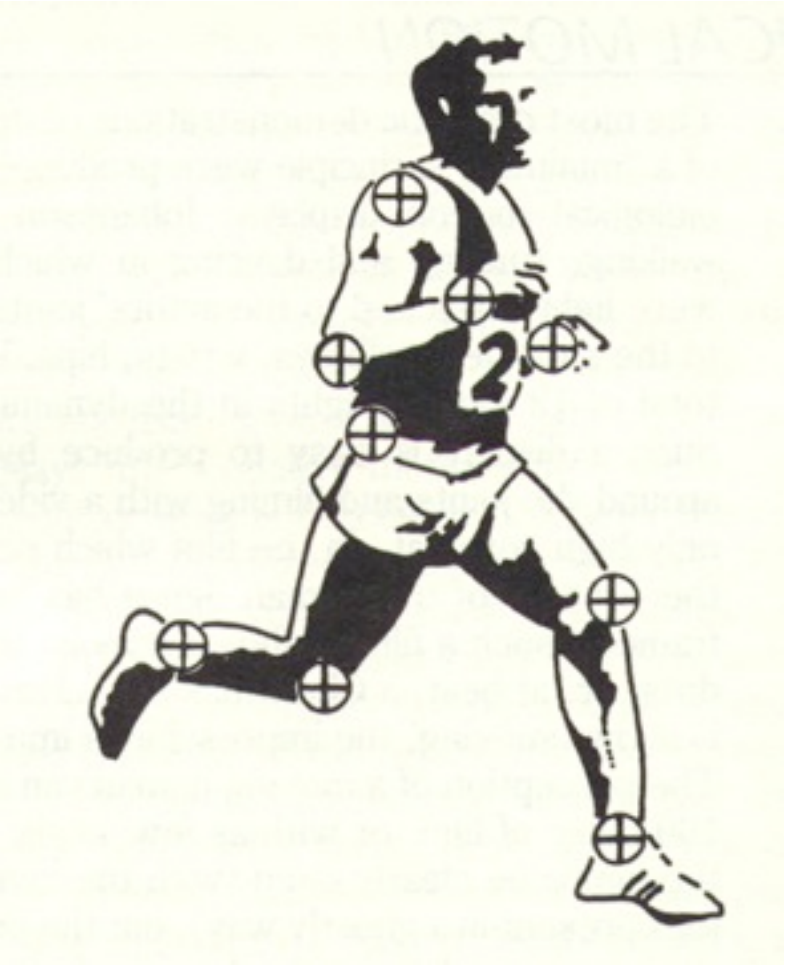
Applications

- understanding of irregular/unfamiliar shapes
- disambiguation of 2D projections

Limits

- 2 frames (large number of structured points)
- 2-3 points (many frames)
- 15 arc min (maximum displacement)

Structure from Motion



Bruce and Green '90, pg. 328.

Image Segmentation

Discontinuities in optical velocity field indicate object boundaries

Boundaries can be detected on the basis of motion alone

Applications

- disambiguation of complex scenes
- grouping of similar objects

At Equiliminance

Motion perception of gratings degrades

Depth perception disappears

Depth from relative motion disappears

Shape from relative motion disappears