THE VISUAL SYSTEM

Visual Perception
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Visual System
- Eye - sensor
- Lateral geniculate nucleus
- Striate cortex
  - Striped Appearance
- Extra striate cortex
Visual System

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Visual System

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Eye: The Sensor

Eye: Structure
Eye: Accommodation

- Accommodation: Flexible focusing ability
  - Cornea – 80% of focusing ability
  - Lens – 20% adaptable focusing ability
- Focus at one depth at a time
- Limitation
  - Depth of field
  - Near and far point

Myopia/Presbyopia

- Far and near point is different for different individuals
  - If near point is far: presbyopia
  - If far point is near: myopia
Iris

- Muscle controlling the pupil size
- Controls the illumination on the retina
- 3mm – 7mm
- Increase by 5 times
- Cannot explain the 10 orders of magnitude light sensitivity

Other

- Pigmented Epithelium
  - Behind the retina – dark
  - Absorbs light and avoid scattering
  - Allows high-contrast sharp retinal image
- Fovea
  - 2 degrees of angle subtended
  - Most densely populated with photoreceptors
  - Image fixated on the retina
  - Stiles-Crawford effect
Receptors in Eye

Receptor Organization

- Rod and cone receptors (R)
- Horizontal cells (H)
- Bipolar cells (B)
- Amacrine cells (A)
- Ganglion cells (G)
- Receptor outer segments
- Receptor inner segments
- Receptor cell bodies
- Optic nerve fibers
Receptors

- Rods
  - 120 million
  - Only in periphery
- Cones
  - 6 million
  - 1% in fovea
  - Rest in periphery
- In periphery 20:1 ratio for rods and cones
- Blind Spot

Receptor Distribution

- Diagram showing receptor distribution with high density in fovea and decrease towards the periphery.
Receptor Distribution

- Turned away from light
- To get nutrition from opaque pigment epithelium
- The other cells are transparent not to block light reaching the retina
- Block the axons of the ganglion cells from leaving the eye

Blind Spot

- Ganglion nerve fibers fold and leave by crossing a part of retina
- This part does not have any receptors
- Filled out by the brain
- Experiment
**Receptor Functions**

- Cones – for vision in photopic conditions
- Rods – for vision in scotopic conditions
  - Saturate at high light levels
- Both – for vision in mesopic conditions

**Conversion of light to electrical energy**

- Light sensitive chemical pigment in the receptors
- Absorbs photons and changes the shape to create a graded potential across the membrane of the outer segment
- Logarithmic response supports Stevens Law
- Potential is transmitted down the outer membrane to other cells
Receptor Functions

- Pigment Bleaching
- Pigment Regeneration
  - 30 minutes for rods and 6 minutes for cone

Effects of Visual Pigments on Perception
Dark Adaptation Curve

Initial rapid increase
- 6 minutes

Slower further increase
- 25-30 minutes

Rods have higher sensitivity than cones
- Rods responsible for dark vision

Pigment Regeneration
- 6 minutes for cones
- 30 minutes for rods
Spectral Sensitivity

Threshold Curve

Sensitivity Curve

Relative threshold of light required to detect monochromatic light of each wavelength

Rod and Cone Sensitivity

- Rods have sensitivity to shorter wavelengths
- Peak near 500nm being maximum sensitive to the blue-green region
- Shift of wavelengths in dark
  - Purkinje shift
  - Things appear bluish in dark
  - Green foliage seems to stand out in the dusk

Green foliage seems to stand out in the dusk
Cone Sensitivity

- Cone curve is the combined sensitivity of three cones
- Short wavelength – S cones
- Medium wavelength – M cones
- Long wavelength – L cones

Inconsistent with parts? – NO
Relative proportions of the S,M and L cones are different
S:M:L = 1:6:12
Rods does not help in color vision. No color perception in dark
Why do we need three cones?

- What happens with one cone?
  - 10 photons of 500nm produce x reaction
  - 10 photons of 560nm produce 4x reaction
  - 40 photons of 500nm produce 4x reaction
- No way to tell between the wavelength

Why do we need three cones?

- What happens with one cone?
  - Two parameters: Which wavelength and what brightness?
  - Cannot measure both with one sensor
Why do we need three cones?

- What happens with two cones?
  - You can distinguish both intensity and wavelength
  - Need more wideband sensitivity to cover all colors
  - Miss out completely parts of the spectrum

With three cones

- We do not need more than three since they cover the visible spectrum
Why rods not considered as the fourth cone?

- Spatial distribution and nature of convergence are completely different
- They are activated usually in completely different light conditions

Effects of Neural Processing on Perception
**Convergence**

- Measured number of neuron synapse on another neuron
  - Eye: Number of receptor neuron synapses on a ganglion cell
- Each ganglion cell receives many synapses
  - Rods to cones convergence ratio is 20:1
  - 1 million ganglion cells, 120 million rods and 6 million cones
  - Rods have higher convergence than cones

**Rods are more sensitive in dark**

Rods have greater spatial summation than cones

Threshold for ganglion triggering = 10

Not triggered
Cones give visual acuity

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Cones give visual acuity

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Neural Circuits and their Effects on Perception

Neural Circuits

- Many neurons connected through convergence
  - Small – a few neurons
  - Large – a few hundred thousand neurons
Neural Processing by Excitation and Inhibition

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Neural Processing by Excitation and Inhibition

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Neural Processing by Excitation and Inhibition

Receptive Fields

- The area of the retina that when stimulated influences the firing rate of the ganglion cells
- Excitatory center
- Inhibitory surround
- Lateral Inhibition
Hermann Grid

Explanation: Lateral Inhibition
Mach Bands

Actual Intensity

Percieved Intensity

Explanation: Lateral Inhibition
Explaination: Lateral Inhibition

Simultaneous Contrast

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Simultaneous Contrast

Explanation: Lateral Inhibition
Artifact of Mach Band

Theory of Continuity
Mach Bands

- Artifacts when any patch or curve does not show $C^1$ continuity
- They are always avoided
  - Shading
  - Blending
    - Image editing, contrast compressing, tone reduction
  - Geometric Modeling
Shading

- \( I_d = k_d \ (L \cdot N) \)
- \( I_s = k_s \ (2N \ (L \cdot N) - L) \cdot V \)

Flat Shading
- \([I(v1)+I(v2)+I(v3)]/3\)
- Is not \( C^1 \) continuous

Interpolated Shading
- Linear Interpolation of \( I(v1), I(v2) \) and \( I(v3) \)
- Is \( C^1 \) continuous
Shading

Flat Shading – Mach Bands

Interpolated Shading

Intensity Blending

 Depends on
  • Width of blending
  • Blending Function

Intensity

0.0

Spatial Location

Overlap Region
Intensity Blending

Depends on
- Width of blending
- Blending Function

Intensity

Overlap Region

Spatial Location

0.0

Proj2
Proj1

Proj2
Proj1

Overlap Region

Overlap Region
Intensity Blending
Applications

- Image Mosaics
- Multi-Projector Displays
- Image Editing

Geometric Modeling Primitives

- Three properties
  - Continuous
  - Continuous with transformations
  - Continuous with subdivisions