Visual Imaging and the Electronic Age

Fundamentals of Human Perception

Lecture #20
November 1, 2016
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Fundamentals of Human Perception

• 1. Rods and Cones, Chemistry and Physics, Color
• 2. Resolution
  – A. Fovea vs periphery, density of cones, percent of field of vision
  – B. Lens, changing focus and size, orientation, and ocular motor signals.
• 3. Interconnections, ganglion bipolar horizontal receptive fields and analog computation.
• 4. Optic nerve, interpolation, interpretation, comparison based on history, memory, and experience.
Cross Section of Eye & Retina
Image Formation by Lenses

Top: Light emanates from a point source in all directions. When some portion of the rays passes through a lens, refraction causes the rays to converge back to a point.

Bottom: An extended object can be considered as a spatially distributed collection of points.

1. Rods and Cones (Chemistry and Physics)
Rods & Cones

Comparison of a rod cell (right) and cone cell (left). This shows how each cell acquired its name from its shape.

**Photoreceptors**

- 120 million rods
- 7-8 million cones in each eye

Light goes in this direction

Rods and Cones
Receptor Distribution
Receptor Distribution

fovea
parafovea
periphery
far periphery

Cone
Rod

Retina Statistics

Receptive Fields –

Individual cone signals can either add together or be subtracted from one another.

The ability to resolve fine details depends ultimately on both the spatial mosaic of the receptors and how they interconnect.
FIGURE 7.8
Origin of spectral opponency in small midget ganglion cell receptive fields. Dominant center input from a single photoreceptor and weak surround inputs from a random mixture of photoreceptor types are sufficient to confer spectral opponency (after Lennie, 2000). Key: dark blue = S cones; green = M cones; red = L cones.
Rods and Cones
Receptive Fields

http://droualb.faculty.mjc.edu/CourseMaterials/Physiology%20101/Chapter%20Notes/Fall%202007/figure_10_39_labeled.jpg
Receptive Fields
2. Resolution and Visual Acuity
Major Components of the Human Eye

Major components of the human eye. Dimensions are also shown for the image produced by a 50 mm tall letter viewed at a distance of 570 mm (similar to a large newspaper headline viewed at arm’s length). The angle subtended by the letter at the nodal point of the eye is 5°. The retinal image of the letter is 1.5 mm tall, and spans approximately 500 photoreceptors.

Side view of the human eye
Field of View for Humans

- Humans have an almost 180 degree frontal horizontal field of view

- The vertical range of the visual field is approximately 135 degrees

- The resolution, color discrimination, and reaction times is not uniform across the field of view
Field of view
Field of View

The visual system includes the retinas, the visual pathway connecting the retinas to the brain, and the visual cortex. The two eyes’ fields of view overlap (top).

Binocular Vision

• Binocular Vision, which is the basis for stereopsis is important for depth perception and covers 114 degrees (horizontally) of the human visual field.

• The remaining sixty to seventy degrees have no binocular vision (because only one eye can see those portions of the visual field)
How many megapixels are necessary to match the resolution of the human eye?
Visual Acuity Example

Assume 120 degree x 90 degree field of view

$$120 \times 90 \times 60 \times 60 / 0.3 \times 0.3 = 432 \text{ megapixels}$$
Changing Lens Shape

Accommodation for a near target:
- Near in focus
- Far blurred

Accommodation for a far target:
- Far in focus
- Near blurred
Visual Acuity

- Visual acuity is defined as “1/a where a is the response in arc-minutes”.
- This acuity is usually measured by a grating test pattern and thus is defined using a line pair.
- It takes two pixels to generate a line pair (black and white).
- Based on a large number of tests, the resolution of the human eye is approximately 0.3 arc minutes.
Measures of Acuity

- **Detection**: min. detectable 0.5"
- **Resolution**: min. resolvable 30"; Snellen letters 30"
- **Localization**: vernier 5-7"
Extraocular Muscles

FIGURE 6.13
The extraocular muscles. Six muscles working in three pairs allow each eye to rotate in its socket about the three possible axes (based on Walls, 1963).
Reducing Bandwidth

A. Opponent Color Theory
B. Analog Computing
Opponent Color Theory

• Four particular colors appear to be “unique”.
  – Red, Green, Blue, and Yellow
• He considered these to be the “cardinal directions” of chromaticity
• All other colors seem to be intermediate between these four
Opponent Color Theory

Hering 1892

Figure 12.1– Foundations of Sensation and Perception, George Mather
Biconical Color Solid

George Joblove
Biconical Color Solid
Luminance Image (Y)
Color Addition (Red/Green Axis)(I)

http://en.wikipedia.org/wiki/YIQ
Color Addition (Yellow/Blue Axis)(Q)
### Opponent Color Theory

<table>
<thead>
<tr>
<th>Channel</th>
<th>Combination</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>black - white</td>
<td>M + L</td>
<td>very high</td>
</tr>
<tr>
<td>Green - red</td>
<td>M – L</td>
<td>High</td>
</tr>
<tr>
<td>yellow - blue</td>
<td>M + L – S</td>
<td>low</td>
</tr>
</tbody>
</table>

Hering 1892
Opponent Color Theory

There are three types of color receptive fields called *opponent channels*.

- Black — White (luminance) channel: $M + L$
- Green — Red channel: $M - L$
- Yellow — Blue channel: $M + L - S$

Hering 1892
Cones interconnect in the retina, eventually leading to opponent-type signals.

Opponent Color Theory  Analog Computing

Figure 12.9 – Foundations of Sensation and Perception, George Mather
Vergence

• The simultaneous movement of the pupils of the eyes toward or away from one another during focusing.

• This measure of the convergence or divergence of a pair of light rays is defined as vergence.
Diagram of Vergence

A. Real world

B. 3D display

Vergence distance

Focal distance

Display screen
Vergence Accommodation Conflict

- Computer and projection displays present images on a single surface but have a focal distance (blur on the retina) which may be in front of or behind the screen.
- The inability to fuse the binocular stimuli causes discomfort and fatigue to the viewer.

Vergence – Accommodation Conflict
Vergence – Accommodation Conflict
Ocular Motor Systems (OMS)

• With normal visual perception, the ocular motor systems control the movement of the eyes to focus on the object of interest (voluntarily controlled)

• The OMS produces adjustments in pupil size, lens refraction, and accommodation.

• Accommodation involves the convergence of the two eyes to direct their images on to the fovea.
Time Dependent Responses
Time Response of Rods and Cones

**FIGURE 7.4**
The time course of responses in rod (top) and cone (bottom) photoreceptors. A brief flash of light was presented at the point marked by the arrow on the horizontal axis. The bar between the two plots represents 500 ms. Re-drawn from Schnapf and Baylor (1987).
Time Response of Cones

500 ms
Time Response of Rods

500 ms
Saccadic Motion

Saccadic Motion

The eye jumps, comes to rest momentarily (producing a small dot on the record), then jumps to a new locus of interest.

End