Announcements

• Homework 5 is due Sat, Jun 9, 11:59 PM
• Final* is due Wed, Jun 13, 9:59 PM
  – Final will be posted on Piazza
• Please complete TA and course evaluations
• Reading:
  – Section 1.1.4: The Human Eye
Kepler

Kepler, 1604

Eye as an optical instrument

Image is inverted on retina

First such experiment by Scheiner, 1625

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.)
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
4. Functional MRI
5. Computational modelling
Psychophysical Testing of Subjects
Example:
Show gratings with different spatial frequencies

2) Spatial Frequency
(cycles/deg)
Gradients/Motion
Perceptual Organization

Occlusion provides a different organization
Perceptual Organization
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.
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

- Pupil
- Aqueous Humor
- Iris
- Ciliary Muscle
- Medial Rectus Muscle
- Lens
- Suspensory Ligament
- Vitreous Humor
- Retina
- Optic Disc
- Fovea
- Choroid
- Optic Nerve
- Lateral Rectus Muscle
- Sclera
# The range of lighting

<table>
<thead>
<tr>
<th>Lighting Type</th>
<th>Lux Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct sun</td>
<td>100,000 Lux</td>
</tr>
<tr>
<td>Sunny day</td>
<td>50,000 Lux</td>
</tr>
<tr>
<td>Cloudy day</td>
<td>5,000 Lux</td>
</tr>
<tr>
<td>Office</td>
<td>400 Lux</td>
</tr>
<tr>
<td>Home lighting</td>
<td>10 Lux</td>
</tr>
<tr>
<td>Street lamps</td>
<td>1 Lux</td>
</tr>
<tr>
<td>Full moon</td>
<td>0.1 Lux</td>
</tr>
<tr>
<td>Quarter moon</td>
<td>0.01 Lux</td>
</tr>
<tr>
<td>Clear moonless night</td>
<td>0.001 Lux</td>
</tr>
<tr>
<td>Cloudy moonless night</td>
<td>0.0001 Lux</td>
</tr>
</tbody>
</table>

1 lux = 1 lumin/m²
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.
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 $k$th 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
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
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.

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

- Hundreds of primitives 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/
Mantis Shrimp

Trinocular vision
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?
In this shot, what is his facial expression?
Hidden Human Face
Horizontal Lines are Parallel
Static Image
Summary of CSE 152

- Geometric image formation
- Photometric image formation
- Photometric stereo
- Binary image processing
- Image filtering
- Edges and corners
- Stereo
- Structure from motion
- Model fitting
- Optical flow and motion
- Tracking
- Recognition, detection, and classification
- Color
- Human visual system