Lecture 5

The Visual Cortex

• Cortical Visual Processing
Lateral Geniculate Nucleus (LGN)

- LGN is located in the Thalamus
- There are two LGN on each (lateral) side of the brain.
- Optic nerve fibers from eye terminate in them
- Fibers in Optic nerve are randomly arranged after Optic Chiasm but are sorted/ordered at the LGN
Anatomical Structure

- Layers 1-2 have monochromatic responses: Magnocellular layers
- Layers 3-6 (parvocellular layers) mediate color vision
- All cells are center-surround responsive
Retinotopic Mapping

- Axons from retina preserve their order.
- There is an entire map of each hemi-field in each layer of the LGN.
- Only 10% of inputs to LGN come from the retina, 90% from Cortex of brain.
- Cortical feedback is not understood.
- LGN may provide brainstem and cortex to modulate visual information (e.g. sleep).
Circle Surround
M and P cell types

• M Cells correspond to parasol retinal ganglia cell and now connected to the Magnocellular layers (1 and 2) of LGN

• P Cells correspond to Midget retinal ganglia cells and now connect to the Parvocellular layers 3-6) of LGN

• Both have On and Off center surround inputs
M and P pathways

- The characteristics of each cell type and pathway are substantially different
- Not complete separation
- Handle different aspects of vision

<table>
<thead>
<tr>
<th>Stimulus feature</th>
<th>M cells</th>
<th>P cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color contrast</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Luminance contrast</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Spatial frequency</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Temporal frequency</td>
<td>Higher</td>
<td>Lower</td>
</tr>
</tbody>
</table>
M and P Pathway characteristics

- Maps visual attributes of M and P cells within Visual System
- This clearly shows different types of vision leading to different types of visual processing

<table>
<thead>
<tr>
<th>Attribute</th>
<th>M Cells</th>
<th>P Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of all ganglion cells</td>
<td>~10</td>
<td>~80</td>
</tr>
<tr>
<td>Distribution on retina</td>
<td>Densest in fovea?</td>
<td>Densest in fovea</td>
</tr>
<tr>
<td>Conduction velocity</td>
<td>~15 m/s</td>
<td>~6 m/s</td>
</tr>
<tr>
<td>Central projection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ganglion cells</td>
<td>LGN, magnocellular</td>
<td>LGN, parvocellular</td>
</tr>
<tr>
<td>LGN³ cells</td>
<td>V1, layer 4Cα</td>
<td>V1, layer 4Cβ</td>
</tr>
<tr>
<td>Chromatic opponency</td>
<td>Almost none</td>
<td>Well-developed (two types: L vs M; S vs L,M)</td>
</tr>
<tr>
<td>Rod input</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Contrast sensitivity</td>
<td>High (~60)</td>
<td>Low (~&lt;20)</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>Lower</td>
<td>Higher (single-cone center in fovea)</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>Higher (~60 Hz)</td>
<td>High (~&gt;30 Hz)</td>
</tr>
<tr>
<td>Periphery effects</td>
<td>Some</td>
<td>None</td>
</tr>
</tbody>
</table>

³LGN = lateral geniculate nucleus.
Mapping of LGN

- Consists of 6 layers
- Layers 3-6 connect to Midget Ganglion Cells
- Layers 3-4 to OFF
- Layer 5-6 to ON
- Layers 1-2 connect to Parasol Cells
- Each layer alternates between input from left and right eye.
- Alternating reverse at layers 4-5
Projections from Retina

- Projections from Retina go to a variety of areas of the brain.
- The LGN routes stimulus to the visual cortex.
- The Pretectum regulates pupillary response.
- The Superior Colliculus contributes to visually guided eye movements.
Optic Radiation

- Optic radiation: a set of nerve tracks connecting the LGN with the Primary Visual Cortex
- Lateral ventricle separates two optic tracks
M and P Pathways from Retina to V1

- Separation begins at Optic Chiasm
- LGN maps each ganglia cell type to different layer
- Also maps each eye separately
- LGN is a nuclei center, sending axons to VERY specific parts of V1
KEY TO FUNCTION

- **V1**: Primary visual cortex; receives all visual input. Begins processing of color, motion and shape. Cells in this area have the smallest receptive fields.

- **V2, V3, and VP**: Continue processing; cells of each area have progressively larger receptive fields.

- **V3A**: Biased for perceiving motion.

- **V4**: Function unknown.

- **MT/V5**: Detects motion.

- **V7**: Function unknown.

- **V8**: Processes color vision.

- **LO**: Plays a role in recognizing large-scale objects.

Note: A V6 region has been identified only in monkeys.
Striated Visual Cortex

- Studied intensely
- Brodmann’s area 17, area V1, SVC: same
- 100 Million Cells!
- Optic nerve is 1 Million
- Enormous Divergence
- Receives input from the 6 layers of LGN
LGN to V1

- LGN layers 1 and 2
- Magnocellular, Parasol ganglion
- LGN layers 3-6
- Parvocellular, Midget ganglion
- LGN layers go to different layers of V1
- V1 has 6 major layers
Retinotopic Mapping

- Each half of visual field goes to contra-lateral area V1
- Calcarine fissure divides lower from upper
- Retina projects onto 50% of V1
- LGN goes to all parts of V1, but to different layers.
- Retinal Mapping is preserved
LGN ⇒ Layer 4C of area V1

- Area V1 composed of 6 major layers
- Layer 4 composed of 3 sub-layers: 4A, 4B, 4C
- Layer 4 is lighter in color and forms the “striated layer” that characterizes “striated cortex”
- Parvo-cellular layers connect to layer 4Cb
- Magno-cellular layers connect to layer 4Ca
Retinotopic Mapping
Experimental Image

- Anaesthetized Monkey views flickering bulleye pattern.
- Injected with radioactive glucose.
- Monkey is “sacrificed”, area V1 is removed and flatten and put on film.
- Areas that were active absorbed radioactive glucose and then expose areas of file, shown below.
- Remarkable pattern.
Measuring Visual Cortex

- Electrode penetrates area of interest, to depth of interest
- Subject’s head/eyes are fixed and allowed to view patterns on fixed screen
- Pattern is changed until cell responds.
Structure within V1

• Above and below Layer 4C are simple cells.
• Unlike the circle-surround inputs from LGN, these respond to linear patterns: edges and bars.
• Three types, all orientation specific
Orientation Specific Simple Cells

- Simple cells created via LGN input.
- Orientation determined by which LGN cells synapse with a simple cell.
- Each simple cell encodes one orientation.
Simple Cell response

- Max response when stimulus aligns to orientation AND fill receptive field
- As stimuli moves out of ON center, response falls off.
- Uniform illumination = no response
- Non-aligned bar = no response
- Response increases as size of stimuli increases
- Responds best to stimuli swept over receptive field
- Receptive field: ¼ by ¼ degrees, optimal simulation 2 minutes of arc
Complex Cells

- Receive input from Simple Cells
- Orientation AND directional sensitivity
- Length summation
- Larger receptive field (e.g. ½ degree by ½ degree: optimal stimulation is 2 minutes of arc)
Hypercomplex Cells

- Inputs from complex cells
- “end-stopping” behavior
- Complex above, Hyper below react to same stimulus
- Orientation AND directionally sensitive
Cortical Processing Improves Acuity

- threshold for detecting dots = acuity of eye
- threshold for detecting 2 lines = acuity of eye + visual cortex

The difference is what the cortex adds.
V1 Columnar Structure

- column architecture
- Adjacent columns respond to slightly different orientations
- Rows alternate from Left to Binocular to Right to...
- Then simple, then Complex, then Hyper
- Maintains retinal mapping
Hypercolumns

- Clever Structure
- LGN input near middle (Layer 4C)
- Then simple, then complex then Hyper
- Orientation columns for one ganglion receptive field is ~750 microns
- “Blobs” in center of these, surrounded by orientation columns
- Intermediate column areas are binocular
Blobs

- Blobs are dark regions in left image
- Blobs within orientation columns in right image
- Blobs are color responsive, not orientation
- In upper layers of V1 (layers 2 & 3)
- Provide an orthogonal capability to columns
- Ocular Dominance provides basis for depth perception
Photographic Images of V1 Structure

- Open skull to reveal surface of brain
- Photograph when one eye is patched
- Photograph when other eye patched
- Subtract one image from other to create bottom image
- Shows ocular dominance columns: NOT orientation columns
HyperColumn Pinwheel

- Upper is 9x13mm area
- Complementary colors represent orthogonal orientation sensitivities
- B is one pinwheel
- C represents one orientation column (about 1x1x2mm)
V1 processing

- V1’s structure/processing has taken top image and produced two (three) representations of it
- Edges and features
- Color areas
- But there’s much more
- Visual processing starts in V1 follows various pathways eventually ending in frontal cortex
Plasticity and Development

- At birth cortex relatively undifferentiated.
- Binocular input to all areas
- No hypercolumn structure
- V1 develops via neonatal binocular visual stimulus
- Amblyopia Deprivation leads to ocular dominance and cortical blindness
Hebbian Development Model

- Cells that fire together: wire together:
  1. Synchronous activity causes strong depolarization
  2. NMDA receptor is activated allowing Ca++ to enter cell
  3. Postsynaptic nerve growth factor released and taken up only by recently activated presynaptic terminals
  4. These enlarge at expense of others
- If one eye is patched or not optically aligned, other eye will develop stronger synapses, leading to dominance, loss of depth perception and possibly blindness.
Learning is Forming Memories and Forgetting

- Left image is when both eyes are active
- Right is example of Strabismus (misaligned eyes)
- B represents Binocular, M = Monocular
- Right Hypercolumn structure would not allow stereopsis.
V1 Summary

- V1 creates three “feature channels”
- Edges: oriented lines
- Ocular dominance columns: depth
- Blobs: color within same area
Visual Processing after V1

- V1 feeds V2 and then V3 and VP
- Retinotopic Mapping is preserved
- Two vision pathways begin at this point
- What pathway
- Where pathway

In each area the retina is re-represented. Note that the ◇ is seen in the right lower visual field and is represented in the left upper visual cortex. It is represented 3 times, once in each area V1, V2, and V3.
Object Recognition

- Line segments recognized in V1
- V2 groups segments into objects
- Before recognition APs are asynchronous
- After, APs fire synchronously
- V2 influences V1 cells to synchronized
Grouping Process

- Objects then grouped into recognized elements
- Left 2 giraffes: which is in front
- Add color (right) and this is easier
- Part of process involves memory to identify grouped objects to known entity.
Illusory Contours

- A lot of “seeing” is to fill in
- The magic square is an occlusion interpretation
- Brightness of square is purely a function of your brain “filling in”
Illusory Contours arise in V2

- Retinal ganglia extract circle-surround
- V1 extracts edges
- V2 creates objects and groups
- It also provides low level feature recognition
- Since edges lose center areas, V2 “fills in”
- Green “square” is illusory, but is just as “real” as not.
Edge Enhancement plus Fill-in

- Sometimes your eyes function “too well”
- Look closely at the edges between areas of different levels of gray.
- One side looks brighter, the other darker
- This is a bi-product of edge detection called lateral inhibition.
Feature Recognition

- Images perceived depend on what we “see” AND
- What we remember
- Memory is a major part of vision
- Expect to see, will cause us to see
- m in example
Beyond V3

• “Seeing” involves two processes
• Perception of objects
• Perceiving where located, their orientation and motion
• Three dozen “higher order” vision centers beyond V3
Where/What Visual Pathway

- fMRI reveals activity
- Ask test subject 2 Questions:
  - Q1: Is the face the same face as previously shown
  - Q2: Is the face in the same location as previously shown
- Q1 causes **What** stream to light up
- Q2 causes **Where** stream to activate
Lateralization of Function

- Left hemisphere is word oriented
- Right is vision oriented
- Stroke patients develop lesions between the two hemispheres resulting in
  - Can see face but don’t know person
  - Can see object but can’t name it
  - Add touch or sound and they can identify
Object Recognition

- Inferior temporal cortex
- Cells respond to classes of objects, invariant of size or color or texture or location or motion
- Some cells respond to animals, hands, fingers, lips, chins, mouths, eyes and FACES
- Some are very important for survival
Similar and Different

• Some images look similar: would fire same cells in V1
• Some are same image but differ in size, color, location, etc: would fire different V1 cells but SAME Inferior Temporal (IT) cells
Properties of **What Stream**

- What responsible for 3D perception
- Perceives line ends (concave and convex)
- Note top is optical illusion
- Bottom (same shapes) is perceived as perspective and is “filled in”
Inferior Temporal

- Employs SAME columnar structure as V1
- Similar shapes near one another
- Similar orientations of same shape near
- This organization minimizes interconnections and keeps information local
Lateralization
Low to High Order processing

• Left side = language
• Right side = images
• Rear = low level
• Front = high level
• As we move toward the front of our head the information gets richer and more meaningful
• At frontal cortex we’ll find spatial memory and reasoning, for example.
• Consciousness and reasoning are at front of brain.