Visual System II
Retina-Geniculate-Cortex

Reading:
BCP Chapters 9/10
The Visual System

The visual system is the part of the NS which enables organisms to process visual details, as well as to perform several non-image-related response functions. It detects (sensation) and interprets (perception) information from visible light to build a representation of the surrounding environment.

Eye and Retina
- Structures
- Transduction

Retina-geniculate-striate cortex
- Pathway
- Receptive field properties

Striate and Association cortex
- Higher-order processing
Transduction

Photoreceptors (rods and cones) in the retina are depolarized in the dark, and hyperpolarized in the light.

In the dark (i.e. unstimulated):
- cGMP-gated Na\(^+\) channels are open, leading to inward (depolarizing) Na\(^+\) current (the so-called “dark current”)
- \(V_{\text{rest}} \sim -40\text{mV}\)
- glutamate released

In response to light (stimulated):
- retinal changes shape
- opsin dissociates and activates a unique G-protein (transducin)
- transducin activates the enzyme phosphodiesterase (PDE) which breaks down cGMP.
- cGMP-Na\(^+\) channels close
- membrane hyperpolarizes (\(\sim -70\text{mV}\))
- reduced release of glutamate
Retinal Receptive Fields (RFs)

The receptive field of an individual sensory neuron is the particular region of sensory space (e.g., the visual field, or body surface) in which a stimulus affects the firing of that neuron.

Receptive fields in the retina are circular in shape and defined in terms of degrees of visual space (from hundredths of a degree in the fovea to tens of degrees in the periphery).
Ganglion cell receptive fields are **circular**, with **antagonistic** (opponent) responses between **center** and **surround**, i.e., they show center-surround organization.

Receptive fields are either “**on-center**” or “**off-center**”
The two types of center-surround receptive fields exhibited by retinal ganglion cells are created in a two-step process:

- First, the opponent center-surround aspect is created by mutual inhibition among photoreceptors that is produced by horizontal cells.

- Second, the on- and off-center aspect is created by bipolar cells which show opposite responses to the glutamate released by their receptor (i.e., bipolar cells express different glutamate receptors).
Ganglion cells inherit the on- and off-center aspect of their receptive field responses from bipolar cells:

- On-center bipolar cells have metabotropic glutamate receptors (activation of which leads to K+ efflux). Thus, on-center bipolar cells respond best when their receptor input releases less glutamate.

- Off-center bipolar cells have ionotropic glutamate receptors (activation leads to Na+ influx). Thus, off-center cells respond best when their photoreceptor input releases more glutamate.

Ganglion cells (and their bipolar inputs) respond weakly if a stimulus activates their entire receptive field.
Ganglion cells are sensitive to spectral contrasts by virtue of their opponent, center-surround organization. The on- and off-center responses create a push-pull system that provides sensory redundancy and decreases sensitivity to common rate changes (e.g., due to body temperature).

- Ganglion cells with inputs mainly from rods (in peripheral retina) are sensitive to light and dark.
- Ganglion cells with inputs primarily from cones (in the fovea) are sensitive to color contrasts.
Most ganglion cells with cone inputs are color-opponent. The two types of color-opponent cells are:

- red-green
- blue-yellow (where yellow sensitivity is created by the sum of inputs from red and green cones)
Retinal Ganglion Cell Properties

**M Cells**
- *Peripheral* retina (~100,000)
- *Large* cell bodies and large RFs
- *Coarse* resolution
- *Inputs* from 1000s of rods and cones – convey light vs. dark information
- *Rapid* adaptation and conduction of APs
- *Motion* response better than stationary
- Optimized for *large-scale, low-contrast moving patterns*

**P Cells**
- *Central* retina (esp. fovea) (~1 million)
- *Small* cell bodies and small RFs
- *Fine* resolution
- *Inputs* from ~1 cone – convey color
- *Slow* adaptation and conduction of APs
- *Stationary* targets better than moving.
- Optimized for *small-scale, high-contrast fine patterns*
Optics of eye project *reversed* and *upside-down* image of monocular visual field onto each retina.

Optic nerves exit each eye and project *bilaterally* to the *lateral geniculate nucleus (LGN)* of the (visual) thalamus.
- Fibers from *temporal* hemi-retina, which views the contralateral half of a monocular visual field, project to *ipsilateral* LGN.
- Fibers from the *nasal* hemi-retina, which views the ipsilateral half of a monocular visual field, *cross* the midline (“decussate”) in the *optic chiasm*, and project to *contralateral* LGN.

LGN on each side projects *ipsilaterally* to the *primary visual cortex*.

Result: Information from each visual hemi-field processed in *contralateral* hemisphere of visual cortex.
Approximately 90% of retinal ganglion cells project to the LGN. The remainder (not M or P cells) project to the hypothalamus, pre-tectum and superior colliculus.
Primate LGN is organized into 6 distinct layers (“laminae”).

- **Layers 1 and 2: Magnocellular**
  Large cells, input from M-RGCs.

- **Layers 3-6: Parvoocellular**
  Small cells, input from P-RGCs.

LGN cells in each layer are **monocular** because they receive RGC input from hemi-retina of **only one eye**:

- **Layers 1, 4, 6: contralateral nasal hemi-retina.**
- **Layers 2, 3, 5: ipsilateral temporal hemi-retina.**

Each lamina is **retinotopically organized** (adjacent points of the visual field are represented in adjacent regions). Each point in contralateral visual space is **precisely aligned** across layers (with the fovea over-represented).
LGN Physiology

Laminae are **retinotopic**: orderly “space map” of contralateral visual hemi-field in each layer of LGN.

Cells are **monocular**: Segregation of RGC input from each eye in overlapping laminae of LGN.

Receptive fields are **circular/opponent**, similar to the RGC inputs.
“Visual Cortex” includes many interconnected cortical areas processing visual information in the **occipital**, **parietal** and **temporal** lobes.

Primate visual cortex occupies more than 50% of the neocortex, reflecting importance of vision for behavior.

LGN projects to **primary visual cortex** (a.k.a. **striate cortex**, V1, Brodman’s **area 17**) in the **occipital lobe** (caudal cortical pole).
**Neocortex** has 6 layers labeled I to VI from top (pia surface) to bottom:
- Layer IV receives inputs from thalamus
- Layers interconnected vertically, forming **cortical columns**, the fundamental processing unit of the cortex.

LGN cells project to lowest part of layer IV (layer IV-C) of striate cortex:
- P and M cells project to different subdivisions of layer IV-C
- Inputs from the two eyes terminate side-by-side

V1 is **retinotopic**; the central (~4°) visual space (esp. fovea) is heavily over-represented.
By and large, the receptive fields of neurons of layer IVC (the input layer of primary visual cortex; striate cortex; V1) are similar to those of their LGN inputs and, in turn, of retinal ganglion cells. They are:

- monocular
- circular
- center-surround