Lect18-19: Vision – Central Pathways
Chapter 12 of Purves et al., 4e

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http://www.cs.sunysb.edu/~cse511 and ~lw
Figure 12.1 Central projections of retinal ganglion cells. Ganglion cell axons terminate in the lateral geniculate nucleus of the thalamus, the superior colliculus, the pretectum, and the hypothalamus. For clarity, only the crossing axons of the right eye are shown (view is looking up at the inferior surface of the brain).
Figure 12.2. The circuitry responsible for the pupillary light reflex. This pathway includes bilateral projections from the retina to the pretectum and projections from the pretectum to the Edinger-Westphal nucleus.

Neurons in the Edinger-Westphal nucleus terminate in the ciliary ganglion, and neurons in the ciliary ganglion innervate the pupillary constrictor muscles. Notice that the afferent axons activate both Edinger-Westphal nuclei via the neurons in the pretectum.
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Figure 12.3. Projection of the visual fields onto the left and right retinas. (A) Projection of an image onto the surface of the retina. The passage of light rays through the pupil of the eye results in images that are inverted and left-right reversed on the retinal surface. (B) Retinal quadrants and their relation to the organization of monocular and binocular visual fields, as viewed from the back surface of the eyes. Vertical and horizontal lines drawn through the center of the fovea define retinal quadrants (bottom). Comparable lines drawn through the point of fixation define visual field quadrants (center).
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Figure 12.3-2 Projection of the visual fields onto the left and right retinas. (B) Retinal quadrants and their relation to the organization of monocular and binocular visual fields, as viewed from the back surface of the eyes. Color coding illustrates corresponding retinal and visual field quadrants. The overlap of the two monocular visual fields is shown at the top. (B)
**Figure 12.3-3** Projection of the visual fields onto the left and right retinas. (B) Retinal quadrants and their relation to the organization of monocular and binocular visual fields, as viewed from the back surface of the eyes. Vertical and horizontal lines drawn through the center of the fovea define retinal quadrants (bottom). Comparable lines drawn through the point of fixation define visual field quadrants (*top*). Color coding illustrates corresponding retinal and visual field quadrants.
Figure 12.4 Projection of the binocular field of view onto the two retinas and its relation to the crossing of fibers in the optic chiasm. Points in the binocular portion of the left visual field (B) fall on the nasal retina of the left eye and the temporal retina of the right eye. Points in the binocular portion of the right visual field (C) fall on the nasal retina of the right eye and the temporal retina of the left eye. Points that lie in the monocular portions of the left and right visual fields (A and D) fall on the left and right nasal retinas, respectively. The axons of ganglion cells in the nasal retina cross in the optic chiasm, whereas those from the temporal retina do not. As a result, information from the left visual field is carried in the right optic tract, and information from the right visual field is carried in the left optic tract.
Figure 12.5. Visuotopic organization of the striate cortex in the right occipital lobe, as seen in midsagittal view. (A) The primary visual cortex occupies a large part of the occipital lobe. The area of central vision (the fovea) is represented over a disproportionately large part of the caudal portion of the lobe, whereas peripheral vision is represented more anteriorly. The upper visual field is represented below the calcarine sulcus, the lower field above the calcarine sulcus. (B) Coronal section of the human striate cortex, showing the characteristic myelinated band, or stria, that gives this region of the cortex its name. The calcarine sulcus on the medial surface of the occipital lobe is indicated. (B courtesy of T. Andrews and D. Purves.)
Figure 12.5-1 Visuotopic organization of the striate cortex in the right occipital lobe, as seen in midsagittal view. (A) The primary visual cortex occupies a large part of the occipital lobe. The area of central vision (the fovea) is represented over a disproportionately large part of the caudal portion of the lobe, whereas peripheral vision is represented more anteriorly. The upper visual field is represented below the calcarine sulcus, the lower field above the calcarine sulcus.
Figure 12.5-2 Visuotopic organization of the striate cortex in the right occipital lobe, (B) as seen in midsagittal view. (B) Coronal section of the human striate cortex, showing the characteristic myelinated band, or *stria*, that gives this region of the cortex its name. The calcarine sulcus on the medial surface of the occipital lobe is indicated. (B courtesy of T. Andrews and D. Purves.)
Figure 12.6 Visual field deficits resulting from damage at different points along the primary visual pathway. The diagram on the left illustrates the basic organization of the primary visual pathway and indicates the location of various lesions. The right panels illustrate the visual field deficits associated with each lesion. (A) Loss of vision in right eye. (B) Bitemporal (heteronomous) hemianopsia. (C) Left homonymous hemianopsia. (D) Left superior quadrantanopsia. (E) Left homonymous hemianopsia with macular sparing. (The reason for macular sparing is unclear, but the centermost visual field sends many axons.)
Figure 12.7 Course of the optic radiation to the striate cortex. Axons carrying information about the superior portion of the visual field sweep around the lateral horn of the ventricle in the temporal lobe (Meyers loop) before reaching the occipital lobe. Those carrying information about the inferior portion of the visual field travel in the parietal lobe.
Figure 12.8. Neurons in the primary visual cortex (V1) respond selectively to oriented edges. (A) An anesthetized animal is fitted with contact lenses to focus the eyes on a screen, where images can be projected; an extracellular electrode records the neuronal responses. (B) Neurons in the primary visual cortex typically respond vigorously to a bar of light oriented at a particular angle and less strongly – or not at all – to other orientations. (C) Orientation tuning curve for a neuron in primary visual cortex. In this example, the highest rate of action potential discharge occurs for vertical edges – the neuron's "preferred" orientation.
Figure 12.8 Neurons in the primary visual cortex respond selectively to oriented edges (Part 1)

**Figure 12.8-1** Neurons in the primary visual cortex (V1) respond selectively to oriented edges.

(A) An anesthetized animal is fitted with contact lenses to focus the eyes on a screen, where images can be projected; an extra-cellular electrode records the neuronal responses.
Figure 12.8-2 Neurons in the primary visual cortex (V1) respond selectively to oriented edges.

(B) Neurons in the primary visual cortex typically respond vigorously to a bar of light oriented at a particular angle and less strongly—or not at all—to other orientations.

(C) Orientation tuning curve for a neuron in primary visual cortex. In this example, the highest rate of action potential discharge occurs for vertical edges—the neuron's "preferred" orientation.
Figure 12.9 The representation of a visual image by neurons selective for different stimulus orientations. This simulation uses image mathematics (selective filtering of the two-dimensional Fourier transform of the image) to illustrate the attributes of a visual image (greyhound and fence) that would be represented in the responses of populations of cortical neurons tuned to different preferred orientations. The panels surrounding the image illustrate the components of the image that would be detected by neurons tuned to vertical, horizontal, and oblique orientations (blue boxes). In ways that are still not understood, the activity in these different populations of neurons is integrated to yield a coherent representation of the image features.

(Photos courtesy of Steve Van Hooser and Elizabeth Johnson.)
Figure 12.10. Organization of primary visual (striate) cortex. Striate cortex is divided into six principal cellular layers that differ in cell packing density, cellular morphology, and connections. (A) Primary visual cortex visualized using a histological stain that reveals neuronal cell bodies. In primates, layer 4 has several subdivisions (4A, 4B, and 4C; see also Figure 12.5). (B) Pyramidal cells with prominent apical and basilar dendrites are the most numerous cell type in the neocortex; they are located in all layers except 4C. Layer 4C is dominated by spiny stellate neurons, whose dendrites are confined to this layer. (C) Laminar organization of inputs from the lateral geniculate nucleus (LGN). Lateral geniculate axons terminate most heavily in layers 4C and 4A with less dense projections to layers 1, 2/3, and 6; the terminations in layer 2/3 are "patchy". (D) Laminar organization of major intracortical connections. Neurons in layer 4C give rise to axons that terminate in more superficial layers (4B and 2/3). Axons of layer 2/3 neurons terminate heavily in layer 5. Axons of layer 6 neurons terminate in layer 4C. (E) Laminar organization of neurons projecting to different targets. Connections with extrastriate cortex arise primarily from neurons in layers 2/3 and 4B (red). Descending projections to the lateral geniculate nucleus arise from layer 6 neurons (blue), while those projecting to the superior colliculus reside in layer 5 (green).
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**NEUROSCIENCE, Fourth Edition, Figure 12.10 (Part 1)**

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Figure 12.10-2 Organization of primary visual (striate) cortex. Striate cortex is divided into six principal cellular layers that differ in cell packing density, cellular morphology, and connections. (D) Laminar organization of major intracortical connections. Neurons in layer 4C give rise to axons that terminate in more superficial layers (4B and 2/3). Axons of layer 2/3 neurons terminate heavily in layer 5. Axons of layer 6 neurons terminate in layer 4C. Connections with extrastriate cortex arise primarily from neurons in layers 2/3 and 4B (red). Descending projections to the lateral geniculate nucleus arise from layer 6 neurons (blue), while those projecting to the superior colliculus reside in layer 5 (green).

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Figure 12.11. Orderly progression of columnar response properties forms the basis of functional maps in primary visual cortex. (A) Neurons displaced along the radial axis of the cortex have receptive fields that are centered on the same region of visual space and exhibit similar orientation preferences. At left is a depiction of a vertical microelectrode penetration into primary visual cortex. Neuronal receptive fields encountered along the electrode track are located in the upper part of the right visual field (central panel, top; intersection of axes represents center of gaze). Note that there is little variation in the location of the receptive field centers (central panel, bottom). The orientation tuning curves (right panel, top) and preferred orientation (right panel, bottom) for neurons encountered along the electrode track show that there is little variation in the orientation preference of the neurons. (B) Neurons displaced along the tangential axis of the cortex exhibit an orderly progression of receptive field properties. Neurons encountered along the electrode penetration have receptive field centers (center panel) and orientation preferences (right panel) that shift in a progressive fashion.
Orderly progression of columnar response properties forms the basis of functional maps in primary visual cortex. (A) Neurons displaced along the radial axis of the cortex have receptive fields that are centered on the same region of visual space and exhibit similar orientation preferences. At left is a depiction of a vertical microelectrode penetration into primary visual cortex. Neuronal receptive fields encountered along the electrode track are located in the upper part of the right visual field (central panel, top; intersection of axes represents center of gaze). Note that there is little variation in the location of the receptive field centers (central panel, bottom). The orientation tuning curves (right panel, top) and preferred orientation (right panel, bottom) for neurons encountered along the electrode track show that there is little variation in the orientation preference of the neurons.
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Figure 12.12 Functional imaging techniques reveal the orderly mapping of orientation preference in primary visual cortex. (A) Surface view of the visual cortex using intrinsic signal imaging techniques to visualize the map of preferred orientation. Colors indicate the average preferred orientation of columns at a given location; red indicates the location of columns that respond preferentially to horizontal orientations, blue those that respond preferentially to vertical orientations. The smooth progression of preferred orientations is interrupted by point discontinuities (pinwheel centers; circle). (B) Single-cell view of a "pinwheel" visualized using two-photon imaging of calcium signals. Note that adjacent cells have similar preferred orientations except at the very center, where nearby cells exhibit nearly orthogonal orientation preferences. (A courtesy of D. Fitzpatrick; B modified from Ohki et al., 2006.)
Figure 12.13. Mixing of the pathways from the two eyes first occurs in the striate cortex. (A) Although the lateral geniculate nucleus receives inputs from both eyes, the inputs are segregated in separate layers. (B) In many species, including most primates, inputs from the two eyes remain segregated in the ocular dominance columns of layer 4. Layer 4 neurons send their axons to other cortical layers; it is at this stage that the information from the two eyes converges onto individual neurons. (B,C) Physiological demonstration of columnar organization of ocular dominance in primary visual cortex. Cortical neurons vary in the strength of their response to inputs from the two eyes, from complete domination by one eye to equal influence by the two eyes. Neurons encountered in a vertical electrode penetration (other than those that lie in layer 4) tend to have similar ocular dominance. Tangential electrode penetration across the superficial cortical layers reveals a gradual shift in the strength of response to the inputs from the two eyes, from complete domination by one eye to equal influence of the two eyes. (D) Pattern of ocular dominance columns in human striate cortex. The alternating left and right eye columns in layer 4 have been reconstructed from tissue sections and projected onto a photograph of the medial wall of the occipital lobe. (D from Horton and Hedley-Whyte, 1984.)
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(D) Pattern of ocular dominance columns in human striate cortex. The alternating left and right eye columns in layer 4 have been reconstructed from tissue sections and projected onto a photograph of the medial wall of the occipital lobe. (D from Horton and Hedley-Whyte, 1984.)
Binocular disparities are generally thought to be the basis of stereopsis. When the eyes are fixated on point b, points that lie beyond the plane of fixation (point c) or in front of the point of fixation (point a) project to noncorresponding points on the two retinas. When these disparities are small, the images are fused and the disparity is interpreted by the brain as small differences in depth. When the disparities are greater; double vision occurs (although this normal phenomenon is generally not noticed).
**Box 12A1.** Random dot stereograms. (A) A random dot pattern is created to be observed by one eye. The stimulus for the other eye is created by copying the first image, displacing a particular region horizontally, and then filling in the gap with a random sample of dots. (B) When the right and left images are viewed simultaneously but independently by the two eyes (by using a stereoscope or fusing the images by converging or diverging the eyes), the shifted region (a square) appears to be in a different plane from the other dots. (After Wandell, 1995.)
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From 30 to 50 cm away, stare gently at the pair of squares. Relax your focus until a middle square appears. Concentrate on the center square until each “fuzzy blob” becomes a shape rising from the background.
Box 12A2 Random dot stereograms. (C) An autostereogram (a single square). The hidden figures (three geometrical forms) emerge by diverging the eyes in this case. (Courtesy of Jun Oi.)
Figure 12.15. Magno-, parvo-, and koniocellular pathways (magn-, parv- in Latin ‘large’, ‘small’ plus Greek koni- ‘dust’). (A) Tracings of M, P, and K ganglion cells as seen in flat mounts of the retina. M cells have large-diameter cell bodies and large dendritic fields. They supply the two magnocellular layers of the lateral geniculate nucleus. P cells have smaller cell bodies and dendritic fields. They supply the four parvocellular layers of the lateral geniculate nucleus. K cells have small cell bodies and intermediate size dendritic fields. They supply the six koniocellular layers of the lateral geniculate nucleus.

(B) The human lateral geniculate nucleus showing the magnocellular, parvocellular, and koniocellular layers.

(C) Termination of lateral geniculate axons in striate cortex. Magnocellular layers terminate in layer 4C $\alpha$; parvocellular layers, in layer 4C $\beta$; and koniocellular layers, in a patchy pattern in layers 2 and 3. Inputs to other layers omitted for simplicity (see Figure 12.10). (A after Watanabe and Rodieck, 1989; B courtesy of T. Andrews and D. Purves.)
Magno-, parvo-, and koniocellular pathways (Part 1)

Magno-, parvo-, and koniocellular pathways (magn-, parv- in Latin ‘large’, ‘small’ plus Greek koni- ‘dust’). (A) Tracings of M, P, and K ganglion cells as seen in flat mounts of the retina. M cells have large-diameter cell bodies, thick axons, and large dendritic fields. They carry motion information and supply the magnocellular two layers of the lateral geniculate nucleus.

P cells have smaller cell bodies and dendritic fields. They supply the four parvocellular layers of the lateral geniculate nucleus with high-resolution color data. K cells have small cell bodies and intermediate size dendritic fields. They supply the six koniocellular layers of the lateral geniculate nucleus with blue-color information. (A after Watanabe and Rodieck, 1989.)
Figure 12.15-2 Magno-, parvo-, and koniocellular pathways (magn-, parv- in Latin ‘large’, ‘small’ plus Greek koni- ‘dust’). (B) The human Lateral Geniculate Nucleus showing the magnocellular, parvocellular, and koniocellular layers. LGN cells in the koniocellular layer are almost invisibly tiny, like motes of ‘dust’. (C) Termination of lateral geniculate axons in striate cortex. Magnocellular layers terminate in layer 4C α, parvocellular layers terminate in layer 4C β, and koniocellular layers terminate in a patchy pattern in layers 2 and 3. Inputs to other layers omitted for simplicity (see Figure 12.10). (B courtesy of T. Andrews and D. Purves.)
Figure 12.16. Subdivisions of the extrastriate cortex in the macaque monkey. (A) Each of the subdivisions indicated in color contains neurons that respond to visual stimulation. Many are buried in sulci, and the overlying cortex must be removed in order to expose them. Some of the more extensively studied extrastriate areas are specifically identified (V2, V3, V4, and MT). V1 is the primary visual cortex; MT is the middle temporal area. (B) The arrangement of extrastriate and other areas of neocortex in a flattened view of the monkey neocortex. There are at least 25 areas that are predominantly or exclusively visual in function, plus 7 other areas suspected to play a role in visual processing. (A after Maunsell and Newsome, 1987; B after Felleman and Van Essen, 1991.)
Some of the more extensively studied extrastriate areas are specifically identified (V2, V3, V4, and MT). V1 is the primary visual cortex; MT is the middle temporal area. (A after Maunsell and Newsome, 1987.) Extrastriate cortical areas are organized into two largely separate systems that feed information into cortical association areas in the temporal and parietal lobes. One, the ventral stream, includes area V4 and leads from the striate cortex into the inferior part of the temporal lobe. This system is responsible for high-resolution form vision and object recognition.

The other, the dorsal stream, includes MT and leads from striate cortex into the parietal lobe. This system is responsible for spatial aspects of vision, such as analysis of motion and positional relationships between objects in the visual scene.
Figure 12.16-2 Subdivisions of the extrastriate cortex in the macaque monkey.

(B) The arrangement of extrastriate and other areas of neocortex in a flattened view of the monkey neocortex. There are at least 25 areas that are predominantly or exclusively visual in function, plus 7 other areas suspected to play a role in visual processing. (B after Felleman and Van Essen, 1991.)
Figure 12.17. Localization of multiple visual areas in the human brain using fMRI. (A, B) Lateral and medial views (respectively) of the human brain, illustrating the location of primary visual cortex (V1) and additional visual areas V2, V3, VP (ventral posterior area), V4, MT (middle temporal area), and MST (medial superior temporal area). (C) Unfolded and flattened view of retinotopically defined visual areas in the occipital lobe. Dark grey areas correspond to cortical regions that were buried in sulci; light areas correspond to regions located on the surface of gyri. Visual areas in humans show a close resemblance to visual areas originally defined in monkeys (compare with Figure 12.16). (After Sereno et al., 1995.)
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(After Sereno et al., 1995.)
Figure 12.18 The visual areas beyond the striate cortex are broadly organized into two pathways: a ventral pathway that leads to the temporal lobe, and a dorsal pathway that leads to the parietal lobe. The ventral pathway plays an important role in object recognition, while the dorsal pathway is involved in spatial vision.