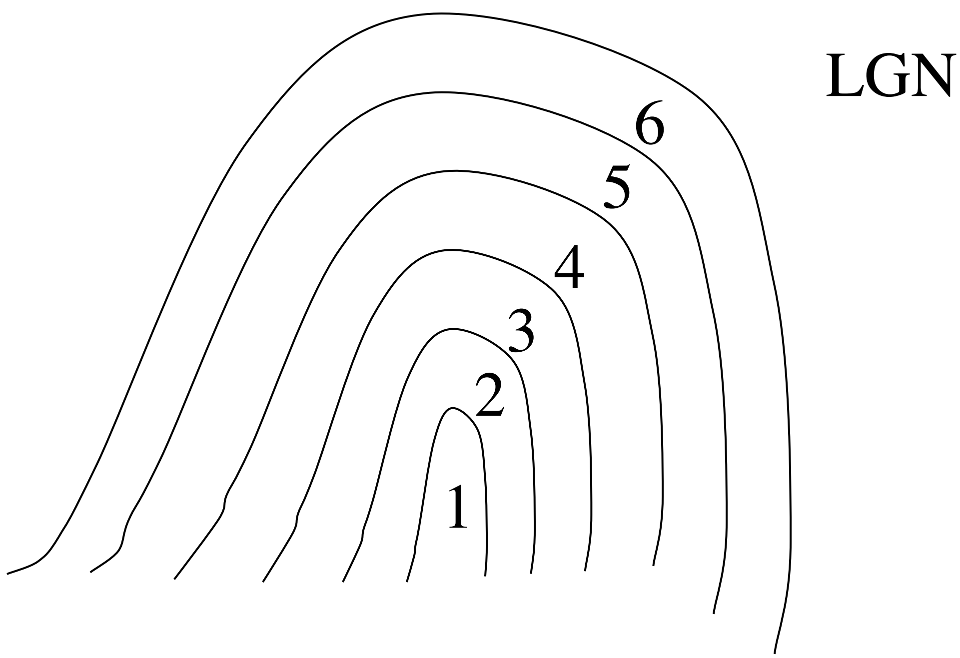
The Visual Pathway - LGN and Cortex

- Ganglion cell axons (the optic nerve) project to the Lateral Geniculate Nucleus (LGN, a part of the thalamus).
- The LGN also receives input from visual cortex, the brain stem, and elsewhere in the thalamus.
- LGN cells project to Primary Visual Cortex (also called striate cortex).
- Both LGN and visual cortex have a retinotopic map of visual space.
- The primary role of the LGN may be a “gate keeper” to modulate the information sent to visual cortex.
- Visual cortex and subsequent visual processing areas continue the elaboration of visual information processing.

LGN

Most of the axons from the ganglion cells project to the LGN. The “map” of the LGN is divided according to a number of different qualities. Each will be described.

The LGN has six distinct layers, numbered 1 through 6. These are illustrated below.



LGN - Left and Right Eyes

The LGN is divided into left and right halves. The left LGN receives projections from the left half of each retina. The right LGN from the right half of each retina.

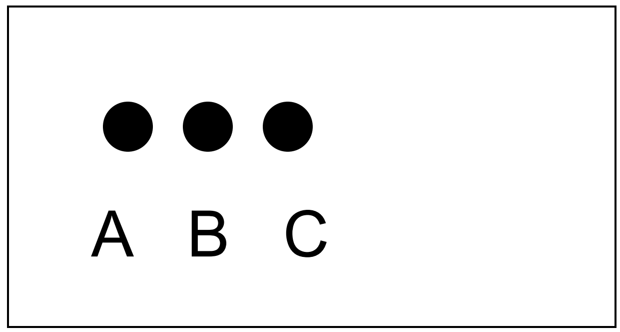
The axons from the half of the retina on the same side of the body as the LGN are called the ipsilateral axons. The axons from the opposite eye are the contralateral axons.

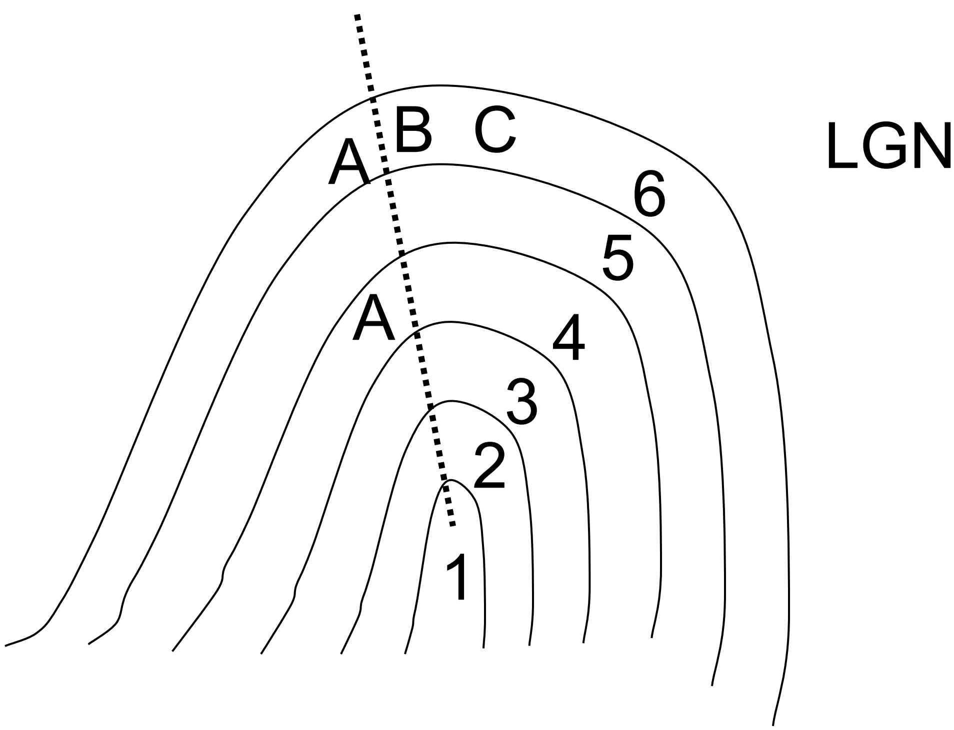
Ipsilateral axons project to layers 2, 3, and 5. Contralateral axons project to layers 1, 4, and 6.

In all layers, adjacent receptive fields on the retina project to adjacent cells in the LGN. The retinotopic maps in each LGN layer are similar.

LGN - Left and Right Eyes 2

Retinal Receptive Fields





LGN - Magno and Parvo Layers

Anatomically and functionally, *ganglion* cells can be divided into two types: M-cells (large cell body) and P-cells (smaller cell body).

M-cells will respond to relatively little contrast and rapidly initiate firing to stimulation in their receptive fields. Their receptive fields tend to be larger. M-cells project to layers 1 (contralateral) and 2 (ipsilateral) of the LGN. These are the magnocellular (magno) layers.

P-cells require more contrast, are more sluggish to respond and have smaller receptive fields. P-cells project to layers 3 (ipsilateral), 4 (contralateral), 5 (ipsilateral), and 6 (contralateral) of the LGN. These are the parvocellular (parvo) layers.

Magno and Parvo Layers - 2

What roles do the magno and parvo layers play in perception?

If the magno layers are destroyed, the animal loses the ability to detect motion. Thus, the M-cells and the magnocellular pathway are involved in the perception of motion.

If the parvo layers are destroyed, the animal loses the ability to detect detail, color and depth. Thus, the P-cells and the parvocellular pathway are involved in the perception of texture, pattern, color, and depth.

Cortex - Overview

- Axons from the LGN project to primary visual cortex (also called striate cortex).
- Like the LGN, visual cortex has a retinotopic map and keeps the parvo and magno systems separate.
- The receptive fields of cortical cells are more complex, and varied, than the center-surround field.
- Three types of cortical cells will be described: simple, complex and hypercomplex (end-stopped).
- The analysis of the visual world by the cortex can be described in terms of the spatial frequencies of objects or in terms of objects being composed of simple features.

Projections from LGN

LGN axons project to layer 4 (of 6 layers) in the visual cortex. Magno cells project to the lower half of this layer, parvo cells to the upper half. Axons from layer 4 project to the other layers. These layers of visual cortex also receive input from other parts of the visual cortex.

Properties of Visual Cortex

Cells in the visual cortex are organized in a retinotopic map. Adjacent areas of cortex represent adjacent areas of the retina.

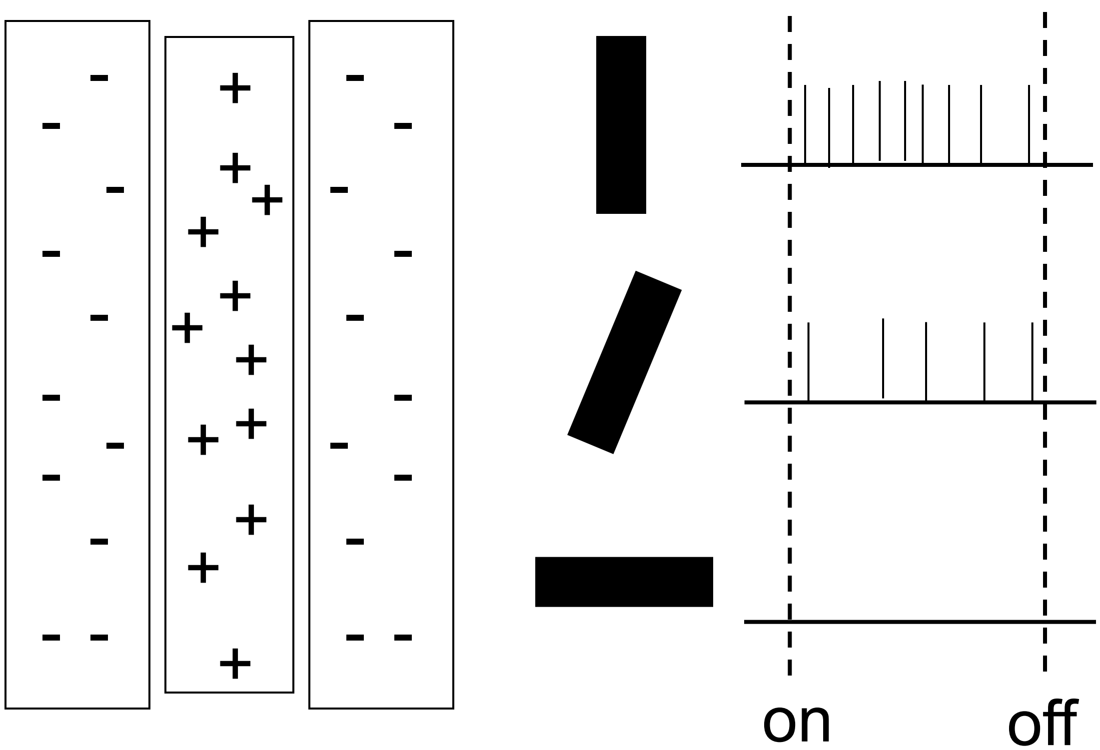
Most cells in the visual cortex are binocular, receiving input from corresponding areas on the two retinas. Even though most cells are binocular, they also have ocular dominance (respond more strongly to the input of one eye).

<Note here the contrast with LGN cells, which are monocular.>

Visual Cortex Receptive Fields

There are three basic types of receptive fields: simple, complex and hypercomplex (end-stopped).

Simple cells have receptive fields such as:

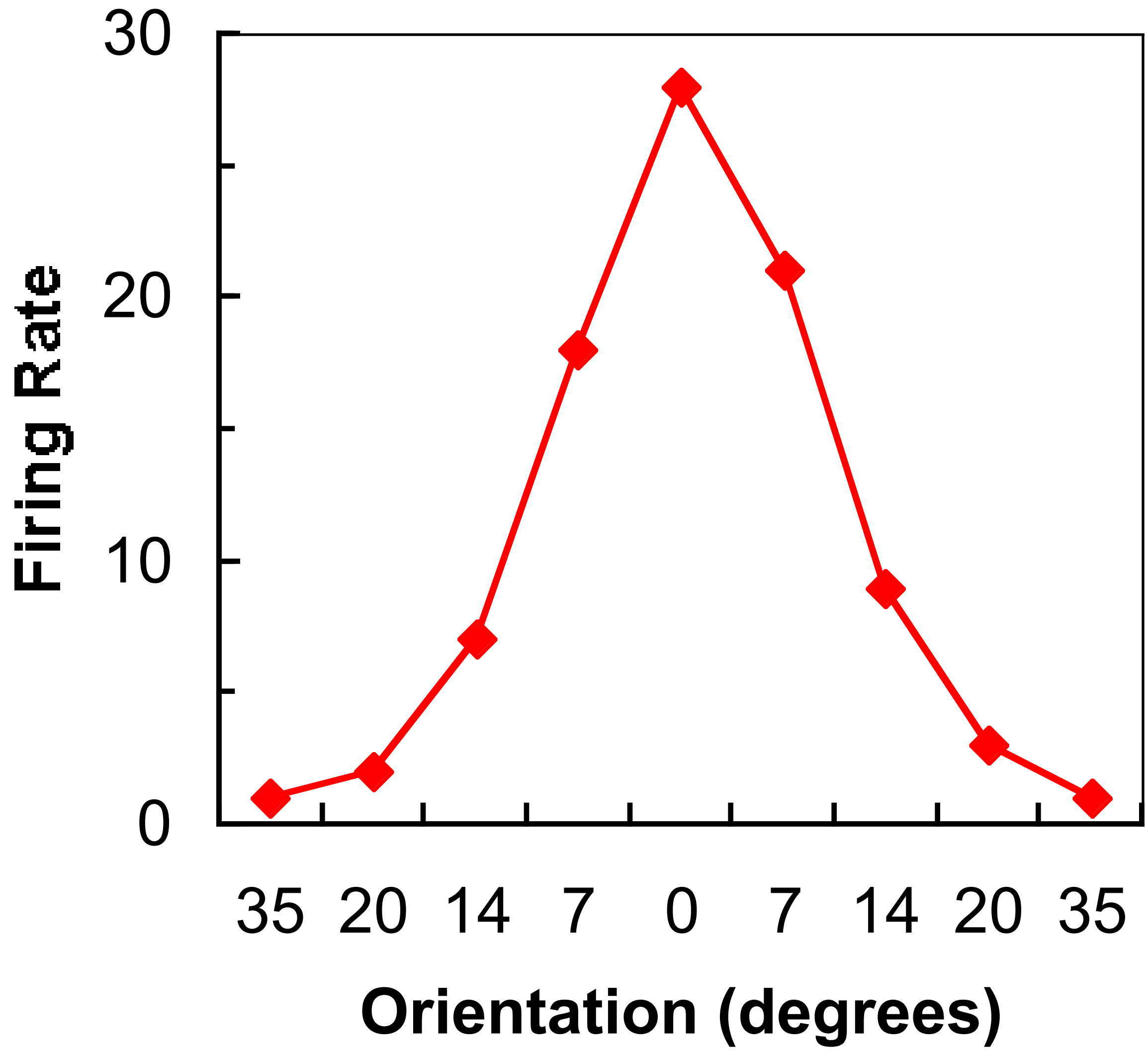


Simple Cell Receptive Fields

Simple cells have the following properties:

1. Their excitatory center is elongated and flanked by inhibitory regions.
2. The field is orientation sensitive.
3. The field is width sensitive.
4. The field is retinotopic.
5. The cell is binocular, but has ocular dominance.
6. Many of these cells code color. Some are achromatic. The color sensitive cells are in the upper part of each layer and receive input from the parvo system.

Simple cell orientation sensitivity



This simple cell fires maximally for a vertically oriented bar.

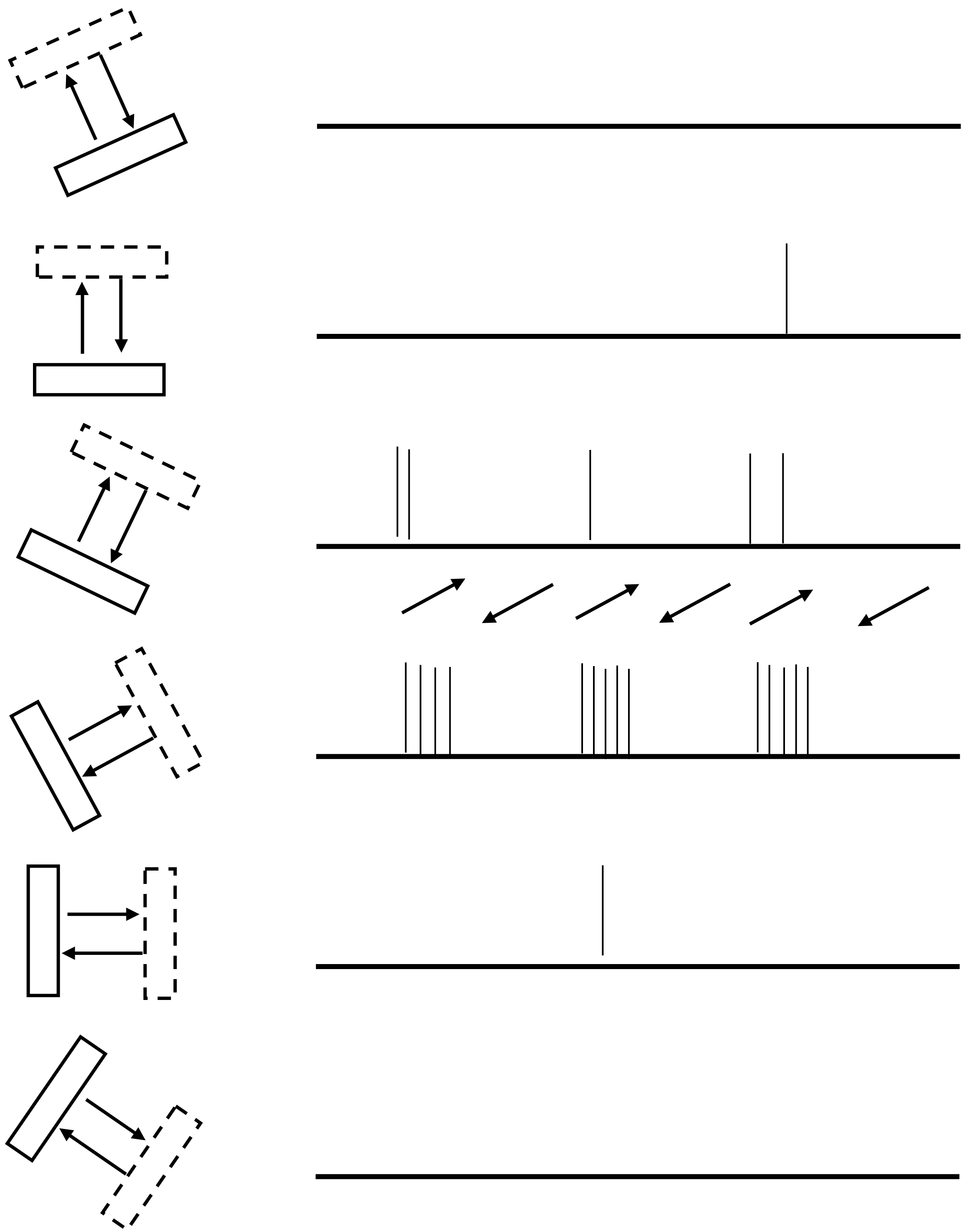
Complex Cell

Complex cells have receptive fields similar to simple cells. They are orientation sensitive and retinotopic. In addition:

1. Most require motion of the oriented bar to respond. Most require motion in only one direction, perpendicular to the orientation of the bar. Some will respond to motion in either direction perpendicular to the bar.

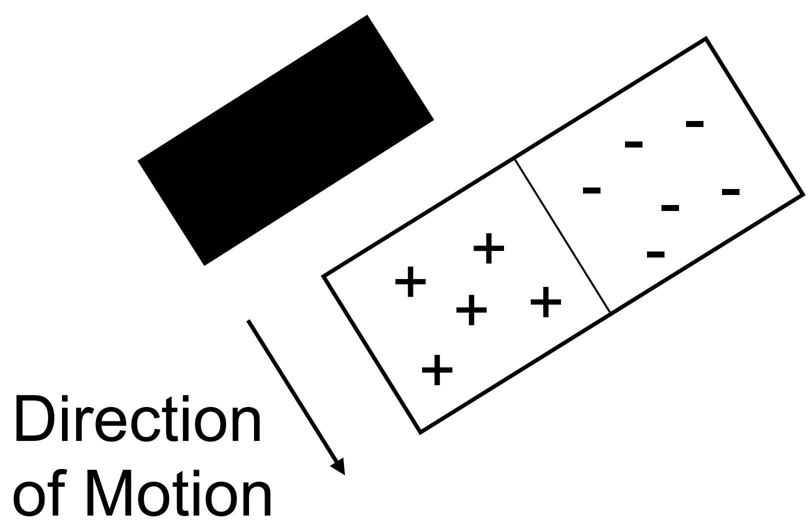
2. Their excitatory and inhibitory regions are not as sharply defined. They will respond to an appropriately oriented bar anywhere in their receptive field.

Complex cell example



Hypercomplex Cells
(End-stopped Cells)

These cells have properties similar to the complex cells. They are orientation selective. However, they also have an optimal length or end to their receptive field.



Cortical Receptive Field Summary

Simple - Respond best to an oriented bar of a particular width. Bar stationary.

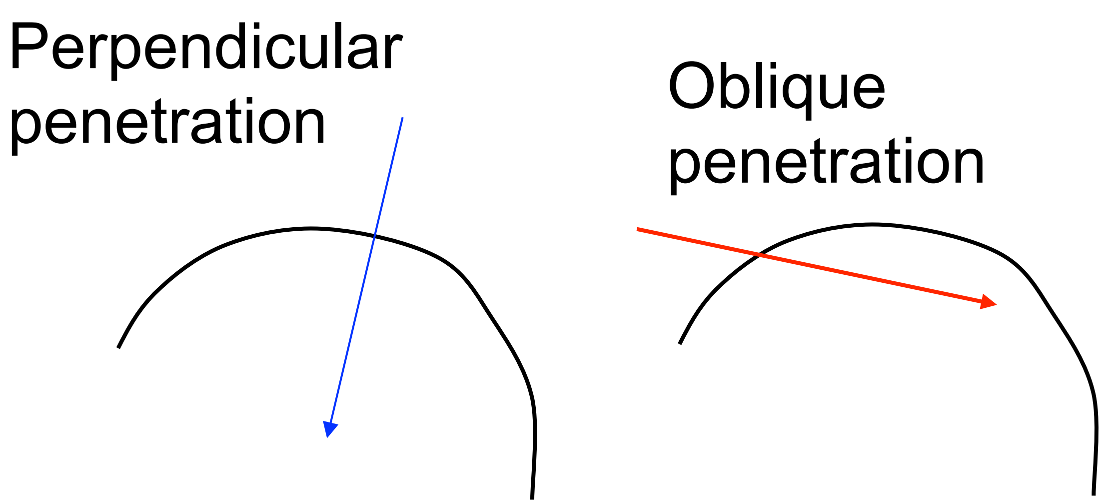
Complex - Responds best to an oriented bar moving in one direction or back and forth. Motion perpendicular to orientation.

End-stopped - Corners, angles or bars of a particular length moving in a particular direction.

Columnar Organization

If we place an electrode in the visual cortex and then move it into the cortex in a *perpendicular* direction, then all of the cells that we encounter have properties in common.

They share orientation, ocular dominance, and retinal location.

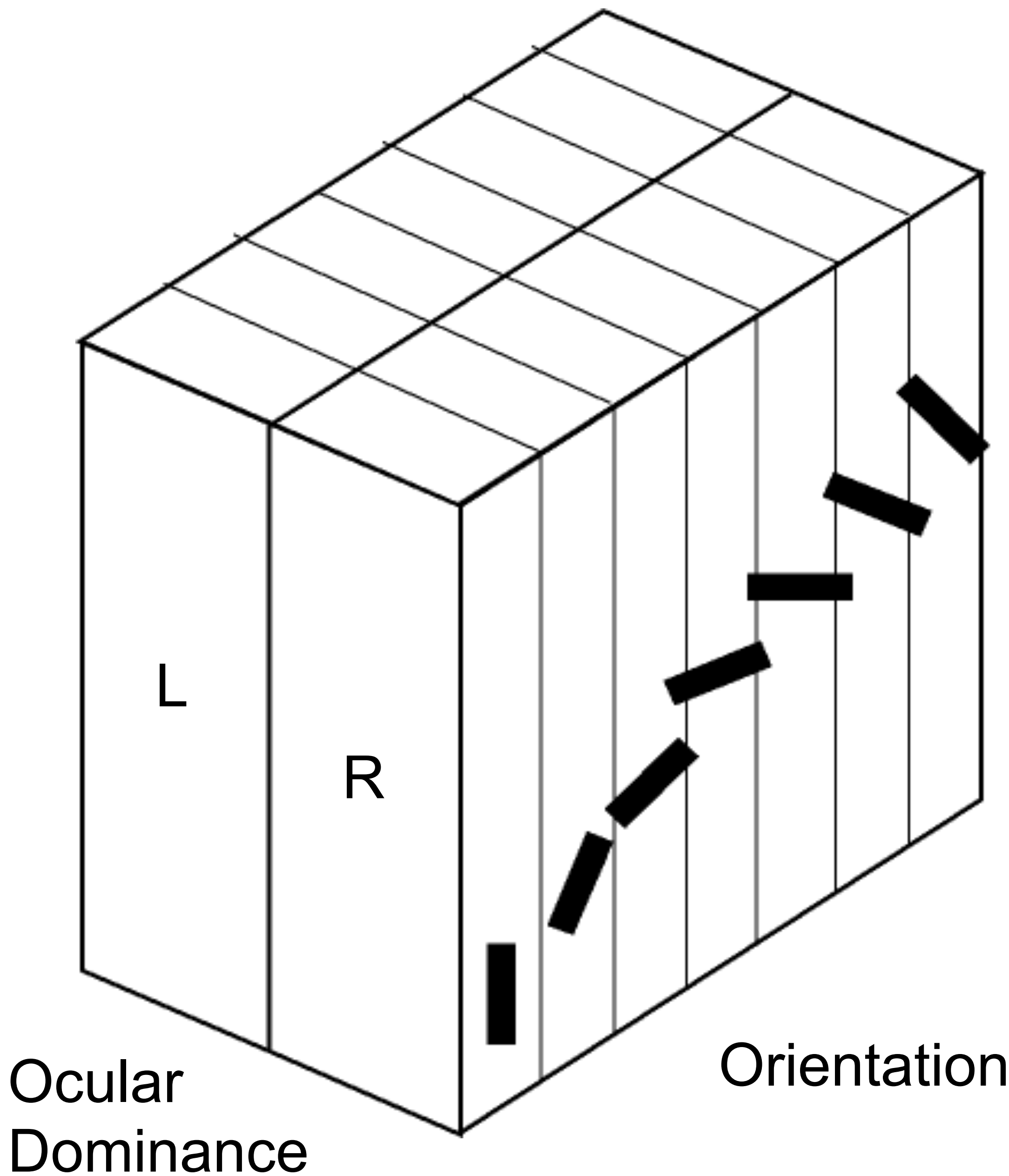


Columnar - 2

For every column that has right eye ocular dominance, there is an adjacent column with left eye ocular dominance. Ocular dominance columns occur in pairs.

Next to one pair of ocular dominance columns with be another pair in which the orientation selectivity is at a slightly different angle. Next to this will be another pair with a yet different angle. There will be a set of adjacent column pairs which, together, cover the full 360 degree range of orientations. This set is called a hypercolumn. All of the columns that make up a hypercolumn correspond to the same area on the retina.

Hypercolumn



Hypercolumn Summary

1. Each hypercolumn codes all orientations, and left and right ocular dominance.

2. Each column within a hypercolumn has simple, complex and end-stopped cells. Some code color, some are achromatic. Different simple cells also code different bar widths.

3. Adjacent hypercolumns code adjacent regions of the retina.

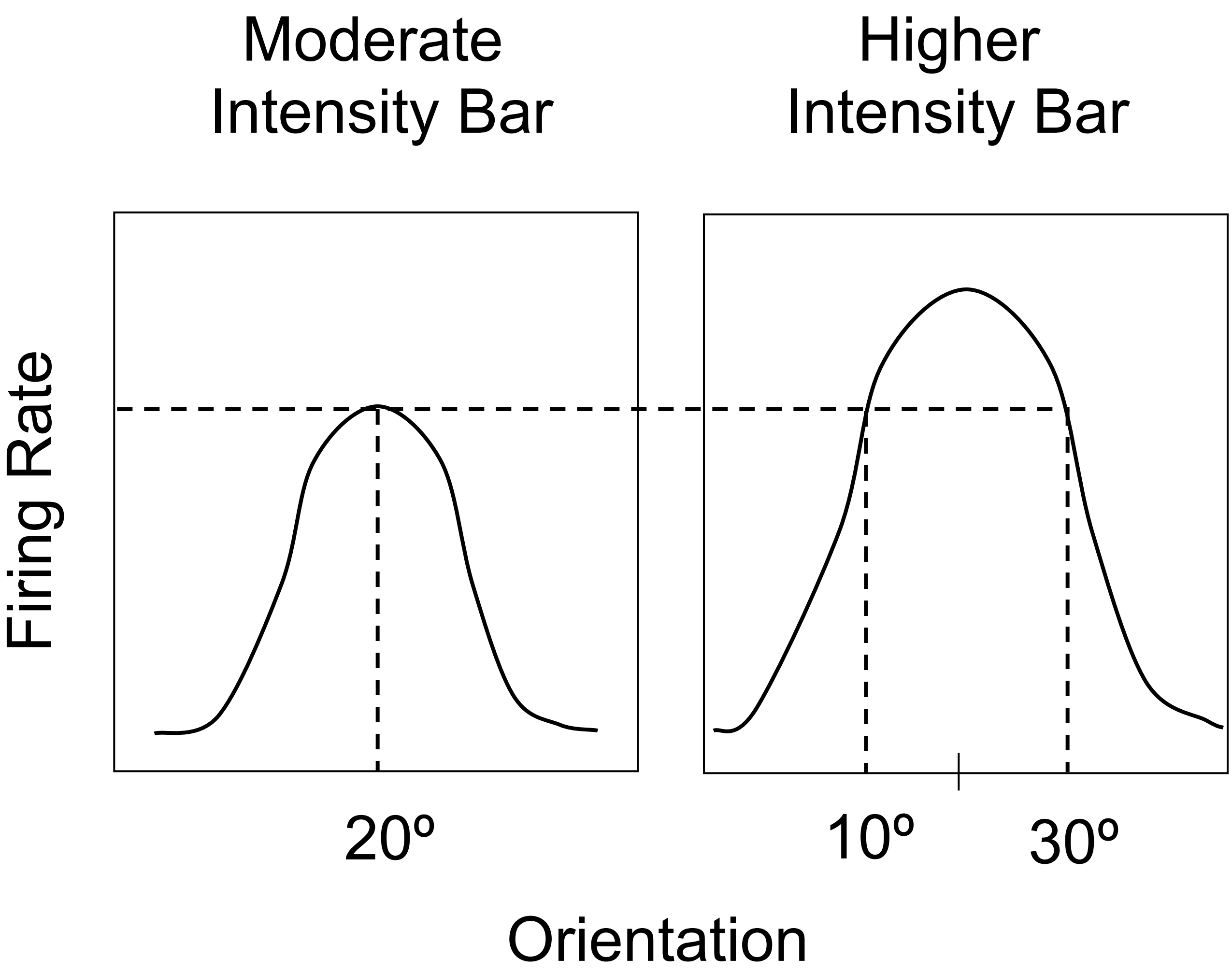
A long edge on the retina would be coded by columns of the same orientation and ocular dominance in adjacent hypercolumns. In this way, the responses of cells in primary visual cortex are a “virtual” representation of the visual world.

The Cortical Neural Code

This description makes it sound like there are individual cells to represent individual perceptions. This is called *specificity coding*. Specificity coding leads to some problems. The most severe one is ambiguity in what the firing of a neuron represents.

In the next graph, the firing of a simple cell, tuned to a 20 degree orientation, is shown for the same bar at a moderate intensity and at a high intensity. As can be seen, when this cell fires 30 times per second (dashed line), it could be the result of a 10 degree or 30 degree bar at high intensity or a 20 degree bar at moderate intensity.

Specificity Coding Graph



This is the tuning curve for a single cell whose optimal response is to a 20º bar.

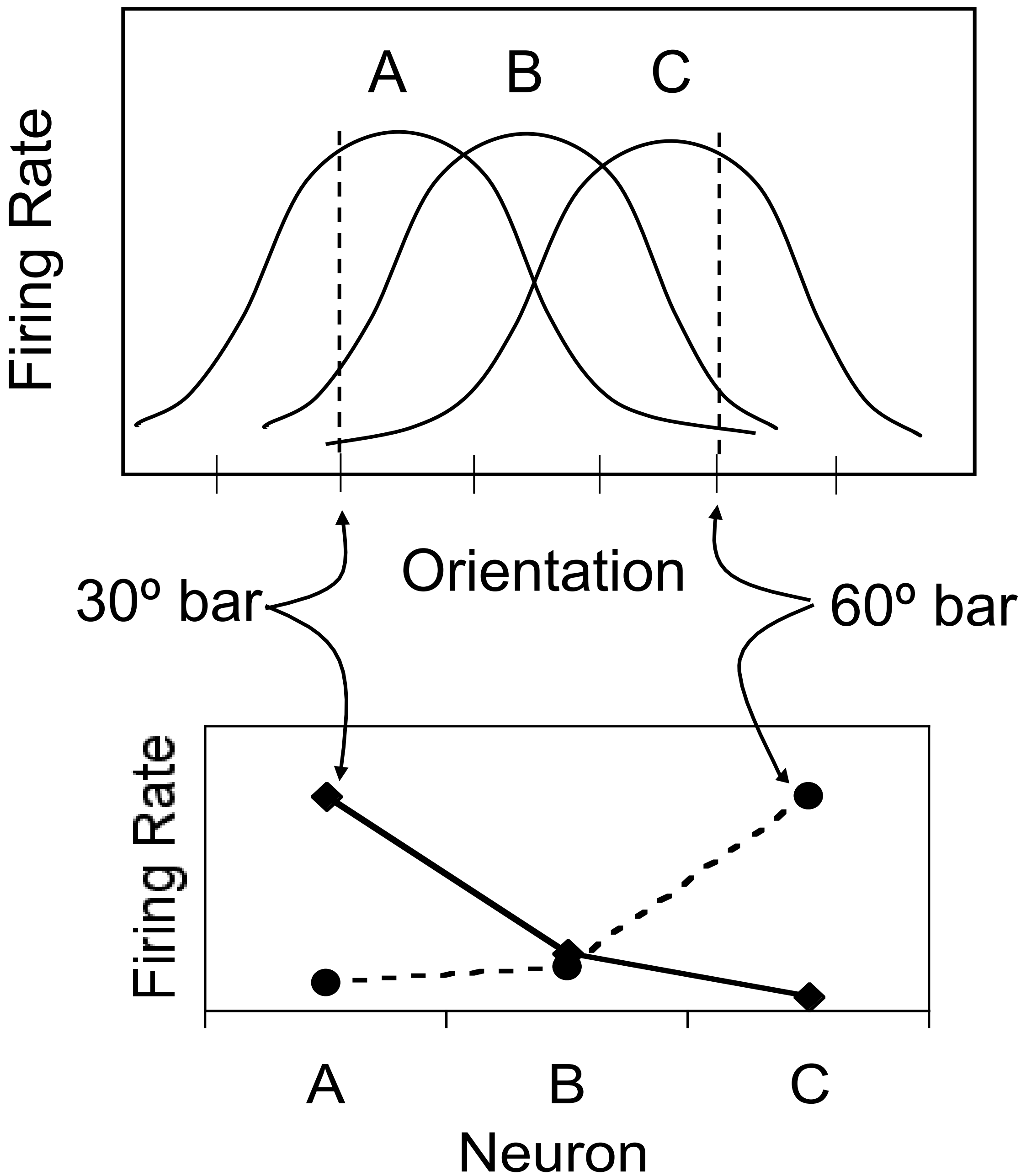
Distributed Coding

The alternative to specificity coding is some form of *distributed coding* (the two alternatives that we previously called distributed and sparse coding).

In distributed coding, it is the pattern of response across cells with overlapping tuning curves that signals the nature of the world.

For example, if we have cells with optimal responses near 30º, 45º, and 60º then the response to a 30º bar *across* the cells would be the same, regardless of intensity since all three cells would change together with a change in intensity. This pattern of response would be very different to a 45º or 60º bar.

Distributed Coding Example



Coding Summary

Pattern coding (distributed, sparse) seems to offer a better solution to how to describe the neural basis of perception.

The representation of basic elements in visual perception is by the combined response of many neurons.

This provides a relatively unambiguous representation.

It is invariant across changes in stimulus intensity.

It can differentiate a virtually unlimited number of visual images.