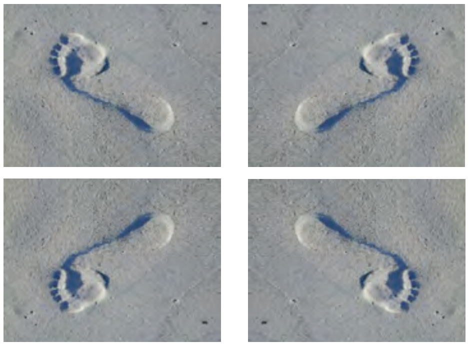
Announcements

- exam this Thursday
- review session **<u>TODAY</u>** @ 6:15PM in Meliora 203
  (email TAs with questions)



Cortical visual processing

- Main visual pathway from retina to V1
- Primary visual cortex (V1)
  - receptive fields (RF) of V1 neurons
  - RF tuning of V1 neurons
  - organization of V1 neurons
- How V1 RF properties determine what we see?
  - contrast sensitivity function
  - selective adaptation
  - art & spatial frequency

Retinal Ganglion Cell Types

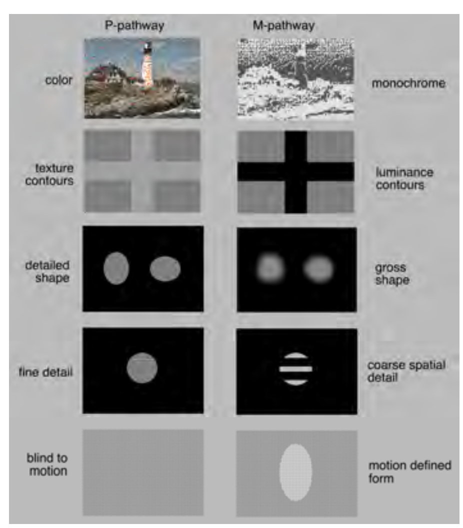
	P Cells	M Cells	K Cells
Cell Size	small	large	very small
Receptive Field Size	small	large	small
Response Duration	Sustained	Transient	Transient
Responds to Color	Yes	No	Yes
Percentage of Cell Population	80%	10%	10%

M Cells

- **M cells** receive input from a relatively large number of photoreceptors (mostly input from rods)
  - –Good light sensitivity, but poor spatial resolution
- Transient responses
  - –Good temporal resolution (sensitive to motion)
- Large – with broad (thick) axons
  - –consequently faster nerve conduction velocities
  - –Good for motion
- Not color-sensitive
- **Origin of the magnocellular pathway**

P Cells

- P cells receive input from a relatively small number of photoreceptors (mostly input from cones)
  - –Good spatial resolution, but poor sensitivity
- Sustained responses
  - –Poor temporal resolution
- Small – with narrow (thin) axons
  - –Slow conduction velocities
  - –Not good for conveying info about rapidly changig events
- Color sensitivity
- **Origin of the parvocellular pathway**



Why parallel pathways?

"Any large computation should be split up and implemented as a collection of small sub-parts that are as nearly independent of one another as the overall task allows.

If a process is not designed in this way, a small change in one place will have consequences in many other places.

This means that the process as a whole becomes extremely difficult to debug or to improve, whether by a human designer or in the course of natural evolution, because a small change to improve one part has to be accompanied by many simultaneous compensating changes elsewhere."

(David Marr, 1976, p. 485)

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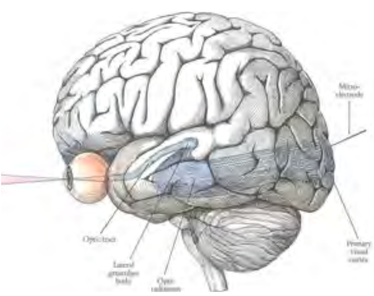
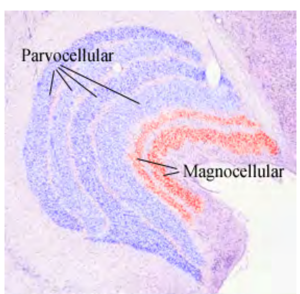
Where from the retina?

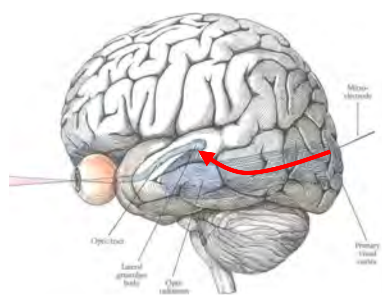
- M cells – project to the magnocellular layers of the lateral geniculate nucleus (LGN)
- P cells – project to the parvocellular layers of the LGN
- K cells – project to koniocellular layers





Where from the retina?

- M cells – project to the magnocellular layers of the lateral geniculate nucleus (LGN)
- P cells – project to the parvocellular layers of the LGN
- K cells – project to koniocellular layers



- Retinal ganglion cells axons: **NOT** the main source of synaptic input to the LGN
- Cortex provides 80% of the synaptic inputs
- Brain stem also projects to LGN and provides modulatory influence on neuronal activity

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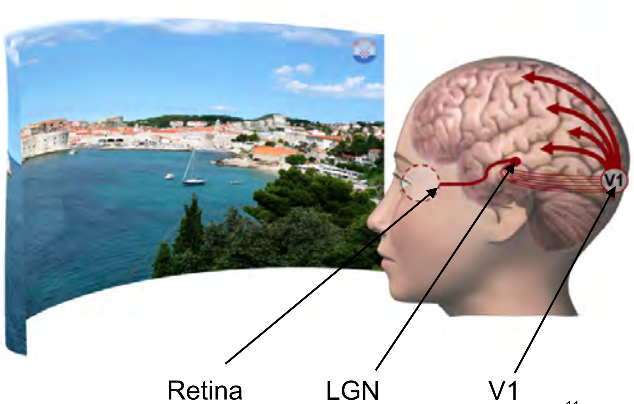
Where from the LGN?



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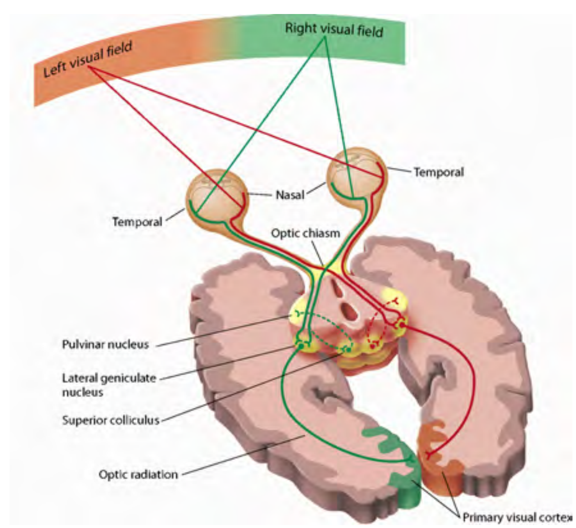
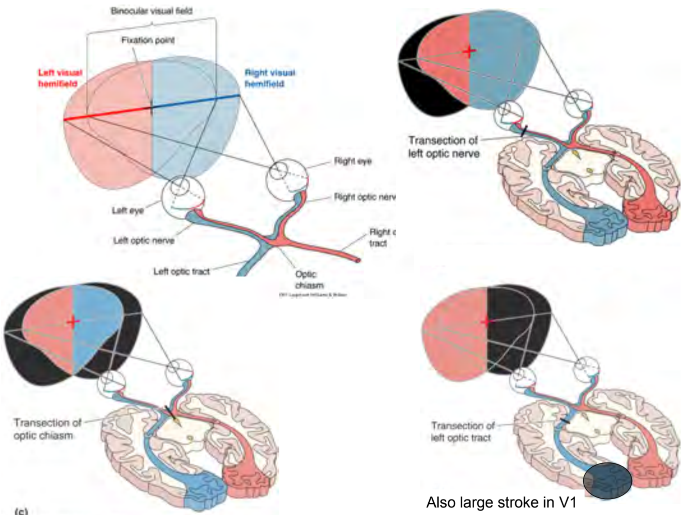
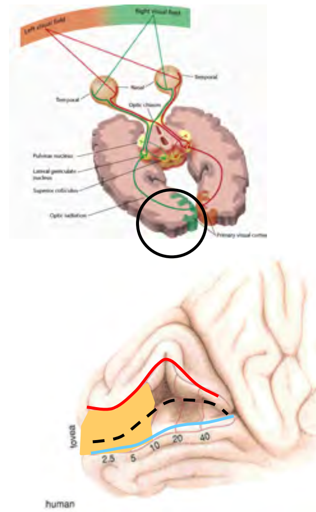
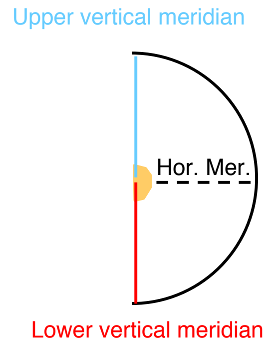


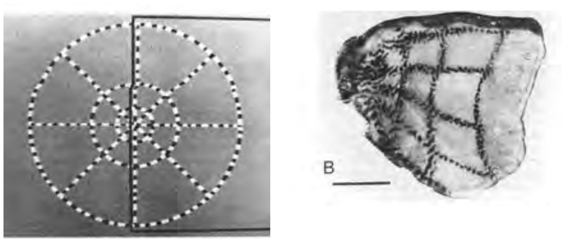


Visual map in V1

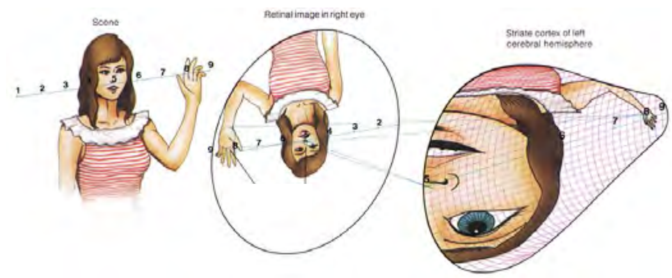




Visual map in V1
Cortical magnification of fovea



Visual map in V1
Cortical magnification of fovea



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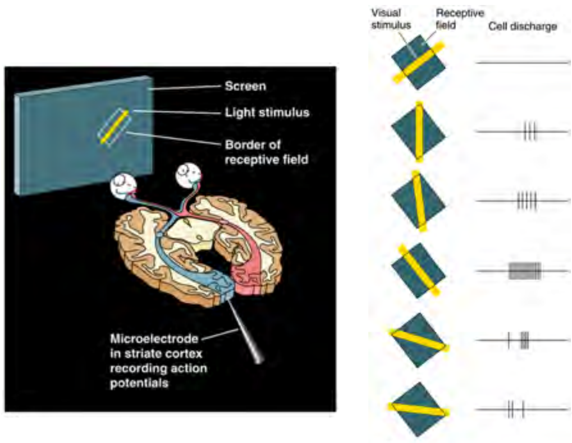
Single-cell recording from visual cortex

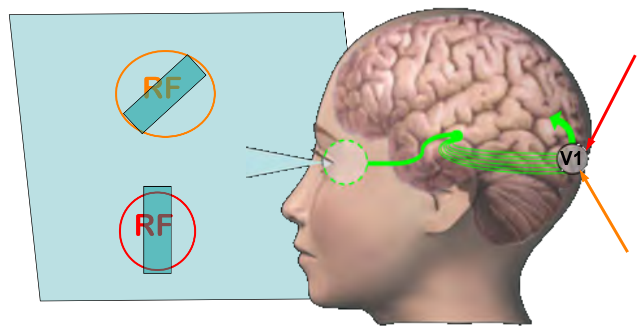
David Hubel & Thorsten Wiesel

1981 Nobel Prize in Physiology or Medicine

Single-cell recording from visual cortex



Receptive fields in V1



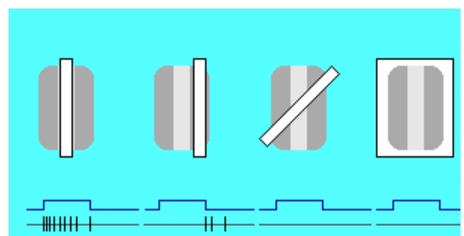
Receptive Fields in V1

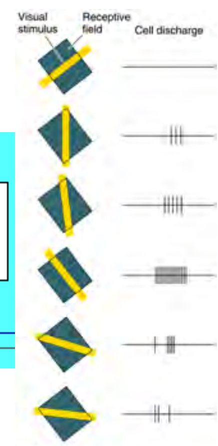
Feature Detectors

1. **Simple Cells**
   respond to bars of light in a particular **orientation** and a particular **location** within the receptive field
2. **Complex cells**
   respond to bars of light in a particular **orientation moving** in a specific **direction**.
3. ***Hypercomplex Cells*:**
   respond to bars of light in a **particular orientation**, moving in a specific **direction**, & of a **specific line length**.

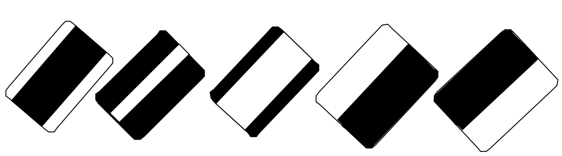
Simple cells

respond to points of light or bars of light in a **particular orientation & location**



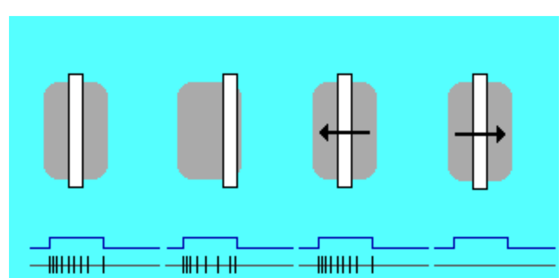


Simple cells: variability



Line Detectors   Edge Detectors

Complex cells

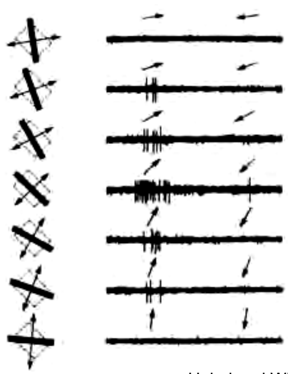


Complex cells also prefer oriented lines but they don't require a particular location.

Also tuned to motion direction

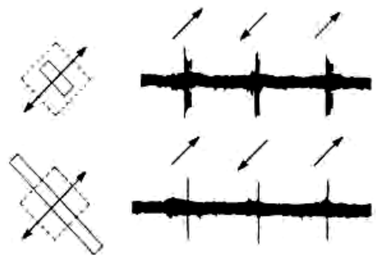
Complex cells

Orientation and motion direction



Hubel and Wiesel

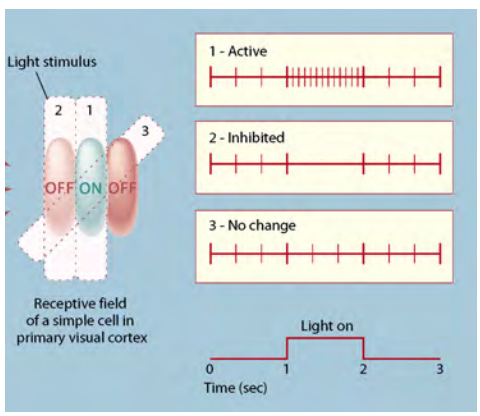
Hypercomplex cells



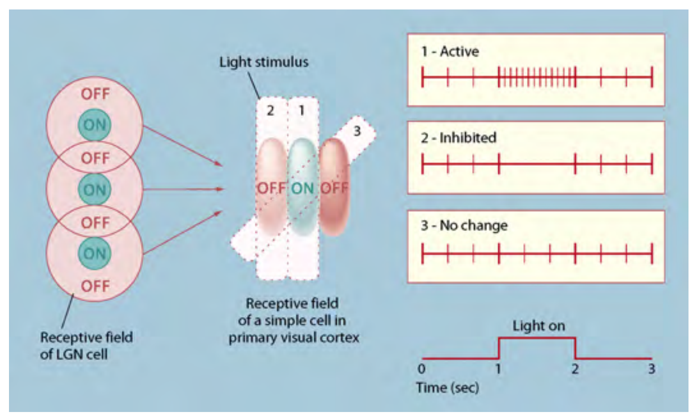
Hubel and Wiesel

end-stopping

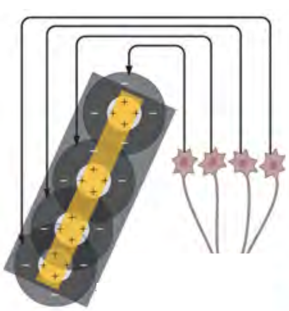
Constructing receptive fields in V1



Constructing receptive fields in V1

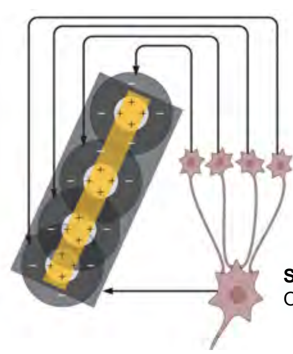


Building simple cells



LGN cells
No orientation selectivity

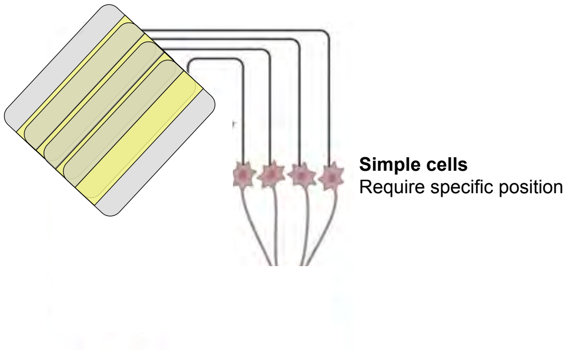
Building simple cells



LGN cells
No orientation selectivity

Simple Cell
Orientation selective

Building complex cells



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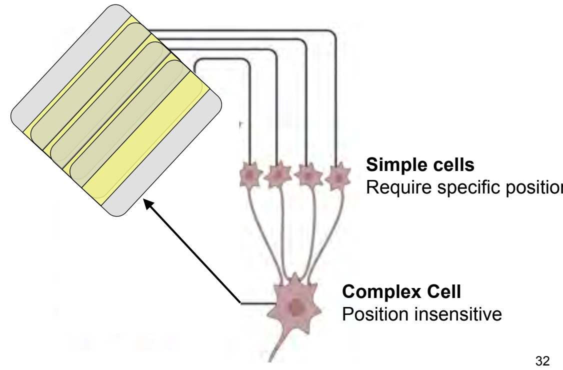
Building complex cells



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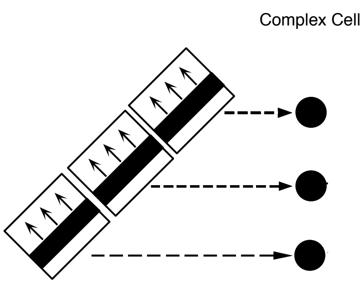
Building hypercomplex cells



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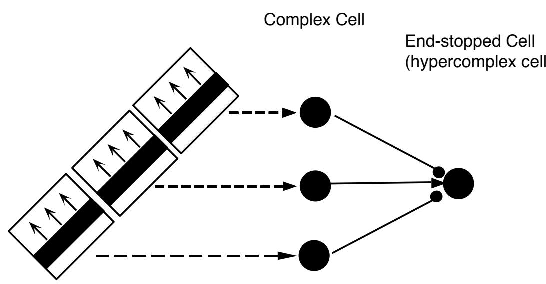
Building hypercomplex cells



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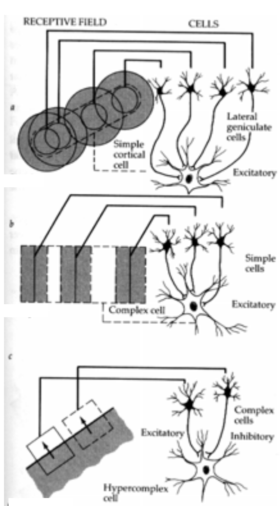

A hierarchy of receptive fields

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Table 3.1 *Properties of neurons in the optic nerve, LGN, and cortex*

Type of cell	Characteristics of Receptive Field
Optic nerve fiber (ganglion cell)	Center-surround receptive field. Responds best to small spots, but will also respond to other stimuli.
Lateral geniculate	Center-surround receptive fields very similar to the receptive field of a ganglion cell.
Simple cortical	Excitatory and inhibitory areas arranged side-by-side. Responds best to bars of a particular orientation.
Complex cortical	Responds best to movement of a correctly oriented bar across the receptive field. Many cells respond best to a particular direction of movement.
End-stopped cortical	Responds to corners, angles, or bars of a particular length moving in a particular direction.

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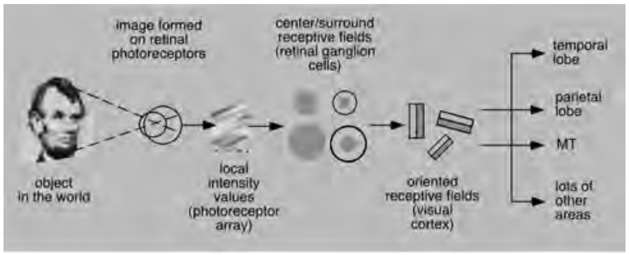
Visual Pathways summary



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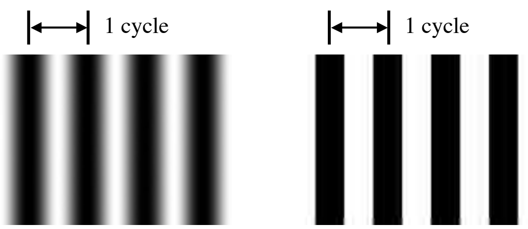
Gratings

Gratings: alternating light and dark bars.
square-wave gratings: abrupt transitions
sine-wave gratings: smooth transitions.



Sine wave **Square wave**

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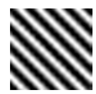
Gratings

- Characterized by 3 important quantities:
  - Spatial Frequency

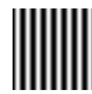
"Low"

"High"

  - Orientation



45°



0°

  - Contrast

ANY visual image can be created by adding together sine waves with the appropriate contrasts, orientations and spatial frequencies (and phases).

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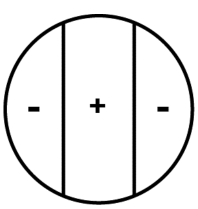
To better understand why simple cells are selective for gratings with a limited range of orientations and frequencies, it is useful to consider the basic structure of their receptive fields.



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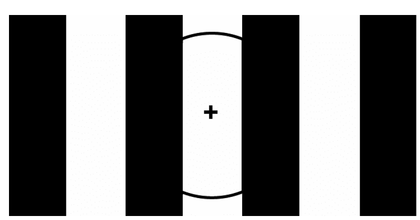
A simple cell will respond maximally when the bars of a grating stimulus have widths and orientations that are perfectly aligned with the excitatory region of a cell's receptive field as shown in the example below.



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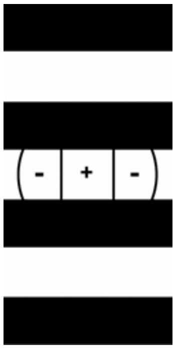
This grating is presented at the wrong orientation so that it stimulates both excitatory and inhibitory regions of the cell's receptive field.



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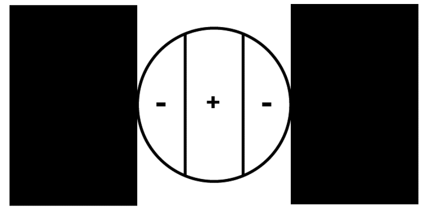
The spatial frequency of this grating is too low for the cell to respond above its background rate.



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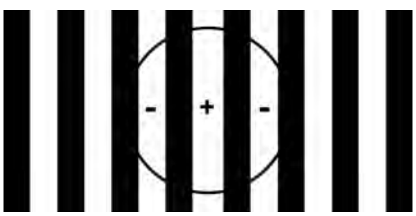
The spatial frequency of this grating is too high for the cell to respond above its background rate.



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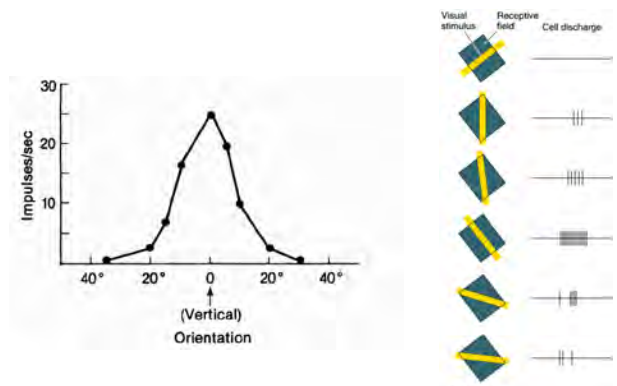
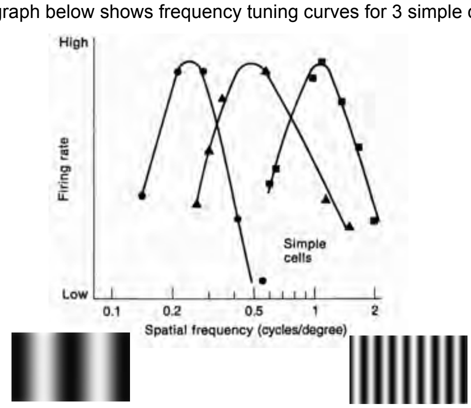
The **orientation tuning curve** of a simple cortical neuron is the relation between the orientation of a bar or grating stimulus and firing rate of the cell.



The **spatial frequency tuning curve** of a simple cortical neuron is the relation between frequency of a grating stimulus and firing rate of the cell.

The graph below shows frequency tuning curves for 3 simple cells in V1



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Development of tuning properties

selective rearing experiments

- Animals reared in specific environment
  - Limits type of stimuli present
  - Use to determine whether stimulus presence is needed for development of RF tuning
  - Shows that neurons need a rich sensory environment to develop fully

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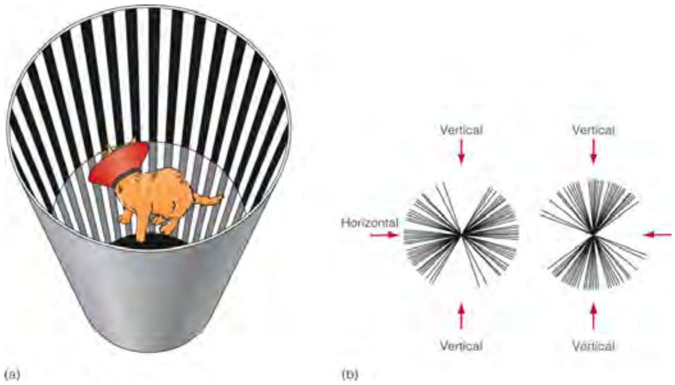

(a) Striped tube used in Blakemore and Cooper's (1970) selective rearing experiments.
(b) Distribution of optimal orientations for 52 cells from a cat reared in an environment of horizontal stripes, on the left, and for 72 cells from a cat reared in an environment of vertical stripes, on the right.

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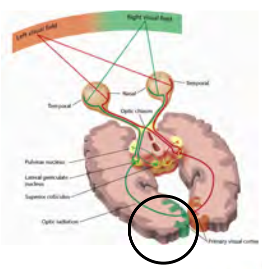
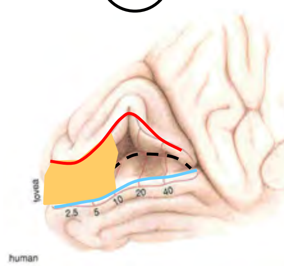
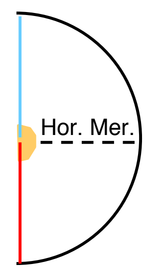
Visual map in V1







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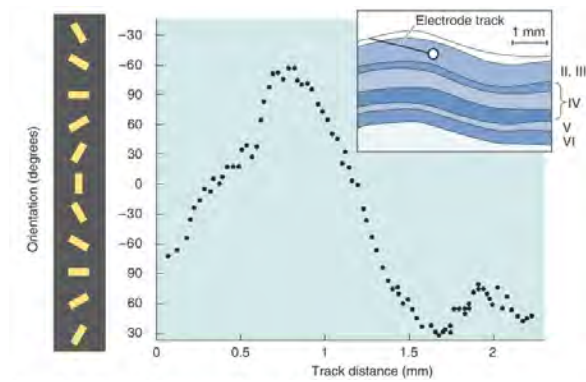
Organization of neurons in V1



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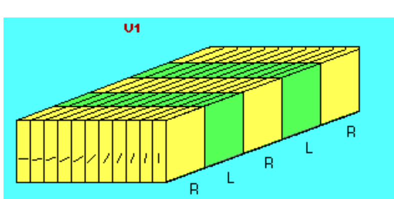
Orientation columns



- Ocular dominance and orientation columns
  - Orientation columns: same preferred orientation
  - Ocular dominance columns: same eye preference
- Geometric vs. Pinwheel

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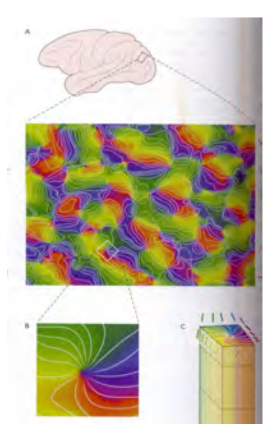
Orientation columns

- For every position of the visual field, all cells are grouped into **hypercolumns**
- Every hypercolumn is a **complete and independent feature detector** for a very small part of the visual field
- Every hypercolumn contains color cells, orientation cells, disparity cells, motion cells



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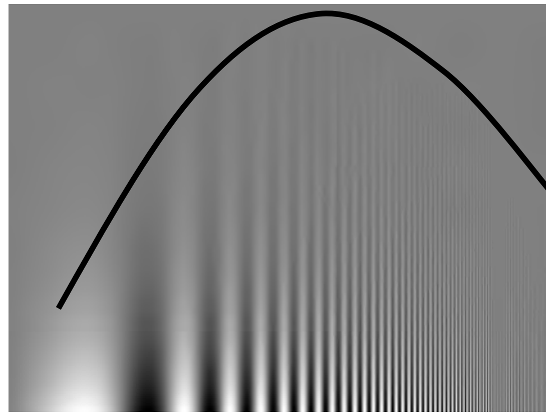
The image in this slide has frequency varying along the horizontal axis and contrast varying along the vertical axis. Note how the bars of the grating are less visible at the highest and lowest frequencies



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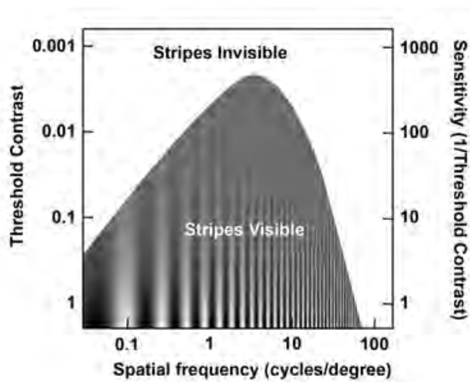
The contrast sensitivity function (CSF) is a plot of the threshold contrast to detect the grating (as opposed to seeing a uniform gray) as a function of spatial frequency.



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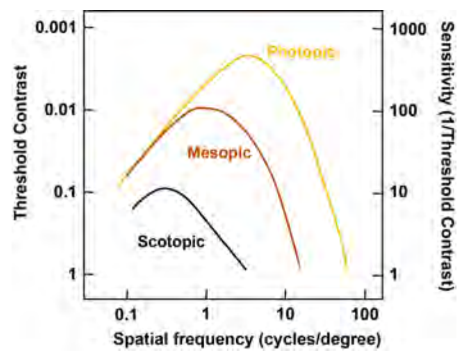
For photopic (daylight) vision, the CSF peaks around 4 cycles per degree. Note how sensitivity is reduced for mesopic (twilight) or scotopic (nighttime) vision.



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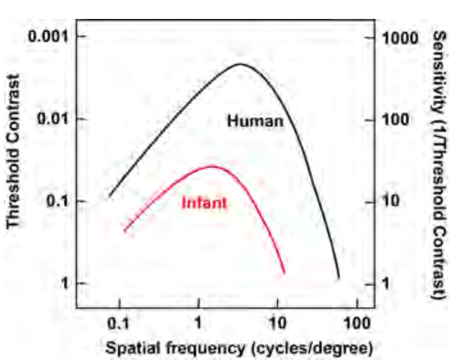
Contrast sensitivity is quite poor at birth, but it improves gradually with development.



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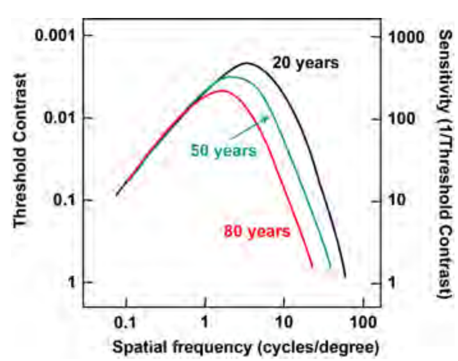
Contrast sensitivity is reduced with aging, primarily for high spatial frequencies.



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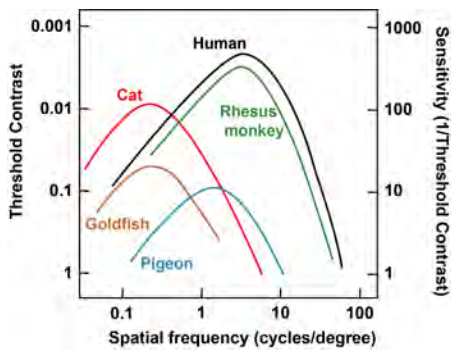
Contrast sensitivity varies dramatically among different species.



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  - receptive fields (RF) of V1 neurons
  - RF tuning of V1 neurons
  - organization of V1 neurons
- How V1 RF properties determine what we see?
  - contrast sensitivity function
  - selective adaptation
  - art & spatial frequency

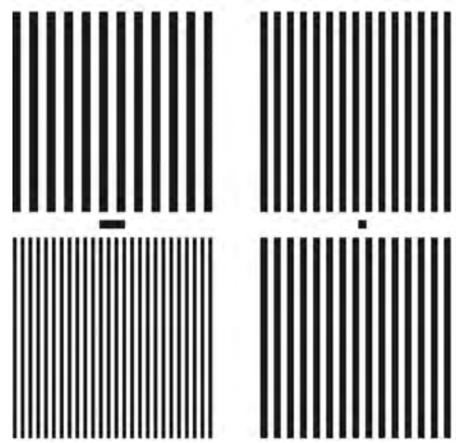
Revealing neural tuning using selective adaptation

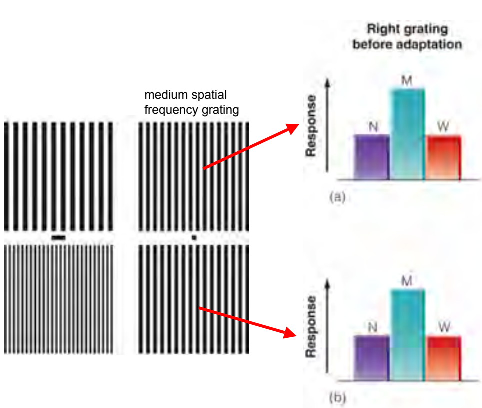
- Neurons tuned to specific stimuli fatigue when exposure is long
- Fatigue causes adaptation to stimulus
  - Neuron's firing rate decreases
  - Neuron will fire less when stimulus presented again
- *Selective* means that only those neurons that respond to the specific stimulus adapt

General Method for Selective Adaptation

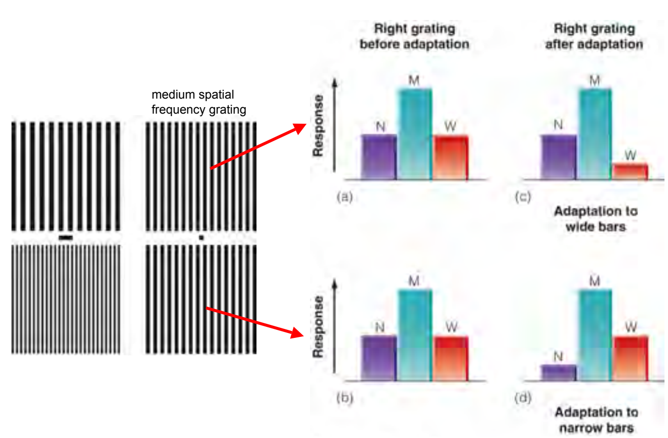
1. Measure sensitivity to range of one stimulus characteristic
2. Adapt to a specific value by extended exposure
3. Re-measure the sensitivity (as in 1)

Effects of spatial frequency adaptation





How neurons that respond best to narrow (N), medium (M), and wide (W) bars respond to the medium spatial frequency grating.
(a-b): Response before adaptation.



How neurons that respond best to narrow (N), medium (M), and wide (W) bars respond to the medium spatial frequency grating.
(a-b): Response before adaptation.
(c) Response after adaptation to the wide-bar (low spatial frequency) grating at the top left.
(d) Response after adaptation to the narrow-bar (high spatial frequency) grating on the bottom left.

Cortical visual processing

- Main visual pathway from retina to V1
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Hypothesis: If visual images are processed by neurons that are tuned to specific spatial frequencies, then perhaps it is possible to **depict unrelated content** in different spatial frequency channels

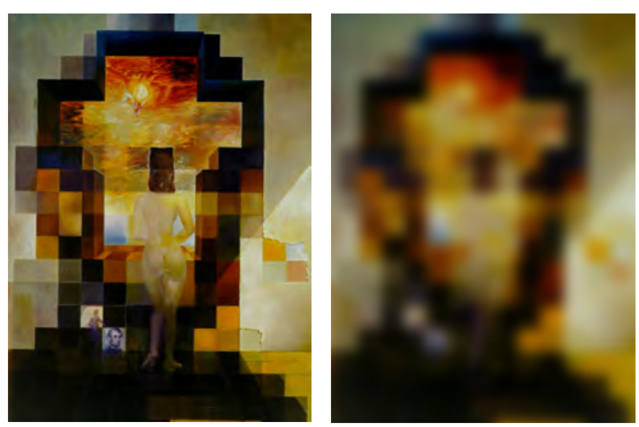
The paintings of Salvador Dali reveal that this is indeed the case.

In the following slides, blurring of the image or squinting can facilitate the perception of the low frequency image.

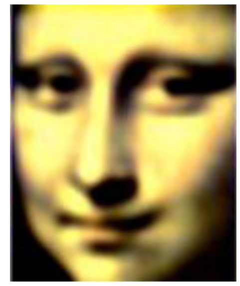
Slave Market with the Disappearing Bust of Voltaire, 1940

Mysterious Mouth Appearing in the Back of My Nurse, 1941

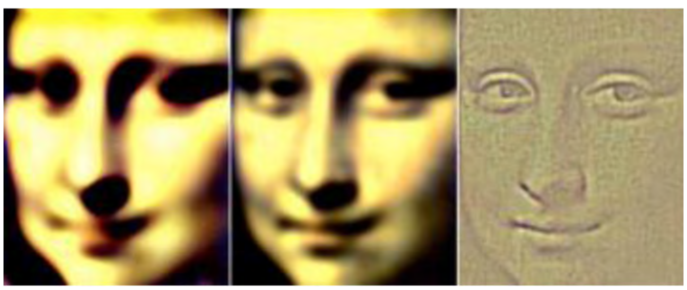
“Gala Contemplating the Mediterranean Sea Which at 20m Becomes the Portrait of Abraham Lincoln”, 1976



Secret of the Mona Lisa's smile



Secret of the Mona Lisa's smile



Low spatial frequencies

High spatial frequencies