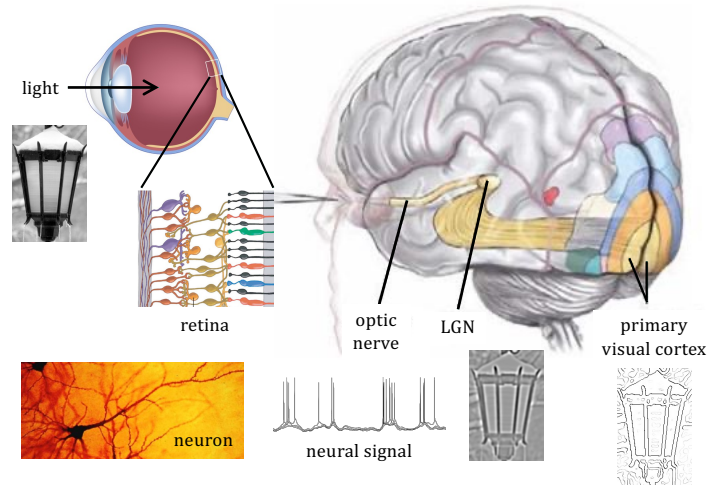
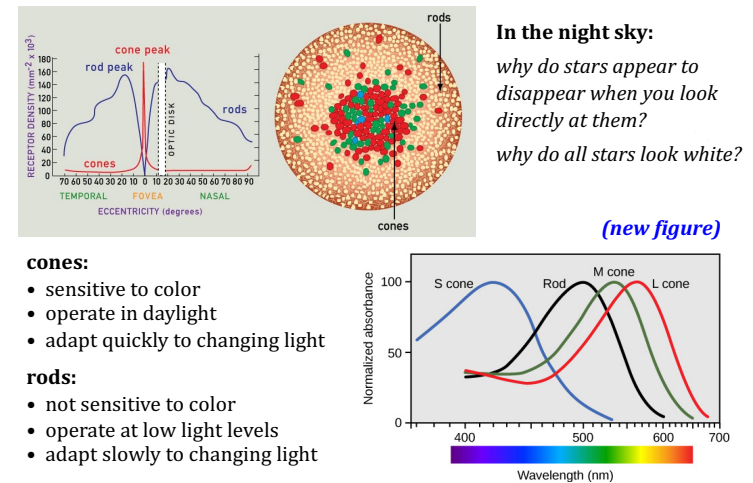


## Early processing in human vision



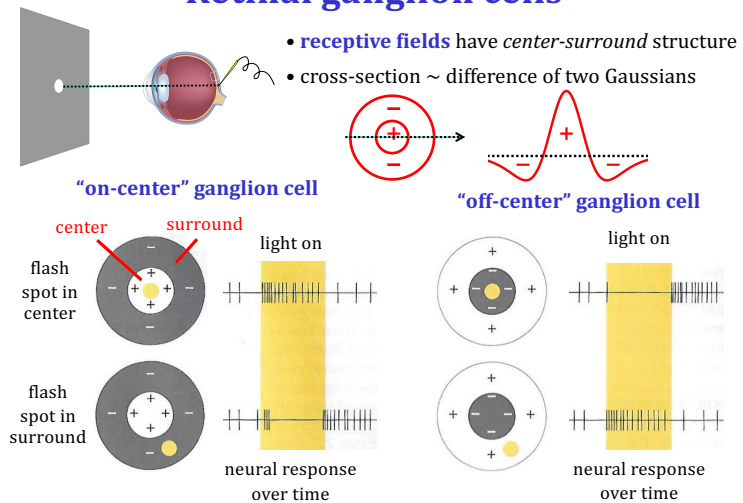
1

## Rods vs. cones



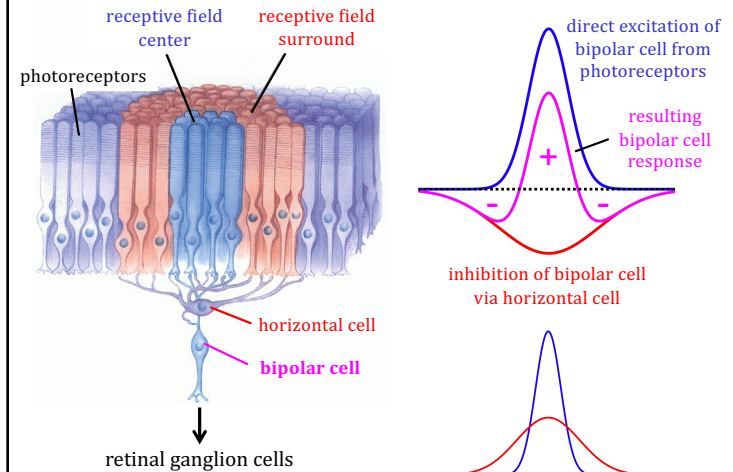
2

## Retinal ganglion cells



3

## Emergence of center-surround receptive field



4

## Analyzing intensity changes in a 2D image

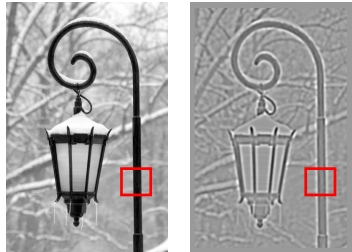
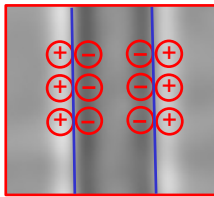
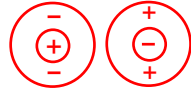


image after smoothing  
& second derivative

convolution with  
 $\nabla^2 G$  operator



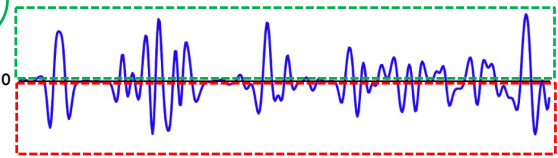
~ convolution of the retinal image is  
passed up the optic nerve

- on-center cells carry positive part
- off-center cells carry negative part

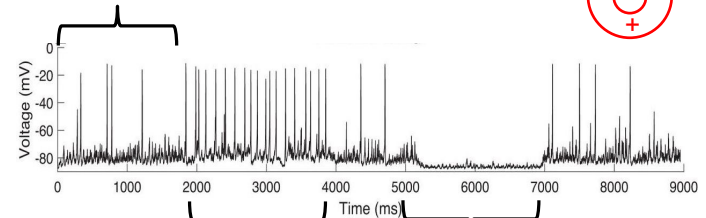
5



second  
derivative



firing rate = (number of spikes)/time

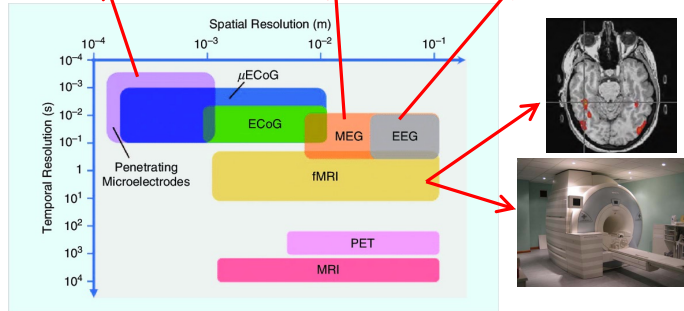


excitation: higher firing rate

inhibition: lower firing rate

6

## Measuring neural activity



7

## Detecting intensity changes at multiple scales



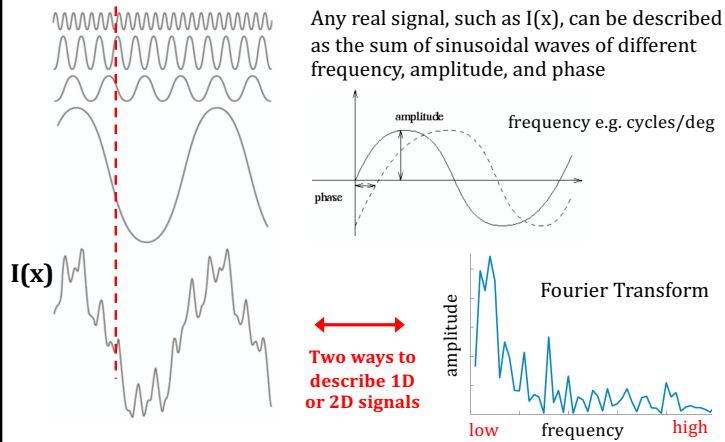
human vision:

- multiple receptive field sizes in the same region of the visual field
- receptive field sizes increase with eccentricity (distance from the center of the eye)



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## Spatial frequency decomposition

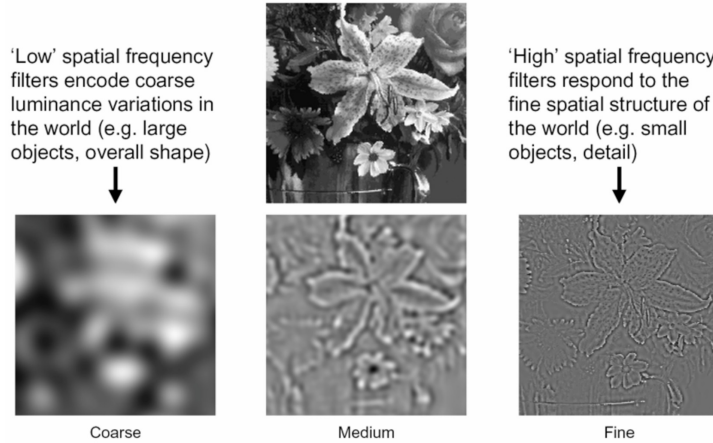


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## Spatial frequency channels

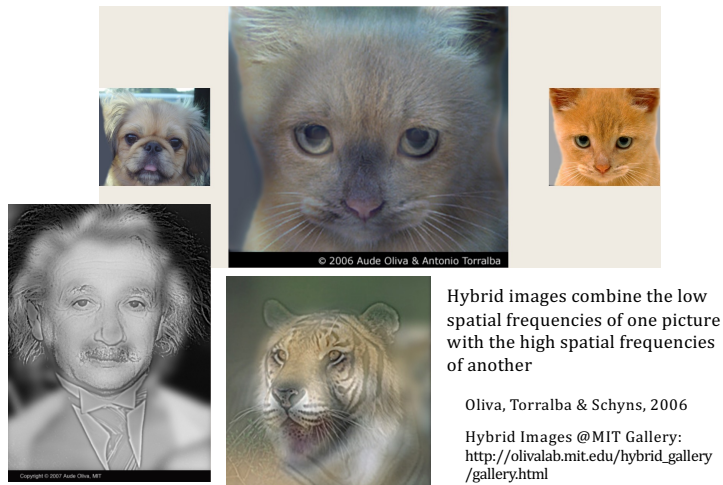
'Low' spatial frequency filters encode coarse luminance variations in the world (e.g. large objects, overall shape)

'High' spatial frequency filters respond to the fine spatial structure of the world (e.g. small objects, detail)



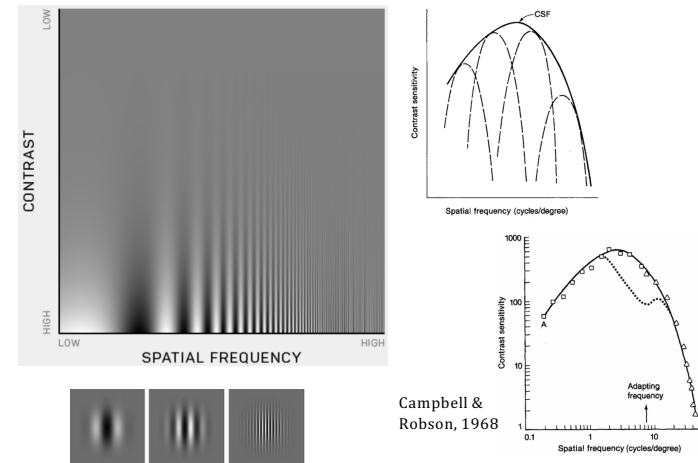
10

## Fun with spatial frequencies: Hybrid images



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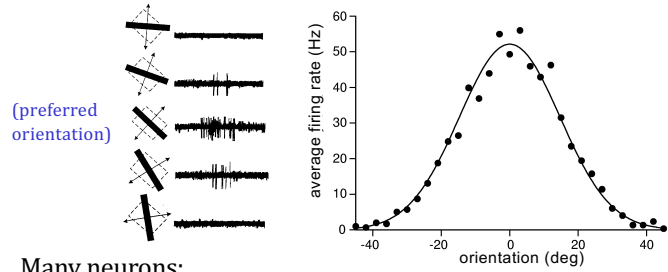
## "Spatial frequency channels" in human vision



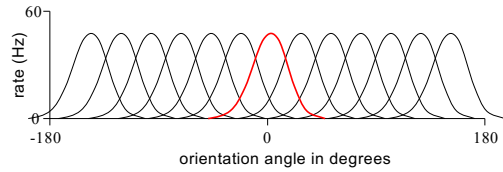
12

## Orientation tuning curves

Single neuron:

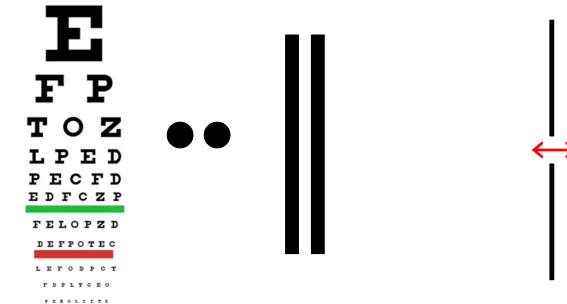


Many neurons:



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## Visual acuity and hyperacuity



**Two-point or two-line acuity:**  
How far apart do the dots or bars need to be, before we can tell that there are two?

about 1' of visual arc

**Vernier acuity:**  
How much relative shift in the horizontal direction is needed to tell if it's shifted left or right?

about 5-6" of visual arc

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