Spatial Vision: Primary Visual Cortex (Chapter 3, part 1)

Lecture 6

Jonathan Pillow
Sensation & Perception
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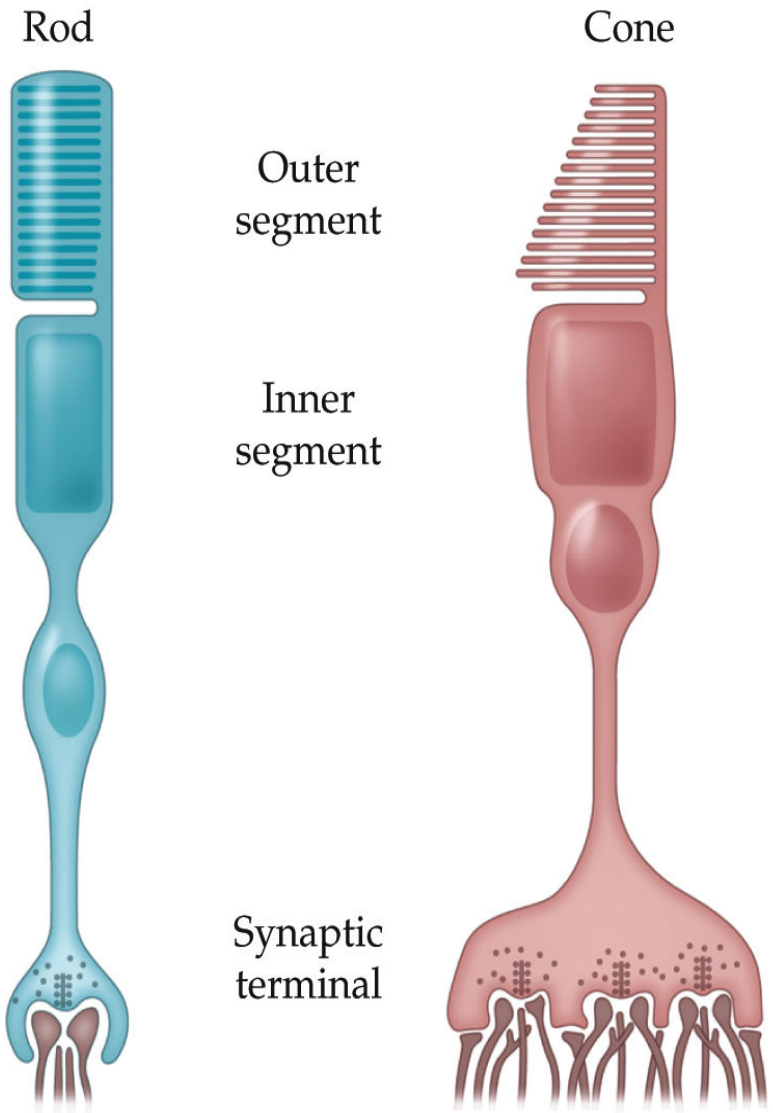
Chapter 2 Leftovers

dark current (recap)

- In the dark, membrane channels in rods and cones are open by default (unusual!)
- current flows in continuously
- membrane is *depolarized* (less negative)

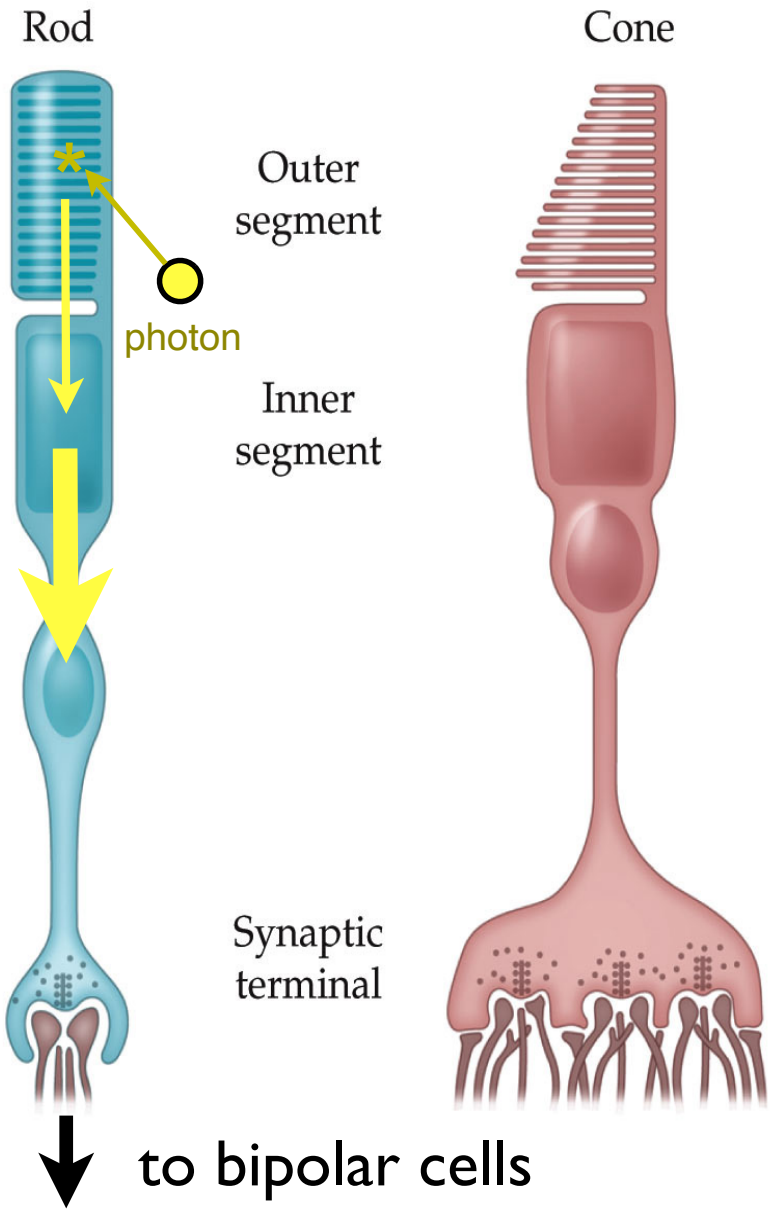


- neurotransmitter is released at a high rate

to bipolar cells

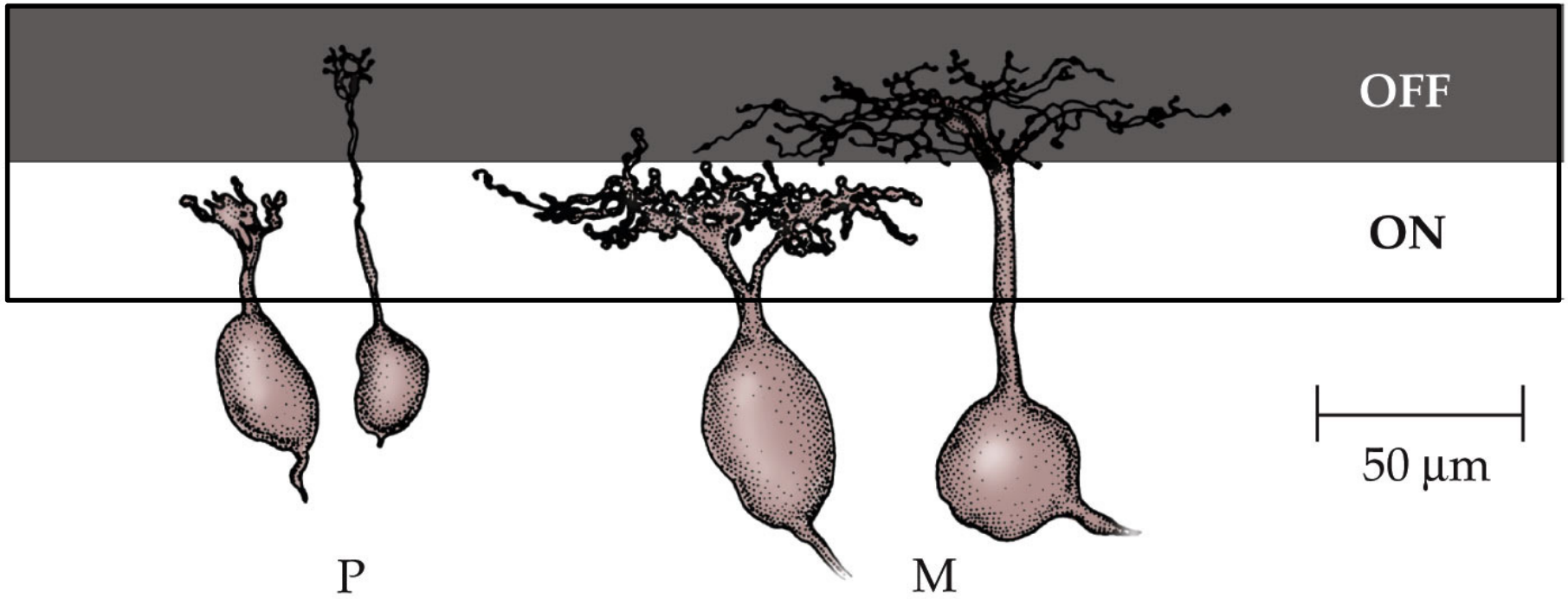
transduction & signal amplification

- photon is absorbed by an opsin
- channels close (dark current turns off)
- membrane becomes *more* polarized (more negative)
- neurotransmitter is released at a **lower rate**



4 classes of retinal ganglion cells:

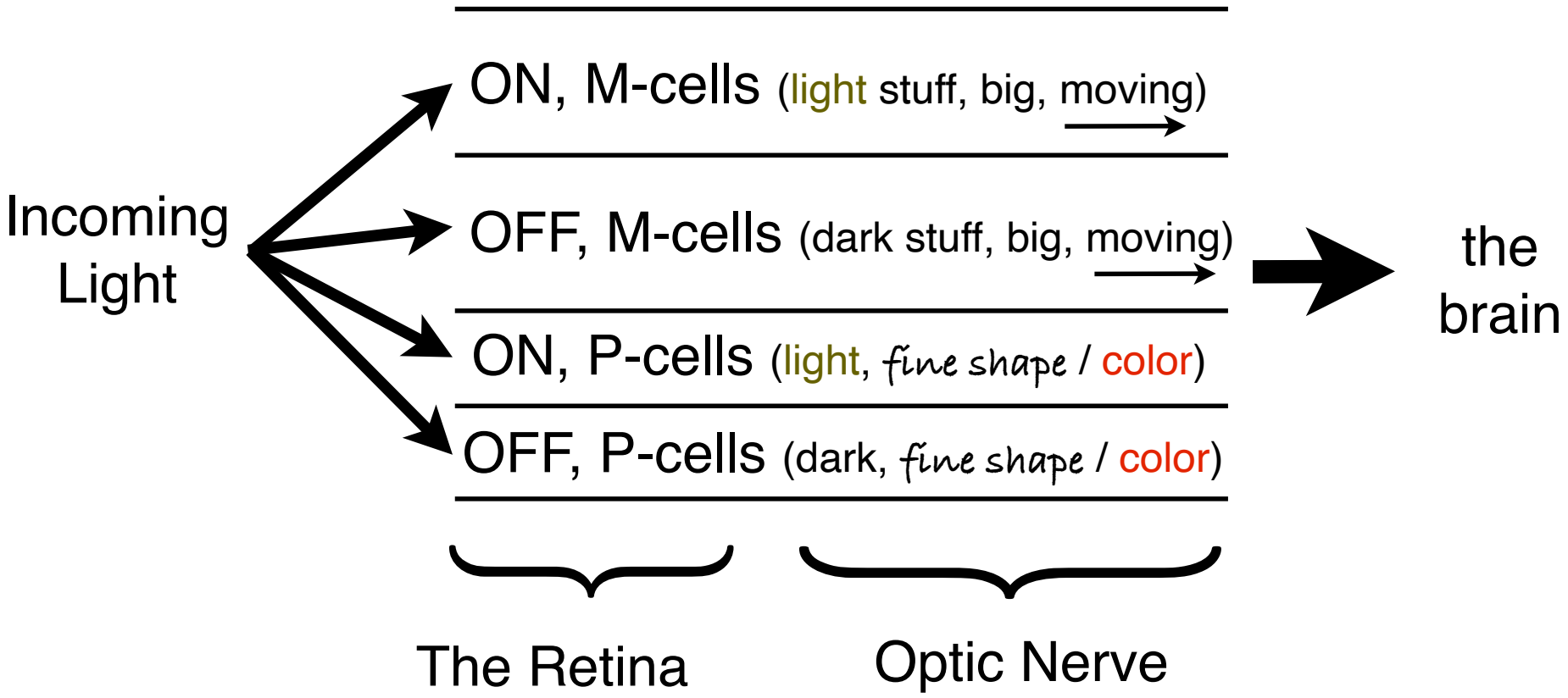
ON and OFF retinal ganglion cells' dendrites arborize ("extend") in different layers:



Parvocellular
("small", feed pathway processing shape, color)

Magnocellular
("big", feed pathway processing motion)

"Channels" in visual processing



Luminance adaptation

remarkable things about the human visual system:

- incredible range of luminance levels to which we can adapt
  (six orders of magnitude, or 1million times difference)

Two mechanisms for **luminance adaptation**
(adaptation to levels of dark and light):

(1) Pupil dilation

(2) Photoreceptors and their photopigment levels

the more light, the more
photopigment gets "used up",
→ less available photopigment,
→ retina becomes less sensitive

The possible range of pupil sizes in bright illumination versus dark

(*a*) Bright illumination

2-mm pupil

(*b*) Dark

8-mm pupil

- 16 times more light entering the eye

Luminance adaptation
- adaptation to light and dark

- It turns out: we're pretty bad at estimating the overall light level.
- All we really need (from an evolutionary standpoint), is to be able to recognize objects *regardless* of the light level
- This can be done using light differences, also known as "contrast".

Contrast = difference in light level, divided by overall light level

$$C = \frac{\Delta I}{I}$$

(Think back to Weber's law!)

Luminance adaptation

"center-surround" receptive field

Contast is (roughly) what retinal neurons compute, taking the difference between light in the center and surround!

$$\Delta I = (5 \cdot I_{ctr}) \; - \; (4 \cdot I_{surround})$$

Contrast = difference in light level, divided by overall light level

$$C = \frac{\Delta I}{I}$$

(Think back to Weber's law!)

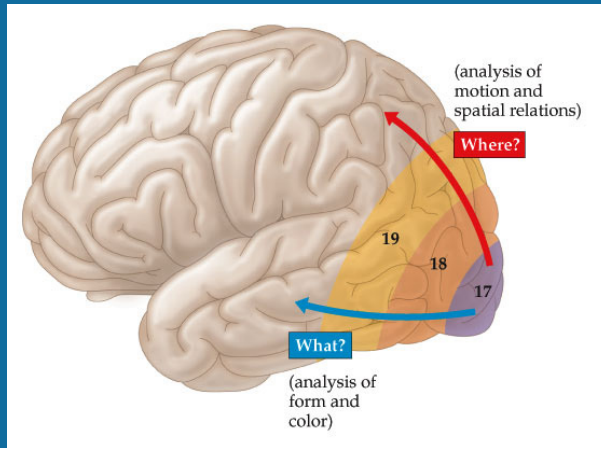
• from an "image compression" standpoint, it's better to just send information about local differences in light

summary: Chap 2

- transduction: changing energy from one state to another
- Retina: photoreceptors, opsins, chromophores, dark current, bipolar cells, retinal ganglion cells.
- "backward" design of the retina
- rods, cones; their relative concentrations in the eye
- Blind spot & "filling in"
- Receptive field
- ON / OFF, M / P channels in retina
- contrast, Mach band illusion
- Light adaptation: pupil dilation and photopigment cycling

3

Spatial Vision: From Stars to Stripes



Motivation

We've now learned:

- how the eye (like a camera) forms an image.
- how the retina processes that image to extract contrast (with "center-surround" receptive fields)

Next:

- how does the brain begin processing that information to extract a visual interpretation?

early visual pathway

optic nerve

optic chiasm

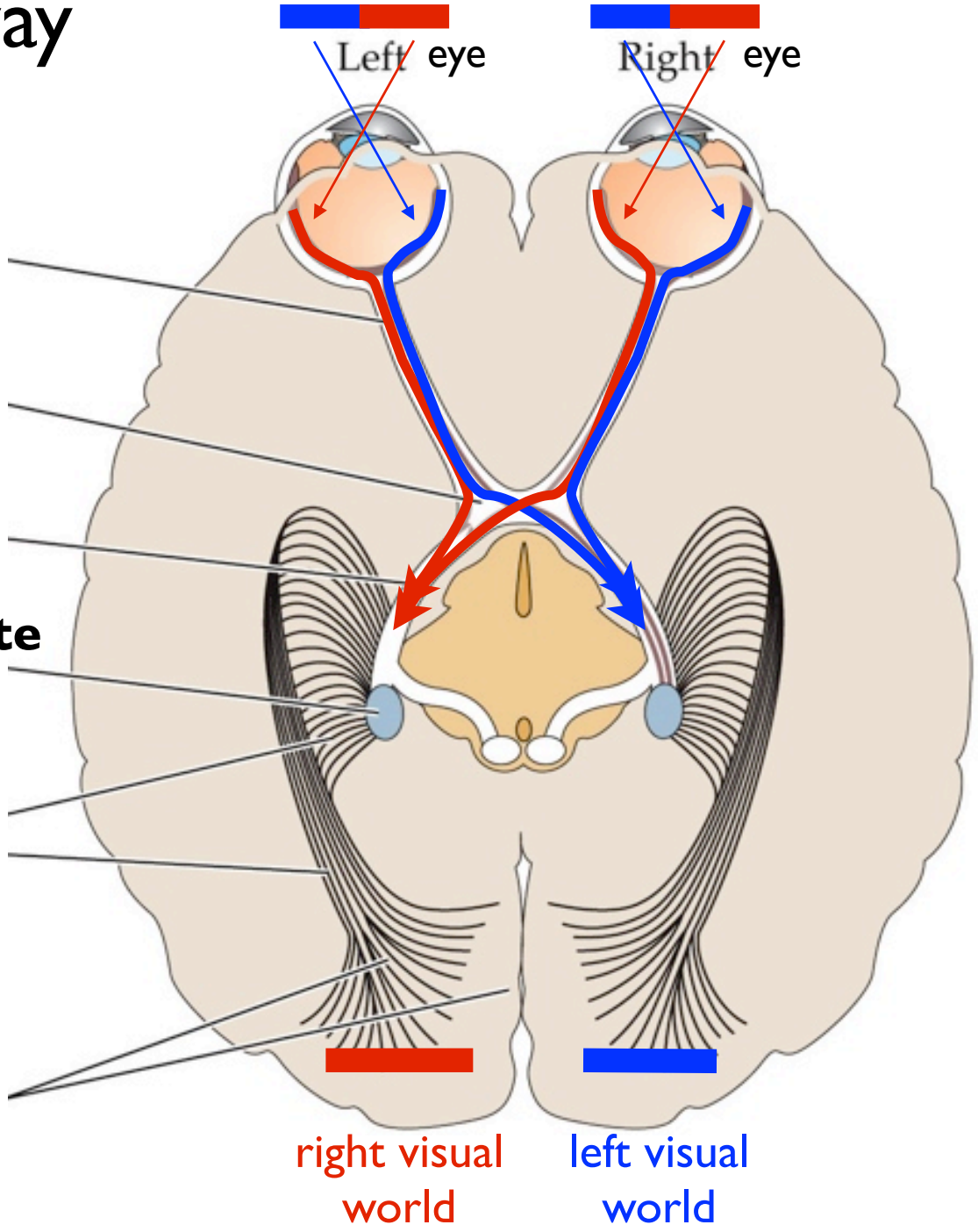
optic tract

thalamus: **lateral geniculate nucleus (LGN)**

optic radiations

cortex: **primary visual cortex ("V1")**

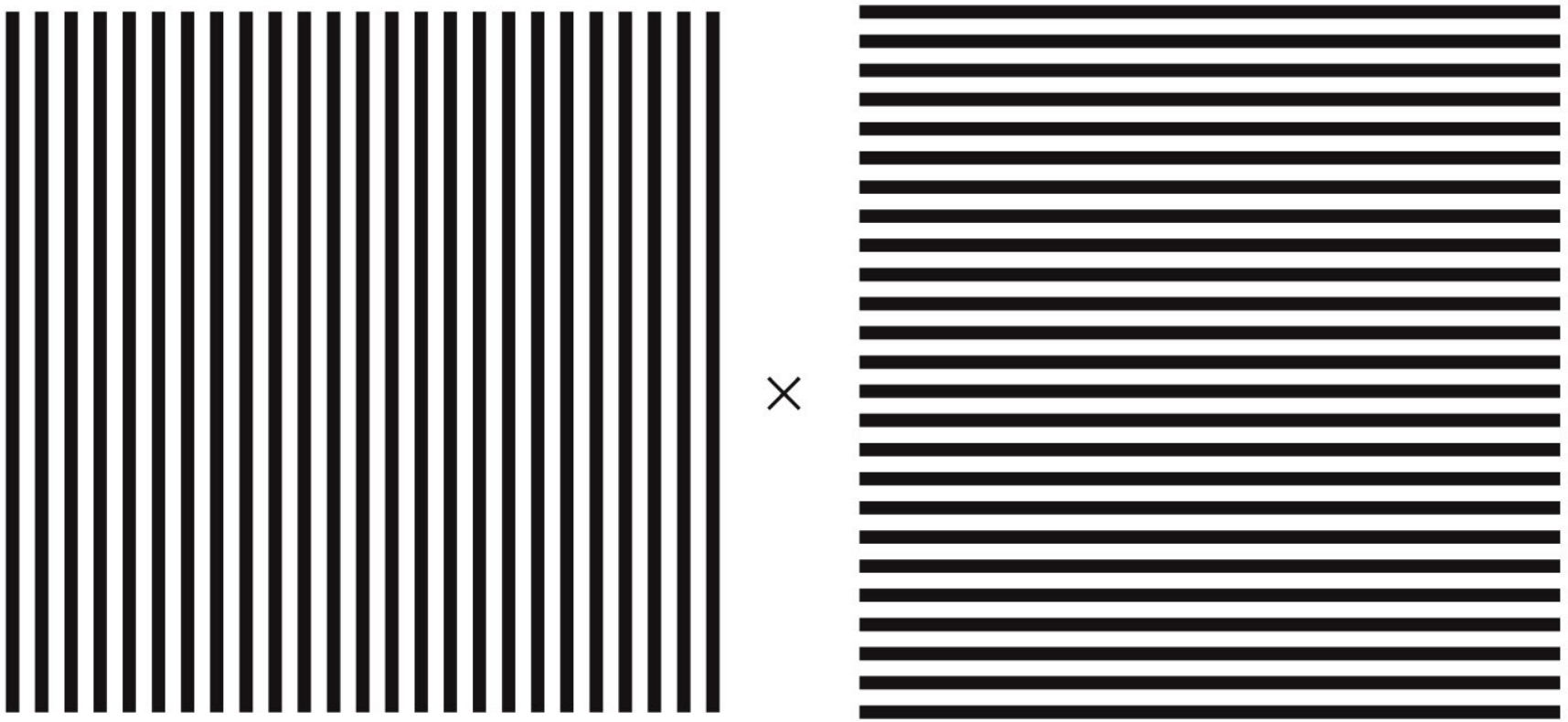
(aka "striate cortex")



- **Acuity**: measure of finest visual detail that can be resolved

Visual Acuity

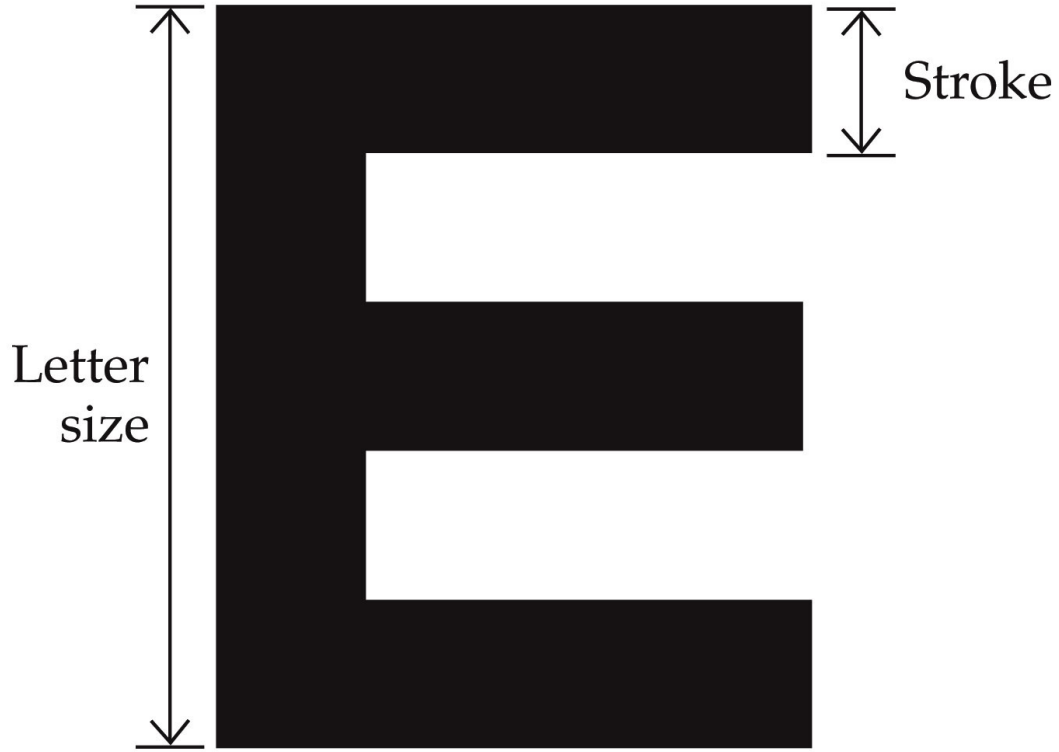
- in the lab



Measuring Visual Acuity

Snellen *E* test

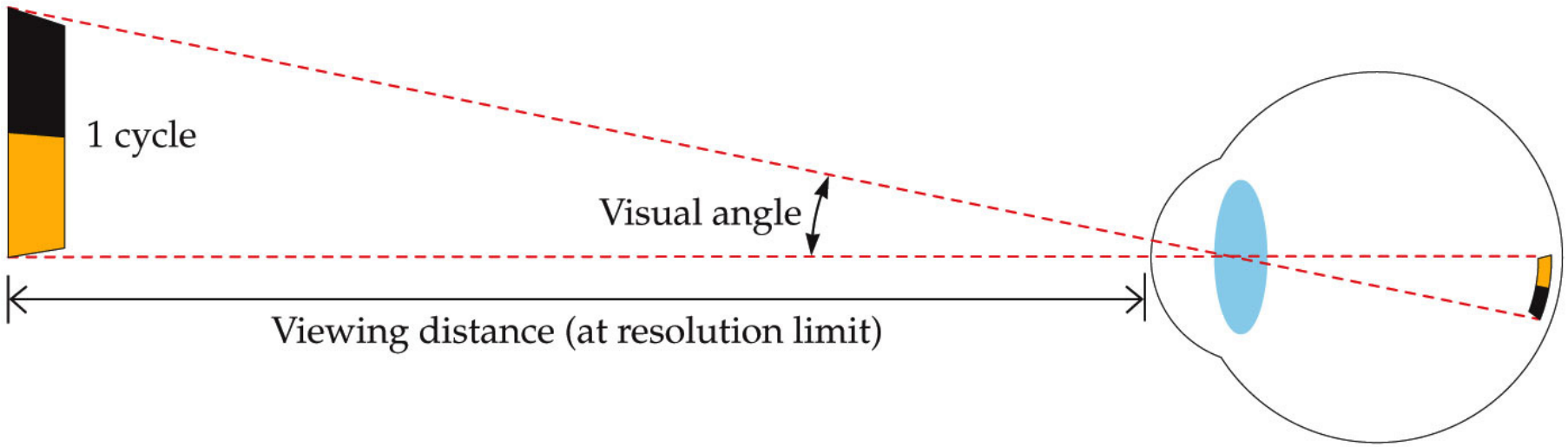
- Herman Snellen invented this method for designating visual acuity in 1862
- Notice that the strokes on the E form a small grating pattern



Acuity

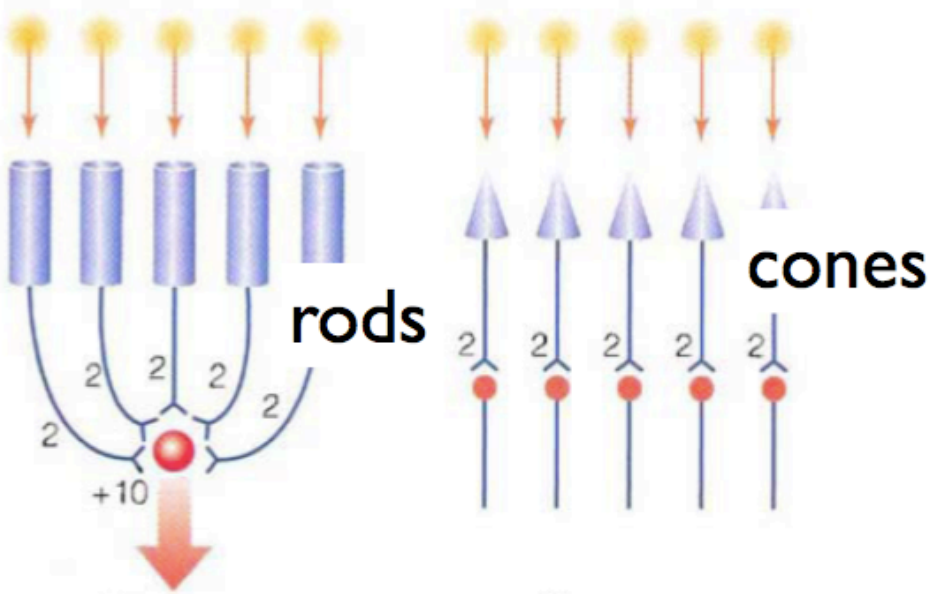
eye doctor: 20 / 20 (your distance / avg person's distance) for letter identification

vision scientist: visual angle of one cycle of the finest grating you can see

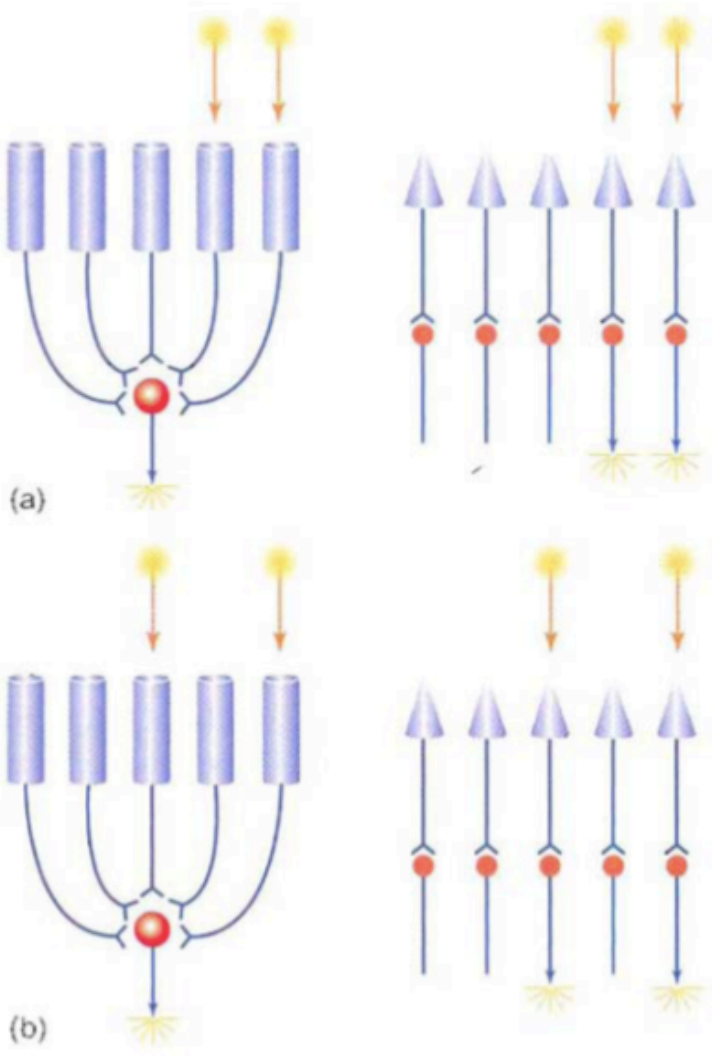


Foveal acuity (for 20/20 vision): 1 arc minutes (i.e., 1/60 of a degree)

sensitivity



acuity

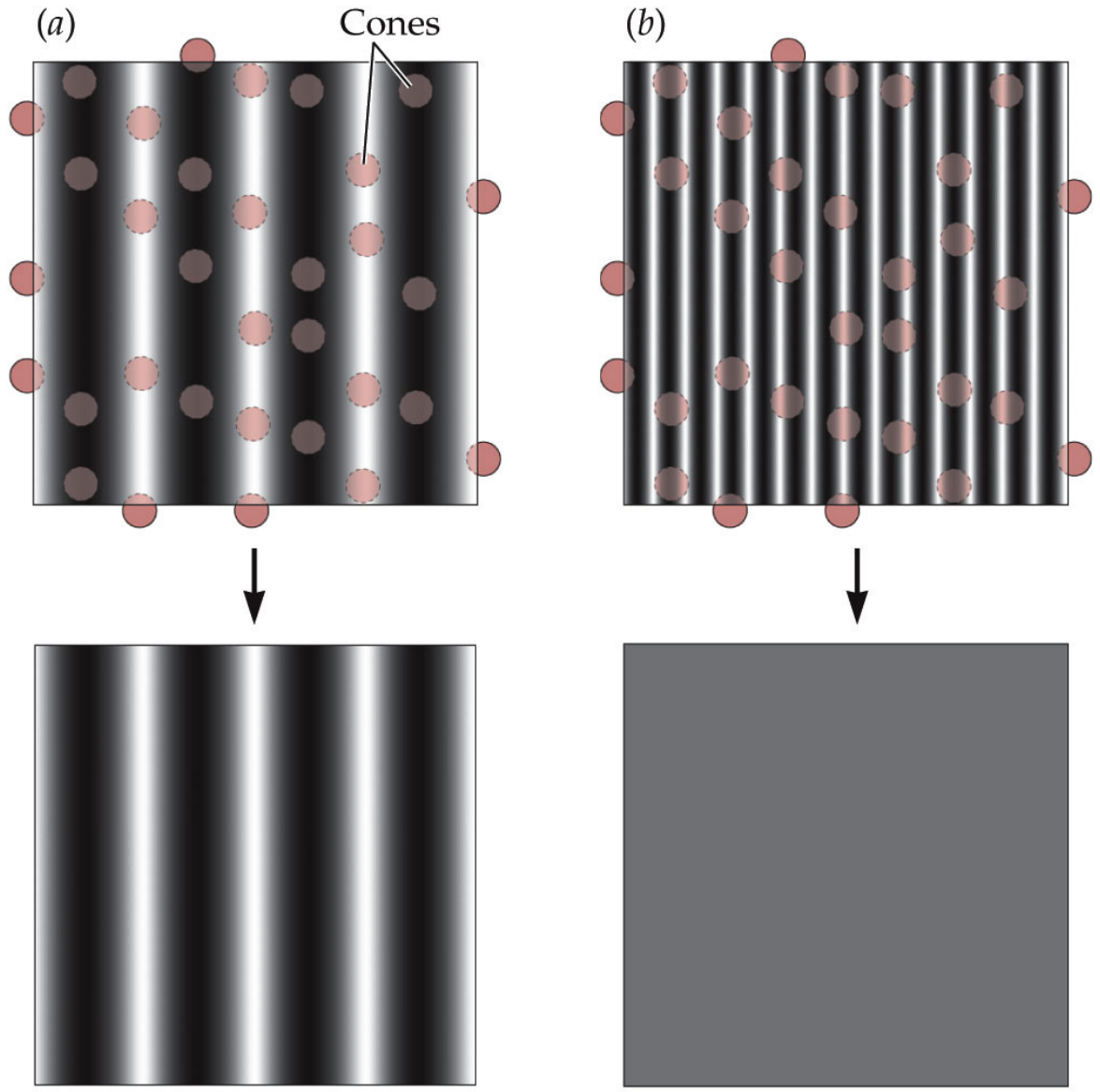


explaining acuity

- striped pattern is a "sine wave grating"
- visual system "samples" the grating at cone locations

acuity limit: 1' of arc

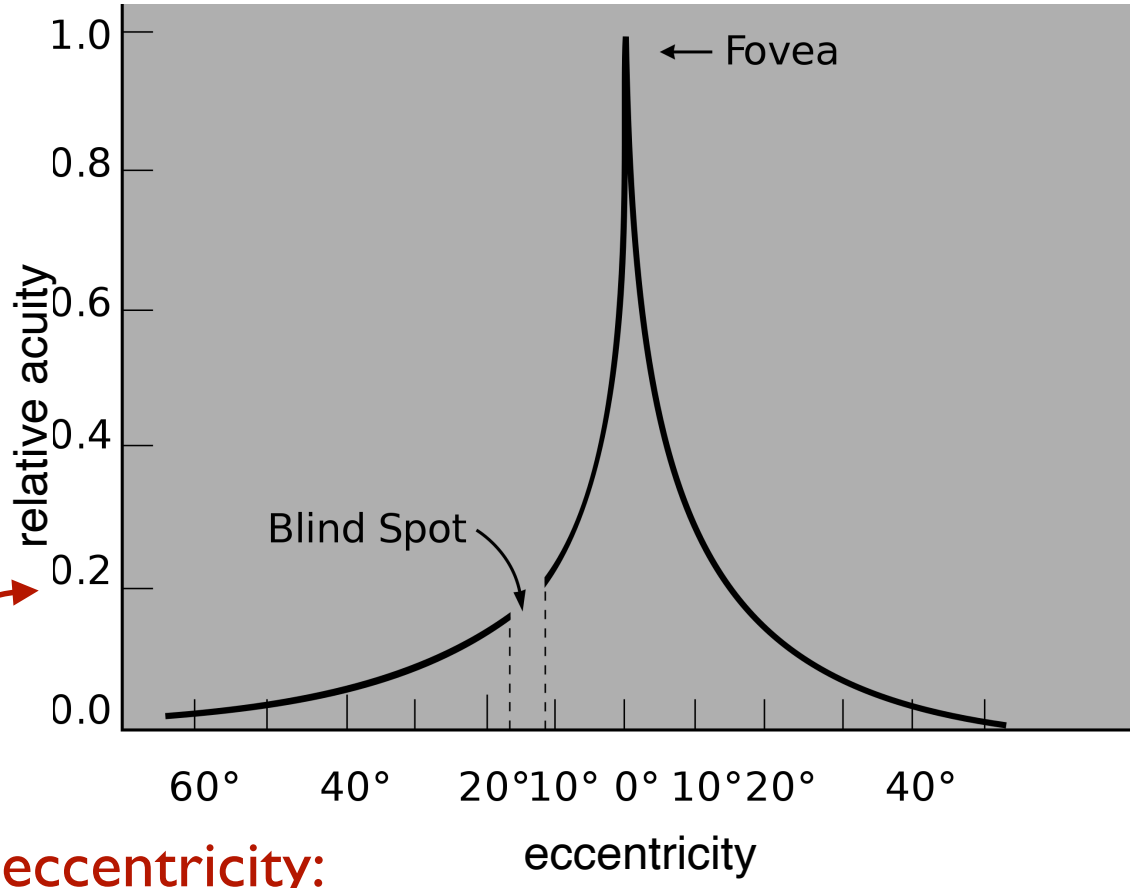
cone spacing in fovea: 0.5' of arc



Q: could myopia compensate for the blind spot?

blind spot: ~7.5 degrees wide

foveal acuity:
1' arc (1/60 deg)



acuity at 10° eccentricity:
5' arc (1/12 deg)

Q: could myopia compensate for the blind spot?

1/12 degree grating

blind spot: ~7.5 degrees wide
(90x bigger across)

answer: probably not (or not much)!

more "channels": spatial frequency channels

spatial frequency: the number of cycles of a grating per unit of visual angle (usually specified in degrees)

- think of it as: # of bars per unit length

low frequency

intermediate

high frequency

Visual Acuity:

Why sine gratings?

- The visual system breaks down images into a vast number of components; each is a sine wave grating with a particular spatial frequency

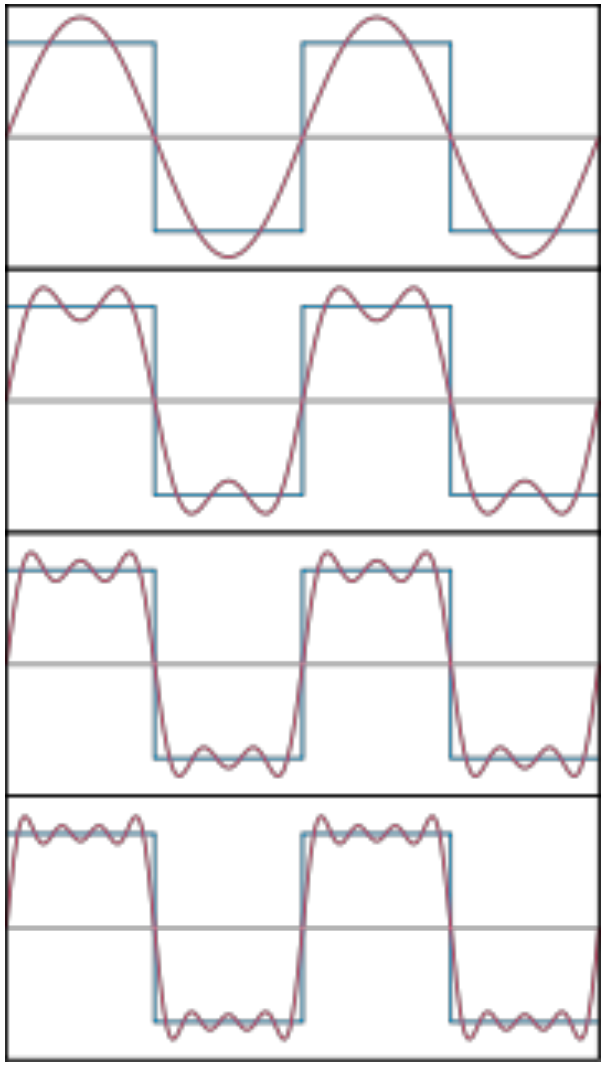
Technical term: **Fourier decomposition**

Fourier decomposition

• mathematical decomposition of an image (or sound) into sine waves.

reconstruction:

"image"



1 sine wave

2 sine waves

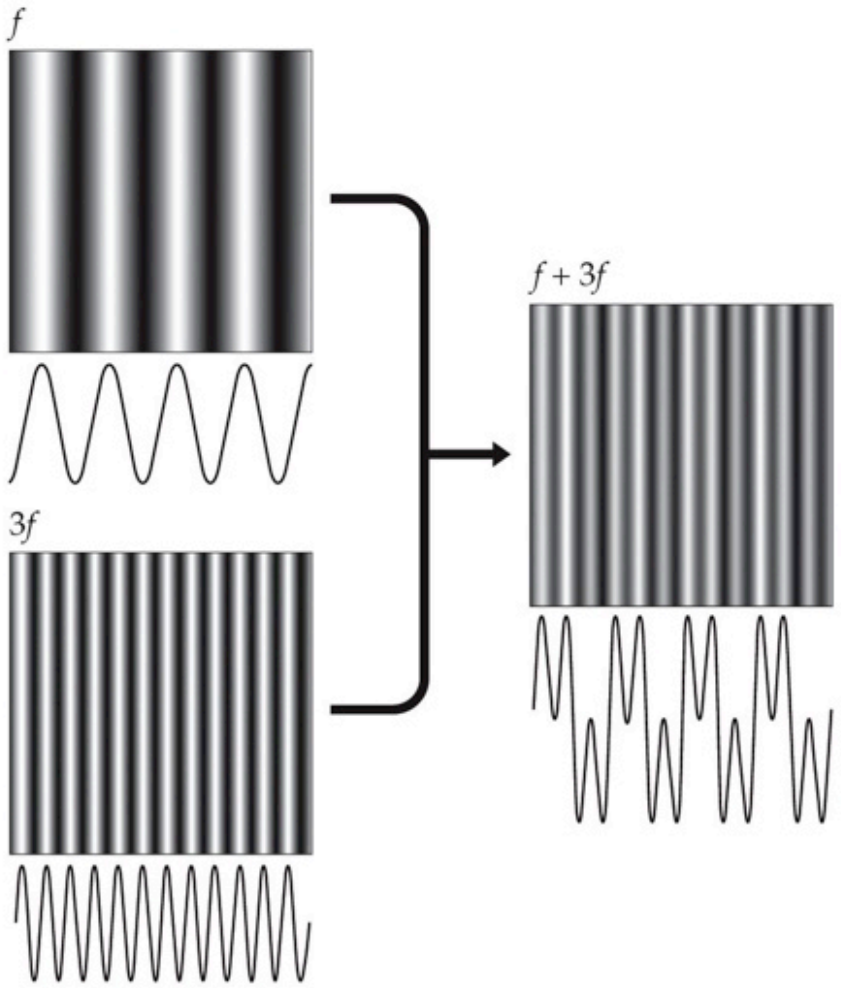
3 sine waves

4 sine waves

"Fourier Decomposition" theory of V1

claim: role of V1 is to do "Fourier decomposition", i.e., break images down into a sum of sine waves

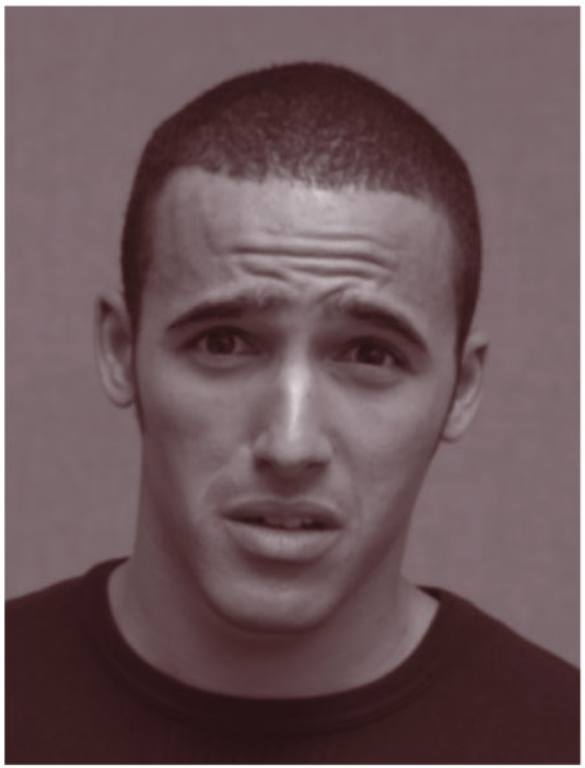
- Summation of two spatial sine waves
- any pattern can be broken down into a sum of sine waves



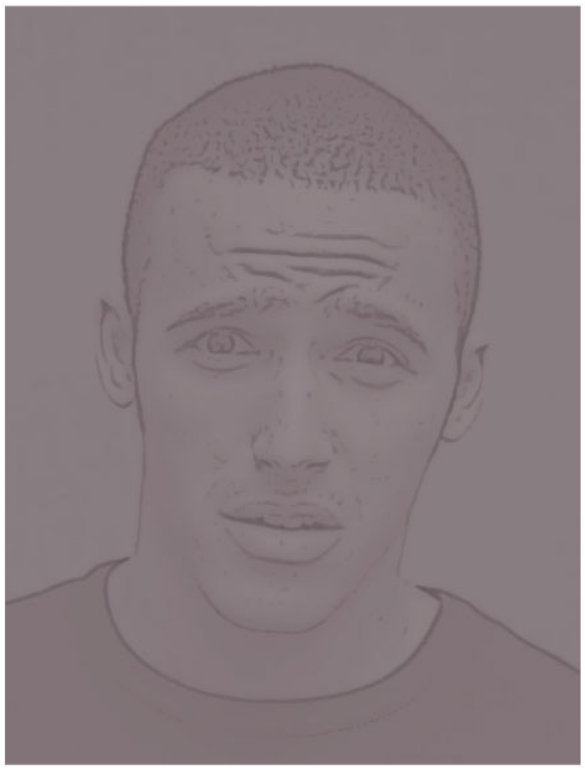
Fourier decomposition

• mathematical decomposition of an image (or sound) into sine waves.

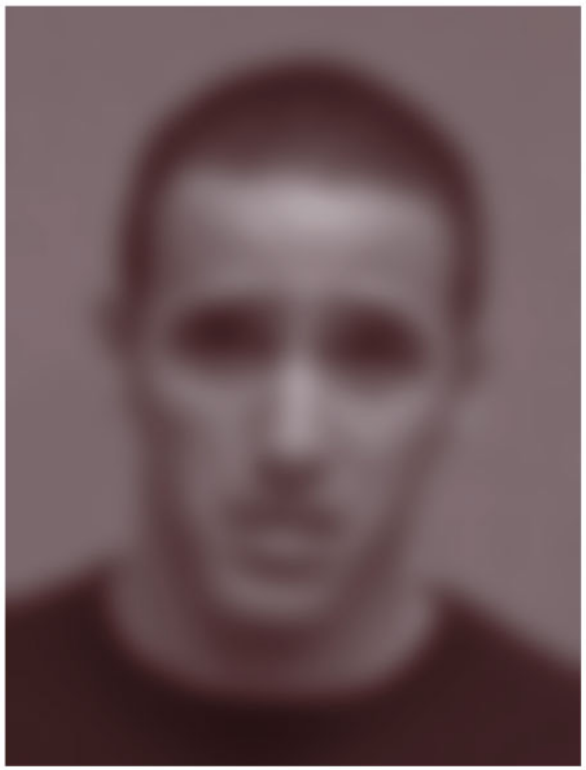
Original image



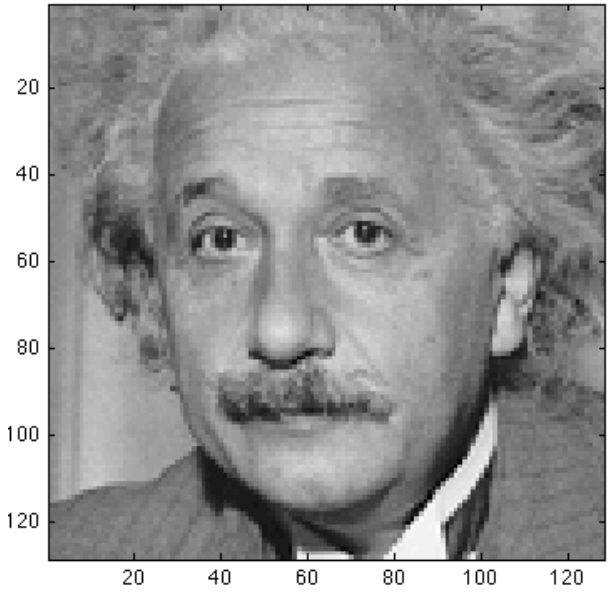
High Frequencies



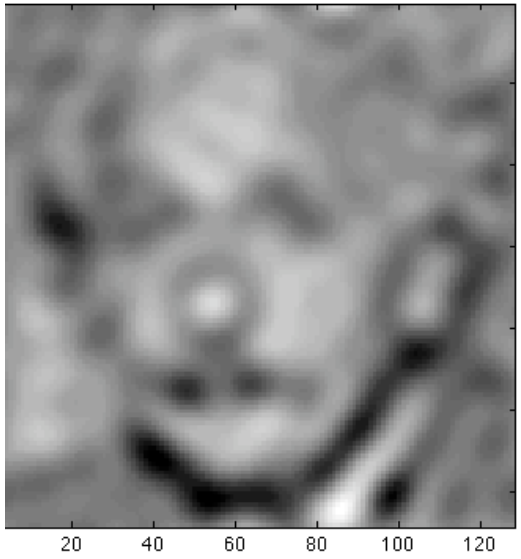
Low Frequencies



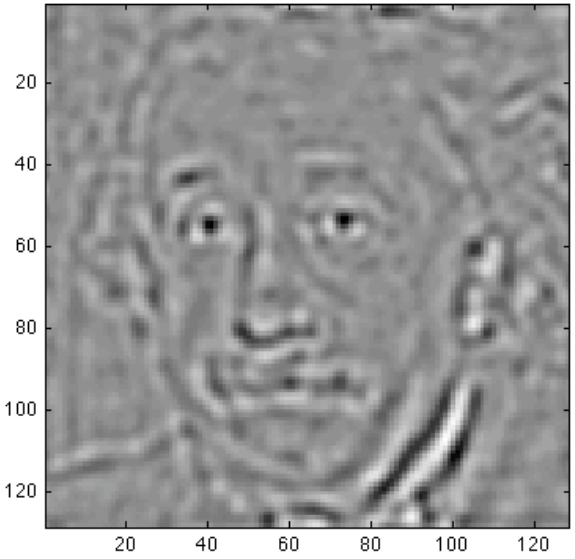
original



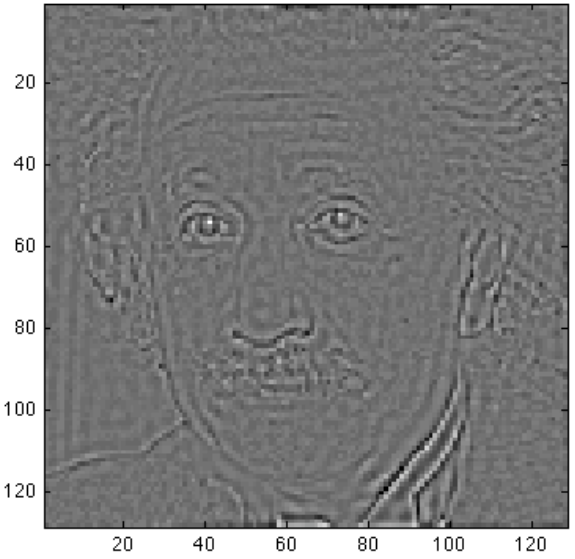
low



medium

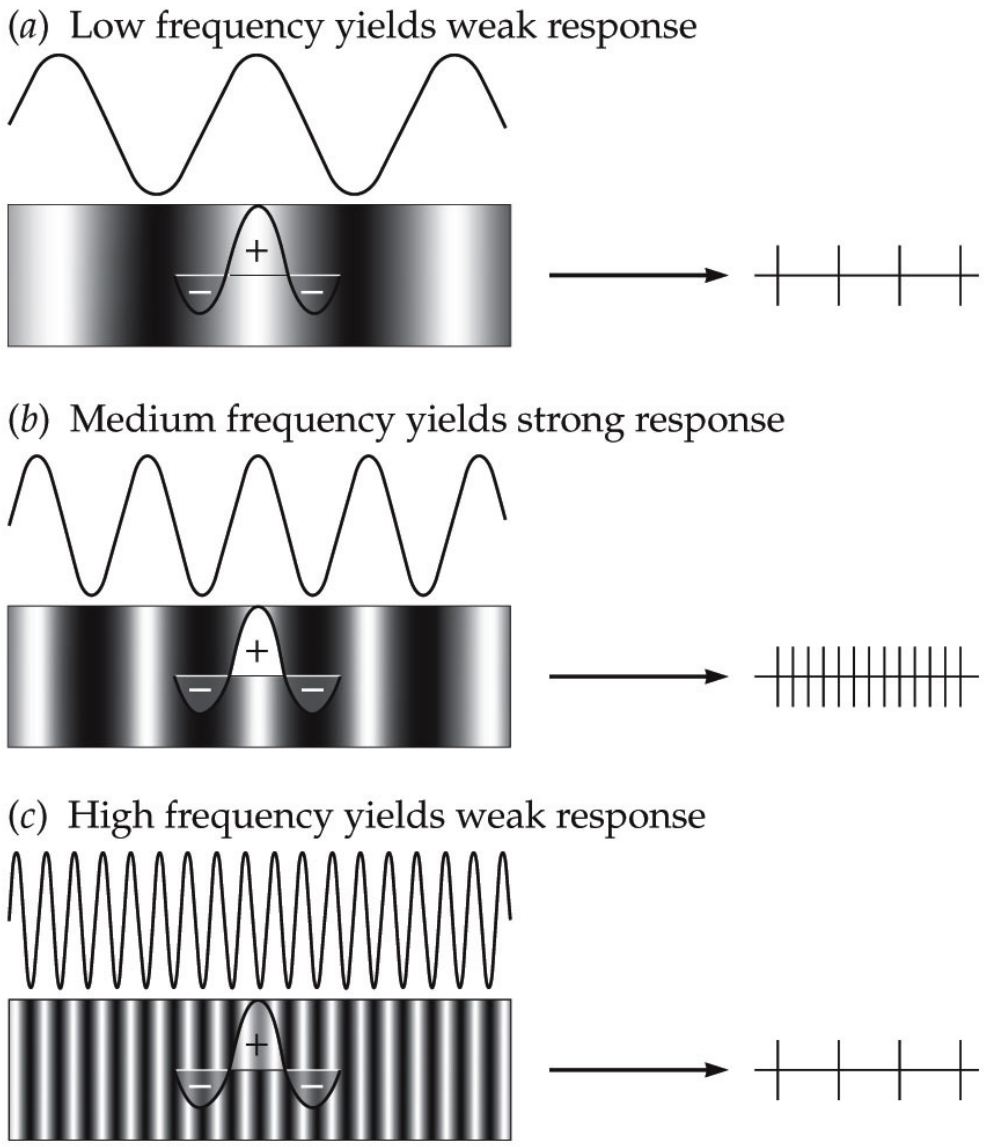


high



Retinal Ganglion Cells: tuned to spatial frequency

Response of a ganglion cell to sine gratings of different frequencies



The contrast sensitivity function

Human contrast sensitivity

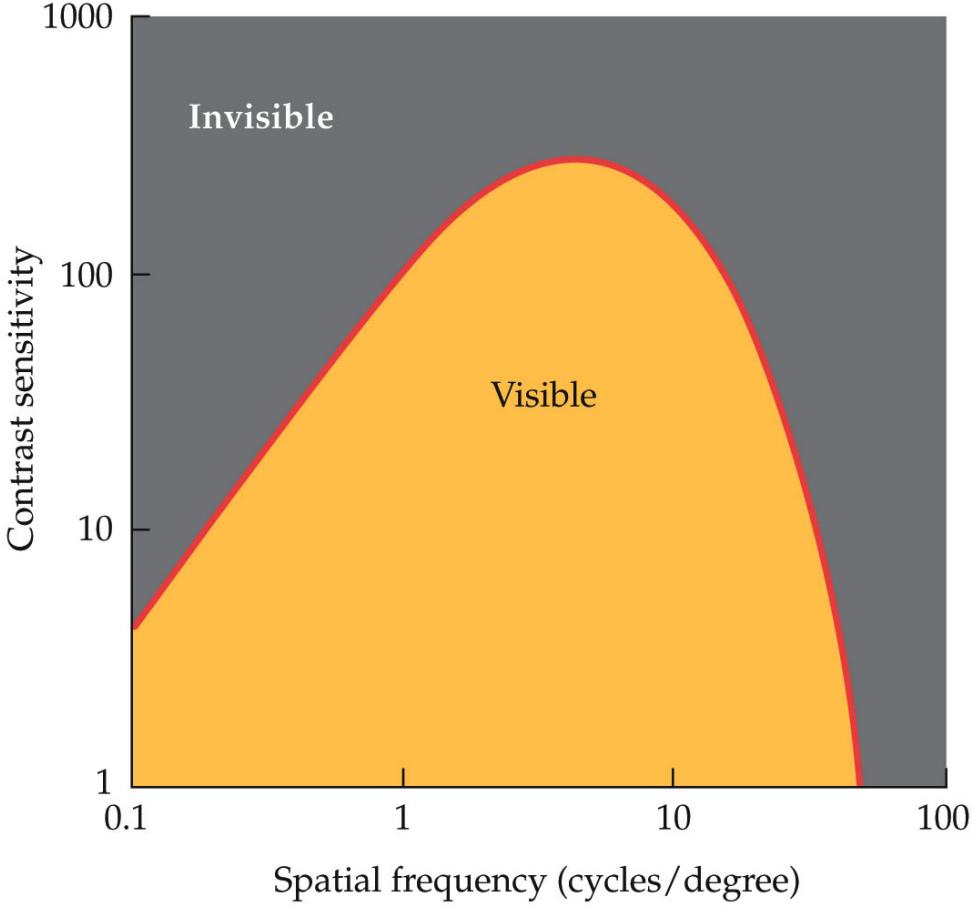


illustration of this sensitivity

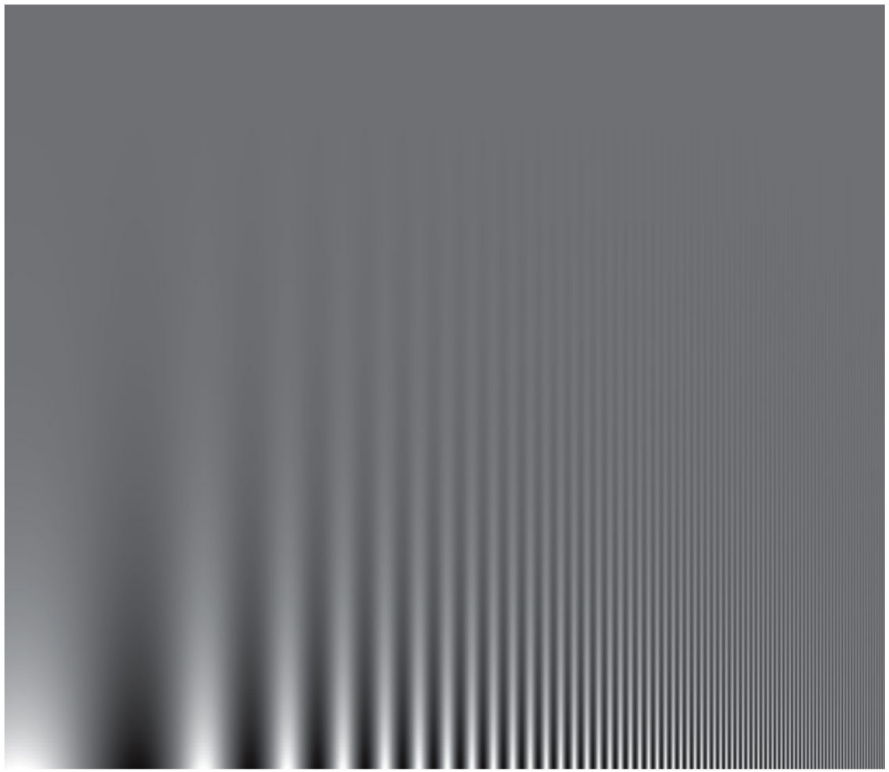


Image Illustrating Spatial Frequency Channels

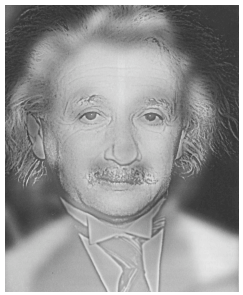
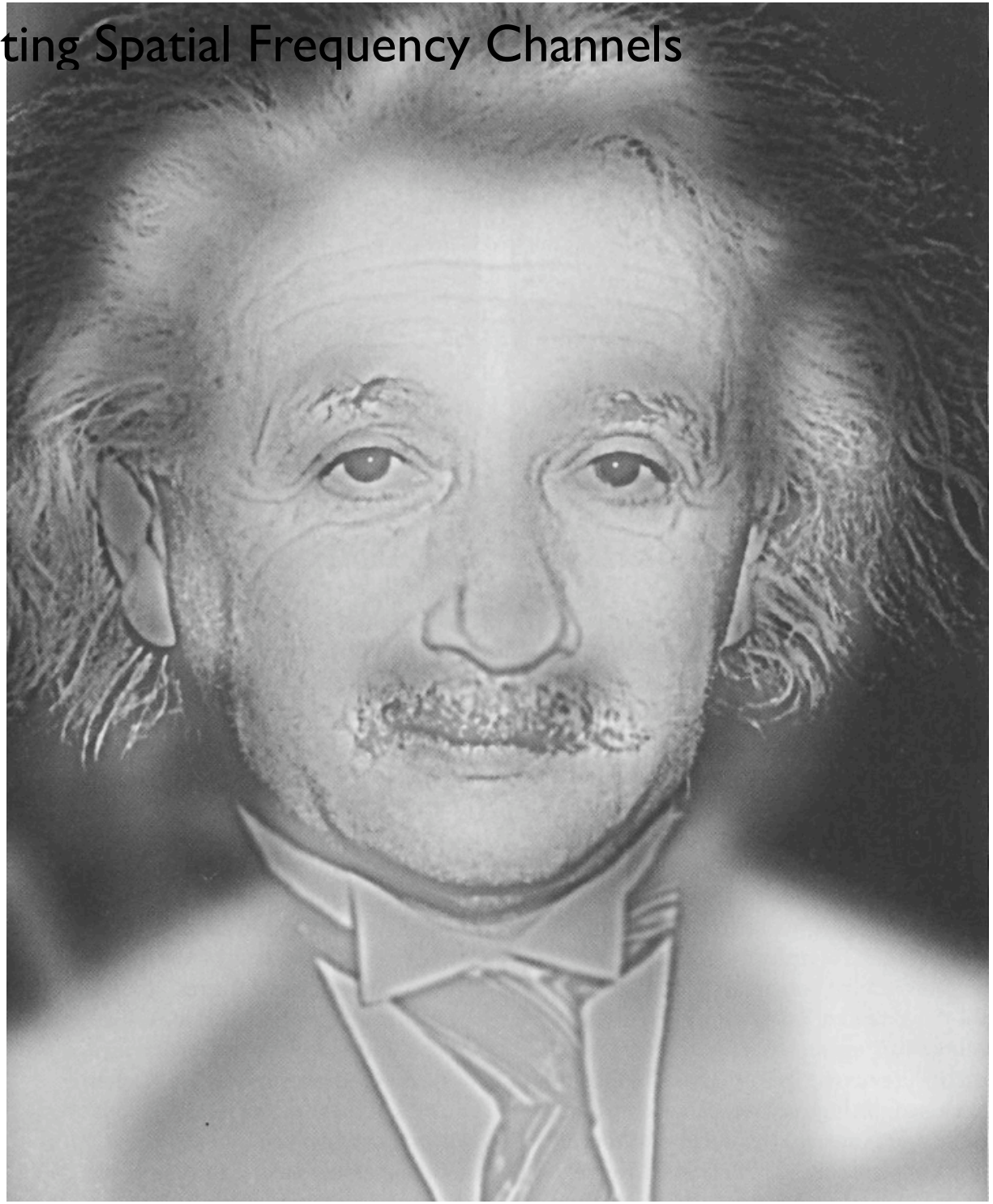
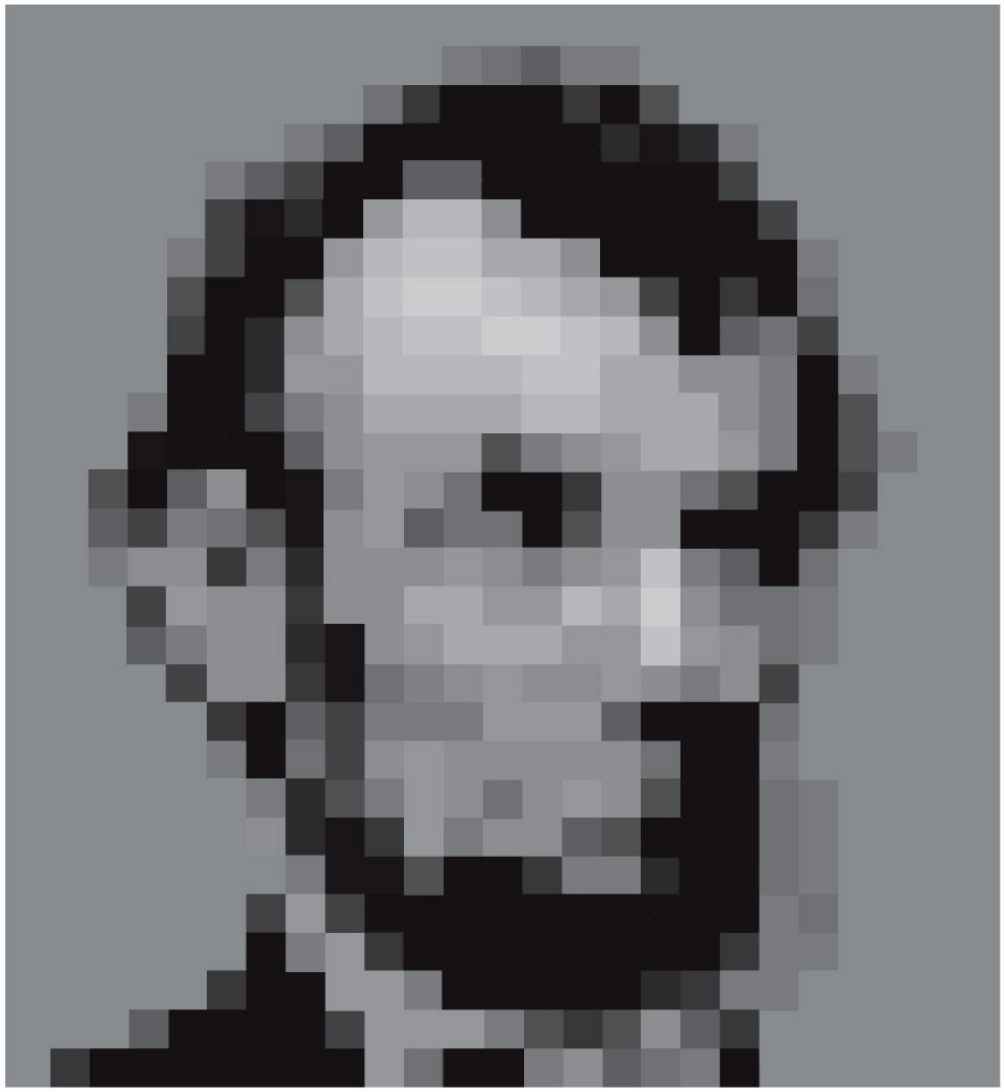


Image Illustrating Spatial Frequency Channels

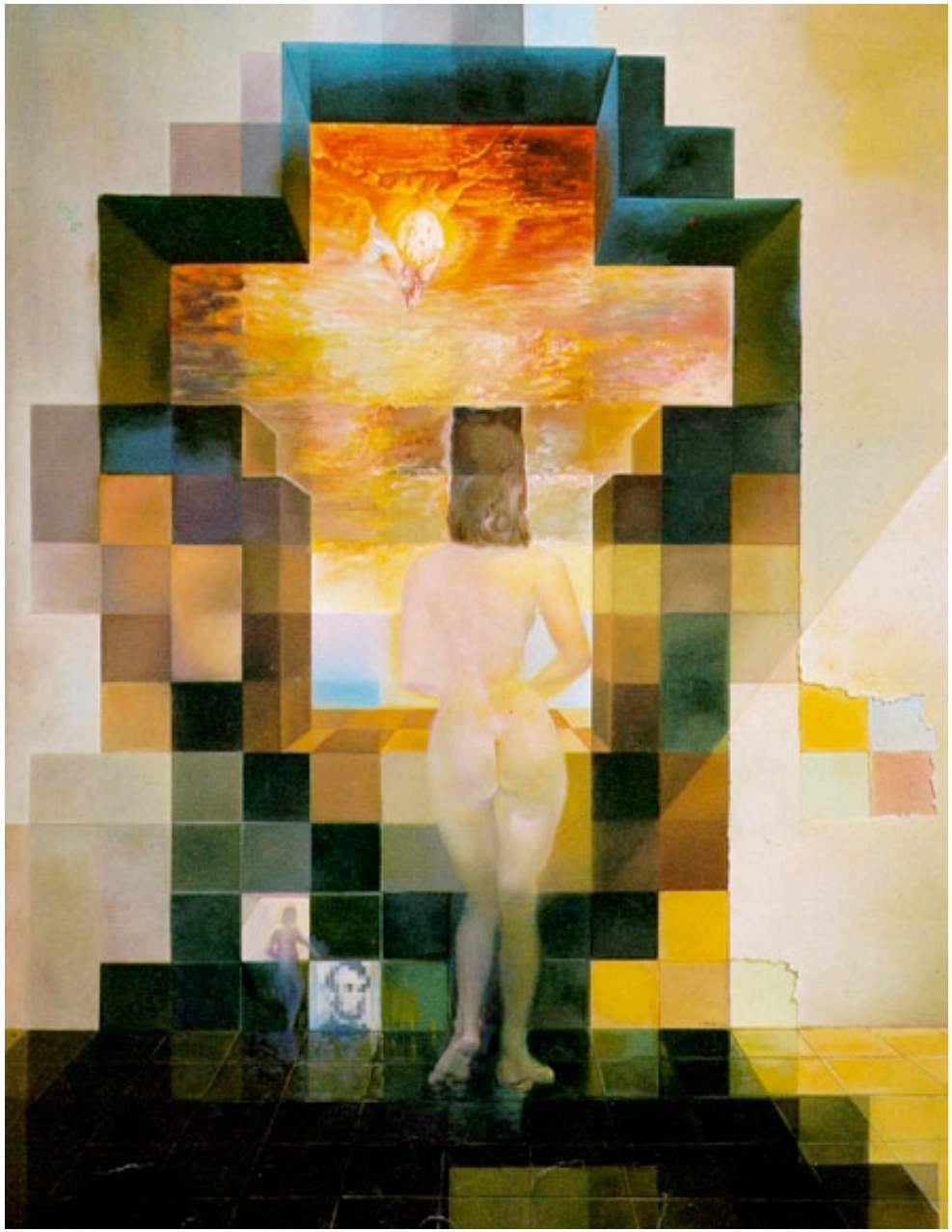


If it is hard to tell who this famous person is, try squinting or defocusing



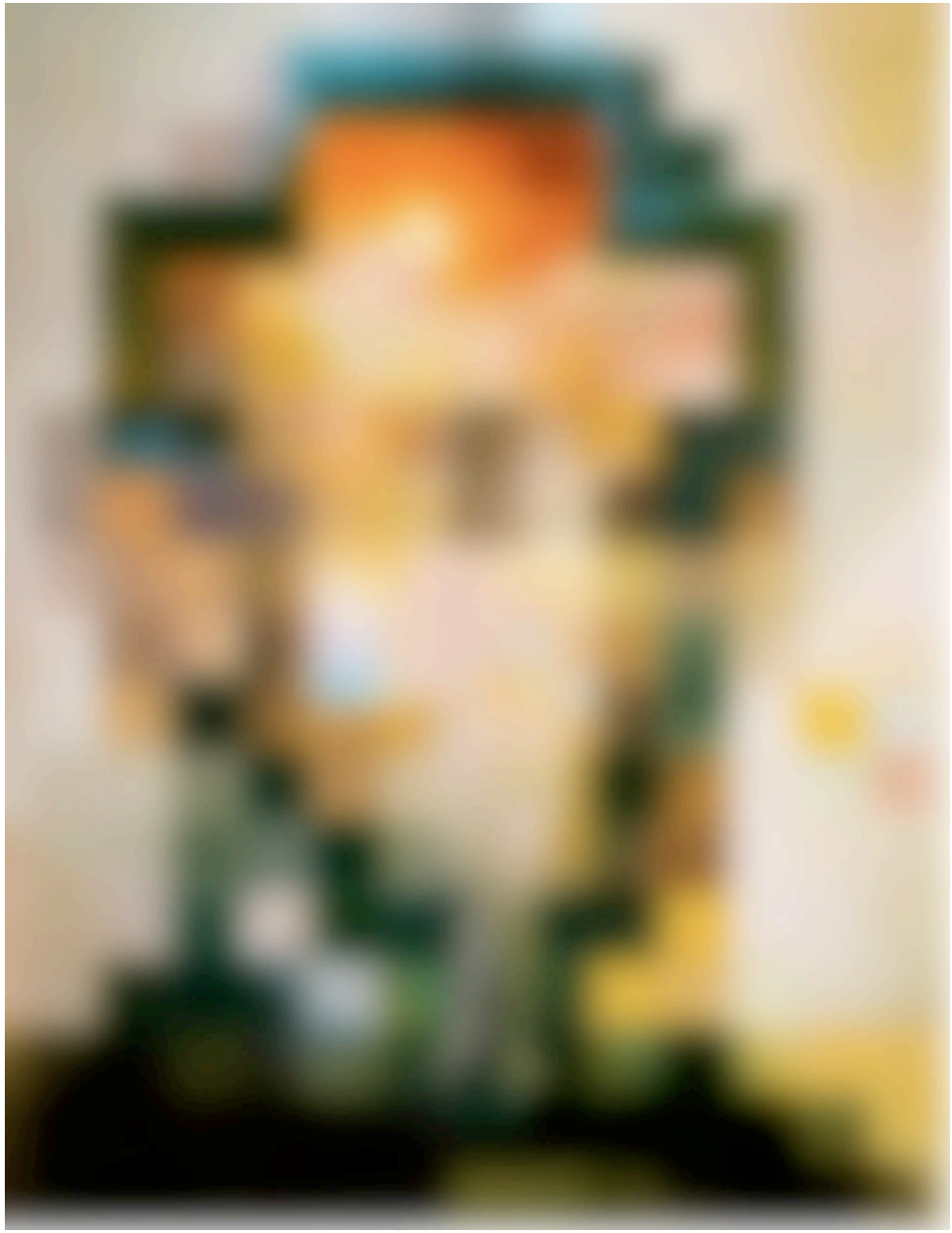
“Lincoln illusion” Harmon & Jules 1973

"Gala Contemplating the Mediterranean Sea, which at 30 meters becomes the portrait of Abraham Lincoln (Homage to Rothko)"



- Salvador Dali (1976)

"Gala Contemplating the Mediterranean Sea, which at 30 meters becomes the portrait of Abraham Lincoln (Homage to Rothko)"



- Salvador Dali (1976)

Summary

- early visual pathway: retina -> LGN -> V1
- “contralateral” representations in visual pathway
- visual acuity (vs. sensitivity)
- spatial frequency channels
- Fourier analysis