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

Lecture 6

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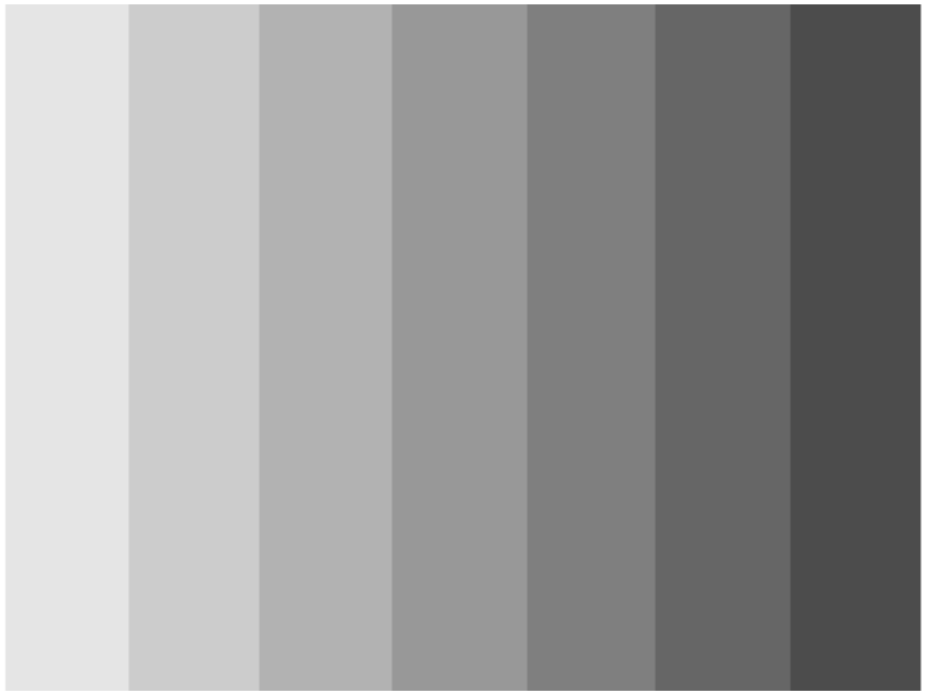
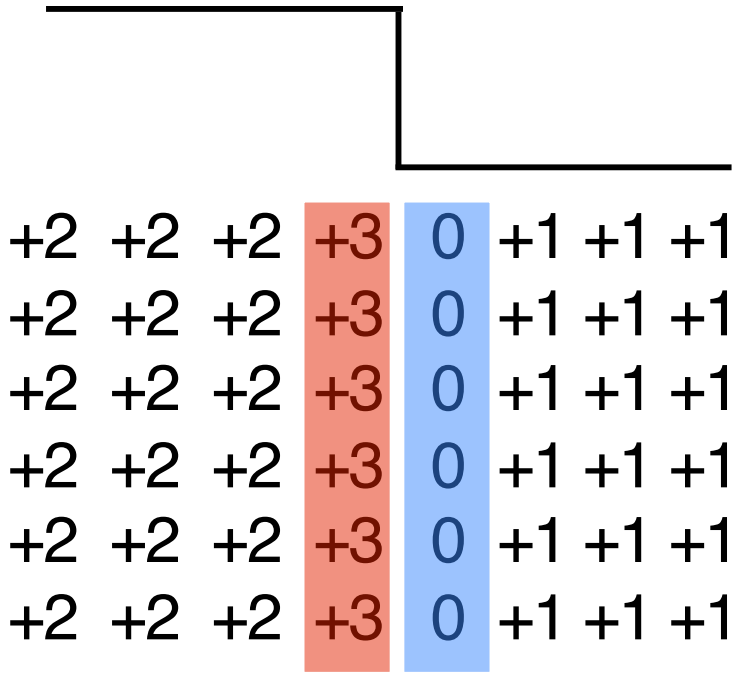
Sensation & Perception
(PSY 345 / NEU 325)
Princeton University, Spring 2019

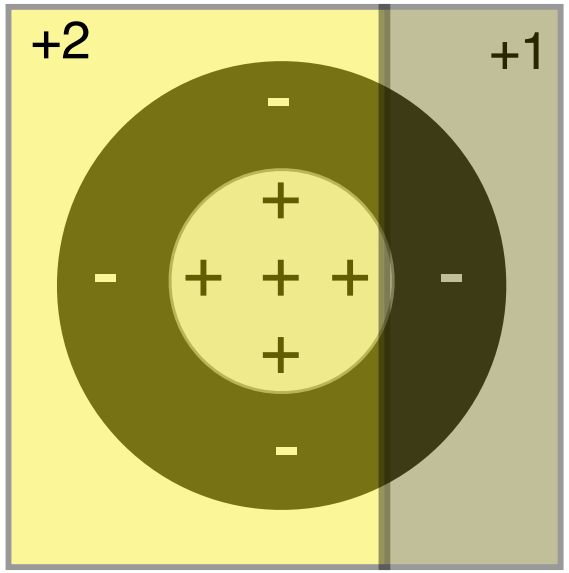
remaining Chapter 2 stuff

Mach Band response

edges are where light difference is greatest







$2\times(+5) + 2\times(-3) + 1\times(-1) = +3$ spikes

"center" weight

"surround" weight

Also (partially) explains:

Lightness illusion

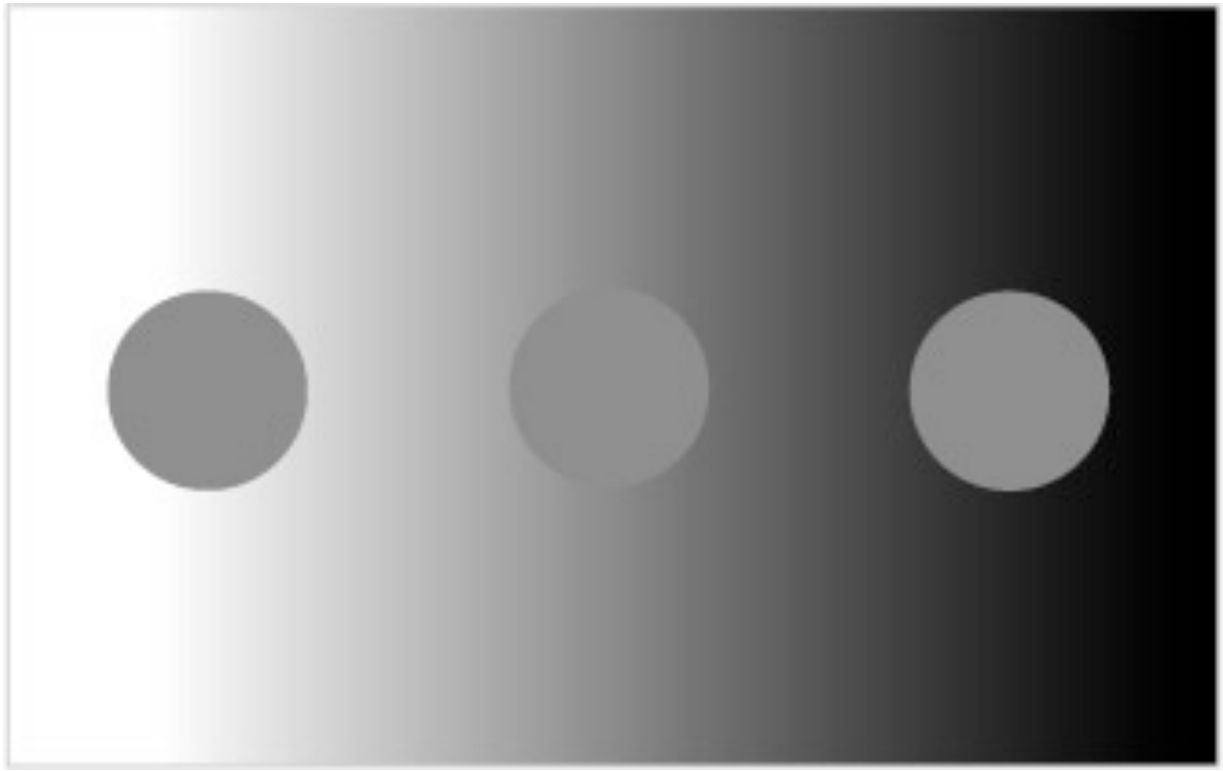
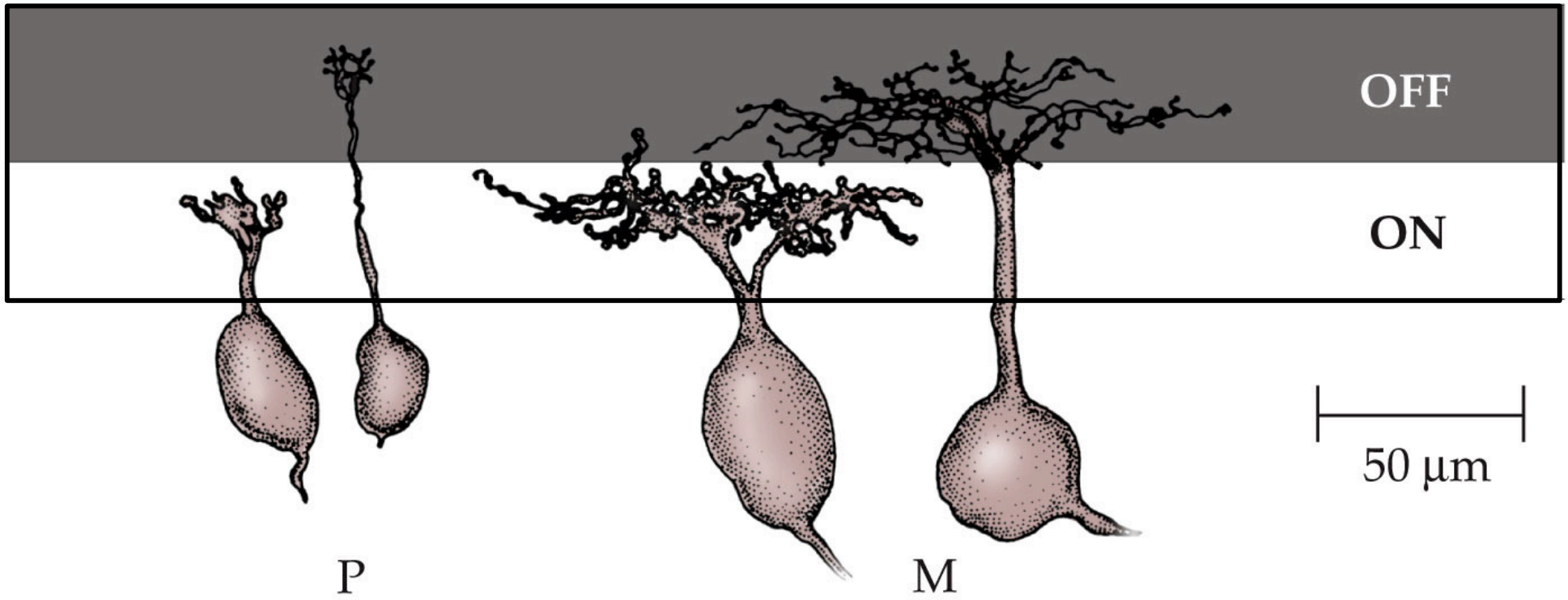


Figure 2.12 Different types of retinal ganglion cells

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



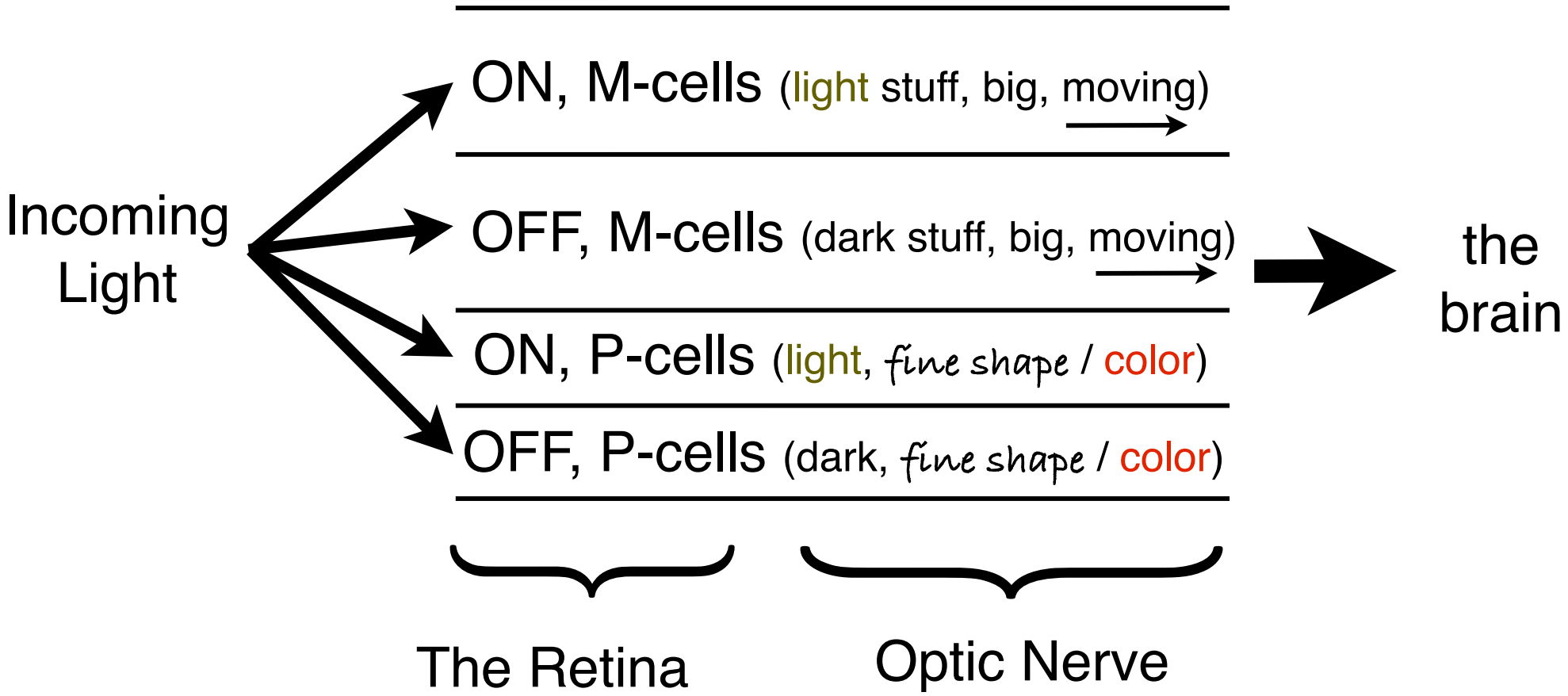
Parvocellular

("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 1 million times difference)

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

(1) Pupil dilation

(2) Photoreceptors and their photopigment levels

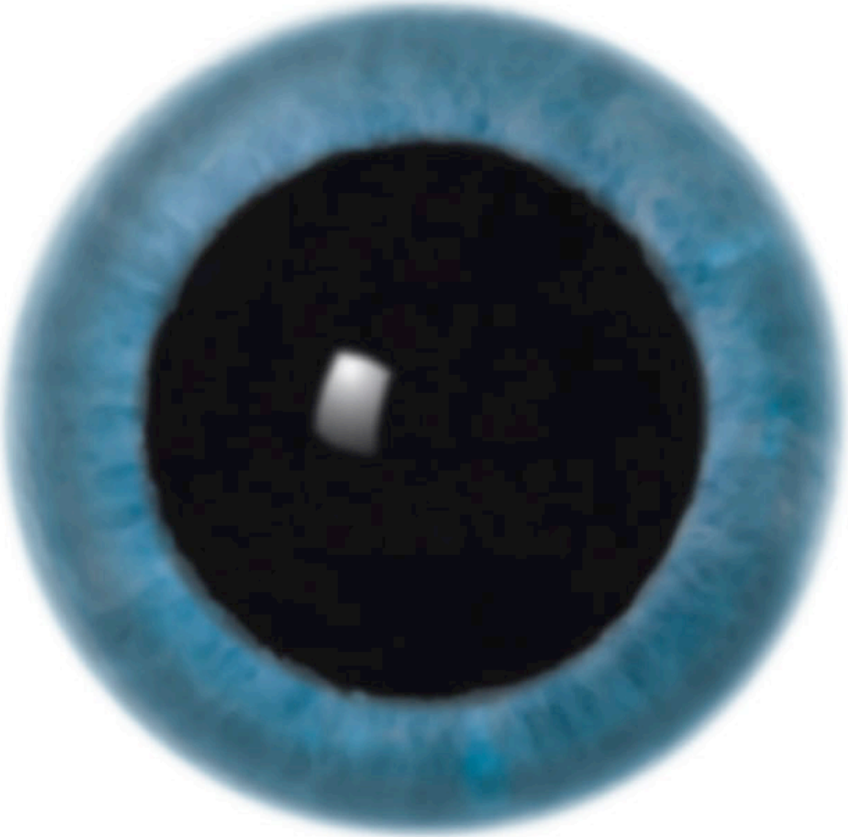
the more light, the more
photopigment gets "used up",
→ less available photopigment,
→ retina becomes less sensitive

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!)

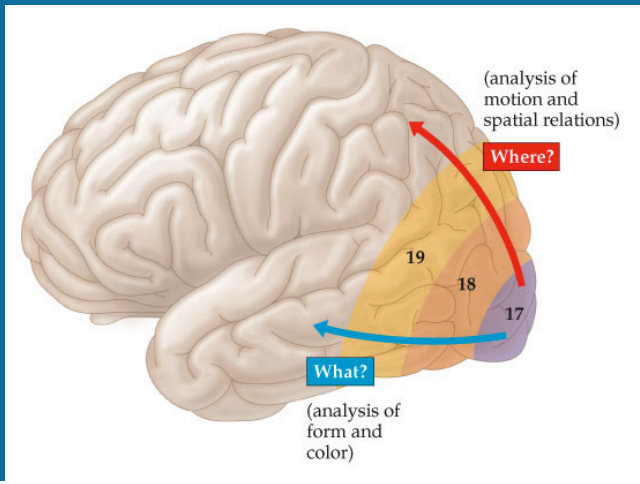
• from an "image compression" standpoint, it's better to just send information about local differences in light

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

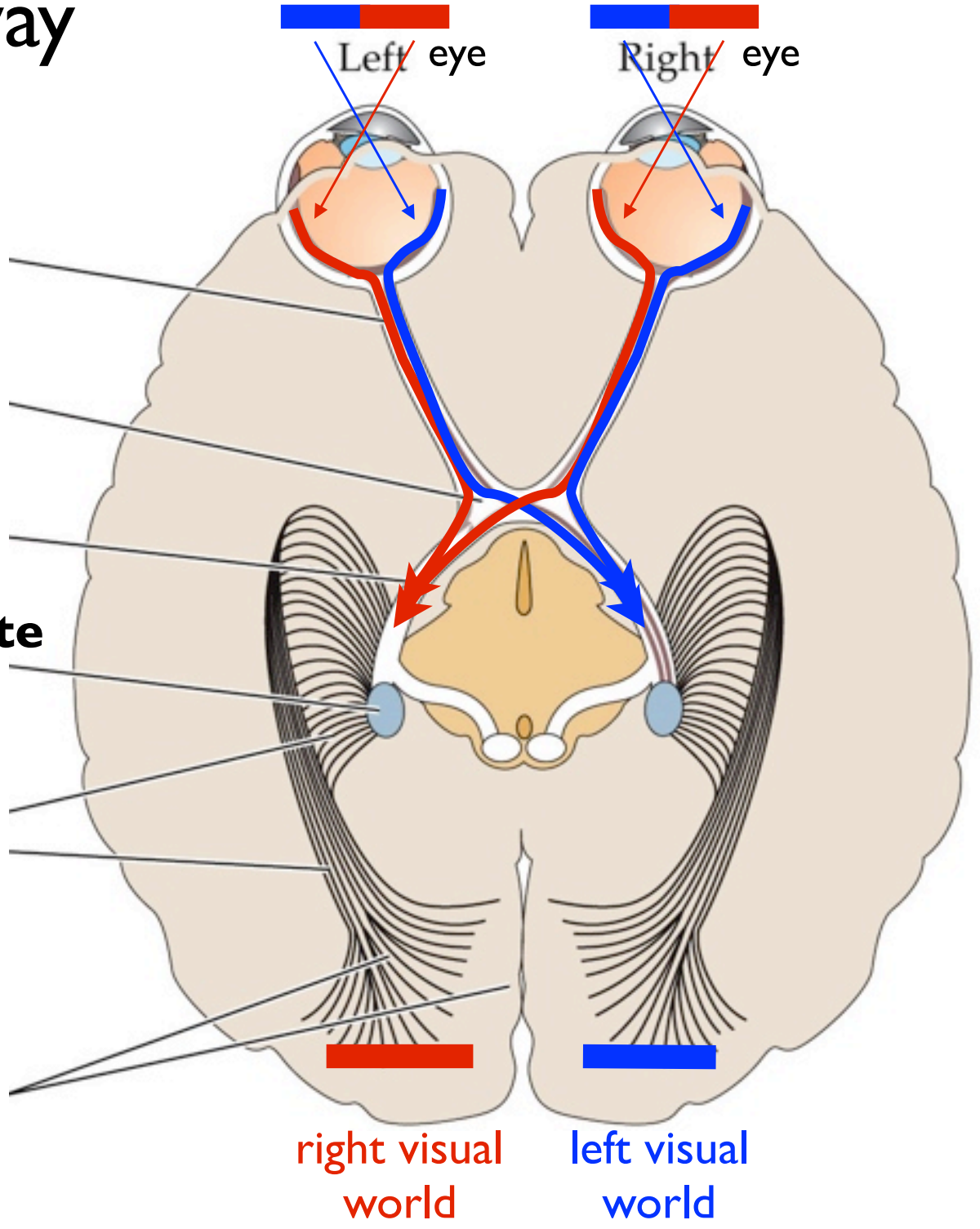
optic tract

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

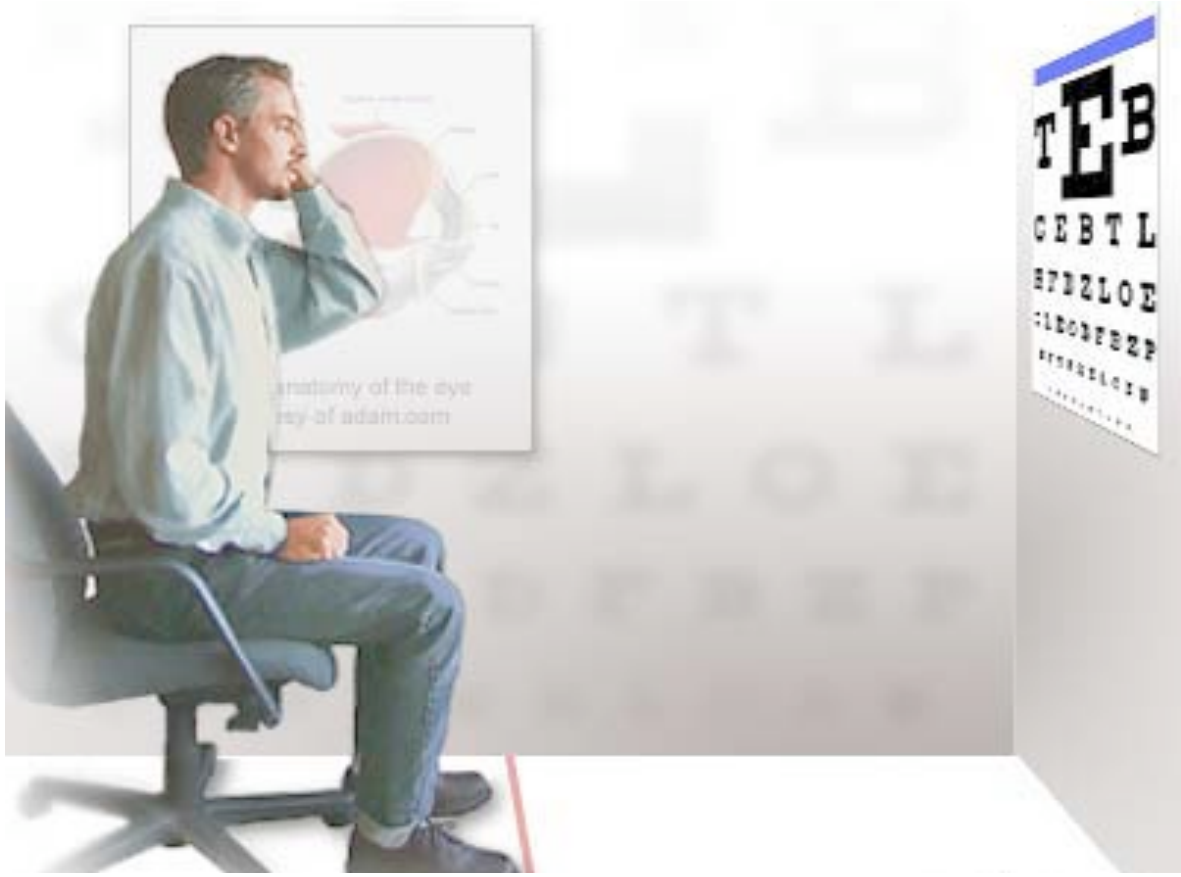
optic radiations

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

(aka "striate cortex")

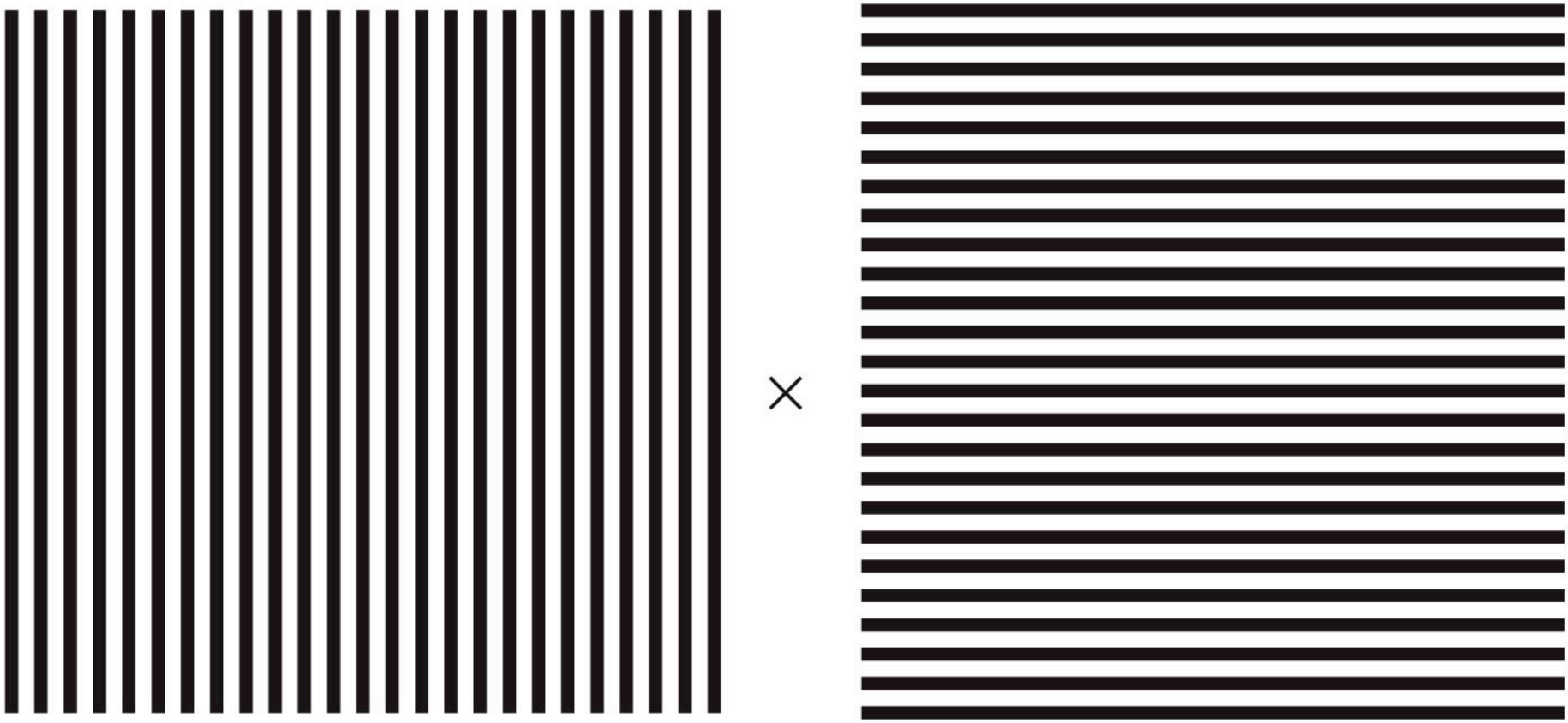


- **Acuity**: measure of finest visual detail that can be resolved



Visual Acuity

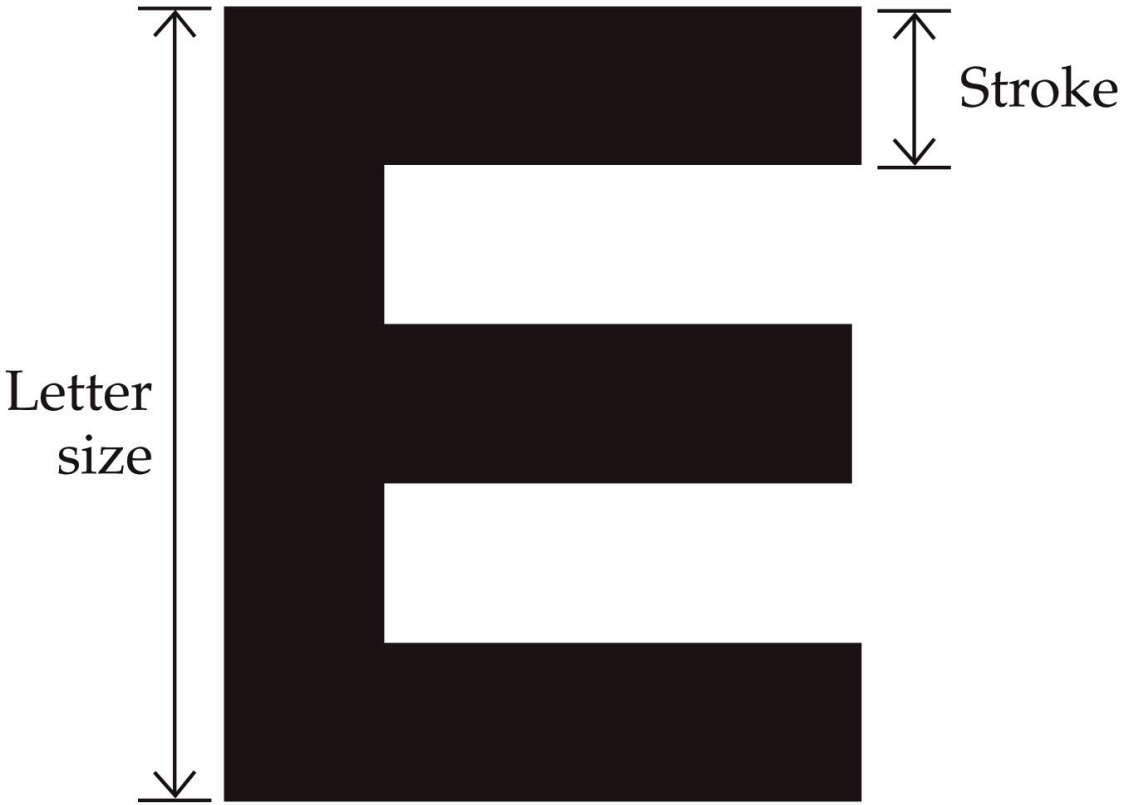
- in the lab



Measuring Visual Acuity

Snellen *E* test

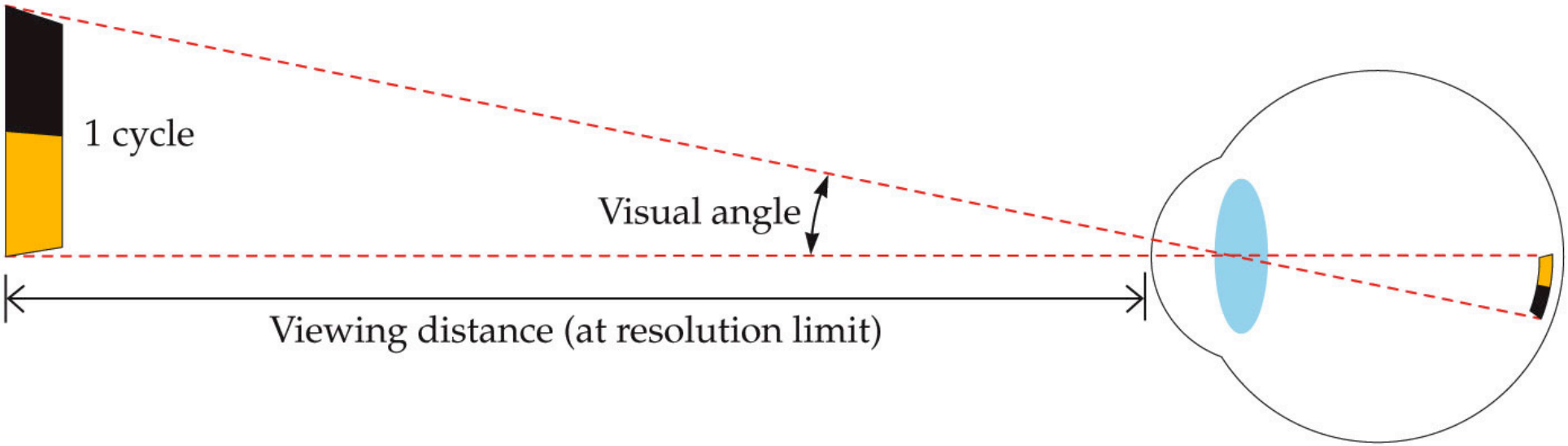
- Herman Snellen invented this method for designating visual acuity in 1862
- Notice that the strokes on the E form a small grating pattern



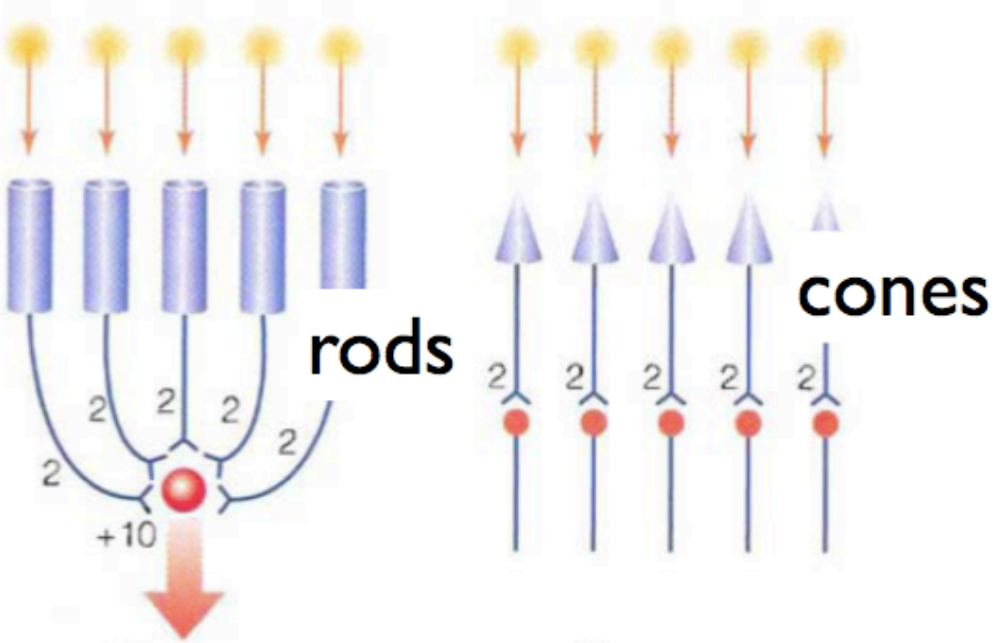
Acuity

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

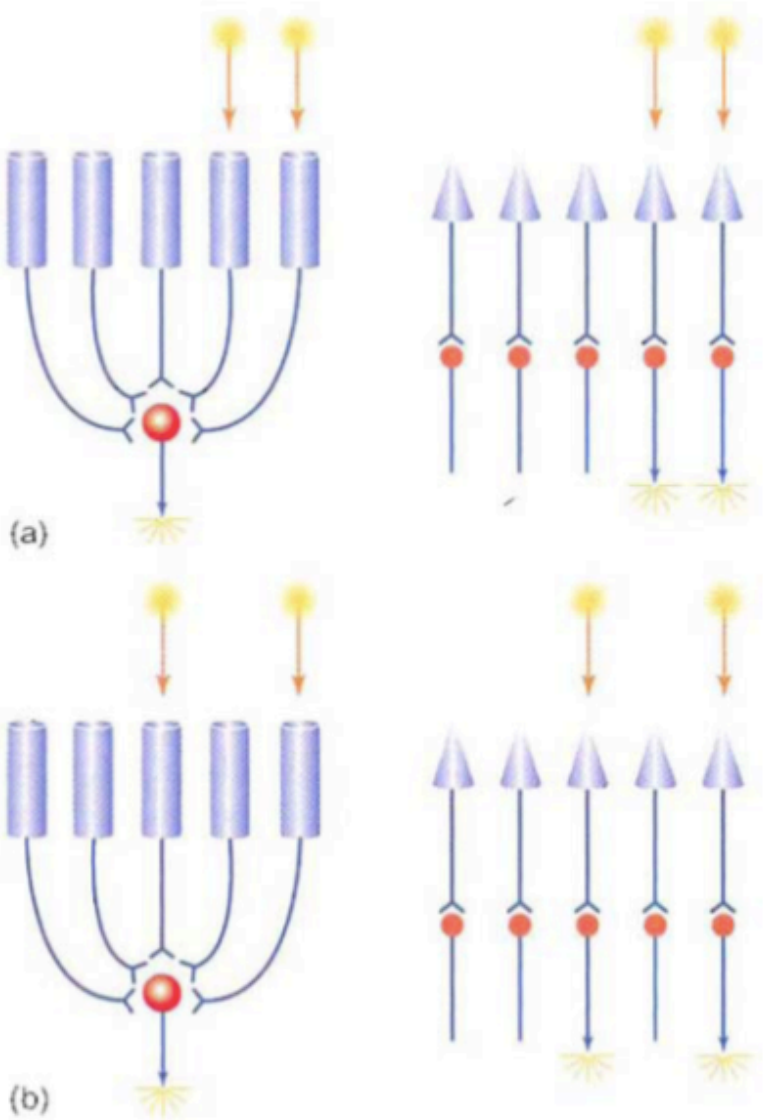
vision scientist: visual angle of one cycle of the finest grating you can see



sensitivity



acuity



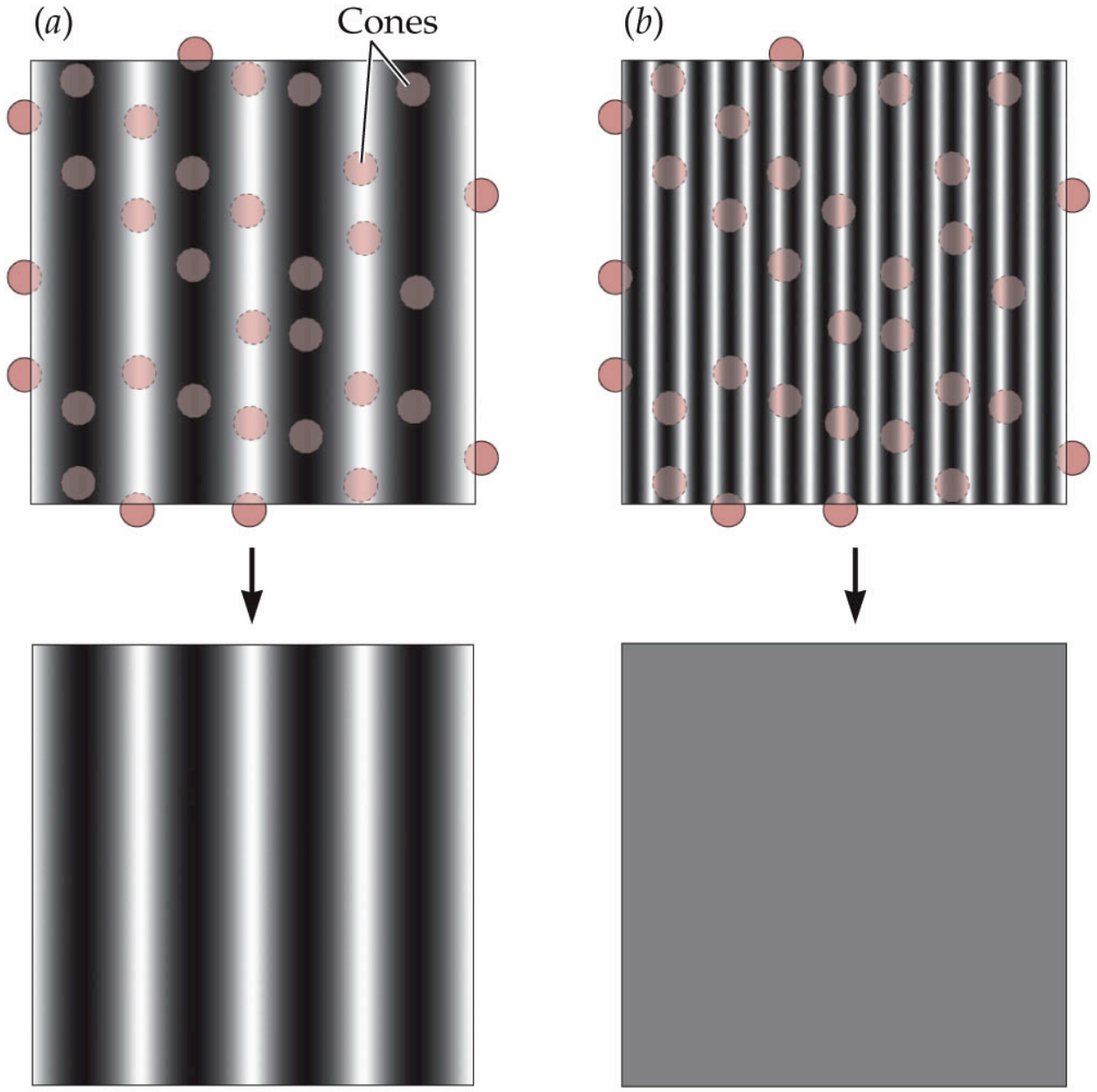
explaining acuity

- 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

stimulus on retina



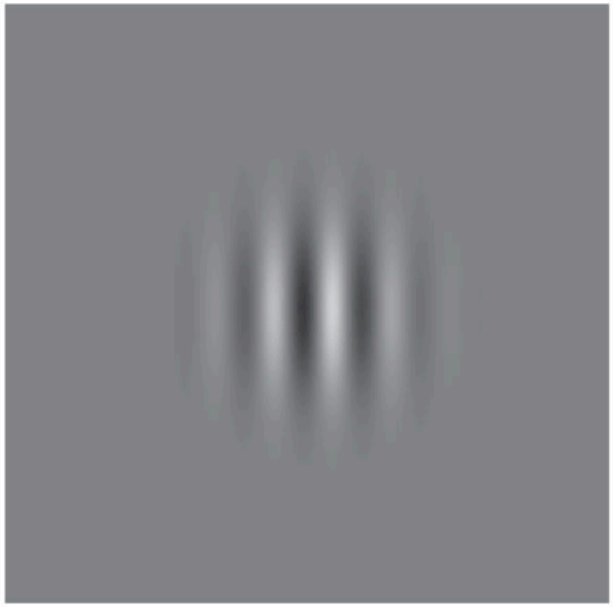
percept

more "channels": spatial frequency channels

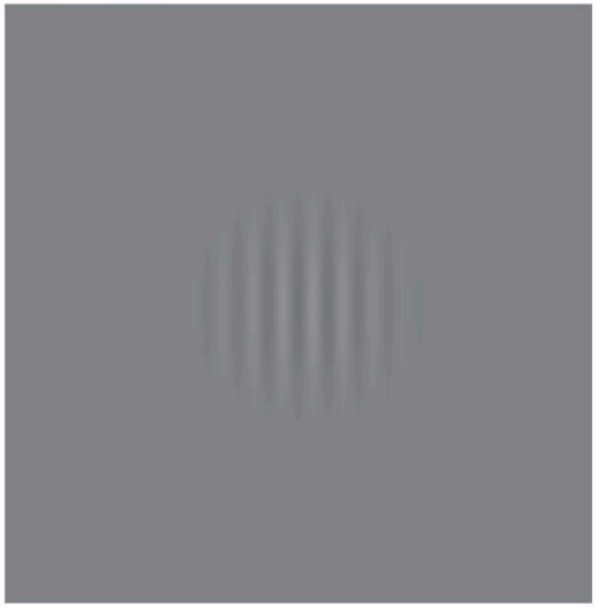
spatial frequency: the number of cycles of a grating per unit of visual angle (usually specified in degrees)

- 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

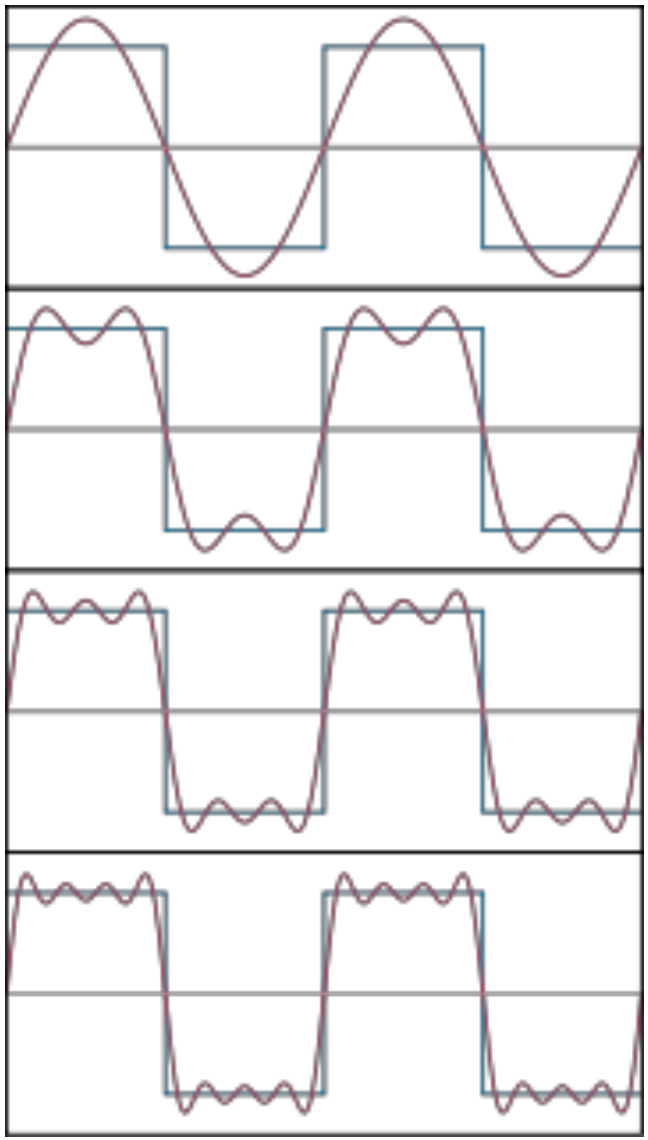
Technical term: **Fourier decomposition**

Fourier decomposition

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

reconstruction:

"image"



1 sine wave

2 sine waves

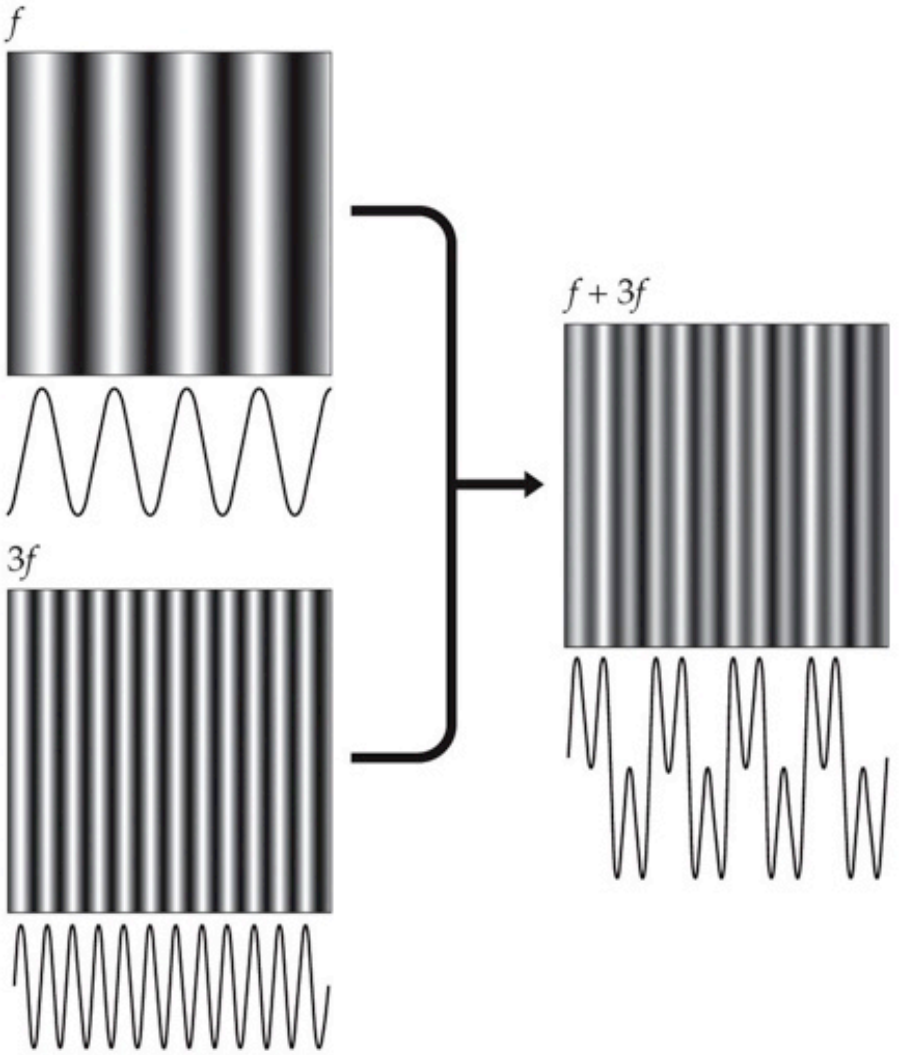
3 sine waves

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

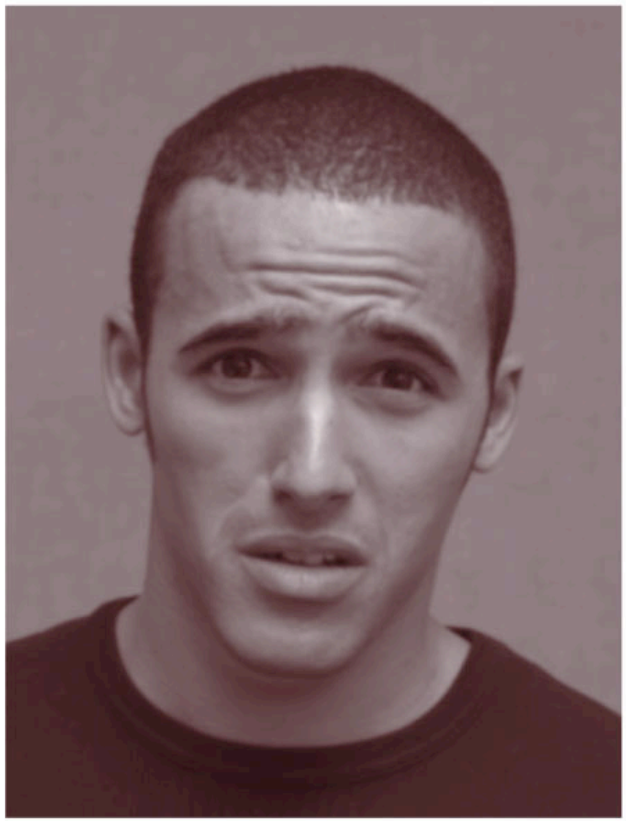
- Summation of two spatial sine waves
- any pattern can be broken down into a sum of sine waves



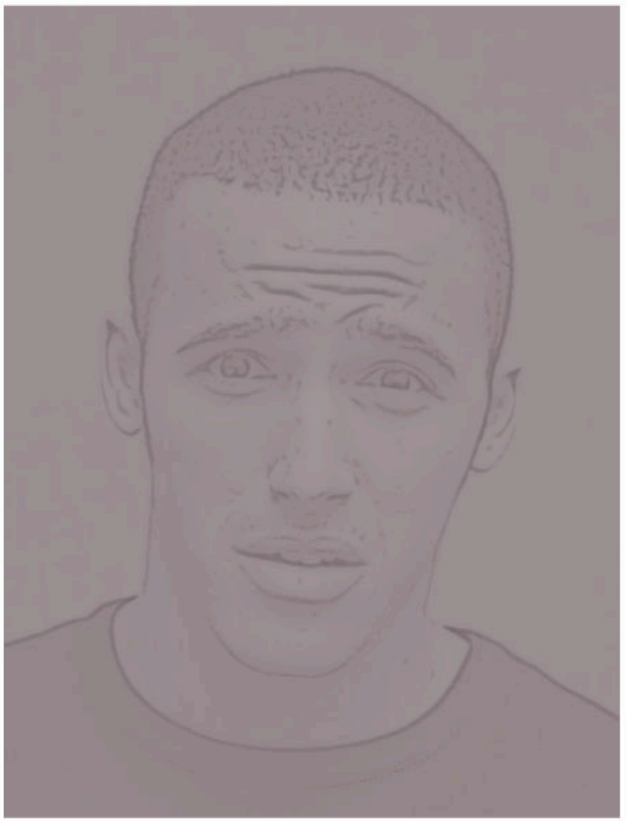
Fourier decomposition

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

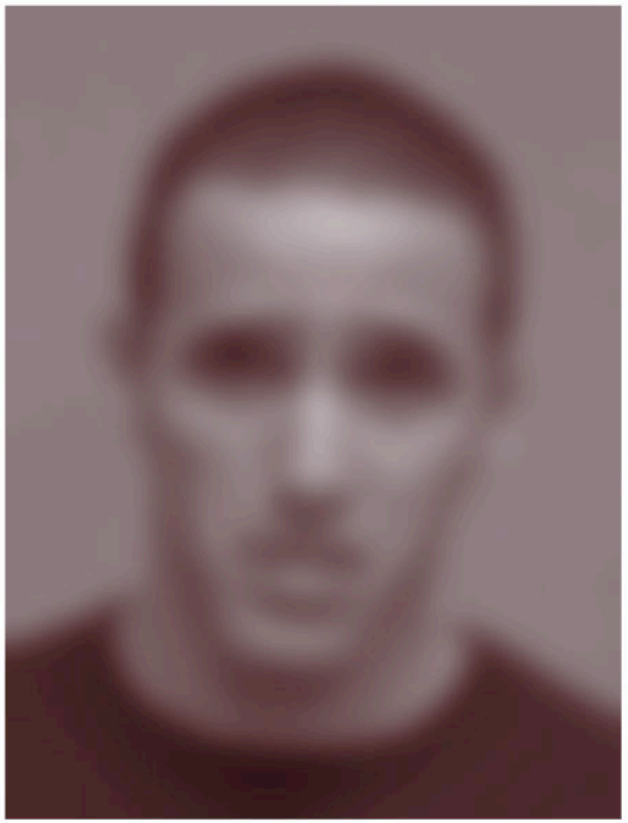
Original image



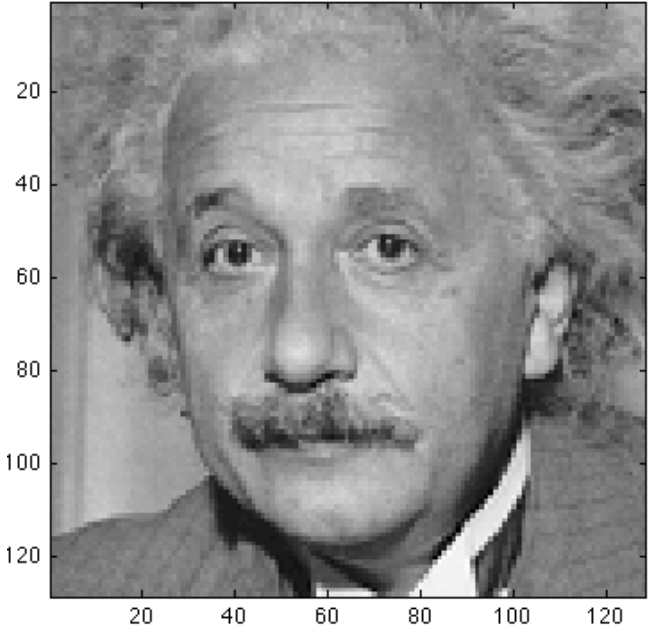
High Frequencies



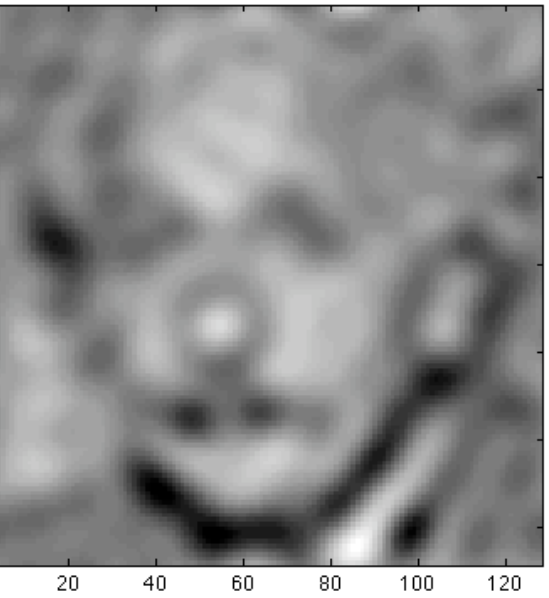
Low Frequencies



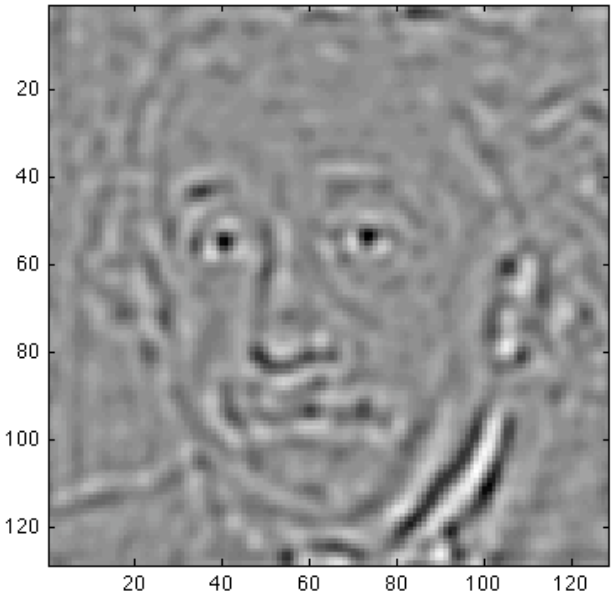
original



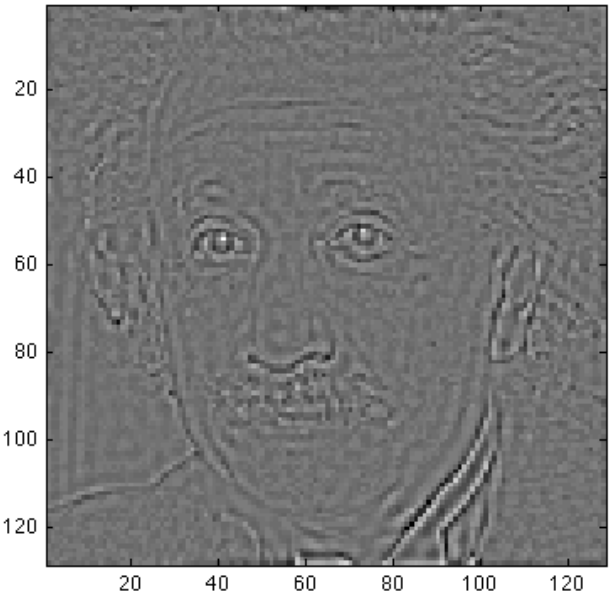
low



medium

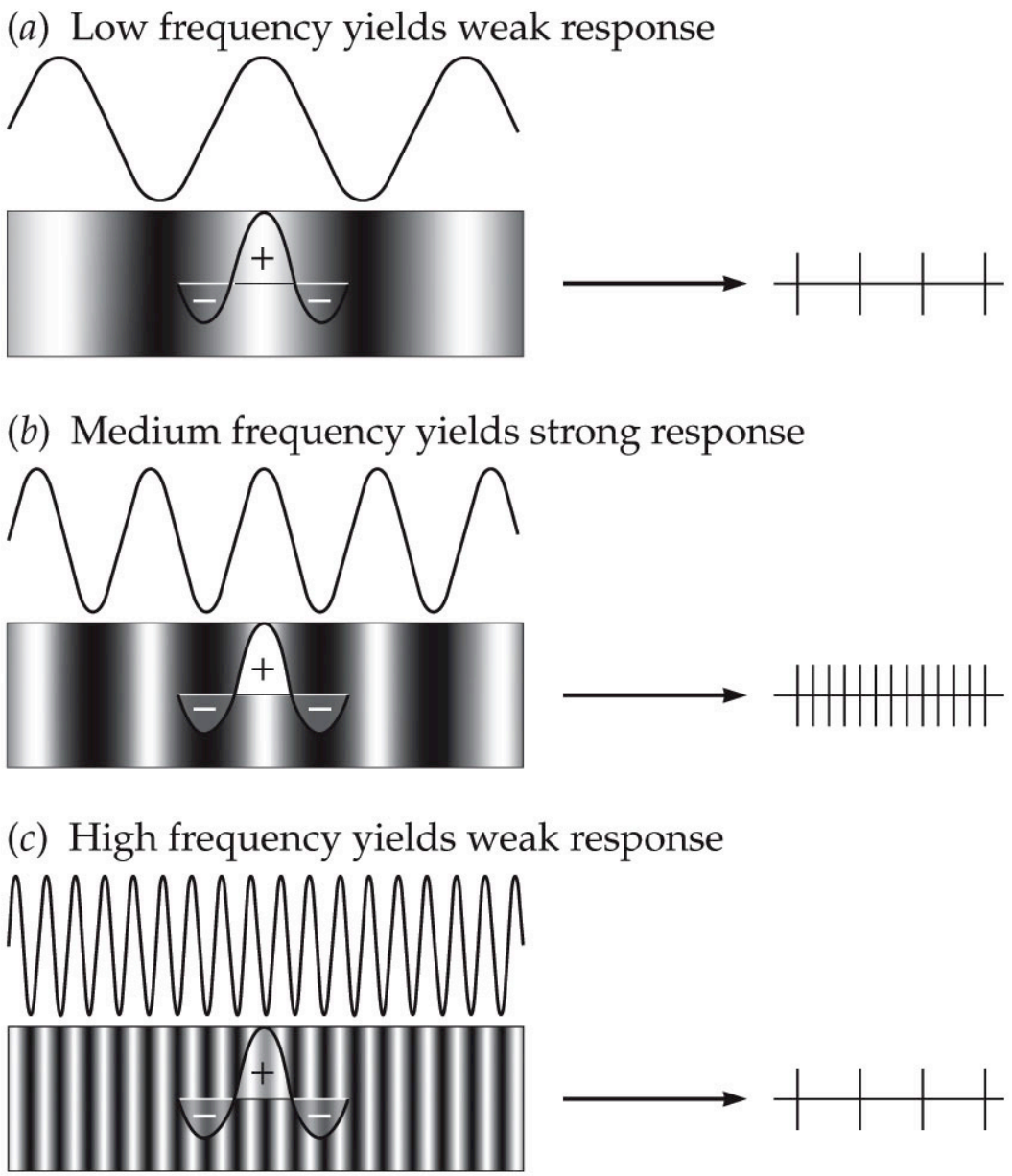


high



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

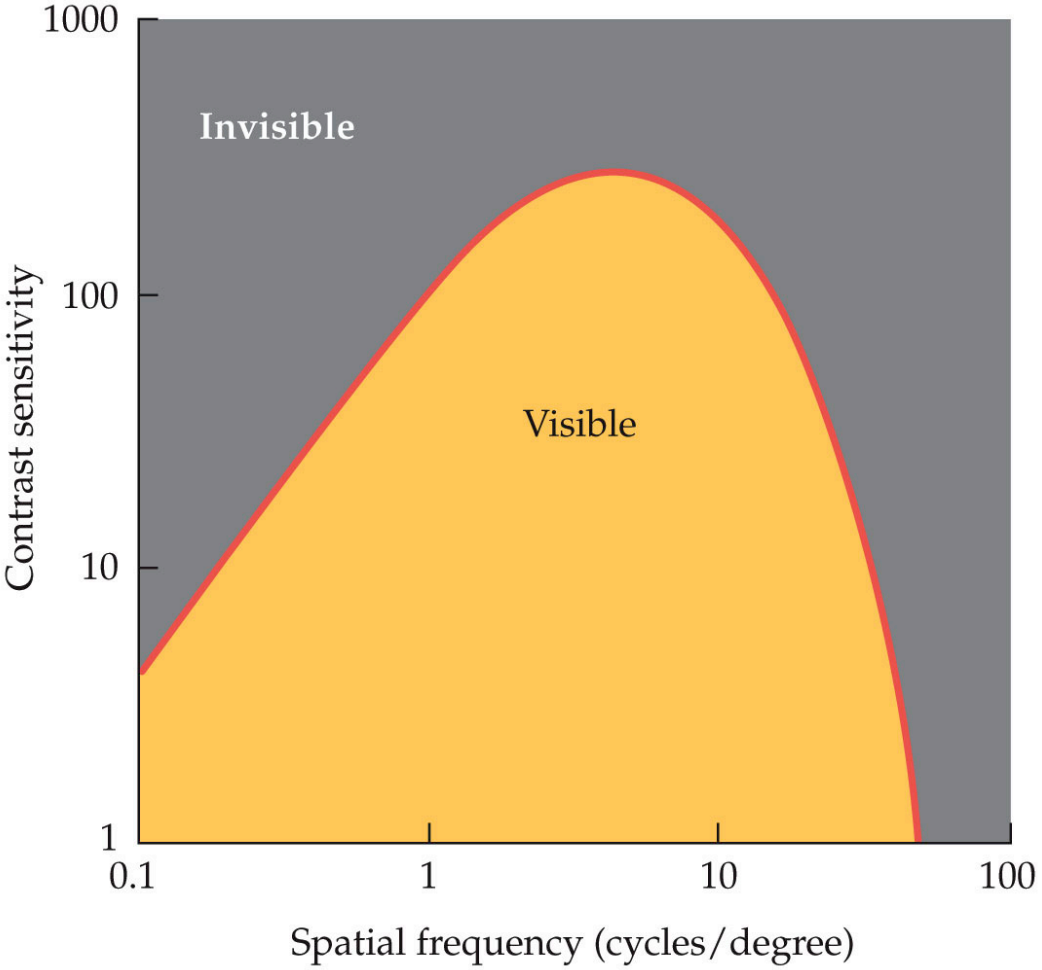


illustration of this sensitivity

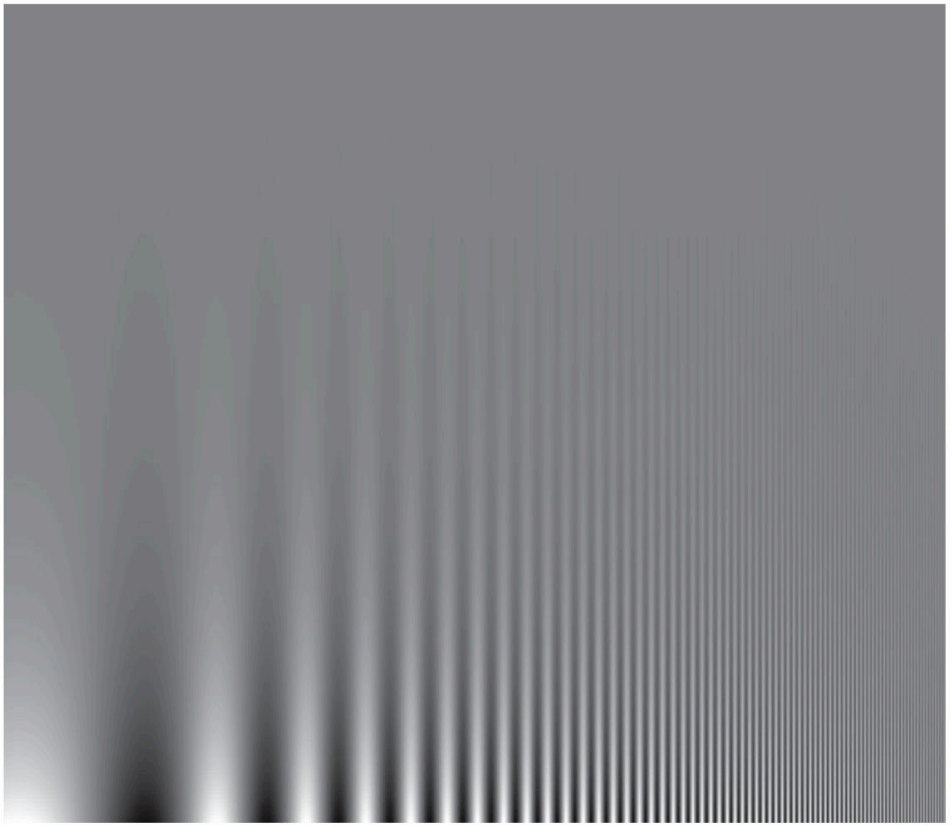
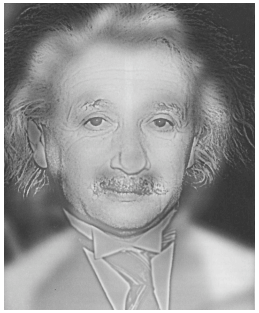


Image Illustrating Spatial Frequency Channels



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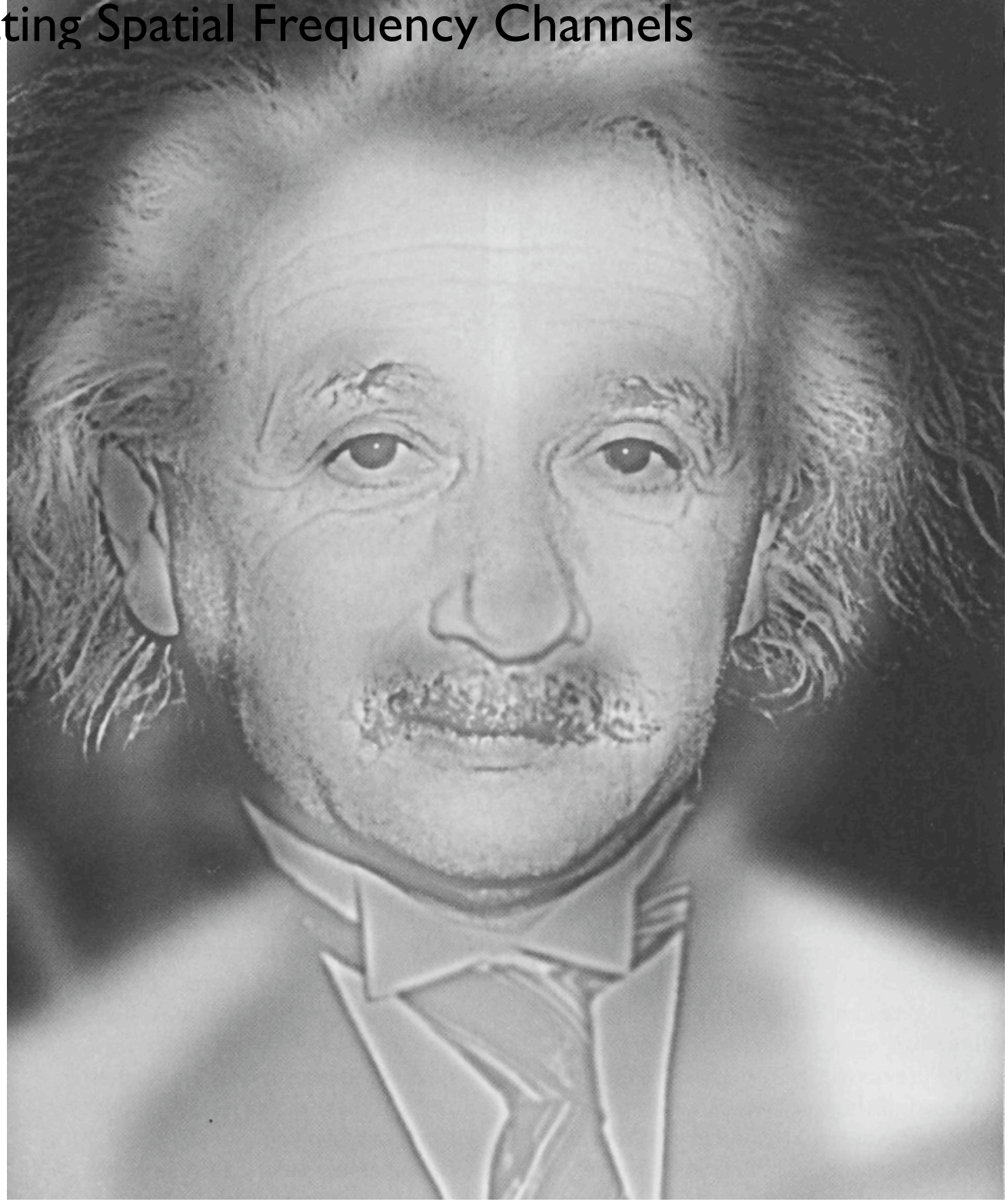
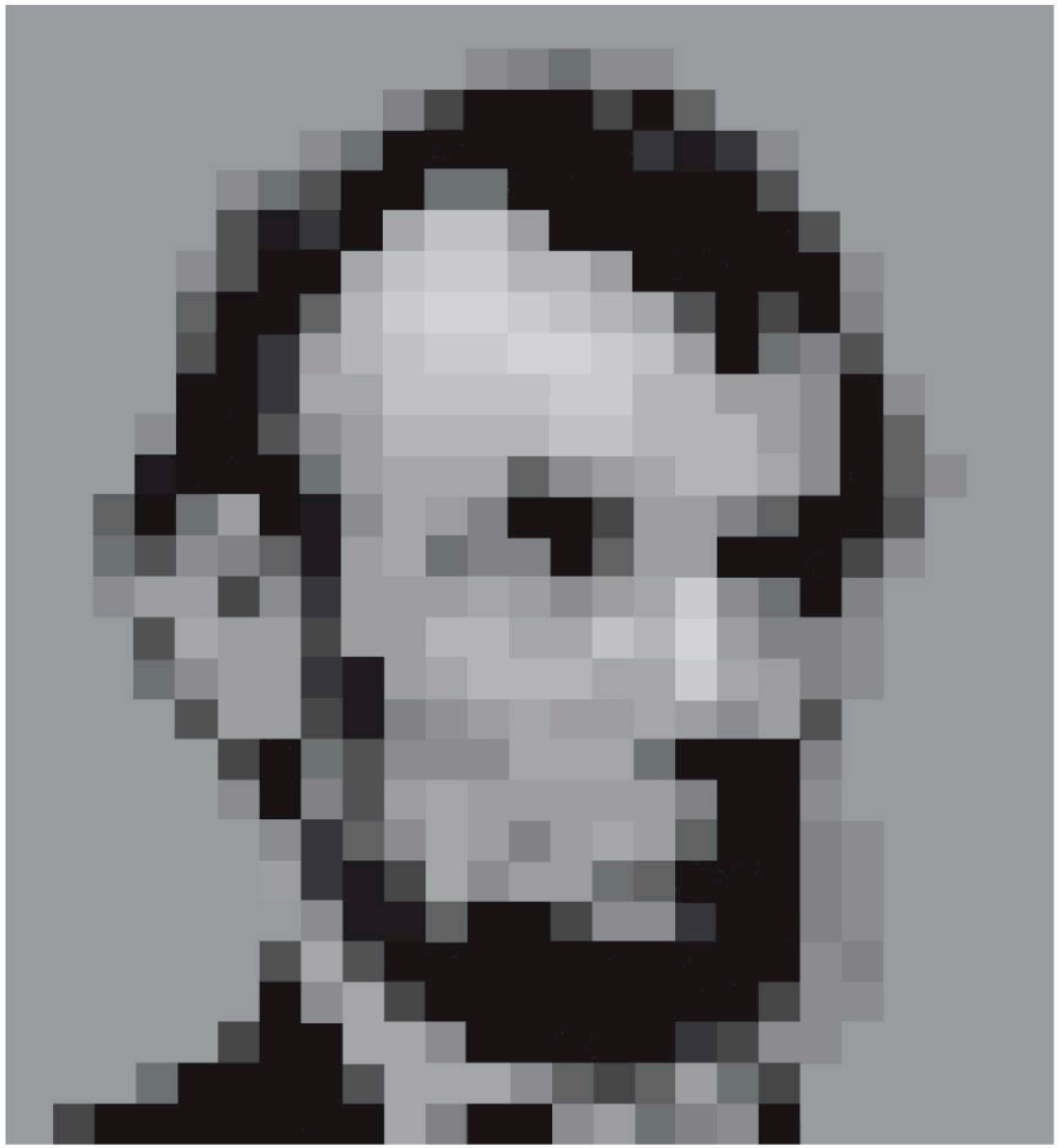
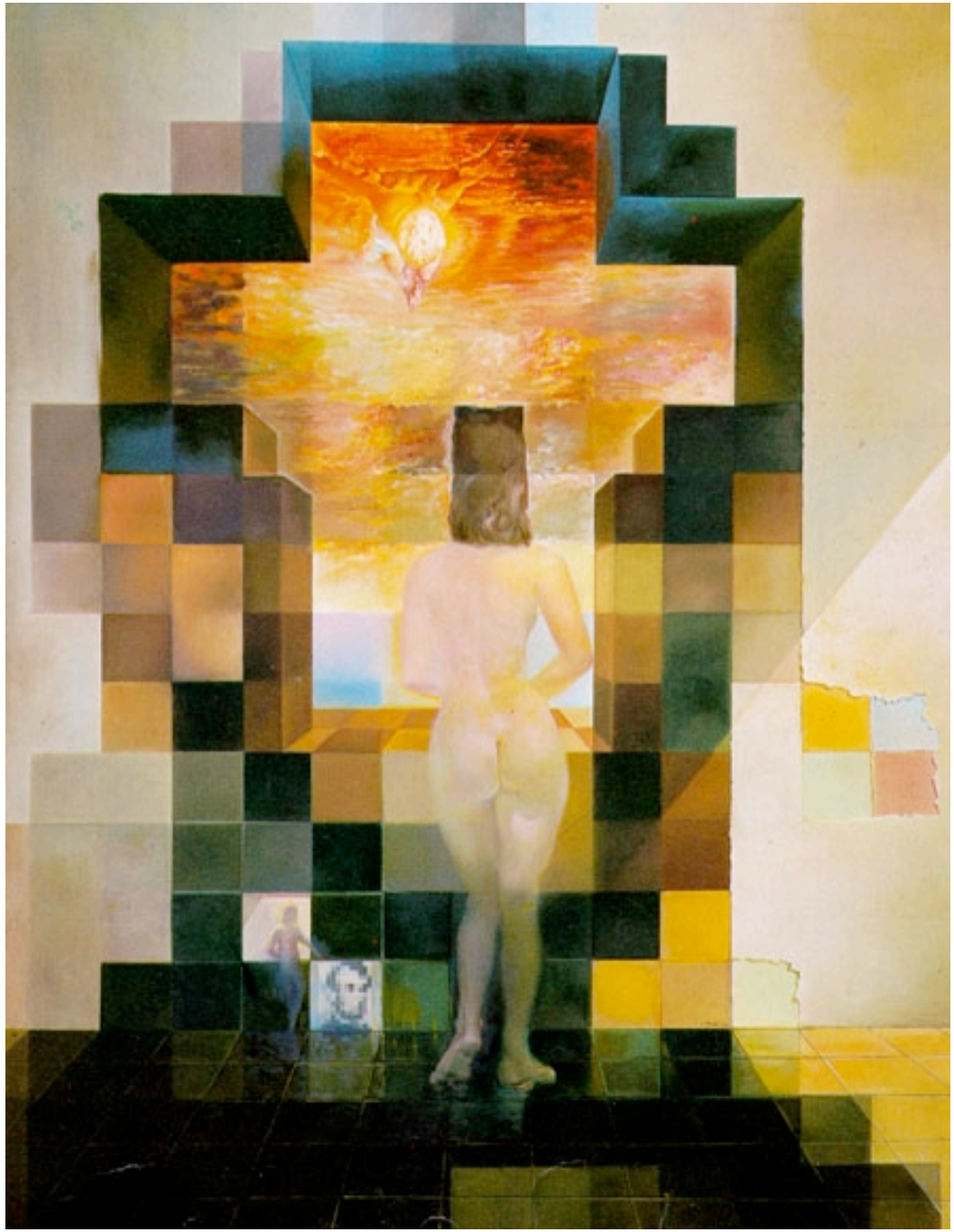


If it is hard to tell who this famous person is, try squinting or defocusing



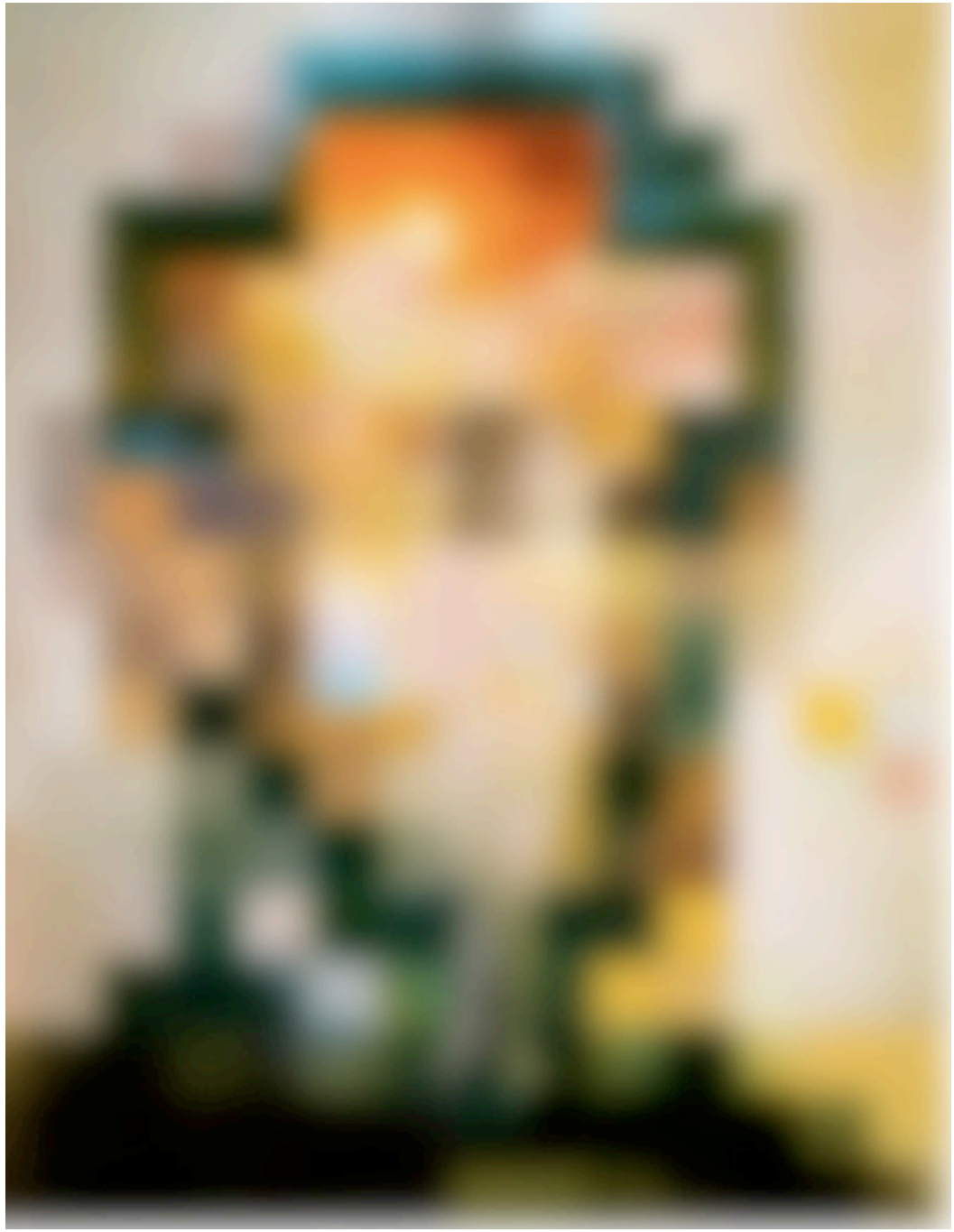
“Lincoln illusion” Harmon & Jules 1973

"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