RUTGERS
UNIVERSITY | NEW BRUNSWICK

Spatial Vision: From Eye to Brain

Summary of Previous Lecture

- Transduction: changing energy from one state to another
- Retina: photoreceptors, opsins, dark current, bipolar cells, lateral inhibition, retinal ganglion cells
- Backward design of retina
- Rods, cones, and retinal geography
- Optic disc (blind spot) and “filling in”
- Receptive fields, on/off, and M/P channels in retina
- Dark/light adaptation

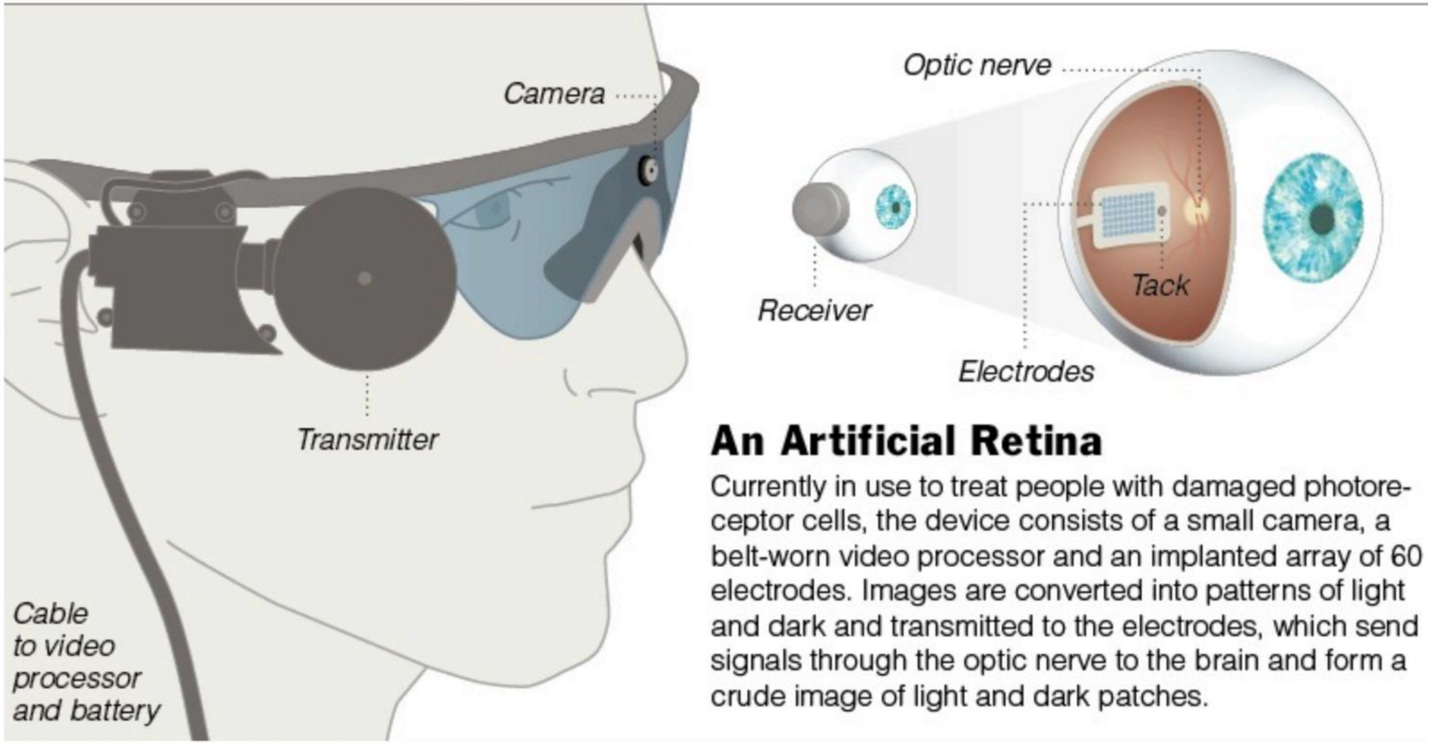
In today’s lecture, we’ll see how the brain builds on this early visual processing. But first ….

… now that you know how the early visual system works,

here’s a little update on futuristic technology:

NYTimes Bionic Eye Video

Retinal Prostheses



https://www.nytimes.com/2013/02/15/health/fda-approves-technology-to-give-limited-vision-to-blind-people.html

shows patterns of light and dark, like the "pixelized" image we see on a stadium scoreboard

- 60 electrodes, covering 11° × 19°
- each 'pixel' covers about 2°
- version with 1500 1/4° electrodes in clinical trials

Motivation

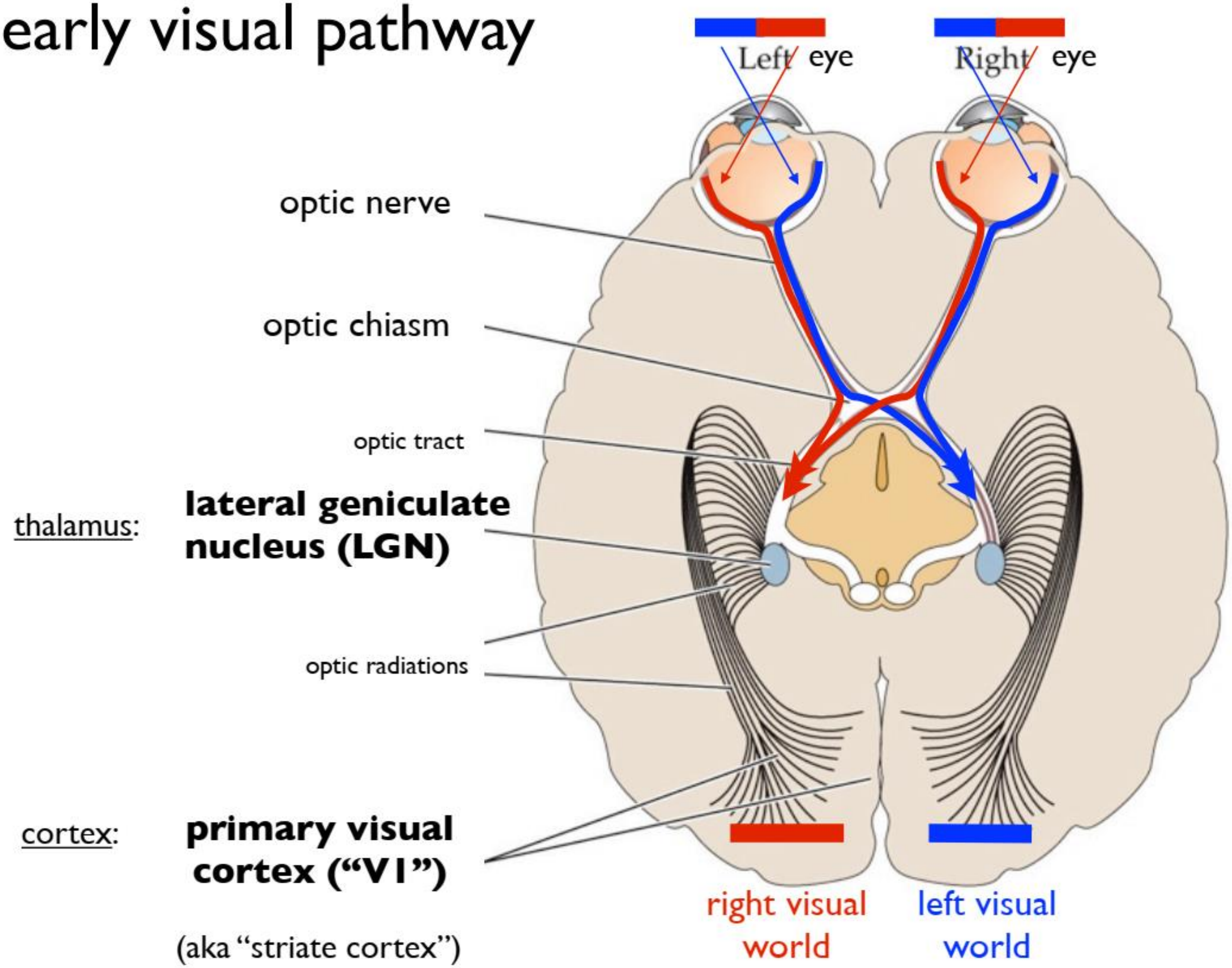
So far we've learned

- How the eye (like a camera) forms an image
- How the retina processes that image to extract local luminance differences (contrast) using "center-surround" receptive fields

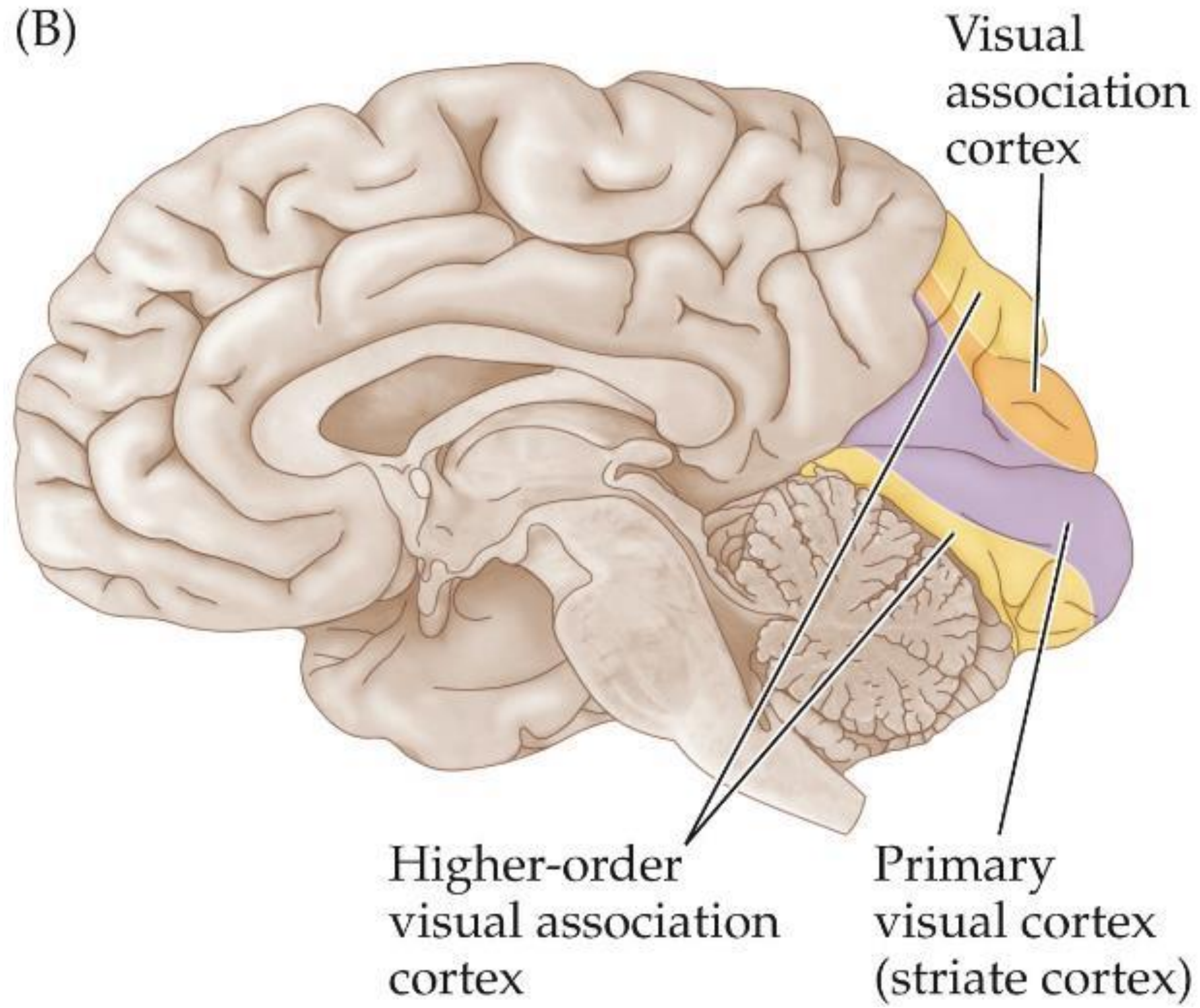
Next:

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

early visual pathway



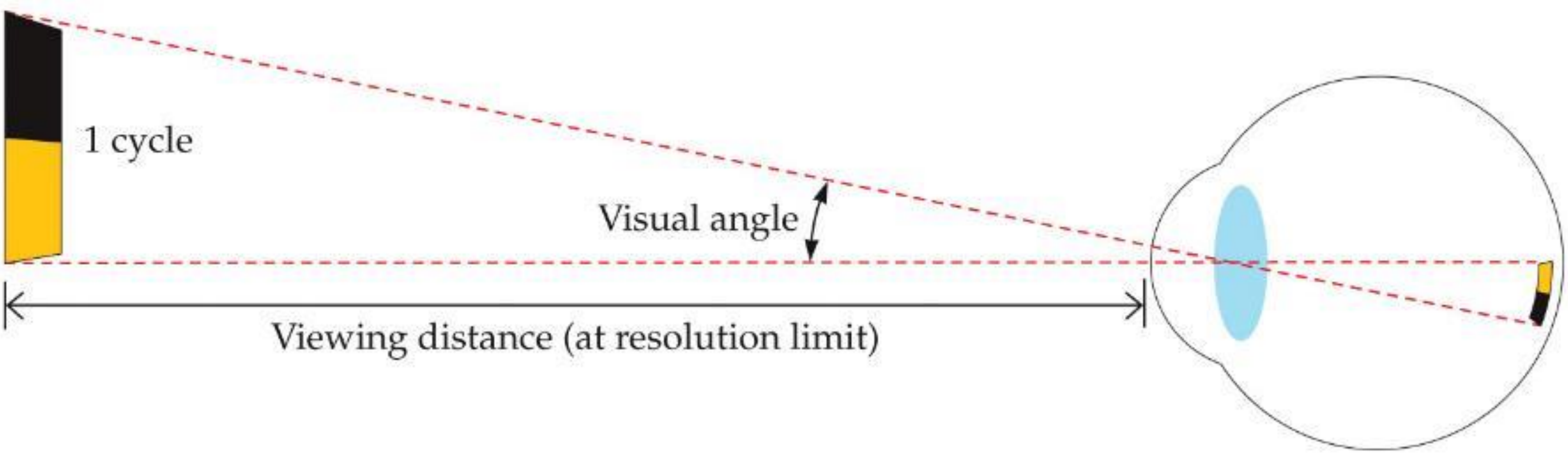
Cortical Visual Pathways



Visual Acuity

- Visual **acuity** is a measure of the finest visual detail that can be resolved
- There are several different types of acuity that can be measured. The most common is **resolution acuity**, which is typically measured in one of two ways:
  - Grating acuity: used by vision researchers
  - Snellen acuity: used by optometrists and ophthalmologists (eye doctors)

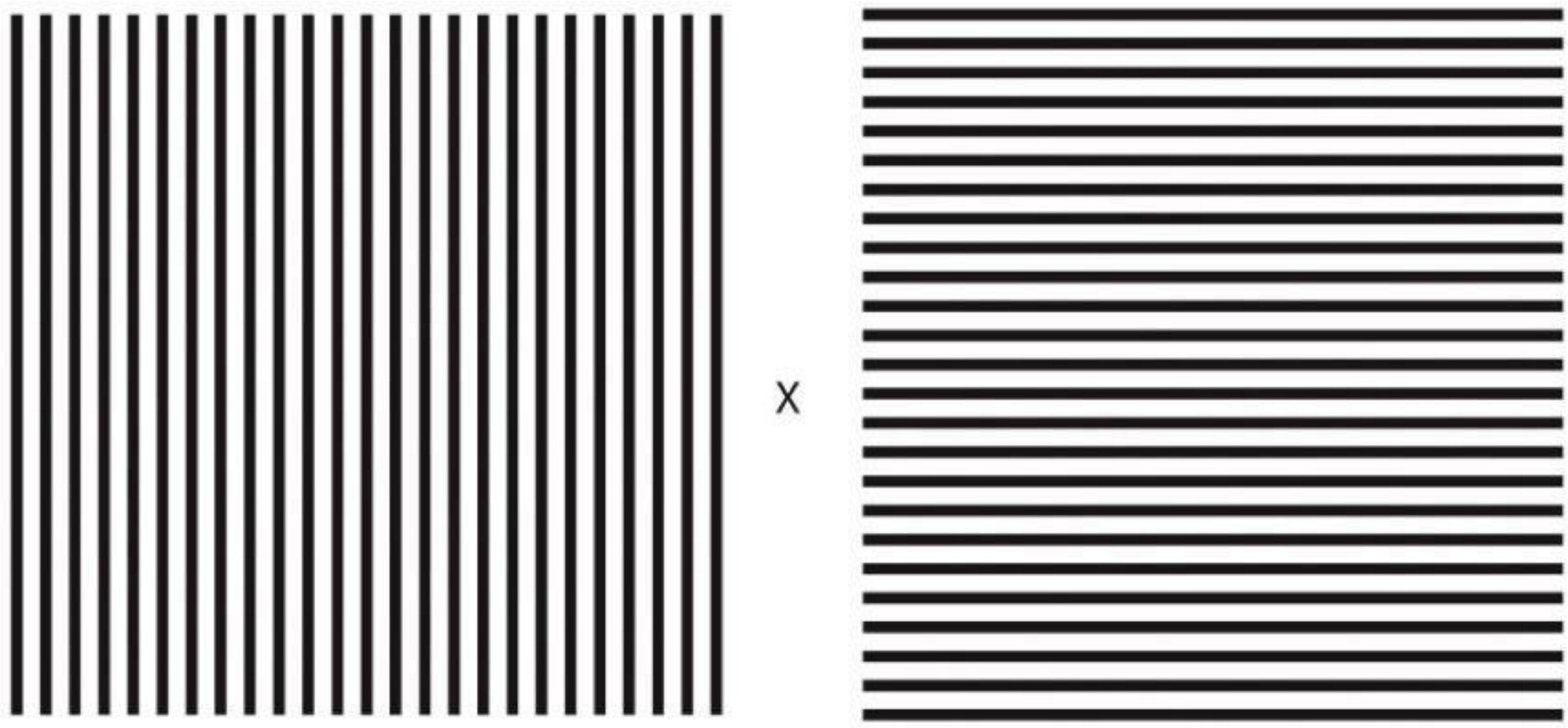
Resolution Acuity



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

Vision scientist: visual angle of once cycle of the finest grating that you can see

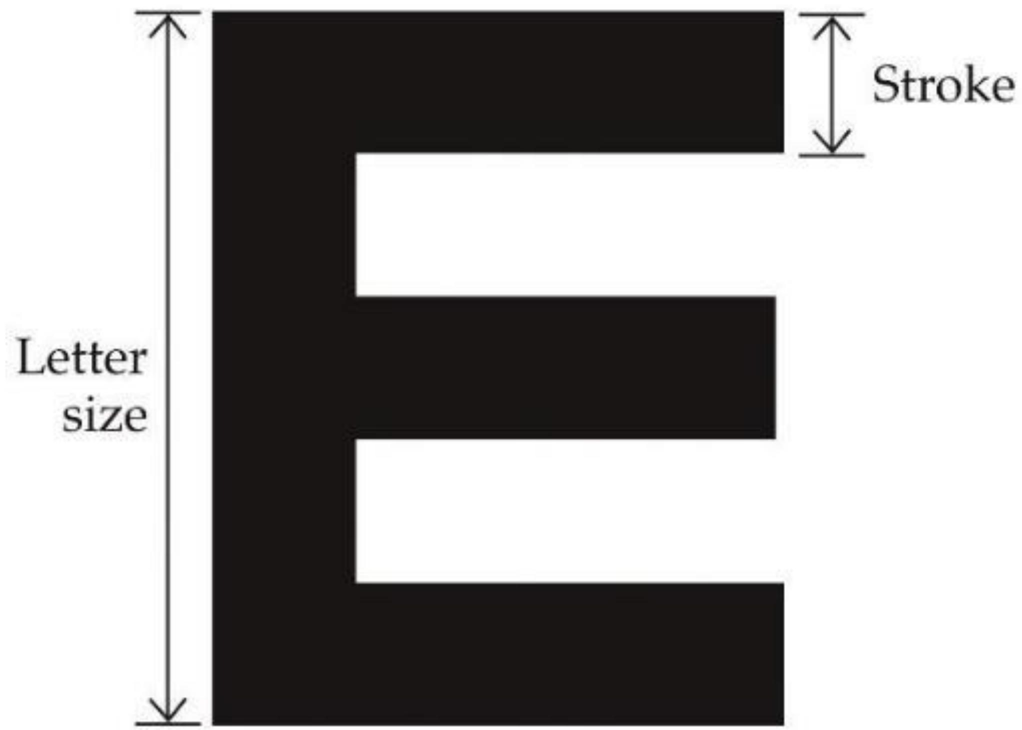
Grating Acuity (in the lab)



observers with good vision can resolve about 60 cyc/°

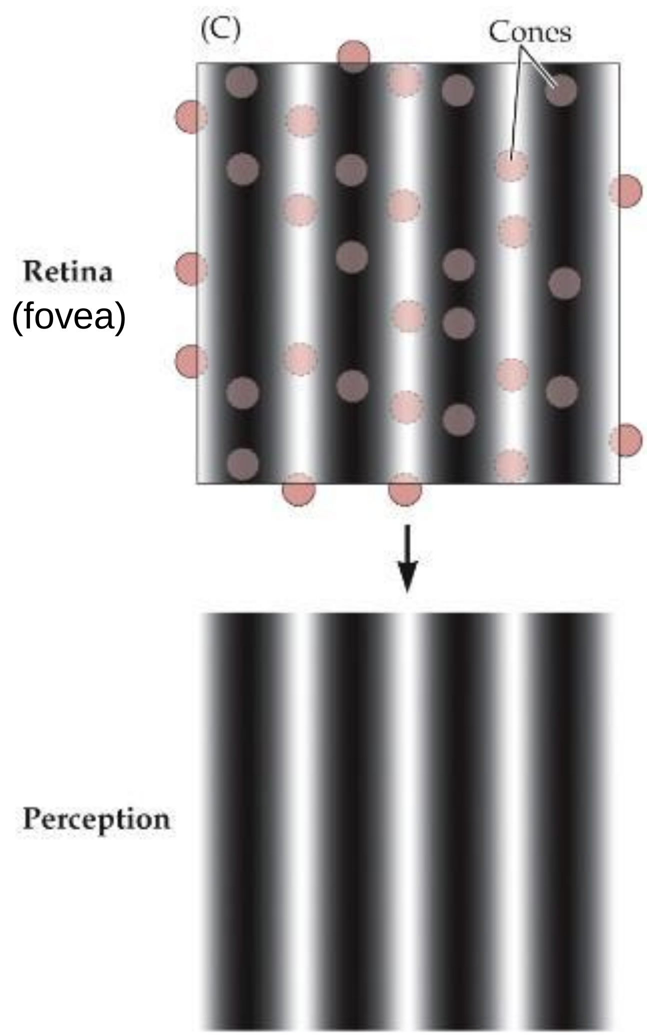
Snellen Acuity

- Heman Snellen invented this method in 1862
- Note that the strokes of the E form a small grating pattern
- At 20/20 the letters are designed to subtend 5 arcmin, while individual strokes subtend 1 arcmin
  - 1 arcmin = 1/60°
- Viewed in this way, 20/20 corresponds to about 2 arcmin (30 cyc/°)



Explaining Acuity

- Striped pattern is a sine-wave grating
- Visual system samples the grating at cone locations



acuity limit: 1 arcmin

cone spacing (in fovea): 0.5 arcmin

- relationship expected based on **Nyquist limit**

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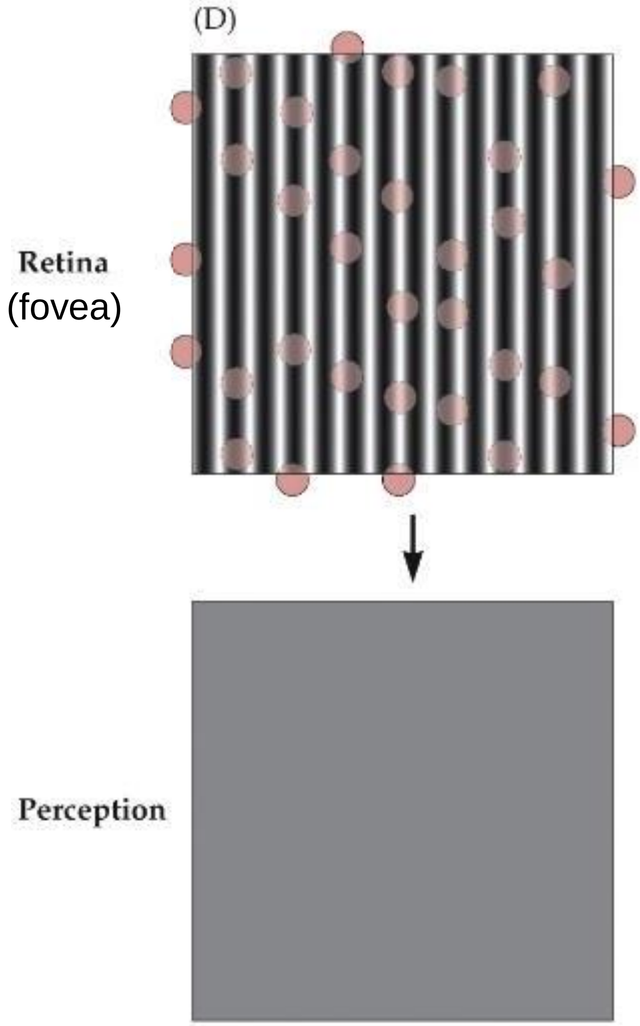


acuity limit: 1 arcmin

cone spacing (in fovea): 0.5 arcmin

- relationship expected based on **Nyquist limit**

Other Types/Measures of Acuity

Table 3.1

Summary of the different forms of acuity and their limits

Type of acuity	Measured	Acuity (degree)
Minimum visible	Detection of a feature	0.00014
Minimum resolvable	Resolution of two features	0.017
Minimum recognizable	Identification of a feature	0.017
Minimum discriminable	Discrimination of a change in a feature	0.00024

Spatial Frequency Channels

Spatial frequency: the number of cycles of a grating per unit of visual angle

low frequency

medium frequency

high frequency

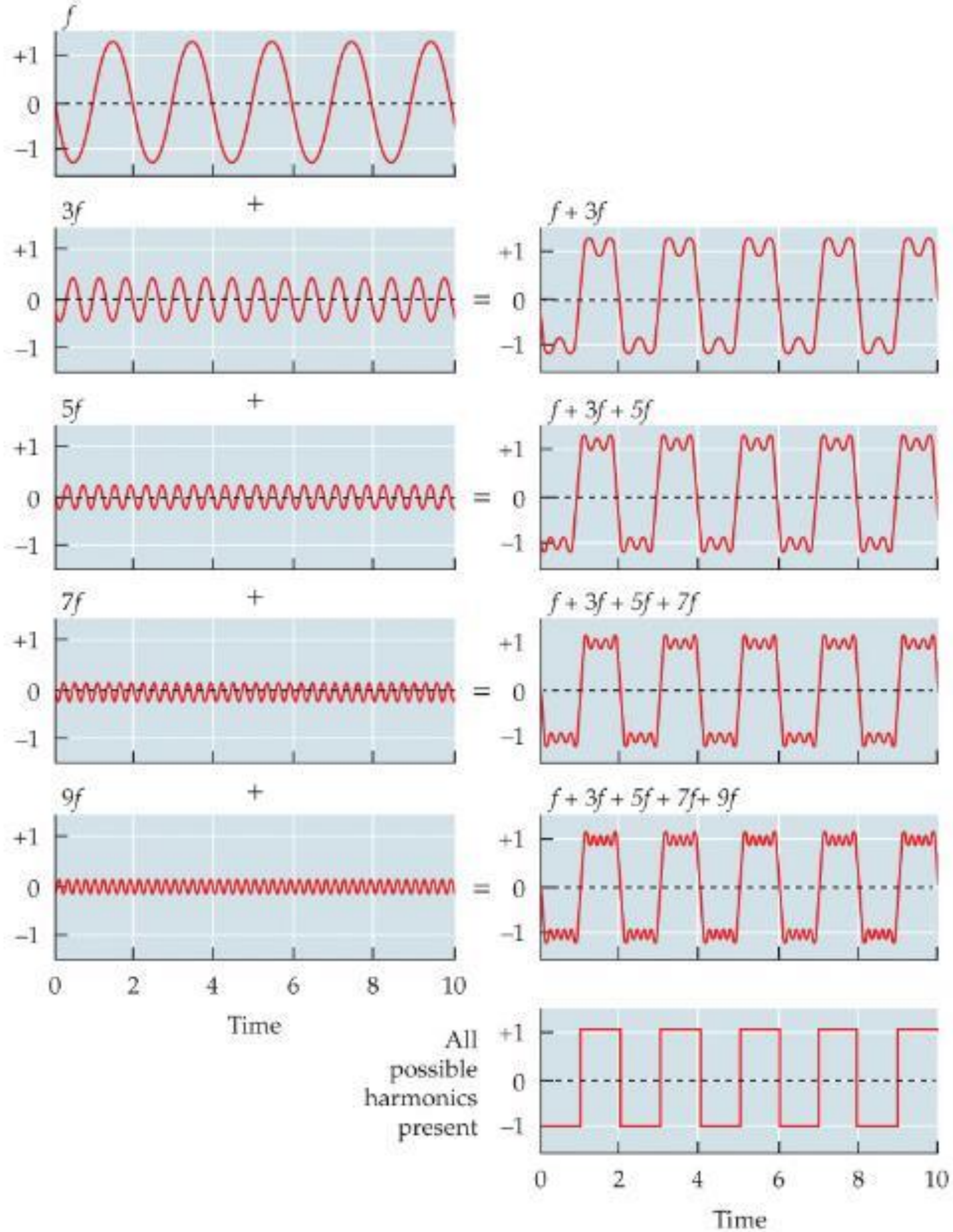
Visual Acuity

Why sine-wave gratings?

- The visual system breaks down images into a vast number of components, each of which is a (localized) sine wave with a particular spatial frequency
  - The early visual system can be seen as a kind of frequency analyzer
  - Technically, this is called **Fourier decomposition (**or **Fourier analysis**)

Fourier Decomposition

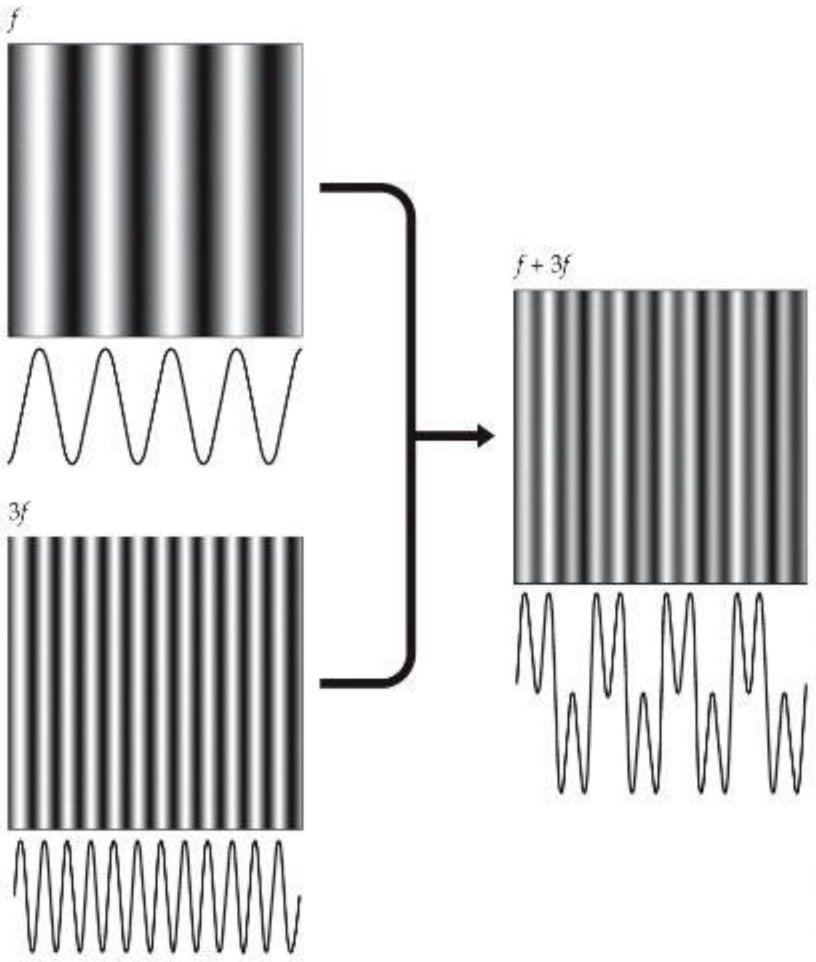
- Mathematical decomposition of signal (e.g., image or sound) into a weighted sum of sine waves
- **Fourier transform** is representation of the signal in terms of these weights


f
+1
0
–1
3f
+
f + 3f
=
5f
f + 3f + 5f
7f
f + 3f + 5f + 7f
9f
f + 3f + 5f + 7f+ 9f
0
2
4
6
8
10
Time
All possible harmonics present
Time

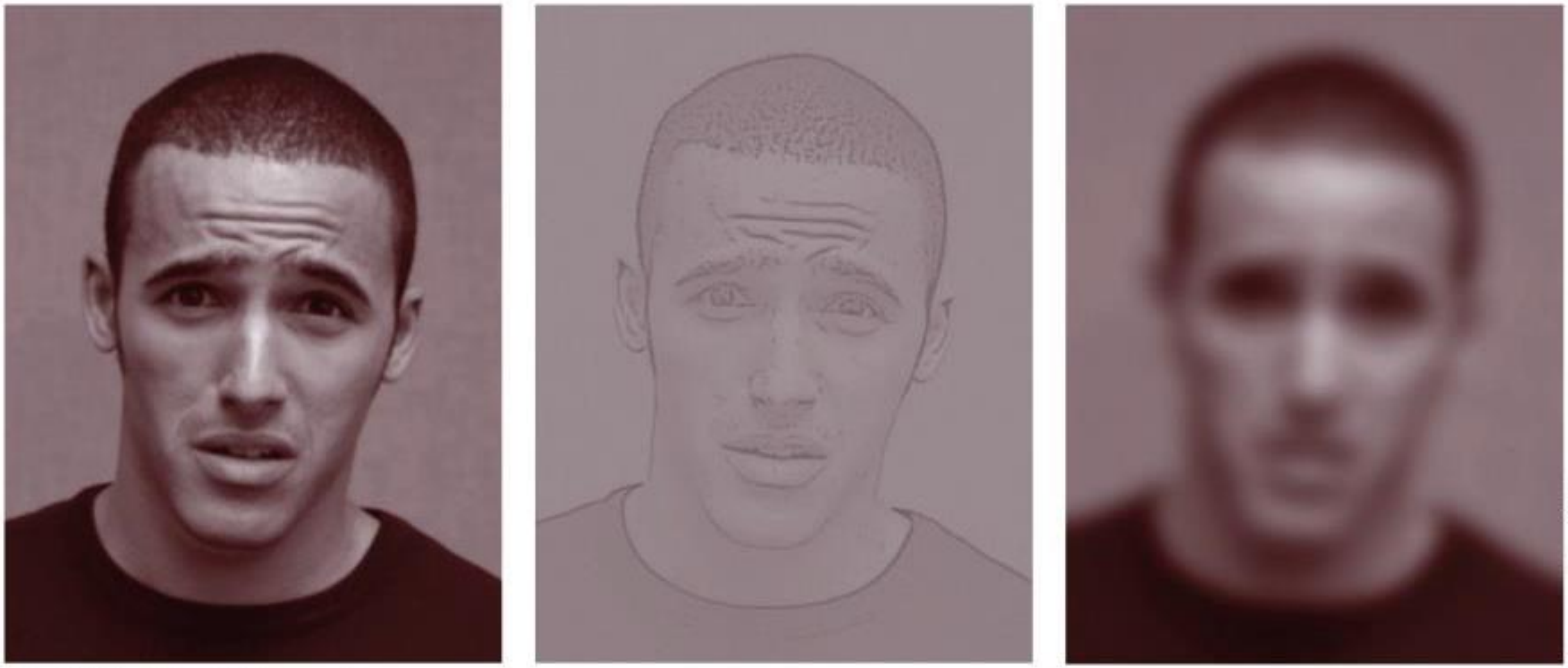
Fourier Decomposition Theory of V1

- Claim: role of V1 is to break down images into their spatial frequency components

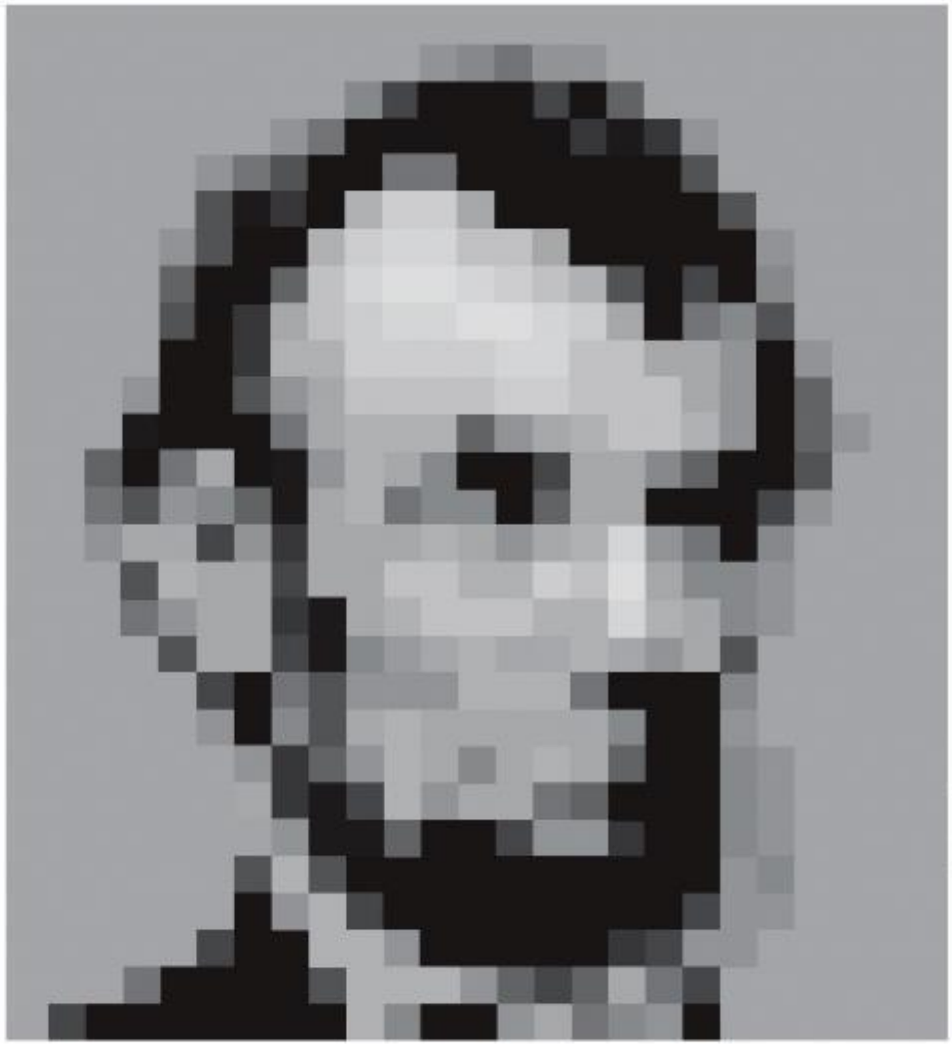
- Summation of two *spatial* sine waves
- *Any* pattern can be broken down into a sum of sine waves



Fourier Decomposition

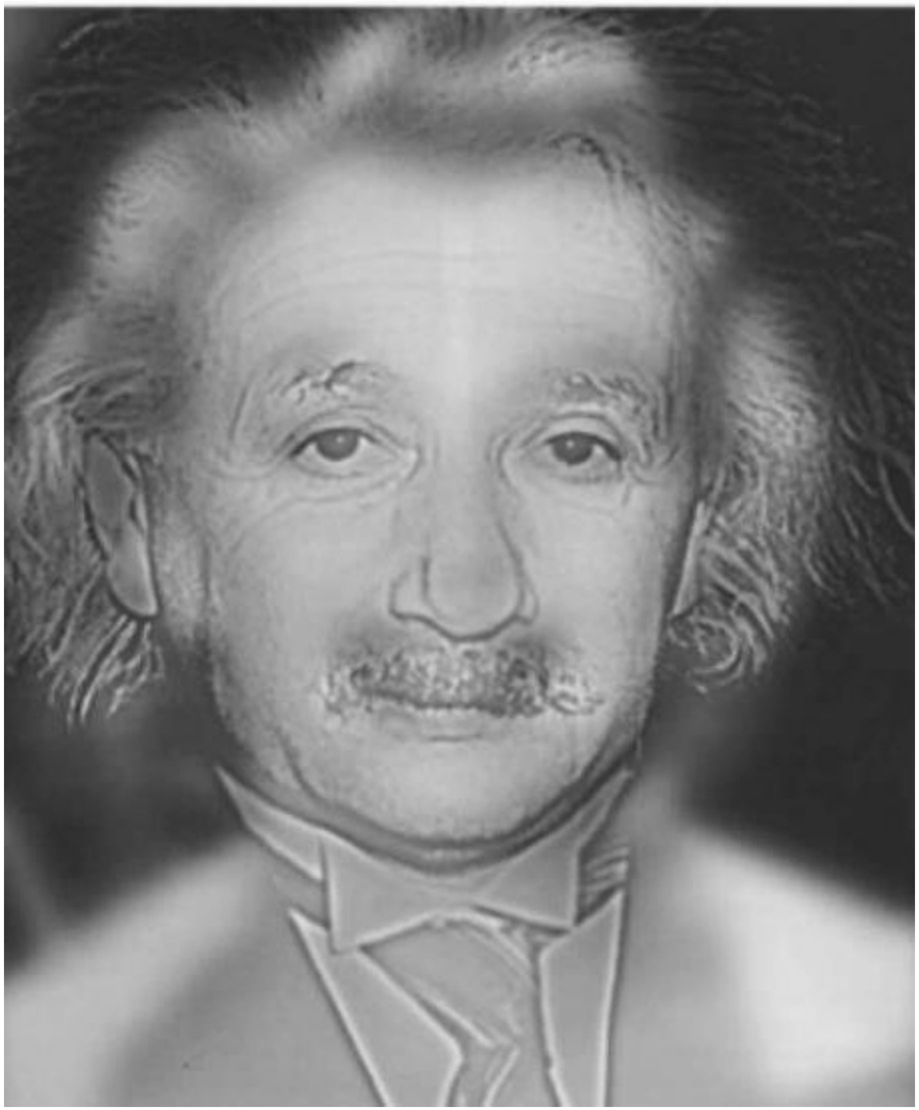


original image high frequencies low frequencies



From Harmon and Julesz (1973) *Science* 180: 1194–1197.

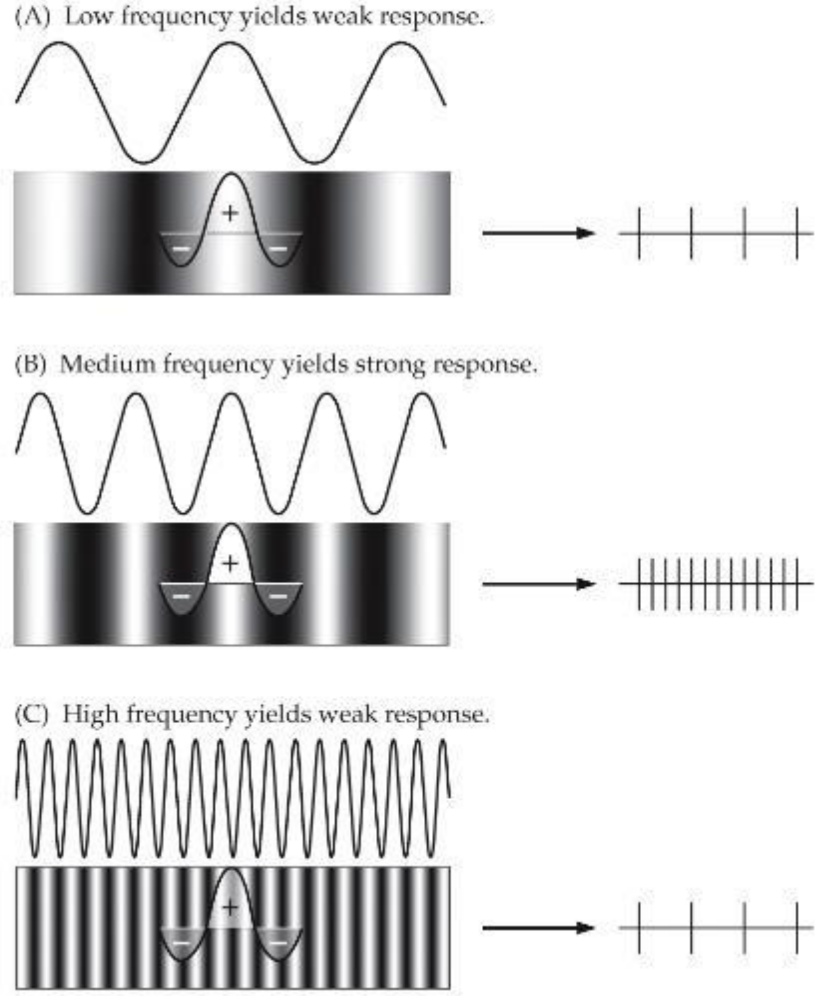
Who is this?



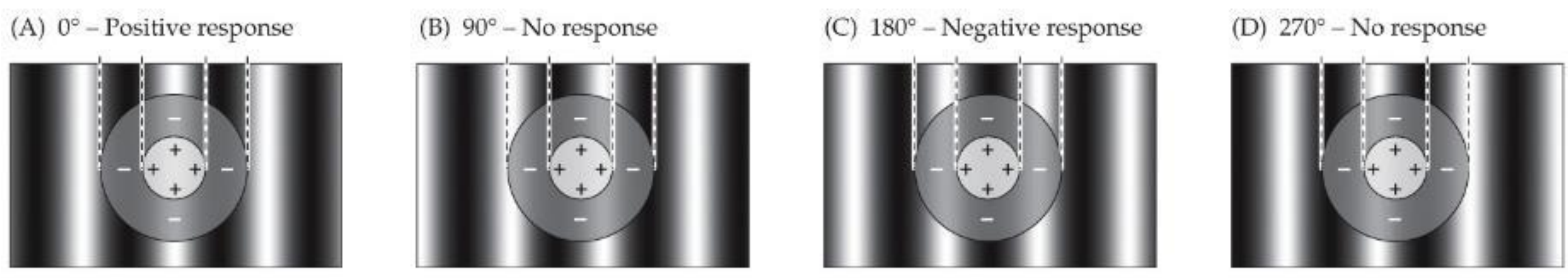
How about now?

Retinal Ganglion Cells: tuned to spatial frequency

Response of a ganglion cell to sine-wave gratings of different frequencies

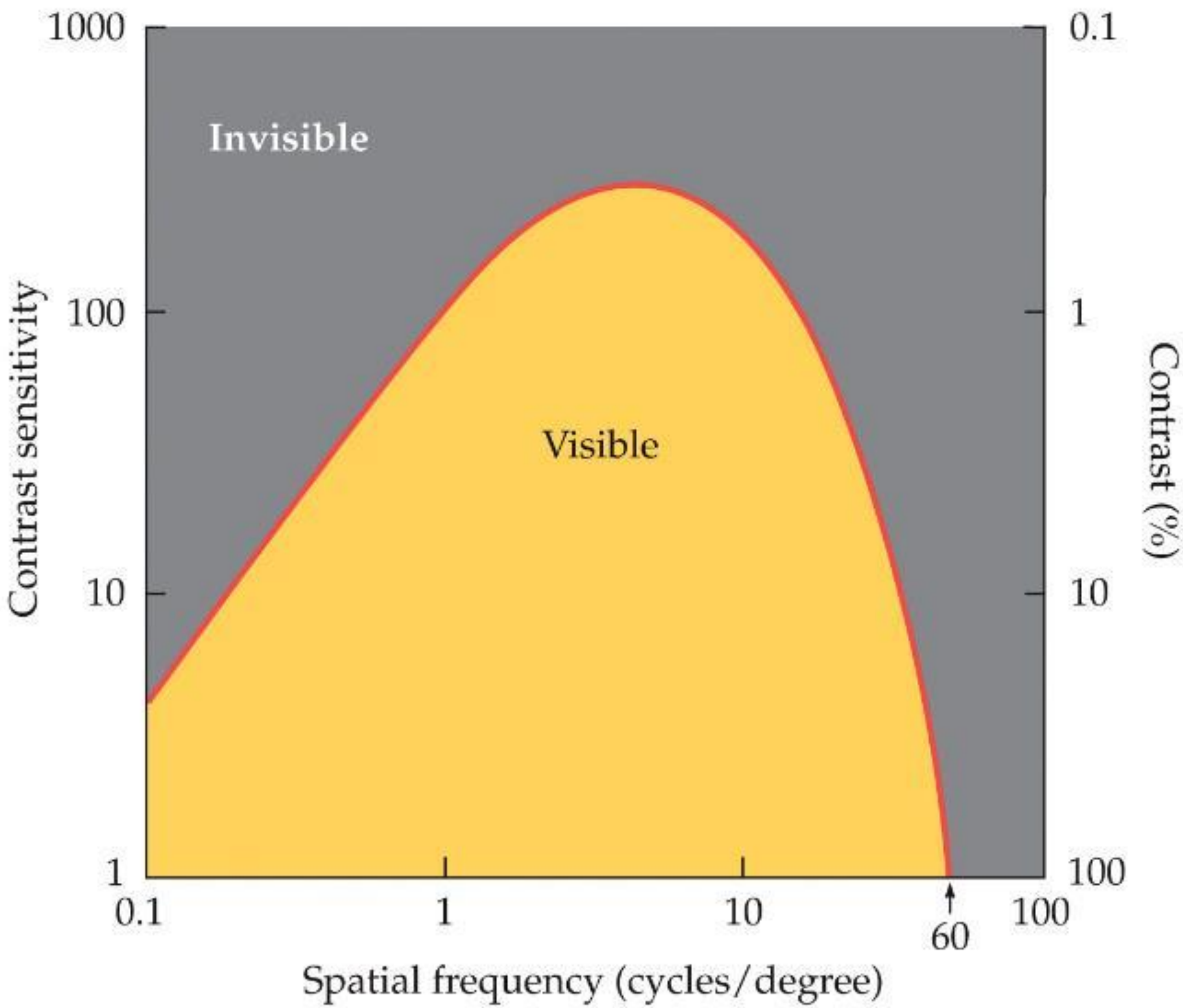


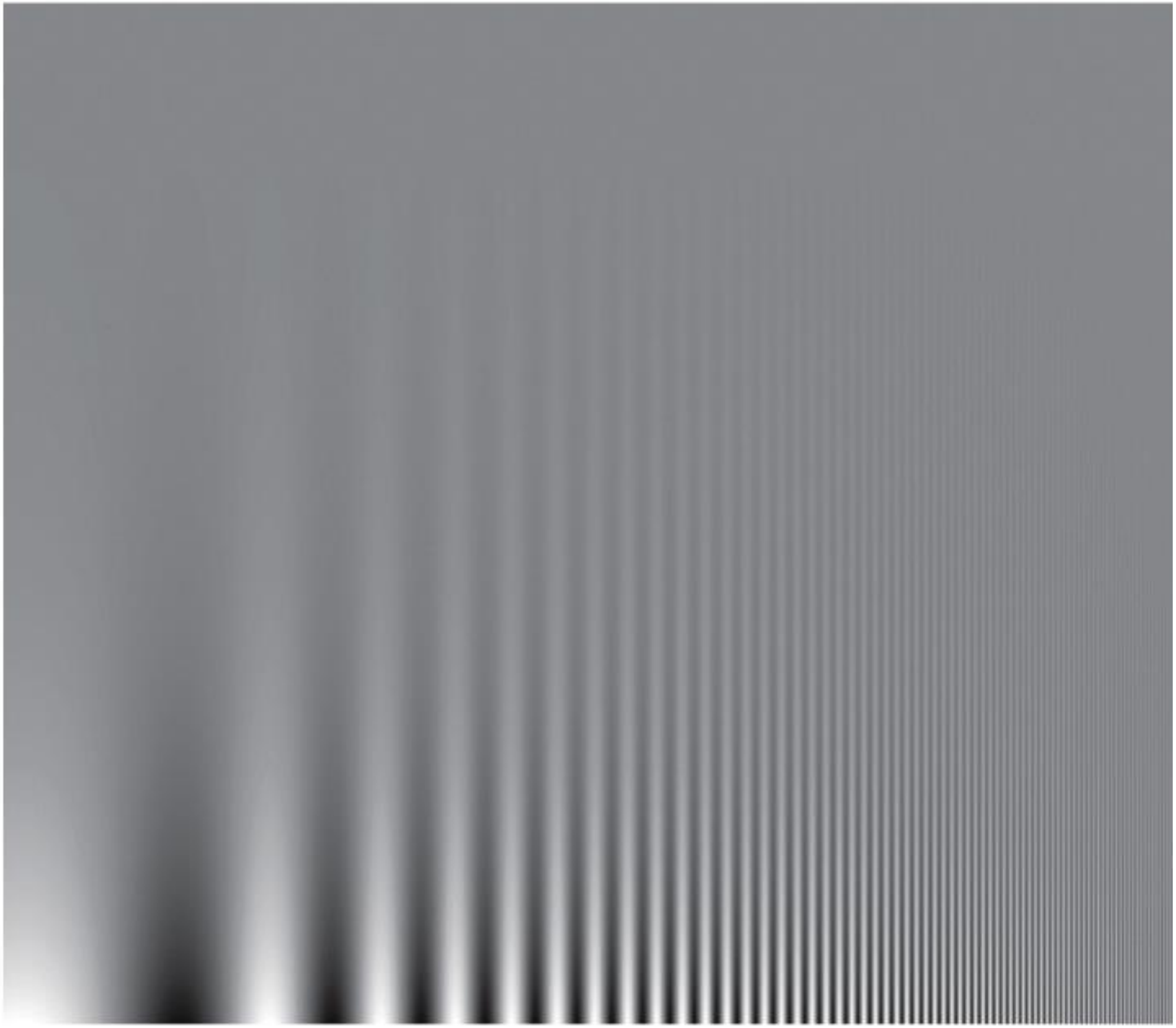
Response of a ganglion cell to sine-wave gratings of different **phases**



phase: the position of a sinusoid or grating (e.g., with respect to the center of a receptive field)

The Contrast Sensitivity Function (CSF)

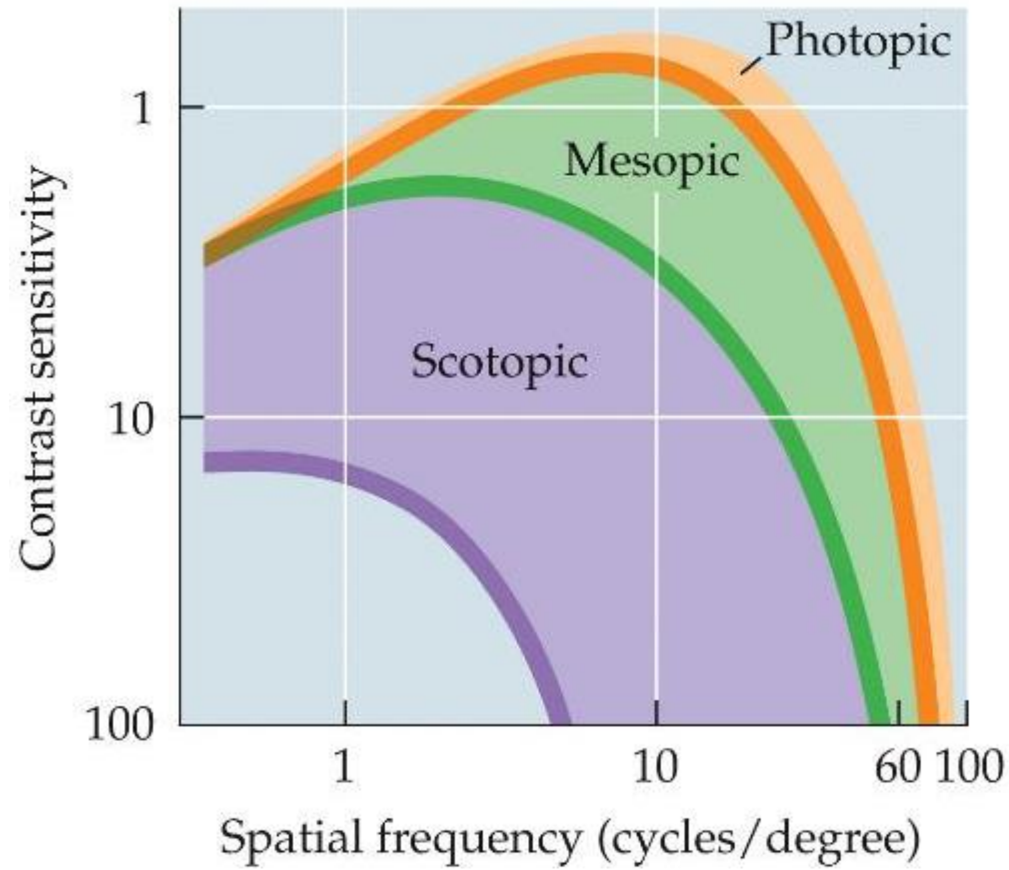




The Contrast Sensitivity Function (CSF)

Varies as a function of:

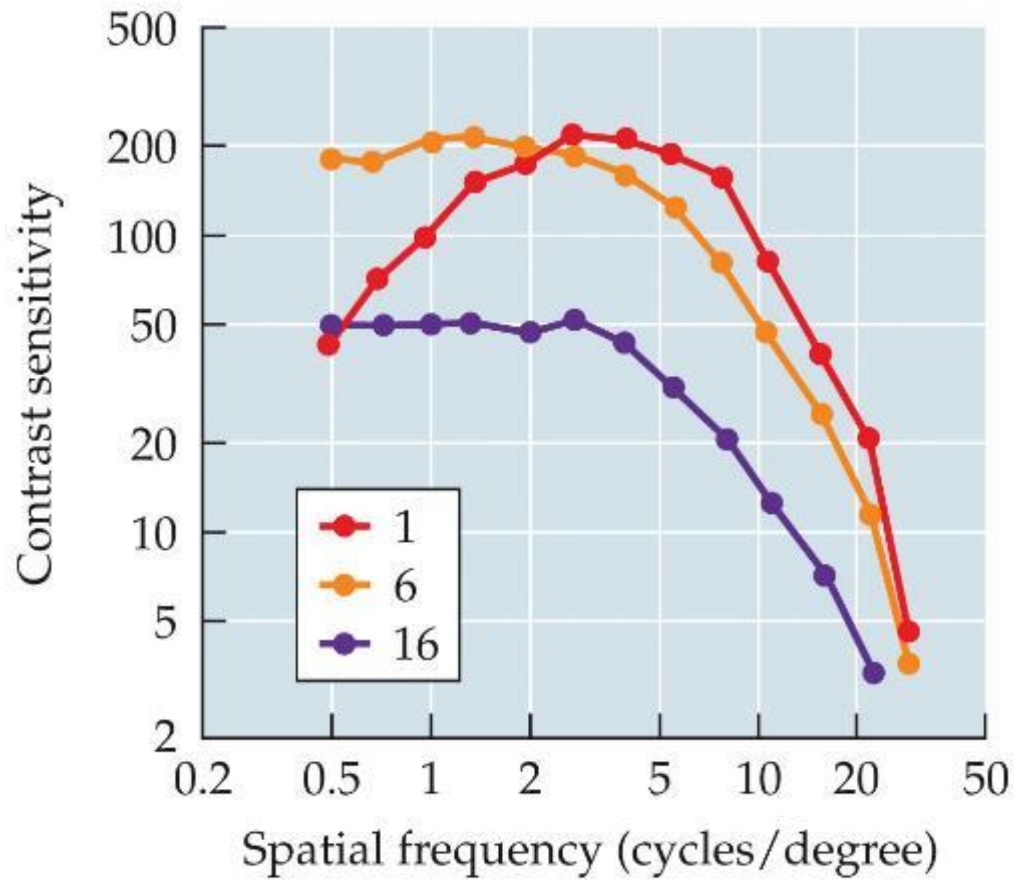
- dark/light adaptation level

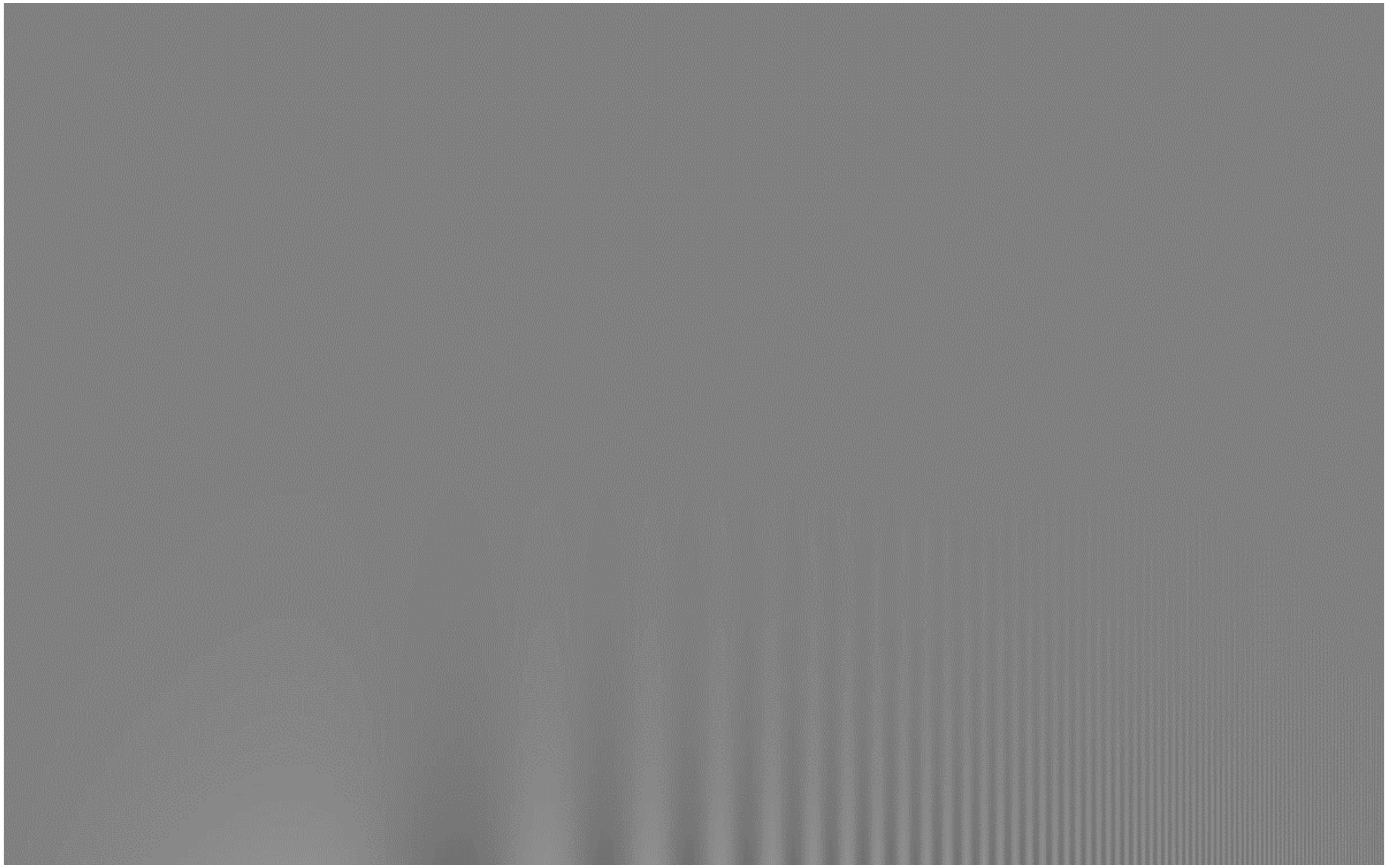


The Contrast Sensitivity Function (CSF)

Varies as a function of:

- dark/light adaptation level
- temporal frequency (flicker)

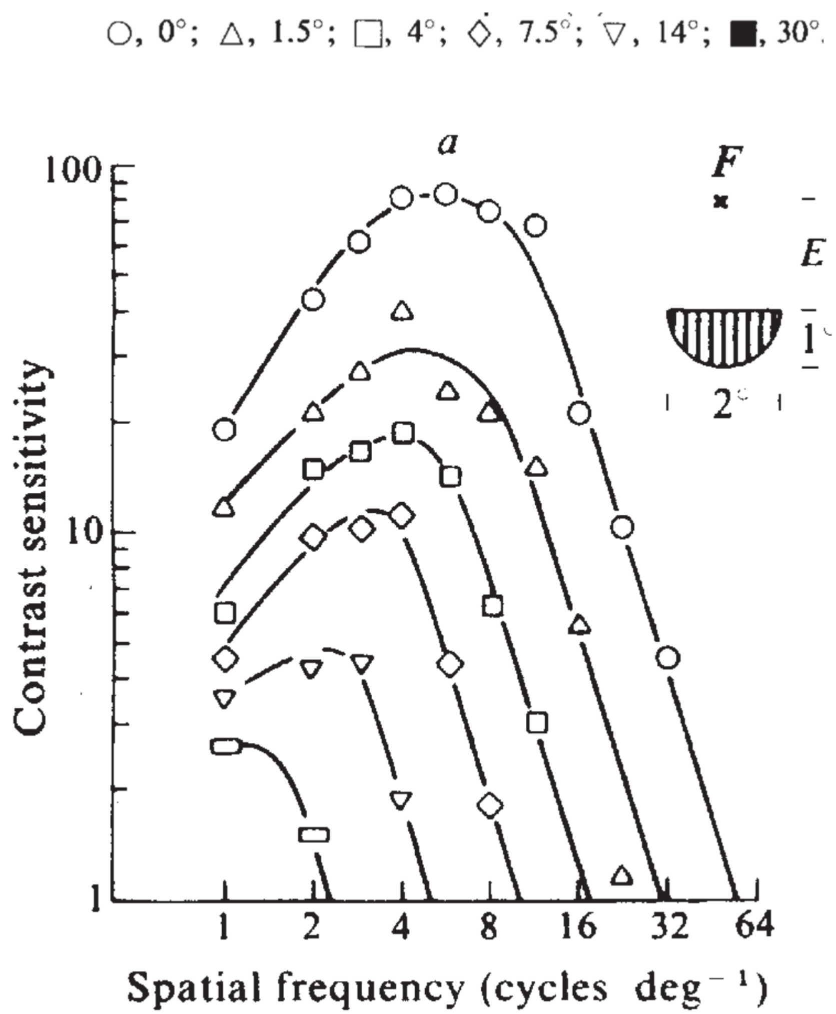




The Contrast Sensitivity Function (CSF)

Varies as a function of:

- dark/light adaptation level
- temporal frequency (flicker)
- retinal position (**eccentricity**)
  - i.e., how far in periphery?



The Contrast Sensitivity Function (CSF)

Varies as a function of:

- dark/light adaptation level
- temporal frequency (flicker)
- retinal position (**eccentricity**)
  - i.e., how far in periphery?
- age
- orientation of grating