2018-01-29 The retinal image

PSY 525.001 • Vision Science • 2018 Spring

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2018-01-26 14:58:18

Today's topics

Today's topics

The retinal image

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The retinal image

Discuss Fourier analysis, esp. Campbell & Robson 1968.

The retinal image

Human retina

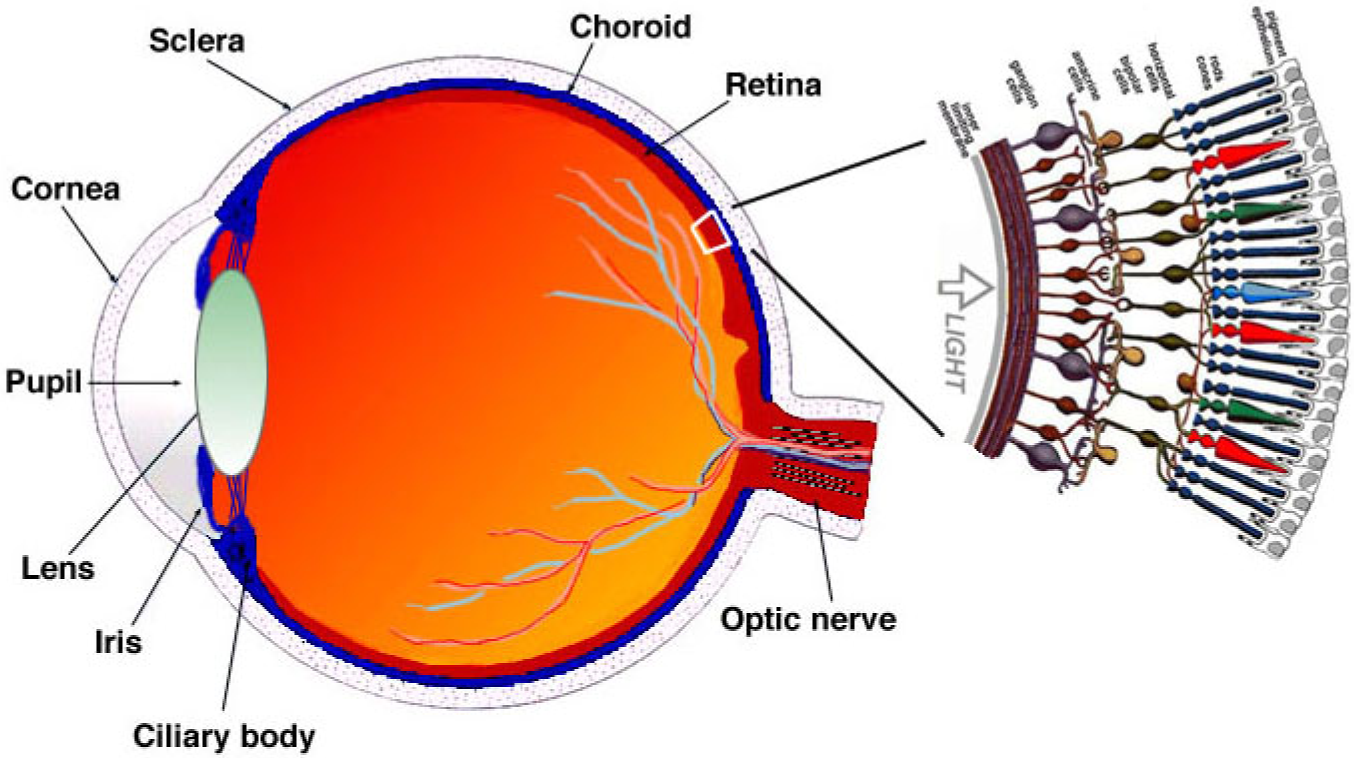


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

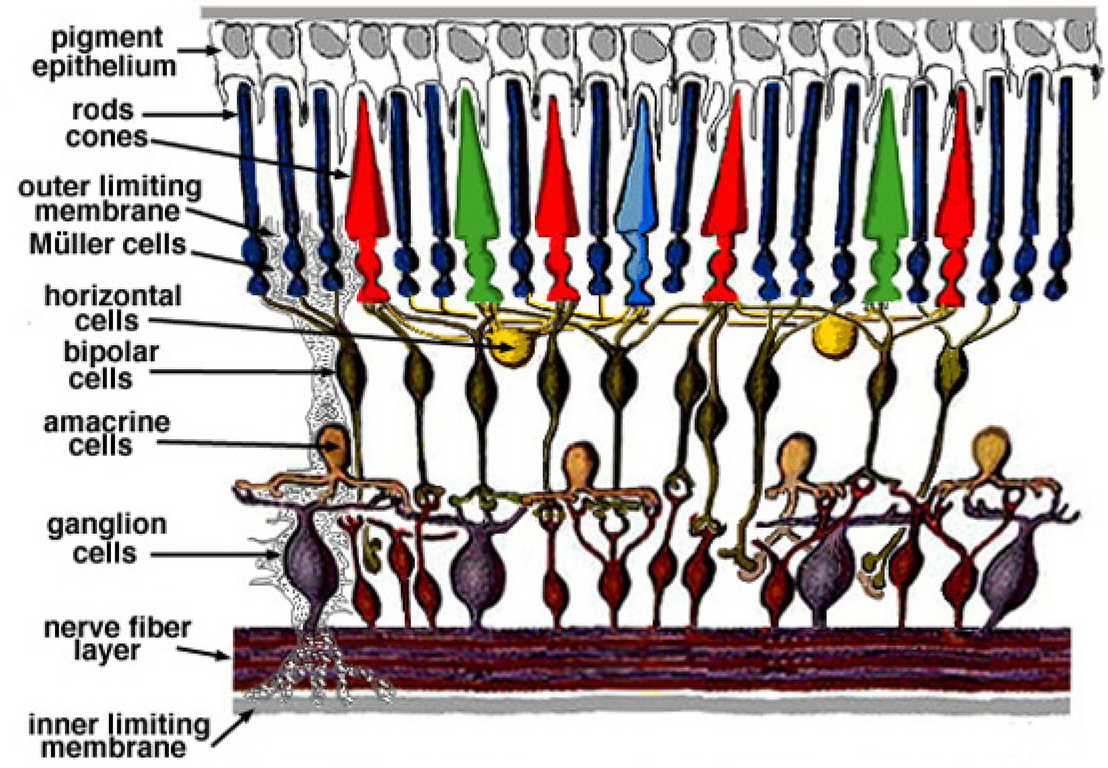


Fig. 2. Simple diagram of the organization of the retina.

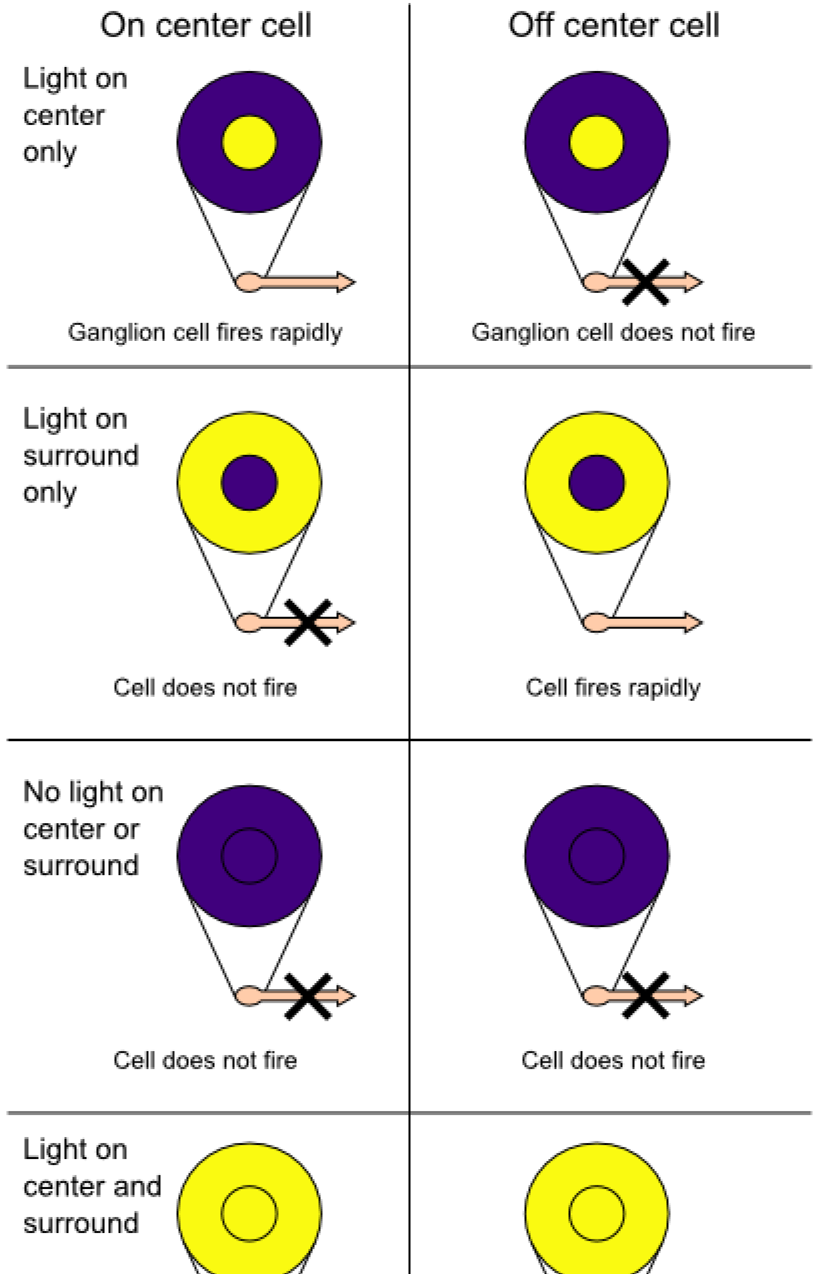
http://webvision.med.utah.edu/

Ganglion cell response properties differ across cells

Individual response function of stimulus location, size

On- and off-center cells

Receptive fields have *center-surround* structure, due to *lateral inhibition*


On center cell
Off center cell
Light on center only
Ganglion cell fires rapidly
Ganglion cell does not fire
Light on surround only
Cell does not fire
Cell fires rapidly
No light on center or surround
Cell does not fire
Cell does not fire
Light on center and surround

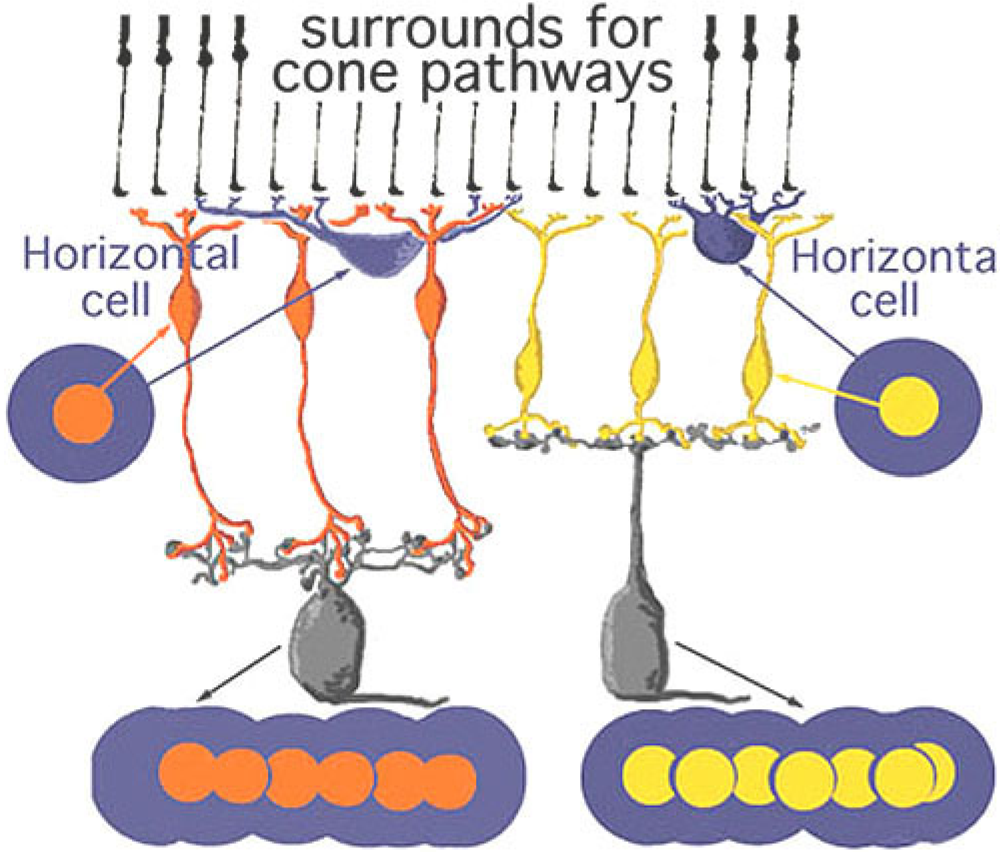
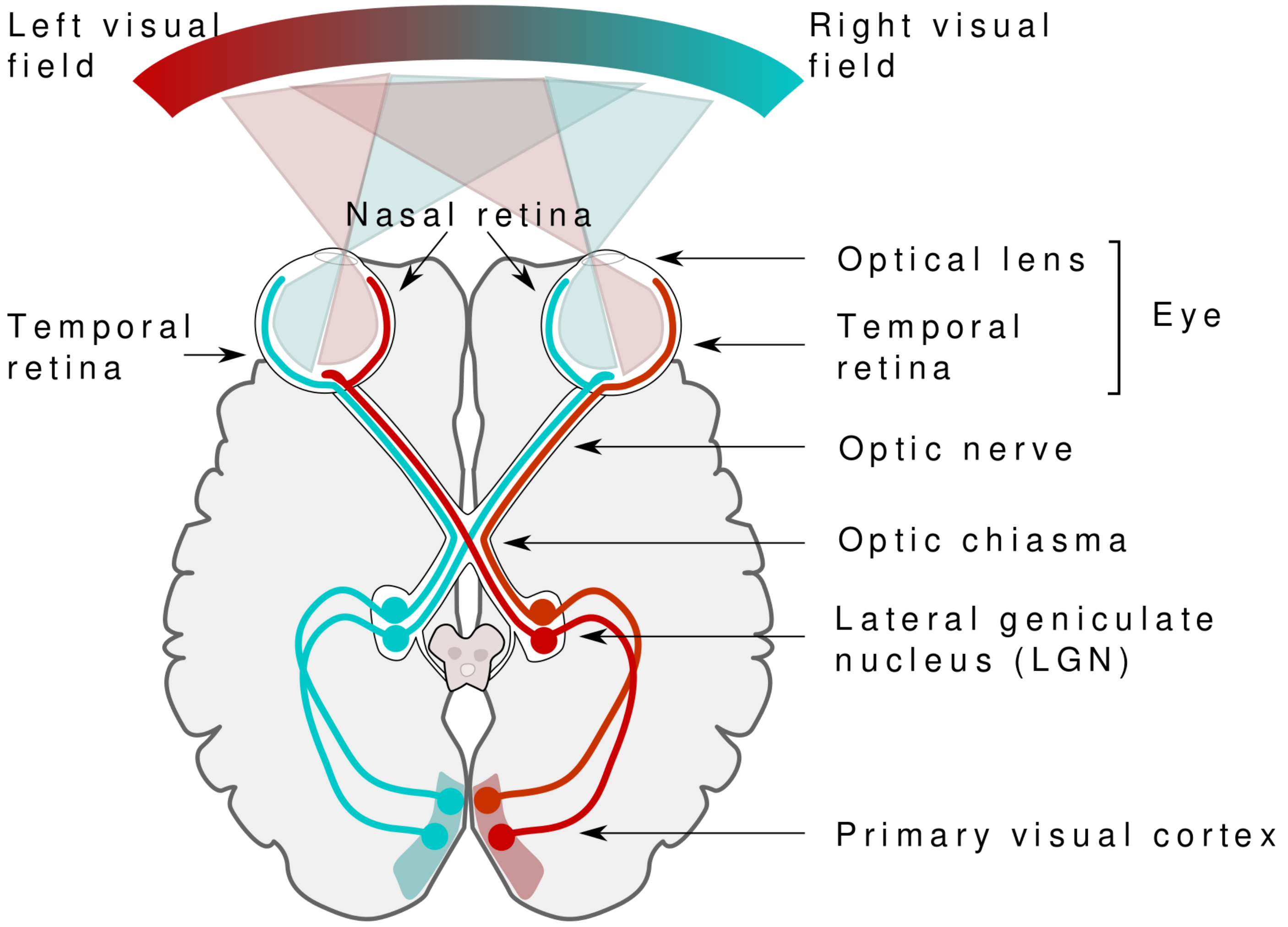
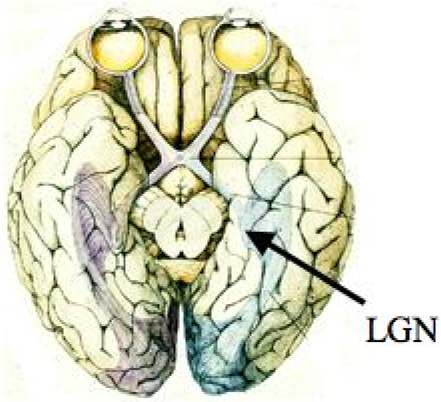


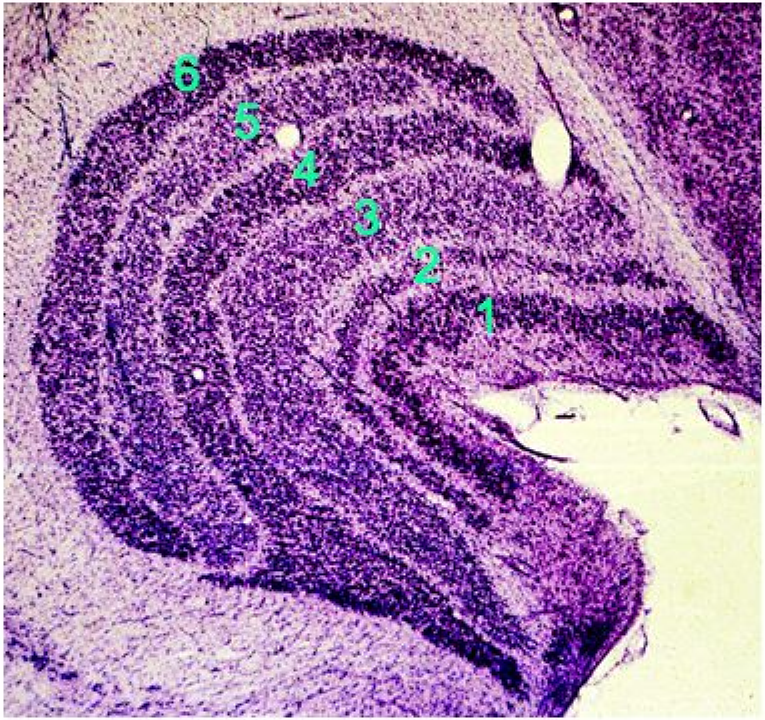
Fig. 12. Diagram of the organization of center-surround responses using horizontal cell circuitry to provide the antagonistic surround.

photoreceptors -> horizontal cells; photoreceptors + horizontal cells -> bipolar cells; bipolar cells -> amacrine + ganglion cells; bipolar + amacrine -> ganglion cells

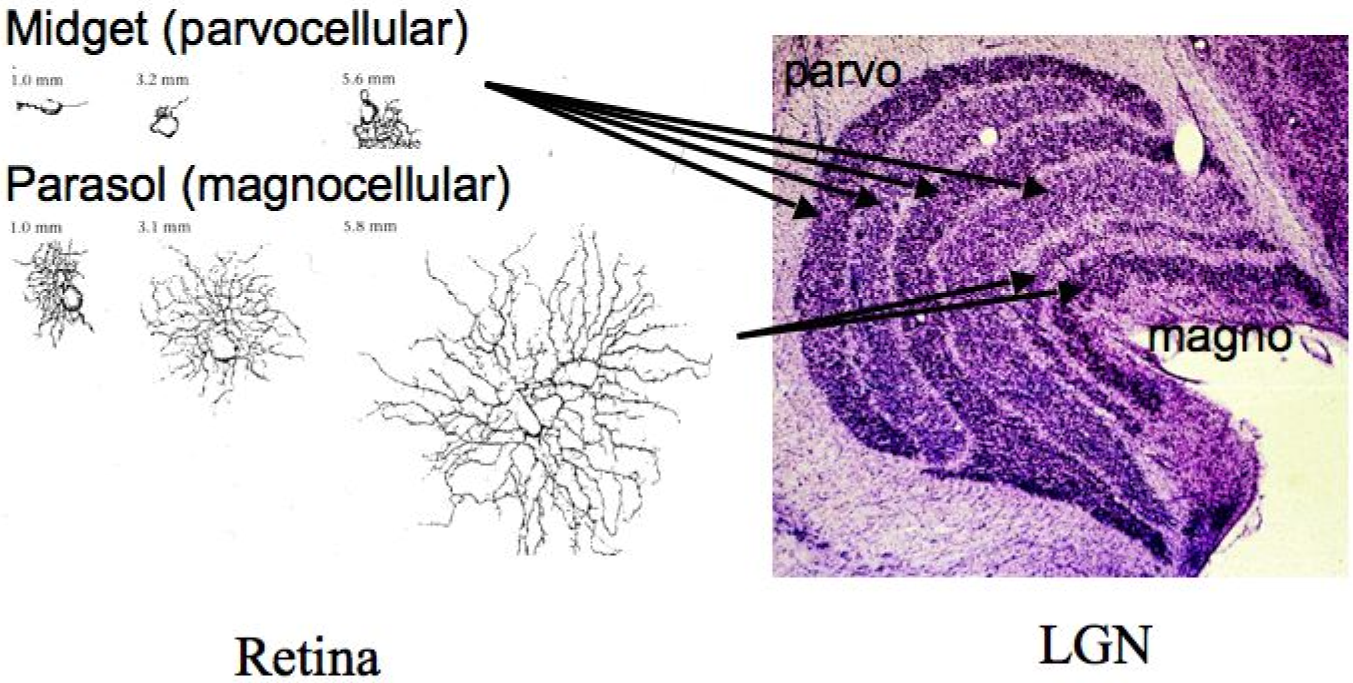

Left visual field
Right visual field
Nasal retina
Optical lens
Temporal retina
Eye
Temporal retina
Optic nerve
Optic chiasma
Lateral geniculate nucleus (LGN)
Primary visual cortex

Lateral Geniculate Nucleus (LGN)





Parallel pathways

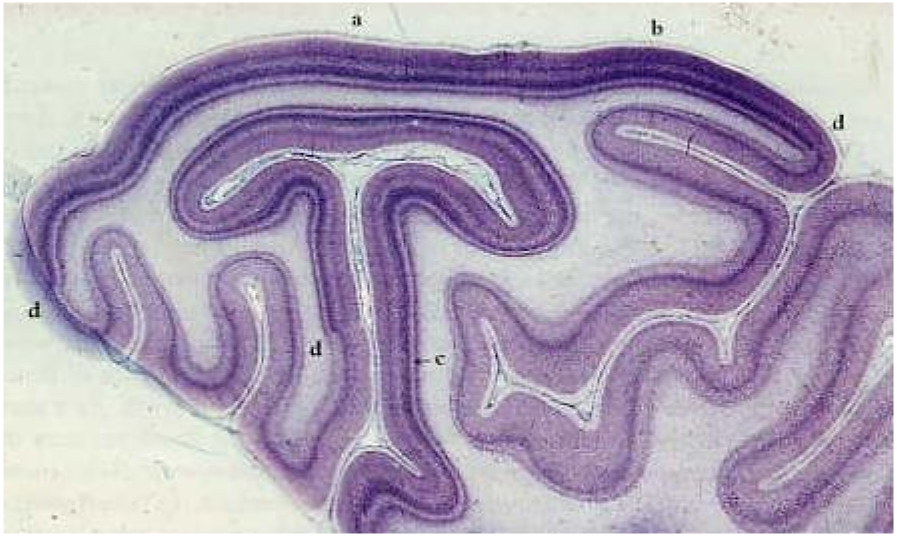


Magno vs. parvo LGN cells

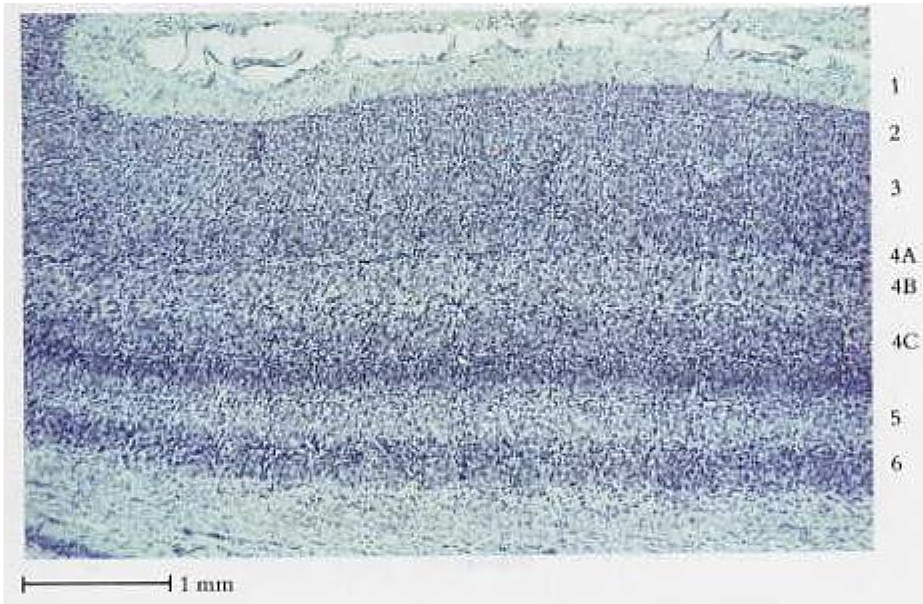
Characteristic	Parvo	Magno
Color sensitivity	High	Low
Contrast sensitivity	Low	High
Spatial resolution	High	Low
Temporal resolution	Slow	Fast
Receptive field size	Small	Large

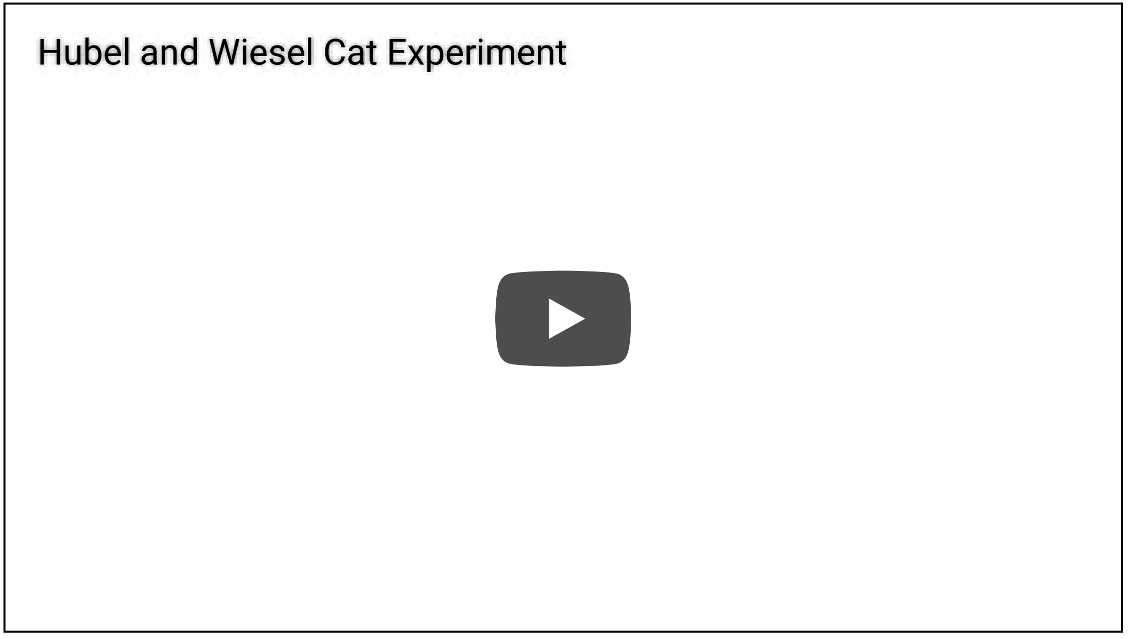
Palmer Table 4.1.1

Visual cortex



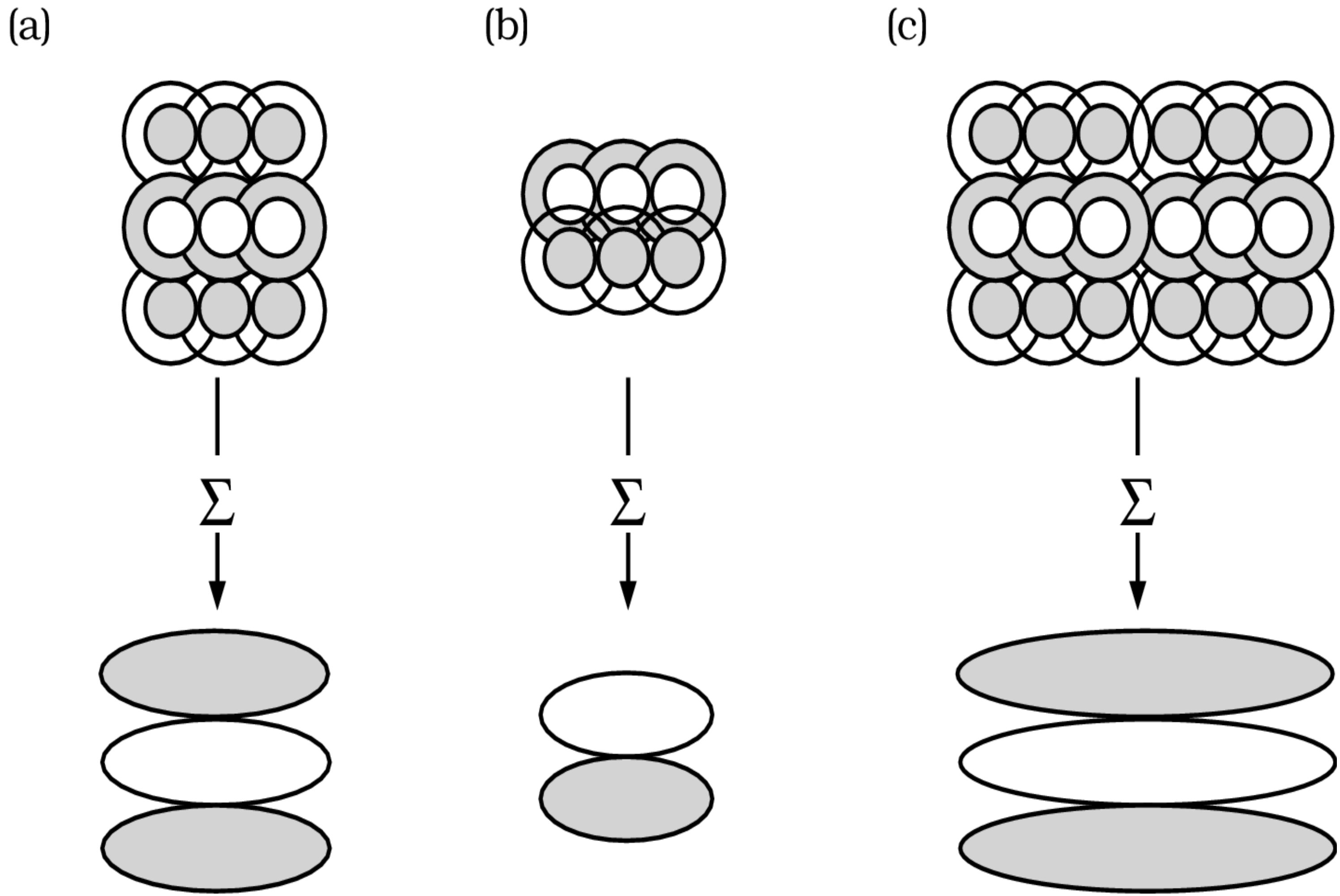
Striate cortex (stria of Gennari), V1, area 17


1
2
3
4A
4B
4C
5
6
1 mm


Hubel and Wiesel Cat Experiment

Center-surround cells rare

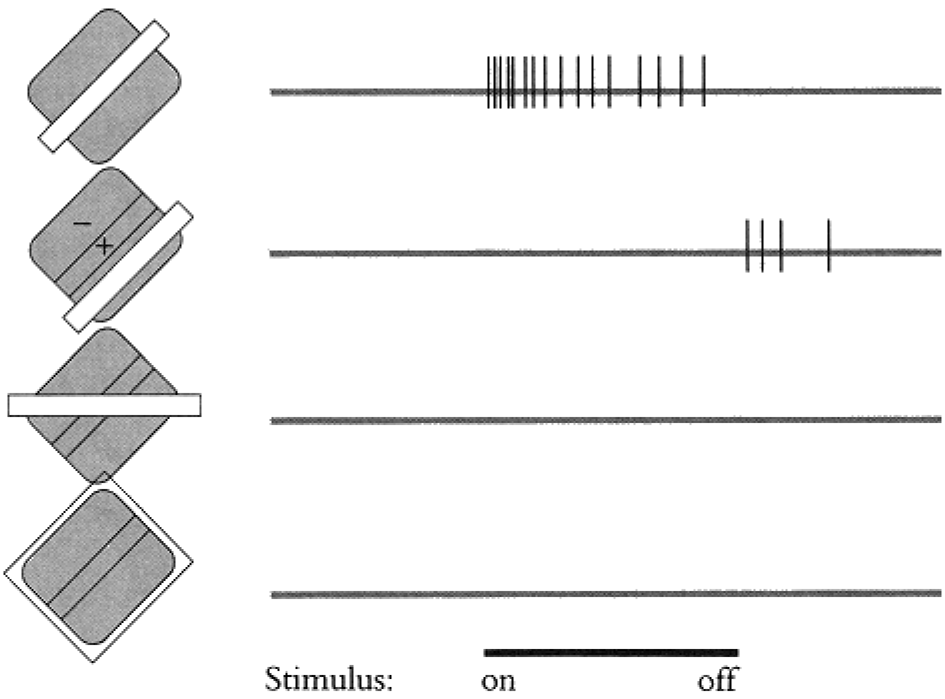
Simple cells, complex cells, & hypercomplex cells were elongated



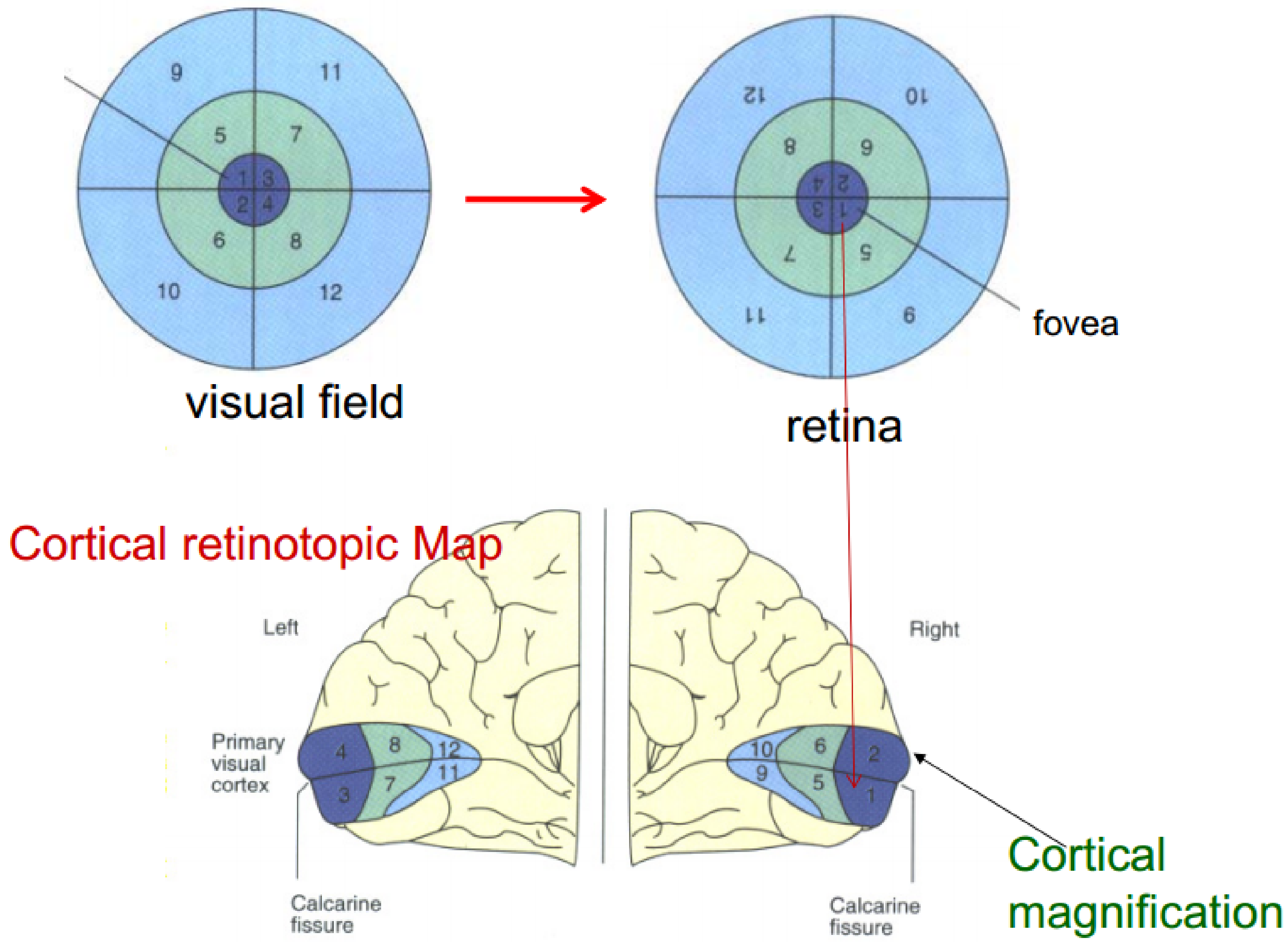
Simple cells

Orientation (angular) selectivity

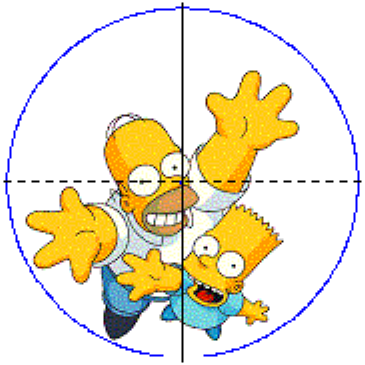
Complex cells nonlinear, motion sensitive, position invariance, spatially extended

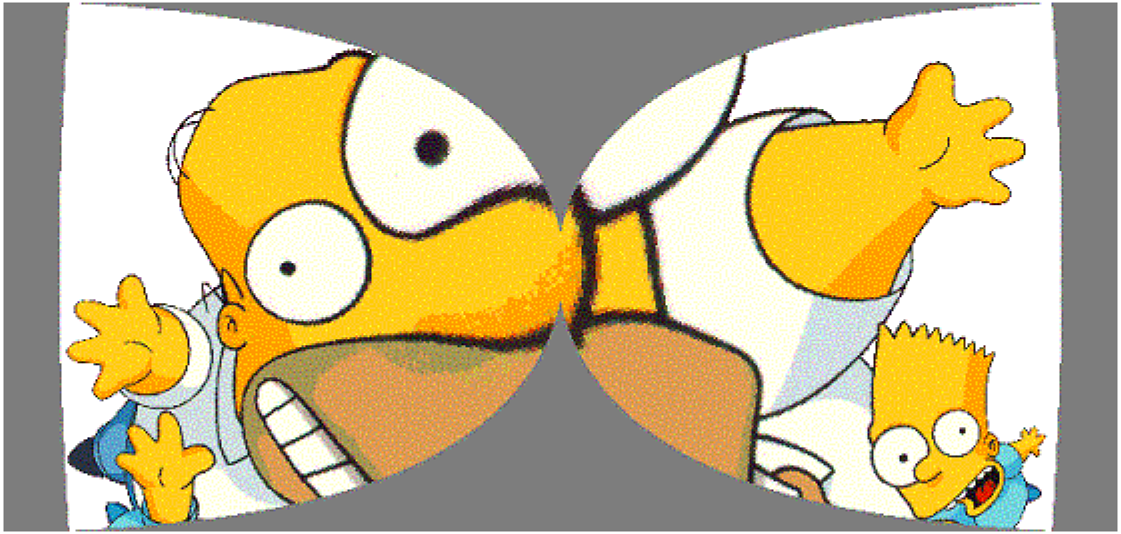


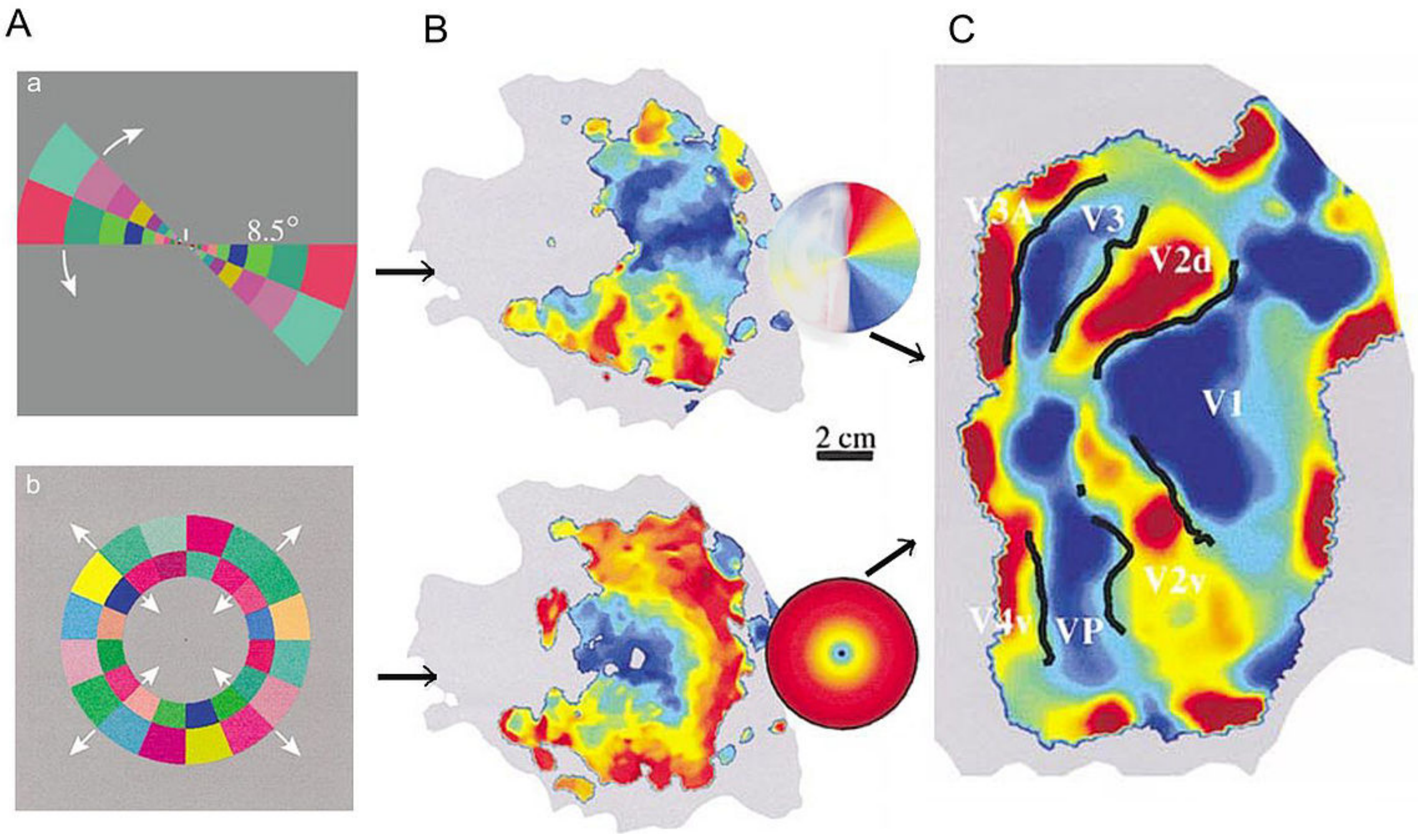
Hypercomplex (end-stopped) cells



Cortical magnification





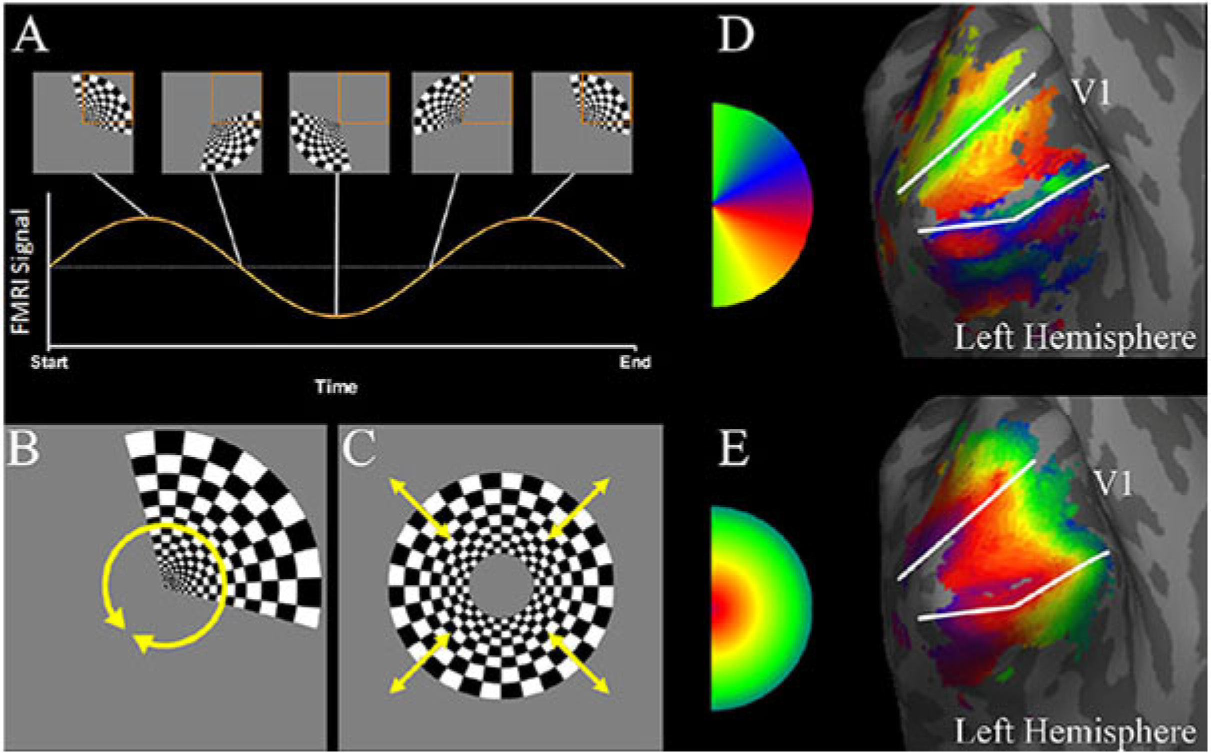


Stimuli: a) Rotating sectors
b) Ring contraction and expansion

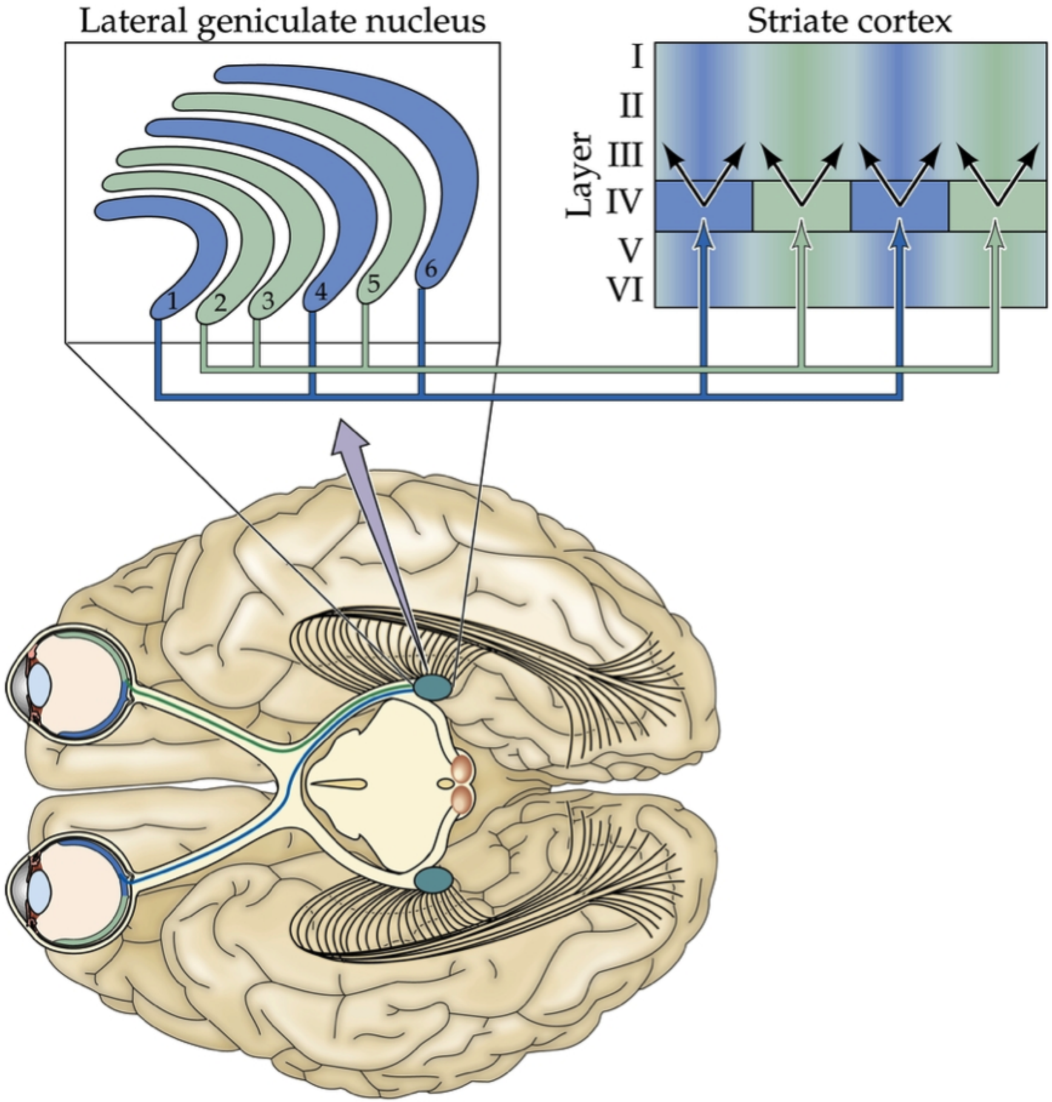
Maps of angle(polarity) and eccentricity

Retinotopic visual areas

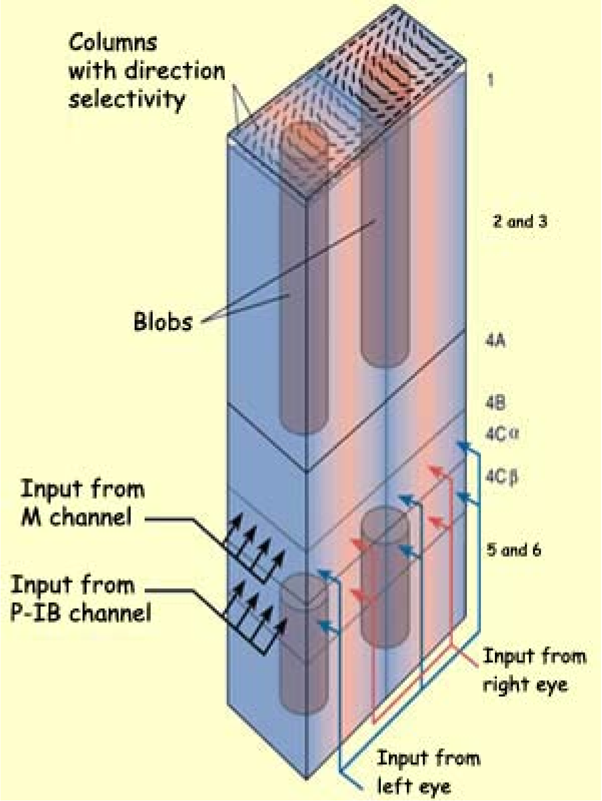
Retinotopy


A
FMRI Signal
Start
End
Time
B
C
D
V1
Left Hemisphere
E
V1
Left Hemisphere

Zhuang, J., Ng, L., Williams, D., Valley, M., Li, Y., Garrett, M., & Waters, J. (2017). An extended retinotopic map of mouse cortex. eLife, 6. Retrieved from http://dx.doi.org/10.7554/eLife.18372



Lateral geniculate nucleus
1
2
3
4
5
6
Striate cortex
Layer
I
II
III
IV
V
VI



Cortical hypercolumn

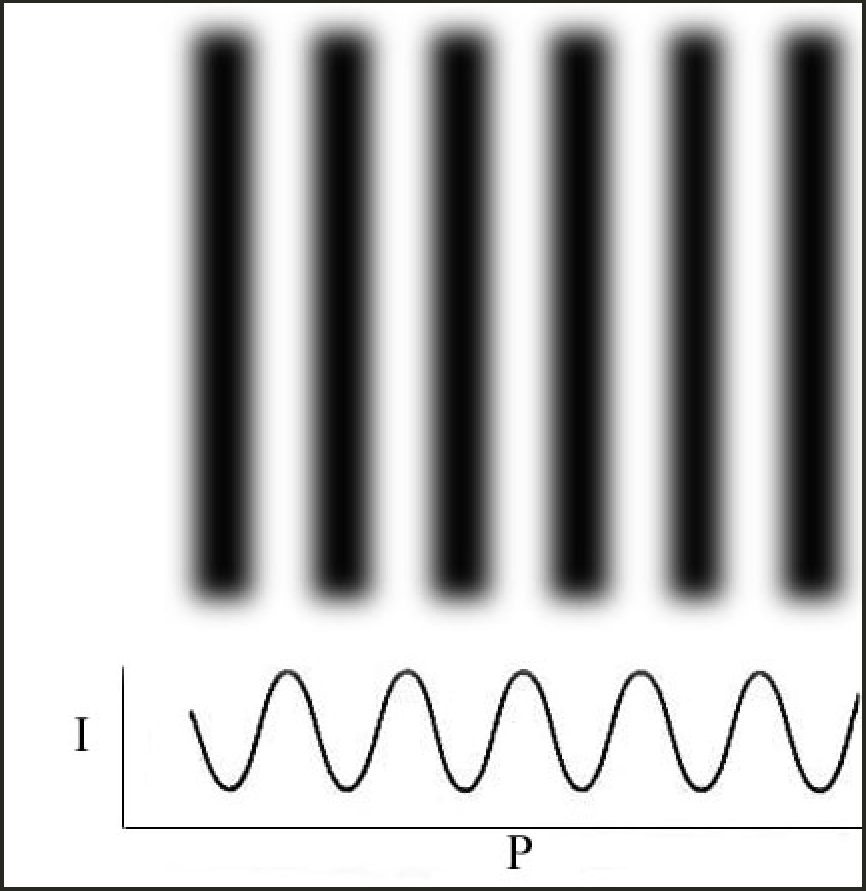
Aspects of the retinal-> V1 image

Topographic, but non-uniform

Functionally segregated (on/off center, wavelength, eye of origin)

Break time

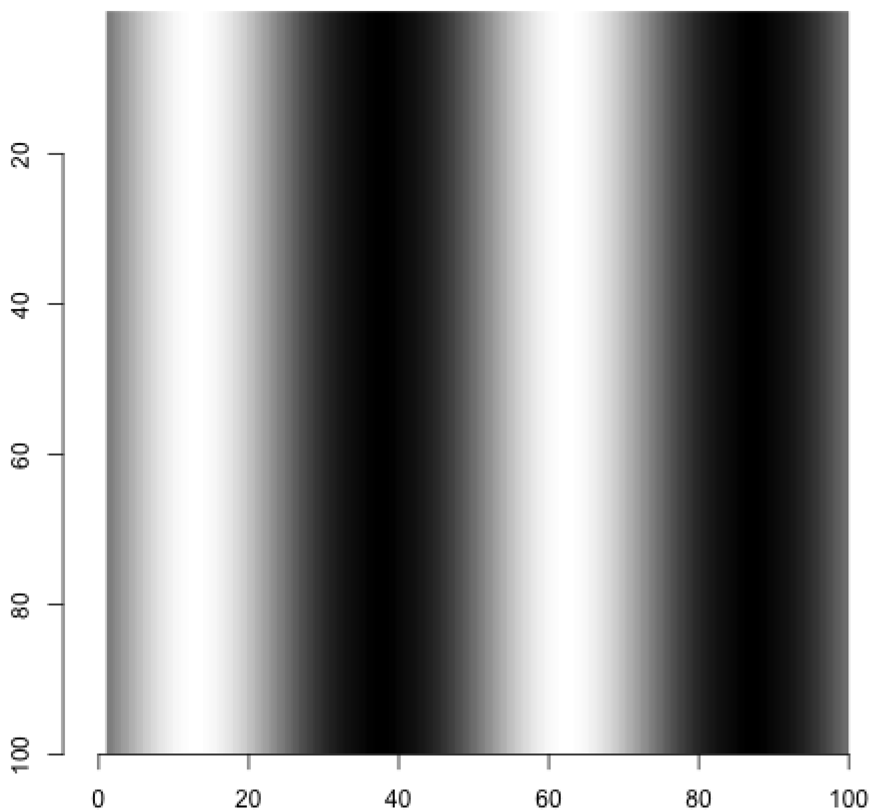
Spatial frequency analysis



But first a bit about images as arrays of numbers

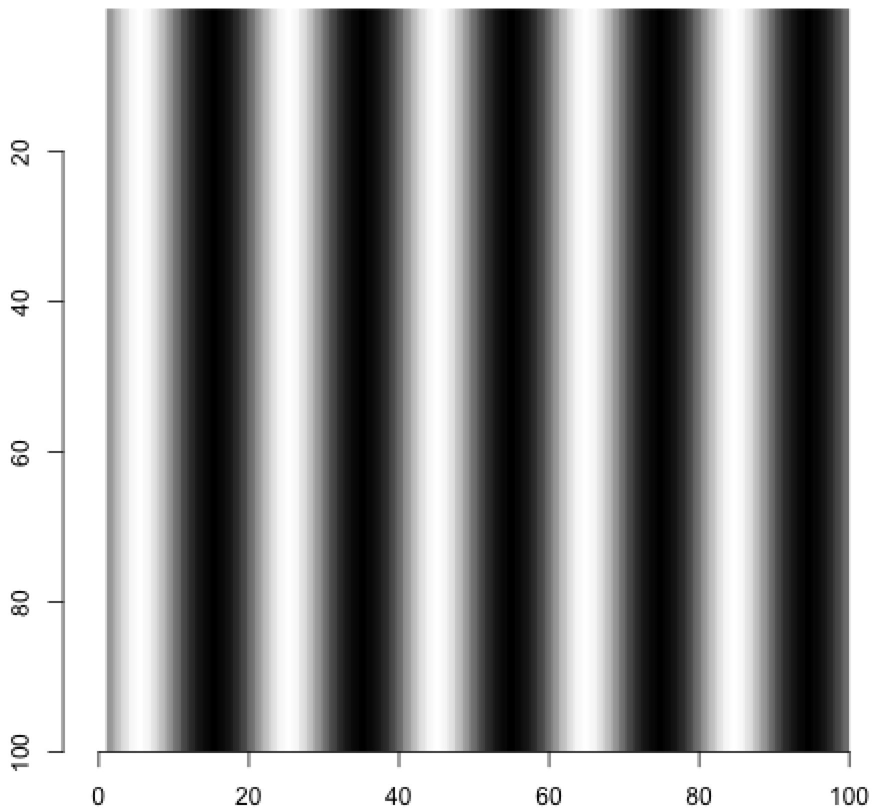
```
pix_per_img <- 100
x <- (1:pix_per_img)/pix_per_img  # Make x on (0,1]
cyc_per_img <- 2                  # spatial frequency f
phase <- 0
one_row <- sin(2*pi*cyc_per_img*x + phase)
plot(one_row)
```

```
sin_array <- array(rep(one_row, pix_per_img),
                   dim = c(pix_per_img, pix_per_img))
sin_img <- as.cimg(sin_array) # Nice image format from package imager
plot(sin_img)
```

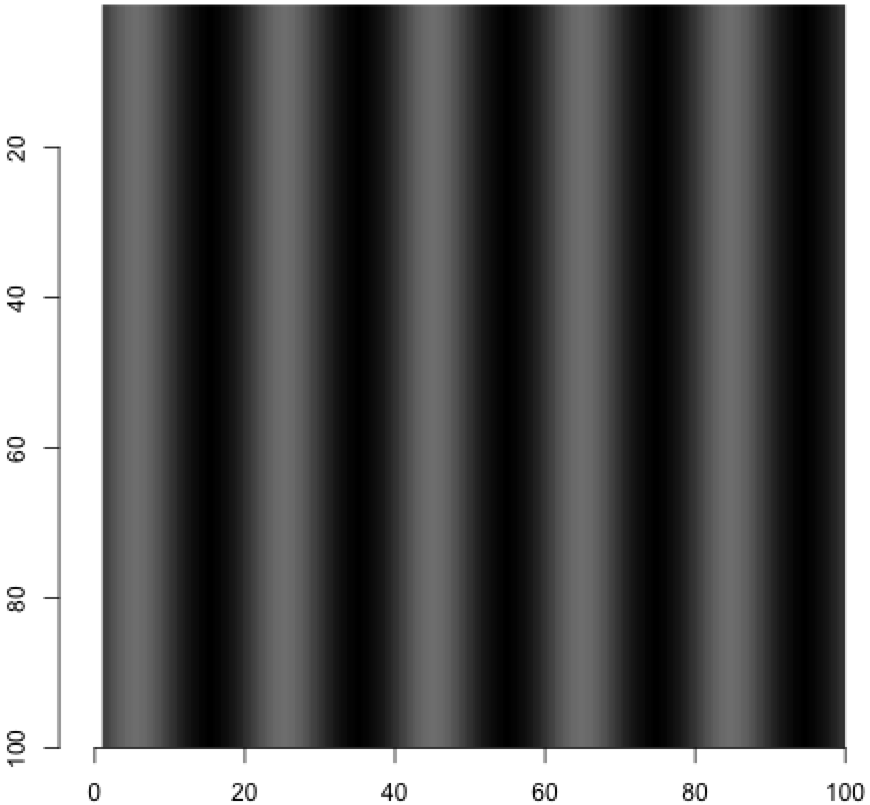


```r
vertical_grating <- function(pix_per_img=100, cyc_per_img=1, phase=0)
  x <- (1:pix_per_img)/pix_per_img
  one_row <- (sin(2*pi*cyc_per_img*x + phase)+1)*0.5 # Scale to [0,1
  as.cimg(array(rep(one_row, pix_per_img),
                dim = c(pix_per_img, pix_per_img)))
}
```

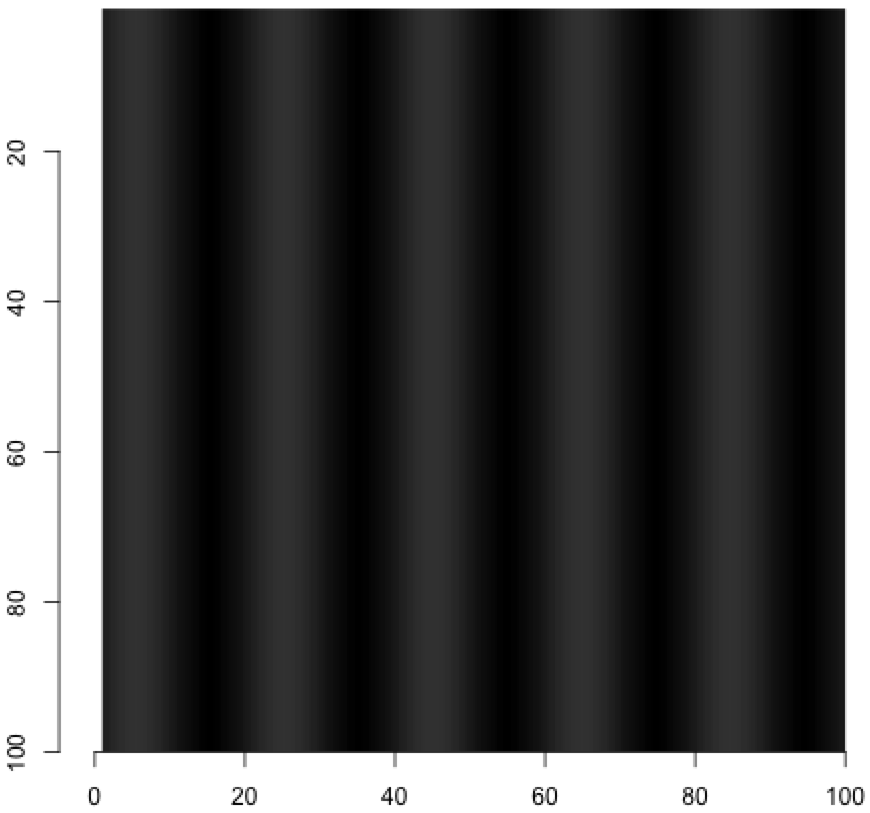
```r
vg_100 <- vertical_grating(cyc_per_img = 5)
plot(vg_100, rescale = FALSE)
```



```r
vg_50 <- vg_100*0.5
plot(vg_50, rescale = FALSE)
```



```
vg_25 <- vg_100*.25
plot(vg_25, rescale = FALSE)
```



Under the hood

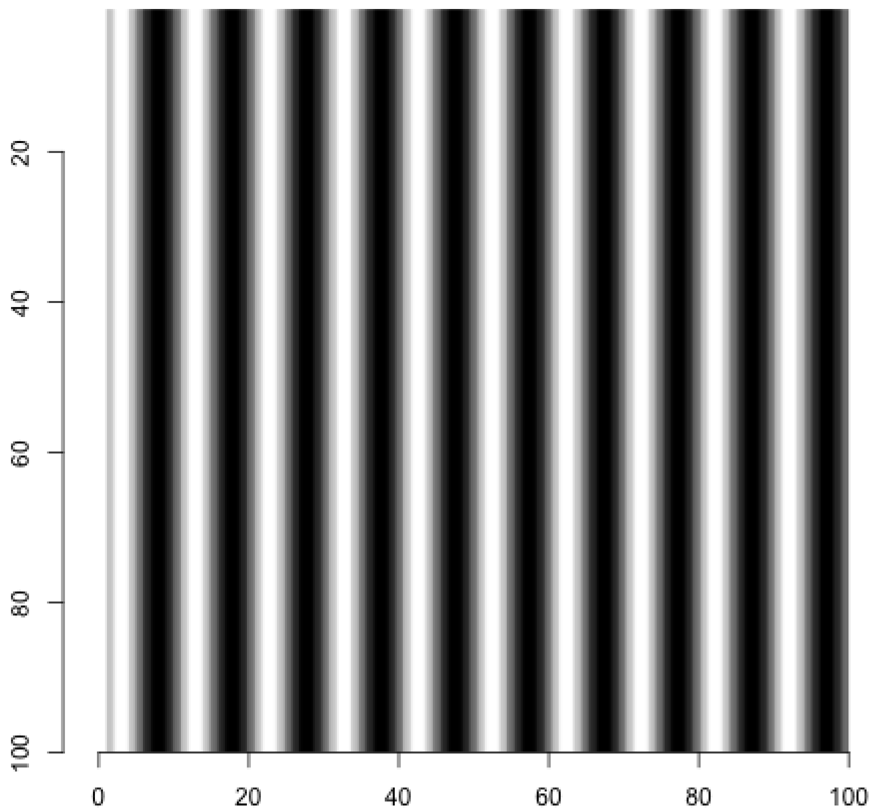
- Value at each x, y pixel is a number $[0, 1]$ (for grayscale)
- `plot` scales that to [0,255] (dark to light)
- [0,255] has 256 levels, $2^8 = 256$, so this is '8-bit grayscale'
- 8-bit color has 3 numbers at each pixel, (r, g, b), one each for the **r**ed, **g**reen, and **b**lue values.

Synthesizing images from sums of gratings

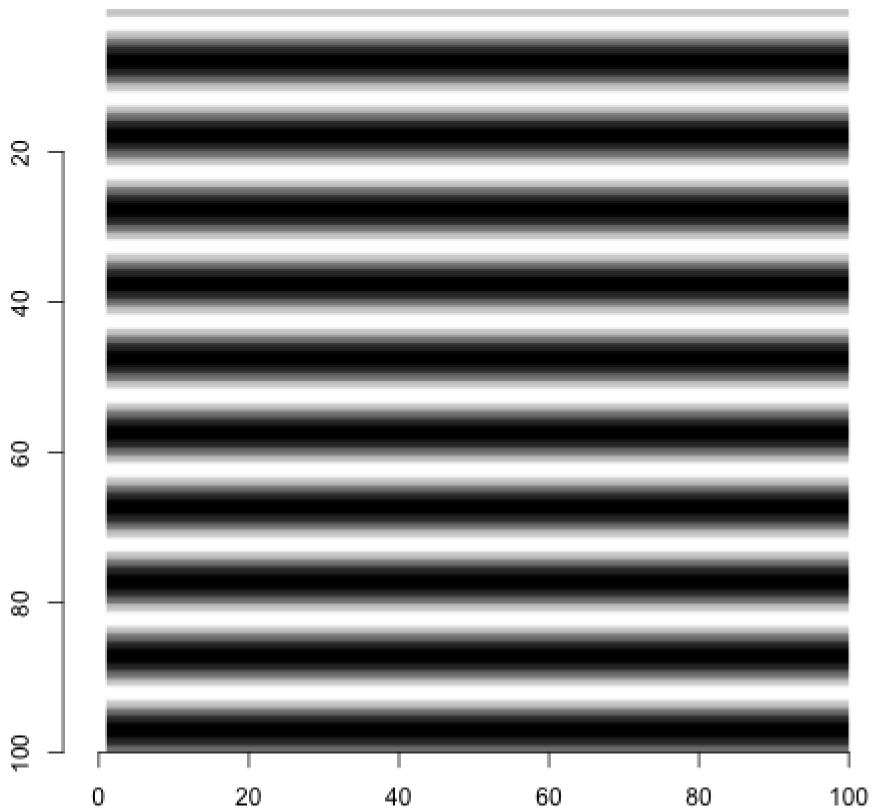
Every ~~periodic~~ pattern consists of an infinite sum of gratings of different spatial frequency, amplitude, phase, and orientation

```
grating <- function(pix_per_img=100, cyc_per_img=1,
                    phase=0, vertical=TRUE){
  x <- (1:pix_per_img)/pix_per_img
  one_row <- (sin(2*pi*cyc_per_img*x + phase)+1)*0.5 # Scale to [0,1_
  many_rows <- array(rep(one_row, pix_per_img),
                     dim = c(pix_per_img, pix_per_img))
  if (vertical)
    as.cimg(many_rows)
  else as.cimg(t(many_rows)) # transpose (rotate 90 deg)
}
```

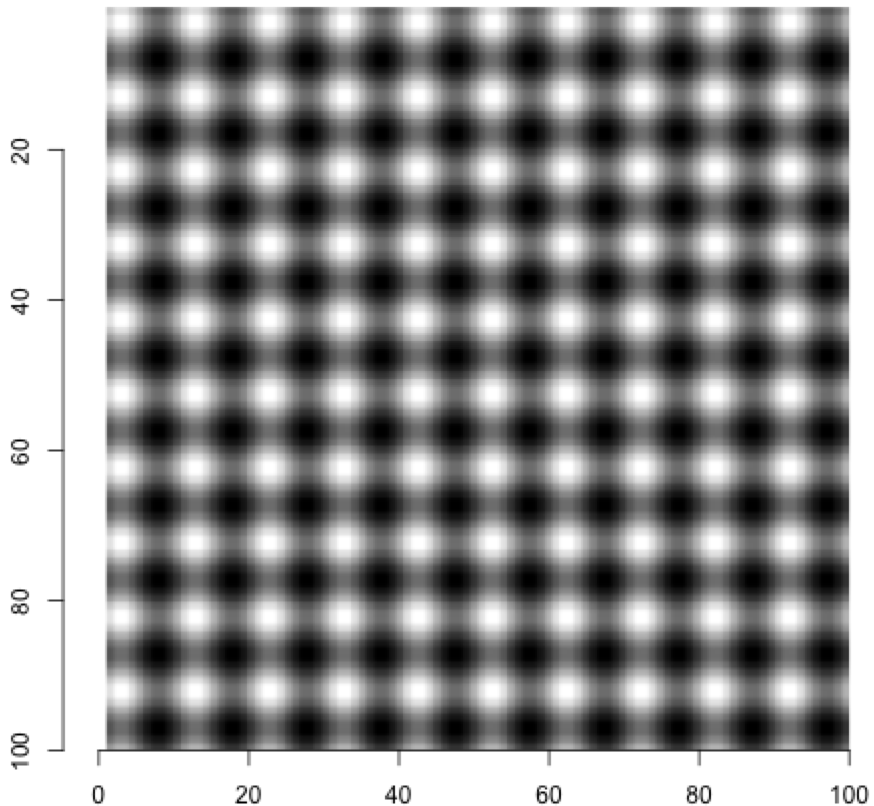
```r
plot(grating(cyc_per_img = 10))
```



```
plot(grating(cyc_per_img = 10, vertical=FALSE))
```



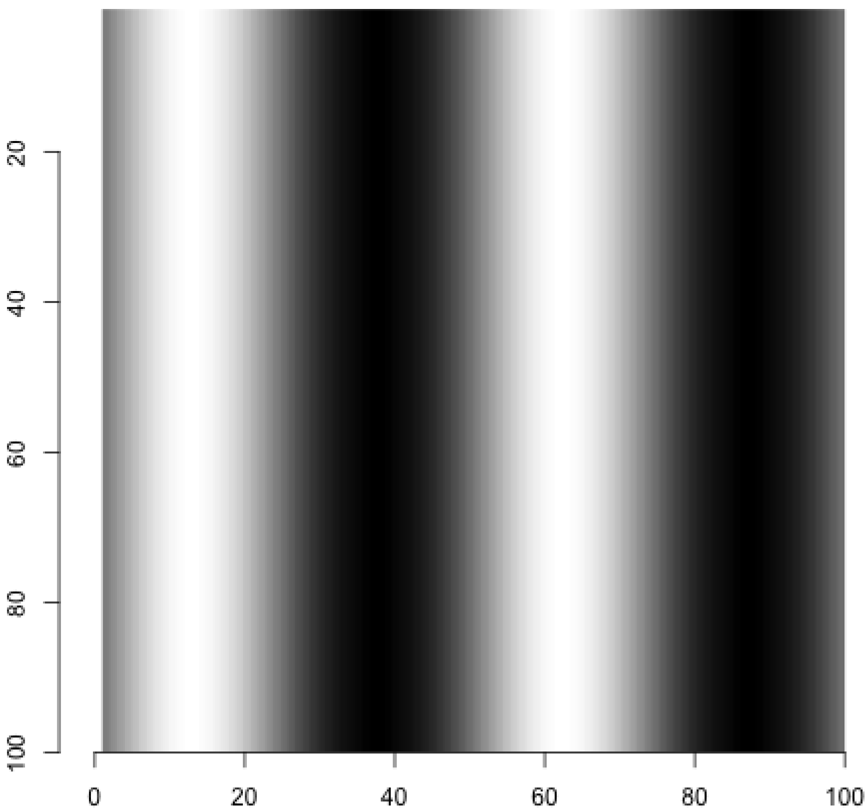
```r
g_vert <- grating(cyc_per_img = 10, vertical = TRUE)
g_horiz <- grating(cyc_per_img = 10, vertical = FALSE)
g_sum <- g_vert + g_horiz
plot(g_sum)
```



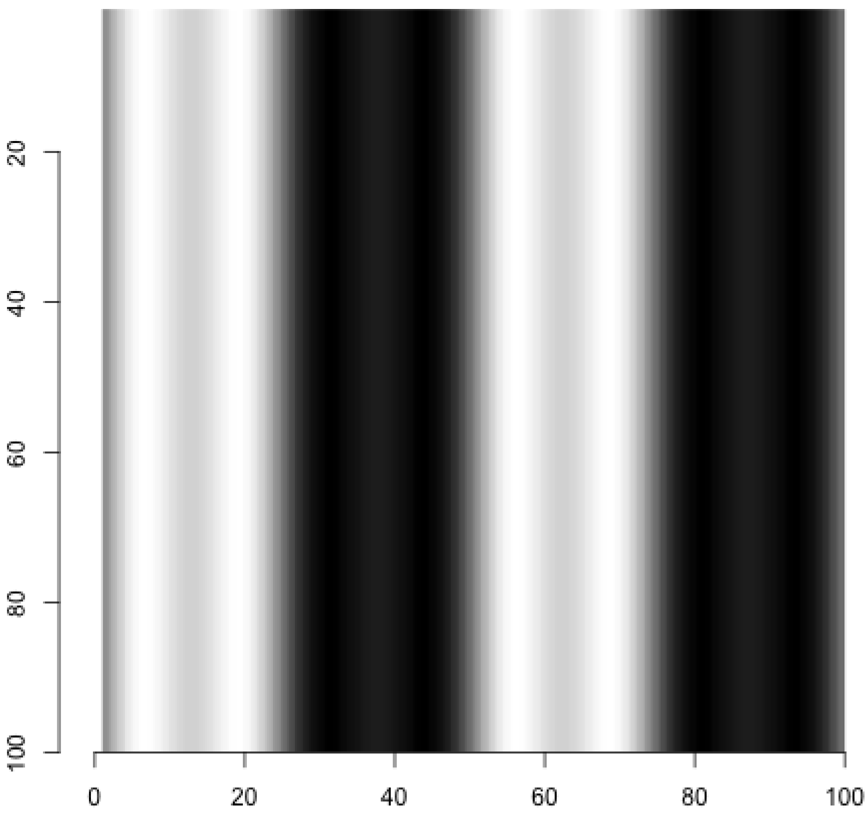
Synthesizing a square wave

```
f <- 2 # Cycles per image
f1 <- grating(cyc_per_img = f)
f3 <- grating(cyc_per_img = 3*f)*(1/3)
f5 <- grating(cyc_per_img = 5*f)*(1/5)
f7 <- grating(cyc_per_img = 7*f)*(1/7)
f9 <- grating(cyc_per_img = 9*f)*(1/9)
```

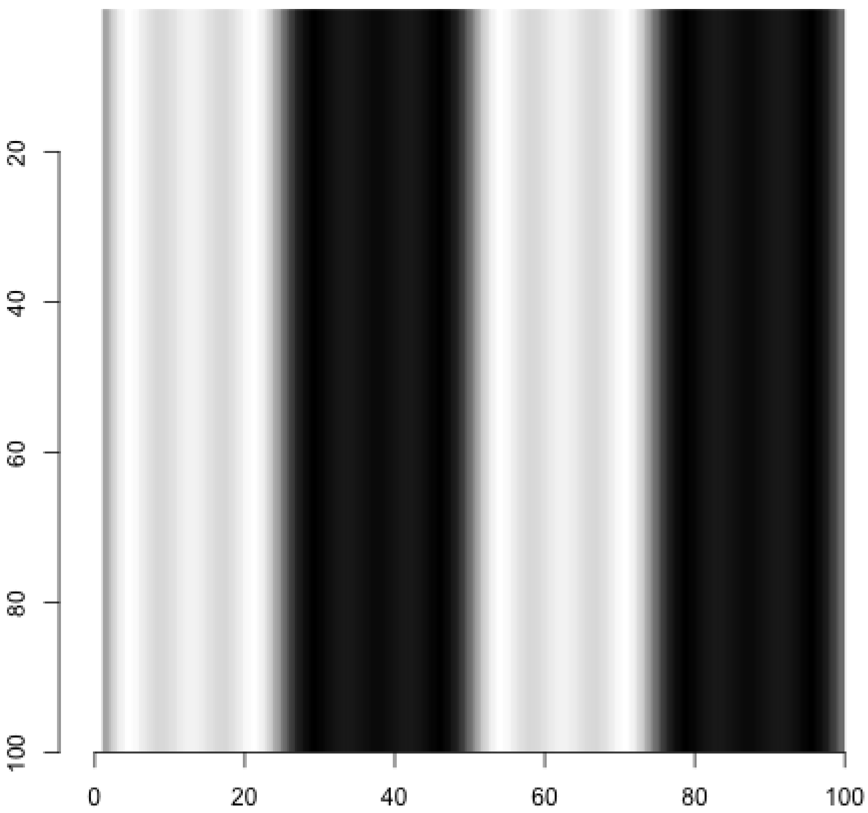
```
plot(f1)
```



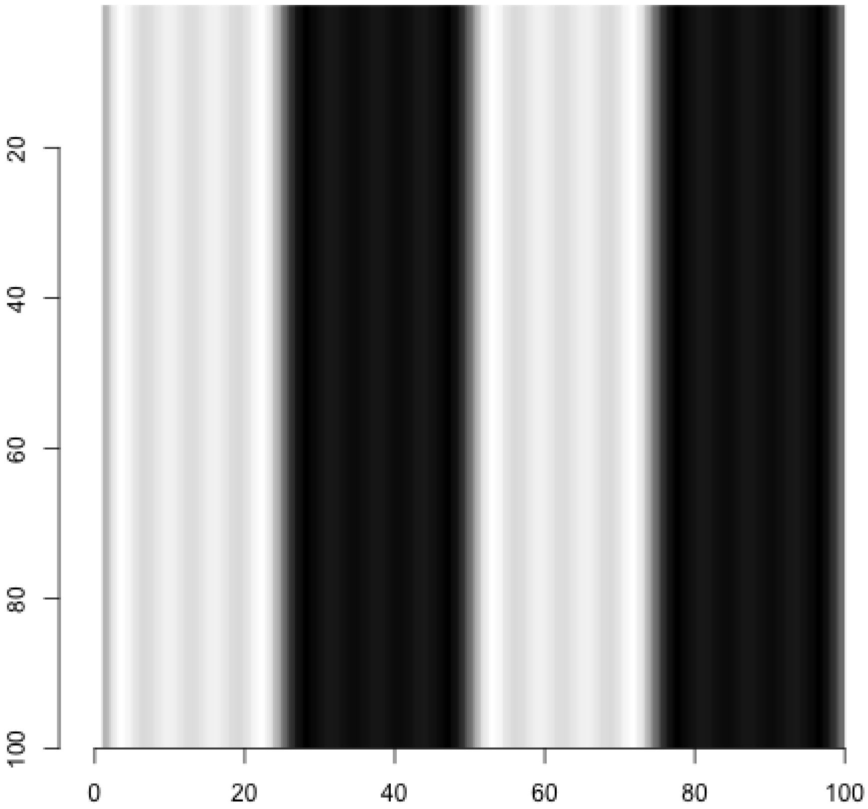
```
plot(f1+f3)
```



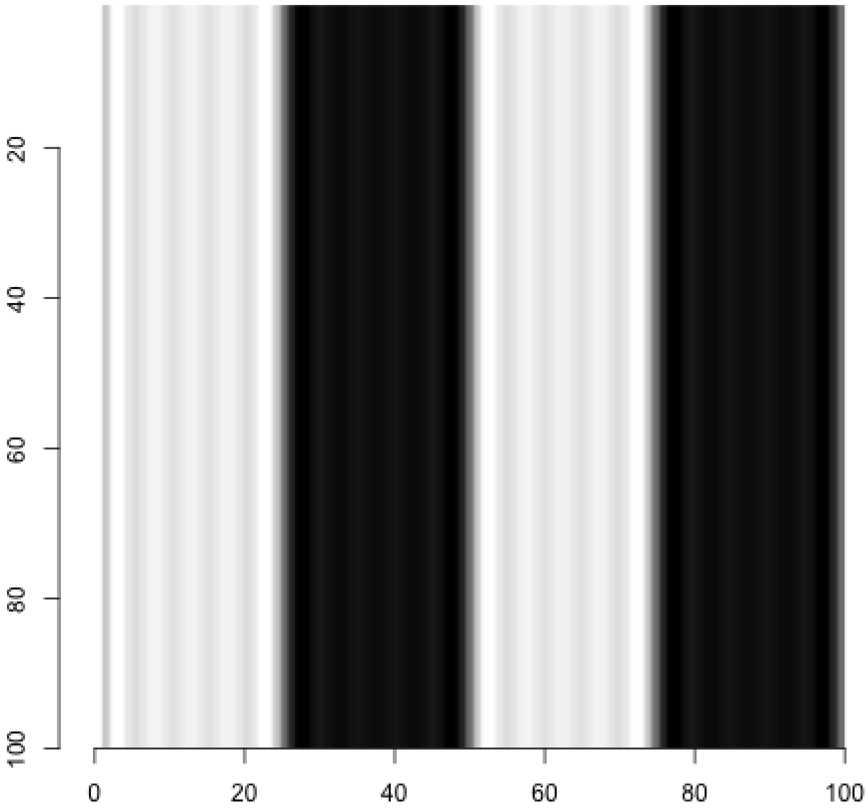
```r
plot(f1+f3+f5)
```



```
plot(f1+f3+f5+f7)
```



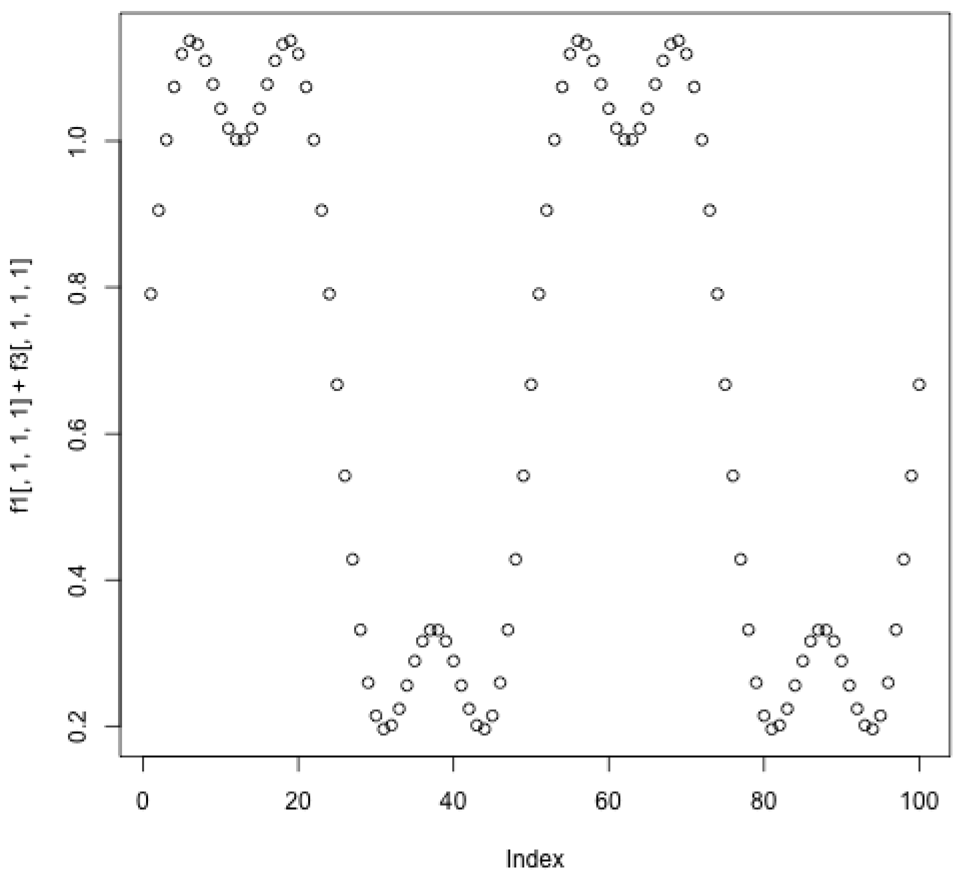
```
plot(f1+f3+f5+f7+f9)
```



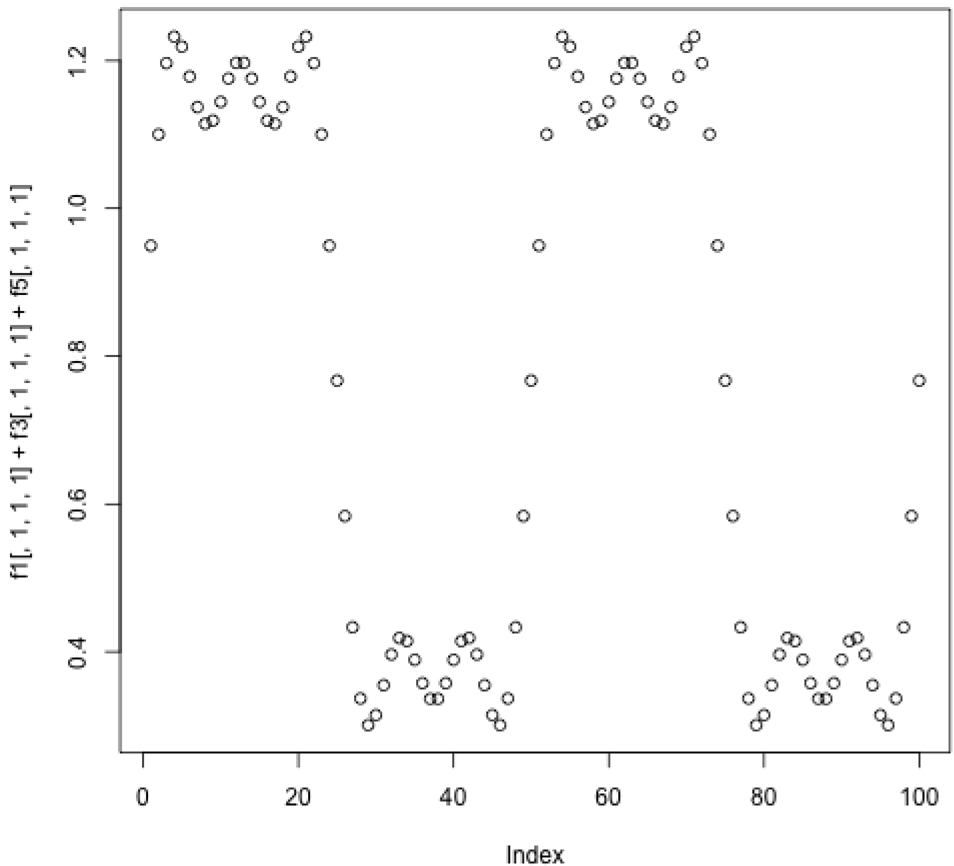
Why this works

```
plot(f1[,1,1,1], ylim = c(0,1))
```

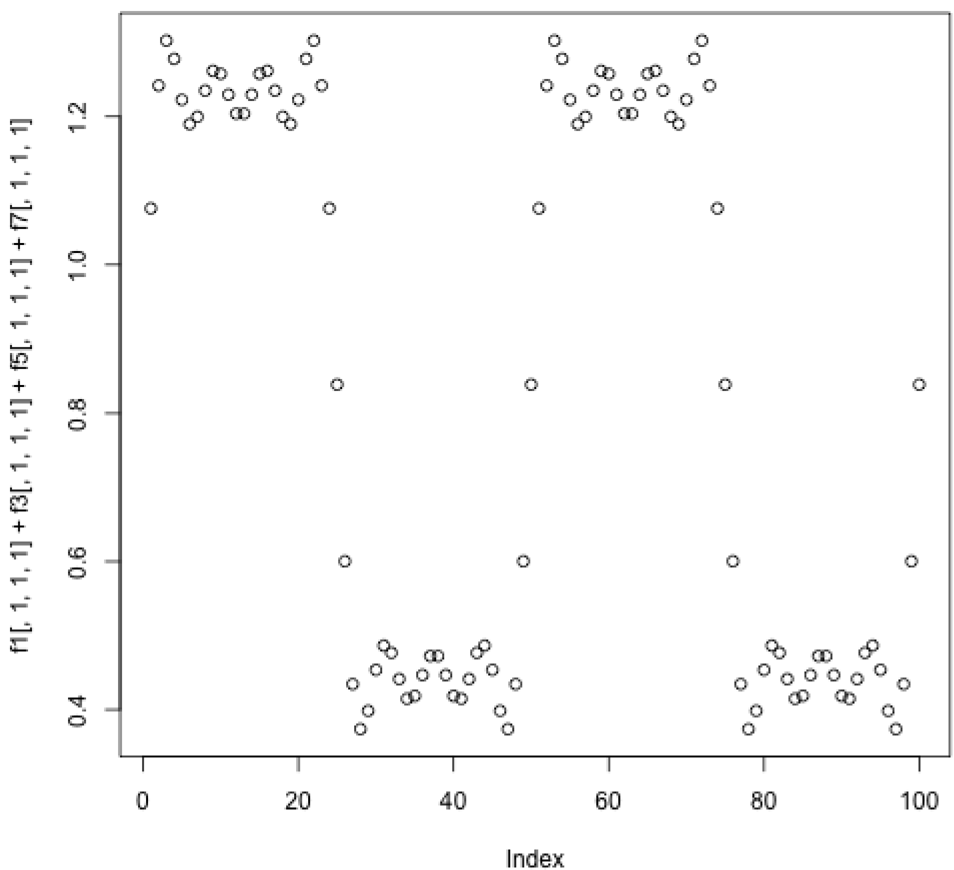
```r
plot(f1[,1,1,1]+f3[,1,1,1])
```



```
plot(f1[,1,1,1]+f3[,1,1,1]+f5[,1,1,1])
```



```
plot(f1[,1,1,1]+f3[,1,1,1]+f5[,1,1,1]+f7[,1,1,1])
```



That's (Fourier) *synthesis*

component_1 + component_2 +…+ component_n = image

or music

Fourier *analysis* goes in reverse

image = component_1 + component_2 +…+ component_n

By Lucas V. Barbosa - Own work, Public Domain, Link

Why is Fourier analysis useful and important for vision science?

Why is it useful and important for other areas of psychological or neural science?

Break time

Discussion of Campbell, F. W., & Robson, J. G. (1968).

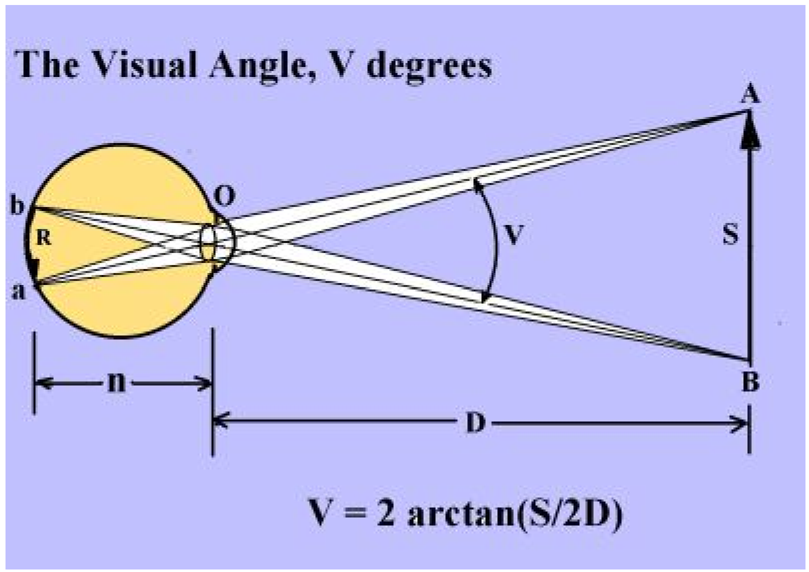
Key terms & parameters

- Contrast sensitivity vs. contrast threshold
- Contrast sensitivity function
- Sine, square, rectangular, saw tooth gratings
- Fourier components
- Luminance (in cd/m^2)
- Spatial frequency (in cyc/deg) vs. spatial period (deg/cyc)
- Temporal frequency (in c/s)
- Duty cycle $(0, 1]$
- Size of image (in deg)
- Viewing distance
- Fundamental frequency

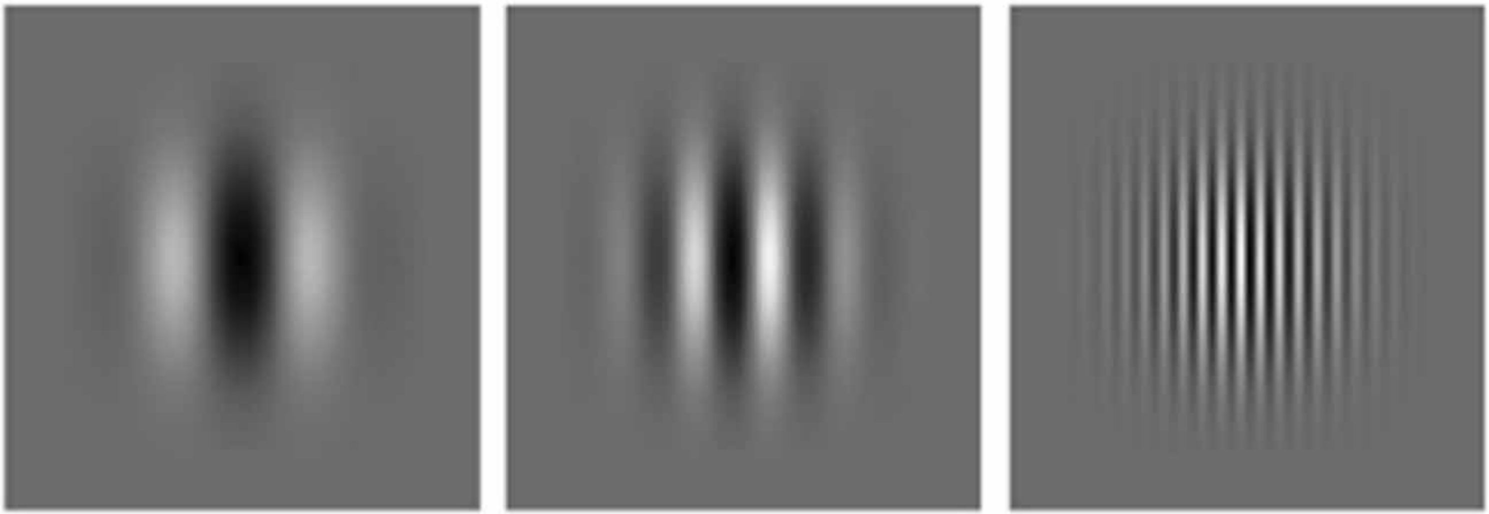
Contrast sensitivity

- sensitivity = 1/threshold
- low threshold -> high sensitivity & *vice versa*

Spatial frequency



Rules of thumb (~$1-2^{\circ}$), vertical fist (~5°), horizontal fist (10°)



Three vertical sine wave gratings at low, medium, and high spatial frequency

Fourier components

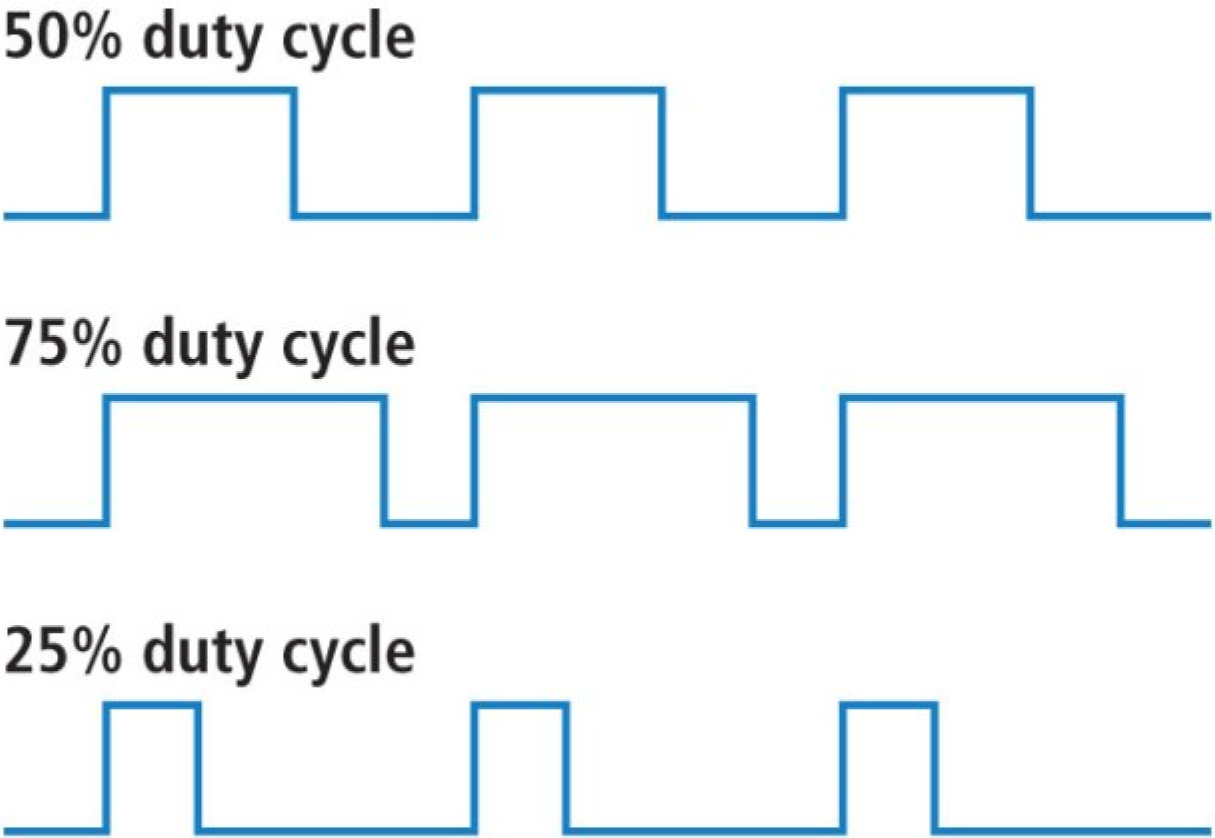
- **Sine wave**:

$$\frac{4m}{\pi} sin(\frac{2\pi x}{X})$$

  where X is the period, $\frac{x}{cycle}$, or $\frac{1}{frequency}$ and m is the contrast, $\frac{L_{max}-L_{min}}{2\bar{L}}$
- There are many measures of contrast, see https://en.wikipedia.org/wiki/Contrast_(vision)
- **Square wave**:

$$\frac{4m}{\pi}[\frac{1}{1} sin(1\frac{2\pi x}{X}) + \frac{1}{3} sin(3\frac{2\pi x}{X}) + \frac{1}{5} sin(5\frac{2\pi x}{X}) + \ldots]$$

Duty cycle



Questions

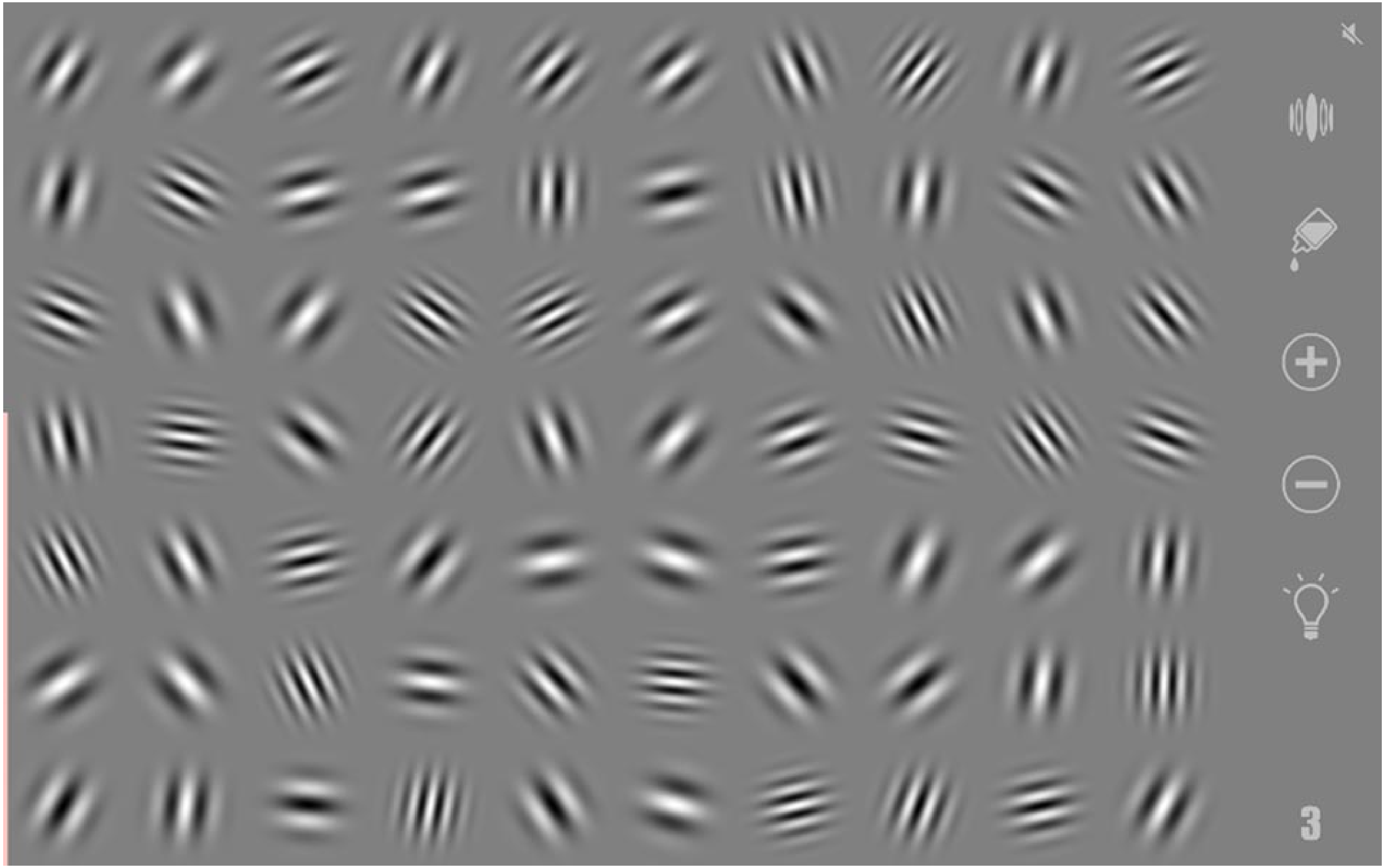
- What psychophysical method was used?
- How were thresholds estimated?
- Why might a larger aperture yield higher sensitivity (lower threshold)?
- What spatial frequency yields the highest sensitivity?

Evaluating Campbell & Robson (1968) claims

1. The contrast thresholds of a variety of grating patterns have been measured over a wide range of spatial frequencies.
2. Contrast thresholds for the detection of gratings whose luminance profiles are sine, square, rectangular or saw-tooth waves can be simply related using Fourier theory.
3. Over a wide range of spatial frequencies the contrast threshold of a grating is determined only by the amplitude of the fundamental Fourier component of its wave form.
4. Gratings of complex wave form cannot be distinguished from sinewave gratings until their contrast has been raised to a level at which the higher harmonic components reach their independent threshold.
5. These findings can be explained by the existence within the nervous system of linearly operating independent mechanisms selectively sensitive to limited ranges of spatial frequencies.

The bigger picture

- Is V1 detecting oriented lines or spatial frequency patterns?
- **Gabor patches** combine a grating and a Gaussian envelope



Gabor patches as models of V1 simple cells?

Real component

$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = exp(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2})cos(2\pi\frac{x'}{\lambda} + \psi)$$

Imaginary component

$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = exp(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2})sin(2\pi\frac{x'}{\lambda} + \psi)$$

with $x' = xcos(\theta) + ysin(\theta)$ and $y' = -xsin(\theta) + ycos(\theta)$

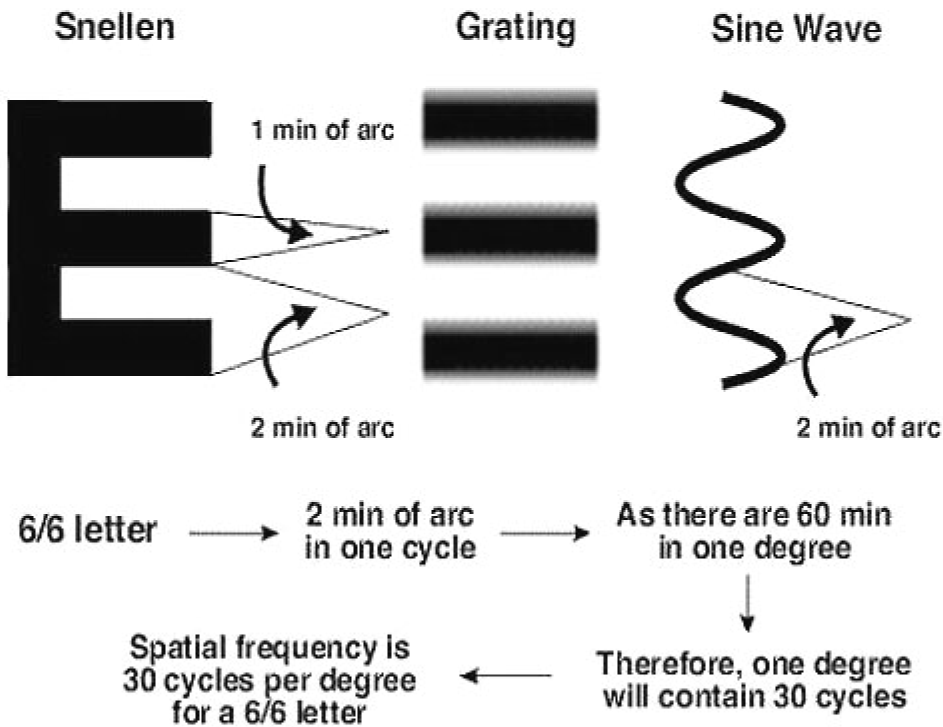
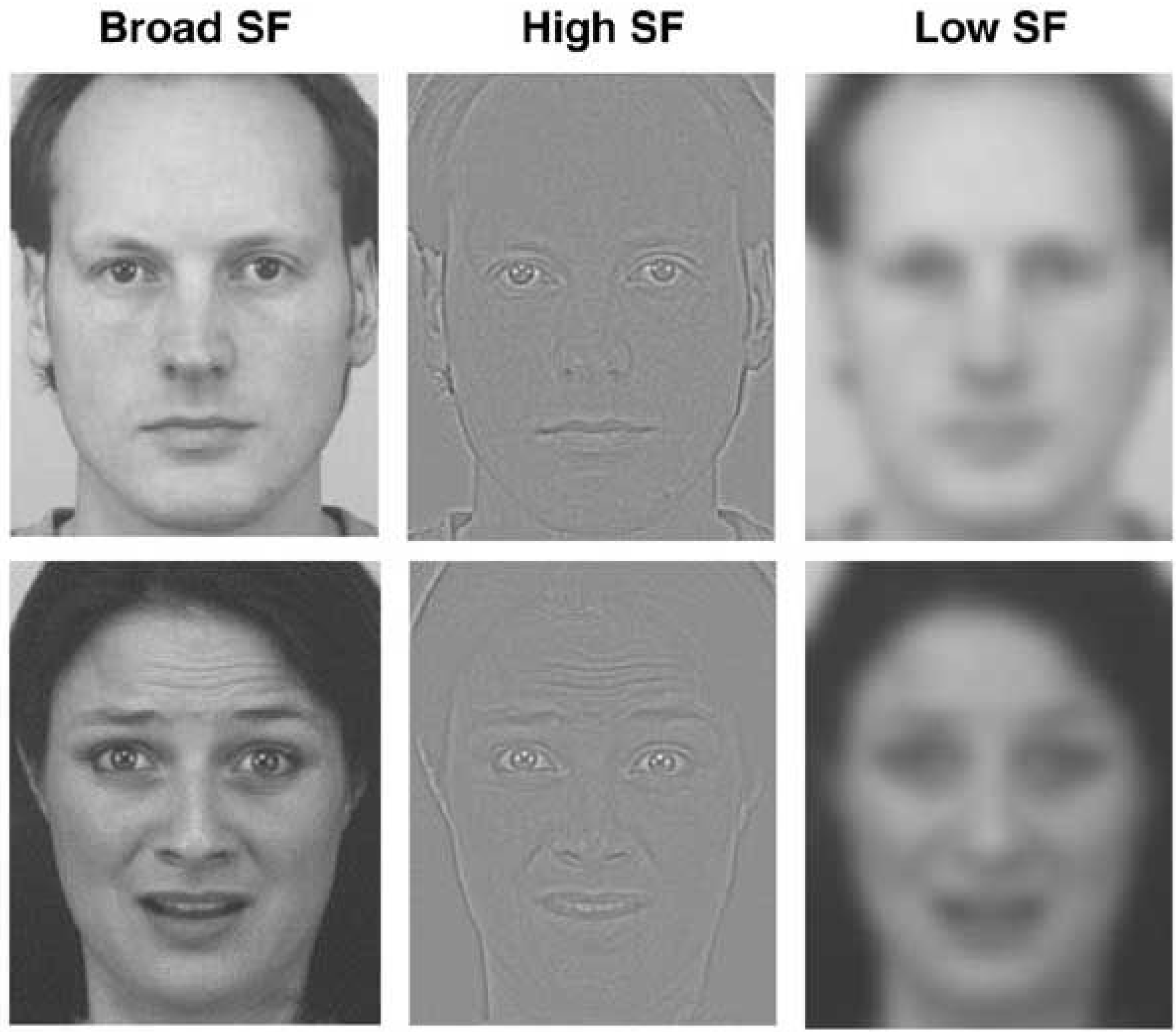


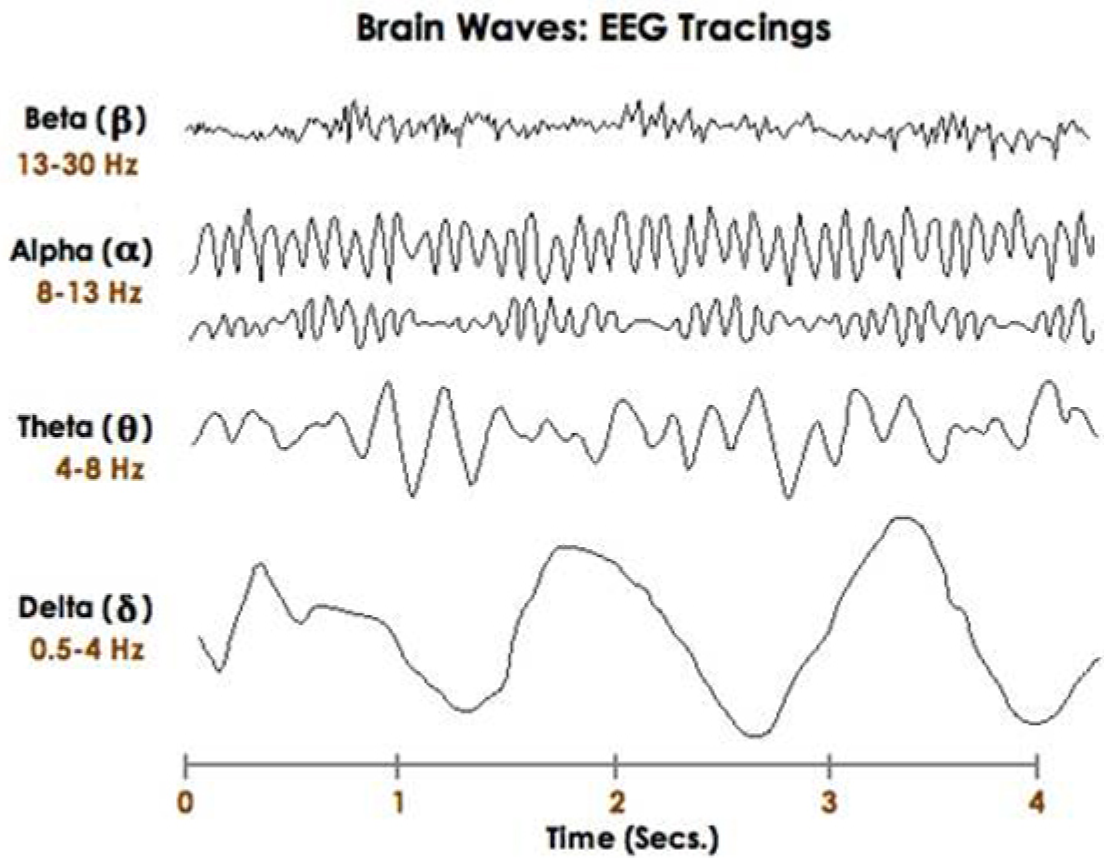
Figure 15. Visual acuity in Snellen notation and its conversion to spatial frequency.

Snellen Metric	Snellen Imperial	MAR	logMAR	Decimal	cyc/deg
6/60	20/200	10	1.0	0.10	3
6/48	20/160	8.0	0.9	0.13	
6/38	20/125	6.3	0.8	0.16	4.76
6/30	20/100	5.0	0.7	0.20	
6/24	20/80	4.0	0.6	0.25	
6/19	20/60	3.2	0.5	0.32	9.375
6/15	20/50	2.5	0.4	0.40	
6/12	20/40	2.0	0.3	0.50	
6/9	20/30	1.6	0.2	0.63	18.75
6/7.5	20/25	1.25	0.1	0.80	
6/6	20/20	1.00	0.0	1.00	30
6/4.8	20/16	0.80	-0.1	1.25	
6/3.8	20/12.5	0.63	-0.2	1.58	
6/3.0	20/10	0.50	-0.3	2.00	60

http://webvision.med.utah.edu/book/part-viii-gabac-receptors/visual-acuity/



High vs. low spatial frequencies carry ≠ information


Brain Waves: EEG Tracings
Beta (β)
13-30 Hz
Alpha (α)
8-13 Hz
Theta (θ)
4-8 Hz
Delta (δ)
0.5-4 Hz
0
1
2
3
4
Time (Secs.)

The Fourier Transform .com

$$\mathscr{F}\{g(t)\} = G(f) = \int_{-\infty}^{\infty} g(t) e^{-i2\pi ft} dt$$

$$\mathscr{F}^{-1}\{G(f)\} = g(t) = \int_{-\infty}^{\infty} G(f) e^{i2\pi ft} df$$

Next time...

Depth perception

Slides created via the R package **xaringan**. Rendered HTML and supporting files are pushed to GitHub where GitHub's 'pages' feature is used to host and serve the course website.