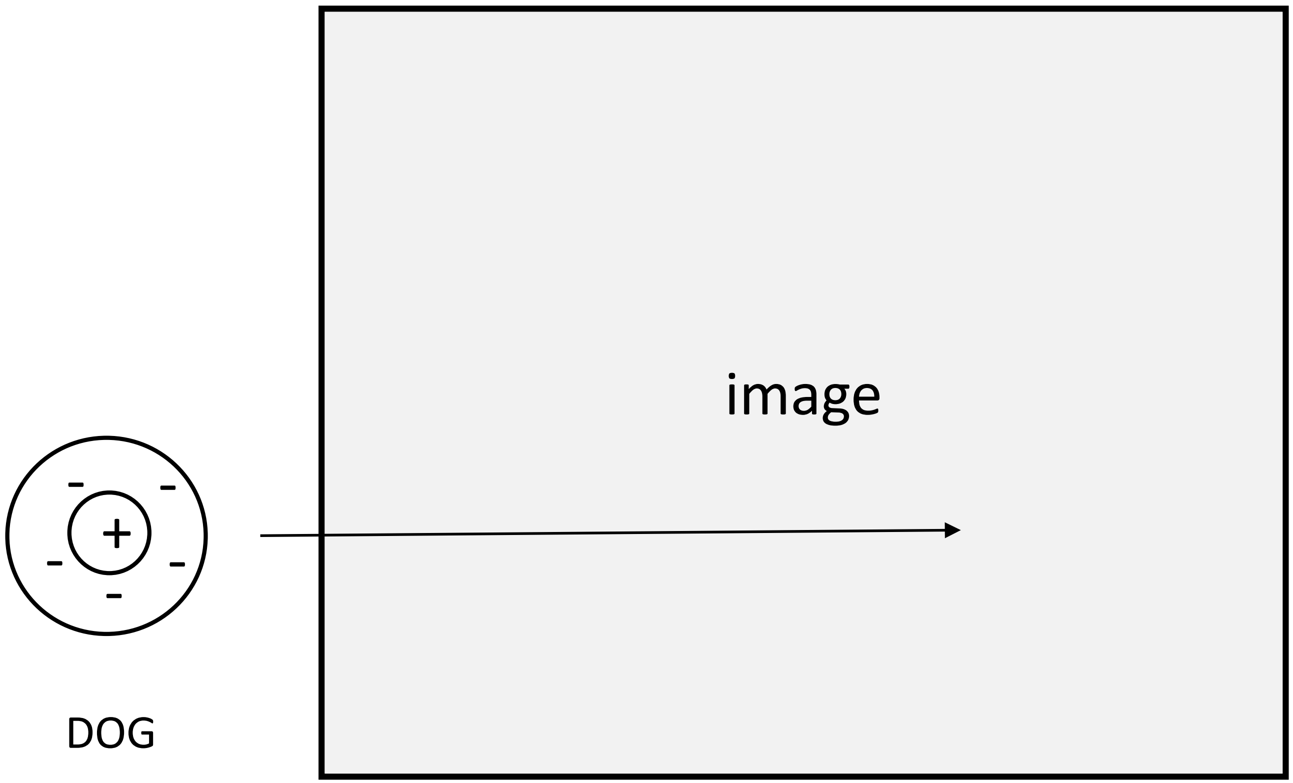
COMP 546

Lecture 5

Orientation Selection 1: Simple Cells

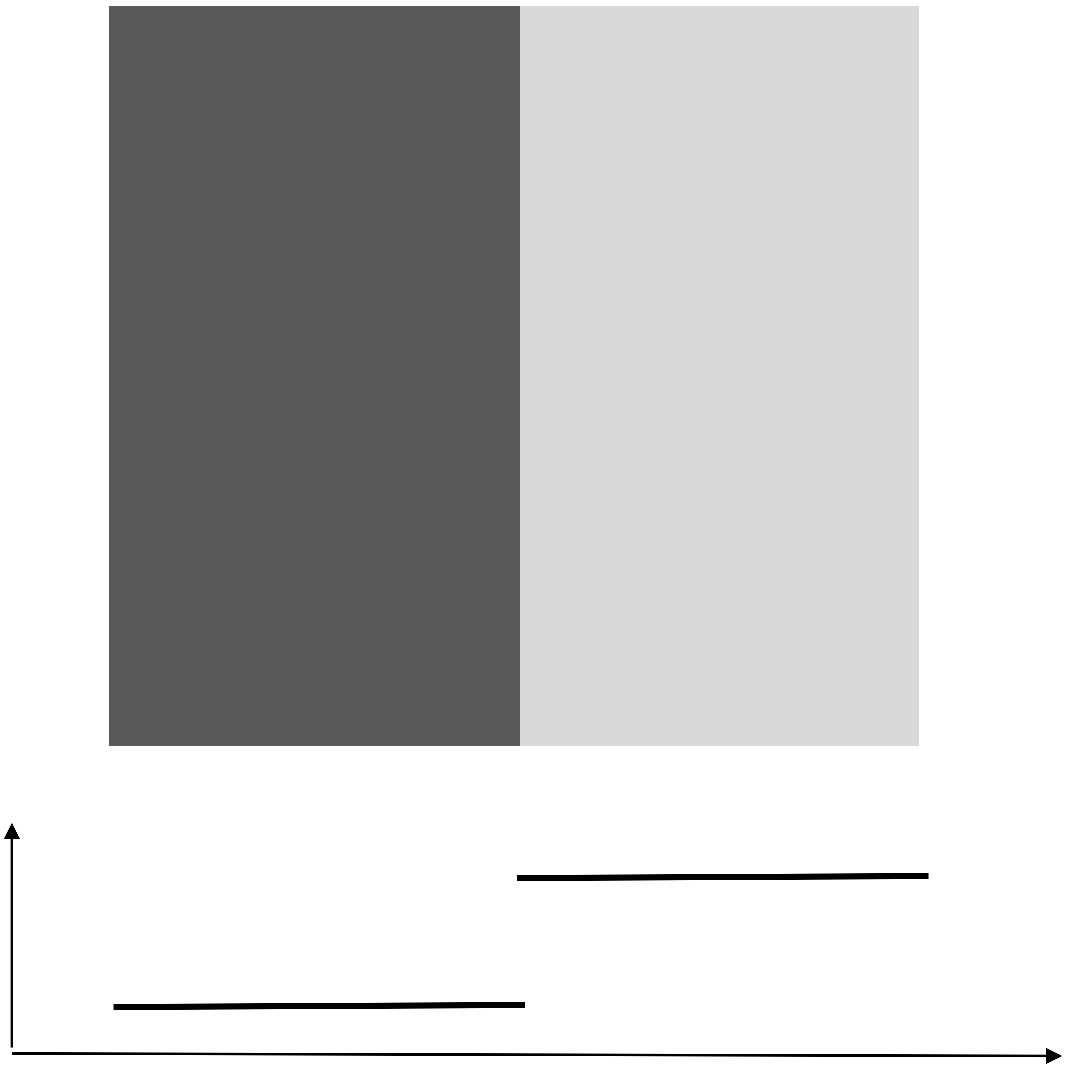
Thurs. Jan. 25, 2018

Recall last lecture:
DOG (lateral inhibition), “cross correlation”



Example: an edge image

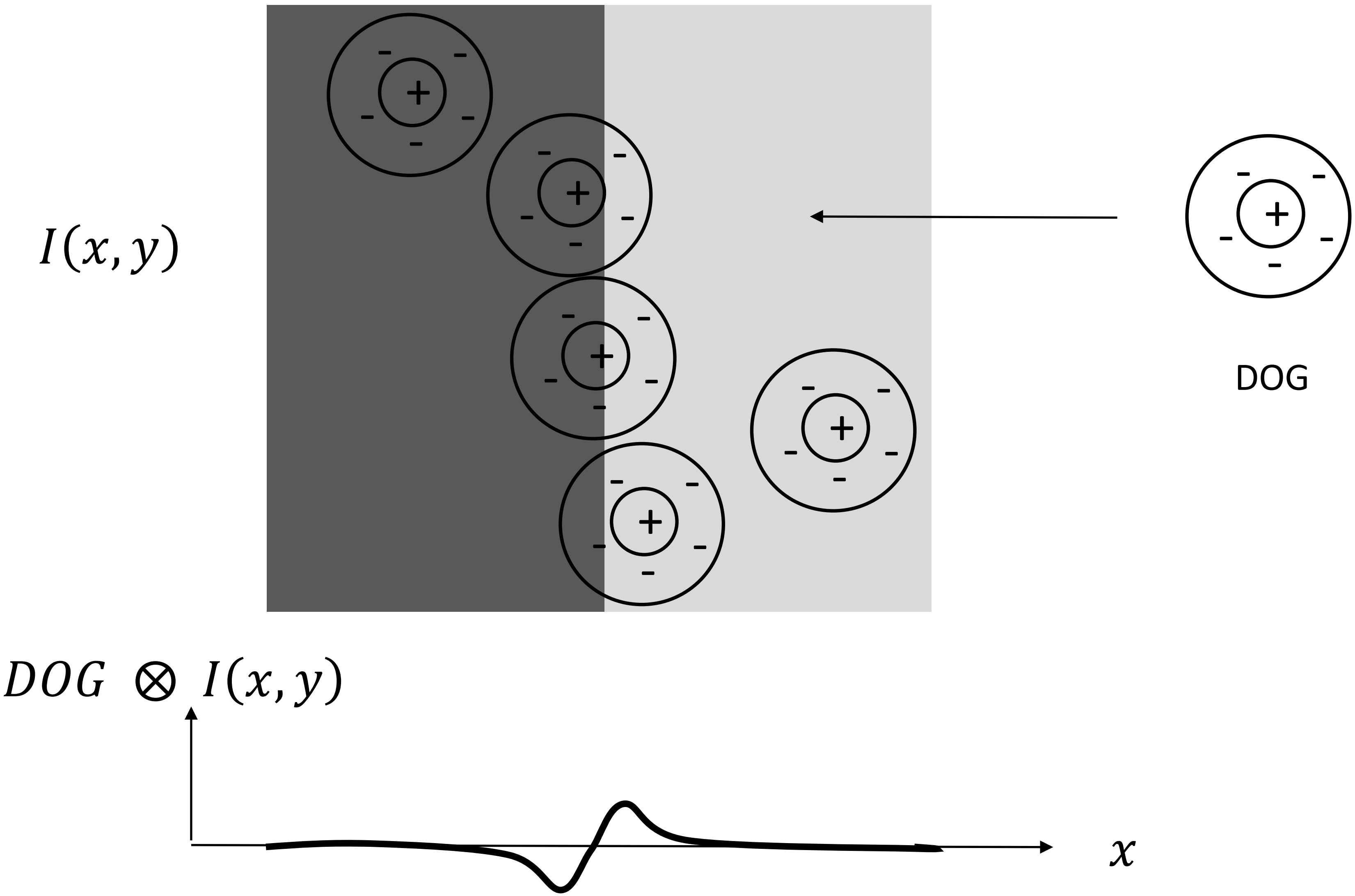
$I(x, y)$



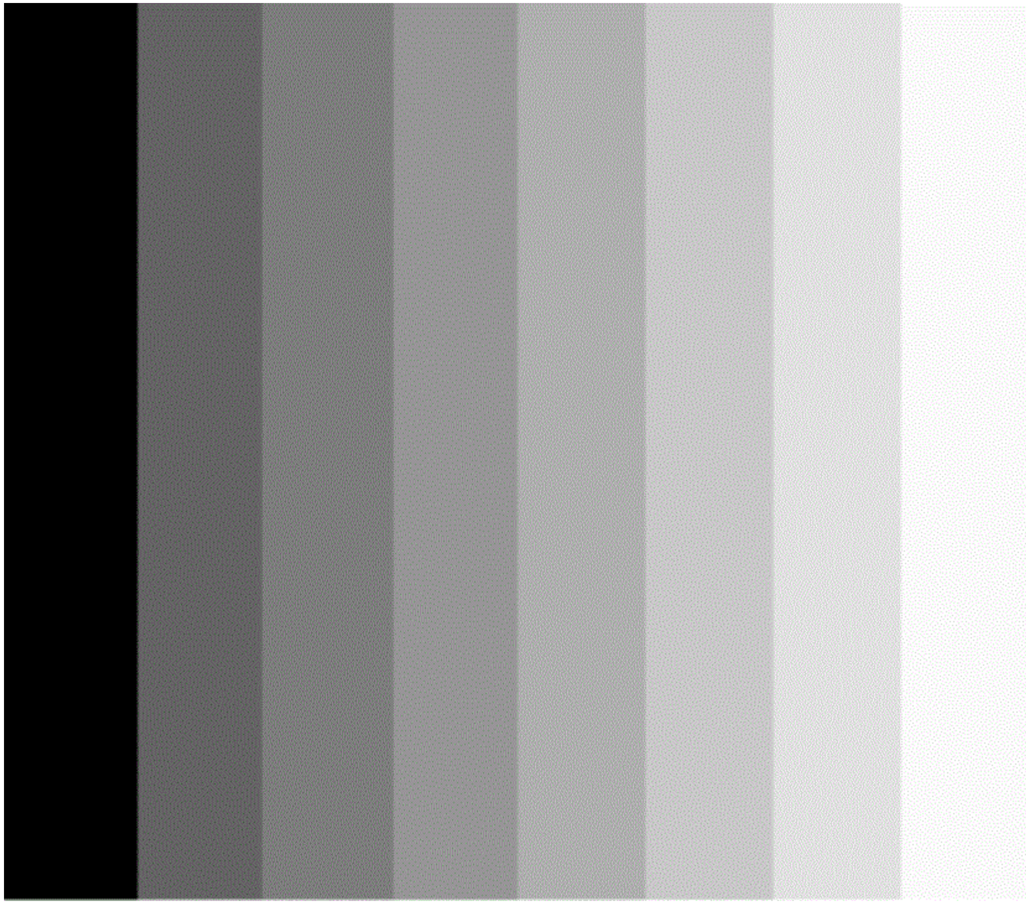
$I(x)$

x

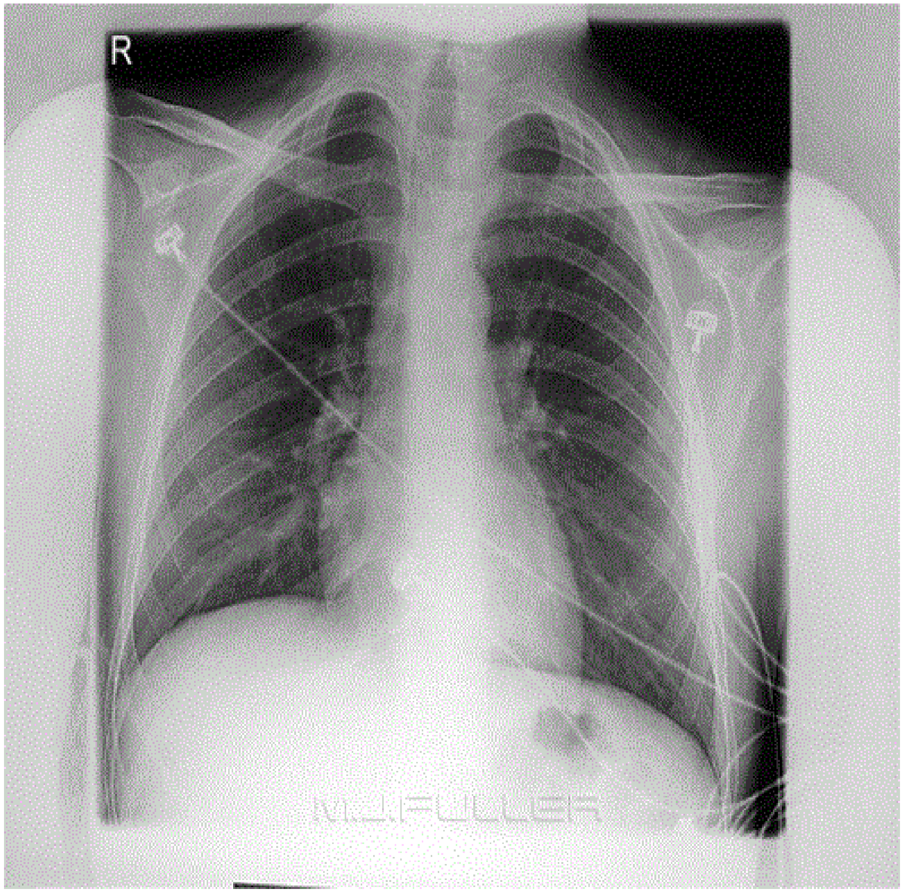
Example: an edge image



Mach Bands



Are they the result of lateral inhibition in the retina ?

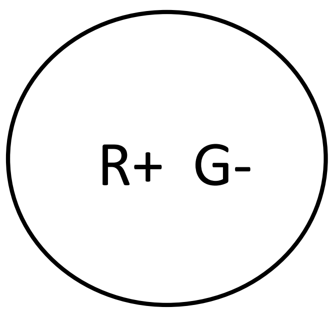


ASIDE: Mach bands are well known problem for interpreting x-ray images. Very subtle changes in dark-bright must be detected and the visual system is often fooled.

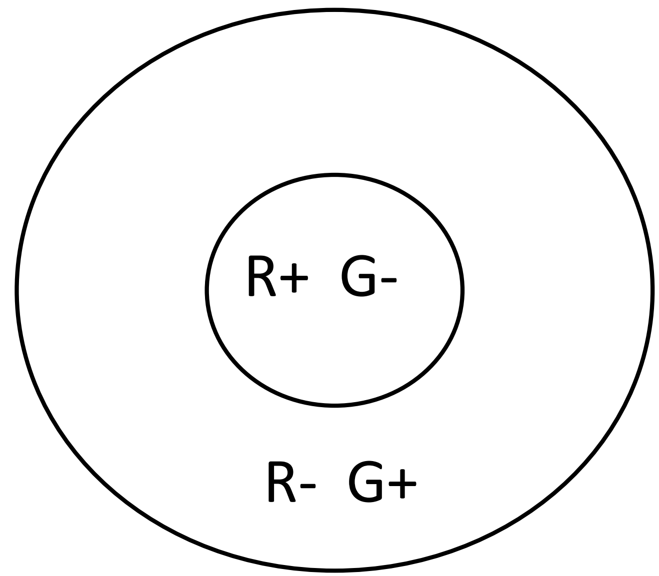
Retinal ganglion cells encode image *differences* :

- spectral (wavelength λ) , "chromatic"
- spatial (x,y)
- temporal (t) -- *will cover this next week*
- spectral-spatial (λ, x, y) - *Assignment 1*
- spectral-spatio-temporal (λ, x, y, t) - omit

Assignment 1

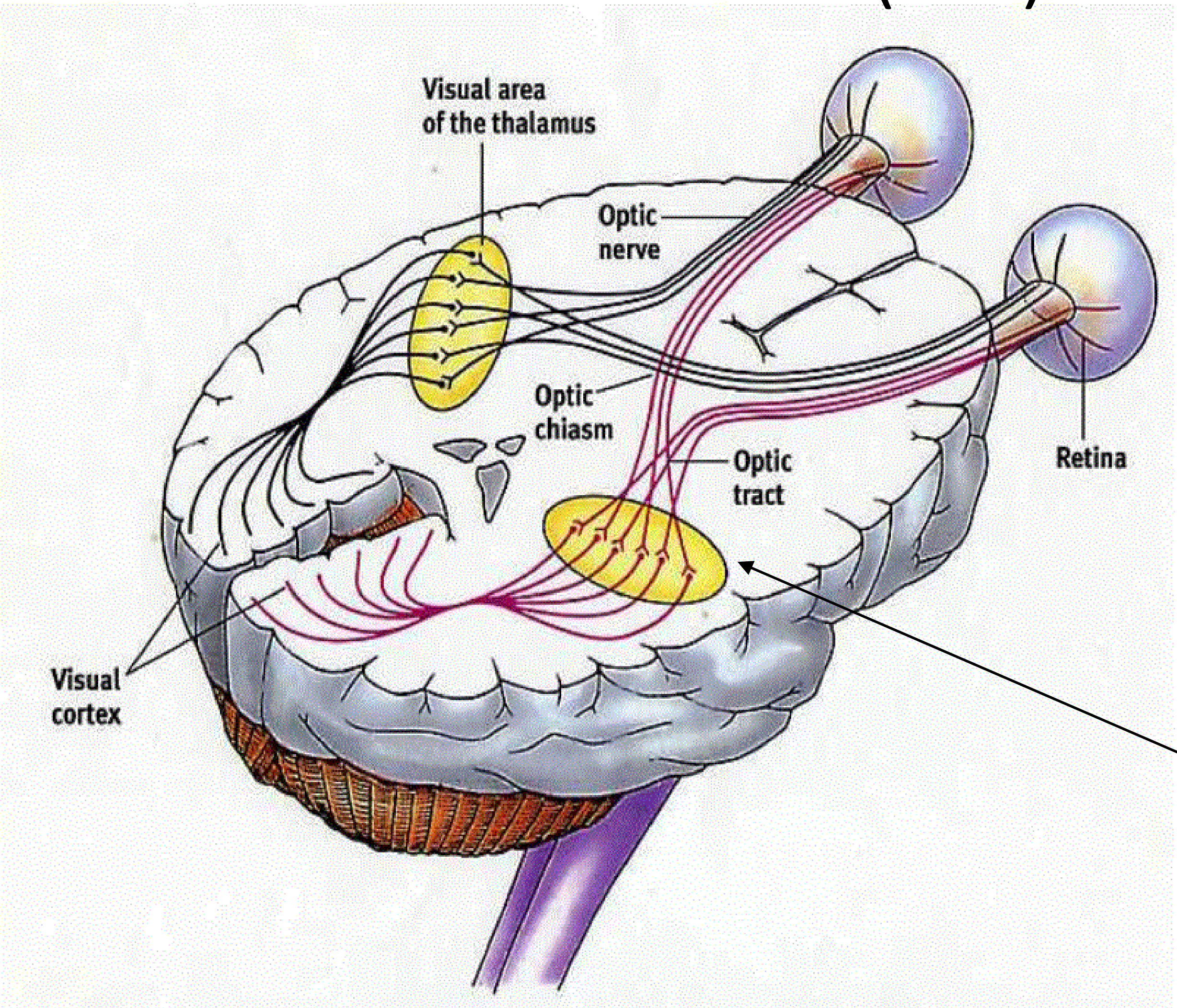


Single opponent cells



Double opponent cells

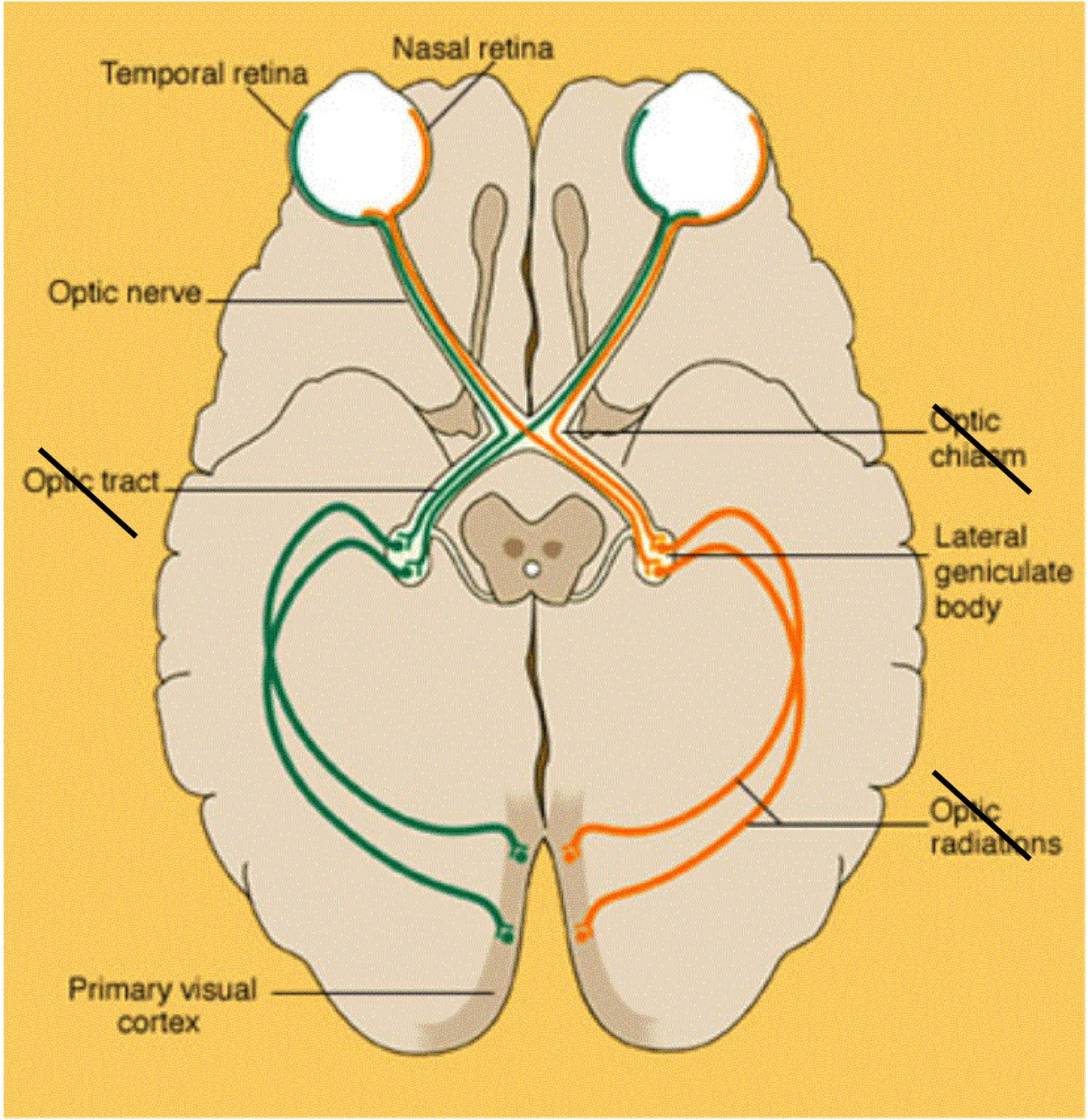
Early visual pathway: retina to cortex (V1)



Lateral geniculate nucleus (LGN)

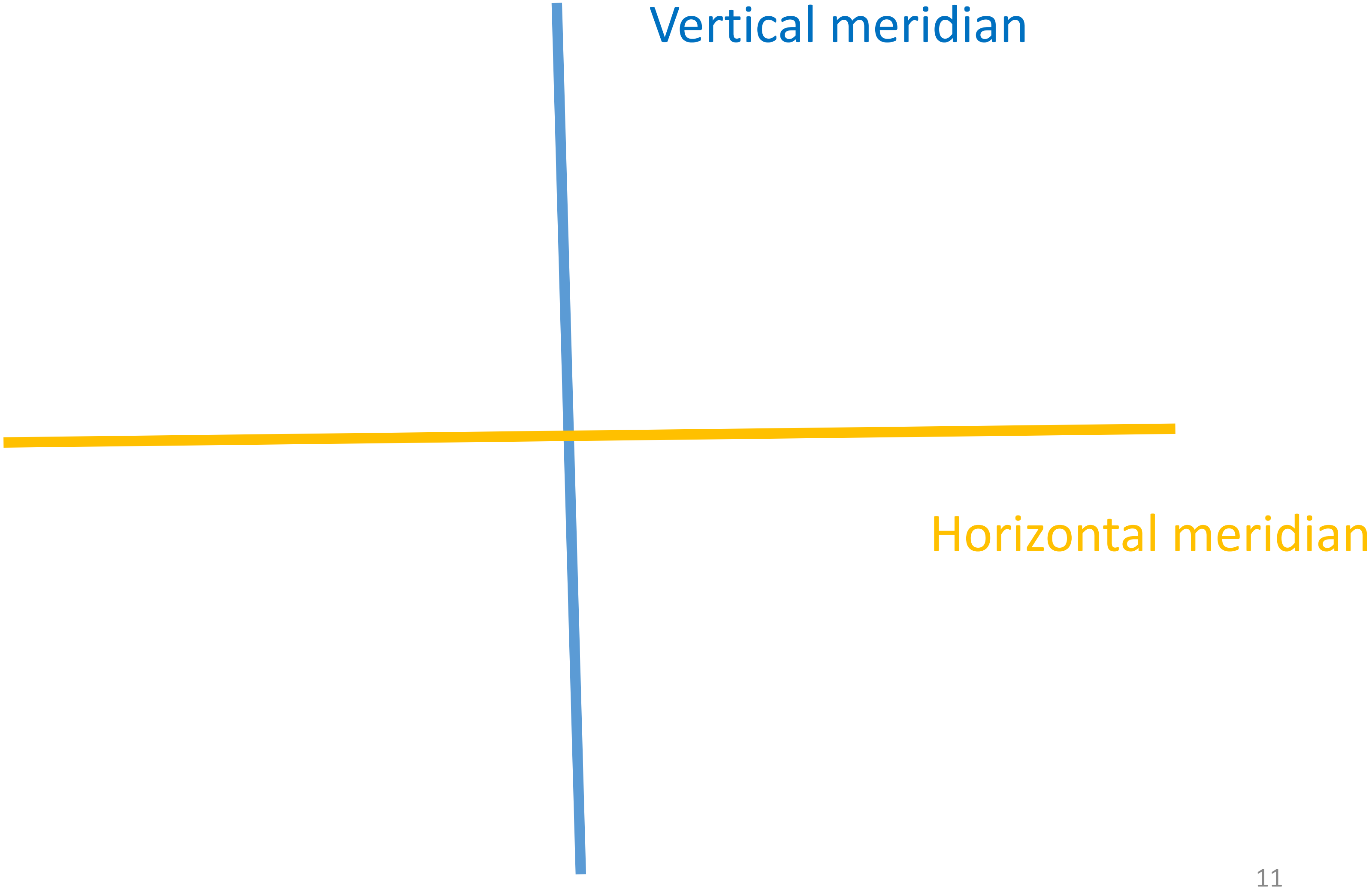
Left visual field

Right visual field

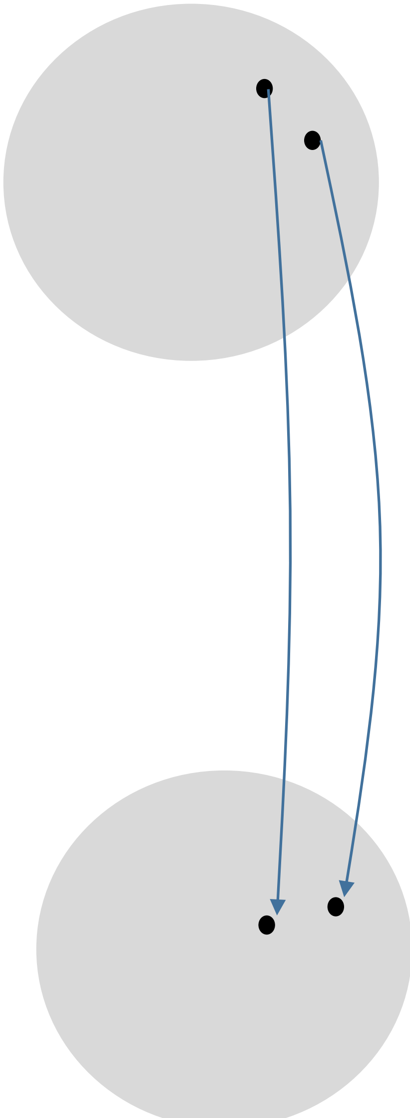


(LGN)

Polar coordinates on the retina



Retinotopic Map

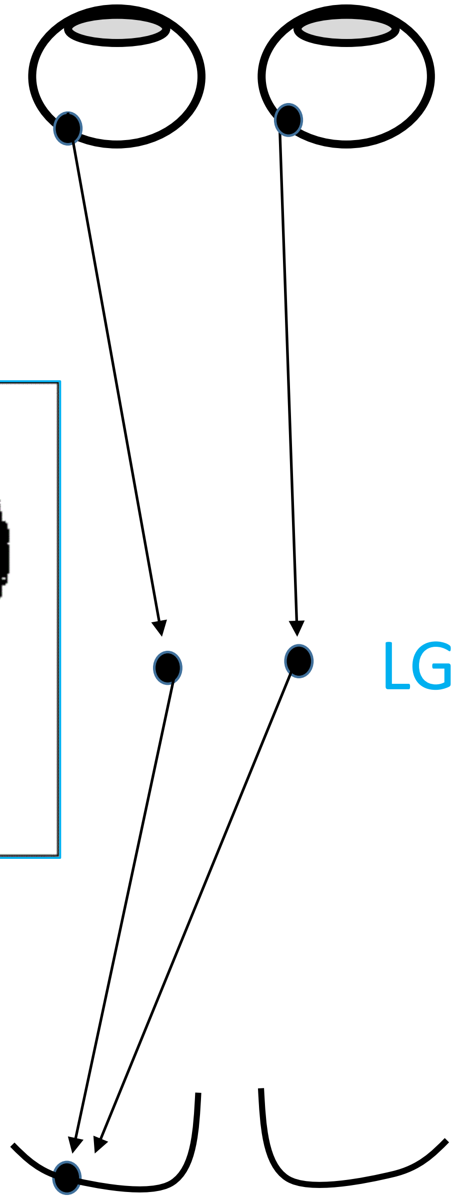


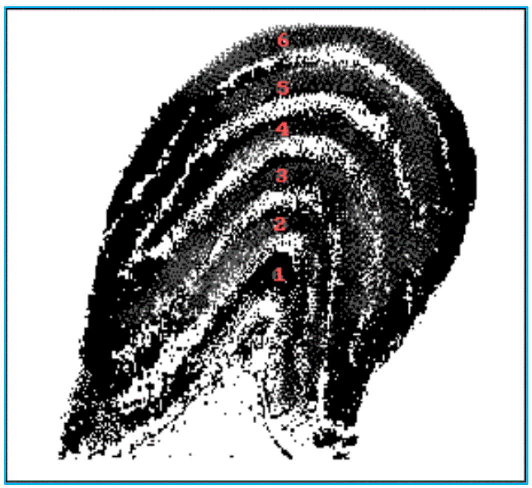
retina

Definition: Cells in a visual area are spatially arranged in a *retinotopic map* if physically adjacent cells in that area have adjacent receptive fields (and hence encode image in adjacent regions of the retina)

Some visual area
in the brain
e.g. LGN, V1

retina





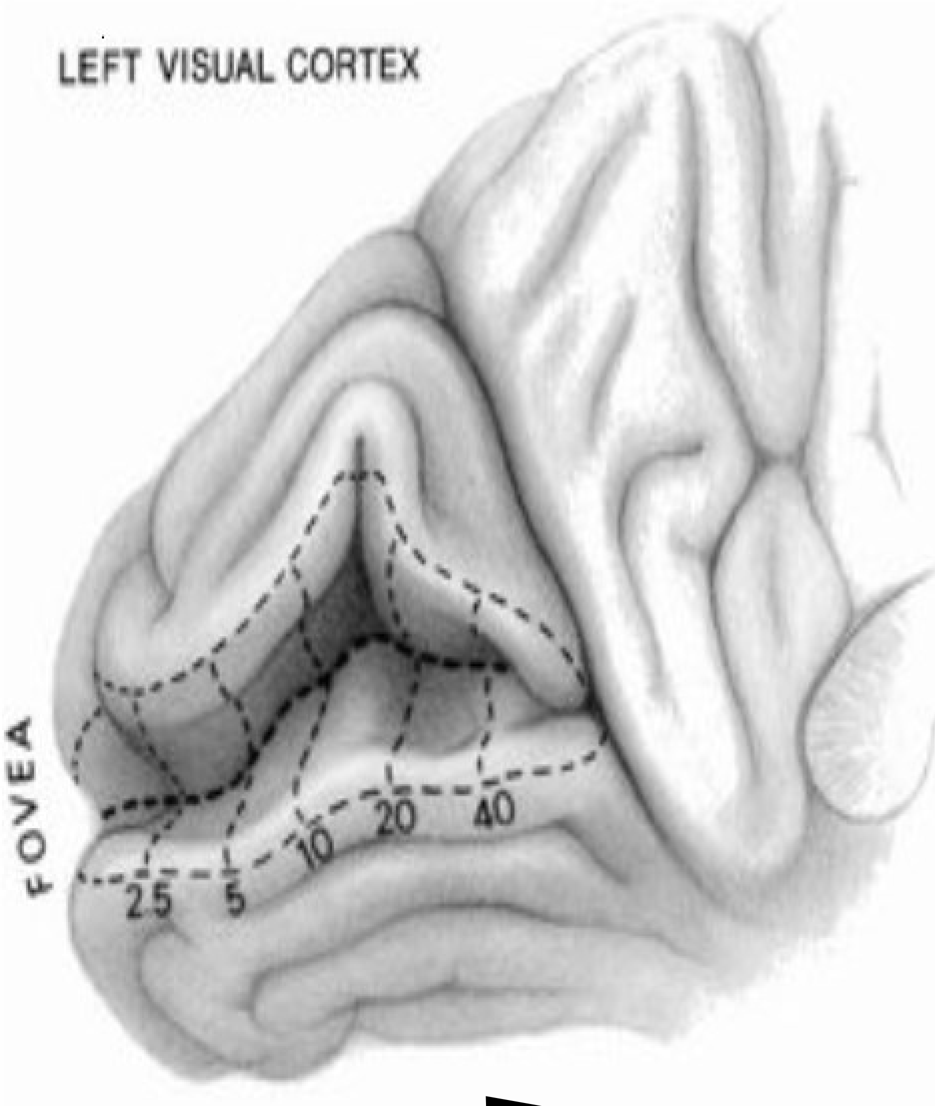
LGN

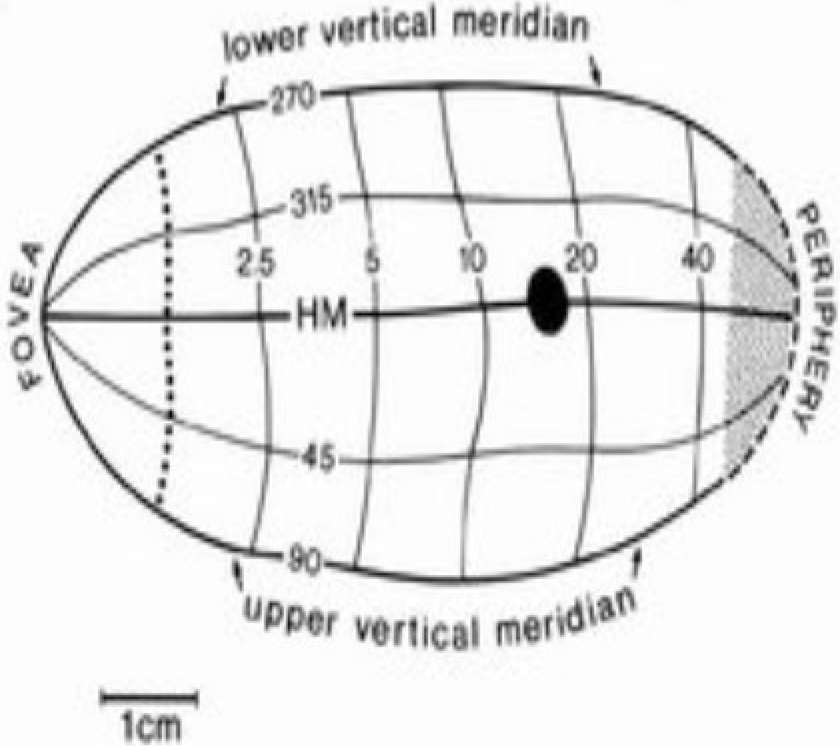
Layers 3, 4, 5, 6
(small receptive
fields, color
opponency)

Layers 1 and 2
(bigger receptive fields
time dependent,
no color opponency)

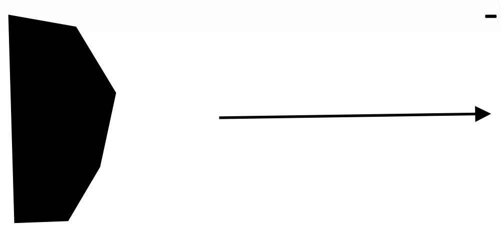
V1

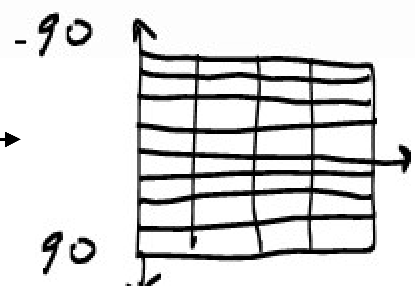
Polar coordinates in primary visual cortex (V1)



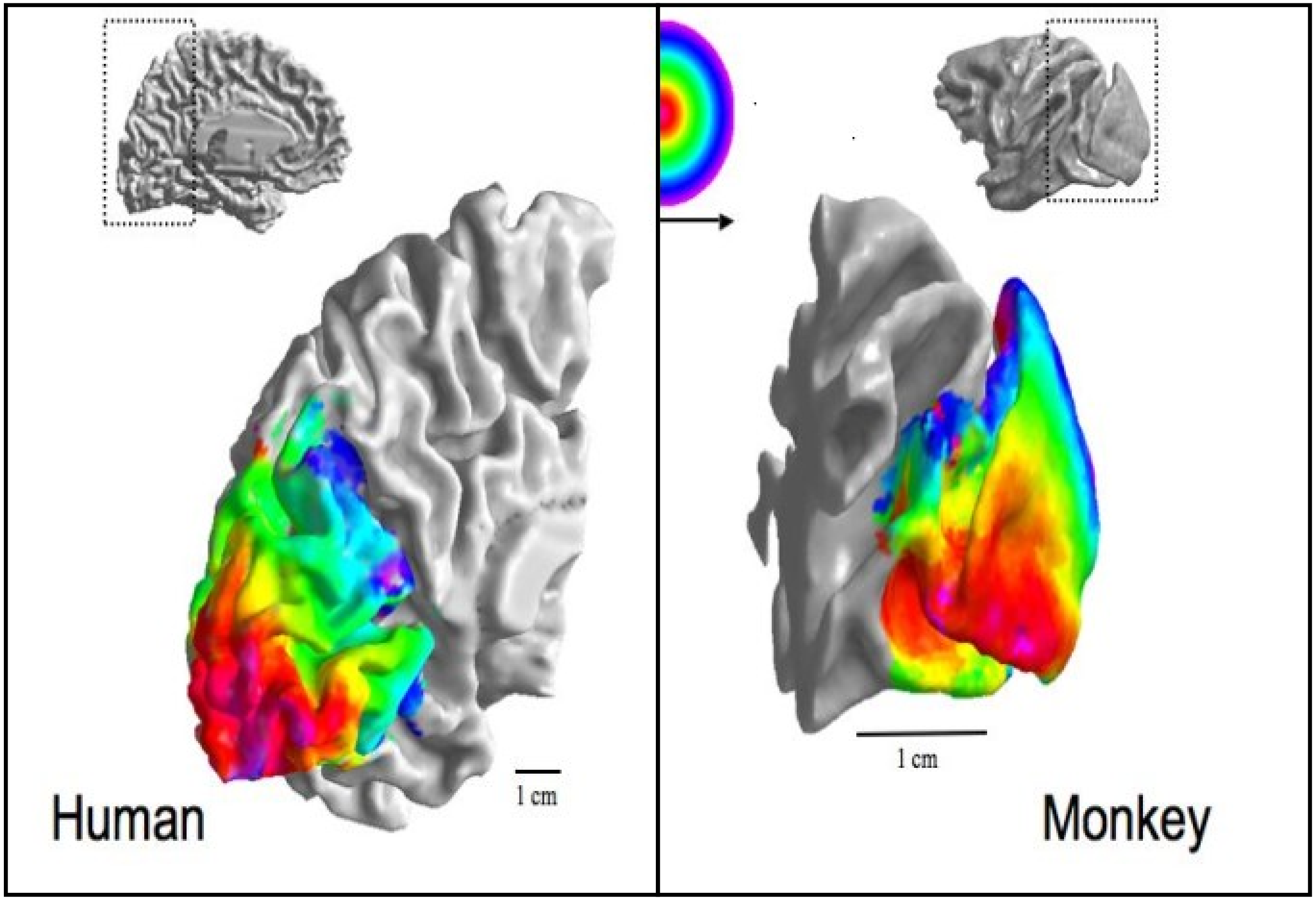


right
visual
field





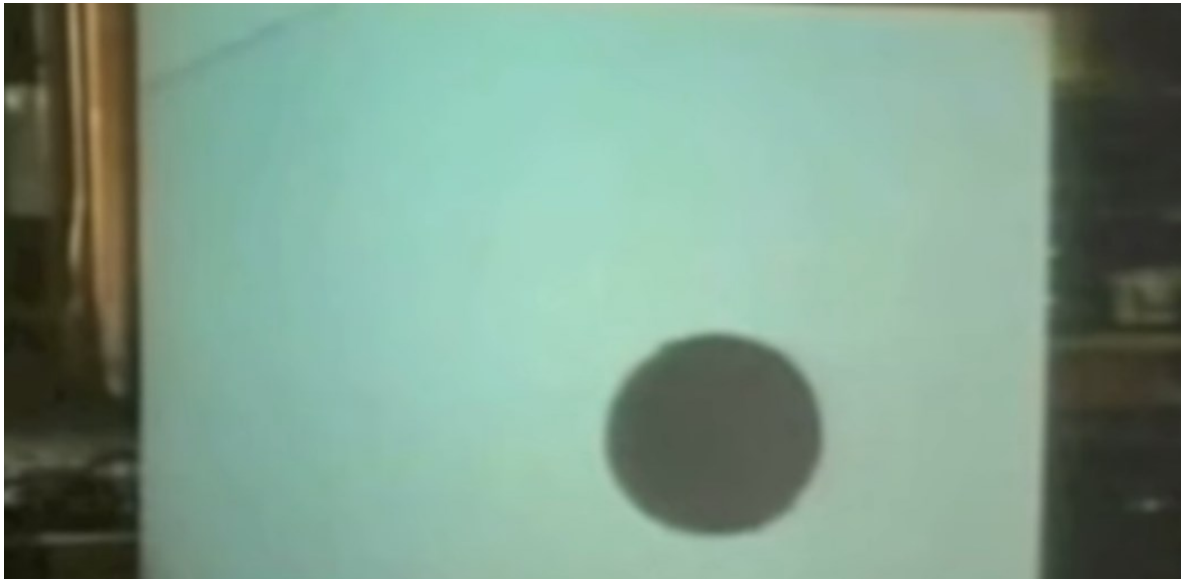
functional magnetic resonance imaging (fMRI)



As in the retina, the density of cells in V1 that represent the fovea is greater than the density the represent the periphery.

What do cells in V1 encode ?

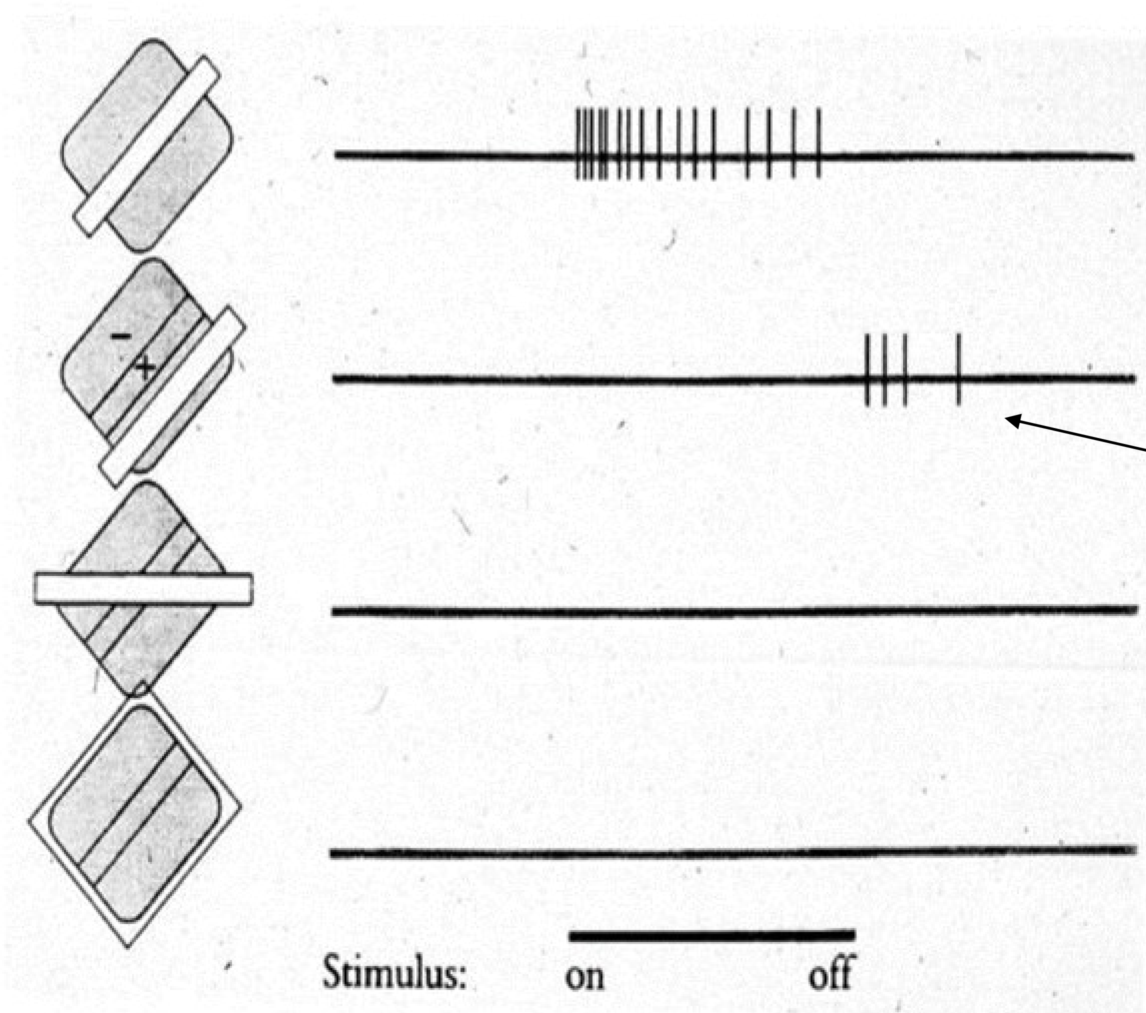
(Hubel & Wiesel 1959)



The moving slide (see 35 sec and on...)
http://www.youtube.com/watch?v=IOHayh06LJ4

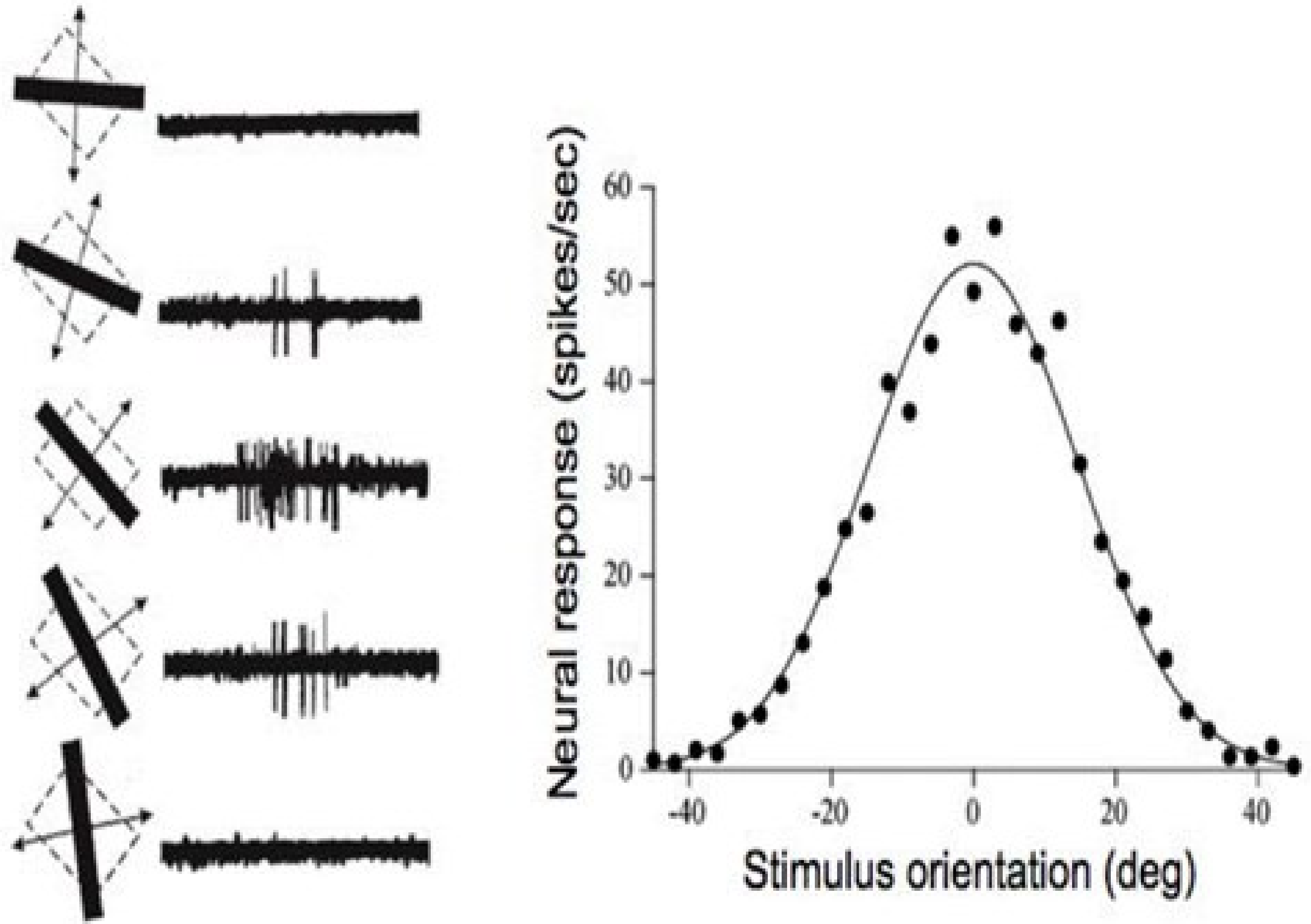
3 minutes of exploration:
https://www.youtube.com/watch?v=Cw5PKV9Rj3o

“Simple Cell”

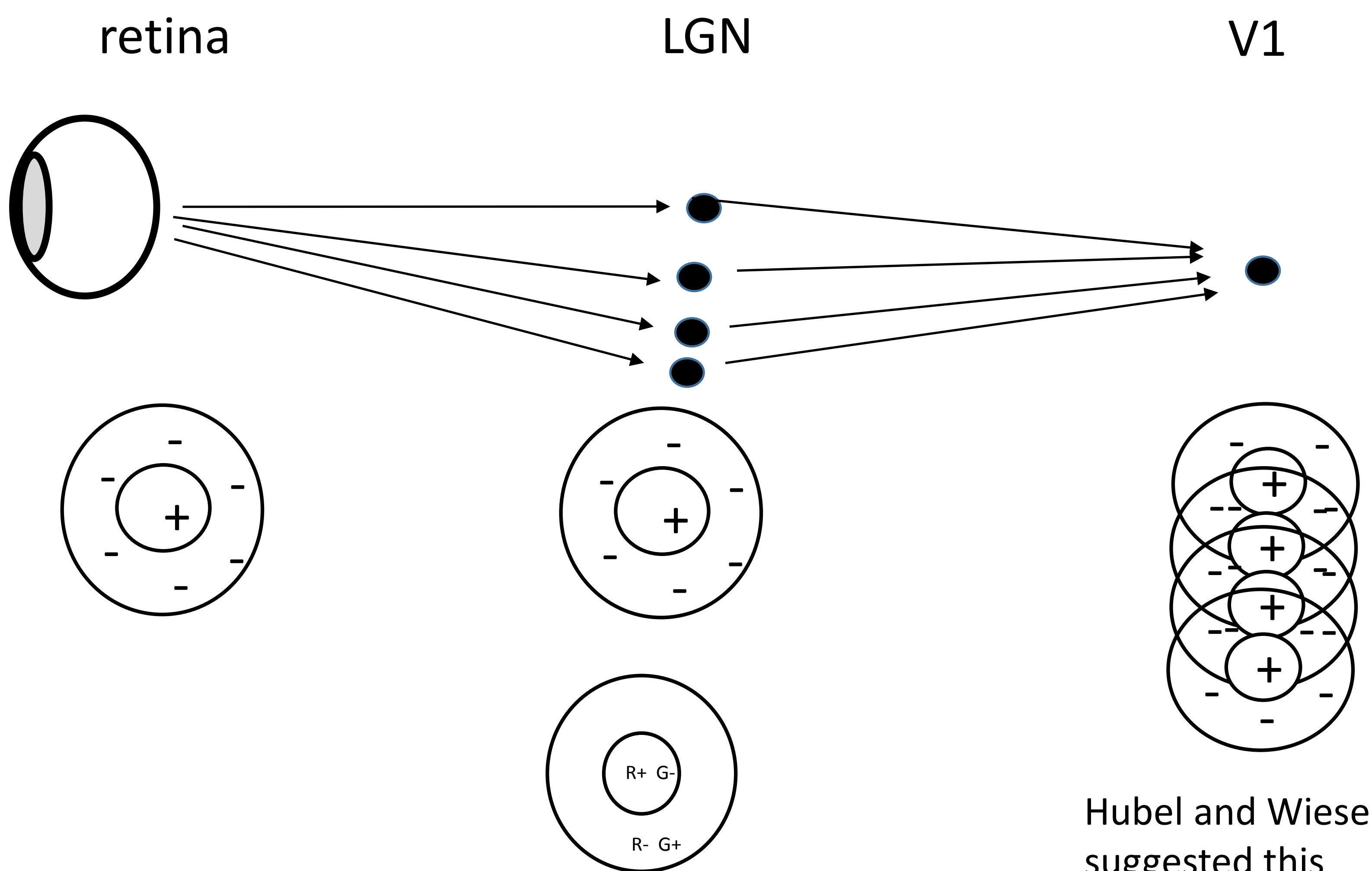


Temporal effects to be discussed in lecture 7

V1 Orientation Tuning Curve



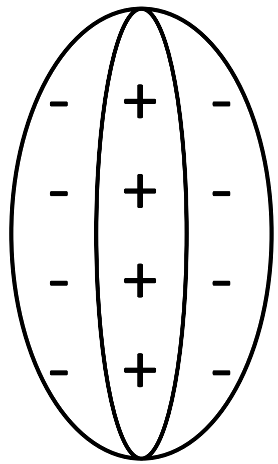
Hubel & Wiesel, 1968



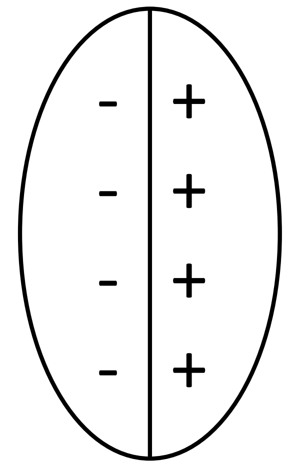
Hubel and Wiesel suggested this mechanism for elongated receptive field profile of V1 simple cell

Model of orientation selectivity in V1

"Line Detector"
(even)



"Edge Detector"
(odd)

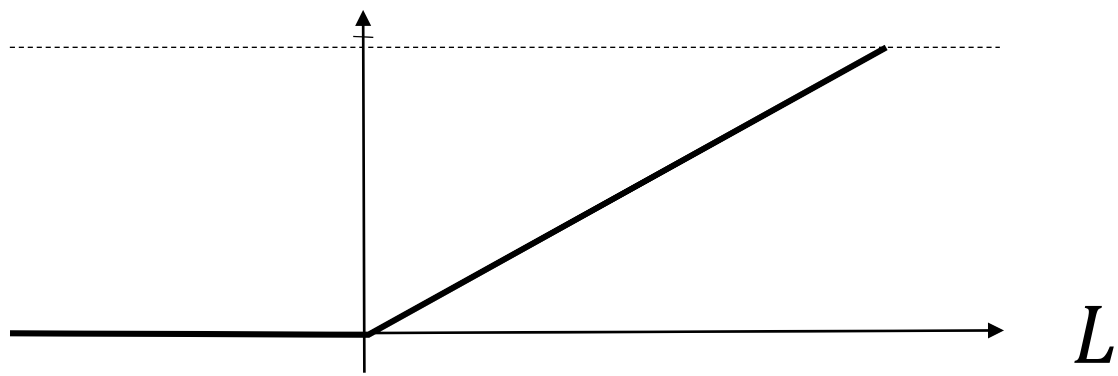


$$L = \sum_{x,y} f(x - x_0, y - y_0)\, I(x, y)$$

Cell centered at (x_0, y_0)

Cell response model:
half-wave rectification

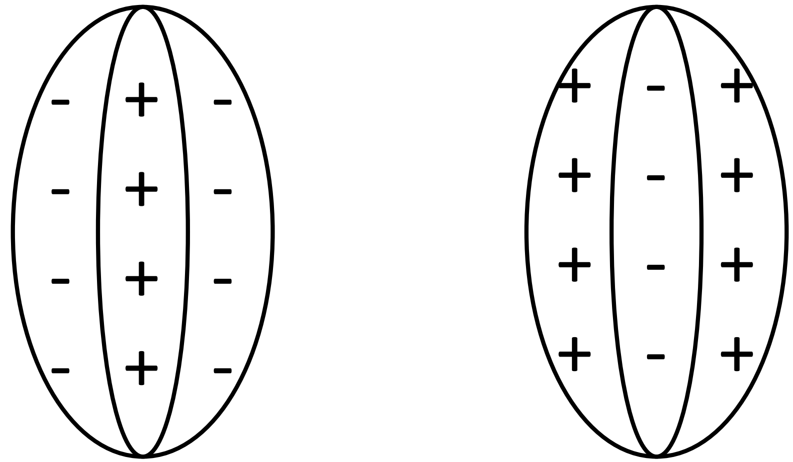
Response (spike rate)



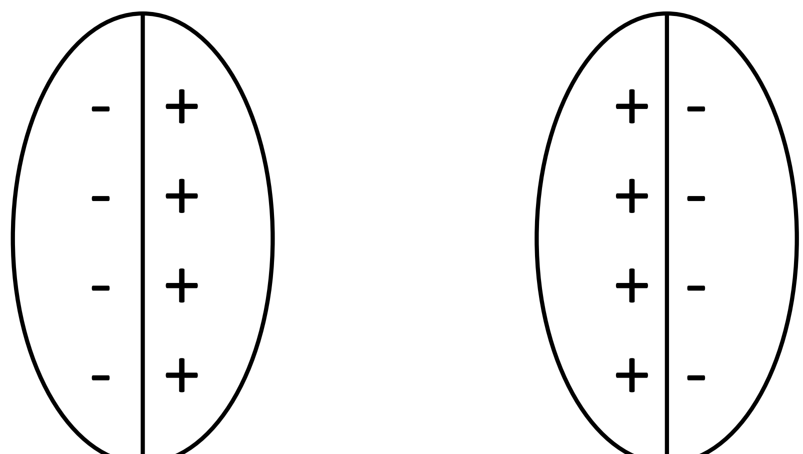
Quasi-linear : cell response is linear over some range.

How to encode the negative values of L ?
(similar idea to last lecture)

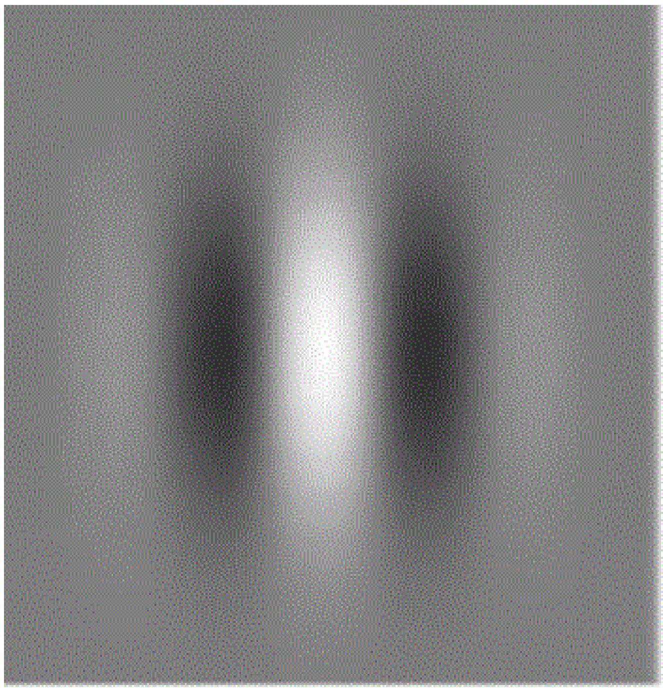
Line Detector
(even)



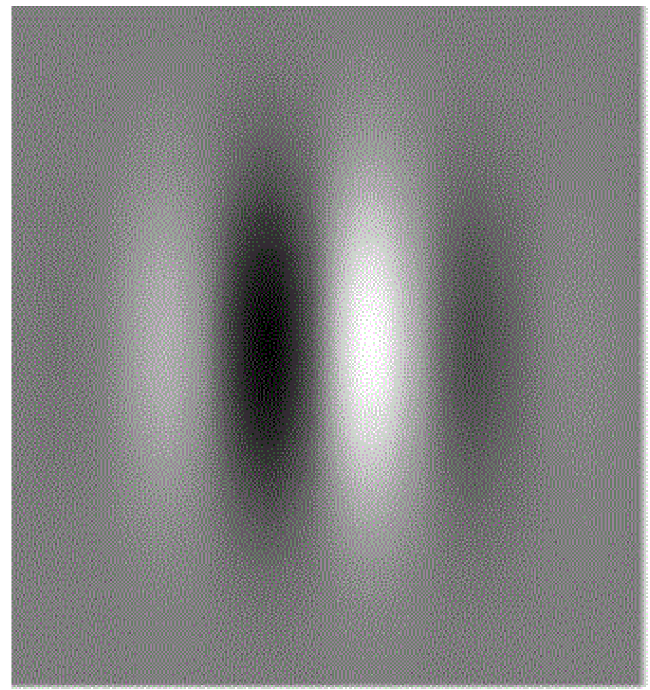
Edge Detector
(odd)



"Gabor" function: classical model of simple cell



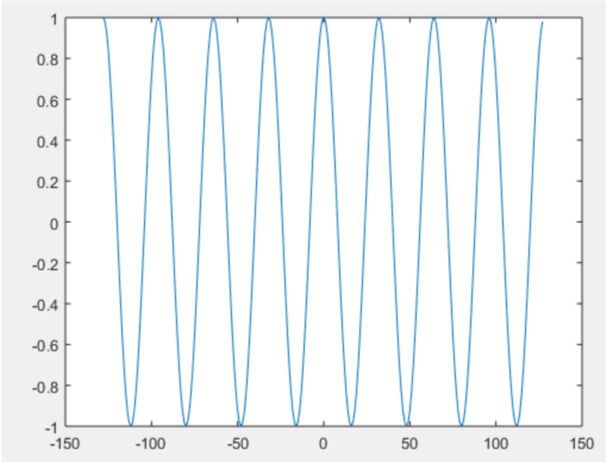
Line (even)



Edge (odd)

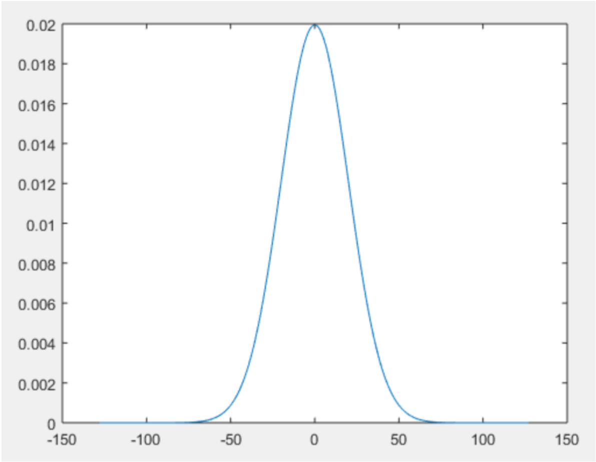
1D Cosine Gabor

cosine



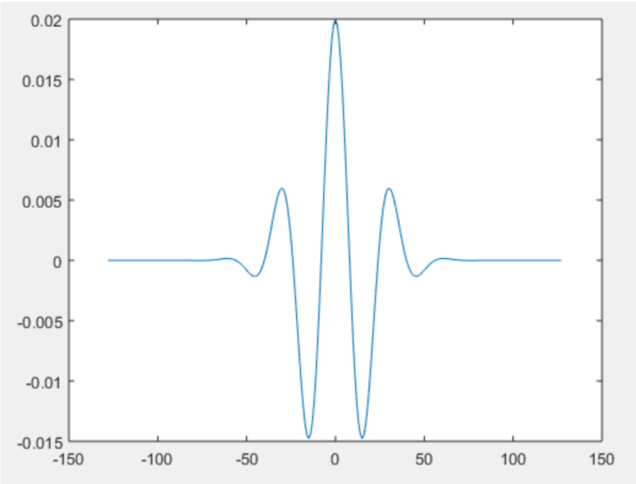
*

Gaussian



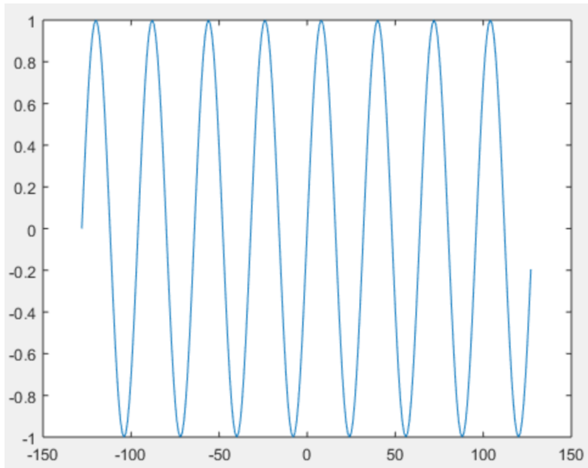
=

cosine Gabor



1D Sine Gabor

sine



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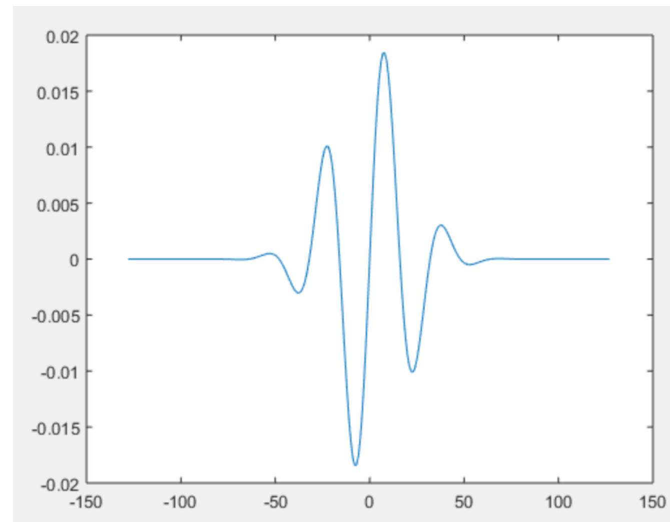
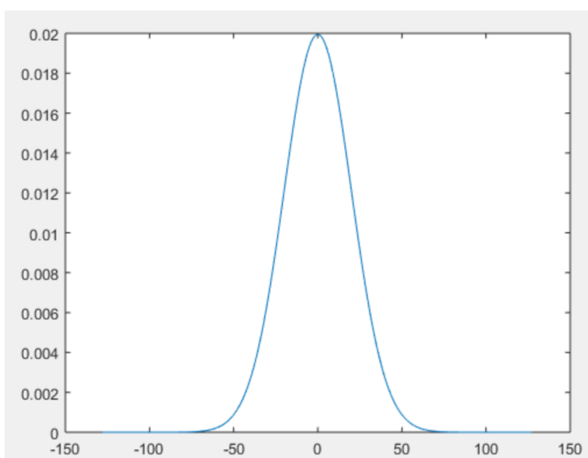
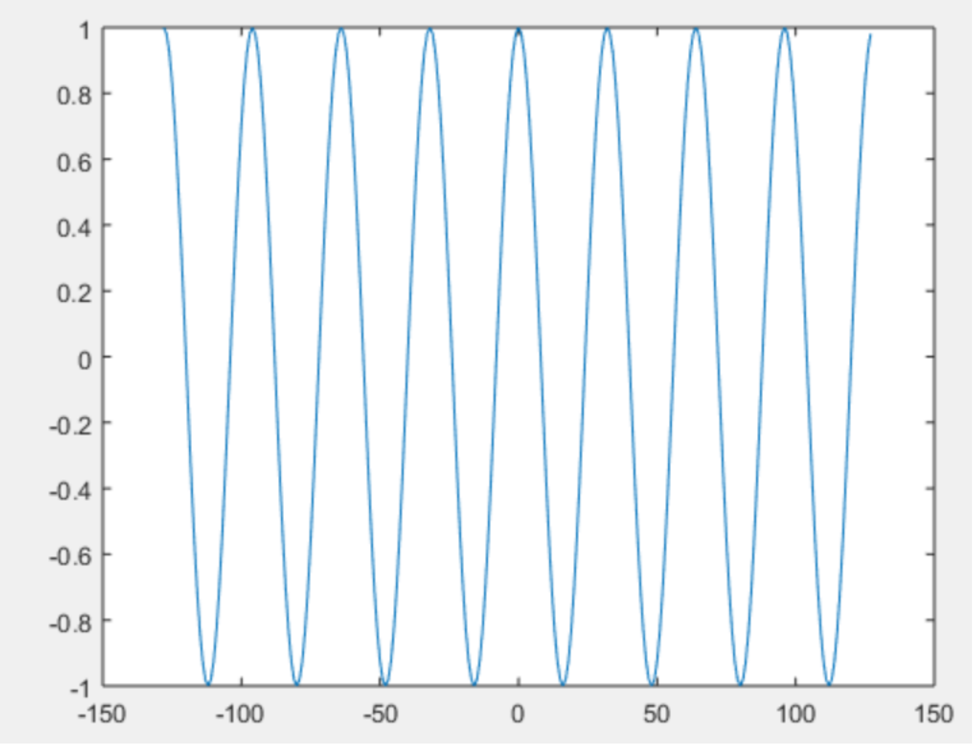
sine Gabor



Gaussian



(Sampled) Cosine



$$\cos(\frac{2\pi}{N} k_x\, x)$$

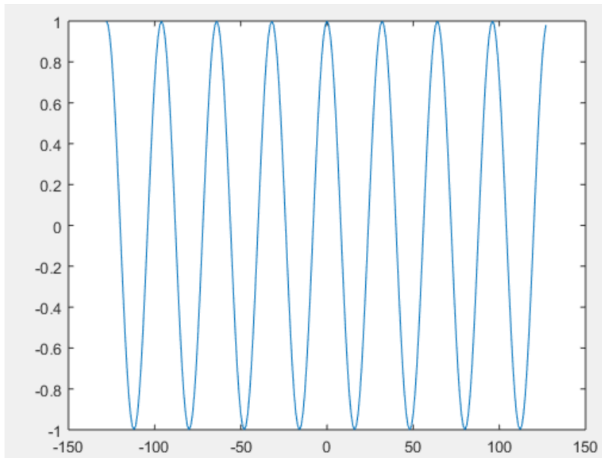
k_x is spatial frequency

$$e.g. \quad k_x = 8$$

$$N = 256$$

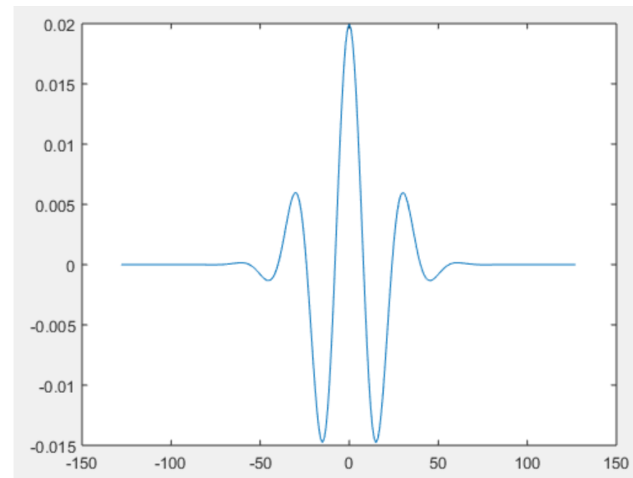
1D Cosine Gabor

$$\cos(\frac{2\pi}{N} k_x \, x)$$

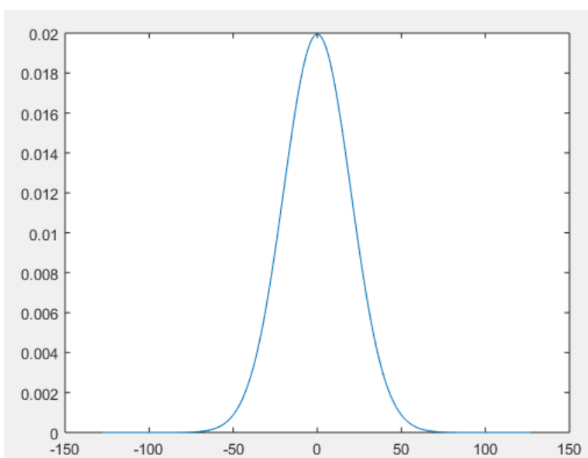


$*$

$=$

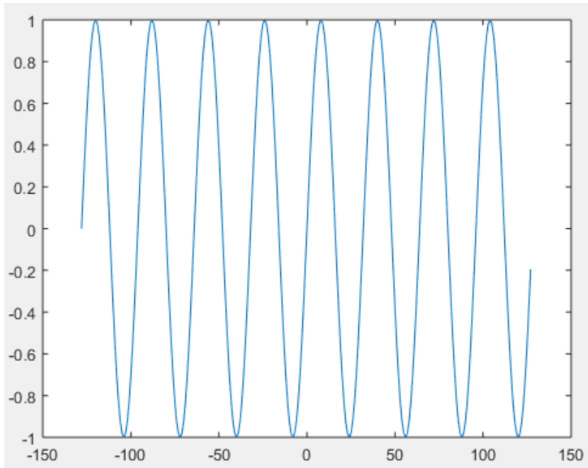


$$\frac{1}{\sqrt{2\pi}\,\sigma} \; e^{-\frac{x^2}{2\sigma^2}}$$



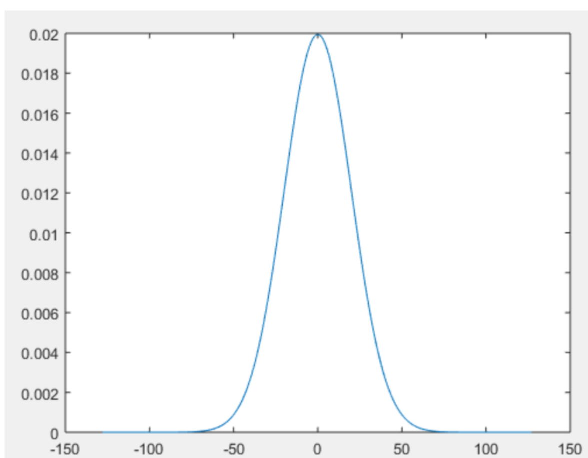
1D Sine Gabor

$$\sin(\frac{2\pi}{N} k_x\, x)$$



$*$

$$\frac{1}{\sqrt{2\pi}\,\sigma}\; e^{-\frac{x^2}{2\sigma^2}}$$



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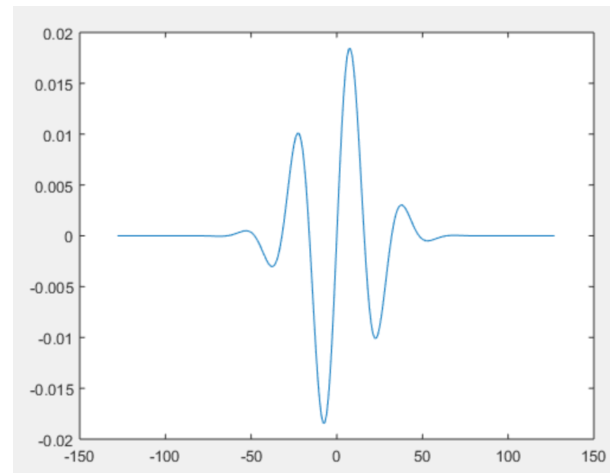
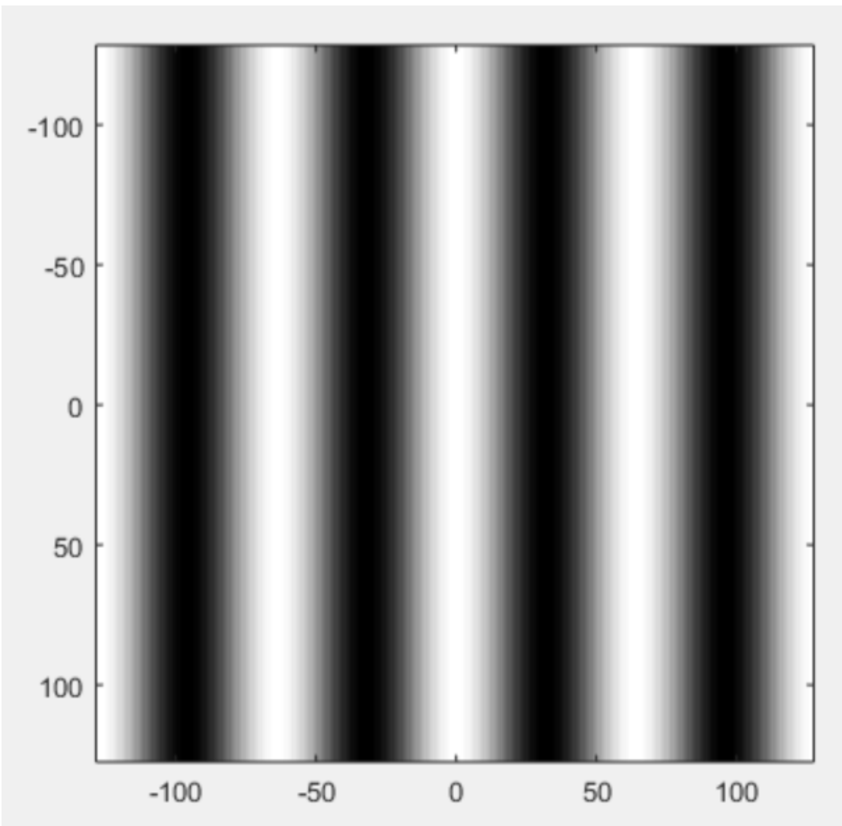


2D cosine



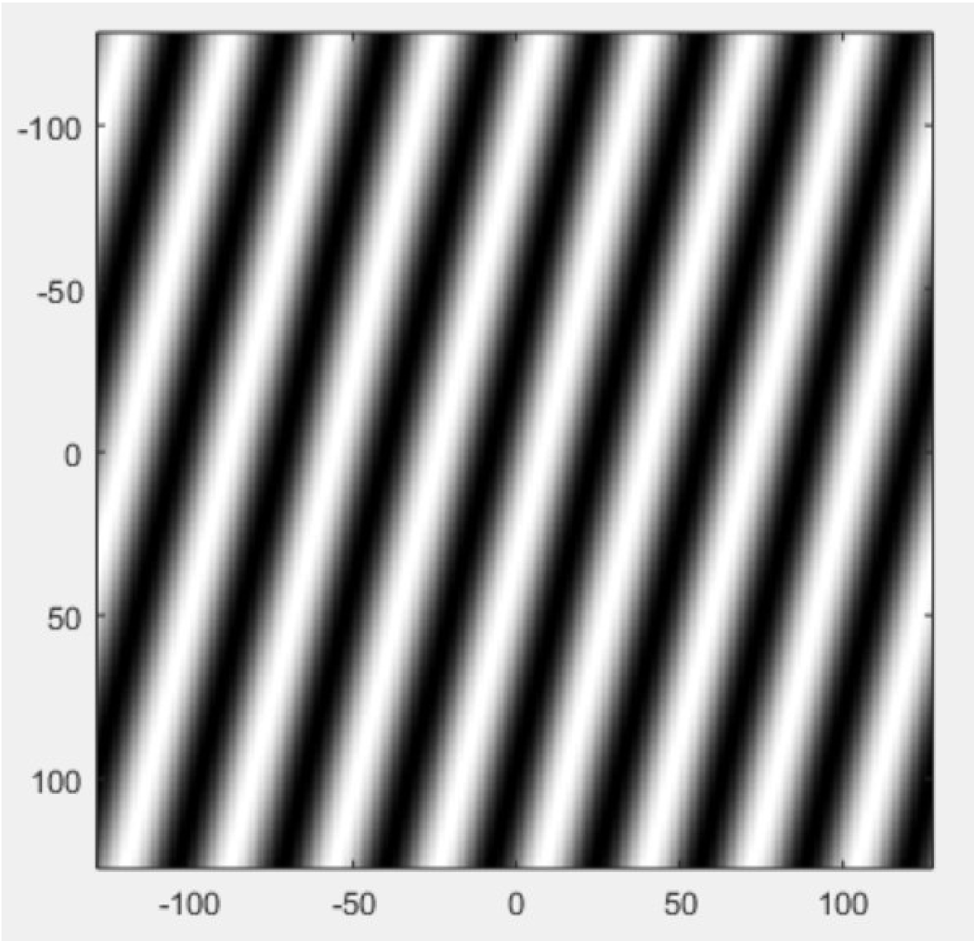
$$\cos\left(\frac{2\pi}{N}(k_x\, x \; + \; k_y\, y)\right)$$

$$e.g. \quad k_x \; = 4$$

$$k_y \; = 0$$

$$N = 256$$

2D sine



$$\sin\left(\frac{2\pi}{N}(k_x\, x + k_y\, y)\right)$$

$$e.g. \quad k_x = 8$$

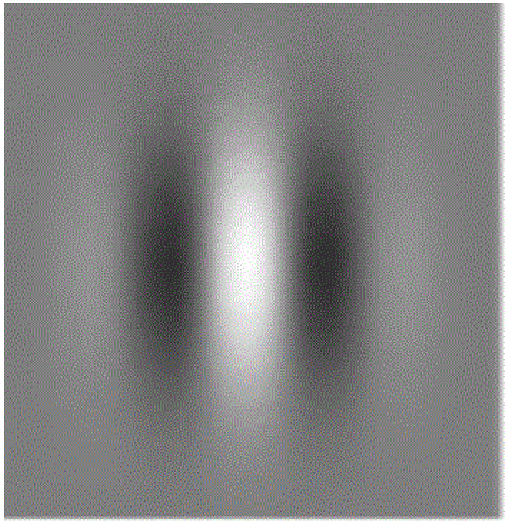
$$k_y = 2$$

$$N = 256$$

model of simple cell: 2D Gabor

$$G(x, y, \sigma) \quad \cos\left(\frac{2\pi}{N}(k_x\, x \;+\; k_y\, y)\right)$$

$e.g. \quad k_y = 0$



$$G(x, y, \sigma) \quad \sin\left(\frac{2\pi}{N}(k_x\, x \;+\; k_y\, y)\right)$$

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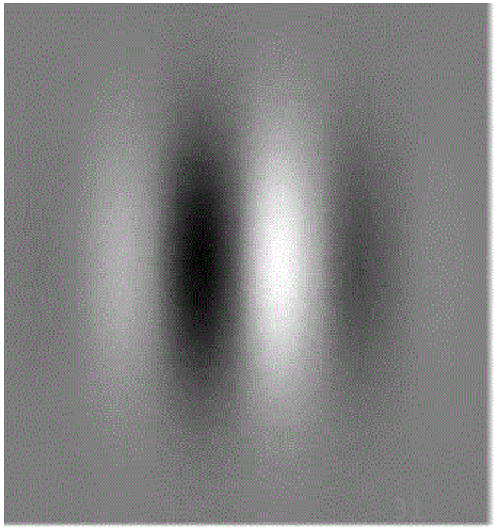
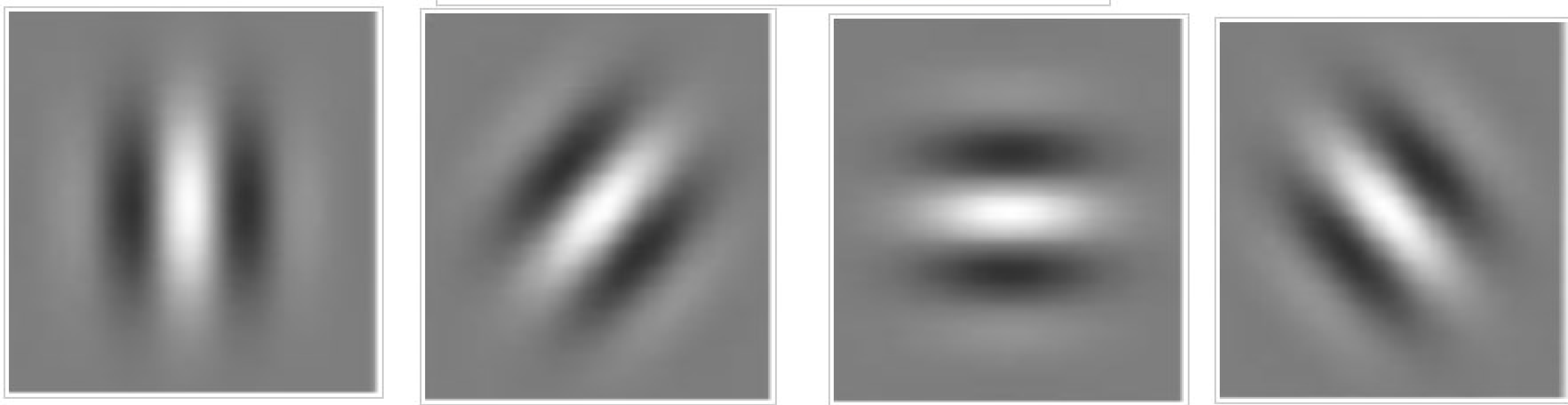
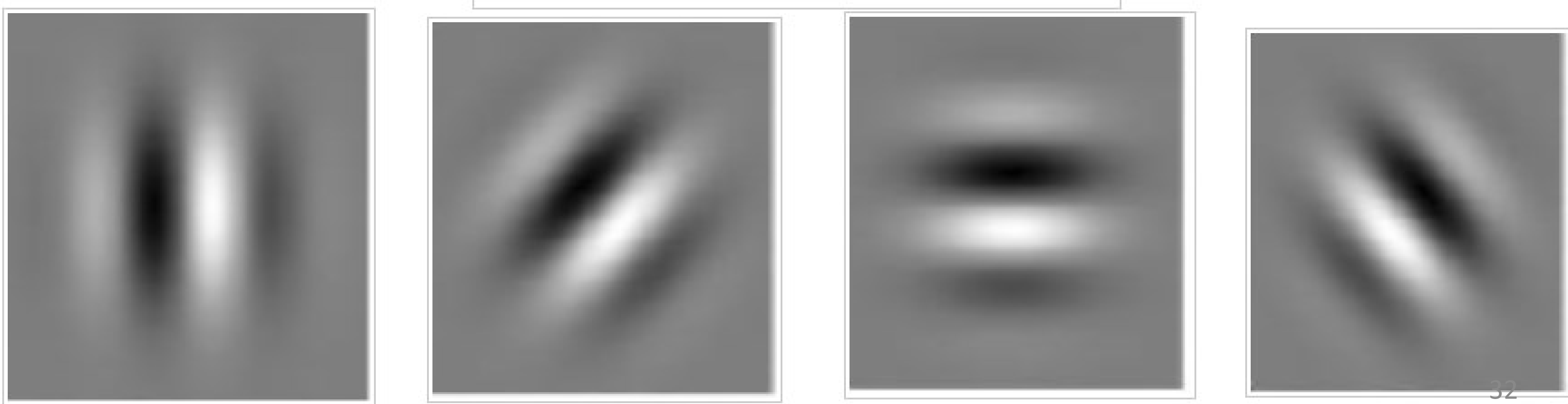


2D cosine Gabors



2D sine Gabors



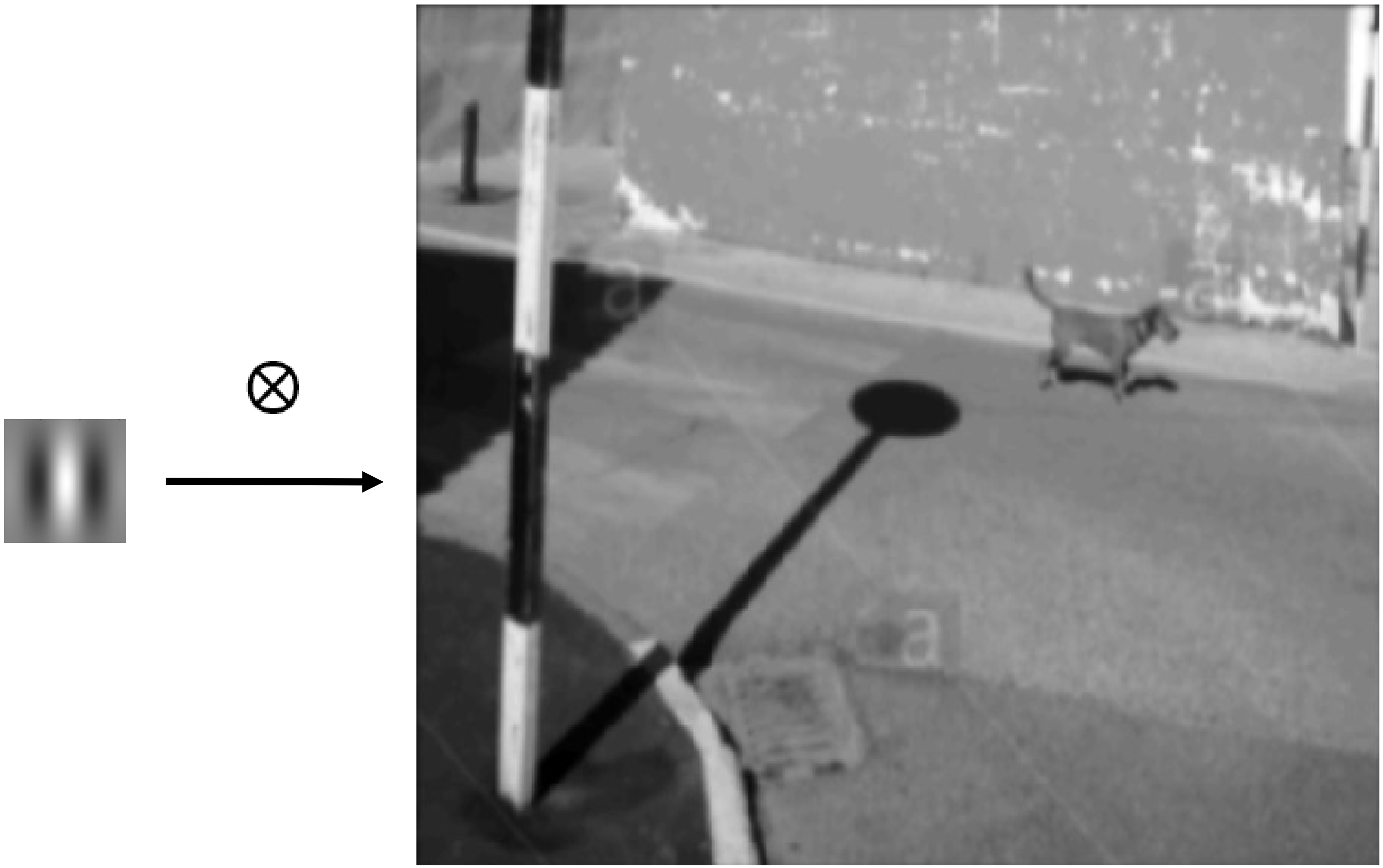
- What is the response of *a family of Gabor cells* to a single image ?

  e.g. Consider shifted versions of the Gabor cell.

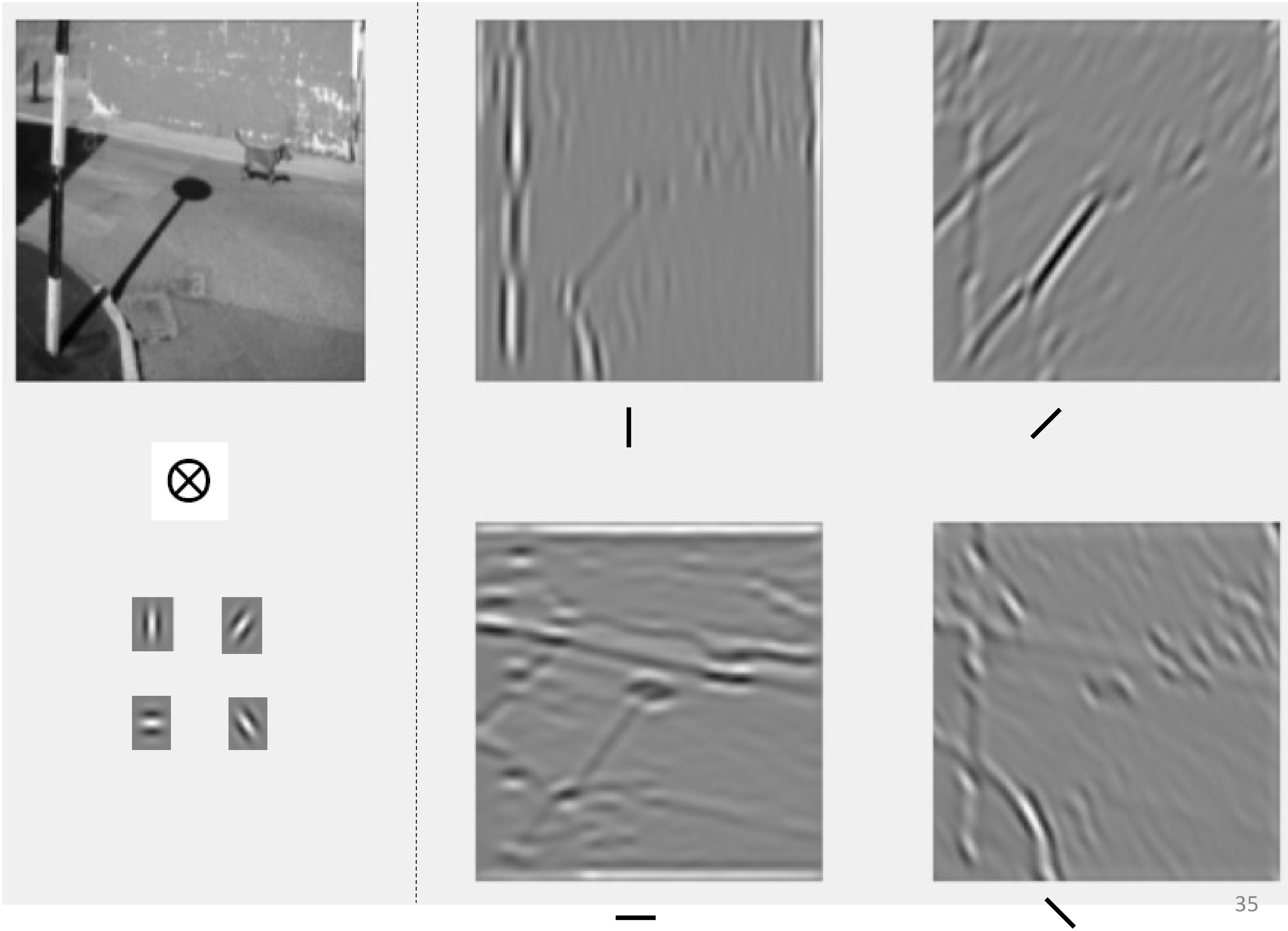
- What is the response of a single Gabor cell to *a parameterized family of images* ?

  e.g. thin white line at different positions in receptive field

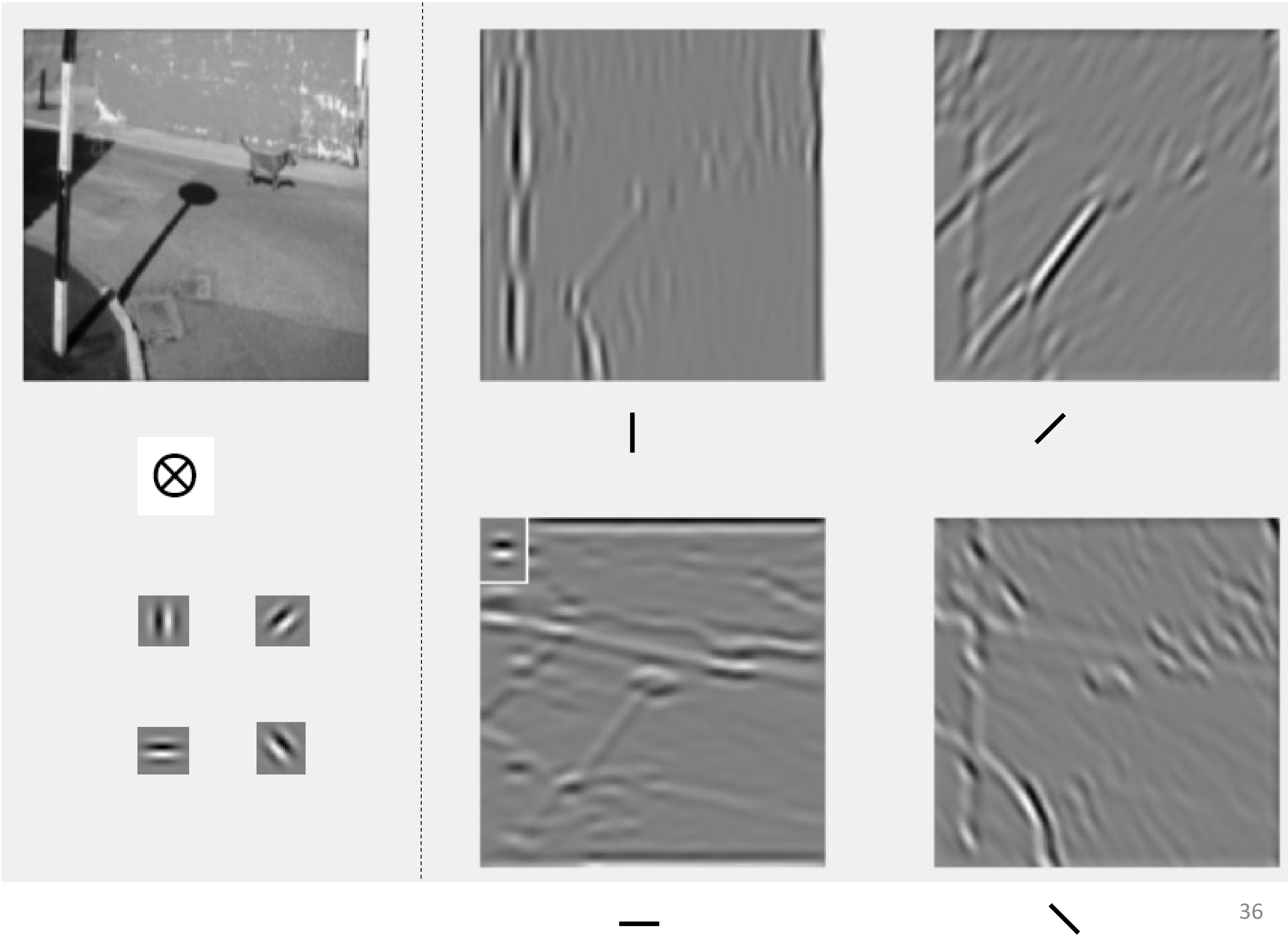
What is the response of *a family of Gabor cells* to a single image?



cross correlation with (four) cosine Gabors



cross correlation with (four) sine Gabors



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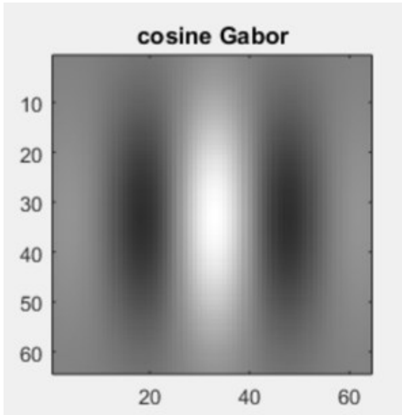
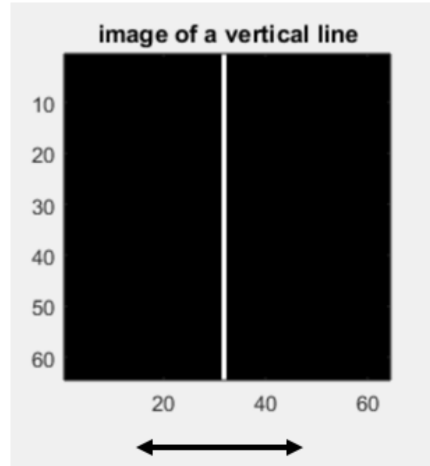
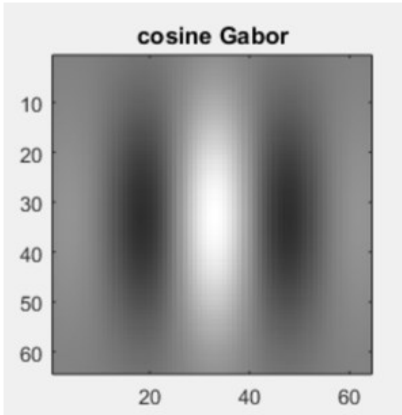
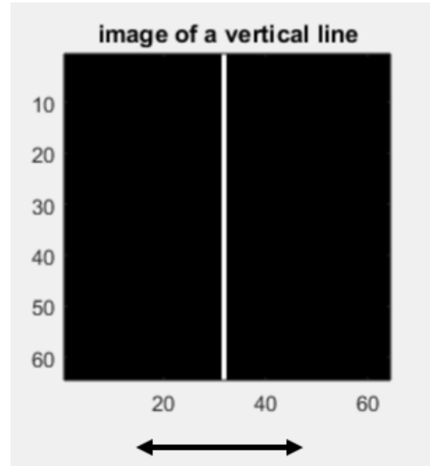




$$L \equiv \sum_{x,y} cosGabor(x, y)\ I(x, y;\ x_{white\ line})$$

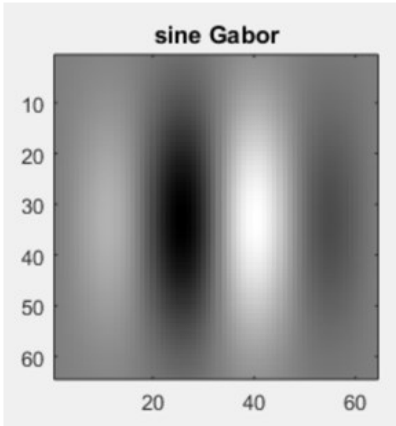


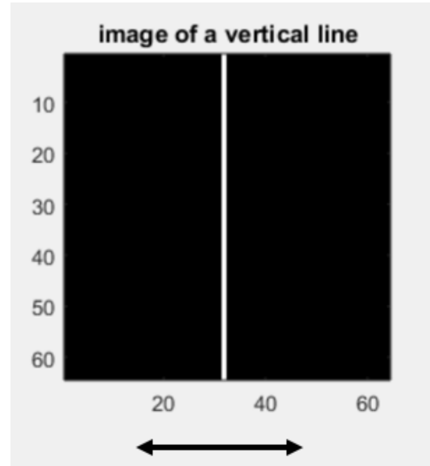


$$L \equiv \sum_{x,y} cosGabor(x\,,y)\ I(x,y;\ x_{white\ line})$$

$$G(x,y,\sigma)\ \cos\left(\frac{2\pi}{N}(k_x\,x)\right)$$

Non-zero only at x position of vertical line

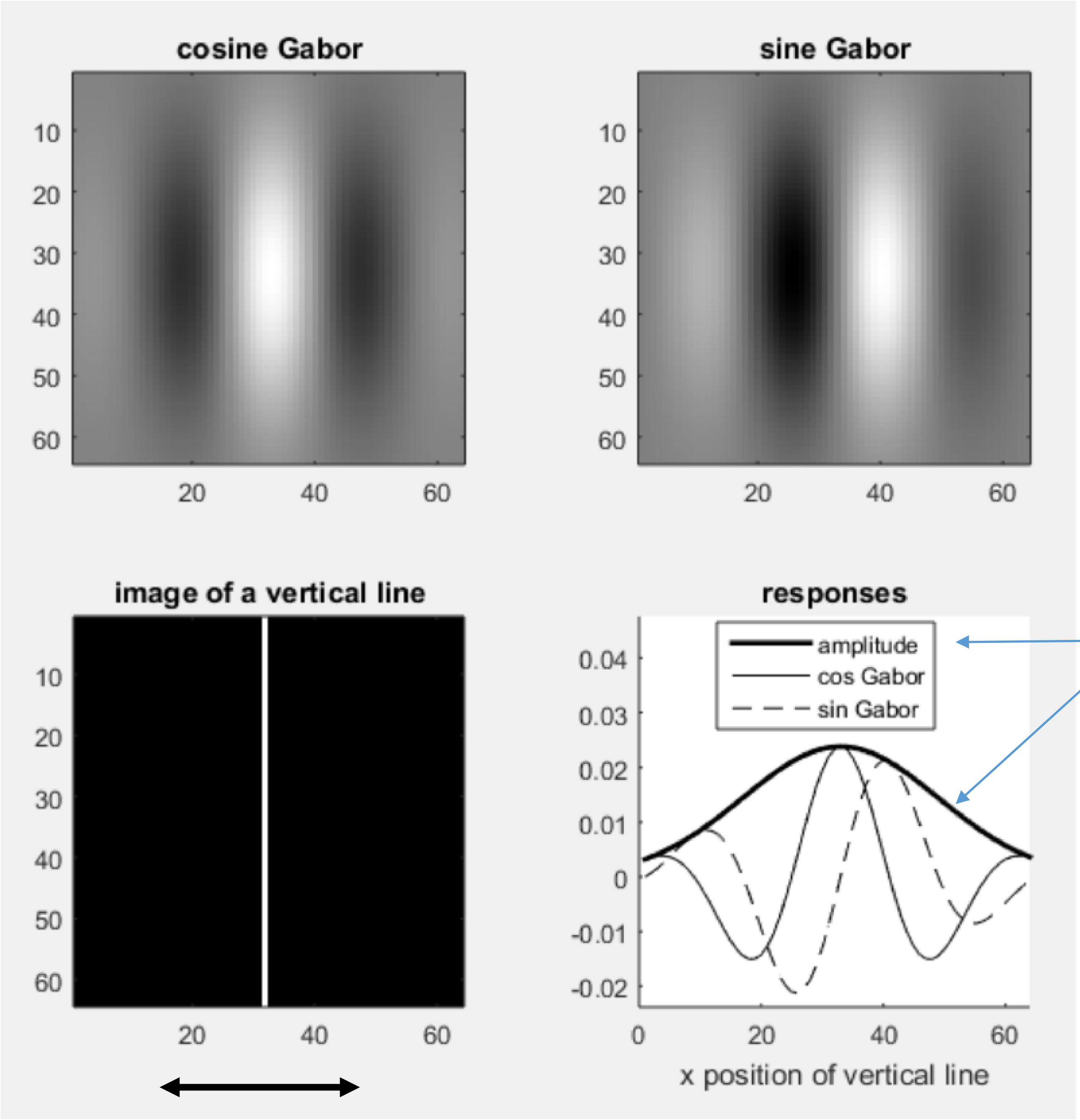




$$L \equiv \sum_{x,y} sinGabor(x, y)\ I(x, y;\ x_{white\ line})$$

$$G(x, y, \sigma)\ \ sin\left(\frac{2\pi}{N}(k_x\, x)\right)$$

Non-zero only at x position of vertical line



Gaussian envelope (discuss next lecture)