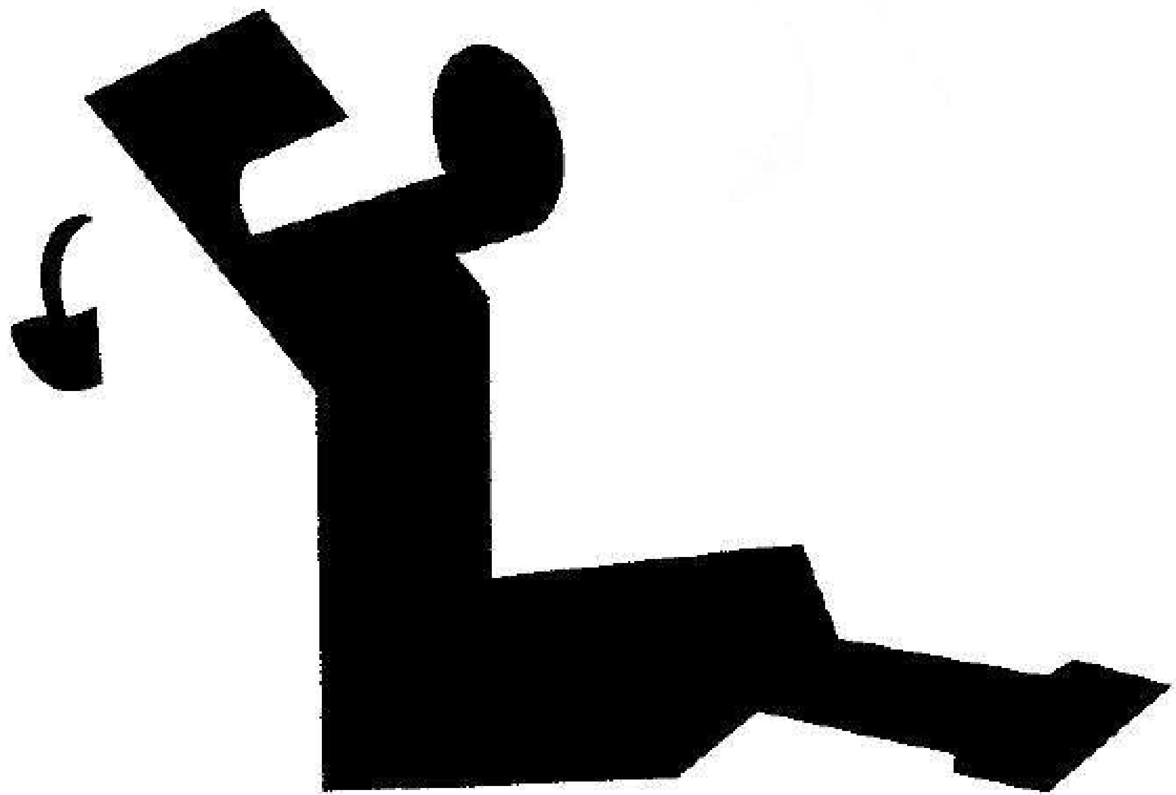
Computer Vision

Edge and Texture

Jianbo Shi

how our brain acts when we see this:



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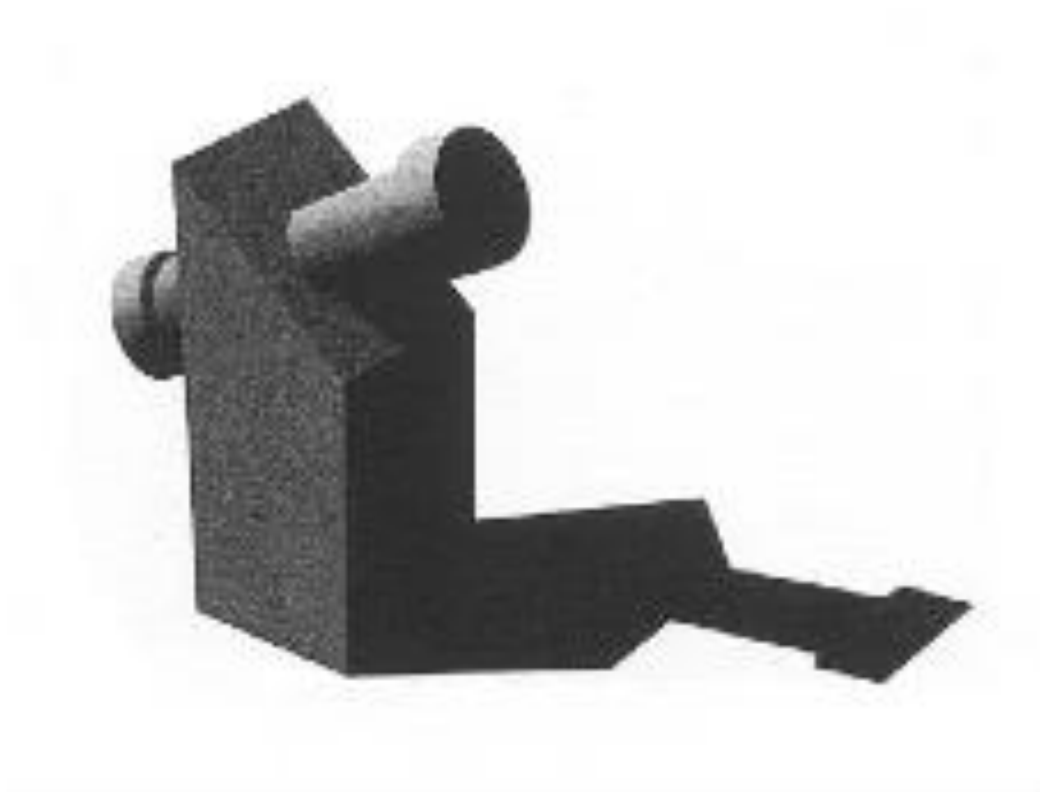
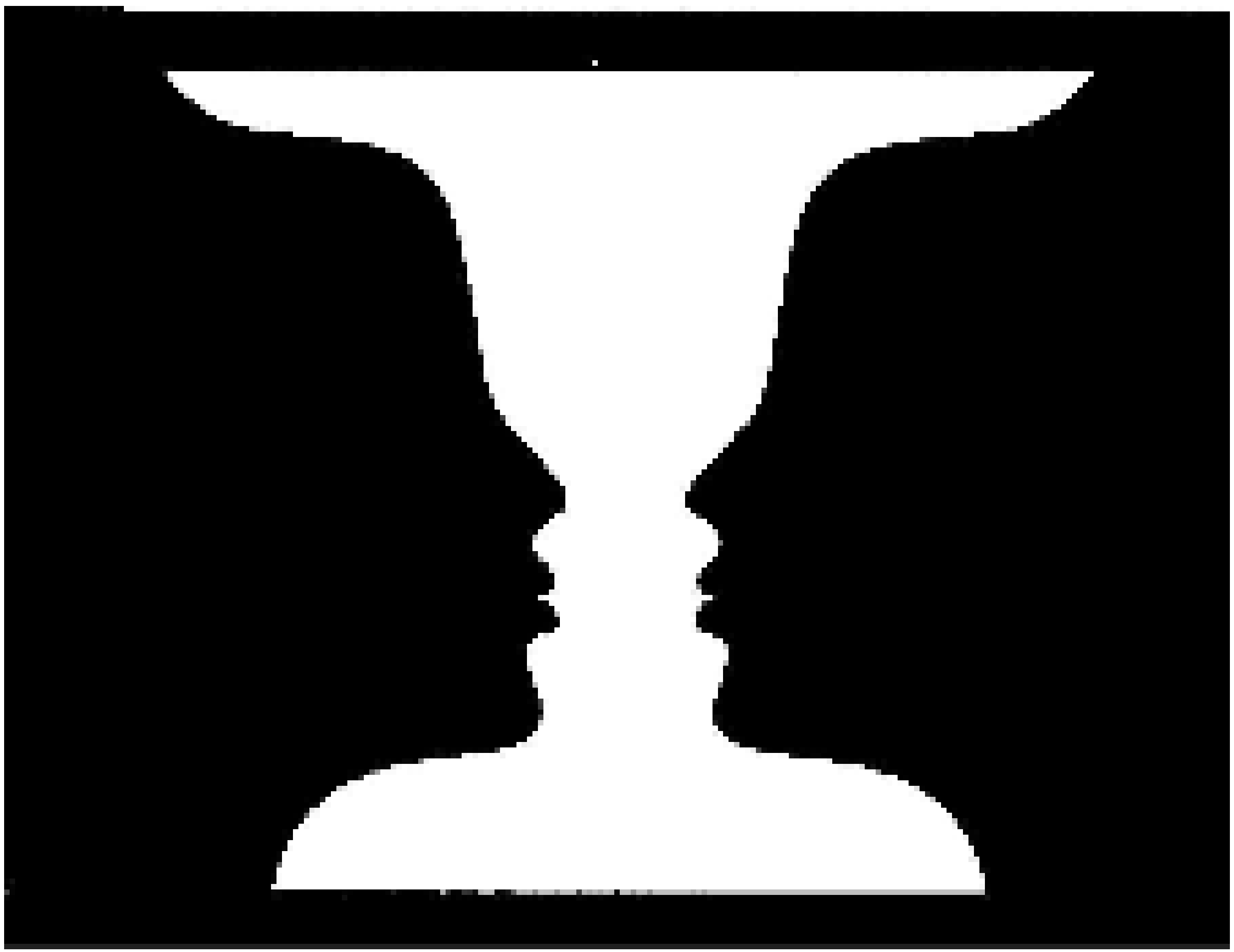
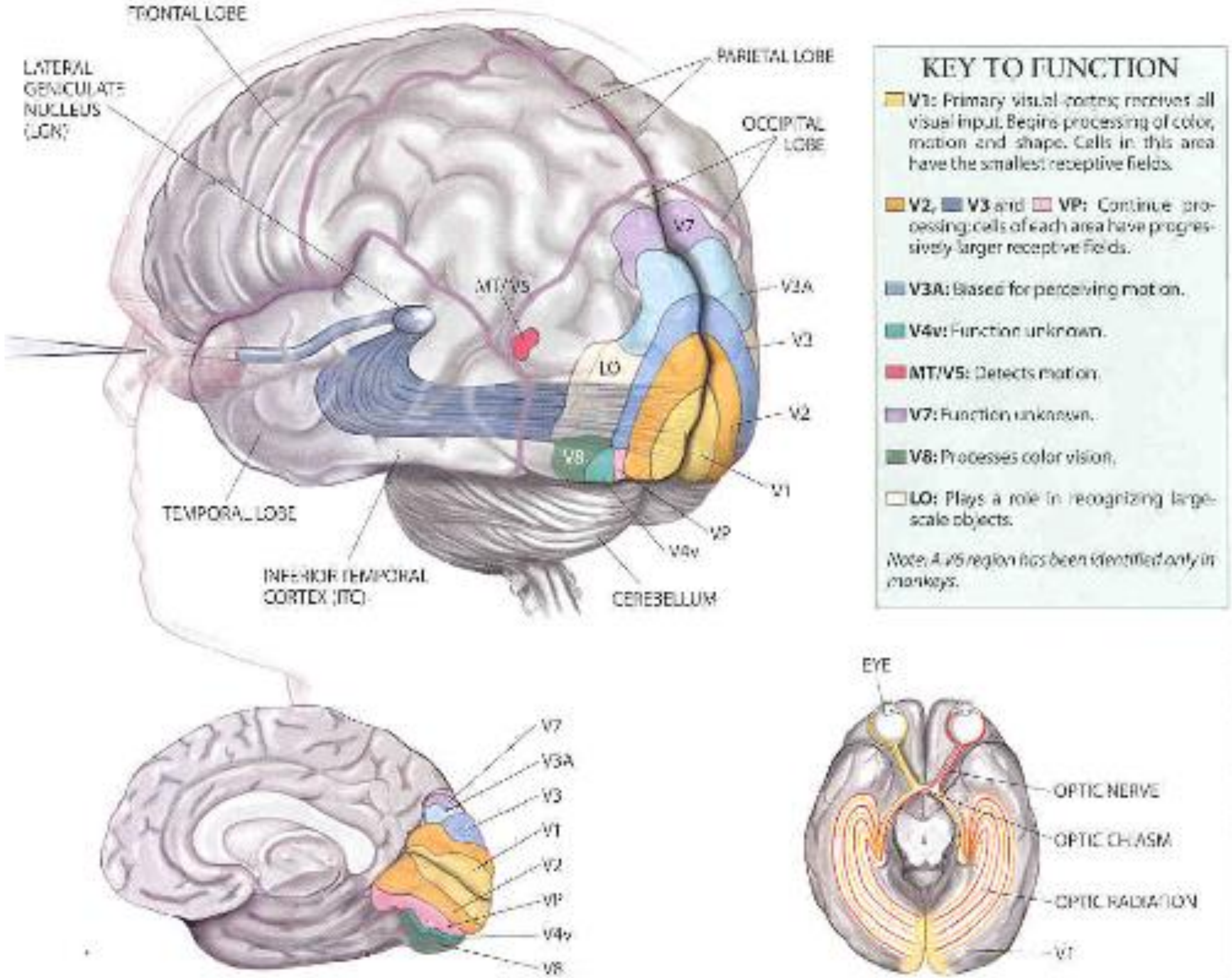


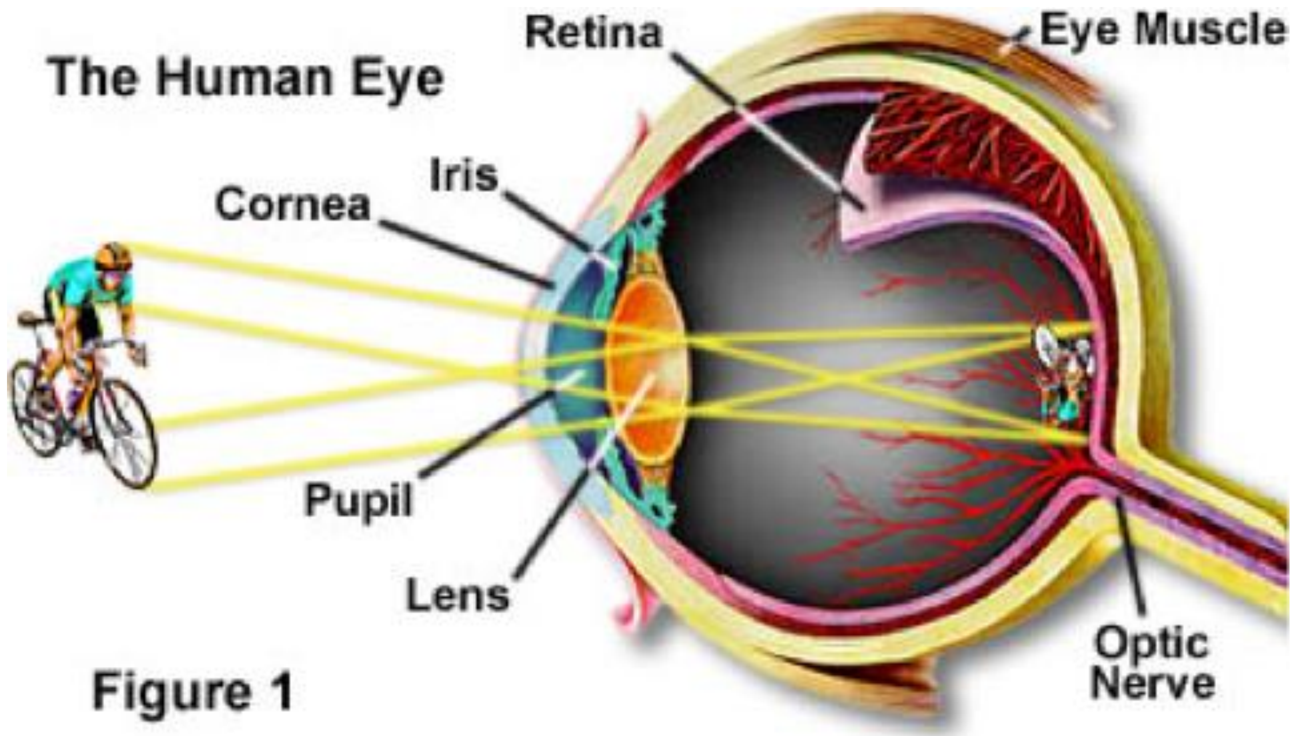
What’s in front?

What it is?

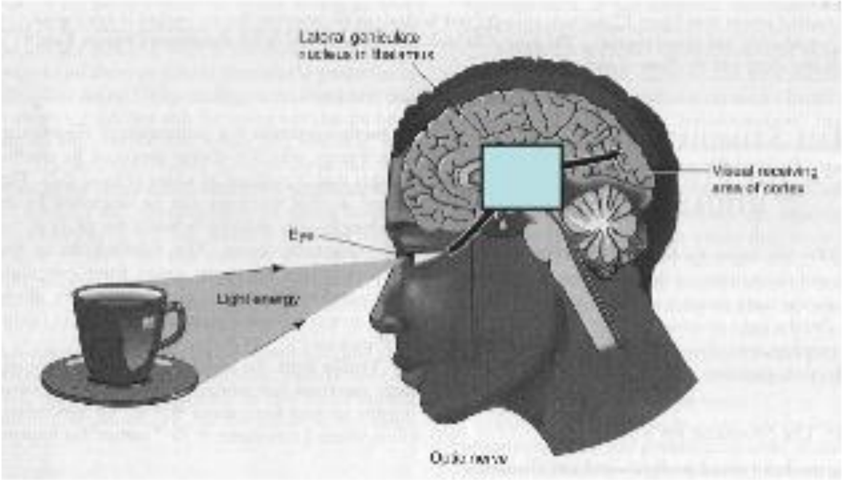


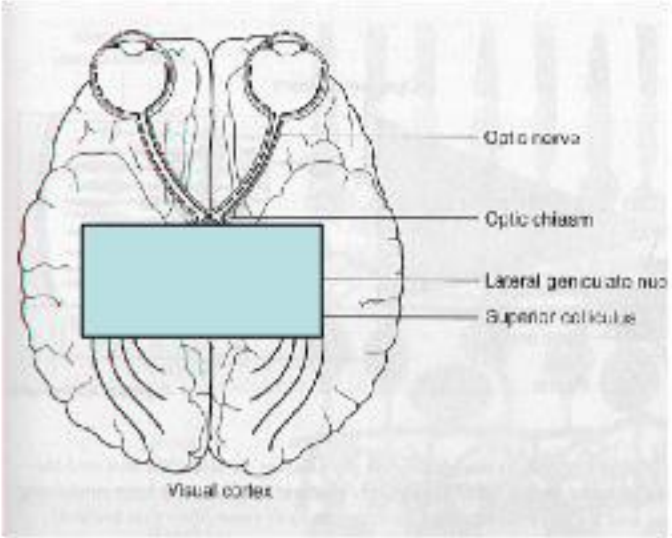


HUMAN VISUAL PATHWAY begins with the eyes and extends through several interior brain structures before ascending to the various regions of the visual cortex (V1, and so on). At the optic chiasm, the optic nerves cross over partially so that each hemisphere of the brain receives input from both eyes. The information is filtered by the lateral geniculate nucleus, which consists of layers of nerve cells that each respond only to stimuli from one eye. The inferior temporal cortex is important for seeing forms. Researchers have found that some cells from each area are active only when a person or monkey becomes conscious of a given stimulus.

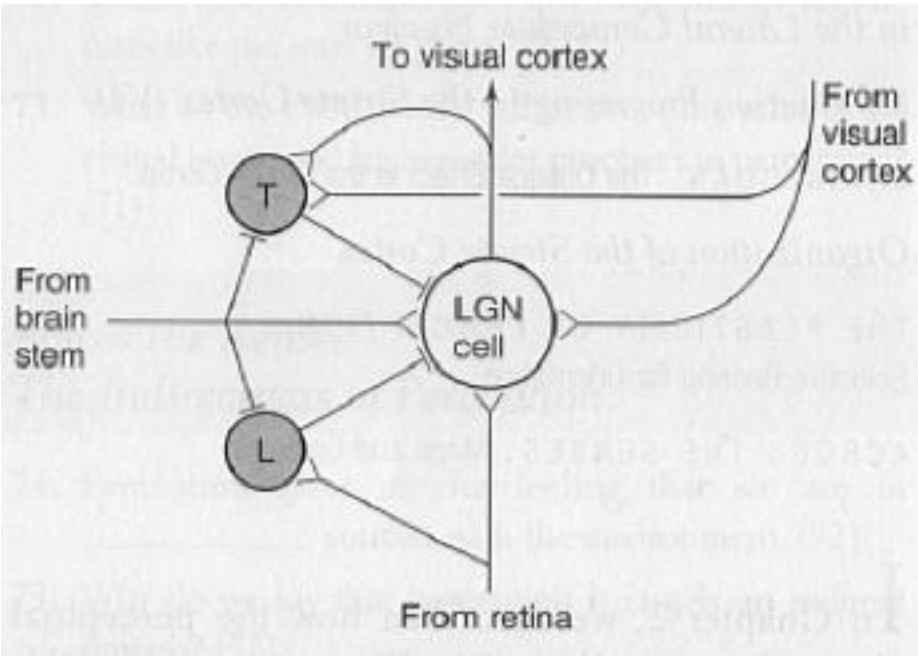

The Human Eye
Retina
Eye Muscle
Iris
Cornea
Pupil
Lens
Optic
Nerve
Figure 1

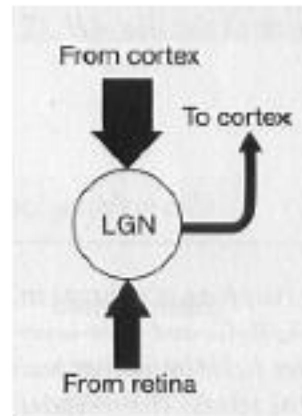
Human Visual System





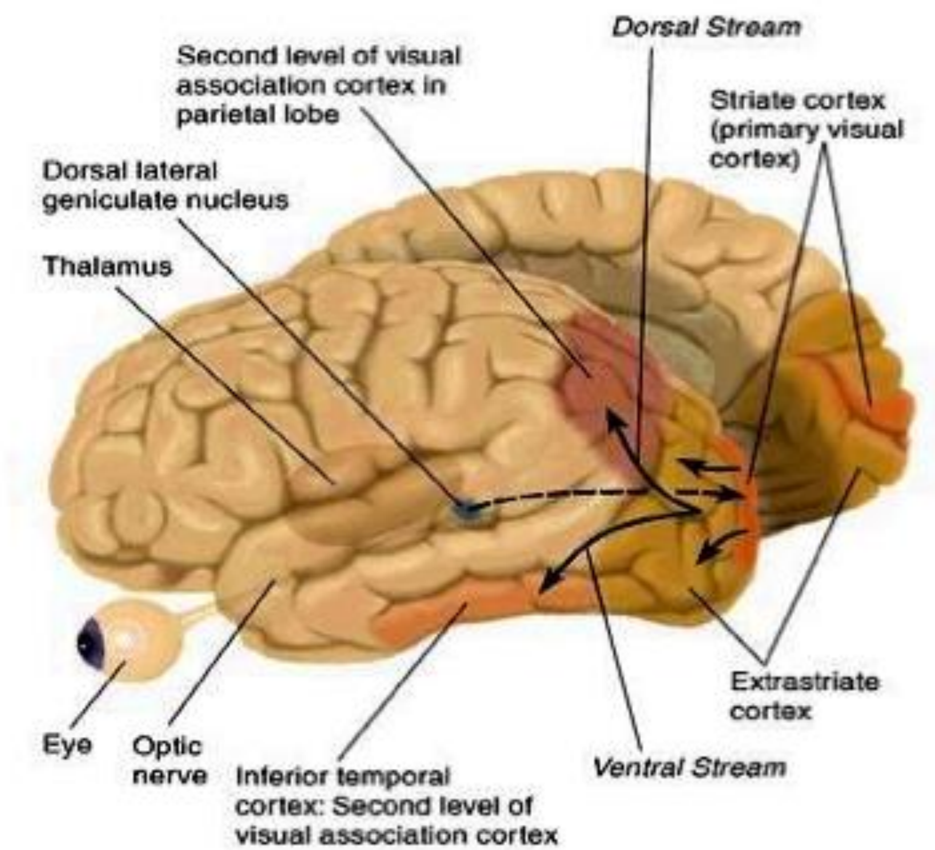
LGN cells





1) **Left and Right LGN, each has 6 Layers**
2) **0.9 Million retinal optic fiber enters each LGN, 0.1 M goes to eye movement controller**
3) **LGN also gets input from visual cortex,**
4) **For every 10 nerve inputs from retina, only 4 got send to cortex**
5) **The optics from the same side of eye goes to layer 2, 3, 5, and opposite to 1, 4, 6**
6) **Retinal map is organized in layer 6**

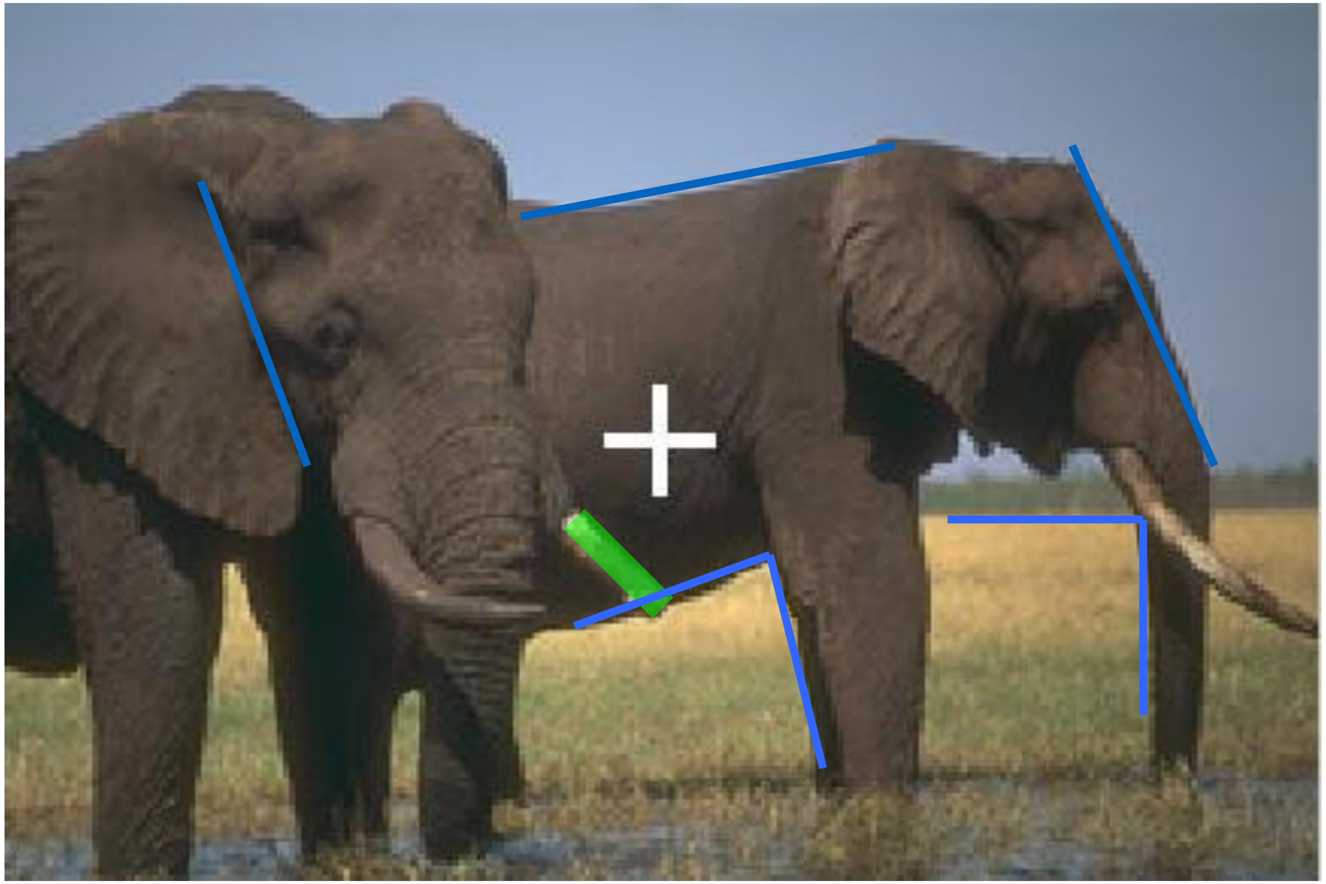
► **The Human Visual System**



http://www.youtube.com/watch?v=BEHpwaUDk3U

Marr's Primary Sketch

Go symbolic



Edge

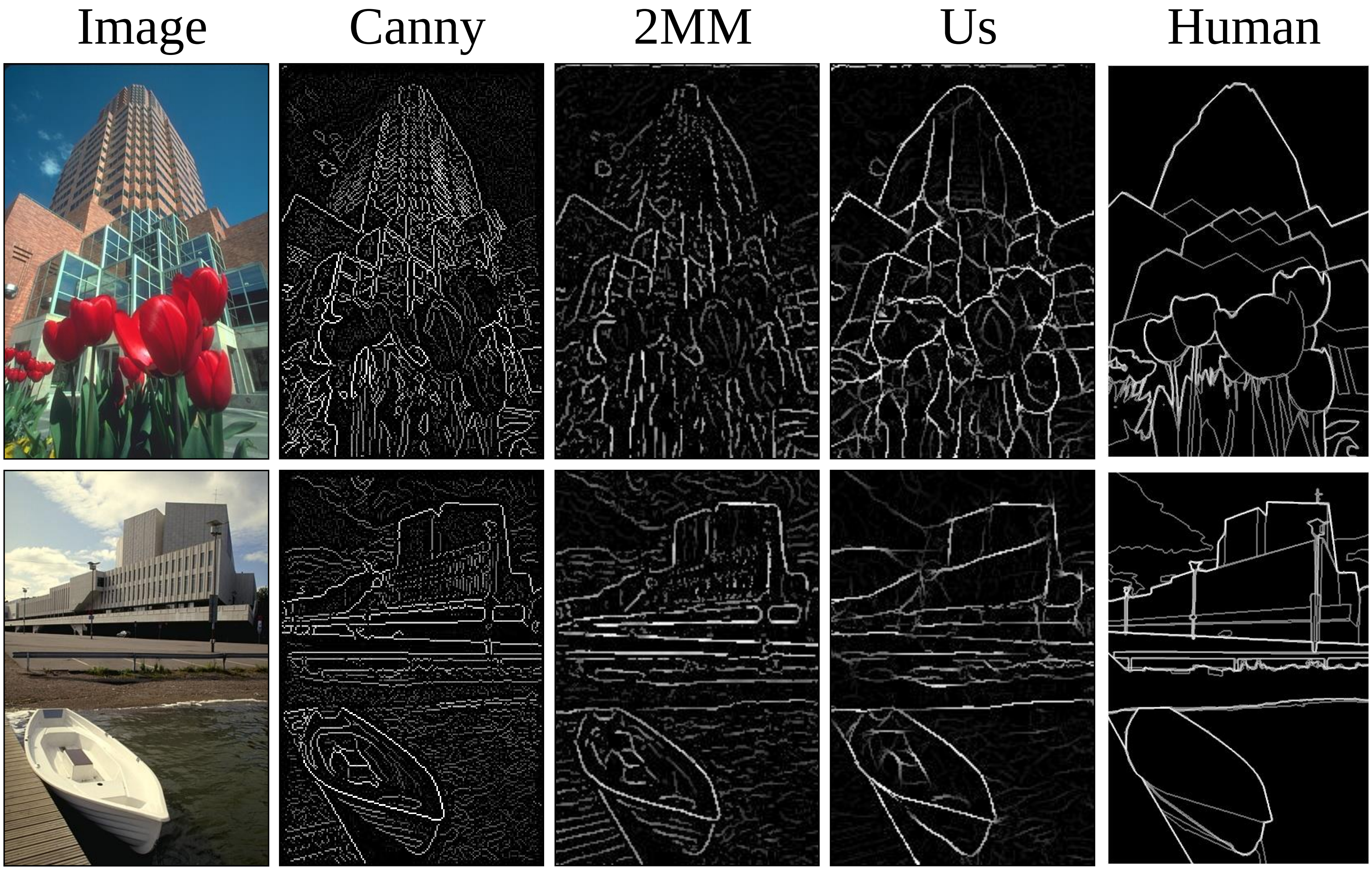
Bar

terminators

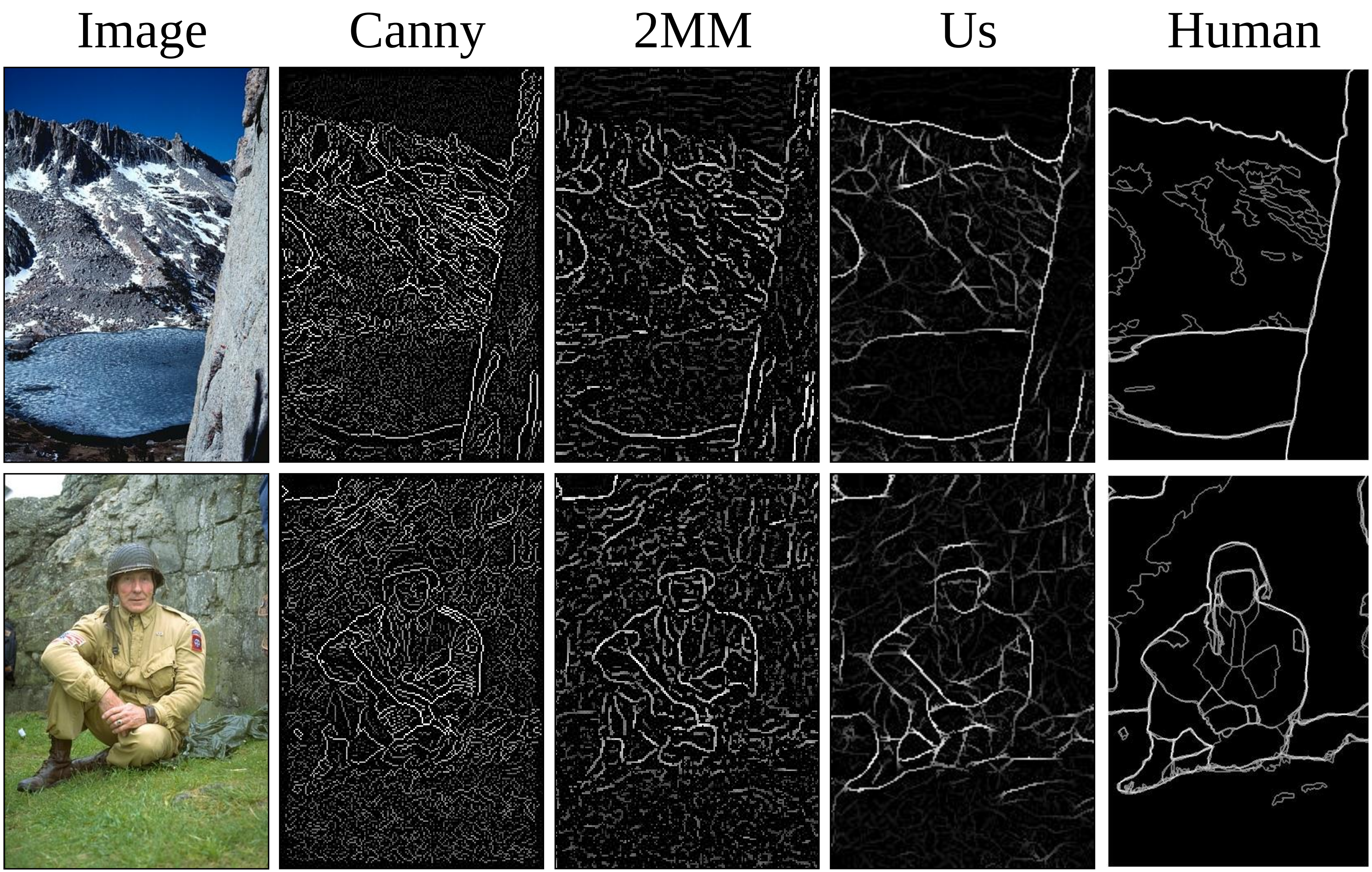
P_b Images I

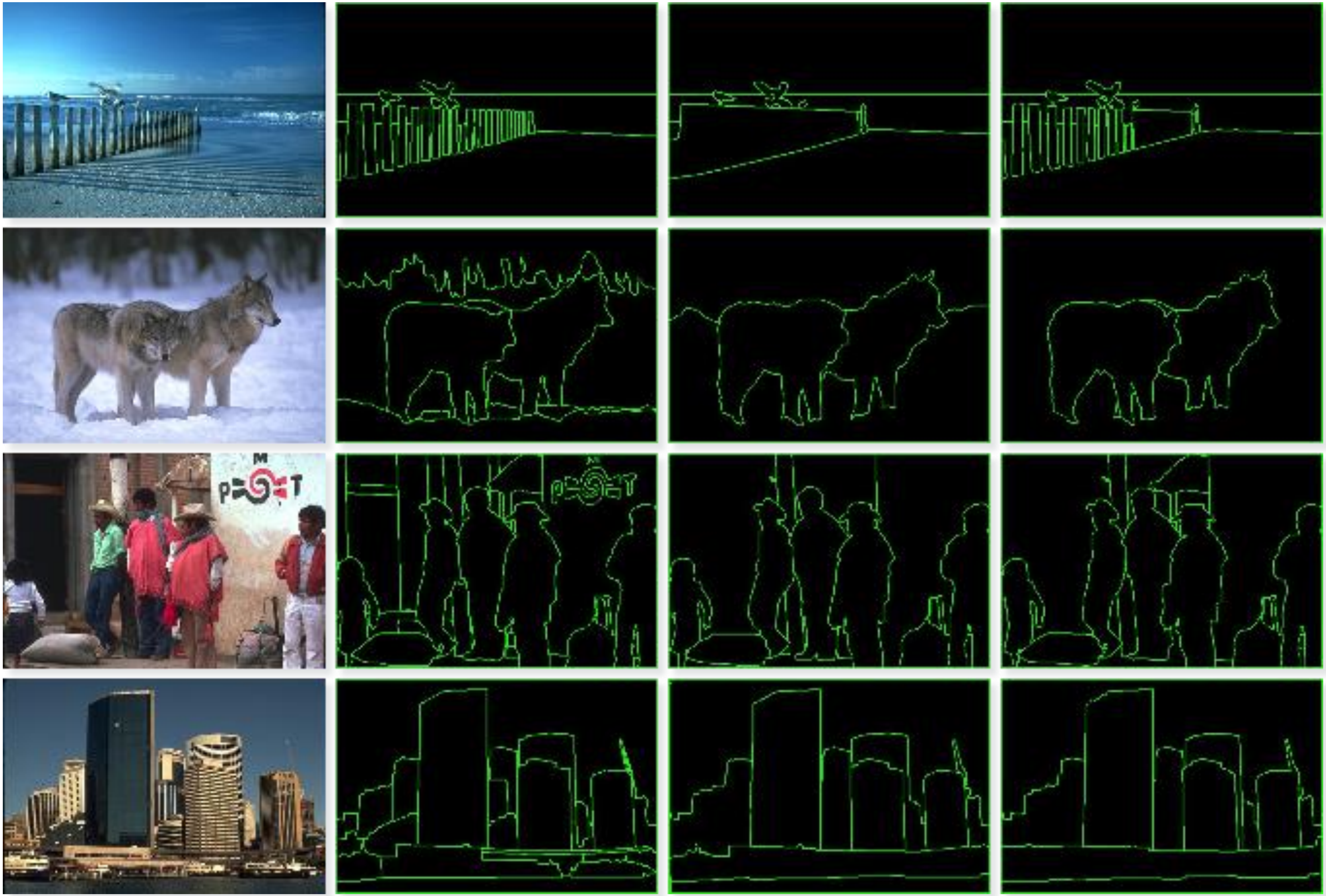
Image Canny 2MM Us Human

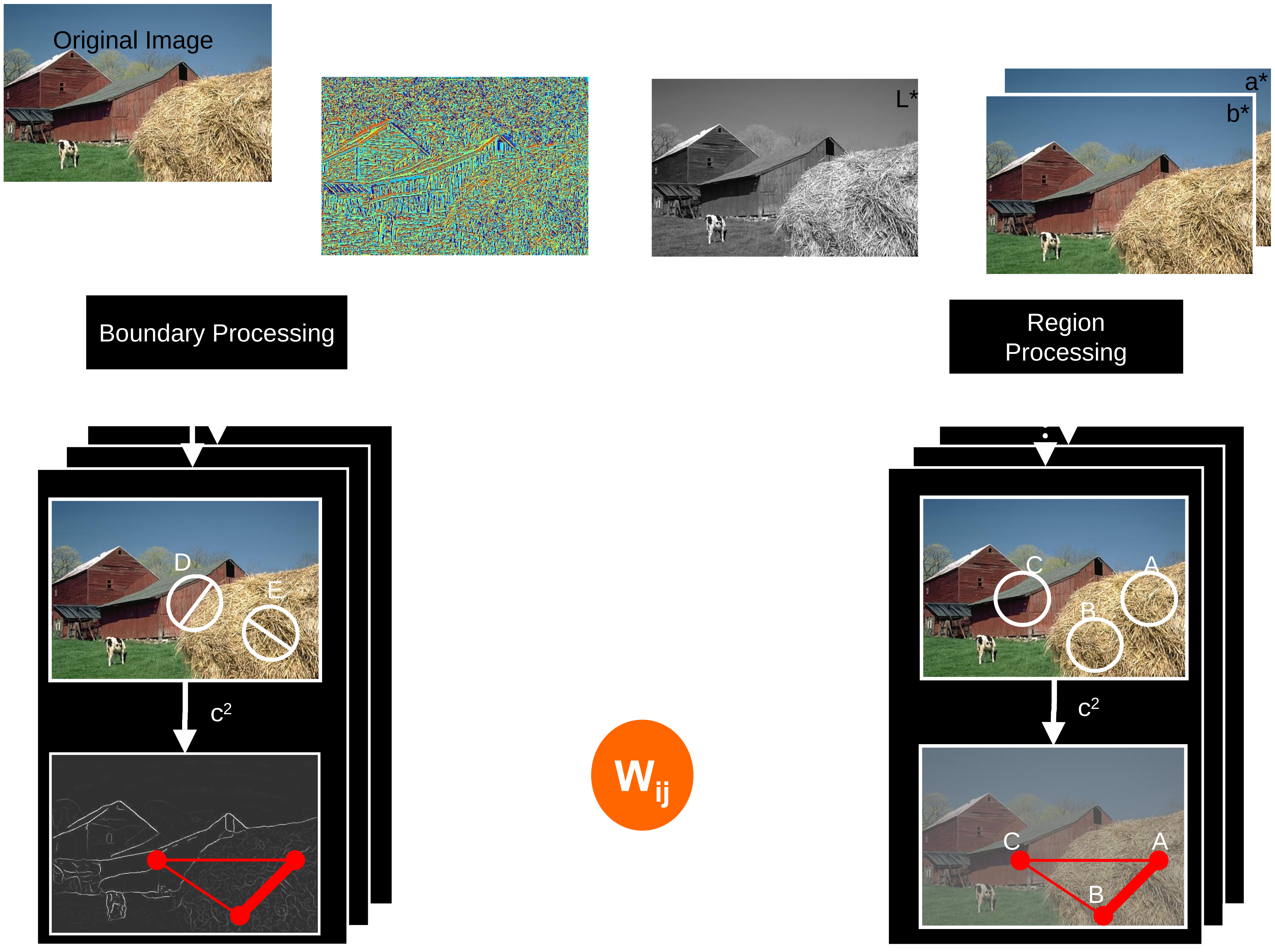
P_b Images II



P_b Images III





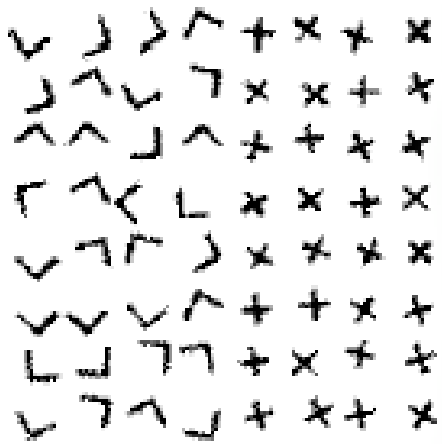


Original Image
L*
a*
b*
Boundary Processing
Region Processing
D
E
c2
C
A
B
c2
C
A
B
Wij

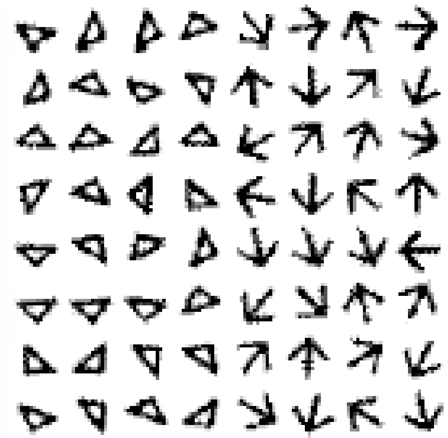
Readings

- *Puzzicha, Buhmann,Rubner, Tomasi*
  - Empirical Evaluation of Dissimilarity measure for color and texture
- *Rubner, Tomasi, Guibas*
  - The earth moving distance as a metric for image retrieval
- Martin, Fowlkes, Malik
  - Learning to Detect Natural Image Boundaries using Brightness and Texture

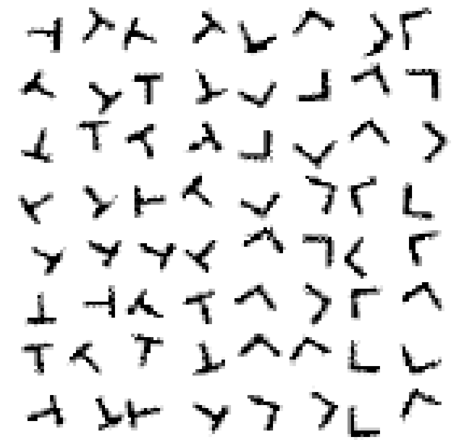
Image Feature: Texture



(Plus-ell)



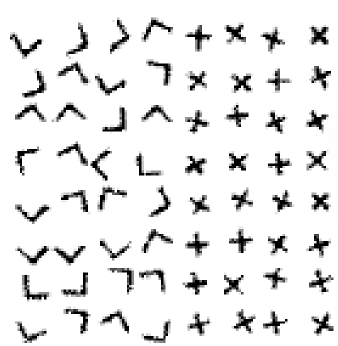
(Tri-arr)



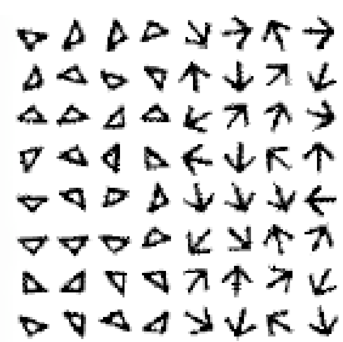
(Ti-ell)

Schools of thoughts on texture

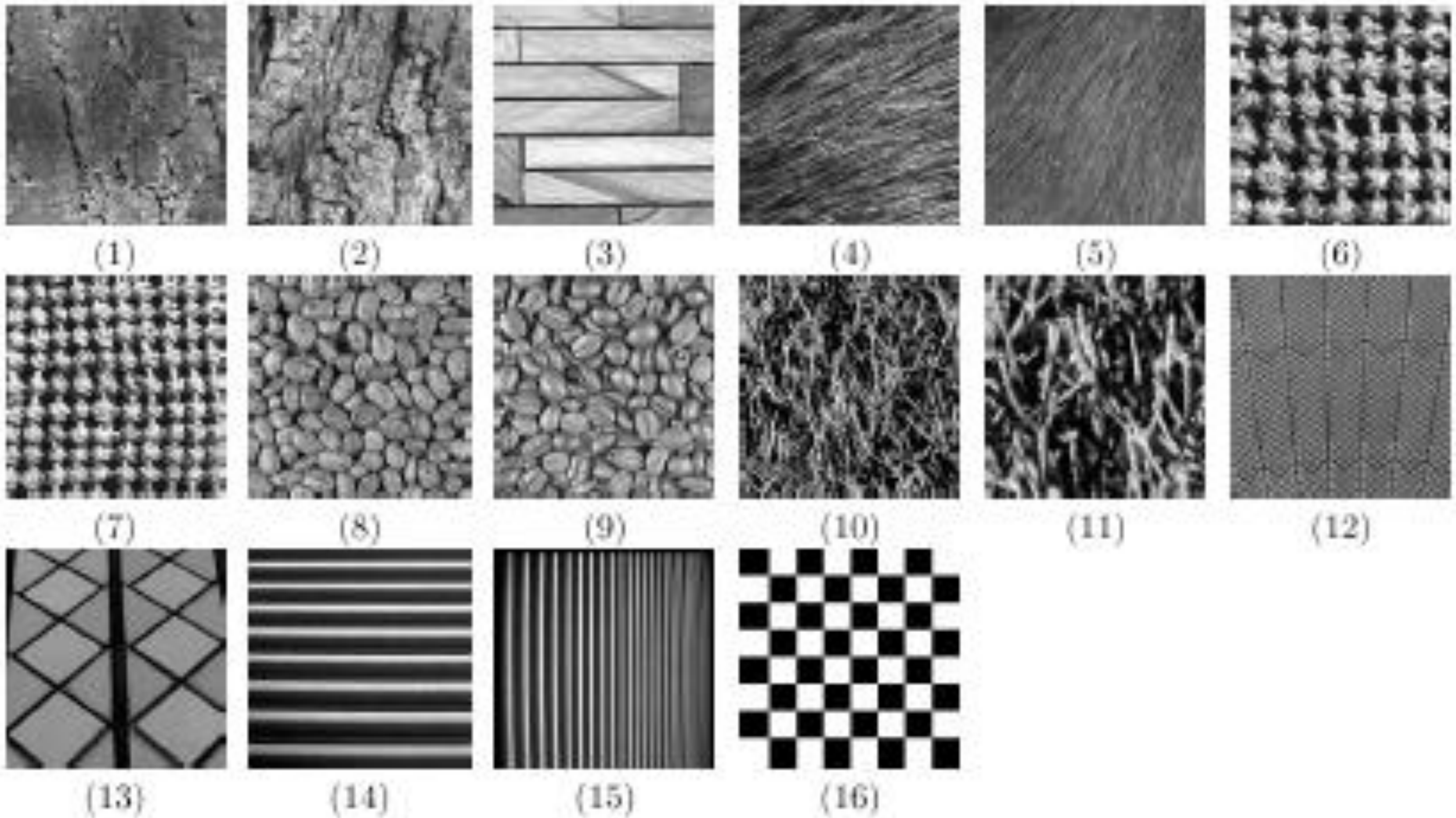
- Texture: repeated elements, subject to randomization of their location, size, color orientation
- Julesz: Nth-order joint empirical densities of textons
- Bergen-Adelson,Malik, Tuner: Multi-scale filter banks, wavelets



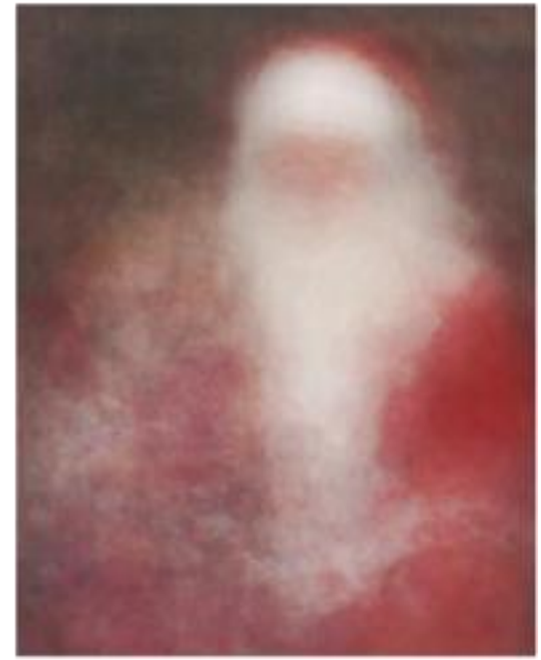
(Plus-ell)



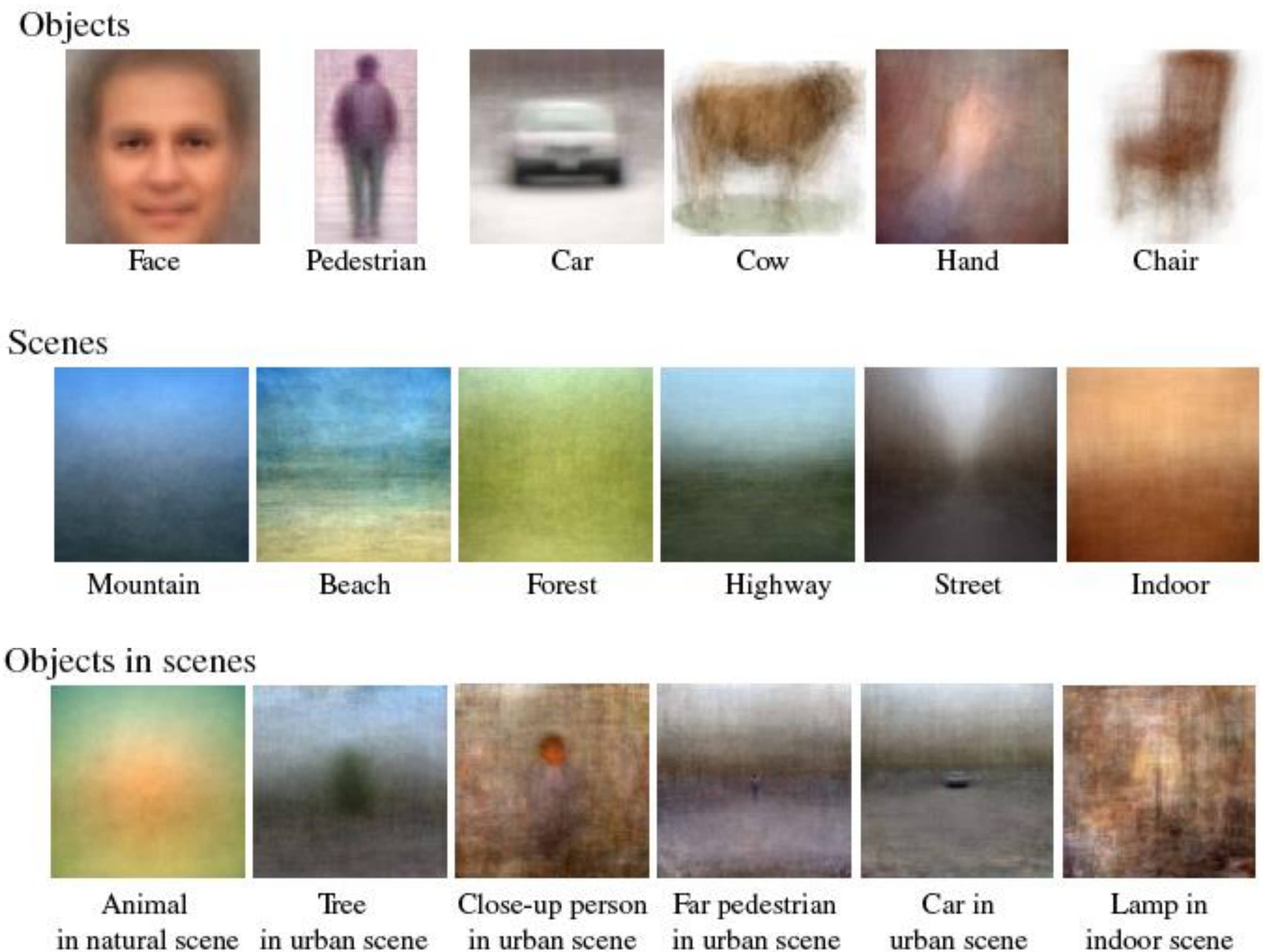
(Tri-arr)


(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)
(14)
(15)
(16)





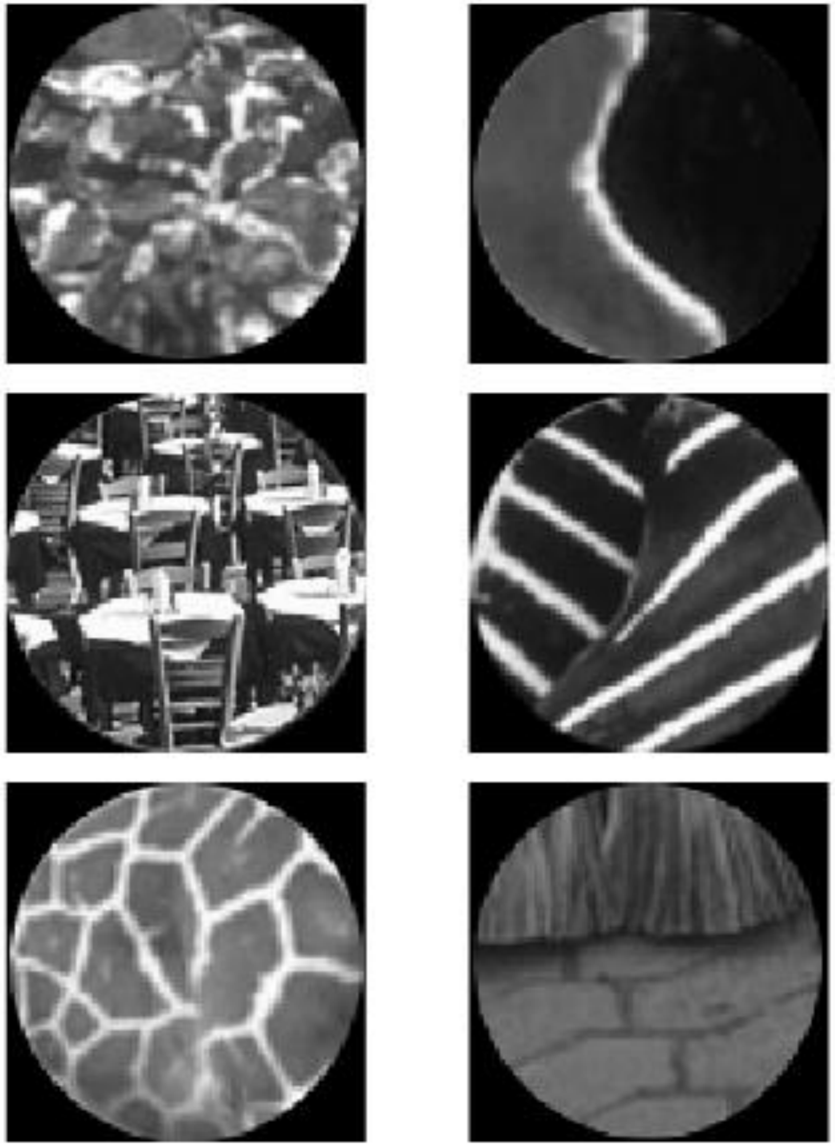
Jason Salavon:
100 Special Moments
http://salavon.com/work.php


Objects
Face
Pedestrian
Car
Cow
Hand
Chair
Scenes
Mountain
Beach
Forest
Highway
Street
Indoor
Objects in scenes
Animal in natural scene
Tree in urban scene
Close-up person in urban scene
Far pedestrian in urban scene
Car in urban scene
Lamp in indoor scene

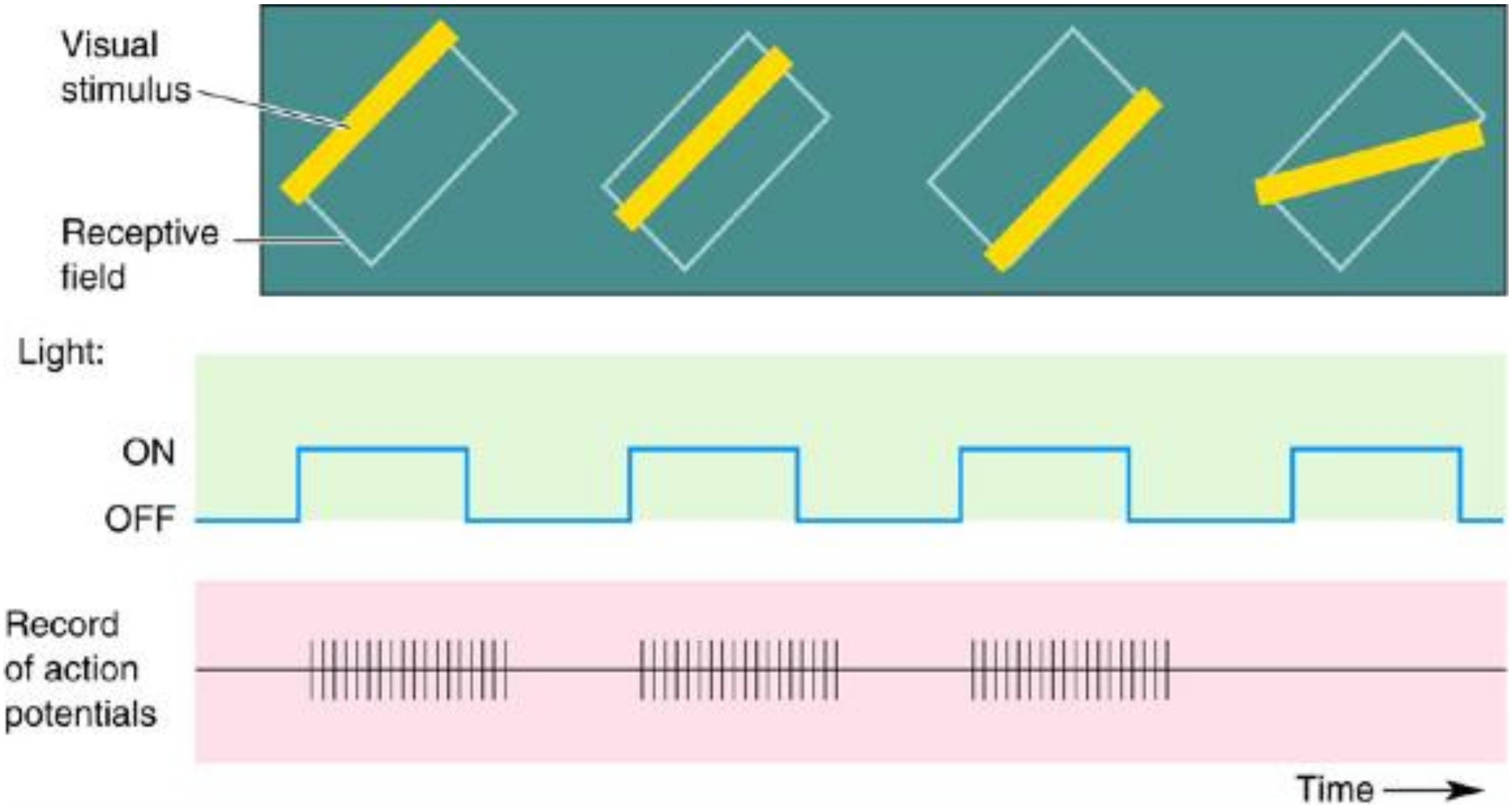
Jason Salavon:

The Top Grossing Film of All Time
http://salavon.com/work.php

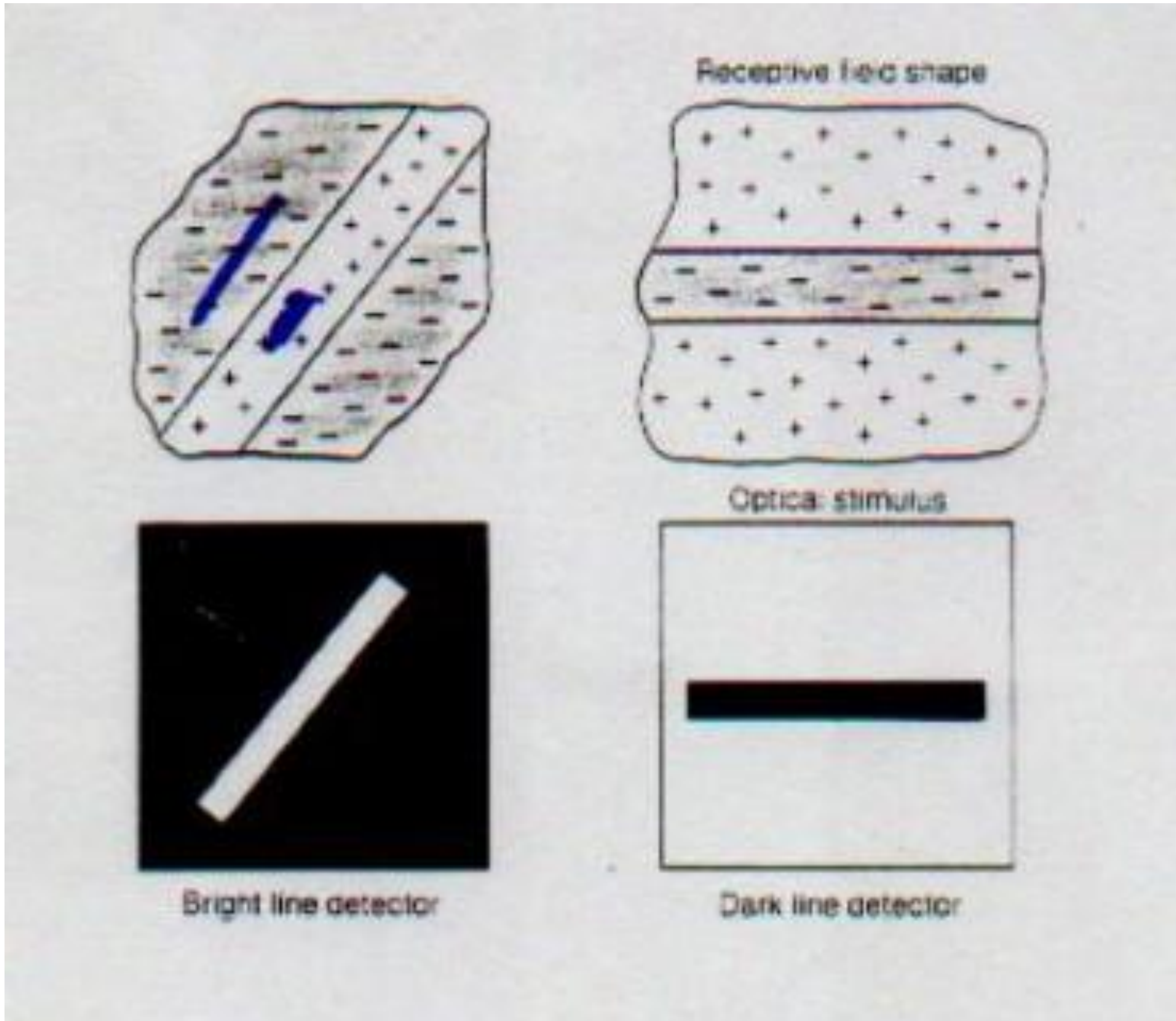
The worldwide top grossing film of all time, Titanic, was digitized from video in its entirety and broken up into its constituent frames. Each of these was then averaged to a single color best representative of that frame and reformatted as a photograph mirroring the narrative sequence of the film. Reading from left-to-right and top-to-bottom, the narrative's visual rhythm is laid out in pure color.



How the brain works (v1):



How the brain works (v1):



How the brain works (v1):

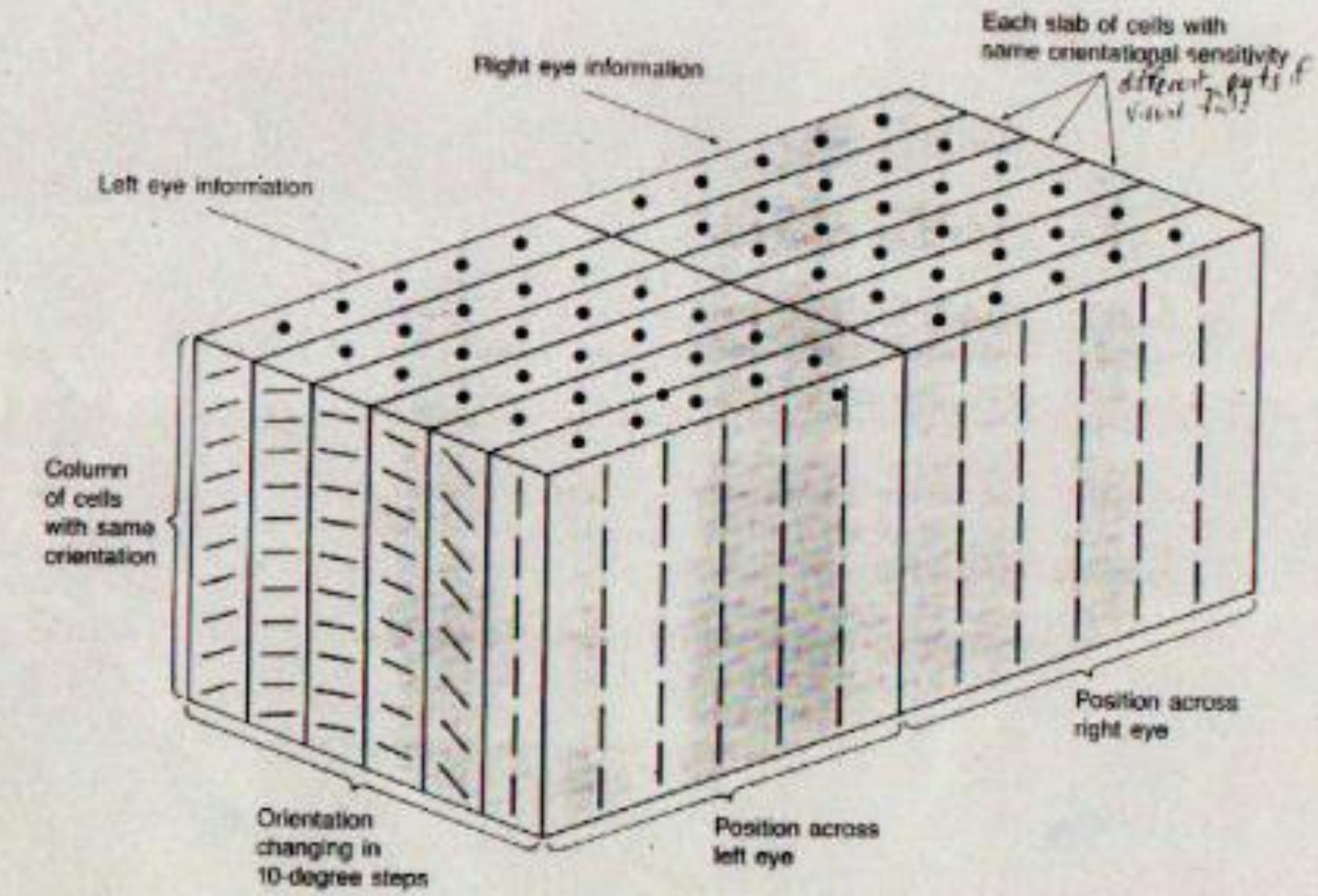


Diagram of a hypercolumn, which is a small region of visual cortex containing inputs from both eyes and all visual orientations, separated spatially, as shown.

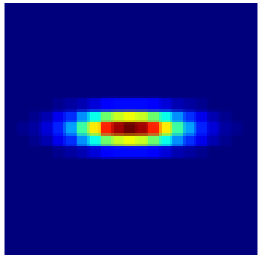
Hubel and Wiesel Cat Experiment

Visual Cortex Cell Recording

Imitation Brain:

$$\boxed{\frac{1}{\sqrt{2\pi}} exp(-\frac{x^2}{2\sigma^2})}$$

Base filter: $$F(x) = G(x, \sigma) \otimes G(x, 3\sigma)$$



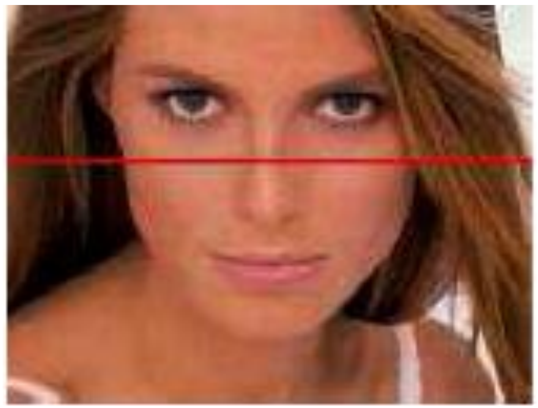
Filters are dedicated to a range of orientation:

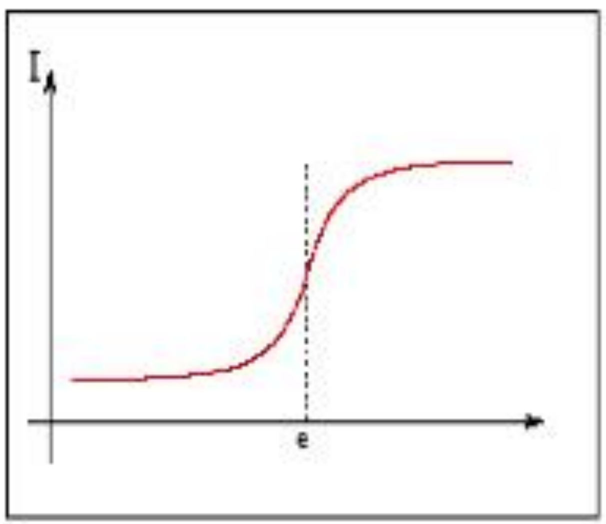
$$\boxed{\frac{1}{\sqrt{2\pi}}exp(-\frac{x^2}{2\sigma^2})}$$

Base filter: $$F(x) = G(x,\sigma) \otimes G(x, 3\sigma)$$

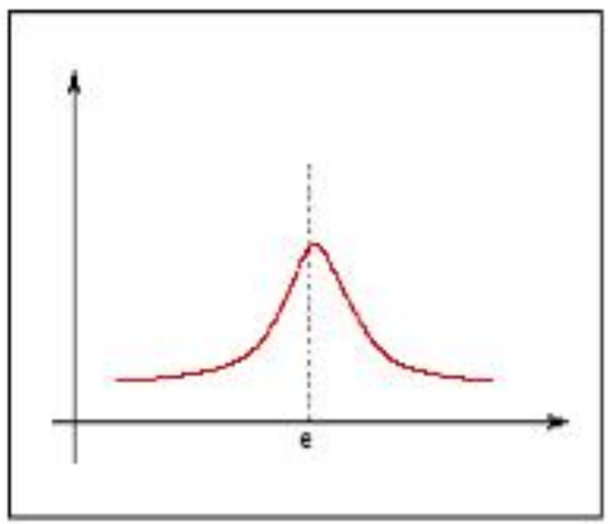
Apply rotation: $$R(\theta) = \begin{pmatrix} cos(\theta) & sin(\theta) \\ -sin(\theta) & cos(\theta) \end{pmatrix}$$

Bank of Filters

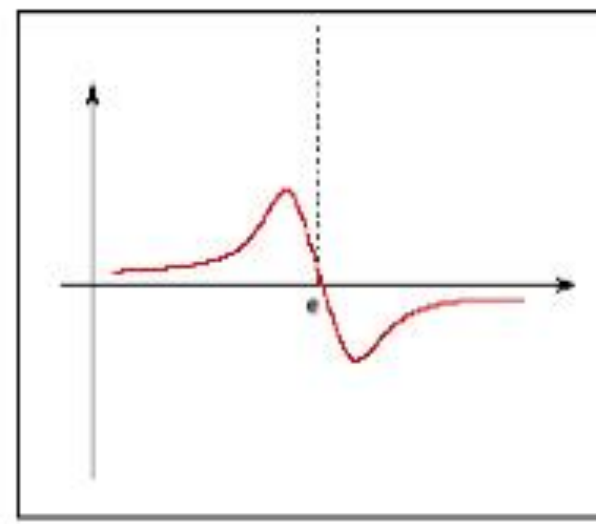




A step in the intensity corresponding to an edge

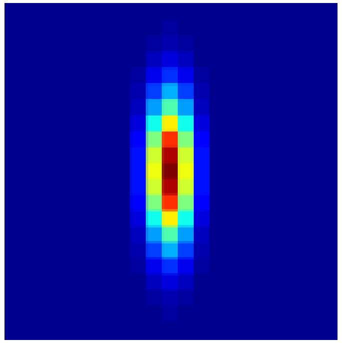


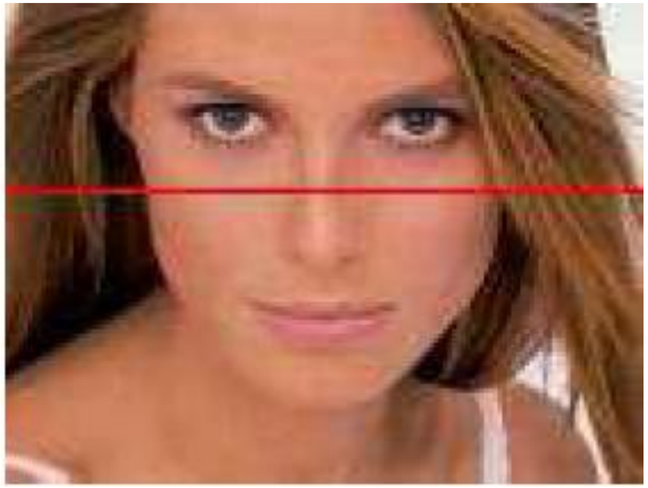
Maximum of the first order derivate



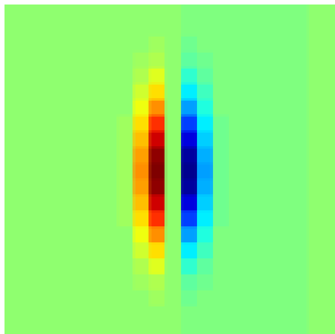
Zero crossing for the second order derivate.
The sign changes around the edge.

Odd-symmetric filters:





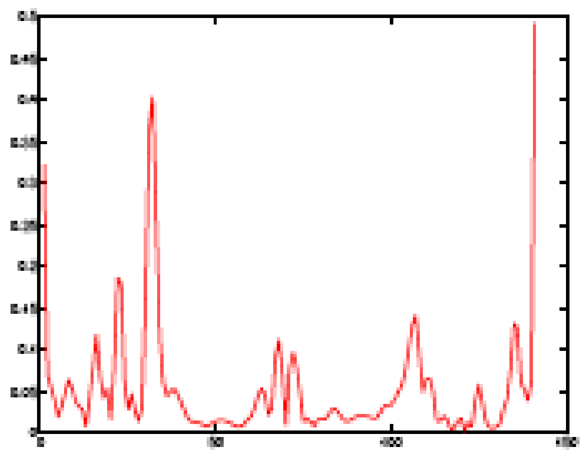
$\otimes$



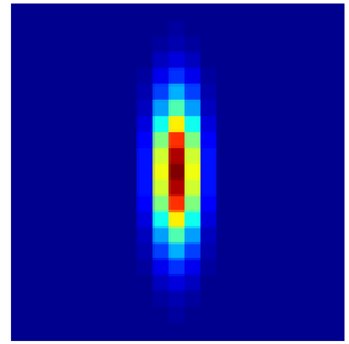
$=$

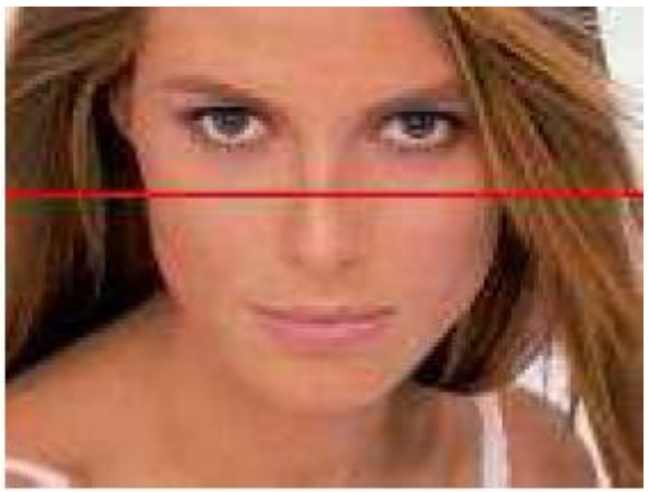
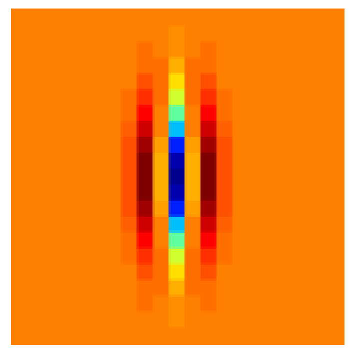
$$F(x) = G_x(x, \sigma) \otimes G(x, 3\sigma)$$

$$\boxed{\frac{\delta G(x,\sigma)}{\delta x}}$$



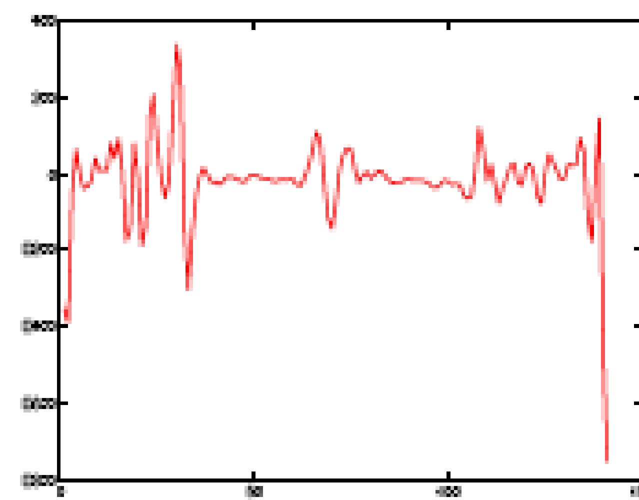
Odd-symmetric filters:

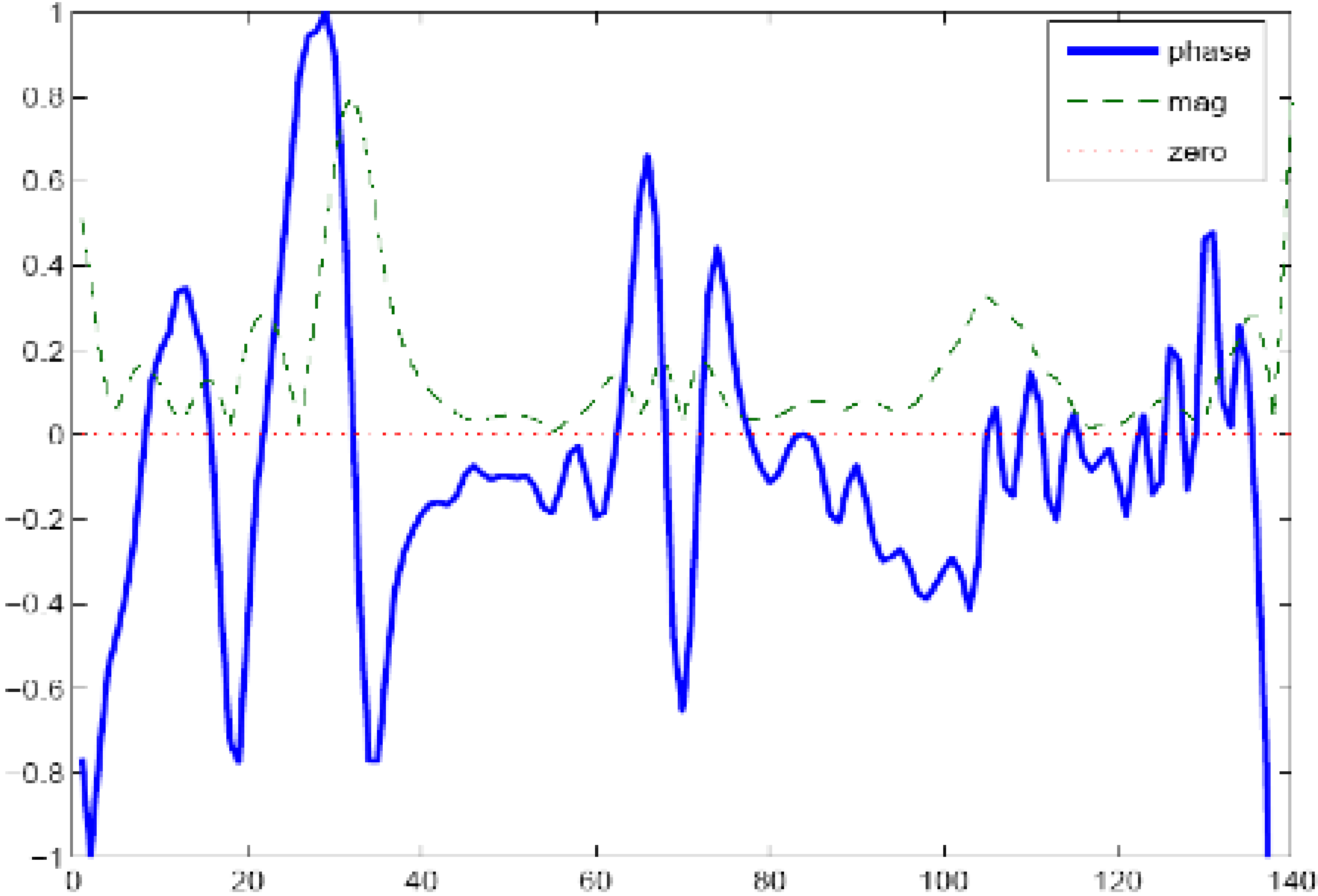


 $\otimes$  $=$ 

$$F(x) = G_{xx}(x, \sigma) \otimes G(x, 3\sigma)$$

$$\boxed{\frac{\delta G_x(x, \sigma)}{\delta x}}$$

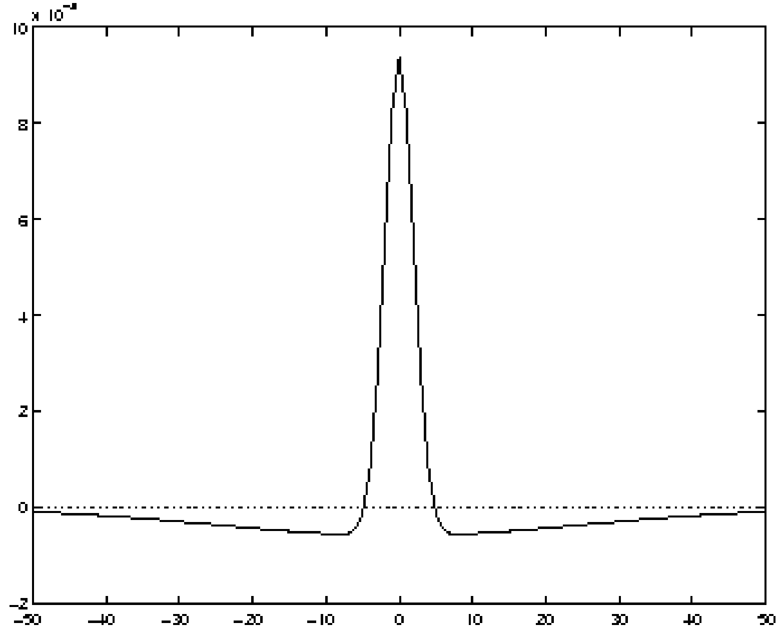




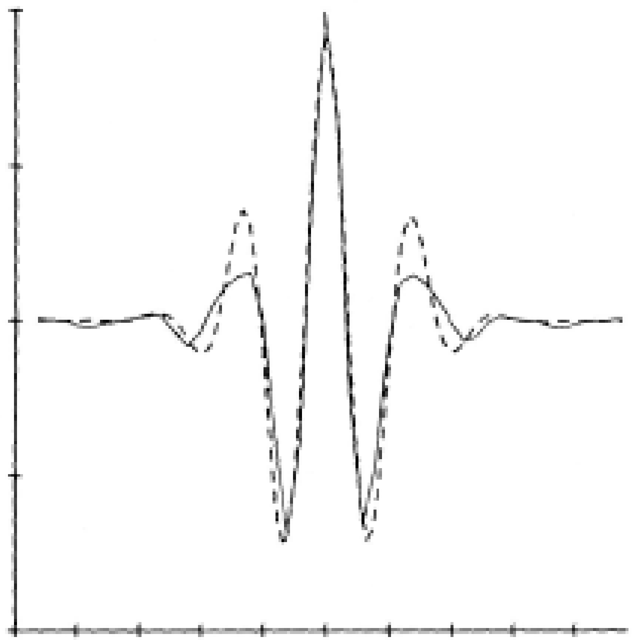
The zero-crossings correspond to magnitude peaks.

Difference of Gaussian (DOG)

$$Dog(x,y) = \frac{\sigma_{ex}^2}{2\pi\sigma_{ex}^2} e^{-\frac{x^2+y^2}{2\sigma_{ex}^2}} - \frac{\sigma_{inh}^2}{2\pi\sigma_{inh}^2} e^{-\frac{x^2+y^2}{2\sigma_{inh}^2}}$$



Simple Cell Receptive Field vs. Gabor Function

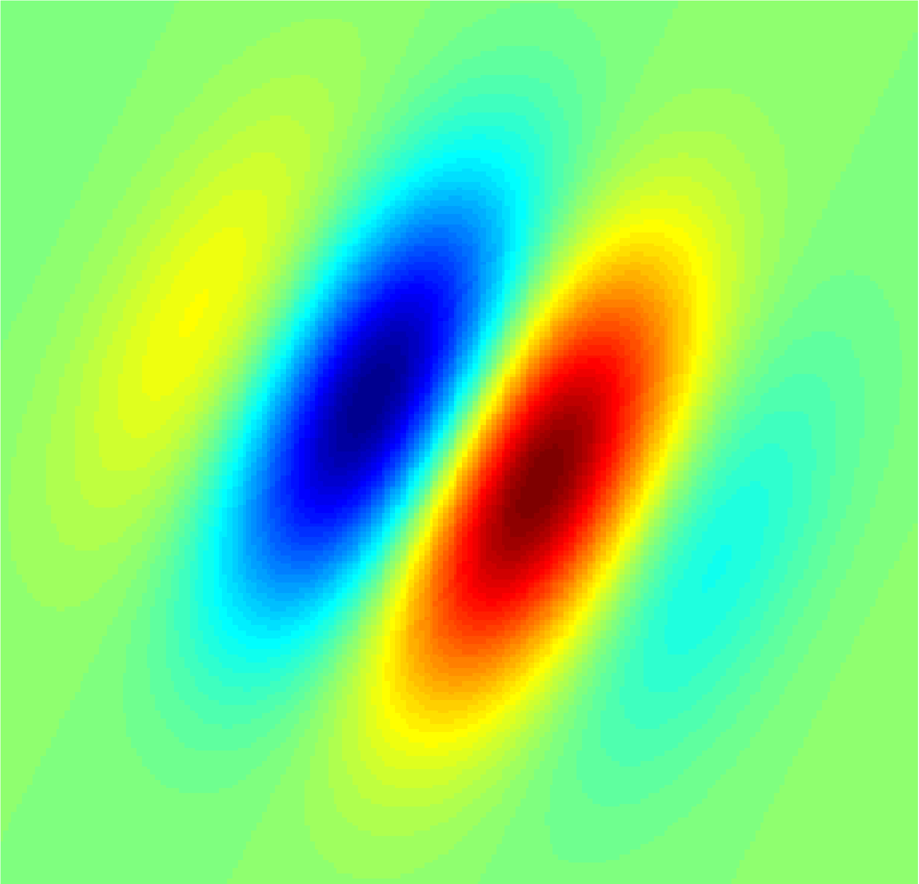


Solid line: Simple Cell Receptive Field.

Dashed line: Best fitting Gabor function.

From: DeValois and DeValois, "Spatial Vision", 1988.

Gabor Filter



Complex

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

Real

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

Imaginary

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

where

$$x' = x\cos\theta + y\sin\theta$$

and

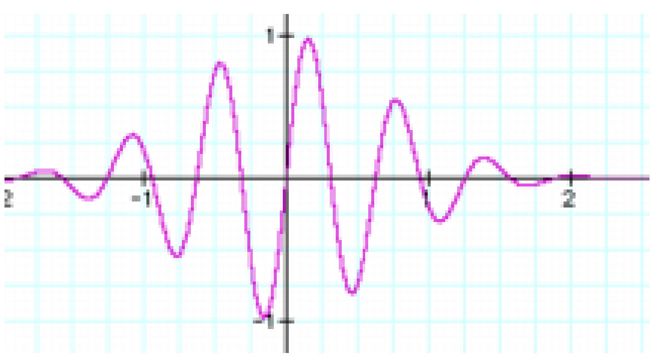
$$y' = -x\sin\theta + y\cos\theta$$

Dennis Gabor

Fourier Transform of a Gabor Filter

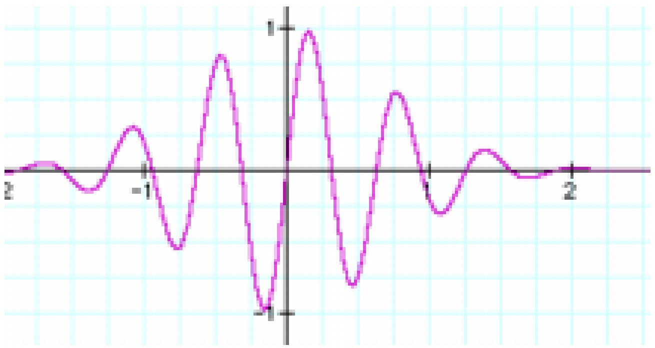
The Fourier Transform of a Gabor filter is a localized set of spatial frequencies.

Gabor filters are band-pass filters. They are tuned to spatial frequency.



Fourier Transform

Fourier Transform of a Gabor Filter

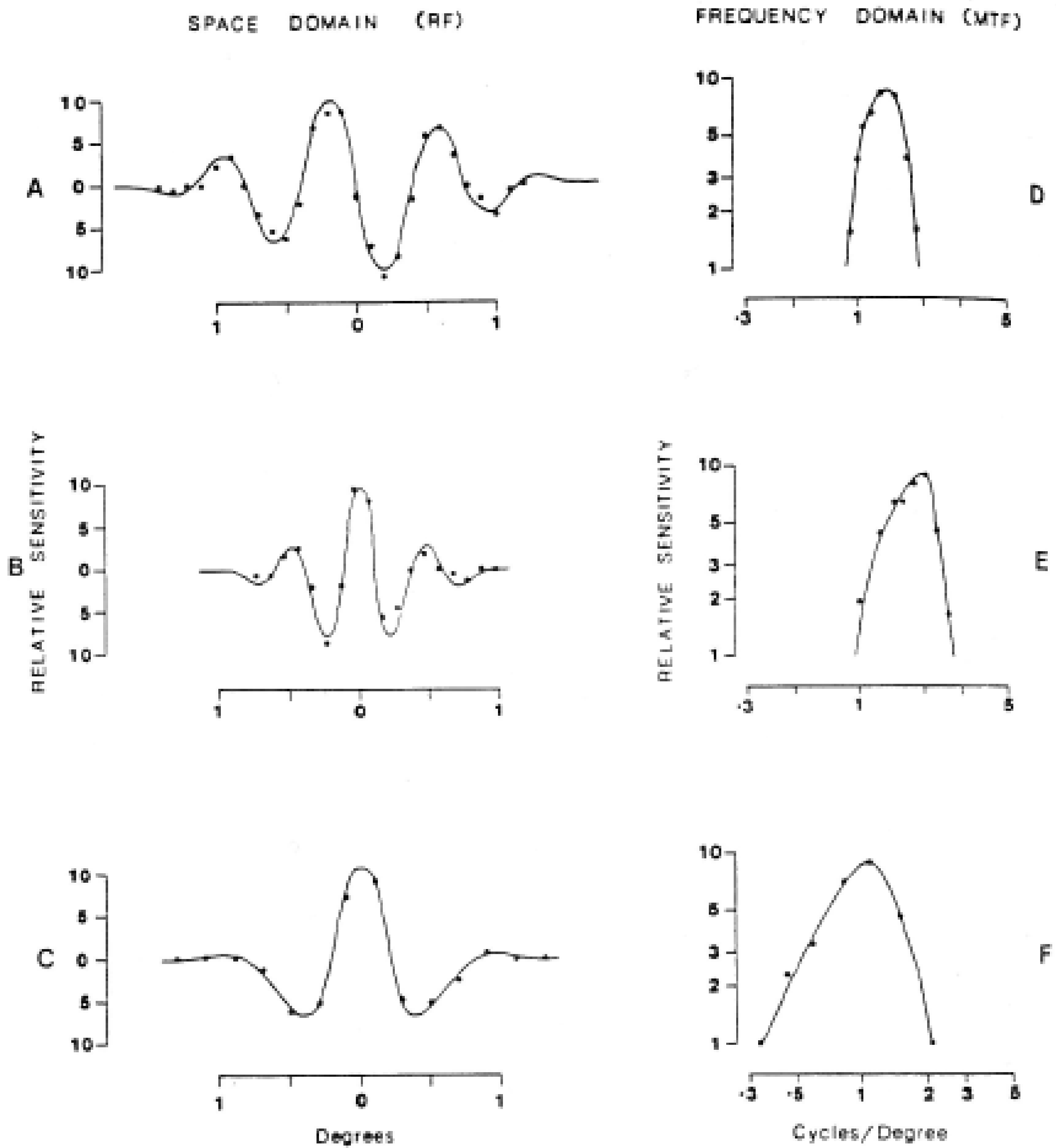


Fourier Transform

$$Gabor(u, \sigma) = G(\sigma) e^{-ux}$$

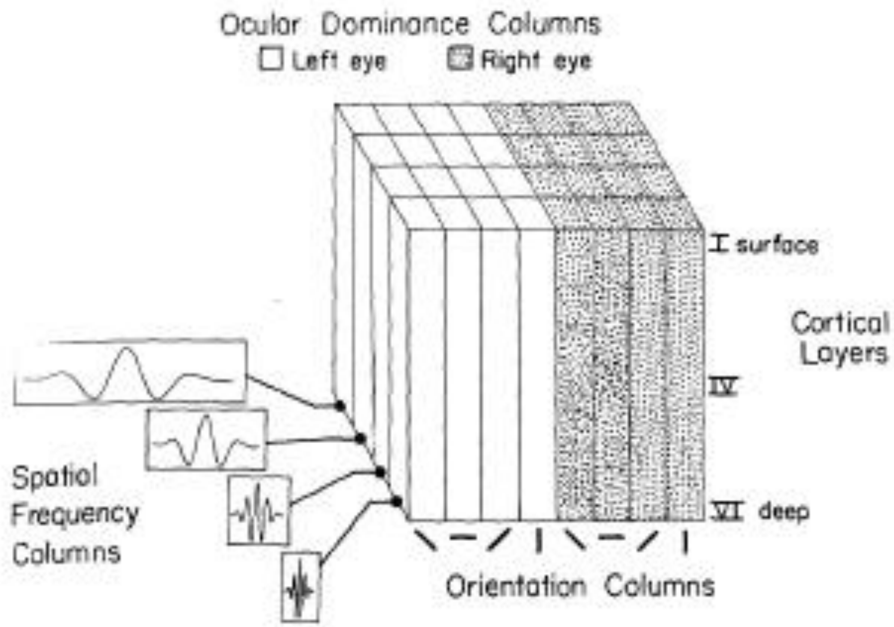
$$FFT(Gabor(u, \sigma)) = FFT(G(\sigma)) \otimes FFT(e^{-ux})$$
$$= \frac{1}{\sigma} G(1/\sigma)) \otimes \delta(u)$$

Spatial Scales



The spatial profile of the simple cell receptive field is predicted by taking the inverse Fourier transform of the contrast sensitivity function for that cell.

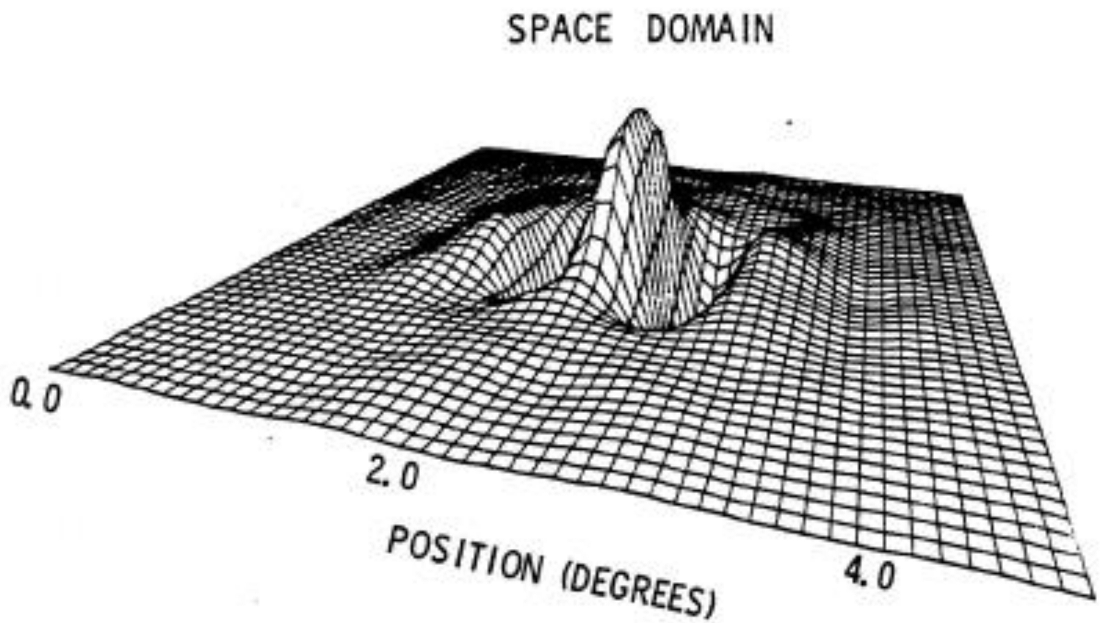
Spatial Frequency Columns

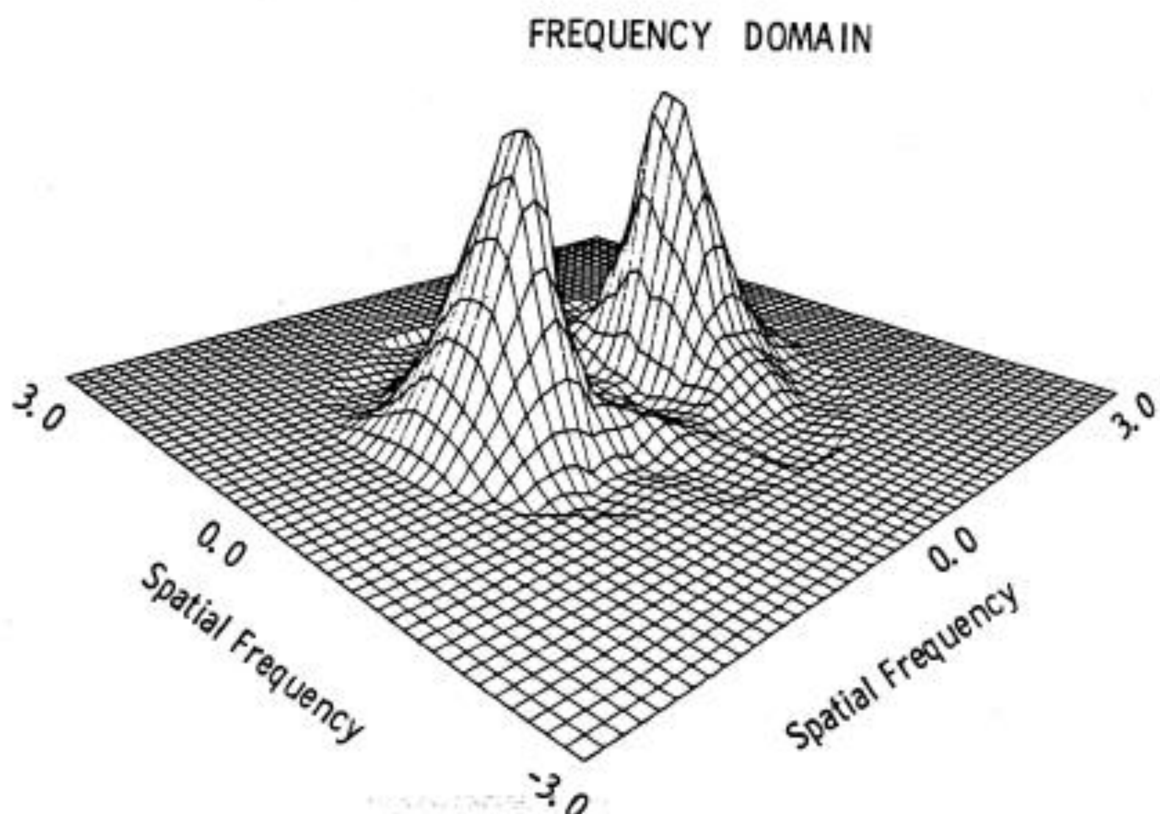


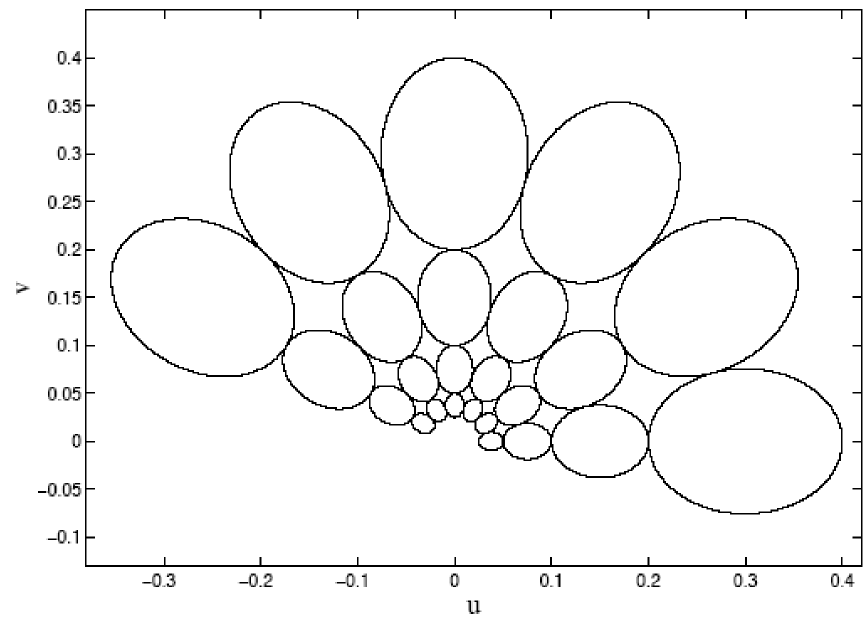
Model of Striate Module in Cats

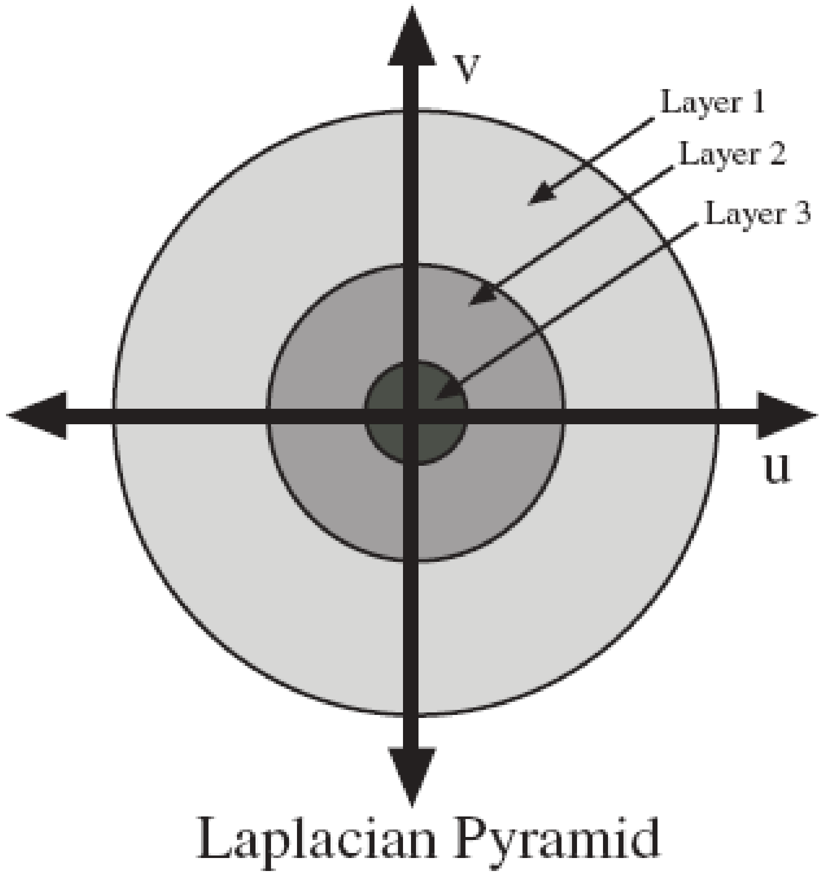
As with orientation and ocular dominance, spatial frequency shows columnar organization in the cortex.

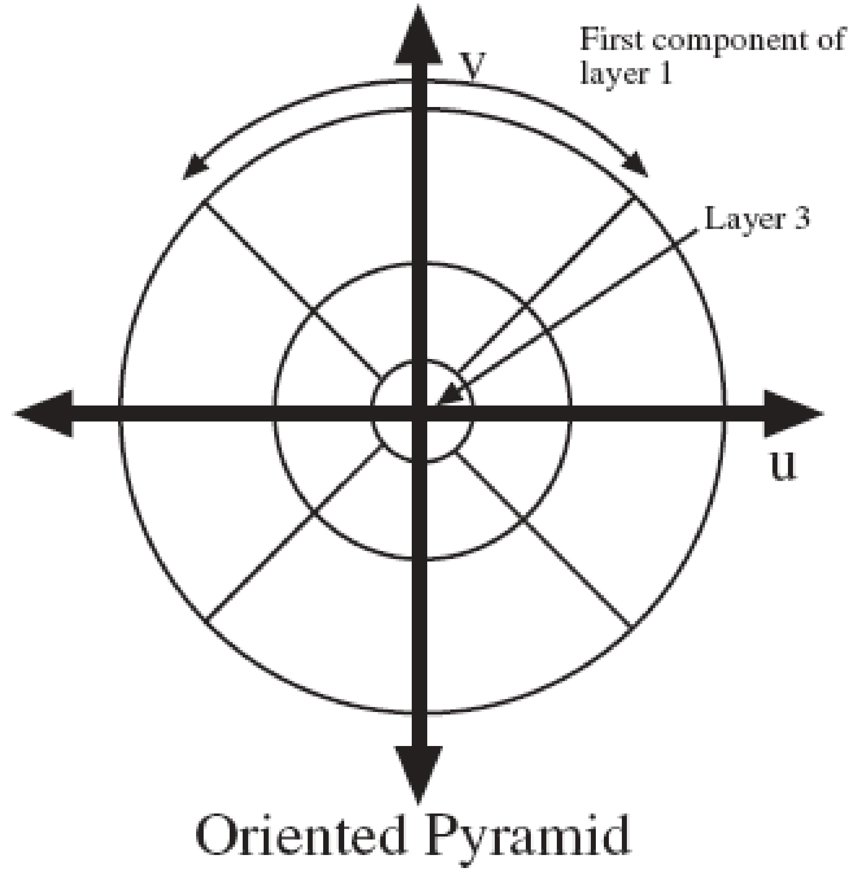
2D Gabor filter







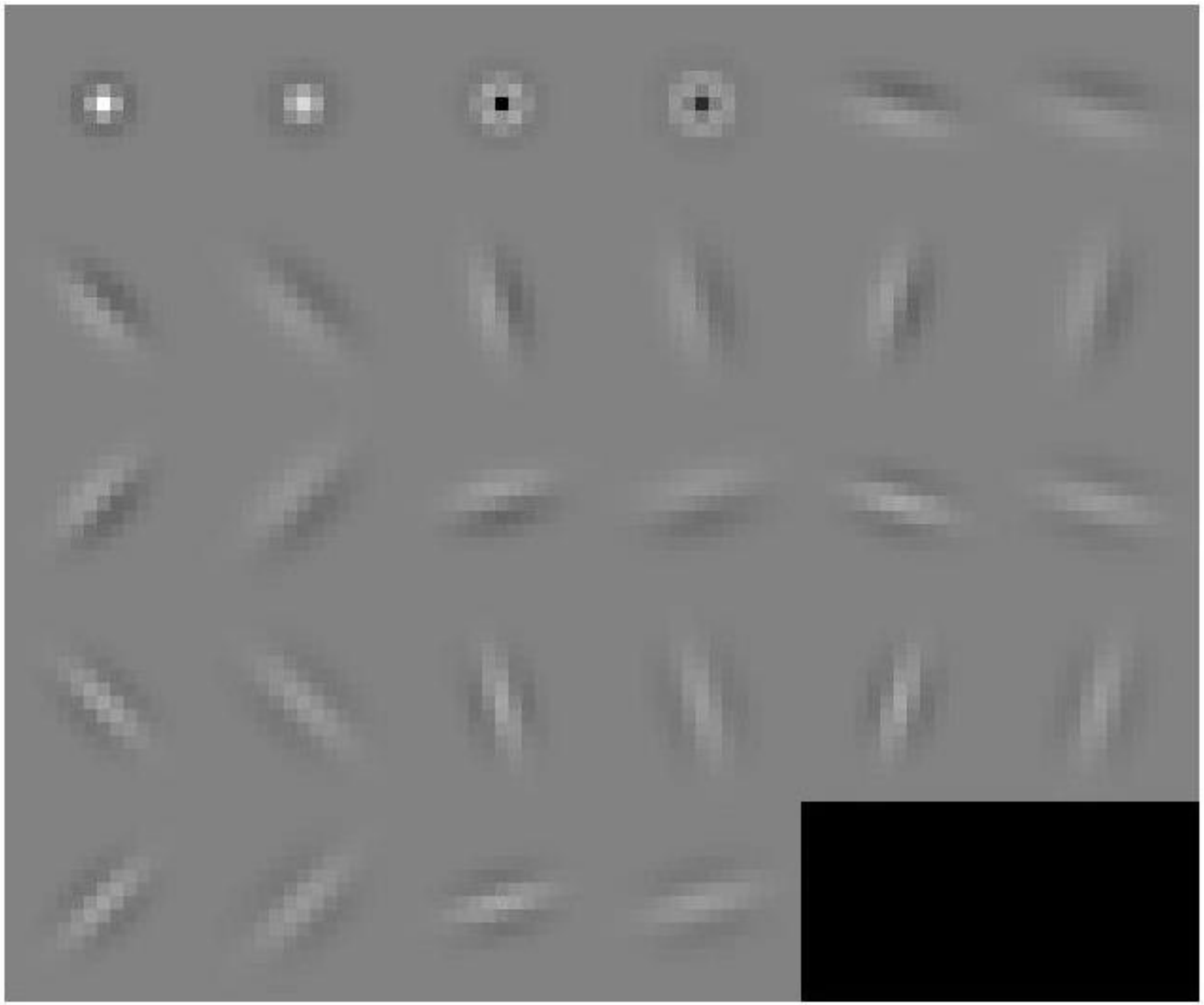




Laplacian pyramid is doing Band-pass filtering

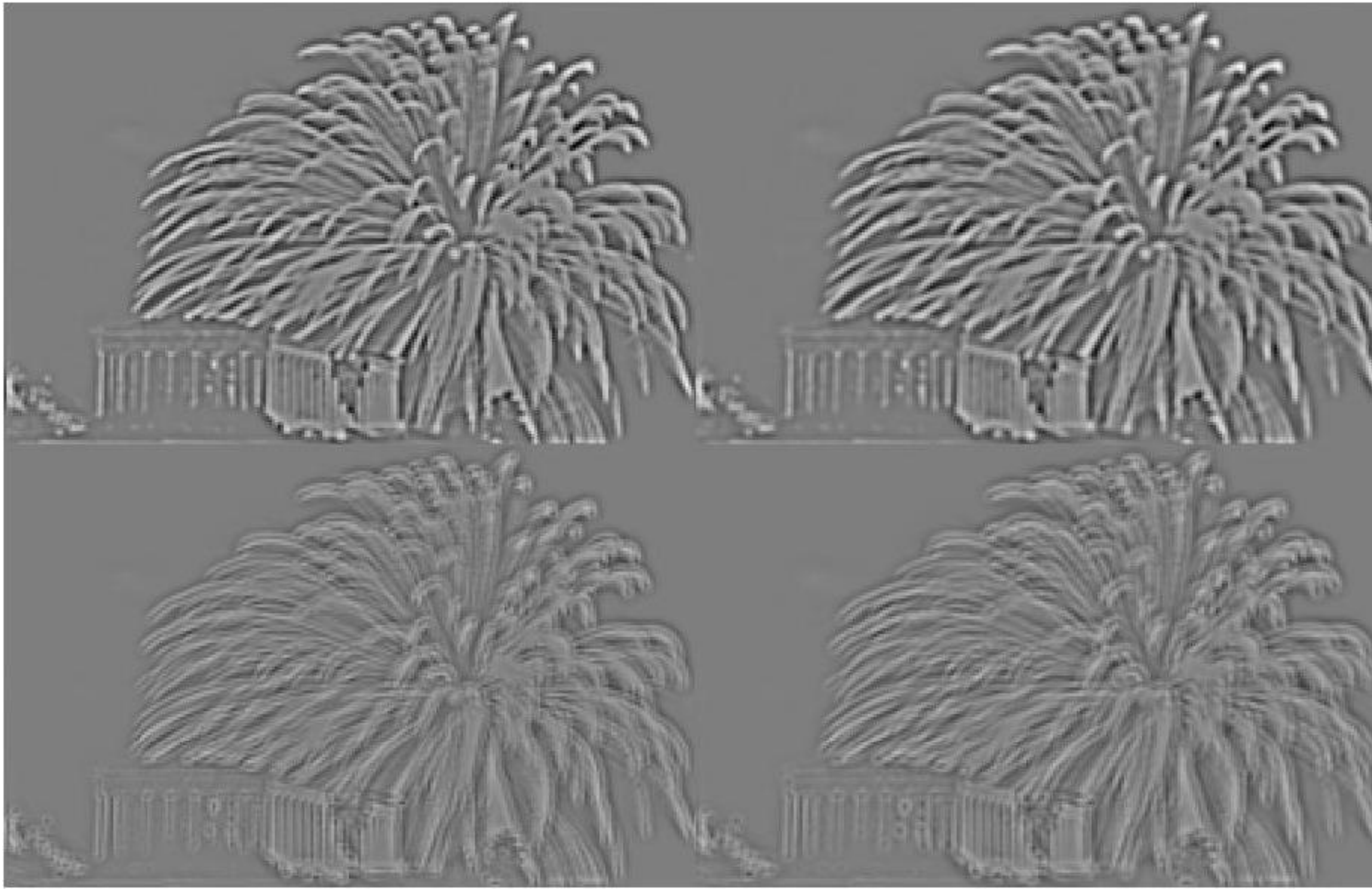
What is a oriented band-pass filter?

Filter Banks

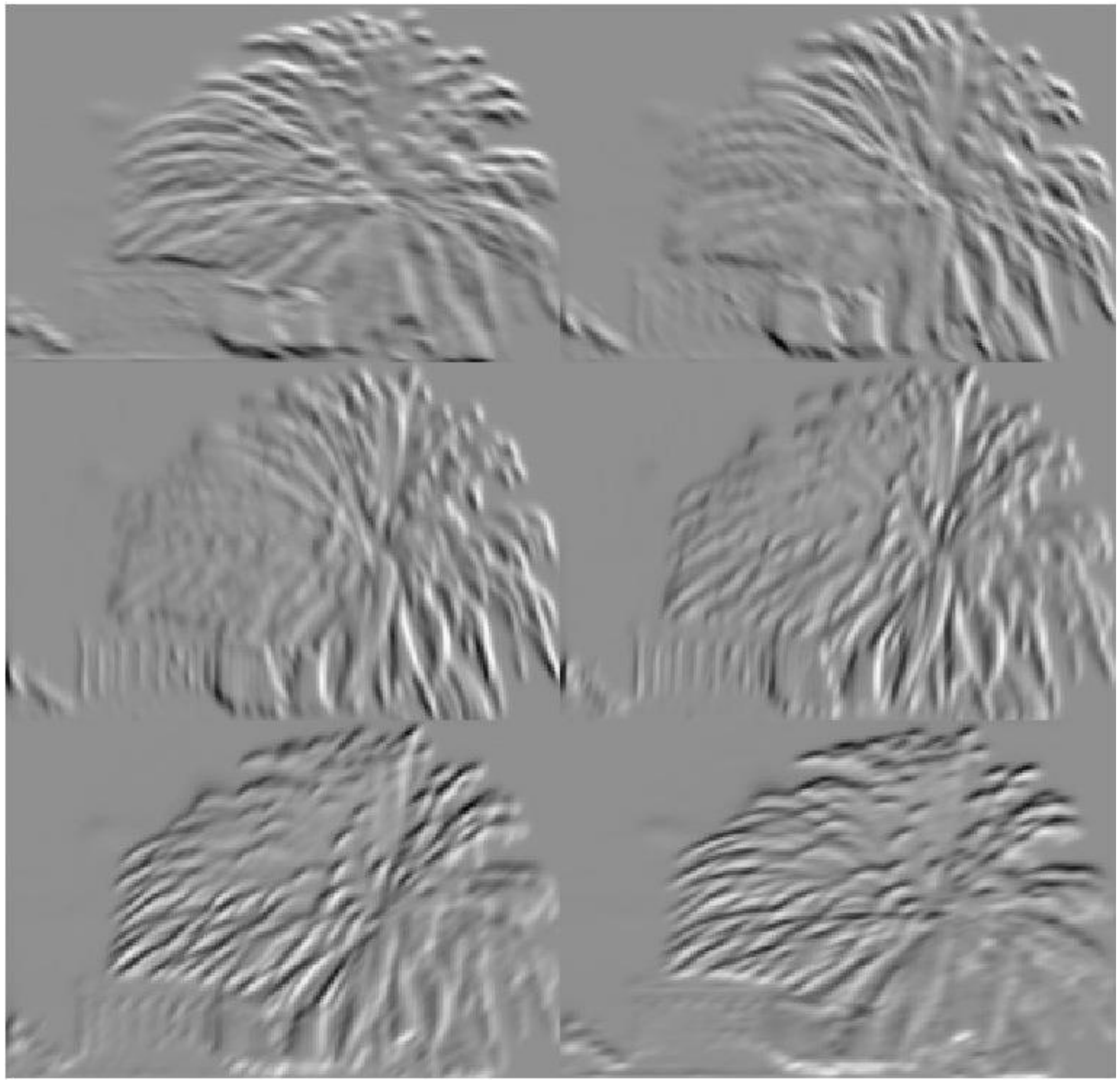


Filter Bank

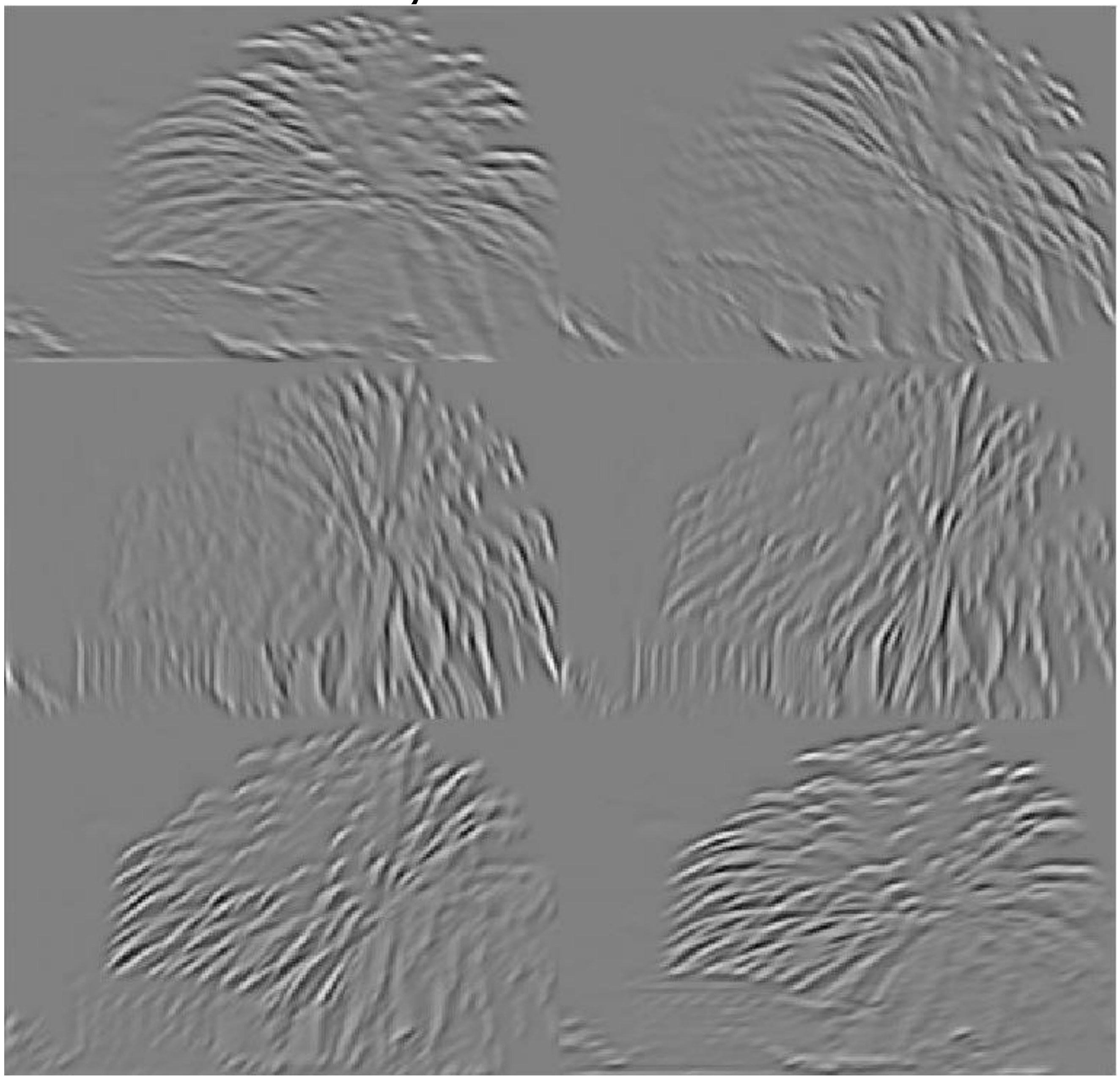
Dot filter response



Odd symmetric filter outputs

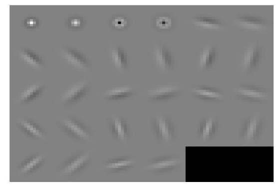


Even symmetric filter



Texture Processing Pipeline

$\otimes$



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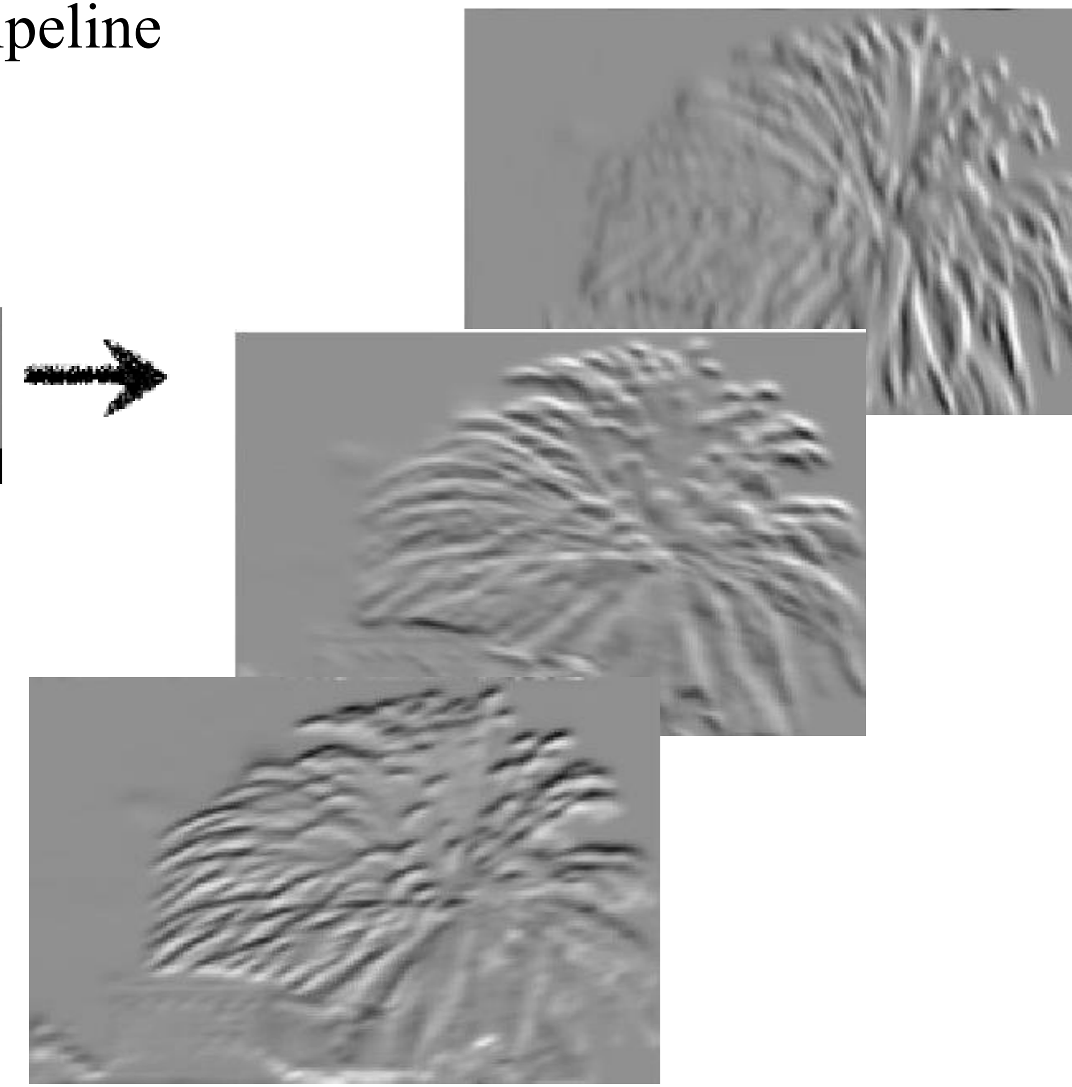
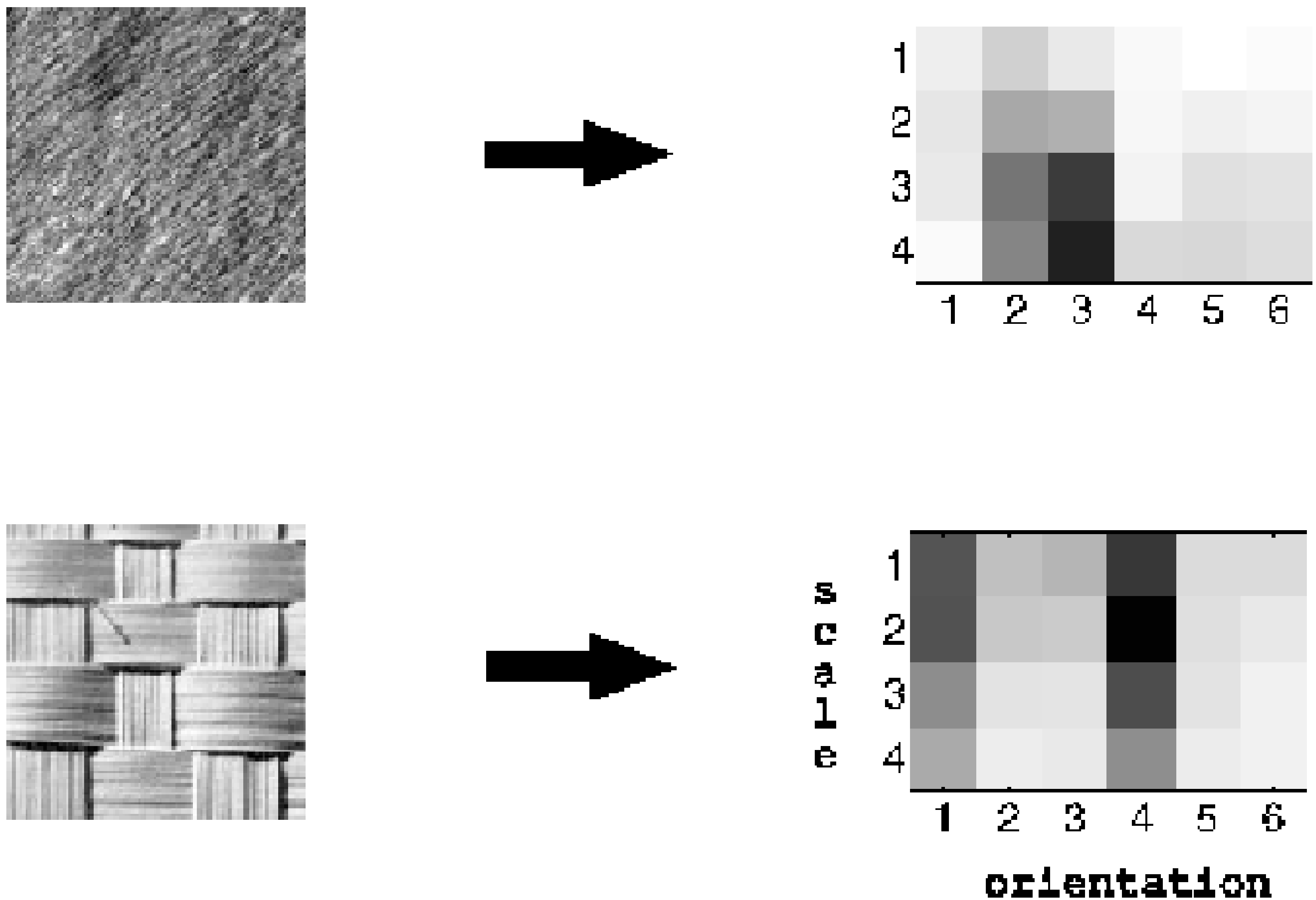
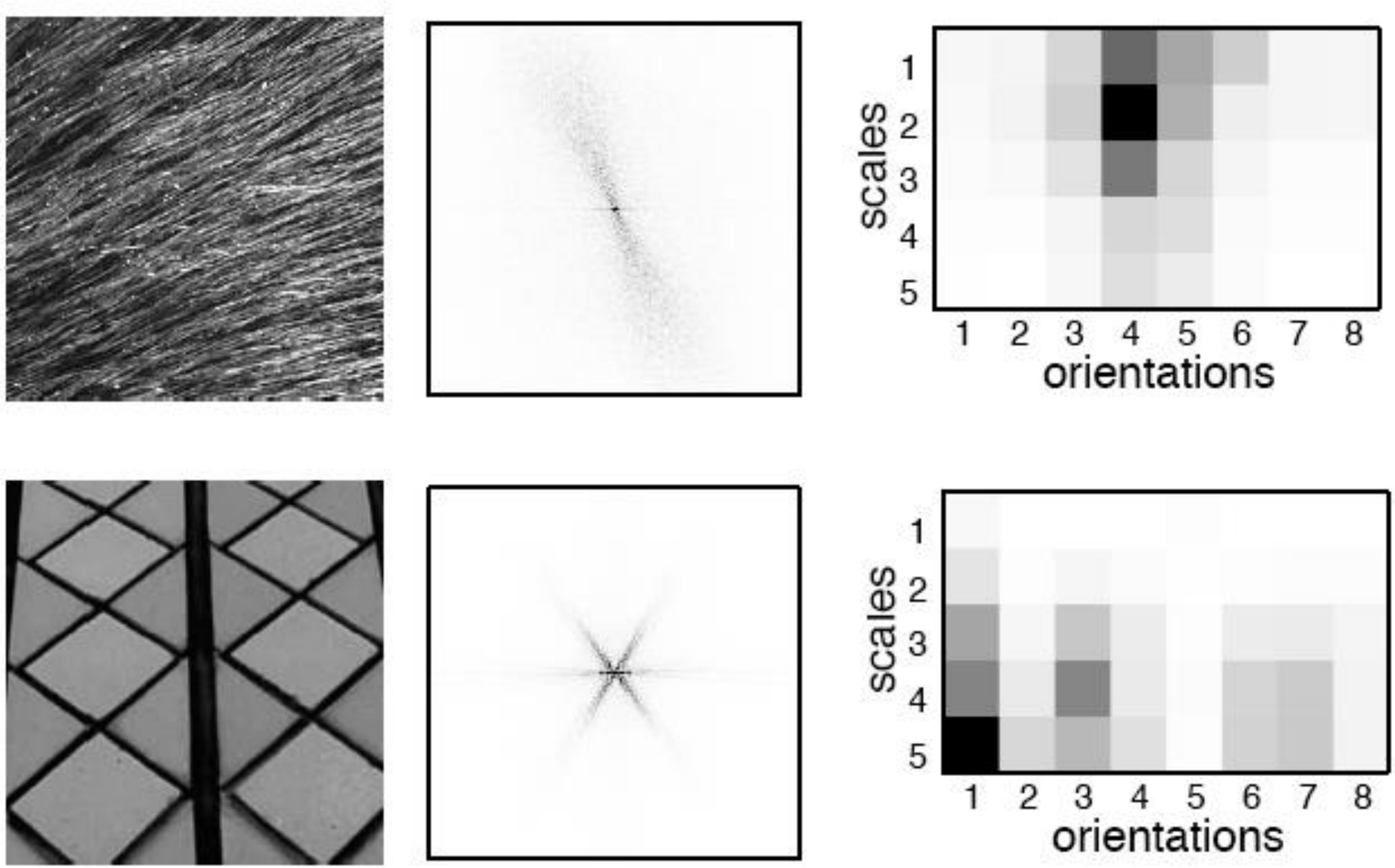
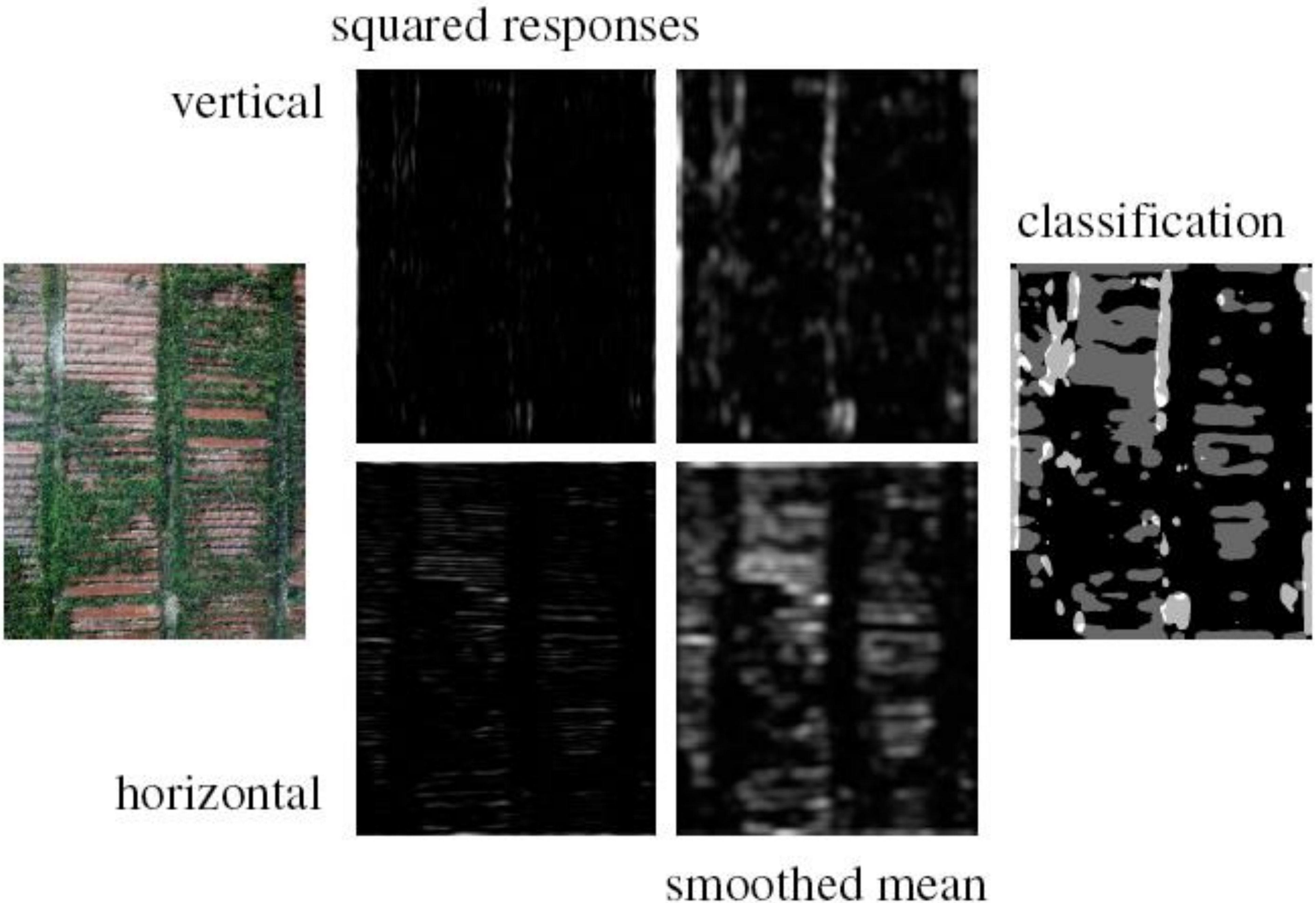


Similarity using ave. filter bank response

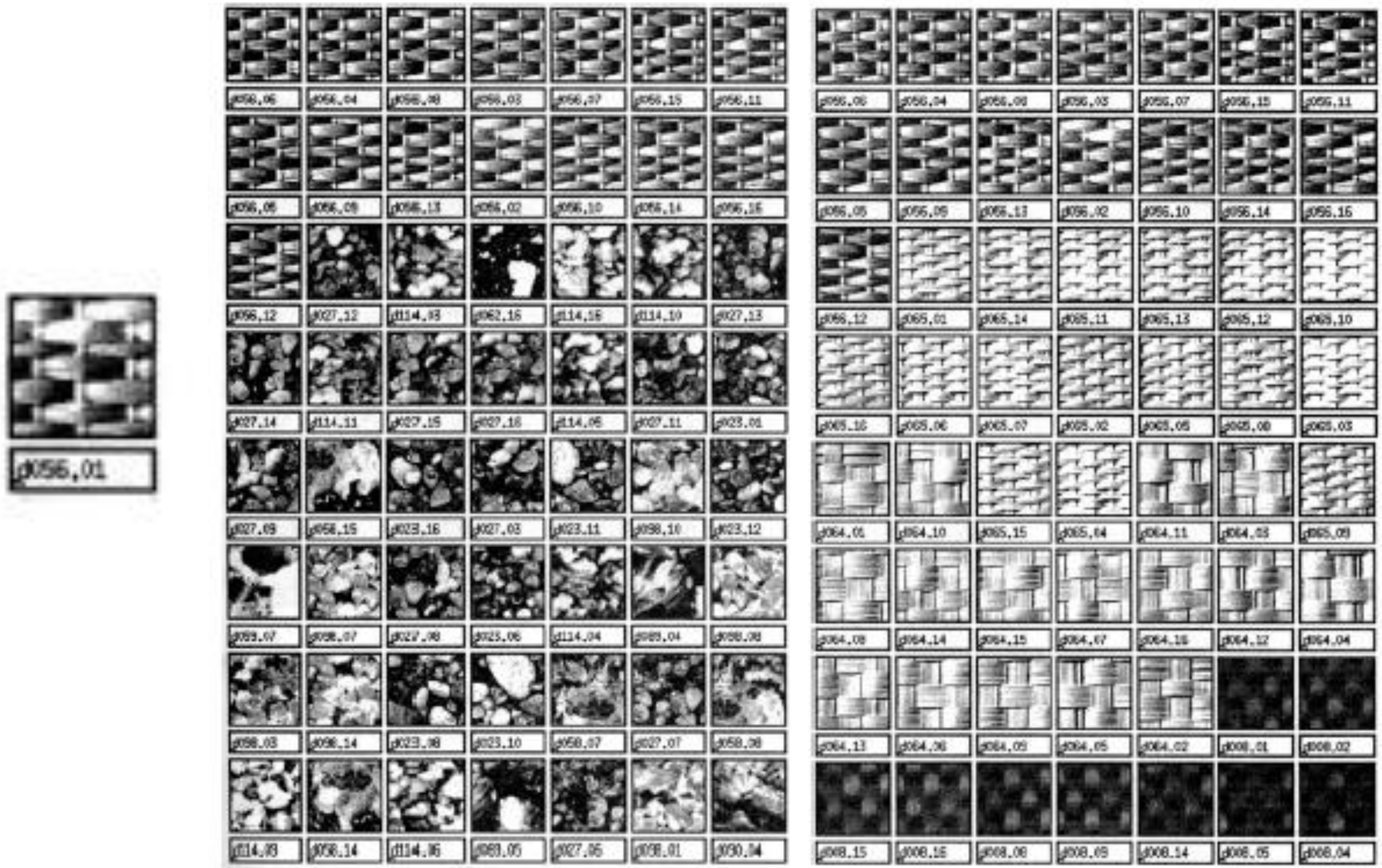



scales
1
2
3
4
5
1 2 3 4 5 6 7 8
orientations
scales
1
2
3
4
5
1 2 3 4 5 6 7 8
orientations

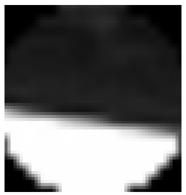
Average filter bank response



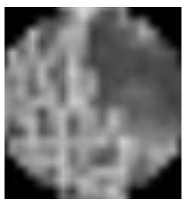
Is mean of filter outputs sufficent?



Texture Patch Types



- Simple: clean step edge

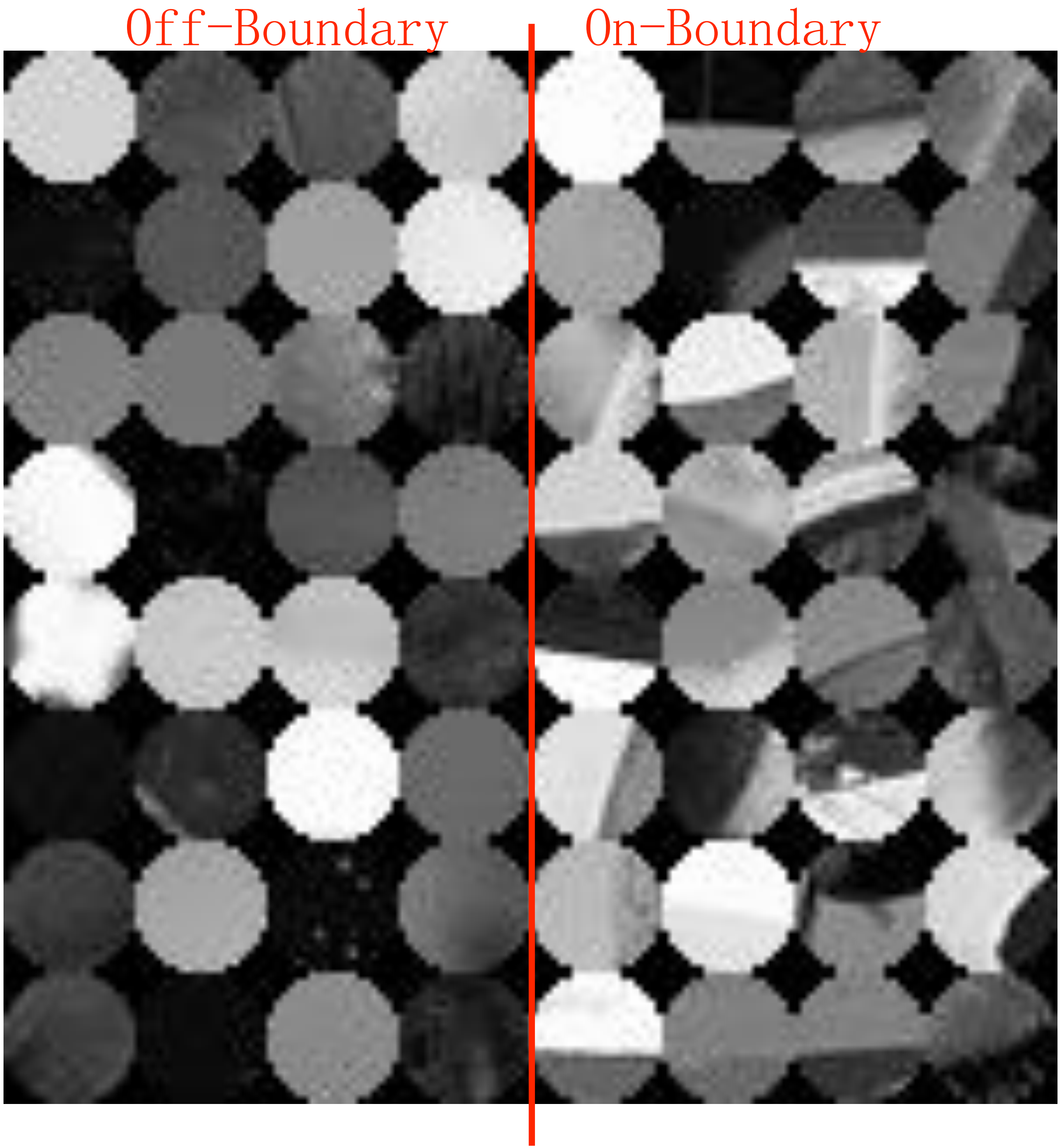


- Textured: on either side, or step with noise

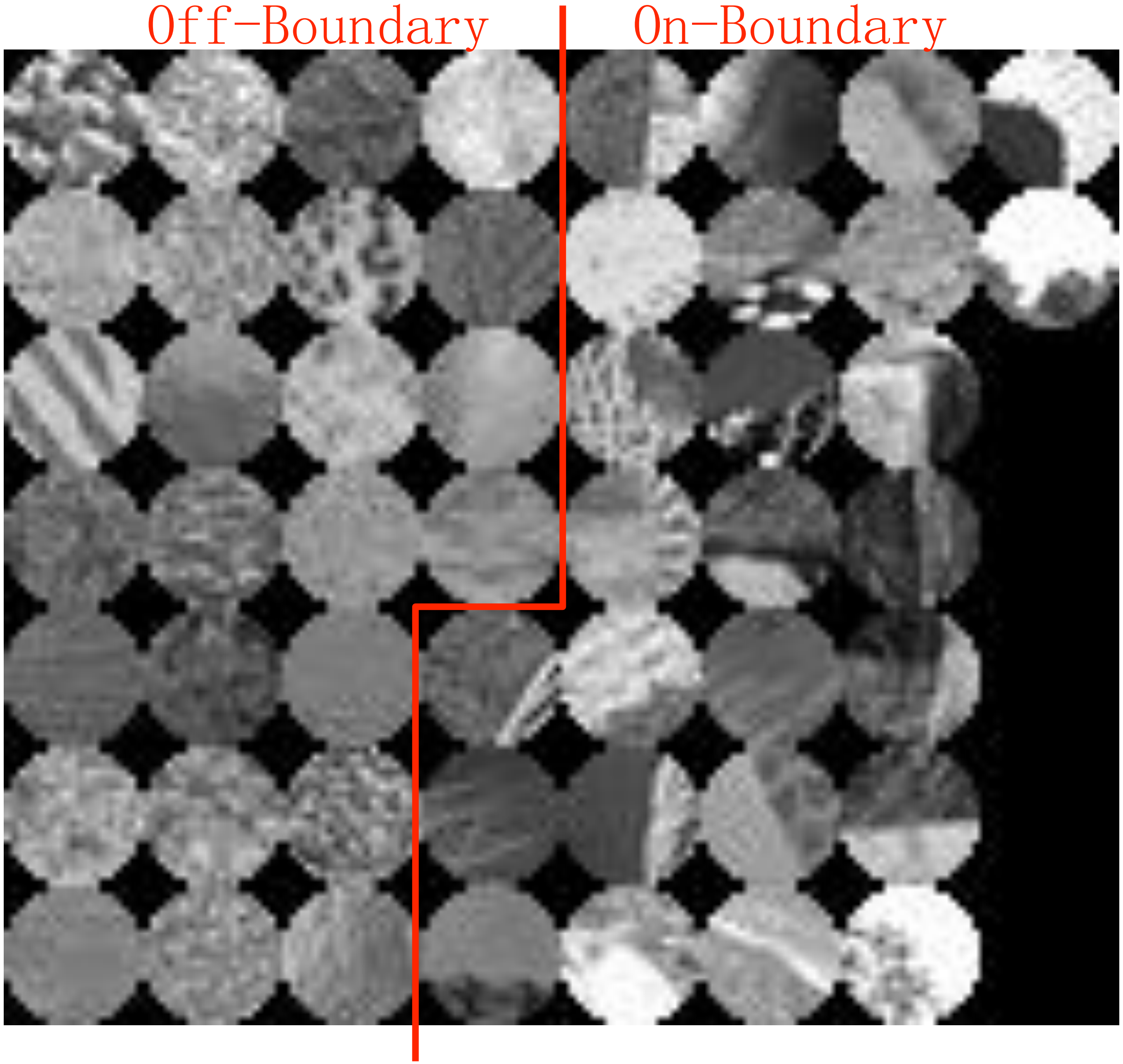
- Complex: wrong scale, or just a mess

- Invisible: boundary but no edge

Simple Patches



Textured Patches



Complex Patches