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Introduction to Image Analysis

This document: http://arnaud-nauwynck.github.io/

Outline

Linear Filter

Non-Linear Filter : Mathematical Morphology
  Erode/Dilate, Open/Close

Visual Cortex – bio mimetism
  Illusory shapes

Object Recognition, Segmentation, Optical Flow, ..

Deep Neural Networks

Who's She?

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Lenna

From Wikipedia, the free encyclopedia

This article is about the test image. For other uses, see Lenna (disambiguation).

Lenna or **Lena** is the name given to a standard test image widely used in the field of image processing since 1973.[1] It is a picture of Lena Söderberg, shot by photographer Dwight Hooker, cropped from the centerfold of the November 1972 issue of *Playboy* magazine.

The spelling "Lenna" comes from the anglicisation used in the original *Playboy* article.

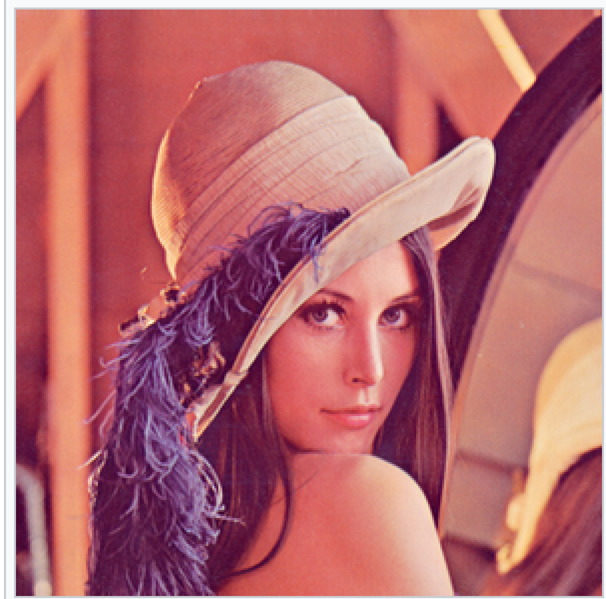

Image of Lena Söderberg used in many image processing experiments. *(Click on the image to access the actual 512×512px standard test version.)*

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Linear Combination of Filters

Definition of Linear:

$$\forall I1, I2\, image, \forall a, b \in \mathbb{R}, F(aI1 + bI2) = aF(I1) + bF(I2)$$

Filter is determined by images of 1 pixel i,j $\delta_{ij}(x,y) = \begin{cases} 1\, if\ x = i \wedge y = j \\ 0\, otherwise \end{cases}$

$$F(Img\ Zero\, except\ at\ ij) = F(\delta_{ij}) = F_{ij}$$

Indeed, decomposing $Img = \sum_{ij} Pixel_{ij}\, \delta_{ij}$

$$F(Img) = F(\sum_{ij} img_{ij}\, \delta_{ij}) = \sum_{ij} img_{ij}\, F(\delta_{ij}) = \sum_{ij} img_{ij}\, F_{ij}$$

$$\forall x, y\ F(Img)(x, y) = \sum_{ij} img_{ij}\, F_{ij}(x, y)$$

There are N^2 Fij matrix … and each Fij is a N^2 matrix image

Invariant by Translation

Filter is invariant by translation
when coefficients Fij(x,y) do NOT depend of ij

$$\forall i, j \; F_{ij} = K = Matr.\, NxN$$

K is called the Kernel of the linear transformation
it is the coefficient applied uniformely (by translation) to all points

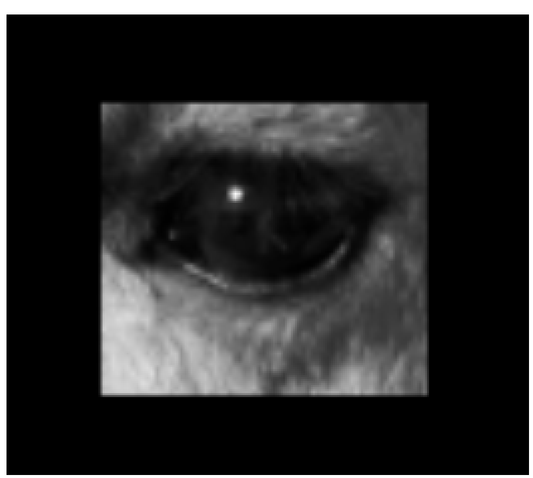
This is possible except on borders of image
(translate Kernel reaches outside of image)

What to do at the Boundary ?

Crop ?

Extend ?

Pad 0 ?



Wrap ?

http://www.coe.utah.edu/~cs4640/slides/Lecture5.pdf

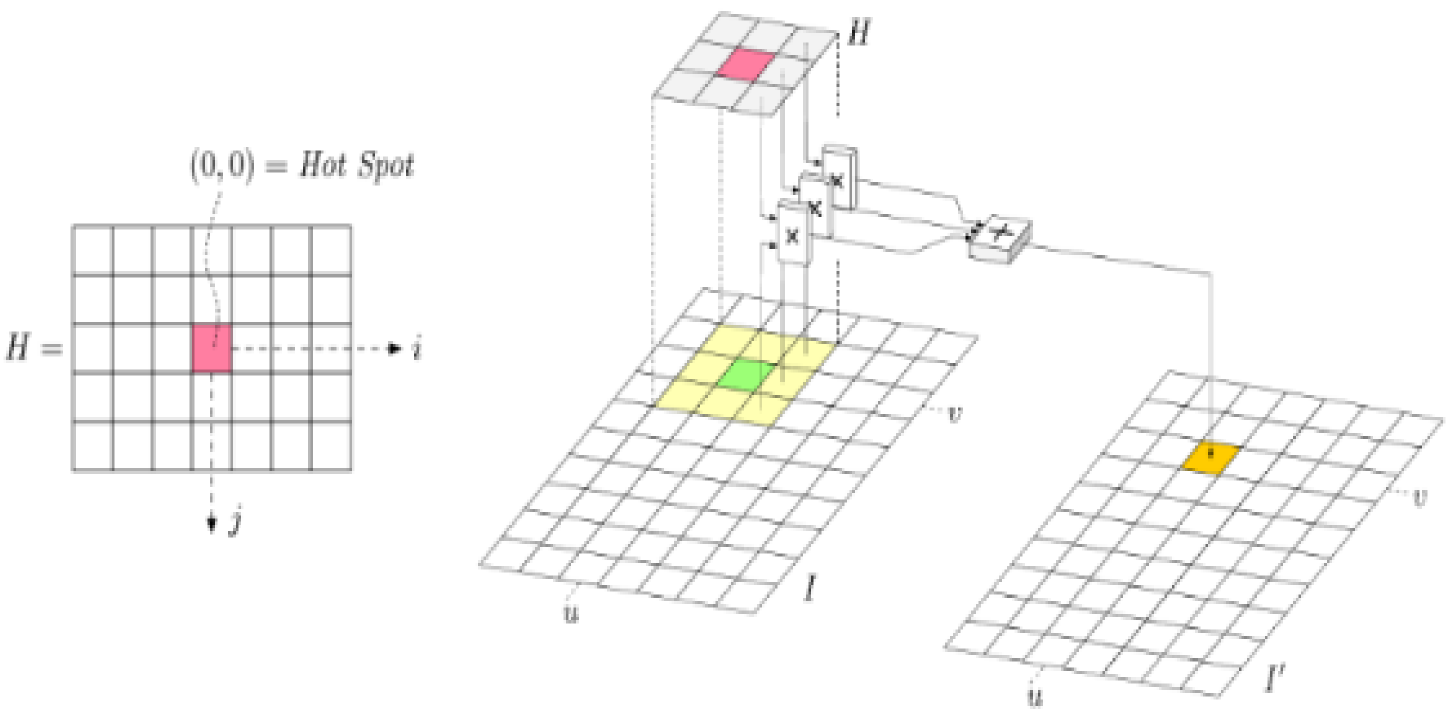
Kernel with small neighborhood only

Example : Kernel with 1 neighbor = matrix 1x1

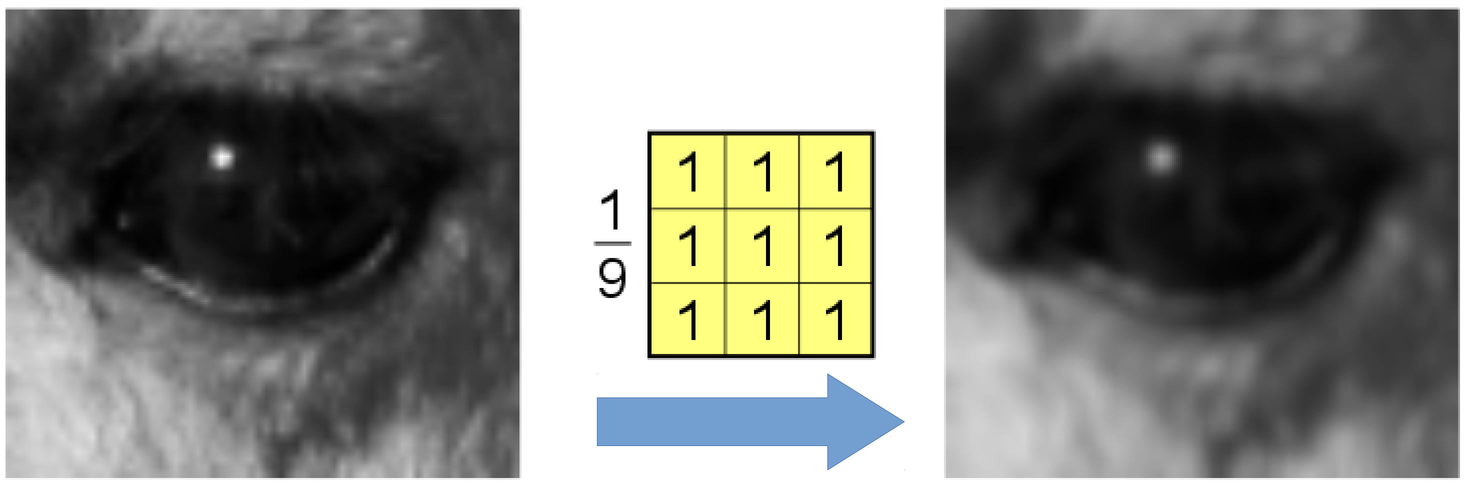
$$K = \begin{pmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{311} & k_{32} & k_{33} \end{pmatrix}$$

Kernel with 2 neighbors = matrix 5x5

$$K = \begin{pmatrix} k_{11} & k_{12} & k_{13} & k_{14} & k_{15} \\ k_{21} & k_{22} & k_{23} & k_{24} & k_{25} \\ k_{31} & k_{32} & k_{33} & k_{34} & k_{35} \\ k_{41} & k_{42} & k_{43} & k_{44} & k_{45} \\ k_{51} & k_{52} & k_{53} & k_{54} & k_{55} \end{pmatrix}$$



Example : Average Kernel



For all pixel = take average of all neighbours

Smooth every value
Make border fuzzy
Remove noise of single isolated pixel

2D Kernel Filter = Correlation

Notice that the kernel H is just a small image!

Let $H : R_H \rightarrow [0, K-1]$

$$I'(u,v) = \sum_{(i,j) \in R_H} I(u+i, v+j) \cdot H(i,j)$$

This is known as a **correlation** of I and H

http://www.coe.utah.edu/~cs4640/slides/Lecture5.pdf

Correlation ~ Convolution (Symmetric Image)

Definition

Convolution of an image I by a kernel H is given by

$$I'(u,v) = \sum_{(i,j)\in R_H} I(u-i, v-j) \cdot H(i,j)$$

This is denoted: $I' = I * H$

- Notice this is the same as correlation with H, but with negative signs on the I indices
- Equivalent to vertical and horizontal flipping of H:

$$I'(u,v) = \sum_{(-i,-j)\in R_H} I(u+i, v+j) \cdot H(-i,-j)$$

http://www.coe.utah.edu/~cs4640/slides/Lecture5.pdf

Comparison with 1D Time Filter

$$y(t) = \int_0^T x(t - \tau)\, h(\tau)\, d\tau$$

$$y_k = \sum_{i=0}^{N} x_{k-i}\, h_i$$

Properties of Convolutions ...

Img * K = K * Img

we can leave the image fixed and slide
the kernel or leave the kernel fixed and slide the image.

Img * (aK1+bK2) = a Img * K1 + b Img * K2

Combine linear convolutions..

(Img * K1) * K2 = Img * (K1 * K2)

Instead of applying K1 to Img then K2 to result,
We can compute (K1*K2) and apply it to Img

Properties of Separation x/y

$$H_x = [1\ 1\ 1\ 1\ 1], \quad \text{and} \quad H_y = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

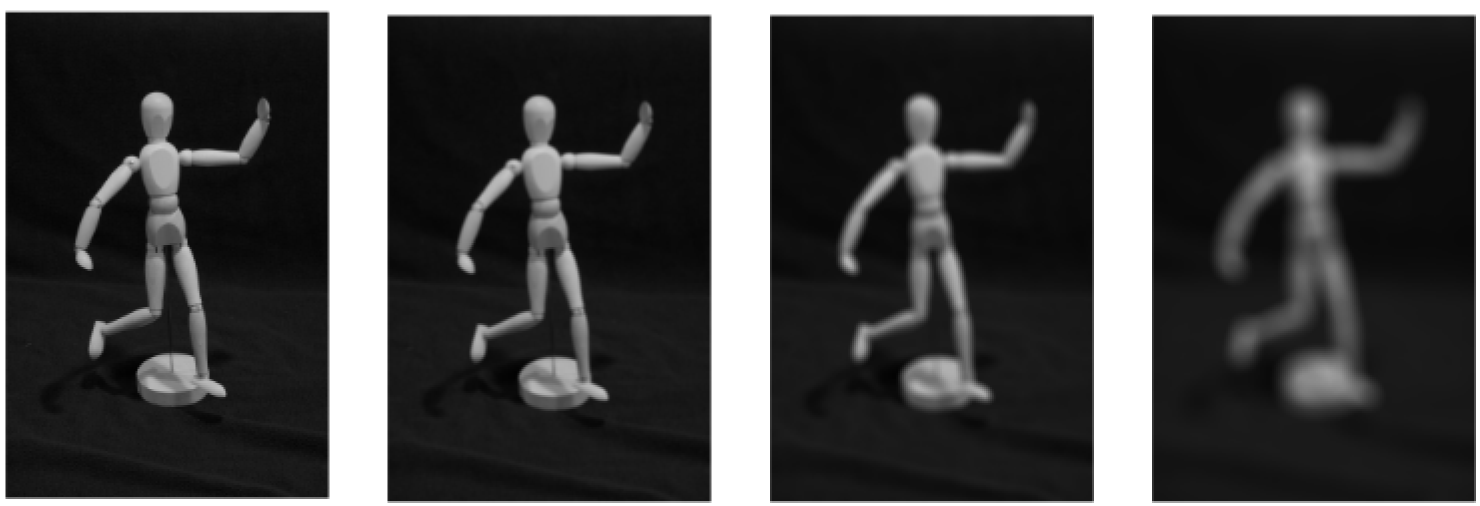
$$H = H_x * H_y = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

Instead of applying H … it is faster applying Hx then Hy

Repeated Smoothing
Effect of Filter Size

Repeat 7 times 3x3 Kernel = 3 times 7x7 Kernel ...

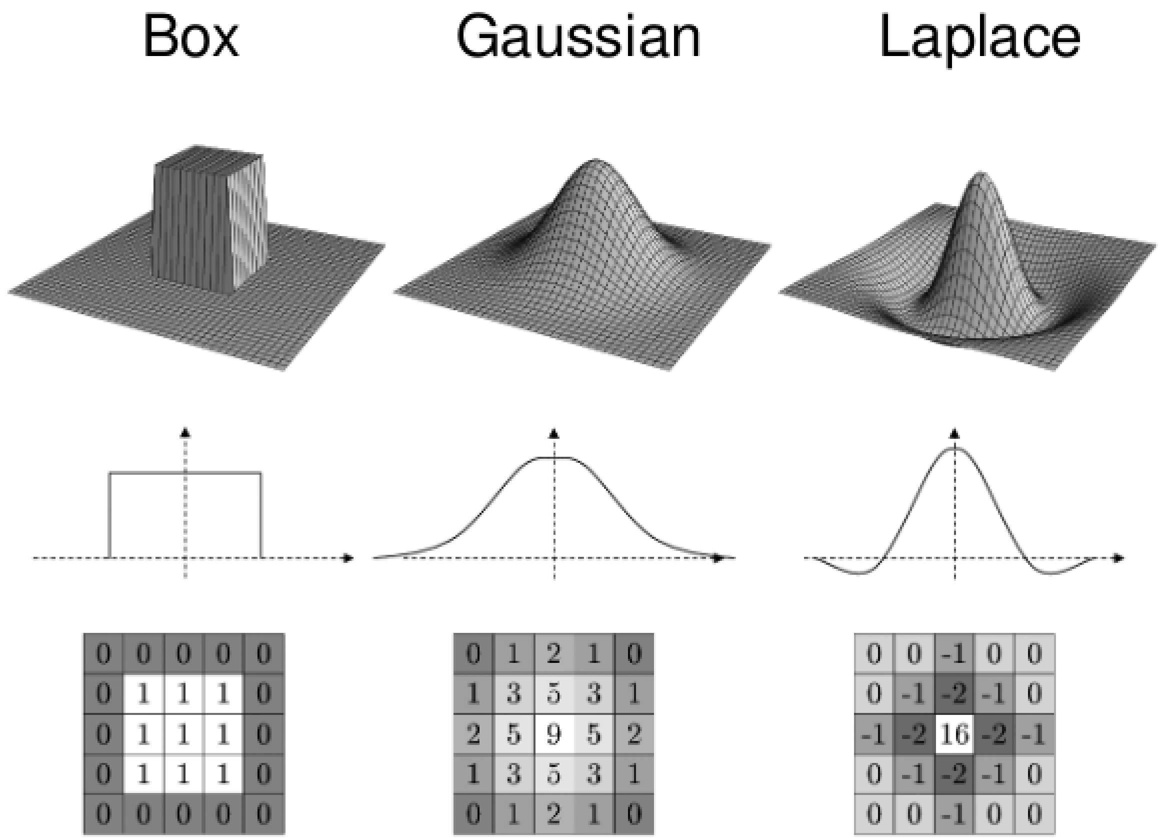
Mean Filters:



Original 7 × 7 15 × 15 41 × 41

http://www.coe.utah.edu/~cs4640/slides/Lecture5.pdf

Box, Gaussian, Laplacian (=Gaussian Derivative 1), ...



Gaussian..

In 1D:

$$g_\sigma(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

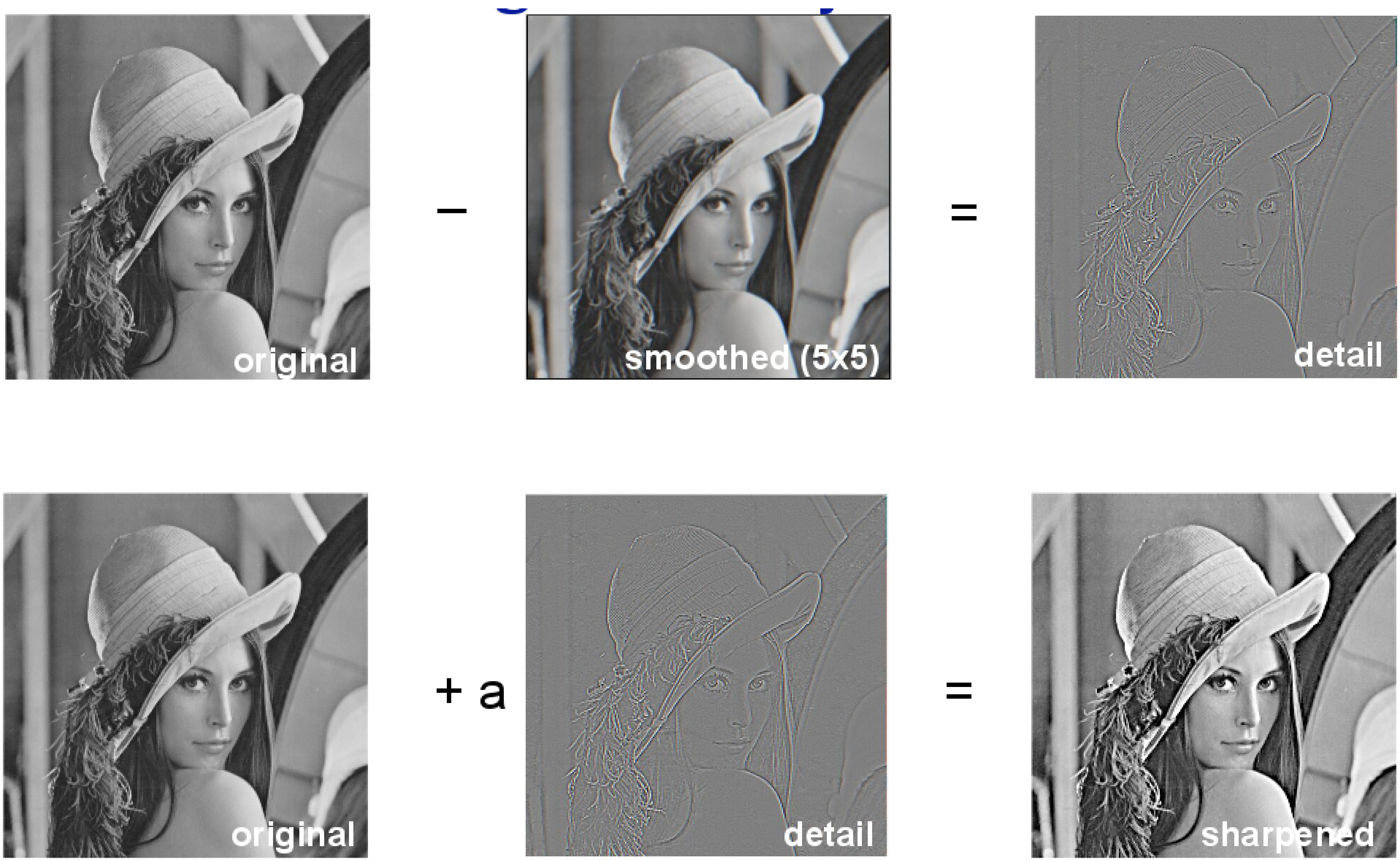
In 2D:

$$G_\sigma(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$

$$= g_\sigma(x) \cdot g_\sigma(y)$$

(A 2-D Gaussian Filter is the product of 2 1-D gaussian)

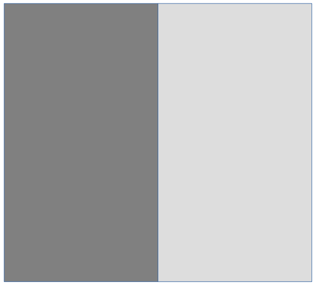
Blurr = Identity - Smooth

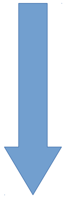


Gradient = Derivatives...

$$Gradient_x = \begin{pmatrix} -1 & 0 & +1 \\ -1 & 0 & +1 \\ -1 & 0 & +1 \end{pmatrix}$$

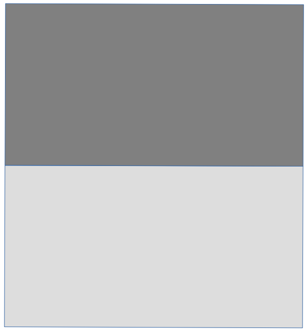
Correlation = Detect changes





$$Gradient_y = \begin{pmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ +1 & +1 & +1 \end{pmatrix}$$

Correlation = Detect changes



GradX .. GradY

GradX
=> detect Vertical Edges

GradY
=> detect Horizontal Edges

Look Closely ..


Horizontal Lines bigger in Right image

Vertical Lines bigger in Left image


Grad at different Orientations

$$Gradient_{45\,deg} = \begin{pmatrix} 0 & +1 & +2 \\ -1 & 0 & +1 \\ -2 & -1 & 0 \end{pmatrix}$$

$$Gradient_{-45\,deg} = \begin{pmatrix} -2 & -1 & 0 \\ -1 & 0 & +1 \\ 0 & +1 & +2 \end{pmatrix}$$

Gradient X (increasing Scale)

Detection of Vertical Edges

Small Scale :
Precise vertical edges position
Many small vertical edges
lot of Noise

Big Scale :
Imprecise edges position
Missed small vertical edges
lower Noise

Sobel Operator (~ Gradient)

$$Sobel_x = \begin{pmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{pmatrix}$$

$$Sobel_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{pmatrix}$$

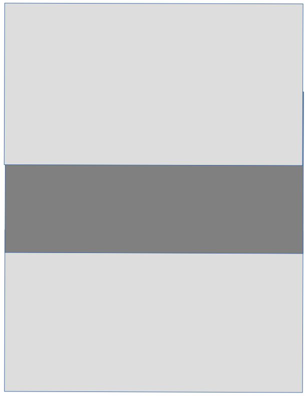
Second Derivatives ...

$$Laplacian_x = \begin{pmatrix} -1 & +2 & -1 \\ -1 & +2 & -1 \\ -1 & +2 & -1 \end{pmatrix}$$

Correlation = Detect changes

$$Laplacian_y = \begin{pmatrix} -1 & -1 & -1 \\ +2 & +2 & +2 \\ -1 & -1 & -1 \end{pmatrix}$$

Correlation = Detect changes



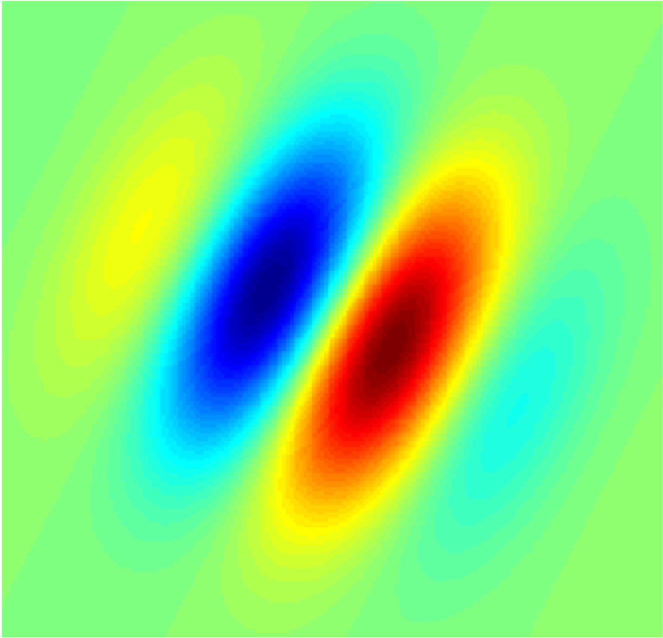
Second Derivative Filters

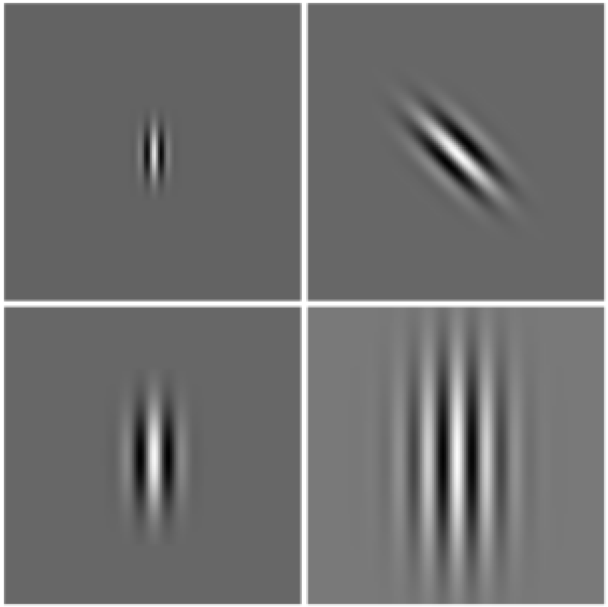
Example..

$$\begin{pmatrix} -1 & -1 & 0 & 4 & 0 & -1 & -1 \\ -1 & -1 & 0 & 4 & 0 & -1 & -1 \\ -1 & -1 & 0 & 4 & 0 & -1 & -1 \\ -1 & -1 & 0 & 4 & 0 & -1 & -1 \\ -1 & -1 & 0 & 4 & 0 & -1 & -1 \end{pmatrix}$$

$$\begin{pmatrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 4 & 4 & 4 & 4 & 4 & 4 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

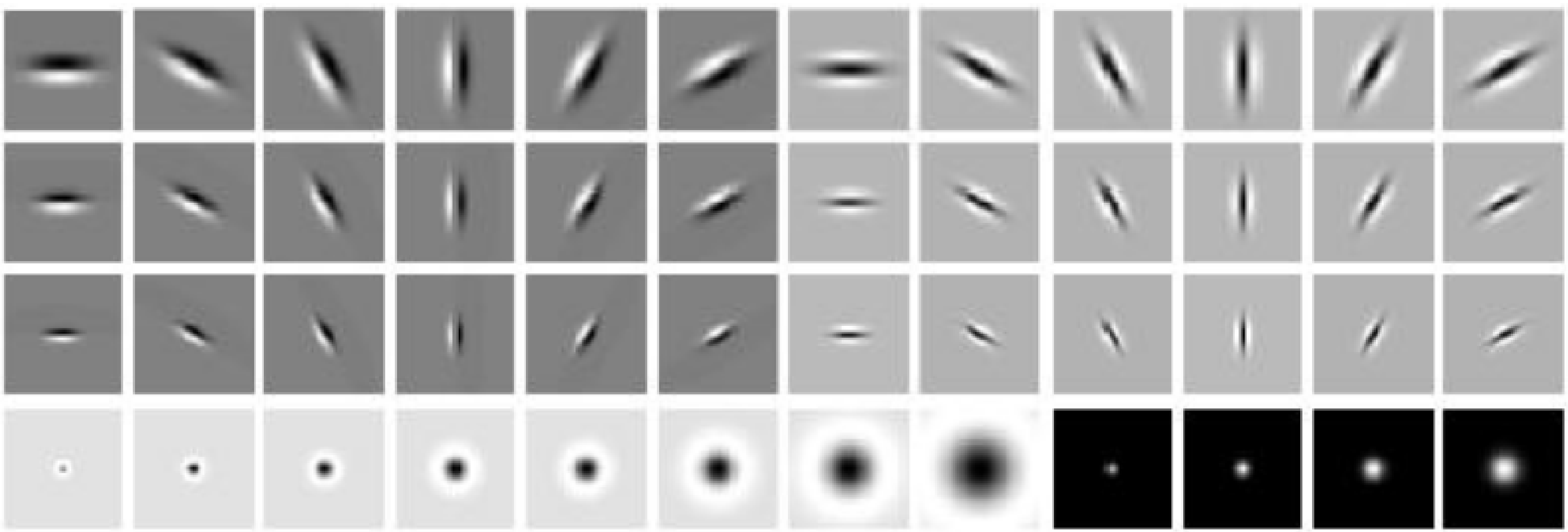
Gabor Filter





Gabor filters are a "local" way of getting image frequency content
(idem Fourier coefficient... but local)
(idem Wavelet)

Familly of Gaussian Filters (Leung-Malik Filter)



Cf next … Same as Visual Cortex in Biology !

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Illusory shapes

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Applying Min , Median, Max ...instead of Linear Sums

Mathematical morphology

From Wikipedia, the free encyclopedia

Mathematical morphology (**MM**) is a theory and technique for the analysis and processing of geometrical structures, based on set theory, lattice theory, topology, and random functions. MM is most commonly applied to digital images, but it can be employed as well on graphs,

The basic morphological operators are erosion, dilation, opening and closing.

MM was originally developed for binary images, and was later extended to grayscale functions and images.

History [edit]

Mathematical Morphology was developed 1964 by the collaborative work of Georges Matheron and Jean Serra, at the *École des Mines de Paris*, France. Matheron supervised the PhD thesis of Serra, devoted to the

Min (Dilate Black - Erode White) / Max(Dilate White – Erode Black)

Min-then-Max != Max-then-Min

Min-then-Max

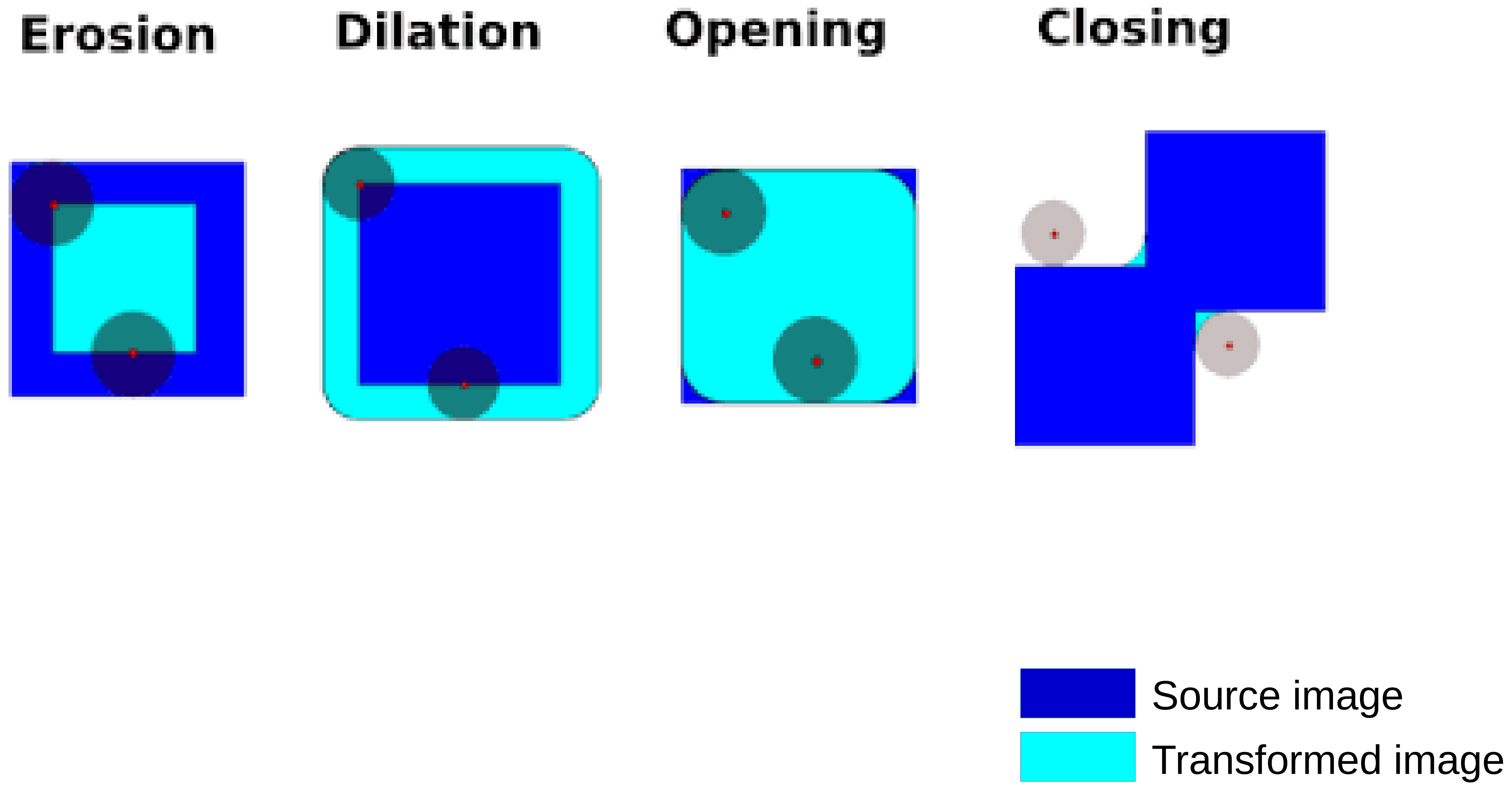
Max-then-Min

Filtering Out All Noise !!

Both OPEN and CLOSE Filter out small noise pixels

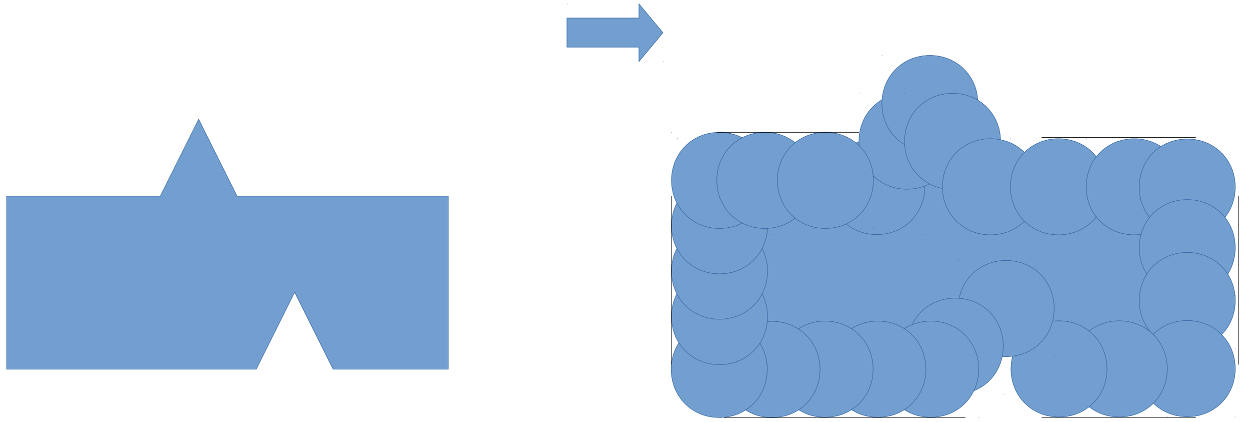
The image is looks similar to original...
(cf next for details)

Interpreting Kernel As Point Touching/Within Figure



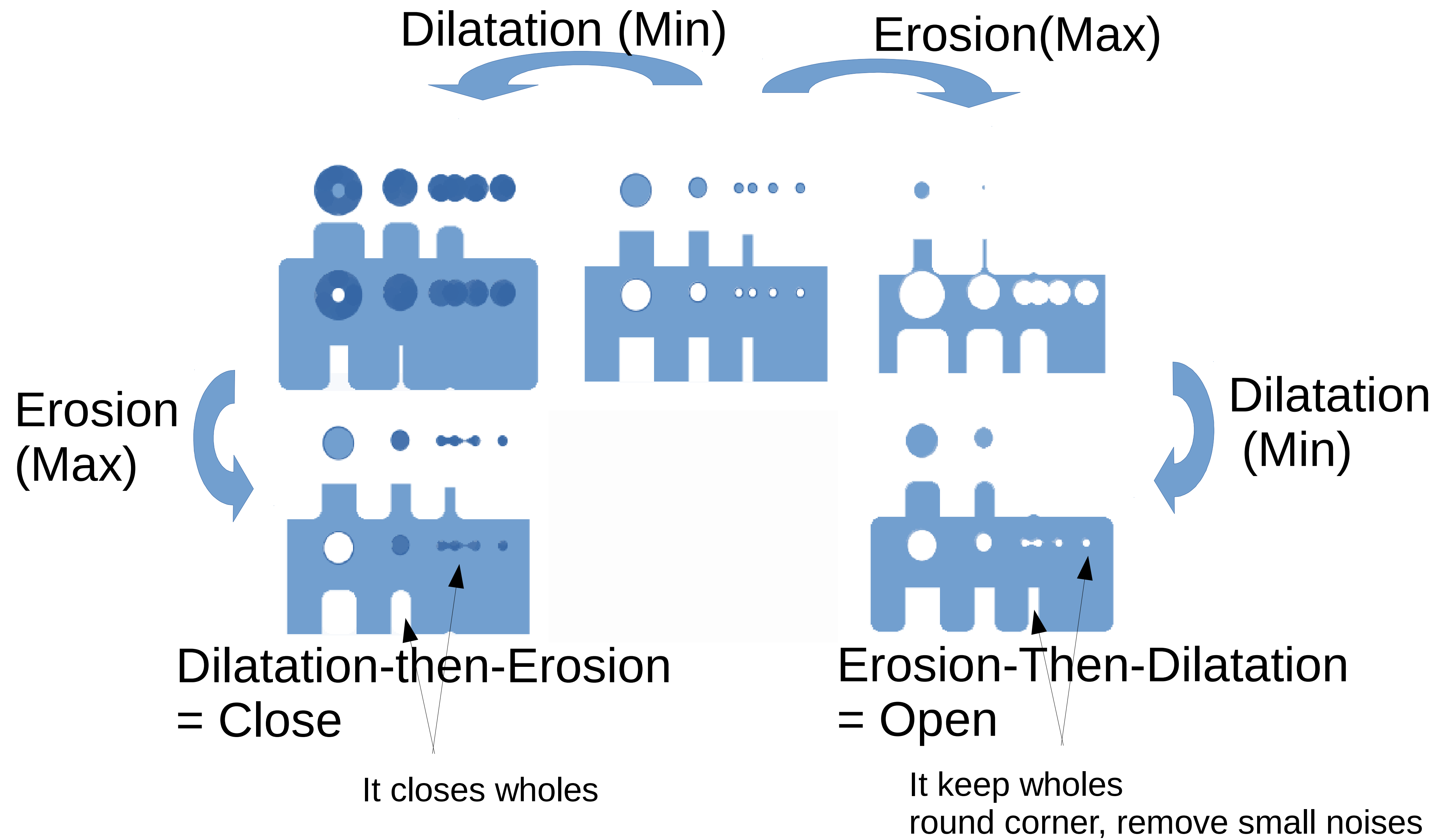
Dilatation (Kernel = Disk)

Dilatation

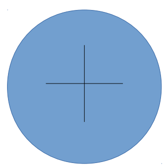


Erosion and Dilatation Kernel do not behave same on small Wholes and Bumps

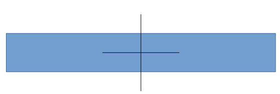
Dilate-then-Erode != Erode-then-Dilate



Using Kernel Shape segment != disk



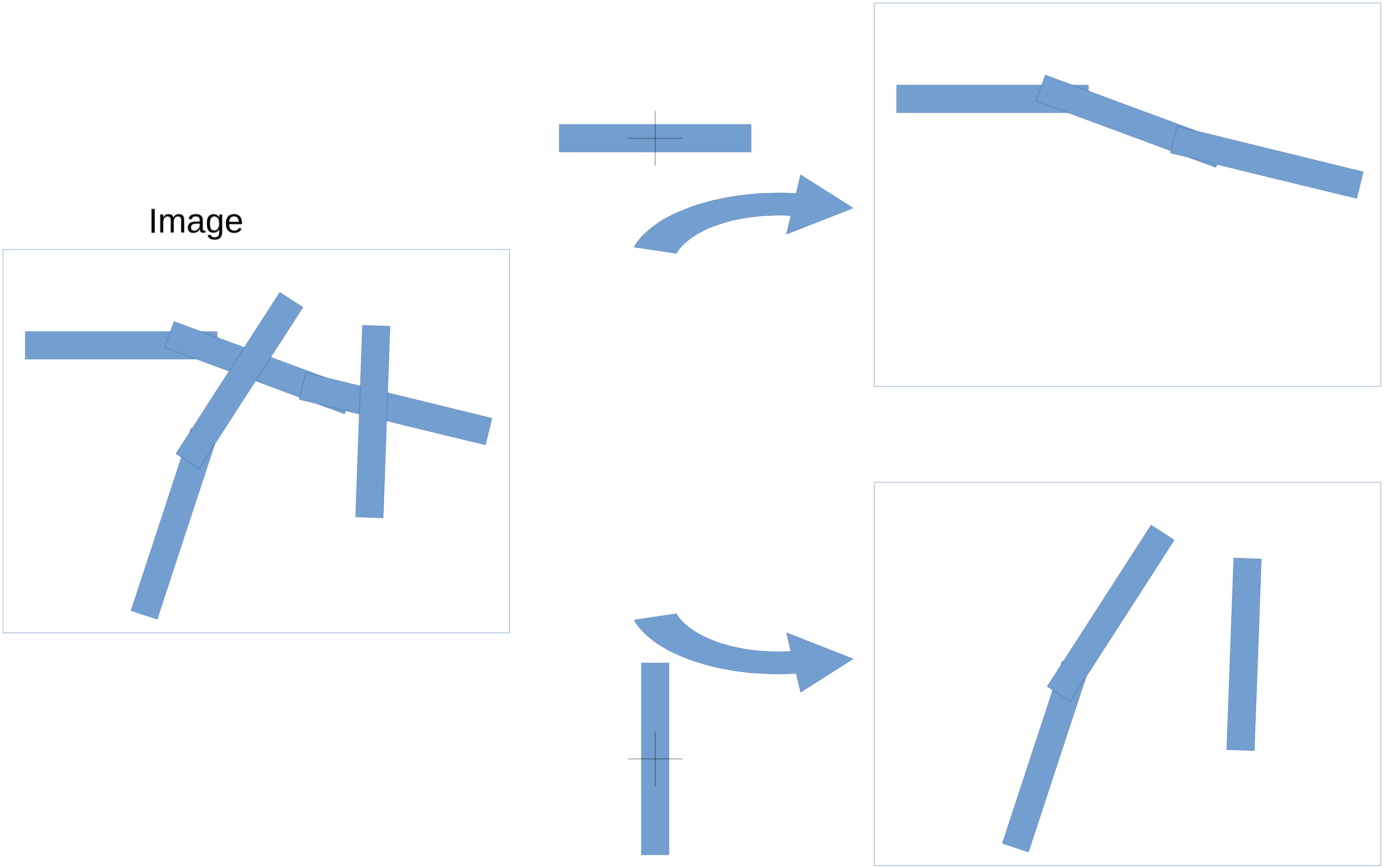
OK For detecting “filled” area
(… Whatever the direction)



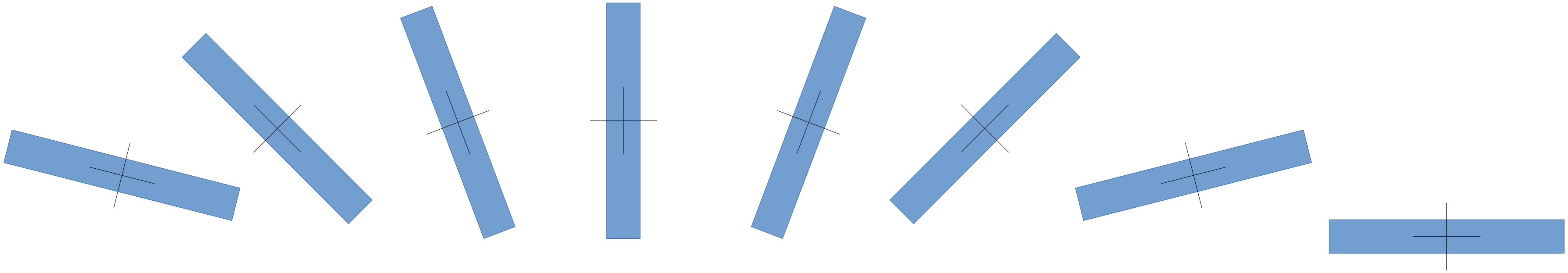
OK For detecting Horyzontal segments!
(… very sensitive to direction)

Similar to GradY Detection for Linear Filters

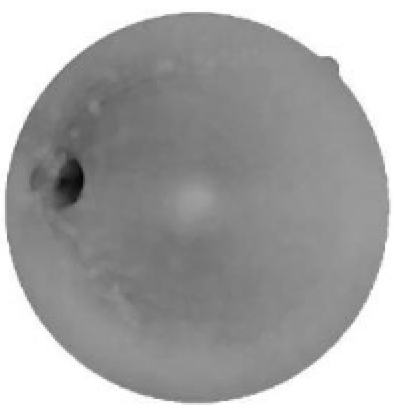
Example: Opening With Segment



Kernel Shapes Orientation



Example : Medical Image
Blood Vessels (image of Eye)



Opening

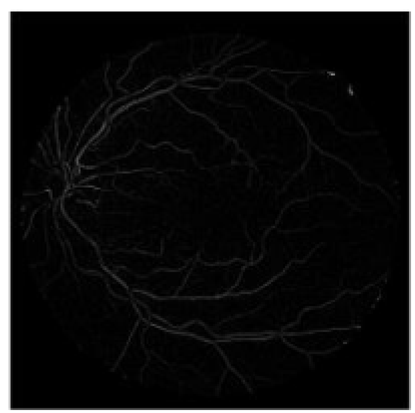


Image-Opening

Reconstruction by Erosion

summing All Segment Erosions
...

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Primary Visual Cortex V1

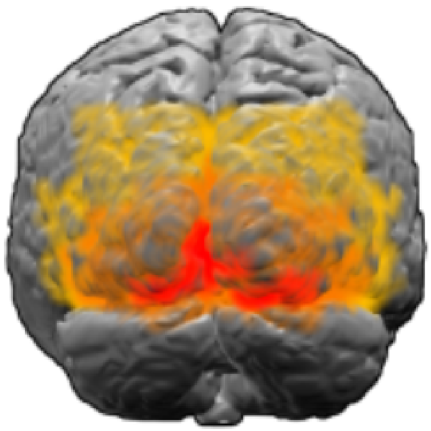
Visual cortex

From Wikipedia, the free encyclopedia

The **visual cortex** of the brain is a part of the cerebral cortex that plays an important role in processing visual information. It is located in the occipital lobe in the back of the skull.

Visual information coming from the eye, goes through the lateral geniculate nucleus, that is located in the thalamus, and then reaches the visual cortex. The part of the visual cortex that receives the sensory inputs from the thalamus is the primary visual cortex, also known as **V**isual area **one**(**V1**), and the **striate cortex**. The **extrastriate areas** consist of visual areas two (**V2**), three (**V3**), four (**V4**), and five (**V5**).[1]

Visual cortex



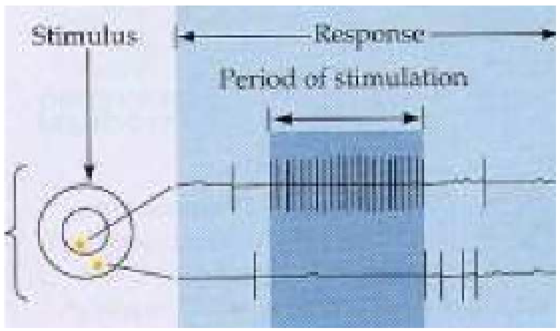
Book: NeuroGeometry of Vision
Jean Petitot

http://jean.petitot.pagesperso-orange.fr/NGV.html

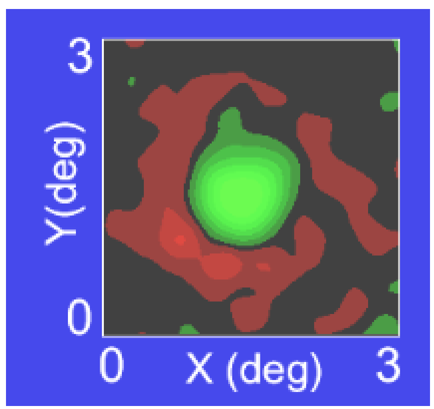
http://jeanpetitot.com/ArticlesPDF/Petitot_NGV_2008.pdf

Measuring Response of Neuron

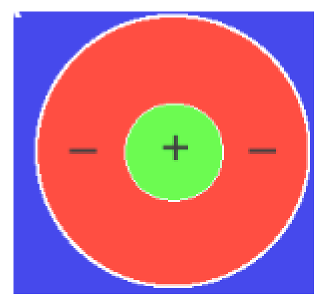
Experiment (on a cat...)



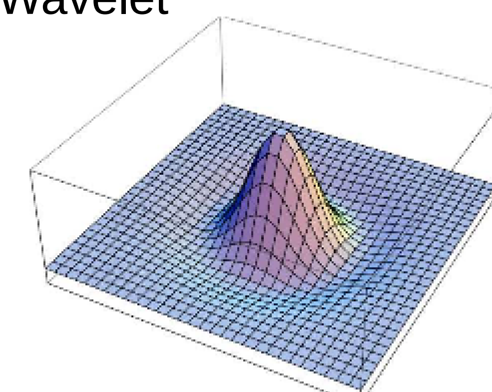
Measured
Response fonction



Idealised
Response fonction

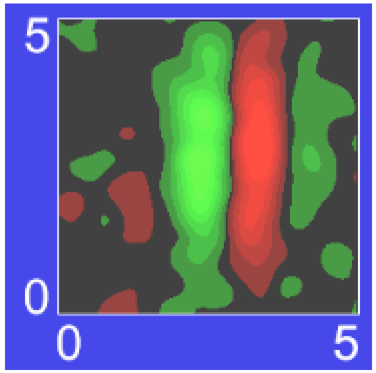


Math
Model (Gabor / Gaussian)
Wavelet

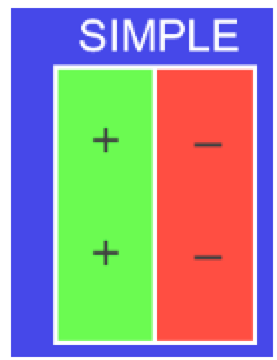


Other Neurons..

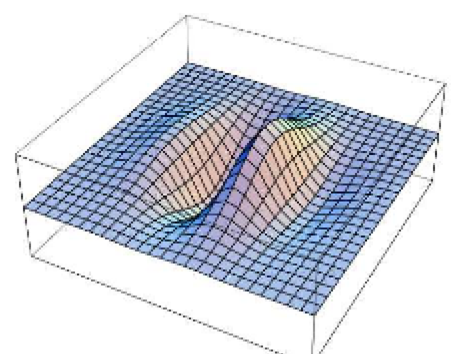
Measured
Response fonction

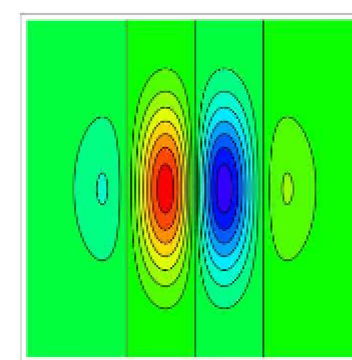


Idealised
Response fonction

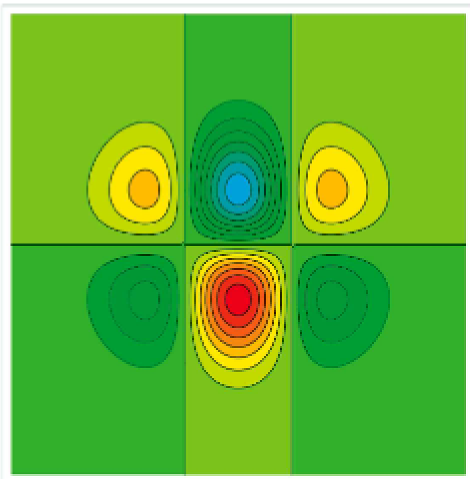


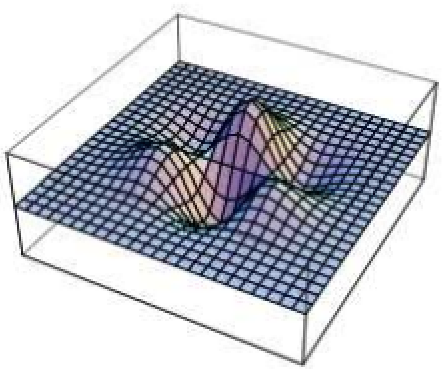
Math
Model (Gabor / Gaussian)
Wavelet

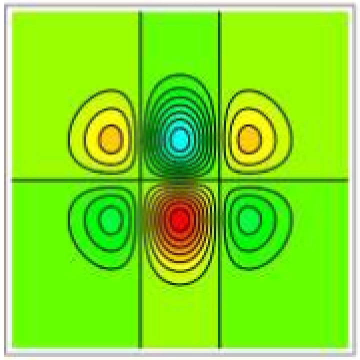


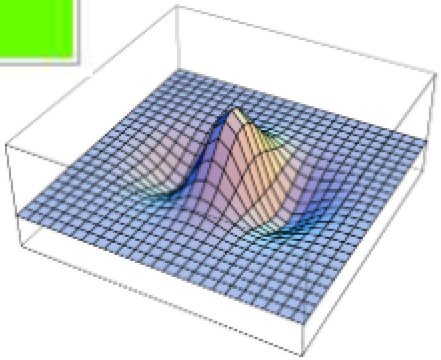


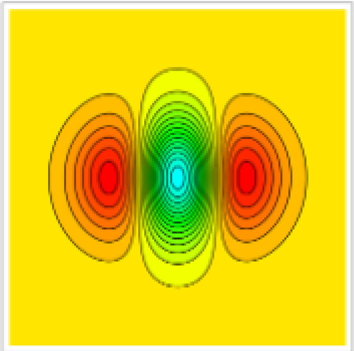
Other Neurons ...



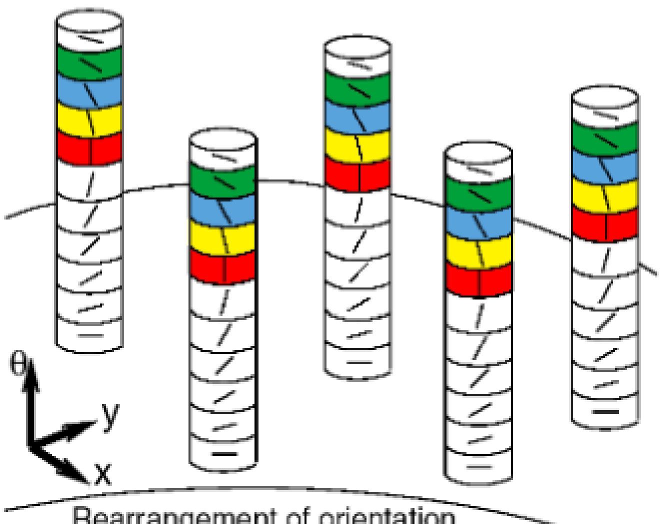






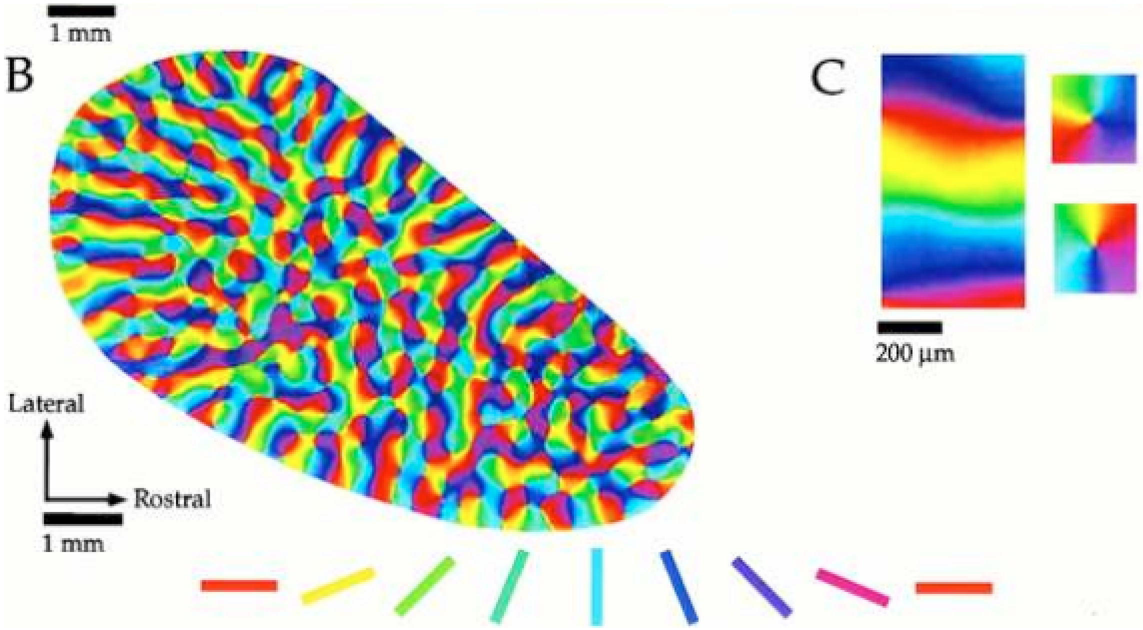


Visual Cortex = Parallel Computing For Wavelets...

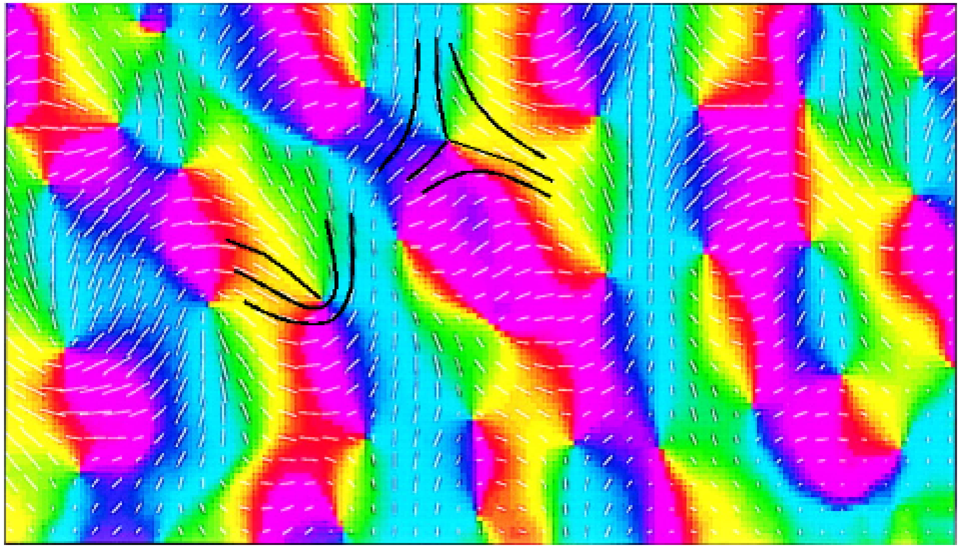


Rearrangement of orientation hypercolumns by retinotopic position abstracts V1 as $R^2 \times S^1$

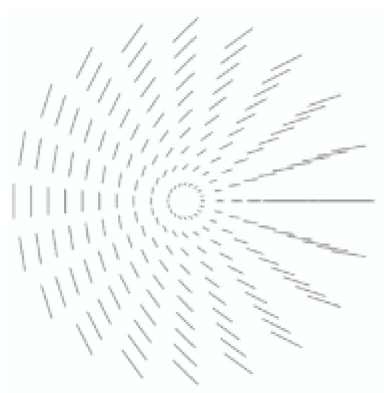
Visual Cortex 2D+Direction
“Bio-Hardware implementation”

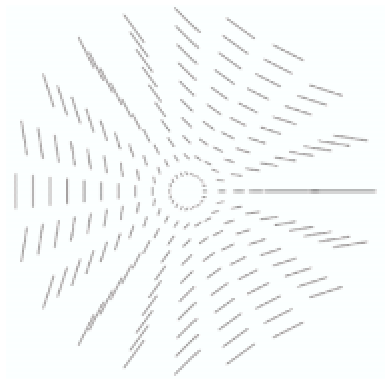


Oerientation Of PinWheels

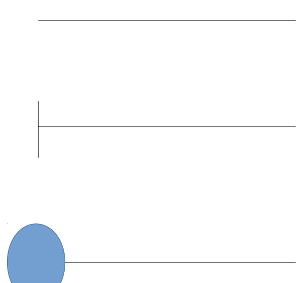


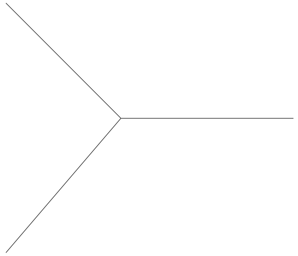
Detection for Special Points
“End-Point” / “Corner” Point



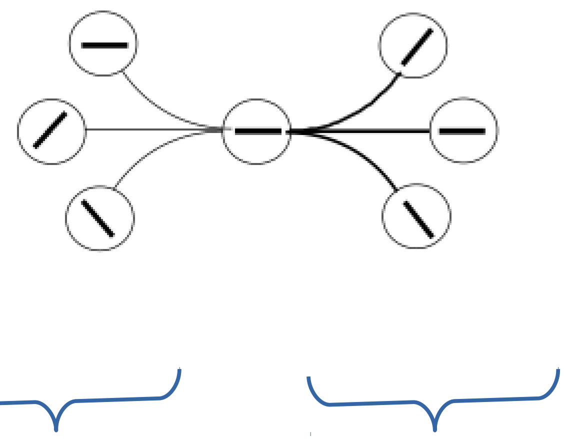


Recognized patterns:



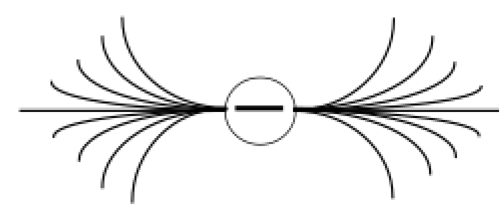


Co-Activation / Inhibition of Neurons



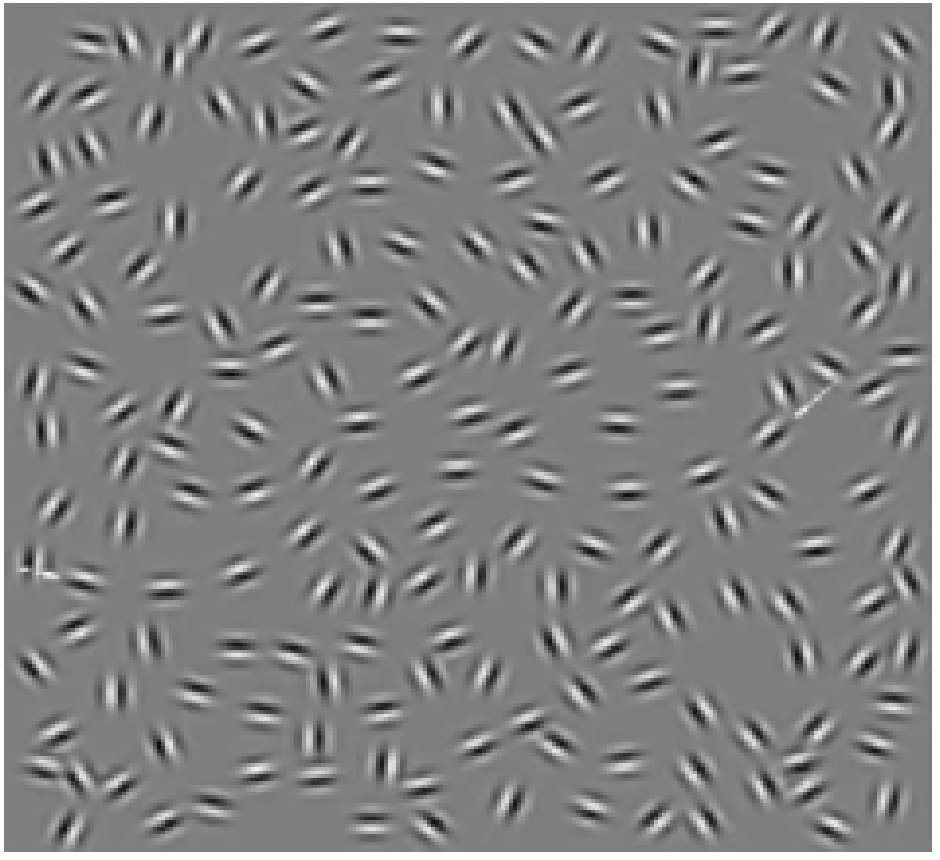
Bad continuation
=> **Inhibition**

Good continuation
=> **activation**



Example of Neuron Co-Activation “good continuation” criteria

Do you see a Line ?

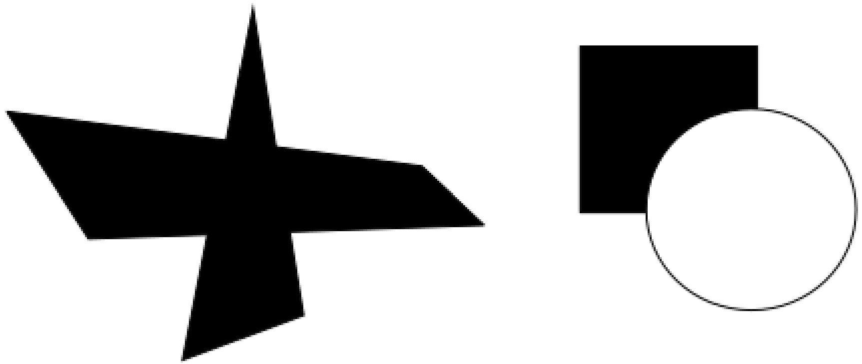


Neon Effect

The inside is perfectly white …
But it looks ilighted by red

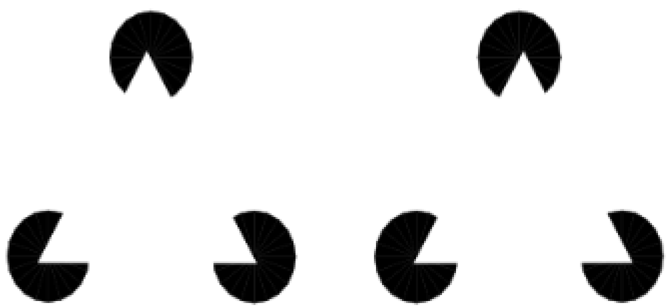
Illusory Contours

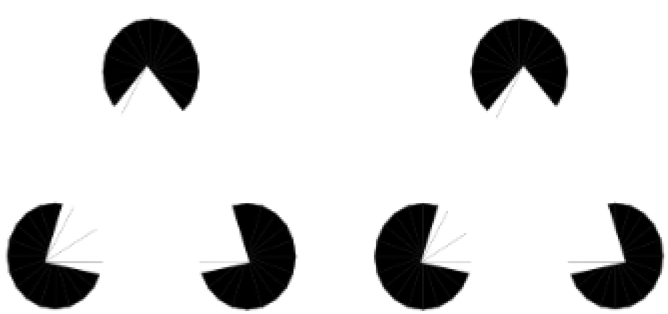
Impression of 3D (shape over other)



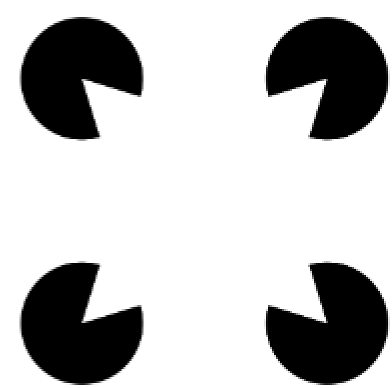
Illusory Kaniksa Triangles

Illusory “Triangle” over circles

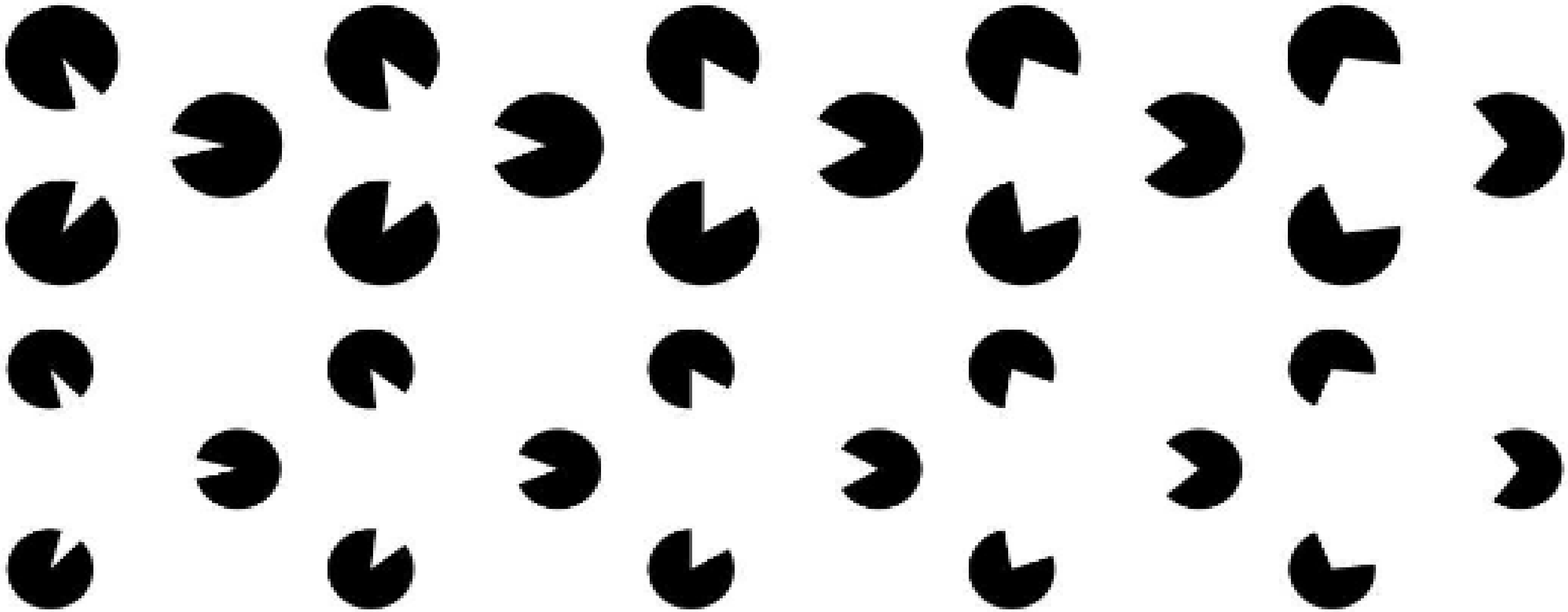




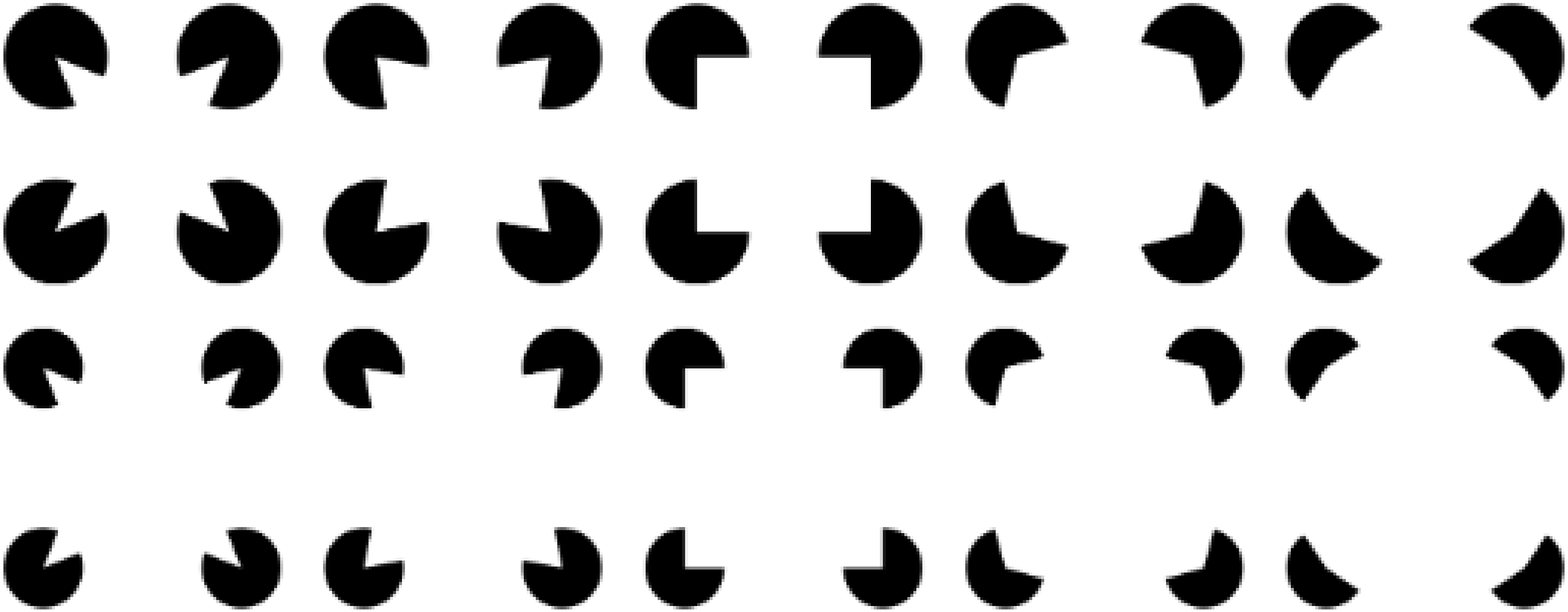
Illusory “Curved” square over circles



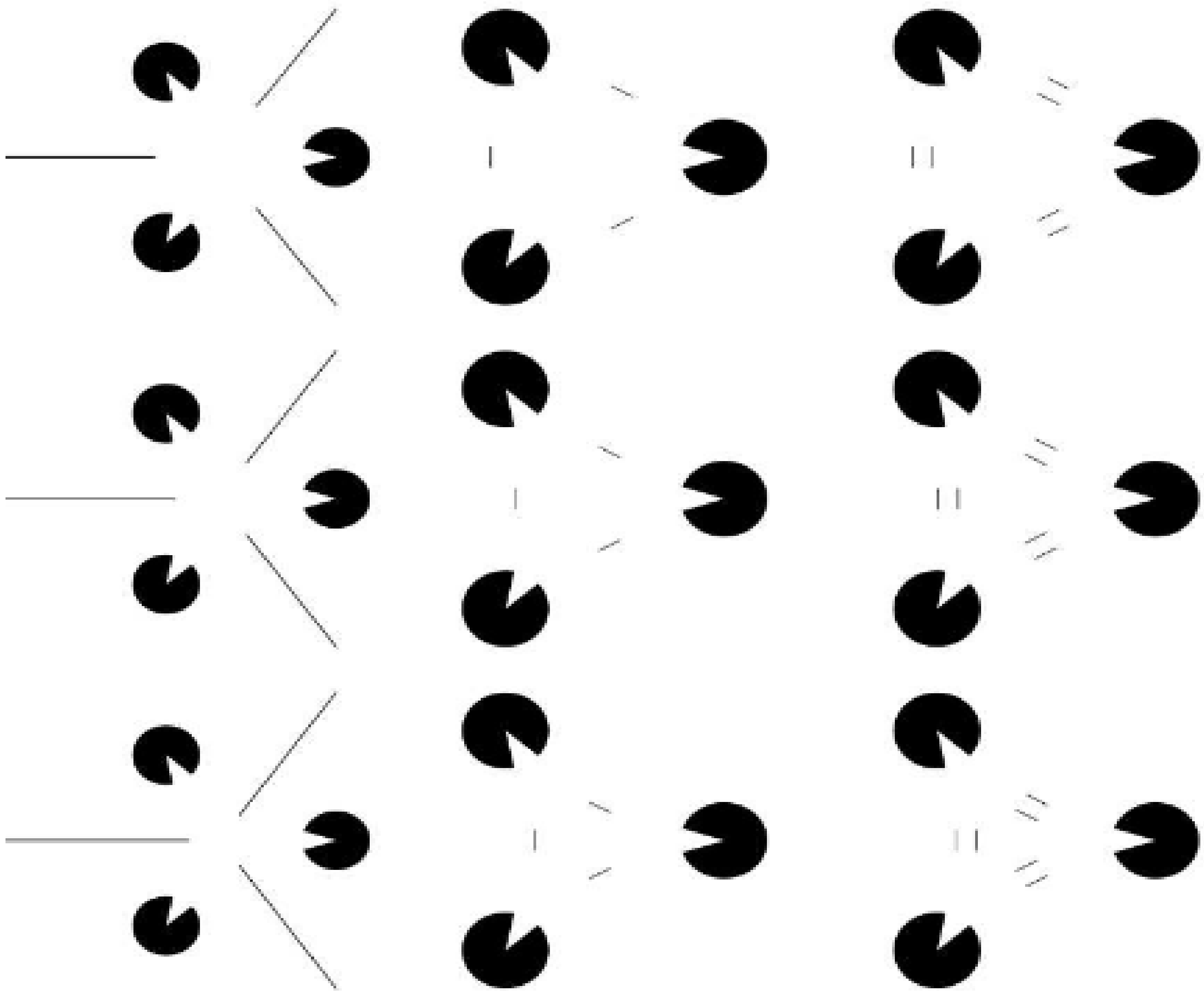
Illusory Kanizsa Triangle ...Up to limit Angle



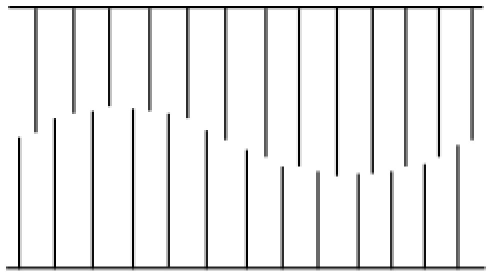
Illusory Kaniksa squares..

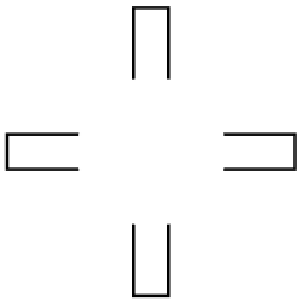


Kaniksa illusories re-inforced by lines



Illusory Line





Illusory "Circle" or "Square"
(oscillating)

Outline

Linear Filter

Non-Linear Filter : Mathematical Morphology
Erode/Dilate, Open/Close

Visual Cortex – bio mimetism

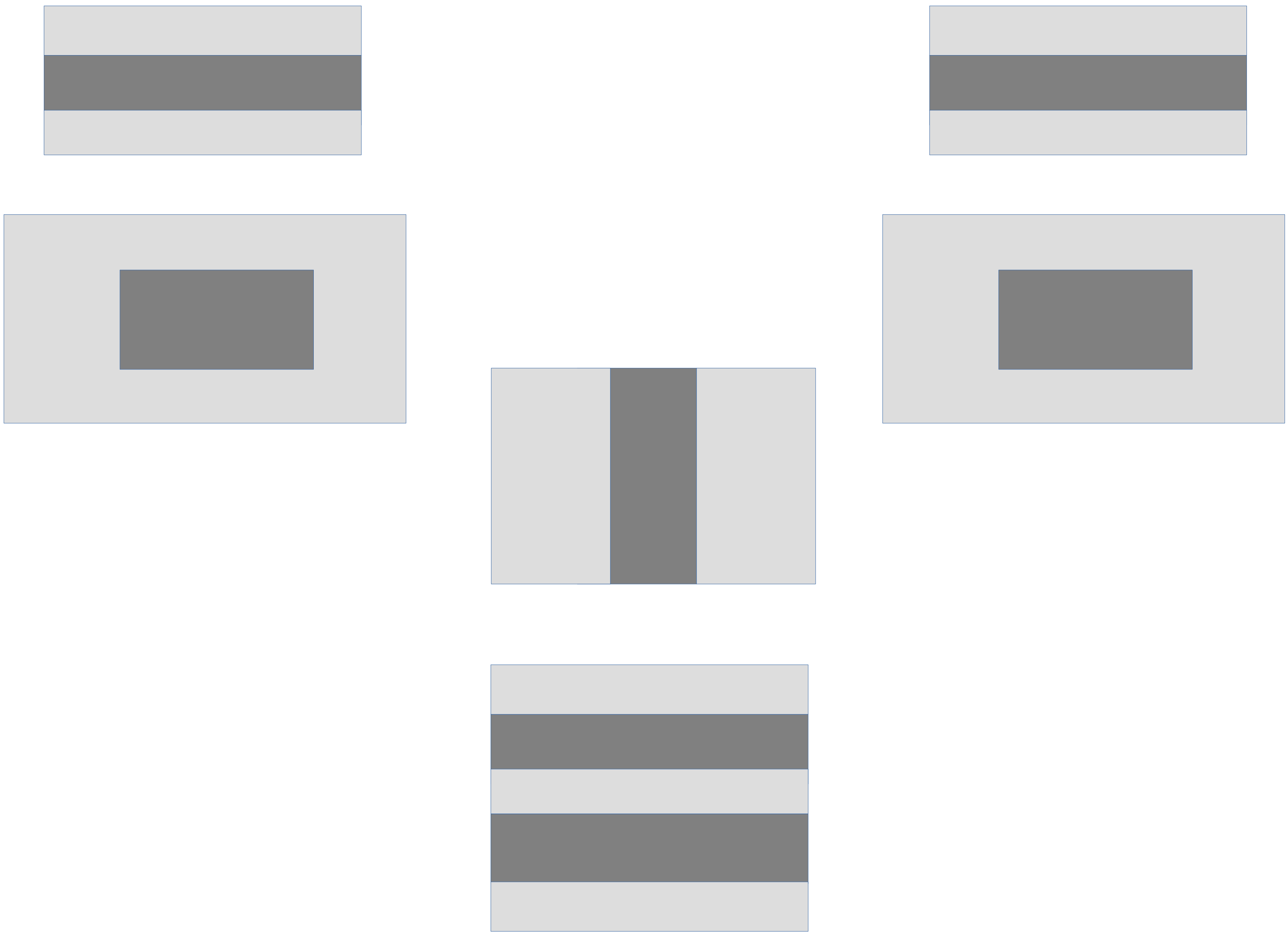
Object Recognition, Segmentation, Optical Flow, ..

Deep Neural Networks

Pattern Matching

Optimise Pattern Matching
= Find Max Correlation

Correlation using Combinations of Rectangular Masks



Integral Image

FAST Compute Correlation for Rectangular Maks

Viola Jones Algorithm

Outline

Linear Filter

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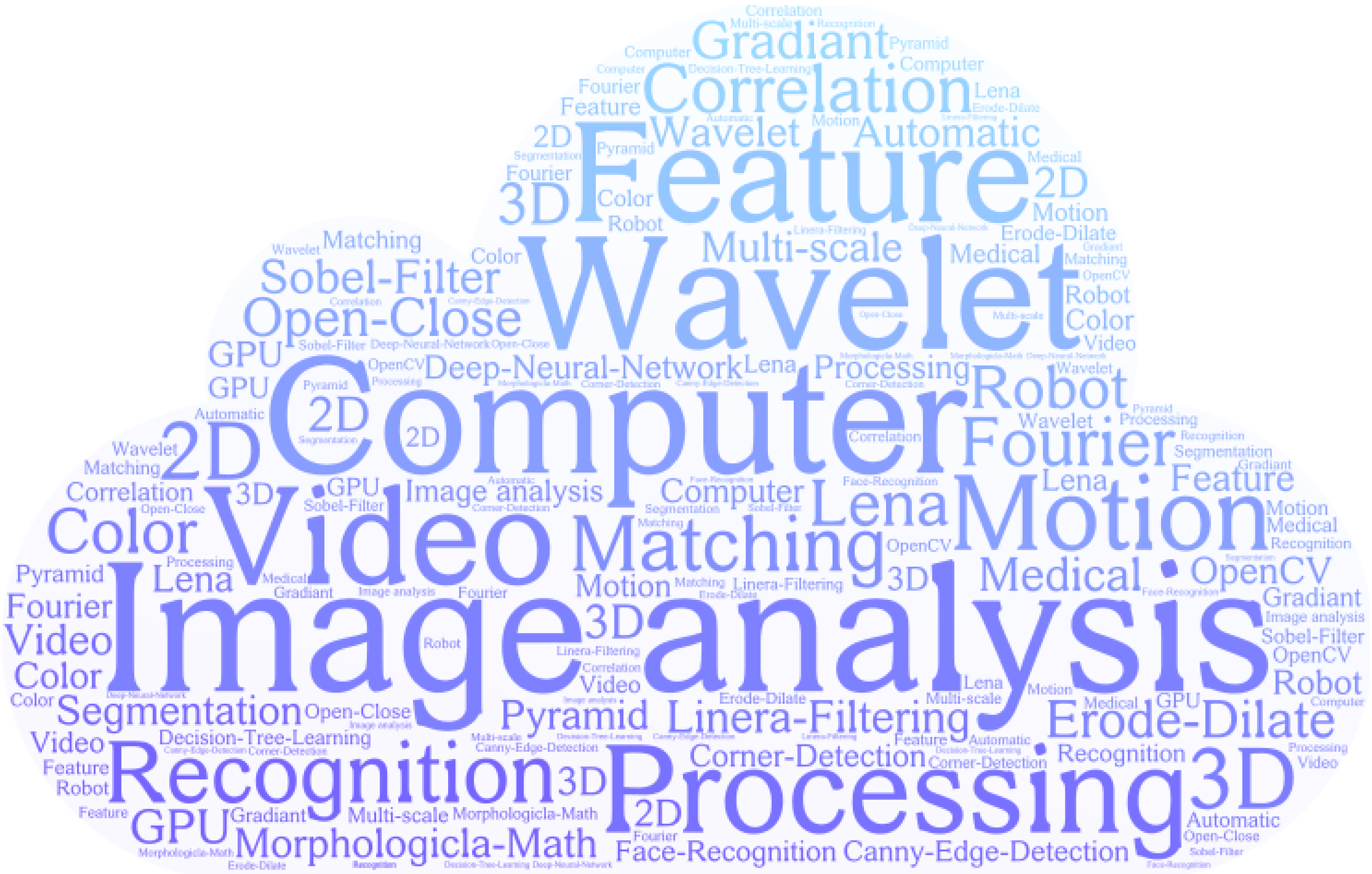
Deep Neural Networks

Conclusion



Gradiant
Correlation
Wavelet
Automatic
Feature
Wavelet
Multi-scale
Sobel-Filter
Open-Close
Deep-Neural-Network
Processing
Computer
Robot
Fourier
2D
Video
Color
Matching
Motion
Lena
Image analysis
Medical
OpenCV
Segmentation
Pyramid
Linera-Filtering
Erode-Dilate
Recognition
Processing
3D
GPU
Morphologicla-Math
Face-Recognition
Canny-Edge-Detection
Corner-Detection
Decision-Tree-Learning