

# COSFIRE

A trainable features approach to pattern recognition



George Azzopardi

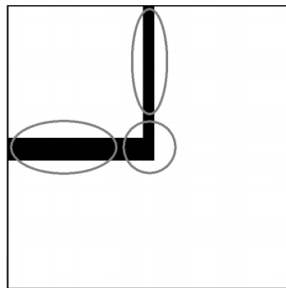
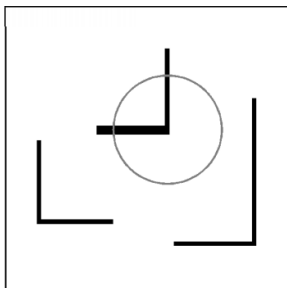


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University of Groningen  
The Netherlands



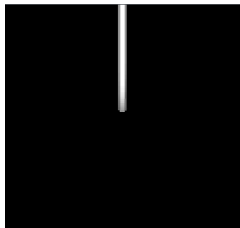
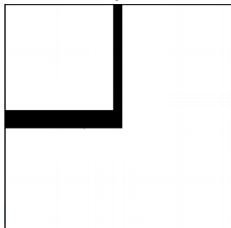
- A filter is automatically configured
  - **Sub-units:** orientation-selective detectors



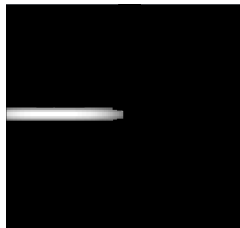
# Step 1: detect oriented stimuli

## 2D Gabor filters

Given pattern



...



...

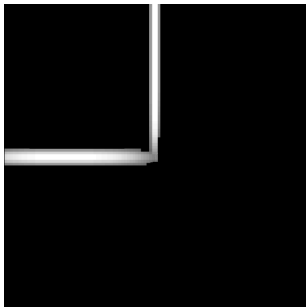


Bank of Gabor filters



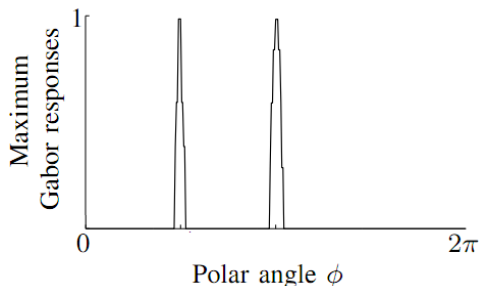
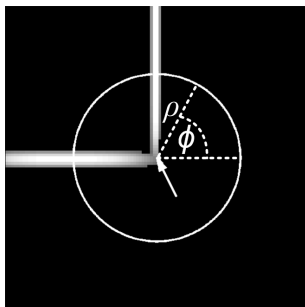
## Step 2: identify dominant orientations

- How? Consider a superposition of Gabor responses



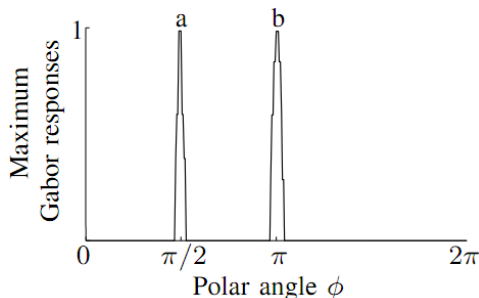
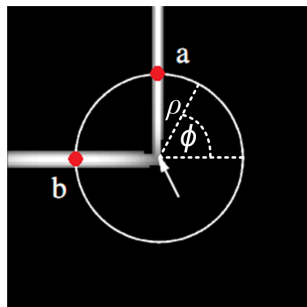
## Step 2: identify dominant orientations

- Consider Gabor responses along a circle of a given radius



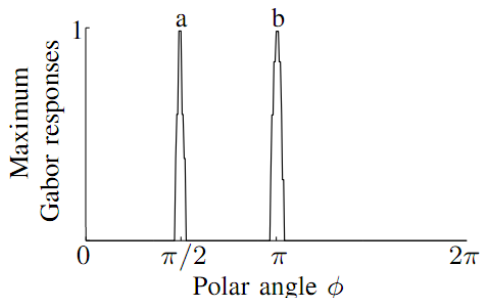
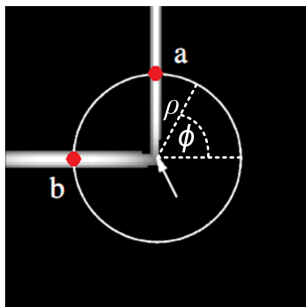
## Step 2: identify dominant orientations

- Identify significant local maxima

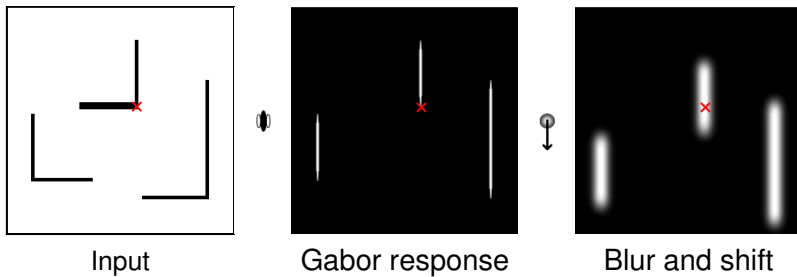


## Step 2: identify dominant orientations

- Result of analysis
  - $(\lambda, \theta)$  - line properties
  - $(\rho, \phi)$  - position w.r.t. filter center

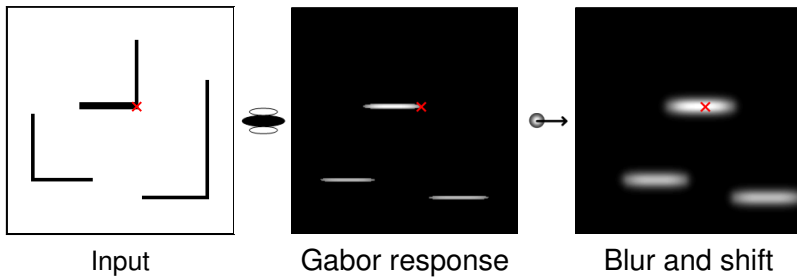


## Step 3: Response of Sub-unit 1



- If this filter responds strongly in the center point this means: **"There is a (nearly) vertical line at (or near) point  $(\rho, \phi)$  from the center of the filter."**

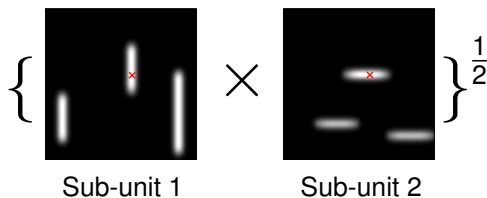
## Step 3: Response of Sub-unit 2



- If this filter responds strongly in the center point this means: **"There is a (nearly) horizontal line at (or near) point  $(\rho, \phi)$  from the center of the filter."**

# Step 4: Filter response

## Geometric mean

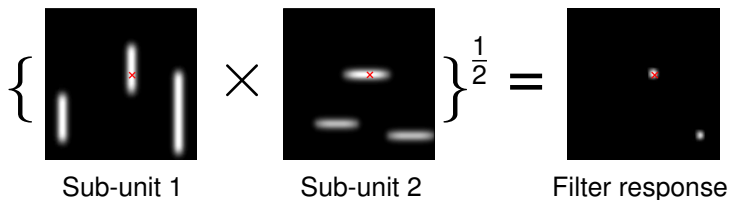


The diagram illustrates the calculation of the geometric mean for two sub-unit filter responses. On the left, a square image labeled "Sub-unit 1" shows three vertical white bars on a black background. A red 'x' marks the intersection of the two central bars. To its left is a large curly brace. In the center is a large 'X' symbol representing multiplication. To the right is another square image labeled "Sub-unit 2" showing three horizontal white bars on a black background. A red 'x' marks the intersection of the two central bars. To its right is another large curly brace. A superscript  $\frac{1}{2}$  is placed to the right of the second curly brace, indicating the square root of the product.

$$\left\{ \text{Sub-unit 1} \right\} \times \left\{ \text{Sub-unit 2} \right\}^{\frac{1}{2}}$$

## Step 4: Filter response

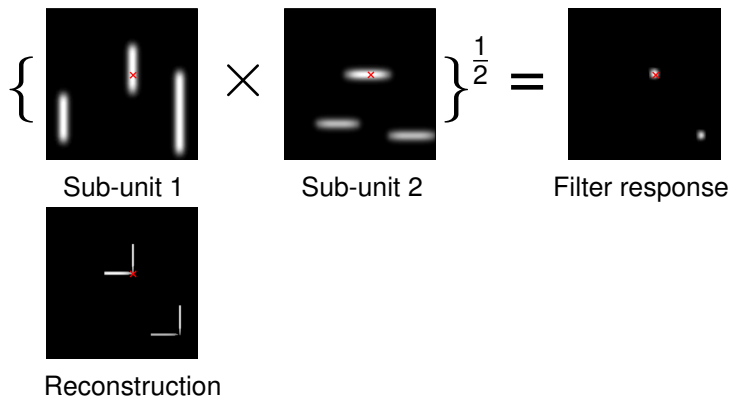
### Geometric mean





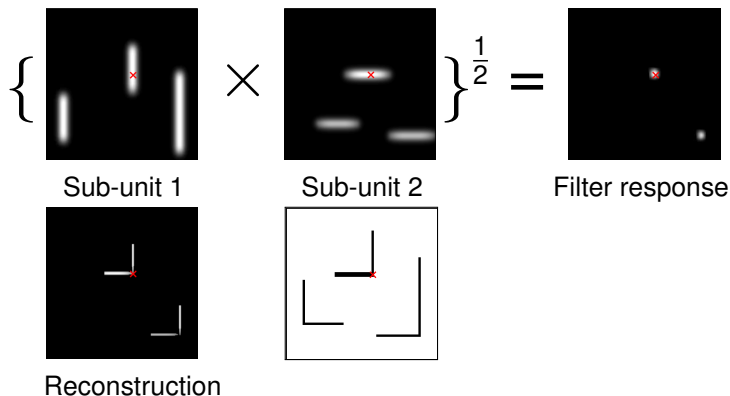
# Step 4: Filter response

## Geometric mean

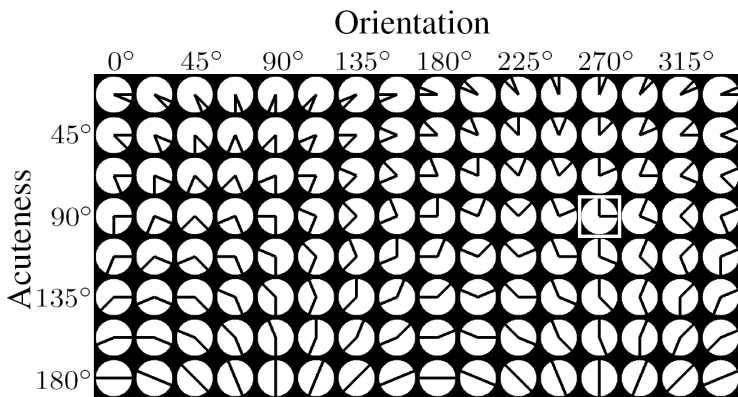


## Step 4: Filter response

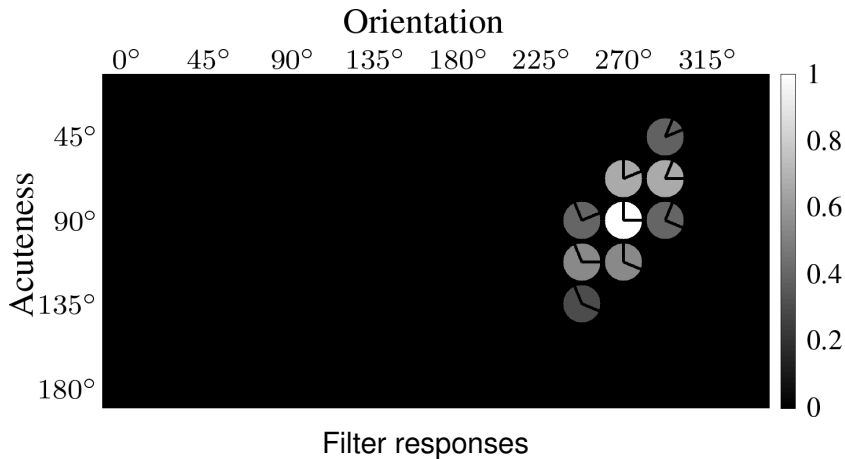
### Geometric mean

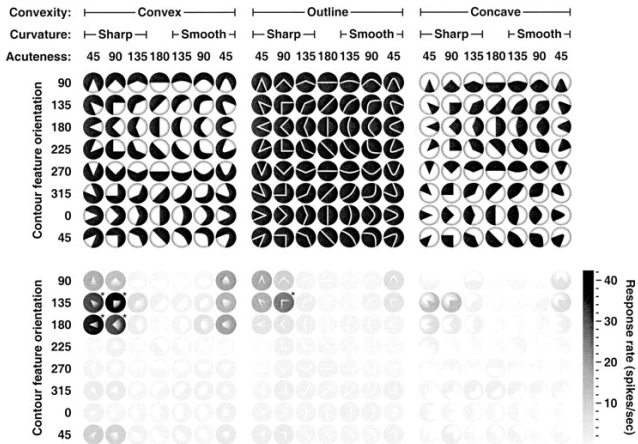


- If the product of the two blurred and shifted Gabor filters is substantial in a given point, this means: **"There is a (nearly) vertical line at a certain distance above and a (nearly) horizontal line at a certain distance to the left of the concerned point"**.



Set of elementary features used in neurophysiological study  
[Pasupathy and Connor, 1999]





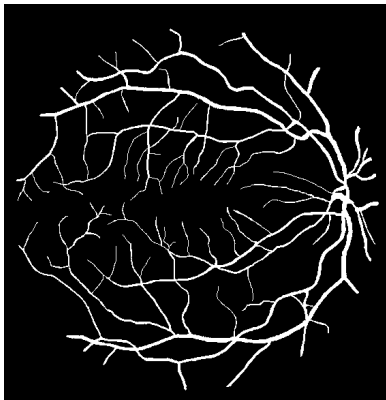
[Pasupathy and Connor, 1999]

# Summary of trainable feature detector

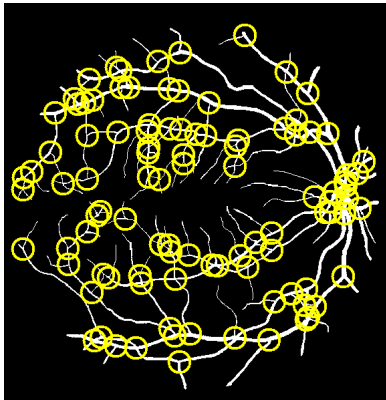
- **COSFIRE** filter (**C**ombination **O**f **S**hifted **F**ilter **R**esponses)
  - Gabor filters → blur and shift → multiply
- **Trainable**
  - can be configured with any given local contour pattern

# 1. Detection of bifurcations in retinal fundus images

- The structure of the retinal vascular tree can reveal signs of cardiovascular diseases



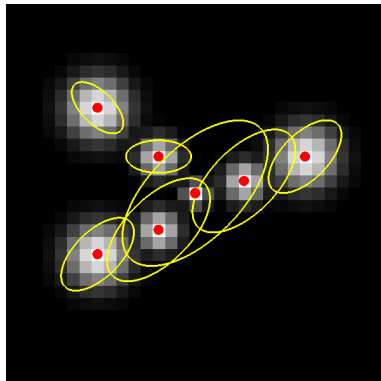
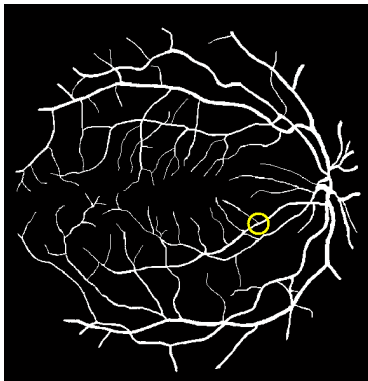
# 1. Detection of bifurcations in retinal fundus images



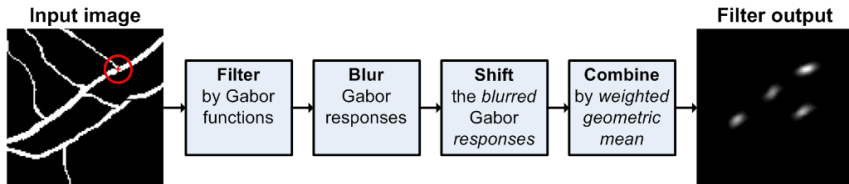
This image contains 101 bifurcations



# Trainable filter configuration

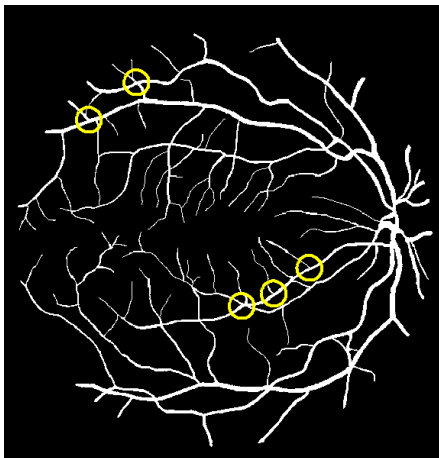


# Apply the configured filter



# COSFIRE: Tolerant to geometric transformations

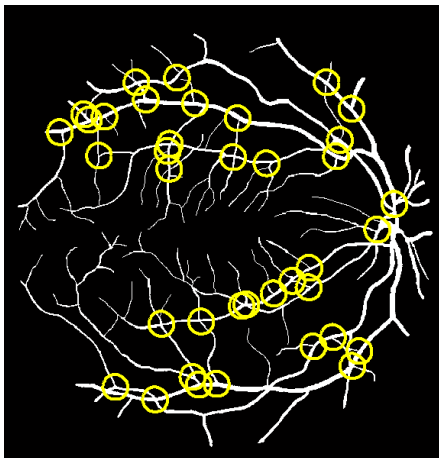
Non-tolerant



5 (out of 101) detected bifurcations

# COSFIRE: Tolerant to geometric transformations

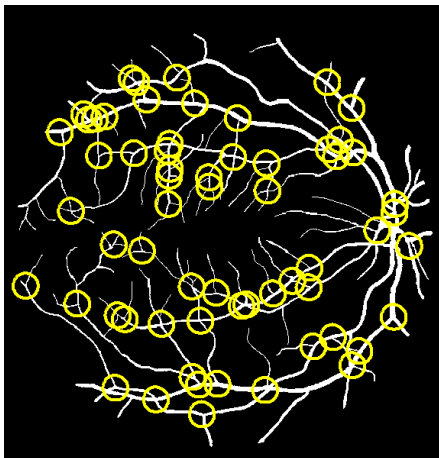
## Rotation-tolerant



38 (out of 101) detected bifurcations

# COSFIRE: Tolerant to geometric transformations

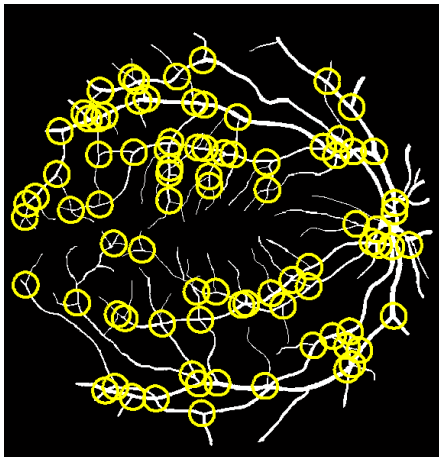
**Rotation-** and **scale**-tolerant



62 (out of 101) detected bifurcations

# COSFIRE: Tolerant to geometric transformations

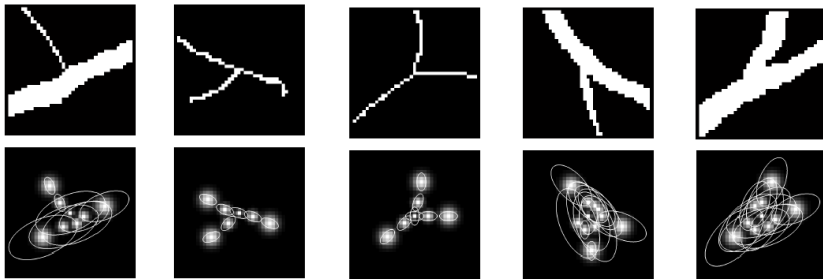
**Rotation-, scale- and reflection-tolerant**



85 (out of 101) detected bifurcations

# Training

100% Precision and 100% Recall for training image



# Testing

**DRIVE** data set: (40 images, more than 5000 bifurcations)  
[Staal et al., 2004]

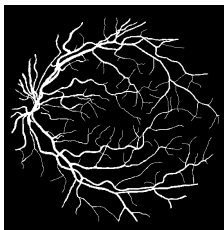


image 1

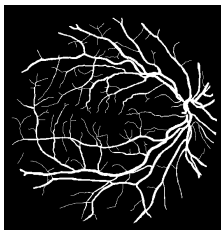


image 2

...

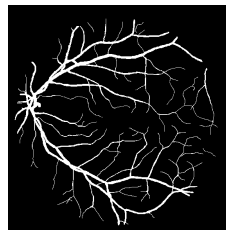


image 40

Results for the whole DRIVE data set  
**Recall:** 97.88% and **Precision:** 96.94%



# <http://matlabserver.cs.rug.nl/RetinalVascularBifurcations>

## Detection of vascular bifurcations in retinal fundus images using trainable COSFIRE filters

[N. Petkov, G. Azzopardi](#) and [Zhe Sun, University of Groningen](#),  
[Department of Computing Science, Intelligent Systems](#)

Other on-line image processing and computer vision applications are available at <http://matlabserver.cs.rug.nl>.

On this site you can: process a binary retinal image taken from the [DRIVE](#) data set<sup>[1]</sup> with some predefined COSFIRE filters, visualize the output of the filters rendered as a gray-level image, visualize the detected vascular bifurcations as encircled features in the input image, use the slider below the images to control the output of the COSFIRE filters: the number of detected features decreases with an increasing threshold value (i.e. moving the slider to the right), and download the output image with the detected features encircled as well as the coordinates of these detected features.

We are currently extending this application by including a facility to upload coloured/binary retinal images, and an algorithm for automatic vessel tree segmentation of the uploaded images. In the near future, we will also include detailed explanations on the parameters of the COSFIRE filters.

Input image:

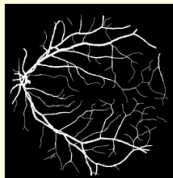
Segmentation of the vessel tree:

Output image:

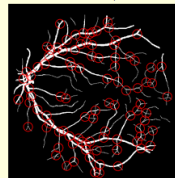
☐ Invert output



Download the [input image](#).



Download the [binary retinal image](#).



Download the [output image](#).

Download the [coordinates of the detected points](#).  
The coordinates of the detected points are given in (row, col) format.

Threshold



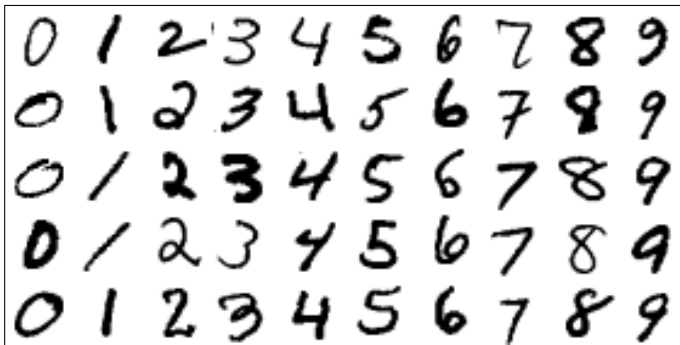
0.5

Ground truth data of vascular bifurcations in retinal images of the DRIVE database

In [http://www.cs.rug.nl/~imaging/databases/retina\\_database/](http://www.cs.rug.nl/~imaging/databases/retina_database/), we provide the (row,col) coordinates of the vascular bifurcations that were manually selected as ground truth data in 40 binary images of the DRIVE data set.

## 2. Handwritten digit recognition

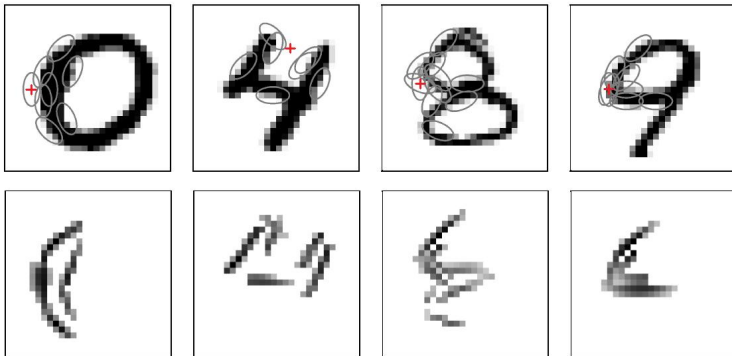
**MNIST** data set  
[LeCun et al., 1998]



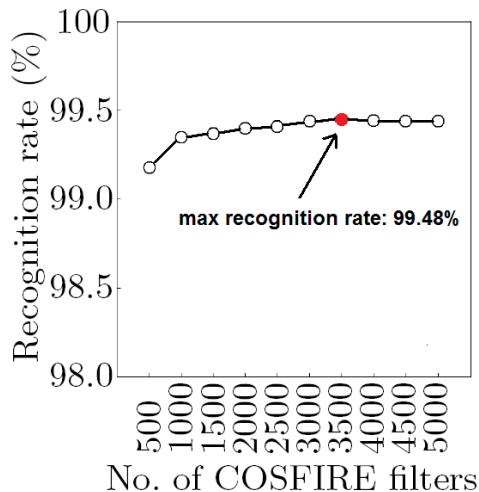
**60,000** training and **10,000** test digits

# Configuration of COSFIRE filters

- Choose a subset of random images from each digit class
- Choose a random location in each selected digit image



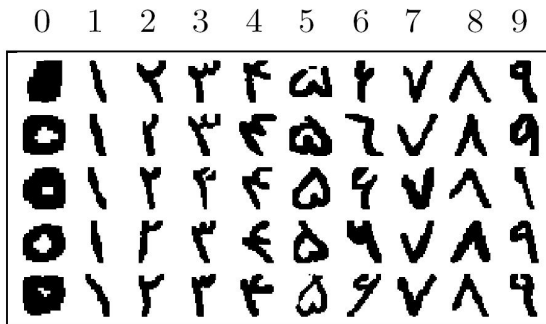
Recognition rate: **99.48%**



## 2. Handwritten digit recognition

**Farsi data set: 99.33%**

[Khosravi and Kabir, 2007]



## 60,000 training and 20,000 test digits

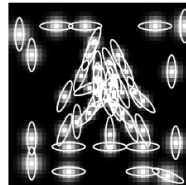
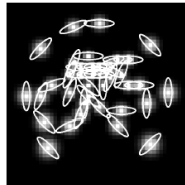
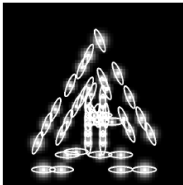
### 3. Detection and recognition of traffic signs

#### **RuG** data set

[Grigorescu and Petkov, 2003]

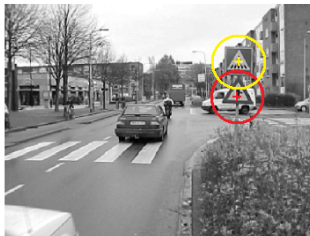
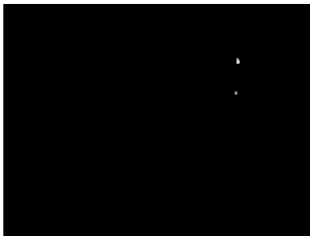


# Configuration of COSFIRE filters



# Data set of 48 grayscale images

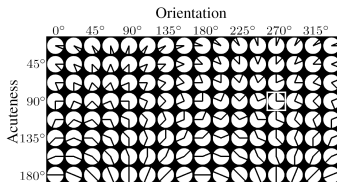
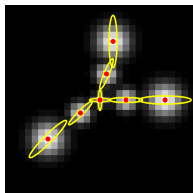
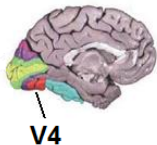
## Detection and recognition rates: **100%**





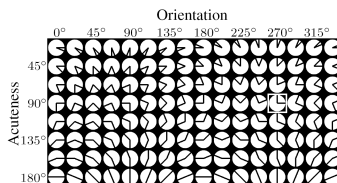
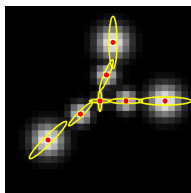
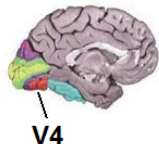
# Conclusions

- **COSFIRE** filter
  - Inspired by shape-selective V4 neurons



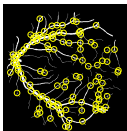
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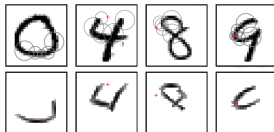


- **Simple implementation:**
  - Gabor filters → blur and shift → multiply
  - <http://matlabserver.cs.rug.nl/>

- Highly **effective** and **versatile** feature detector



✓ Retinal bifurcations



✓ Handwritten digits

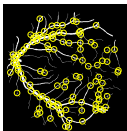


✓ Traffic signs

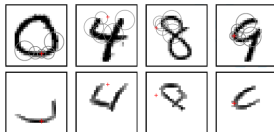


✓ Camera calibration

- Highly **effective** and **versatile** feature detector



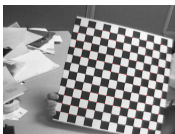
✓ Retinal bifurcations



✓ Handwritten digits



✓ Traffic signs



✓ Camera calibration



Signatures



Architectural symbols

# Outlook/Work in progress

- Extend it with color properties
- Extend it to 3D images and video streams
- Investigate it with non-visual time series data; e.g. sound
- Quantitative comparison with SIFT keypoint detector

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**Thank you!** ☺

# Publication

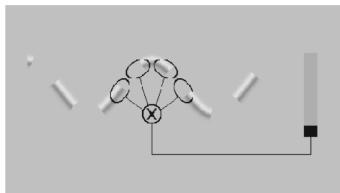
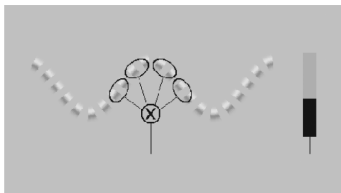
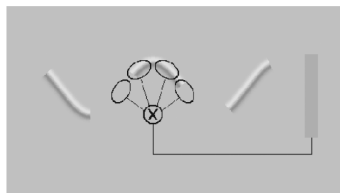
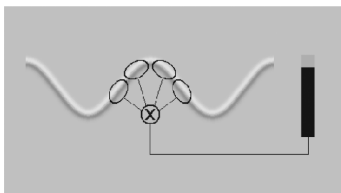


G. Azzopardi and N. Petkov, **Trainable COSFIRE filters for keypoint detection and pattern recognition**, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 35(2), pp. 490-503, 2013



# Psychophysics

Curved contour parts are detected by **multiplication**



[Gheorghiu and Kingdom, 2009]

# References



Gheorghiu, Elena and Frederick A. A. Kingdom [2009]. "Multiplication in curvature processing". In: *Journal of Vision* 9.2.



Grigorescu, C and N Petkov [2003]. "Distance sets for shape filters and shape recognition". In: *IEEE Transactions on Image Processing* 12.10, 1274–1286.



Khosravi, Hossein and Ehsanollah Kabir [2007]. "Introducing a very large dataset of handwritten Farsi digits and a study on their varieties". In: *Pattern Recognition Letters* 28.10, 1133–1141.



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Pasupathy, A. and C. E. Connor [1999]. "Responses to contour features in macaque area V4". In: *Journal of Neurophysiology* 82.5, pp. 2490–2502.



Staal, J et al. [2004]. "Ridge-based vessel segmentation in color images of the retina". In: *IEEE Transactions on Medical Imaging* 23.4, 501–509.