

Trainable COSFIRE filters for pattern detection and representation learning

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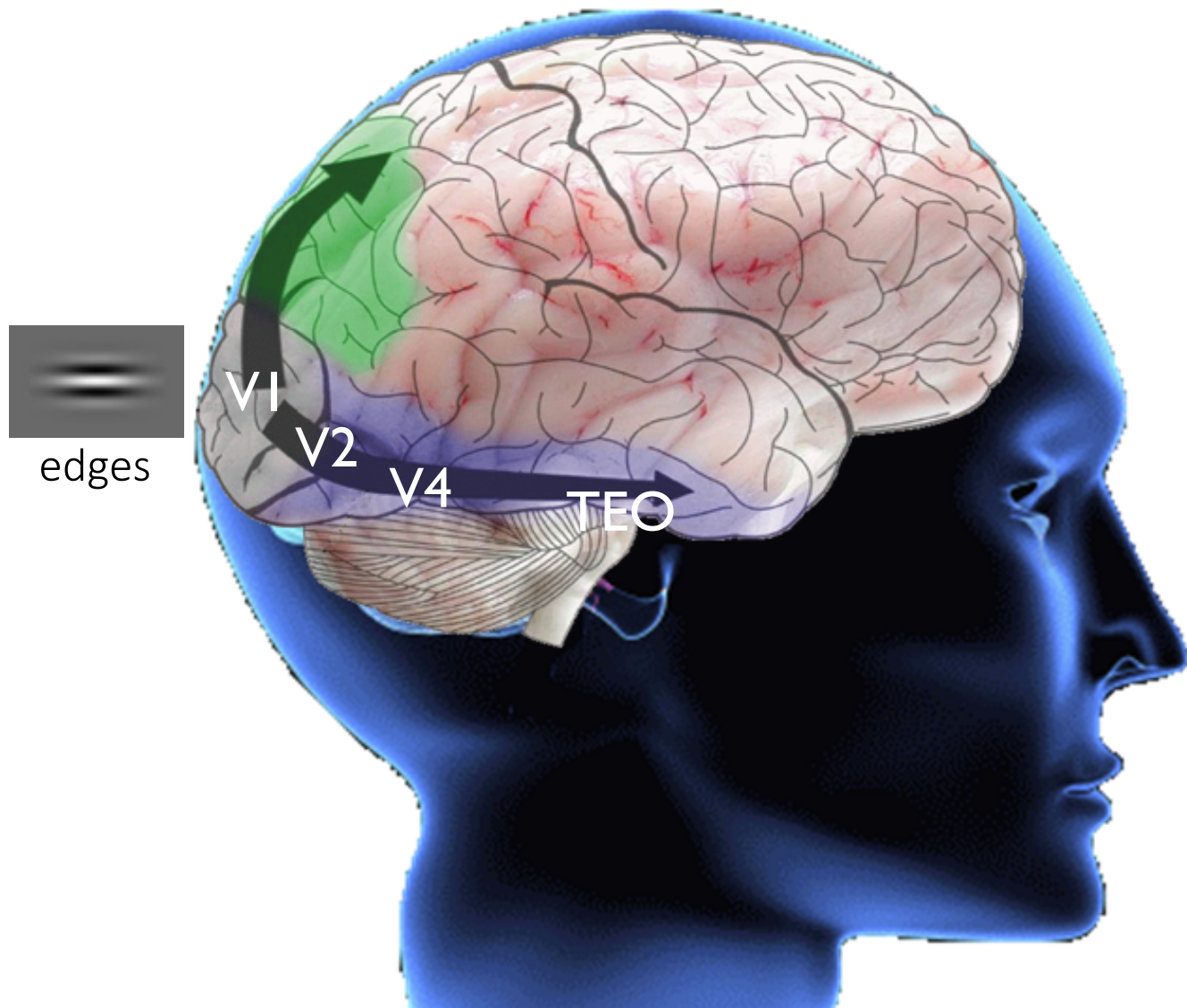


COSFIRE

stands for

Combination of Shifted Filter Responses

Biological inspiration

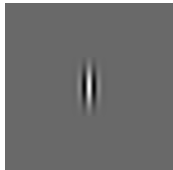


Bank of 2D Gabor filters

Input

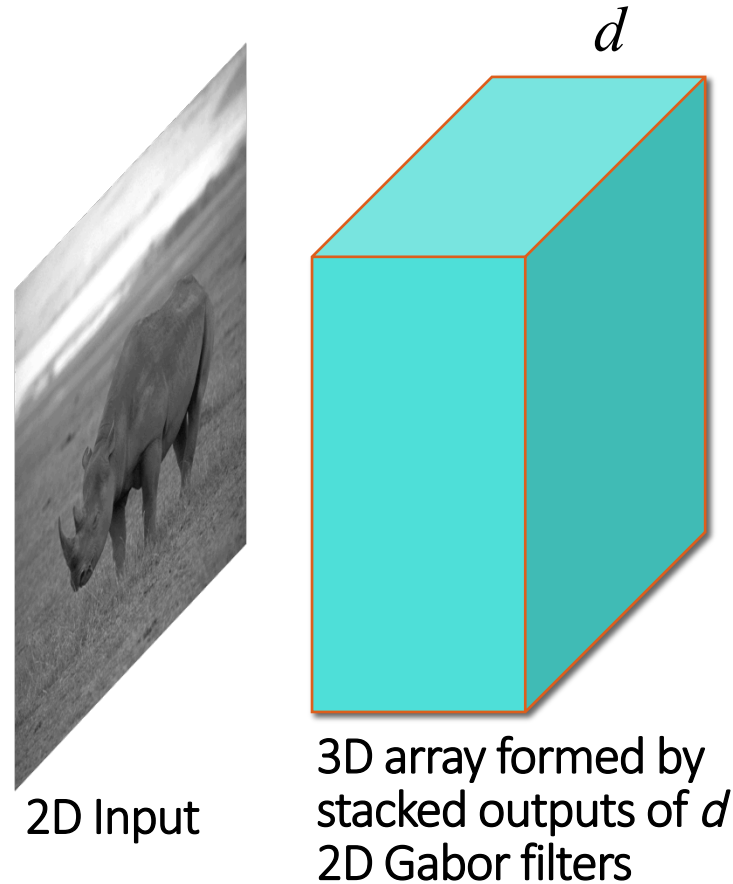


Gabor kernels



Outputs of Gabor filters

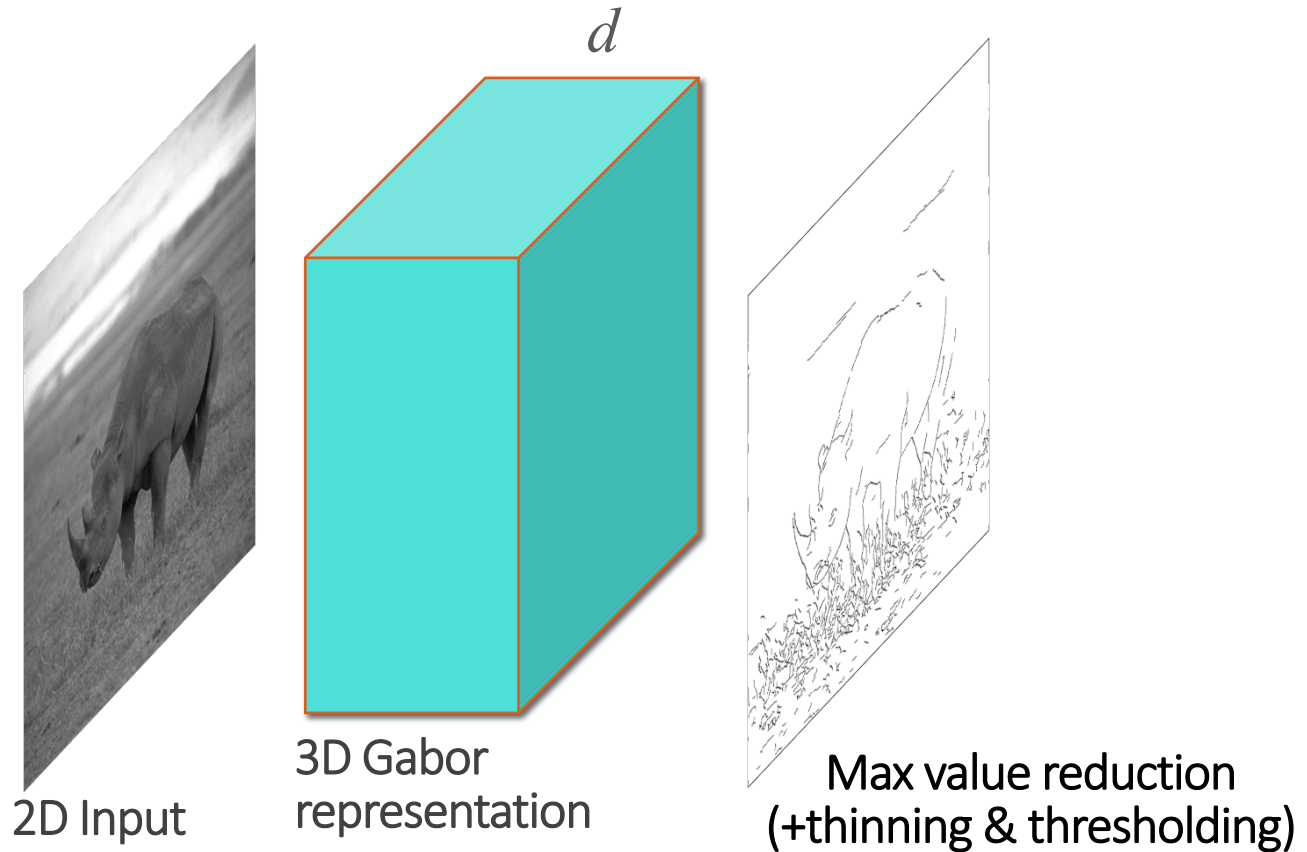
Gabor 3D representation



The use of a set of convolutions to compute a 3D tensor representation of a 2D image is older than CNNs

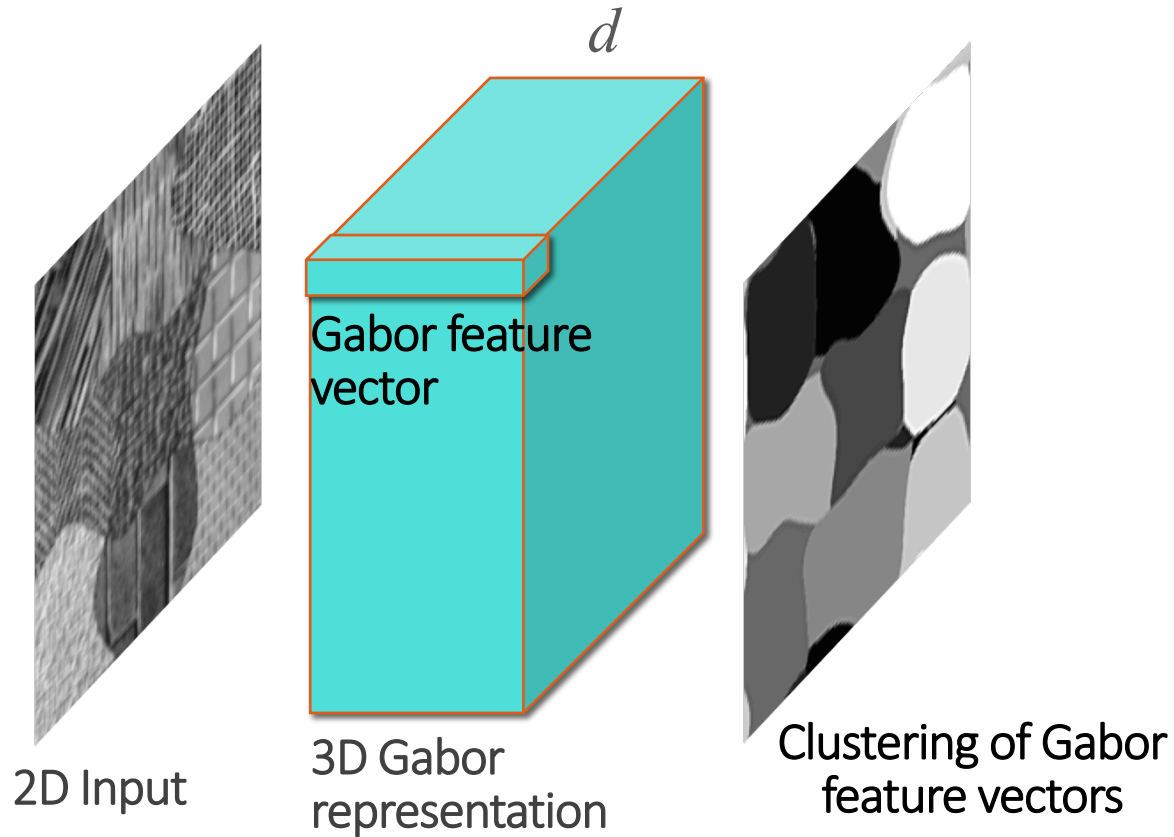


Use for edge detection



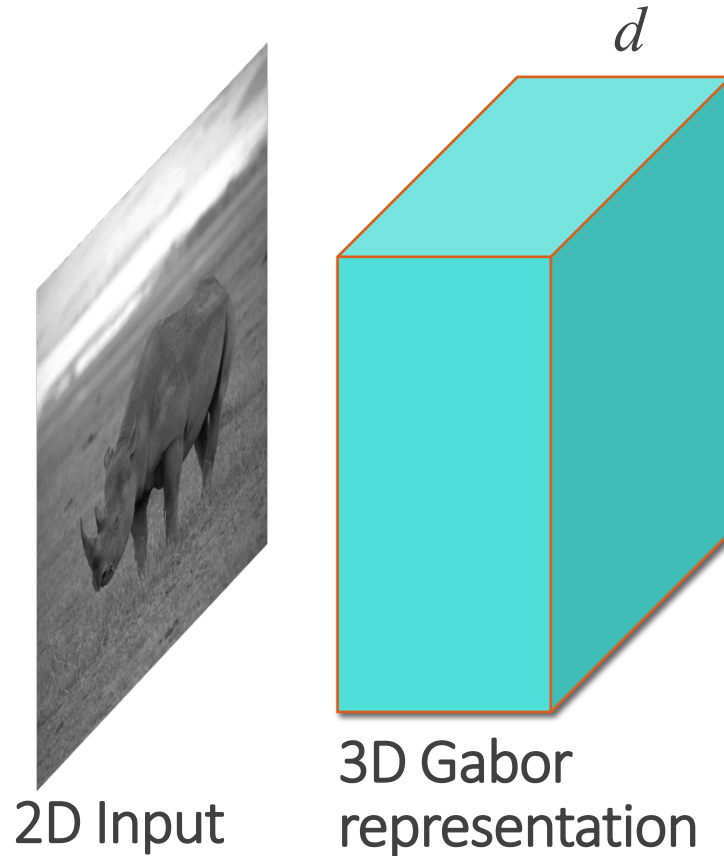
The likely role of this type of processing in the brain is edge detection. In computer vision gradient computation (Canny) is preferred over Gabor representations for edge detection due to better efficiency.

Use for texture analysis



In computer vision Gabor representations are mainly used for texture analysis, e.g. segmentation.

Use for object recognition ?

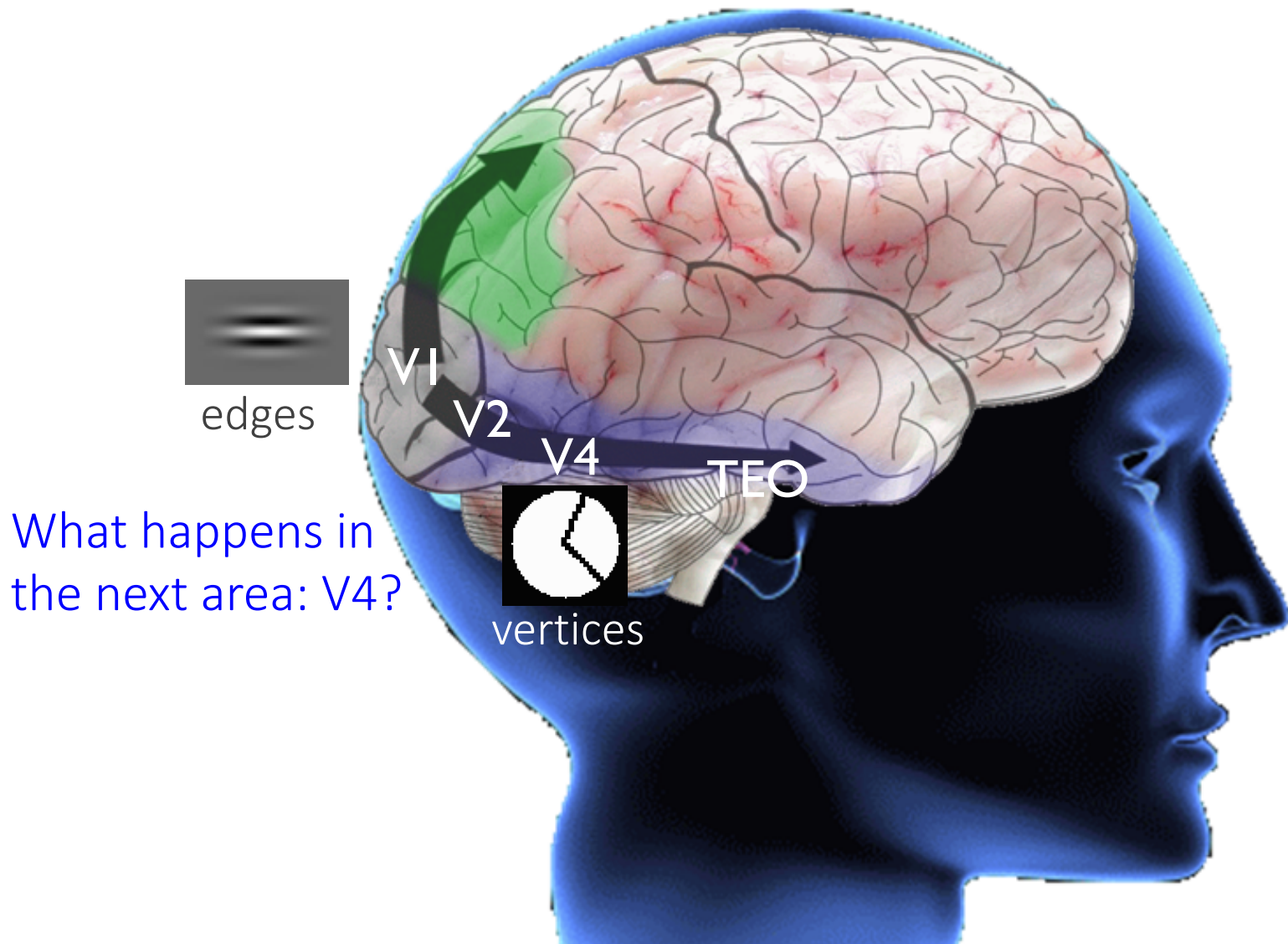


How to process this representation further to come to object recognition

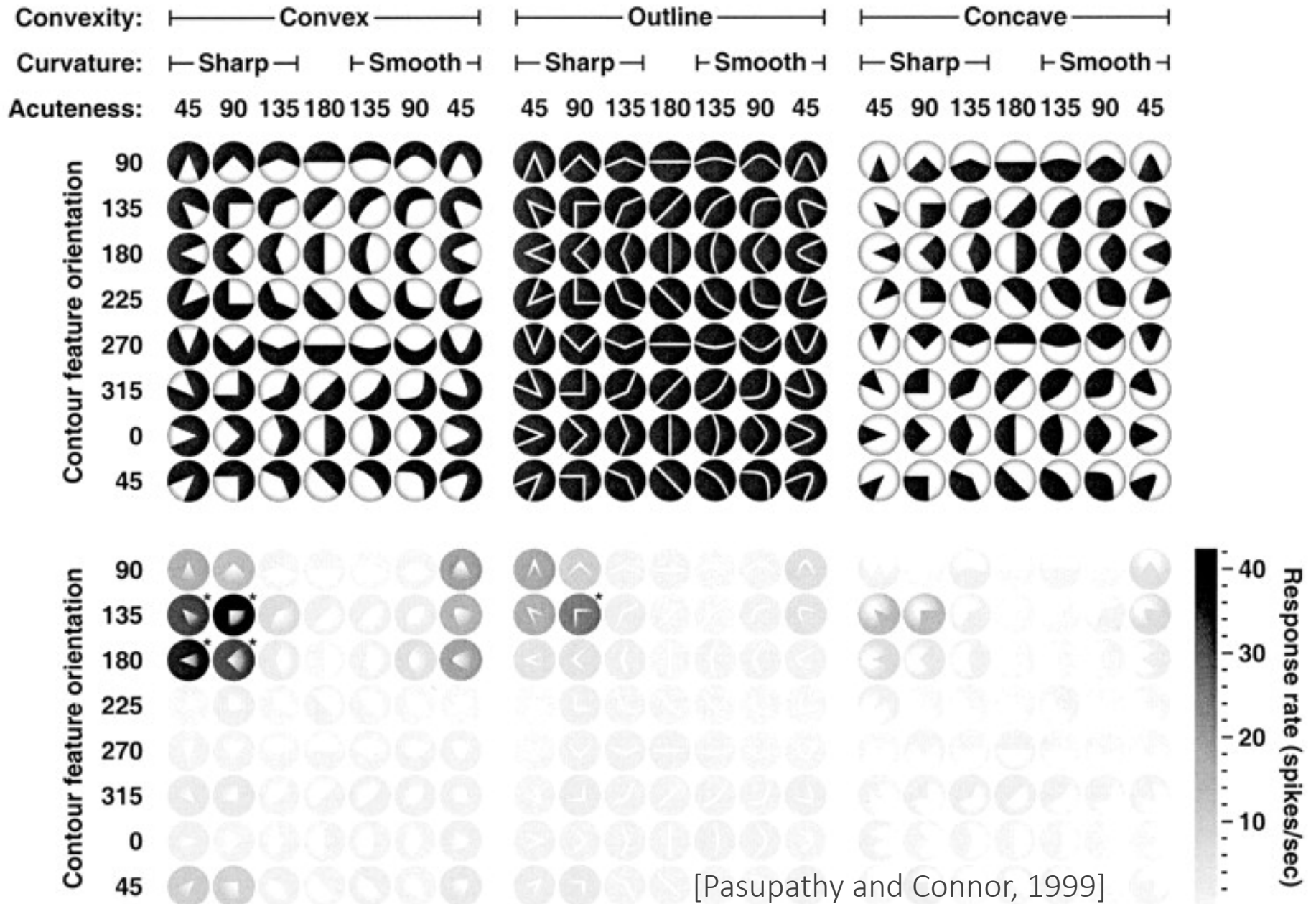
?

Some attempts, such as the shape context and the distance set are prone to noise and background.

Back to biological inspiration

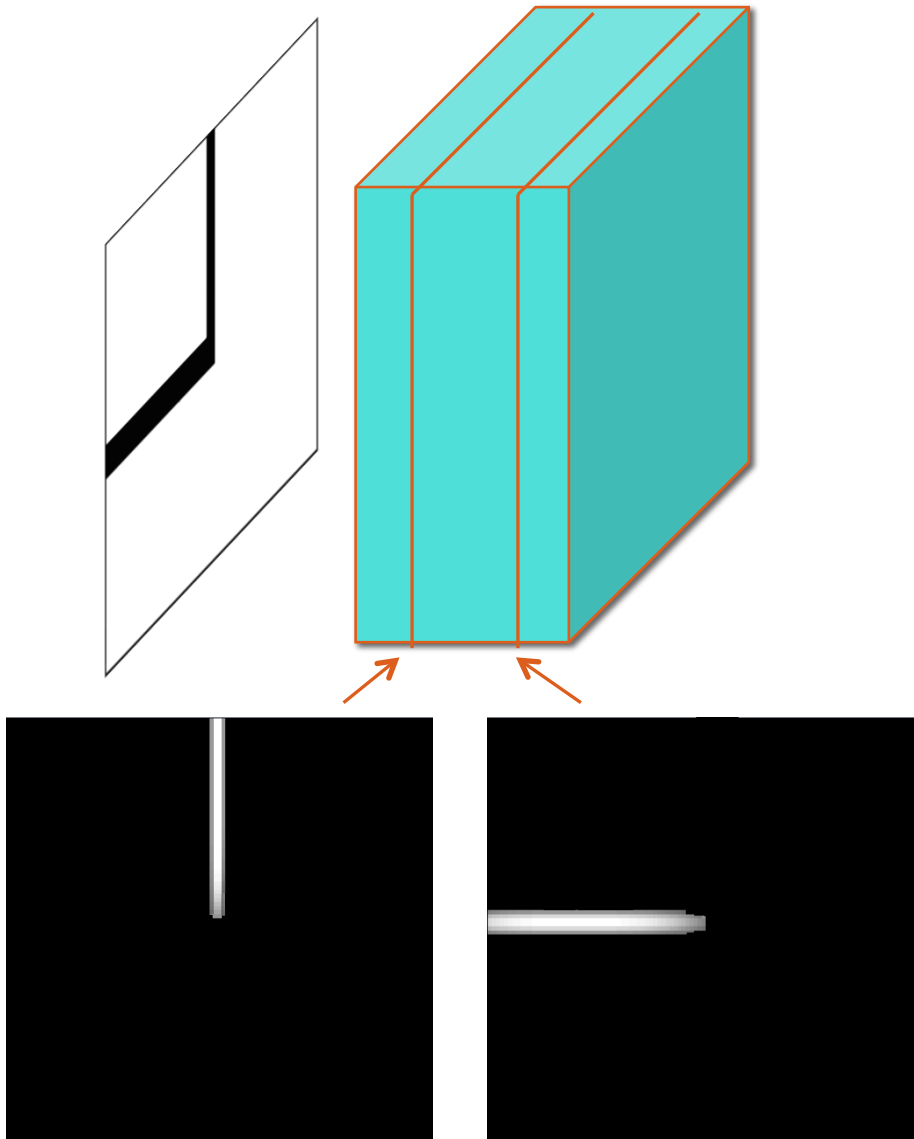


Vertex shape selective neurons in area V4

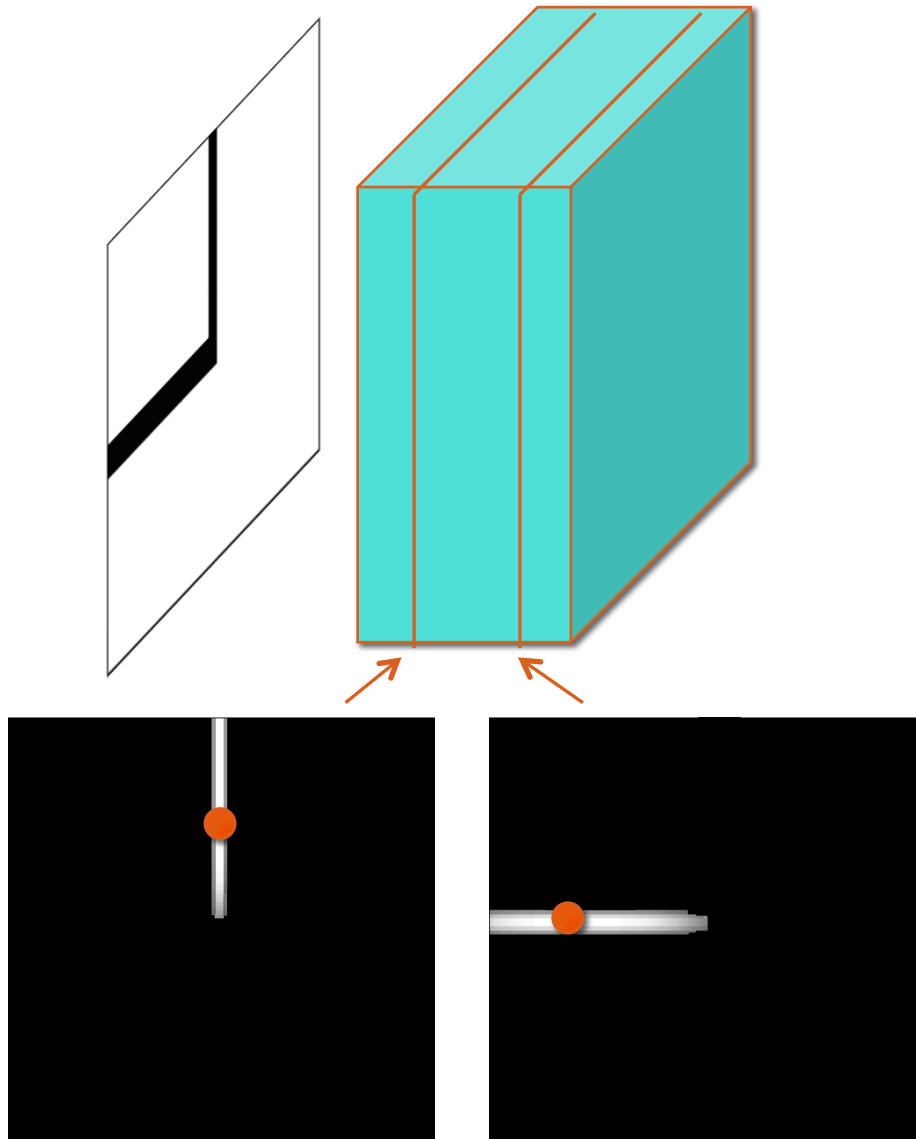


Constructing a vertex detector by combining the outputs of line detectors

- 1) Identify features that give strong response.

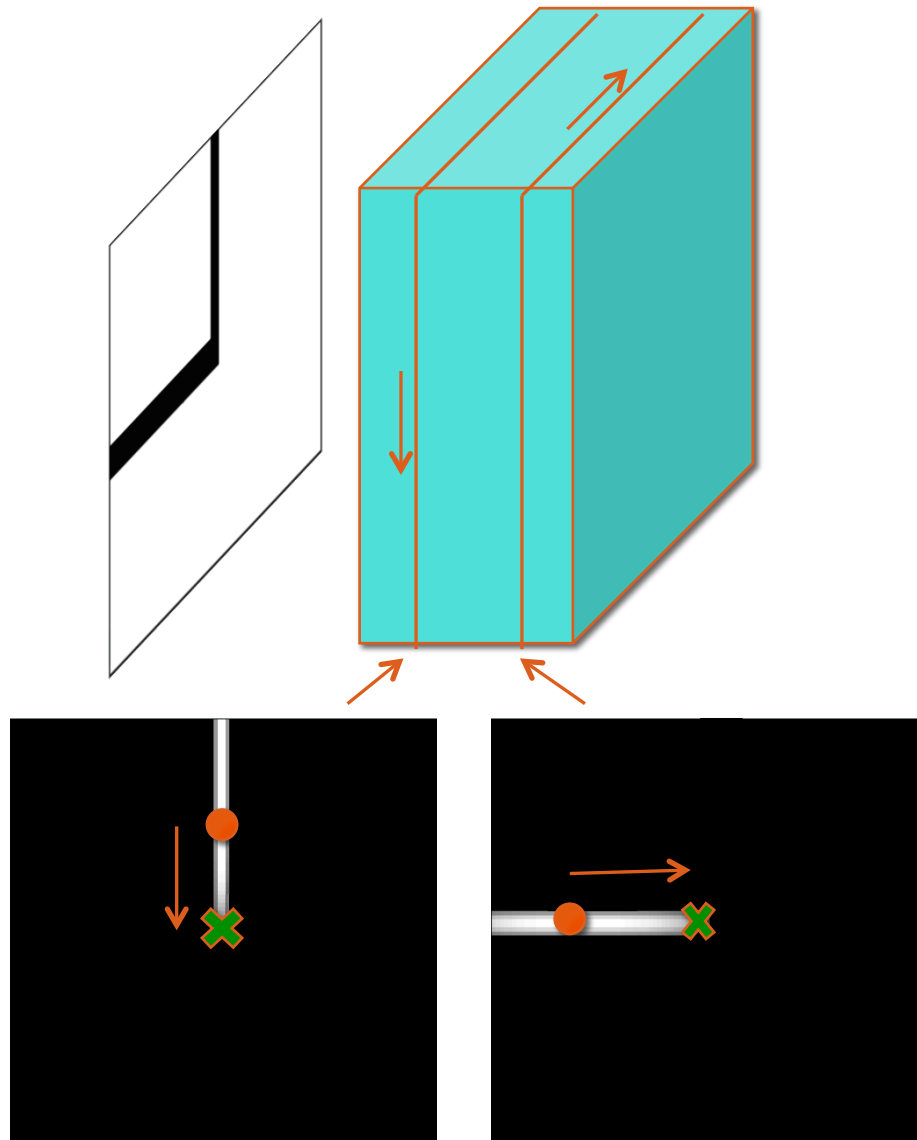


Constructing a vertex detector by combining the outputs of line detectors



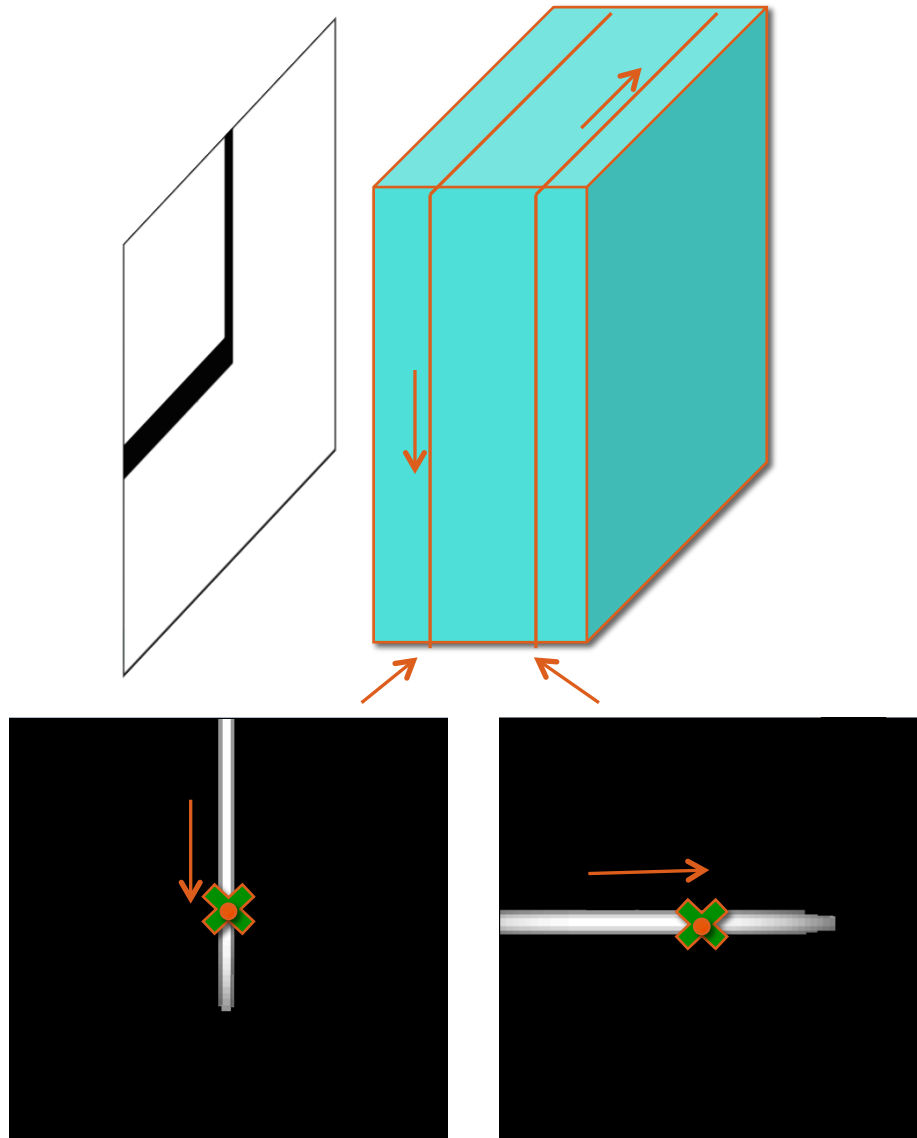
- 1) Identify features that give strong response.
- 2) Identify locations of strong response. ●

Constructing a vertex detector by combining the outputs of line detectors



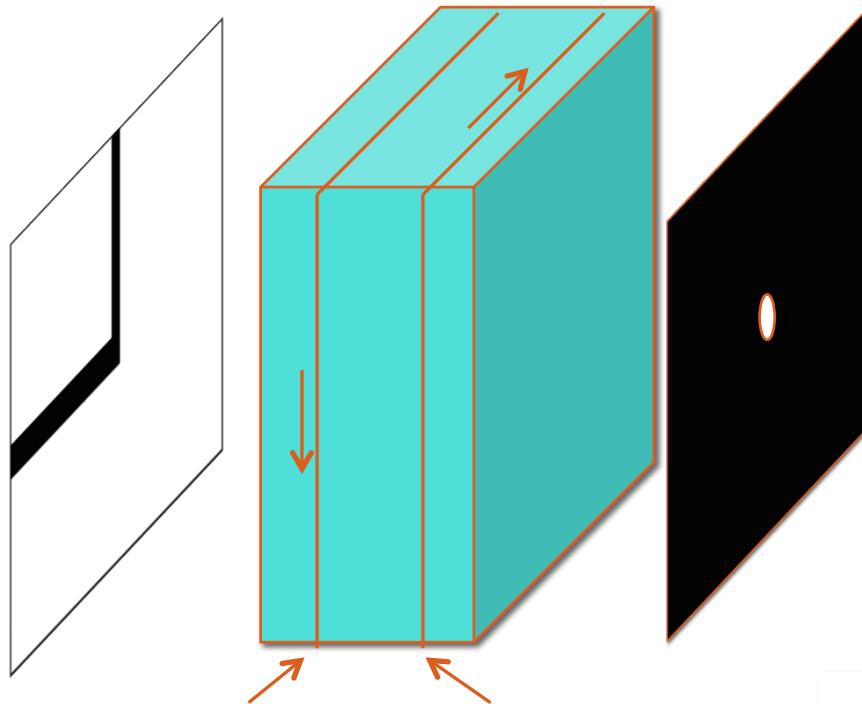
- 1) Identify features that give strong response.
- 2) Identify locations of strong response. ●
- 3) Shift selected feature planes to bring strong responses together to some common point. ✕

Constructing a vertex detector by combining the outputs of line detectors

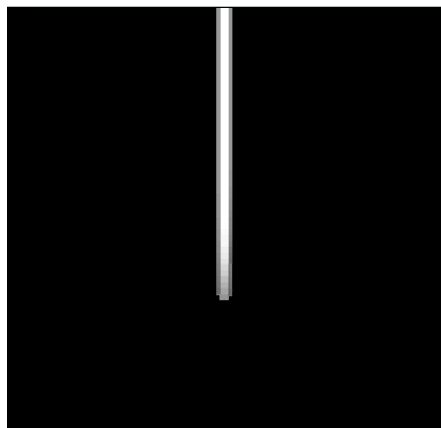


- 1) Identify features that give strong response.
- 2) Identify locations of strong response. ●
- 3) Shift selected feature planes to bring strong responses together to some common point. ✕

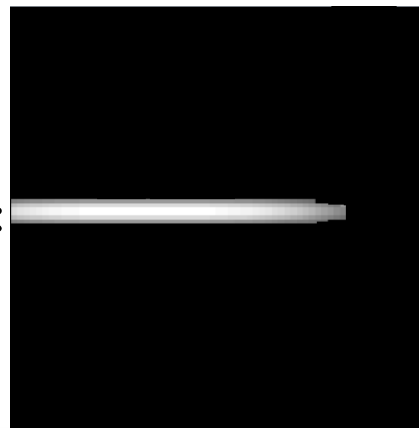
Constructing a vertex detector by combining the outputs of line detectors



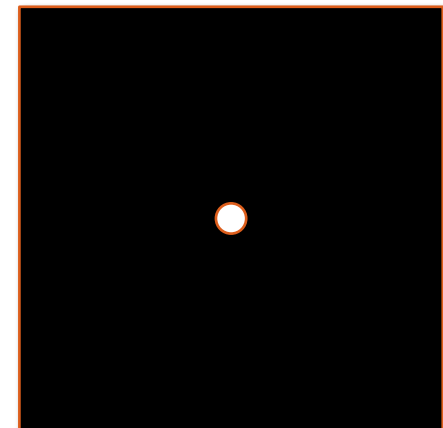
- 1) Identify features that give strong response.
- 2) Identify locations of strong response.
- 3) Shift selected feature planes to bring strong responses together to some common point.
- 4) **Multiply selected shifted feature planes.**



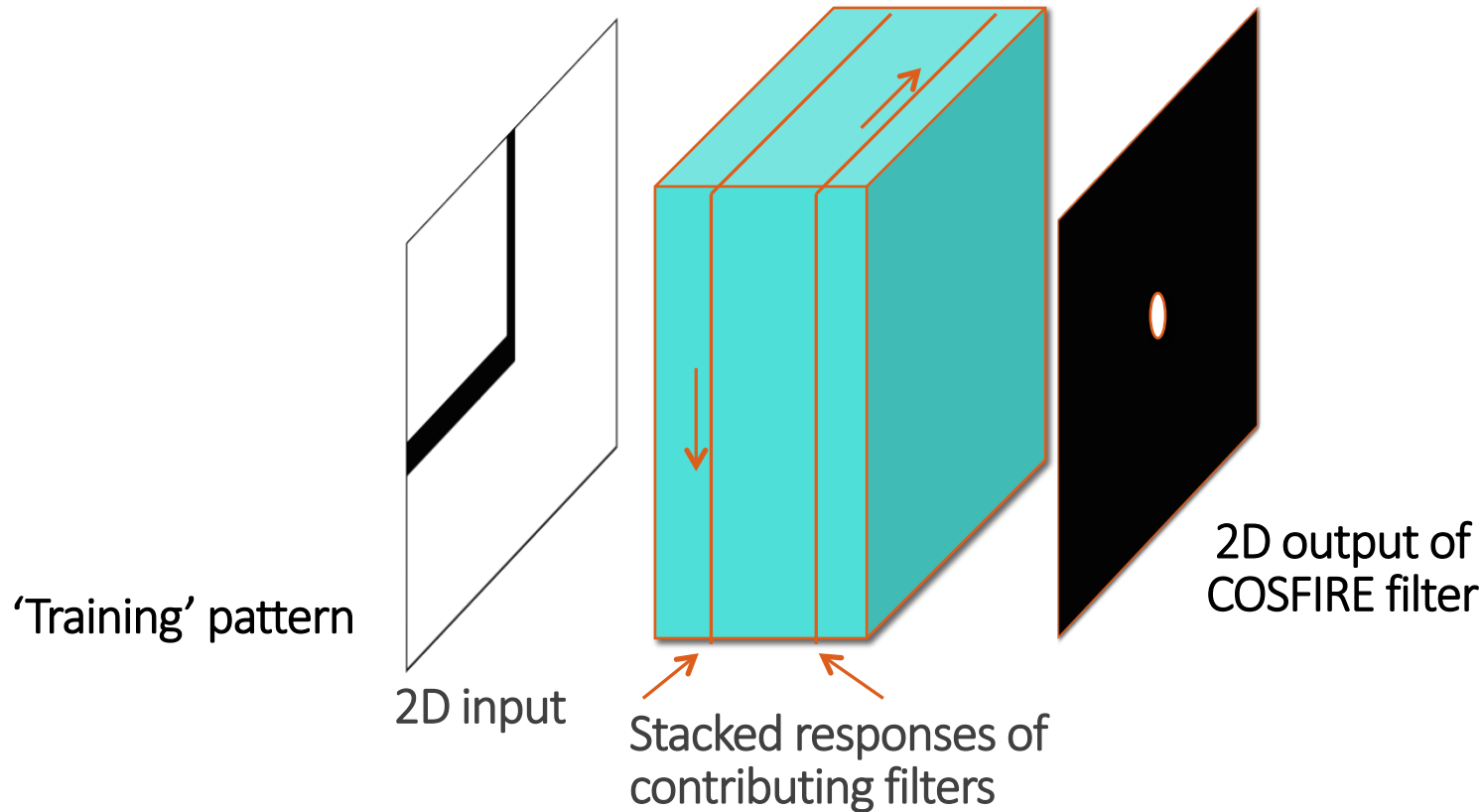
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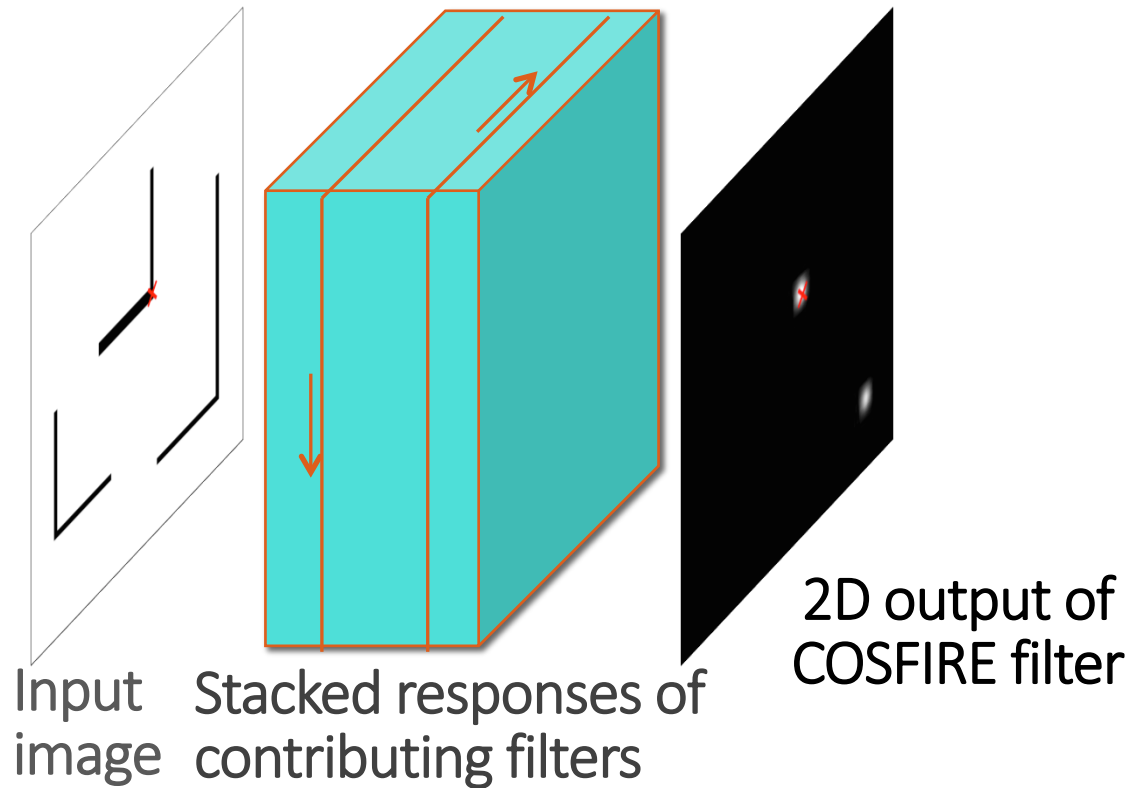


Configuration of a COSFIRE filter



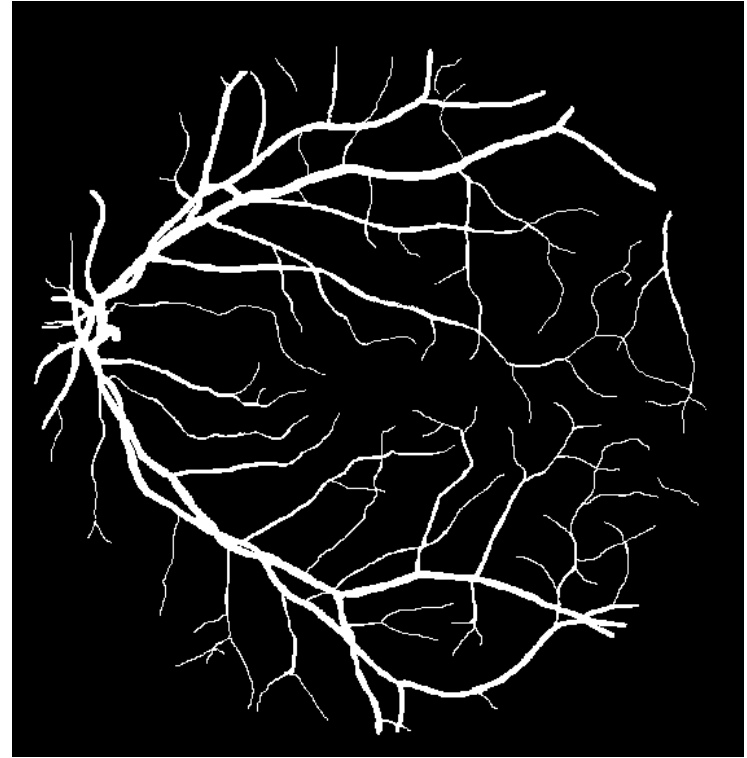
- 1) Identify features/filters that give strong response.
- 2) Identify locations of strong response.
- 3) Shift selected feature planes (responses of selected filters) to bring strong responses together to a common point.
- 4) Multiply selected shifted feature planes (responses of contributing filters).

Application of a configured COSFIRE filter



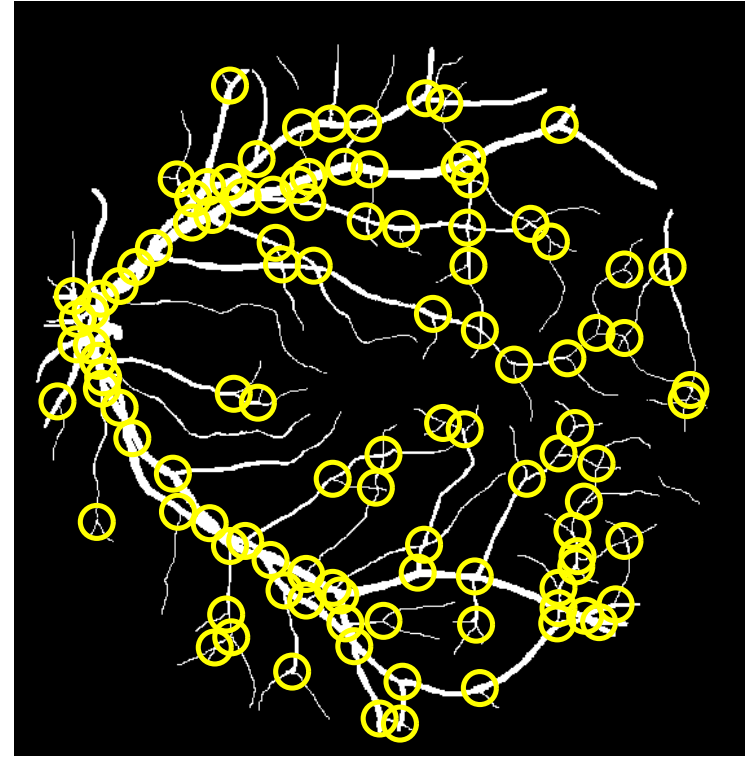
- 1) Apply a set of contributing filters, selected in the configuration phase.
- 2) Shift their responses by the respective shift vectors determined in the configuration phase.
- 3) Multiply the shifted responses of the selected contributing filters.

Application to the detection of vascular bifurcations



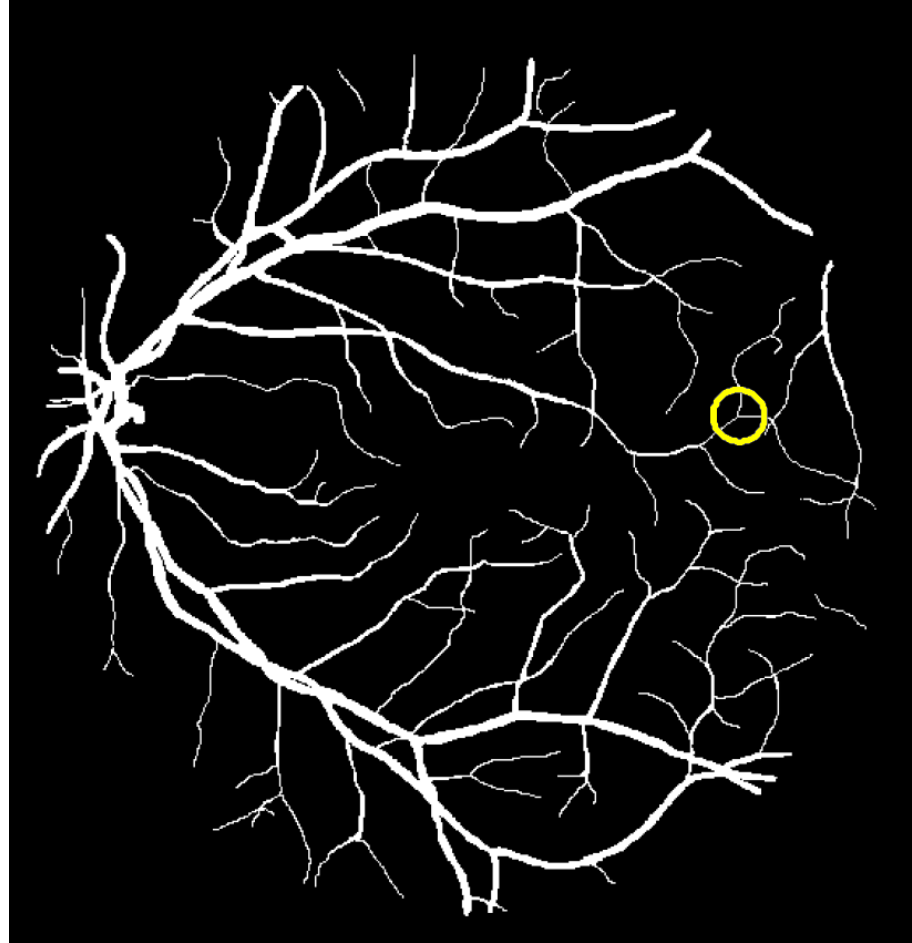
(Left) Retinal fundus image and (right) its vessel segmentation from DRIVE data set [Staal et al., 2004]

Application to the detection of vascular bifurcations

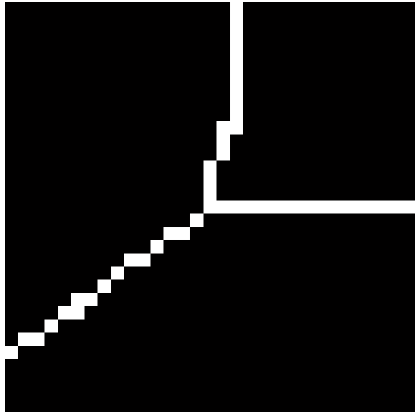


(Left) Retinal fundus image and (right) localization of its (107) vessel bifurcations [Azzopardi & Petkov, 2011]

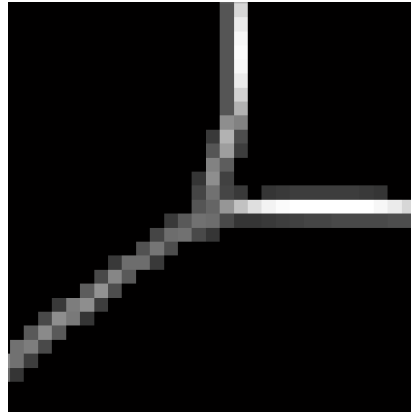
Specify a pattern of interest



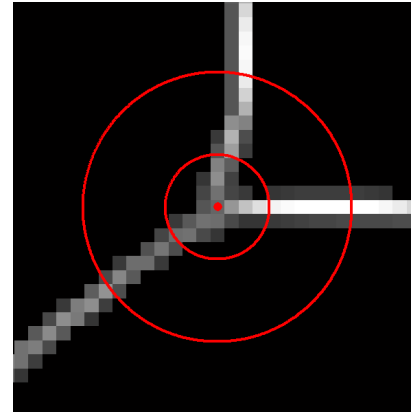
Configuration of a COSFIRE filter



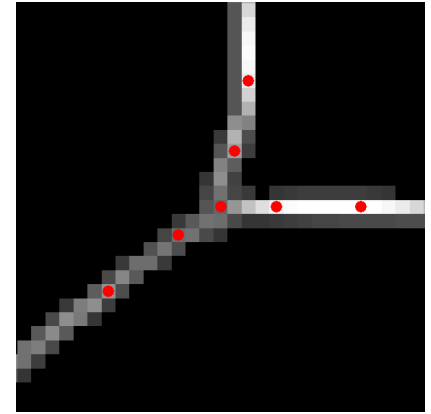
Selected pattern of interest



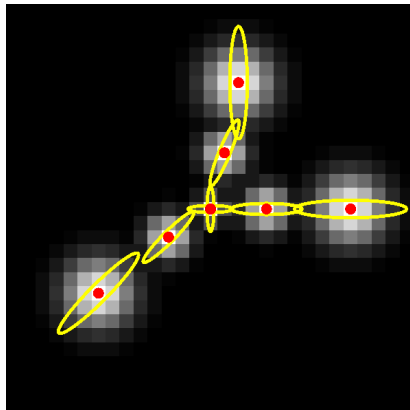
Superposition of Gabor responses



Set of circles for finding strong responses



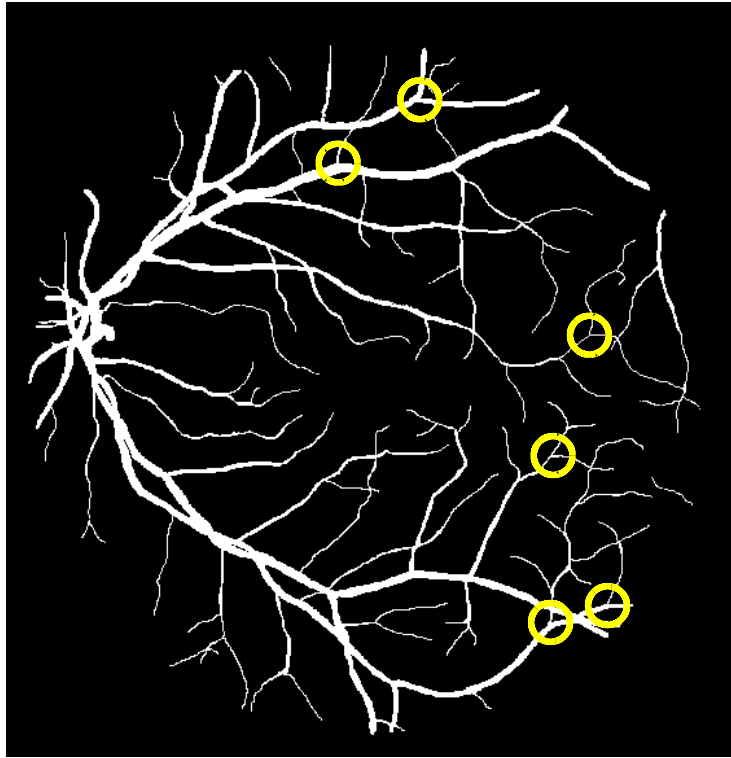
Points of strong responses



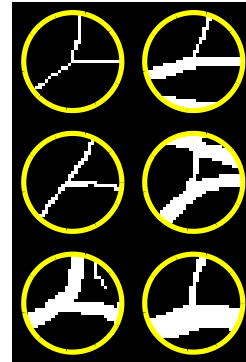
COSFIRE filter structure:

- 1) Ellipses indicate the selected Gabor filters.
- 2) Red dots indicate the positions in which responses are to be taken -> shift vectors.

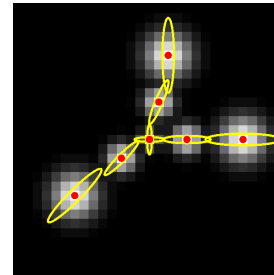
Detection of similar bifurcations



6 out of 107 bifurcations
detected. 😞

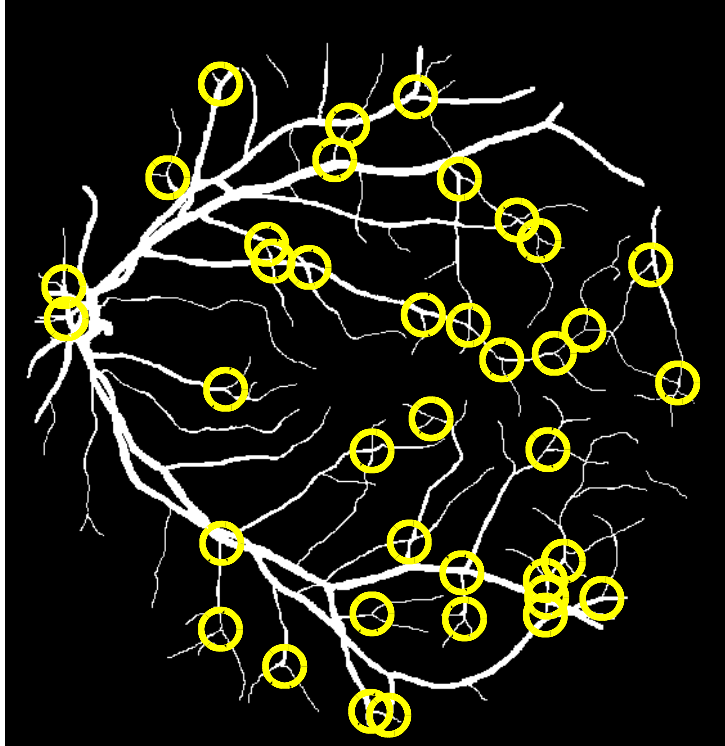


Enlarged.

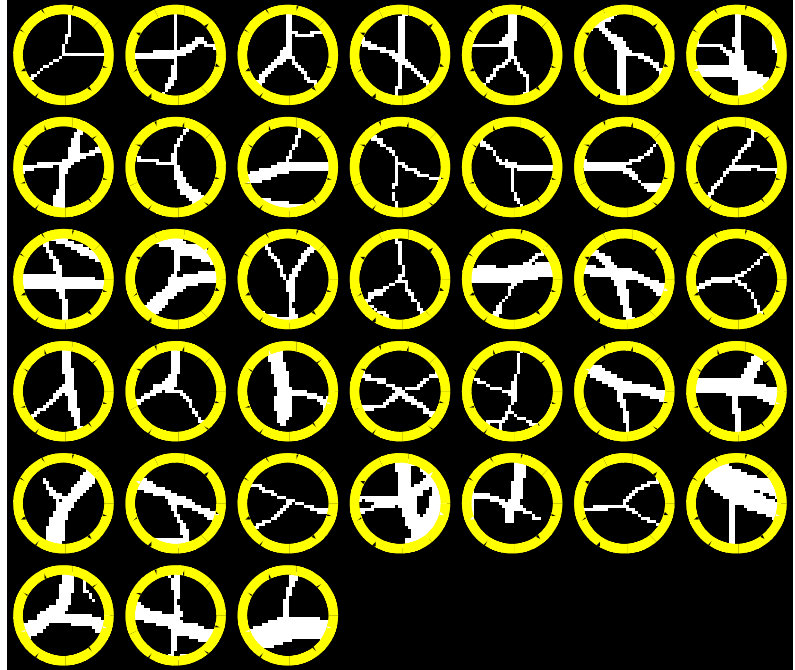


COSFIRE filter
structure

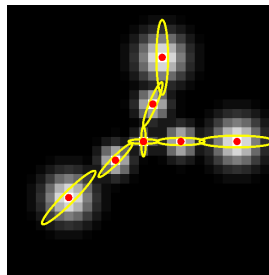
Detection of similar bifurcations



38 out of 107 bifurcations detected. This is better ... but not perfect.

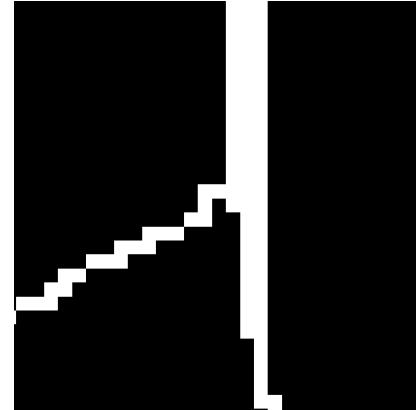
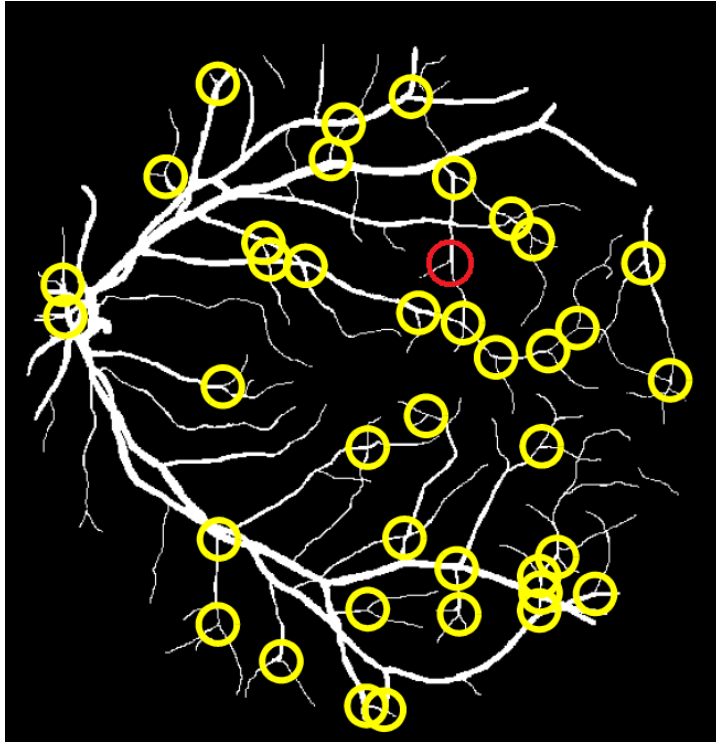


Enlarged detected bifurcations.



COSFIRE filter
+ rotated versions
(made by symbolic manipulation)

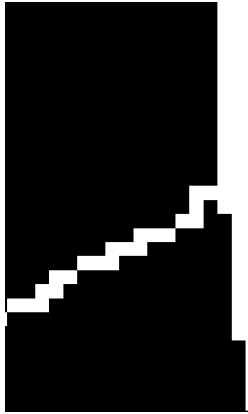
Specifying another pattern of interest



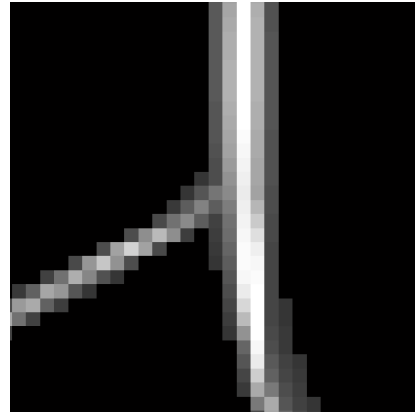
Another selected pattern of interest (enlarged).

Configure another COSFIRE filter, using an undetected bifurcation.

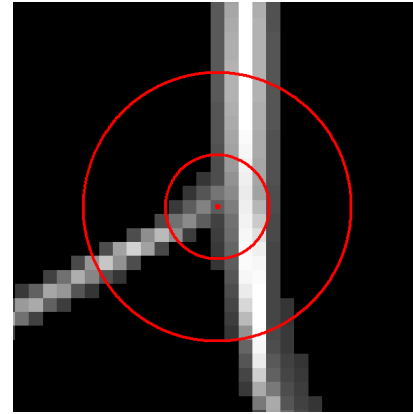
Configuration of COSFIRE filter #2



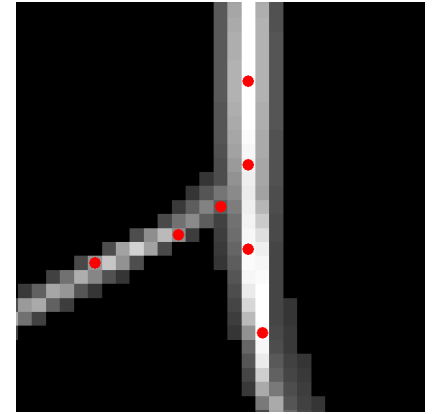
Selected pattern of interest #2



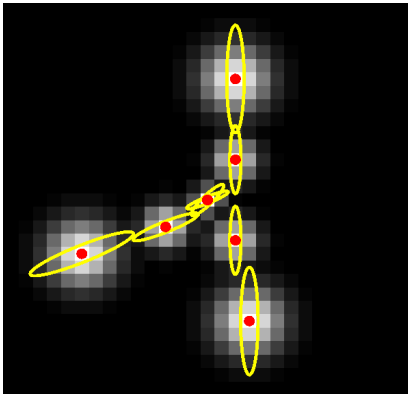
Superposition of Gabor responses



Set of circles for analysis



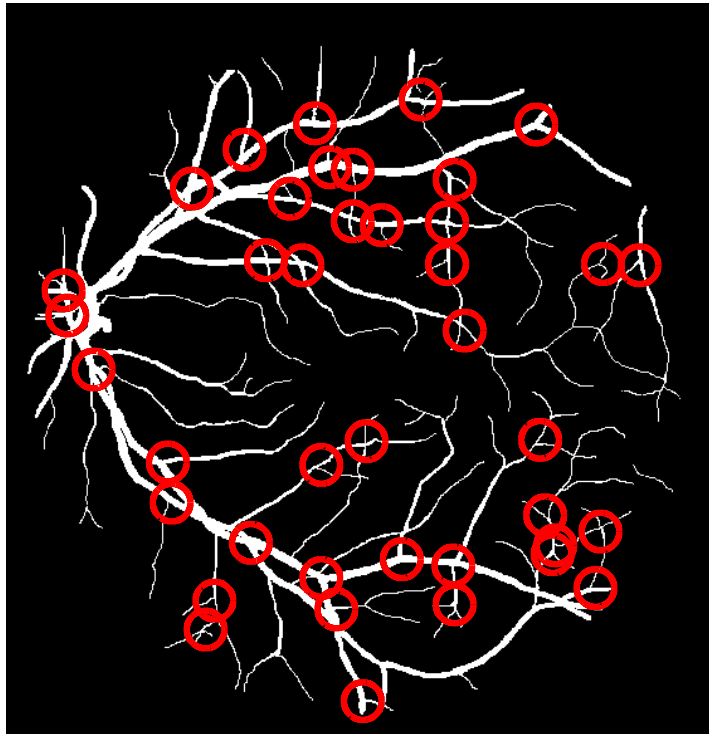
Points of essential responses



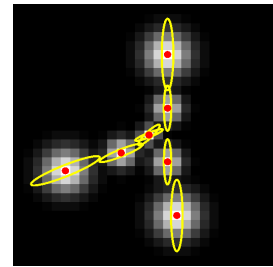
Structure of COSFIRE filter #2:

- 1) Ellipses indicate the selected Gabor filters.
- 2) Red dots indicate the positions in which responses are to be taken -> shift vectors.

Detection of similar bifurcations

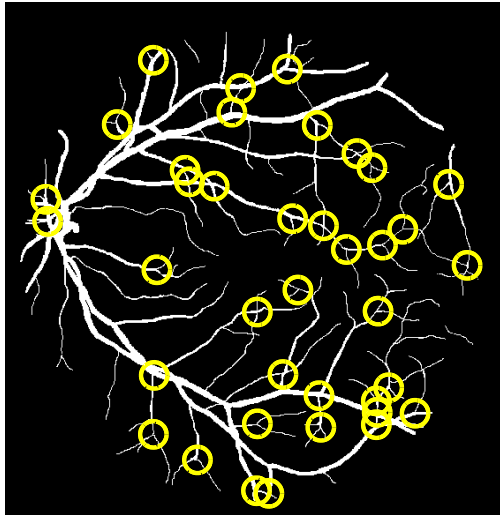


40 out of 107 bifurcations
detected.

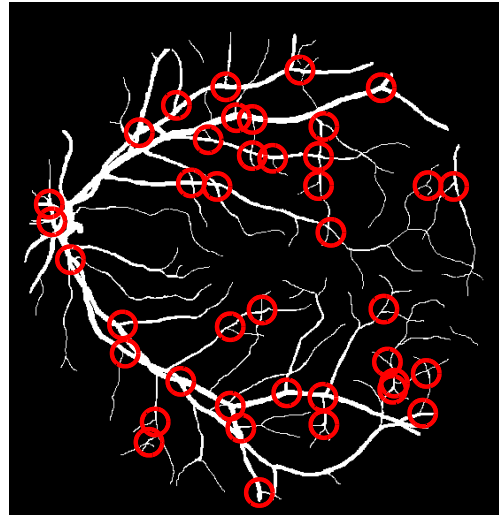


COSFIRE filter #2
+ rotated versions
(made by symbolic
manipulation)

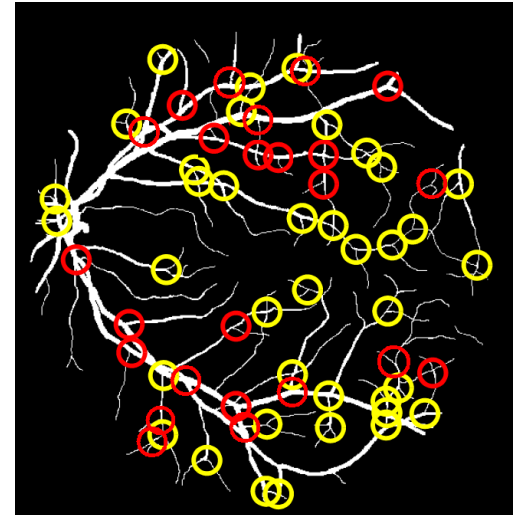
Detection of similar bifurcations



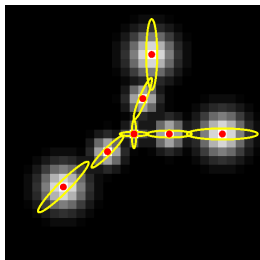
38 bifurcations
detected by #1



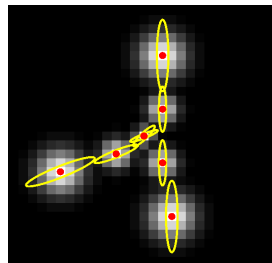
40 bifurcations
detected by #2



62 bifurcations
detected by #1 & #2



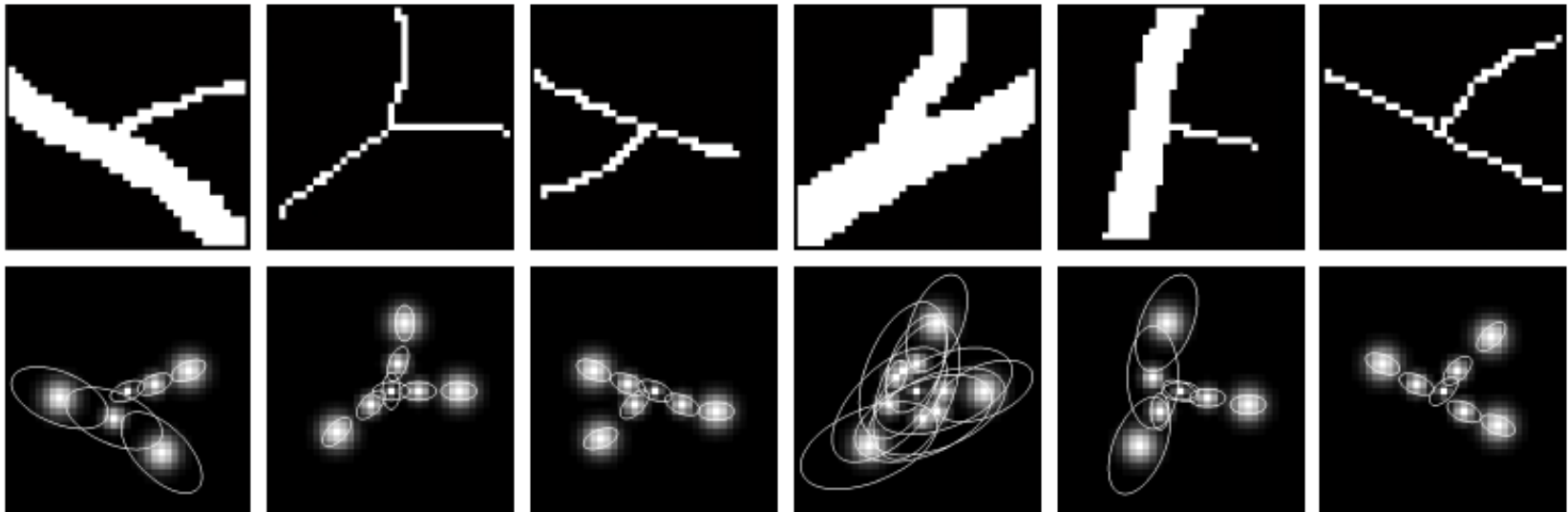
COSFIRE #1



COSFIRE #2

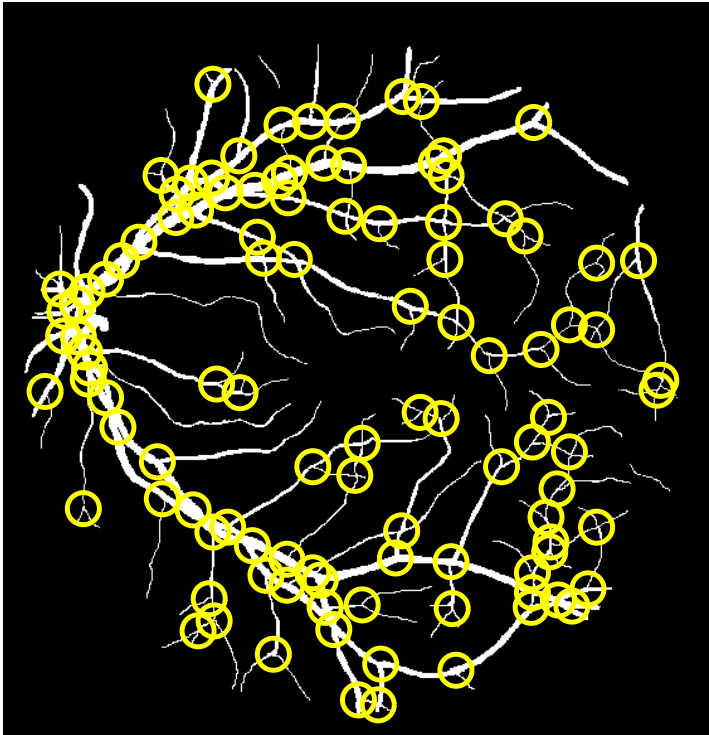
Detection of similar bifurcations

6 Iteratively selected bifurcations.

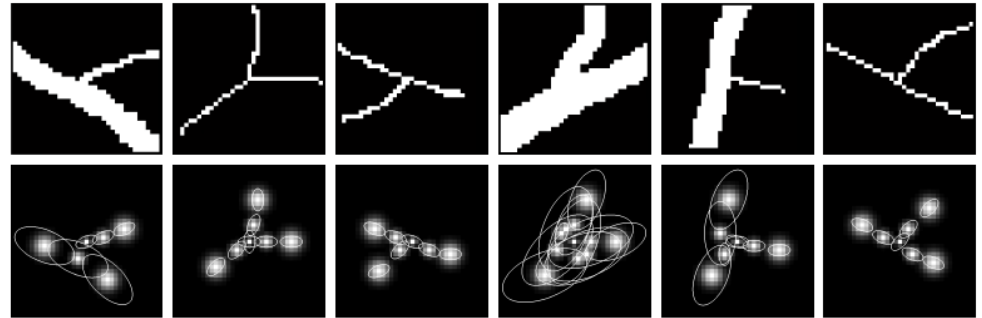


Structures of the corresponding 6 COSFIRE filters.

Detection of vascular bifurcations

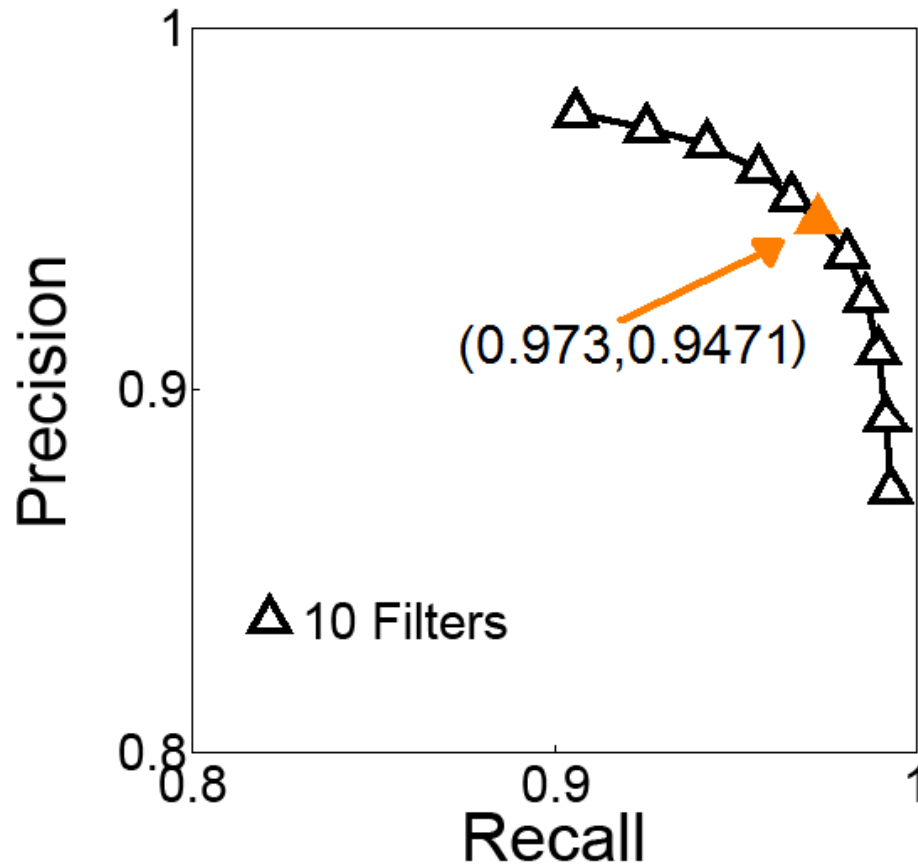


Result achieved with 6 COSFIRE filters: all 107 bifurcations are detected, no false positives. 😊



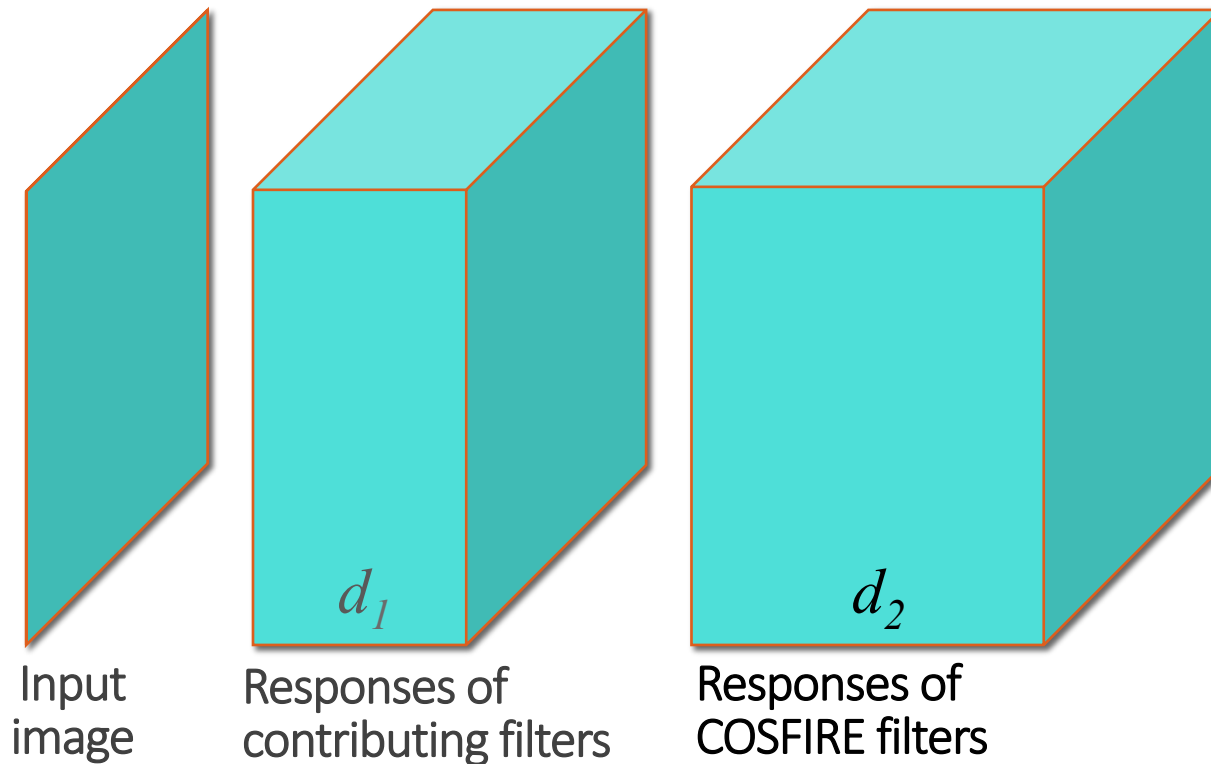
Patterns used for filter configuration and the corresponding COSFIRE filters. All filters use the outputs of **the same bank of Gabor filters**. The only additional operations are shifts and point-wise geometric mean computations. 😊

Detection of vascular bifurcations



Result achieved with 6 COSFIRE filters for the DRIVE data set (40 images, more than 5000 bifurcations) 😊

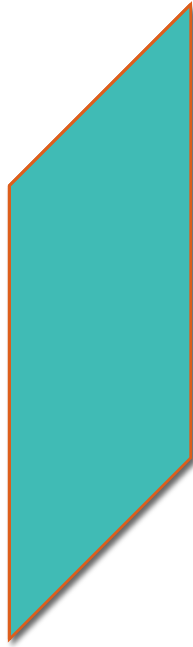
Bank of COSFIRE filters



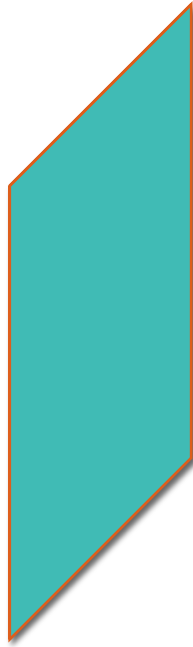
- First layer: some fixed filters (e.g. Gabor filters).
- Second layer: COSFIRE filters. A different training pattern is used for the configuration of each plane. In total d_2 different training patterns.



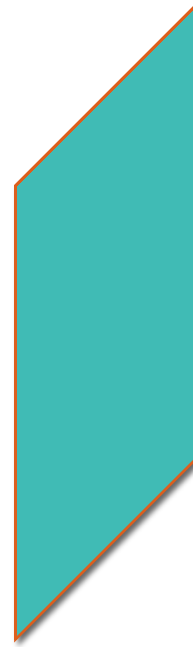
Another type of contributing filter - DoG



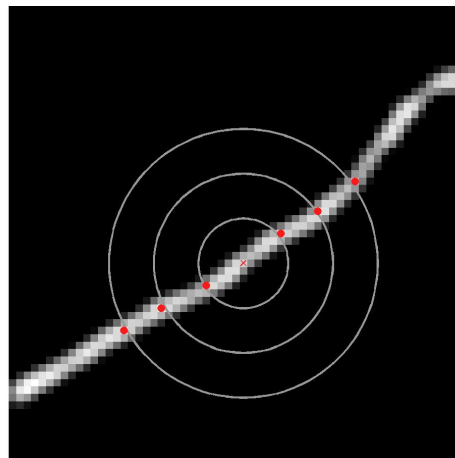
Input
image



Response of
a DoG filter

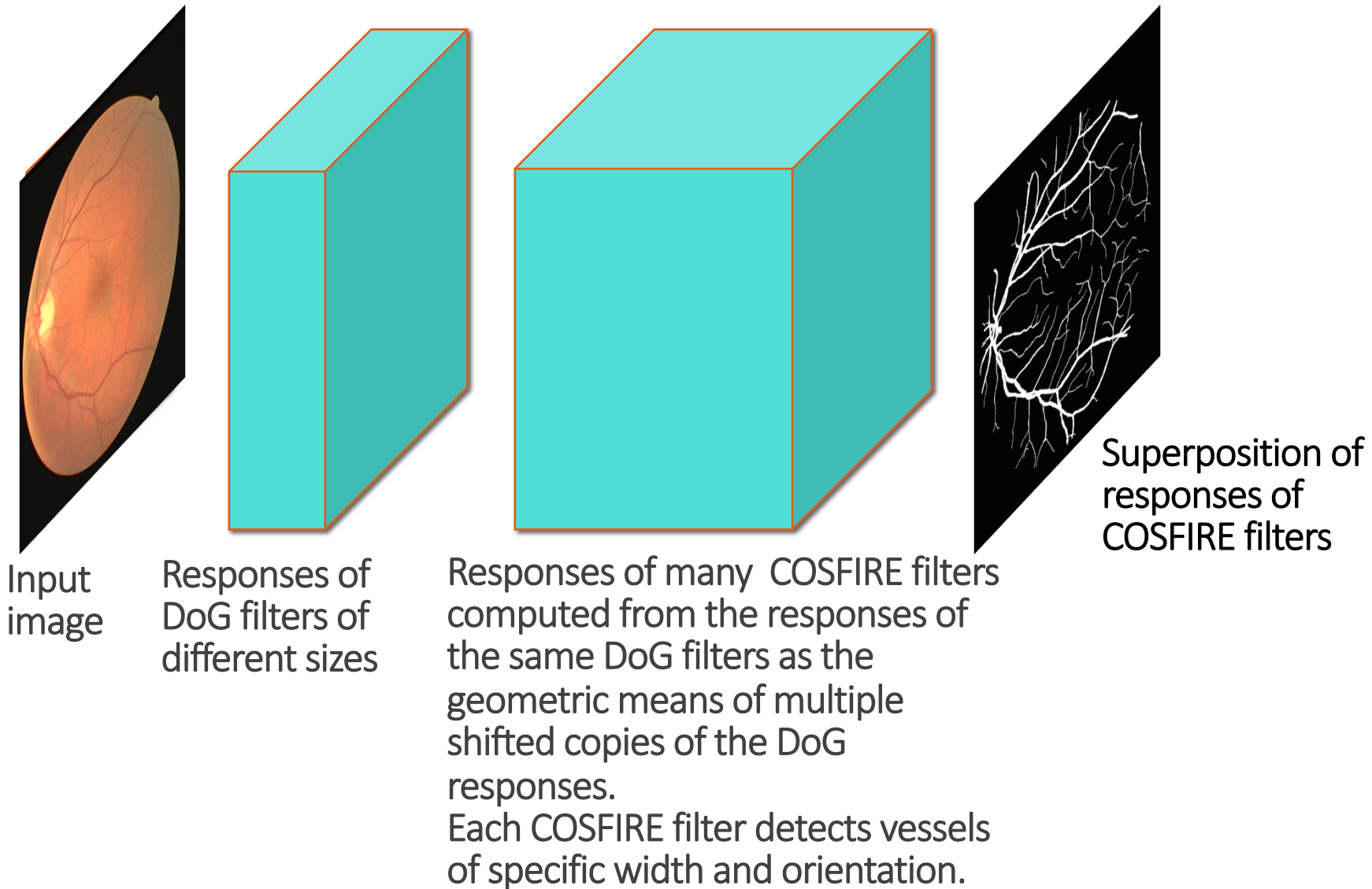


Response of a COSFIRE filter
computed as the geometric
mean of multiple shifted copies
of the DoG response.

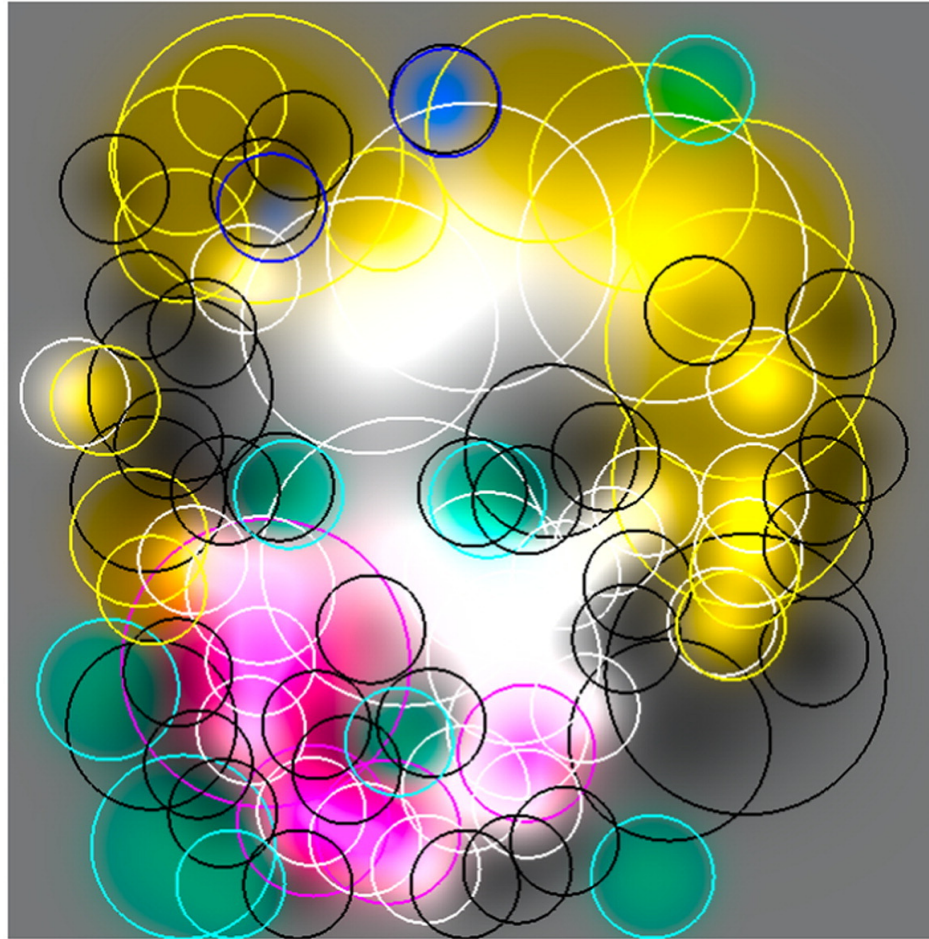


The shift vectors are determined
by the analysis of a prototype
pattern.

DoG-COSFIRE filters for vessel segmentation

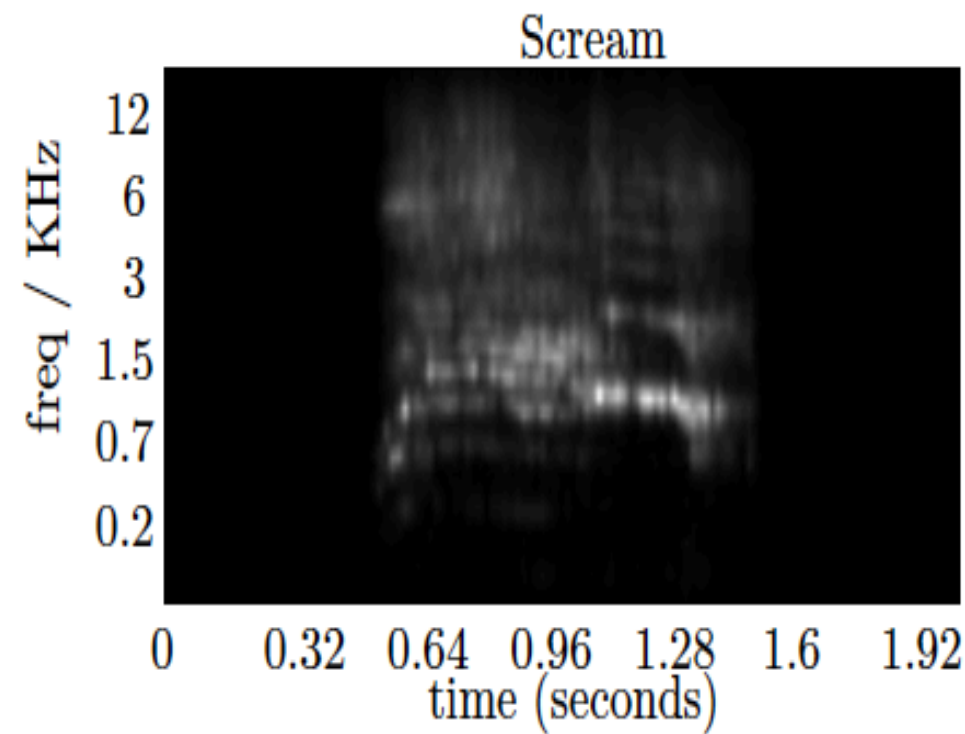


Color-DoG-COSFIRE filters

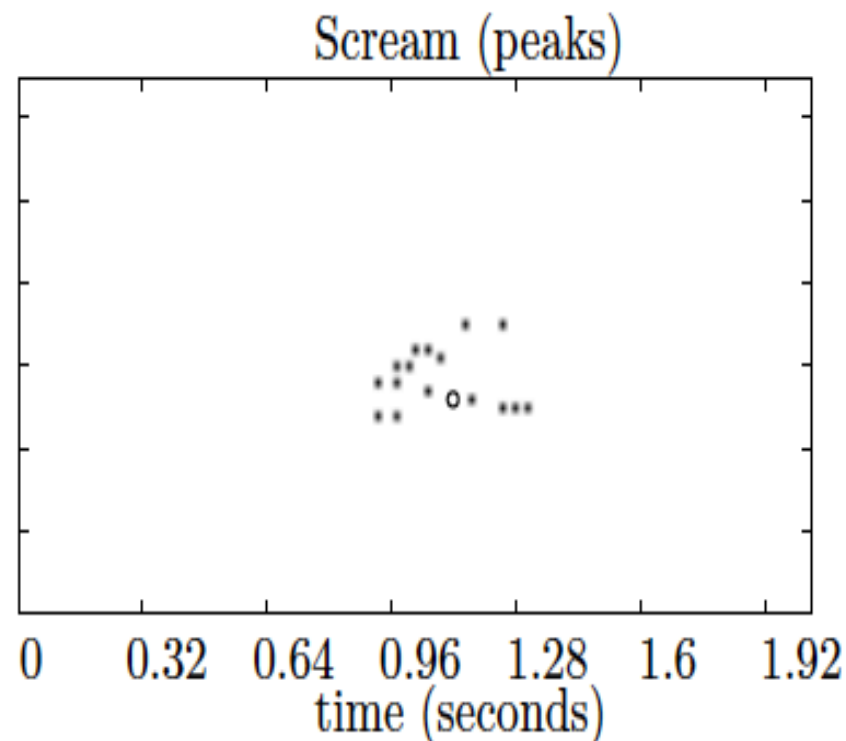


The contributing filters are DoG of different sizes applied to the color planes of an input image.

COSFIRE features for sound



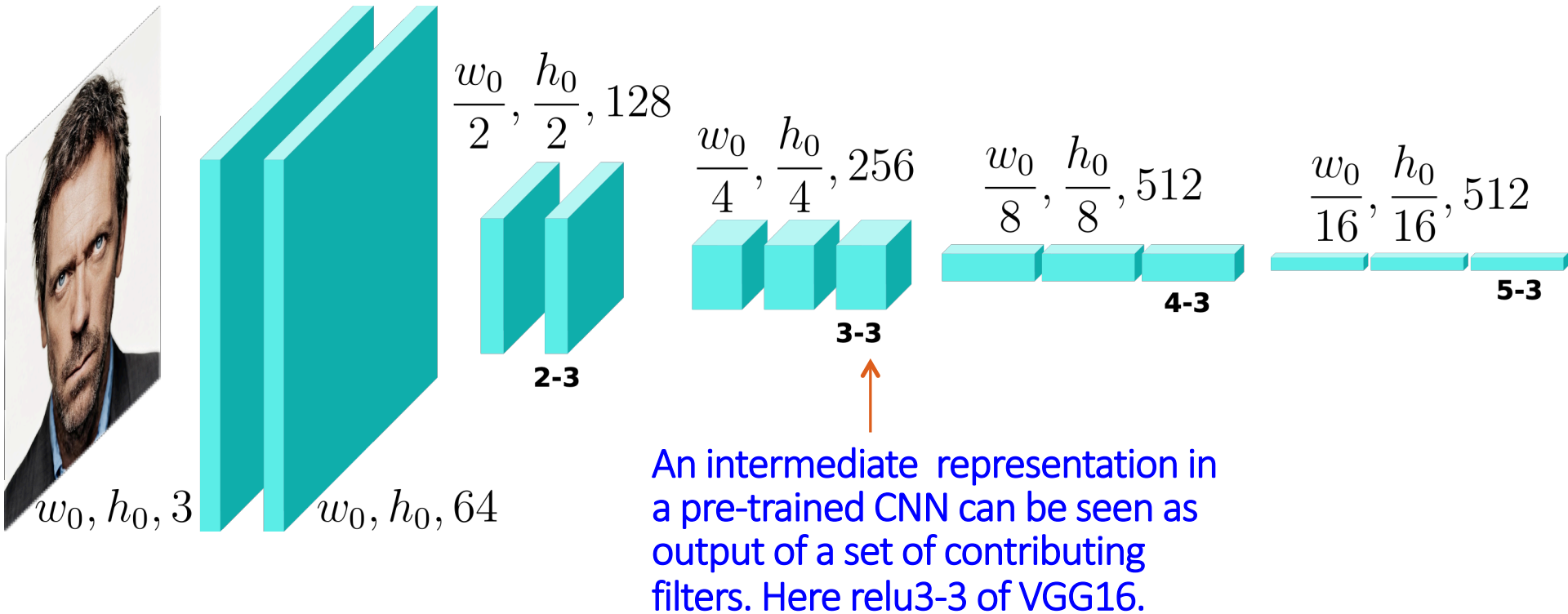
Gammatone representation in the time-frequency domain



Constellation of local energy peaks in the time-frequency domain

Different filters can be configured for different sound types (scream, gun shot, breaking glass, etc.) and instances of sound.

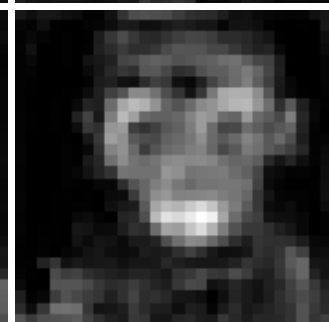
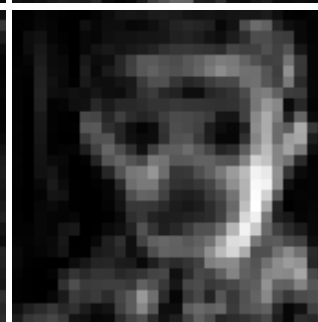
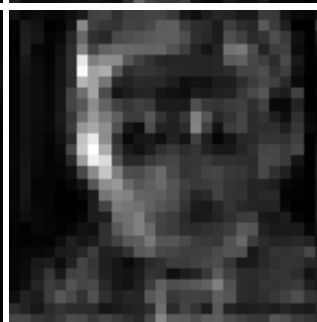
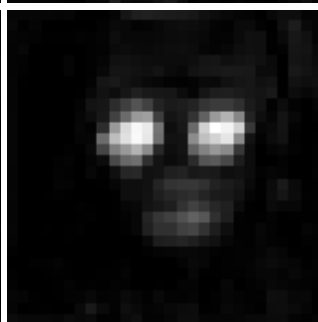
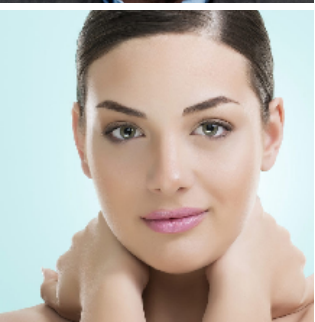
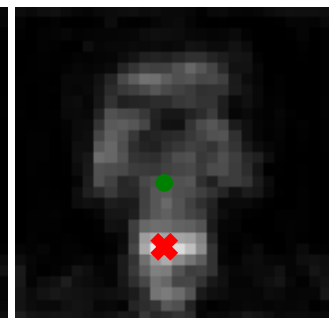
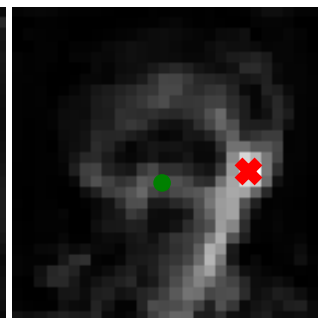
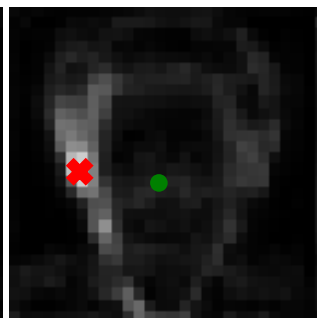
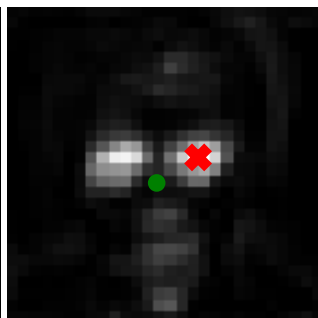
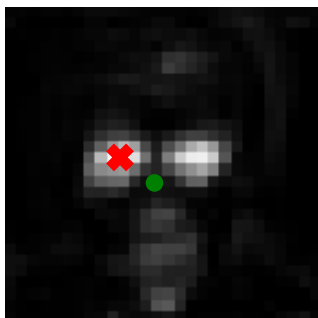
CNN-COSFIRE filters



CNN-COSFIRE contributing filters

Configuration
pattern

Relu3-3 (of VGG16) representation of configuration pattern



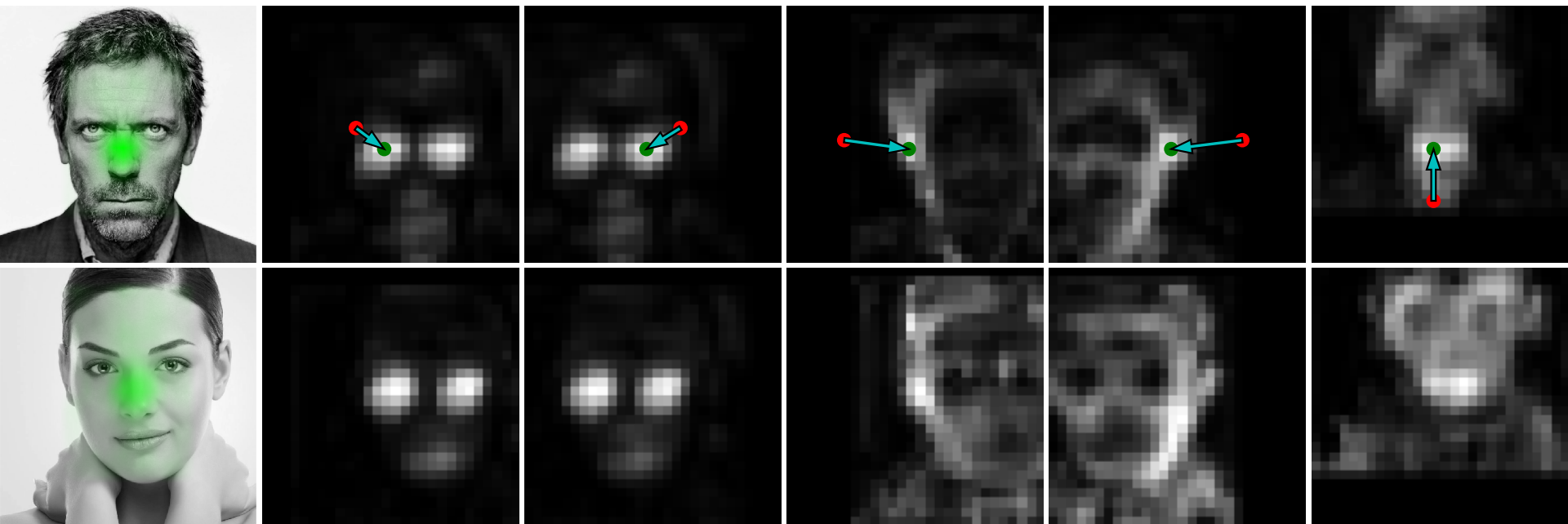
Test
pattern

Relu3-3 (of VGG16) representation of test pattern

CNN-COSFIRE filter (for face detection)

COSFIRE
output (green)

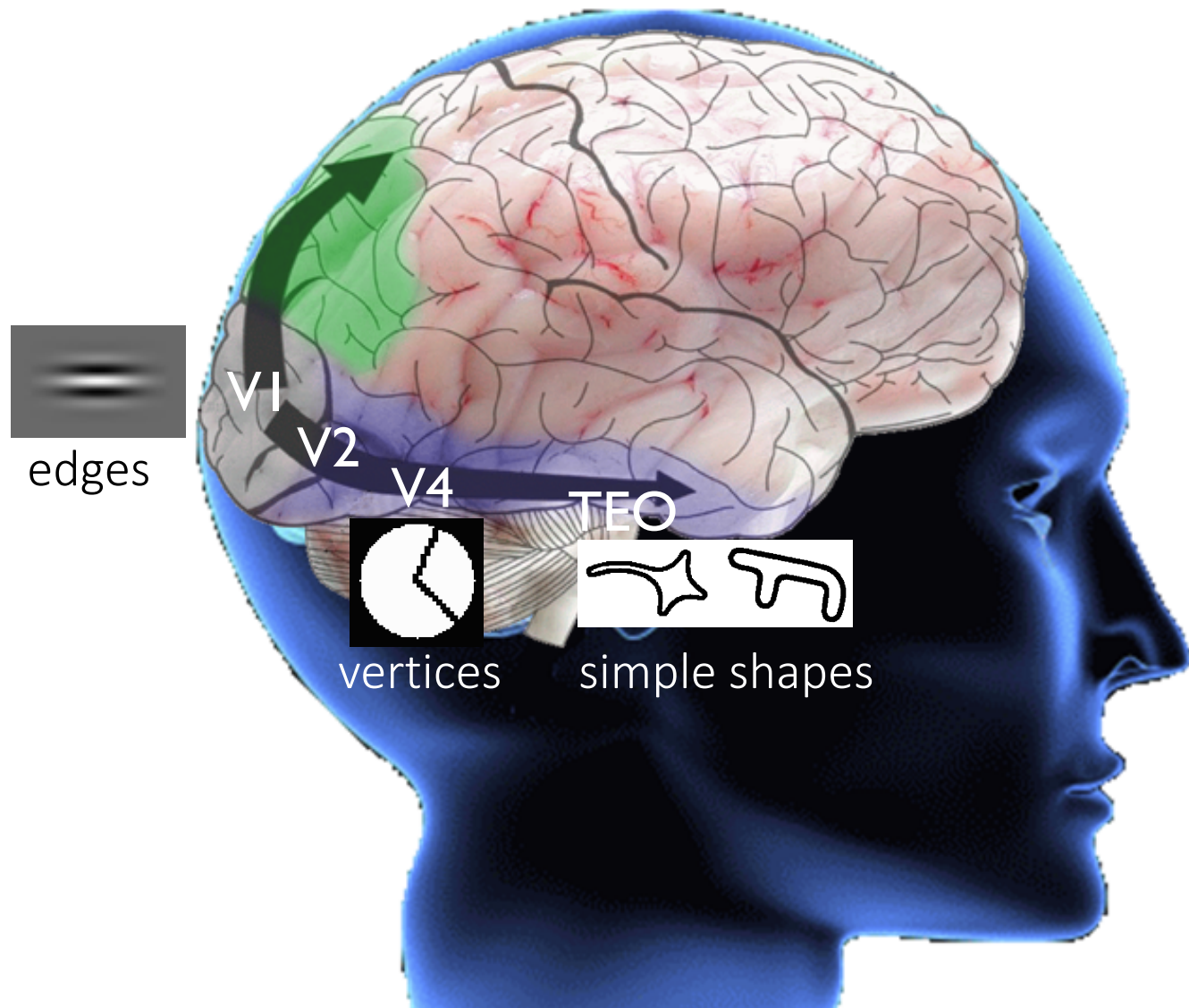
Selected shifted Relu3-3 planes



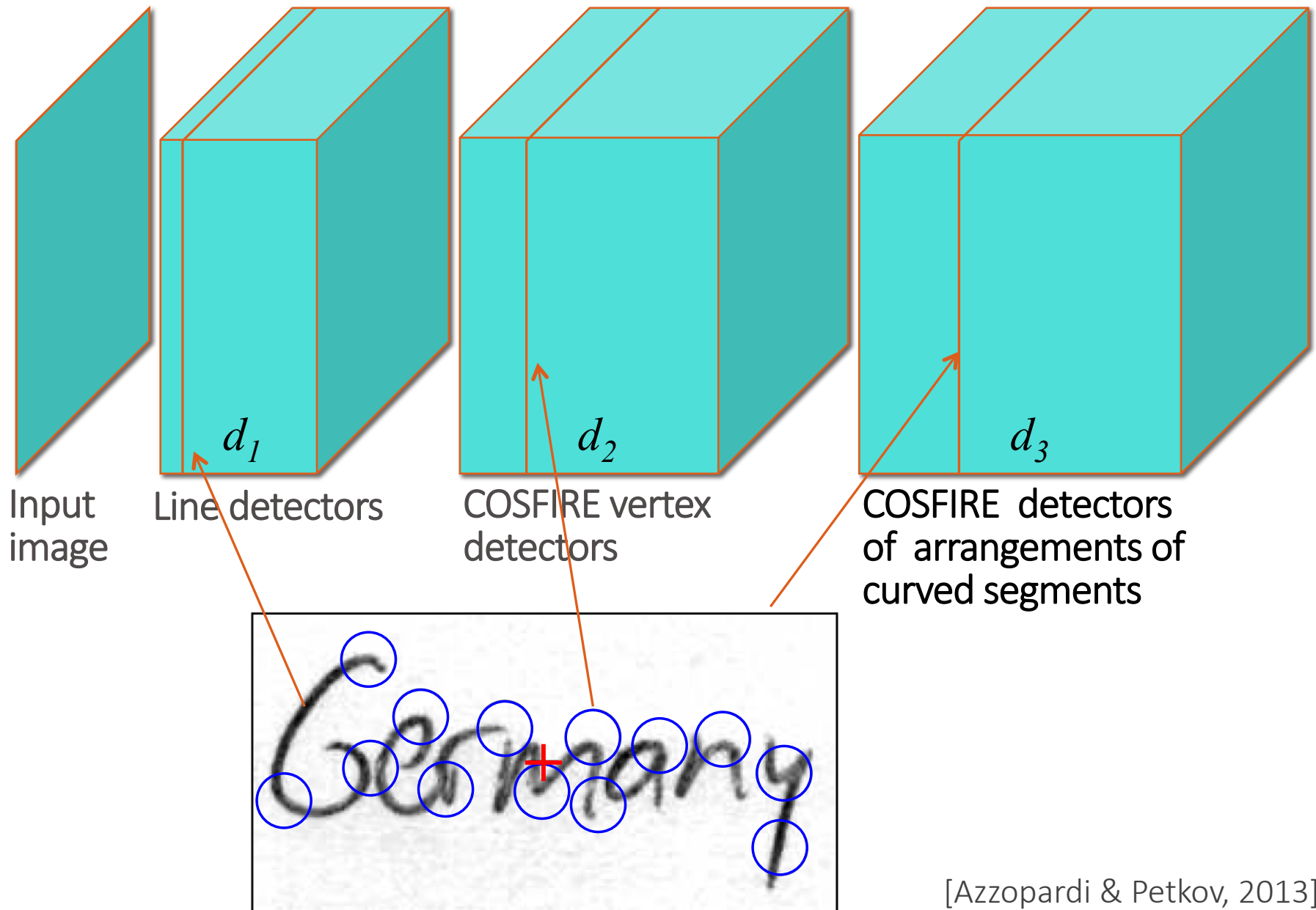
COSFIRE
output (green)

Selected shifted Relu3-3 planes

More biological inspiration



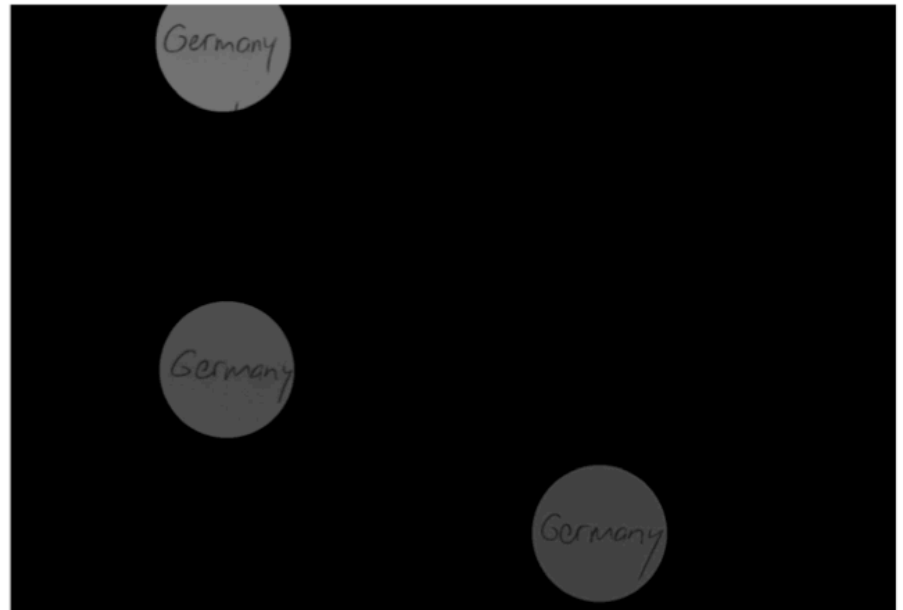
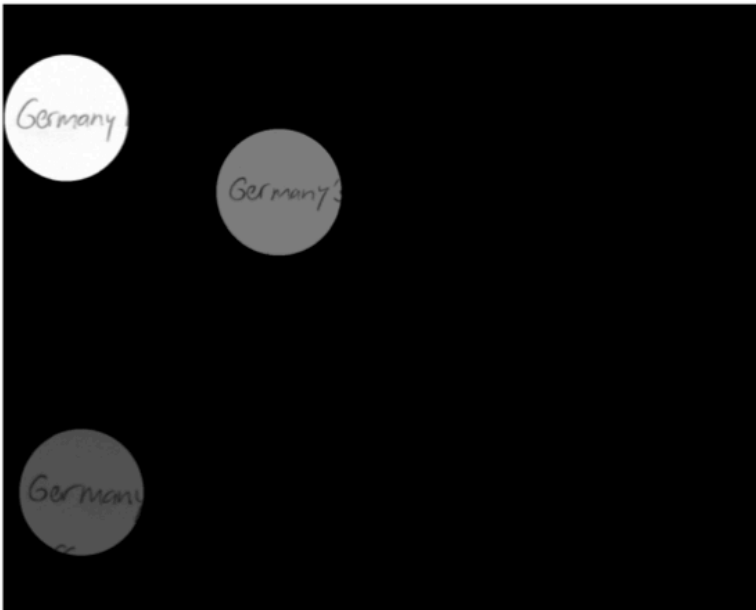
Hierarchy of COSFIRE filter banks



Word spotting

There they have stayed uselessly locked up because
Germany has no tradition of trading abroad. In addition
the strength of Germany's trading position has attracted
speculators to hold marks rather than pounds or dollars,
hoping for the mark to rise, as has now happened.
Will the new valuation be enough to correct
Germany's massive trading surplus and choke
off speculation against dollar and pound?

Booming Germany is deliberately encouraging more imports
as a means to curb rising prices at home. She is
also aware how ~~un~~popular she has been growing
by failing until now to co-operate as a creditor nation
should. Germany exports much more than she imports.
For upwards of five years the world's reserves of
dollars have been drained into Germany.

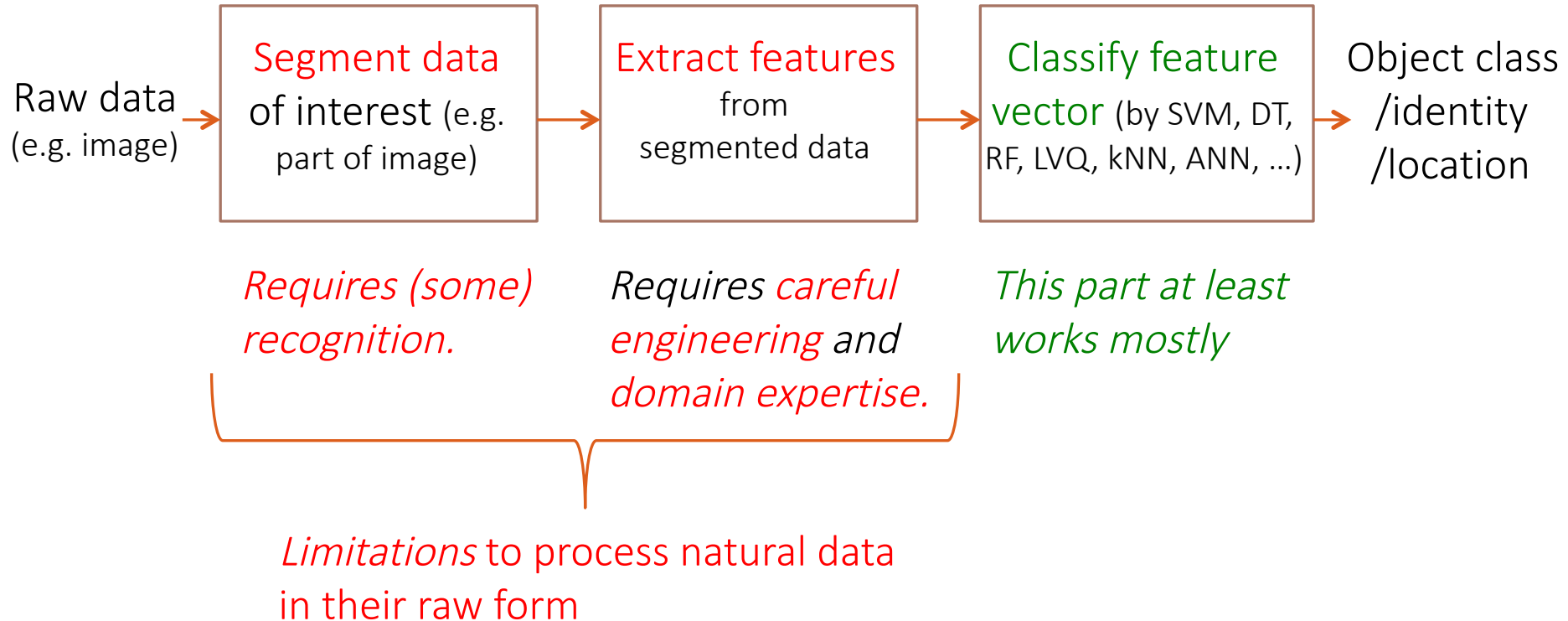


1

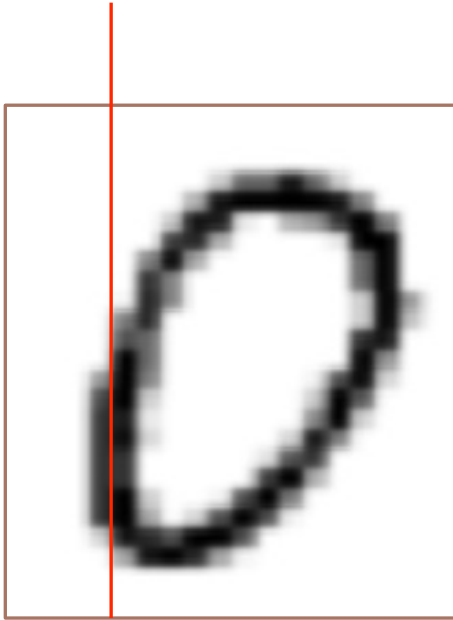
0

COSFIRE filters as trainable
feature extractors

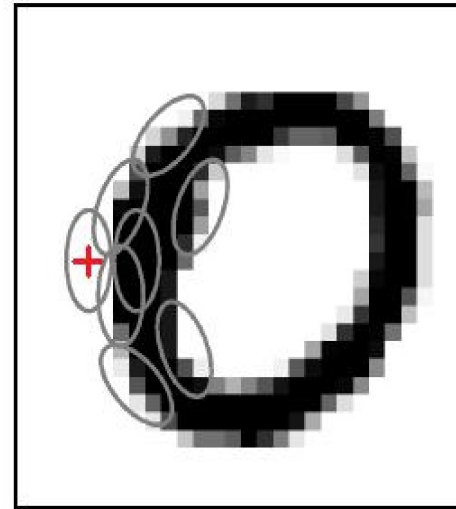
Traditional pattern recognition framework



COSFIRE features vs. hand crafted features

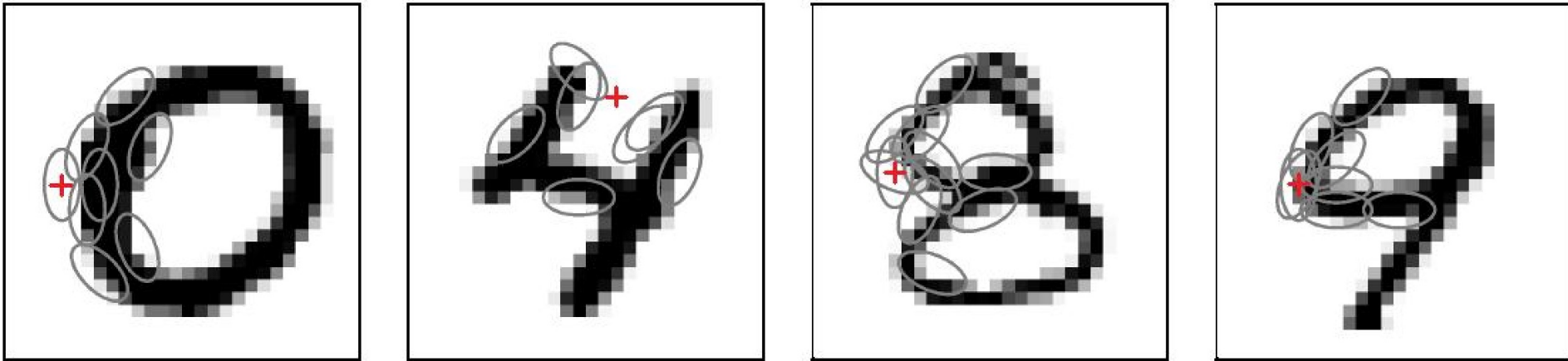


Hand crafted feature - number of crossings of a stroke with a fixed line.



COSFIRE feature: graded response of a COSFIRE filter configured using training data.

Set of COSFIRE features



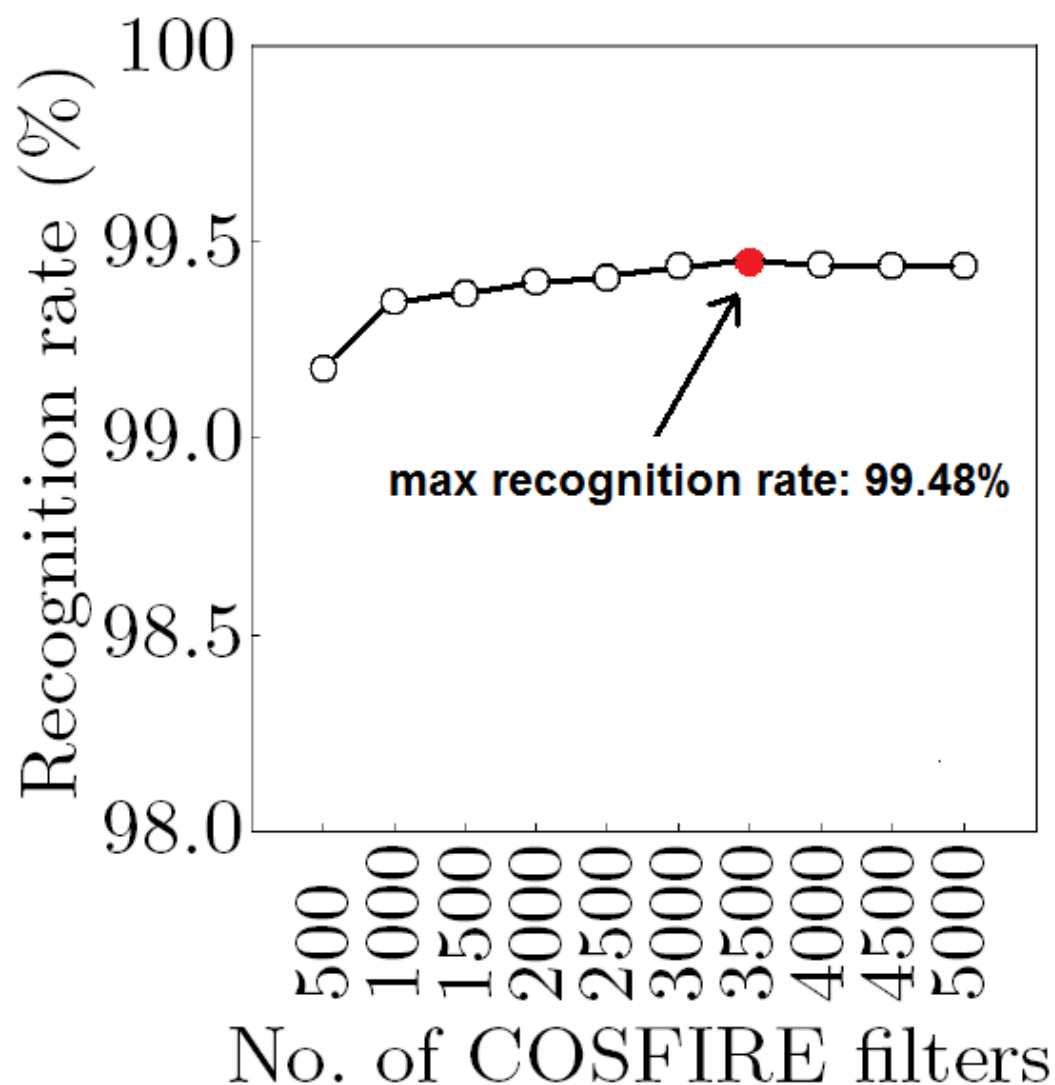
A set of COSFIRE filters that are automatically configured using training data.

One single example is needed to configure a COSFIRE filter.

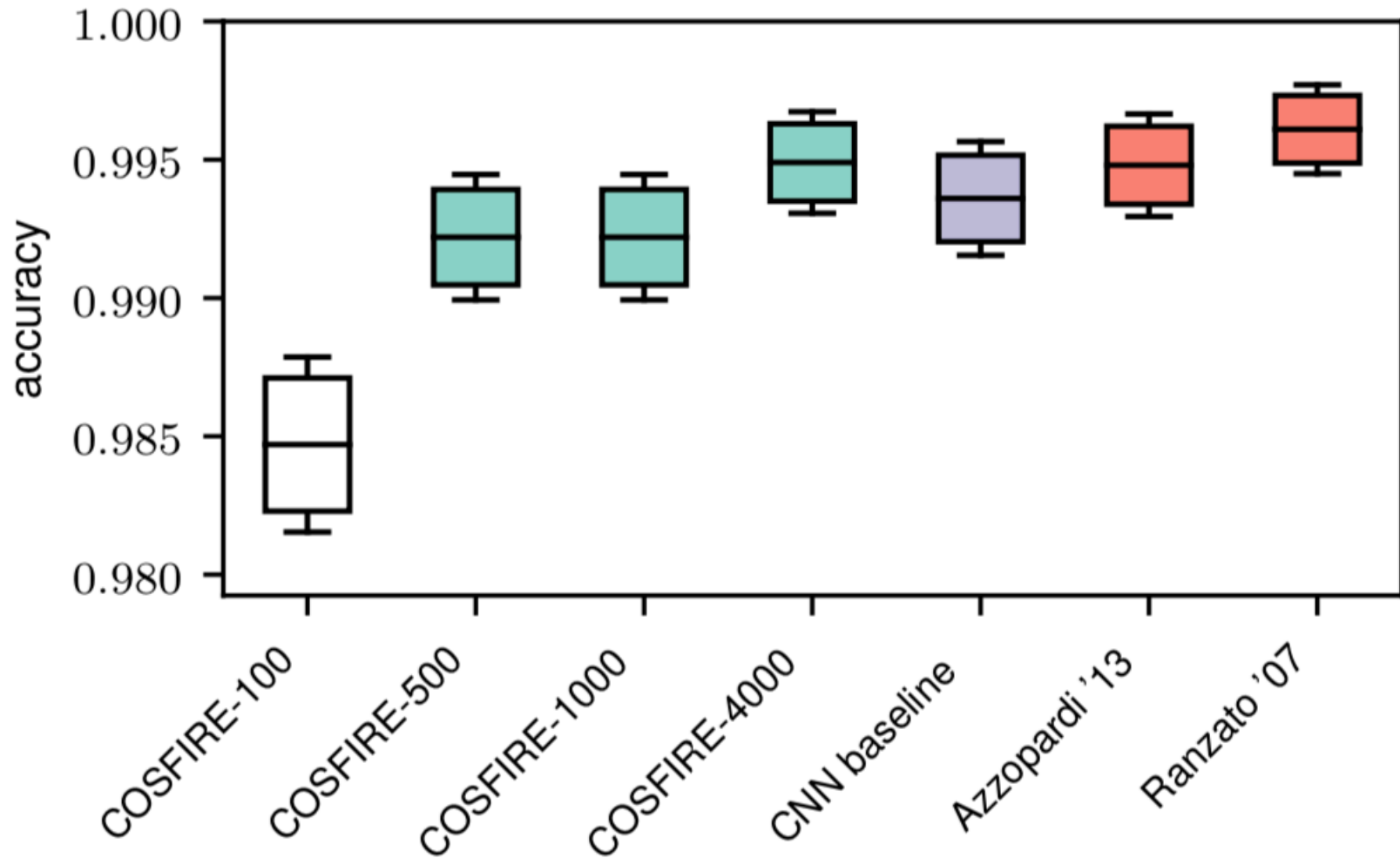
A large number of COSFIRE filters can be configured automatically using different images and different positions in each image.

The feature vector computed from an image is the set of maximum responses of the configured COSFIRE filters to that image.

MNIST results with Gabor-COSFIRE feature



MNIST results with CNN-COSFIRE feature vectors












GTSRB
results
with
color-
DoG-
COSFIRE

Method	All signs	Speed limits	Other prohibitions	Derestriction	Mandatory	Danger	Unique
Multi-column deep NN [55]	99.46	99.47	99.93	99.72	99.89	99.07	99.22
Proposed method	98.94	99.09	99.93	93.33	99.72	97.78	99.80
Human performance [58]	98.84	97.63	99.93	98.89	99.72	98.67	100
Multi-scale CNNs [59]	98.31	98.61	99.87	94.44	97.18	98.03	98.63
Random forests [56]	96.14	95.95	99.13	87.50	99.27	92.08	98.73
LDA on HOG 2 [58]	95.68	95.37	96.80	85.83	97.18	93.73	98.63

[Gecer et al., 2017]

Butterfly data set results with color-DoG-COSFIRE

								
Method	All butterflies	Admiral	Swallowtail	Machaon	Monarch 1	Monarch 2	Peacock	Zebra
[61]	90.61	92.9	100	91.2	85.4	81.0	95.4	89.2
[60]	90.4	87.1	75.0	96.5	72.9	91.4	100	89.2
[62]	89.4	91	81	95	67	84	98	92
Ours	89.02	95.29	93.75	85.96	77.08	84.48	93.51	87.69

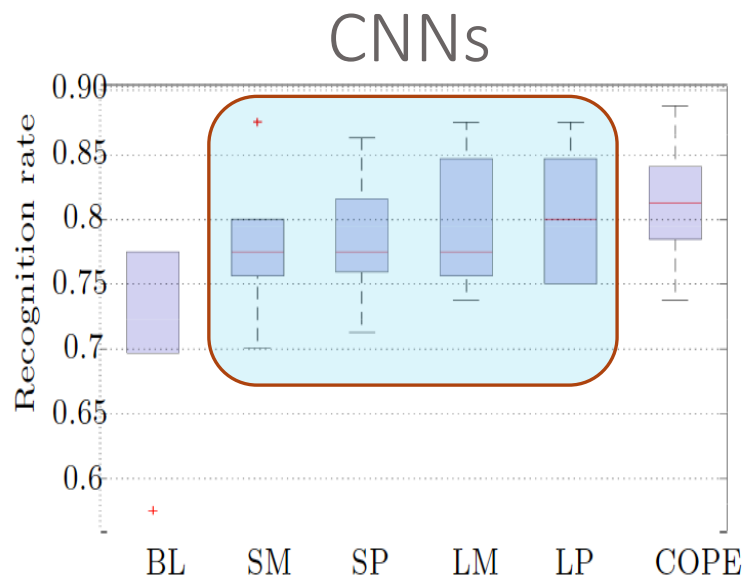
Results for home event detection

Result comparison on TU Dortmund data set

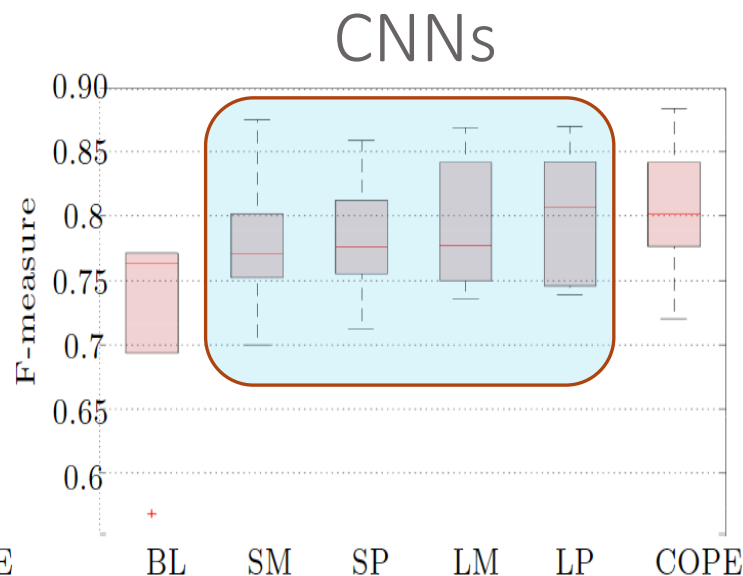
11 classes

[Plinge et al., 2014]

	RR	Pr	Re	F
COPE	94.27%	94.79%	95.19%	94.69%
BoF [20]	90.05%	92.39%	88.82%	90.57%
P-BoF [20]	89.94%	92.24%	88.67%	90.42%
BoSF [20]	90.31%	92.73%	88.13%	90%



(a)



(b)

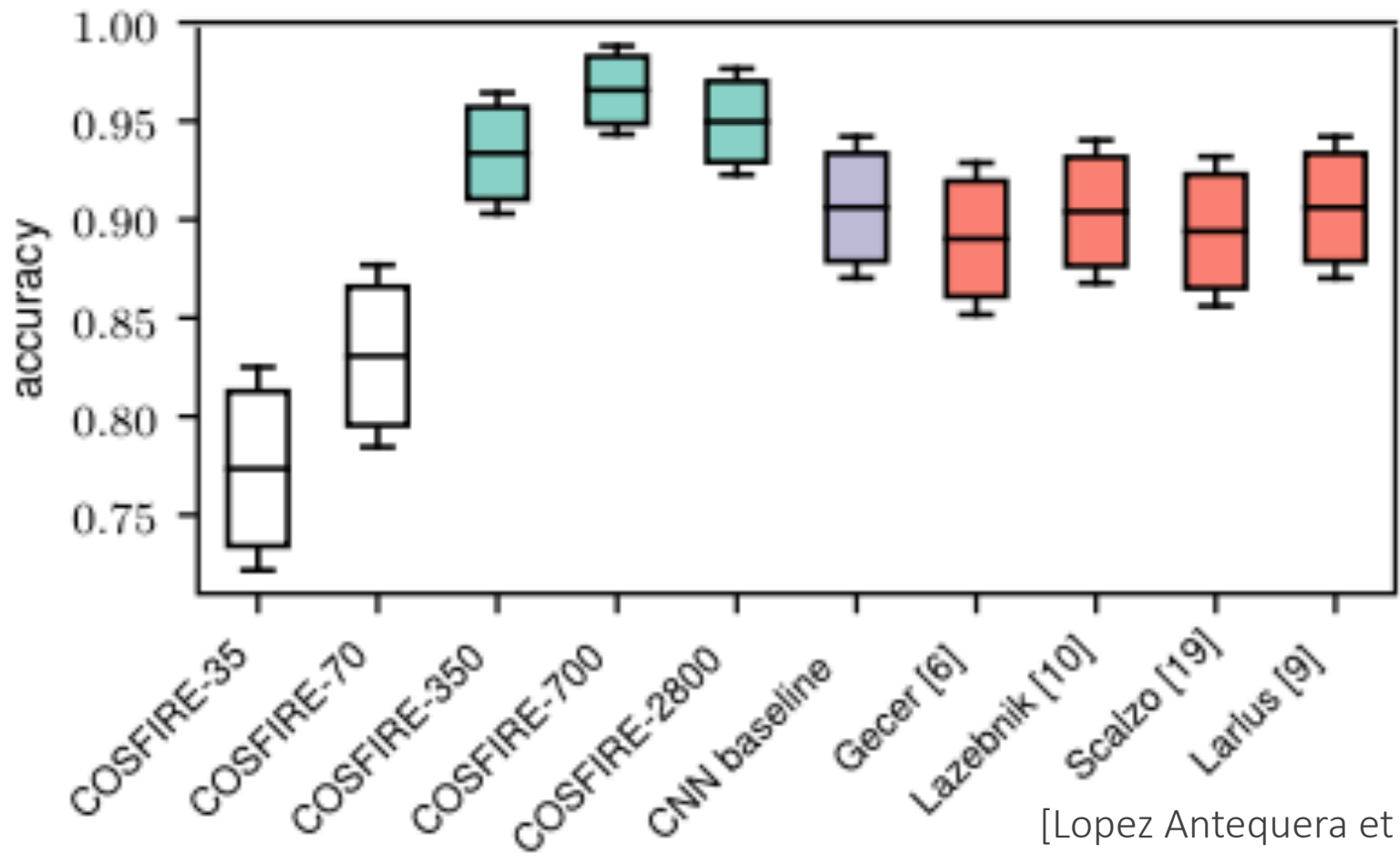
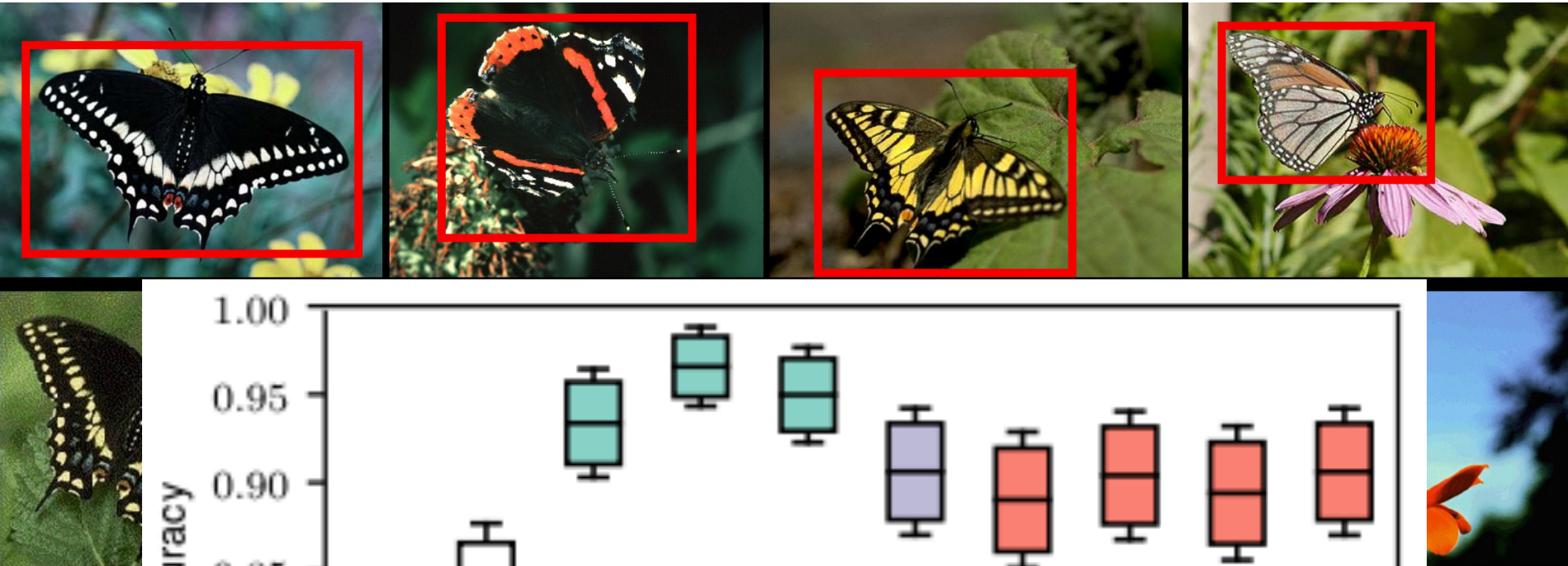
ESC-10

10 classes

[Piczak, 2015]

[Strisciuglio et al., 2017, 2019]

Results for butterfly data set with CNN-COSFIRE



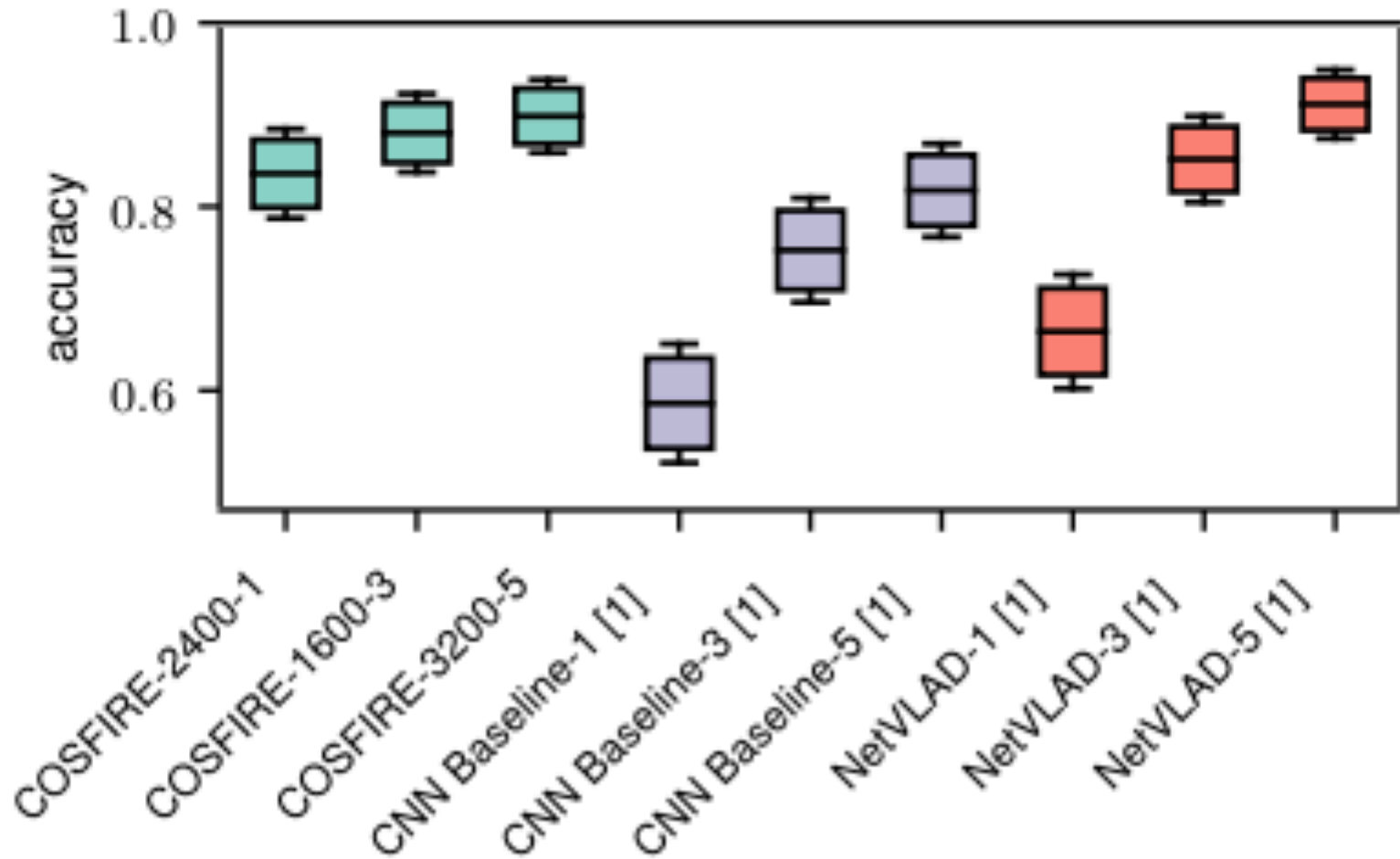
CNN-COSFIRE for place recognition

Reference

Query



CNN-COSFIRE for place recognition



COSFIRE vs. CNN

	COSFIRE	CNN
Feature Definition	data driven	data driven
Training	single step	many iterations
Amount of data	one example per filter	very large number of examples

Conclusions

COSFIRE filters:

Trainable with a single example

Effective for pattern detection and localization and representation learning

Simple implementation

Available Matlab source code: matlabserver.cs.rug.nl

Thank you!

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- [Guo et al., 2016] MVA 27, 1137-1149
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- [Guo et al., 2019] IEEE Access 9, 8527-8541
- [Strisciuglio et al., 2019] Pat. Rec. 92, 25-36