



# Filtered Channel Features for Pedestrian Detection



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Zhang**



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Benenson**



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Schiele**

# Cooperation



**Prof. Luc Van Gool (ETH & KU Leuven)**



**TOYOTA**



**D2 Computer Vision and Multimodal Computing**

**Prof. Bernt Schiele**

# Outline

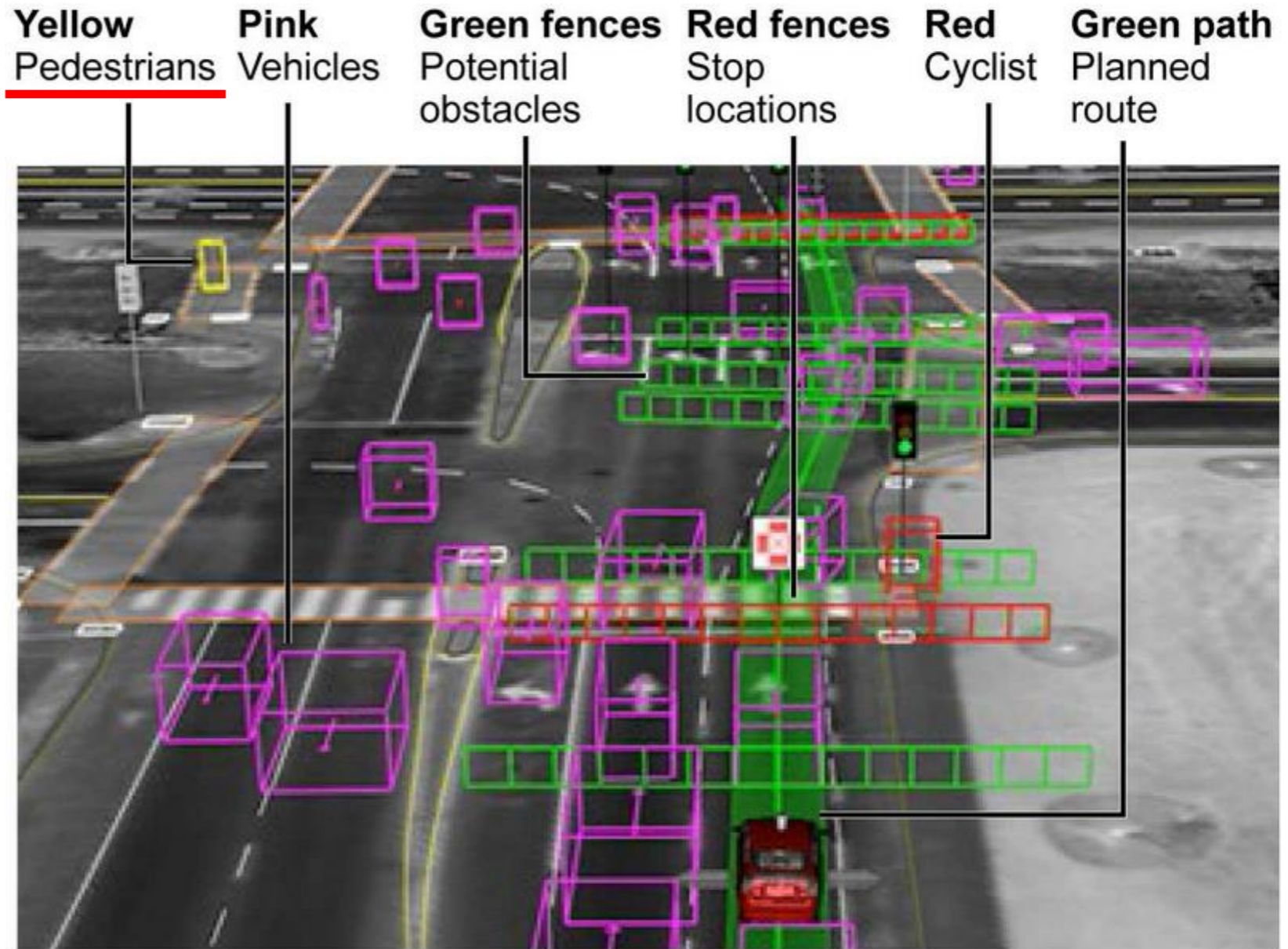
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- **Background**
- **Baseline detectors**
  - ACF
  - InformedHaar
  - LDCF
- **Unified framework**
- **Experimental setup**
- **Test set results**
- **Take-away messages**

# Google driverless car

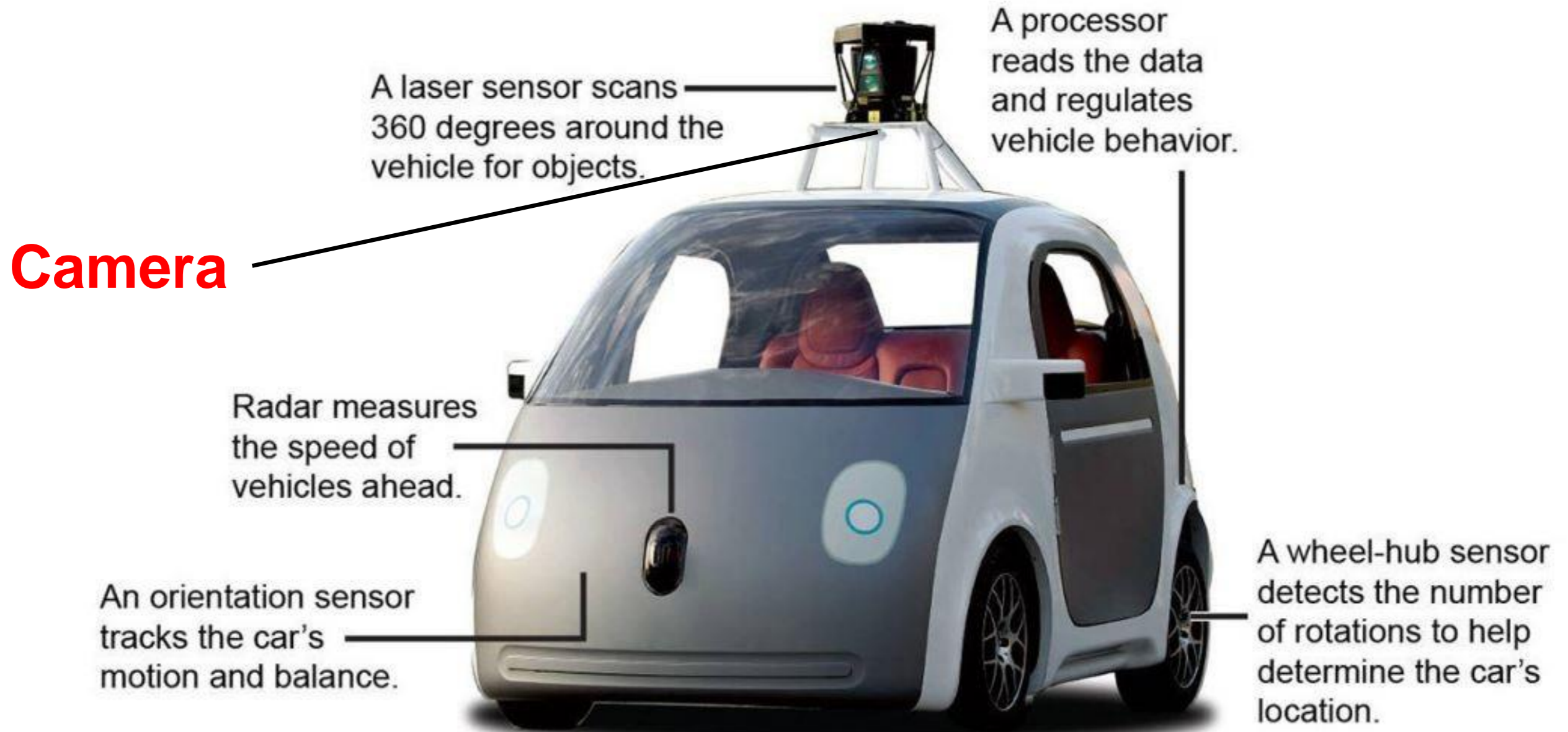


## How the car sees the world

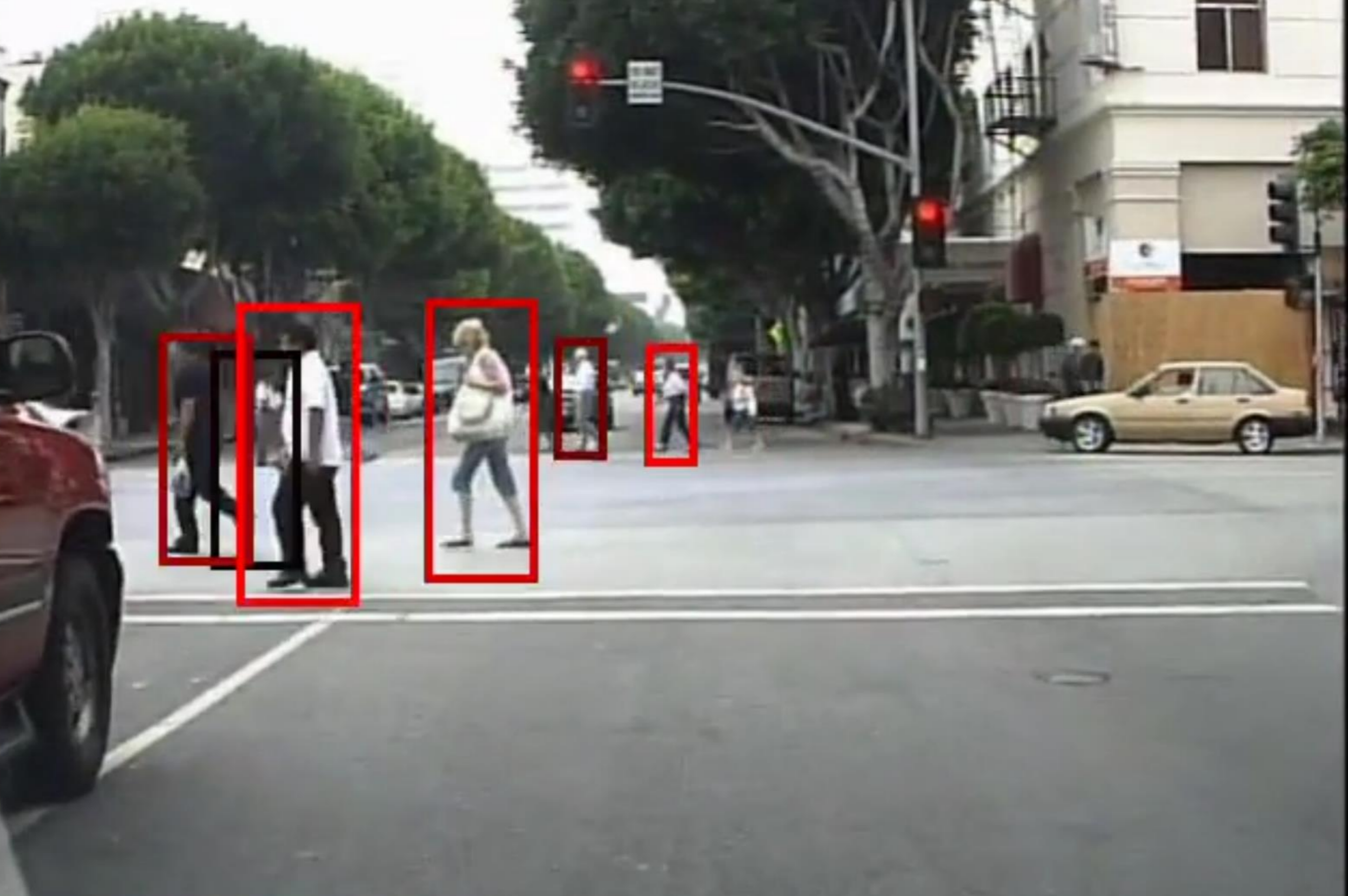


**Sebastian Thrun  
(Google & Stanford)**

# Sensors



Source: Google



Detection confidence

# Benchmarks

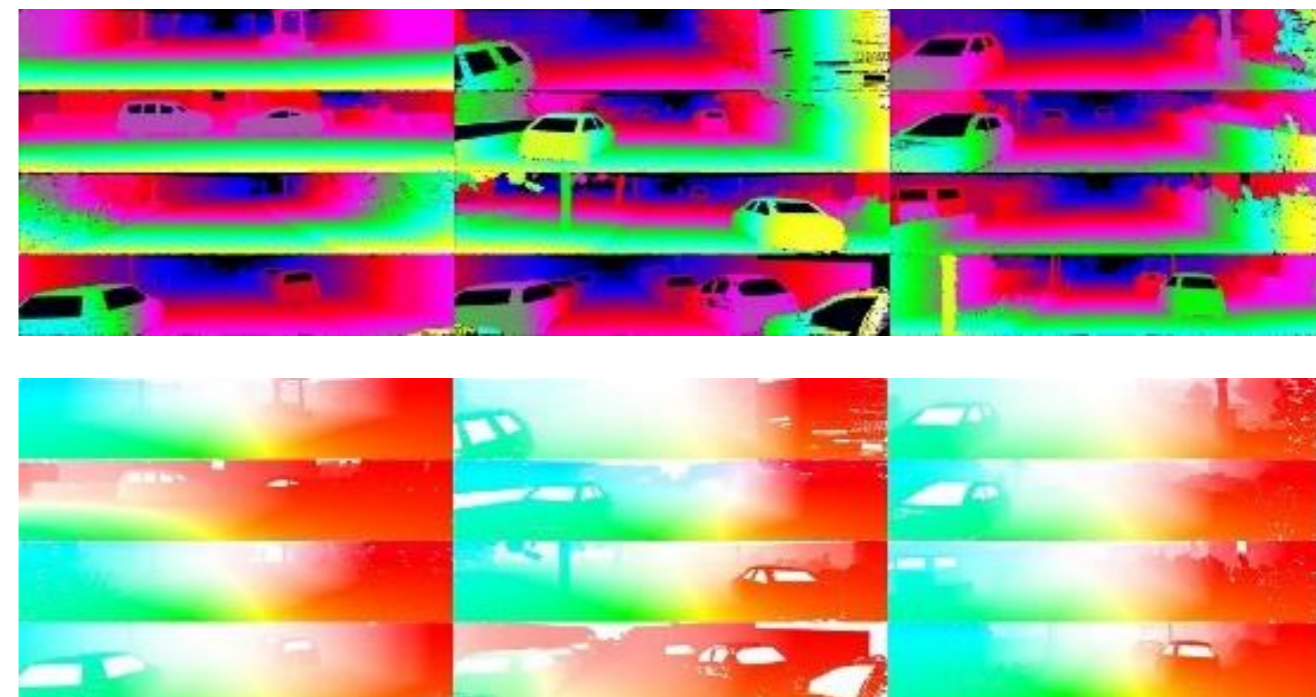
- Caltech

[http://www.vision.caltech.edu/Image\\_Datasets/CaltechPedestrians/](http://www.vision.caltech.edu/Image_Datasets/CaltechPedestrians/)



- KITTI

<http://www.cvlibs.net/datasets/kitti/>

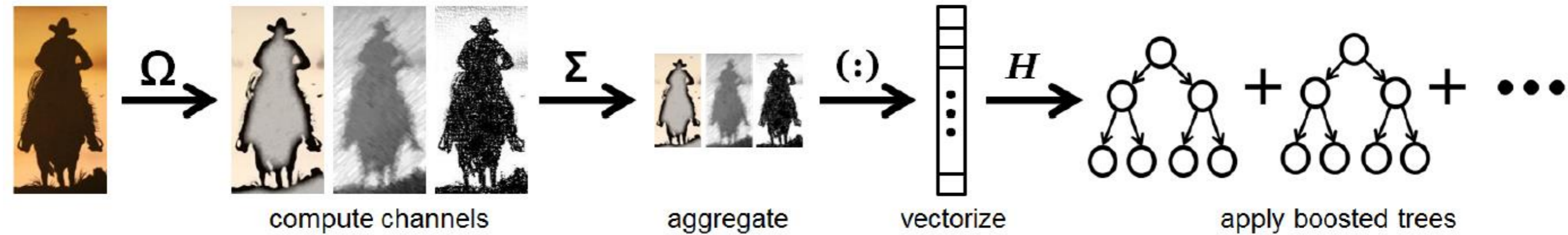


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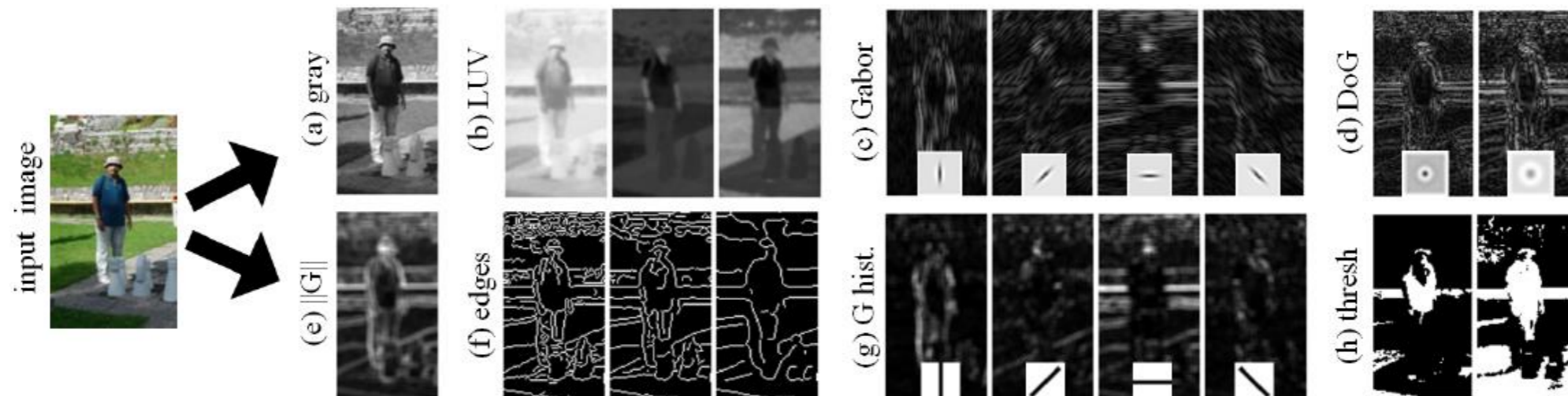
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# ACF



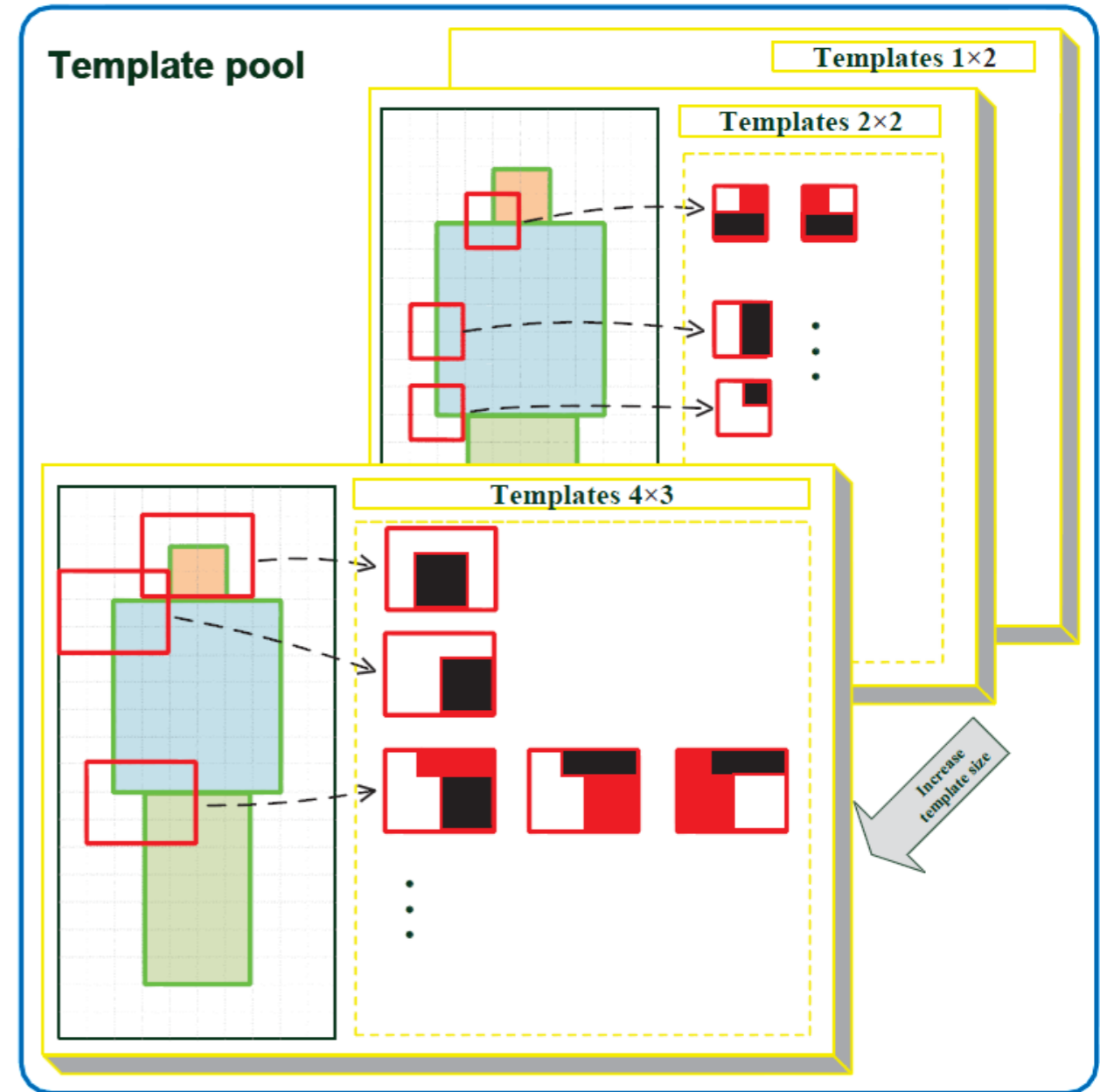
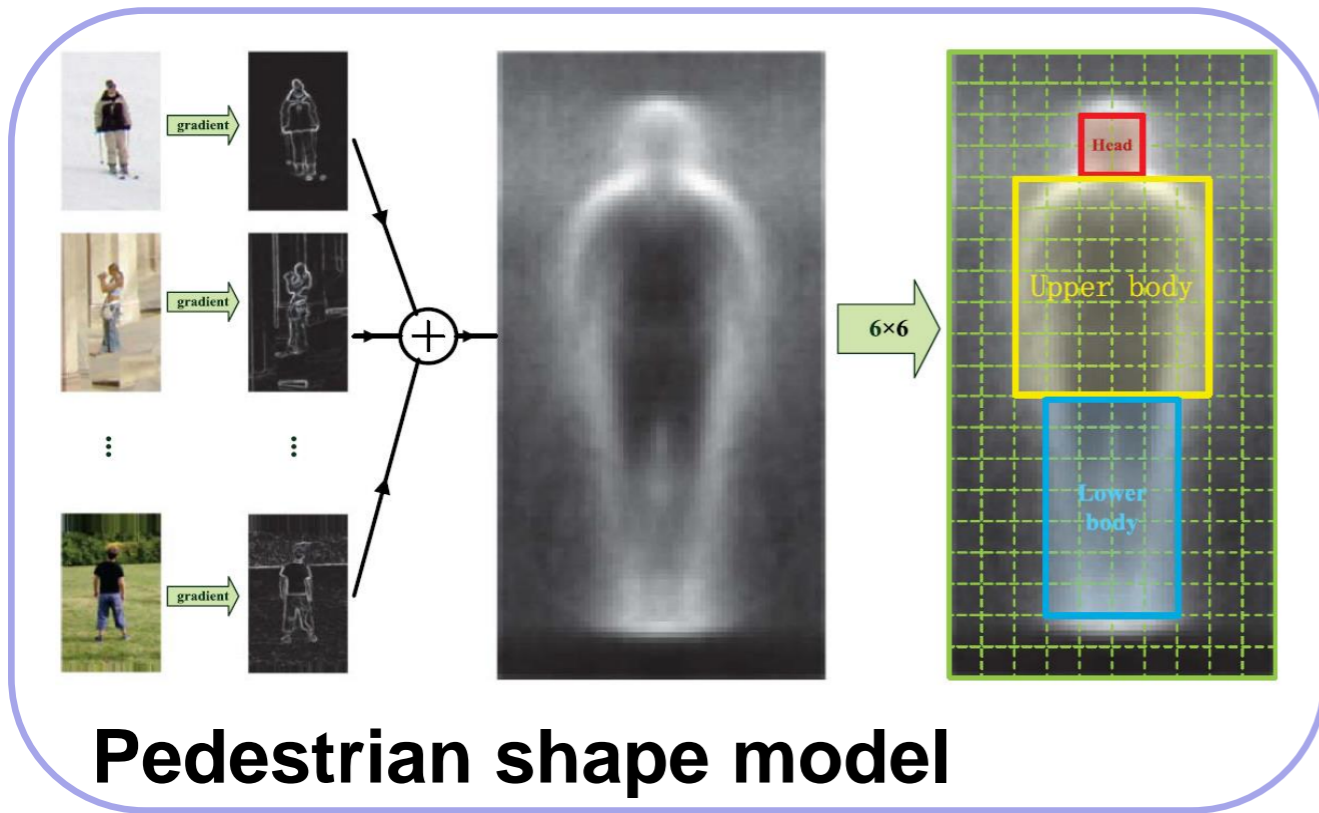
P. Dollar, R. Appel, S. Belongie, and P. Perona. Fast Feature Pyramids for Object Detection. PAMI 2014.

# ICF



P. Dollar, Z. Tu, P. Perona and S. Belongie. Integral Channel Features. BMVC 2009.

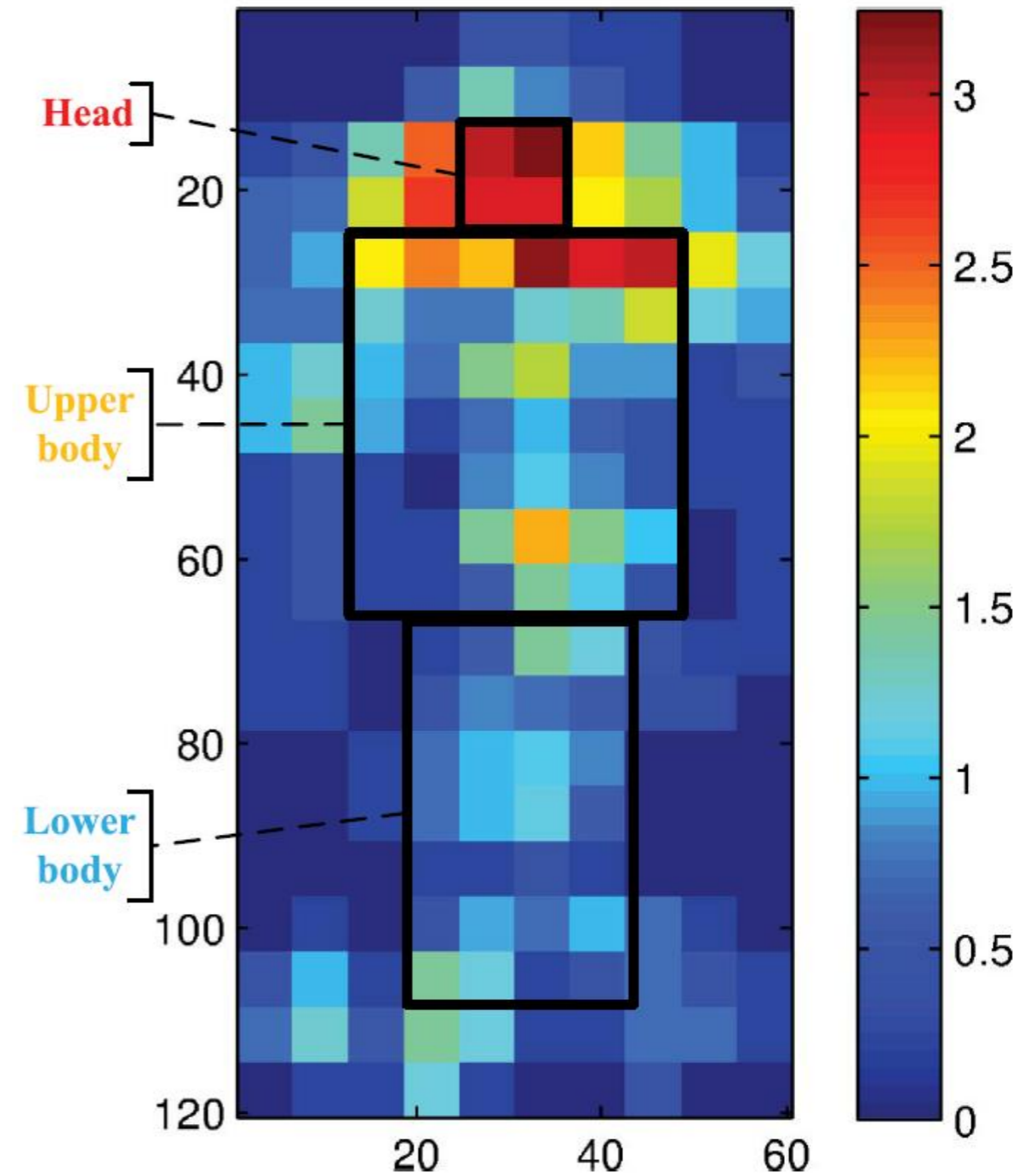
# Informed Haar



S. Zhang, C. Bauckhage, A. B. Cremers. Informed Haar-like Features Improve Pedestrian Detection. CVPR 2014.

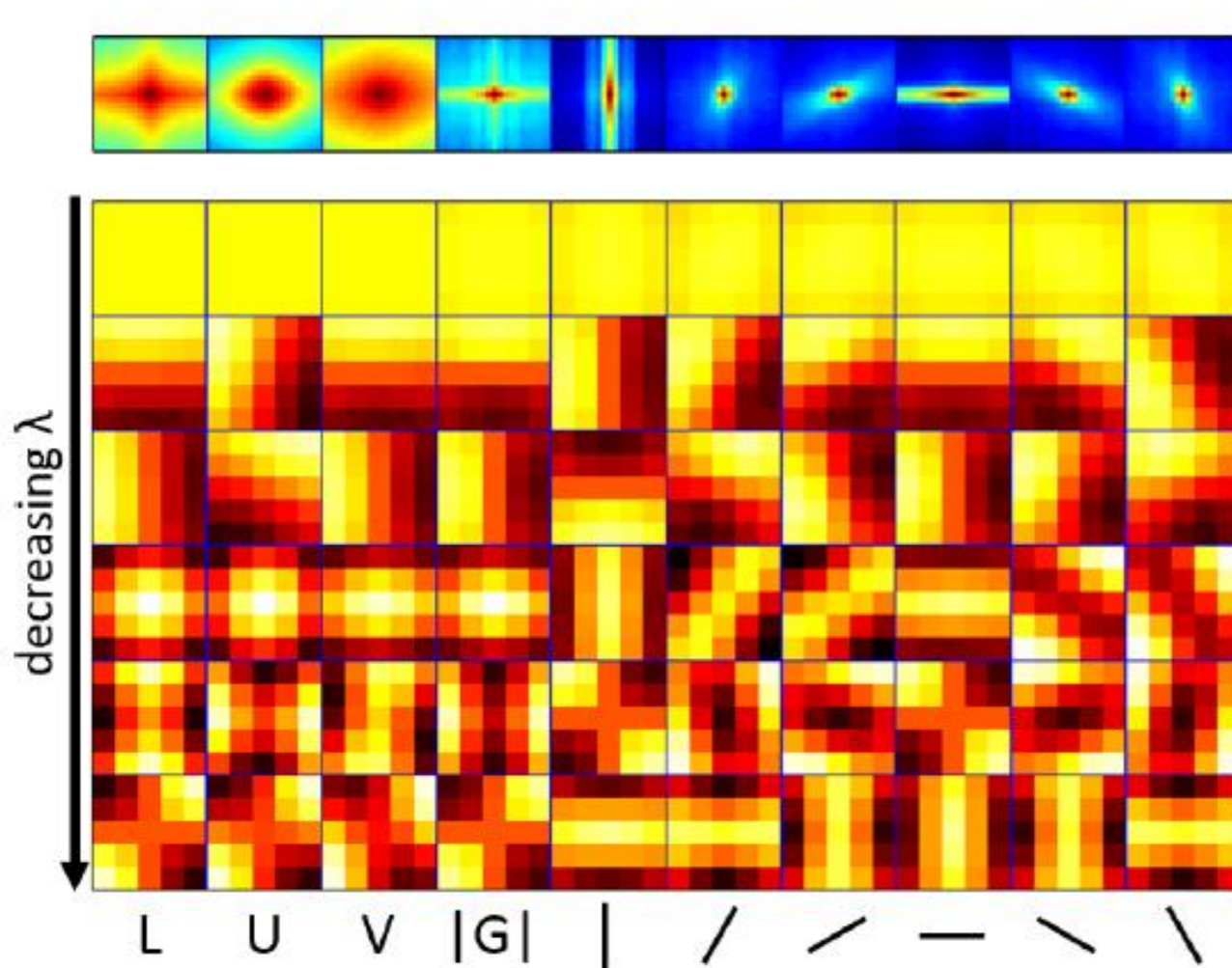
# InformedHaar

- Which body part is more discriminative?
- Robustness against variations from
  - Occlusion
  - Viewpoints

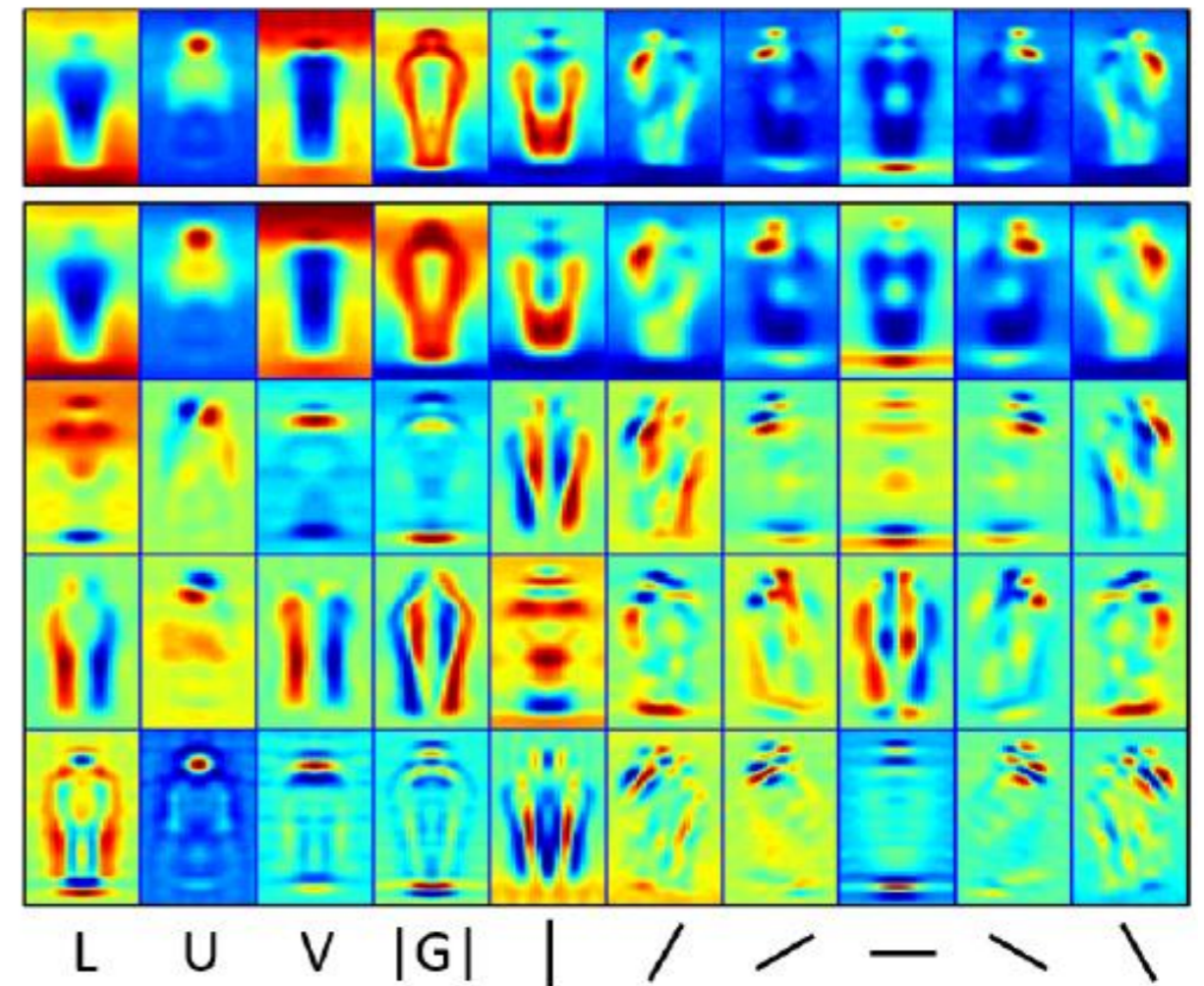


Accumulative weight map

# LDCF



**Learned decorrelation filters**



**Original and decorrelated channels averaged over positive samples**

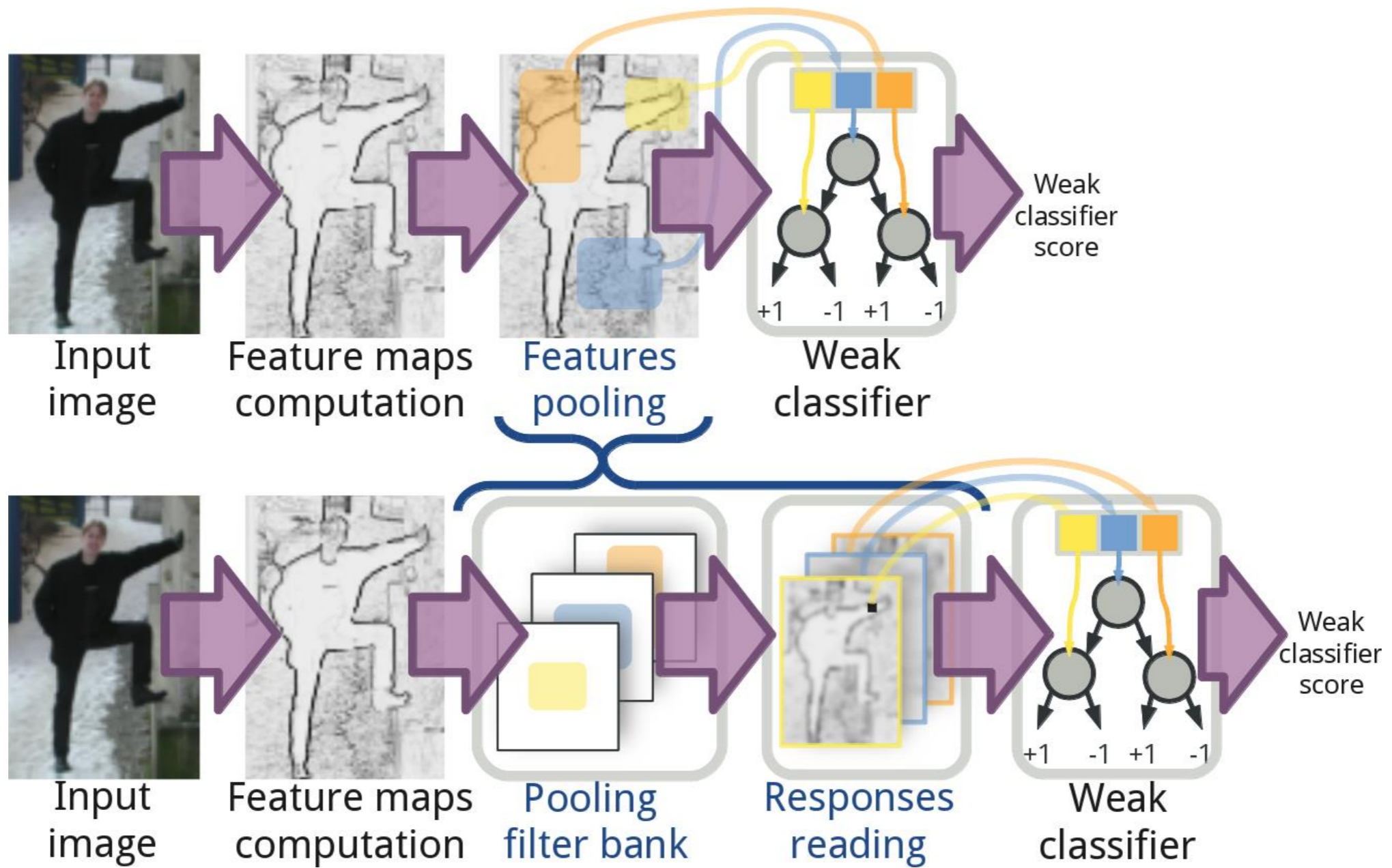
W. Nam, P. Dollar, and J. H. Han. Local Decorrelation for Improved Pedestrian Detection. NIPS 2014.

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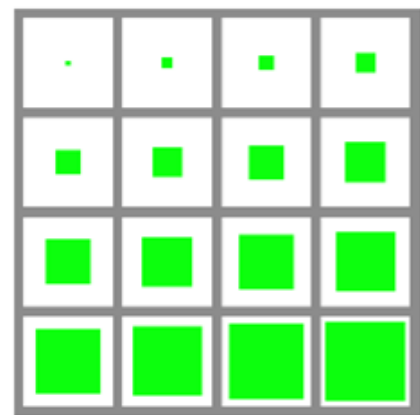
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# Unified framework

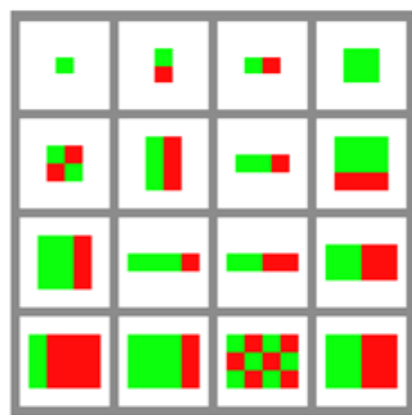


# Filter bank families

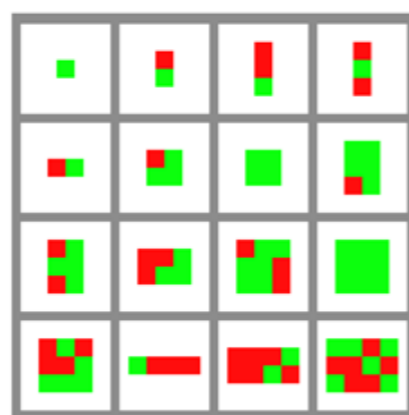
Which one is the **best** ?



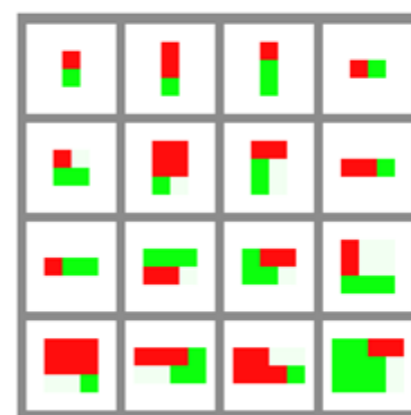
(a) SquaresChntrs filters



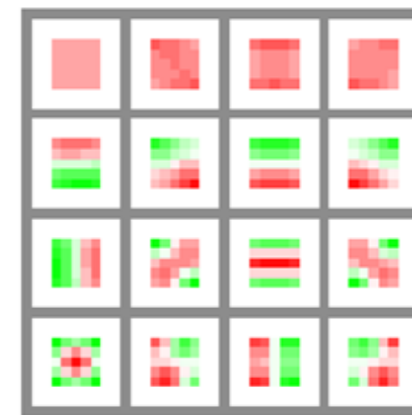
(b) Checkerboards filters



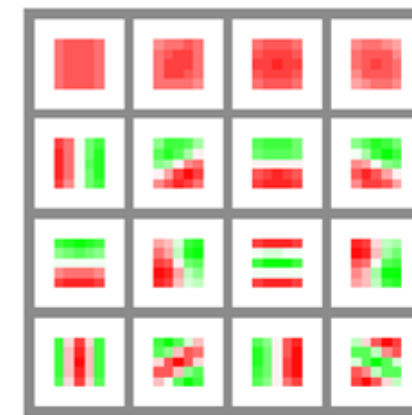
(c) RandomFilters



(d) InformedFilters



(e) LDCF8 filters



(f) PcaForeground filters

## SquaresChntrs

R. Benenson, M. Mathias, T. Tuytelaars and L. Van Gool. Seeking the Strongest Rigid Detector. CVPR 2013.

## InformedFilters

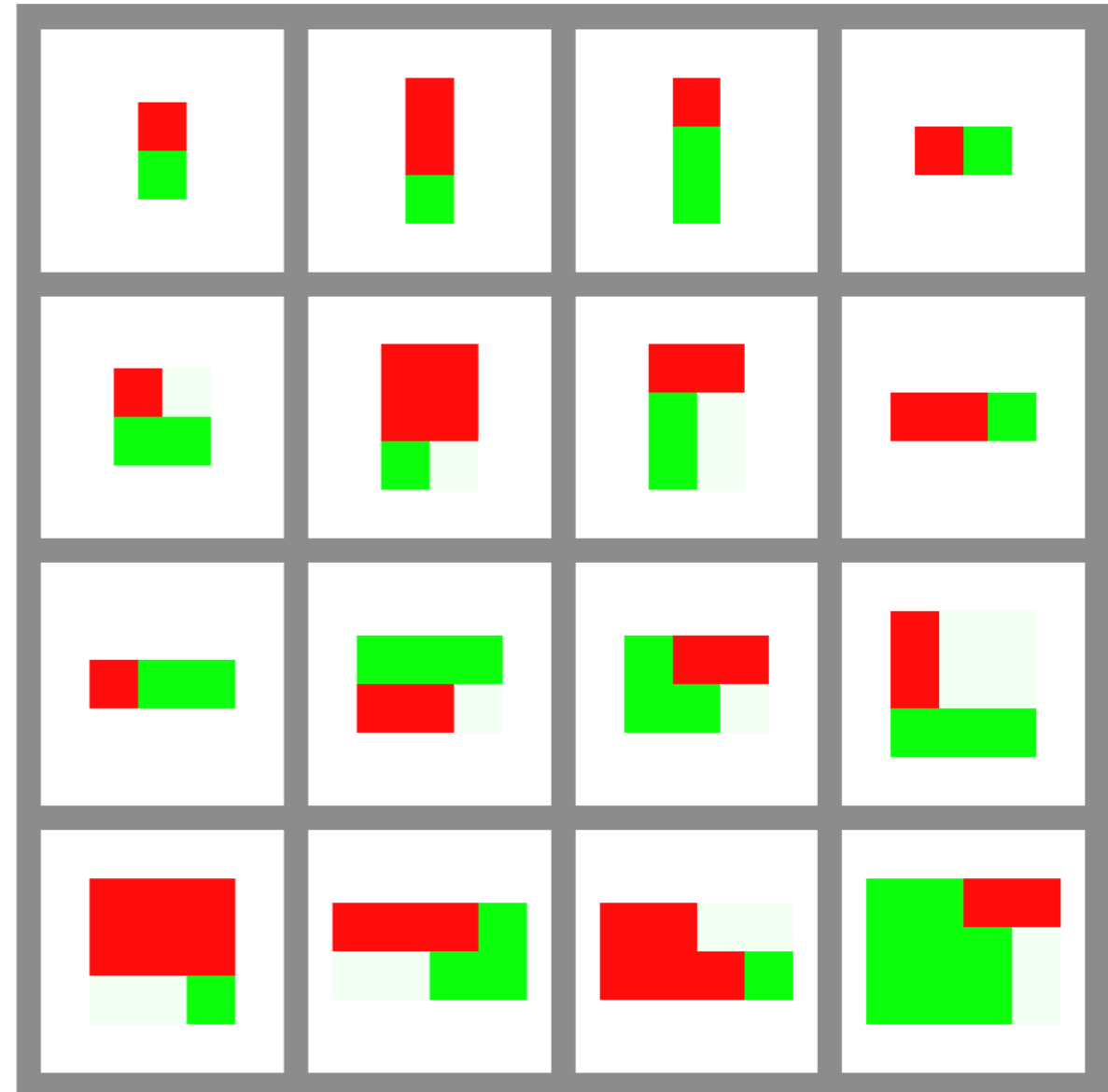
S. Zhang, C. Bauckhage, A. B. Cremers. Informed Haar-like Features Improve Pedestrian Detection. CVPR 2014.

## LDCF

W. Nam, P. Dollar, and J. H. Han. Local Decorrelation for Improved Pedestrian Detection. NIPS 2014.

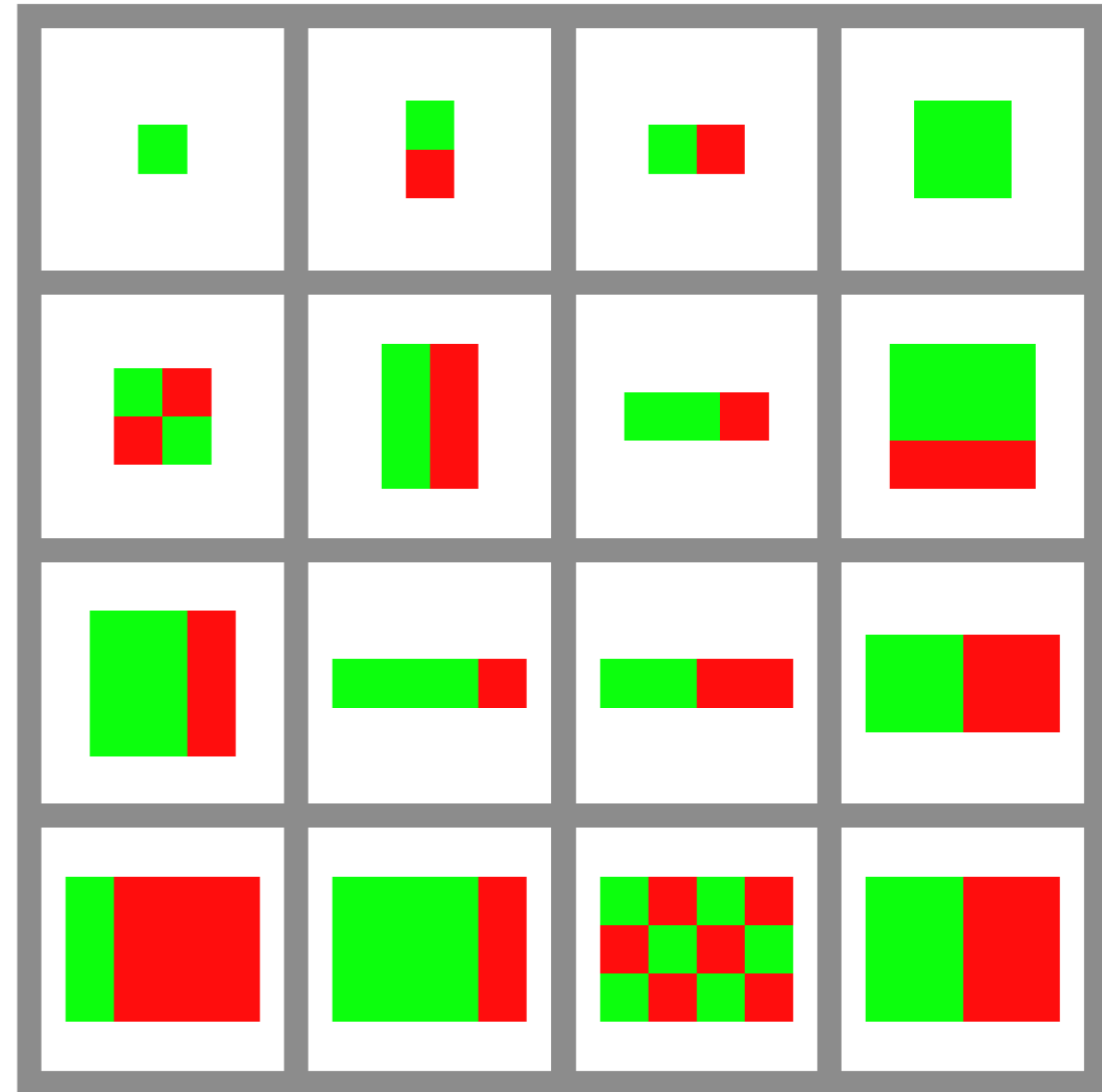
# InformedFilters

- Filter contents: informed
- Filter positions: everywhere
- How many identical filters?
  - Redundancy removal
  - 212(209+3) filters by 4x3



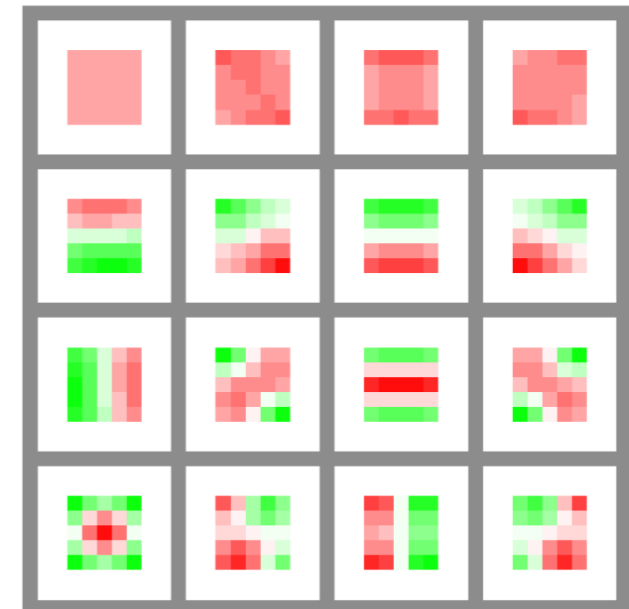
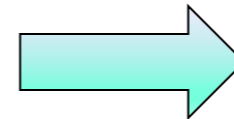
# Checkerboards

- Blurring filters
- Horizontal filters
- Vertical filters
- How many filters?
  - 7 filters by 2x2
  - 25 filters by 3x3
  - 39 filters by 4x3
  - 61 filters by 4x4

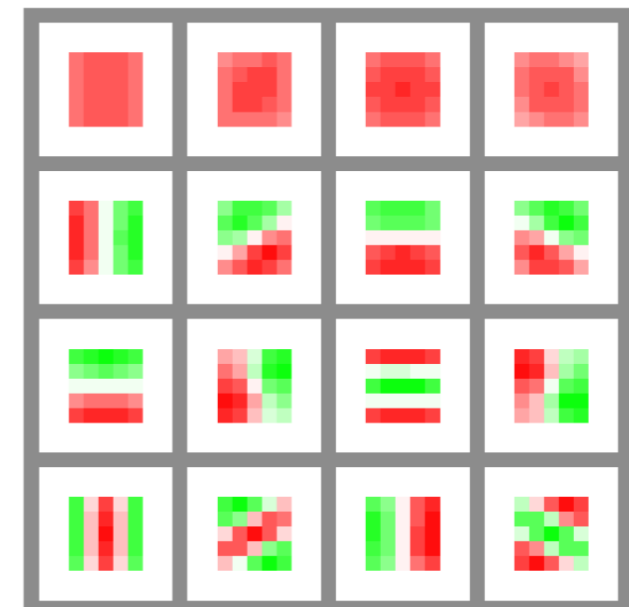
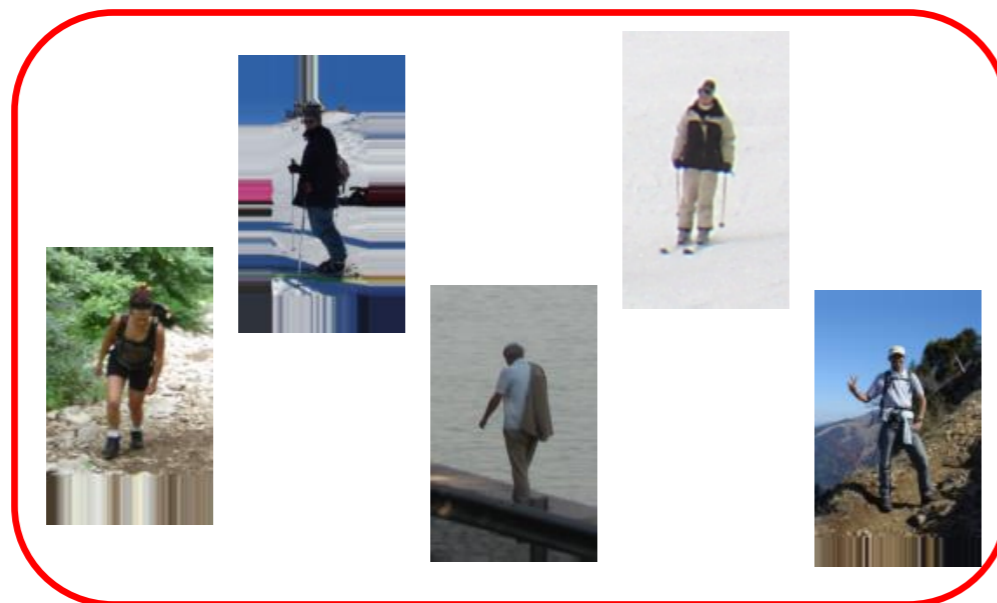


# PCA filters

- Background (4 filters)

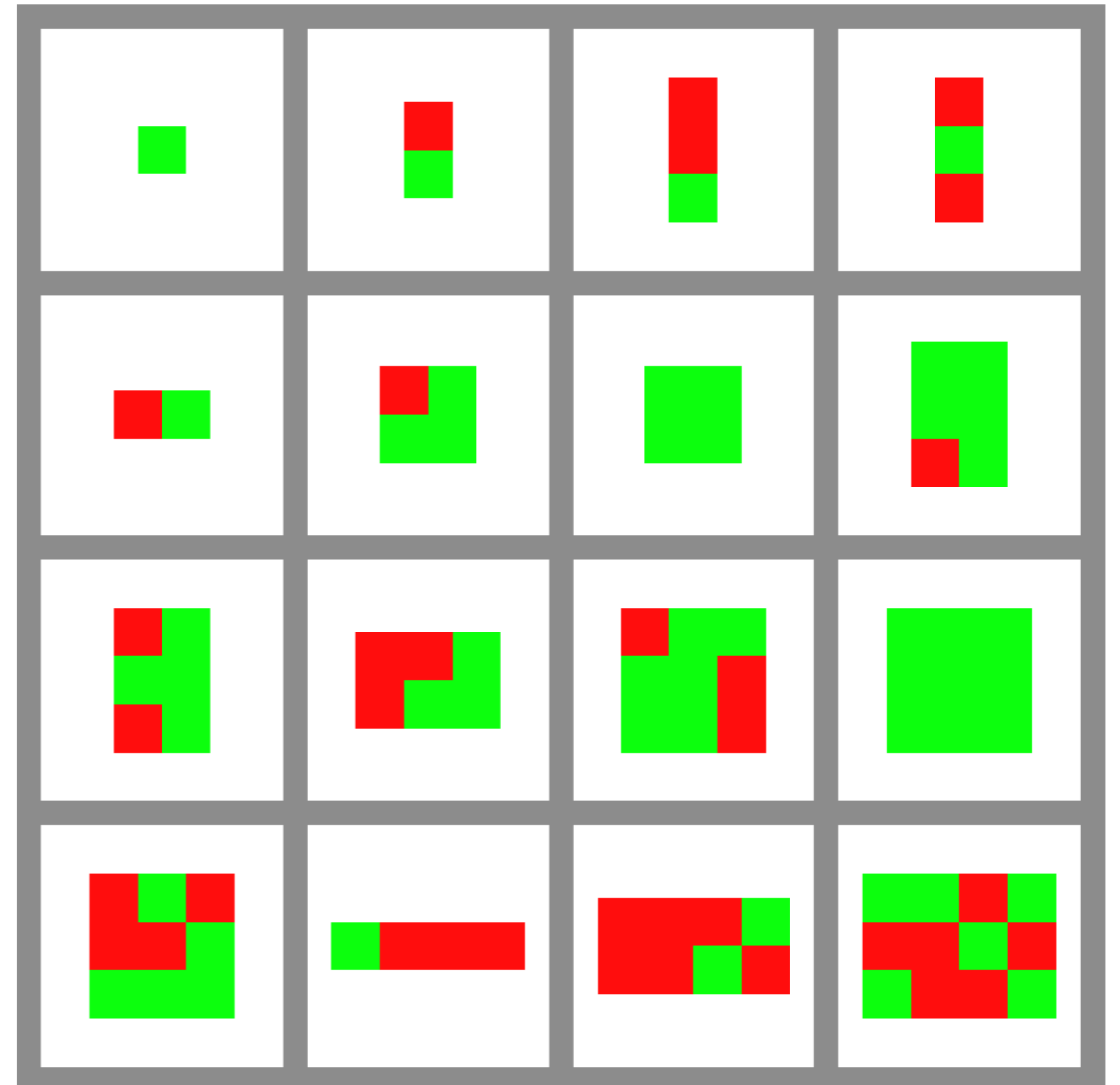


- Foreground (4 filters)



# RandomFilters

- Random
  - 15
  - 50
  - ...
- Selected from random
  - Top 15 / 50xN
  - Top 50 / 50xN
  - ...

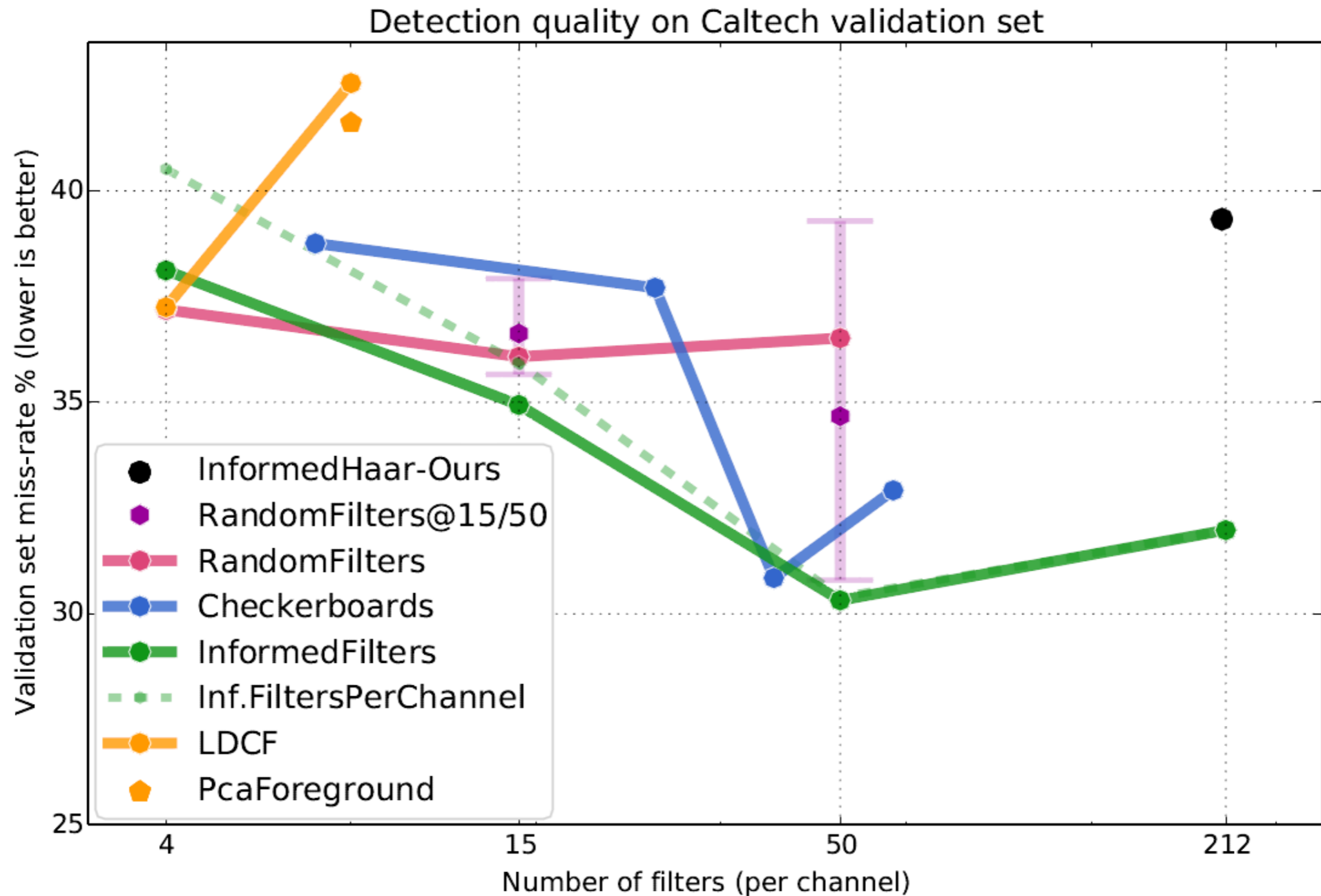


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# How many filters?



# More data & deeper trees

Training	Method	L2	L3	L4	L5
Caltech	ACF	50.2	<i>42.1</i>	48.8	48.7
Caltech10x		52.6	49.9	44.9	<i>41.3</i>
Caltech	Checker-boards	32.9	30.4	<i>28.0</i>	31.5
Caltech10x		37.0	31.6	<i>24.7</i>	<i>24.7</i>

# Ingradients to improve

Aspect	MR	$\Delta$ MR
ACF-Ours	50.8	-
+ filters	32.9	+17.9
+ L4	28.0	+4.9
+ Caltech10x	24.7	+3.3
+ Realboost	24.4	+0.3
Checkerboards4x4	24.4	+26.4

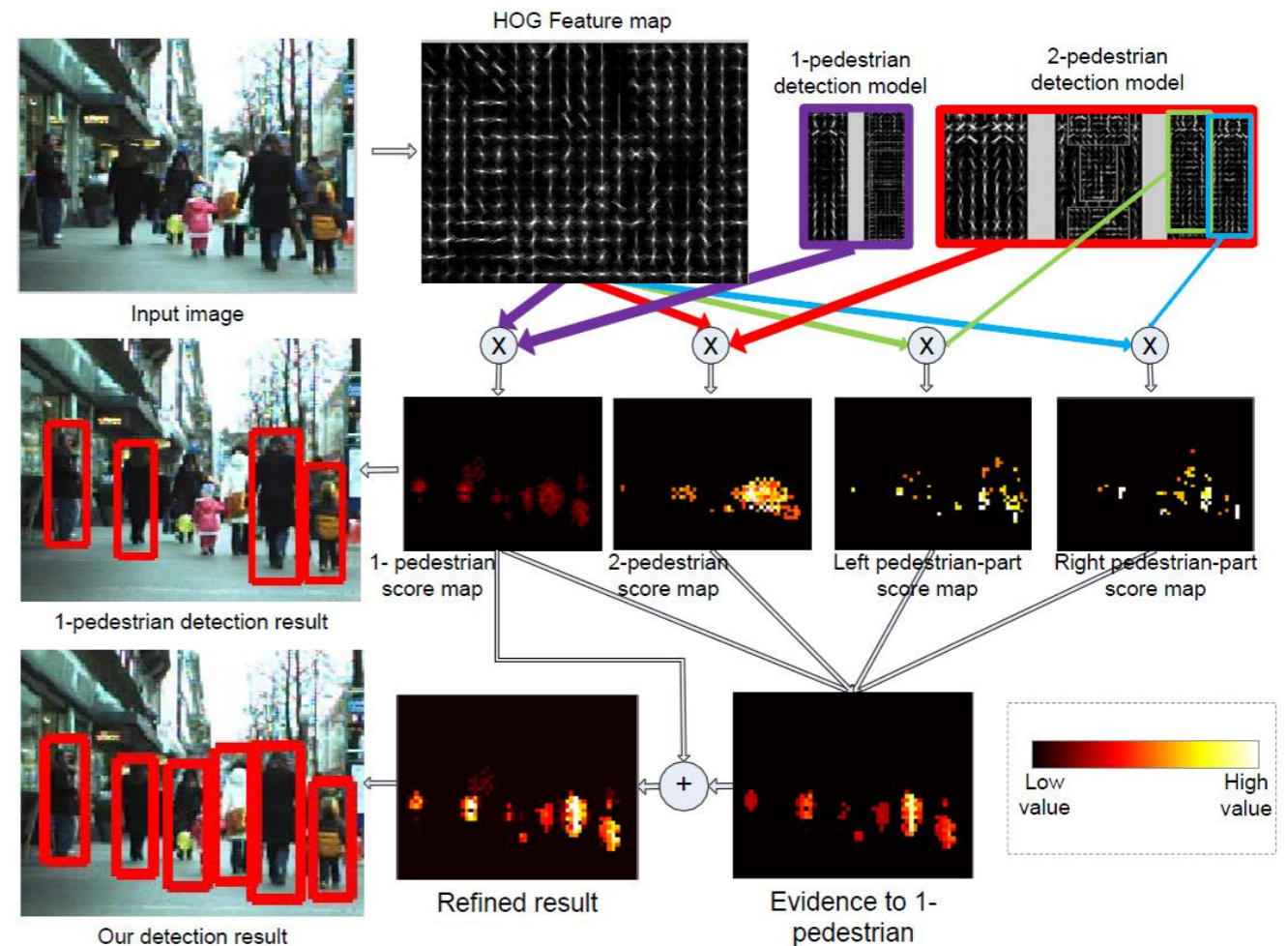
**Which ingredient is the most important ?**

# Comparison of improvements

Filters type	# filters	Caltech MR	Caltech10x MR	$\Delta$ MR
ACF-Ours	1	50.2	39.8	10.4
LDCF-Ours	4	37.3	34.1	3.2
LDCF8	8	42.6	30.7	11.9
PcaForeground	8	41.6	28.6	13.0
RandomFilters	50	36.5	28.2	8.3
InformedFilters	50	30.3	26.6	3.7
Checkerboards	39	30.9	25.9	5.0
Checkerboards	61	32.9	24.4	8.5

# Add-ons

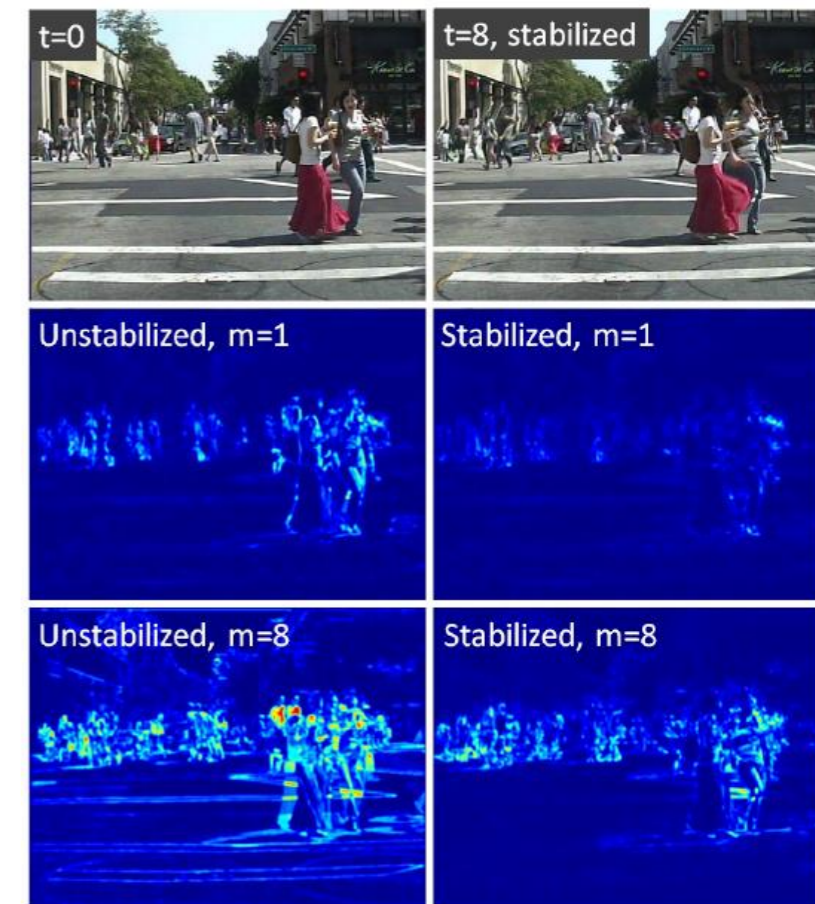
- Context: 2Ped
  - ~5.0pp improvement (Ouyang et al. CVPR 2013)
  - ~2.8pp improvement (Benenson et al. ECCV Workshop 2014)
  - <0.5pp improvement (Checkerboards)



W. Ouyang and X. Wang. Single-pedestrian Detection Aided by Multi-pedestrian Detection. CVPR 2013.

# Add-ons

- Flow: SDt
  - ~7pp improvement (ACF)
  - ~5pp improvement (Benenson et al. ECCV Workshop 2014)
  - 1.4pp improvement (Checkerboards)



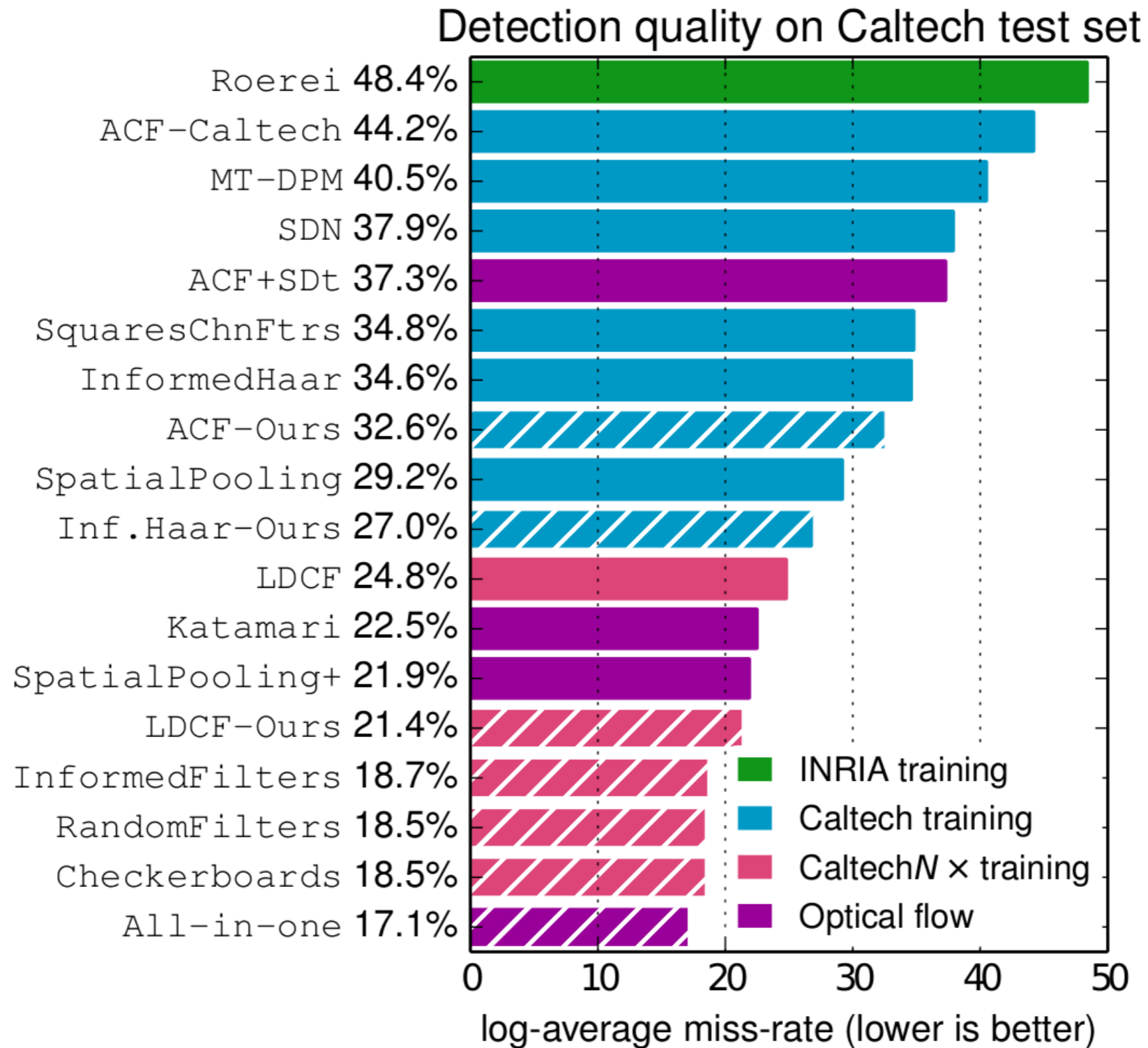
D. Park, C. L. Zitnick, D. Ramanan, and P. Dollar. Exploring Weak Stabilization for Motion Feature Extraction. CVPR 2013.

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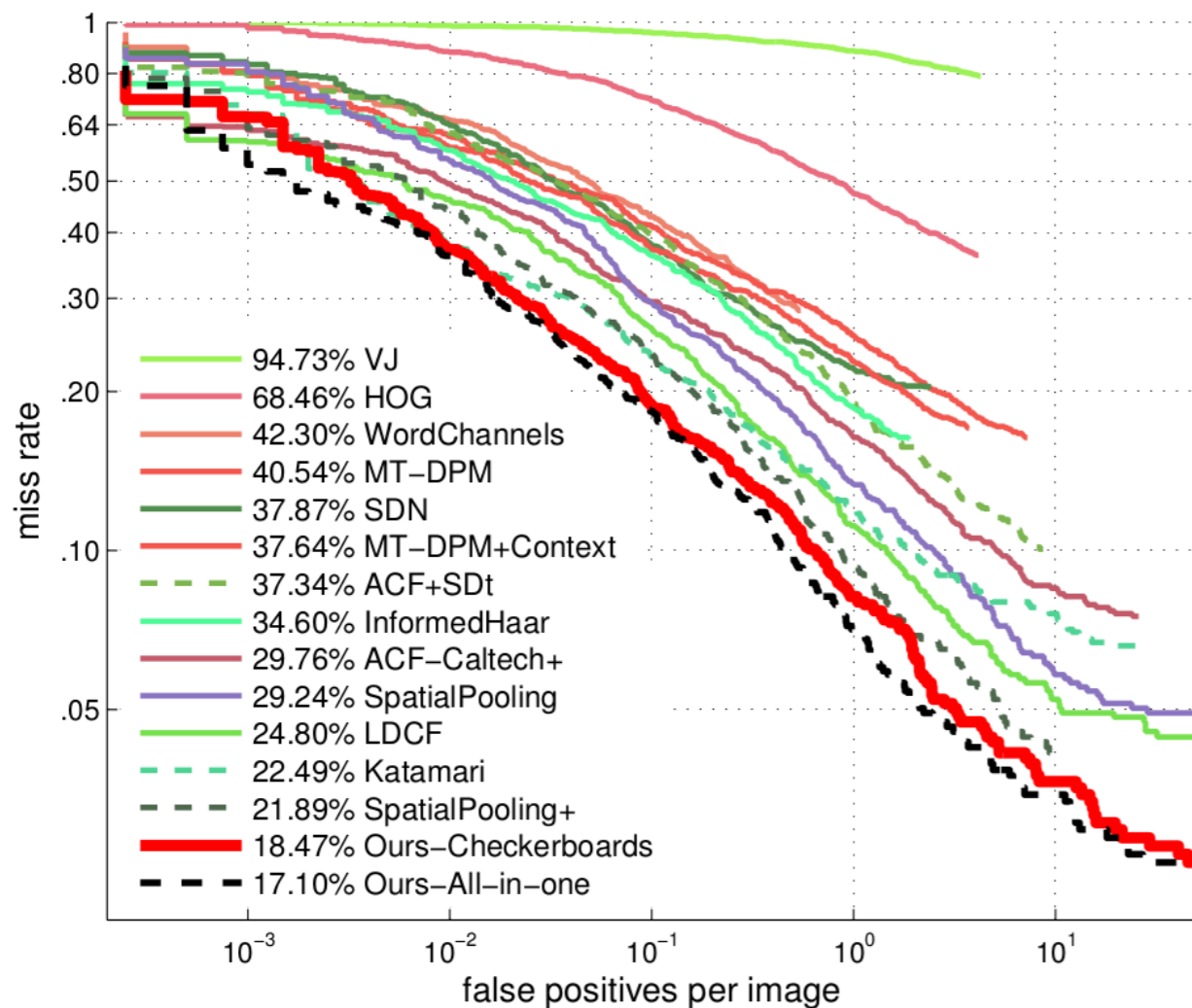
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# Test set results

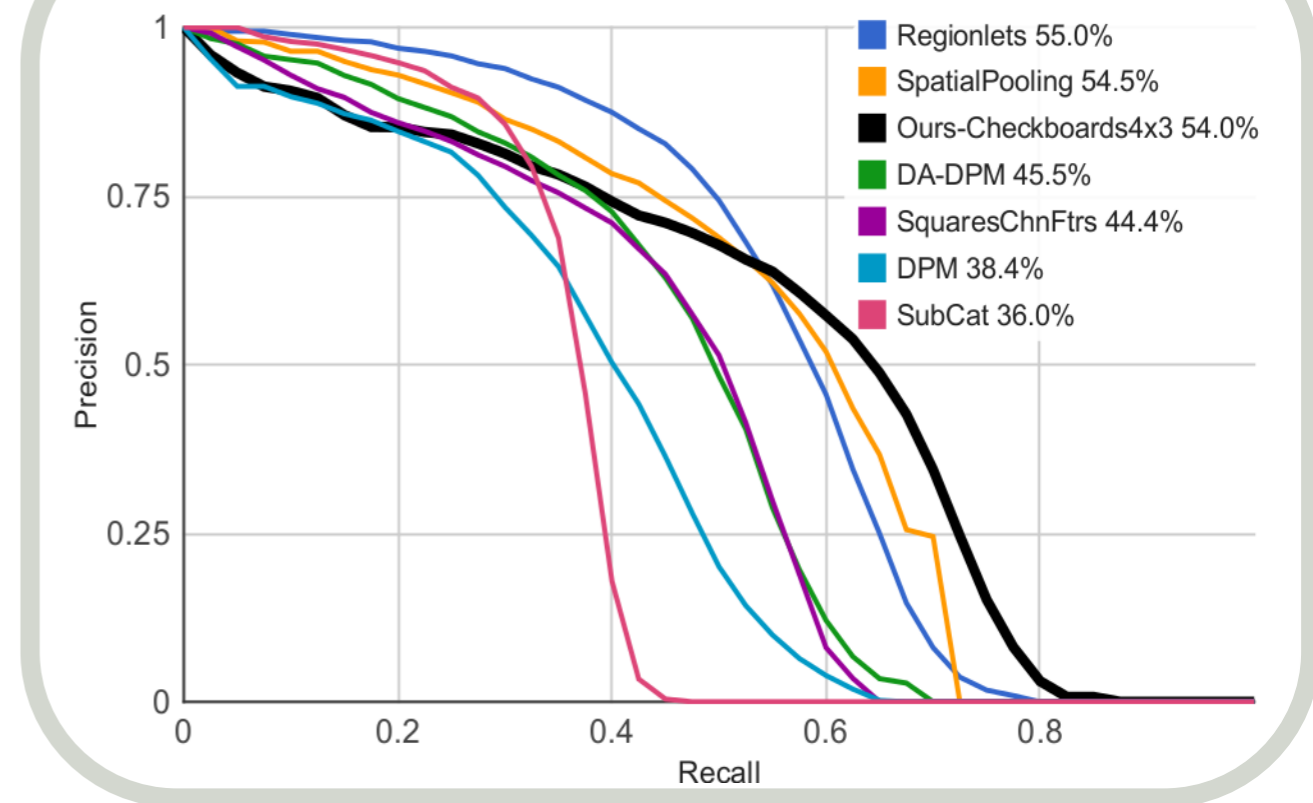


# Test set results

## Caltech test set



## KITTI Pedestrians, moderate difficulty



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# Take-away messages

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- Filtered channel features are great!
- There is no flagrant difference between different filter types.
- More training data and deeper trees help a lot.
- The improvements from current context models and optical flow features become smaller as the baseline detector grows stronger.

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Thank you for your attention!

Q & A