



## VI Jornada de Encuentros Doctorales LSI

# Deep learning applied to driving environments

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- **Ph.D. David Martín**



- Deep learning basics
- Applications in driving environments
- Future prospects
- Conclusions



- Deep learning basics
- Applications in driving environments
- Future prospects
- Conclusions

- Why deep learning?
  - What is this?



- Why deep learning?
  - Query



Source: BVLC Caffe demo, <http://demo.caffe.berkeleyvision.org>

- Why deep learning?

- Result (after ~0.06 seconds)



Maximally accurate

Maximally specific

car

motor vehicle

self-propelled vehicle

wheeled vehicle

vehicle

Source: BVLC Caffe demo, <http://demo.caffe.berkeleyvision.org>

- Why deep learning?
  - Query



Source: BVLC Caffe demo, <http://demo.caffe.berkeleyvision.org>

- Why deep learning?
  - Result (after 0.062 seconds)



Maximally accurate

Maximally specific

golfcart

motor vehicle

self-propelled vehicle

wheeled vehicle

golf equipment

Source: BVLC Caffe demo, <http://demo.caffe.berkeleyvision.org>

# Deep learning basics

- Why deep learning?
  - Query



Source: Microsoft Captionbot: <https://www.captionbot.ai/>

# Deep learning basics

- Why deep learning?
  - Result



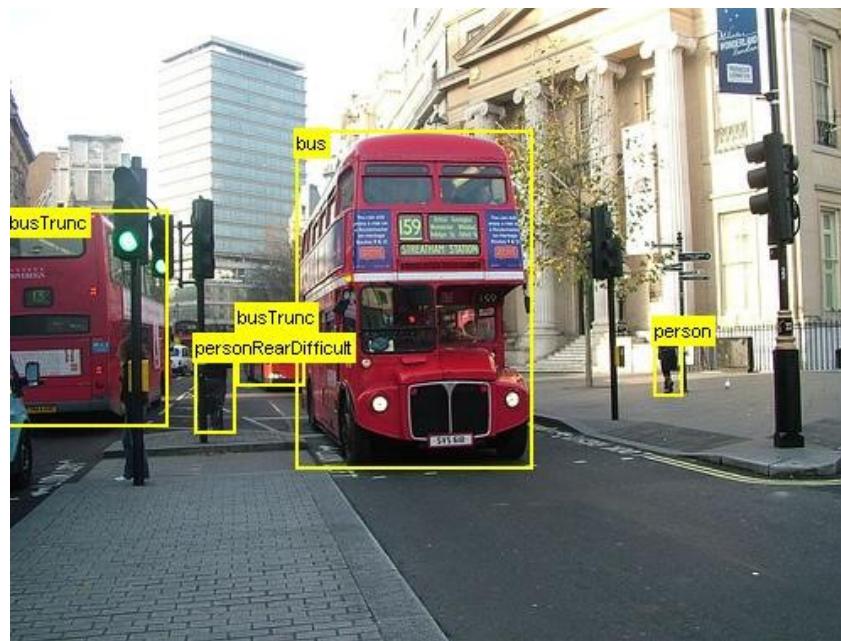
I think it's a group of people standing on the side of a road.



Source: Microsoft Captionbot: <https://www.captionbot.ai/>

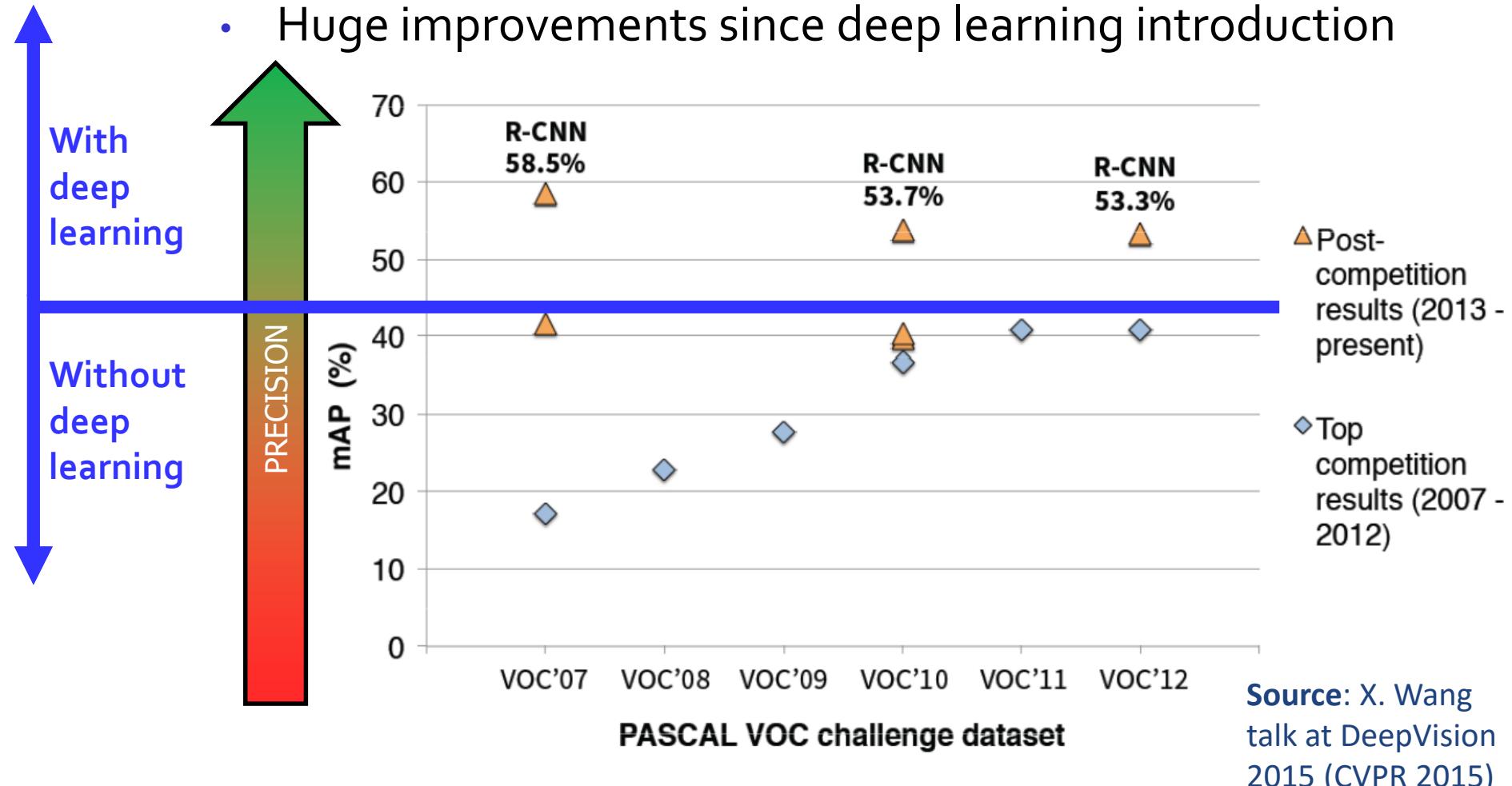
## ○ Why deep learning?

- Image classification and object detection challenges: comparable results across scientific works
- PASCAL Visual Object Classes Challenge: 20 classes



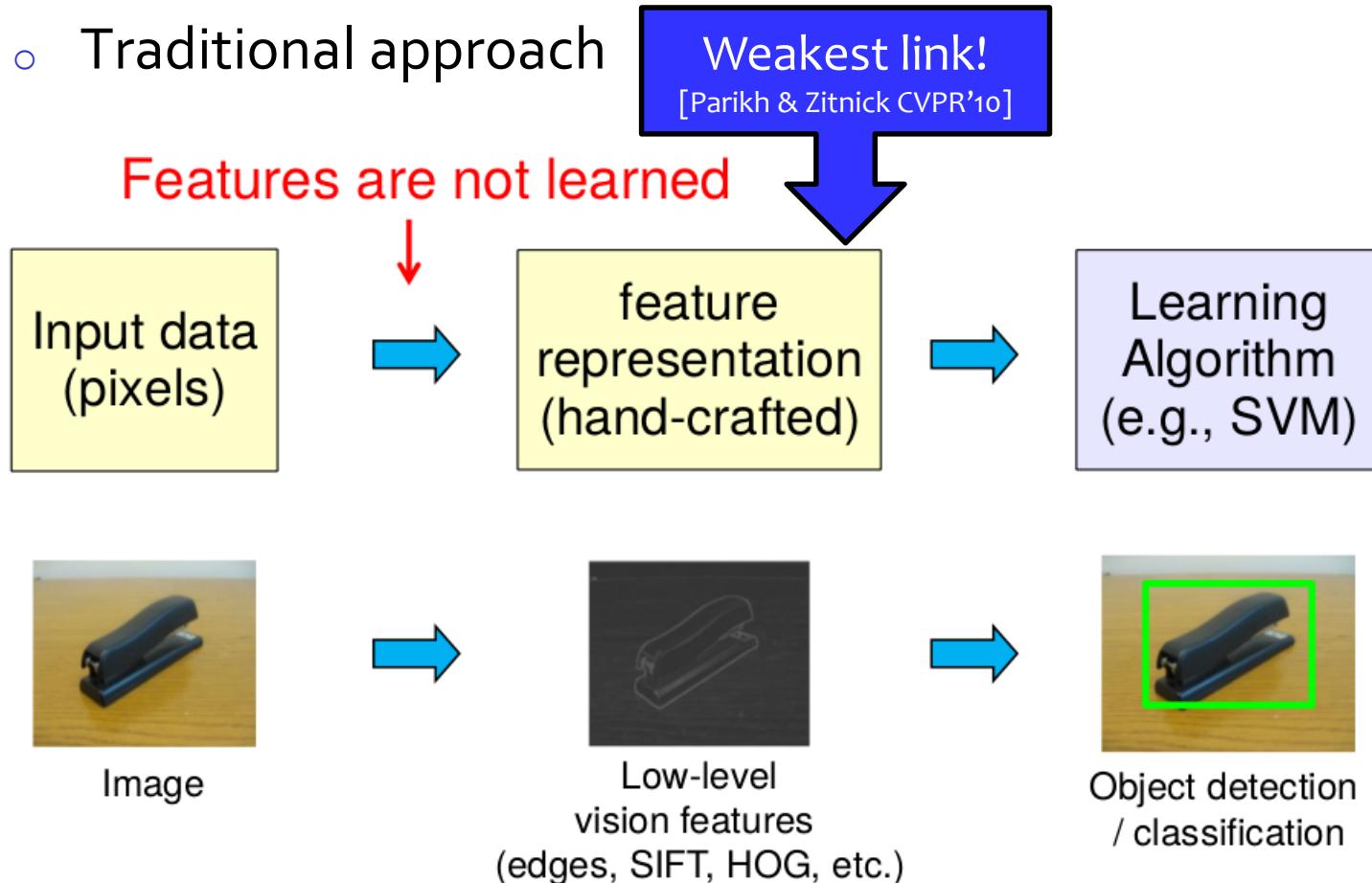
- Why deep learning?

- Huge improvements since deep learning introduction

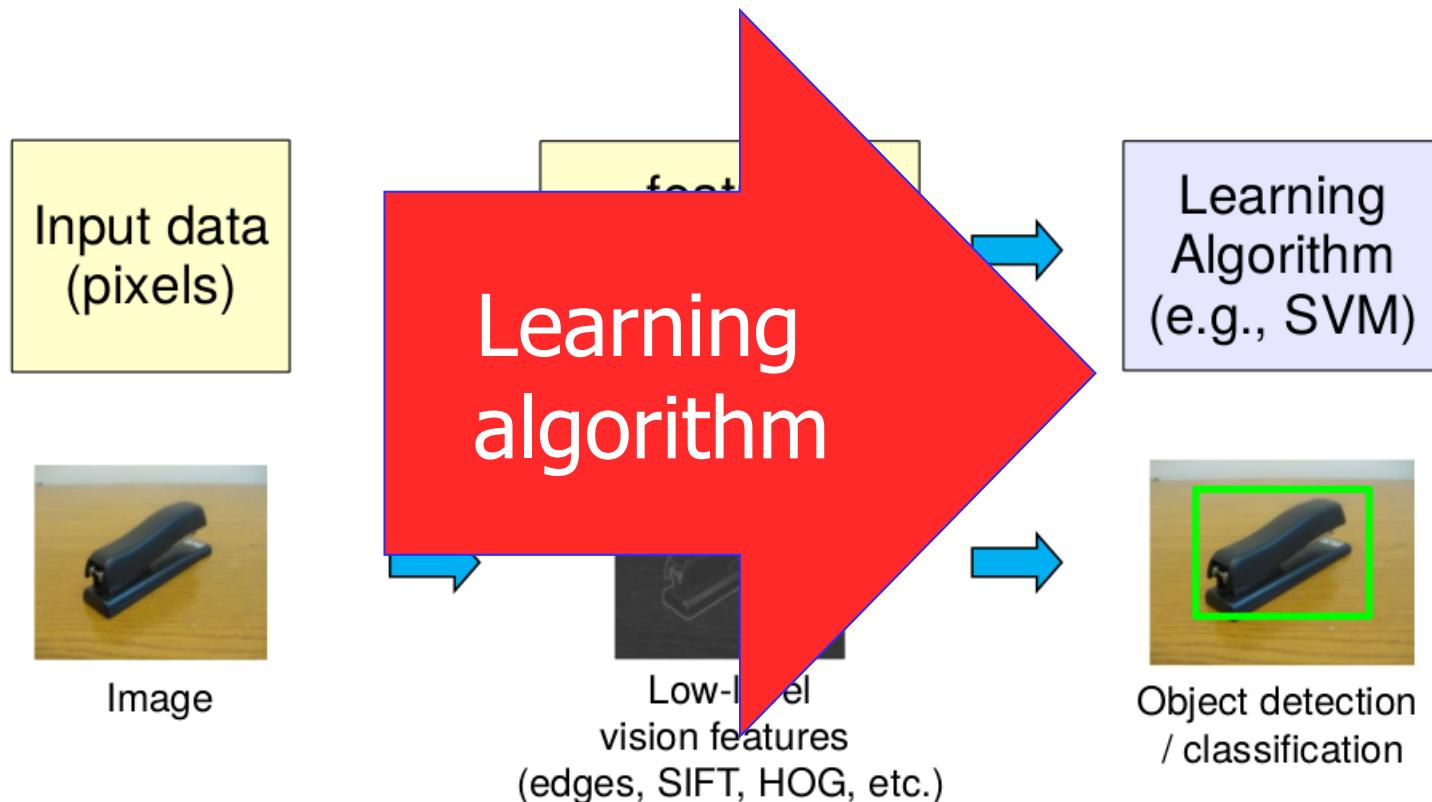


- **What is deep learning?**

- Traditional approach

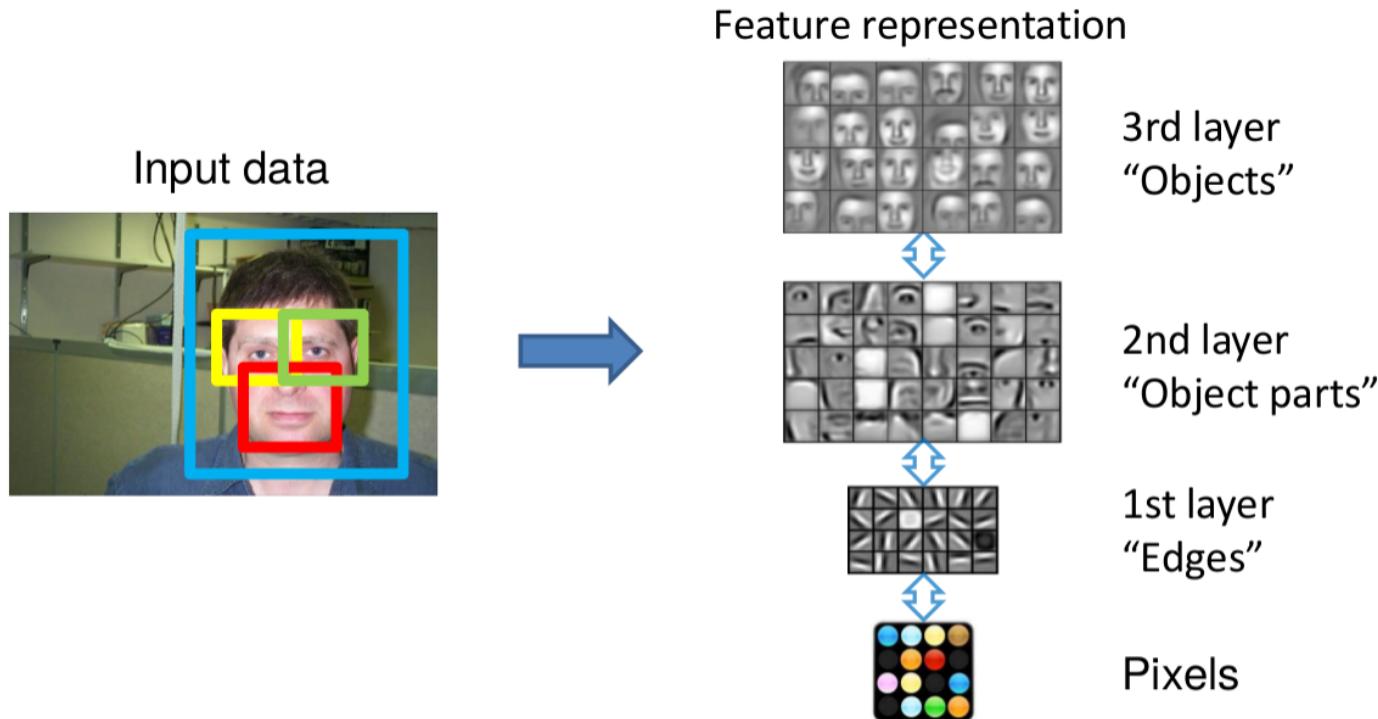


- What is deep learning?
  - New approach: deep learning

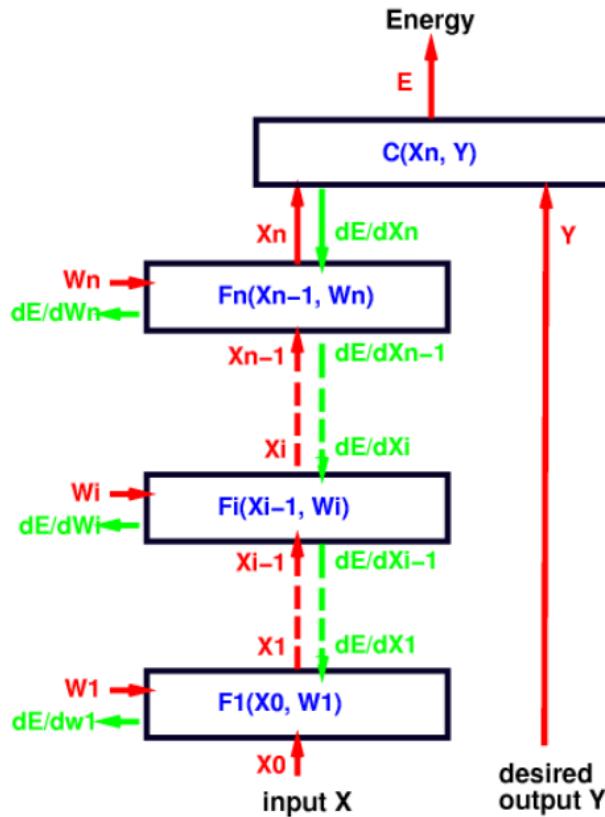


# Deep learning basics

- **What is deep learning?**
  - End-to-end learning of deep architectures
  - They can learn a hierarchy of representations...

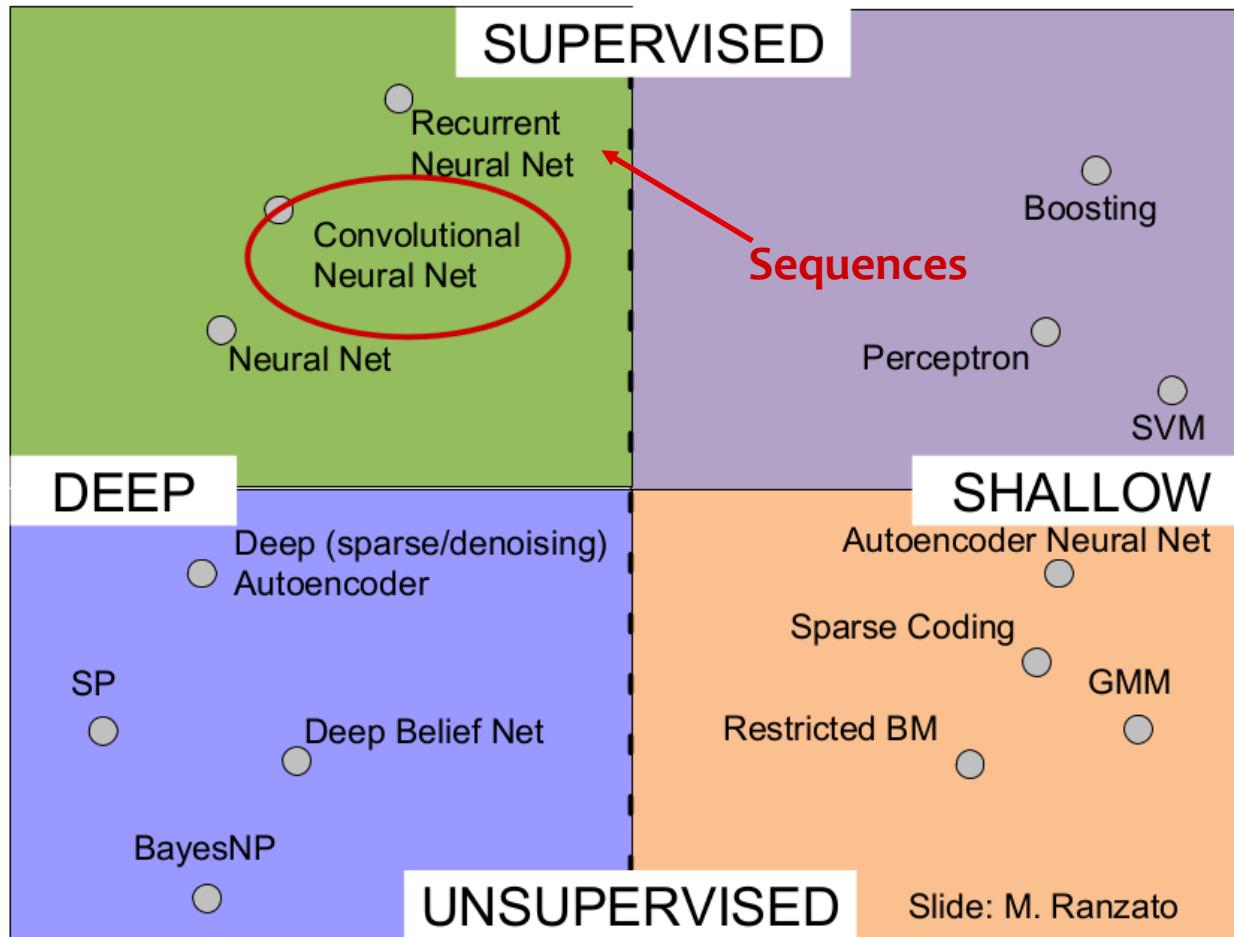


- What is deep learning?
  - ... and they are the best representations!

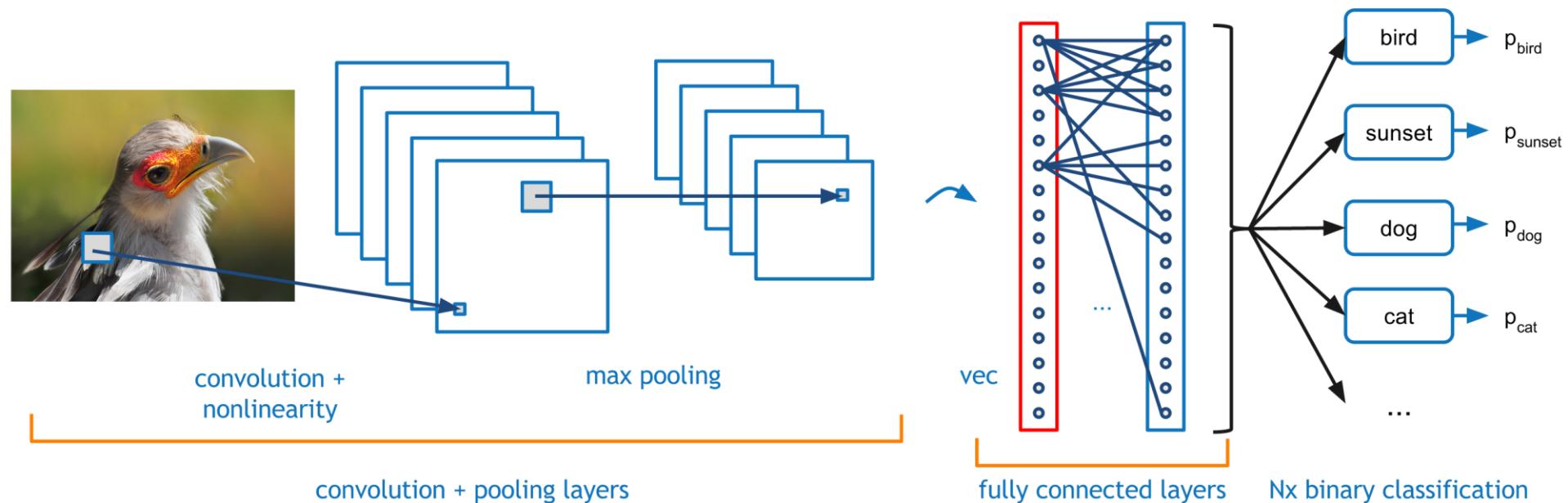


- Model parameters are jointly learnt through **back-propagation** to optimize the output for the task

- Deep learning in computer vision: CNNs



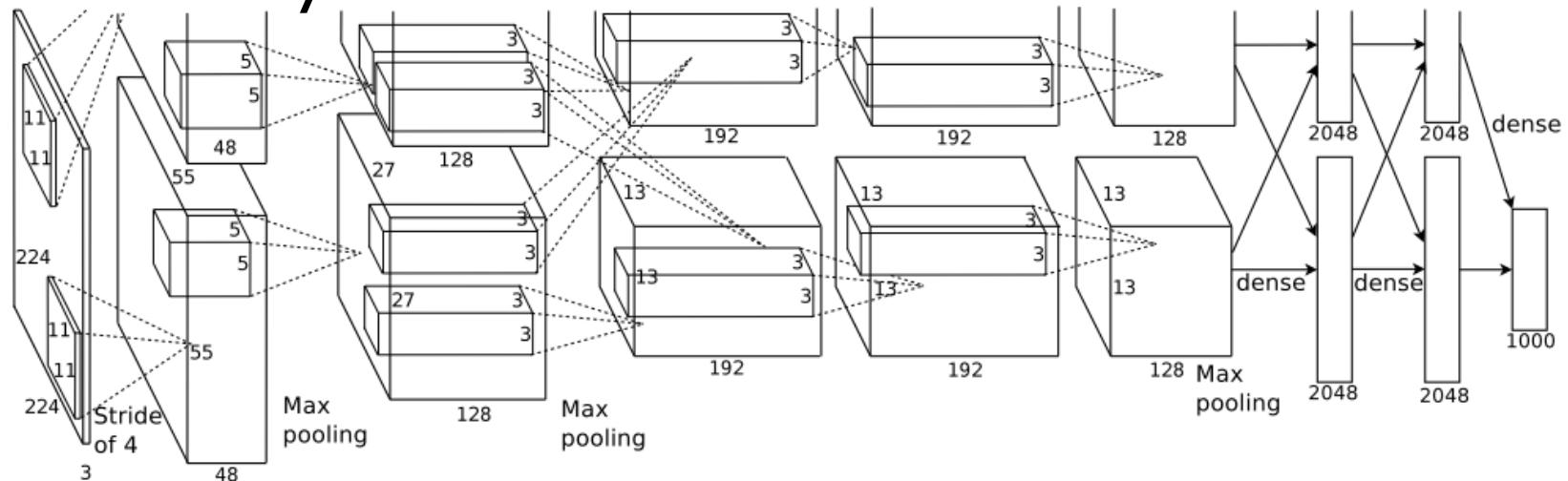
- Deep learning in computer vision: CNNs
  - Convolutional Neural Networks



Source: Flickr, Introducing: Flickr PARK or BIRD,  
<http://code.flickr.net/2014/10/20/introducing-flickr-park-or-bird/>

# Deep learning basics

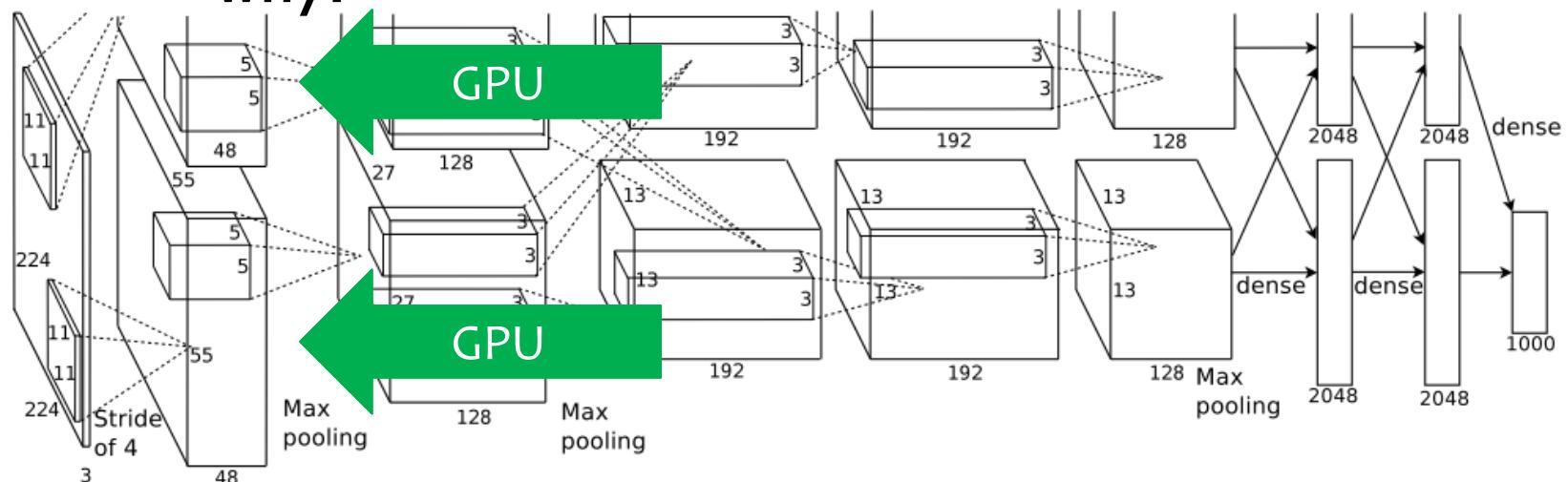
- Deep learning in computer vision: CNNs
  - They are basically huge neural networks (with improvements)...
  - ...but they could not be effectively trained until 2012, why?



A. Krizhevsky, I. Sutskever, and G. E. Hinton, “ImageNet Classification with Deep Convolutional Neural Networks,” in NIPS 2012, pp. 1097–1105.

# Deep learning basics

- Deep learning in computer vision: CNNs
  - They are basically huge neural networks (with improvements)...
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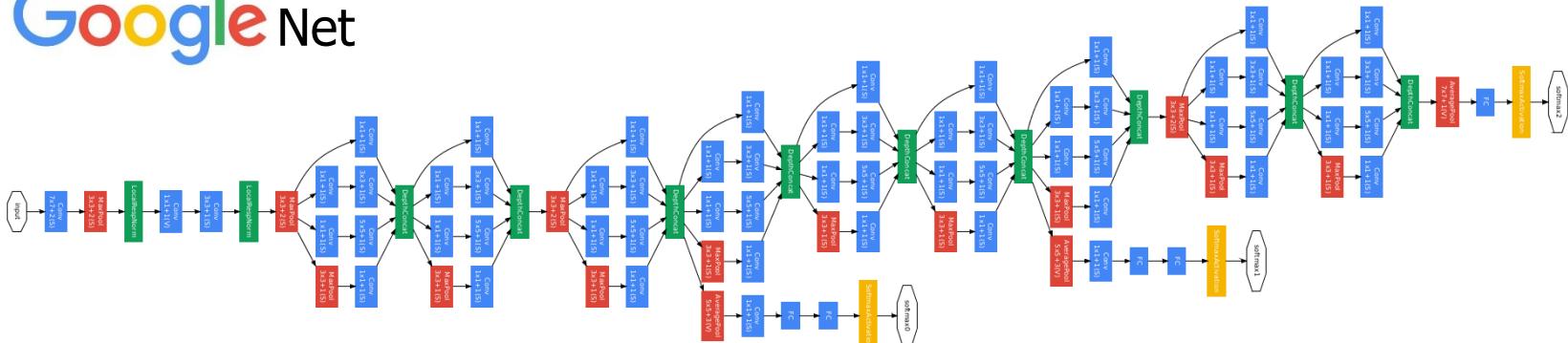


A. Krizhevsky, I. Sutskever, and G. E. Hinton, “ImageNet Classification with Deep Convolutional Neural Networks,” in NIPS 2012, pp. 1097–1105.

# Deep learning basics

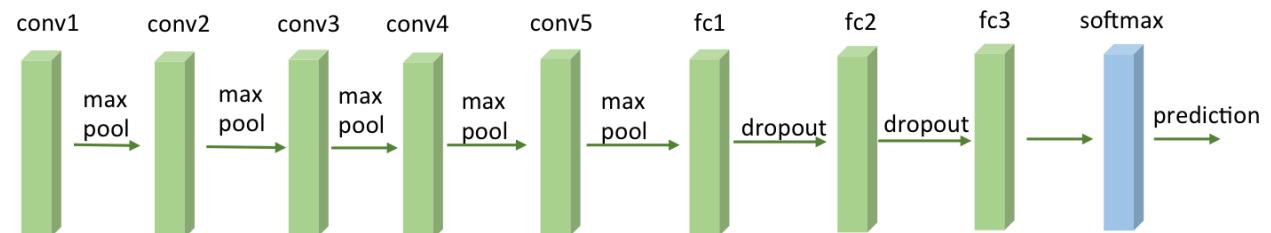
- Deep learning in computer vision: CNNs
  - A large number of architectures have been (and still are being) proposed

Google Net



Visual Geometry Group  
(VGG Net)

each conv includes 3 convolutional layers



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- **Deep learning in computer vision: CNNs**

“It can be concluded that from now on, deep learning with CNN has to be considered as the primary candidate in essentially any visual recognition task.”

A. S. Razavian, H. Azizpour, J. Sullivan, and S. Carlsson, “CNN Features off-the-shelf: an Astounding Baseline for Recognition,” in CVPR 2014, pp. 512–519.



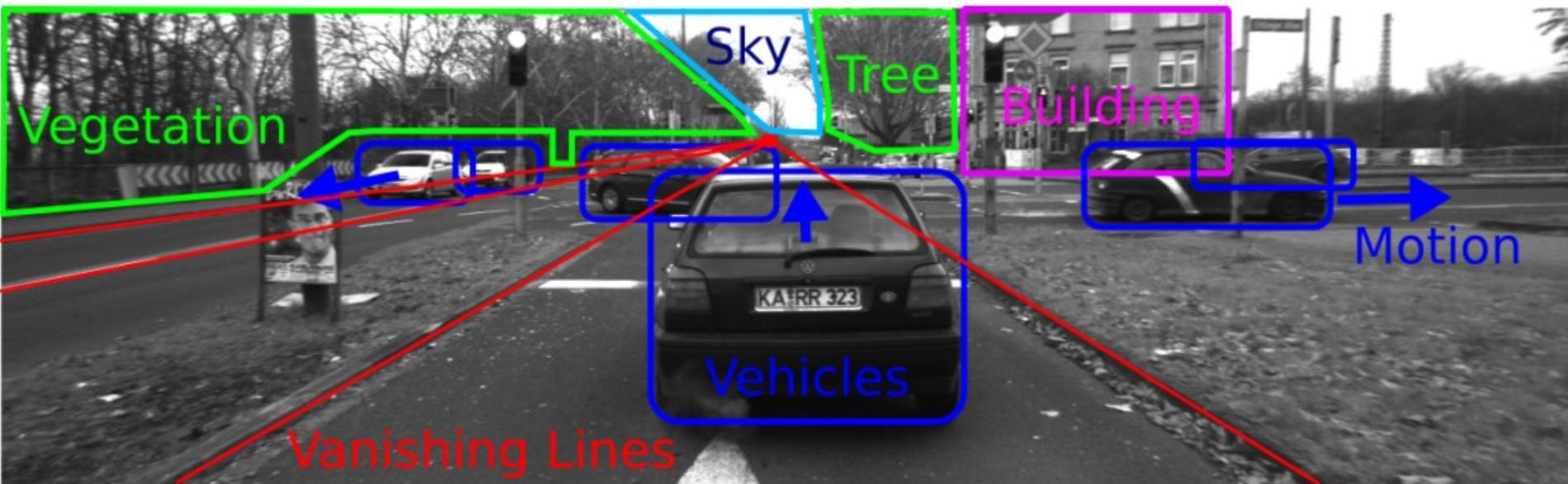
- Deep learning basics
- **Applications in driving environments**
- Future prospects
- Conclusions

- **What is this?**



**Source:** A. Geiger, "Probabilistic Models for 3D Urban Scene Understanding from Movable Platforms," Ph.D dissertation, Karlsruher Institut für Technologie, 2013.

- What is this?



Source: A. Geiger, "Probabilistic Models for 3D Urban Scene Understanding from Movable Platforms," Ph.D dissertation, Karlsruher Institut für Technologie, 2013.

# Apps. on driving environments

- **Levels**

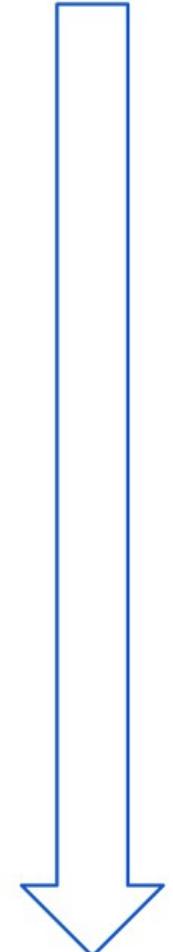
- classification



- detection

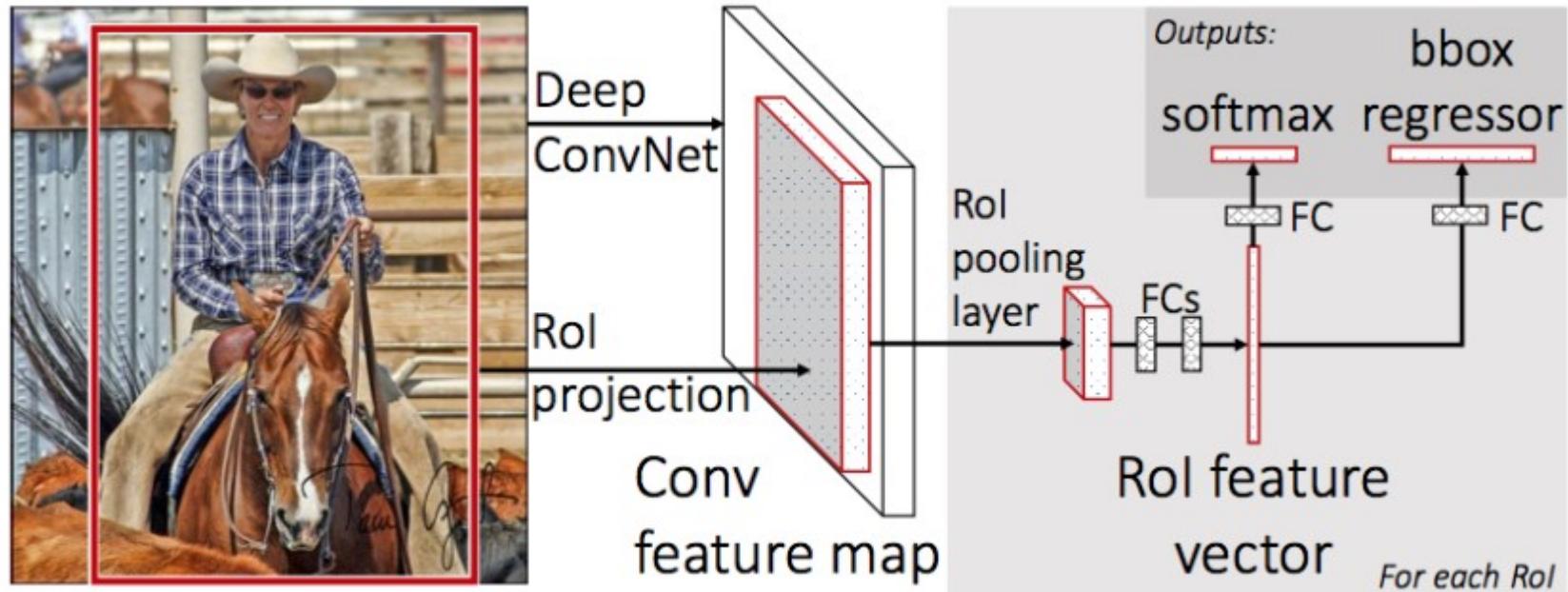


- segmentation



difficulty

- Object detection with CNNs: (Fast) R-CNN
  - Fast R-CNN test time: < 0.5 second

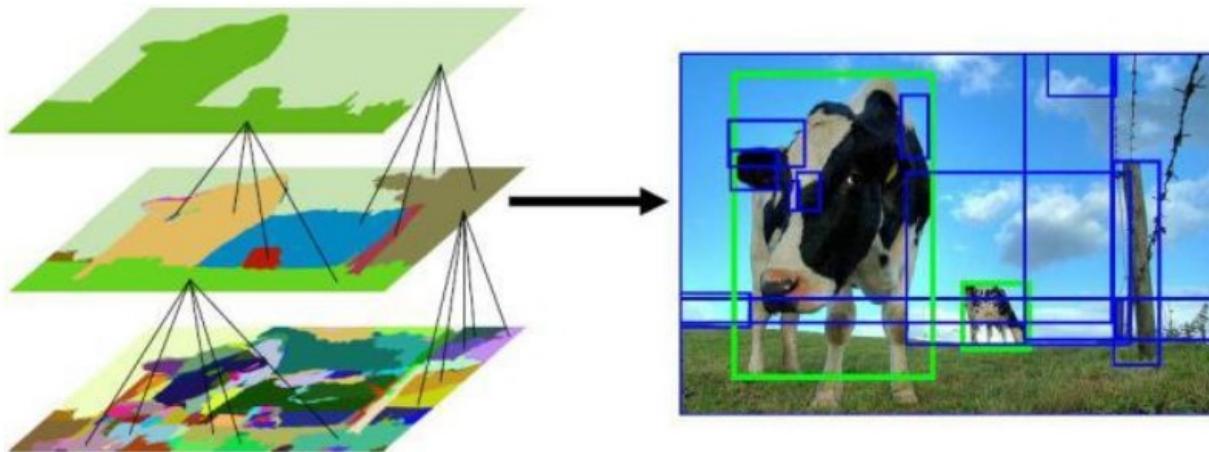


R. Girshick, J. Donahue, T. Darrell, and J. Malik, “Rich feature hierarchies for accurate object detection and semantic segmentation,” in CVPR 2014, pp. 580–587.

# Apps. on driving environments

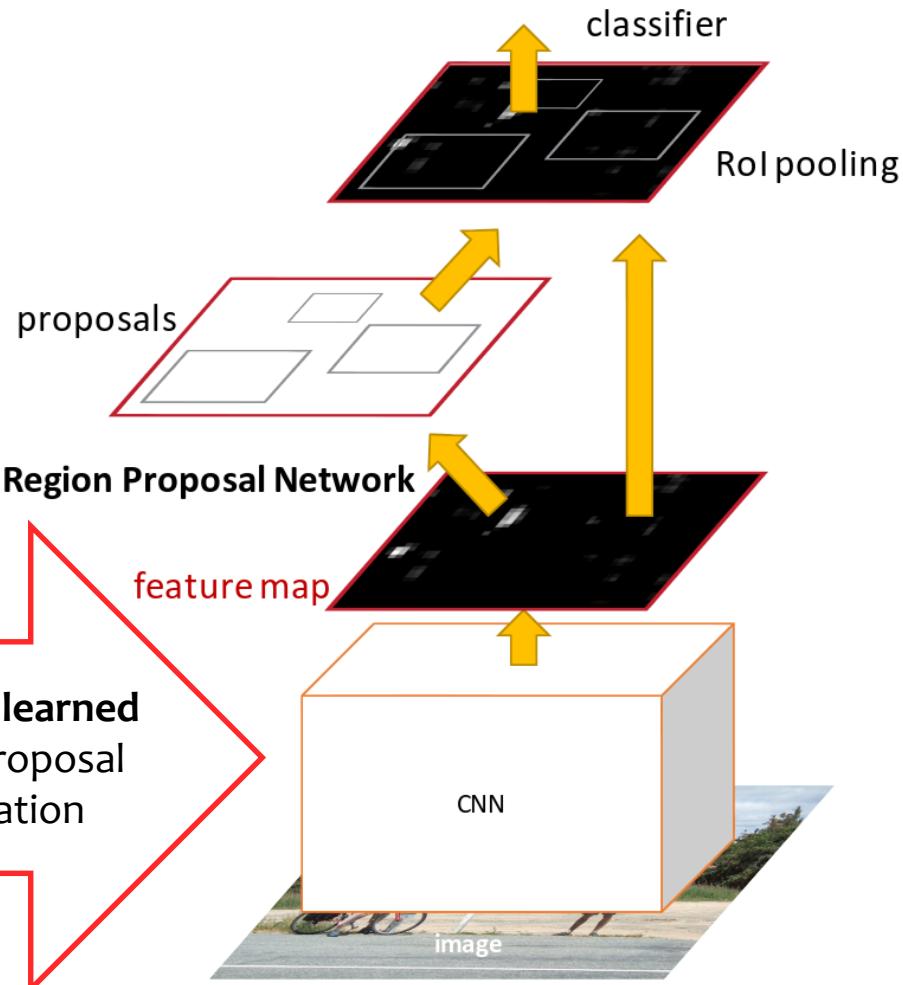
- **Where do Rols come from?**

- In the original work, they were proposed through Selective Search (a classical segmentation method) in a previous step.
- But they could be from anywhere (laser, stereo information, etc.)



J. R. R. Uijlings, K. E. a Van De Sande, T. Gevers, and a. W. M. Smeulders, “Selective search for object recognition,” Int. J. Comput. Vis., vol. 104, no. 2, pp. 154–171, 2013.

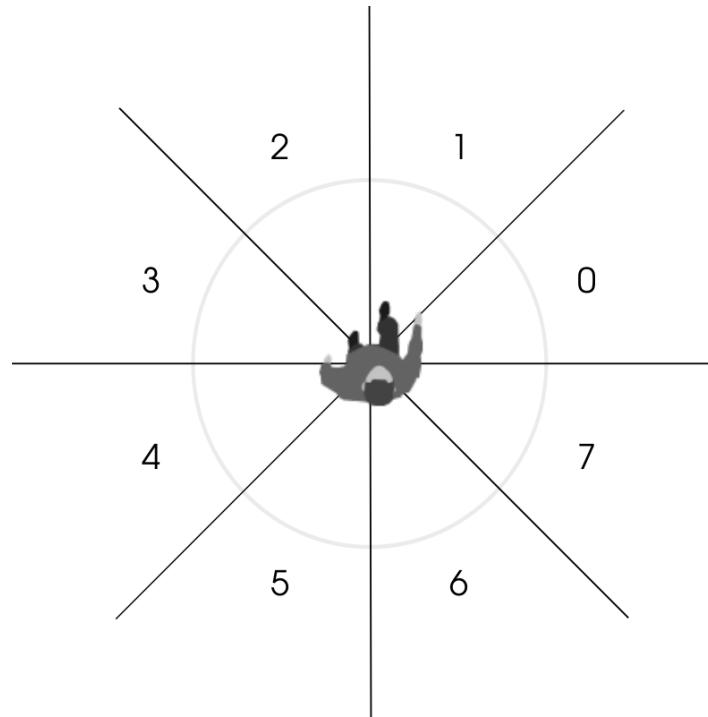
- **Skipping the Roi proposal step: Faster R-CNN**



- Real-time: up to 17 fps (with small resolutions)

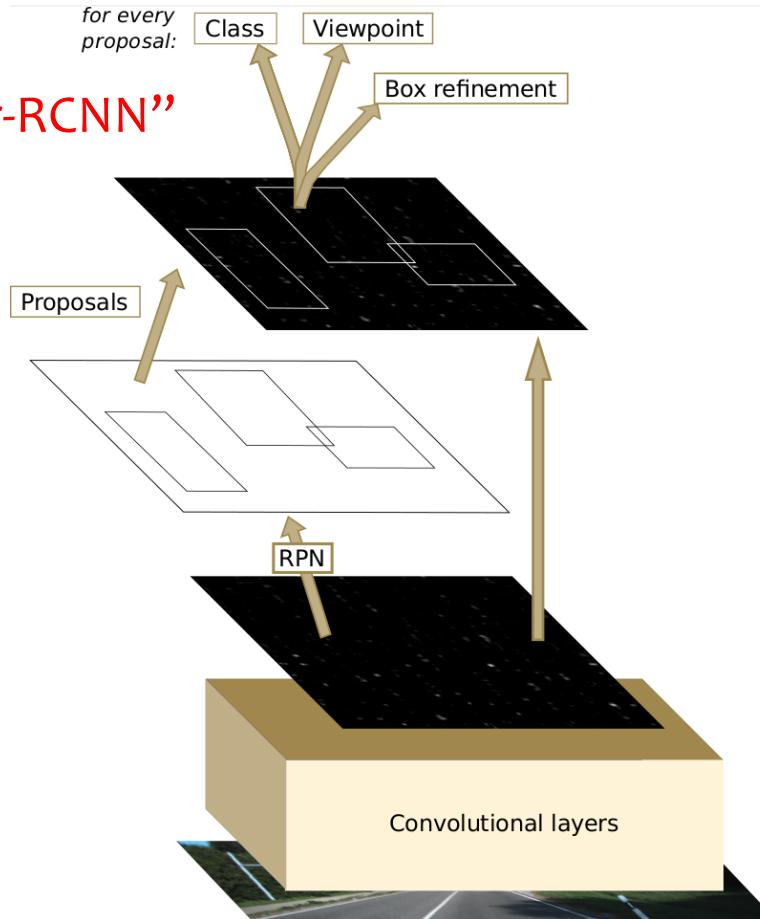
S. Ren, K. He, R. Girshick, and J. Sun, "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks," in NIPS 2015.

- **Why settle for detection?**
  - Obstacle viewpoint estimation
  - Important feature when understanding driving situations
  - Discrete viewpoint approach



- **Obstacle viewpoint estimation**
  - Naturally integrated into the Faster R-CNN framework

“LSI-Faster-RCNN”



- Based on the Zeiler-Fergus architecture
- Input:
  - RGB Image (no additional features)
- Outputs
  - Bounding boxes (Rois)
  - Class (for every RoI)
  - **Viewpoint** (for every RoI)

- Let's apply it to driving environments

**The KITTI Vision Benchmark Suite**

A project of Karlsruhe Institute of Technology and Toyota Technological Institute at Chicago

home    Not occluded    Partly occluded    Fully occluded    Unknown    Don't care region

Andrea    Welcome

2D Bounding Boxes

training set frame 10/7480

PACE: Next Image | '-' Previous Image | 'x': +1000 | 'y': >1000 | 'q': quit

TOYOTA  
TECHNOLOGICAL INSTITUTE  
CHICAGO

KIT  
Karlsruhe Institute of Technology

Why do I love KITTI?

9 classes

- Car
- Van
- Truck
- Pedestrian
- Person\_sitting
- Cyclist
- Tram
- Misc
- DontCare

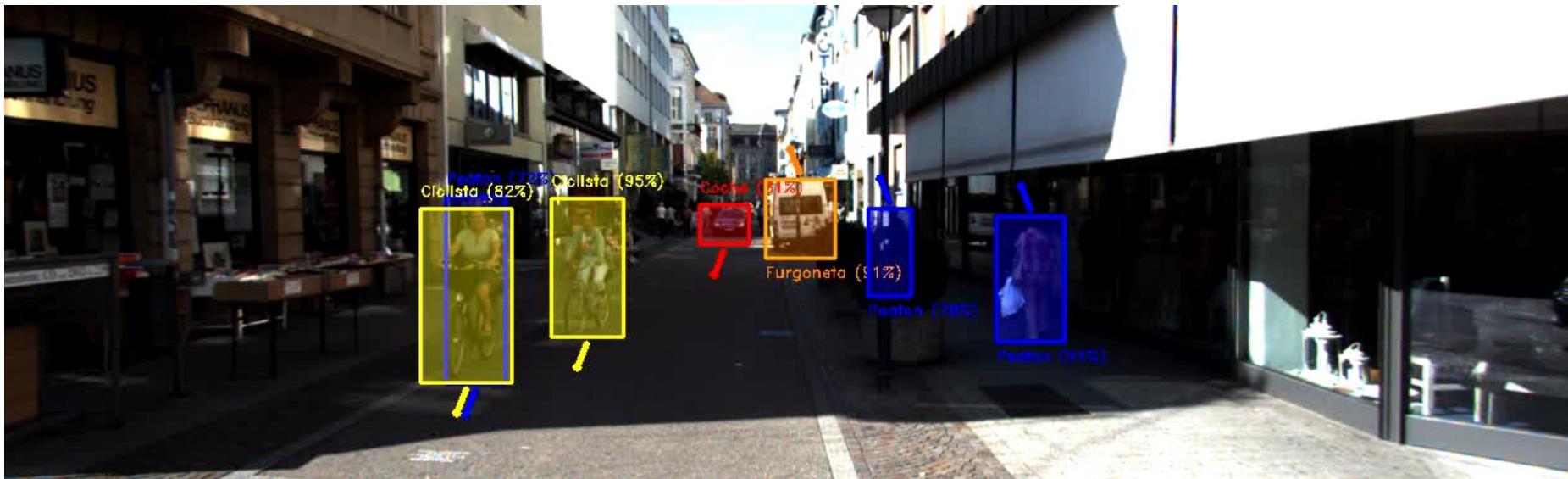
Additional info:

Truncated  
Occluded  
Viewpoint  
Dimensions  
Location  
Yaw angle

+ Table of results

# Apps. on driving environments

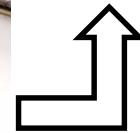
- Now available in IVVI 2.0



- Detection time per image: ~100 ms (depending on the selected image scale)
- Work in progress

- **New GPU equipment: NVIDIA Tesla K40c**

- Kindly donated by NVIDIA to the LSI
- Deep learning training & test hugely accelerated



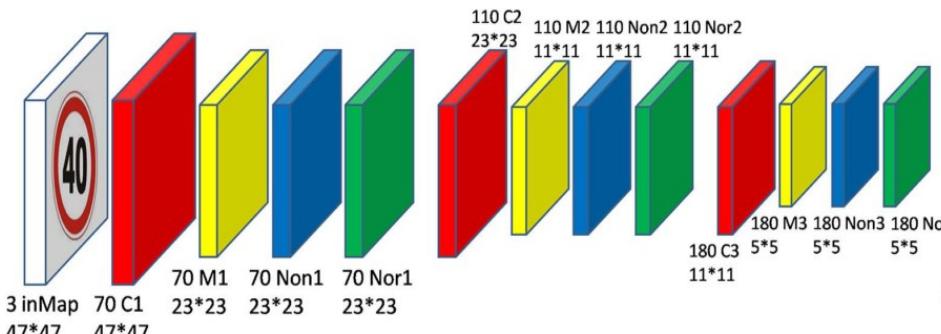
BEFORE  
448 CUDA cores  
6 GB GDDR5  
cuDNN not supported

NOW  
2880 CUDA cores  
12 GB GDDR5  
cuDNN supported



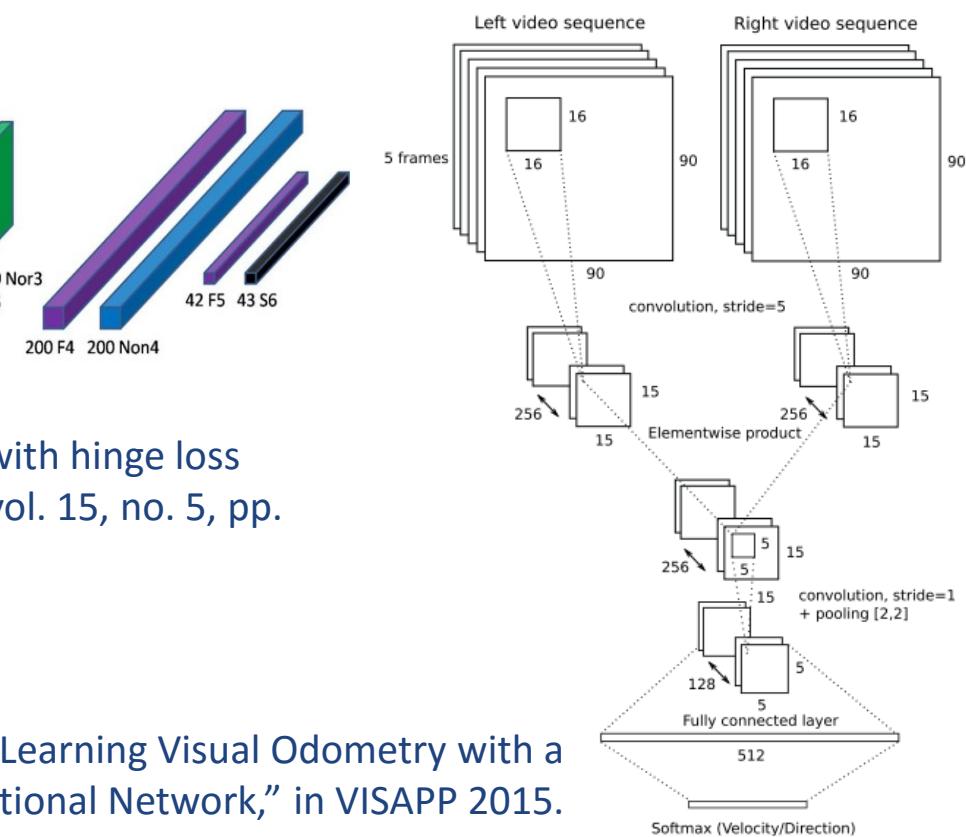
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- Deep learning for traffic signs, vehicle color... even visual odometry!



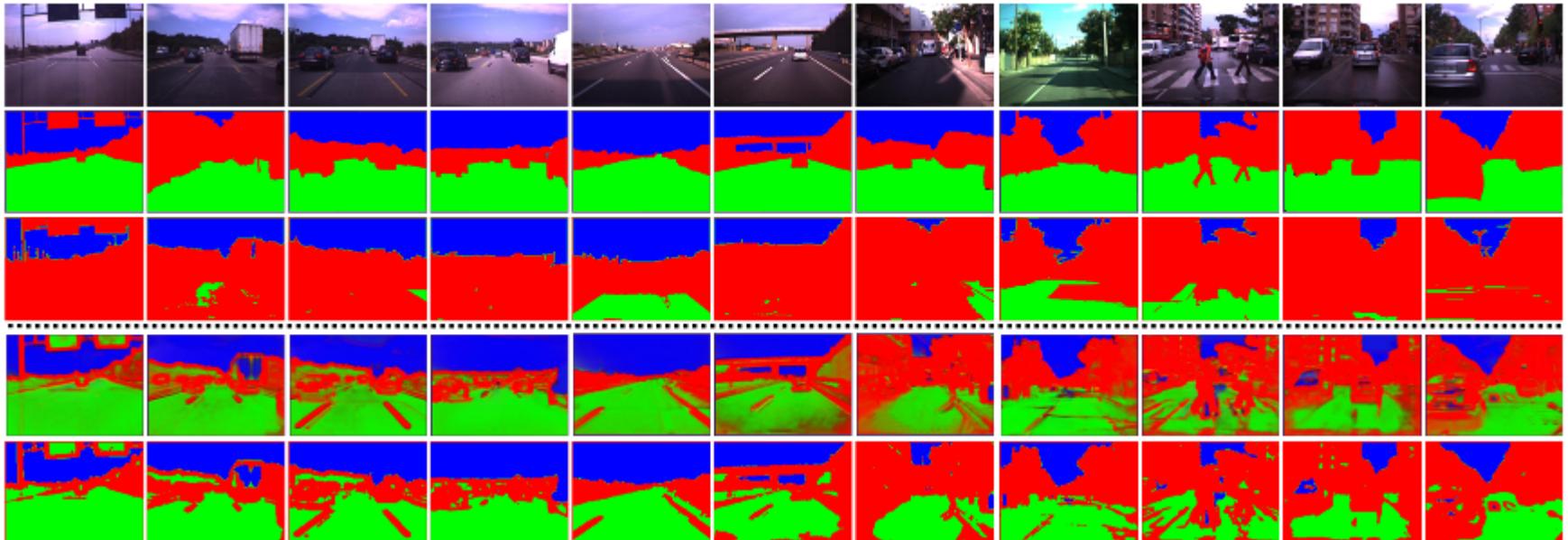
J. Jin, K. Fu, and C. Zhang, "Traffic sign recognition with hinge loss trained convolutional neural networks," IEEE TITS, vol. 15, no. 5, pp. 1991–2000, 2014.

K. Konda and R. Memisevic, "Learning Visual Odometry with a Convolutional Network," in VISAPP 2015.



# Future prospects

- Per-pixel scene labeling using ConvNets



J. M. Alvarez, T. Gevers, Y. Lecun, and A. M. Lopez, "Road Scene Segmentation from a Single Image," in ECCV 2012, pp. 376–389.

# Future prospects

- Per-pixel scene labeling using ConvNets



C. Farabet, C. Couprie, L. Najman, and Y. Lecun, "Learning hierarchical features for scene labeling," IEEE Trans. PAMI, vol. 35, no. 8, pp. 1915–1929, 2013.



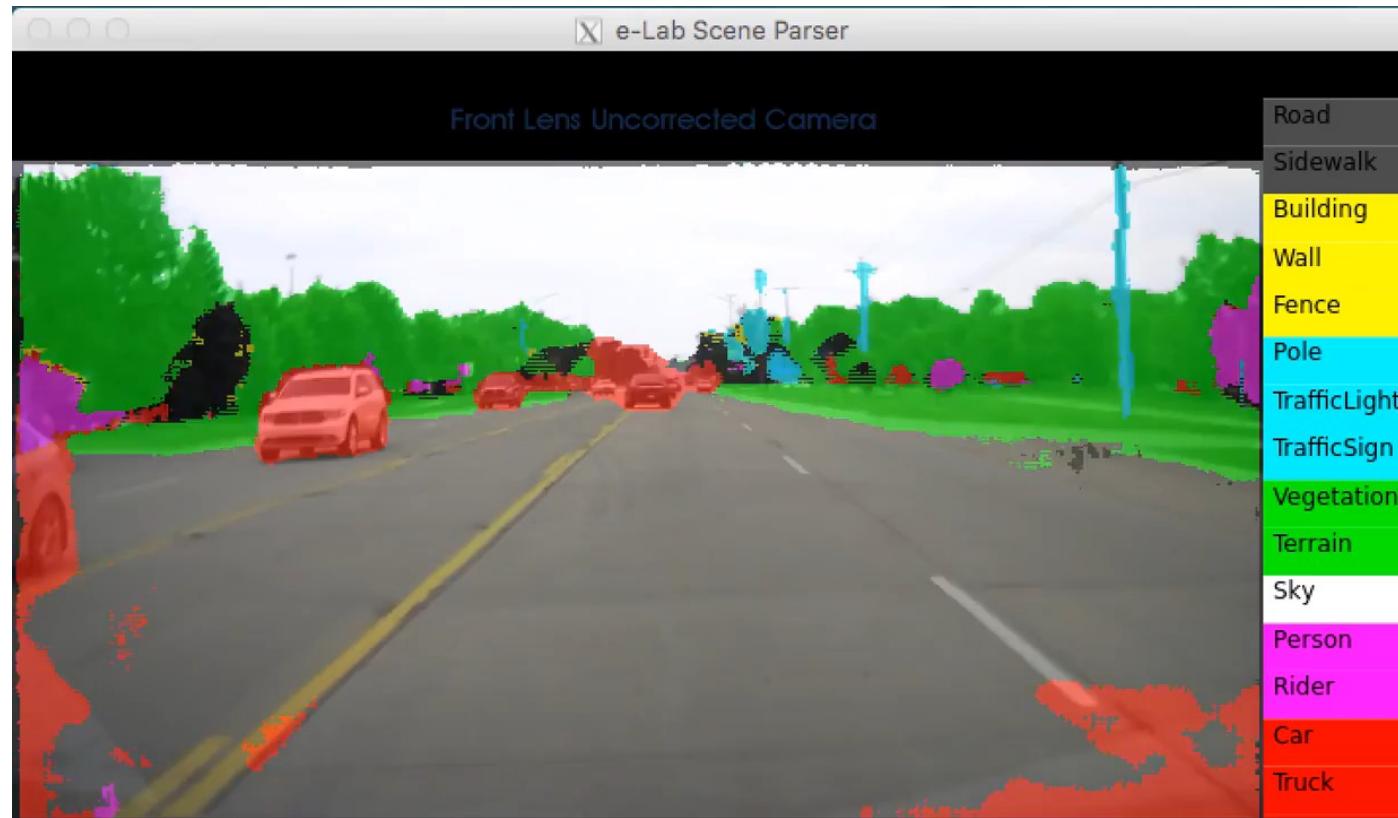
- 
- **Scene understanding in driving environments remains an enormous challenge**



- 
- **Scene understanding in driving environments remains an enormous challenge**
  - **First of all, what is scene understanding?**

# Future prospects

- **Scene understanding meaning #1: video labeling (NNs)**



Source: Eugenio Culurciello, <https://www.youtube.com/watch?v=3jq4FnO5Nco>

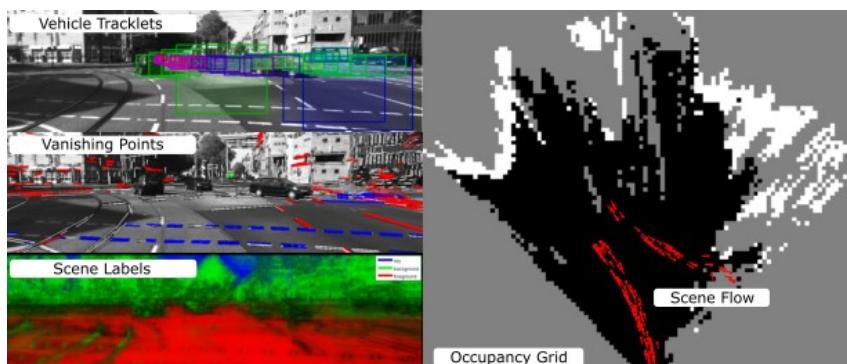
# Future prospects

- 
- **Scene understanding meaning #2: video parsing  
(Recurrent ConvNets)**

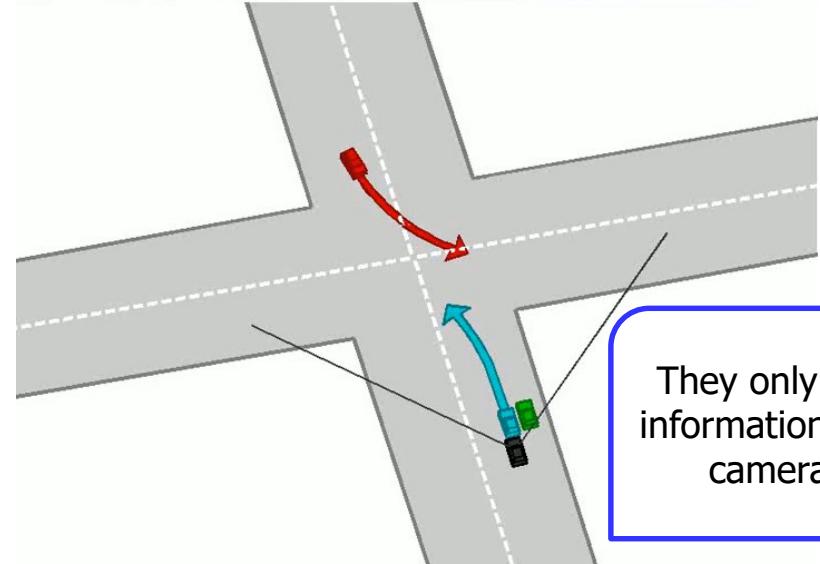
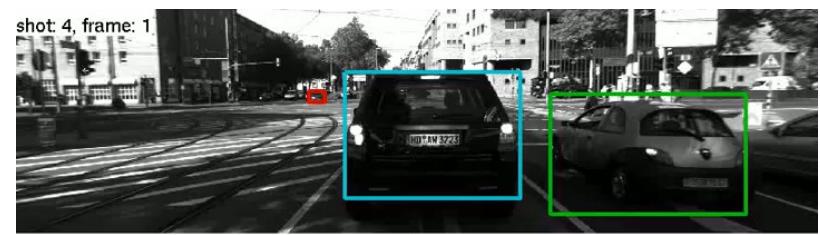
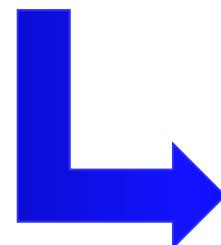


Source: <http://jeffdonahue.com/lrcn/>

- Scene understanding meaning #3: scene models (probabilistic methods)

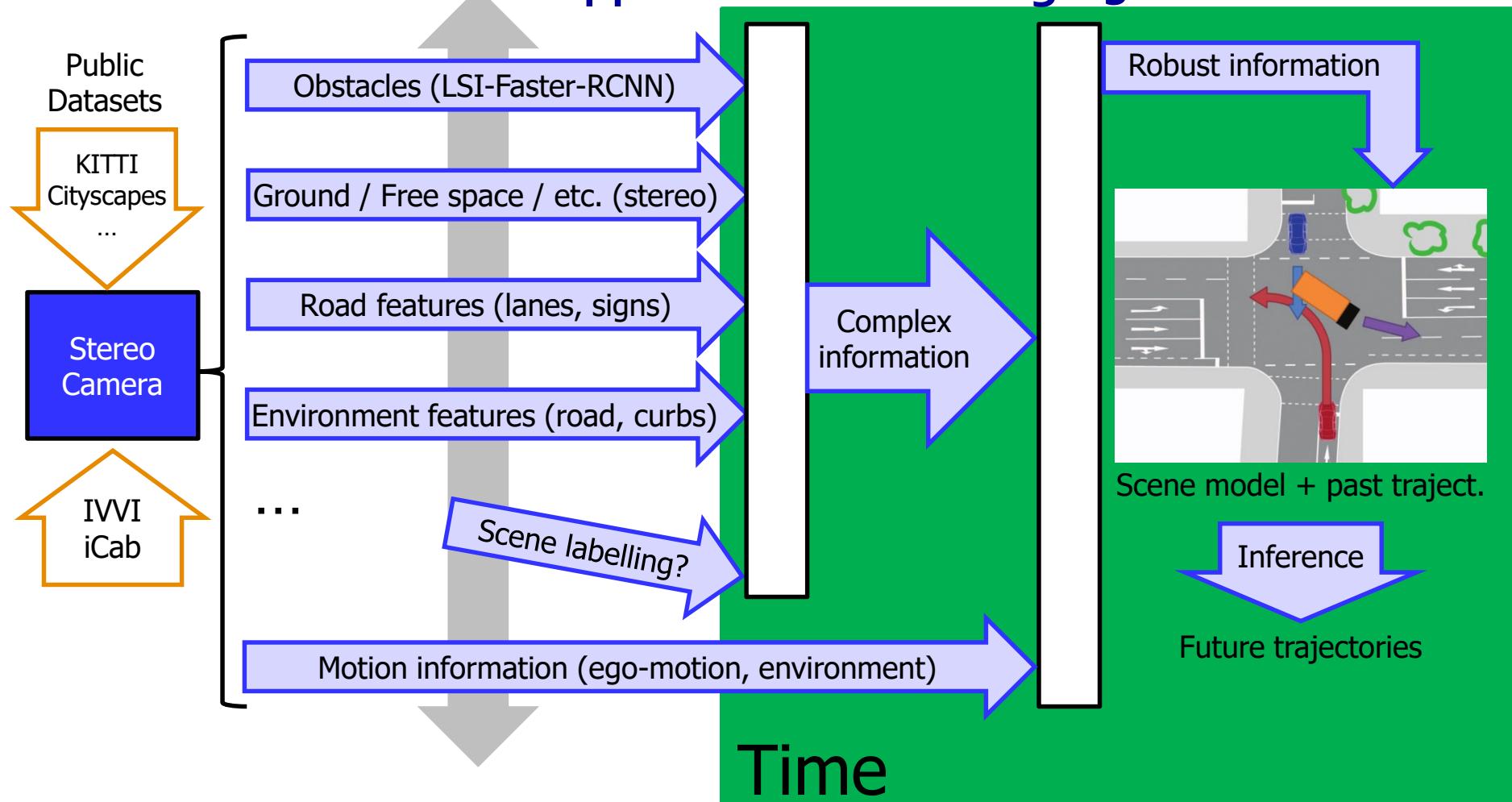


A large number of stochastic (non-perfect) sources of information

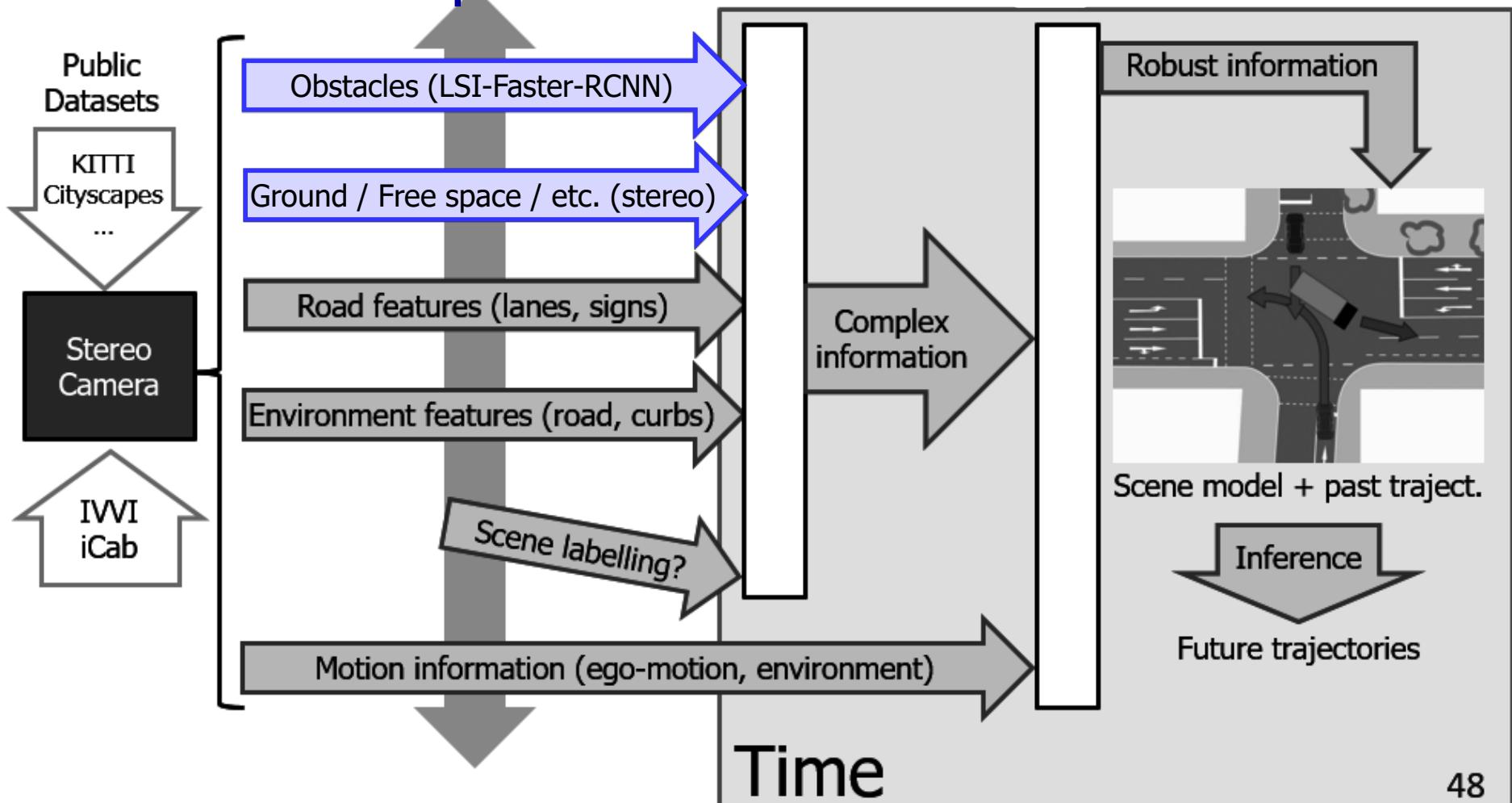


They only use information from cameras

- **What could our approach be? Meaning #3: Scene model**

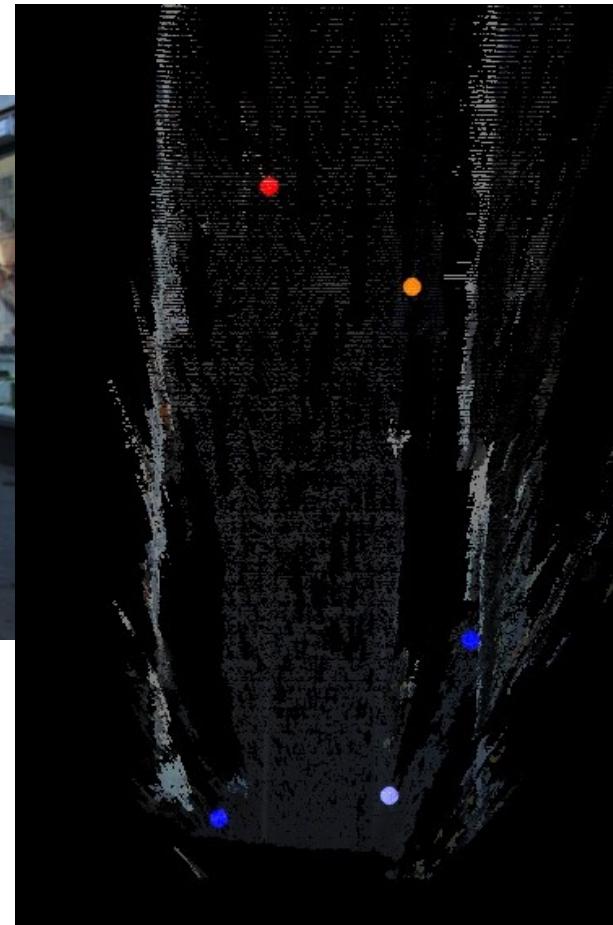


- First attempts:



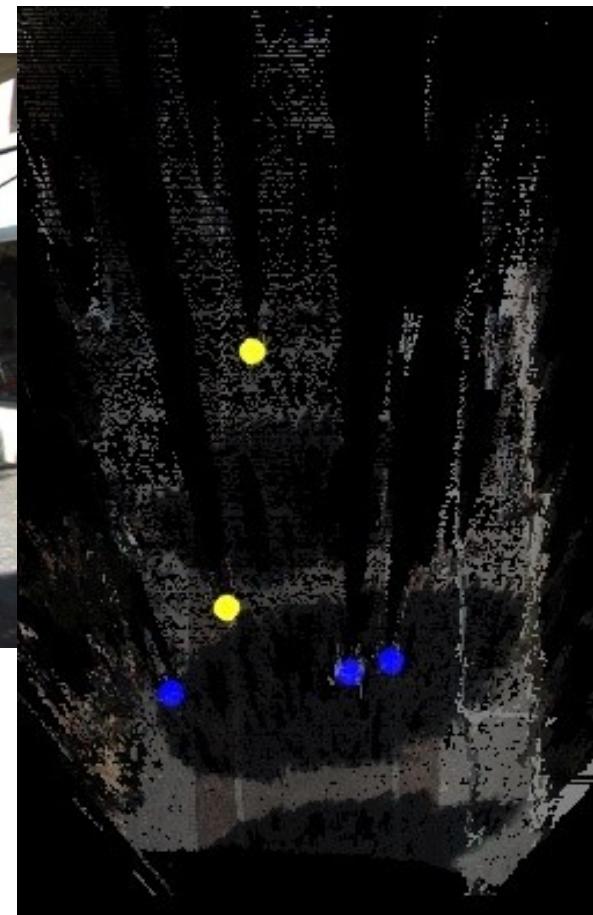
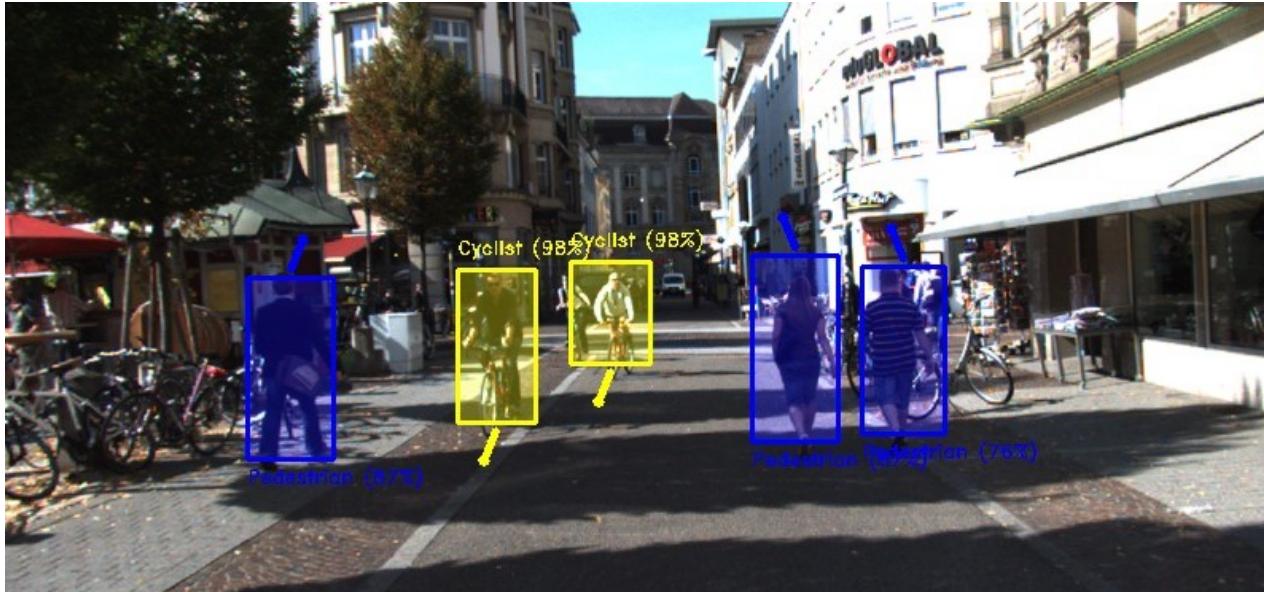
# Future prospects

- **First attempts (now available in IVVI 2.0)**
  - A sparse 3D model or a loosely labeled pointcloud?

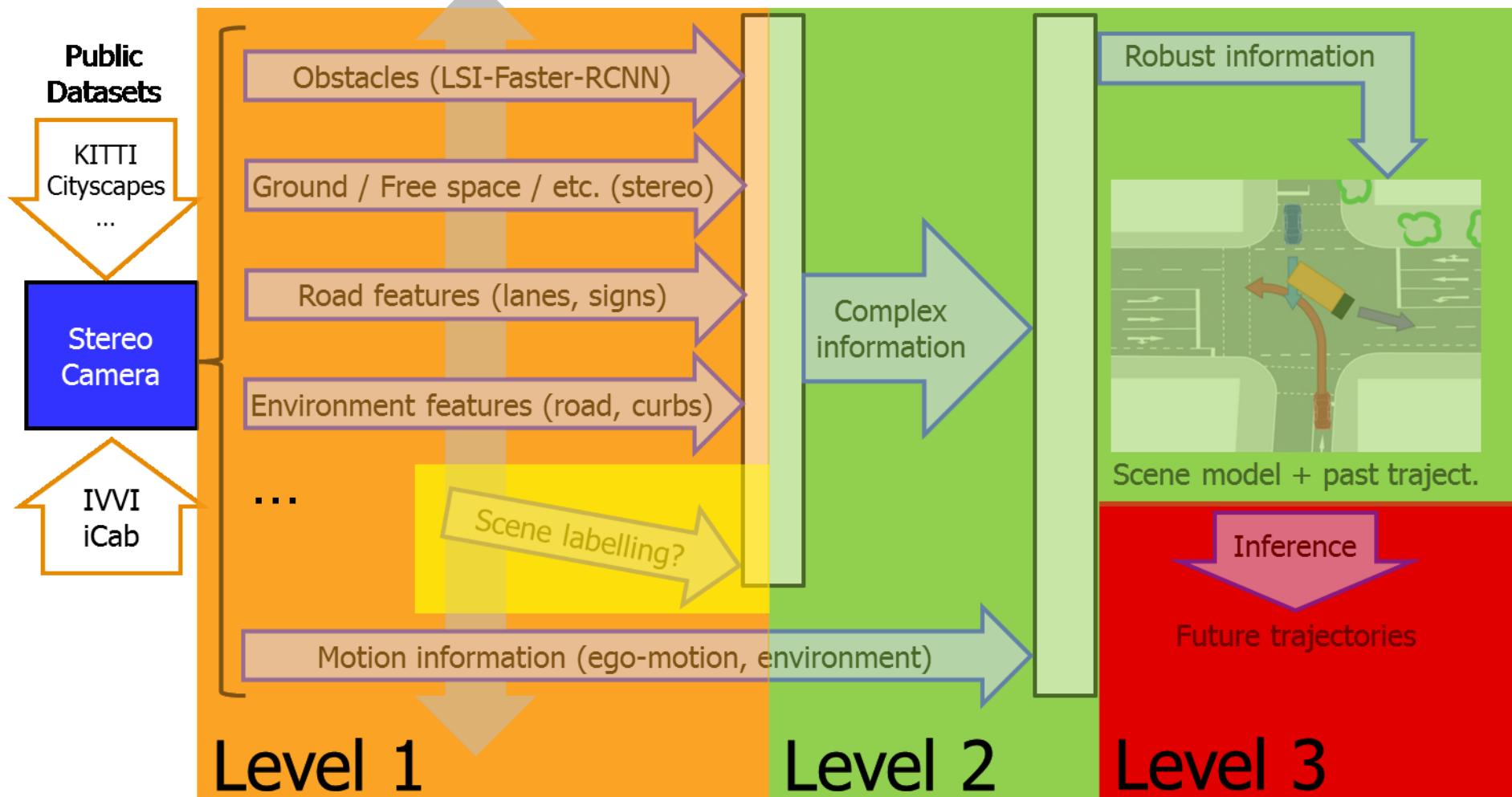


# Future prospects

- **First attempts (now available in IVVI 2.0)**
  - A sparse 3D model or a loosely labeled pointcloud?



- A large number of information sources still to integrate...



- ...and obstacle detection can be largely improved
- Thousands of *different* options:
  - More sensors?
    - Cons: lots of time-consuming engineering tasks (and also labeling tasks) before getting meaningful information
  - Less sensors?
    - E.g.: no stereo information. Cons: depth information is not straightforwardly available, structure-from-motion is a whole research field
  - Less information sources?
    - Cons: obstacles are not enough to understand the current driving scenario, inference would not be based on strong evidences
  - Focus on only one thing? Which one?
  - Shortcuts to the last level? "Scene understanding meaning #2"



- Deep learning basics
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# Conclusions

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- 1. Deep learning is becoming the new baseline in computer vision**
- 2. Intelligent transportation systems offer many opportunities to take advantage of it**
- 3. Scene understanding is a very high-level goal where multiple approaches can be adopted**



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# Deep learning applied to driving environments

Thank you for your attention

# The End

- **Bonus track:**



IN CS, IT CAN BE HARD TO EXPLAIN  
THE DIFFERENCE BETWEEN THE EASY  
AND THE VIRTUALLY IMPOSSIBLE.