# Outline

Beyond ImageNet

1. Fully Convolutional Networks (FCNs)
2. Supervised Segmentation with Deep ConvNets

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1. Fully Convolutional Networks (FCNs)
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# From ImageNet to complex scenes

- ImageNet: huge dataset (1.2M training images) with labels ... but centered objects

ImageNet

- How to apply/adapt/modify learning strategies to deal with:

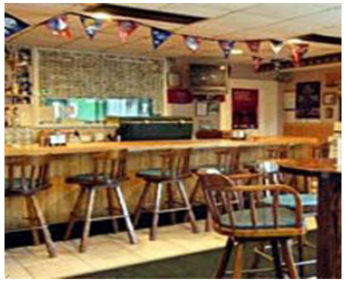
VOC 2012

MS COCO

# From ImageNet to complex scenes?

- Working on datasets with complex scenes (large and cluttered background), not centered objects, variable size, ...

VOC07/12



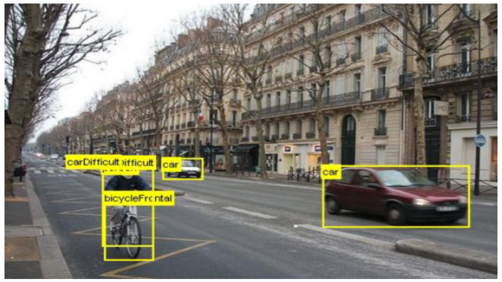
MIT67

15 Scene

COCO

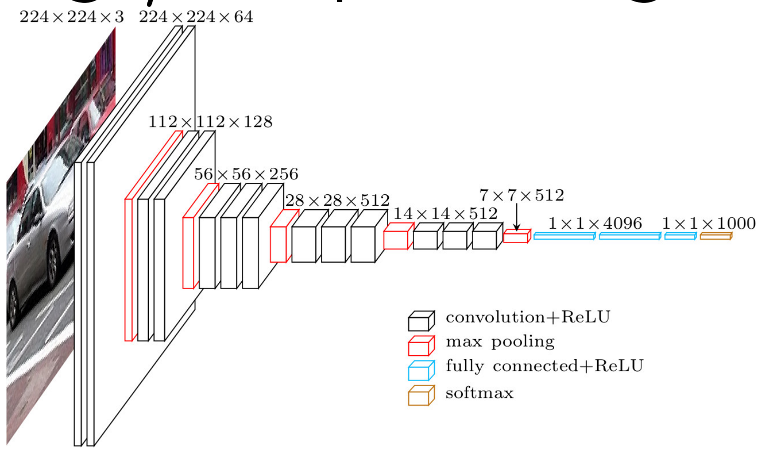
VOC12 Action

- Select relevant regions $\rightarrow$ better prediction




- Full annotations expensive $\Rightarrow$ training with weak supervision

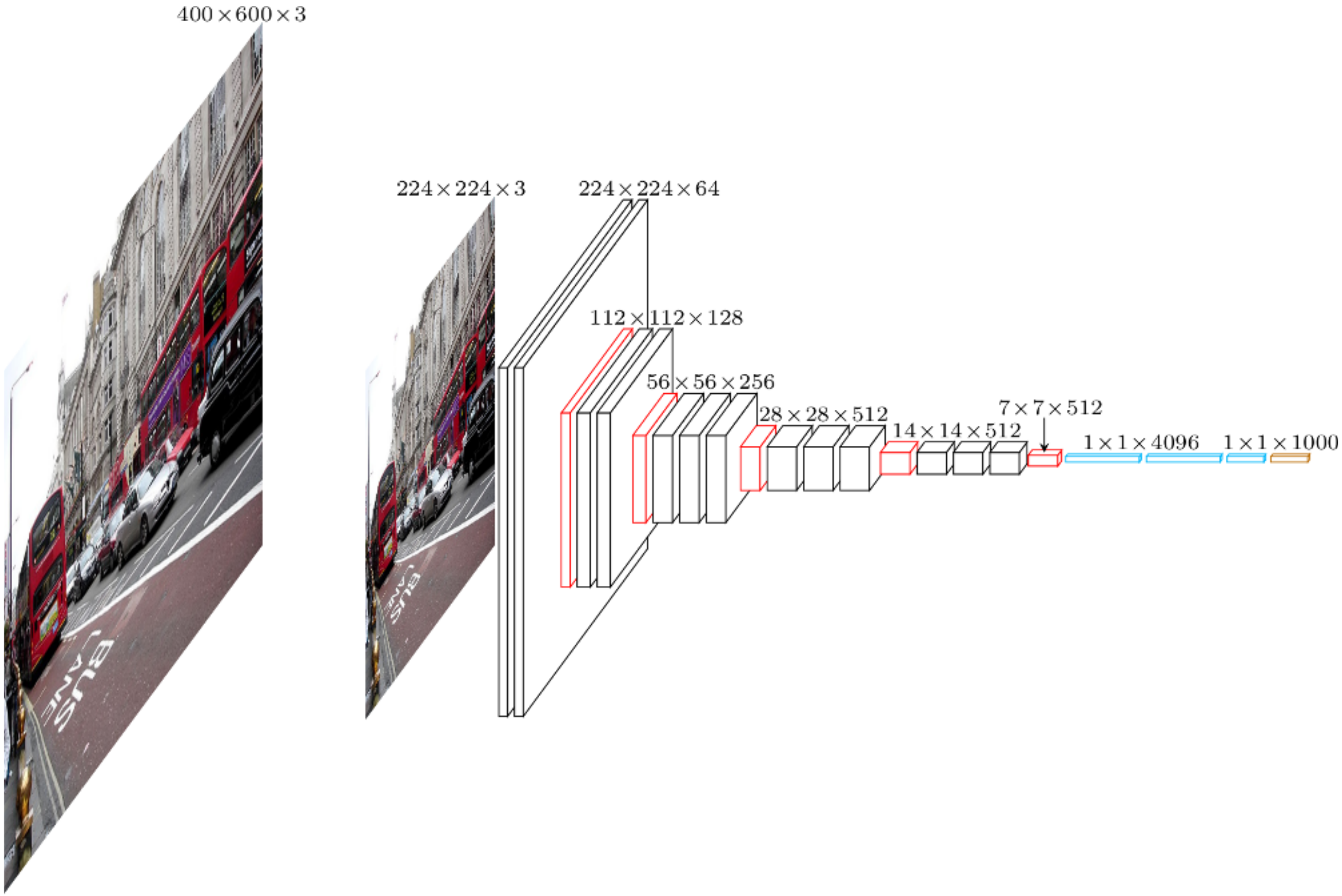
# How to adapt VGG16 archi. for large/complex images?



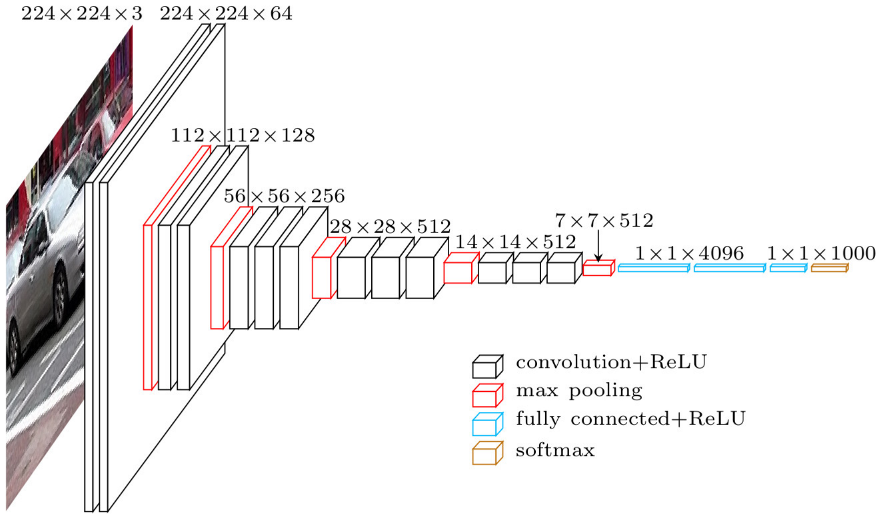

?

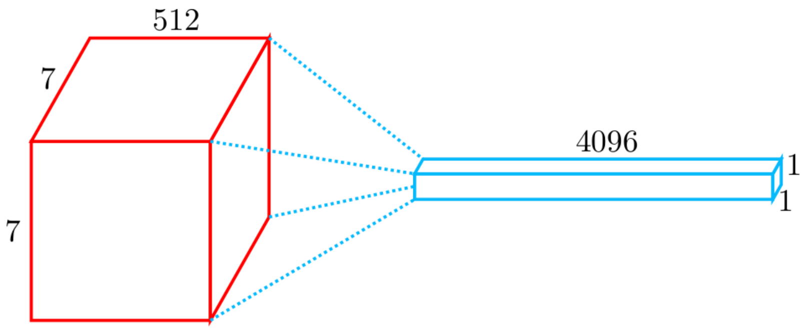
# Naïve approach: brut transfer (next Section)

- Resize the image



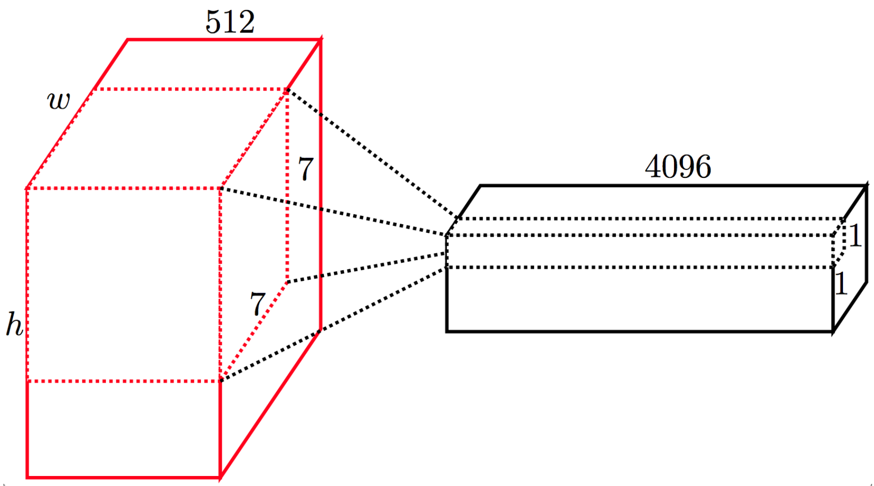
# Sliding window ⇒ convolutional layers



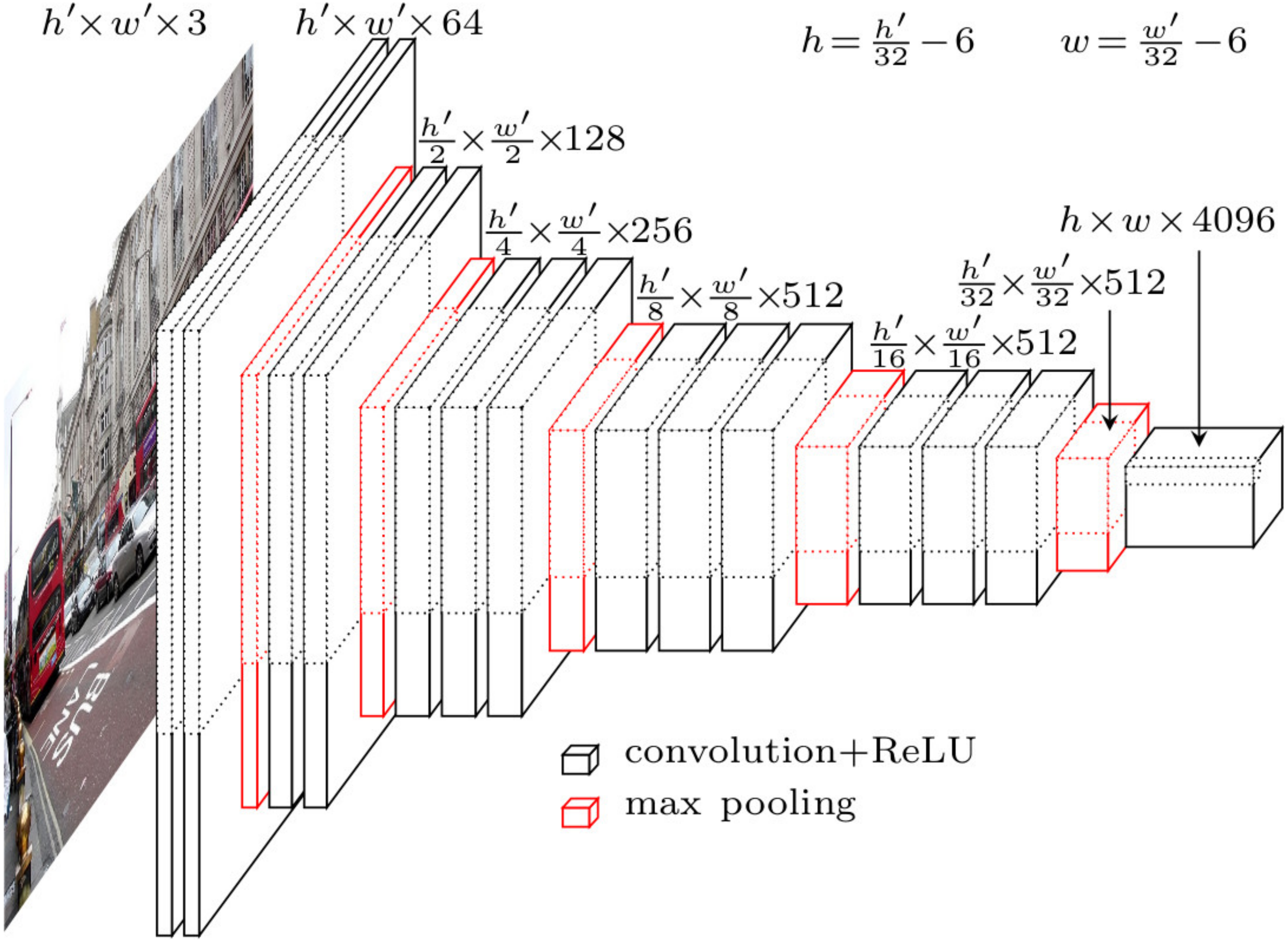



# Sliding window ⇒ convolutional layers

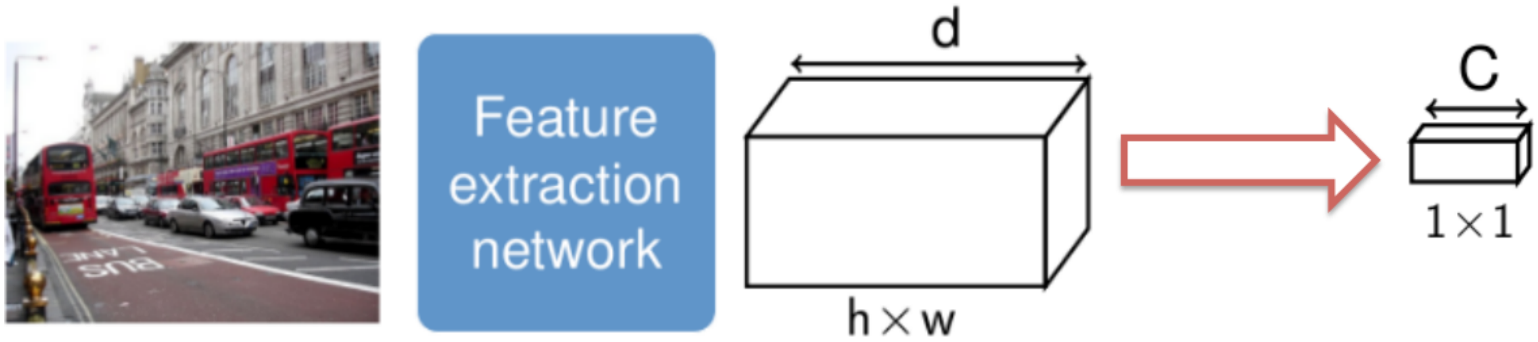
- Fully connected as convolutional layer (here 4096 conv. filters 7x7x512)



# Sliding window ⇒ convolutional layers

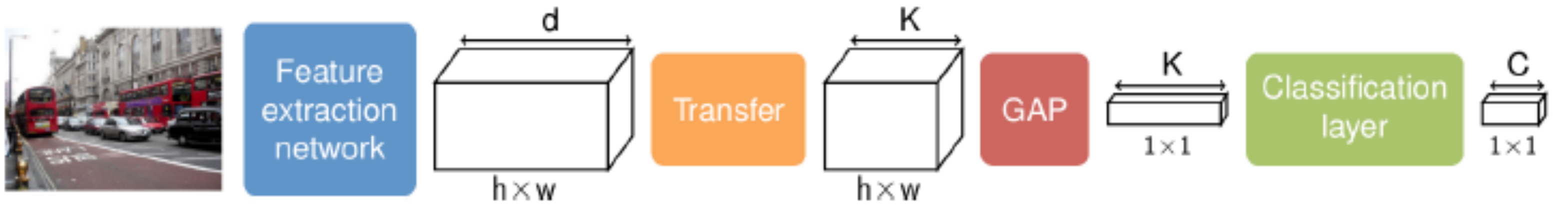


# Transfer – Pooling – Classification



# Image-based strategy

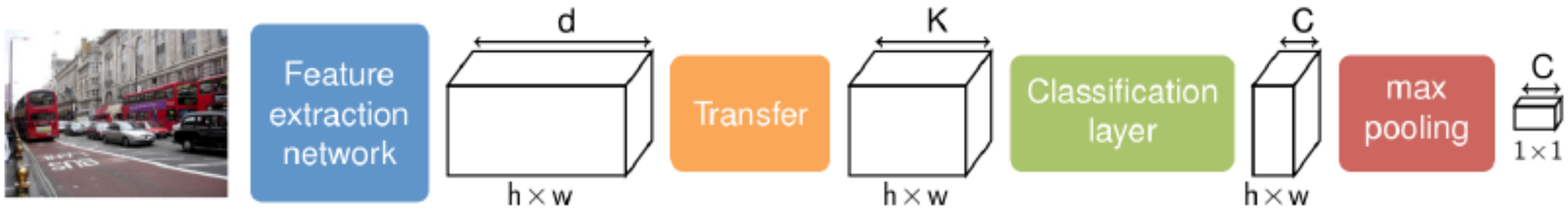
- Global Average Pooling (GoogLeNet, ResNet)




Bolei Zhou, Aditya Khosla, Agata Lapedriza, Aude Oliva, and Antonio Torralba
Learning Deep Features for Discriminative Localization.
In *CVPR*, 2016.

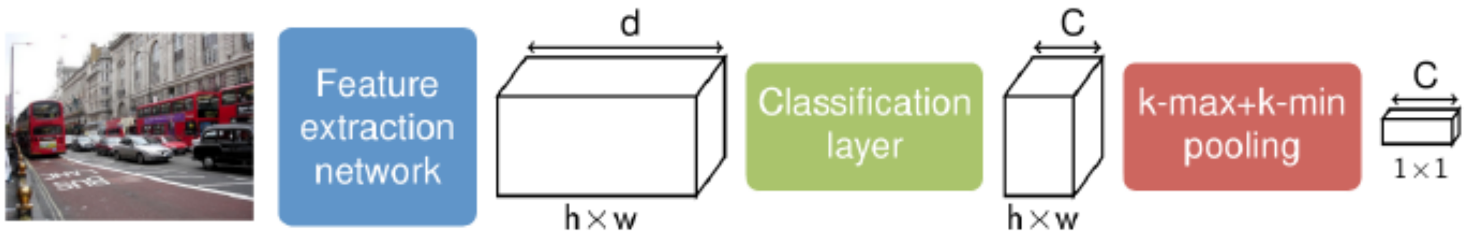
# Region-based strategy

- Deep MIL



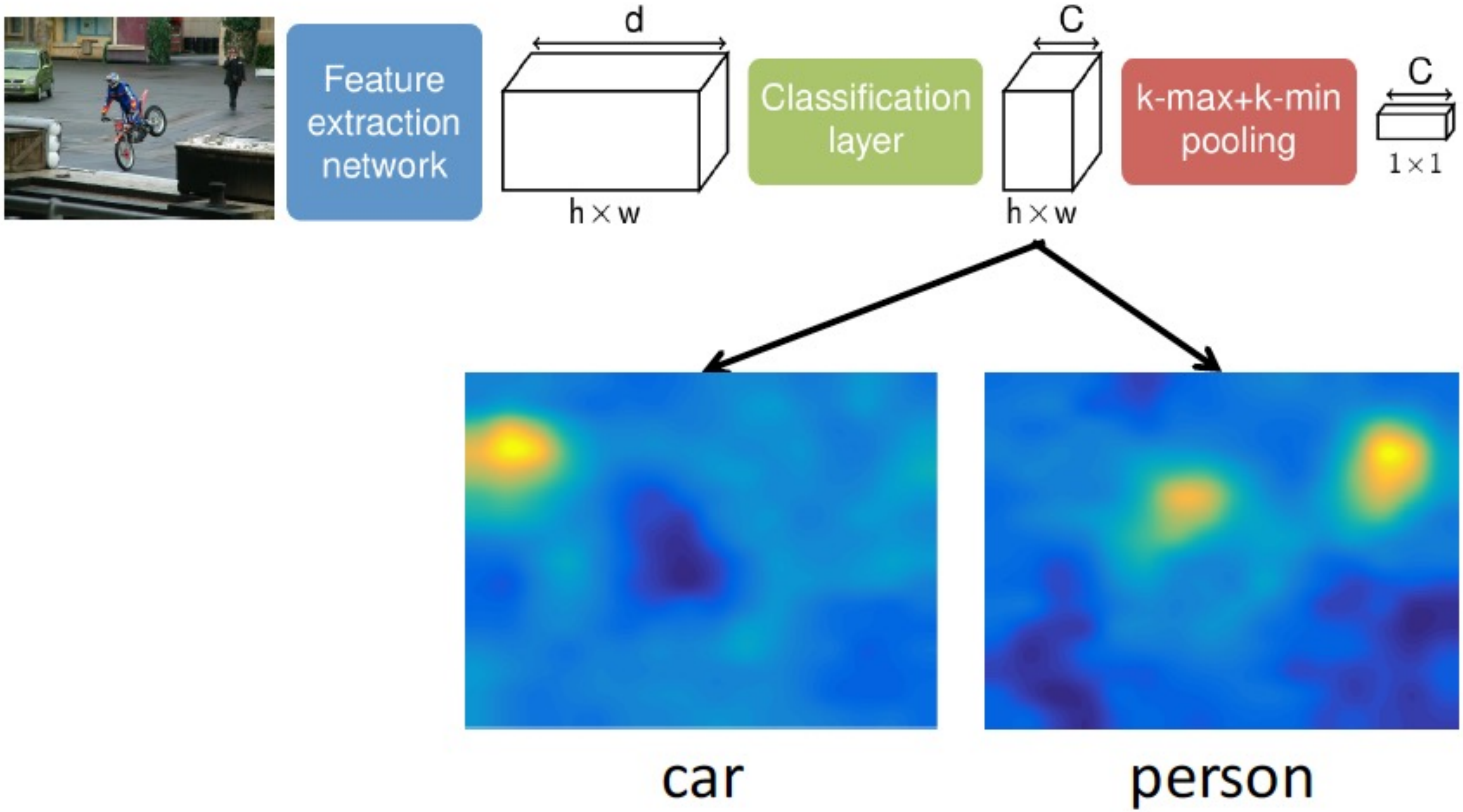

Maxime Oquab, Léon Bottou, Ivan Laptev and Josef Sivic
Is object localization for free? – Weakly-supervised learning with CNNs.
In *CVPR*, 2015.

- WELDON and ProNet [Sun, CVPR16]

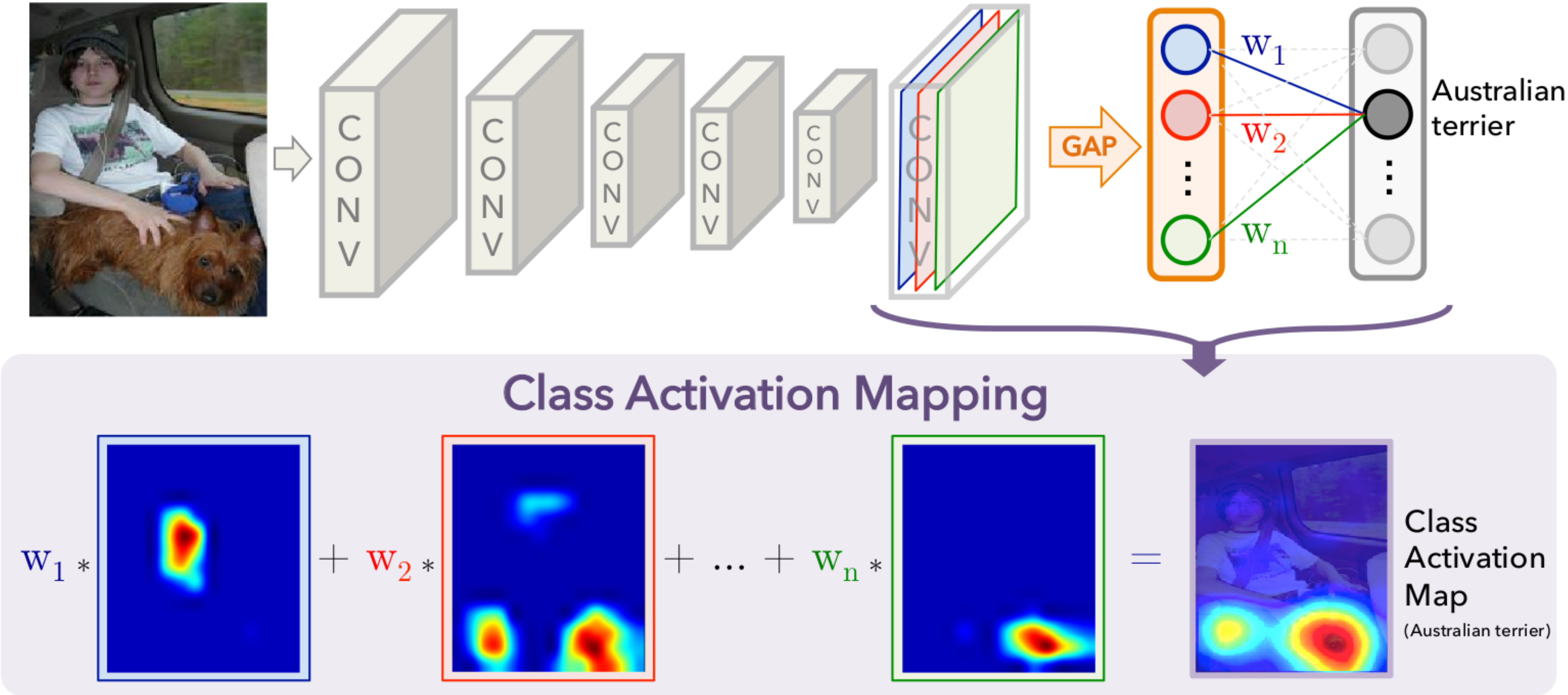



Thibaut Durand, Nicolas Thome, and Matthieu Cord
WELDON: Weakly Supervised Learning of Deep ConvNets.
In *CVPR*, 2016.

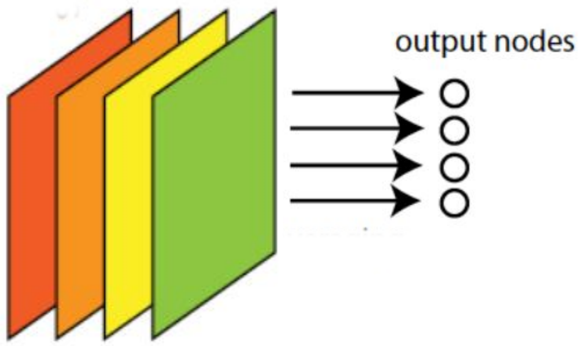
# Pixel contribution to the classification



# Pixel contribution to the classification



# Pooling schemes

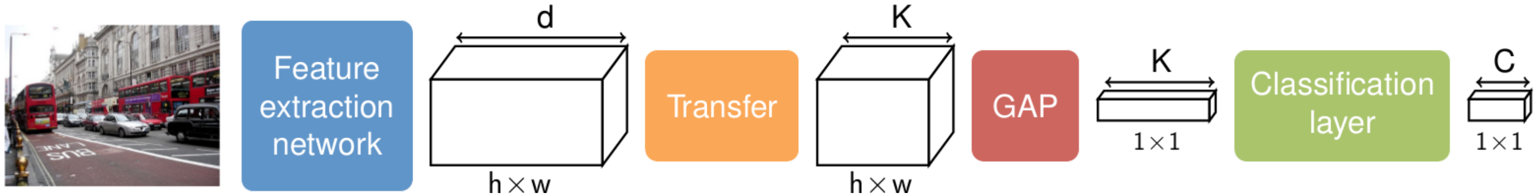



- Max [Oquab, CVPR15]

$$y^c = \max_{i,j} z_{ij}^c$$

- GAP [Zhou, CVPR16]

$$y^c = \frac{1}{N} \sum_{i,j} z_{ij}^c$$




- LSE [Pinheiro, CVPR15] / SPLeap [Kulkarni, ECCV16]

$$y^c = \frac{1}{\beta} \log \left( \frac{1}{N} \sum_{i,j} \exp(\beta \cdot z_{ij}^c) \right)$$

# Max pooling limitation

- Classifying only with the max scoring region

- Loss of contextual information

# Max pooling limitation

- Classifying only with the max scoring region

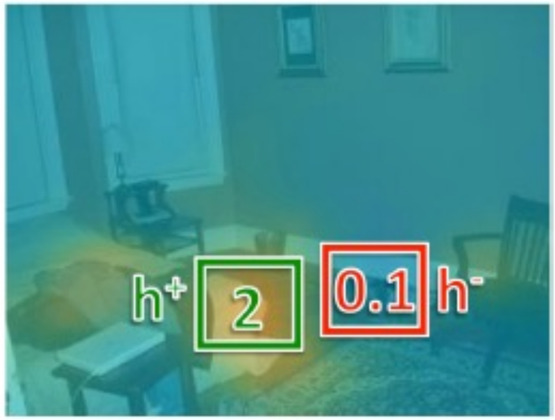
 

- Loss of contextual information

# WELDON: `max+min` pooling

- $\mathbf{h}^+$: presence of the class $\rightarrow$ high $\mathbf{h}^+$
- $\mathbf{h}^-$: localized evidence of the absence of class

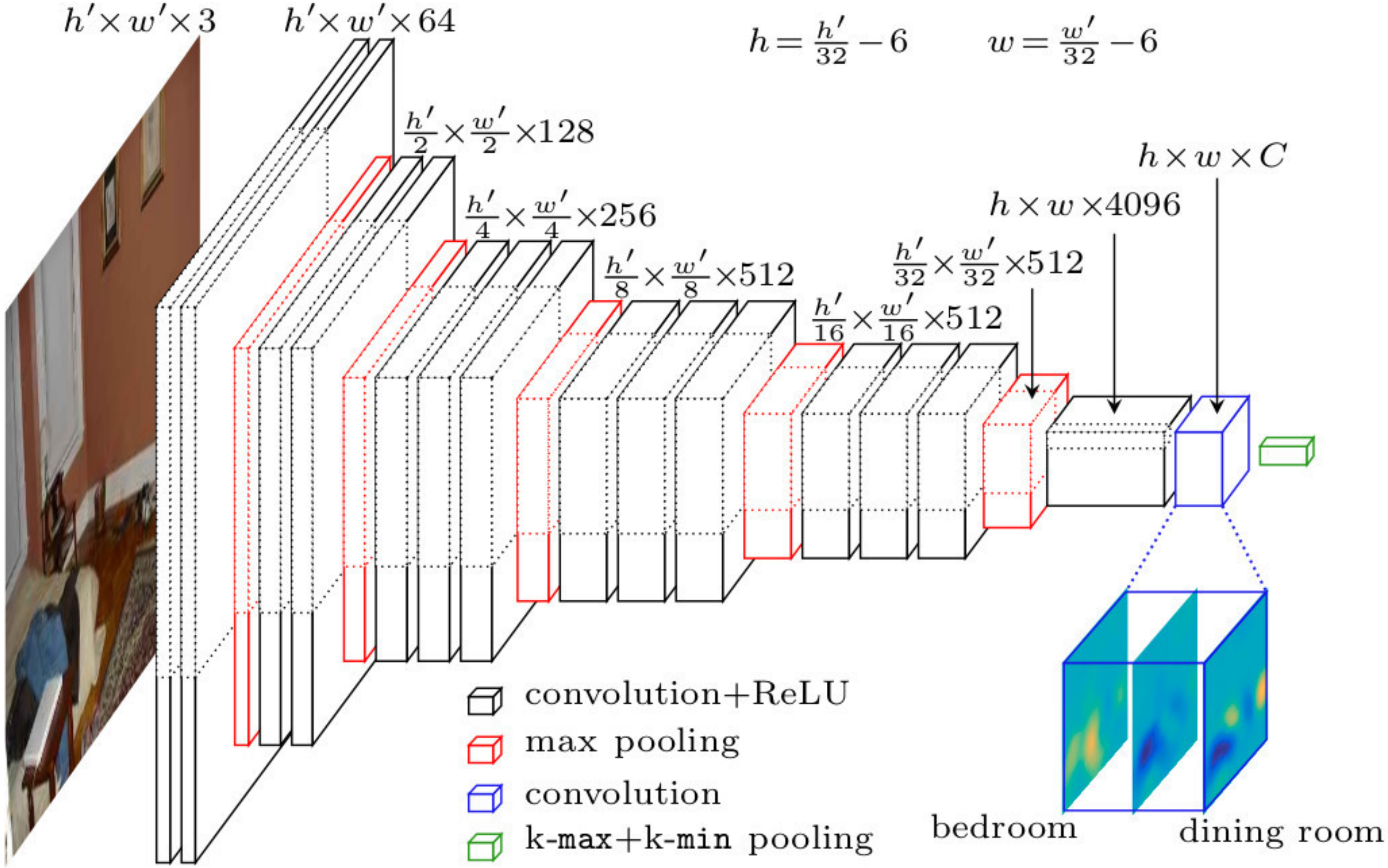
original image




bedroom

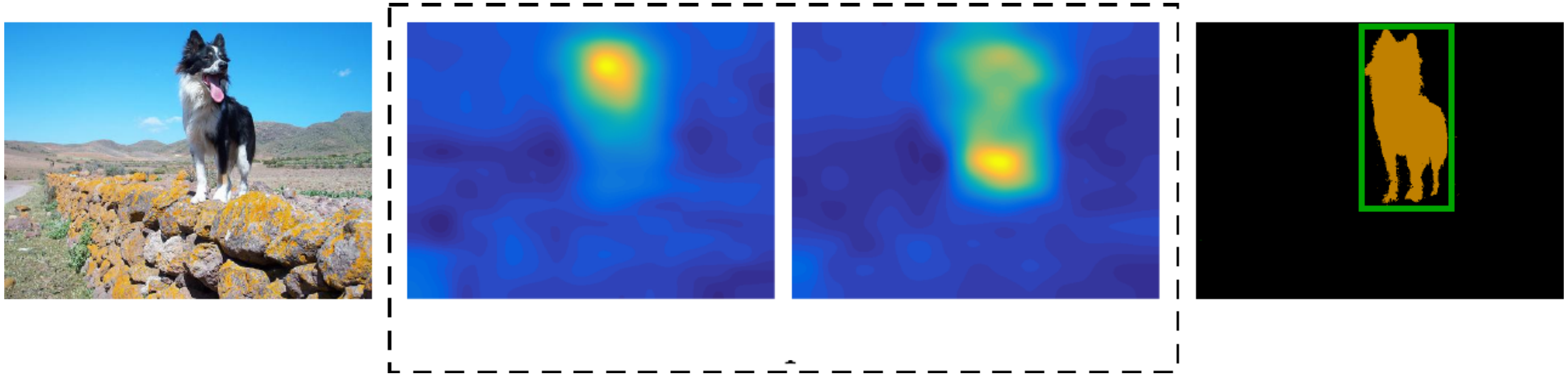

airport inside

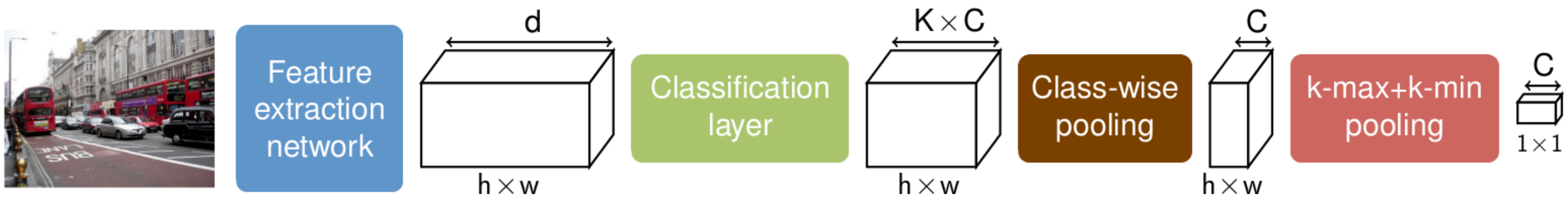

dining room

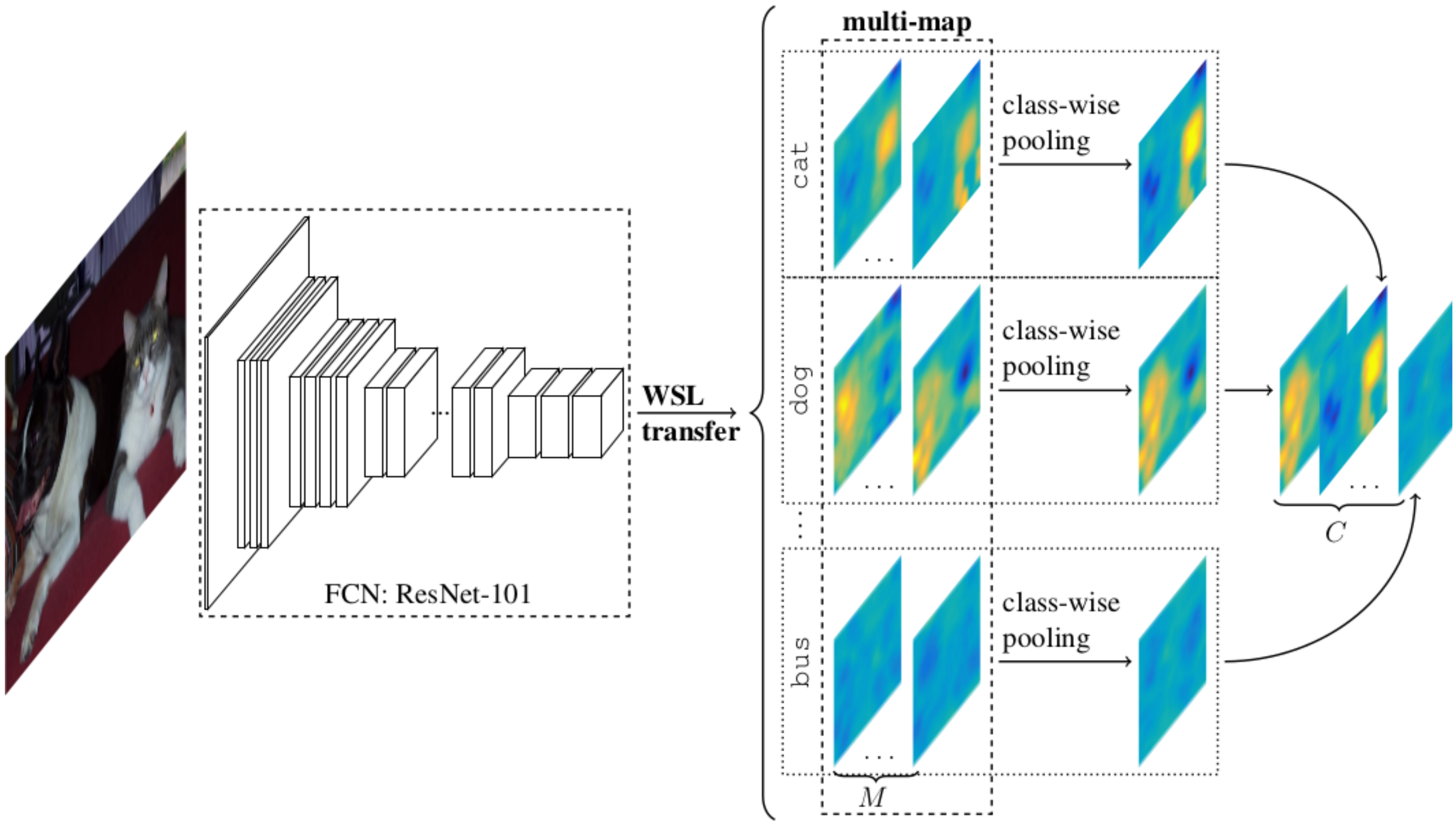


$h' \times w' \times 3$
$h' \times w' \times 64$
$h = \frac{h'}{32} - 6$
$w = \frac{w'}{32} - 6$
$\frac{h'}{2} \times \frac{w'}{2} \times 128$
$\frac{h'}{4} \times \frac{w'}{4} \times 256$
$\frac{h'}{8} \times \frac{w'}{8} \times 512$
$\frac{h'}{16} \times \frac{w'}{16} \times 512$
$\frac{h'}{32} \times \frac{w'}{32} \times 512$
$h \times w \times 4096$
$h \times w \times C$
convolution+ReLU
max pooling
convolution
k-max+k-min pooling
bedroom
dining room

- Generalization to $K$ models per class
- Catch multiple class-related modalities

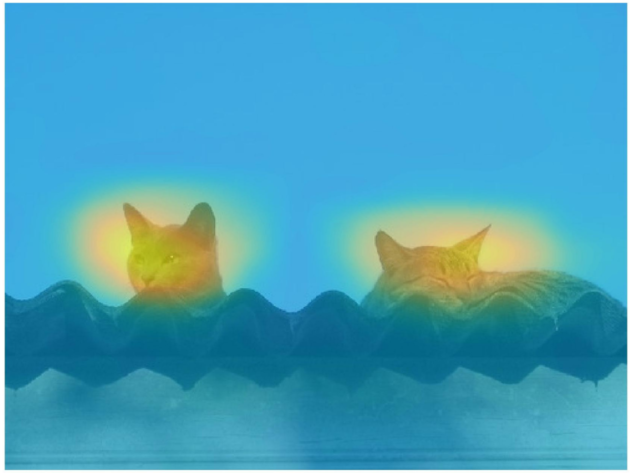





FCN: ResNet-101
WSL
transfer
multi-map
cat
dog
bus
class-wise
pooling
class-wise
pooling
class-wise
pooling
M
C

# Class activation maps

bus



cat

horse

aeroplane

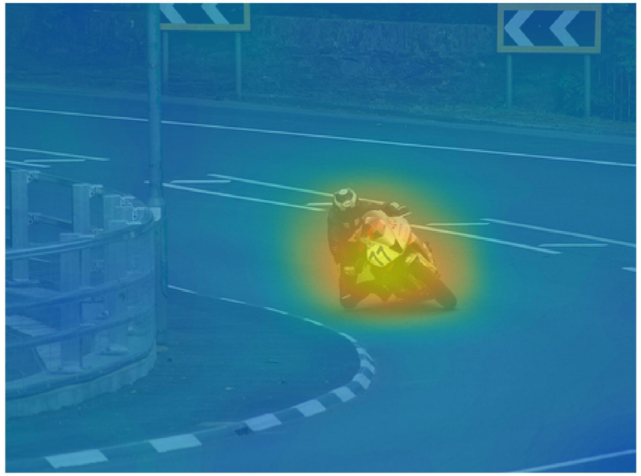
bottle

bicycle

# Class activation maps

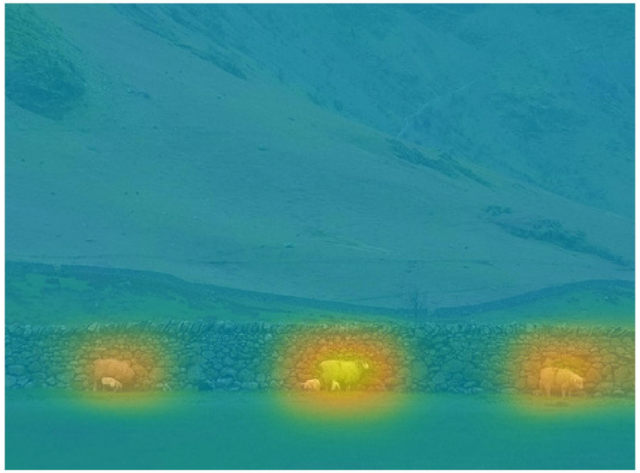
bicycle

bird



motorbike

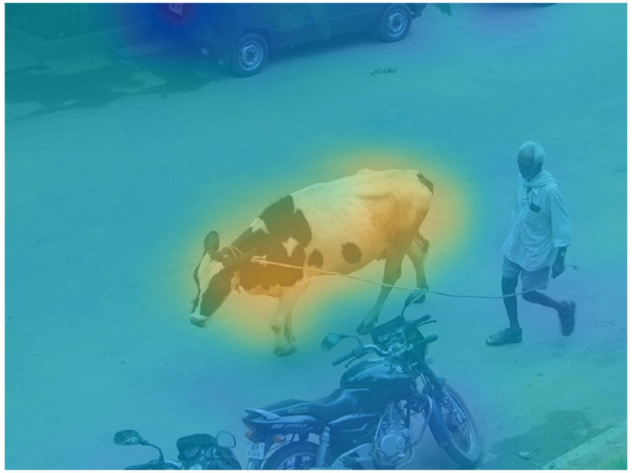

person



sheep

bird

# Class activation maps



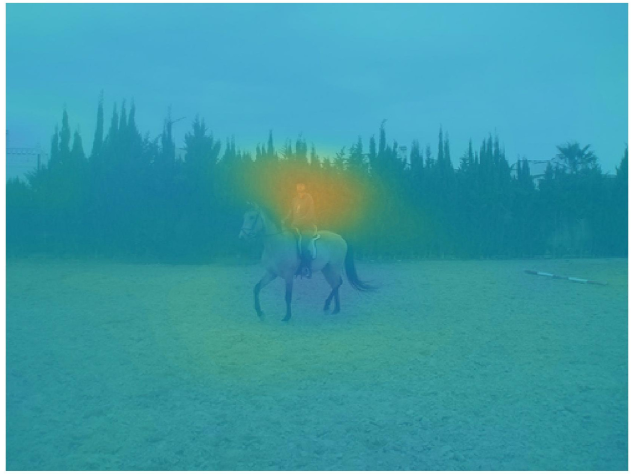
cow

motorbike

horse

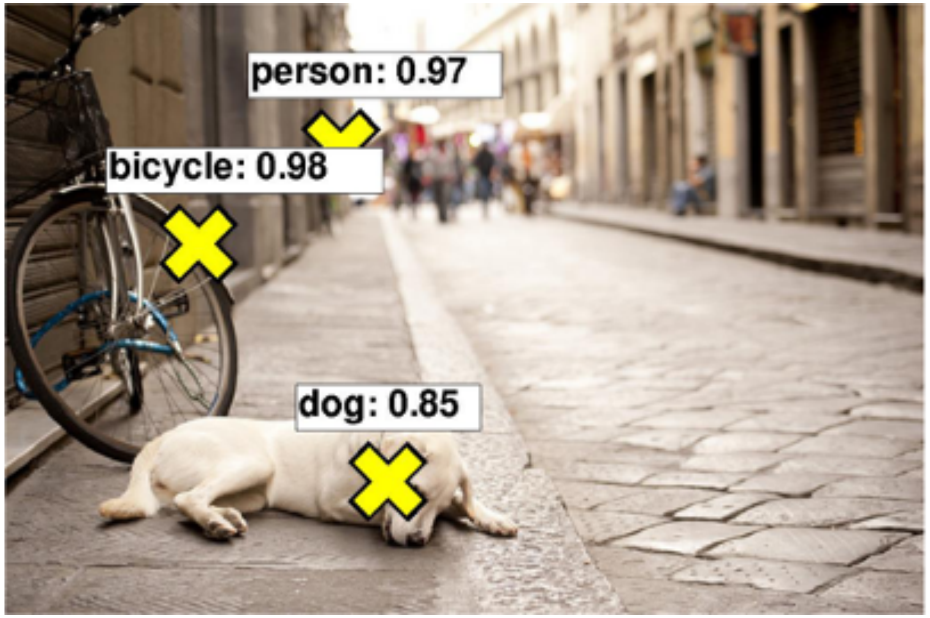
person

car



person

# Visual recognition task: localization

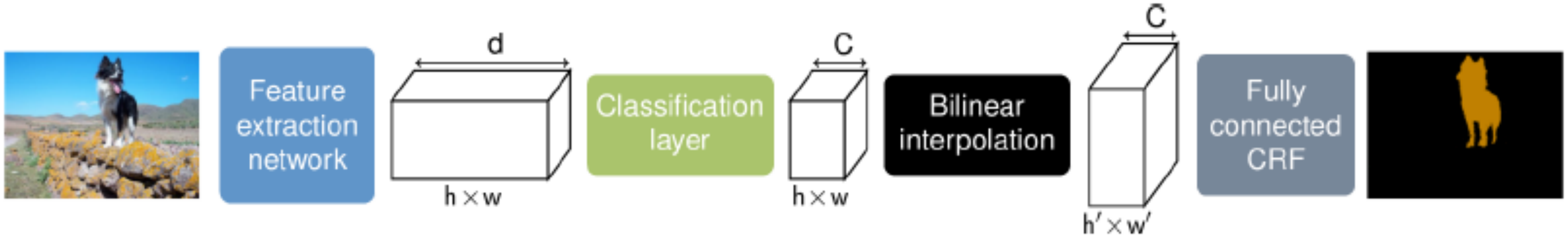




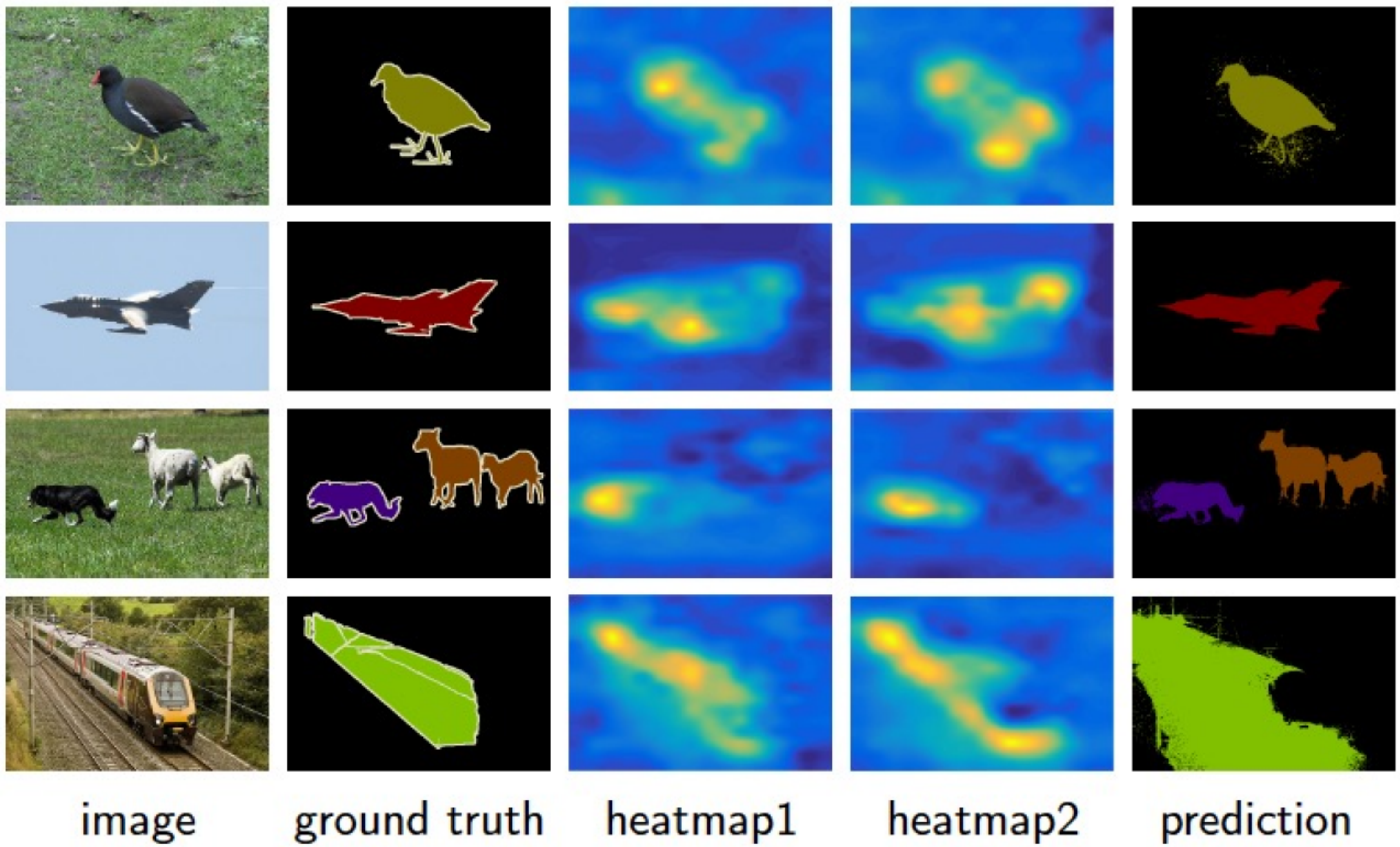
| Method | VOC 2012 | MS COCO |
|---|---|---|
| Deep MIL | 74.5 | 41.2 |
| ProNet | 77.7 | 46.4 |
| WSLocalization | 79.7 | 49.2 |

# In preview Segmentation

- WSL segmentation framework
  - Learning with image-level labels (presence/absence of the class)
  - Difficult task: no information about location and extend of objects
- Localized features in spatial maps
- Deep + fully connected CRFs



# In preview Segmentation



# Outline

Beyond ImageNet

1. Fully Convolutional Networks (FCNs)
2. **Supervised Segmentation with Deep ConvNets**
    1. F-CN Fully Convolutional Network
    2. DeepLab approach for supervised segmentation
    3. Deconvolution Networks

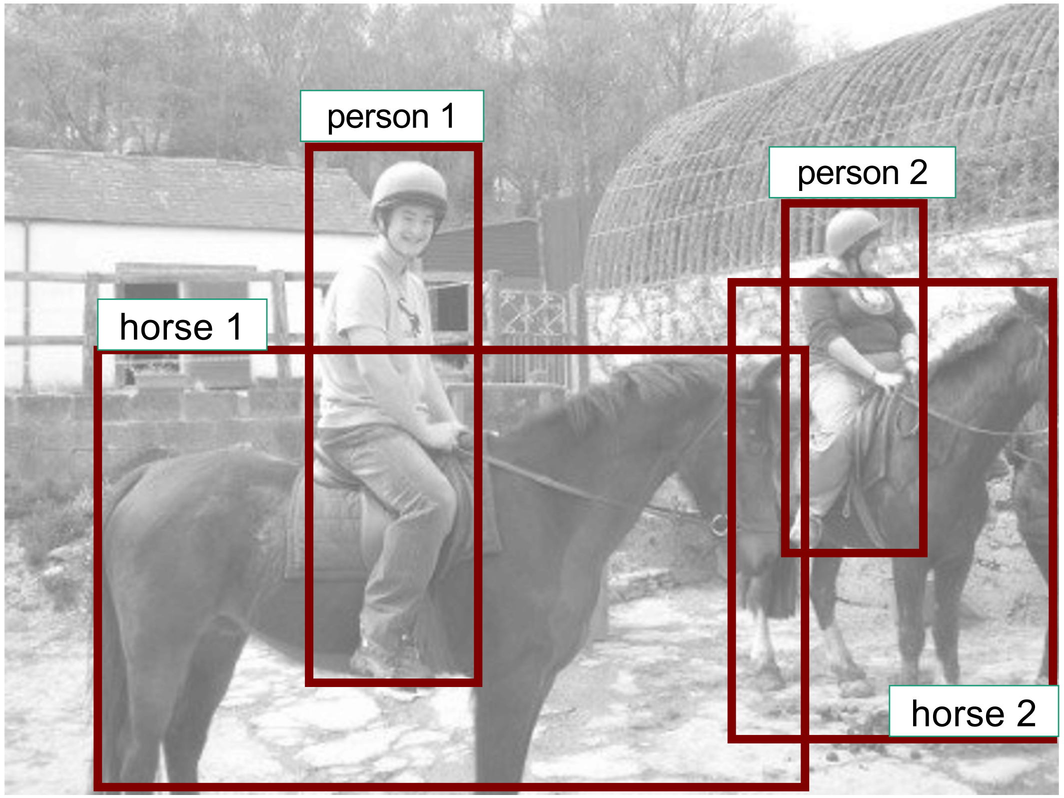
# Segmentation: definitions

# Def1: **Semantic** Segmentation

*Label each pixel with a category label*

# Object Detection

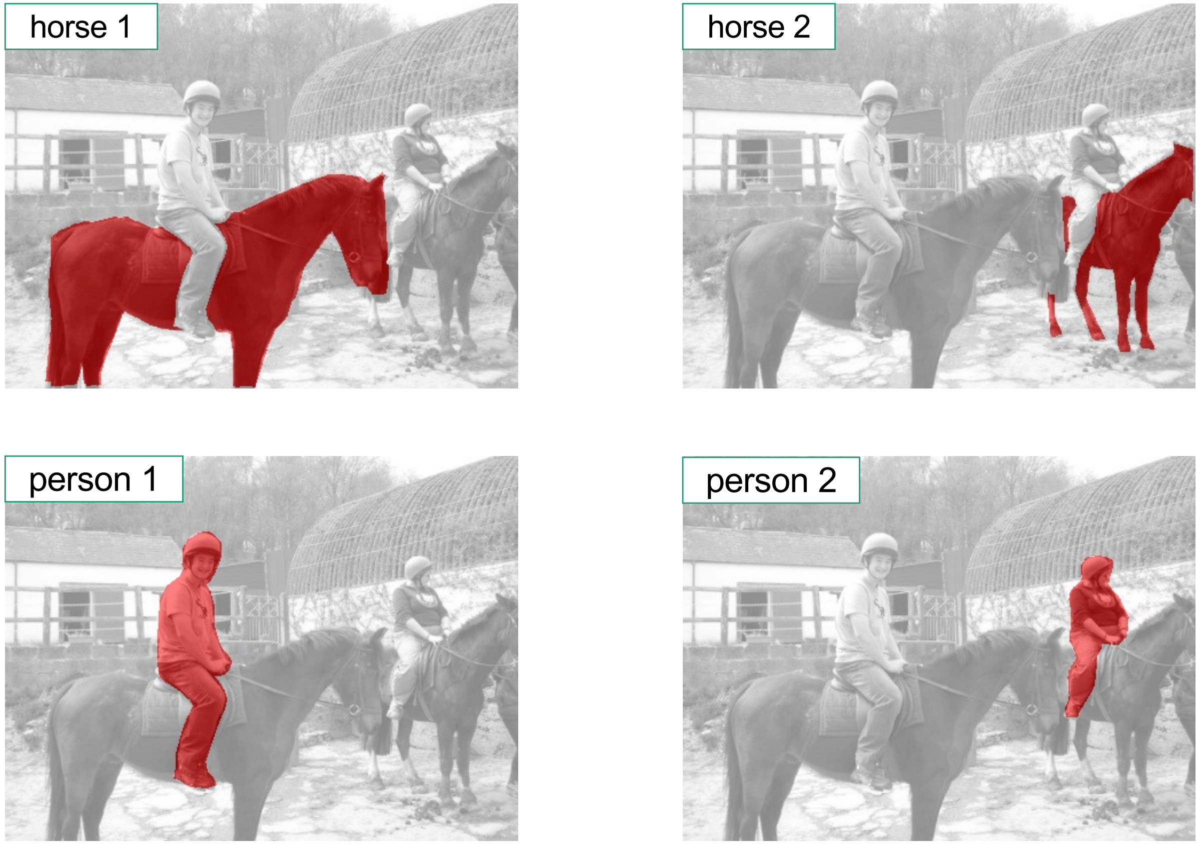
*Detect every instance of the category and localize it with a bounding box.*



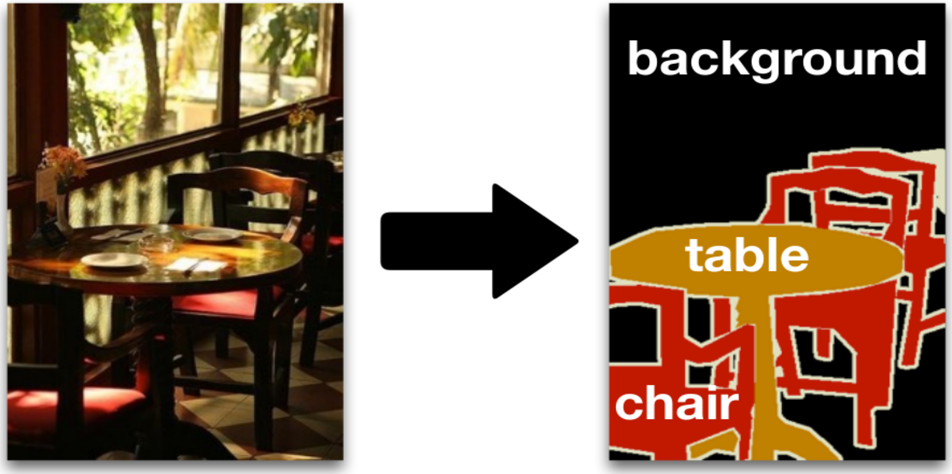
# Def2: **Instance** segmentation

Simultaneous Detection and Segmentation

*Detect and segment every instance of the category in the image*



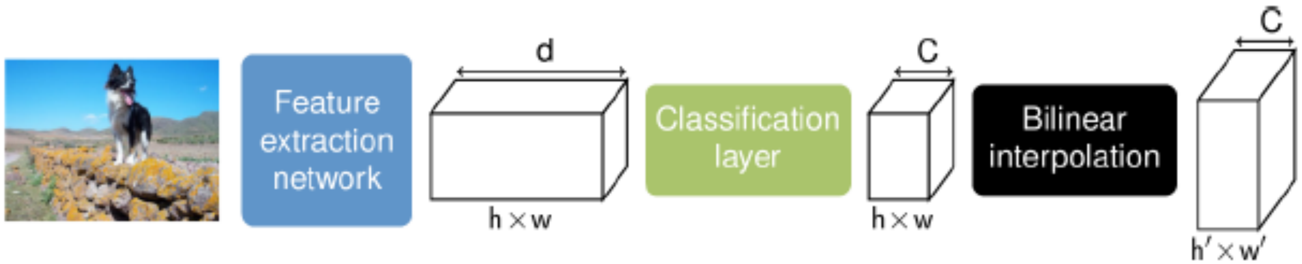
# **Supervised** Segmentation with Deep ConvNets



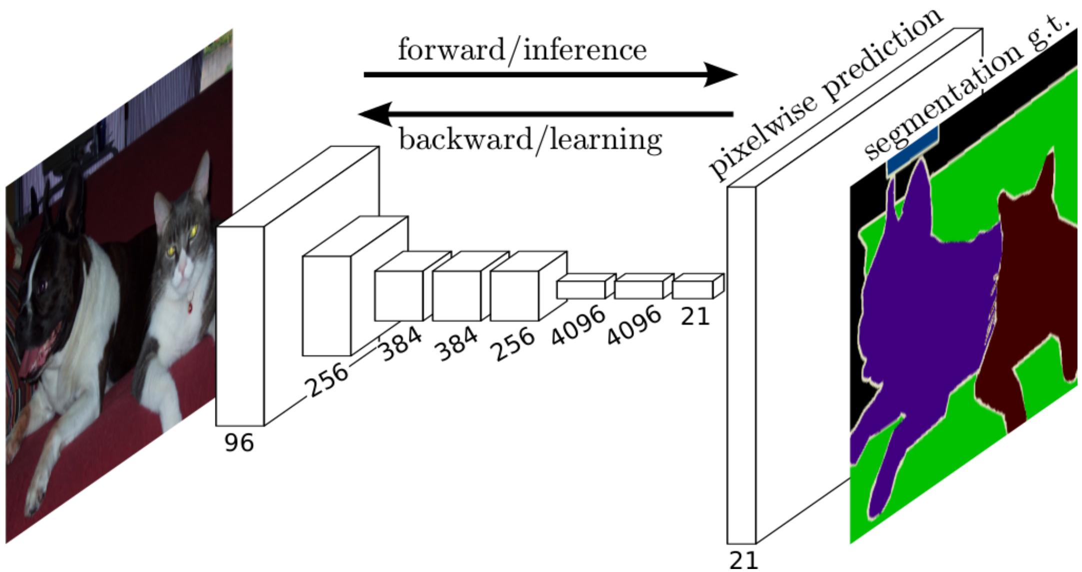

1. **F-CN Fully Convolutional Network**
2. DeepLab approach for supervised segmentation
3. Deconvolution Networks

# **Supervised** Segmentation with Deep ConvNets

## F-CN Fully Convolutional Network




- Fully-convolutional network: classify each "pixel"
- Upsampling output (bilinear interpolation + deconvolution)
- Network architecture: AlexNet, VGG16, GoogleNet
- Loss: soft-max per pixel



# **Supervised** Segmentation with Deep ConvNets

## F-CN Fully Convolutional Network

Learning process

1. Model pretrained on ImageNet
2. Decapitate each net by discarding the final classifier layer
3. Convert all fully-connected layers to convolutions
4. Append $n$[1] $1 \times 1$ convolutions
5. Fine-tuning all layers by backpropagation

[1] n=number of classes

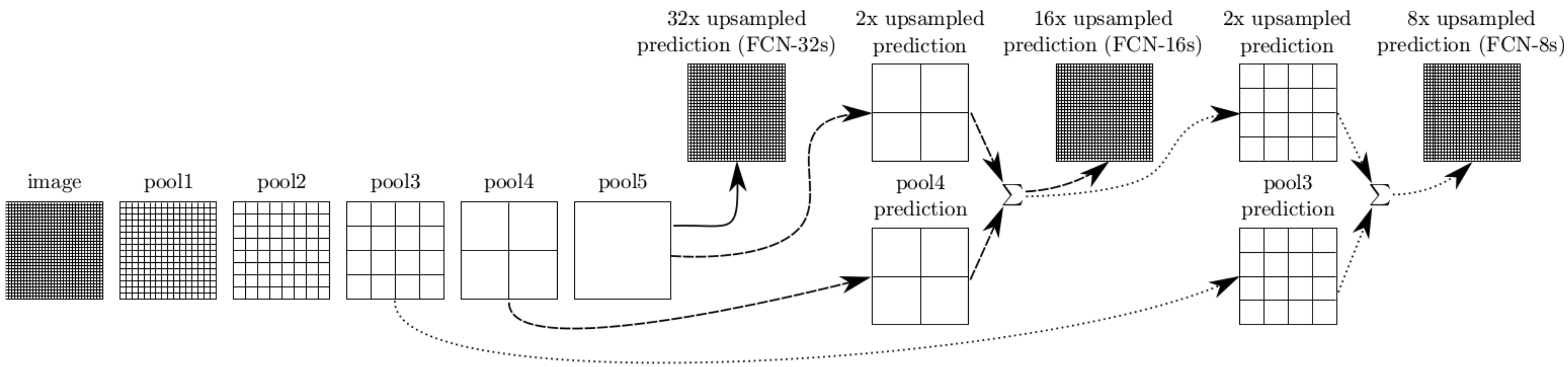
# **Supervised** Segmentation with Deep ConvNets

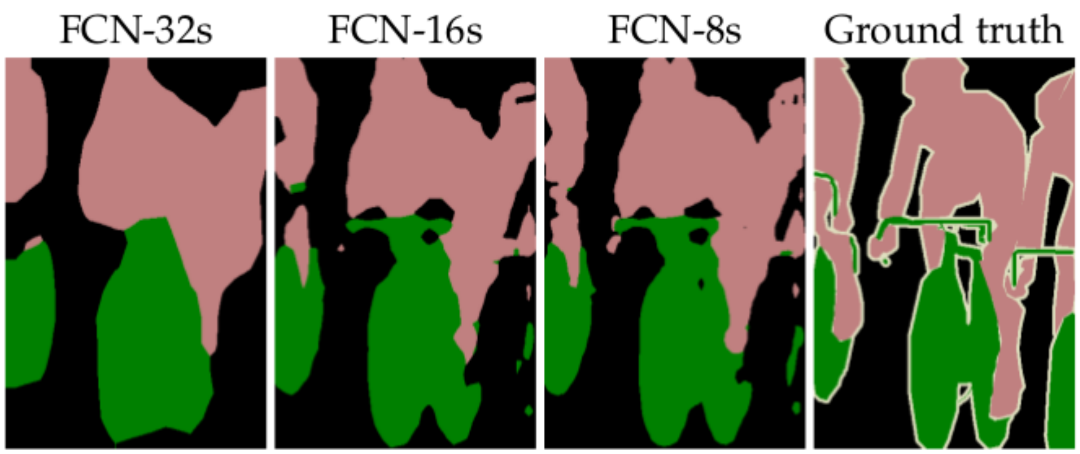
## F-CN Fully Convolutional Network

- Problem: max pooling and striding reduces spatial resolution

Solution of the FCN approach

- Dense prediction: combines feature hierarchies
- Initialized with the parameters of coarse net
- Fine-tuning all layers by backpropagation



# **Supervised** Segmentation with Deep ConvNets

1. F-CN Fully Convolutional Network
2. **DeepLab approach for supervised segmentation**
3. Deconvolution Networks

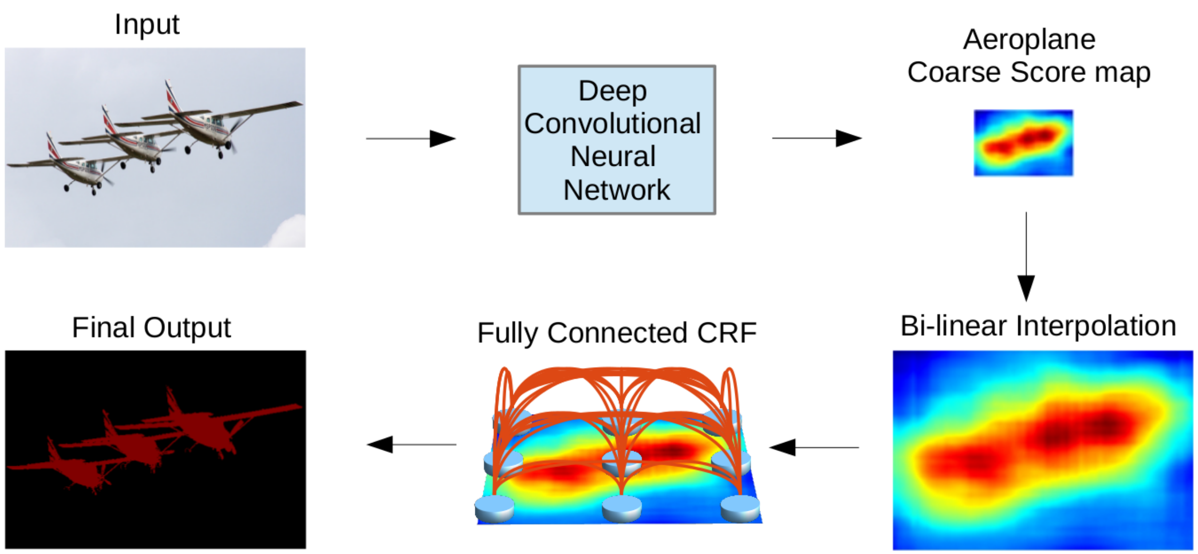
# **Supervised** Segmentation with Deep ConvNets

## DeepLab (v123) approach for supervised segmentation

### Problem of the spatial resolution reduction

Solution of the DeepLab approach

1. Learn CNN for dense prediction tasks (Atrous)
2. Improve the localization of object boundaries with fully-connected CRF [?] (FC-CRF)



# **Supervised** Segmentation with Deep ConvNets

## DeepLab approach: **Atrous filtering** algo

- Remove the down-sampling from the last pooling layers.
- Up-sample the original filter by a factor of the strides:

  Atrous convolution for 1-D signal:

$$y[i] = \sum_{k=1}^{K} x[i + r \cdot k] w[k]$$

Introduce zeros between filter values

$x[i]$ 1-D input signal

$w[k]$ filter of length $K$

$r$ *rate* parameter corresponds to the stride with which we sample the input signal.

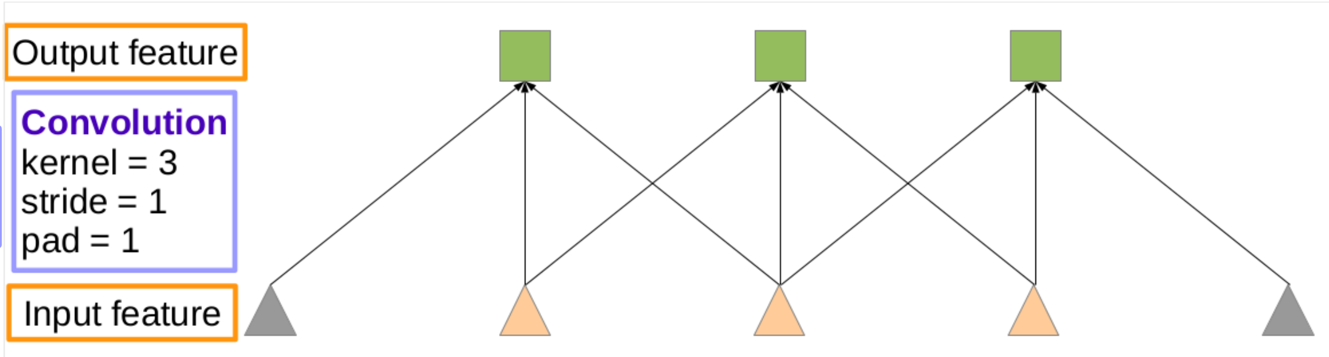
$y[i]$ output of atrous convolution.

- Note: standard convolution is a special case for *rate* $r$=1.

# **Supervised** Segmentation with Deep ConvNets

## Classical filtering/pooling/downsampling

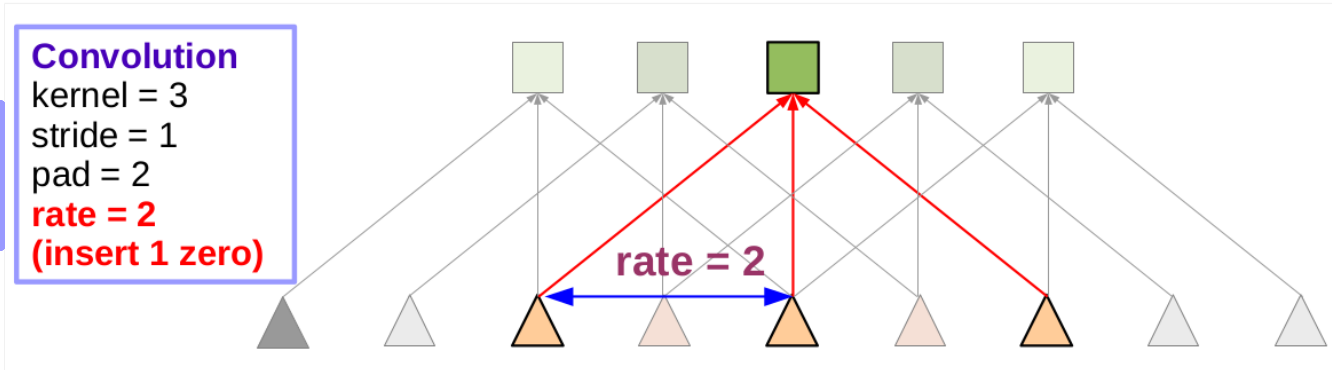
Downsampling
+




+
Upsampling

## DeepLab approach: **Atrous filtering** algo

NO
downsampling



# **Supervised** Segmentation with Deep ConvNets

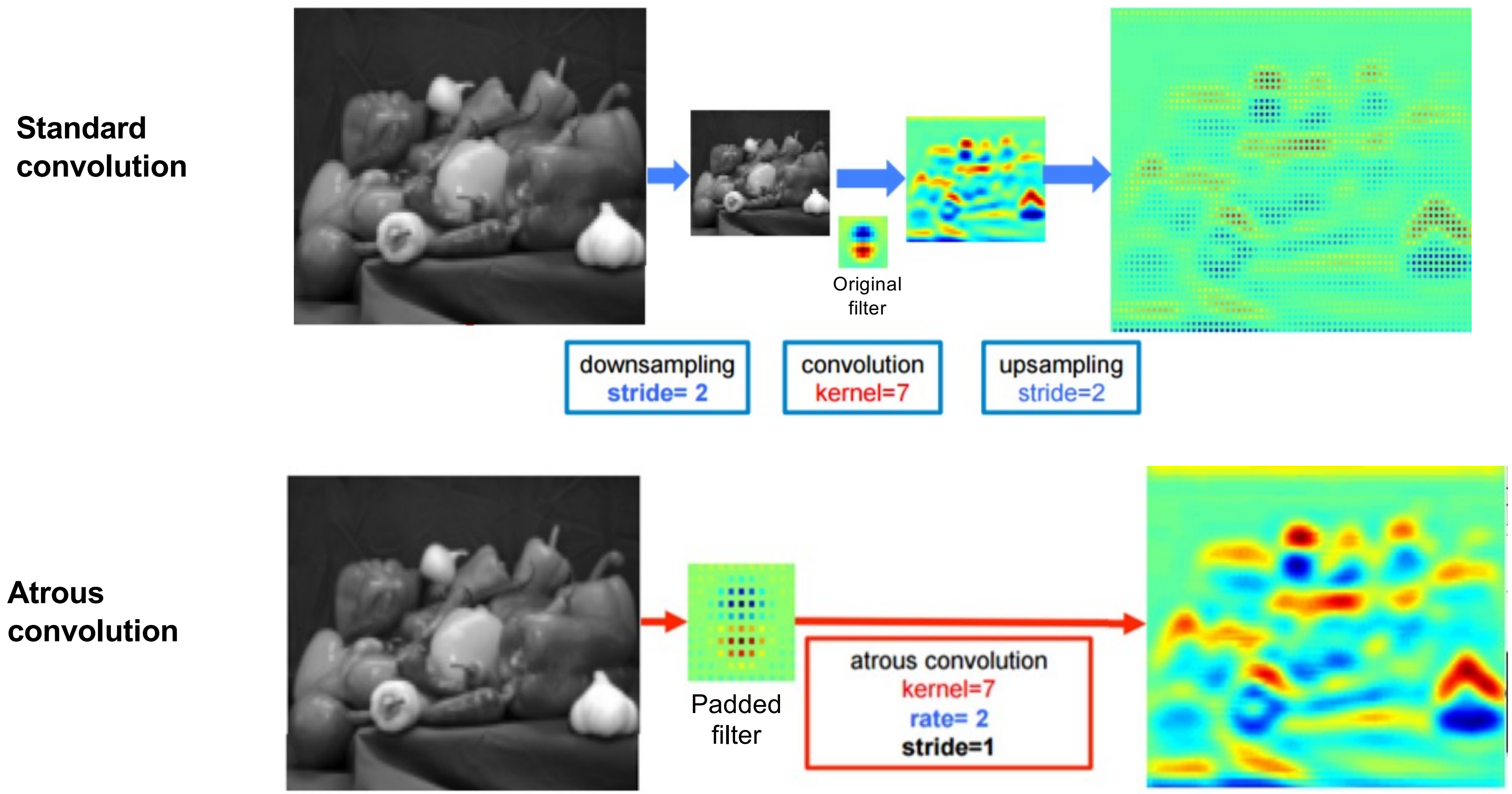
## DeepLab approach: **Atrous filtering** algo

### Filters field-of-view

- **Small** field-of-view → accurate **localization**
- **Large** field-of-view → **context** assimilation
- 'Holes': Introduce zeros between filter values.
- **Effective filter size increases** (enlarge the **field-of-view** of filter): $k \times k$ filter to $k_e = k + (k-1)(r-1)$
- However, we take into account **only** the **non-zero** filter values:
  - ✓ Number of filter parameters is the same.
  - ✓ Number of operations per position is the same.

# **Supervised** Segmentation with Deep ConvNets

## DeepLab approach: **Atrous filtering** algo



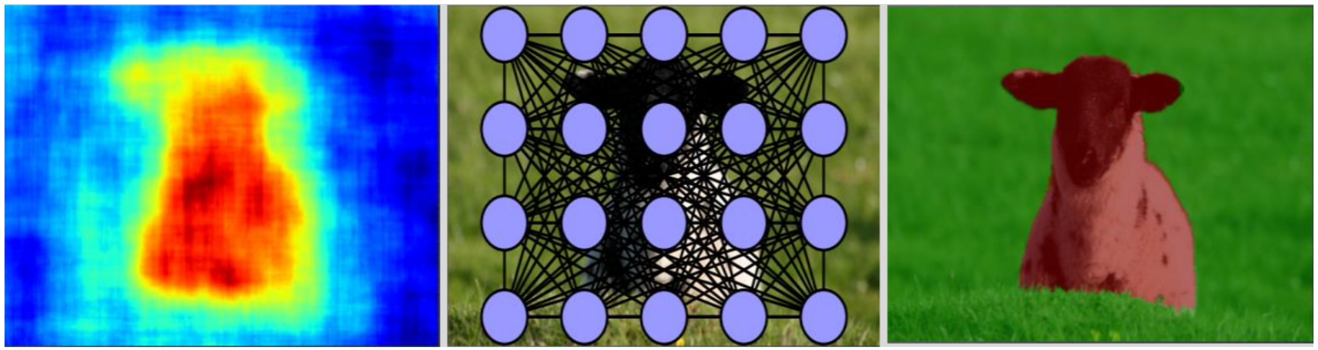
# **Supervised** Segmentation with Deep ConvNets

## DeepLab: Fully-Connected CRF

- Problem: poor object delineation (spatial and appearance consistency neglected)
- Solution: fully-connected CRF accounts for contextual information in the image

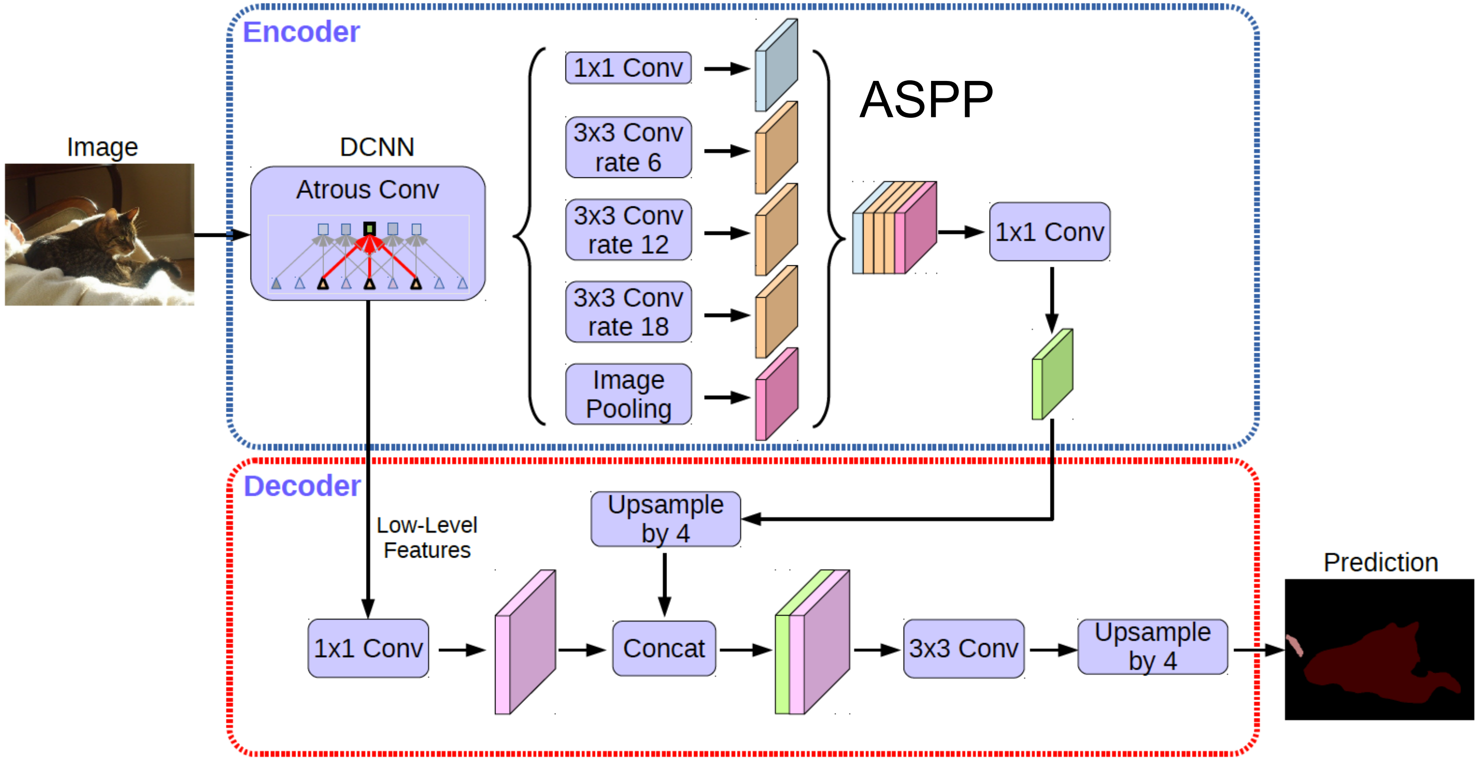
$$E(\mathbf{y}) = \sum_i \theta_i(y_i) + \sum_{i,j} \theta_{ij}(y_i, y_j)$$

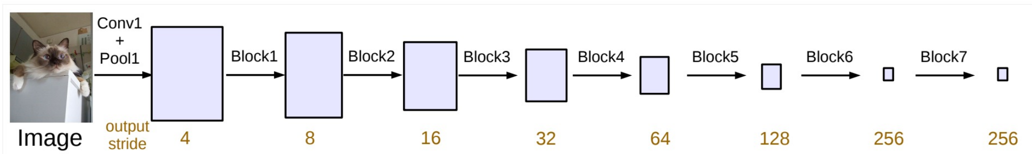
  - Unary term: output of FCN (upscaled)
  - Pairwise term: penalizes similar pixels having different labels



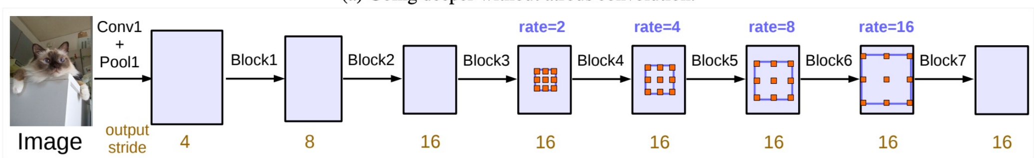
# **Supervised** Segmentation with Deep ConvNets

- DeepLab V3+ [ECCV 2018]




(a) Going deeper without atrous convolution.




(b) Going deeper with atrous convolution. Atrous convolution with $rate > 1$ is applied after block3 when $output\_stride = 16$.
Figure 3. Cascaded modules without and with atrous convolution.

# **Supervised** Segmentation with Deep ConvNets

1. F-CN Fully Convolutional Network
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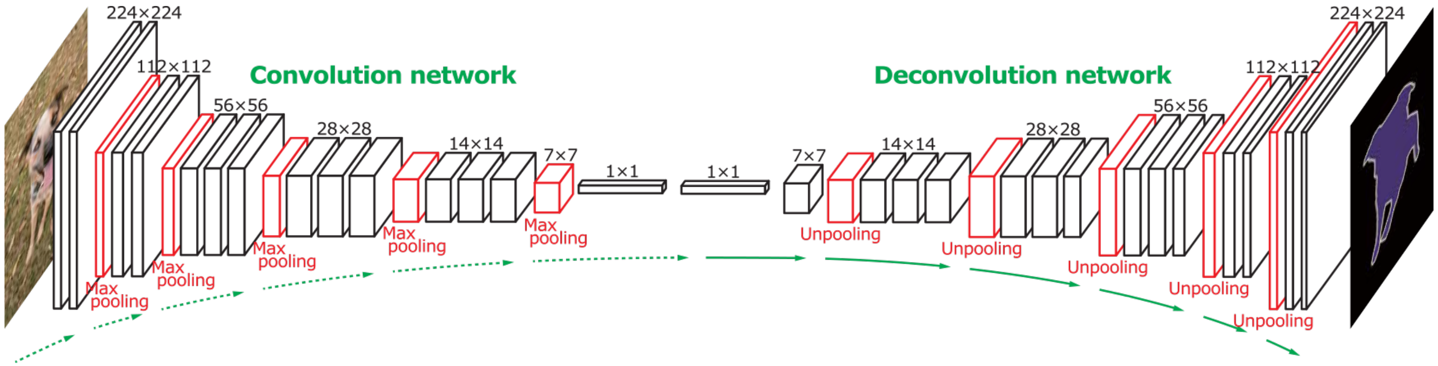
3. **Deconvolution Networks**

# **Supervised** Segmentation with Deep ConvNets

## Deconvolution Network

- Learn a multi-layer deconvolution network
- Network is composed of two parts:
  1. Convolution: feature extractor
  2. Deconvolution: shape generator that produces object segmentation from the feature extracted
- Deconvolution net is a mirrored version of the convolution net



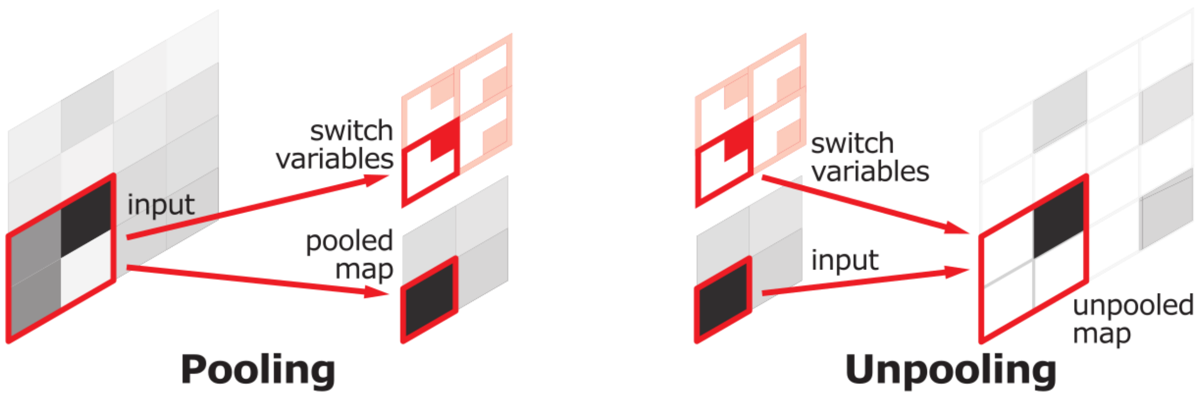

Hyeonwoo Noh, Seunghoon Hong, and Bohyung Han.
Learning deconvolution network for semantic segmentation.
In *ICCV*, 2015. [paper]

# **Supervised** Segmentation with Deep ConvNets

## Deconvolution Network

### Unpooling

- Perform the reverse operation of pooling
- Reconstruct the original size of activations
- Useful to reconstruct the structure of input object
- Output: sparse activation map

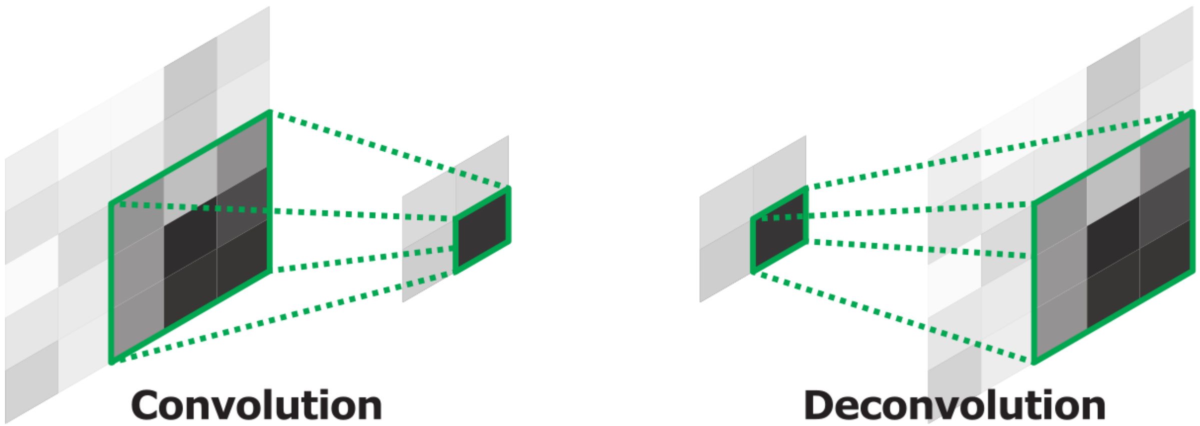


# **Supervised** Segmentation with Deep ConvNets

## Deconvolution Network

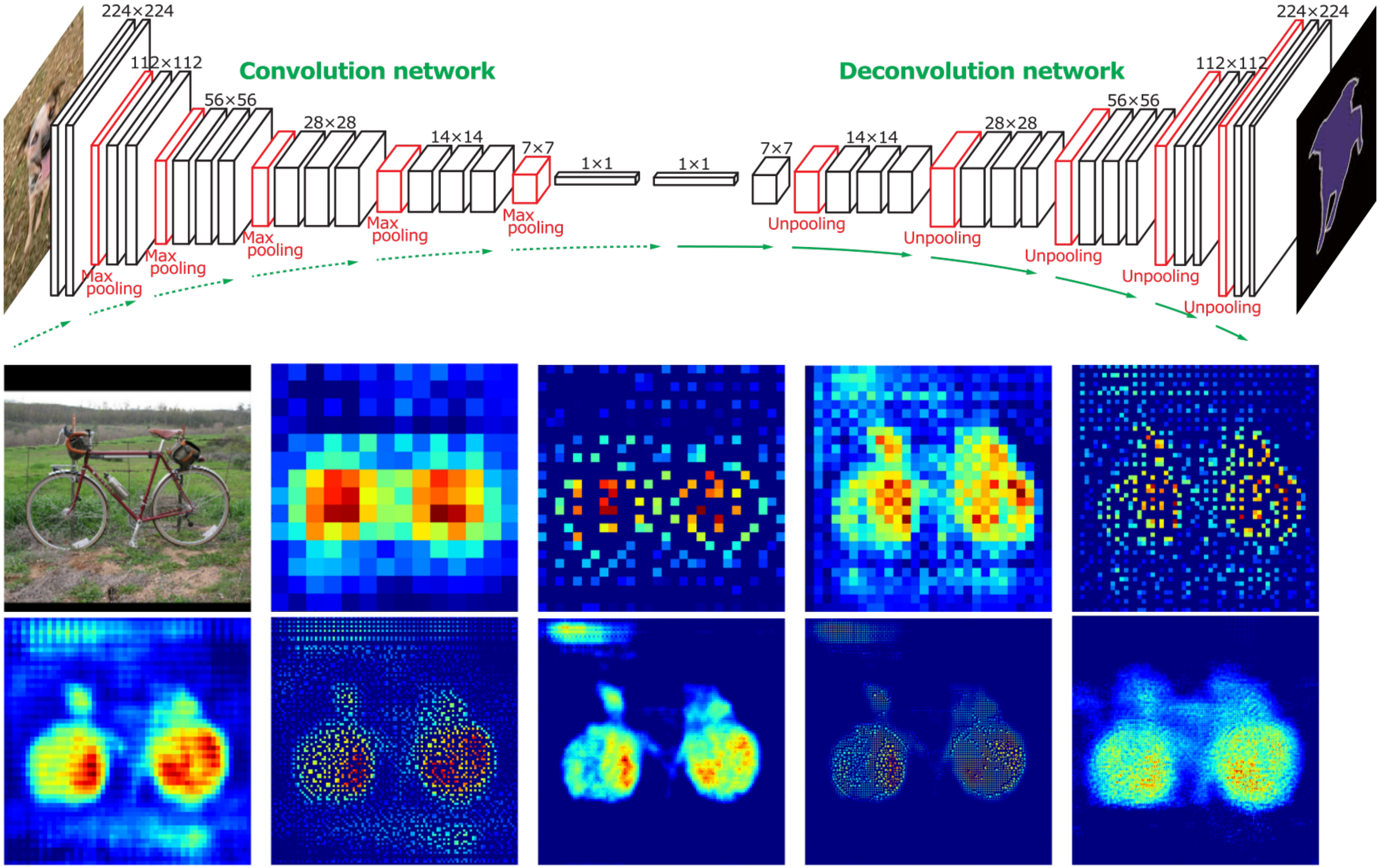
### Deconvolution

- Connect single input activation to a multiple activations
- Learned filters correspond to bases to reconstruct shape of an input object
- Output: enlarged and dense activation map



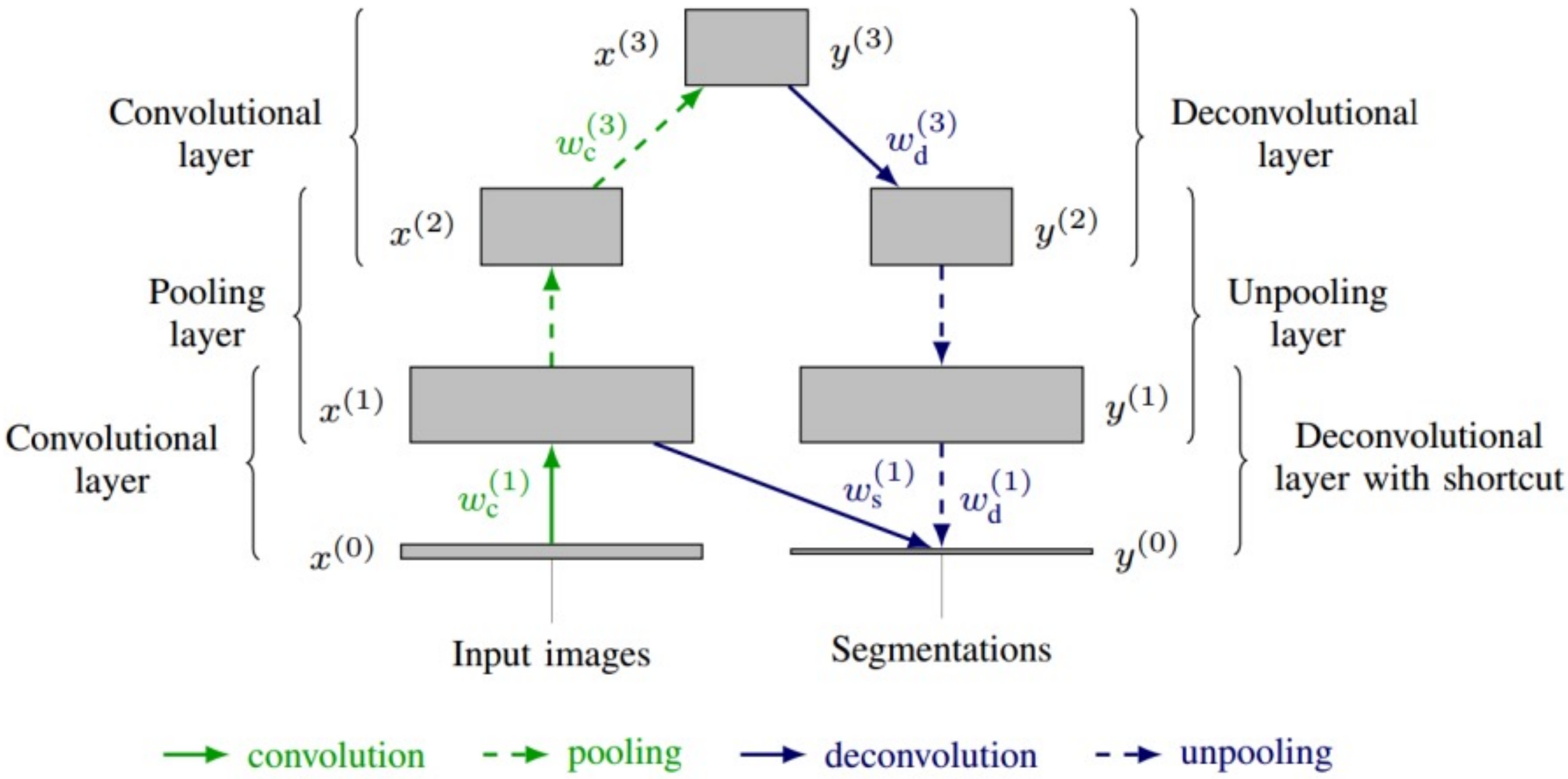
# **Supervised** Segmentation with Deep ConvNets

Deconvolution Net: hourglass structure + unpooling switch variables



# **Supervised** Segmentation with Deep ConvNets

Deconvolution Net + shortcut connection



# **Supervised** Segmentation with Deep ConvNets

U-Net:
Hourglass/U shape Net
+ shortcut connection
by feature copies

Very popular in medical
Works well with low
training data

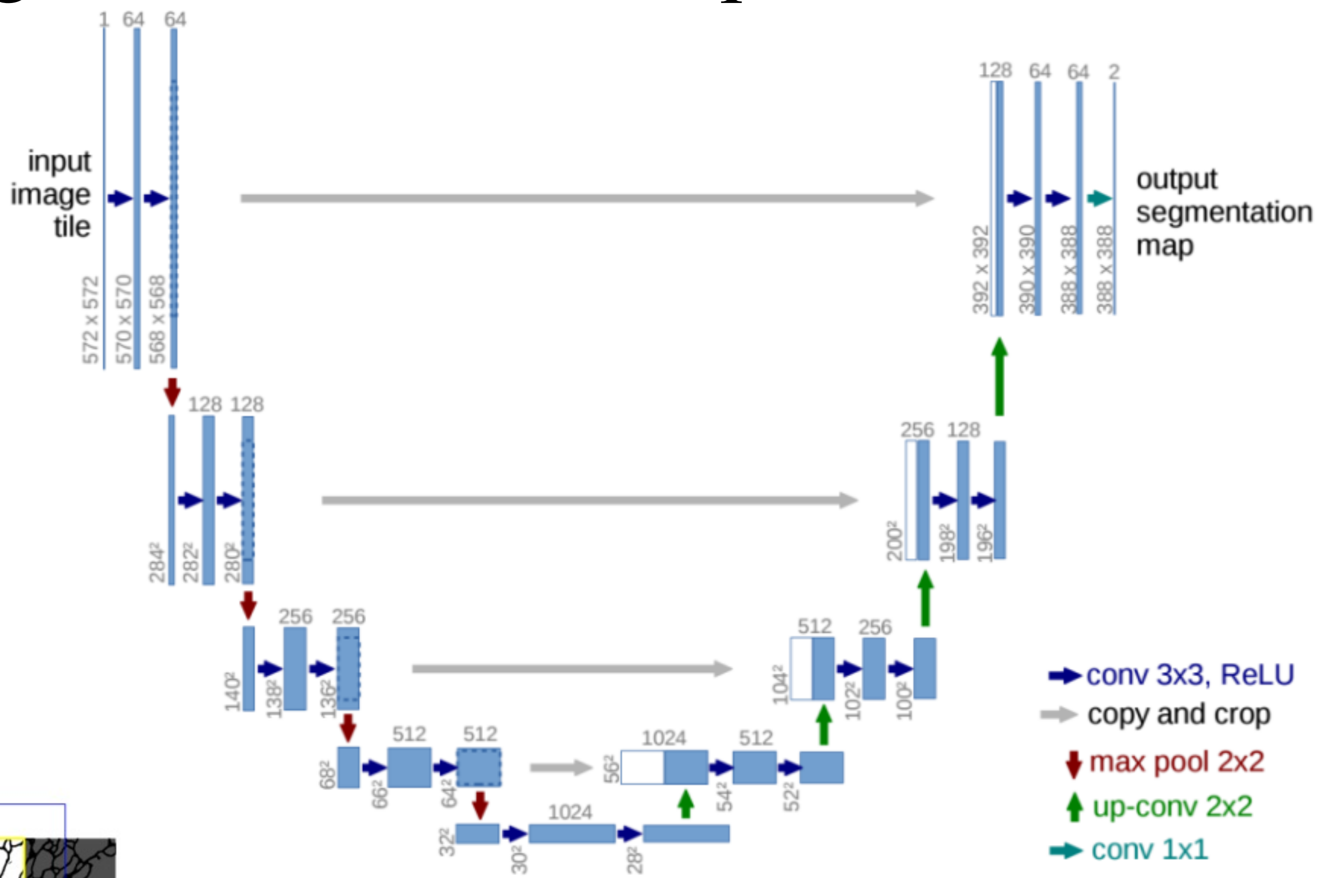



**Fig. 1.** U-net architecture (example for 32x32 pixels in the lowest resolution). Each blue box corresponds to a multi-channel feature map. The number of channels is denoted on top of the box. The x-y-size is provided at the lower left edge of the box. White boxes represent copied feature maps. The arrows denote the different operations.

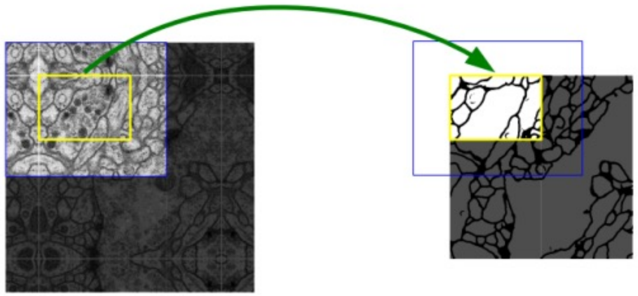


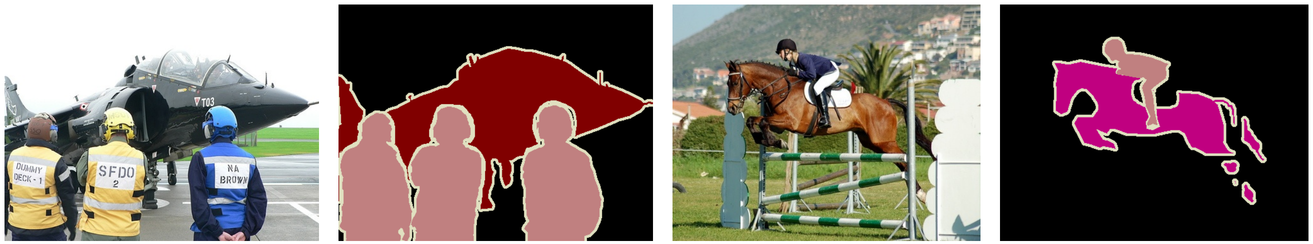
**Fig. 2.** Overlap-tile strategy for seamless segmentation of arbitrary large images (here segmentation of neuronal structures in EM stacks). Prediction of the segmentation in the yellow area, requires image data within the blue area as input. Missing input data is extrapolated by mirroring

http://deeplearning.net/tutorial/unet.html

# Extra: Datasets

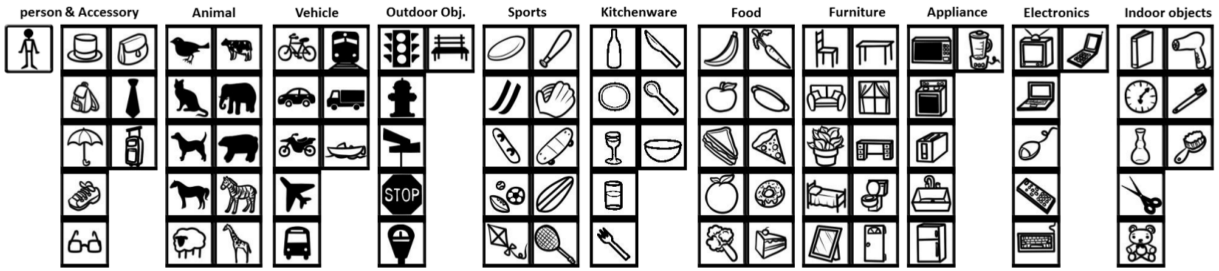
# PASCAL VOC 12

- Train 1464 images / Val 1449 images / Test 1456 images
- 21 classes: *aeroplane, bicycle, bird, boat, bottle, bus, car, cat, chair, cow, dining table, dog, horse, motorbike, person, potted plant, sheep, sofa, train, tv/monitor* + background
- Evaluation: intersection-over-union metric
- Webpage: `http://host.robots.ox.ac.uk/pascal/VOC/voc2012/`



# COCO

- Train 80k images / Val 20k images
- 91 classes, 11 super-categories:




- 3 challenges: detection, instance segmentation, captioning
- Webpage: `http://mscoco.org` [paper]

# Extra: Weakly Supervised Segmentation

# Supervised Image Segmentation Methods

## Full supervision

- Precise annotation ☺
- Expensive and time consuming to obtain
  - "79s per label per image" [RBFL15] ☹
- Bottleneck for learning models at large scale ☹

# Weakly Supervised Image Segmentation Methods

## Weak supervision

- Reduce supervision: class labels (or tags) ☹ ☹
- Cheap to obtain
  - "1s per label per image" [RBFL15] ☺
- Scalable to large number of categories ☺

✓ background
✗ aeroplane
✗ cat
✓ chair
✗ dog
✗ person
✗ sheep
✓ table
✗ tvmonitor

# Weakly supervised segmentation with CNN

## Standard learning algorithms

- Maximize the likelihood of the observed training data

## Problem

- Require full knowledge of the ground truth labeling
  - not available in the weakly supervised setting ☹

## Solutions

1. Generation of segmentation mask

   George Papandreou, Liang-Chieh Chen, Kevin Murphy, and Alan L. Yuille.
   Weakly-and semi-supervised learning of a dcnn for semantic image segmentation. In *ICCV*, 2015.

2. Modified loss function: CNN optimized for classification

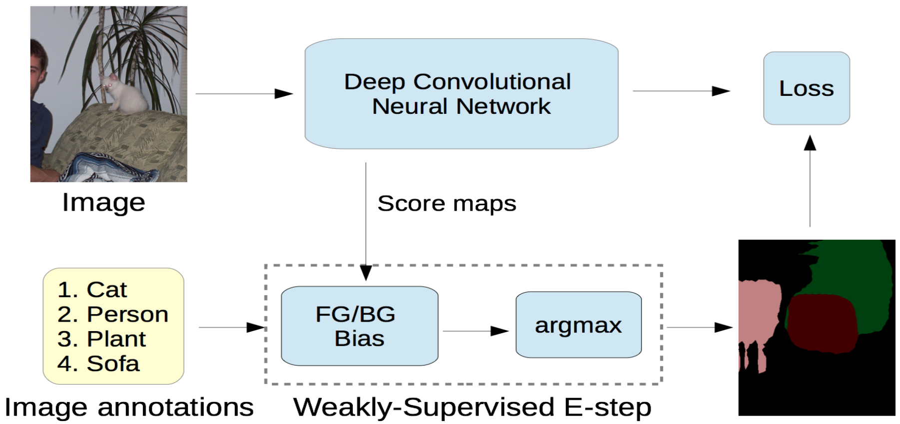
   Pedro O. Pinheiro and Ronan Collobert.
   From image-level to pixel-level labeling with convolutional networks.
   In *CVPR*, 2015.

# Generation of segmentation mask

George Papandreou, Liang-Chieh Chen, Kevin Murphy, and Alan L. Yuille.
Weakly-and semi-supervised learning of a dcnn for semantic image segmentation.
In *ICCV*, 2015.

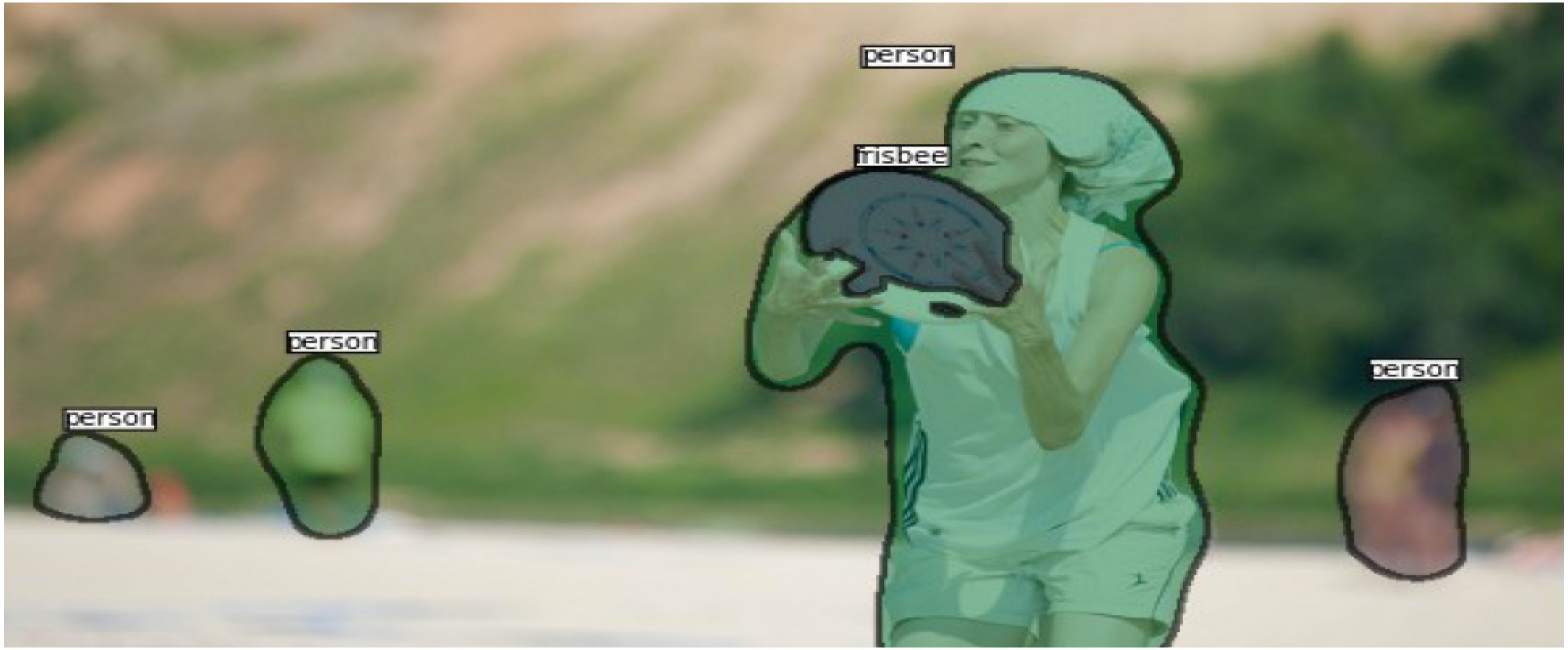
## Idea: adaptive bias

- Generated segmentation mask and train fully-supervised CNN
- Adaptive bias into the multi-instance learning framework
  - Boost classes known to be present
  - Suppress all others



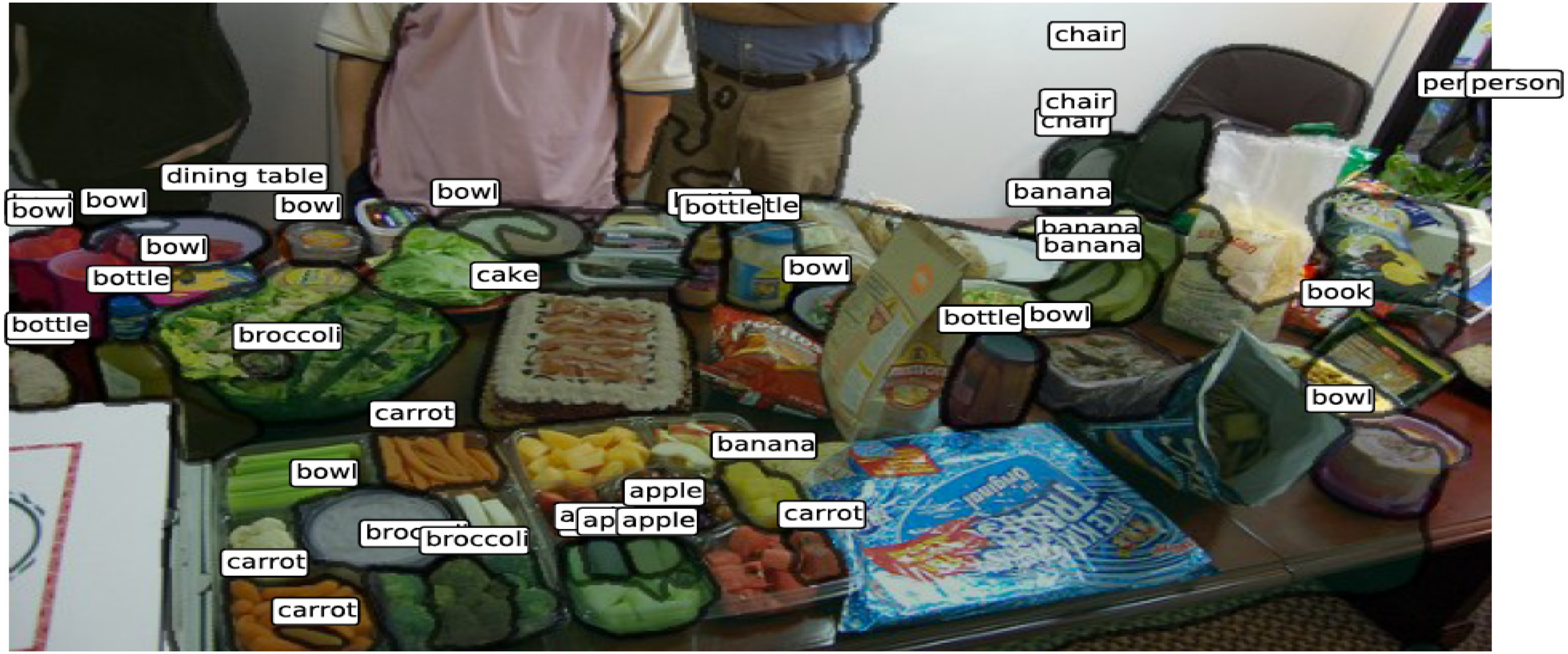
# Segmentation Results

# Segmentation Results




@Y. LeCun

# Segmentation Results




@Y. LeCun

=> Mask-R-CNN