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Object Detection

Object
localization

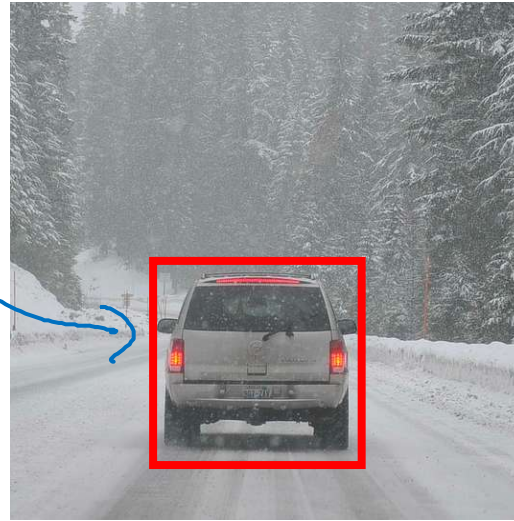
What are localization and detection?

Image classification



"Car"

Classification with
localization



"Car"

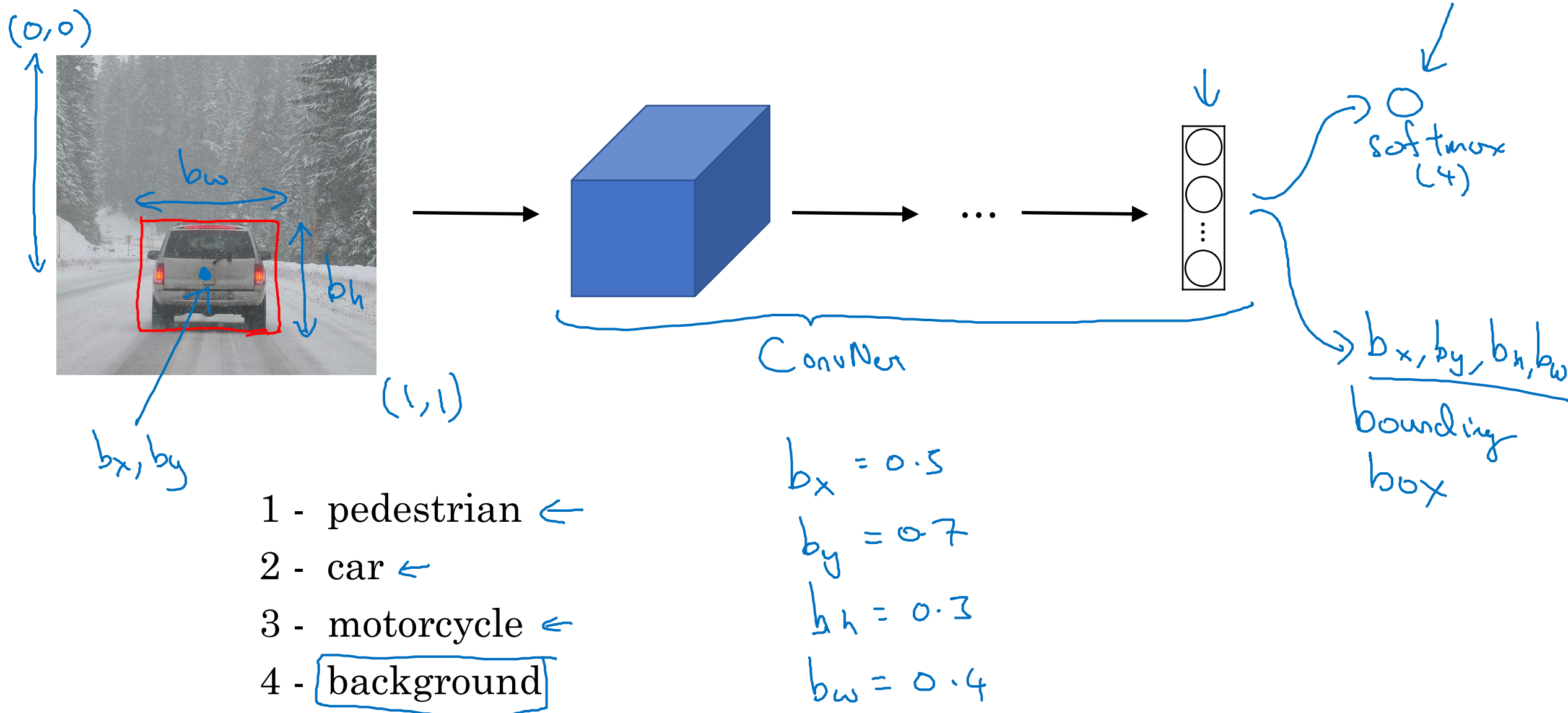
1 object

Detection



multiple
objects

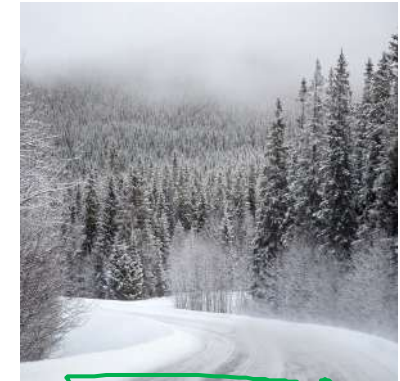
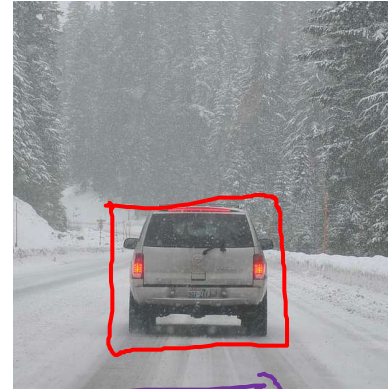
Classification with localization



Defining the target label y

- 1 - pedestrian
- 2 - car ←
- 3 - motorcycle
- 4 - background ←

Need to output b_x, b_y, b_h, b_w , class label (1-4)



$x =$

$$L(\hat{y}, y) = \begin{cases} (\hat{y}_1 - y_1)^2 + (\hat{y}_2 - y_2)^2 + \dots + (\hat{y}_8 - y_8)^2 & \text{if } \underline{y_1 = 1} \\ (\hat{y}_1 - y_1)^2 & \text{if } \underline{y_1 = 0} \end{cases}$$

$$y = \begin{bmatrix} p_c \\ b_x \\ b_y \\ b_h \\ b_w \\ c_1 \\ c_2 \\ c_3 \end{bmatrix}$$

is there any object?

(x, y)

$$\begin{bmatrix} 1 \\ b_x \\ b_y \\ b_h \\ b_w \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 \\ \vdots \end{bmatrix}$$

← "don't care"

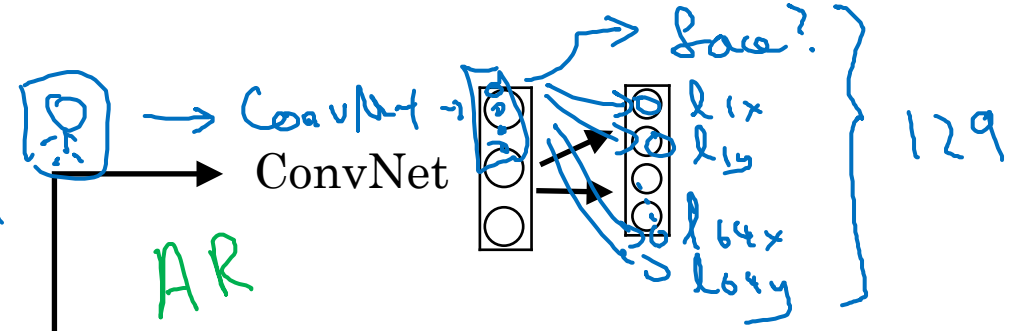


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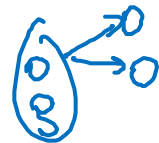
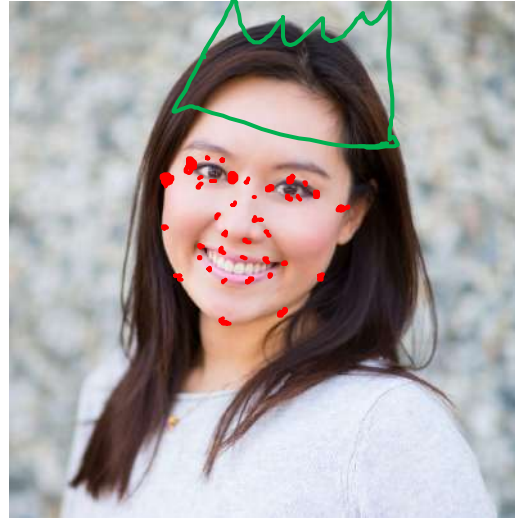
Object Detection

Landmark
detection

Landmark detection



b_x, b_y, b_h, b_w



$l_{1x}, l_{1y}, l_{2x}, l_{2y}, l_{3x}, l_{3y}, l_{4x}, l_{4y}, \dots, l_{64x}, l_{64y}$

x, y

$l_{1x}, l_{1y}, \dots, l_{32x}, l_{32y}$



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Object Detection

Object
detection

Car detection example

Training set:

X

y



1



1



1



0



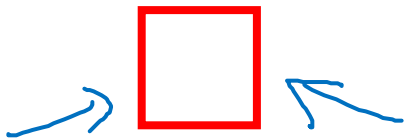
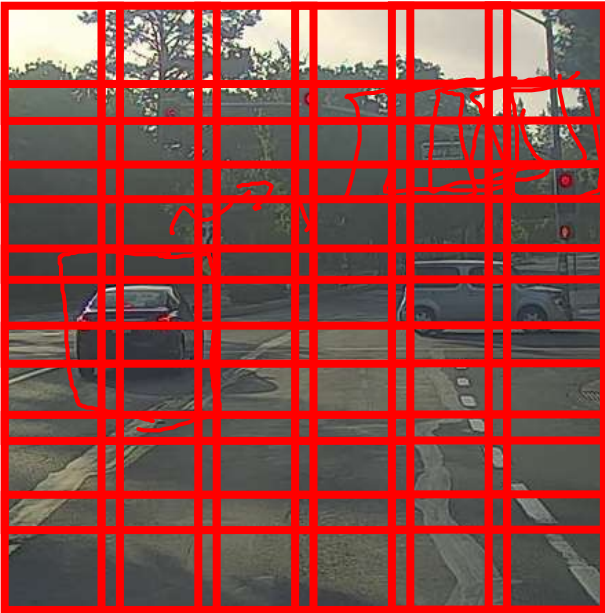
0



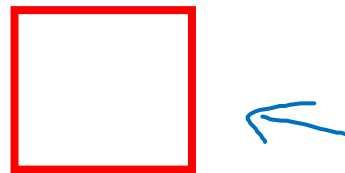
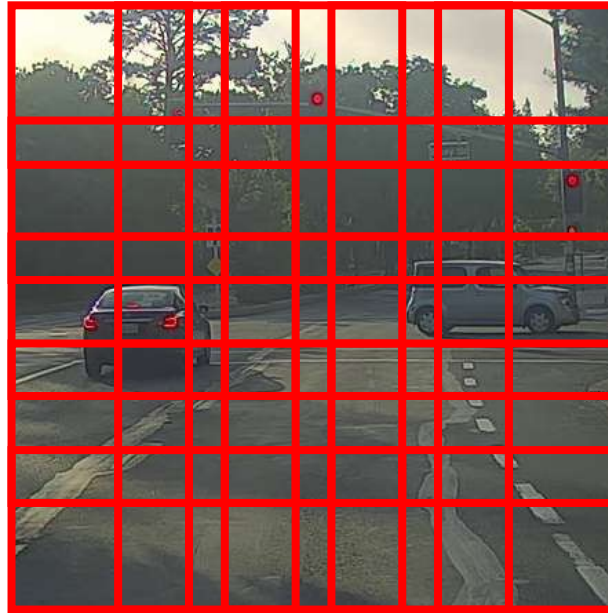
→ ConvNet → y

Sliding windows detection

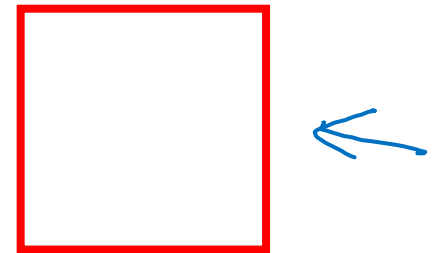
→ ConvNet → 0



→ ConvNet



Computation cost



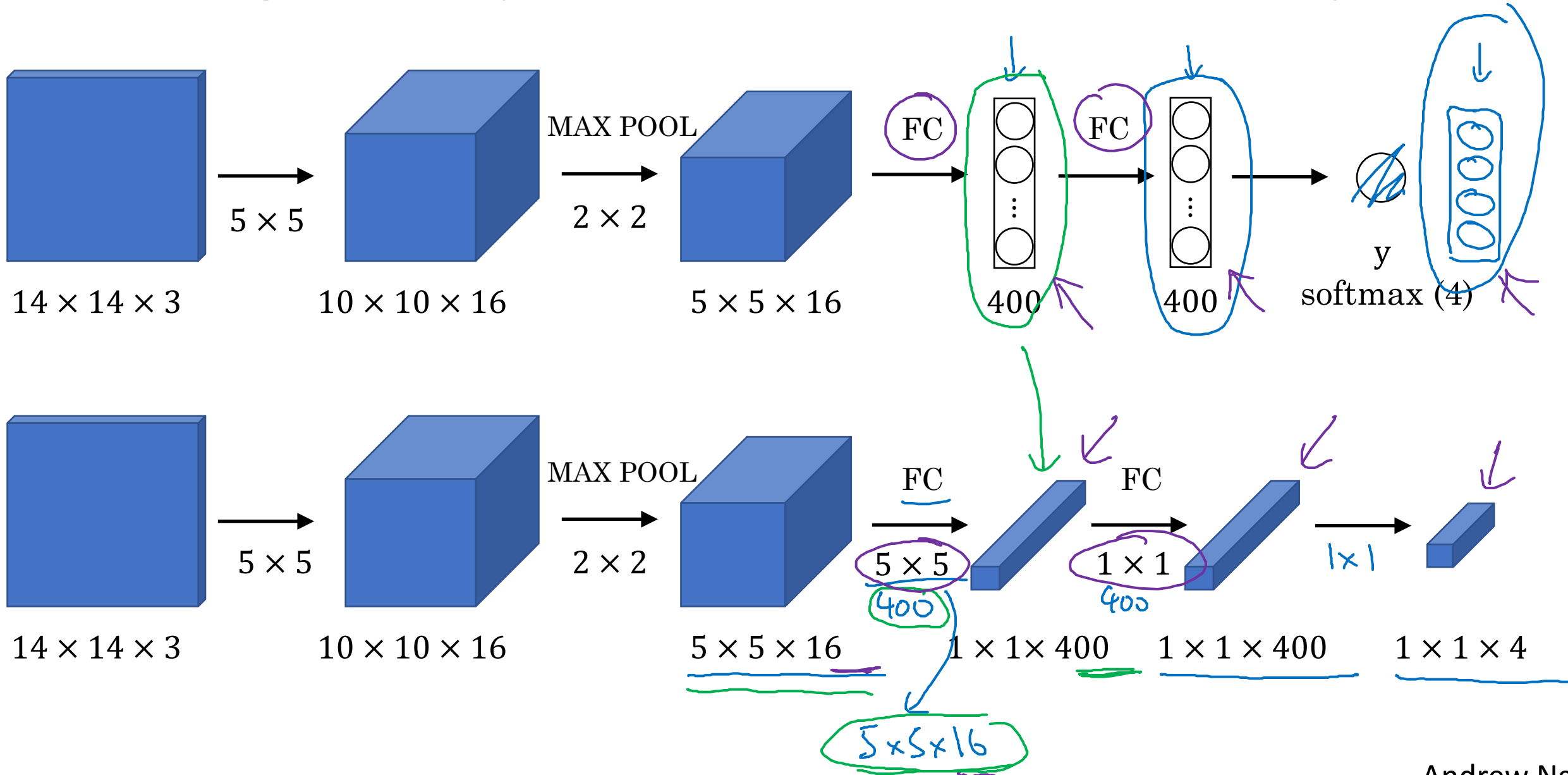


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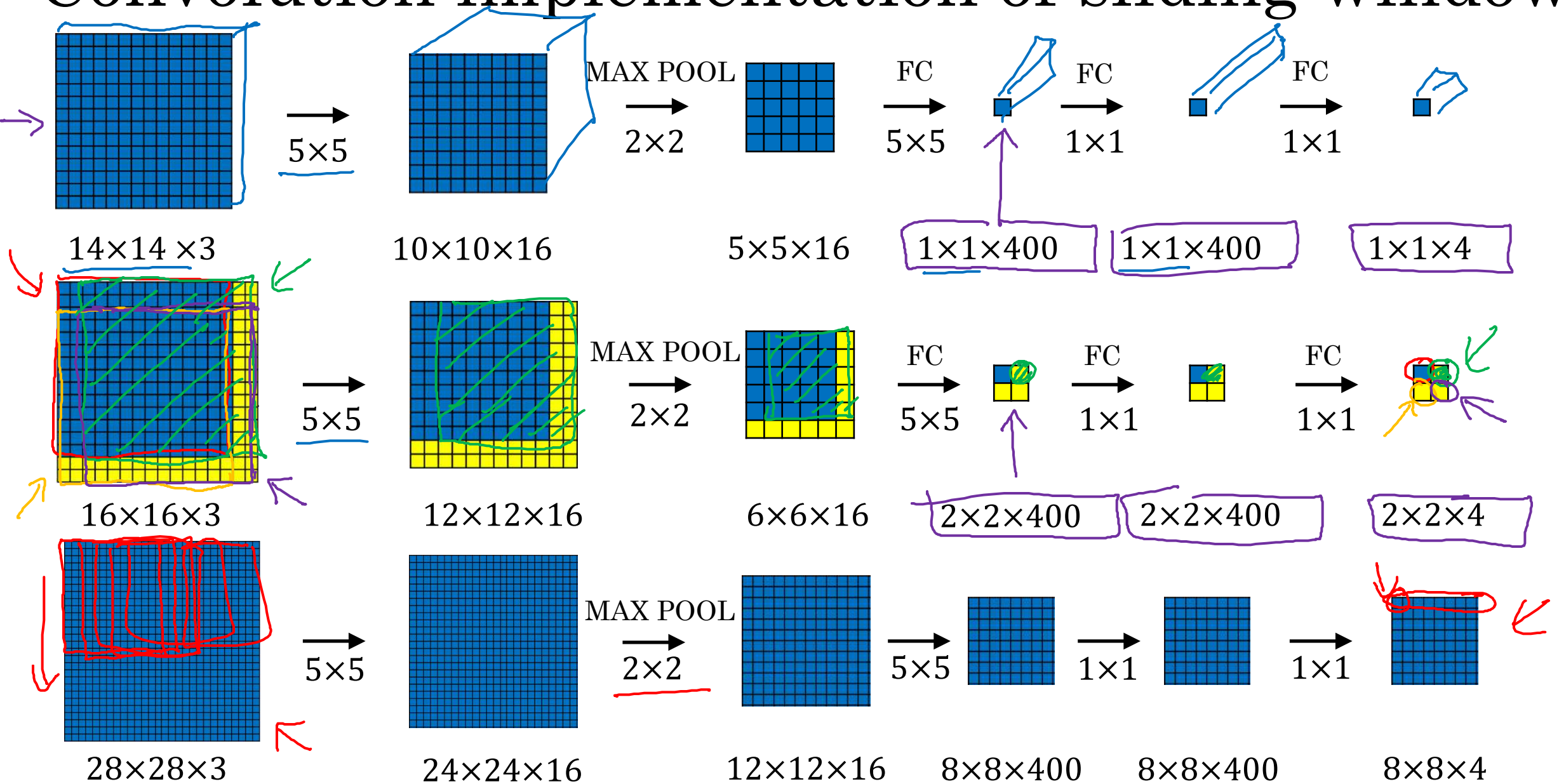
Object Detection

Convolutional
implementation of
sliding windows

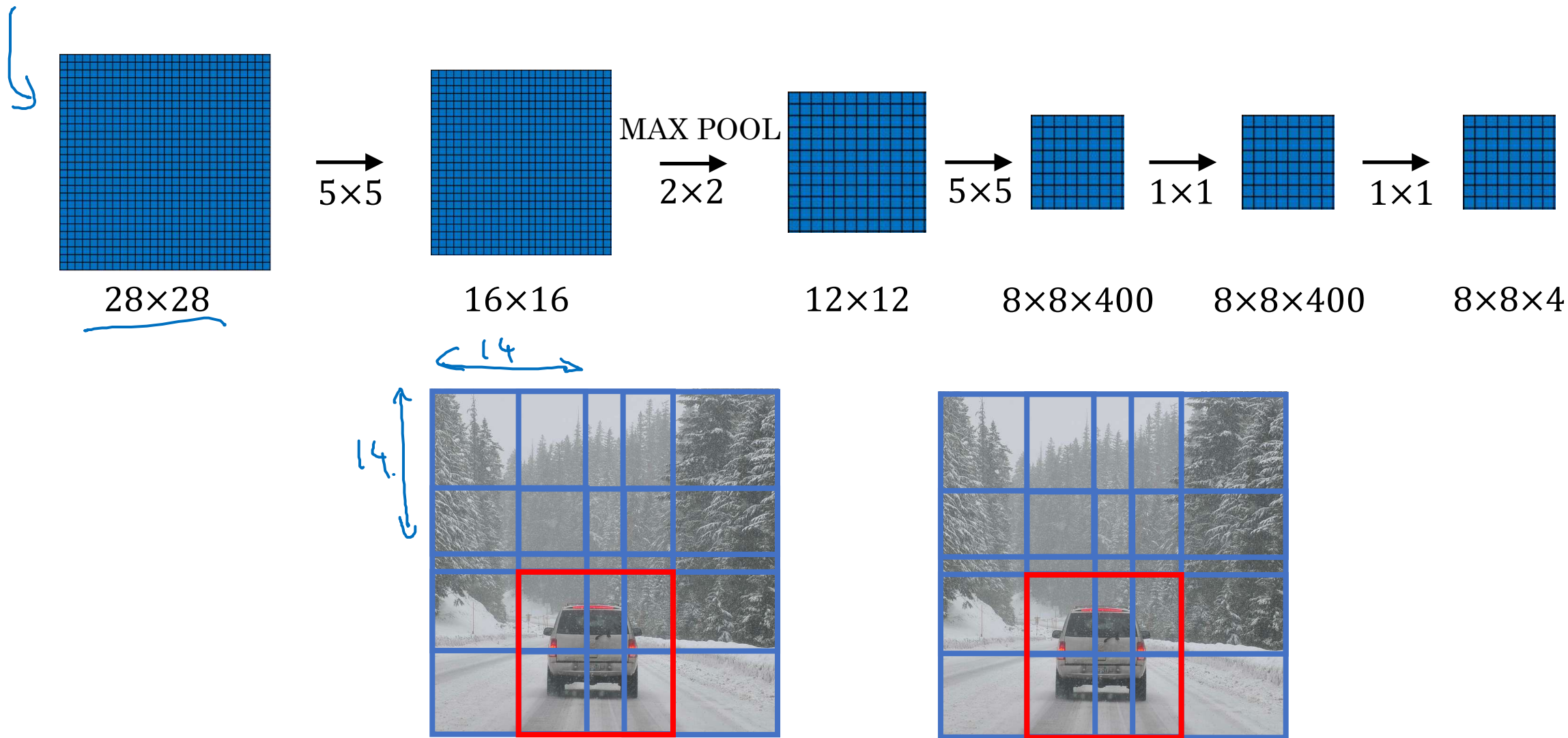
Turning FC layer into convolutional layers



Convolution implementation of sliding windows



Convolution implementation of sliding windows



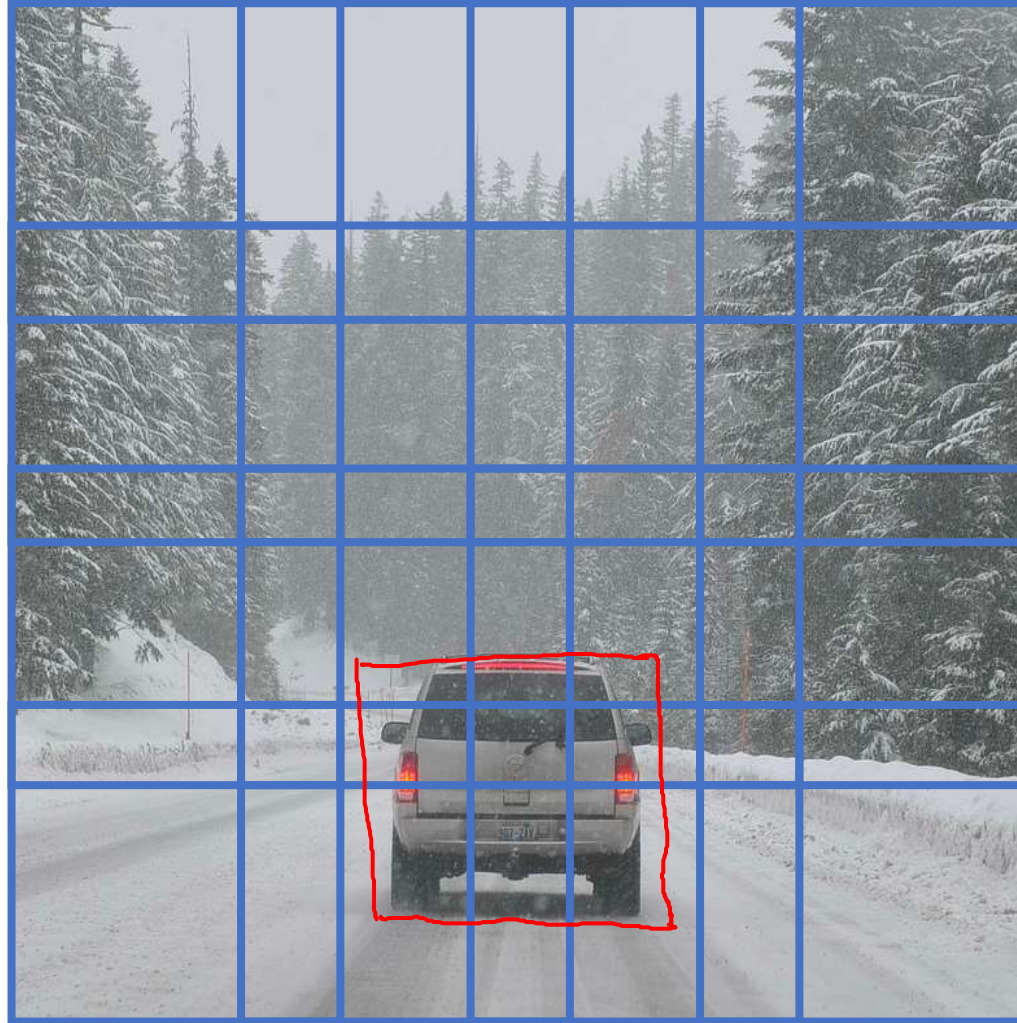


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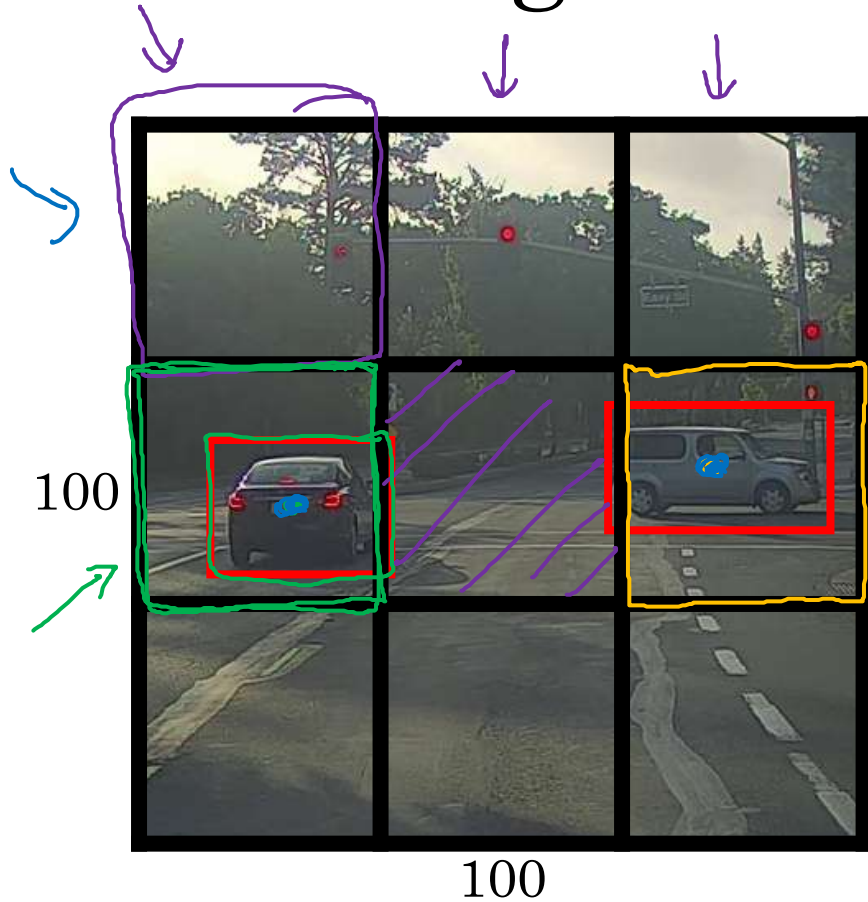
Object Detection

Bounding box
predictions

Output accurate bounding boxes



YOLO algorithm

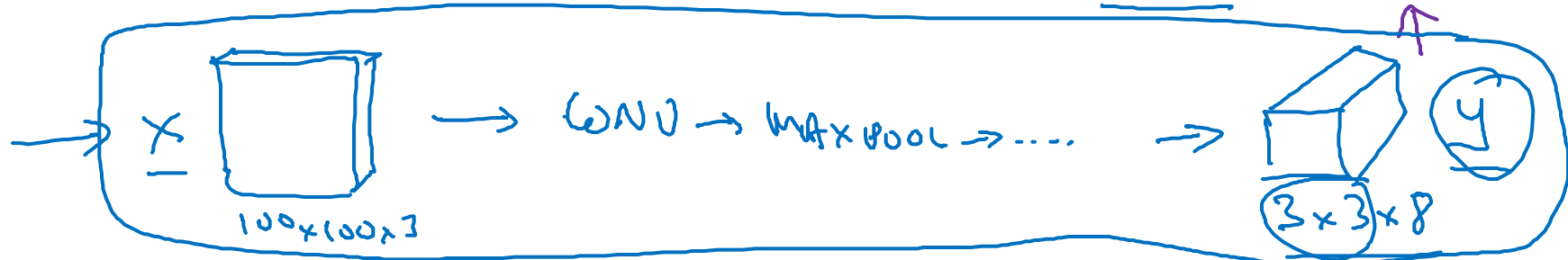
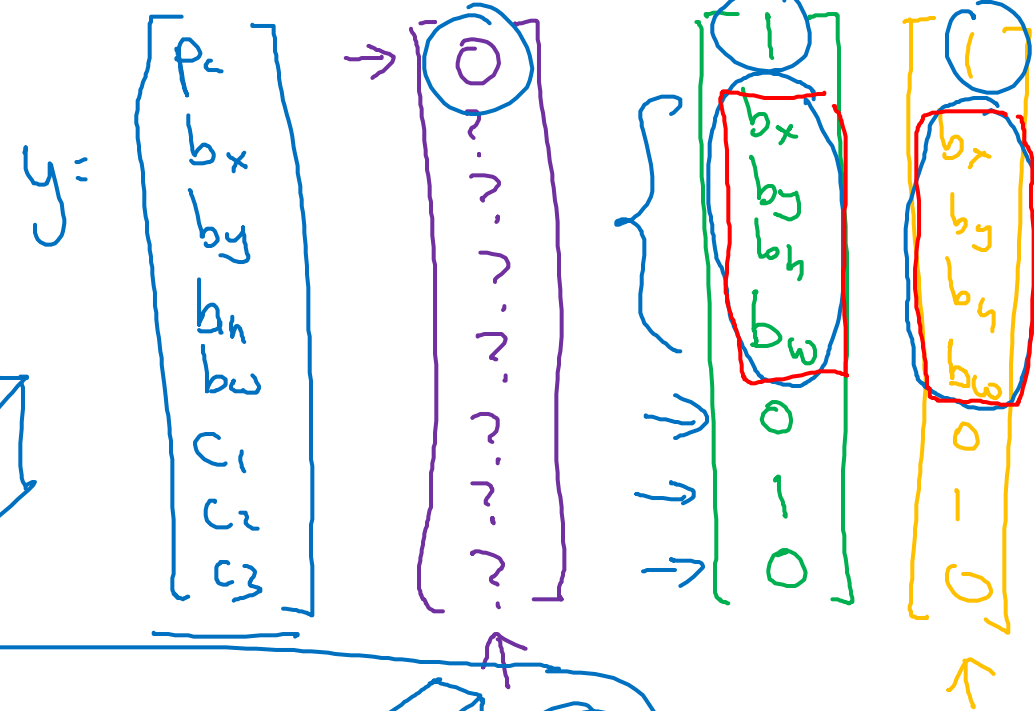
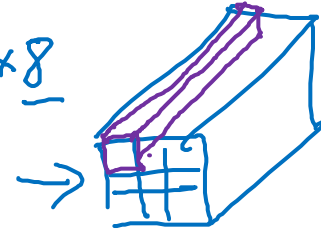


Labels for training

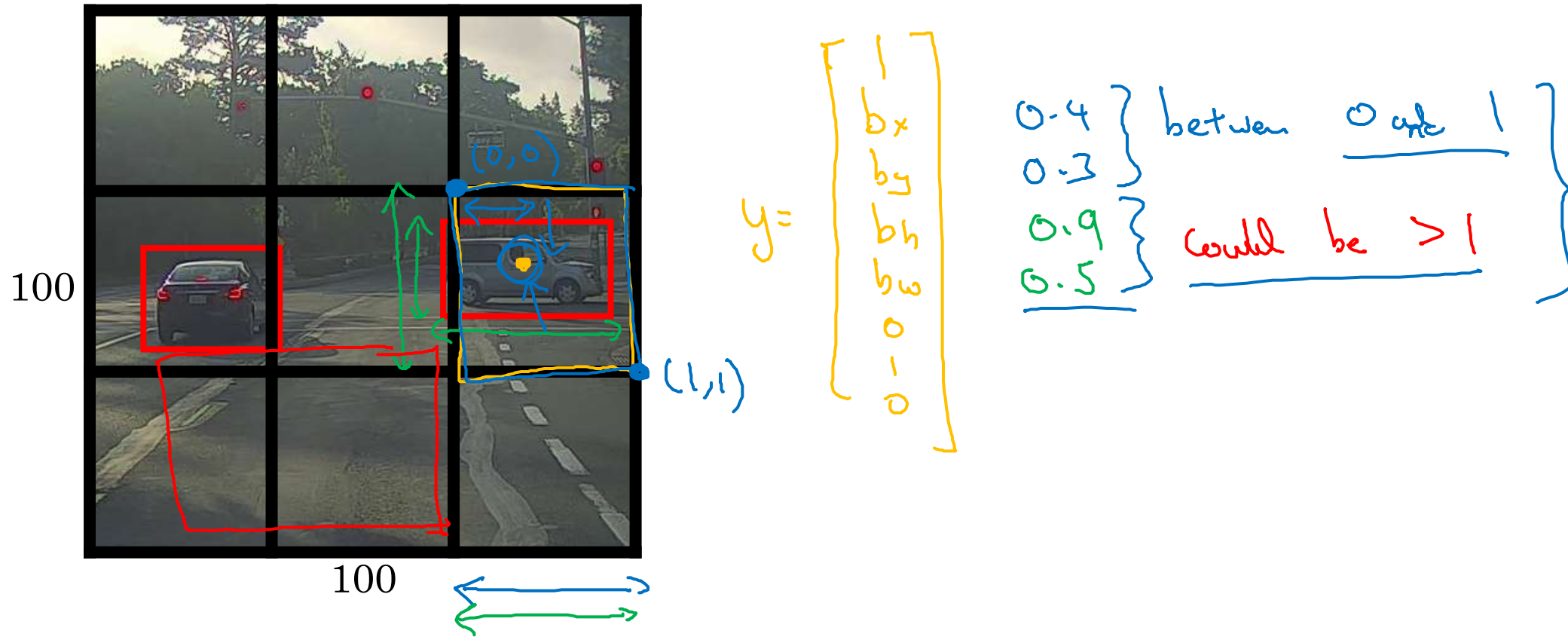
For each grid cell:

Target output:

$3 \times 3 \times 8$



Specify the bounding boxes



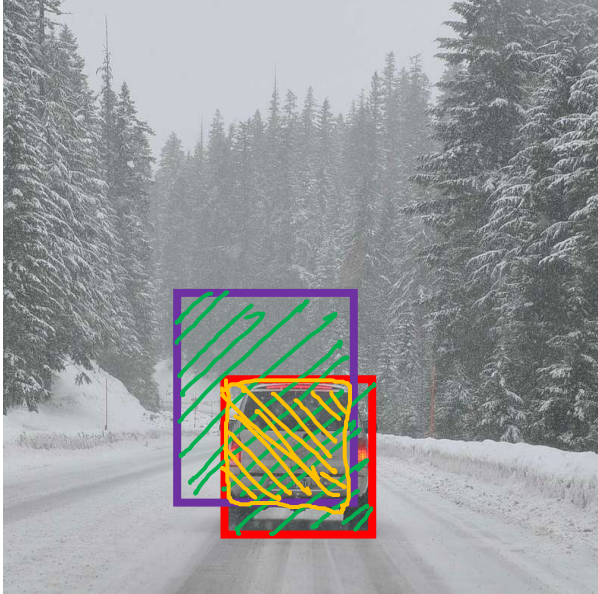


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Object Detection

Intersection
over union

Evaluating object localization



Intersection over Union (IoU)

$$= \frac{\text{size of } \text{yellow box}}{\text{size of } \text{green box}}$$

“Correct” if IoU \geq 0.5 \leftarrow

0.6 \leftarrow

More generally, IoU is a measure of the overlap between two bounding boxes.



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Object Detection

Non-max
suppression

Non-max suppression example

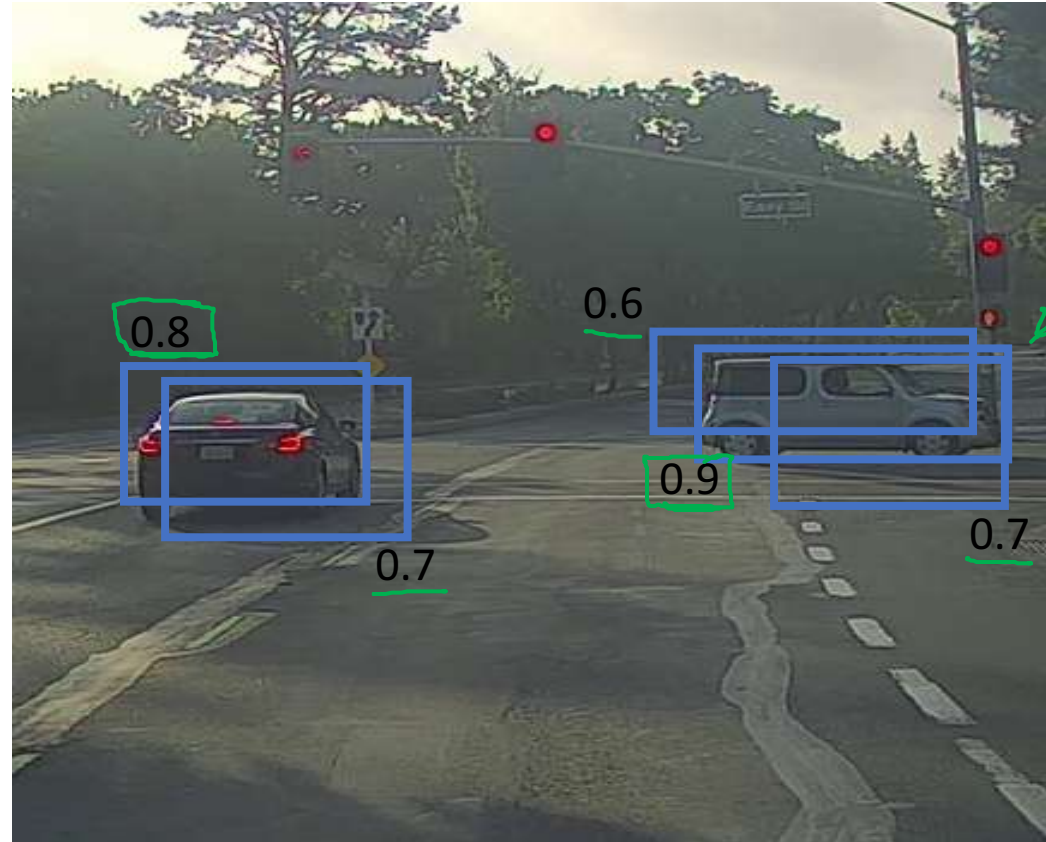


Non-max suppression example



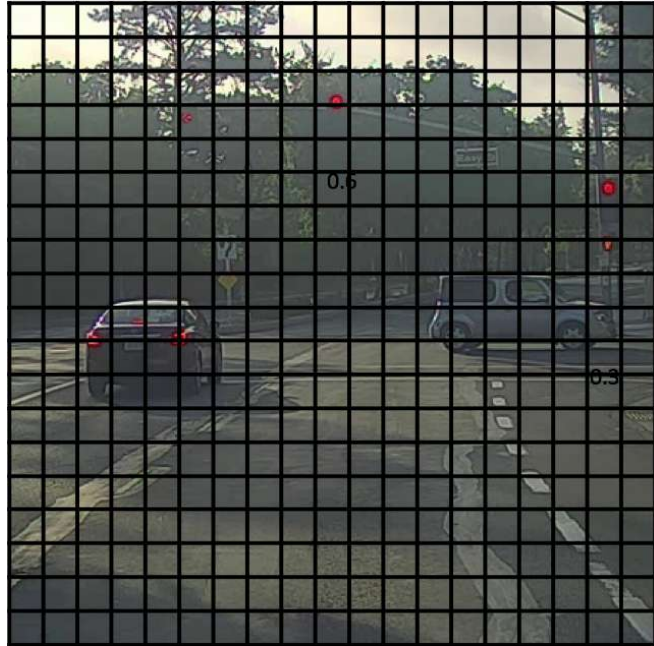
19x19

Non-max suppression example



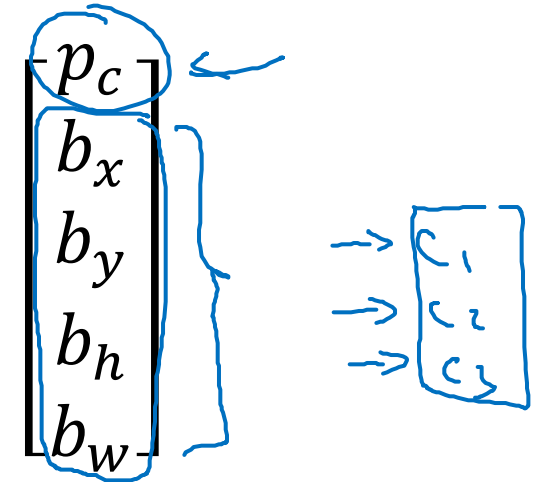
P_c

Non-max suppression algorithm



19x19

Each output prediction is:



Discard all boxes with $p_c \leq 0.6$

→ While there are any remaining boxes:

- Pick the box with the largest p_c
Output that as a prediction.
- Discard any remaining box with $\text{IoU} \geq 0.5$ with the box output in the previous step

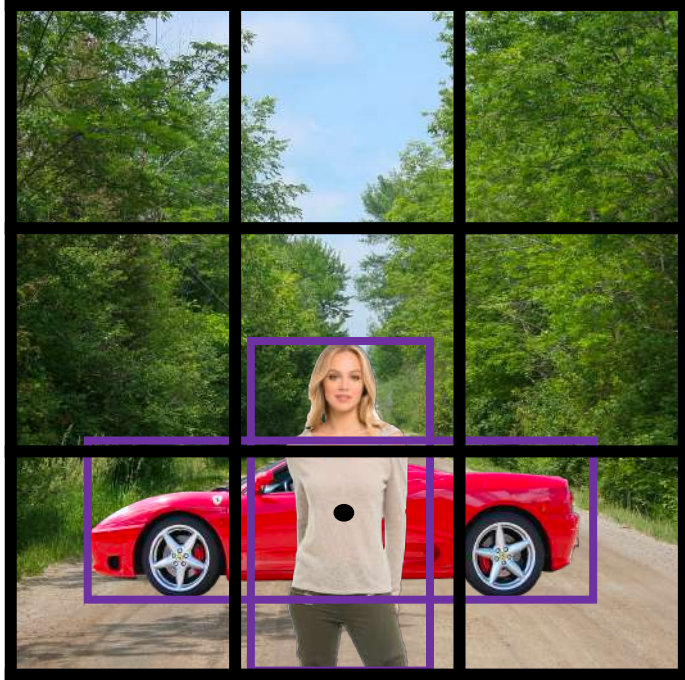


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Object Detection

Anchor boxes

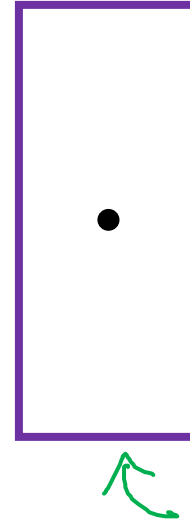
Overlapping objects:



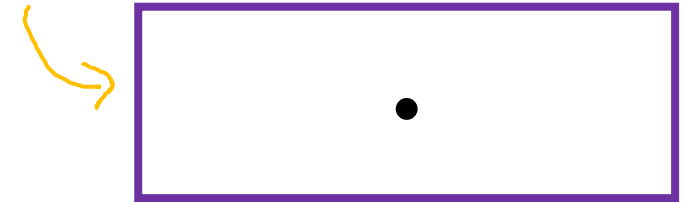
$$y = \begin{bmatrix} p_c \\ b_x \\ b_y \\ b_h \\ b_w \\ c_1 \\ c_2 \\ c_3 \end{bmatrix}$$

Handwritten annotations: A green arrow points to p_c , a blue arrow points to b_x , and a blue bracket groups c_1, c_2, c_3 .

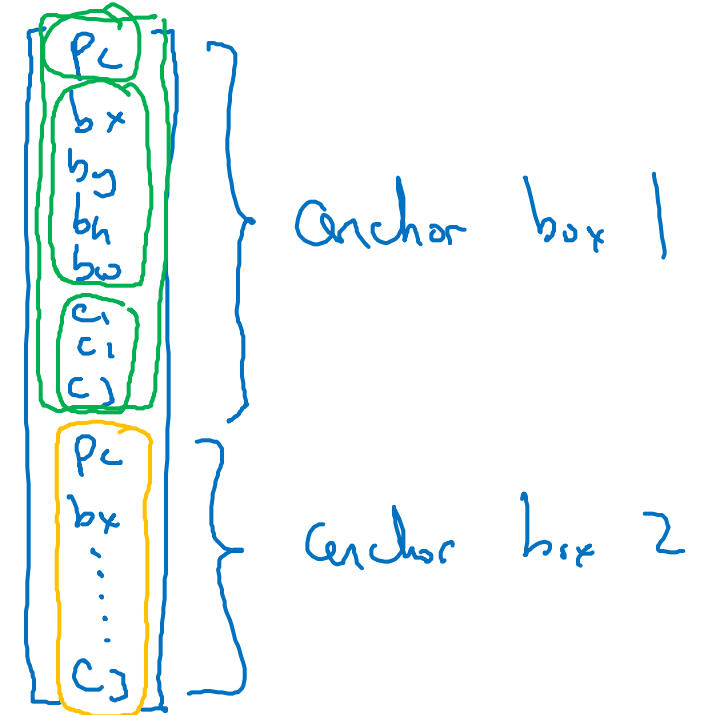
Anchor box 1:



Anchor box 2:



$y =$

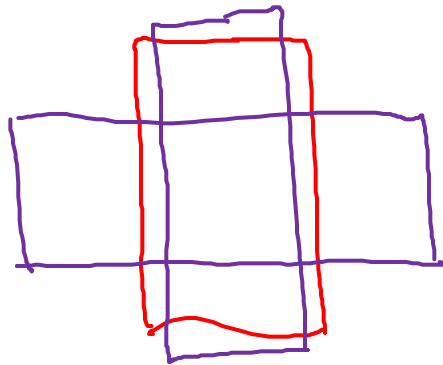


Anchor box algorithm

Previously:

Each object in training image is assigned to grid cell that contains that object's midpoint.

Output y :
 $3 \times 3 \times 8$



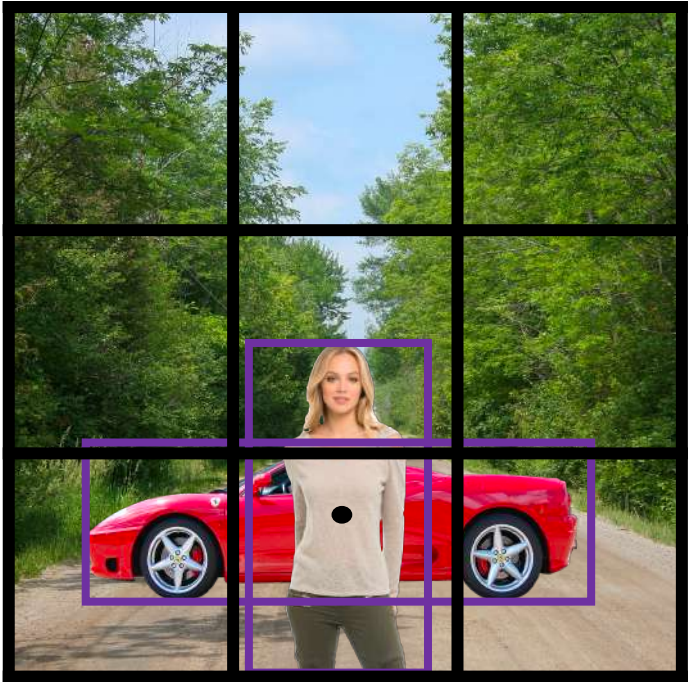
With two anchor boxes:

Each object in training image is assigned to grid cell that contains object's midpoint and anchor box for the grid cell with highest IoU.

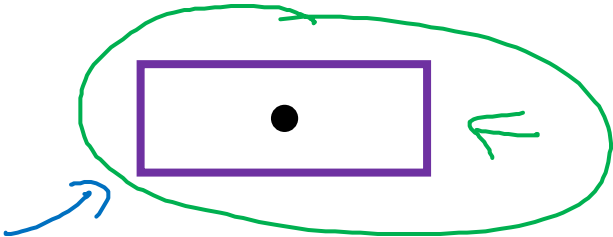
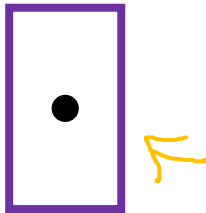
(grid cell, anchor box)

Output y :
 $3 \times 3 \times 16$
 $3 \times 3 \times 2 \times 8$

Anchor box example



Anchor box 1: Anchor box 2:



y =

$$\begin{bmatrix} p_c \\ b_x \\ b_y \\ b_h \\ b_w \\ c_1 \\ c_2 \\ c_3 \\ p_c \\ b_x \\ b_y \\ b_h \\ b_w \\ c_1 \\ c_2 \\ c_3 \end{bmatrix}$$

$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Car only?

$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

anchor box 1

anchor box 2



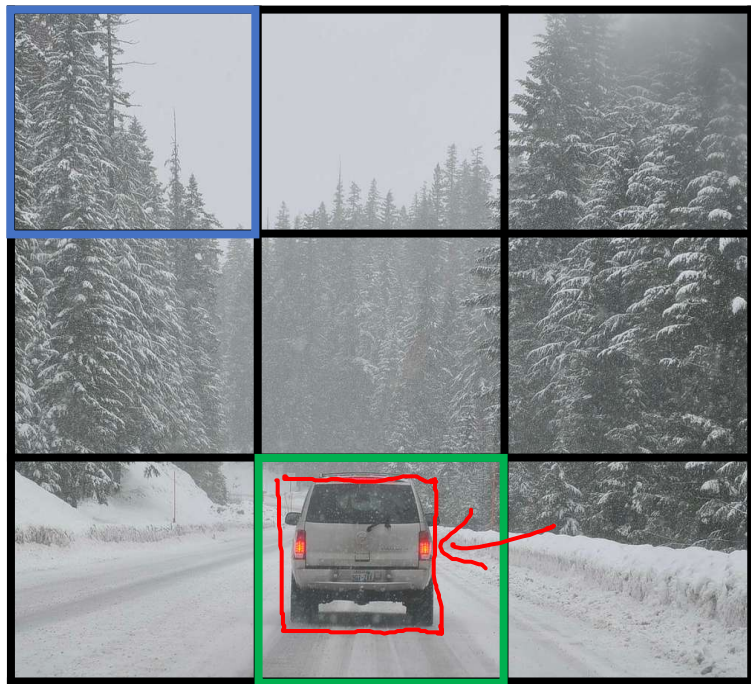
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Object Detection

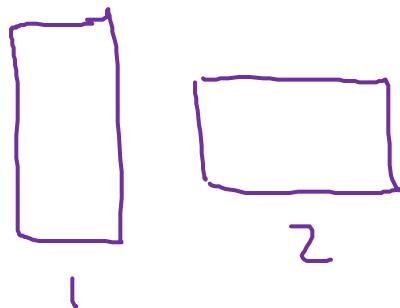
Putting it together:
YOLO algorithm

Training

- 1 - pedestrian
- 2 - car ←
- 3 - motorcycle



$y =$



$\begin{bmatrix} p_c \\ b_x \\ b_y \\ b_h \\ b_w \\ c_1 \\ c_2 \\ c_3 \end{bmatrix}$

$\begin{bmatrix} 0 \\ ? \\ ? \\ ? \\ ? \\ ? \\ ? \\ ? \end{bmatrix}$

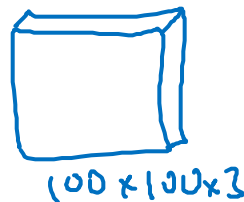
$\begin{bmatrix} 0 \\ ? \\ ? \\ ? \\ ? \\ ? \\ ? \\ 1 \\ b_x \\ b_y \\ b_h \\ b_w \\ 0 \\ 1 \\ 0 \end{bmatrix}$

y is $3 \times 3 \times 2 \times 8$

$19 \times 19 \times 16$
 $19 \times 19 \times 40$

↑
#anchors

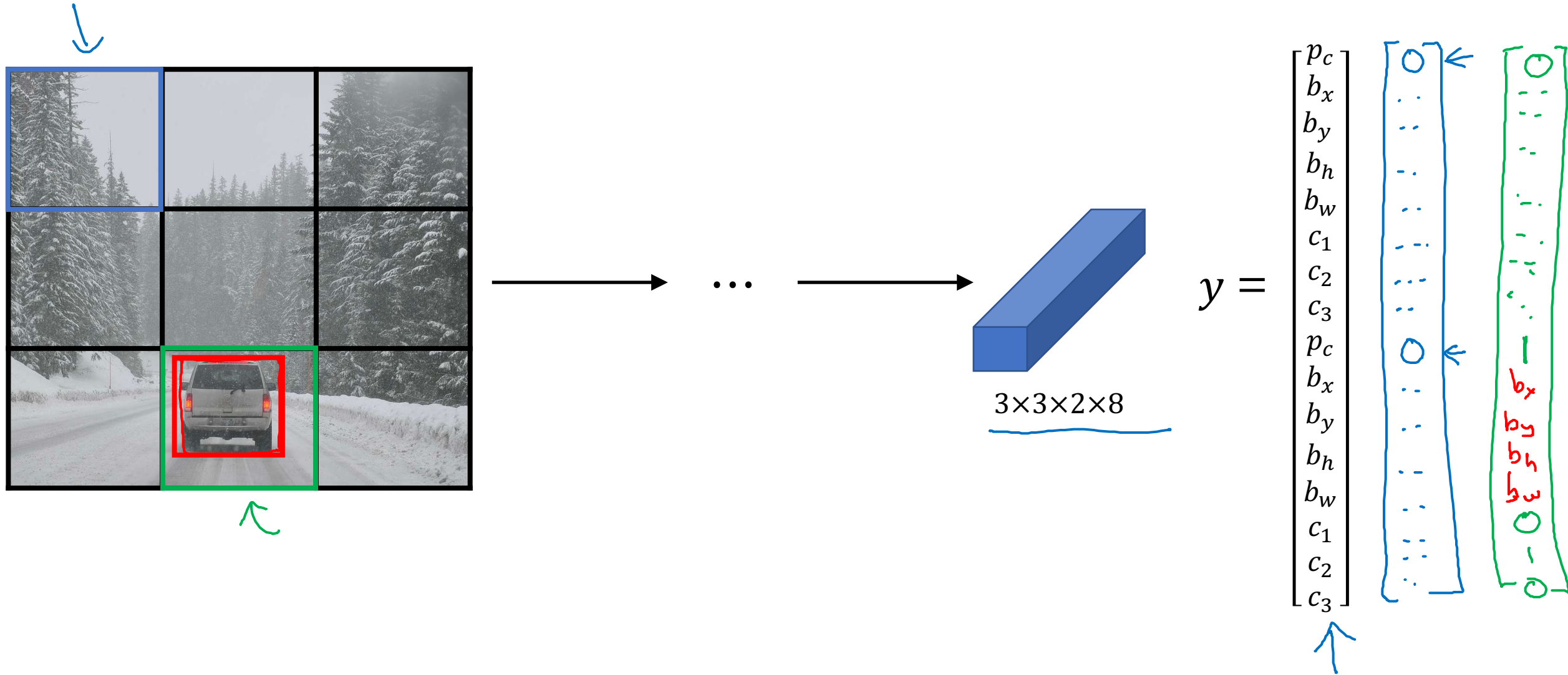
↑
5 + #classes



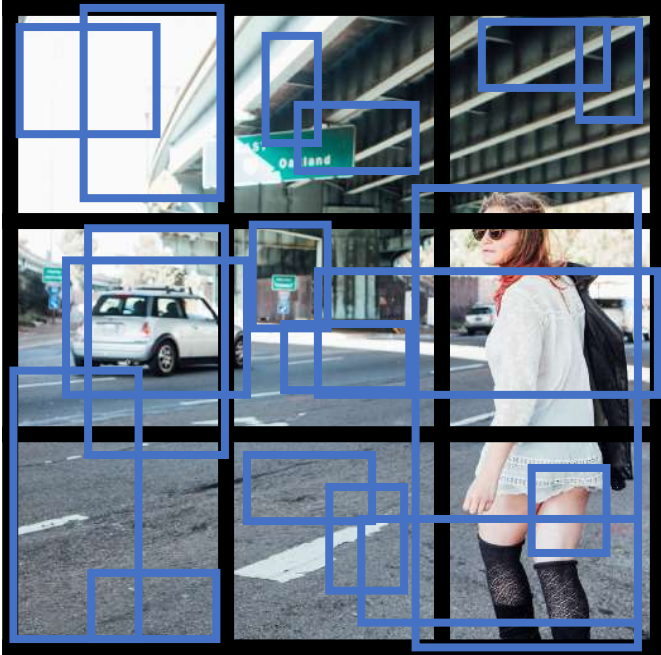
→ ConvNet →



Making predictions



Outputting the non-max suppressed outputs



- For each grid cell, get 2 predicted bounding boxes.
- Get rid of low probability predictions.
- For each class (pedestrian, car, motorcycle) use non-max suppression to generate final predictions.

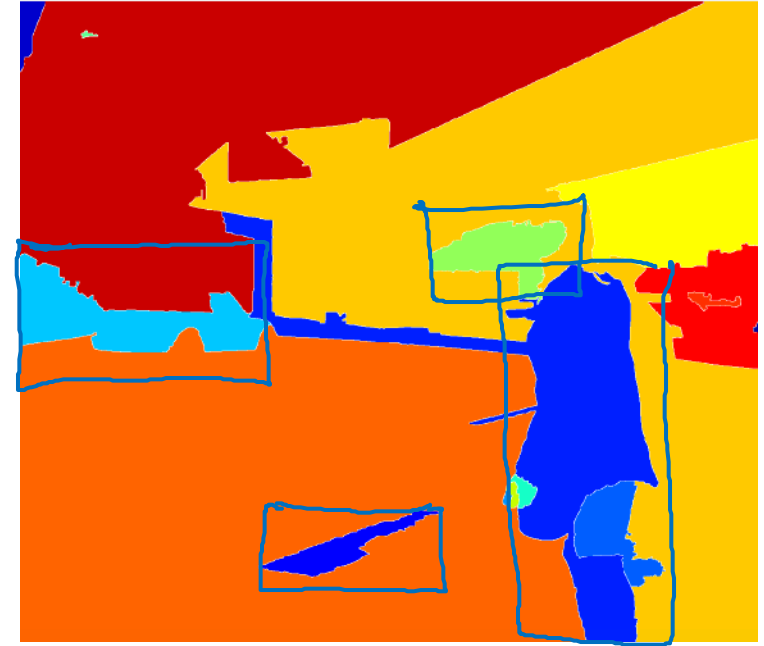
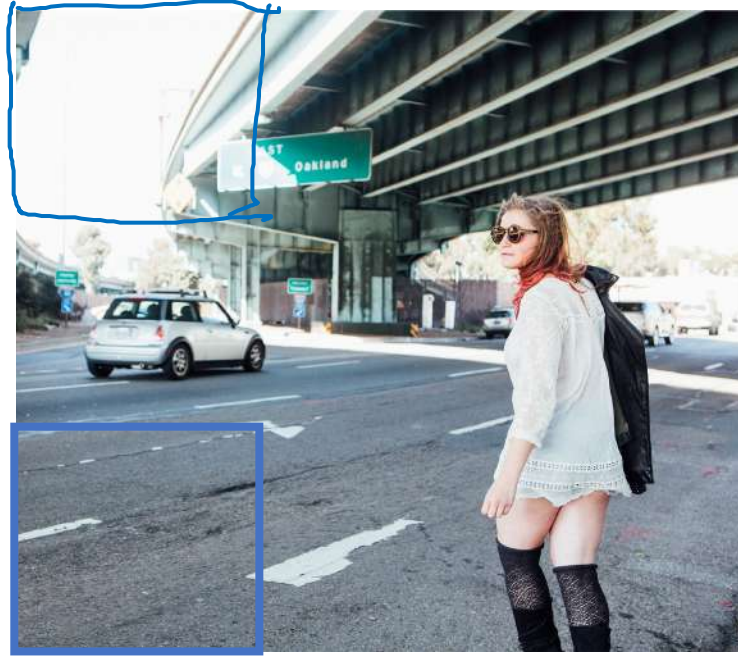
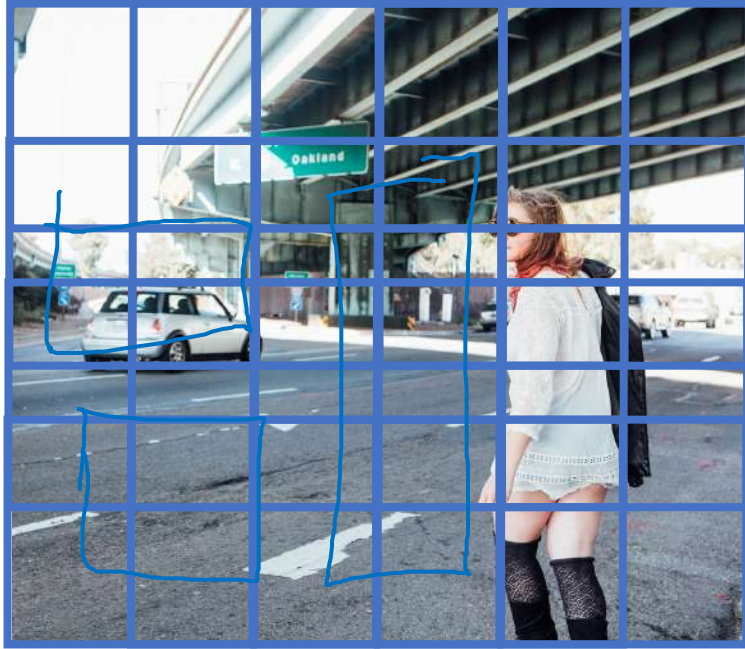


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Object Detection

Region proposals
(Optional)

Region proposal: R-CNN



Segmentation algorithm
 $\sim 2,000$

Faster algorithms

→ R-CNN: Propose regions. Classify proposed regions one at a time. Output label + bounding box. ←

Fast R-CNN: Propose regions. Use convolution implementation of sliding windows to classify all the proposed regions. ←

Faster R-CNN: Use convolutional network to propose regions.

[Girshik et. al, 2013. Rich feature hierarchies for accurate object detection and semantic segmentation]

[Girshik, 2015. Fast R-CNN]

[Ren et. al, 2016. Faster R-CNN: Towards real-time object detection with region proposal networks]

Andrew Ng