CS 1674/2074: Object Recognition and Image Segmentation

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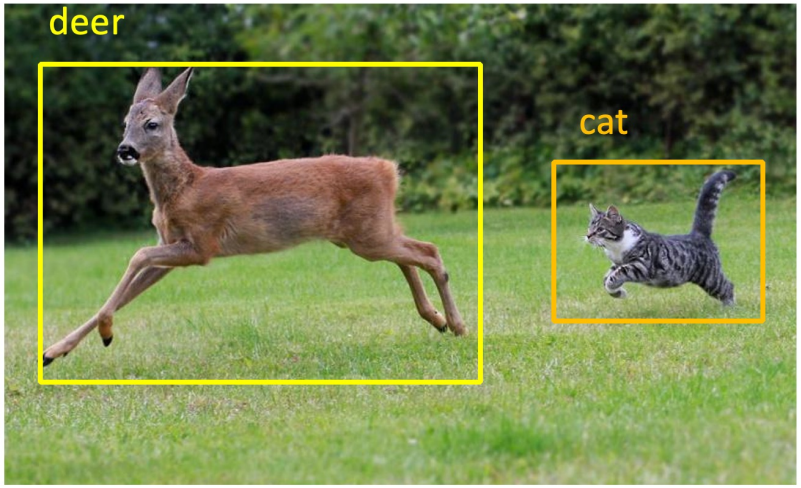
What tasks can with Computer Vision do?

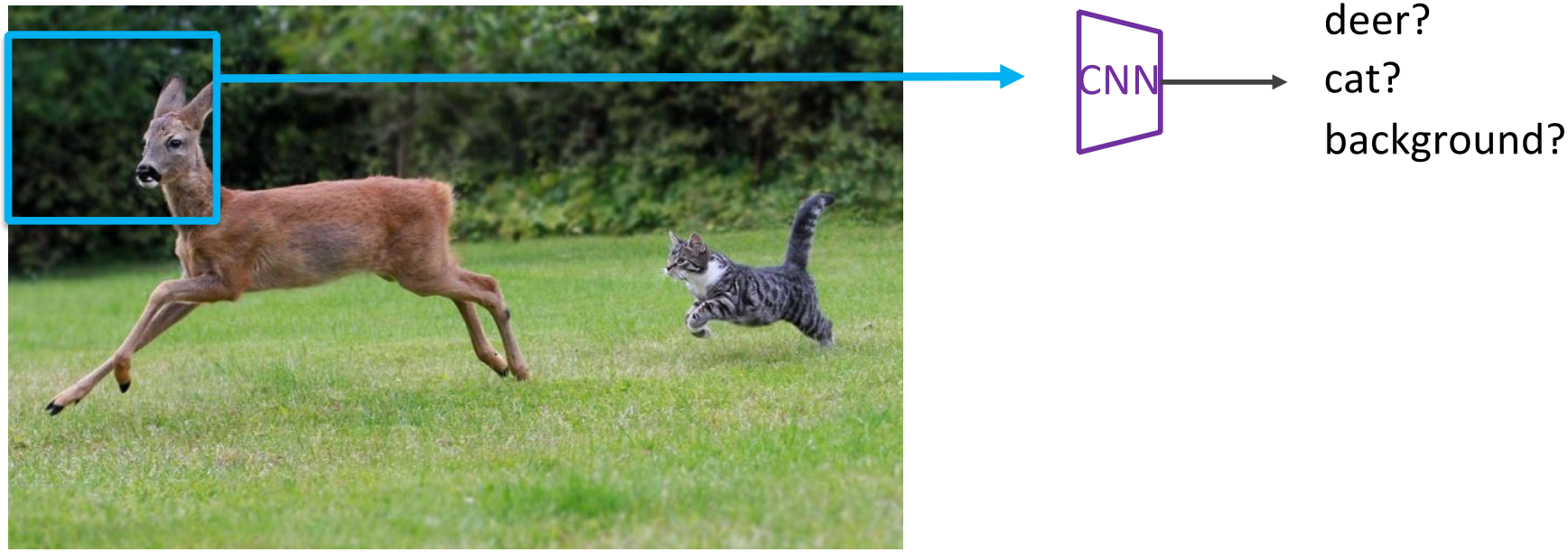
Jupyter Notebook: link

What will be the output of an Object Detector?



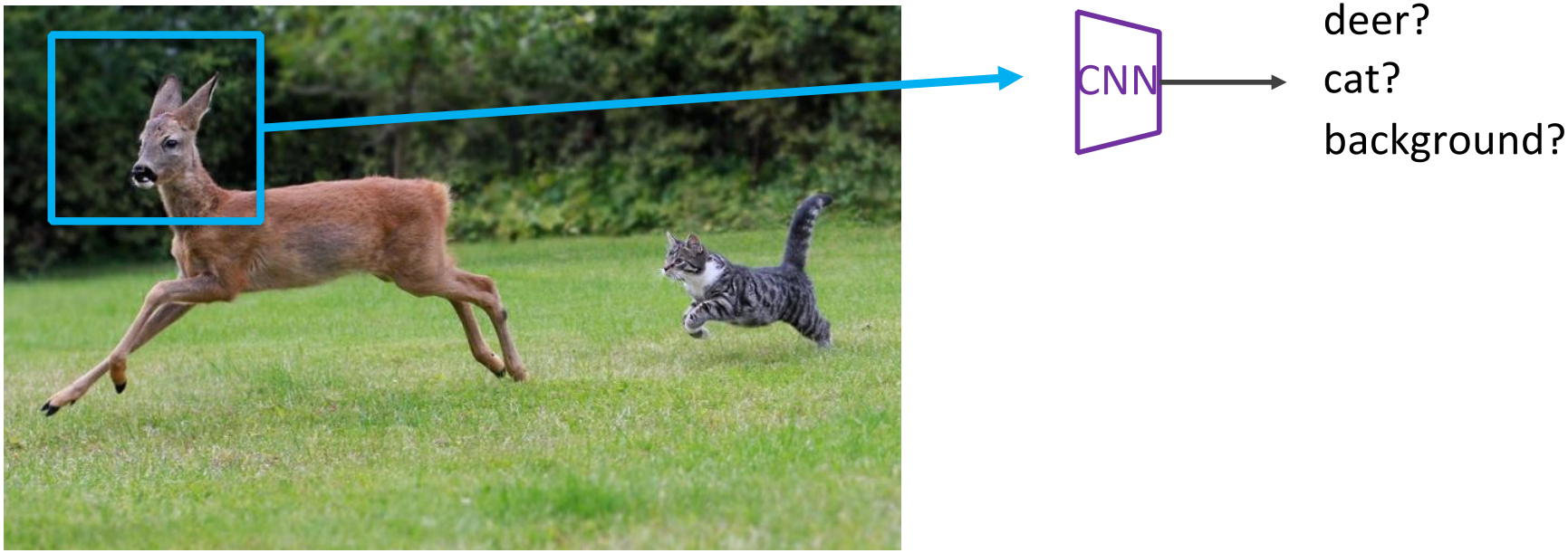
Adapted from Vicente Ordoñez

Object Detection as Classification



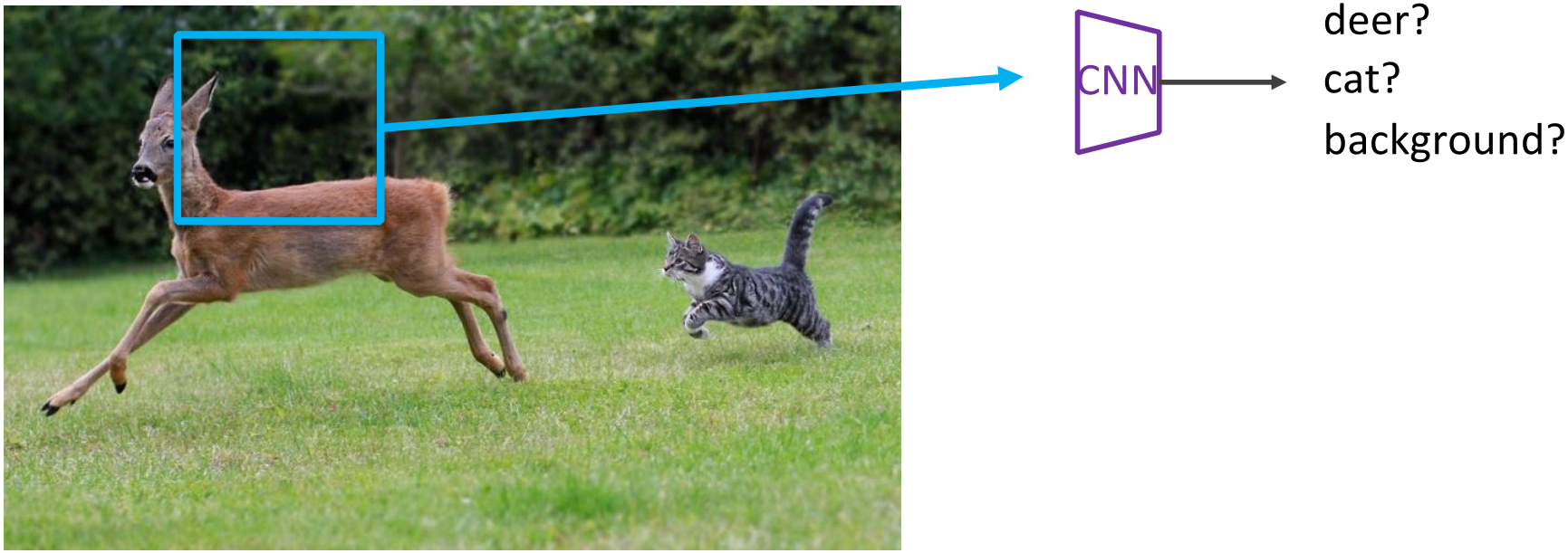
Adapted from Vicente Ordoñez

Object Detection as Classification



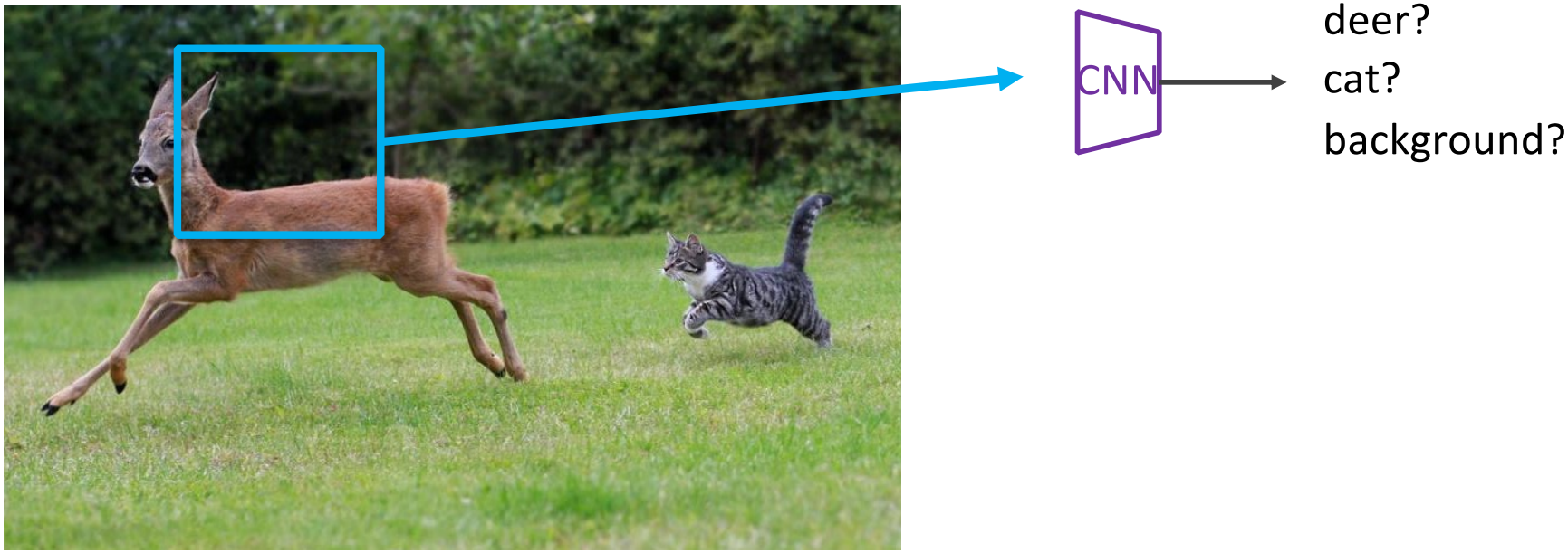
Adapted from Vicente Ordoñez

Object Detection as Classification



Adapted from Vicente Ordoñez

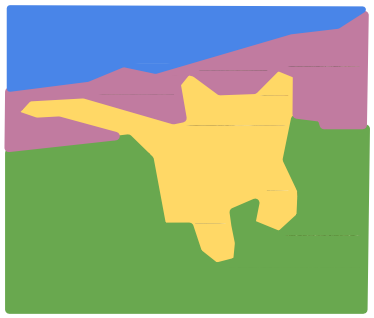
Object Detection as Classification with Sliding Window



Adapted from Vicente Ordoñez

Different Flavors of Object Recognition

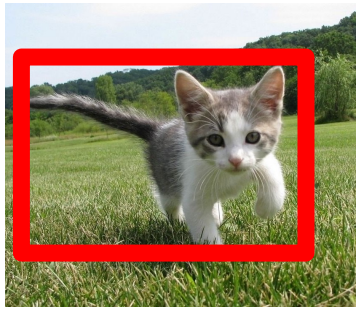
Semantic Segmentation



GRASS, CAT, TREE, SKY

No objects, just pixels

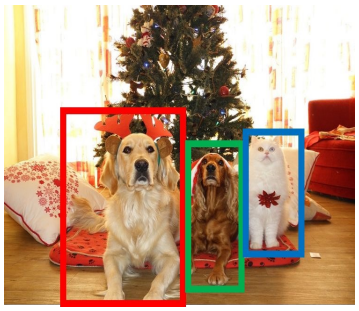
Classification + Localization



CAT

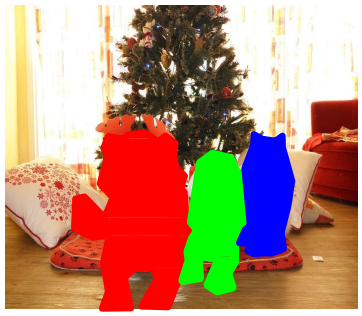
Single Object

Object Detection



DOG, DOG, CAT

Instance Segmentation



DOG, DOG, CAT

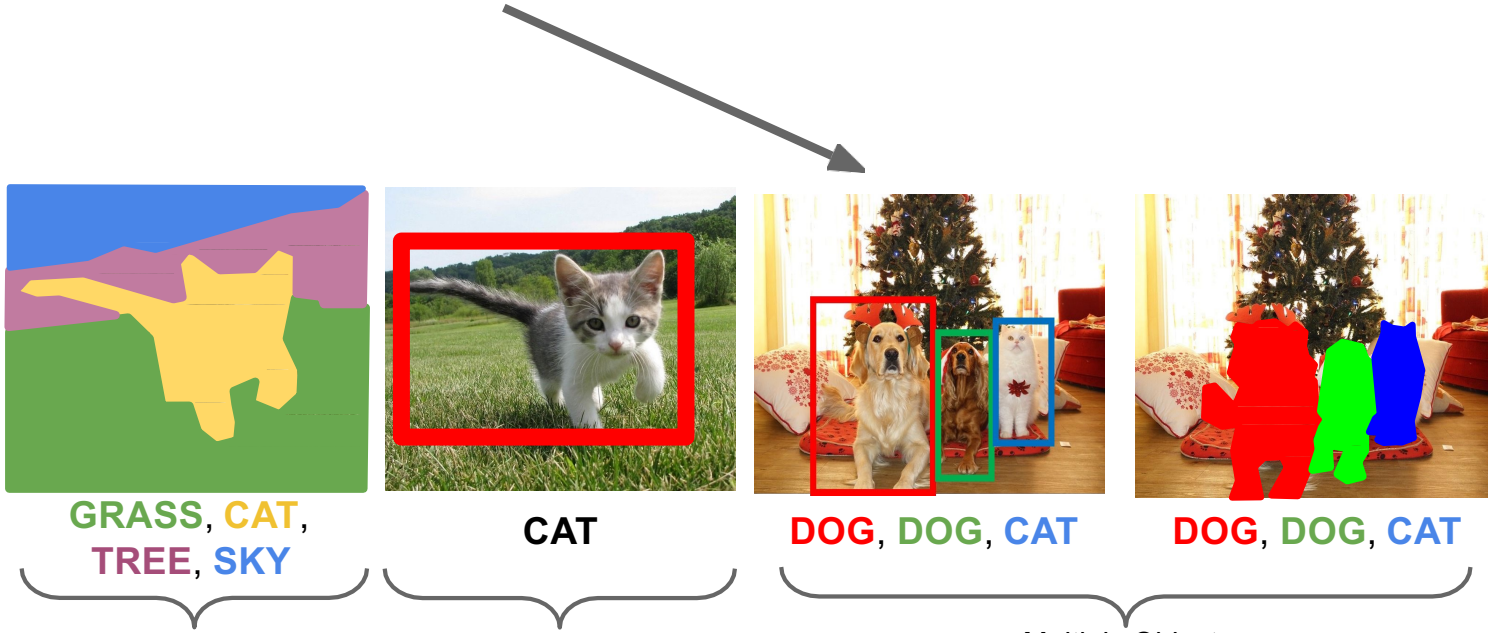
Multiple Object

Adapted from Justin Johnson

Plan for Today

- Detection approaches
  - Pre-CNNs
    - Detection with whole windows: Pedestrian detection
    - Part-based detection: Deformable Part Models
  - Post-CNNs
    - Detection with region proposals: R-CNN, Fast R-CNN, Faster-R-CNN
    - Detection without region proposals: YOLO, SSD
- Segmentation approaches
  - Semantic segmentation: FCN
  - Instance segmentation: Mask R-CNN

Object Detection



Slide by: Justin Johnson

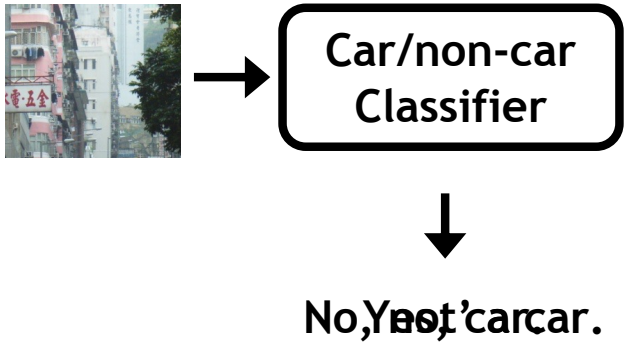
Object detection: basic framework

- Build/train object model
- Generate candidate regions in new image
- Score the candidates

Adapted from Kristen Grauman

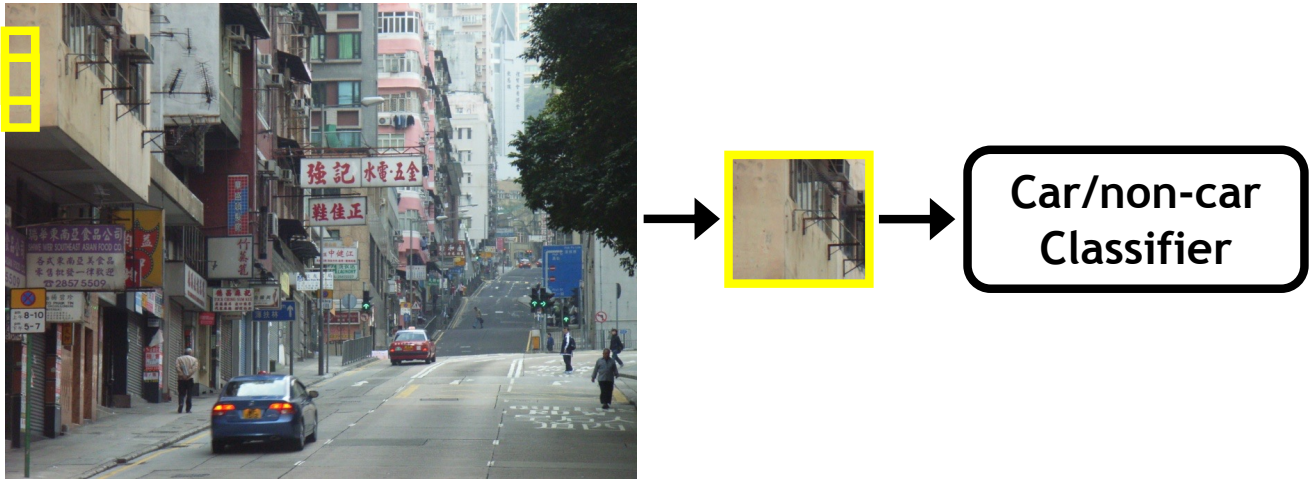
Window-template-based models Building an object model

Given the representation, train a binary classifier



Kristen Grauman

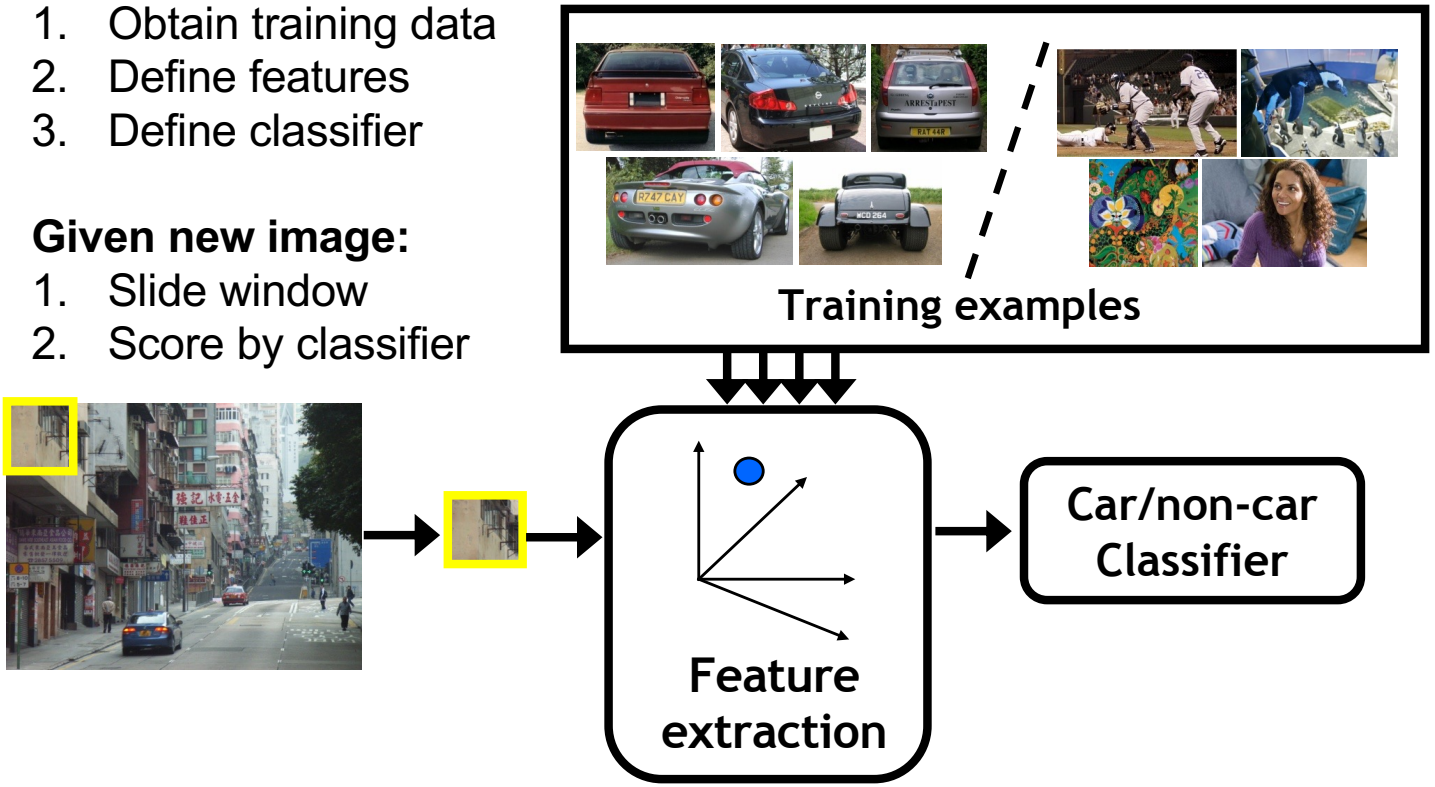
Window-template-based models Generating and scoring candidates



Window-template-based object detection: recap

Training:
1. Obtain training data
2. Define features
3. Define classifier

Given new image:
1. Slide window
2. Score by classifier

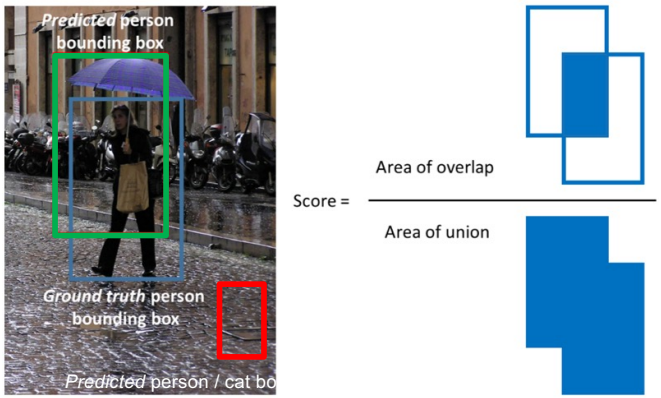


Kristen Grauman

Evaluating detection methods

$$mAP = \frac{1}{|classes|} \sum_{c \in classes} \frac{\#TP(c)}{\#TP(c) + \#FP(c)}$$

- True Positive - TP(c): a predicted bounding box (pred_bb) was made for class c, there is a ground truth bounding box (gt_bb) of class c, and IoU(pred_bb, gt_bb) >= 0.5.
- False Positive - FP(c): a pred_bb was made for class c, and there is no gt_bb of class c. Or there is a gt_bb of class c, but IoU(pred_bb, gt_bb) < 0.5.



Dalal-Triggs pedestrian detector

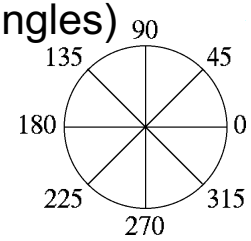
1. Extract fixed-sized (64x128 pixel) window at multiple positions and scales
2. Compute HOG (histogram of gradient) features within each window
3. Score the window with a linear SVM classifier
4. Perform non-maxima suppression to remove overlapping detections with lower scores

Navneet Dalal and Bill Triggs, Histograms of Oriented Gradients for Human Detection, CVPR05

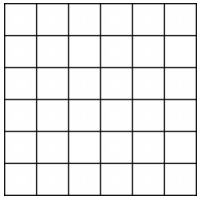
Histograms of oriented gradients (HOG)

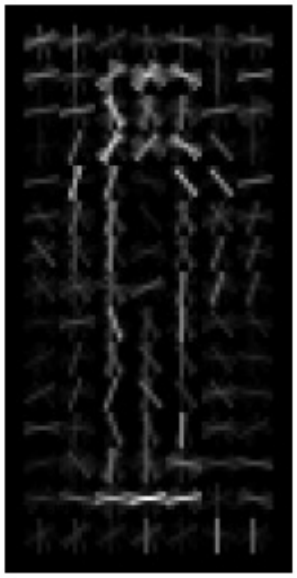
Divide image into 8x8 regions

Orientation: 9 bins (for unsigned angles)



Histograms in 8x8 pixel cells





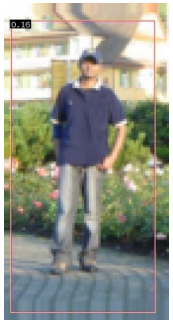
Votes weighted by magnitude

Adapted from Pete Barnum

Navneet Dalal and Bill Triggs, Histograms of Oriented Gradients for Human Detection, CVPR05

Train SVM for pedestrian detection using HoG

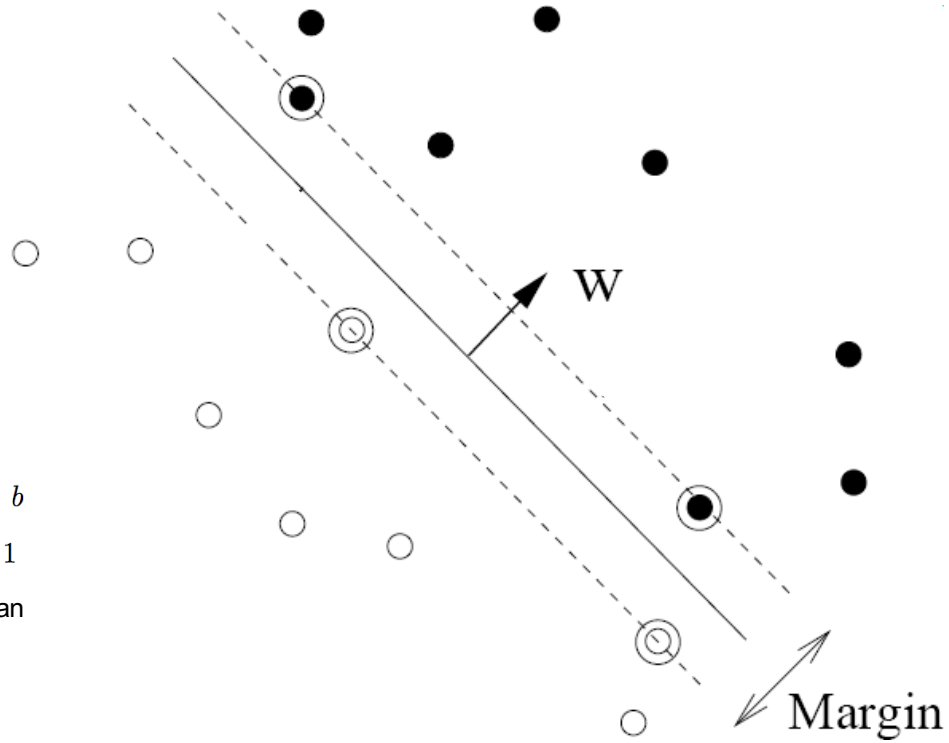
pos w



$0.16 = w^T x + b$

$sign(0.16) = 1$

=> pedestrian

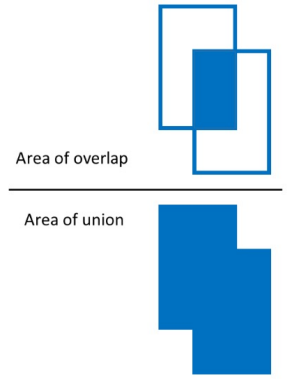


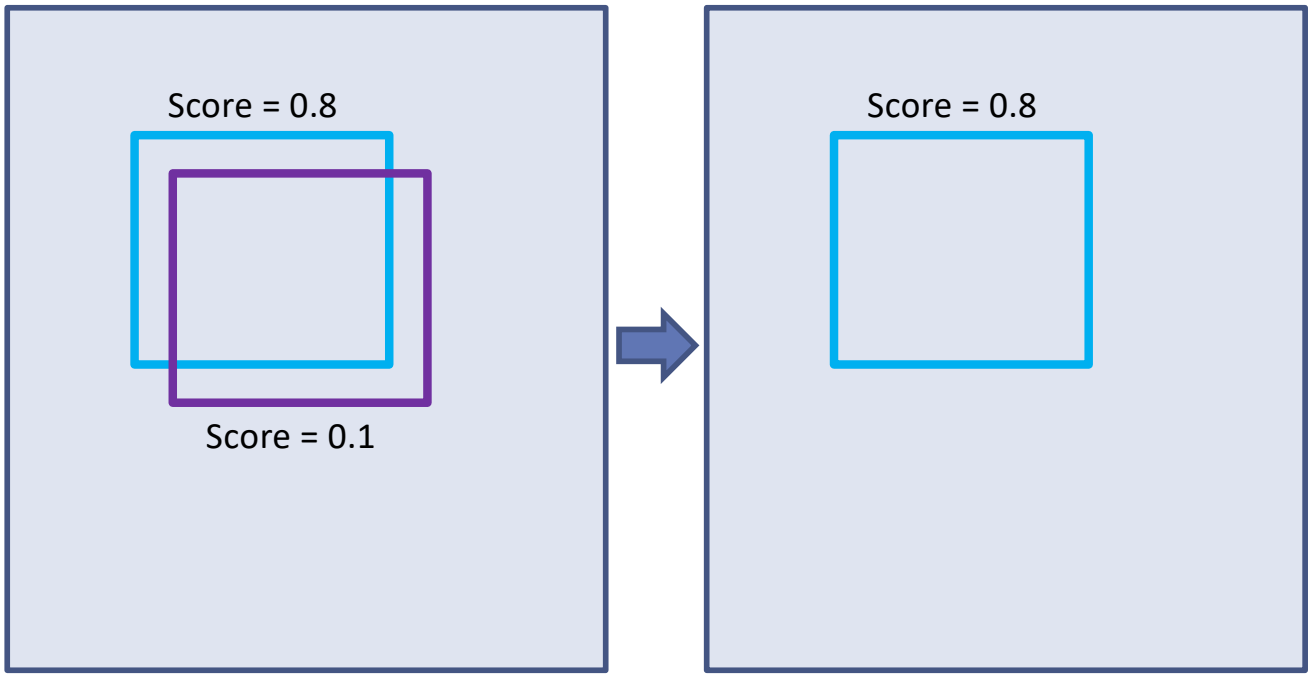
Adapted from Pete Barnum

Navneet Dalal and Bill Triggs, Histograms of Oriented Gradients for Human Detection, CVPR05

Remove overlapping detections

Non-max suppression





Adapted from Derek Hoiem

Are window templates enough?

- Many objects are articulated, or have parts that can vary in configuration

Images from Caltech-256, D. Ramanan

- Many object categories look very different from different viewpoints, or from instance to instance

Adapted from N. Snavely, D. Tran

Parts-based Models

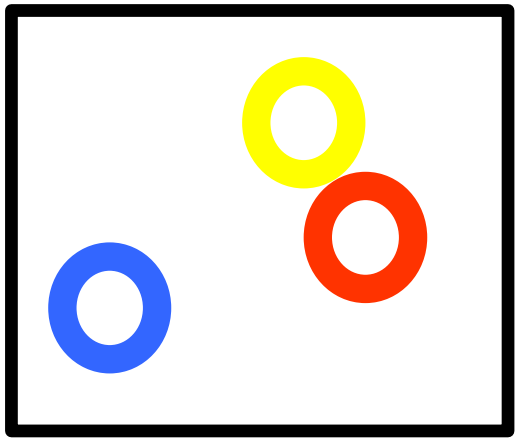
Define object by collection of parts modeled by

1. Appearance
2. Spatial configuration

Slide credit: Rob Fergus

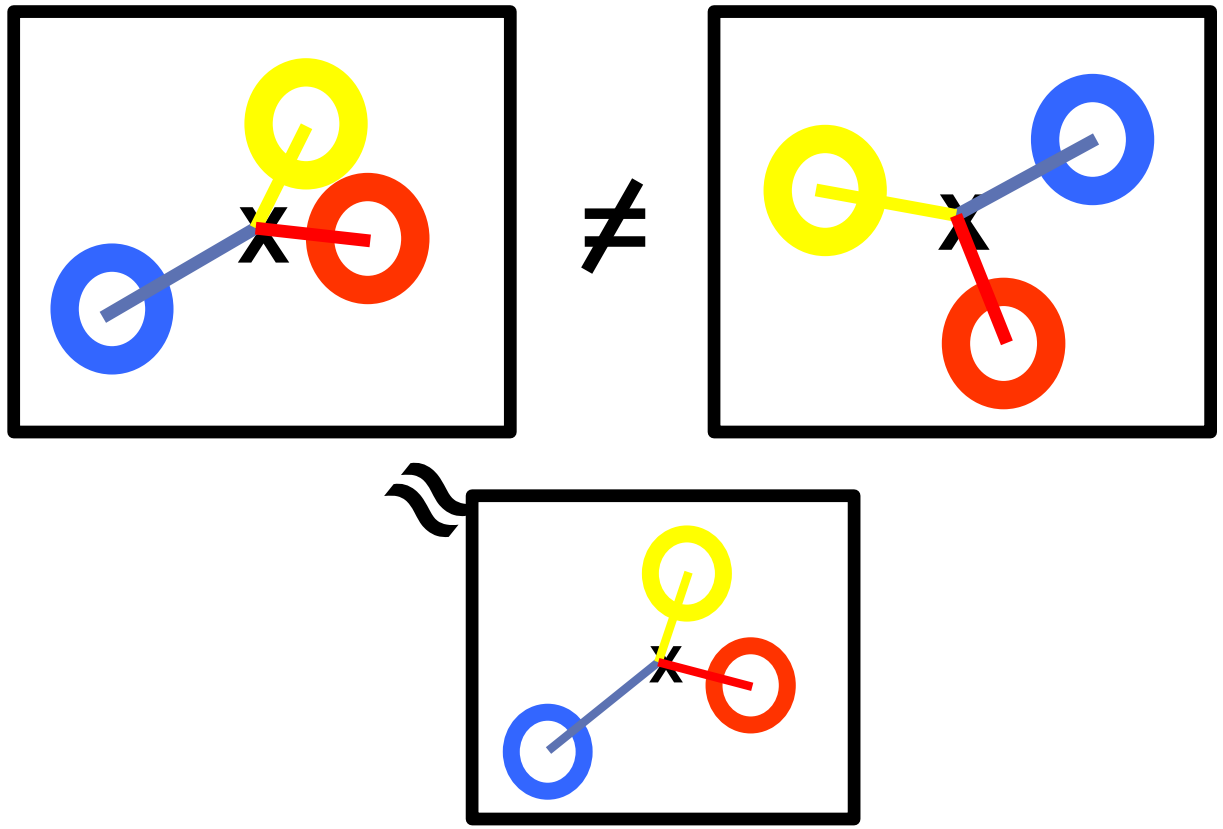
How to model spatial relations?

- One extreme: fixed template



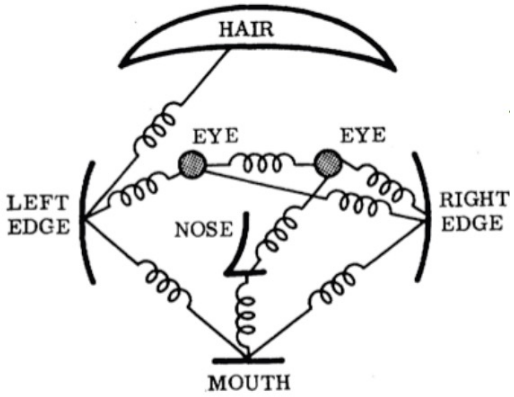
How to model spatial relations?

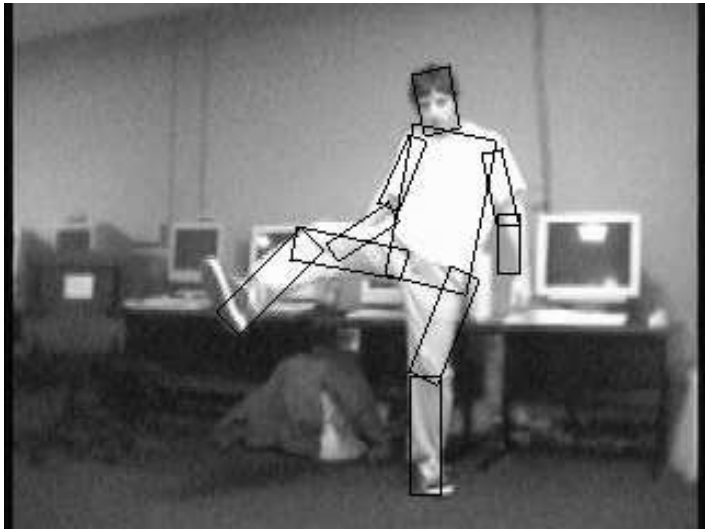
- Star-shaped model



Parts-based Models

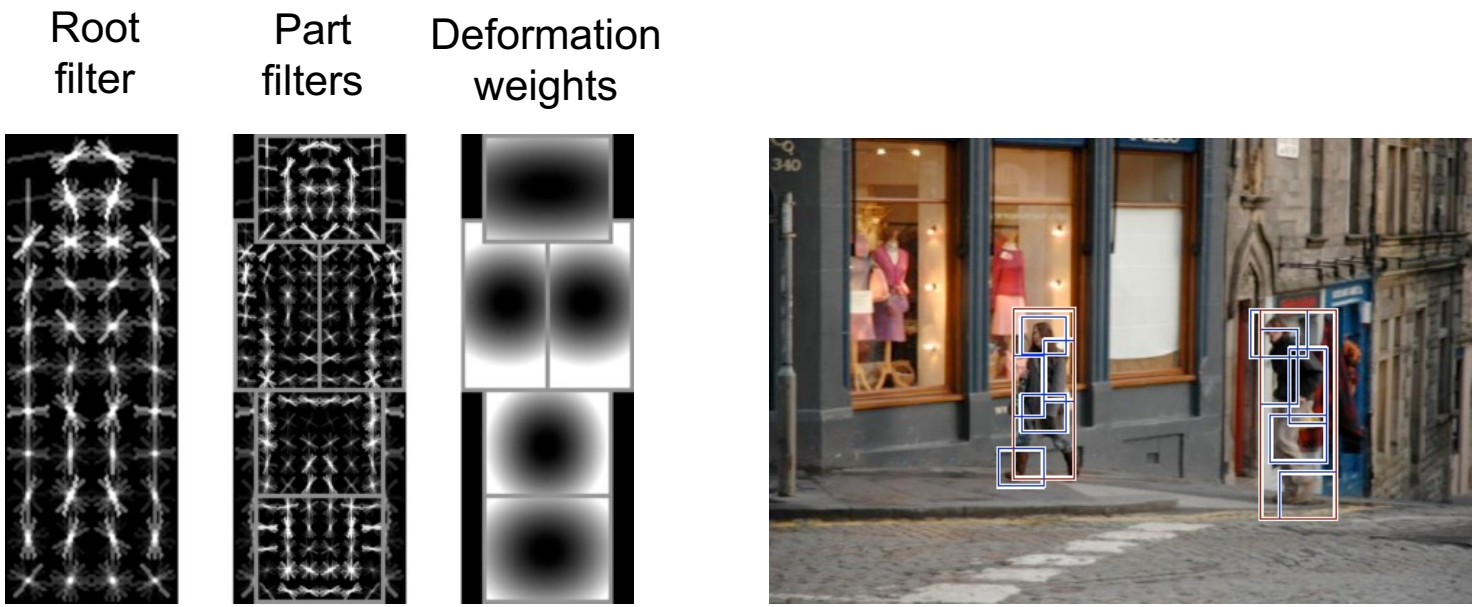
- Articulated parts model
  - Object is configuration of parts
  - Each part is detectable and can move around





Adapted from Derek Hoiem, images from Felzenszwalb

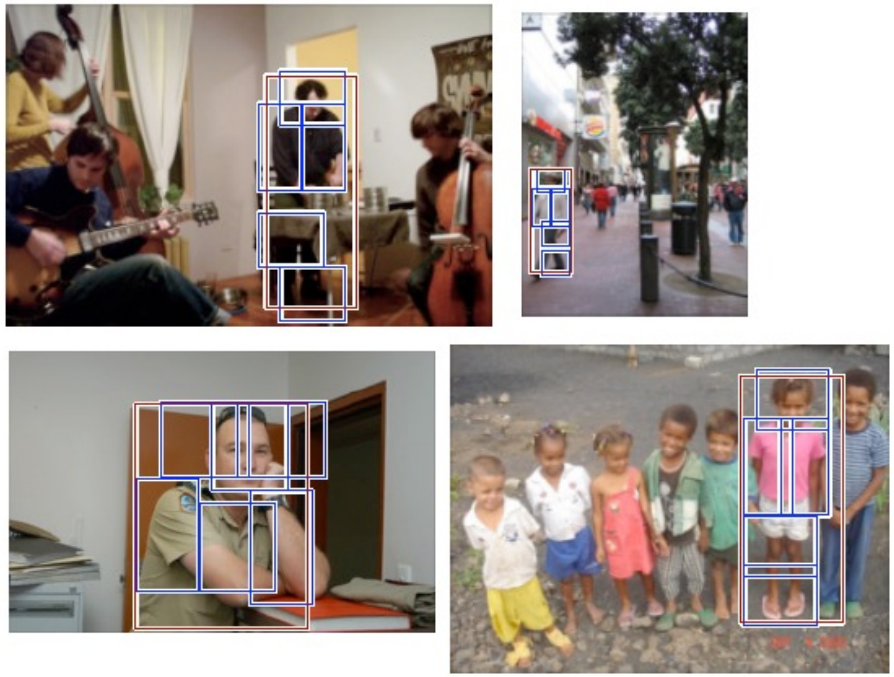
Deformable Part Models



P. Felzenszwalb, R. Girshick, D. McAllester, D. Ramanan, Object Detection with Discriminatively Trained Part Based Models, PAMI 32(9), 2010

Person Detections

high scoring true positives



high scoring false positives
(not enough overlap)

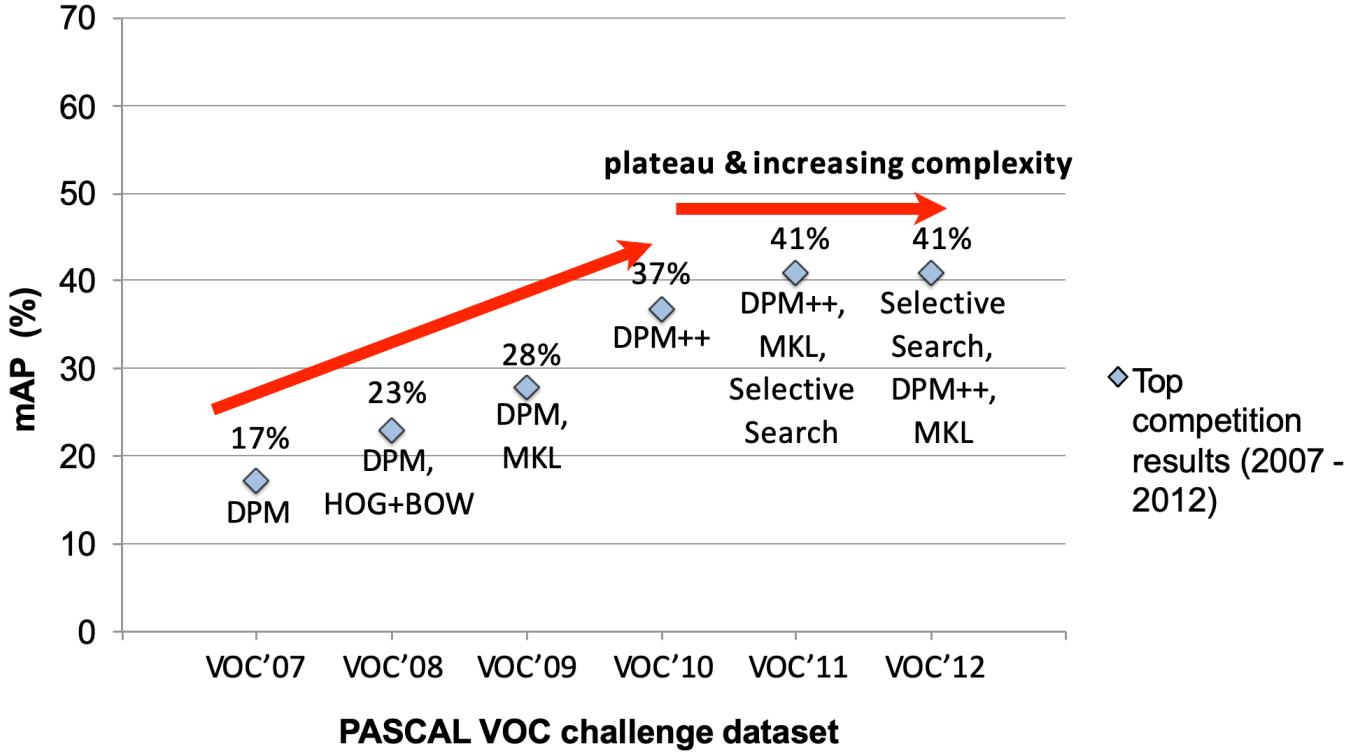
Lana Lazebnik

Plan for the next three lectures

- Detection approaches
  - Pre-CNNs
    - Detection with whole windows: Pedestrian detection
    - Part-based detection: Deformable Part Models
  - Post-CNNs
    - Detection with region proposals: R-CNN, Fast R-CNN, Faster-R-CNN
    - Detection without region proposals: YOLO, SSD
- Segmentation approaches
  - Semantic segmentation: FCN
  - Instance segmentation: Mask R-CNN

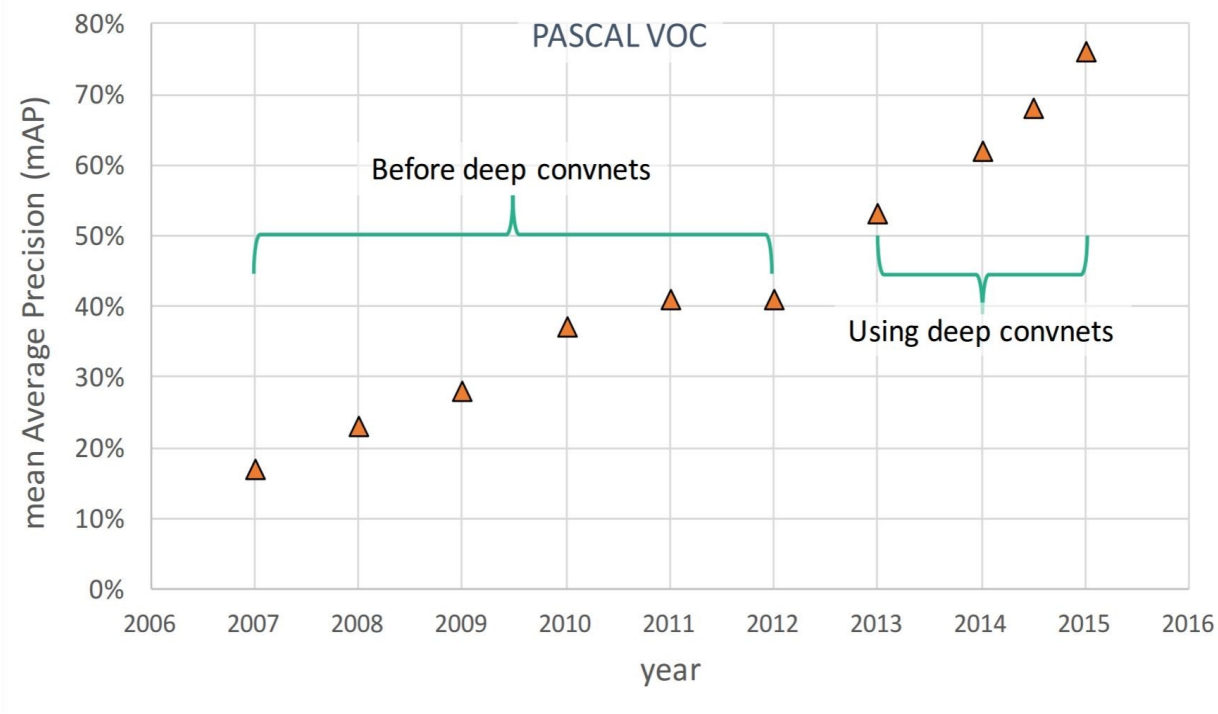
Complexity and the plateau

[Source: http://pascallin.ecs.soton.ac.uk/challenges/VOC/voc20{07,08,09,10,11,12}/results/index.html]



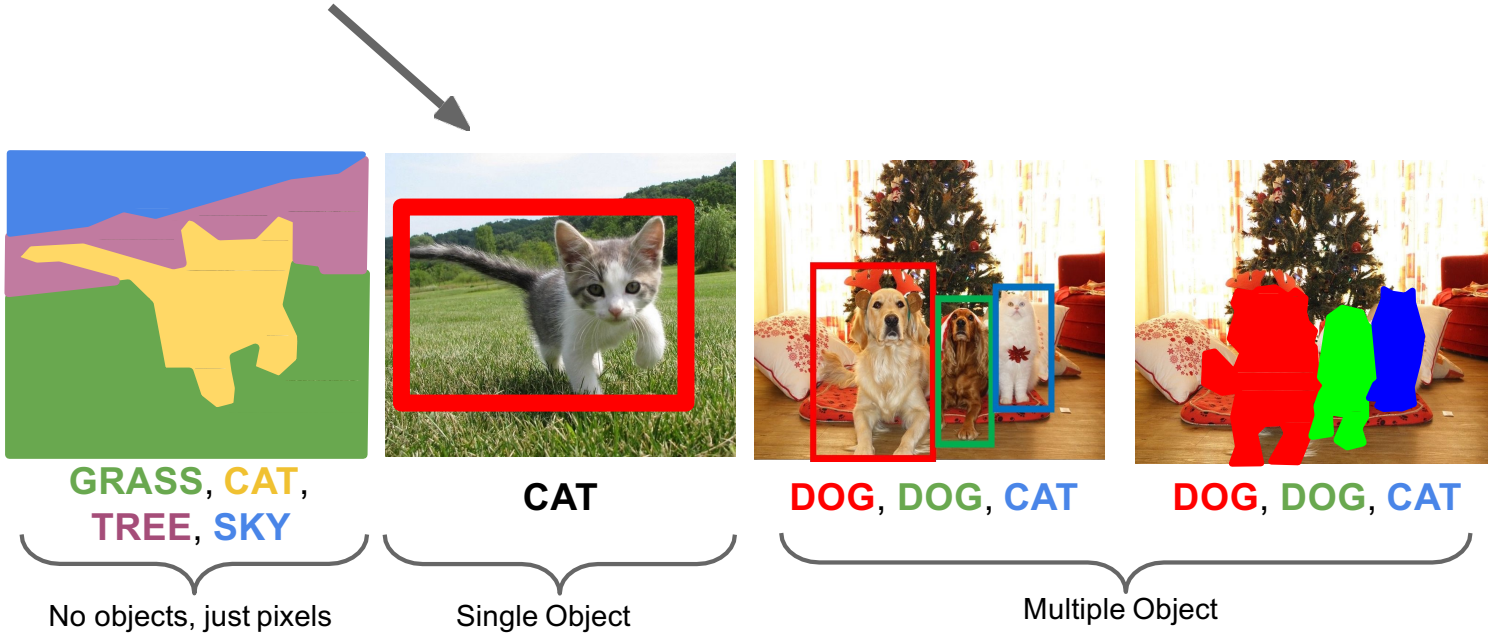
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

Impact of Deep Learning



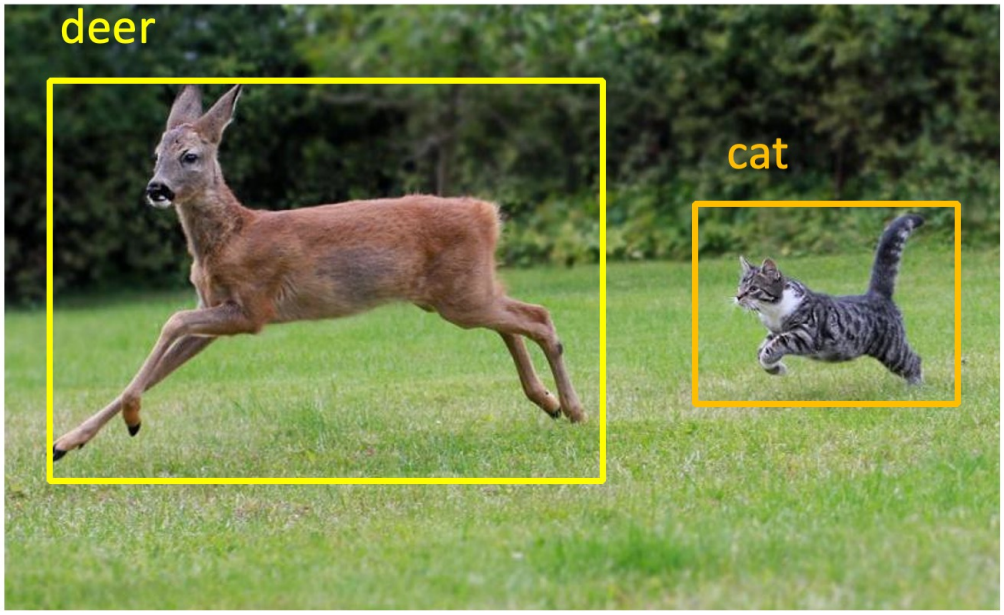
Slide by: Justin Johnson

Classification + Localization



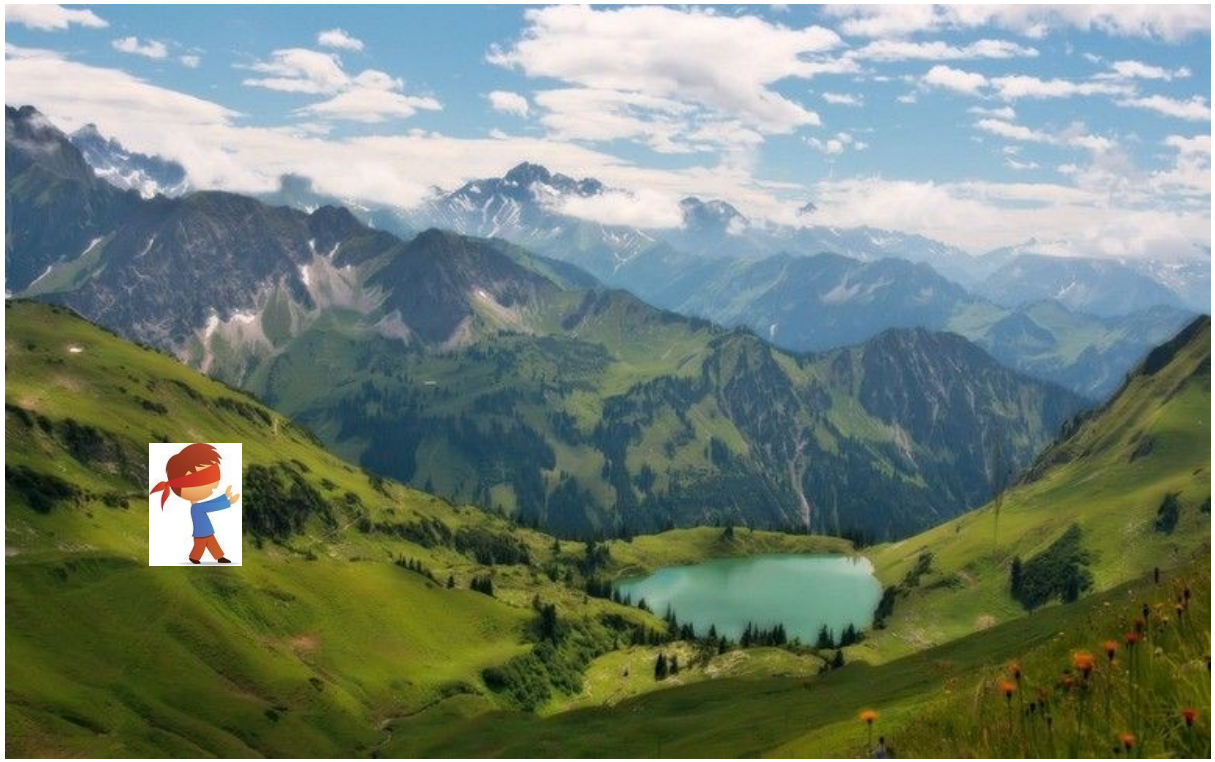
Slide by: Justin Johnson

What will be the output of a neural network for object detection?

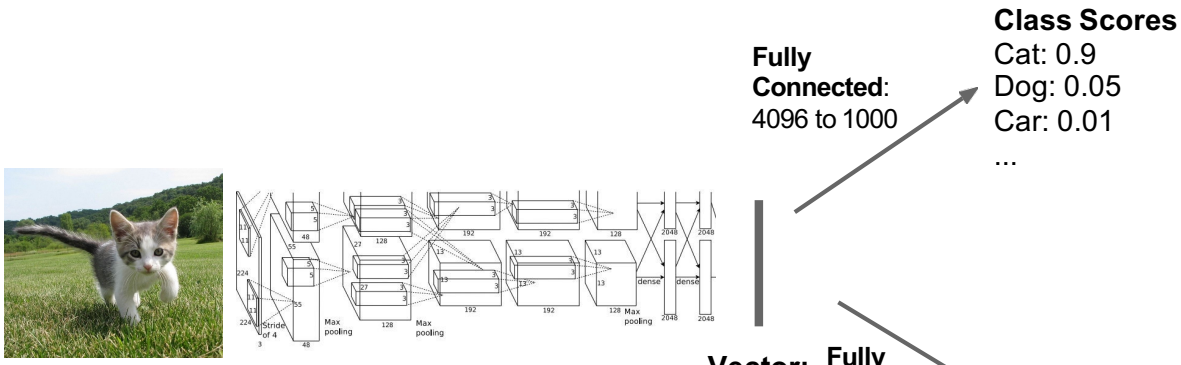


Adapted from Vicente Ordoñez

What guides the learning of a neural network?



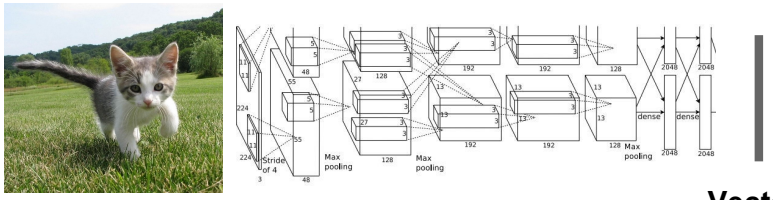
Classification + Localization



Treat localization as a regression problem!

Slide by: Justin Johnson

Classification + Localization



Fully Connected: 4096 to 1000

Class Scores
Cat: 0.9
Dog: 0.05
Car: 0.01
...

Softmax Loss

Correct label: Cat

Vector: 4096

Fully Connected: 4096 to 4

Box Coordinates (x, y, w, h)

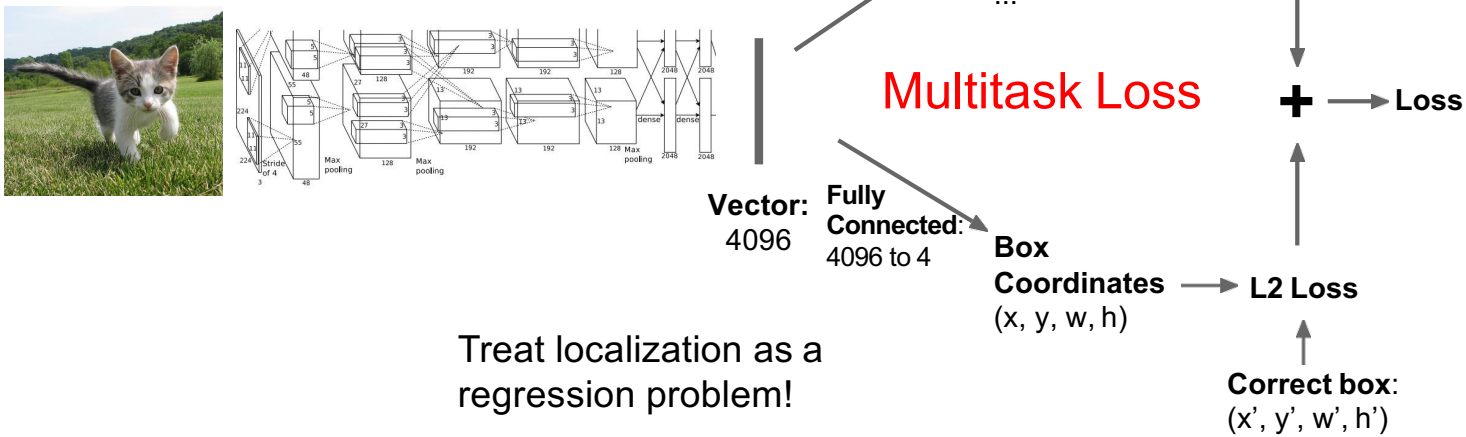
L2 Loss

Correct box: (x', y', w', h')

Treat localization as a regression problem!

Slide by: Justin Johnson

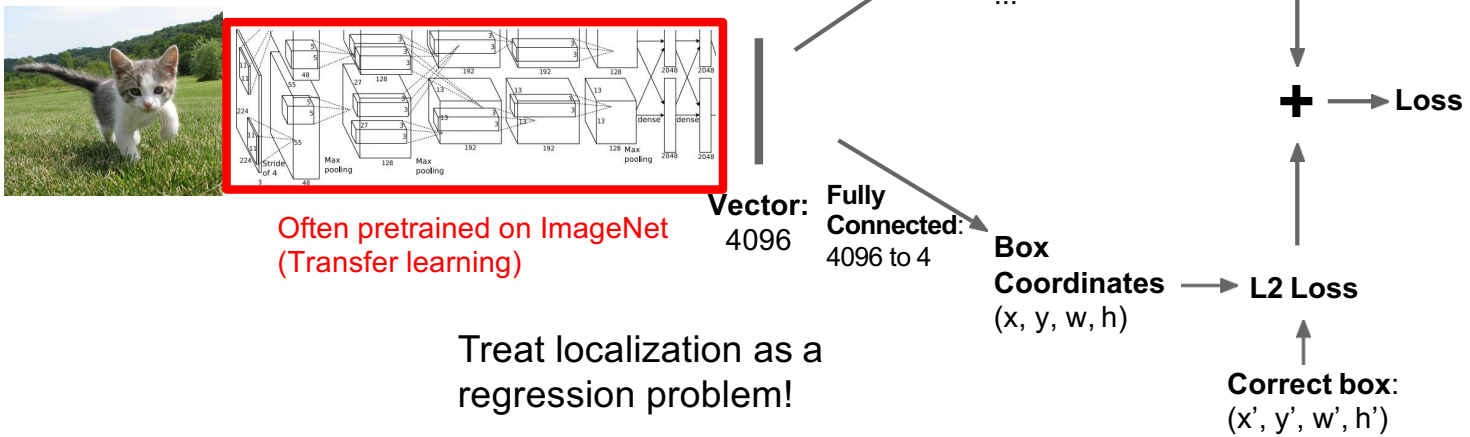
Classification + Localization



Treat localization as a regression problem!

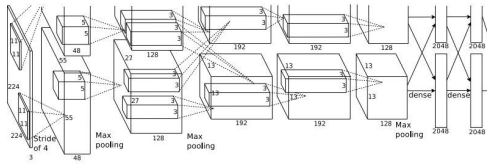
Slide by: Justin Johnson

Classification + Localization

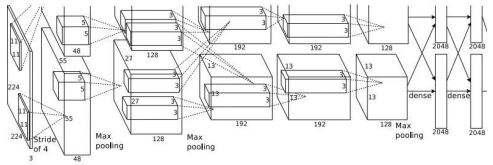


Slide by: Justin Johnson

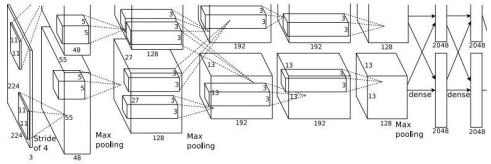
Object Detection as Regression?



CAT: (x, y, w, h)



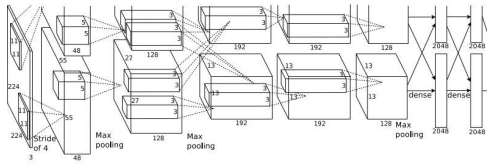
DOG: (x, y, w, h)
DOG: (x, y, w, h)
CAT: (x, y, w, h)



DUCK: (x, y, w, h)
DUCK: (x, y, w, h)
….

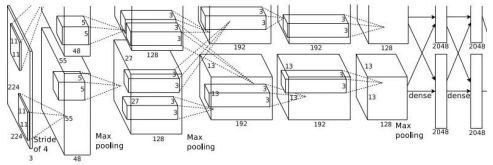
Slide by: Justin Johnson

Object Detection as Regression?



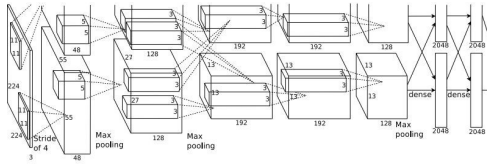
CAT: (x, y, w, h)

4 numbers



DOG: (x, y, w, h)
DOG: (x, y, w, h)
CAT: (x, y, w, h)

16 numbers



DUCK: (x, y, w, h)
DUCK: (x, y, w, h)
….

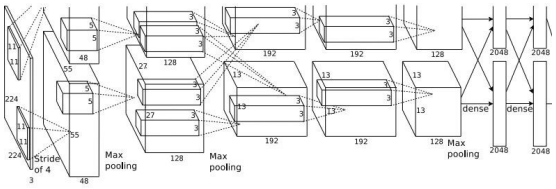
Many numbers!

Each image needs a different number of outputs!

Slide by: Justin Johnson

Object Detection as Classification: Sliding Window

Apply a CNN to many different crops of the image, CNN classifies each crop as object or background

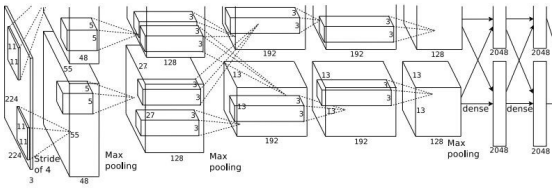


Dog? NO
Cat? NO
Background? YES

Slide by: Justin Johnson

Object Detection as Classification: Sliding Window

Apply a CNN to many different crops of the image, CNN classifies each crop as object or background

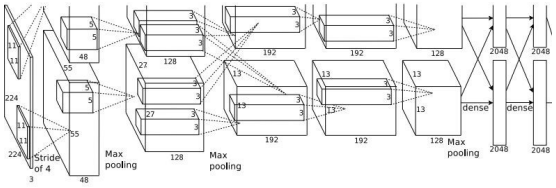


Dog? YES
Cat? NO
Background? NO

Slide by: Justin Johnson

Object Detection as Classification: Sliding Window

Apply a CNN to many different crops of the image, CNN classifies each crop as object or background

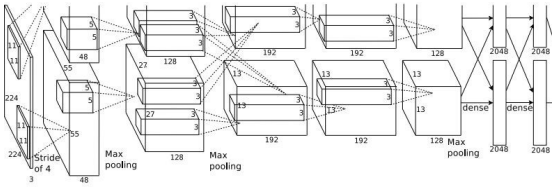


Dog? YES
Cat? NO
Background? NO

Slide by: Justin Johnson

Object Detection as Classification: Sliding Window

Apply a CNN to many different crops of the image, CNN classifies each crop as object or background

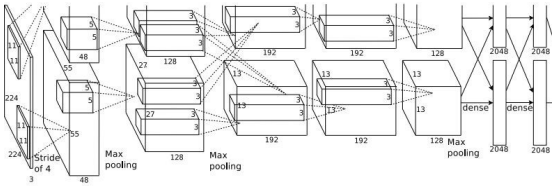


Dog? NO
Cat? YES
Background? NO

Slide by: Justin Johnson

Object Detection as Classification: Sliding Window

Apply a CNN to many different crops of the image, CNN classifies each crop as object or background



Dog? NO
Cat? YES
Background? NO

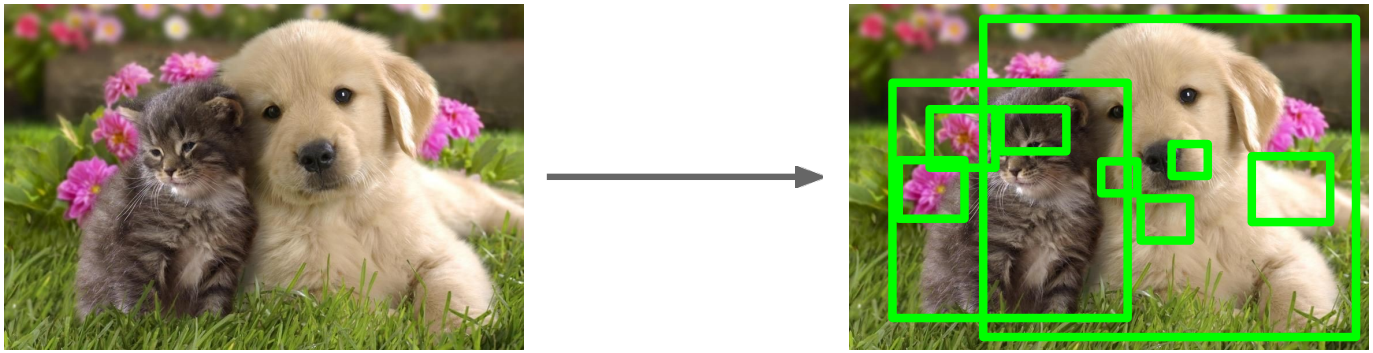
Problem: Need to apply CNN to huge number of locations and scales, very computationally expensive!

What can we do?

Slide by: Justin Johnson

Region Proposals

- Find “blobby” image regions that are likely to contain objects
- Relatively fast to run; e.g. Selective Search gives 1000 region proposals in a few seconds on CPU



Alexe et al, “Measuring the objectness of image windows”, TPAMI 2012
Uijlings et al, “Selective Search for Object Recognition”, IJCV 2013
Cheng et al, “BING: Binarized normed gradients for objectness estimation at 300fps”, CVPR 2014
Zitnick and Dollar, “Edge boxes: Locating object proposals from edges”, ECCV 2014

Slide by: Justin Johnson

Objectness cue #1: Where people look

Fig. 2: **MS success and failure.**

Alexe et al., CVPR 2010

Objectness cue #2: color contrast at boundary

(a) (b) (c)

Fig. 3: **CC success and failure. Success:** *the windows containing the objects (cyan) have high color contrast with their surrounding ring (yellow) in images (a) and (b).* **Failure:** *the color contrast for windows in cyan in image (c) is much lower.*

Alexe et al., CVPR 2010

Objectness cue #3: no segments “straddling” the object box

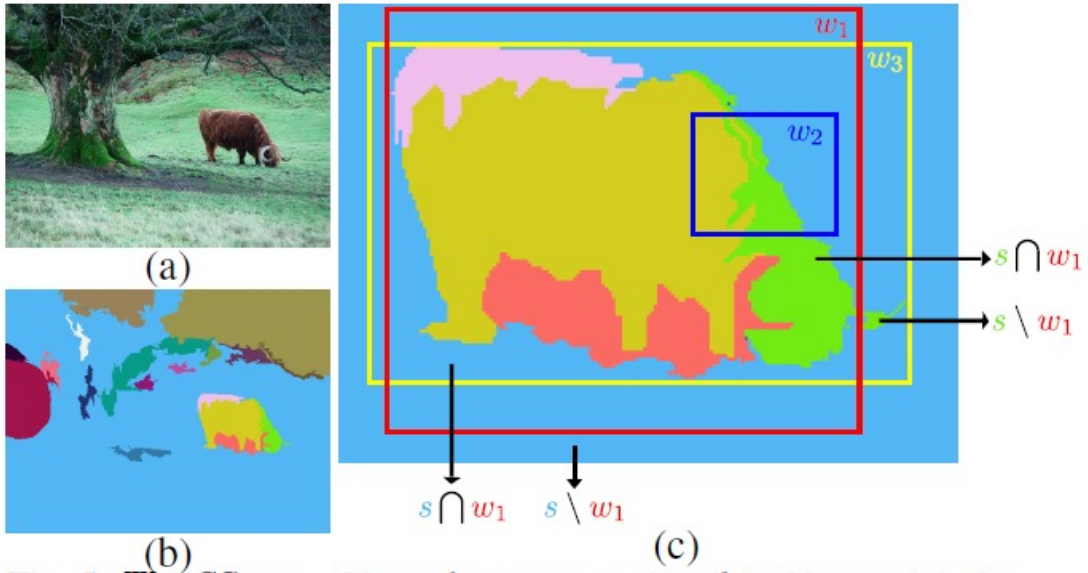
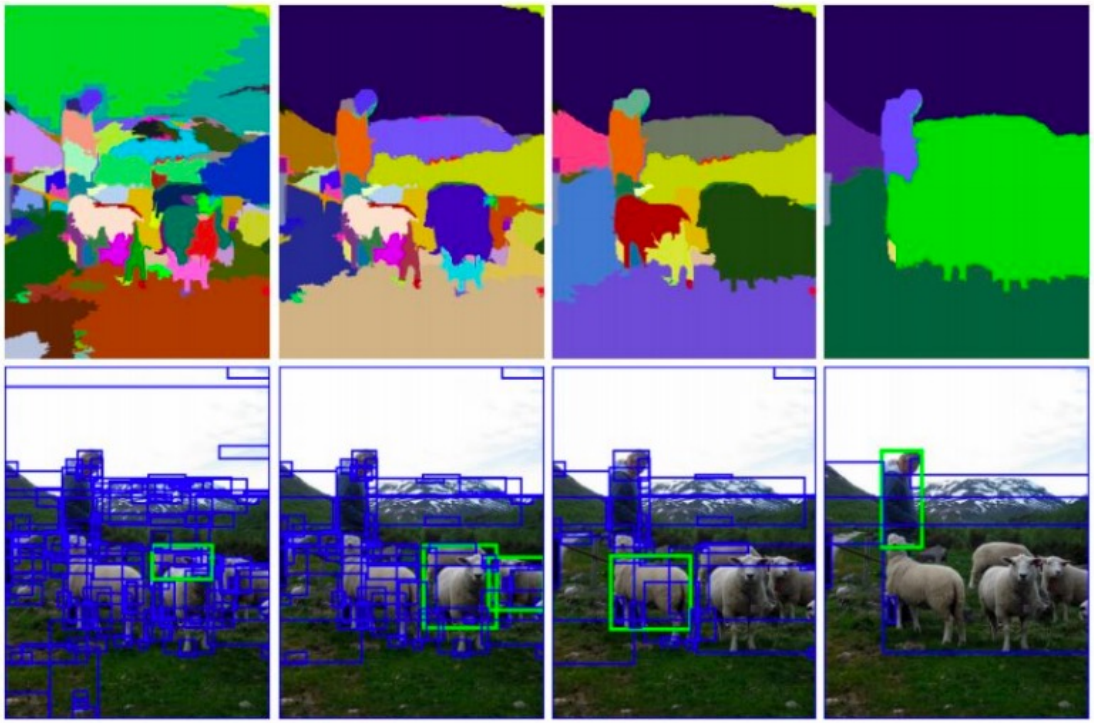


Fig. 5: **The SS cue.** *Given the segmentation (b) of image (a), for a window w we compute $\mathrm{SS}(\mathrm{w}, \theta_{\mathrm{SS}})$ (eq. 4). In (c), most of the surface of w_1 is covered by superpixels contained almost entirely inside it. Instead, all superpixels passing by w_2 continue largely outside it. Therefore, w_1 has a higher SS score than w_2. The window w_3 has an even higher score as it fits the object tightly.*

Alexe et al., CVPR 2010

Box Proposal Method – SS: Selective Search



Segmentation As Selective Search for Object Recognition. van de Sande et al. ICCV 2011

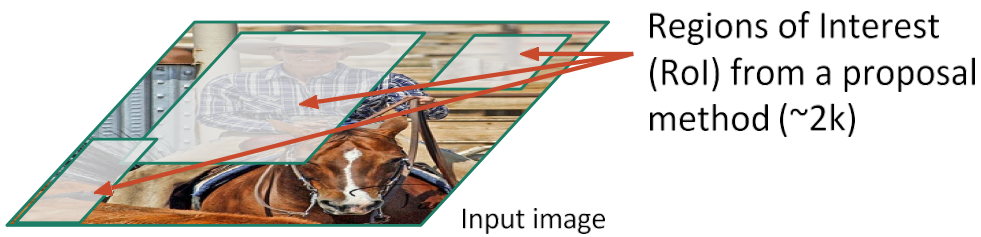
Adapted from Vicente Ordoñez

R-CNN

Input image

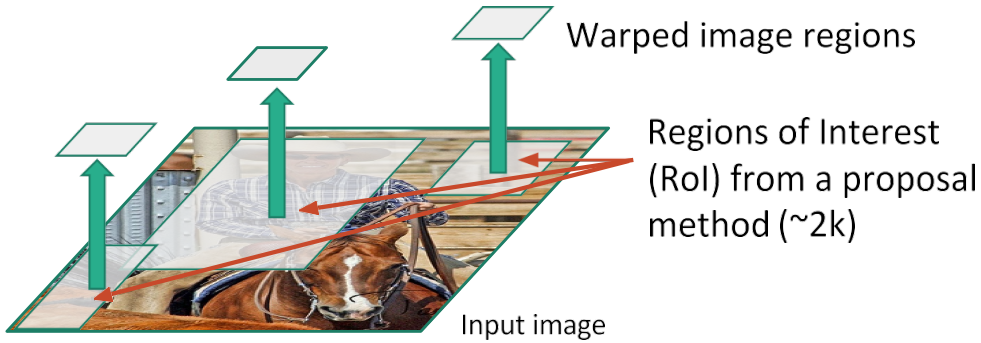
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN



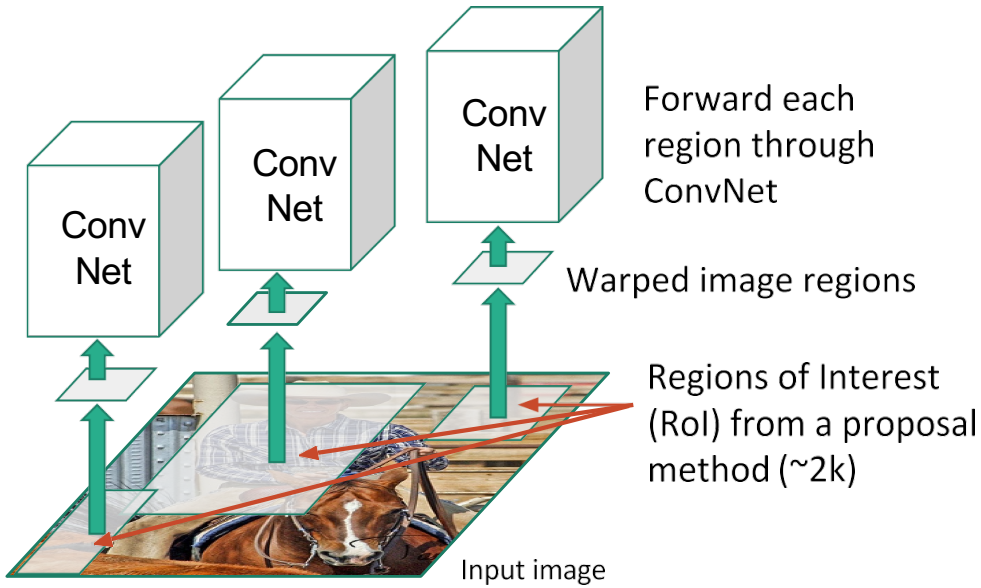
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN



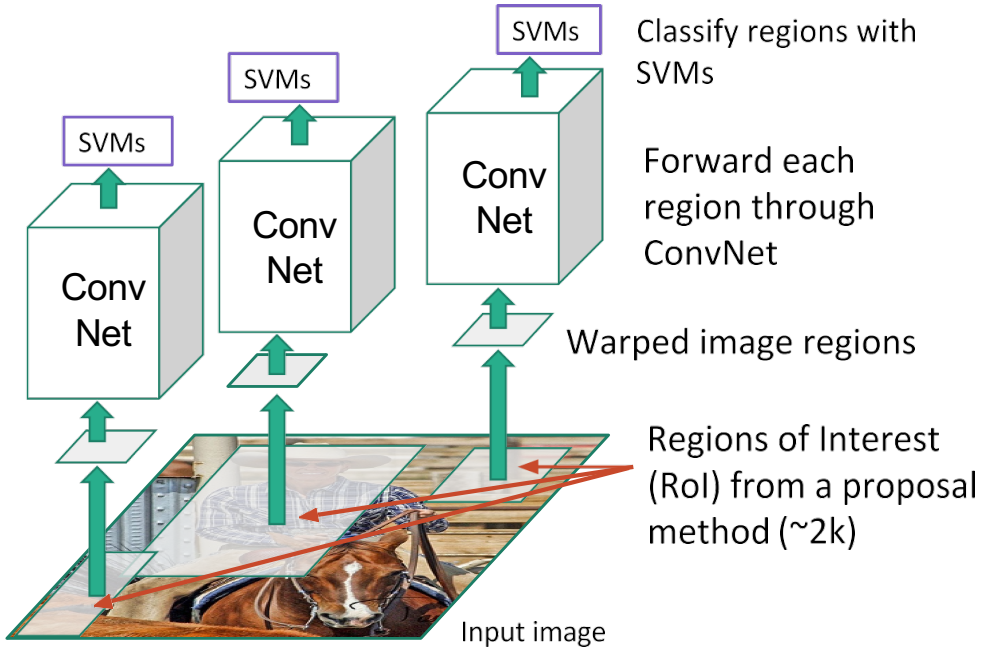
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN



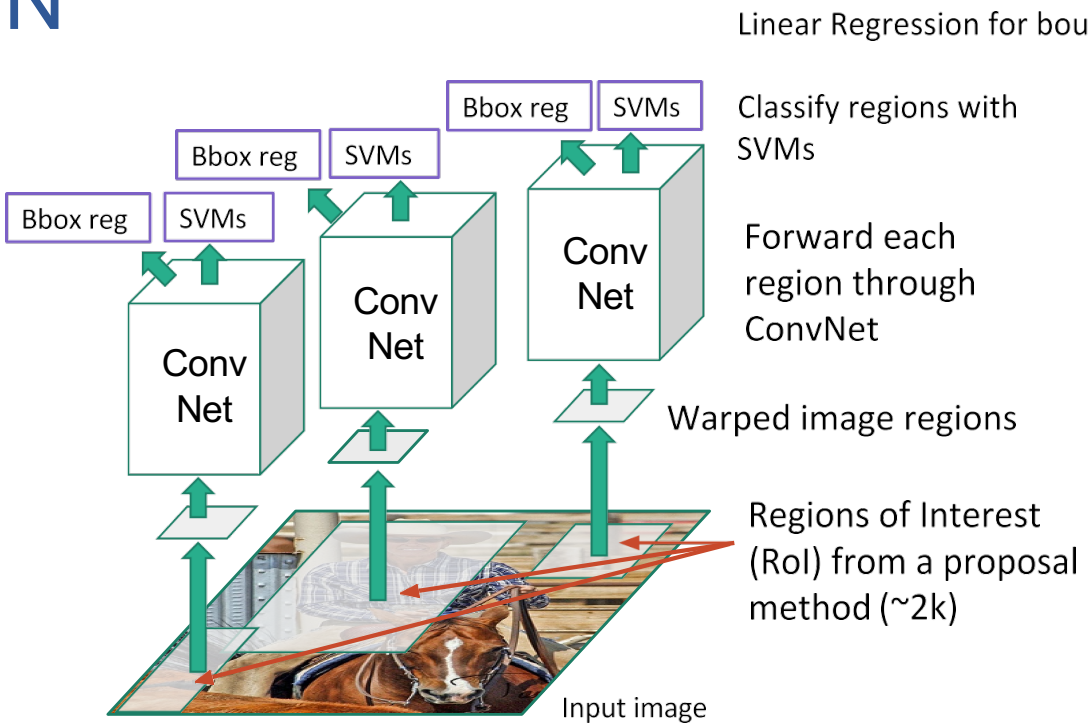
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN



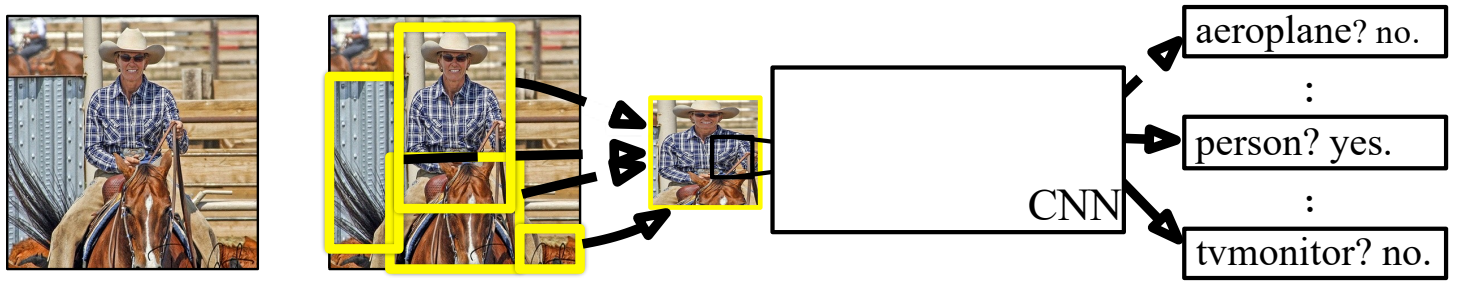
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN



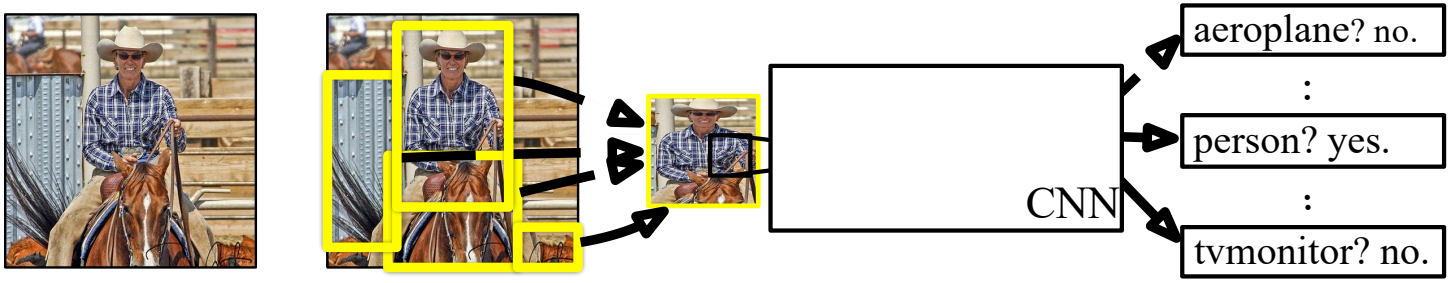
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN: Regions with CNN features



Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN at test time: Step 1



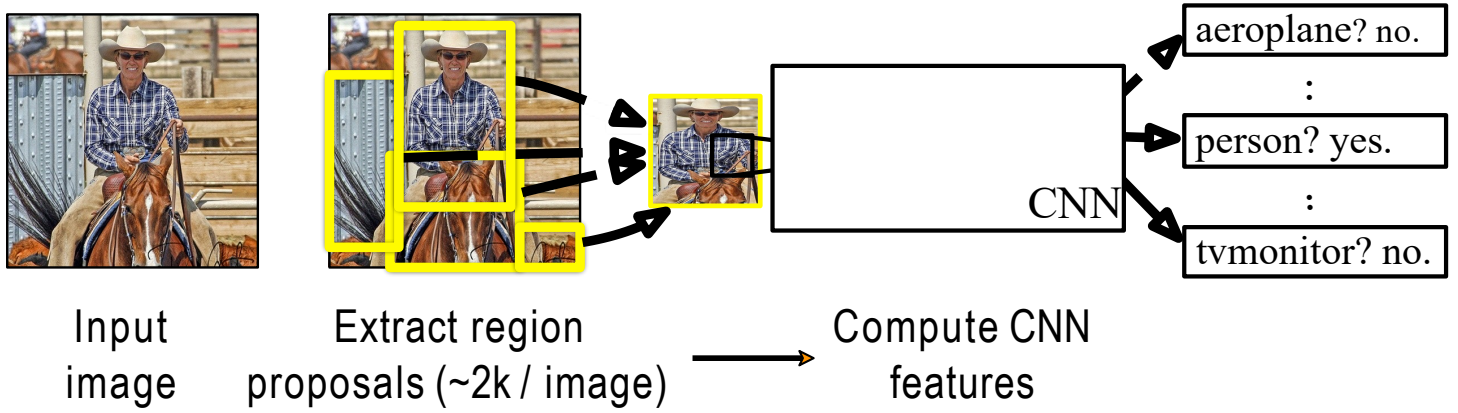
Input image → Extract region proposals (~2k / image)

Proposal-method agnostic, many choices

- Selective Search [van de Sande, Uijlings et al.] (Used in this work)
- Objectness [Alexe et al.]
- Category independent object proposals [Endres & Hoiem]
- CPMC [Carreira & Sminchisescu]

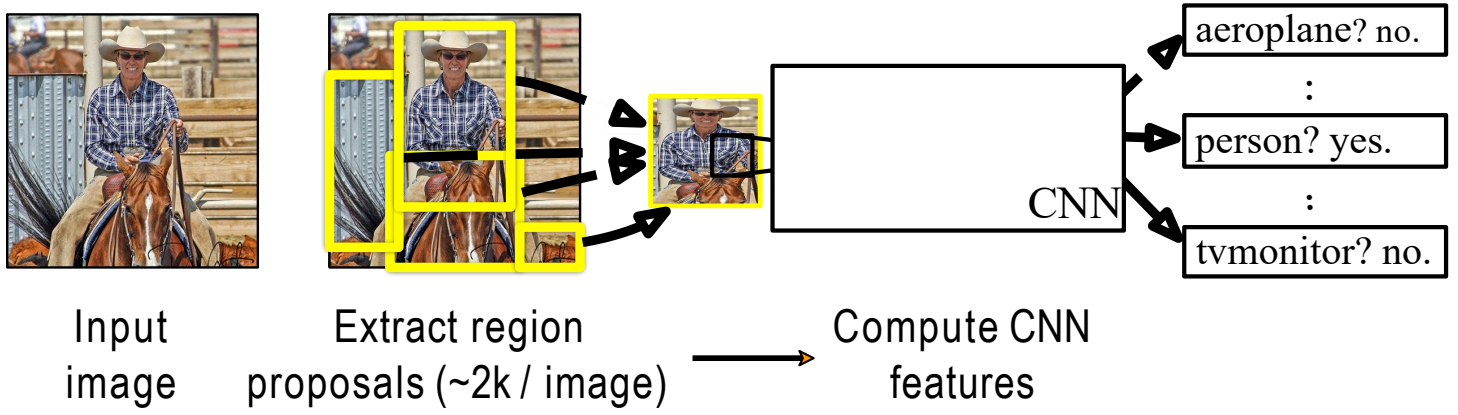
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

R-CNN at test time: Step 2



Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

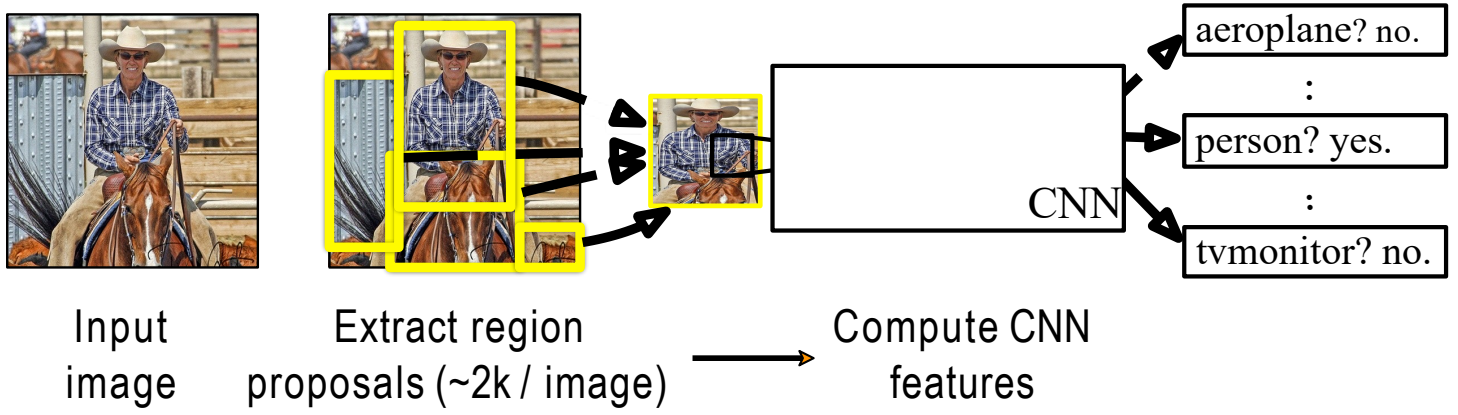
R-CNN at test time: Step 2



Dilate proposal

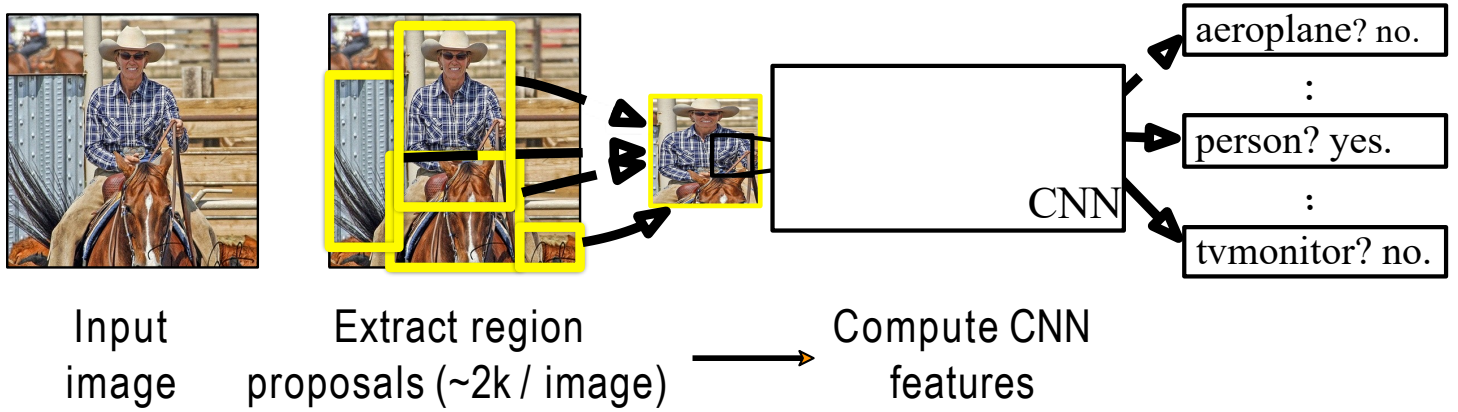
Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

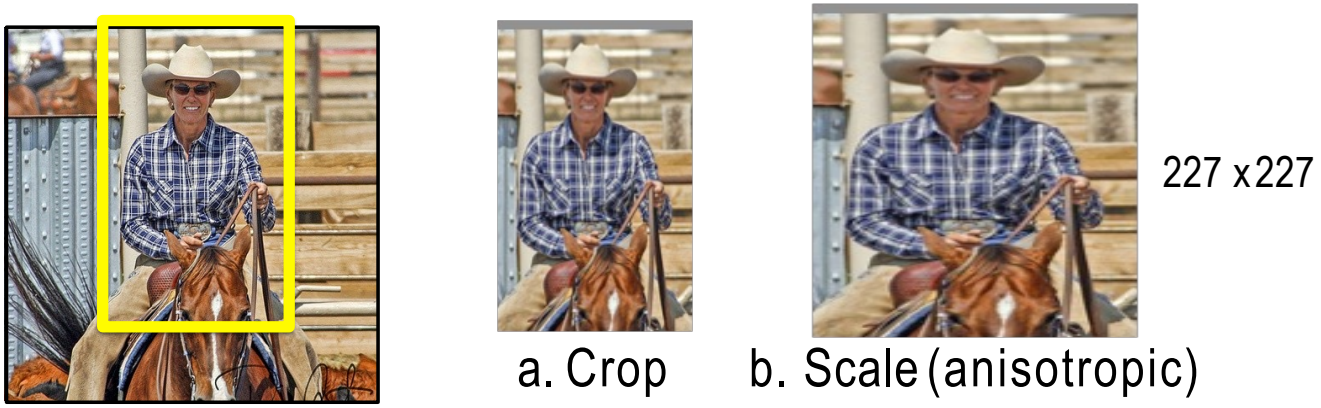
R-CNN at test time: Step 2



Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

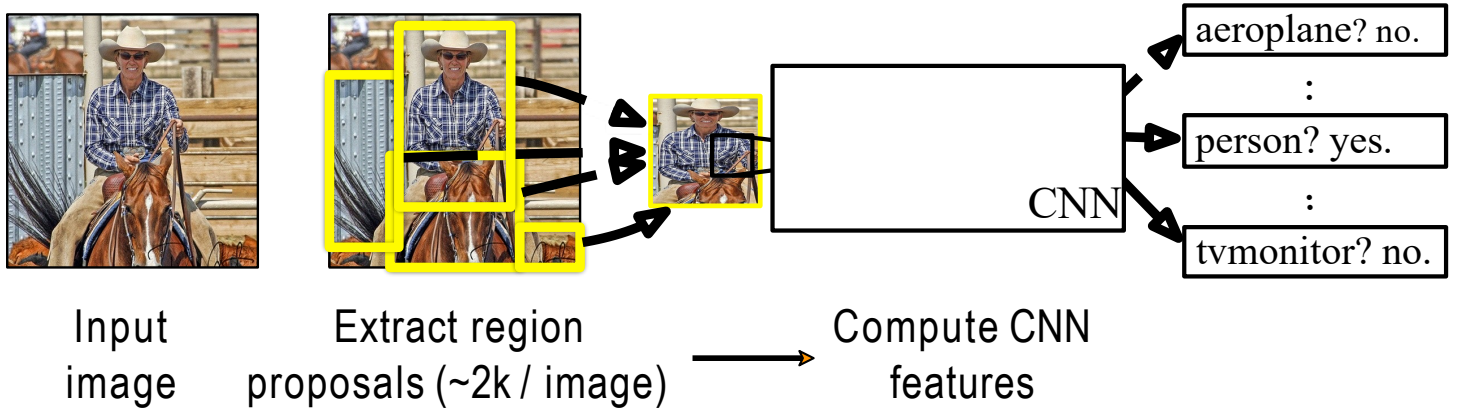
R-CNN at test time: Step 2

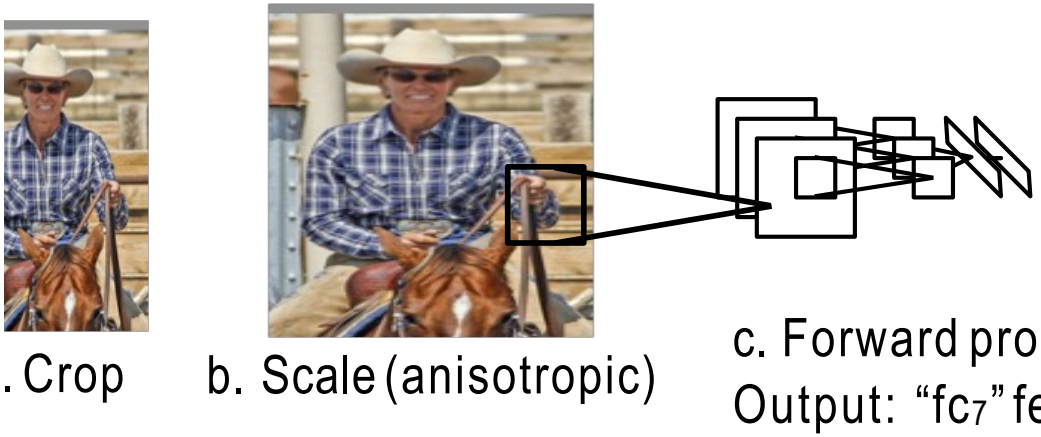




Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

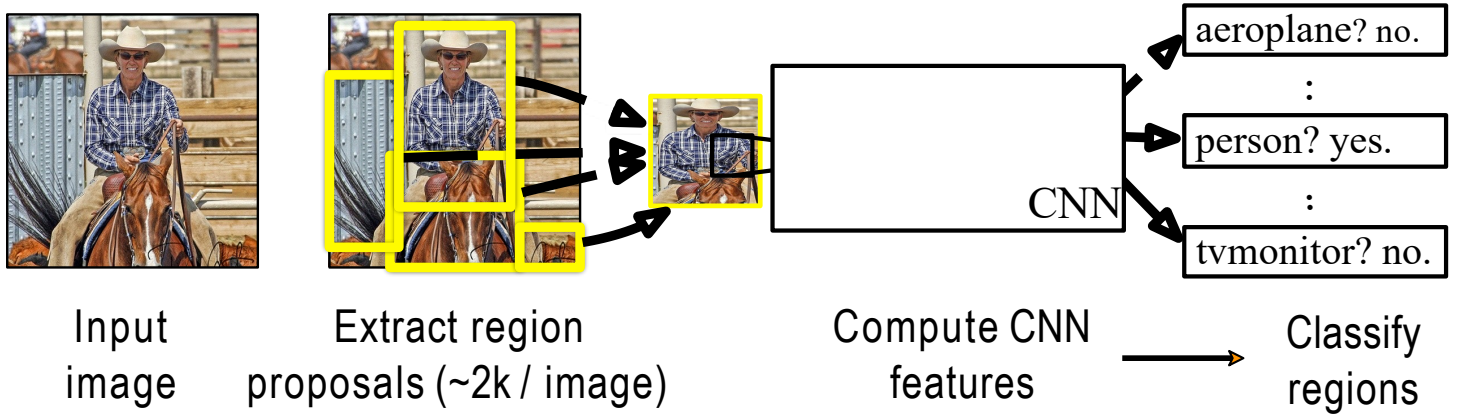
R-CNN at test time: Step 2

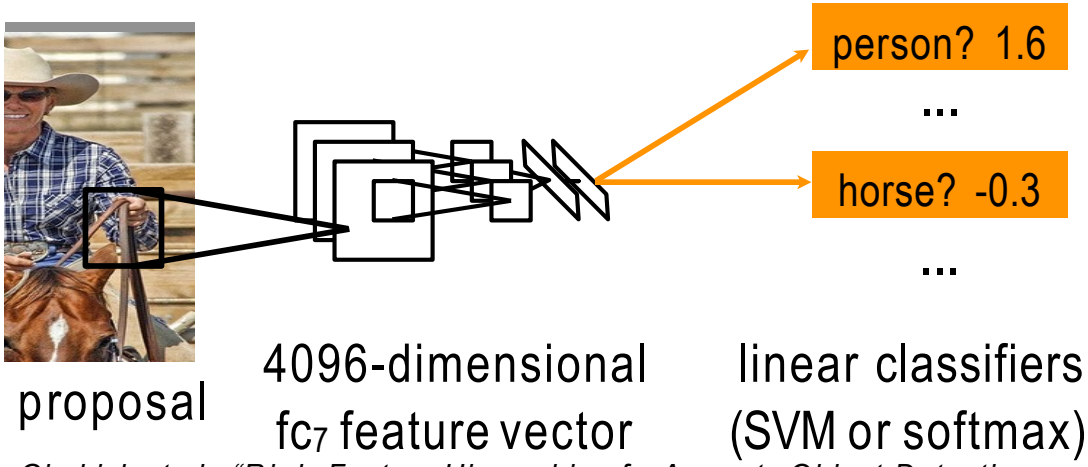




Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

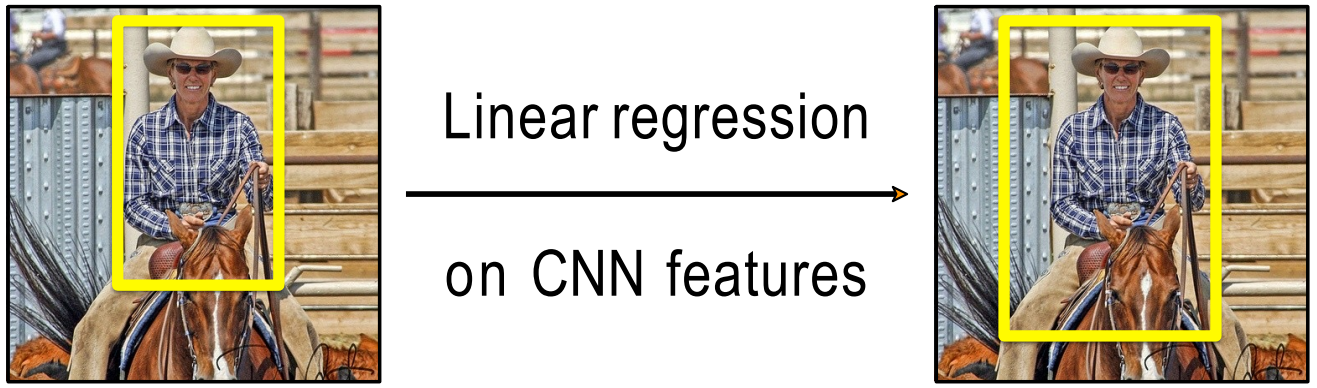
R-CNN at test time: Step 3





Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

Step 4: Object proposal refinement



Original proposal

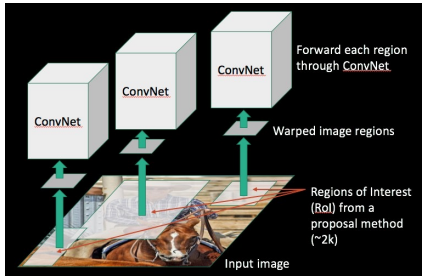
Predicted object bounding box

Bounding-box regression

Girshick et al., "Rich Feature Hierarchies for Accurate Object Detection and Semantic Segmentation", CVPR 2014

What's wrong with slow R-CNN?

- Ad-hoc training objectives
  - Train post-hoc linear SVMs (hinge loss)
  - Train post-hoc bounding-box regressions (L2 loss)
- Training is slow (84h), takes a lot of disk space
  - Need to store all region crops
- Inference (detection) is slow
  - 47s / image with VGG16 [Simonyan & Zisserman, ICLR15]



~2000 ConvNet forward passes per image

Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN

- One network, applied one time, not 2000 times
- Trained end-to-end (in one stage)
- Fast test time
- Higher mean average precision

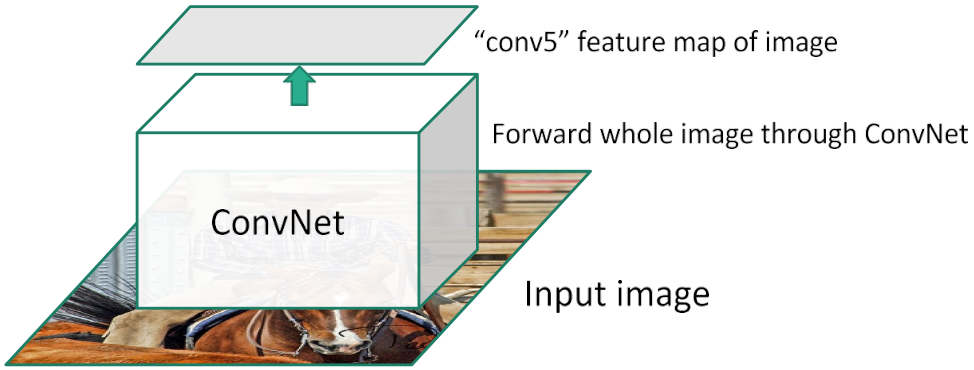
Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN

Input image

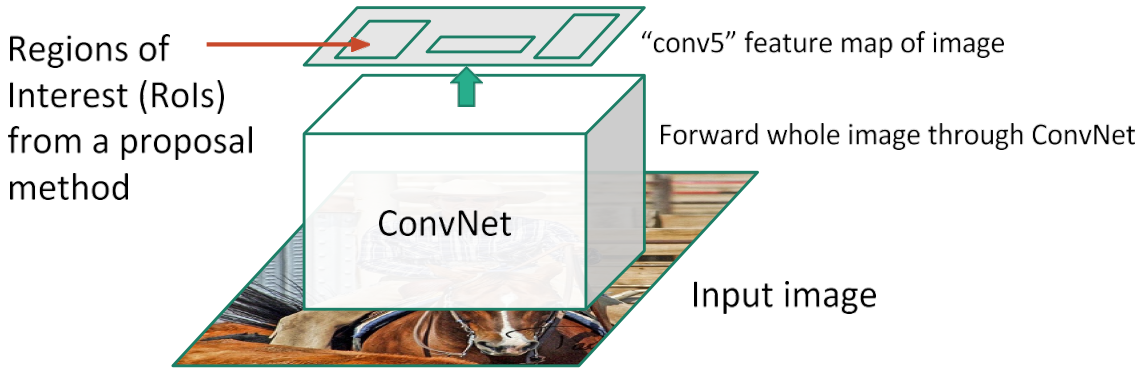
Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN



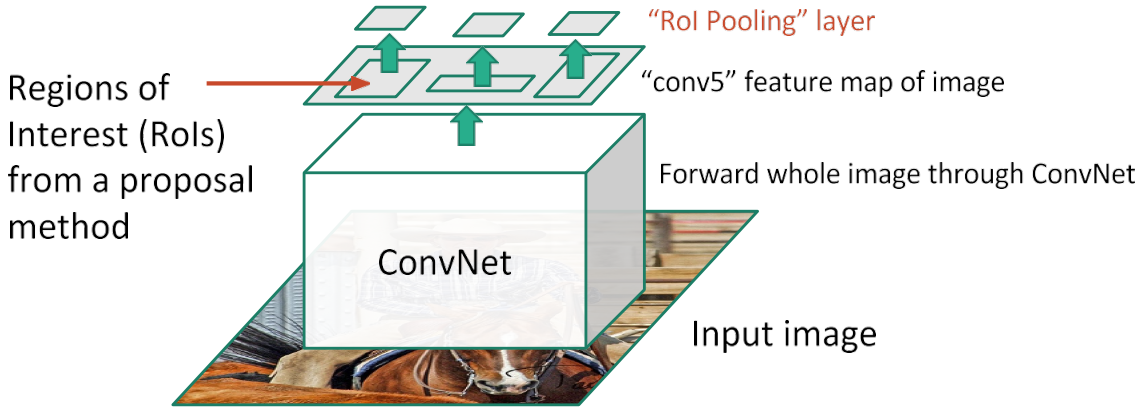
Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN



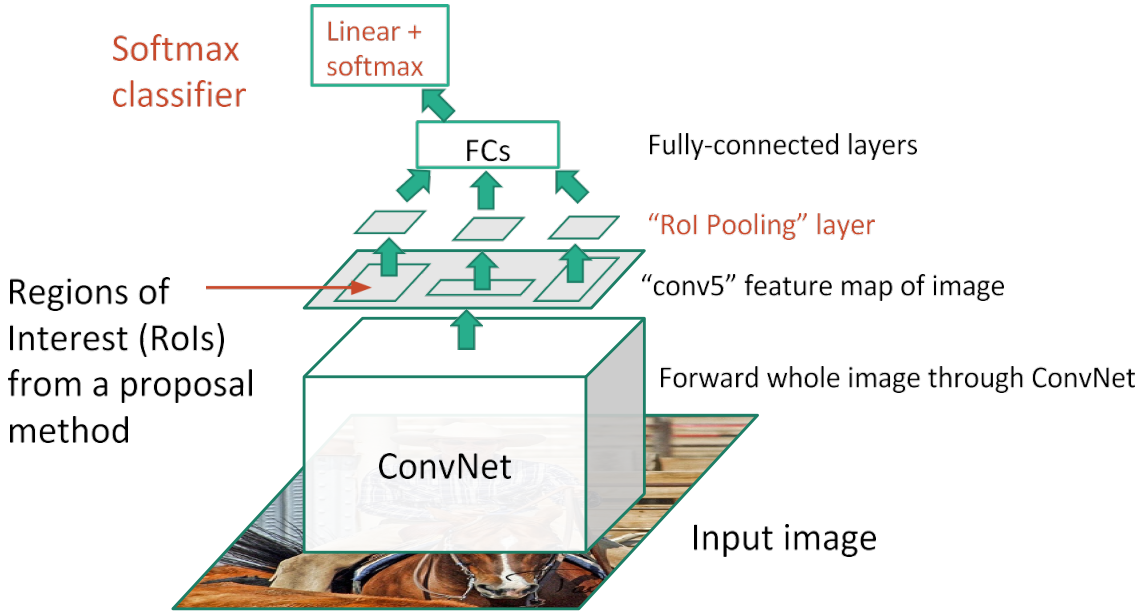
Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN



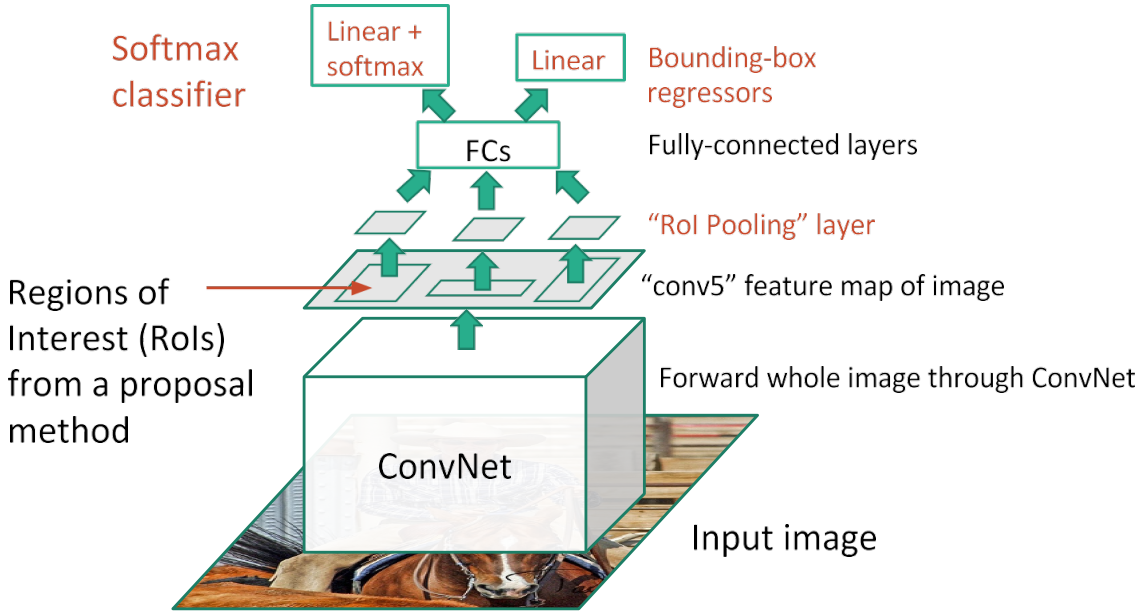
Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN



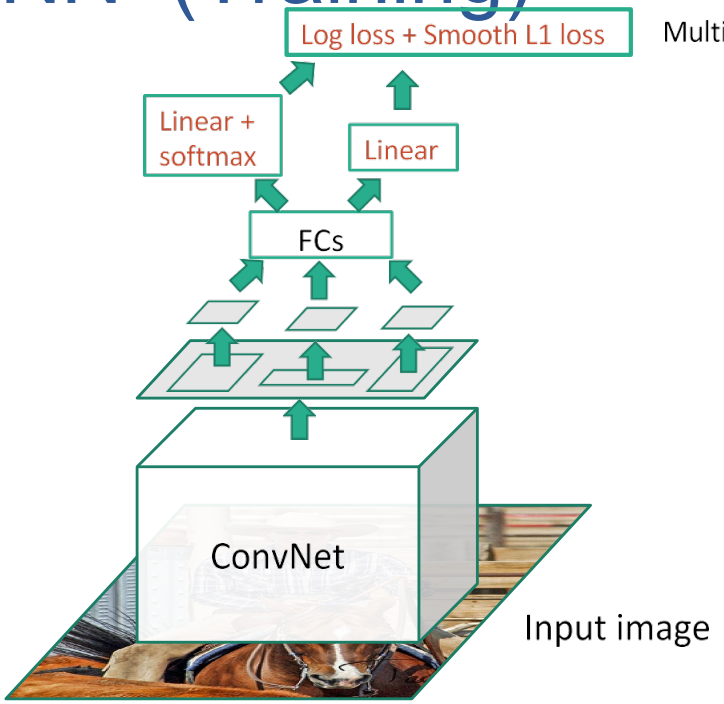
Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN



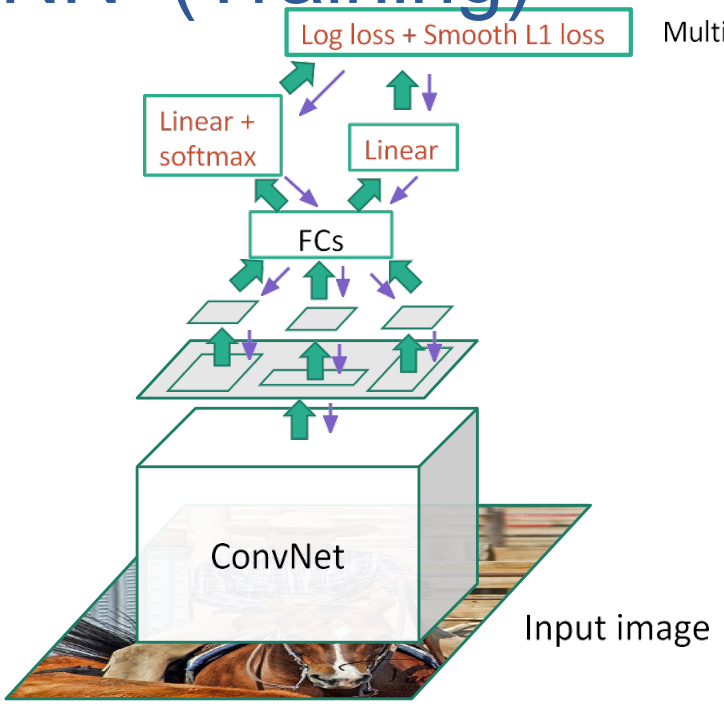
Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN (Training)



Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN (Training)



Adapted from Girshick, "Fast R-CNN", ICCV 2015

Fast R-CNN vs R-CNN

	Fast R-CNN	R-CNN
Train time (h)	9.5	84
Speedup	8.8x	1x
Test time / image	0.32s	47.0s
Test speedup	146x	1x
mAP	66.9%	66.0%

Timings exclude object proposal time, which is equal for all methods. All methods use VGG16 from Simonyan and Zisserman.

Adapted from Girshick, "Fast R-CNN", ICCV 2015

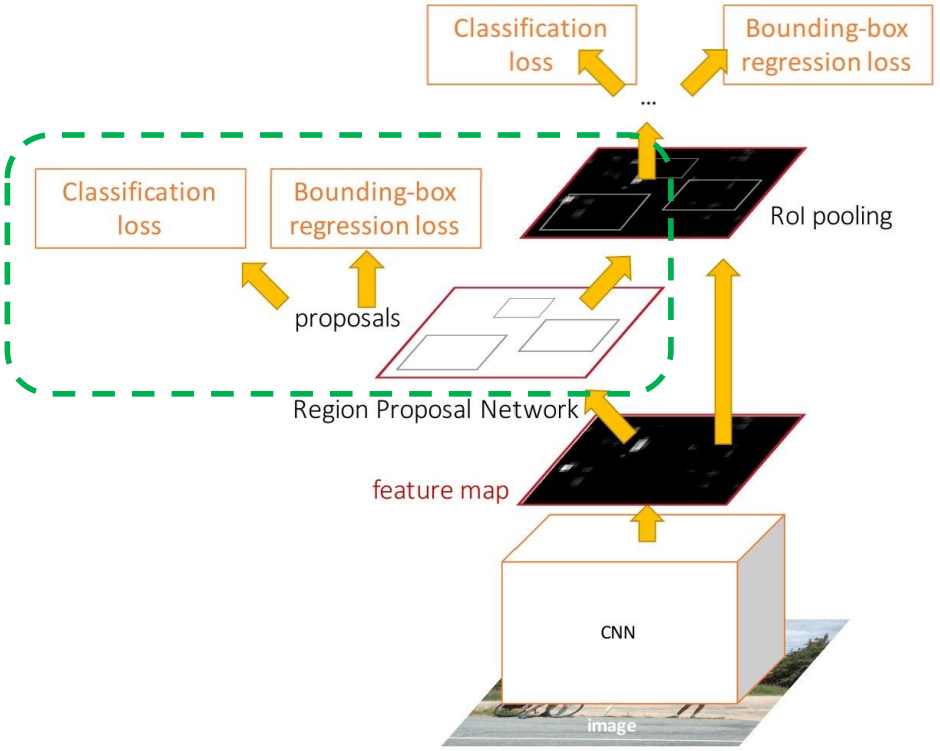
Faster R-CNN

Make CNN do proposals!

Insert **Region Proposal Network (RPN)** to predict proposals from features

Jointly train with 4 losses:

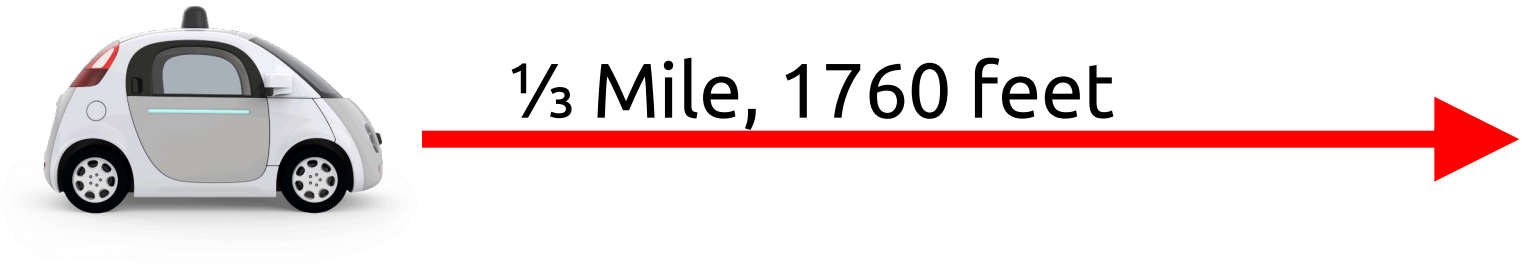
1. RPN classify object / not object
2. RPN regress box coordinates
3. Final classification score (object classes)
4. Final box coordinates



Ren et al, "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks", NIPS 2015

Accurate object detection is slow!

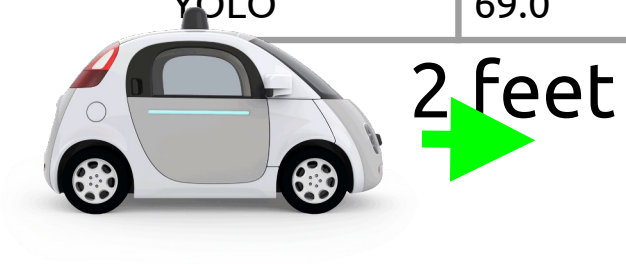
	Pascal 2007 mAP	Speed	
DPM v5	33.7	.07 FPS	14 s/img
R-CNN	66.0	.05 FPS	20 s/img



Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

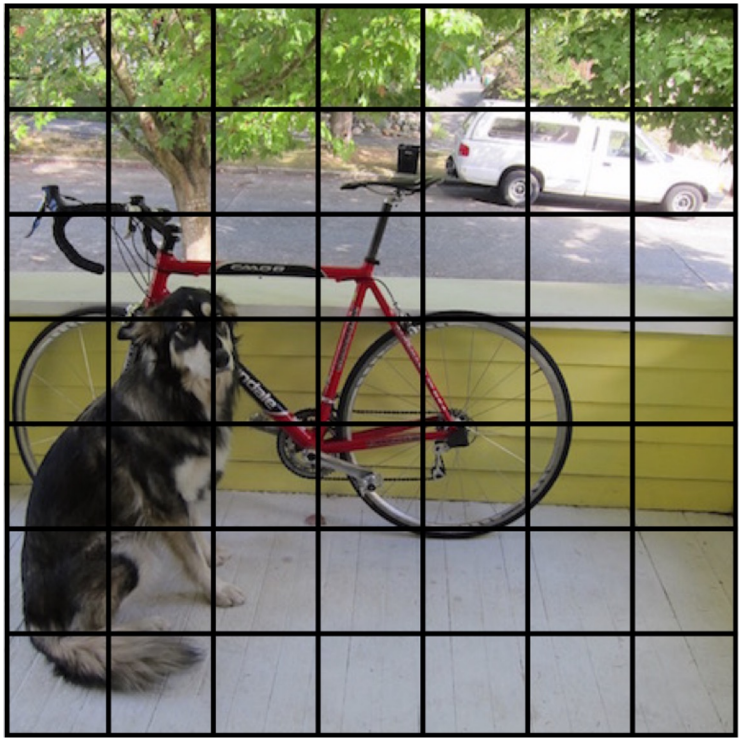
Accurate object detection is slow!

	Pascal 2007 mAP	Speed	
DPM v5	33.7	.07 FPS	14 s/img
R-CNN	66.0	.05 FPS	20 s/img
Fast R-CNN	70.0	.5 FPS	2 s/img
Faster R-CNN	73.2	7 FPS	140 ms/img
YOLO	69.0	45 FPS	22 ms/img



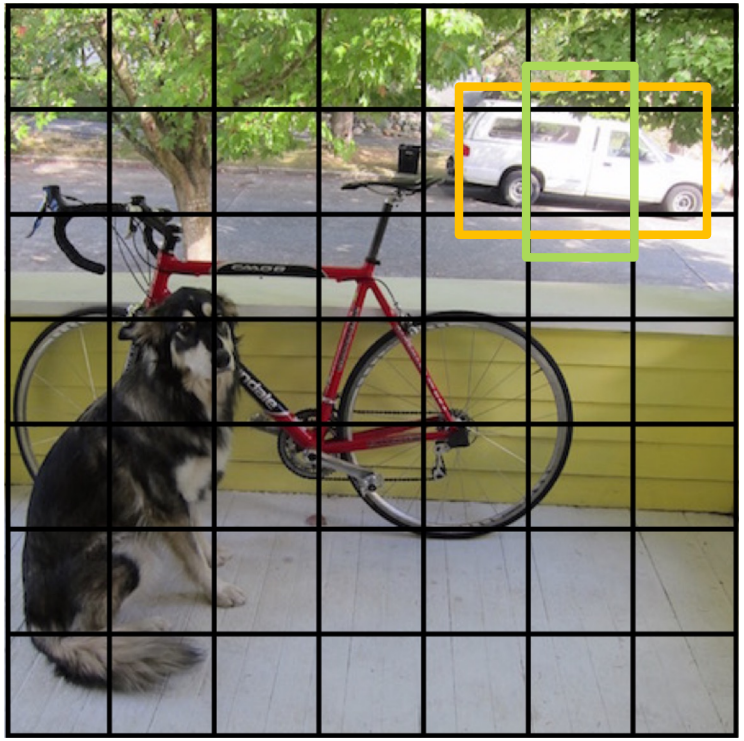
Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

Detection without Proposals: YOLO



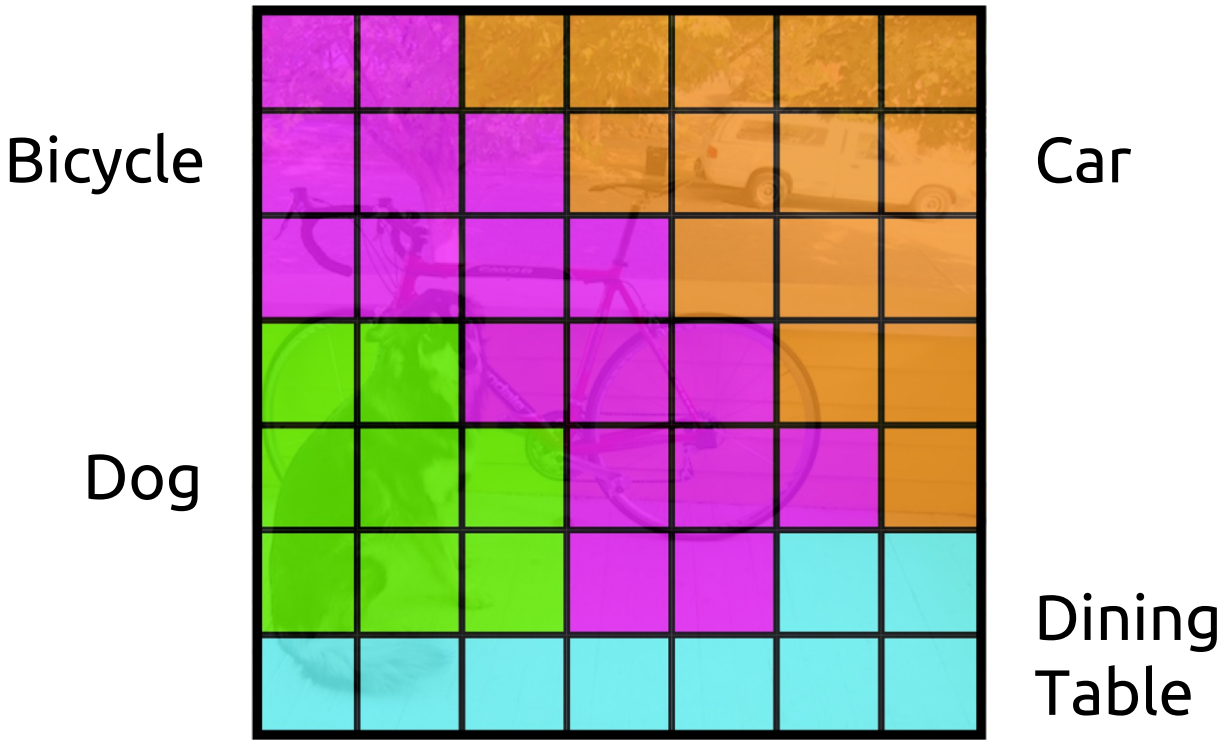
Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

Each cell predicts boxes and confidences: P(Object)



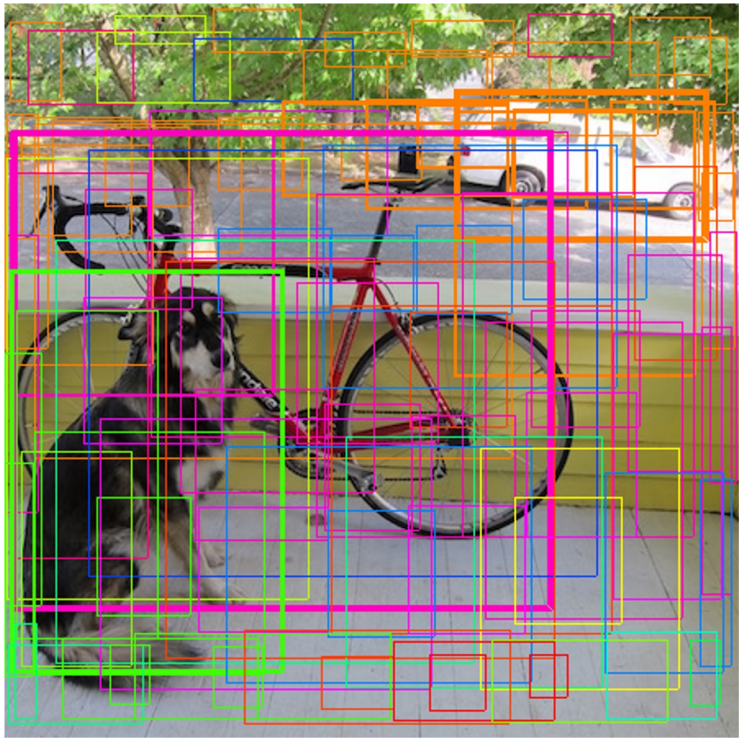
Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

Each cell also predicts a probability P(Class | Object)



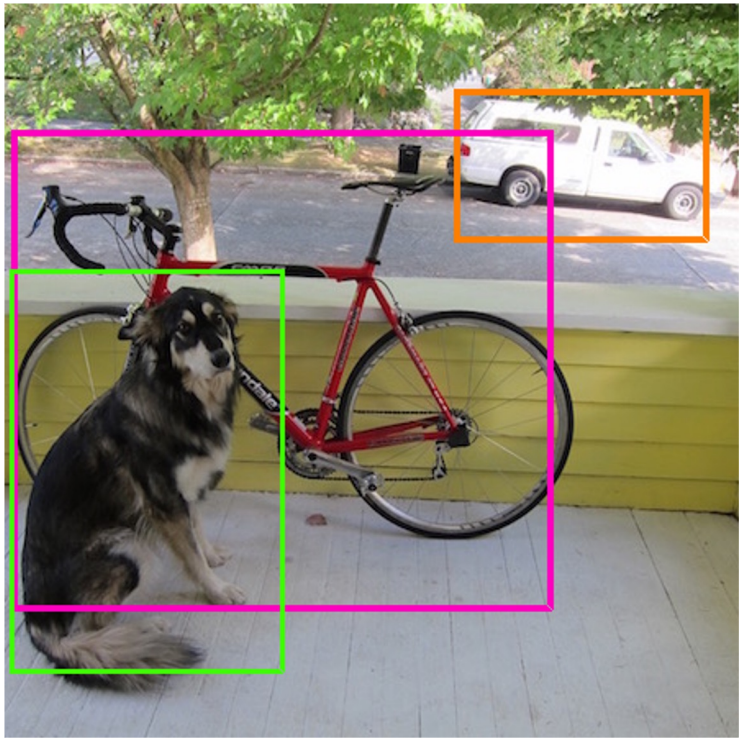
Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

Combine the box and class predictions



Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

Finally do NMS and threshold detections

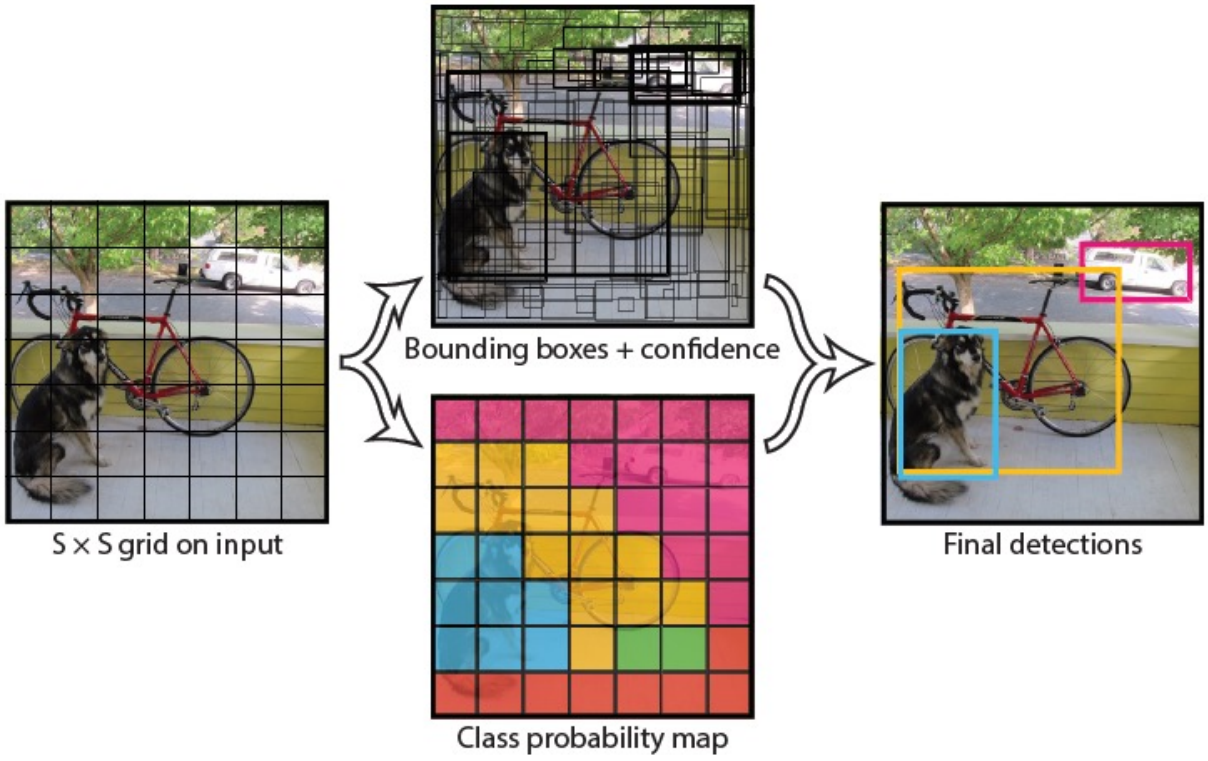


Redmon et al., “You Only Look Once: Unified, Real-Time Object Detection”, CVPR 2016

YOLO- You Only Look Once

Idea: No bounding box proposals.

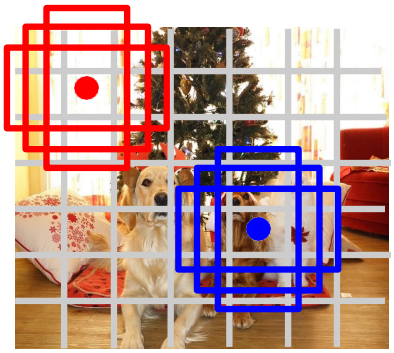
Predict a class and a box for every location in a grid.



https://arxiv.org/abs/1506.02640 Redmon et al. CVPR 2016.

Detection without Proposals: YOLO

Input image
3 x H x W



Divide image into grid
7 x 7

Image a set of **base boxes** centered at each grid cell
Here B = 3

Within each grid cell:

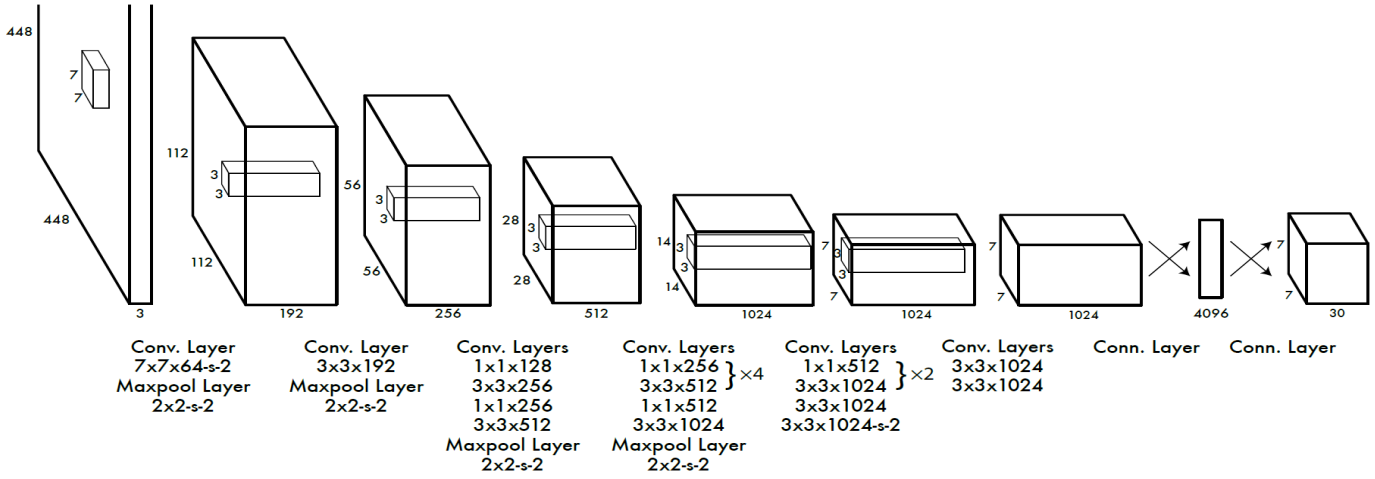
- Regress from each of the B base boxes to a final box with 5 numbers: (x, y, w, h, confidence)
- Predict scores for each of C classes (including background as a class)

Output:
7 x 7 x (5 * B + C)

Redmon et al, "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016
Liu et al, "SSD: Single-Shot MultiBox Detector", ECCV 2016

Slide by: Justin Johnson

YOLO- You Only Look Once



Divide the image into 7x7 cells.
Each cell trains a detector.
The detector needs to predict the object's class distributions.
The detector has 2 bounding-box predictors to predict bounding-boxes and confidence scores.

https://arxiv.org/abs/1506.02640 Redmon et al. CVPR 2016.

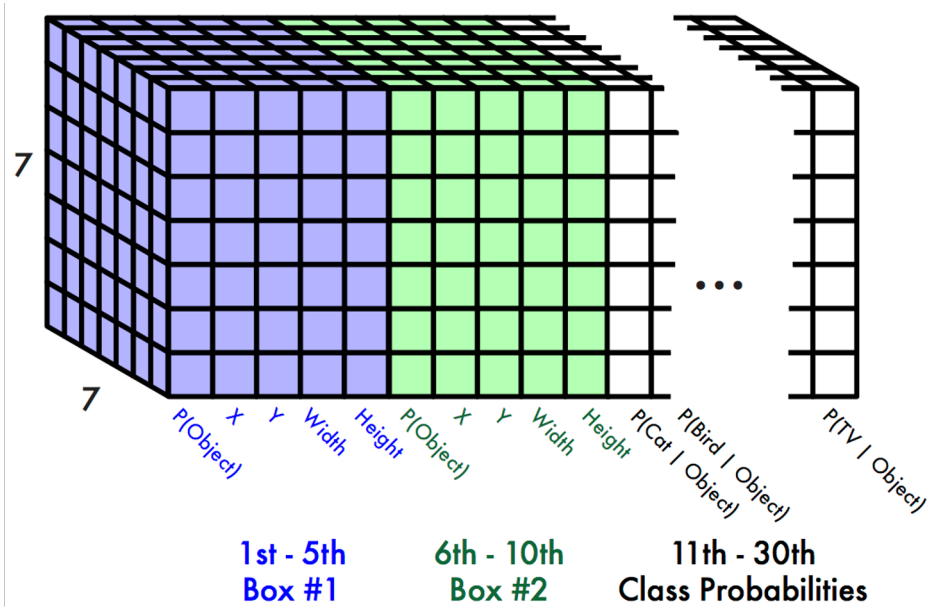
This parameterization fixes the output size

Each cell predicts:

- For each bounding box:
  - 4 coordinates (x, y, w, h)
  - 1 confidence value
- Some number of class probabilities

For Pascal VOC:

- 7x7 grid
- 2 bounding boxes / cell
- 20 classes



7 x 7 x (5 x 2 + 20) = 7 x 7 x 30 tensor = **1470 outputs**

Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

YOLO - Loss Function

$$\lambda_{\text{coord}} \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{obj}} \left[(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 \right]$$

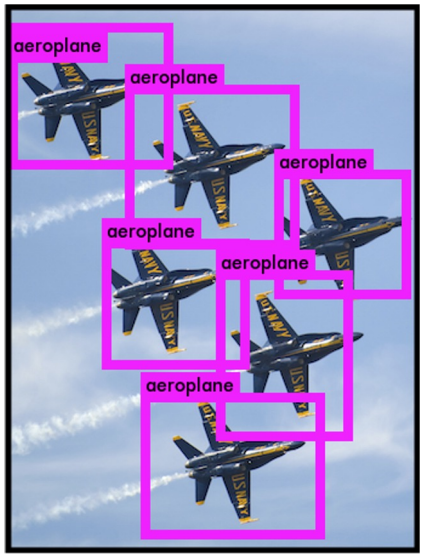
$$+ \lambda_{\text{coord}} \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{obj}} \left[\left(\sqrt{w_i} - \sqrt{\hat{w}_i} \right)^2 + \left(\sqrt{h_i} - \sqrt{\hat{h}_i} \right)^2 \right]$$

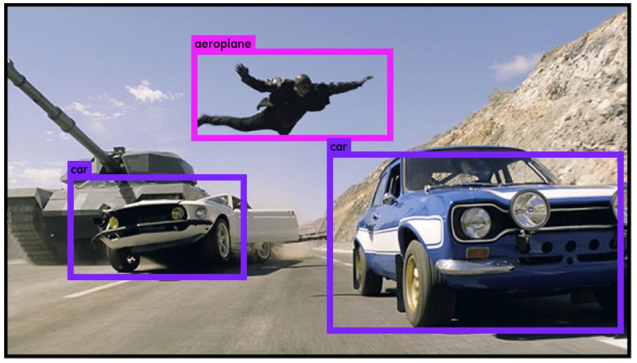
$$+ \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{obj}} \left(C_i - \hat{C}_i \right)^2$$

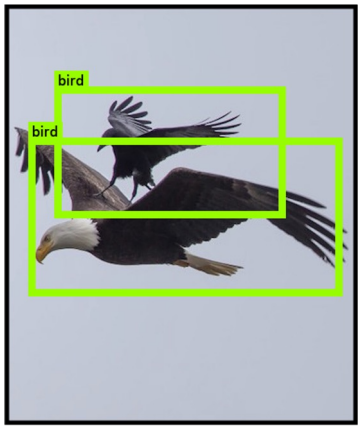
$$+ \lambda_{\text{noobj}} \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{noobj}} \left(C_i - \hat{C}_i \right)^2$$

$$+ \sum_{i=0}^{S^2} \mathbb{1}_{i}^{\text{obj}} \sum_{c \in \text{classes}} \left(p_i(c) - \hat{p}_i(c) \right)^2$$

YOLO works across many natural images

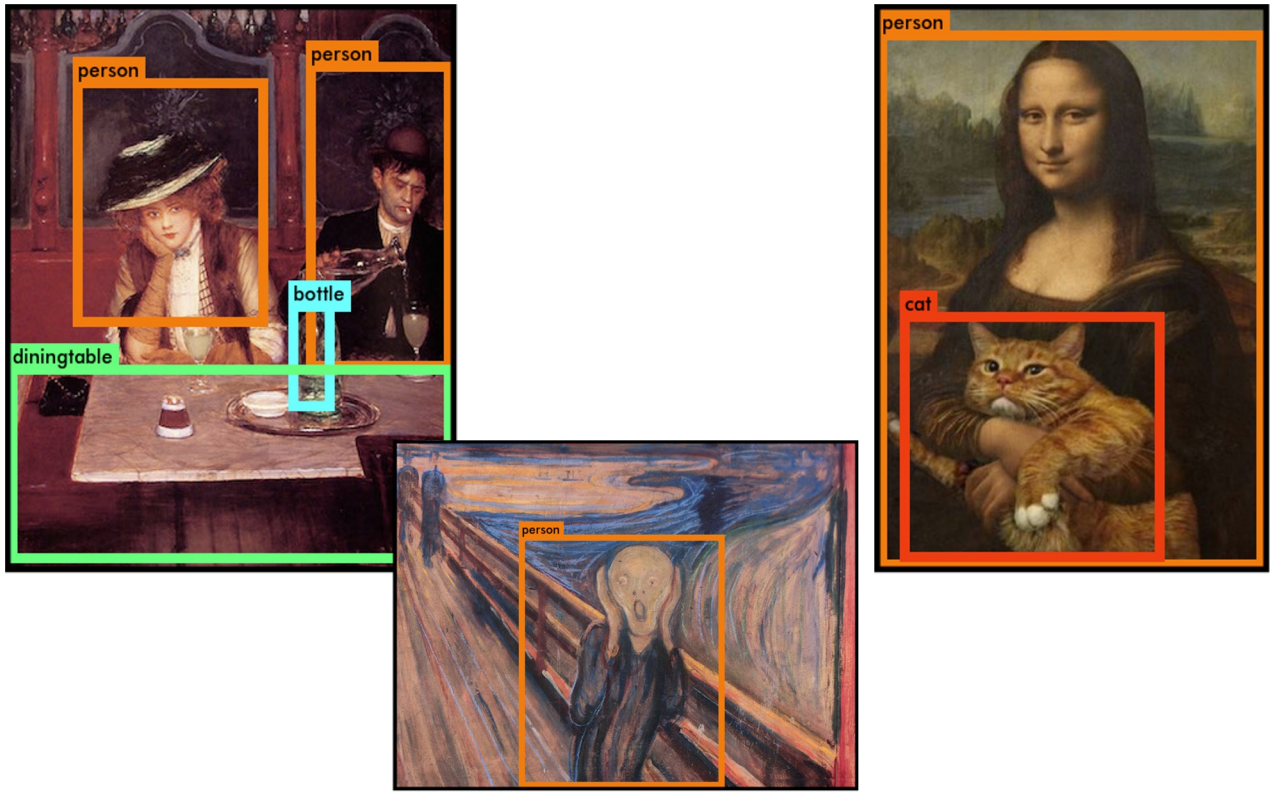






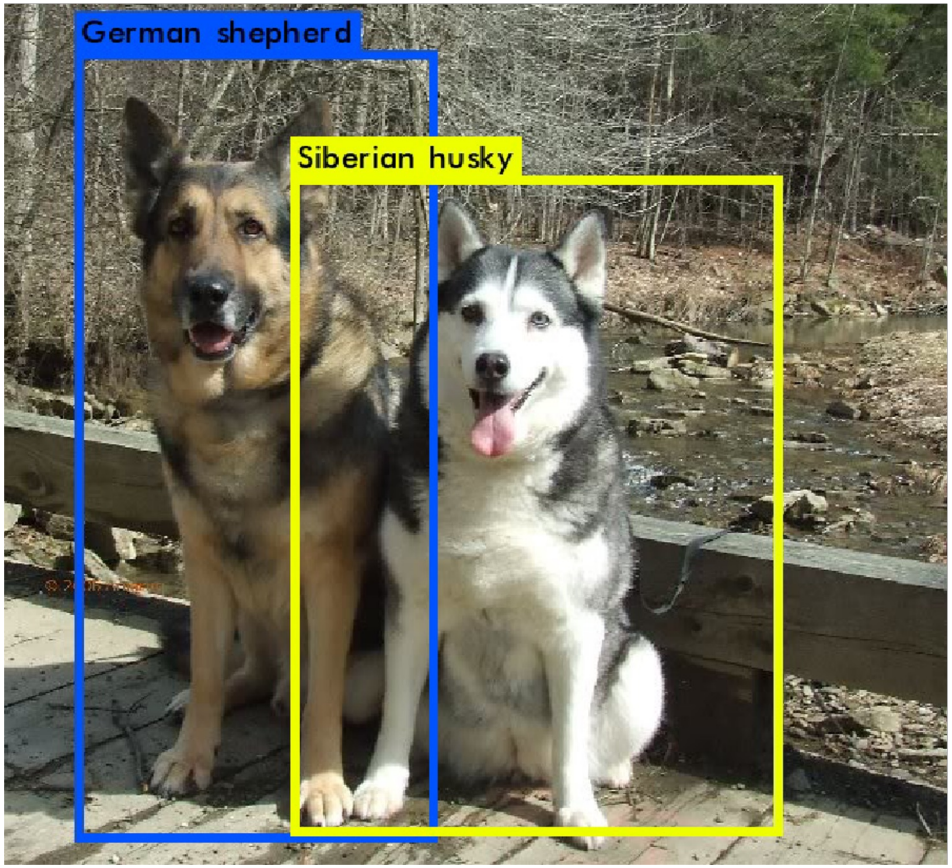
Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

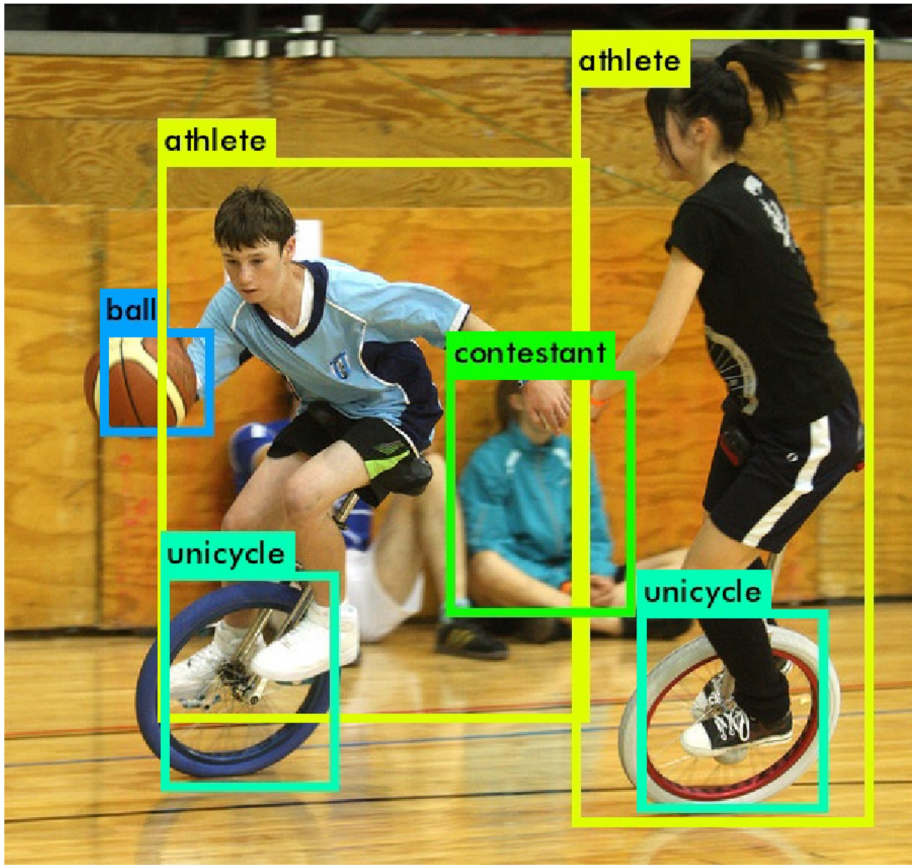
It also generalizes well to new domains



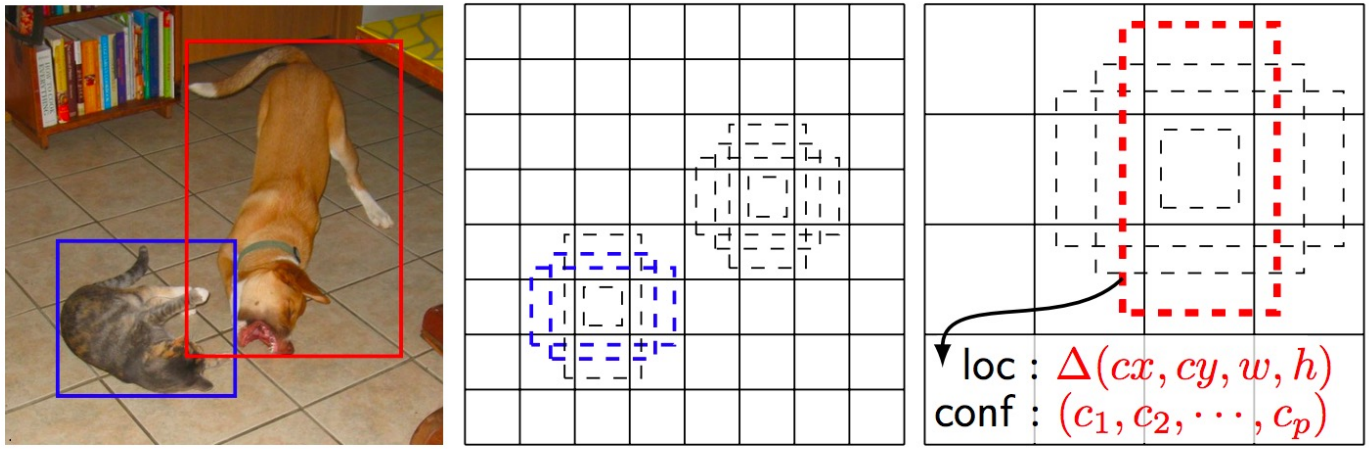
Redmon et al., "You Only Look Once: Unified, Real-Time Object Detection", CVPR 2016

Redmon and Farhadi, "YOLO9000: Better, Faster, Stronger", CVPR 2017


German shepherd
Siberian husky


athlete
athlete
ball
contestant
unicycle
unicycle

SSD: Single Shot Detector



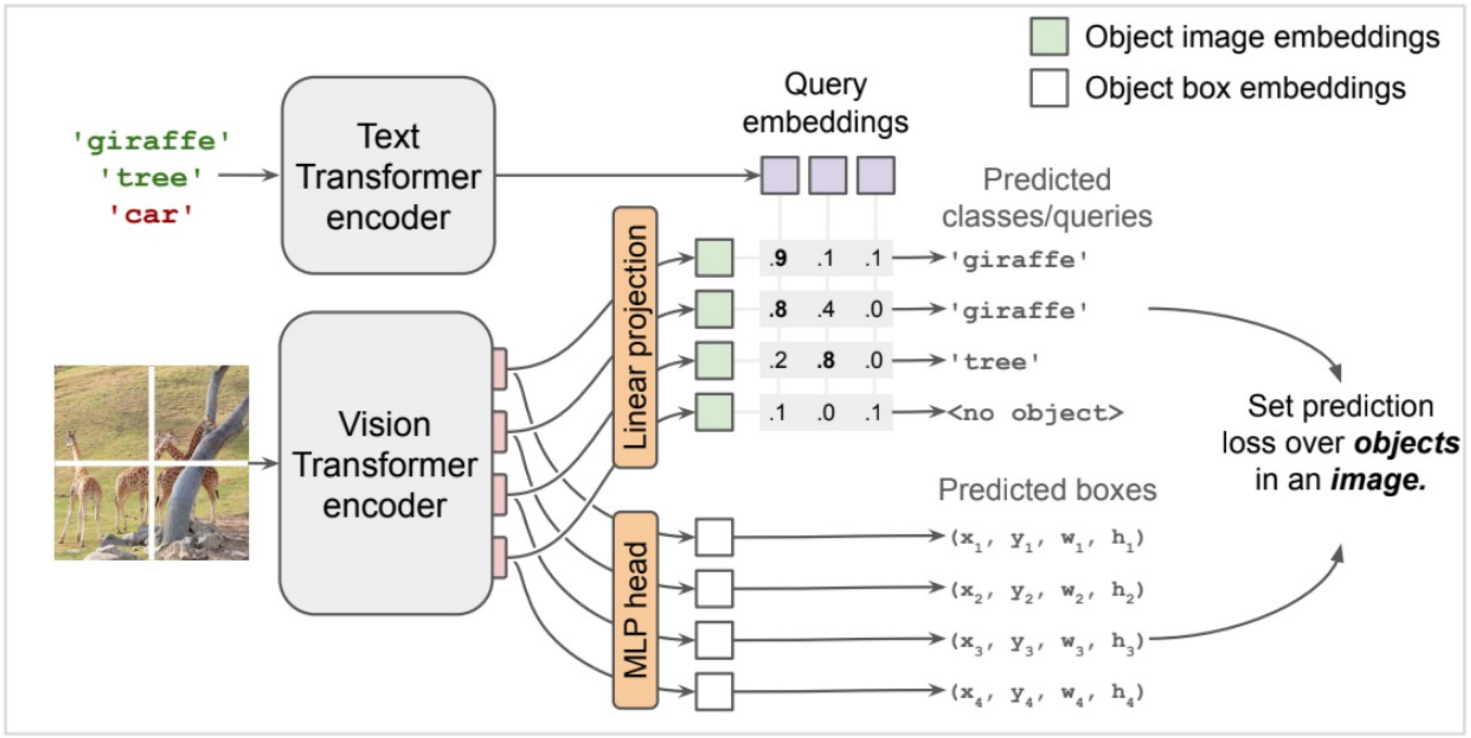
(a) Image with GT boxes (b) 8×8 feature map (c) 4×4 feature map

See on our

Idea: Similar to YOLO, but denser grid map, multiscale grid m aps. + Data augmentation + Hard negative mining + Other de sign choices in the network.

Liu et al. ECCV 2016.

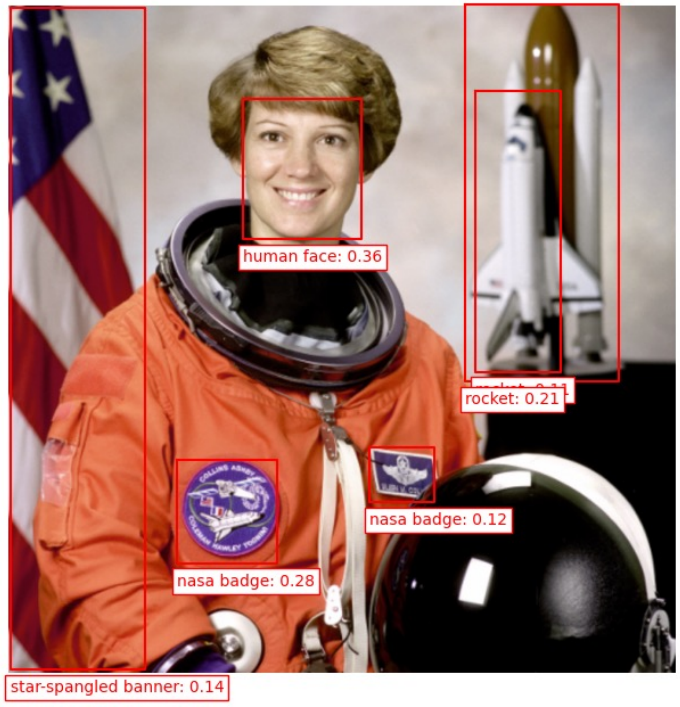
[SOTA] OWL-ViT: open-vocabulary object detector



https://arxiv.org/pdf/2205.06230

[SOTA] OWL-ViT: open-vocabulary object detector

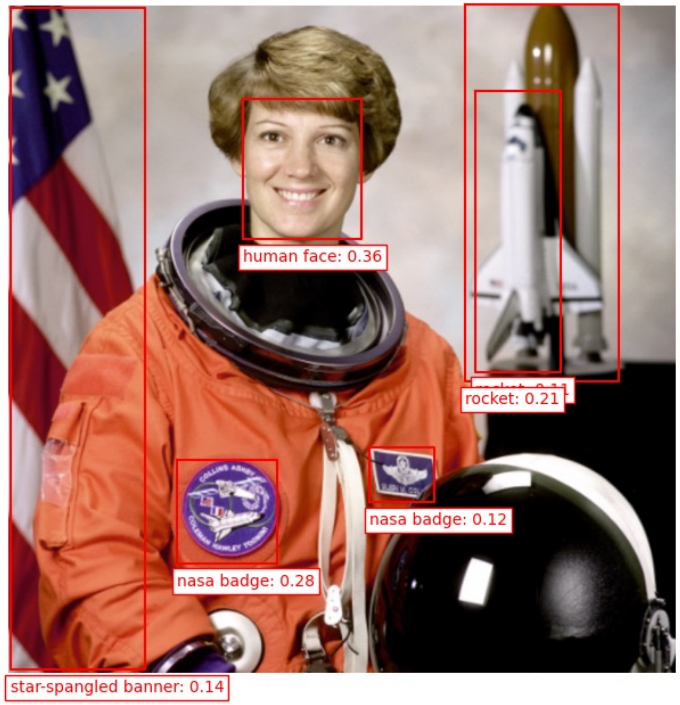
```
text_queries = ["human face", "rocket",
 "nasa badge", "star-spangled banner"]
```



jupyter

Jupyter Notebook: link

[SOTA] OWL-ViT: open-vocabulary object detector



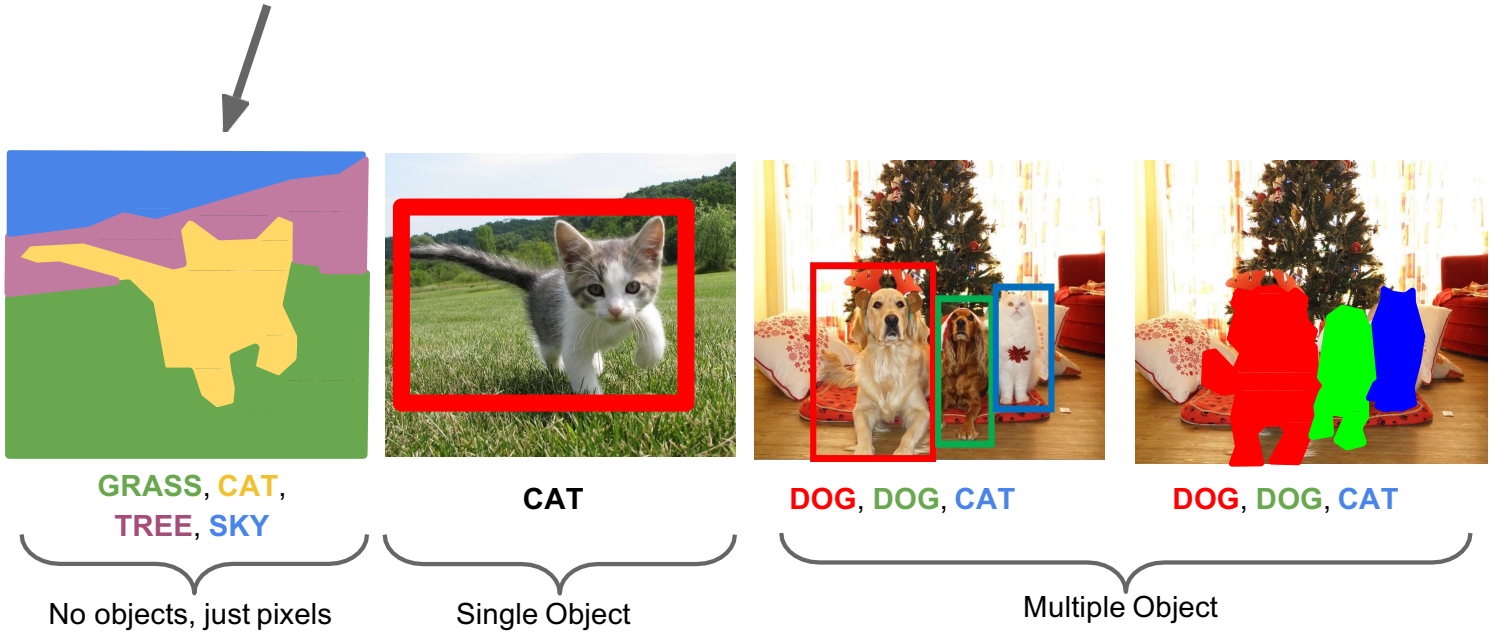
How Bounding Boxes are encoded?

Jupyter Notebook: link

Plan for the next lectures

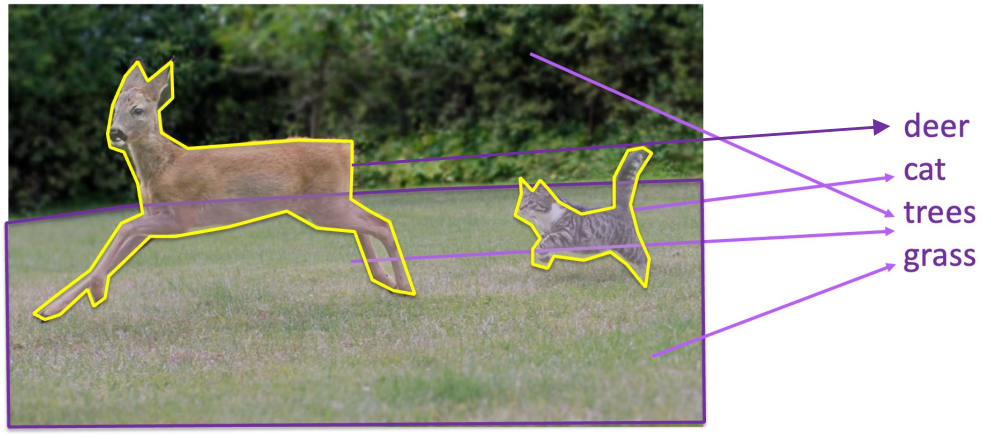
- Detection approaches
  - Pre-CNNs
    - Detection with whole windows: Pedestrian detection
    - Part-based detection: Deformable Part Models
  - Post-CNNs
    - Detection with region proposals: R-CNN, Fast R-CNN, Faster-R-CNN
    - Detection without region proposals: YOLO, SSD
- Segmentation approaches
  - Semantic segmentation: FCN
  - Instance segmentation: Mask R-CNN

Semantic Segmentation



Slide by: Justin Johnson

Semantic Segmentation

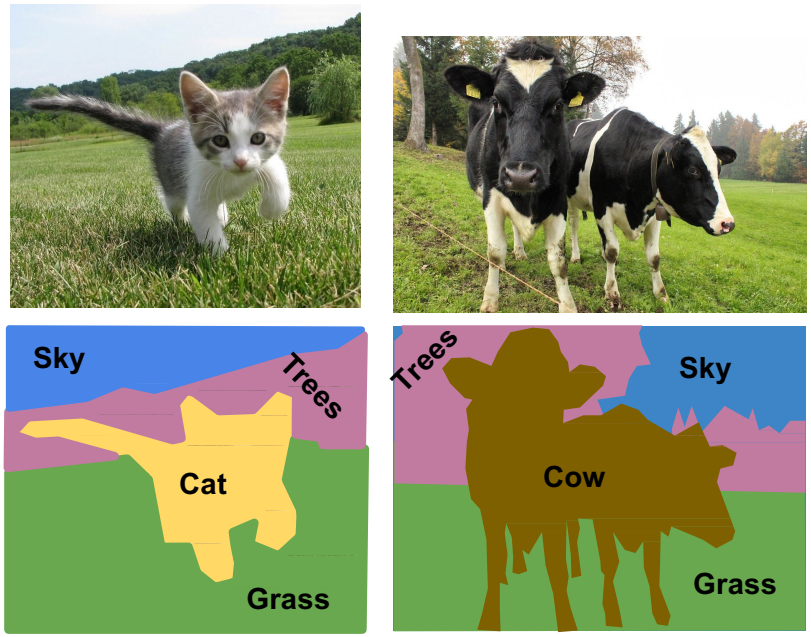


Adapted from Vicente Ordoñez

Semantic Segmentation

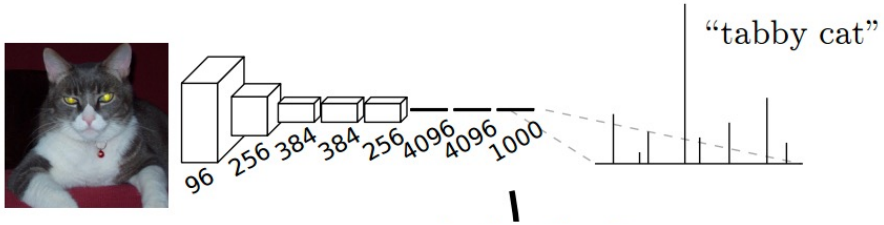
Label each pixel in the image with a category label

Don't differentiate instances, only care about pixels



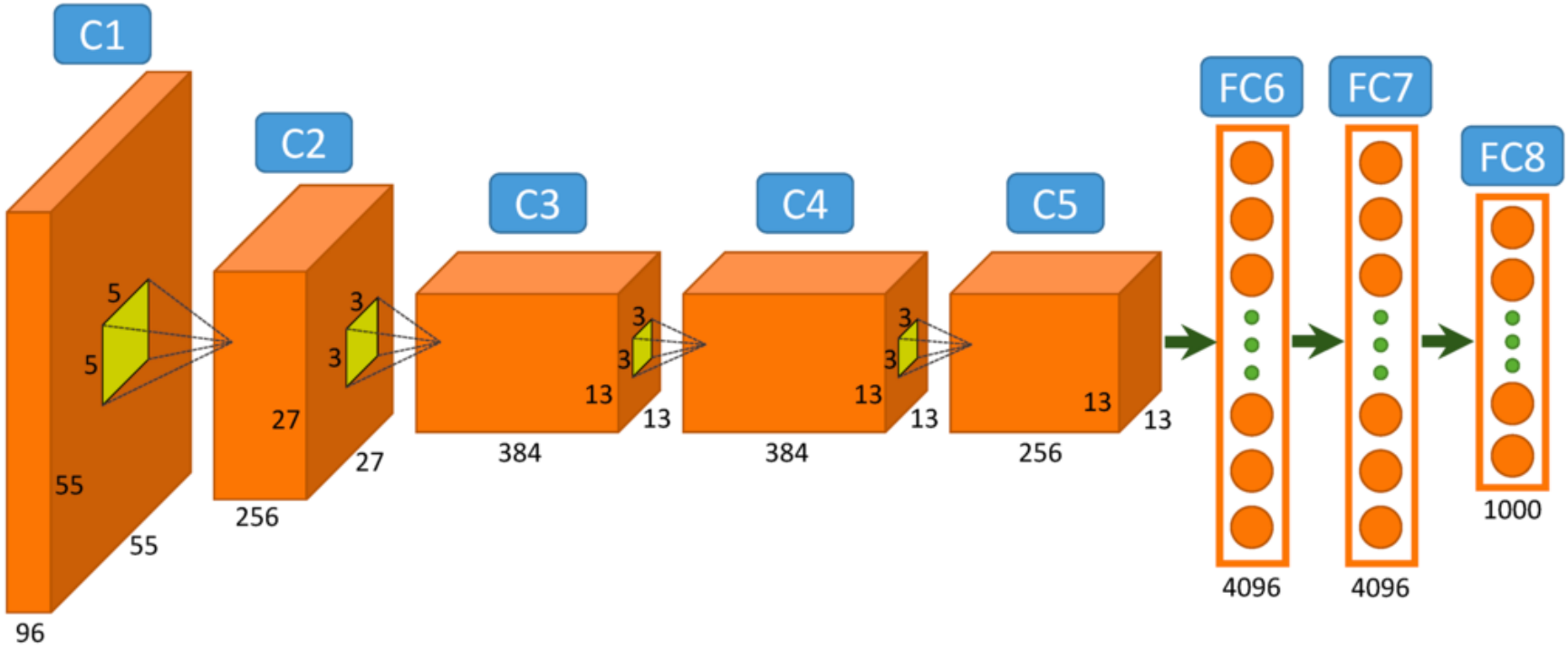
Slide by: Justin Johnson

Idea 1: Convolutionalization



Adapted from Vicente Ordoñez

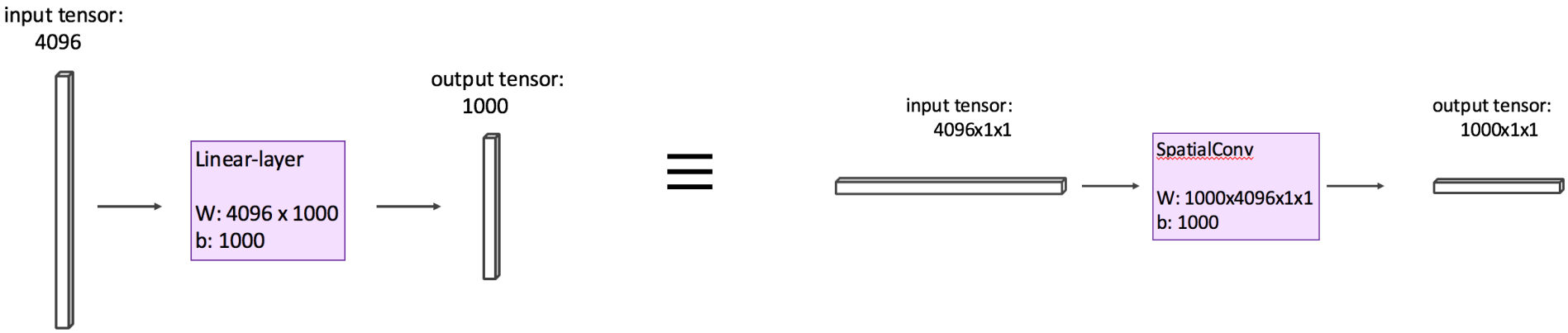
Idea 1: Convolutionalization



https://www.saagie.com/fr/blog/object-detection-part1

Idea 1: Convolutionalization

nn.Linear(4096, 1000) == nn.Conv2D(4096, 1000, kernel_size = 1, stride = 1)

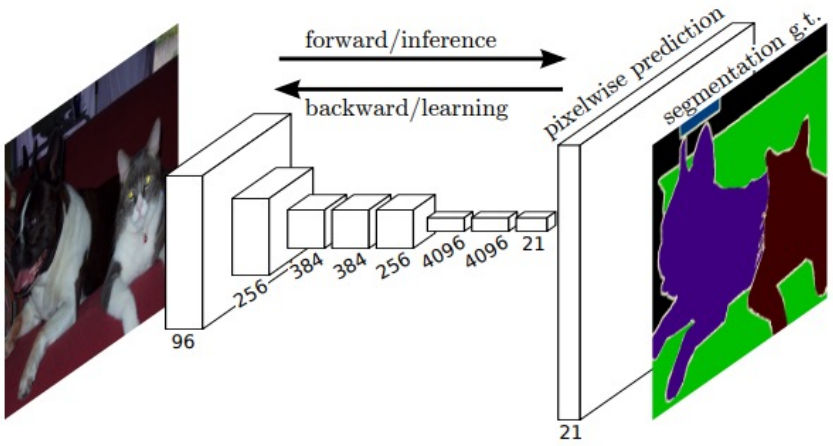


Adapted from Vicente Ordoñez

Idea 2: Fully Convolutional Networks (CVPR 2015)

Fully Convolutional Networks for Semantic Segmentation

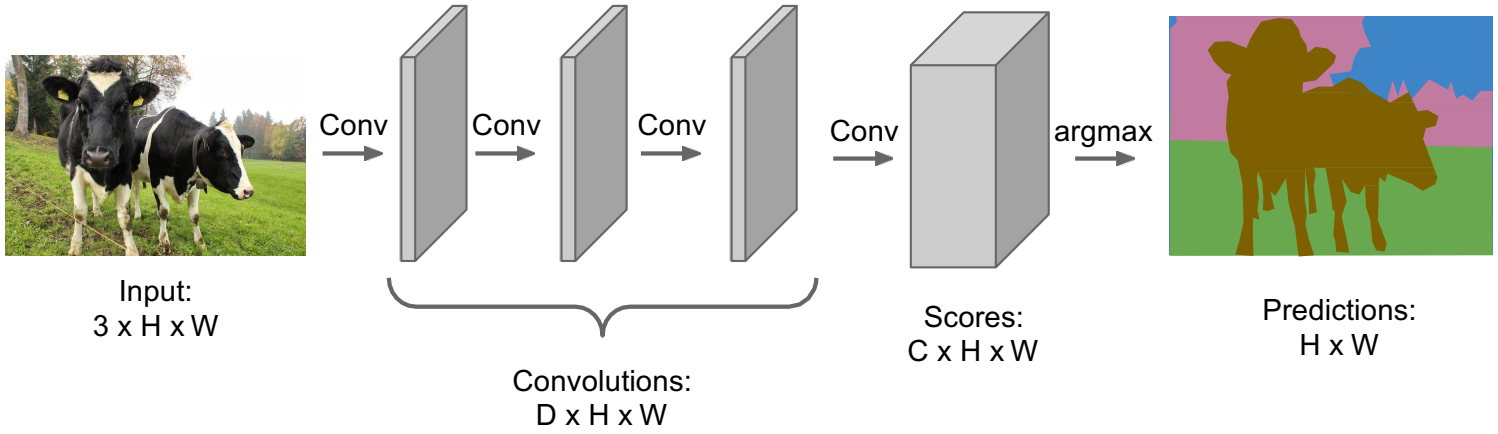
Jonathan Long* Evan Shelhamer* Trevor Darrell
UC Berkeley
{jonlong,shelhamer,trevor}@cs.berkeley.edu



See on our

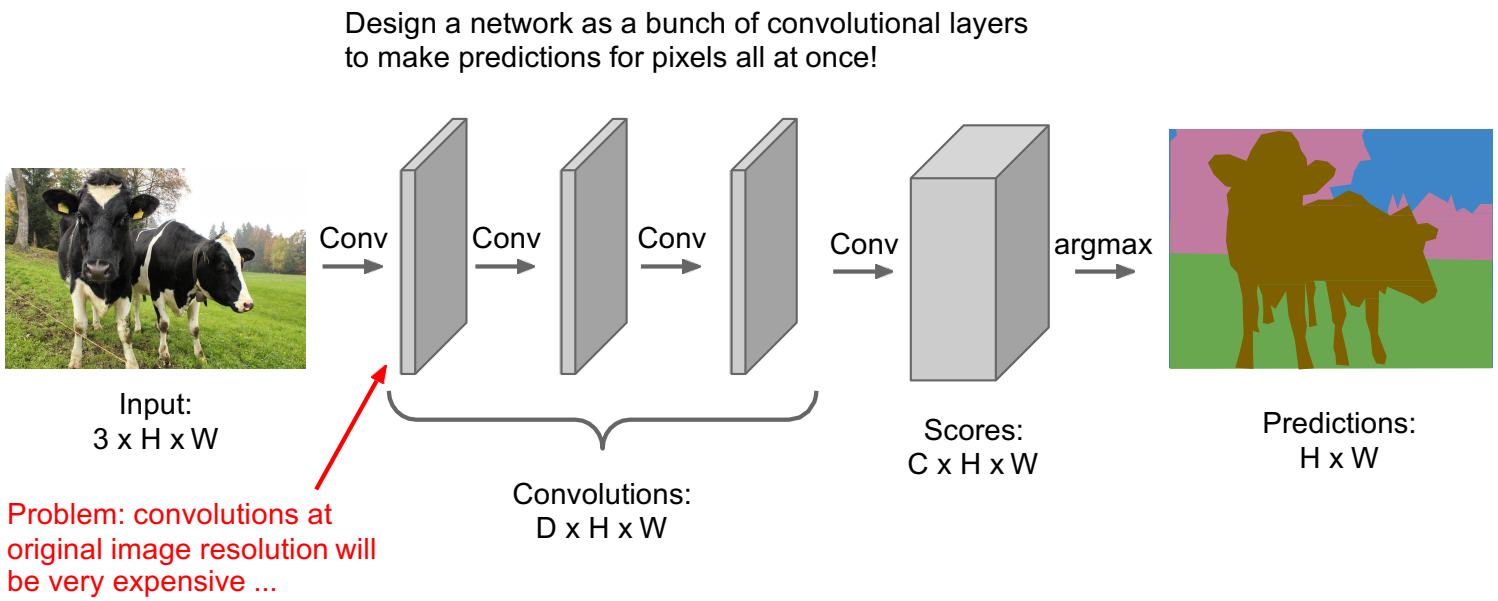
Idea 2: Fully Convolutional

Design a network as a bunch of convolutional layers to make predictions for pixels all at once!



Slide by: Justin Johnson

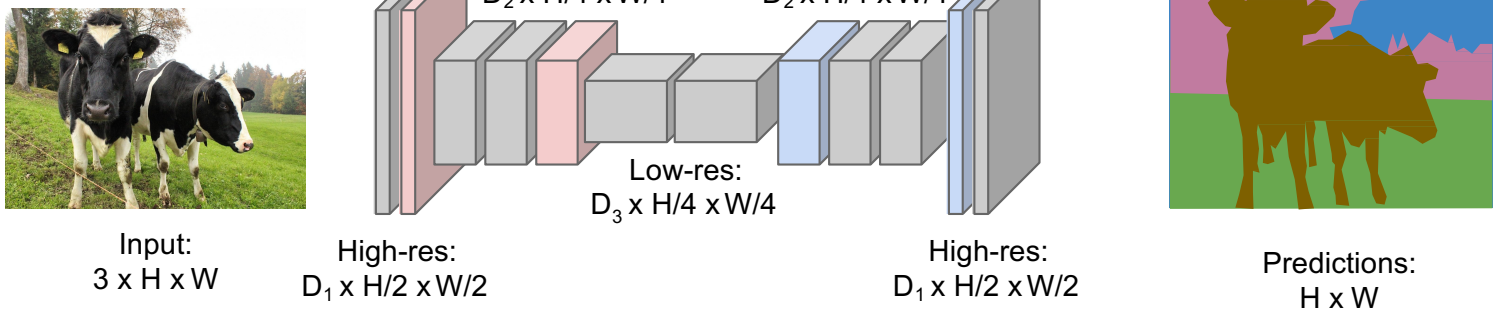
Idea 2: Fully Convolutional



Slide by: Justin Johnson

Idea 2: Fully Convolutional

Design network as a bunch of convolutional layers, with **downsampling** and **upsampling** inside the network!



Long, Shelhamer, and Darrell, "Fully Convolutional Networks for Semantic Segmentation", CVPR 2015
Noh et al, "Learning Deconvolution Network for Semantic Segmentation", ICCV 2015

Slide by: Justin Johnson

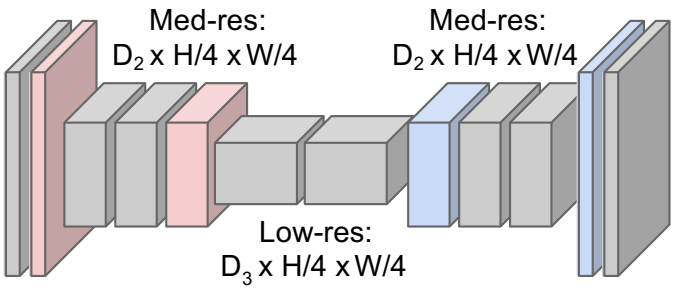
Idea 2: Fully Convolutional

Downsampling:
Pooling, strided convolution

Design network as a bunch of convolutional layers, with **downsampling** and **upsampling** inside the network!

Upsampling:
???

Input:
3 x H x W



High-res:
D_1 x H/2 x W/2

High-res:
D_1 x H/2 x W/2

Predictions:
H x W

Long, Shelhamer, and Darrell, "Fully Convolutional Networks for Semantic Segmentation", CVPR 2015
Noh et al, "Learning Deconvolution Network for Semantic Segmentation", ICCV 2015

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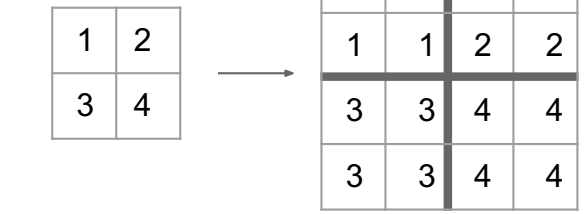
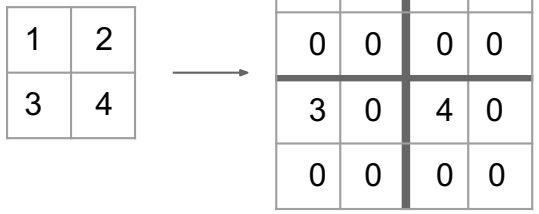
In-Network upsampling: “Unpooling”

Nearest Neighbor



Input: 2 x 2 Output: 4 x 4

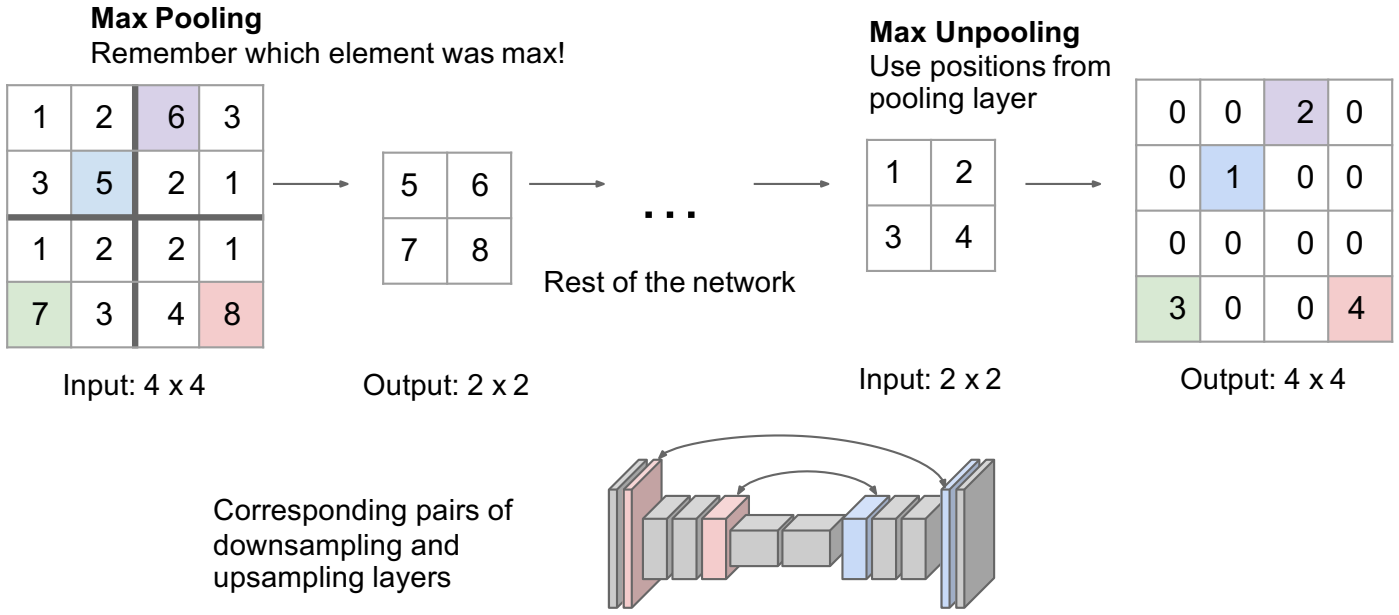
“Bed of Nails”



Input: 2 x 2 Output: 4 x 4

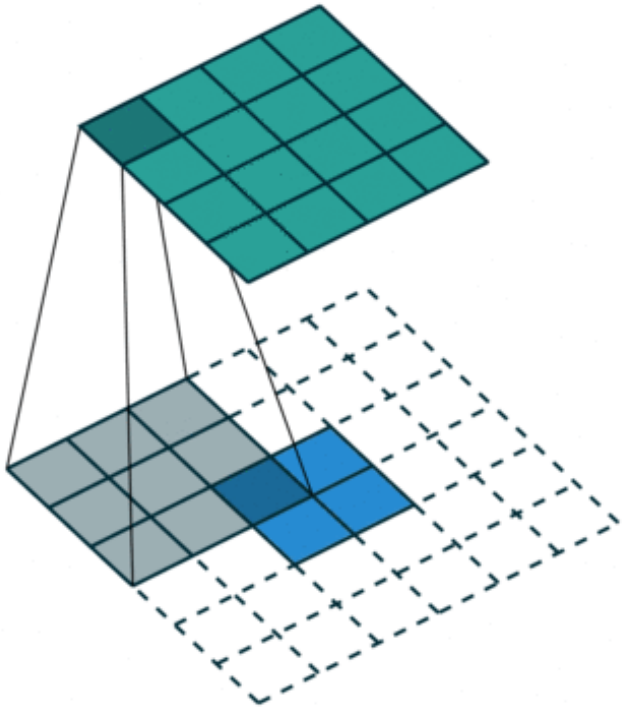
Slide by: Justin Johnson

In-Network upsampling: “Max Unpooling”



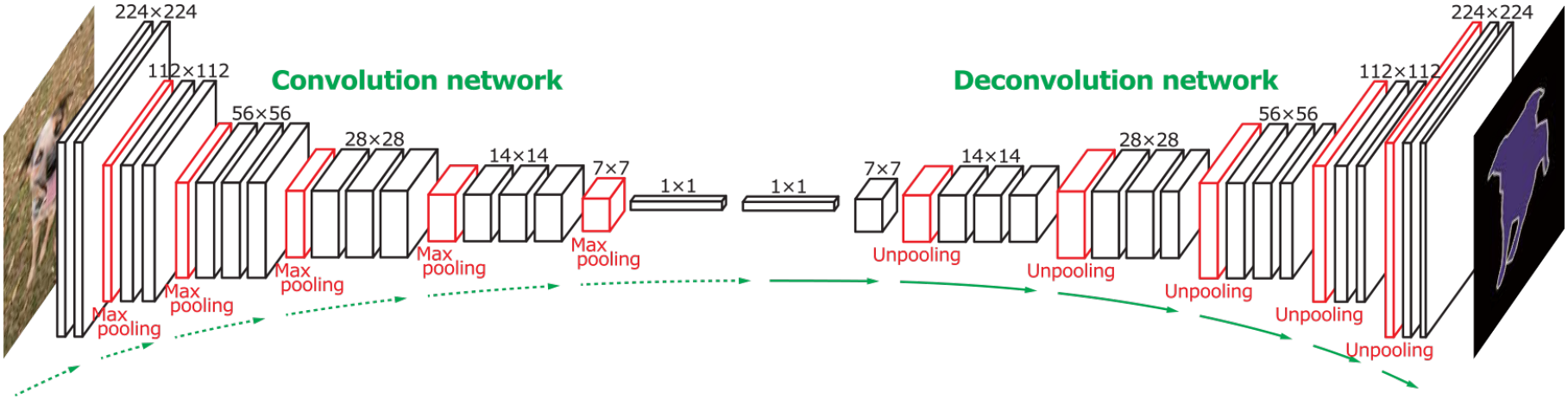
Slide by: Justin Johnson

In-Network Up-sampling Convolutions or ”Deconvolutions”



https://github.com/vdumoulin/conv_arithmetic

Idea 2: Fully Convolutional Networks



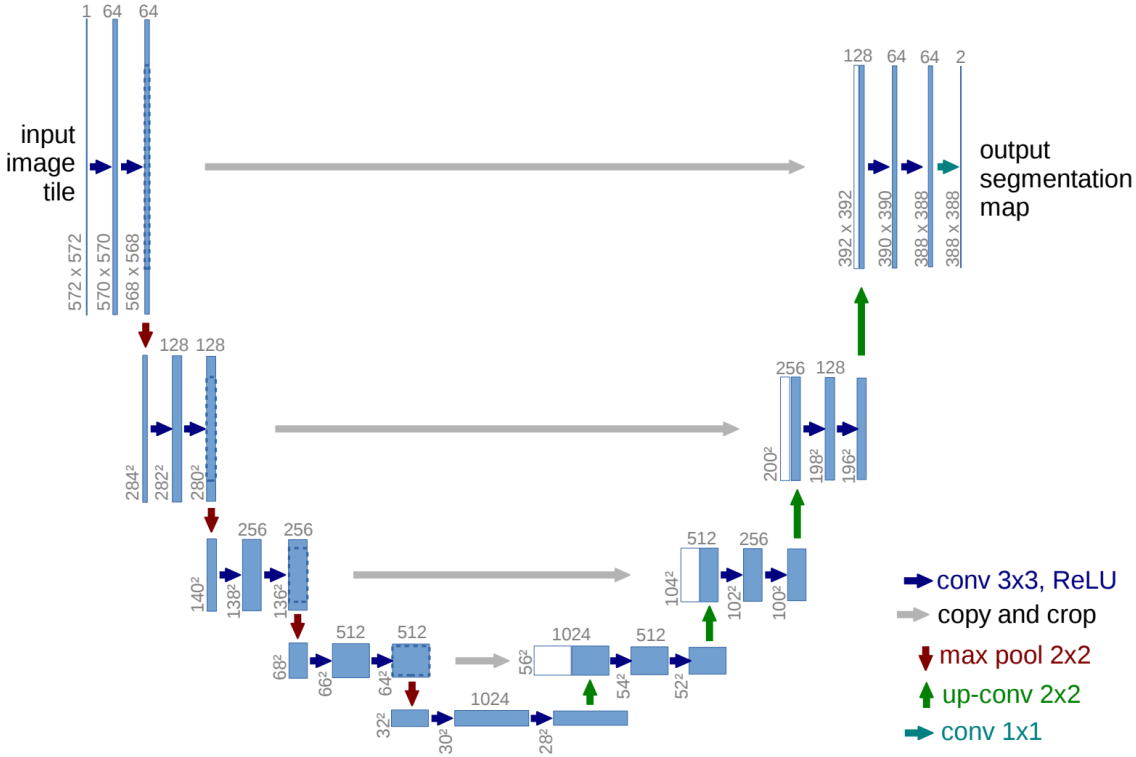
Learning Deconvolution Network for Semantic Segmentation

Hyeonwoo Noh Seunghoon Hong Bohyung Han
Department of Computer Science and Engineering, POSTECH, Korea
{hyeonwoonoh_,maga33,bhhan}@postech.ac.kr

http://cvlab.postech.ac.kr/research/deconvnet/

U-Net: Convolutional Networks for Biomedical Image Segmentation

Olaf Ronneberger, Philipp Fischer, and Thomas Brox



https://arxiv.org/abs/1505.04597

https://github.com/milesial/Pytorch-UNet

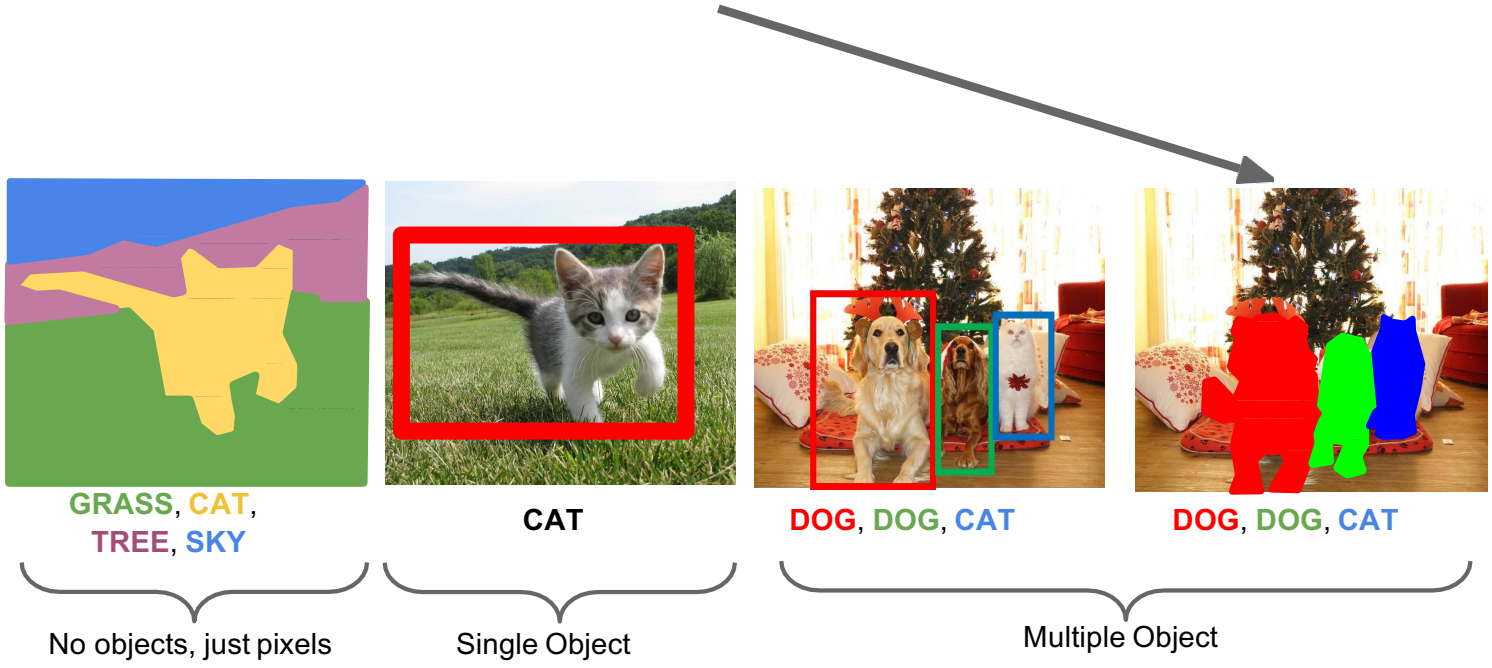
https://github.com/usuyama/pytorch-unet

UNet in Pytorch

```
from .unet_parts import *


class UNet(nn.Module):
    def __init__(self, n_channels, n_classes, bilinear=False):
        super(UNet, self).__init__()
        self.n_channels = n_channels
        self.n_classes = n_classes
        self.bilinear = bilinear

        self.inc = (DoubleConv(n_channels, 64))
        self.down1 = (Down(64, 128))
        self.down2 = (Down(128, 256))
        self.down3 = (Down(256, 512))
        factor = 2 if bilinear else 1
        self.down4 = (Down(512, 1024 // factor))
        self.up1 = (Up(1024, 512 // factor, bilinear))
        self.up2 = (Up(512, 256 // factor, bilinear))
        self.up3 = (Up(256, 128 // factor, bilinear))
        self.up4 = (Up(128, 64, bilinear))
        self.outc = (OutConv(64, n_classes))

    def forward(self, x):
        x1 = self.inc(x)
        x2 = self.down1(x1)
        x3 = self.down2(x2)
        x4 = self.down3(x3)
        x5 = self.down4(x4)
        x = self.up1(x5, x4)
        x = self.up2(x, x3)
        x = self.up3(x, x2)
        x = self.up4(x, x1)
        logits = self.outc(x)
        return logits
```

https://github.com/milesial/Pytorch-UNet/blob/master/unet/unet_model.py

Instance Segmentation



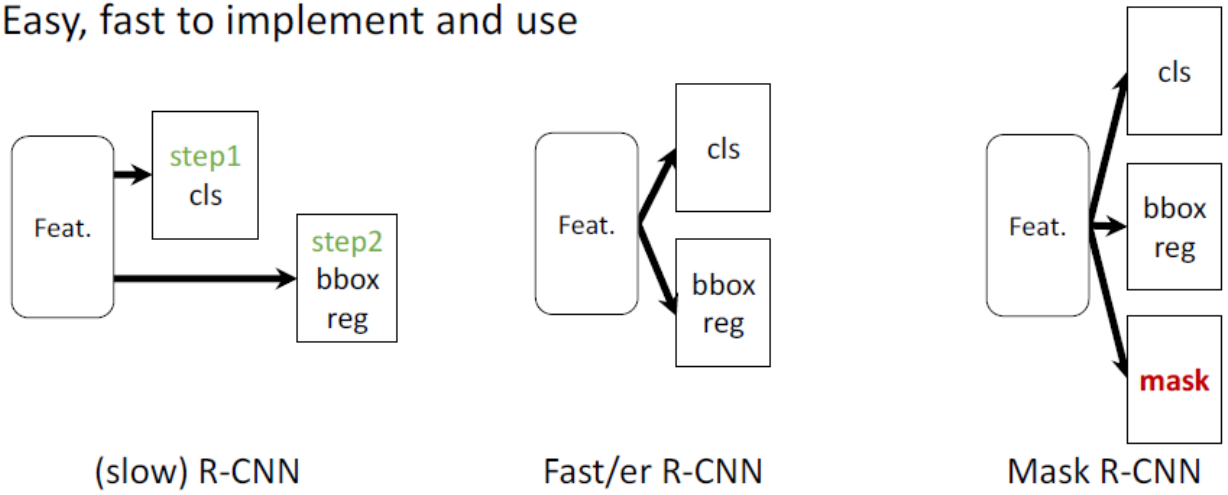
Slide by: Justin Johnson

Mask R-CNN

He et al, "Mask R-CNN", ICCV 2017

What is Mask R-CNN: Parallel Heads

- Easy, fast to implement and use

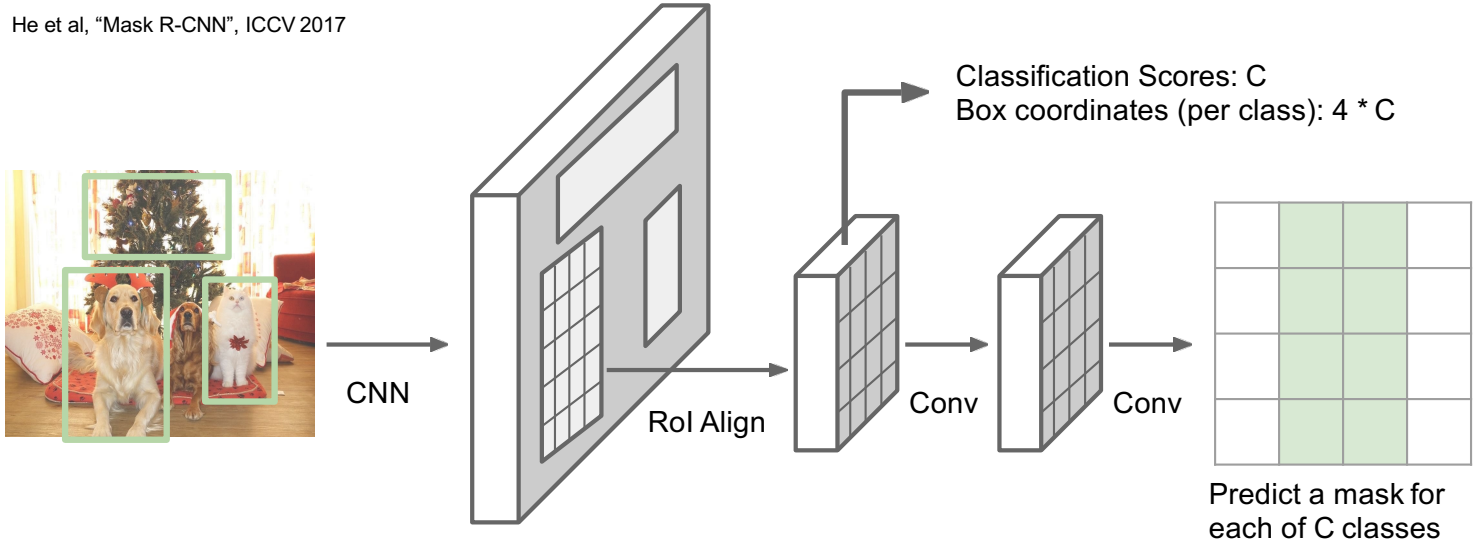


(slow) R-CNN | Fast/er R-CNN | Mask R-CNN

Slide by: Kaiming He

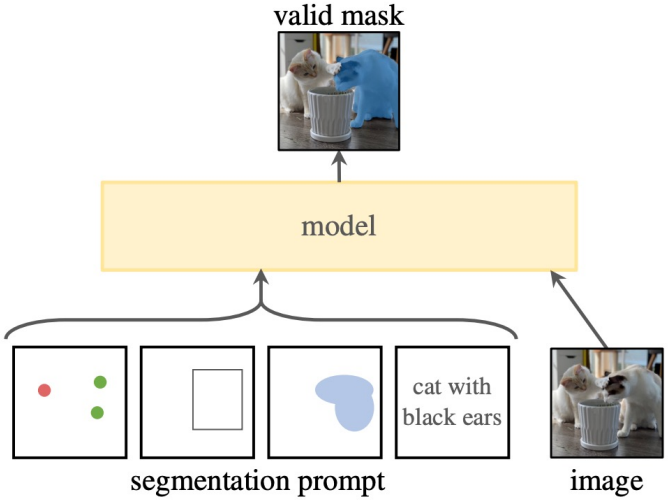
Mask R-CNN

He et al, “Mask R-CNN”, ICCV 2017

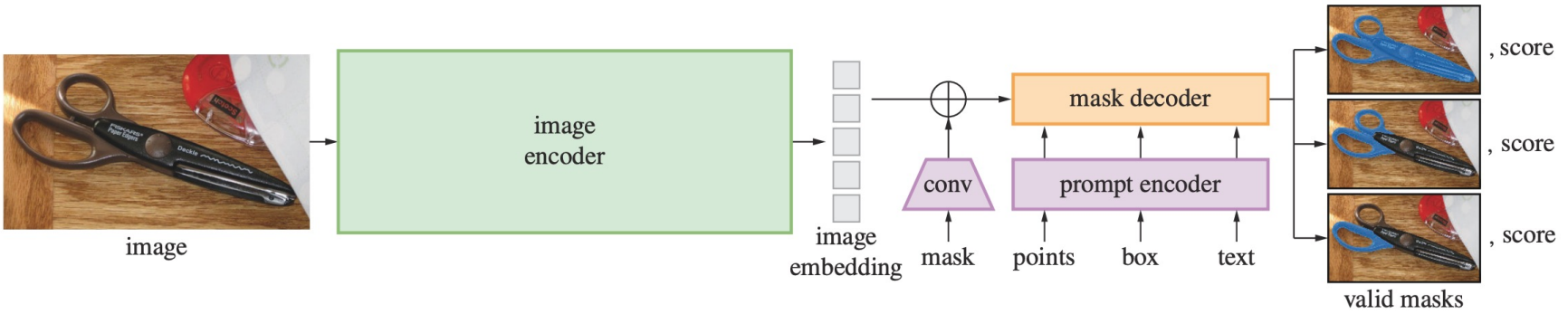


Adapted from Justin Johnson

[SOTA] Segment Anything



Jupyter Notebook: link



https://arxiv.org/abs/2304.02643

Plan for the next few lectures

- Detection approaches
  - Pre-CNNs
    - Detection with whole windows: Pedestrian detection
    - Part-based detection: Deformable Part Models
  - Post-CNNs
    - Detection with region proposals: R-CNN, Fast R-CNN, Faster-R-CNN
    - Detection without region proposals: YOLO, SSD
- Segmentation approaches
  - Semantic segmentation
    - Fully-Convolutional Networks (FCN)
  - Instance segmentation
    - Mask R-CNN
    - Segment Anything
- Learning from noisy web image-text data
  - Contrastive Language-Image Pretraining (CLIP)
    - Prompting
  - Open-vocabulary object detection

Learning from noisy web data

- Massive datasets of image-text pairs from the web
  - E.g. alt text, Flickr, Reddit, Wikipedia, etc
- Images and their co-occurring text assumed related (text provides a reasonable description of image?)
- Train text and image feature extractors using the objective that matched (co-occurring) image-text should be more similar than mismatched ones
- Great performance at a low annotation cost (data already existed)

Contrastive Language-Image Pretraining (CLIP)

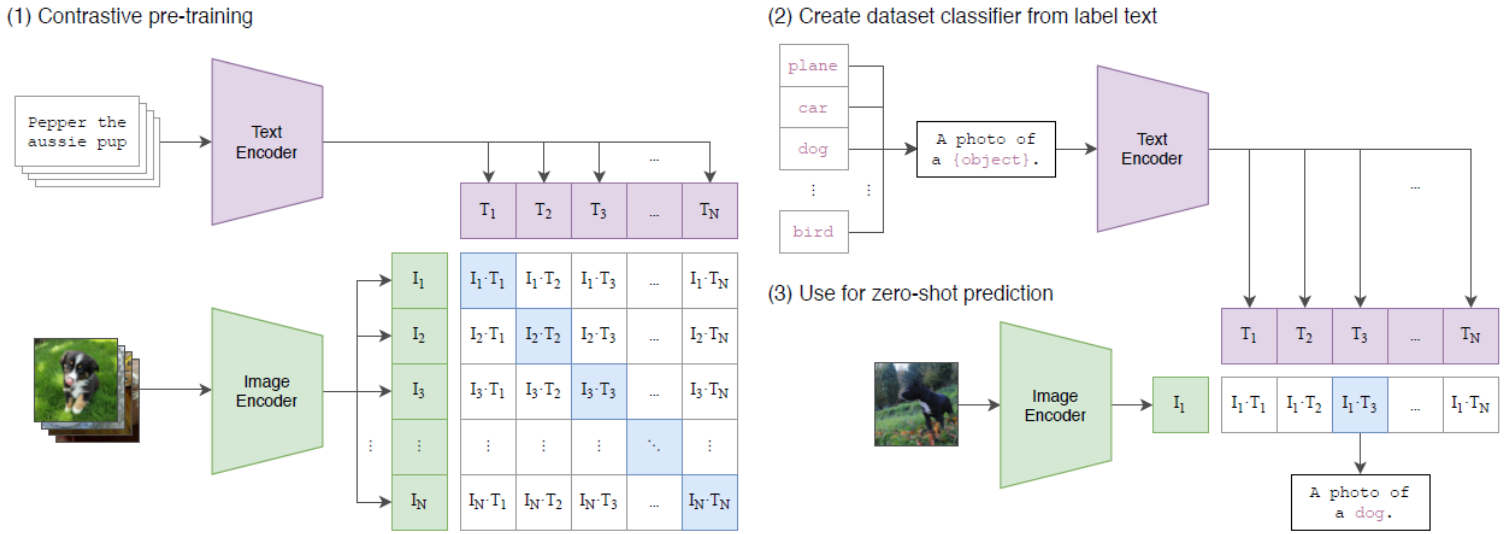
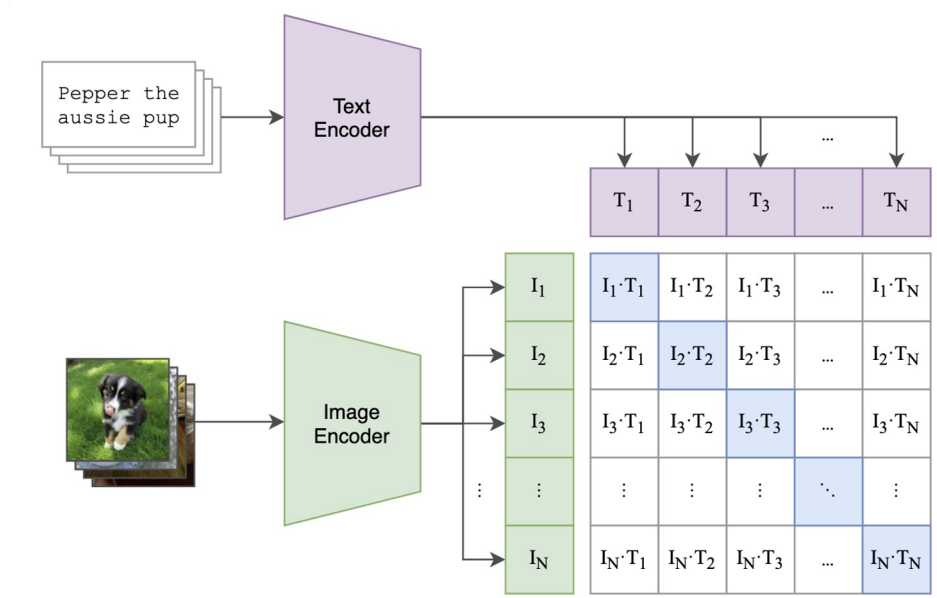


Figure 1. Summary of our approach. While standard image models jointly train an image feature extractor and a linear classifier to predict some label, CLIP jointly trains an image encoder and a text encoder to predict the correct pairings of a batch of (image, text) training examples. At test time the learned text encoder synthesizes a zero-shot linear classifier by embedding the names or descriptions of the target dataset's classes.

Radford et al. "Learning Transferable Visual Models From Natural Language Supervision." ICML 2021.

Contrastive Language-Image Pretraining (CLIP)



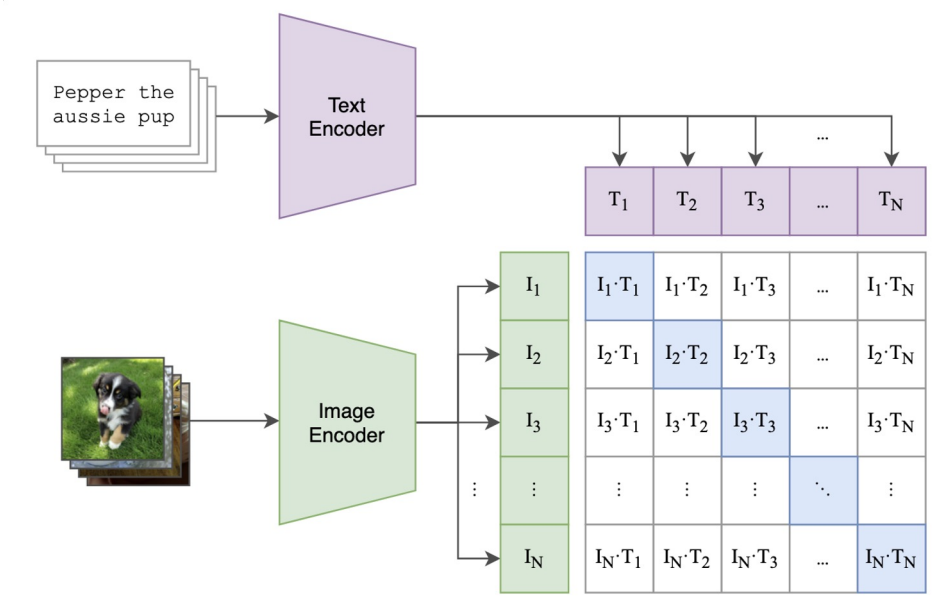
$$L = \sum_k \ell(I_k T_k)$$

$$\ell(I_k T_k) = -\log\left(\frac{\exp(sim(I_k, T_k))}{\sum_{t=1}^{2N} 1[k \neq i]\exp(sim(I_k, T_t))}\right)$$

Radford et al. "Learning Transferable Visual Models From Natural Language Supervision." ICML 2021.

Adapted from Vicente Ordoñez

Contrastive Language-Image Pretraining (CLIP)



$$L = \sum_k \ell_1(I_k T_k) + \ell_2(I_k T_k)$$

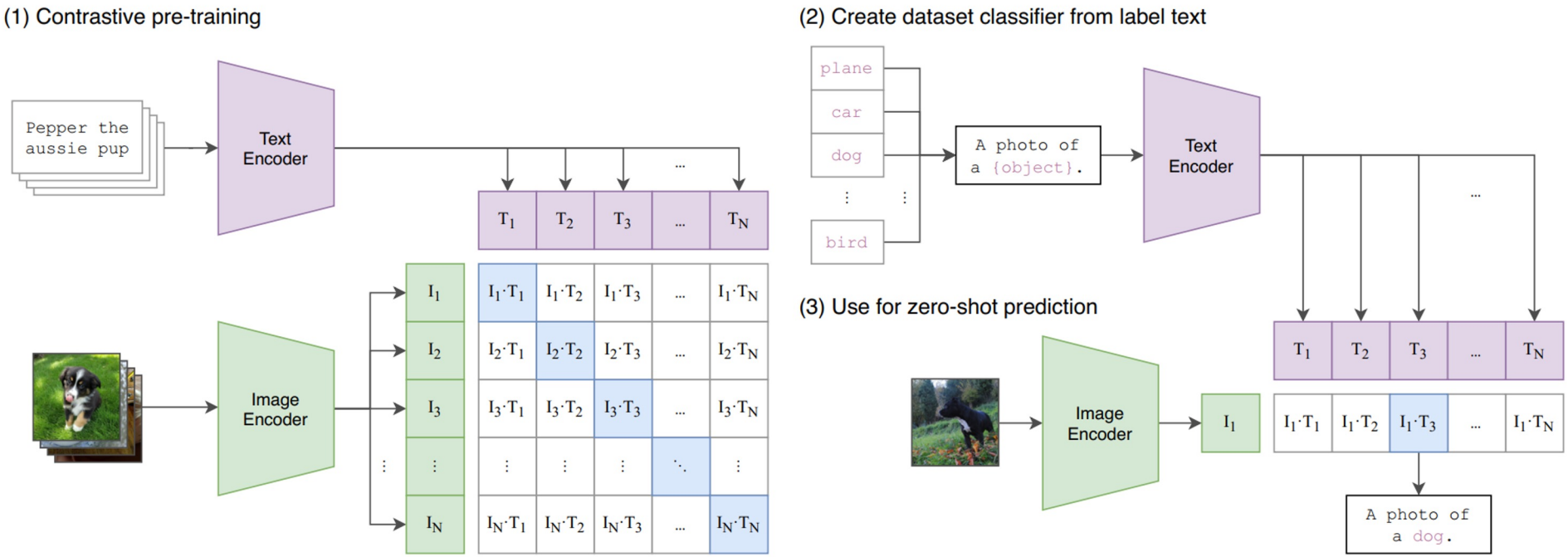
$$\ell_1(I_k T_k) = -\log\left(\frac{\exp(sim(I_k, T_k))}{\sum_{t=1}^{2N} 1[k \neq i]\exp(sim(I_k, T_t))}\right)$$

$$\ell_2(I_k T_k) = -\log\left(\frac{\exp(sim(I_k, T_k))}{\sum_{t=1}^{2N} 1[k \neq i]\exp(sim(I_t, T_k))}\right)$$

Radford et al. "Learning Transferable Visual Models From Natural Language Supervision." ICML 2021.

Adapted from Vicente Ordoñez

Zero-shot Image Classification with CLIP



Radford et al. "Learning Transferable Visual Models From Natural Language Supervision." ICML 2021.

Adapted from Vicente Ordoñez

Variants of CLIP

- CLIP: https://github.com/openai/CLIP
- OpenCLIP: https://github.com/mlfoundations/open_clip
- MetaCLIP: https://github.com/facebookresearch/MetaCLIP
- CLIPA: https://github.com/UCSC-VLAA/CLIPA
- SigLIP: https://github.com/merveenoyan/siglip
- DFN-5b: https://huggingface.co/apple/DFN5B-CLIP-ViT-H-14-378

Using CLIP for Object Recognition

- Compute dot product of image and prompt for each class, e.g. “A photo of dog”
- Return class with highest dot product for each image
- Prompt can be optimized manually or through training
- Can extend idea for object detection

Using CLIP for Object Recognition

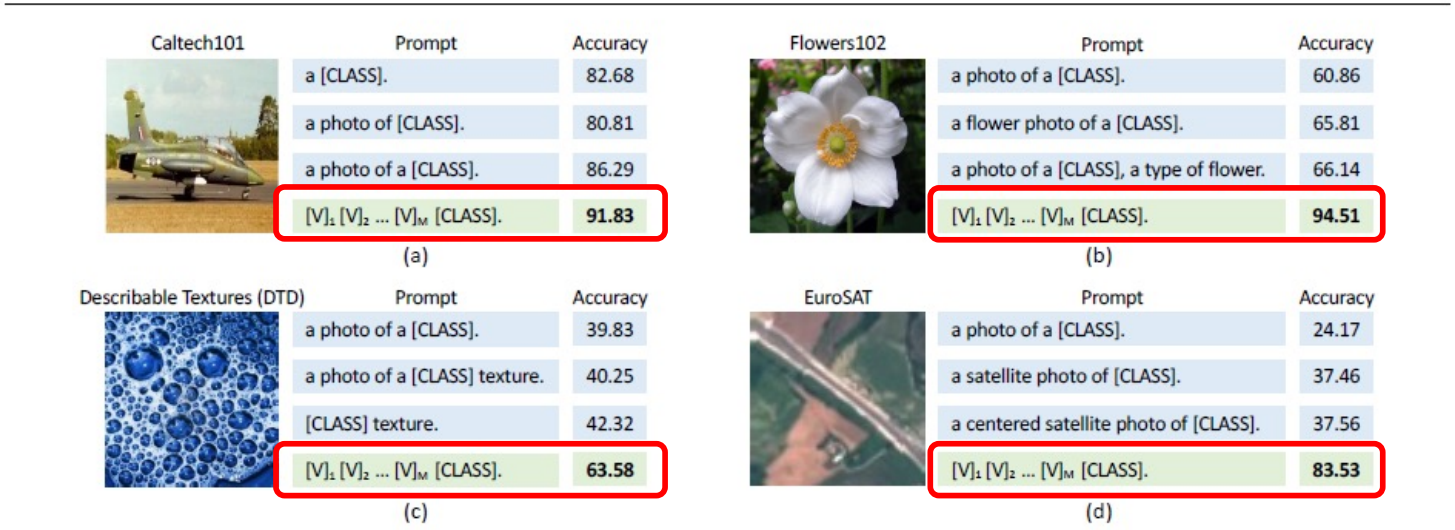


Fig. 1 Prompt engineering vs Context Optimization (CoOp). The former needs to use a held-out validation set for words tuning, which is inefficient; the latter automates the process and requires only a few labeled images for learning.

Zhou et al. "Learning to Prompt for Vision-Language Models." IJCV 2022.

Using CLIP for Object Recognition

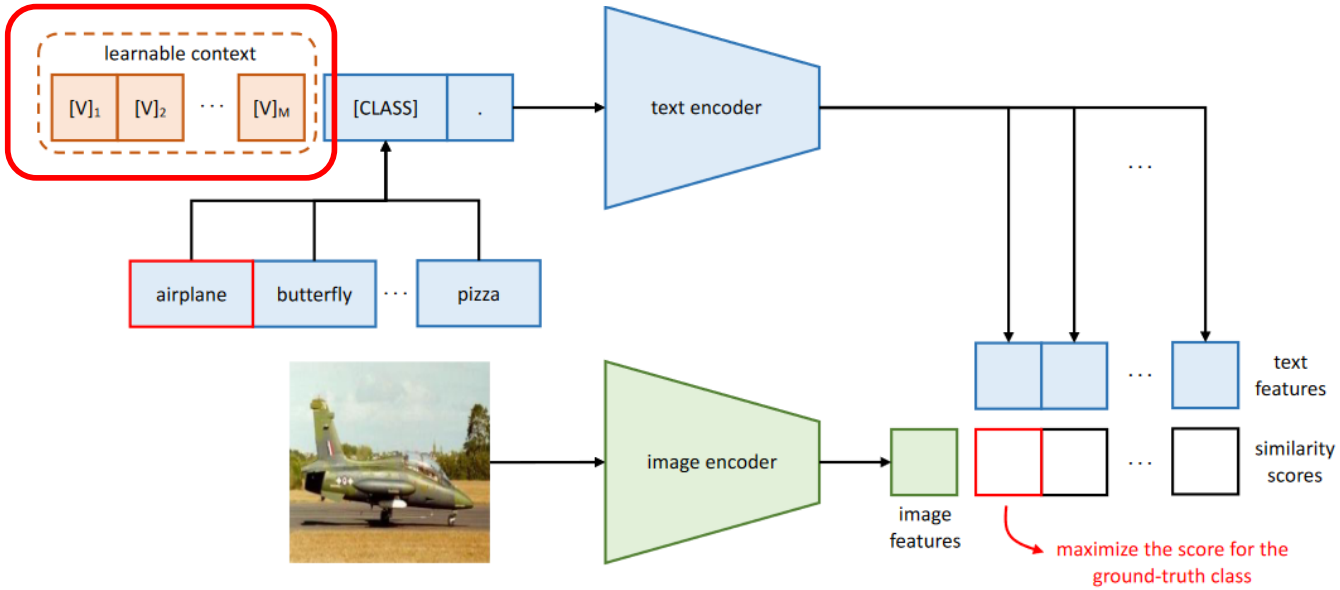


Fig. 2 Overview of Context Optimization (CoOp). The main idea is to model a prompt's context using a set of learnable vectors, which can be optimized through minimizing the classification loss. Two designs are proposed: one is unified context, which shares the same context vectors with all classes; and the other is class-specific context, which learns for each class a specific set of context vectors.

Zhou et al. "Learning to Prompt for Vision-Language Models." IJCV 2022.

Using CLIP for Object Recognition [Open Vocab]

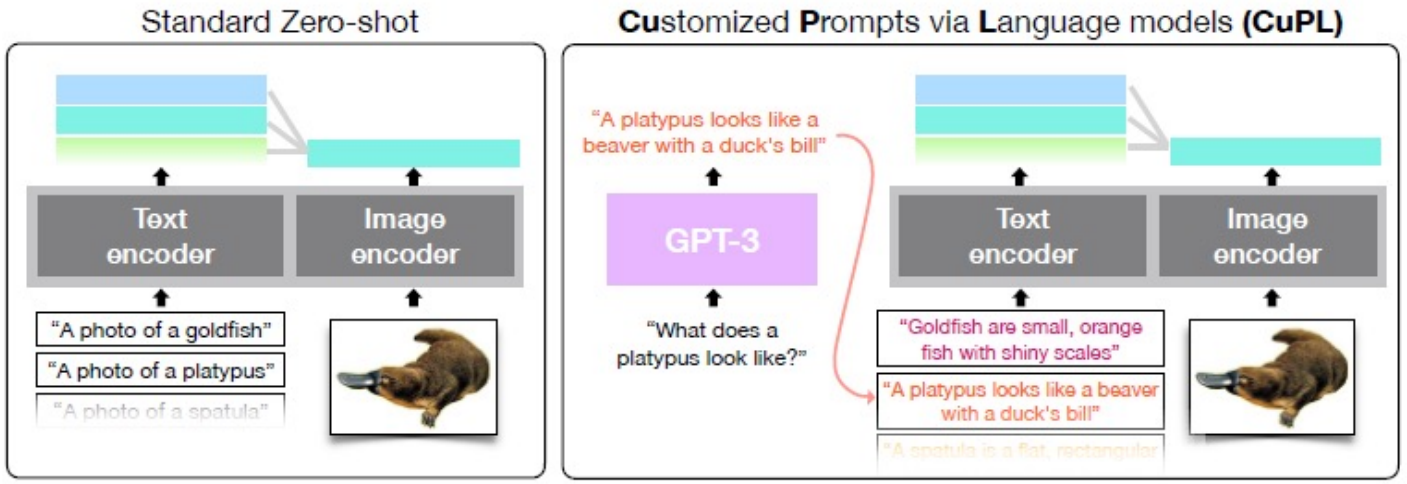


Figure 1: **Schematic of the method.** (Left) The standard method of a zero-shot open vocabulary image classification model (e.g., CLIP (Radford et al., 2021)). (Right) Our method of CuPL. First, an LLM generates descriptive captions for given class categories. Next, an open vocabulary model uses these captions as prompts for performing classification.

Pratt et al. "What does a platypus look like? Generating customized prompts for zero-shot image classification." ICCV 2023.

Using CLIP for Object Recognition

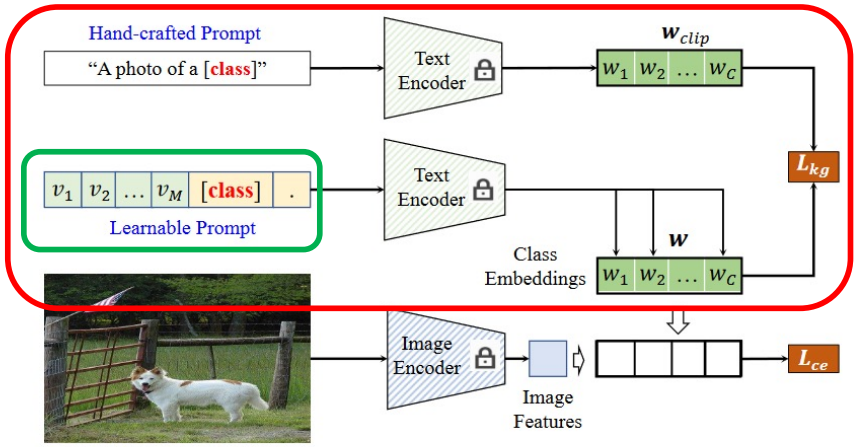


Figure 2. The framework of the Knowledge-guided Context Optimization for prompt tuning. $\mathcal{L}_{ce}$ is the standard cross-entropy loss, and $\mathcal{L}_{kg}$ is the proposed Knowledge-guided Context Optimization contraint to minimize the discrepancy between the special knowledge (learnable textual embeddings) and the general knowledge(the textual embeddings generated by the hand-crafted prompt).

degradation. Therefore, we can minimize the distance between $\mathbf{w}_i$ and $\mathbf{w}_i^{clip}$ for boosting the generability of the unseen classes,

$$\mathcal{L}_{kg} = \frac{1}{N_c}\sum_{i=1}^{N_c} ||\mathbf{w}_i - \mathbf{w}_i^{clip}||_2^2, \tag{3}$$

where $||\cdot||$ is the euclidean distance, N_c is the number of seen classes. Meanwhile, the standard contrastive loss is:

$$\mathcal{L}_{ce} = -\sum_{\mathbf{x}\in\mathbf{X}} \log \frac{\exp(d(\mathbf{x}, \mathbf{w}_y)/\tau)}{\sum_{i=1}^{N_c}\exp(d(\mathbf{x}, \mathbf{w}_i)/\tau)}, \tag{4}$$

where y is the corresponding label of the image embedding.

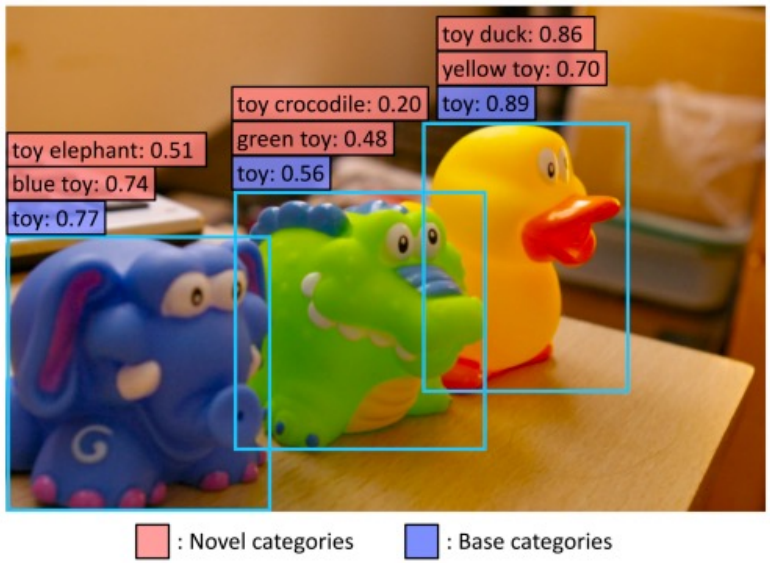
By combining the standard cross-entropy loss $\mathcal{L}_{ce}$, the final objective is:

$$\mathcal{L} = \mathcal{L}_{ce} + \lambda\mathcal{L}_{kg}, \tag{5}$$

where λ is used balance the effect of $\mathcal{L}_{kg}$.

Yao et al. "Visual-Language Prompt Tuning with Knowledge-guided Context Optimization." CVPR 2023.

Using CLIP for Object Recognition [Open Vocab]



Change Detected/Base categories
to Novel Categories

Google Colab: link

Gu et al. "Open-vocabulary Object Detection via Vision and Language Knowledge Distillation." ICLR 2021.

Using CLIP for Object Recognition [Open Vocab]

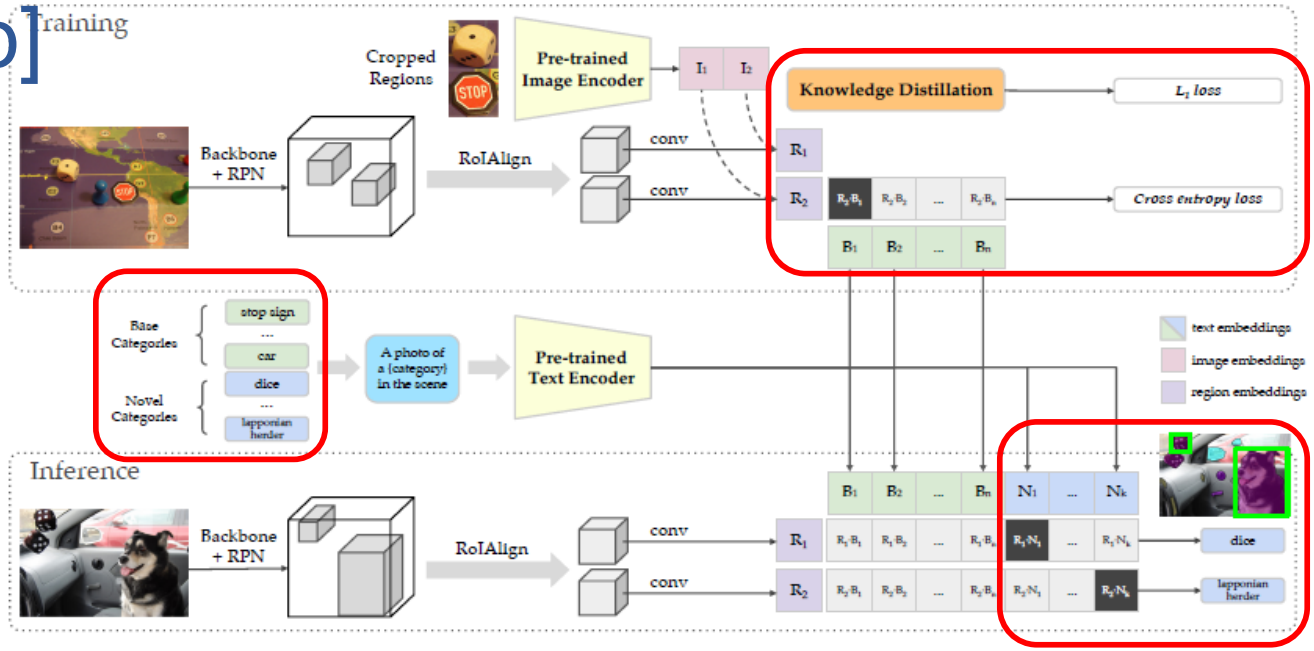


Figure 2: **An overview of using ViLD for open-vocabulary object detection.** ViLD distills the knowledge from a pretrained open-vocabulary image classification model. First, the category text embeddings and the image embeddings of cropped object proposals are computed, using the text and image encoders in the pretrained classification model. Then, ViLD employs the text embeddings as the region classifier (ViLD-text) and minimizes the distance between the region embedding and the image embedding for each proposal (ViLD-image). During inference, text embeddings of novel categories are used to enable open-vocabulary detection.

Gu et al. "Open-vocabulary Object Detection via Vision and Language Knowledge Distillation." ICLR 2021.