SSD: Single Shot MultiBox Detector

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Scott Reed(4), Cheng-Yang Fu(1), Alexander C. Berg(1)

UNC Chapel Hill(1), **Zoox Inc.(2)**, Google Inc.(3),
University of Michigan(4)

VGGNet
Titan X Pascal

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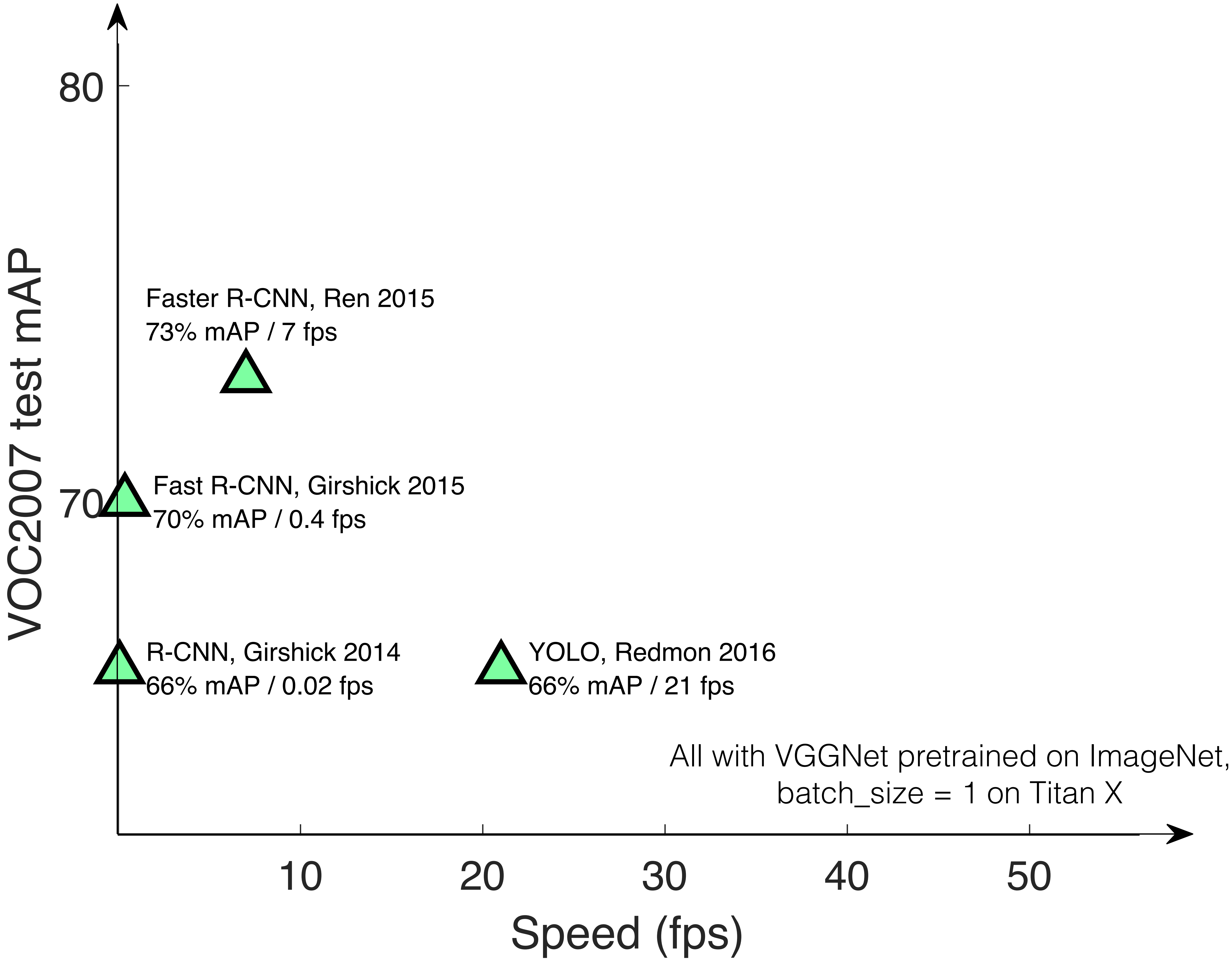
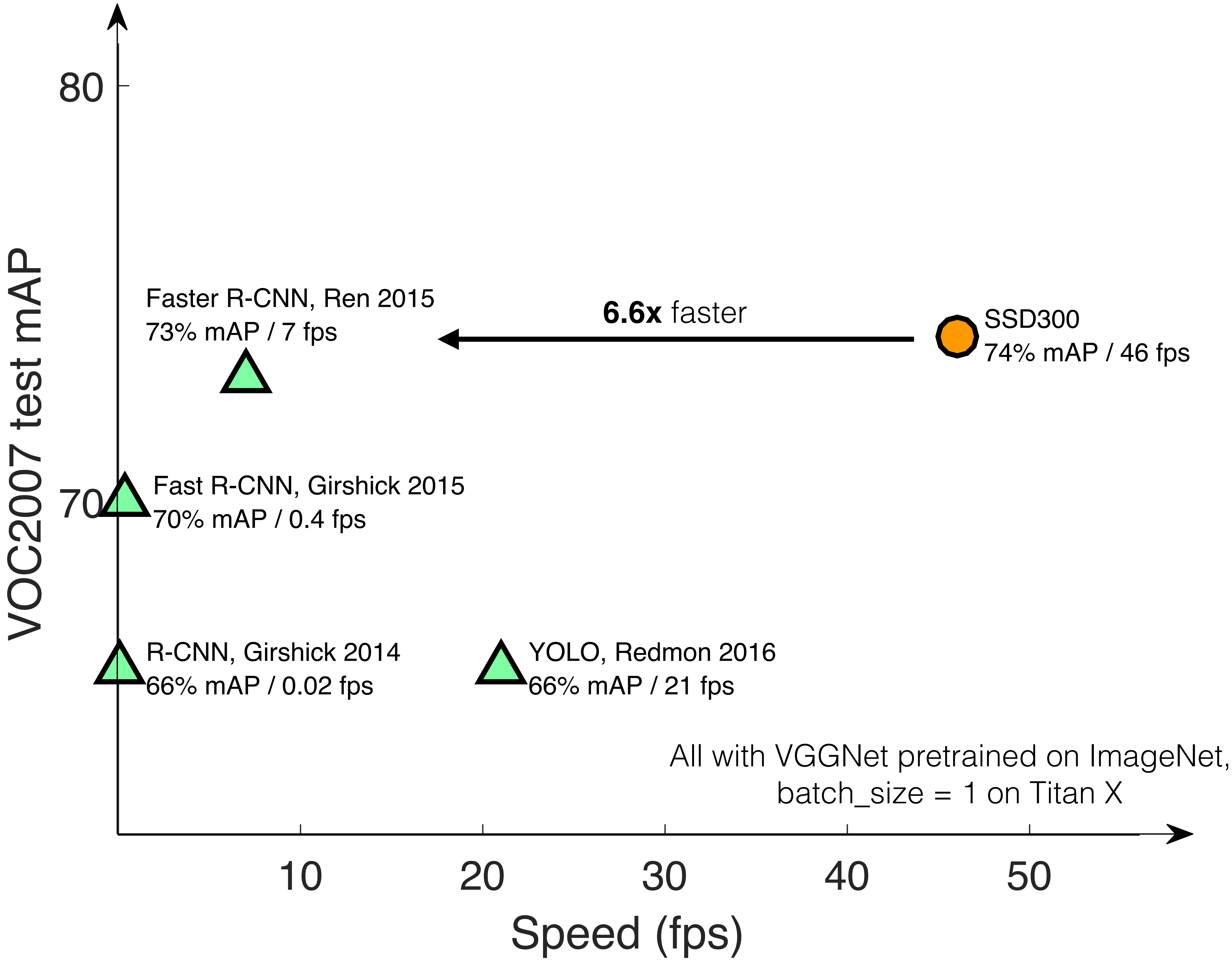
Titan X Pascal


VOC2007 test mAP
80
70
Faster R-CNN, Ren 2015
73% mAP / 7 fps
Fast R-CNN, Girshick 2015
70% mAP / 0.4 fps
R-CNN, Girshick 2014
66% mAP / 0.02 fps
YOLO, Redmon 2016
66% mAP / 21 fps
All with VGGNet pretrained on ImageNet,
batch_size = 1 on Titan X
10
20
30
40
50
Speed (fps)



VOC2007 test mAP
80
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Faster R-CNN, Ren 2015
73% mAP / 7 fps
6.6x faster
SSD300
74% mAP / 46 fps
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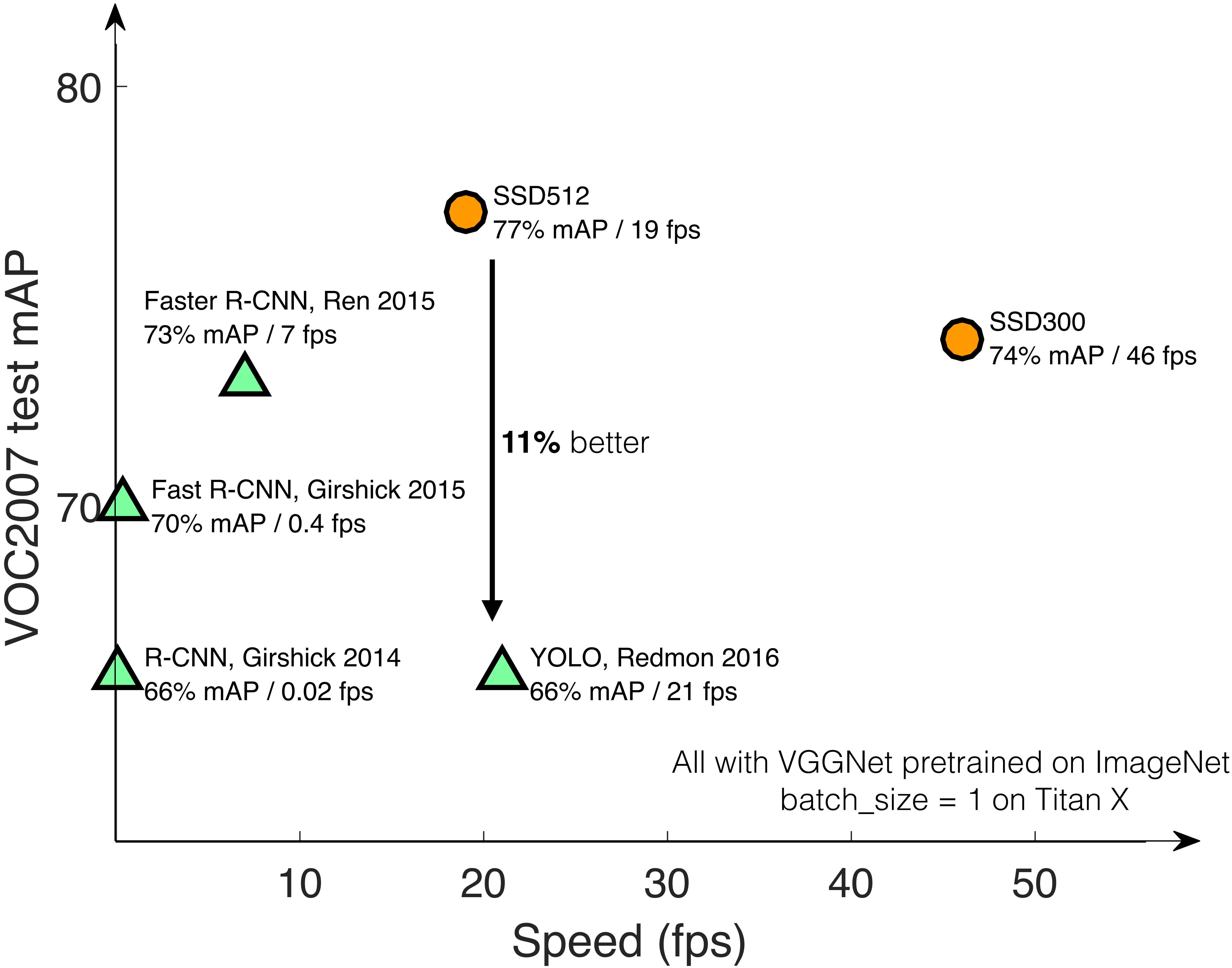

VOC2007 test mAP
80
70
SSD512
77% mAP / 19 fps
Faster R-CNN, Ren 2015
73% mAP / 7 fps
SSD300
74% mAP / 46 fps
11% better
Fast R-CNN, Girshick 2015
70% mAP / 0.4 fps
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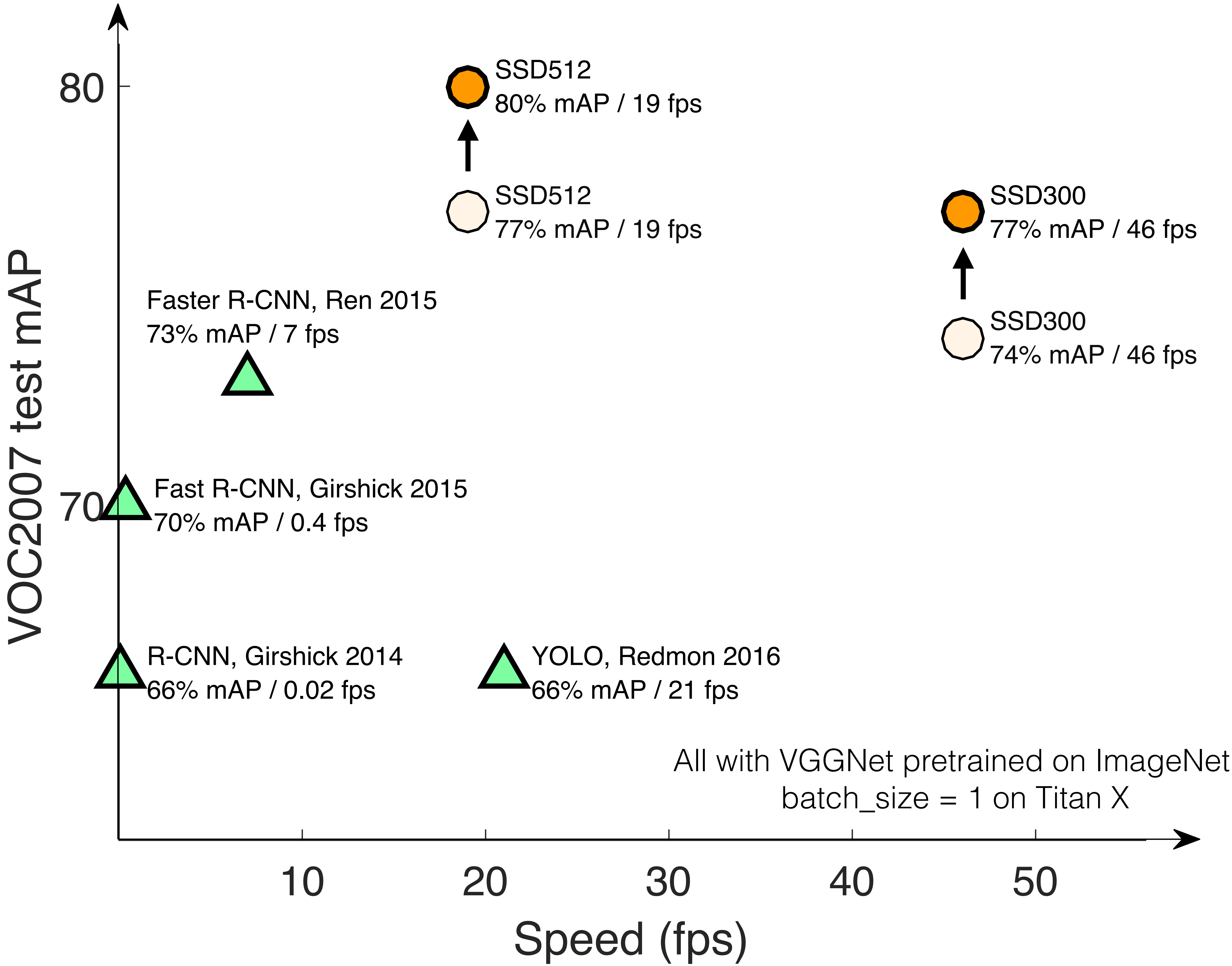

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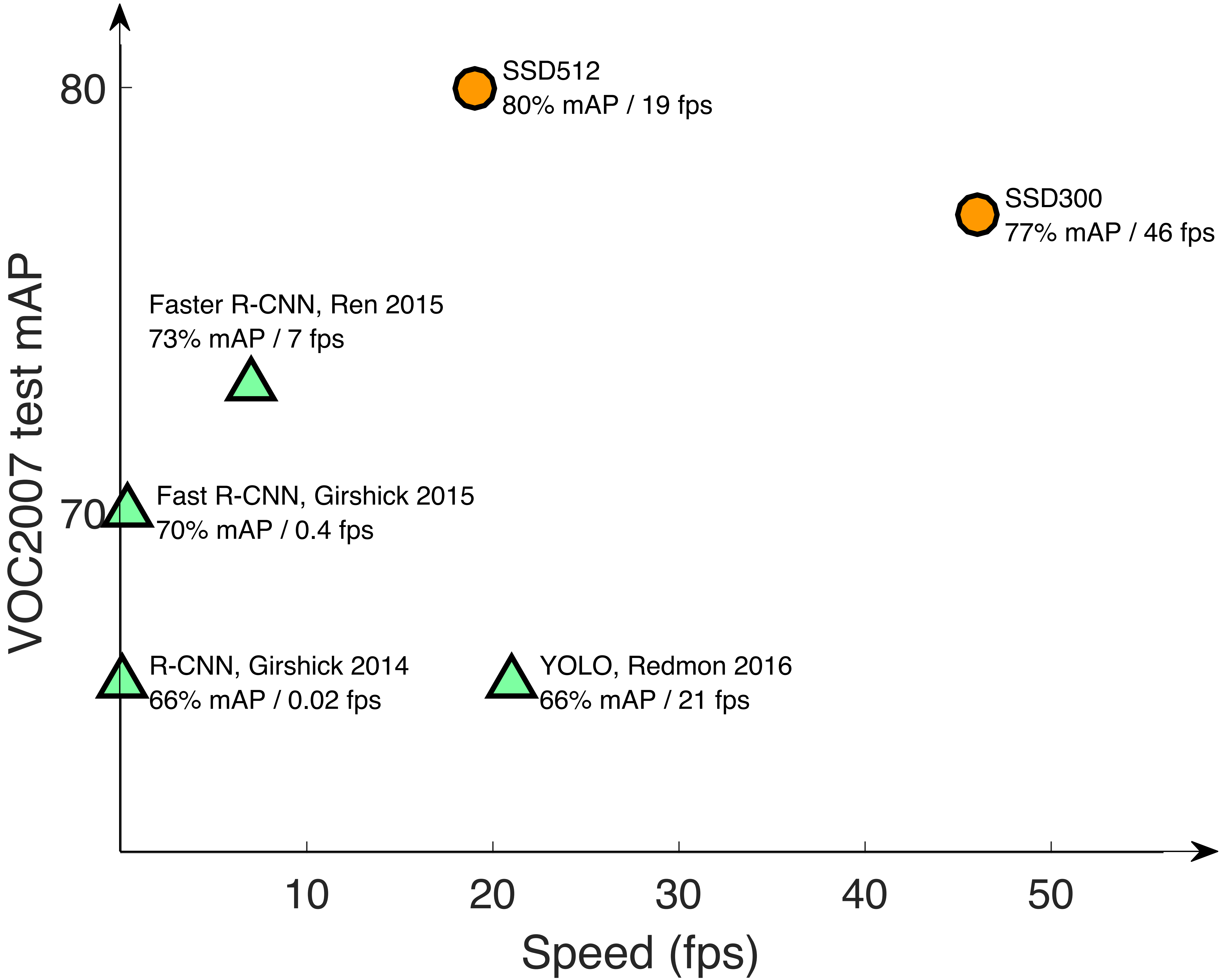

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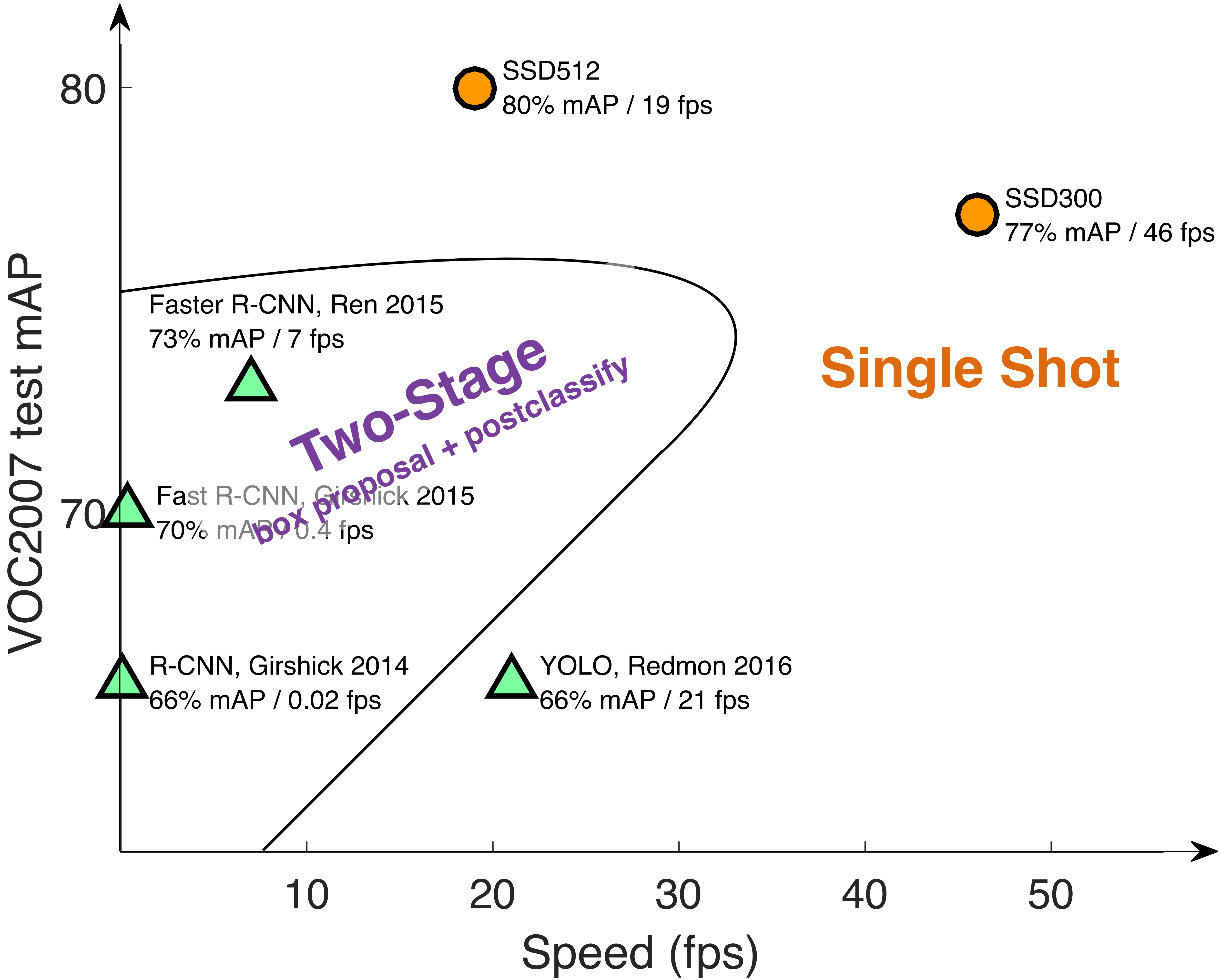
Speed (fps)


SSD512
80% mAP / 19 fps
SSD300
77% mAP / 46 fps
Faster R-CNN, Ren 2015
73% mAP / 7 fps
Two-Stage
box proposal + postclassify
Single Shot
Fast R-CNN, Girshick 2015
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R-CNN, Girshick 2014
66% mAP / 0.02 fps
YOLO, Redmon 2016
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Speed (fps)

Bounding Box Prediction

Classical sliding windows

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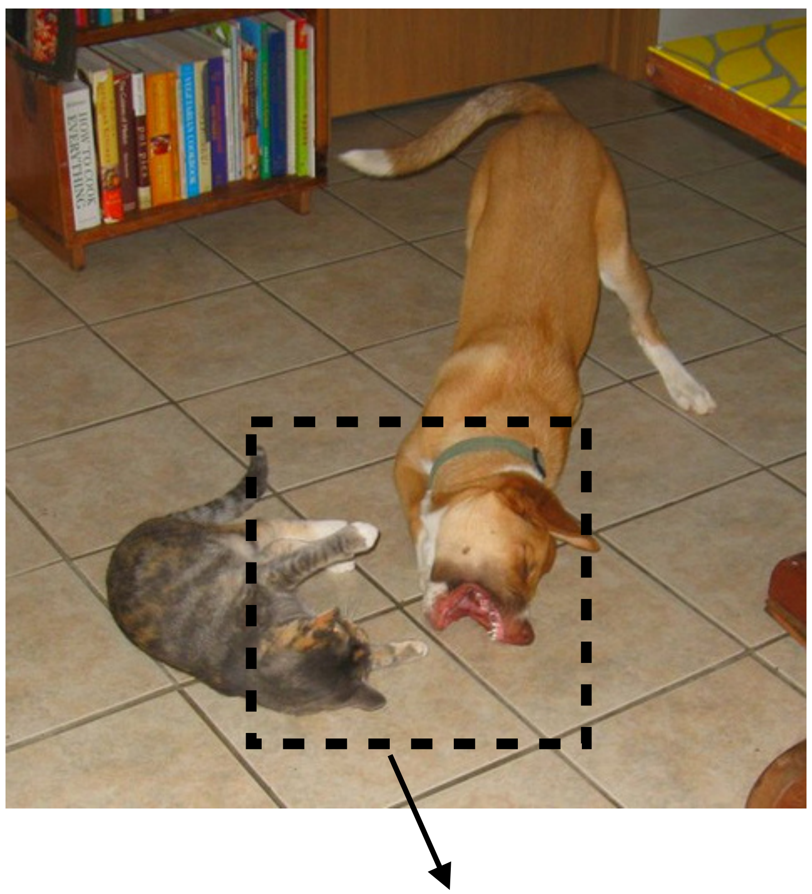
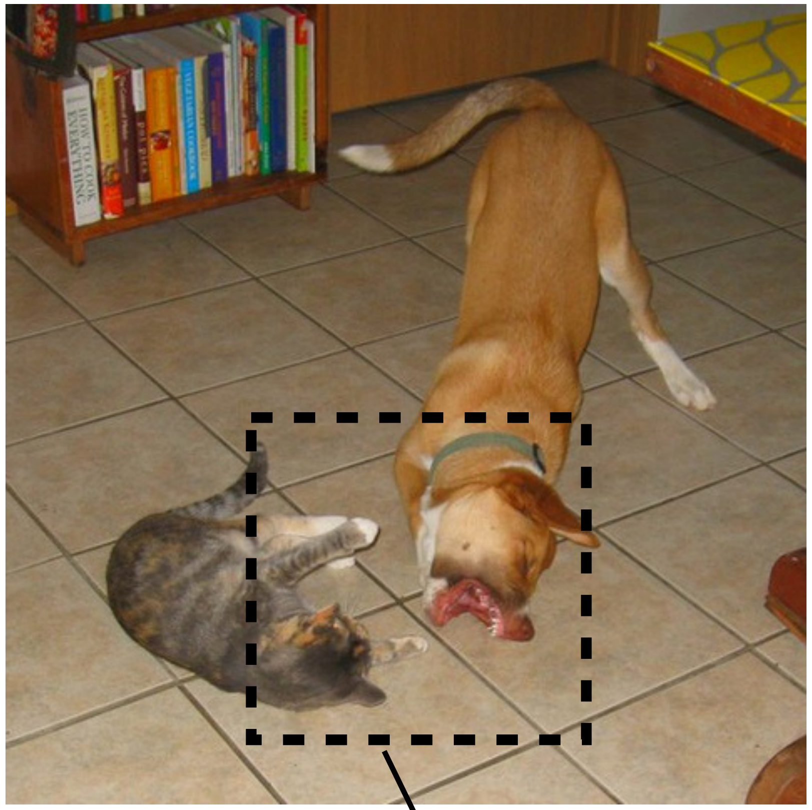
Classical sliding windows



Is it a cat? **No**

Bounding Box Prediction

Classical sliding windows

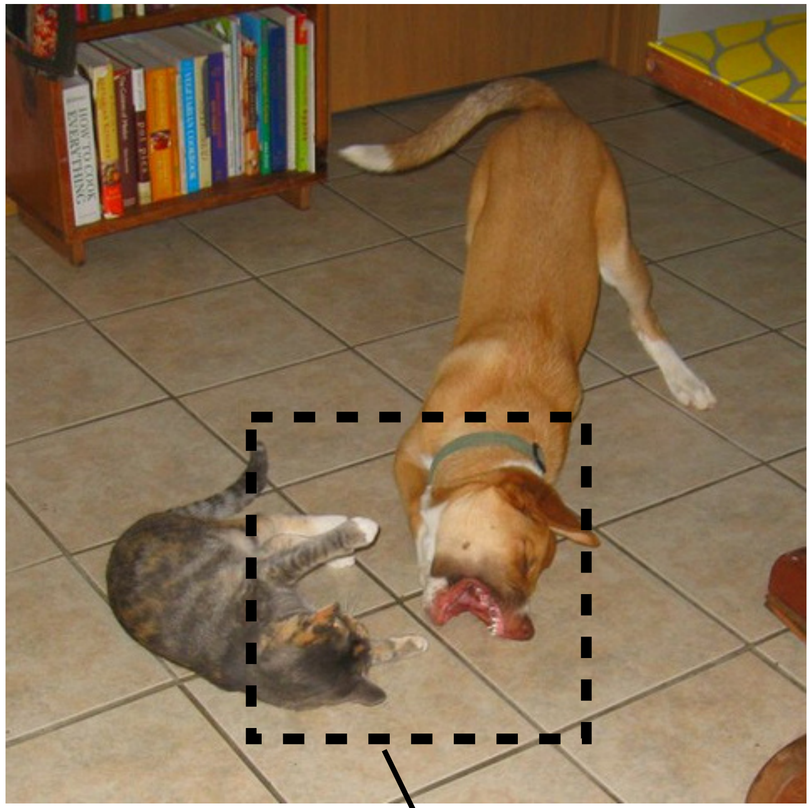


Is it a cat? **No**

Discretize the box space **densely**

Bounding Box Prediction

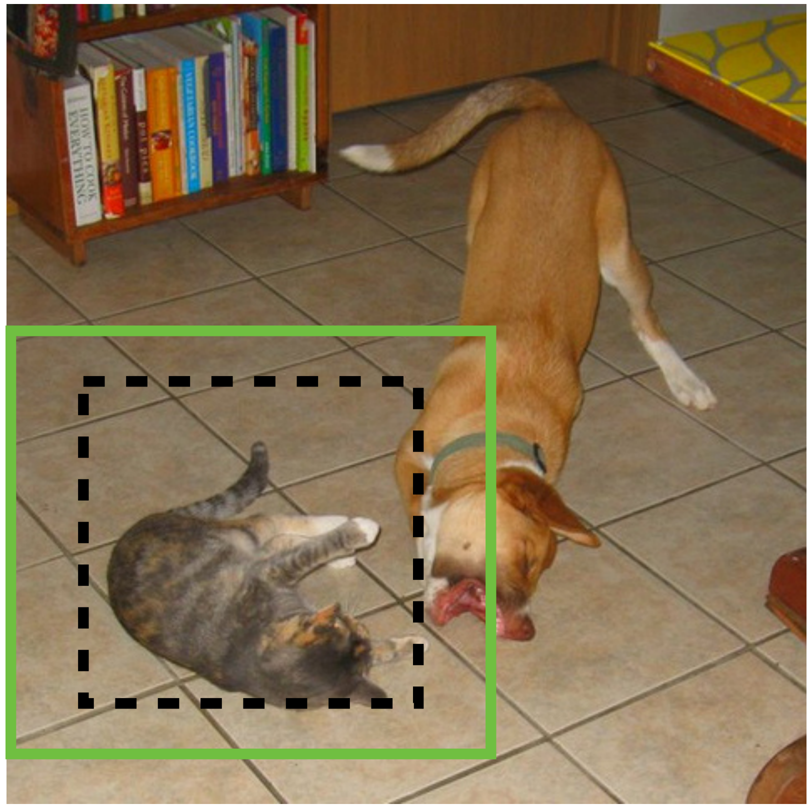
Classical sliding windows



Is it a cat? **No**

Discretize the box space **densely**

SSD and other deep approaches



Bounding Box Prediction

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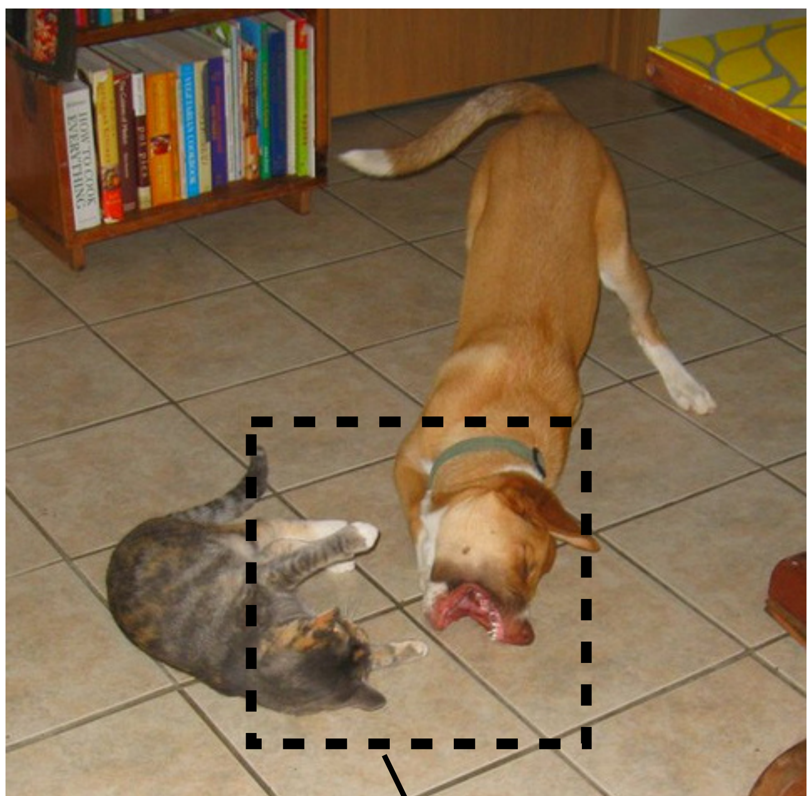

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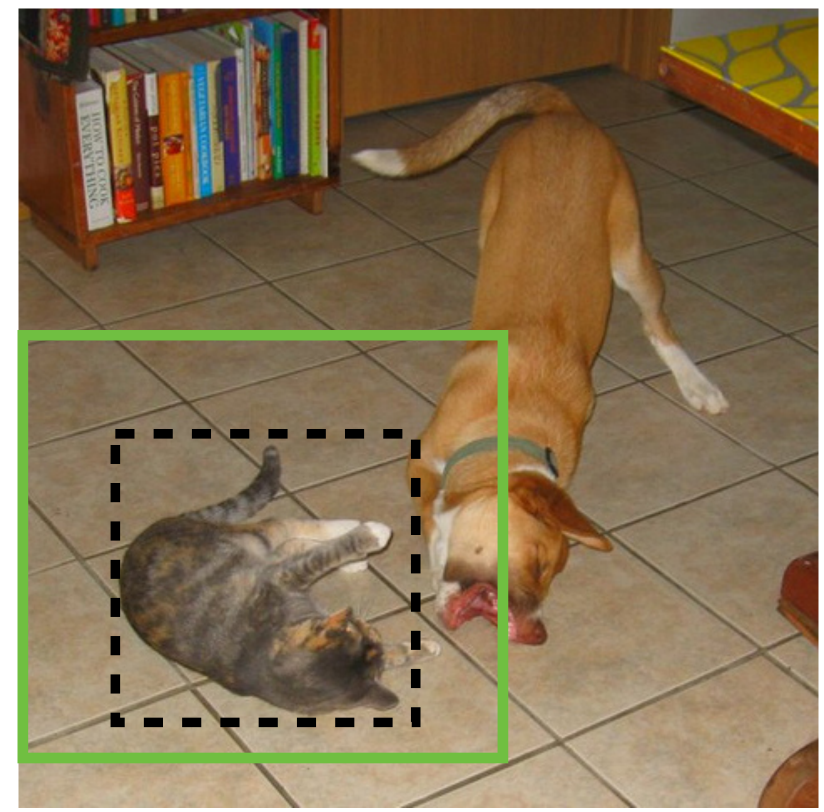

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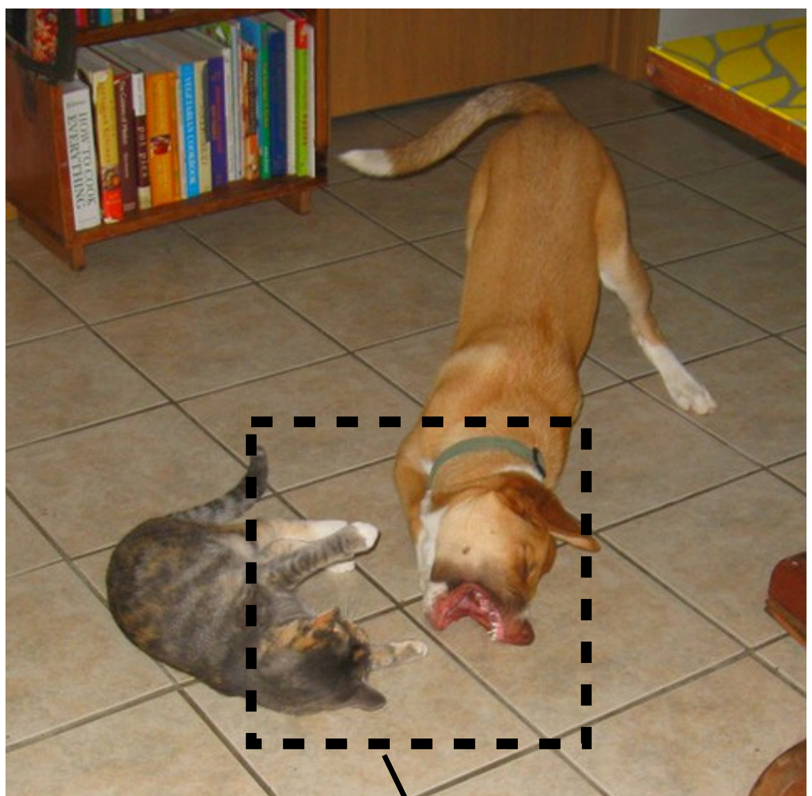

Is it a cat? **No**

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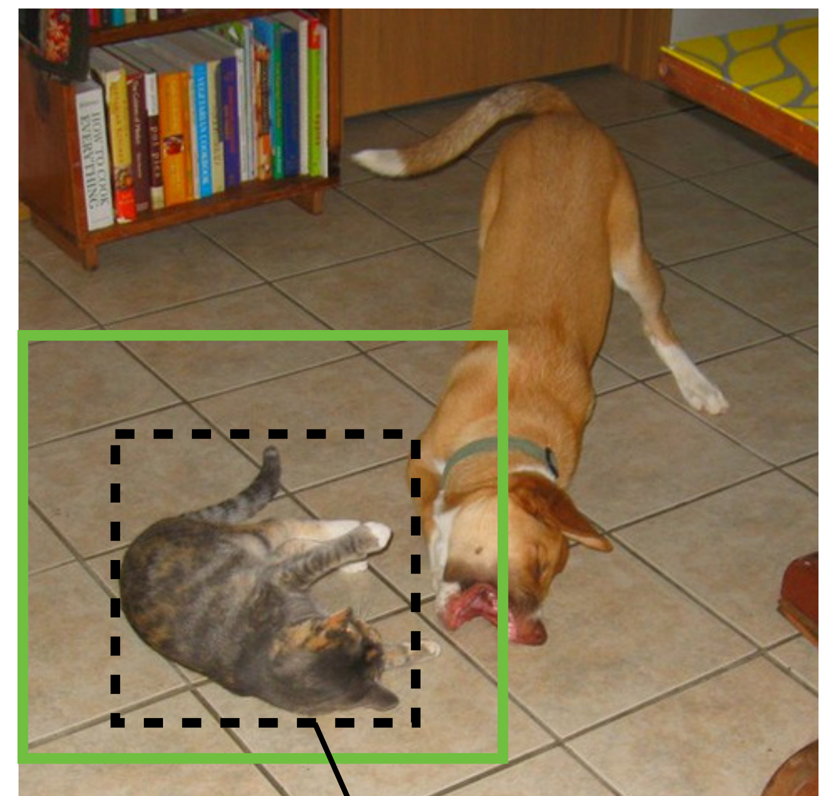
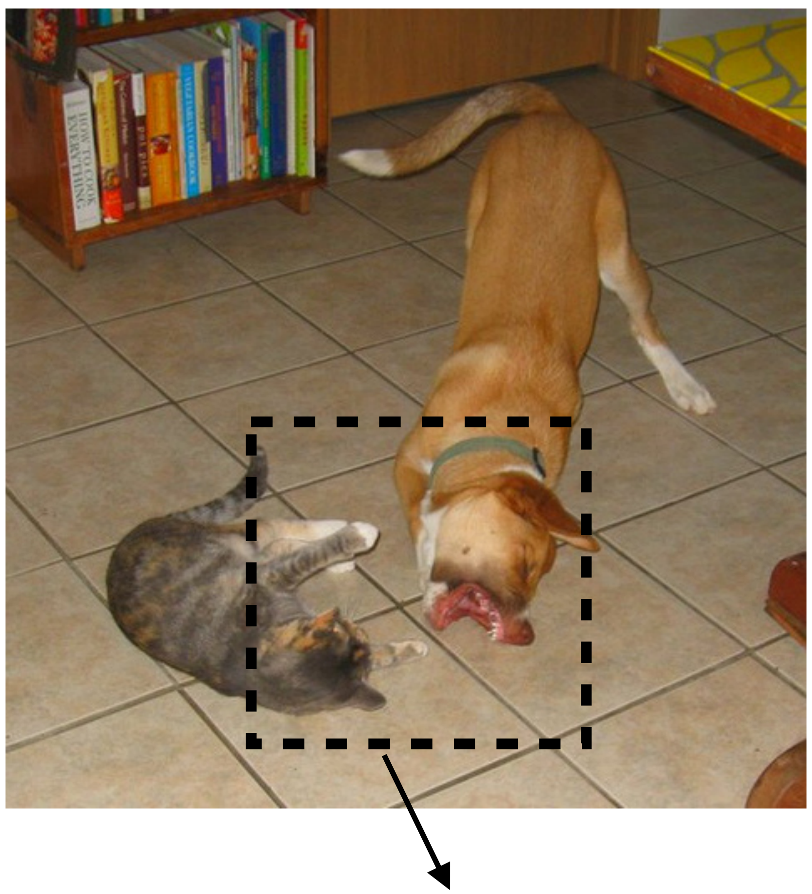


cat: 0.8 dog: 0.1

Discretize the box space **densely**

Bounding Box Prediction

Classical sliding windows



Is it a cat? **No**

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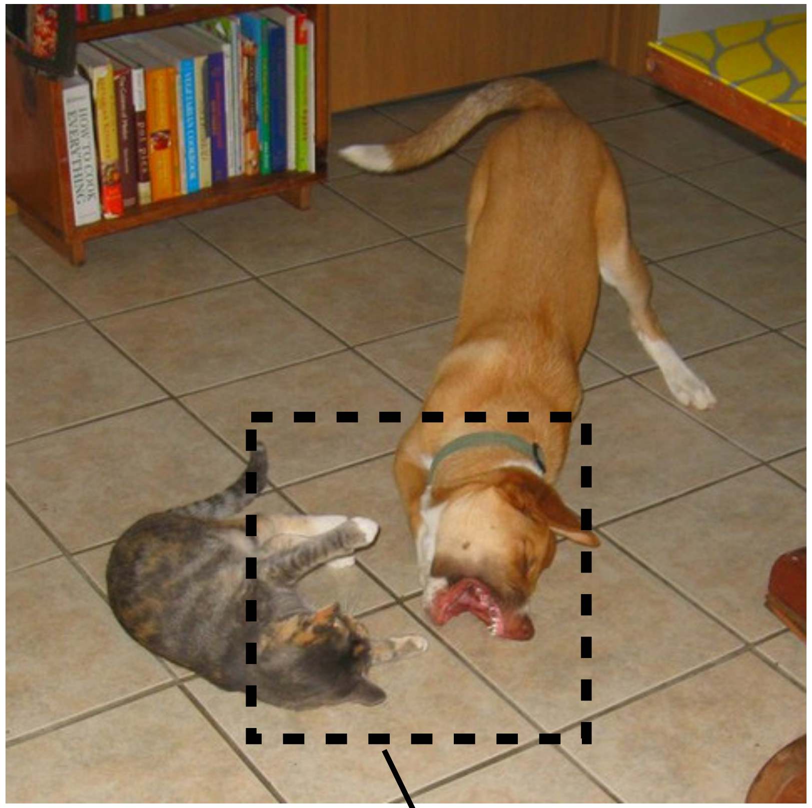
SSD and other deep approaches

Bounding Box Prediction

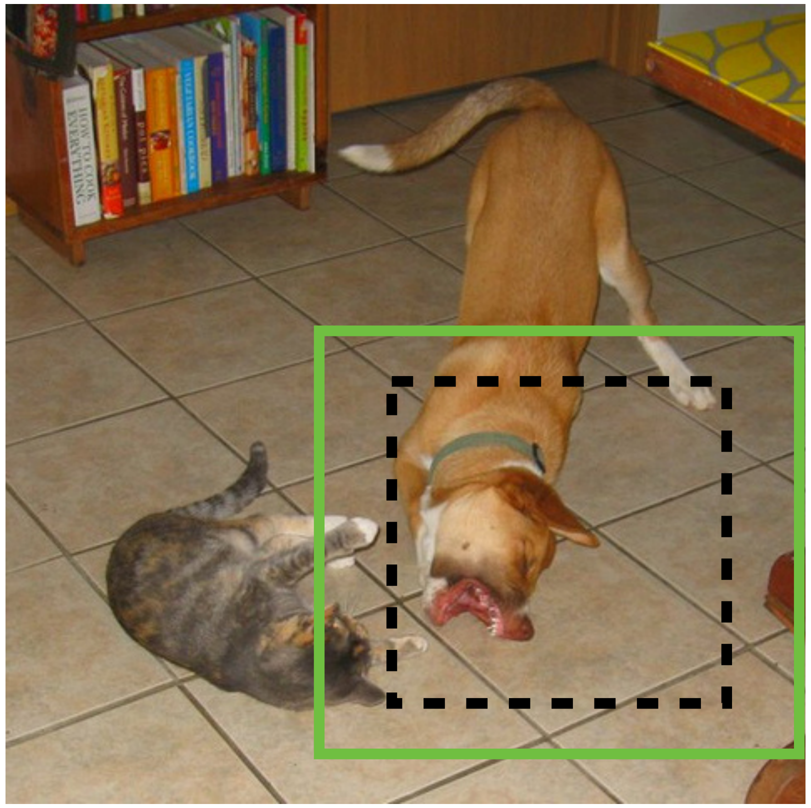
Classical sliding windows



Is it a cat? No

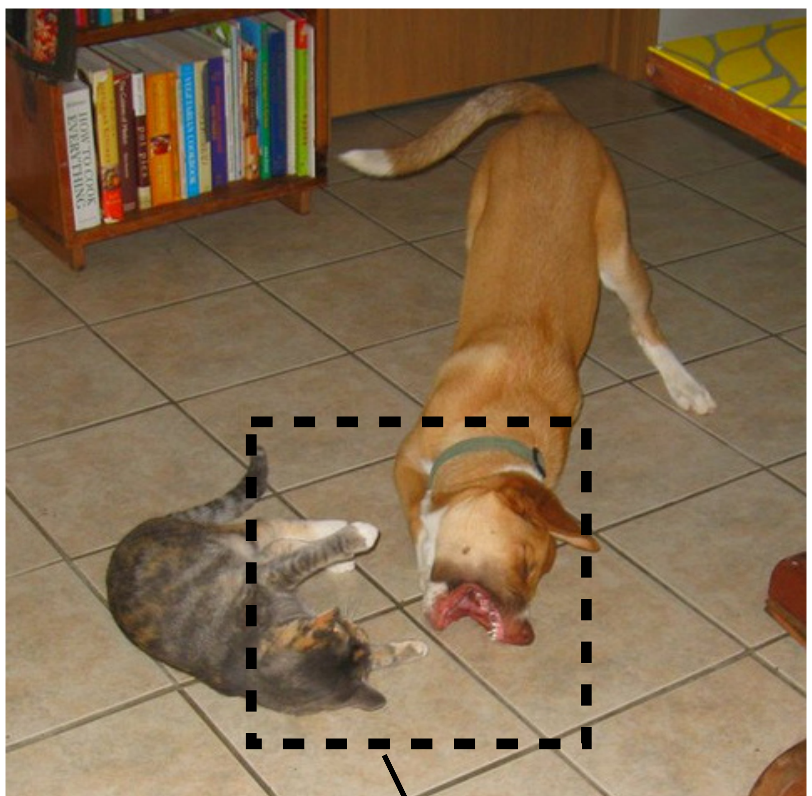
Discretize the box space **densely**

SSD and other deep approaches



Bounding Box Prediction

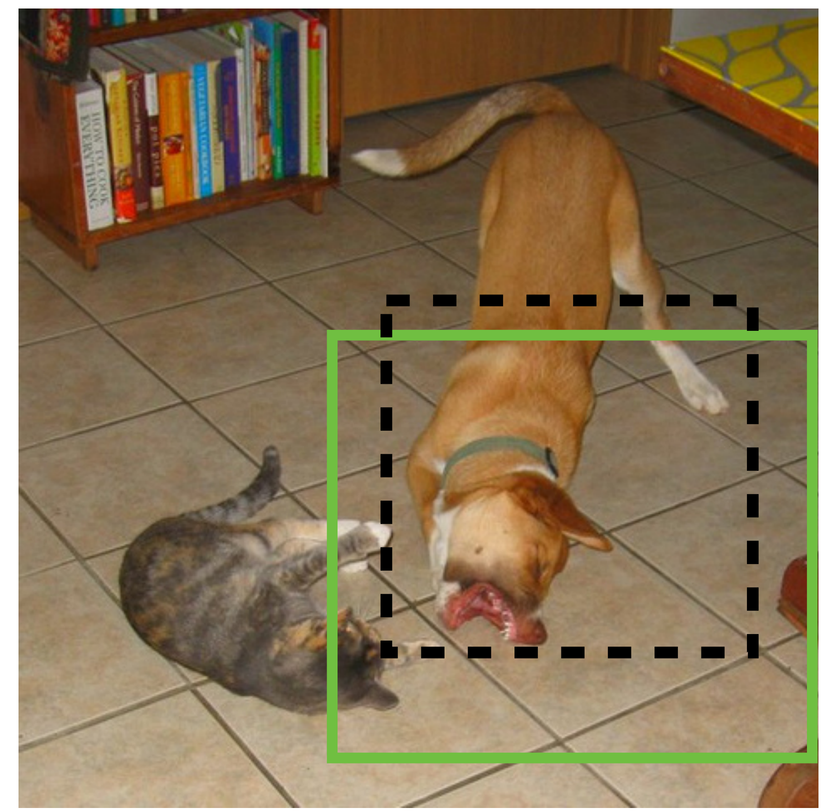
Classical sliding windows



Is it a cat? **No**

Discretize the box space **densely**

SSD and other deep approaches



Bounding Box Prediction

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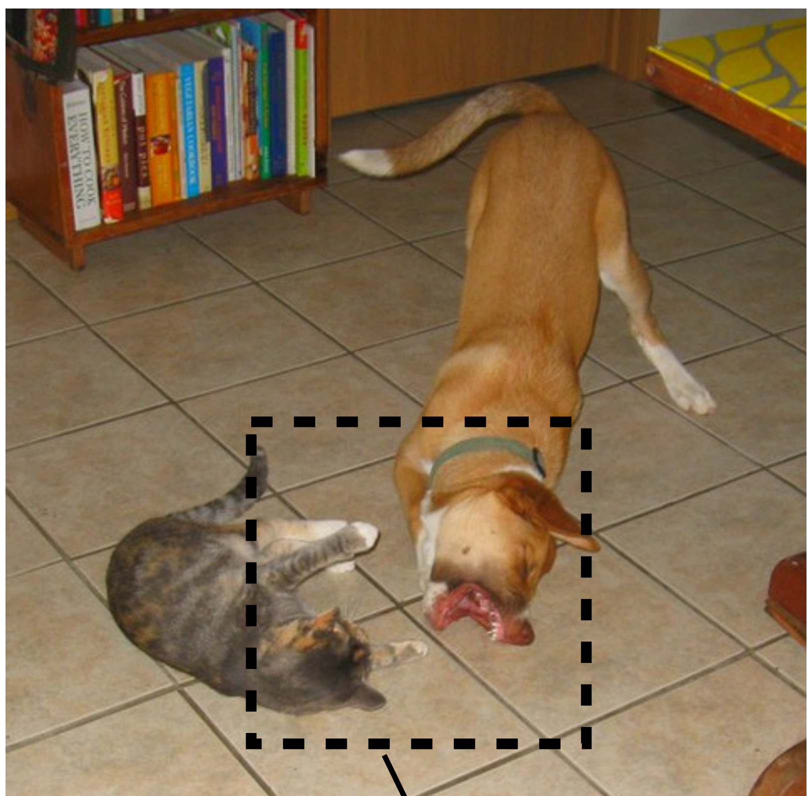
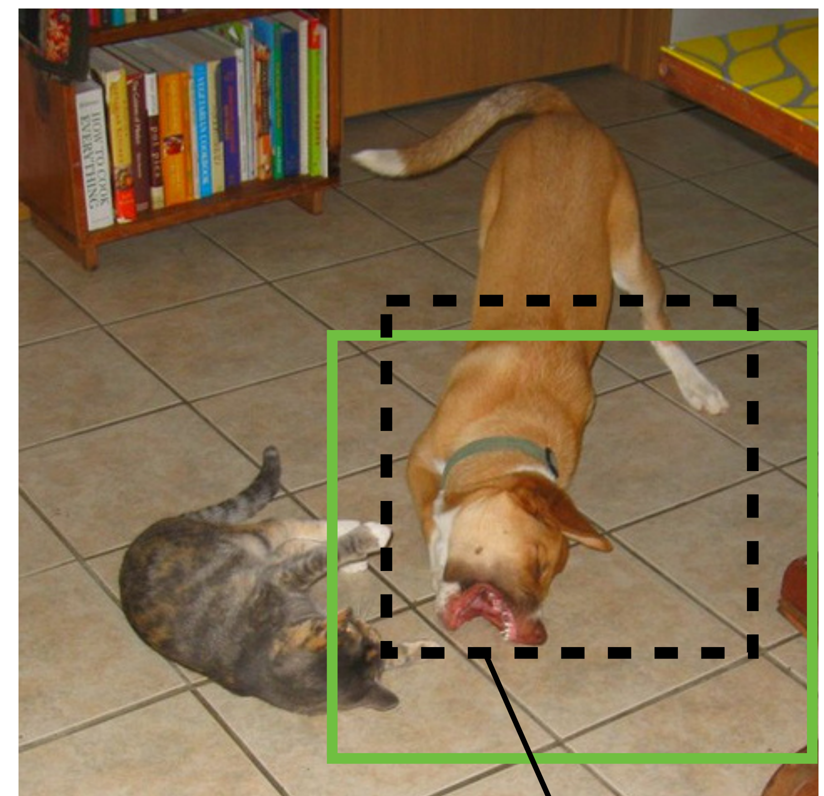


Is it a cat? **No**

Discretize the box space **densely**

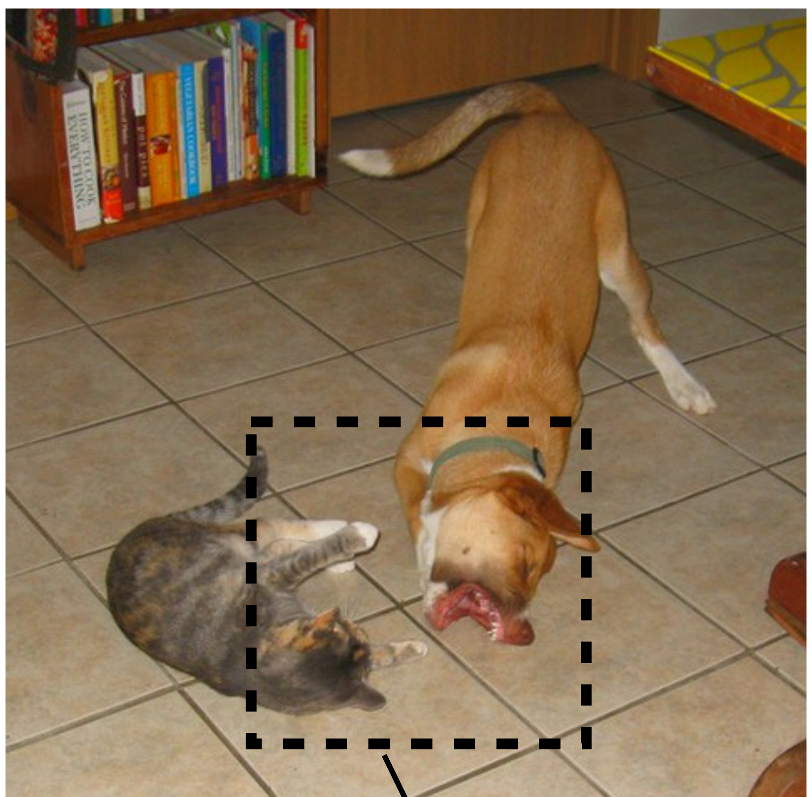
SSD and other deep approaches



dog: 0.4 cat: 0.2

Bounding Box Prediction

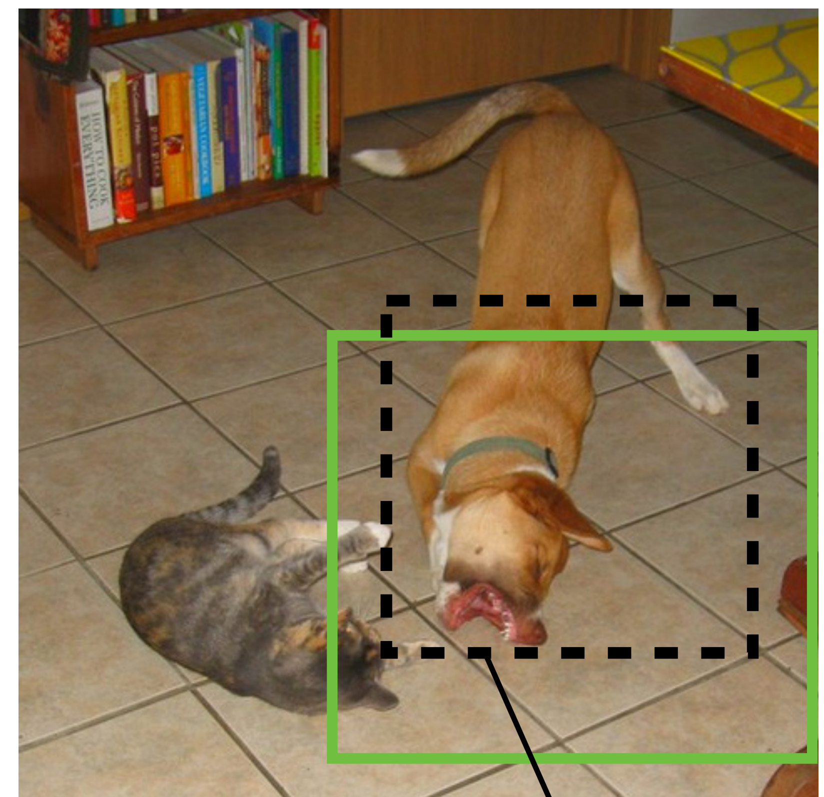
Classical sliding windows



Is it a cat? **No**

Discretize the box space **densely**

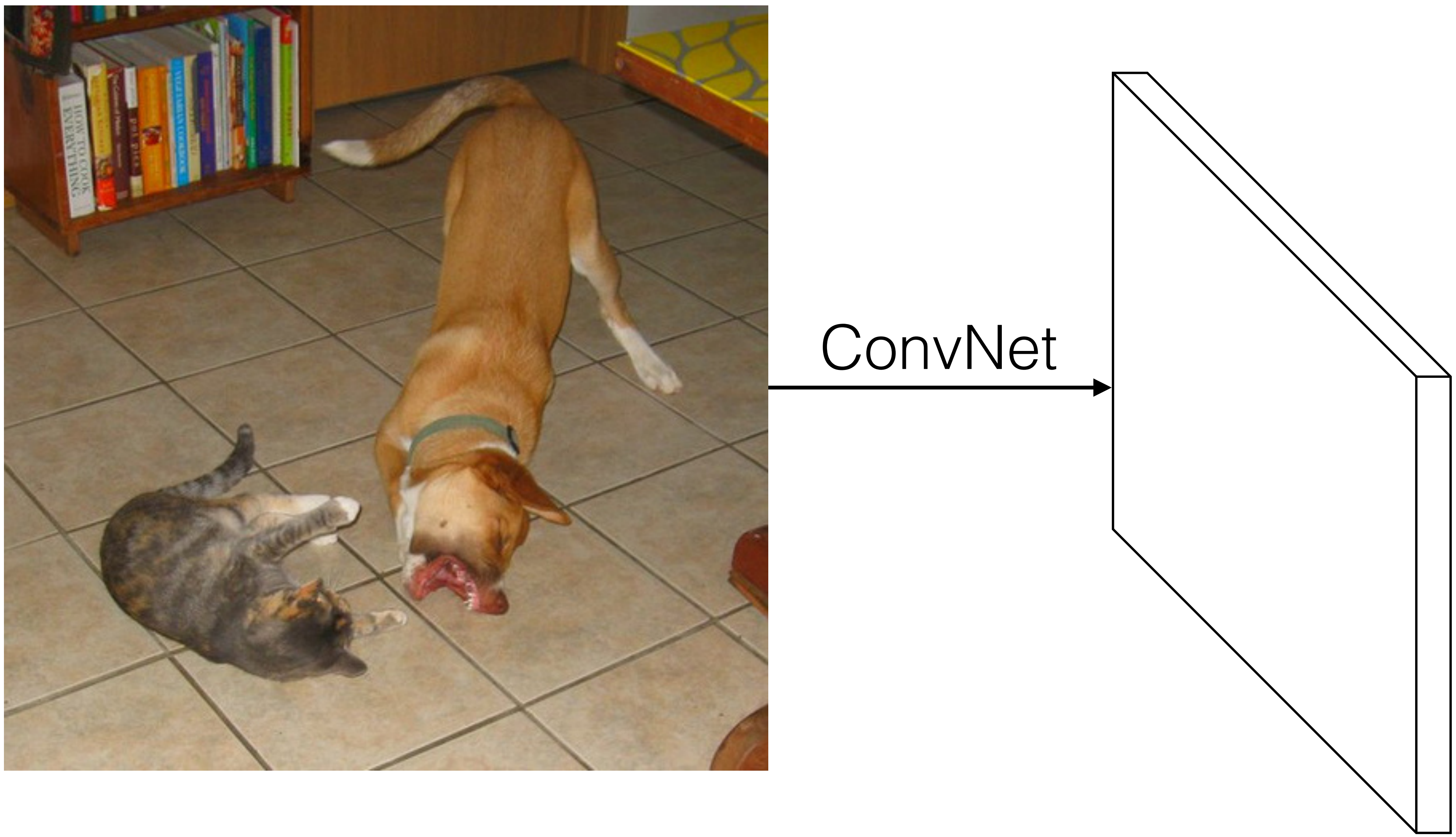
SSD and other deep approaches



dog: 0.4 cat: 0.2

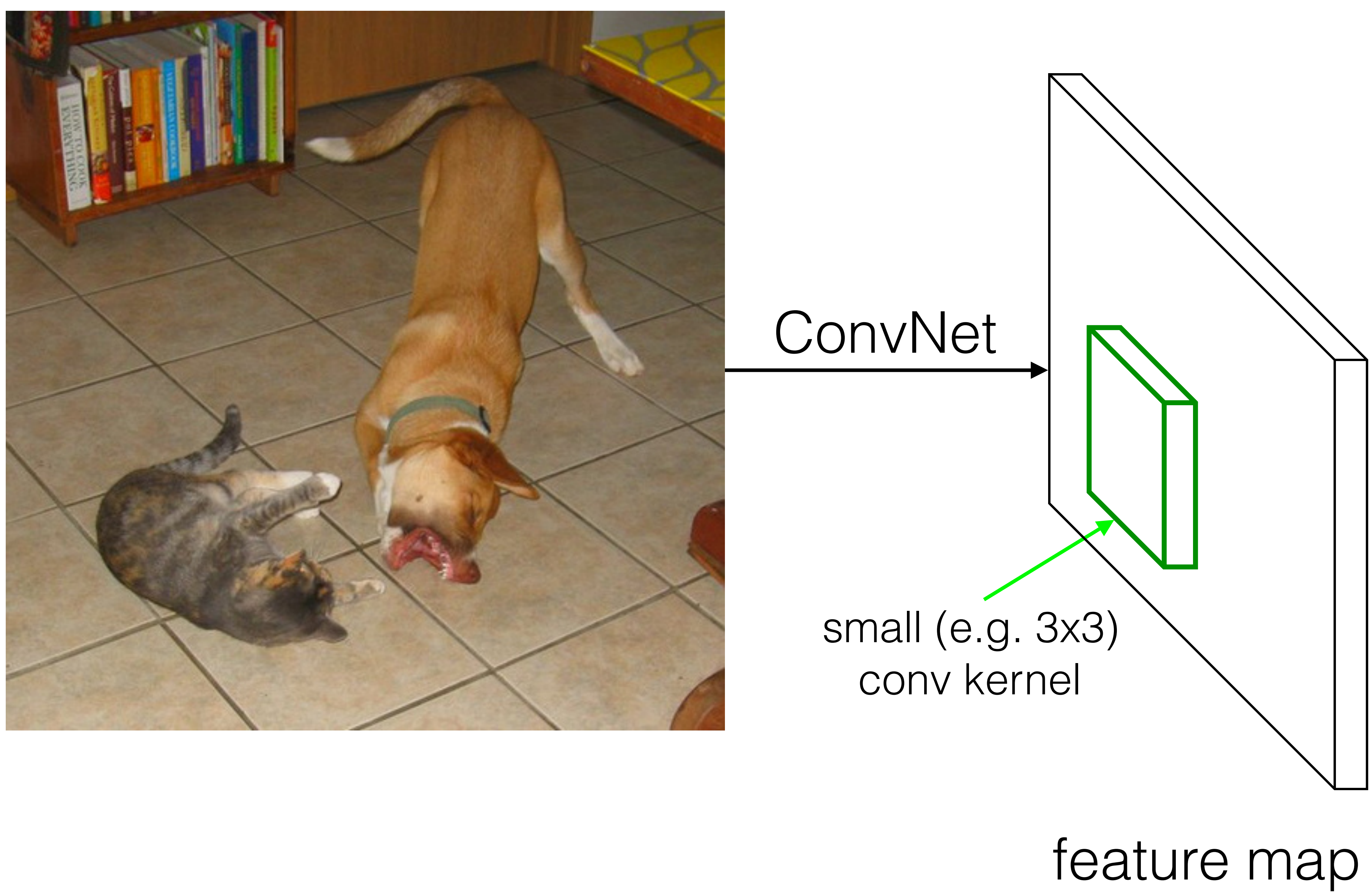
Discretize the box space more **coarsely**
Refine the coordinates of each box

SSD Output Layer



feature map

SSD Output Layer



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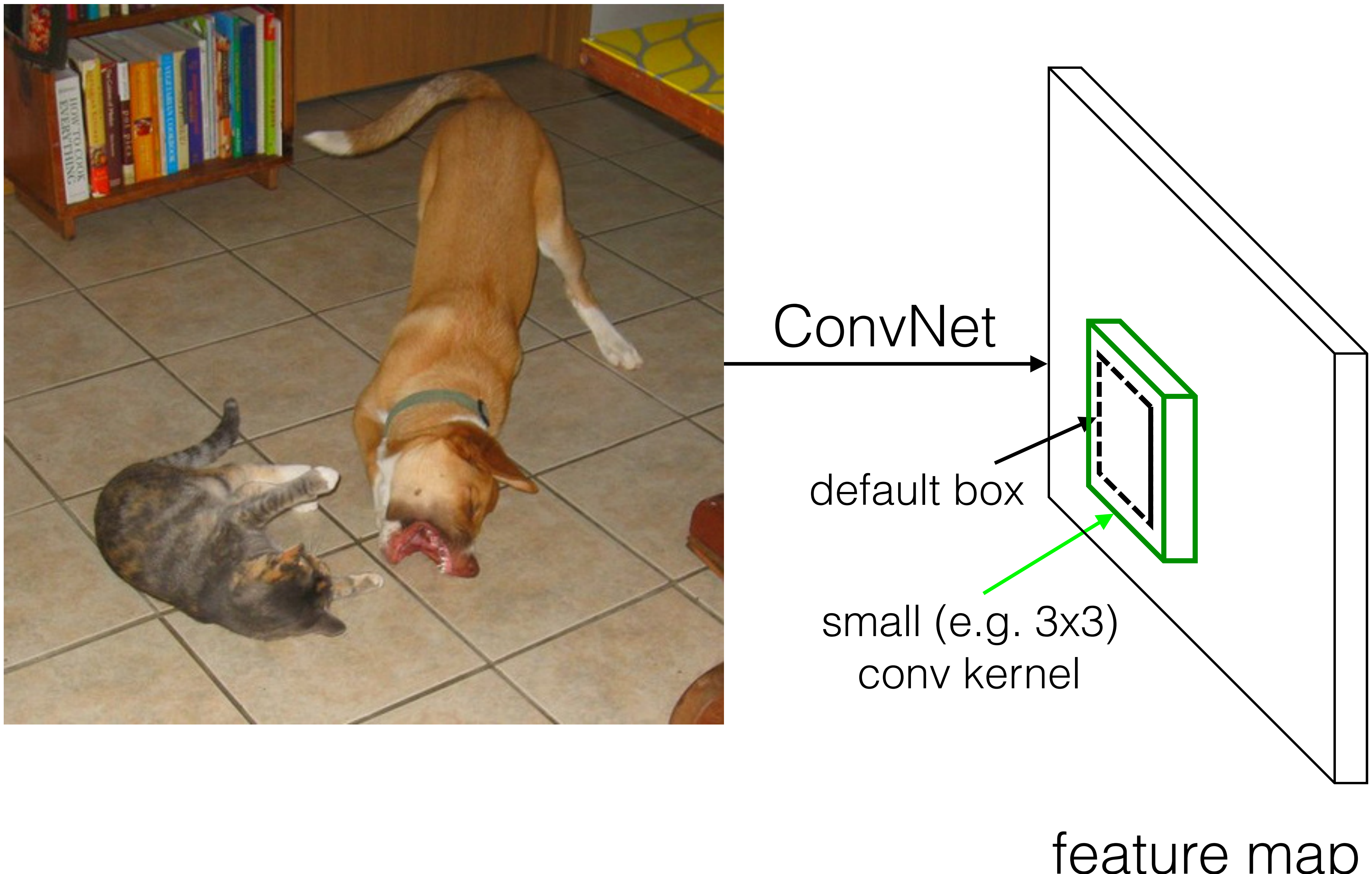

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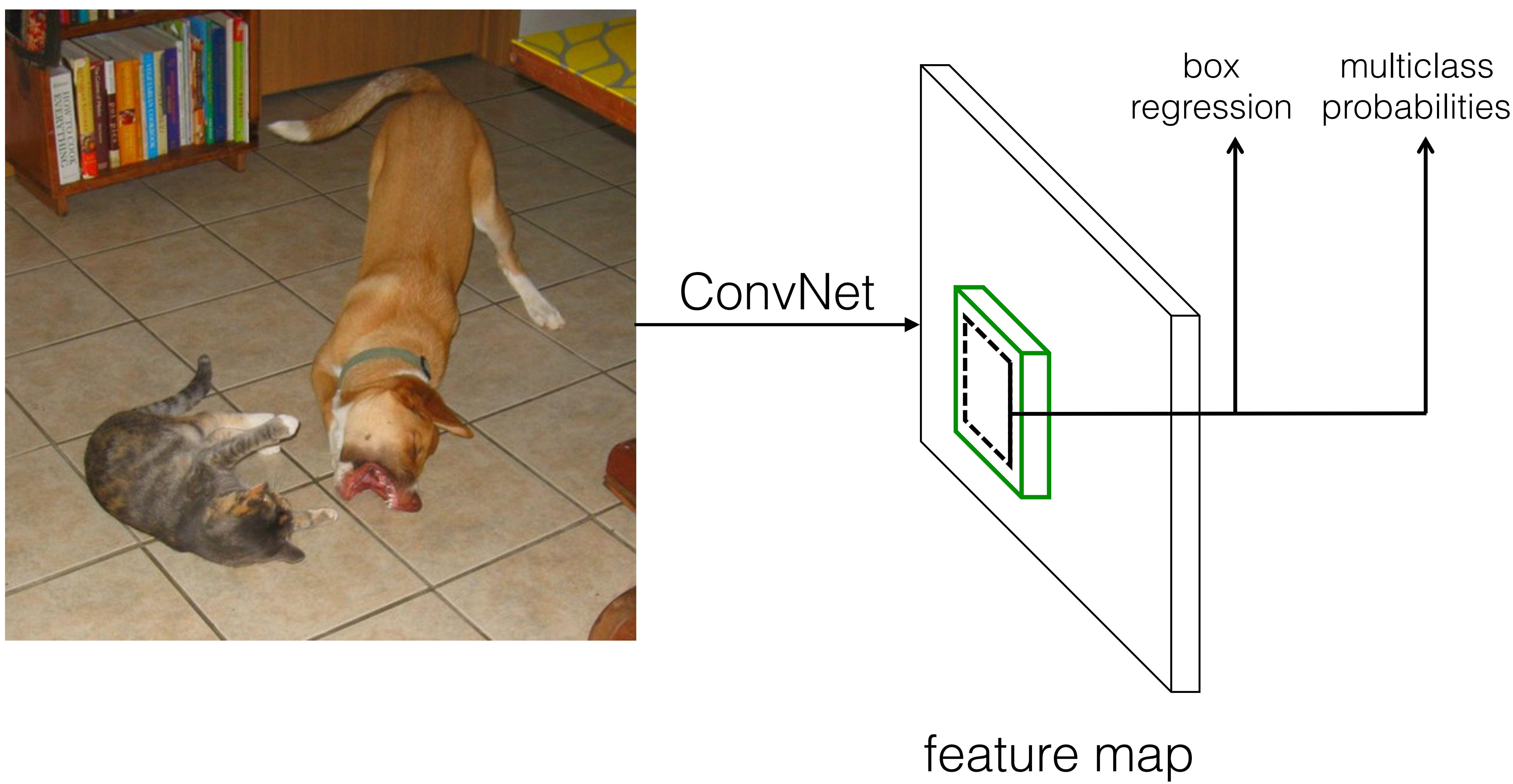
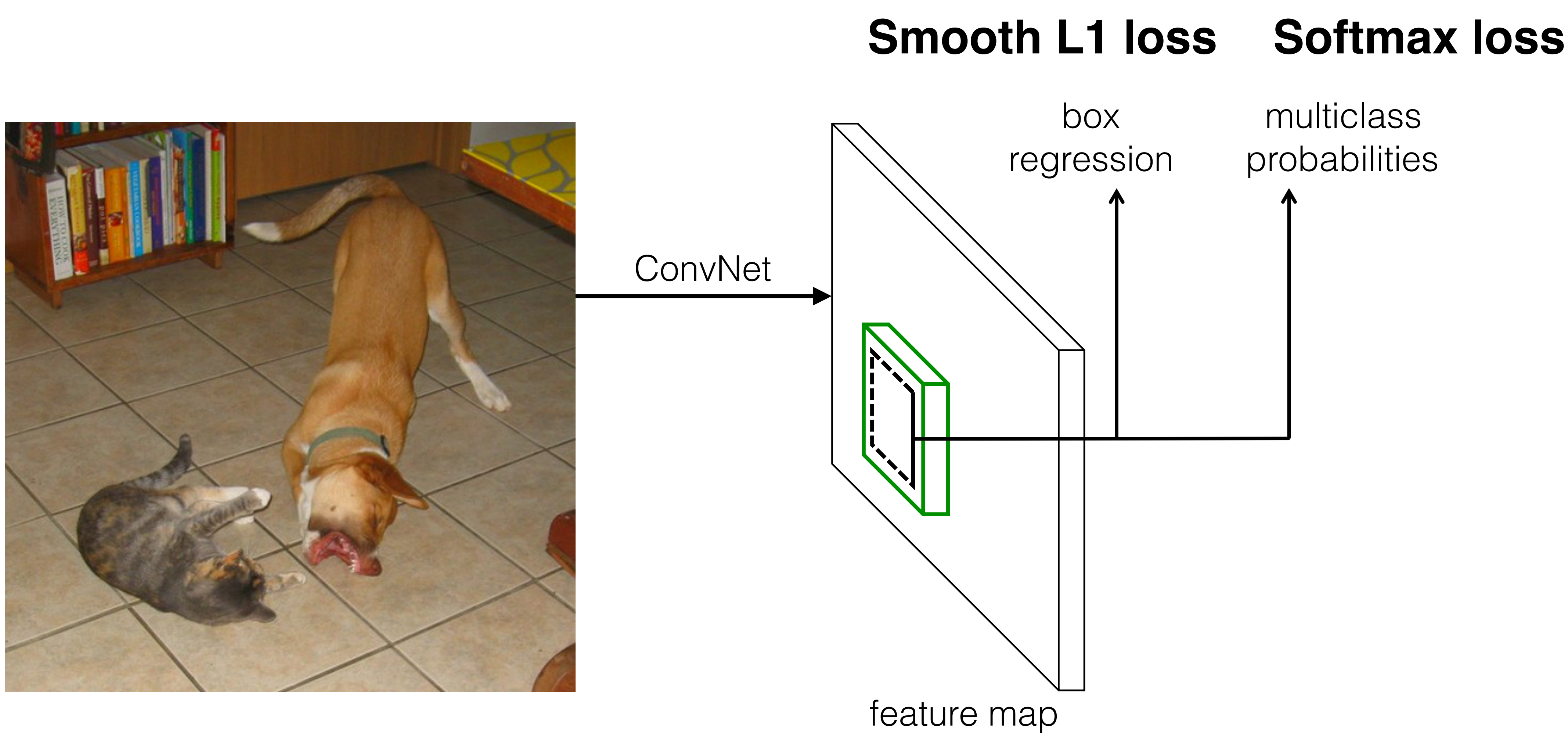


SSD Training

- Match default boxes to ground truth boxes to determine true/false positives.

- Loss = **SmoothL1**(box param) + **Softmax**(class prob)



Related Work

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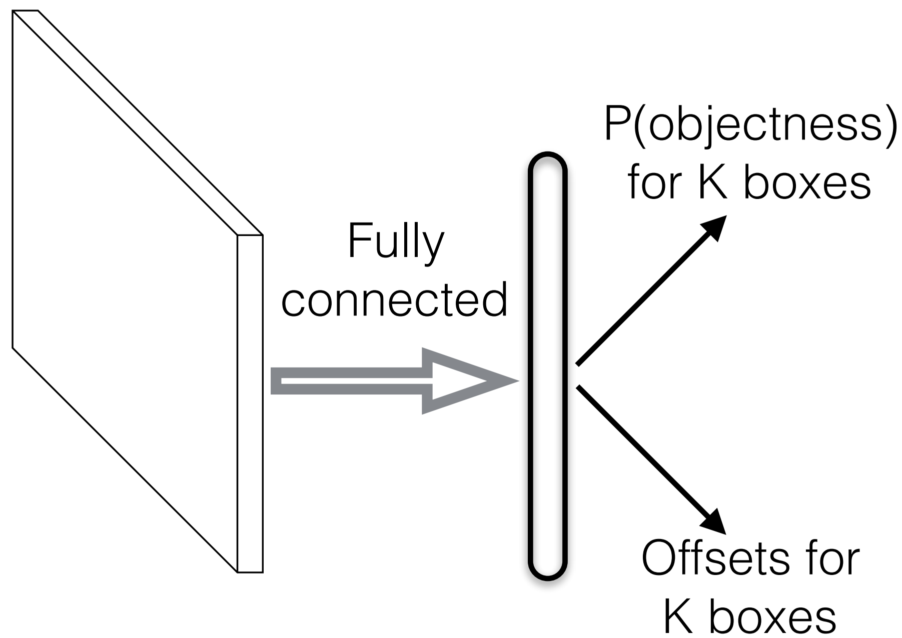
MultiBox [Erhan et al. CVPR14]



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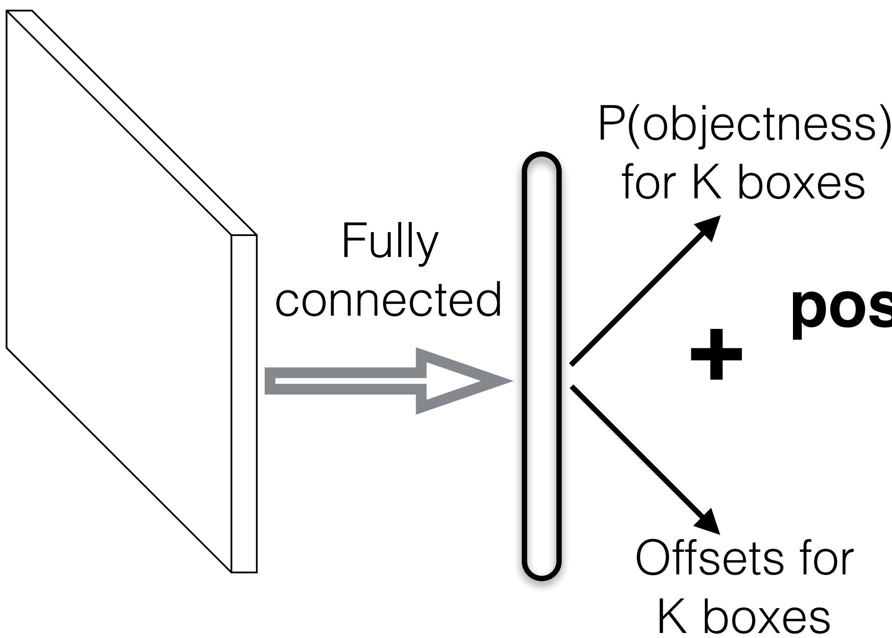

+ post classify boxes

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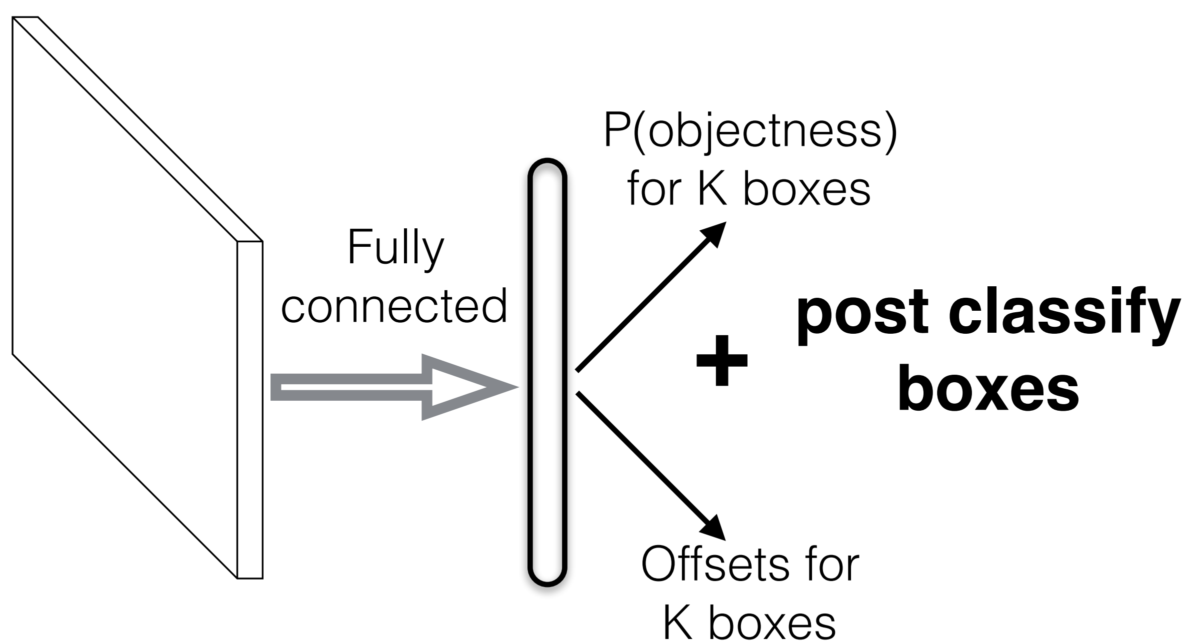
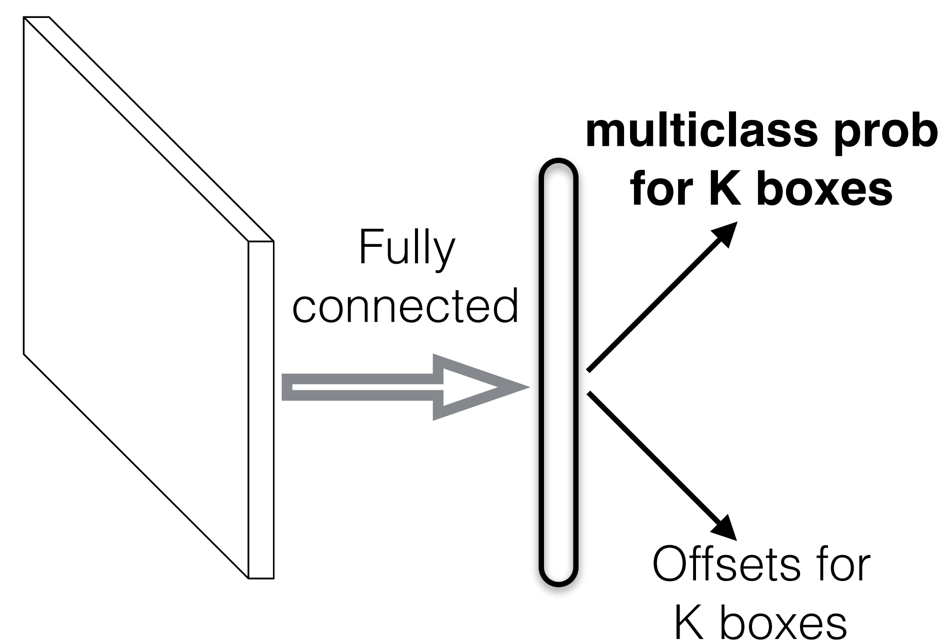


YOLO [Redmon et al. CVPR16]



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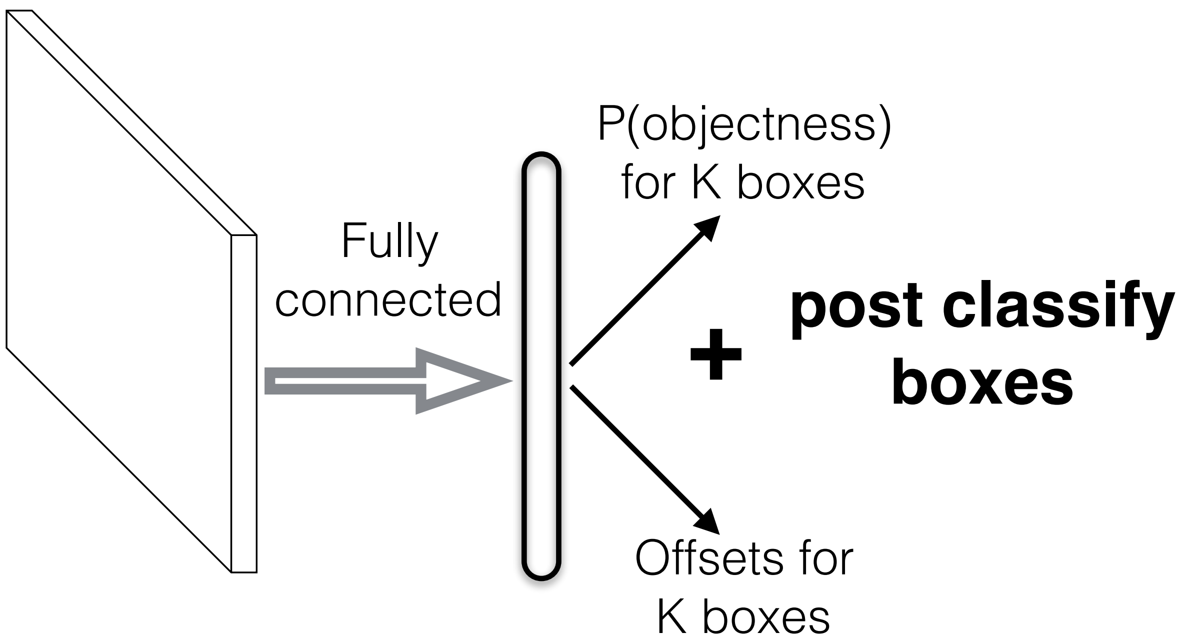

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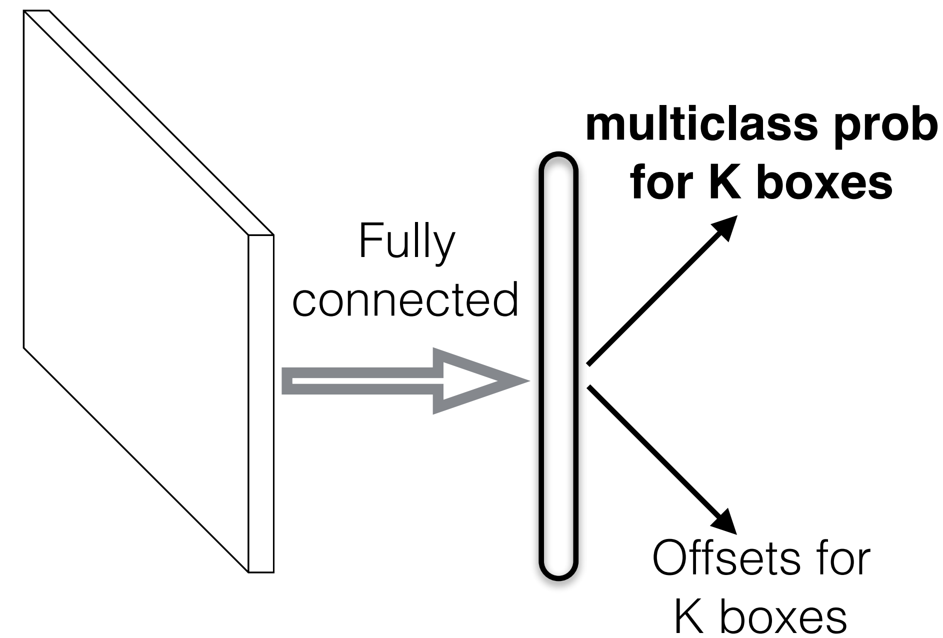
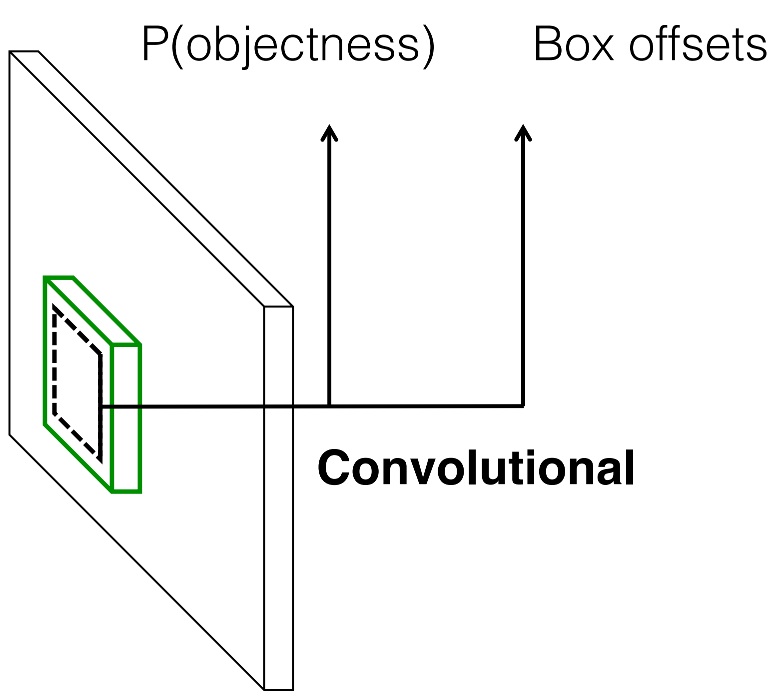


Faster R-CNN [Ren et al. NIPS15]



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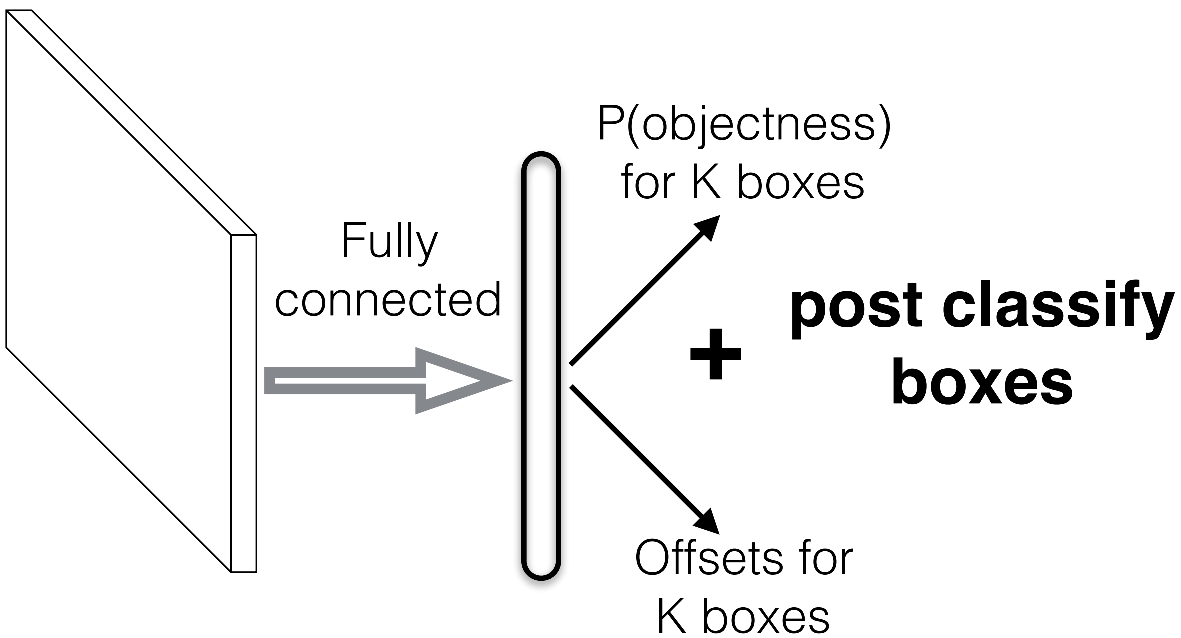

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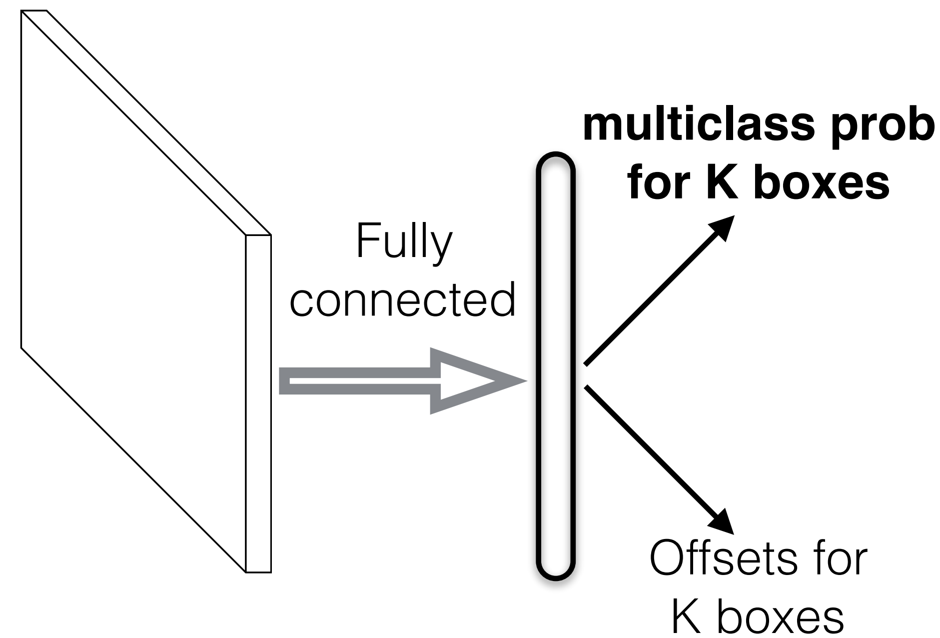

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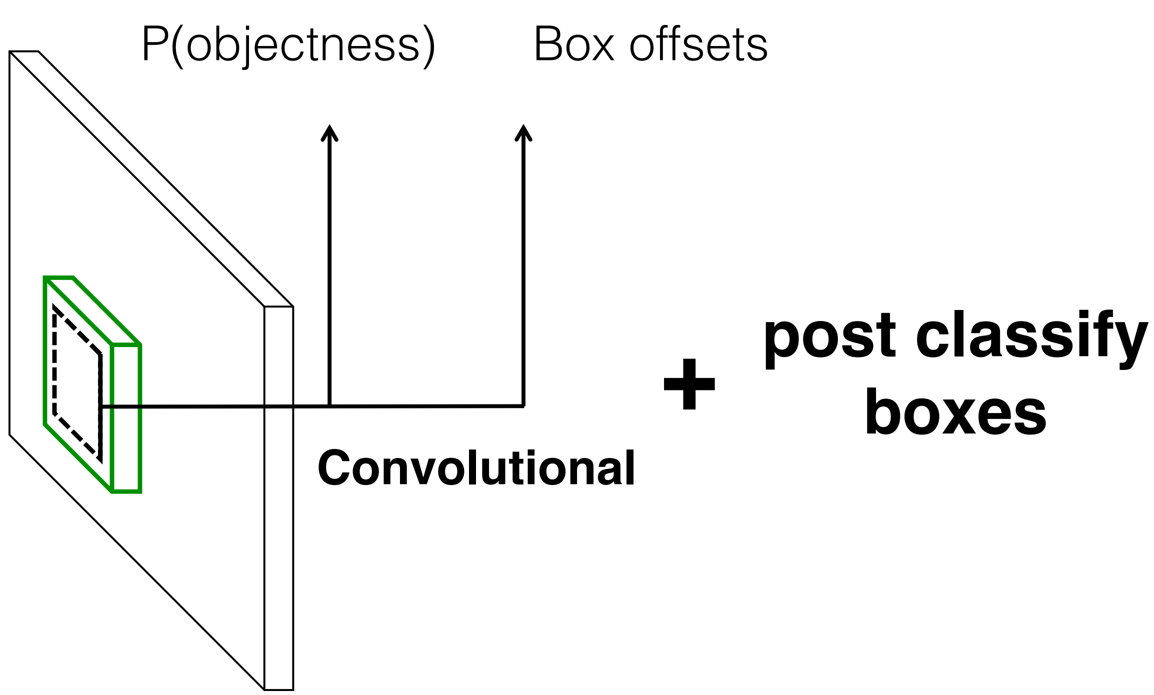

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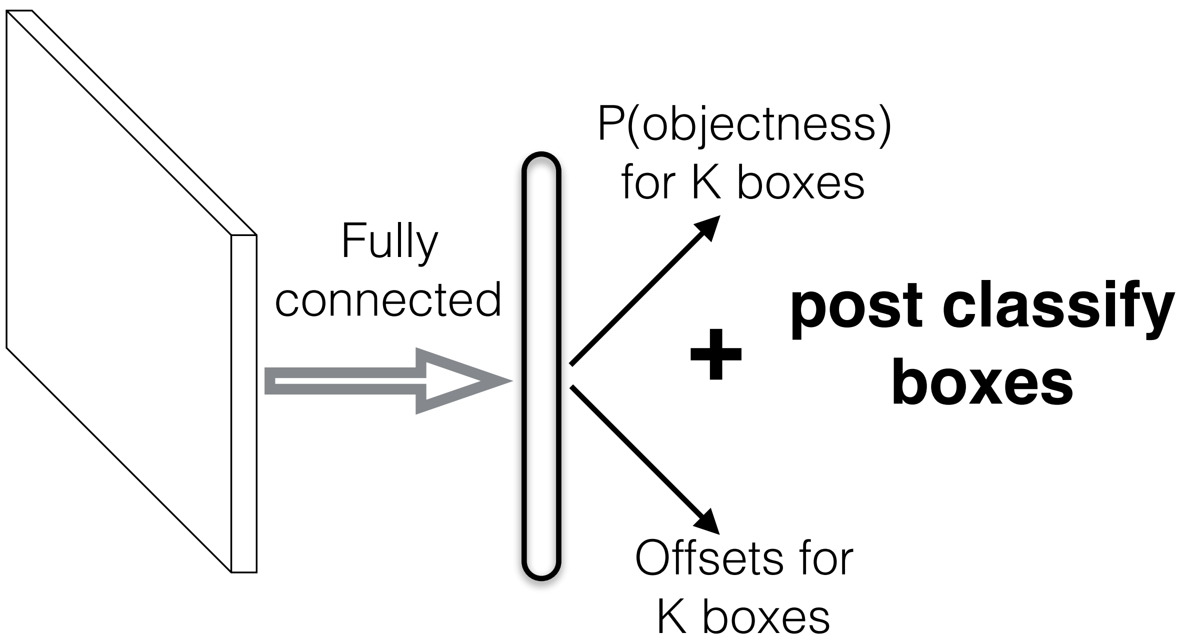

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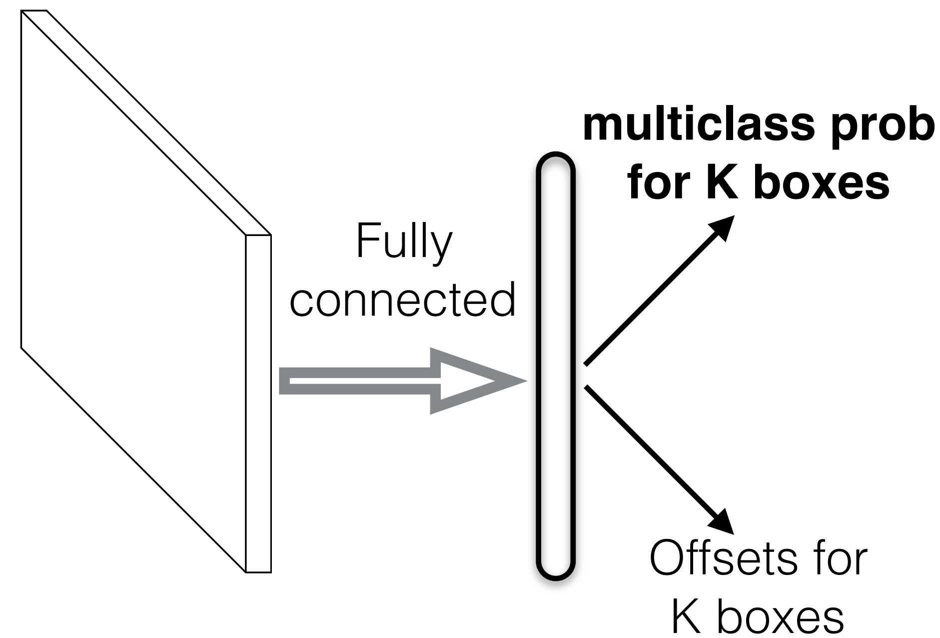

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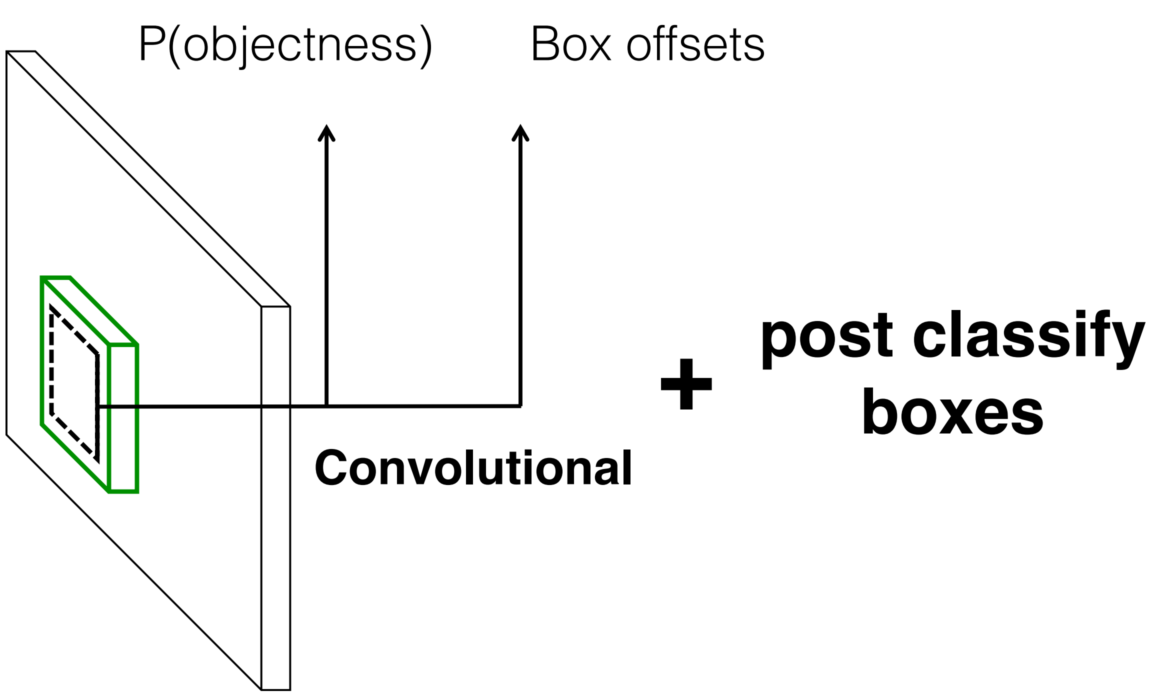
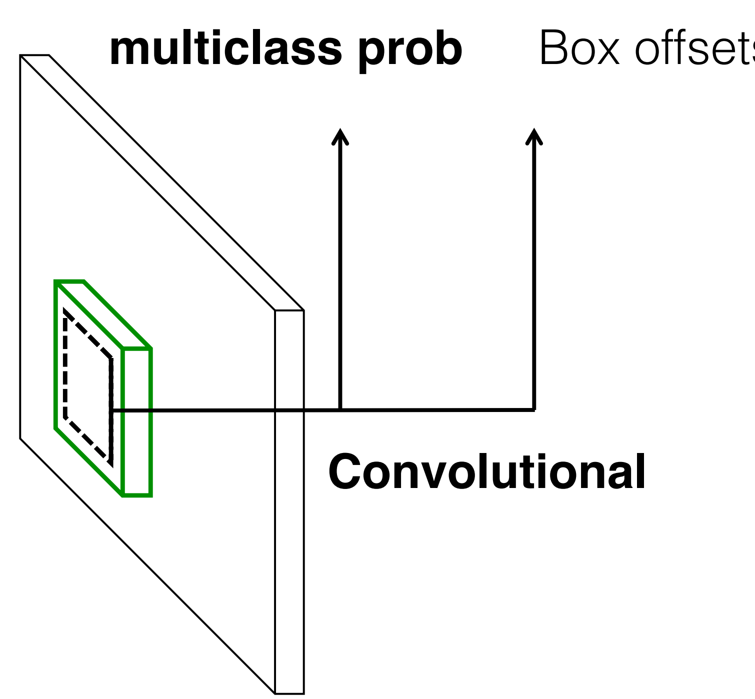
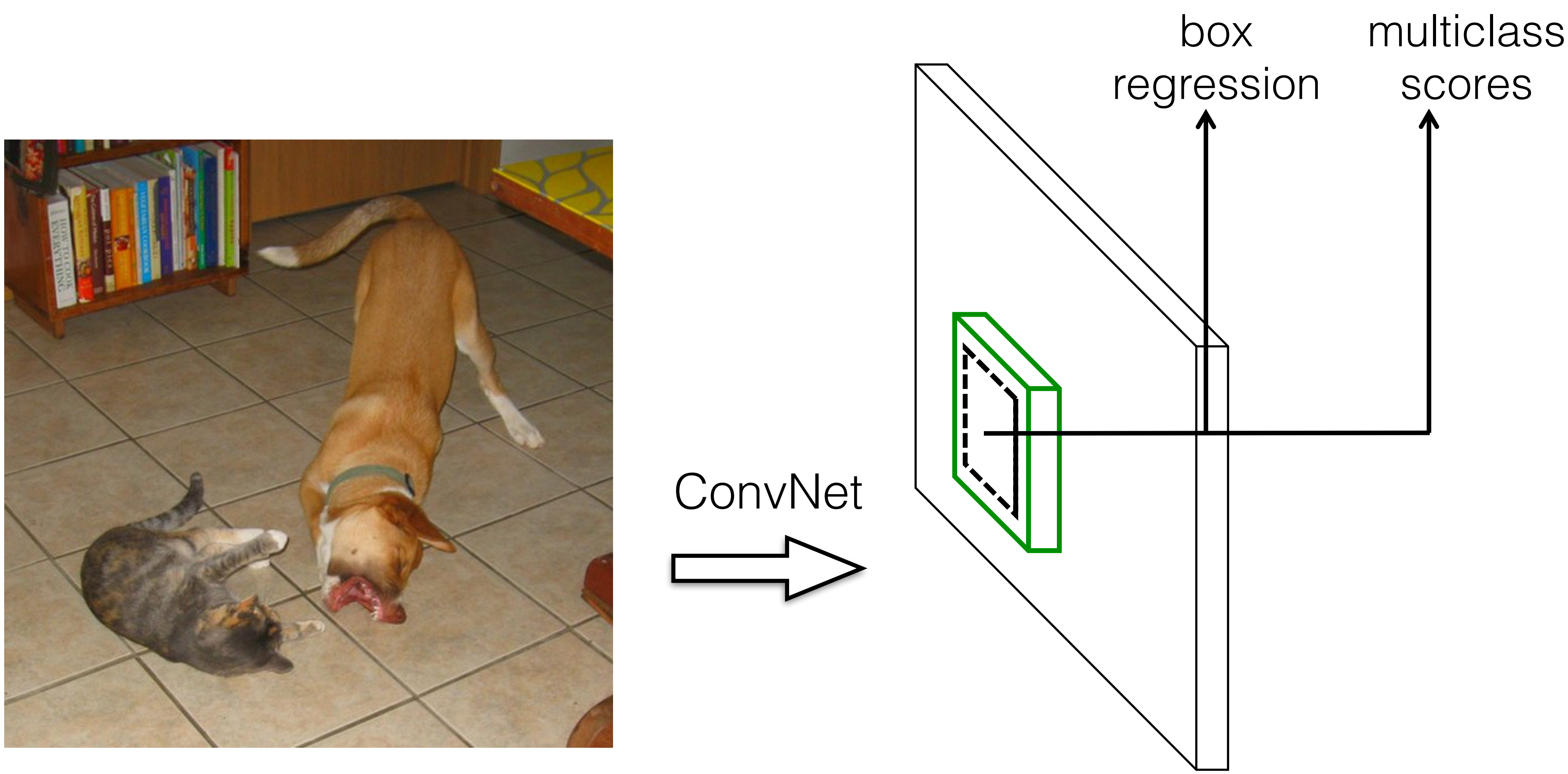


SSD



Contribution #1: Multi-Scale Feature Maps



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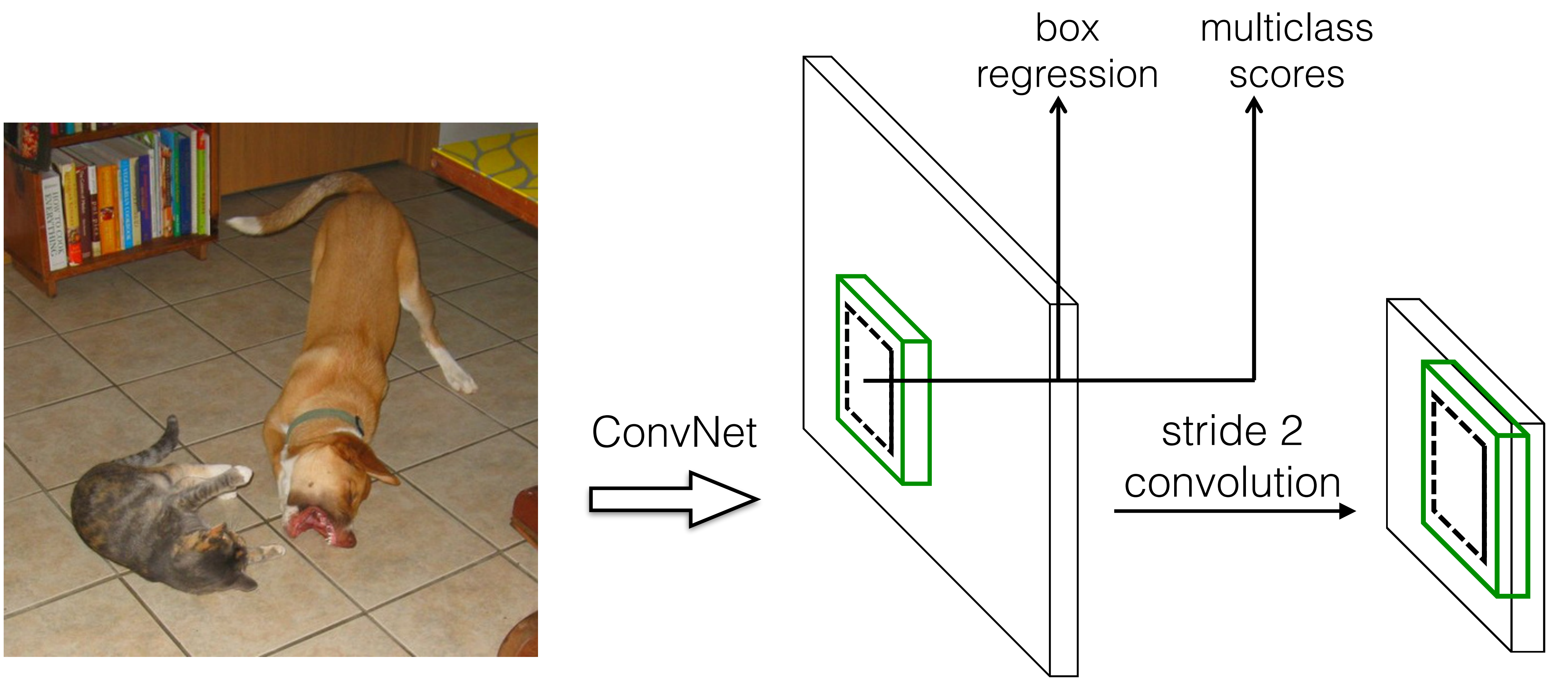

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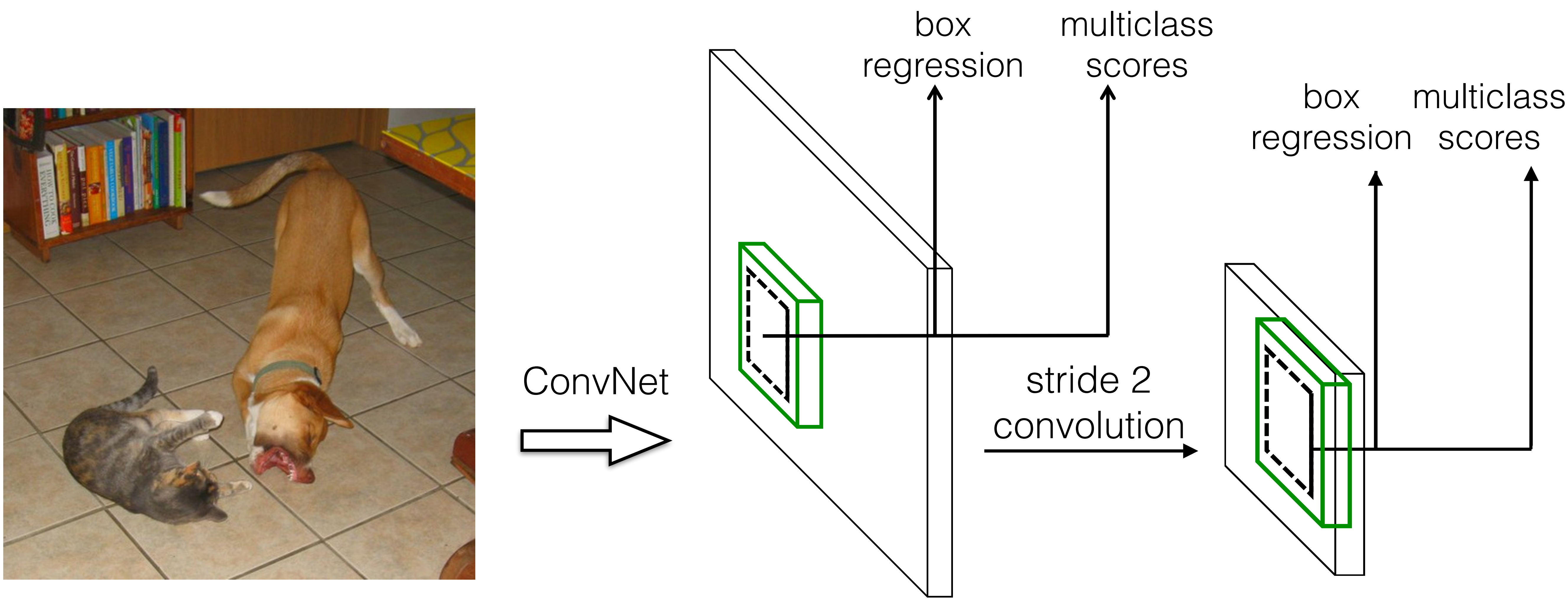
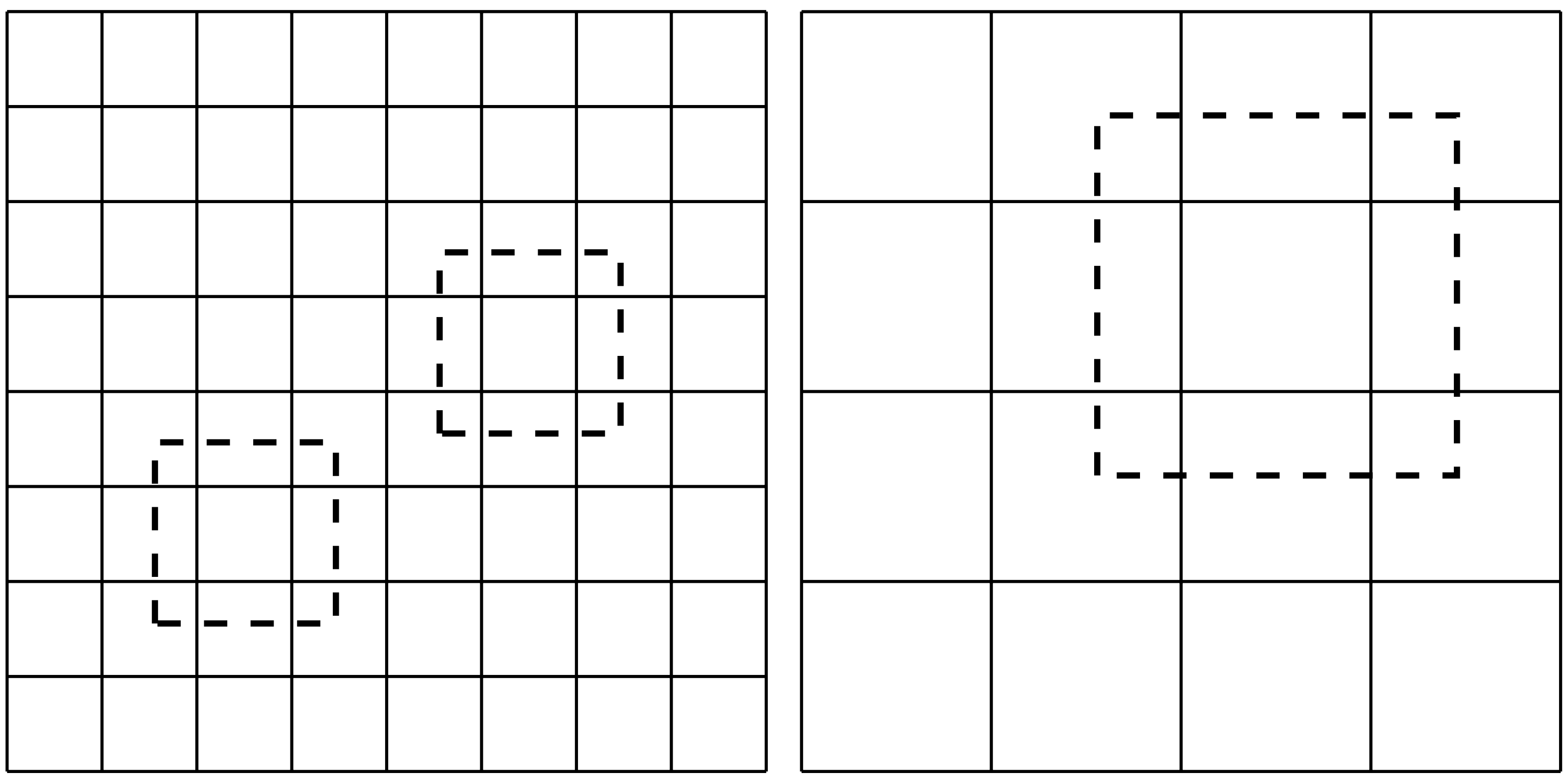


Multi-Scale Feature Maps

SSD



8×8 feature map $\quad$ 4×4 feature map

Multi-Scale Feature Maps

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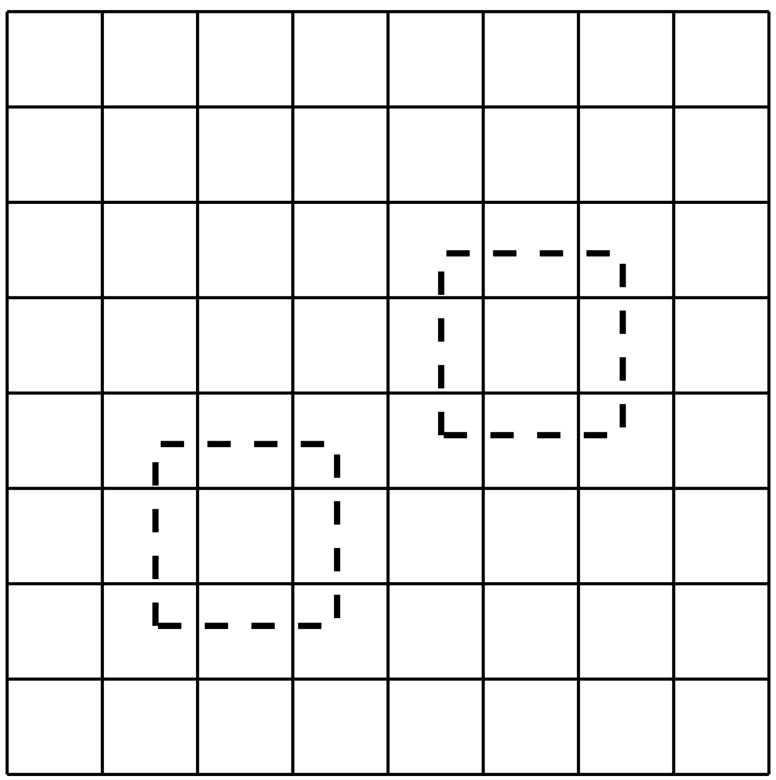

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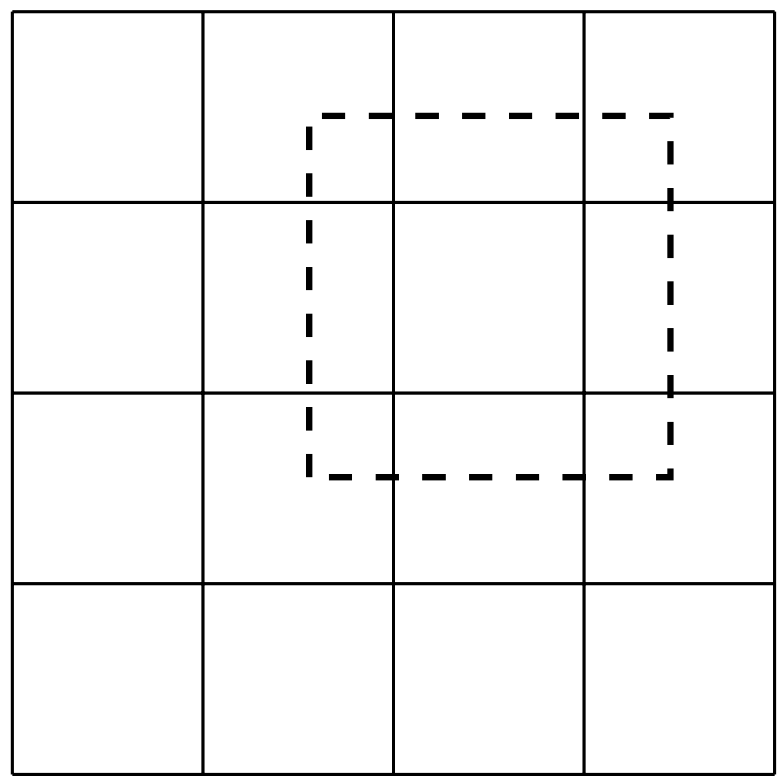
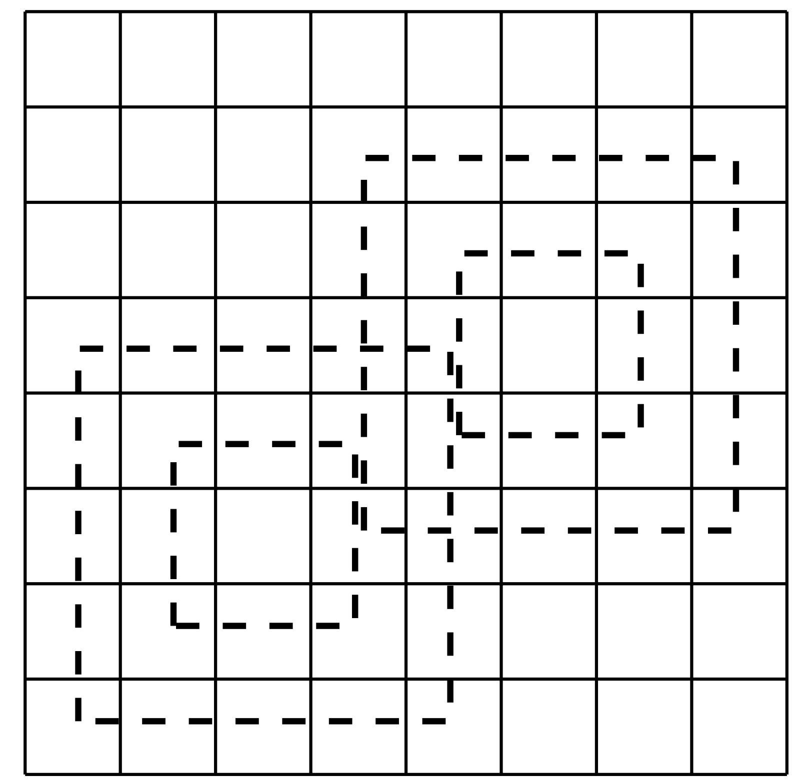


4×4 feature map

vs.

Faster R-CNN Objectness Proposal, Ren 2015



8×8 feature map

Multi-Scale Feature Maps Experiment

Prediction source layers from:						mAP use boundary boxes?		# Boxes
38×38	19×19	10×10	5×5	3×3	1×1	Yes	No	
✔	✔	✔	✔	✔	✔	74.3	63.4	8732
✔	✔	✔				70.7	69.2	9864
	✔					62.4	64.0	8664

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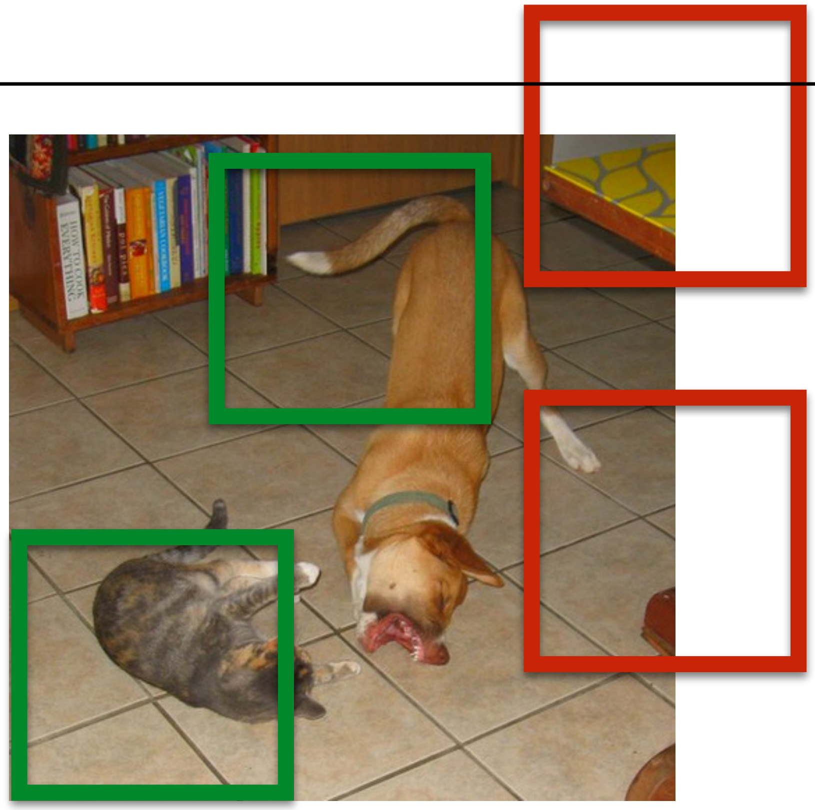

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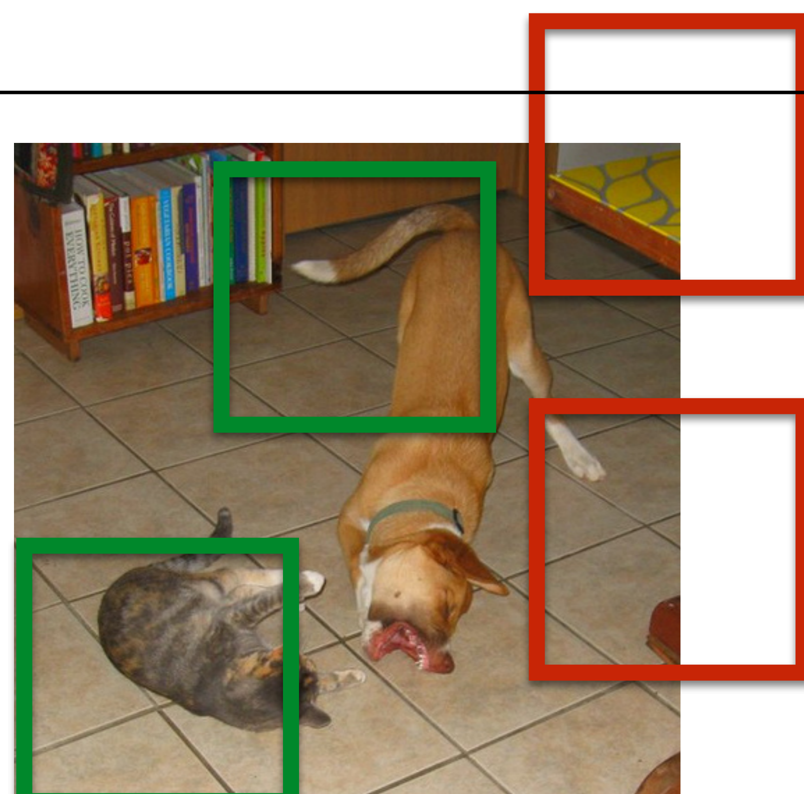

boundary boxes

Multi-Scale Feature Maps Experiment

Prediction source layers from:						mAP use boundary boxes?		# Boxes
38×38	19×19	10×10	5×5	3×3	1×1	Yes	No	
✔	✔	✔	✔	✔	✔	74.3	63.4	8732
✔	✔	✔				70.7	69.2	9864
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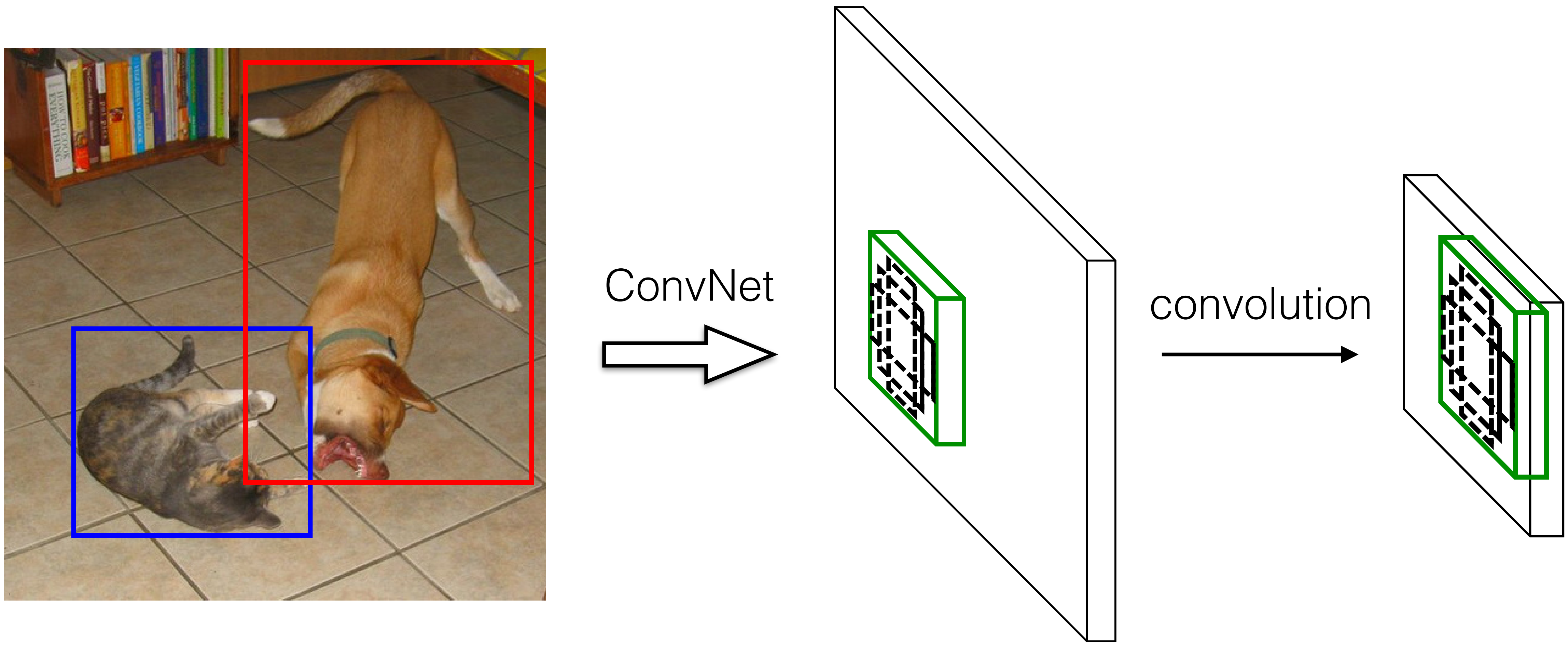
Contribution #2: Splitting the Region Space



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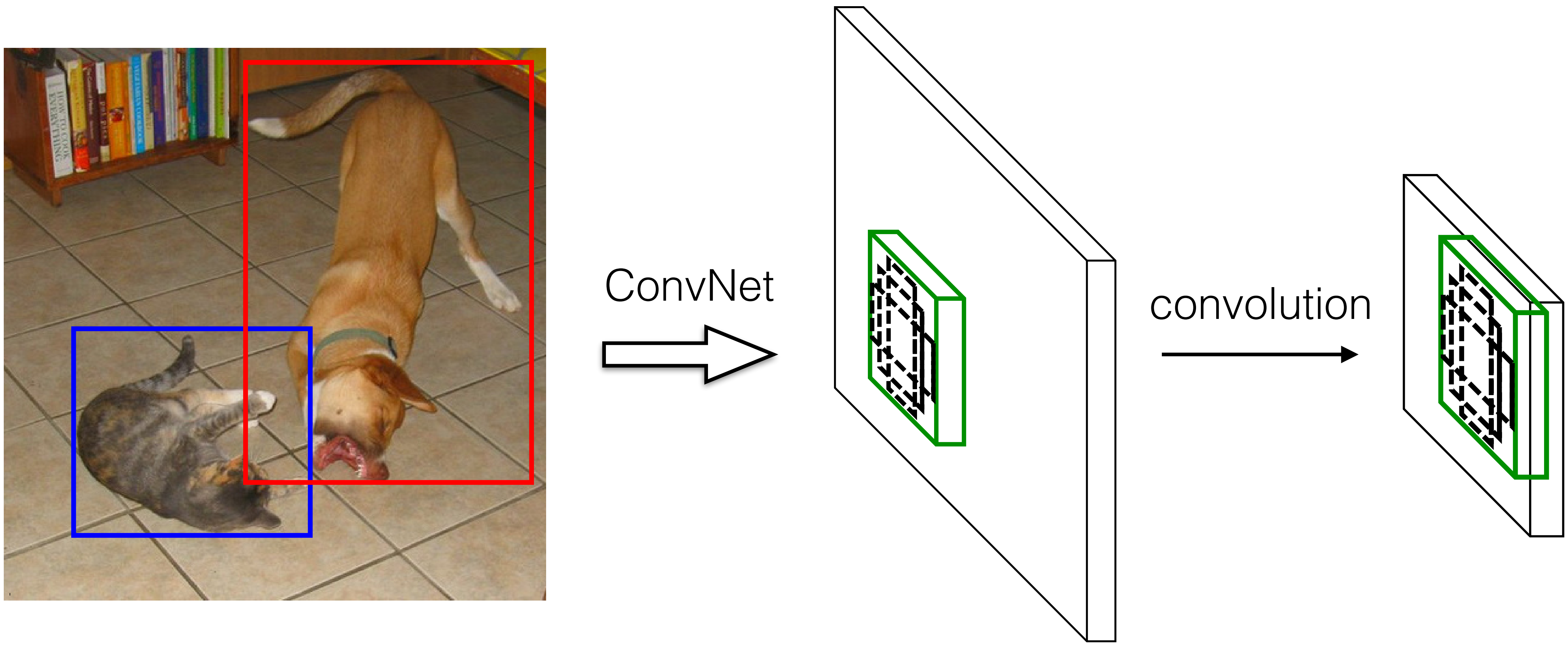
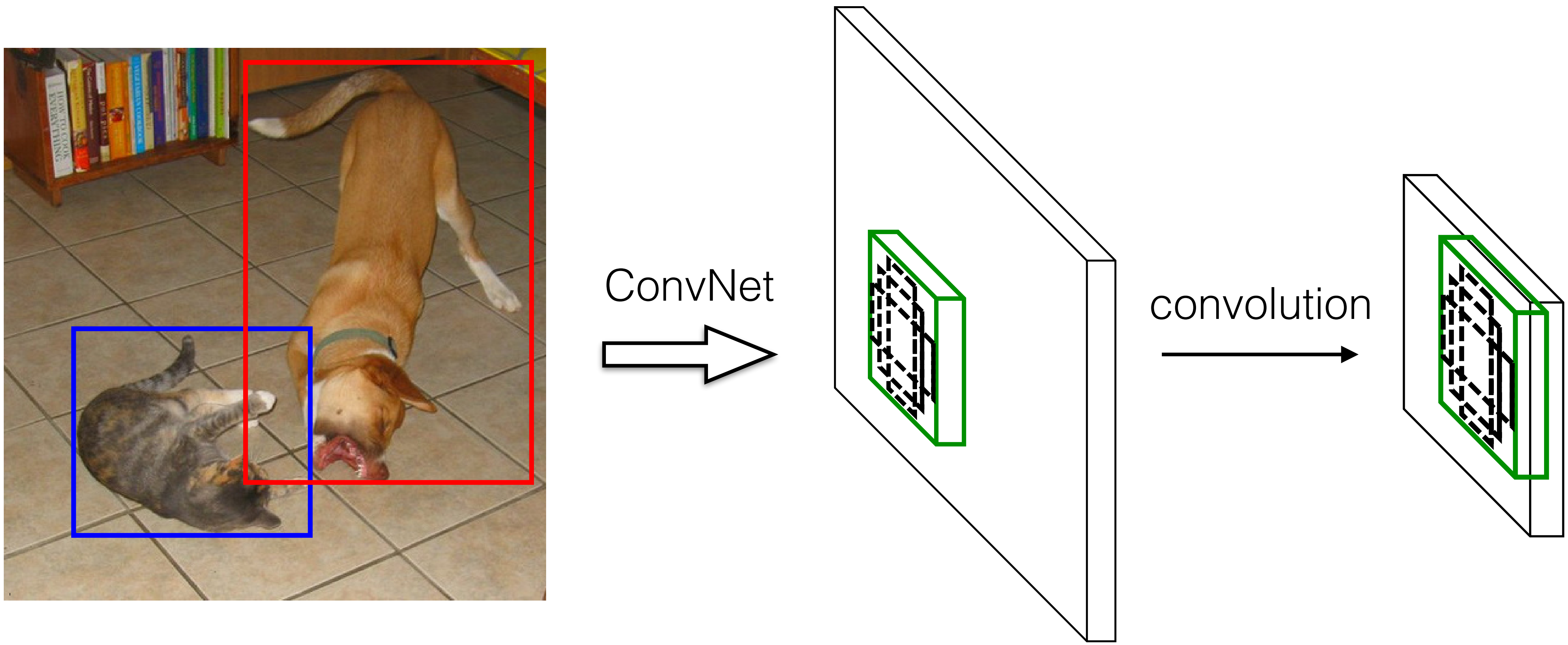


	SSD300		
include $\{\frac{1}{2}, 2\}$ box?		✔	✔
include $\{\frac{1}{3}, 3\}$ box?			✔
number of Boxes	3880	7760	**8732**
VOC2007 `test` mAP	71.6	73.7	**74.3**

Contribution #2: Splitting the Region Space



Use 38x38 feature map : **+2.5 mAP**
(conv4_3)

Why So Many Default Boxes?

	Faster R-CNN	YOLO	SSD300	SSD512
# Default Boxes	6000	98	8732	24564
Resolution	1000x600	448x448	300x300	512x512

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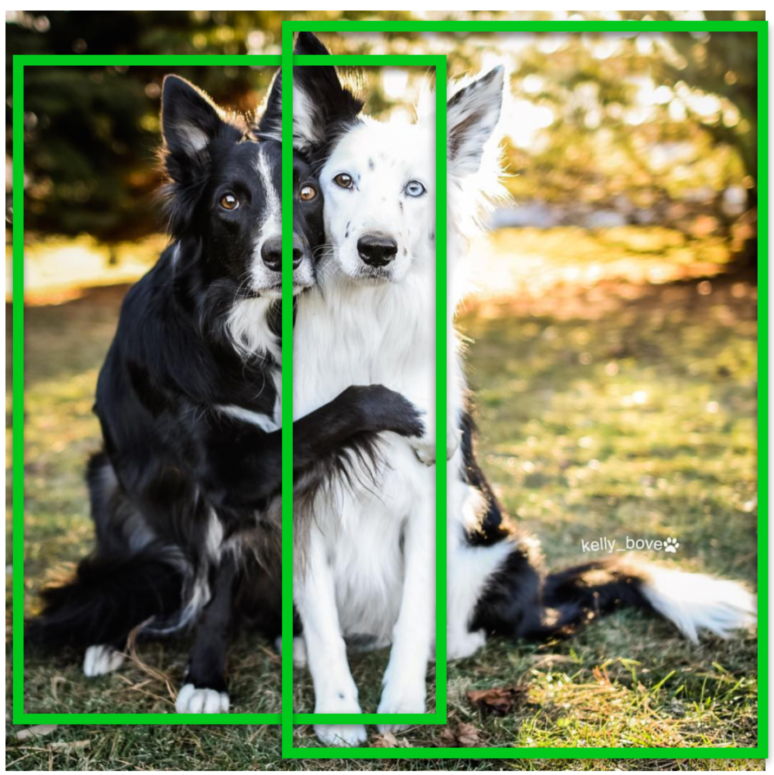
GT



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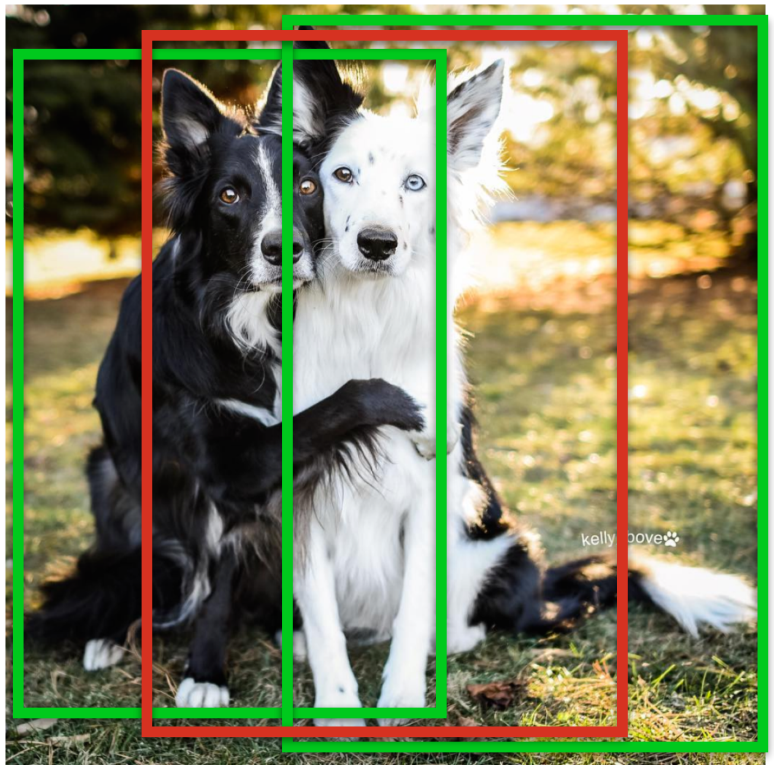
GT DETECTION



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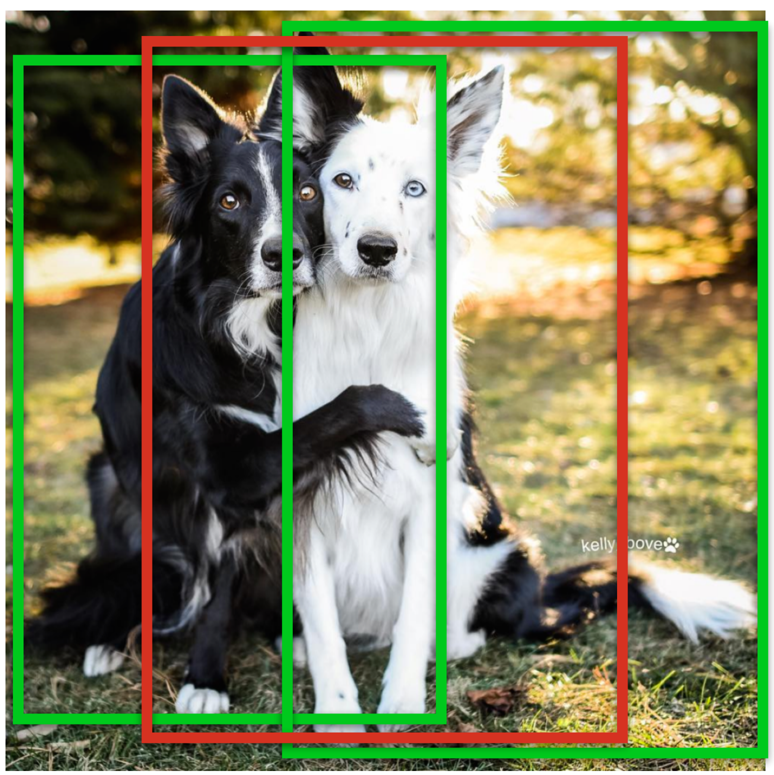

- SmoothL1 or L2 loss for box shape averages among likely hypotheses

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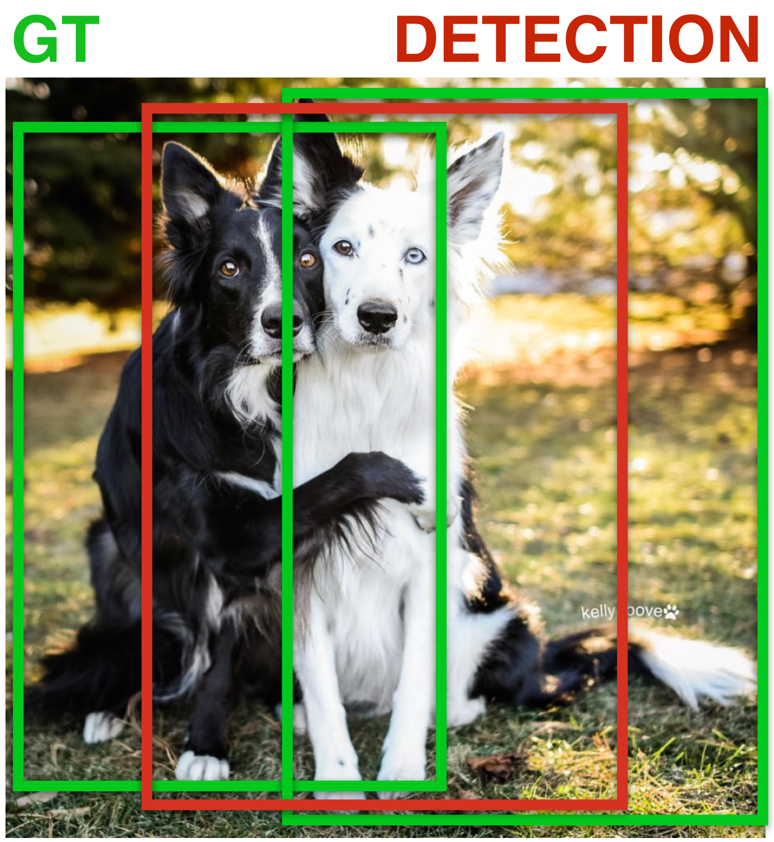

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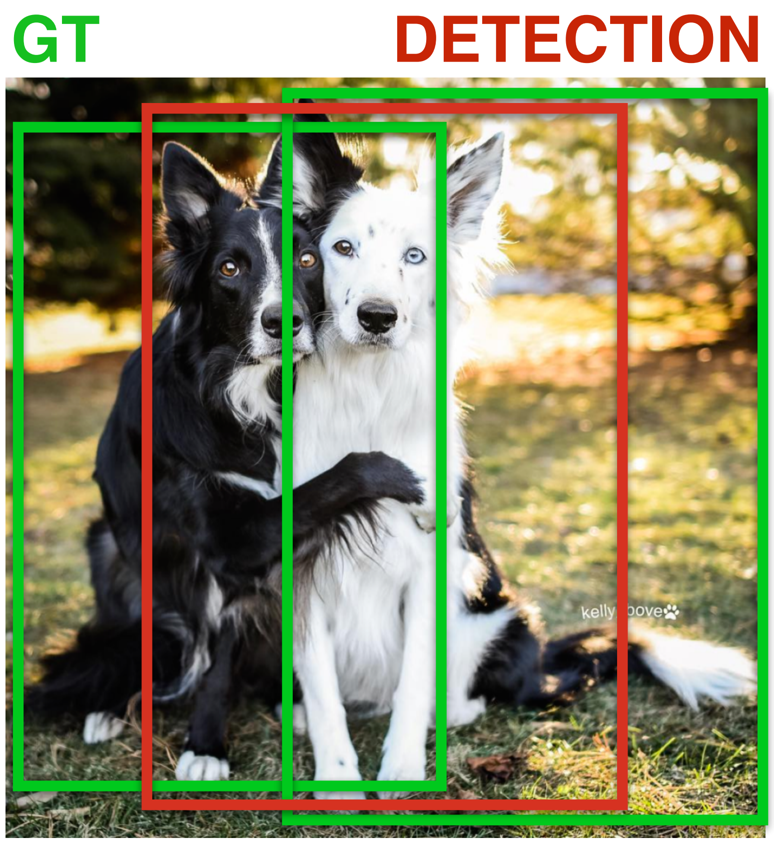


- SmoothL1 or L2 loss for box shape averages among likely hypotheses
- Need to have enough default boxes (discrete bins) to do accurate regression in each
- General principle for regressing complex continuous outputs with deep nets

Handling Many Default Boxes

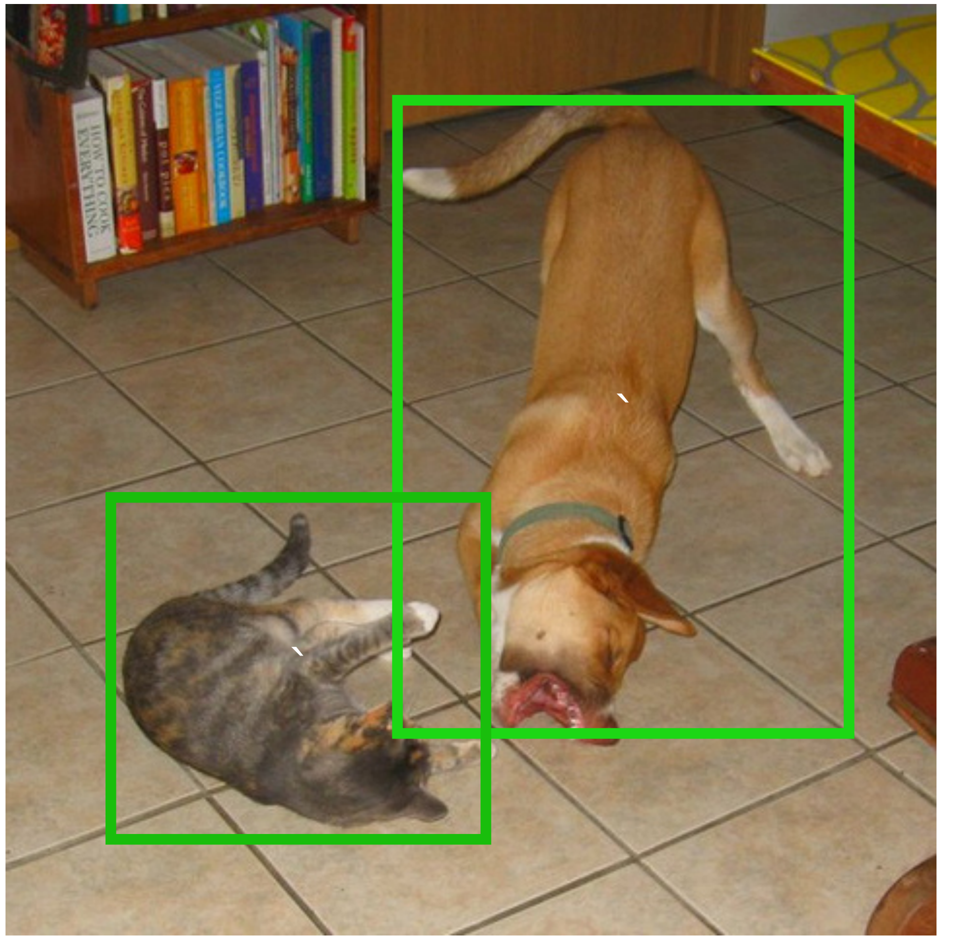
Handling Many Default Boxes

- Matching ground truth and default boxes

Handling Many Default Boxes

- Matching ground truth and default boxes

GT



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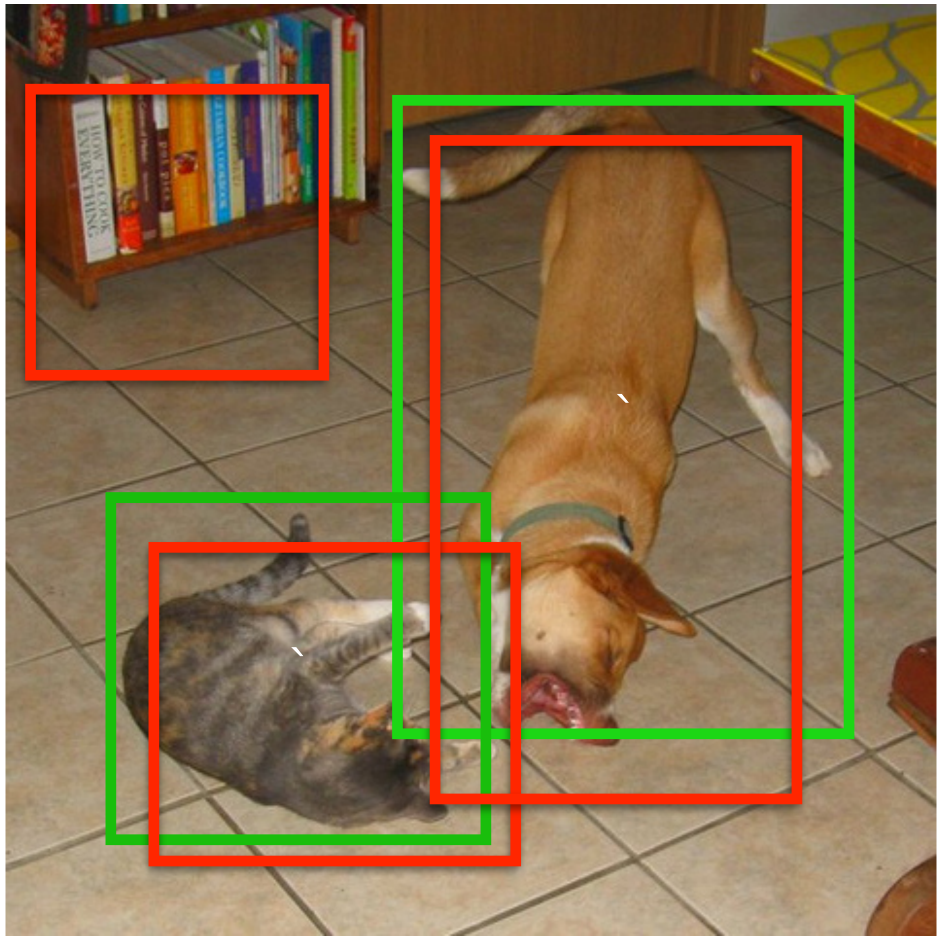
- Matching ground truth and default boxes

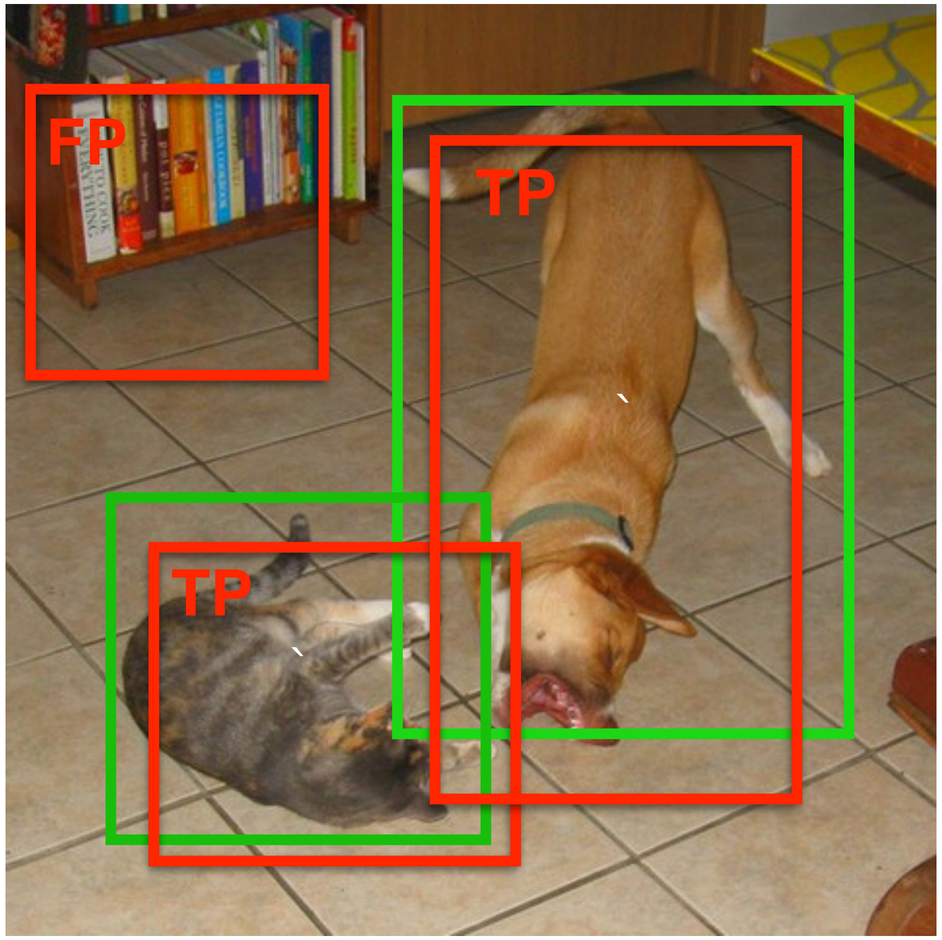


Handling Many Default Boxes

- Matching ground truth and default boxes

GT

Default box



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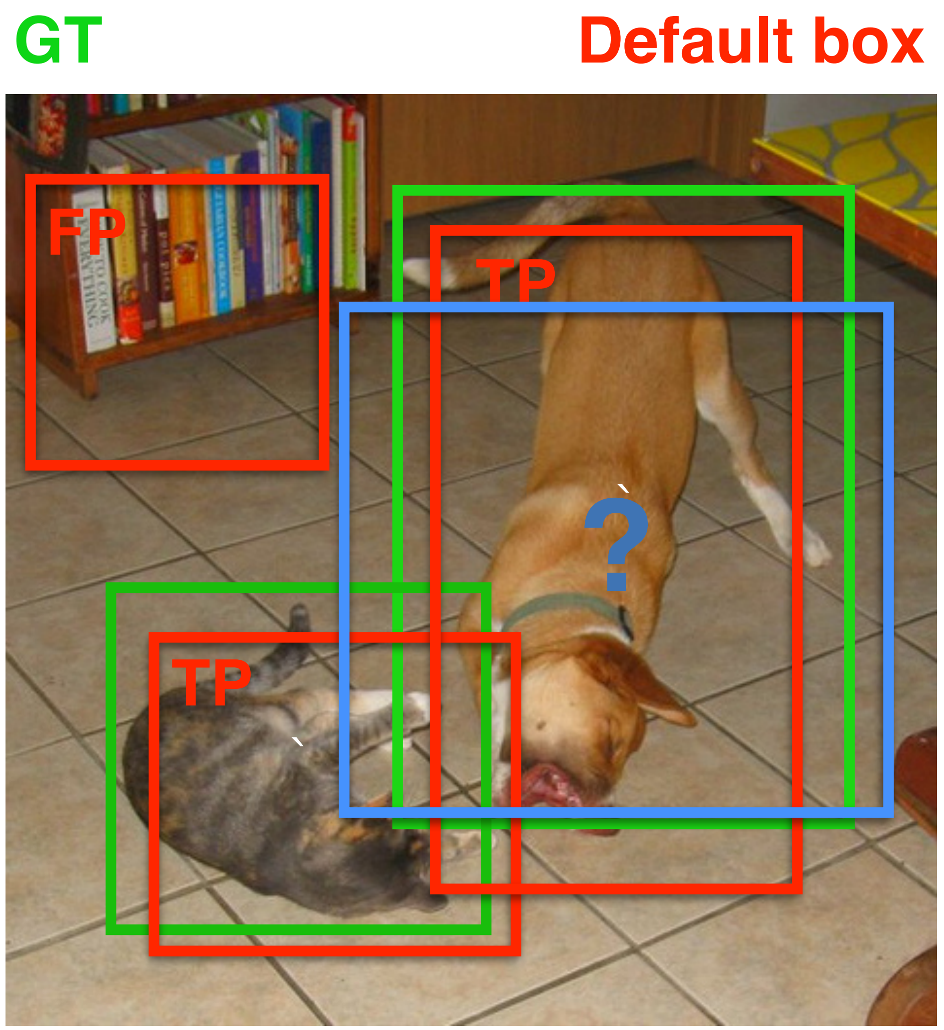
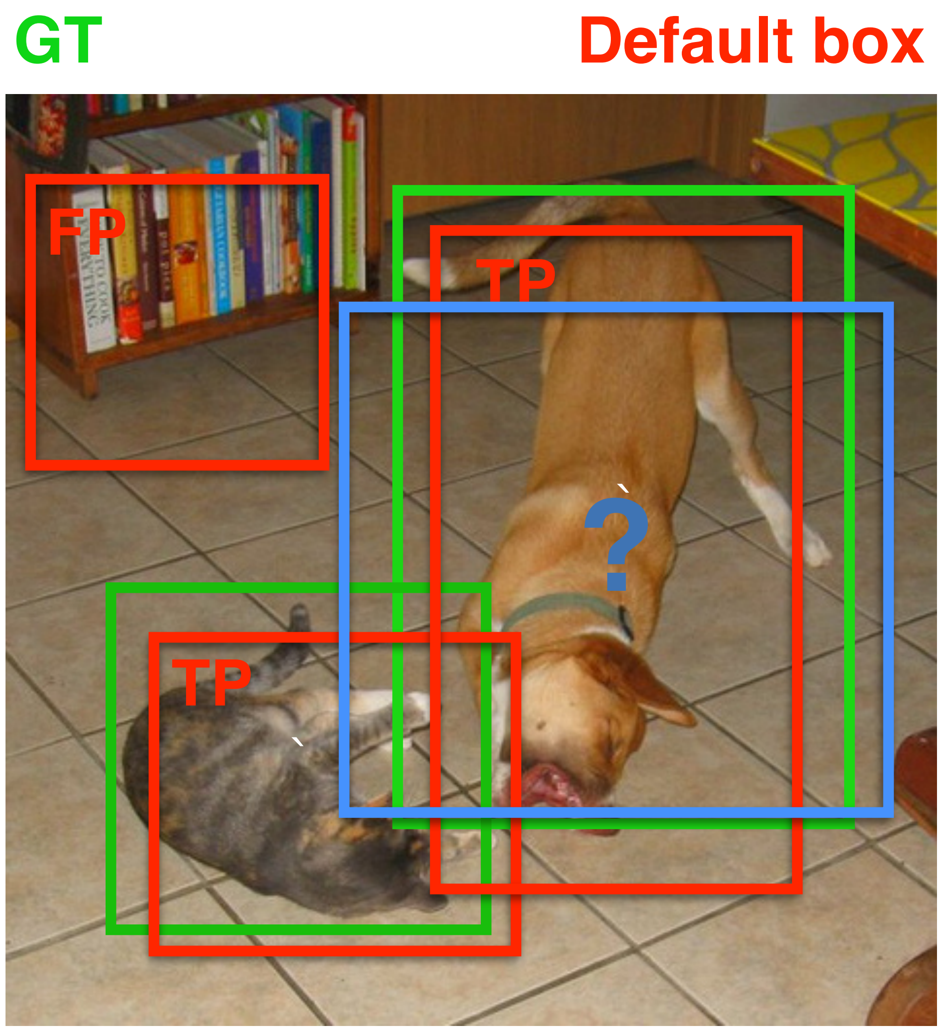


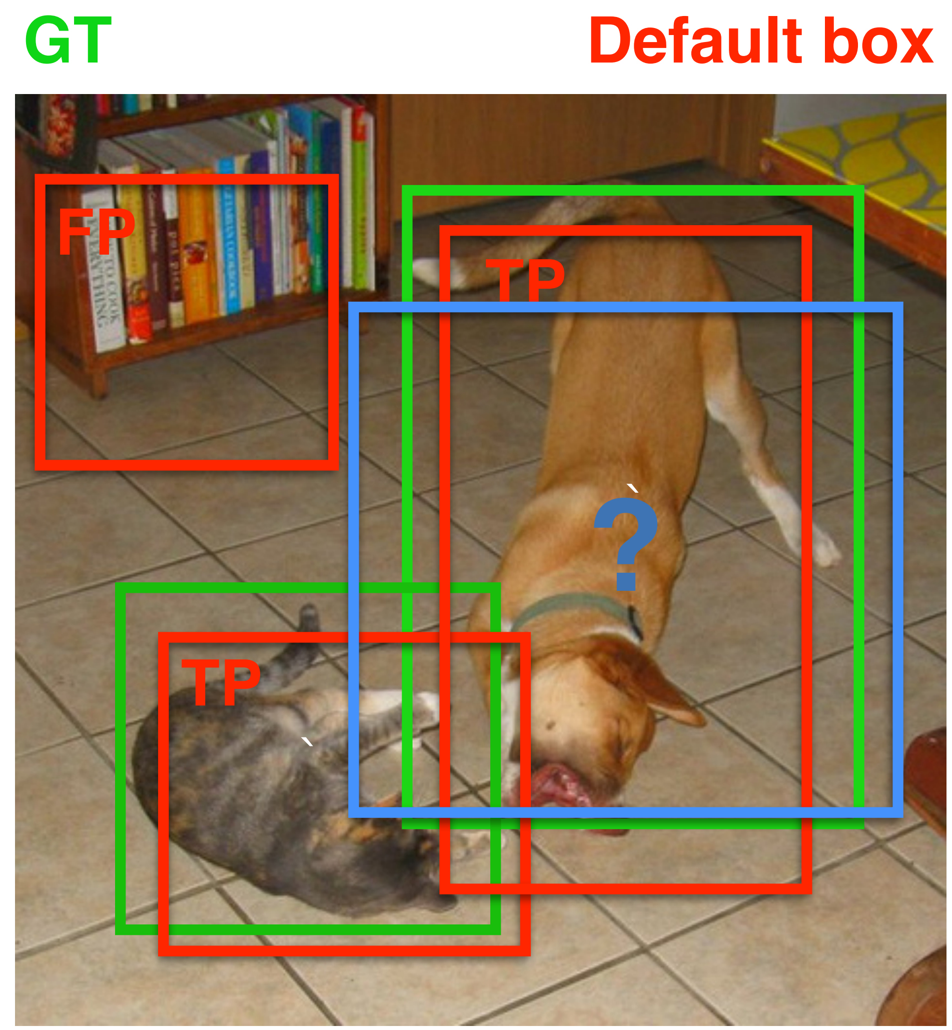
Handling Many Default Boxes

- Matching ground truth and default boxes
  - Match each GT box to closest default box



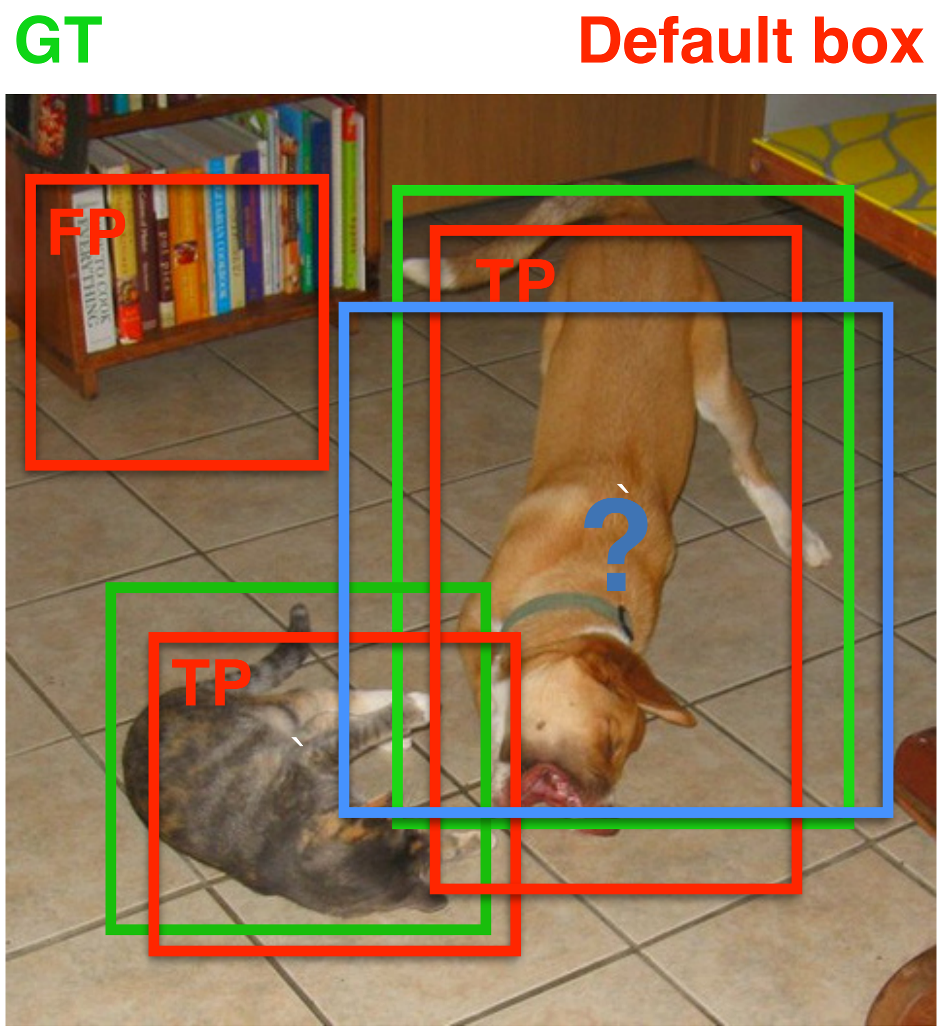
Handling Many Default Boxes

- Matching ground truth and default boxes
  - Match each GT box to closest default box
  - Also match each GT box to all unassigned default boxes with IoU > 0.5



Handling Many Default Boxes

- Matching ground truth and default boxes
  - Match each GT box to closest default box
  - Also match each GT box to all unassigned default boxes with IoU > 0.5
- Hard negative mining



Handling Many Default Boxes

- Matching ground truth and default boxes
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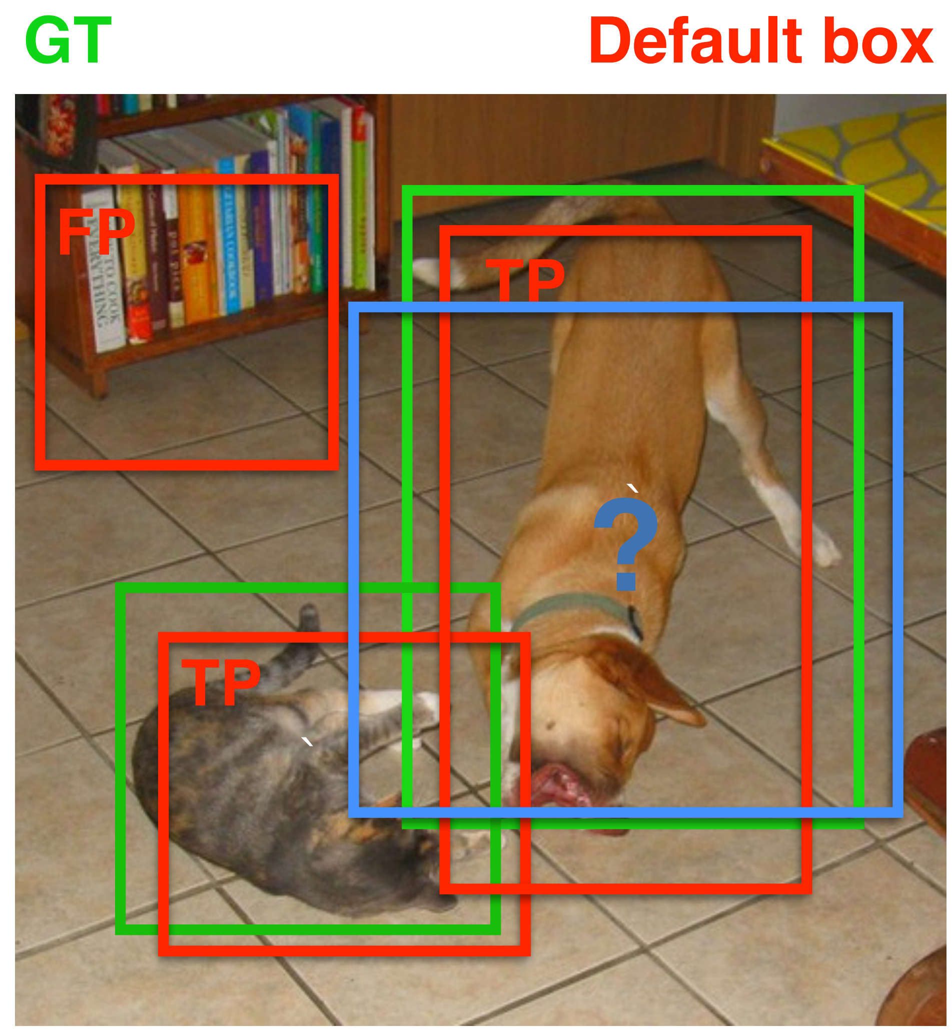
  - Also match each GT box to all unassigned default boxes with IoU > 0.5
- Hard negative mining
  - Unbalanced training: 1-30 TP, 8k-25k FP



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  - Also match each GT box to all unassigned default boxes with IoU > 0.5
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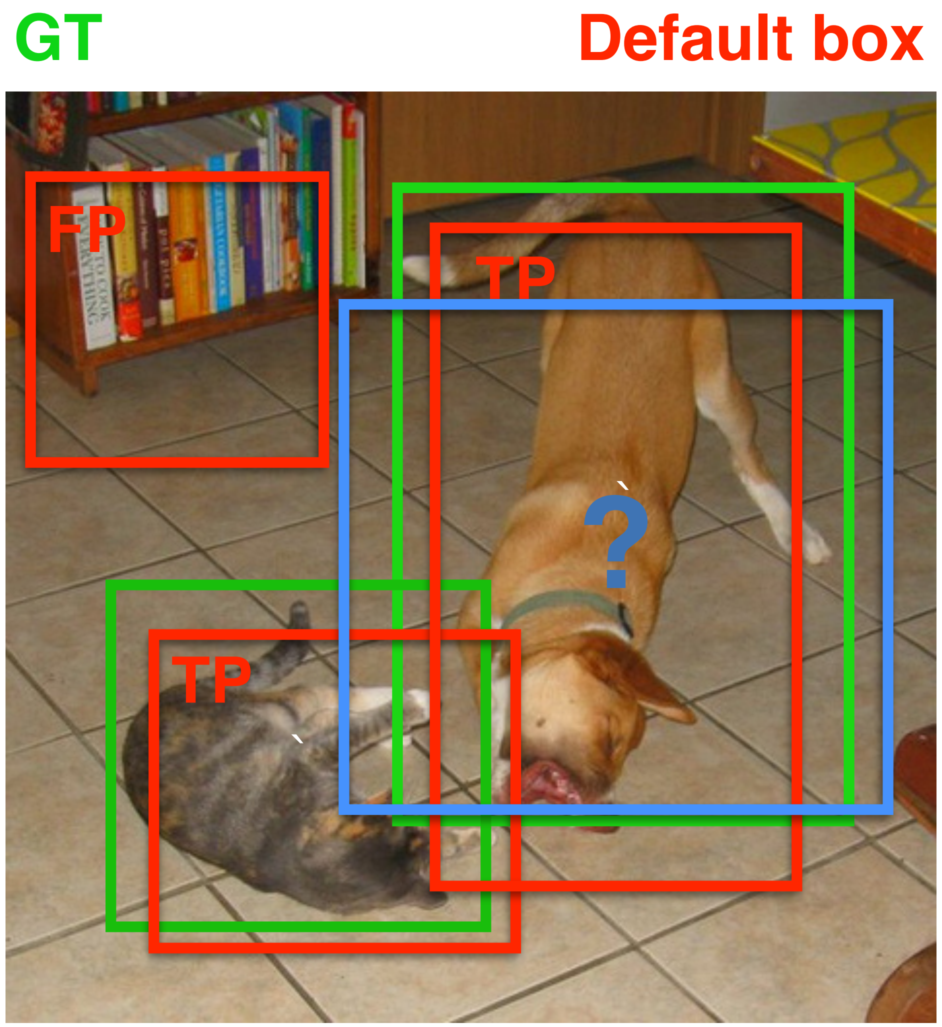
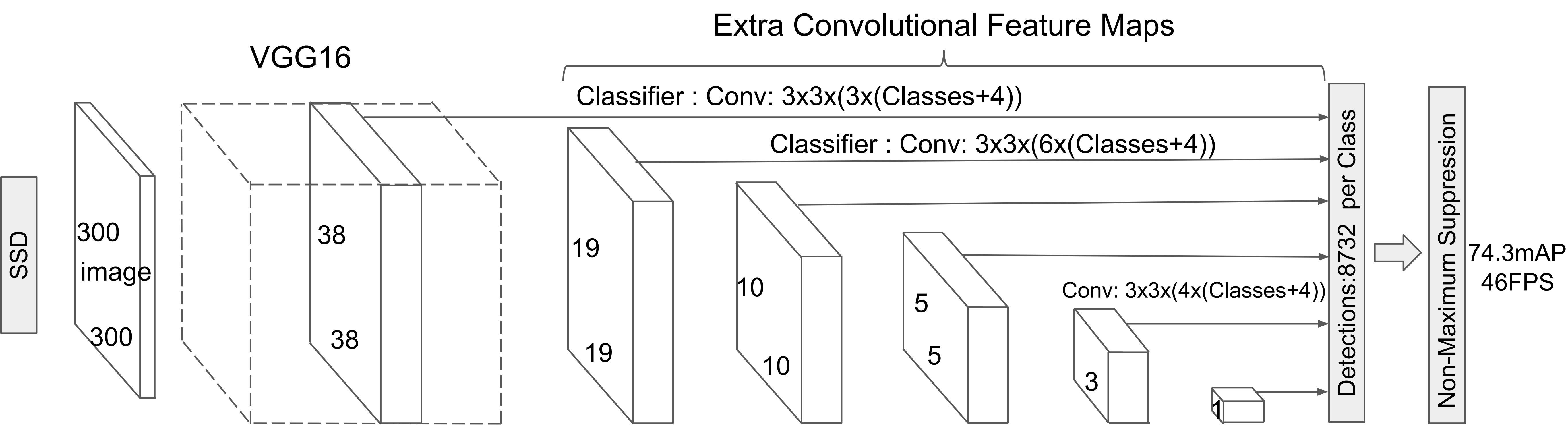
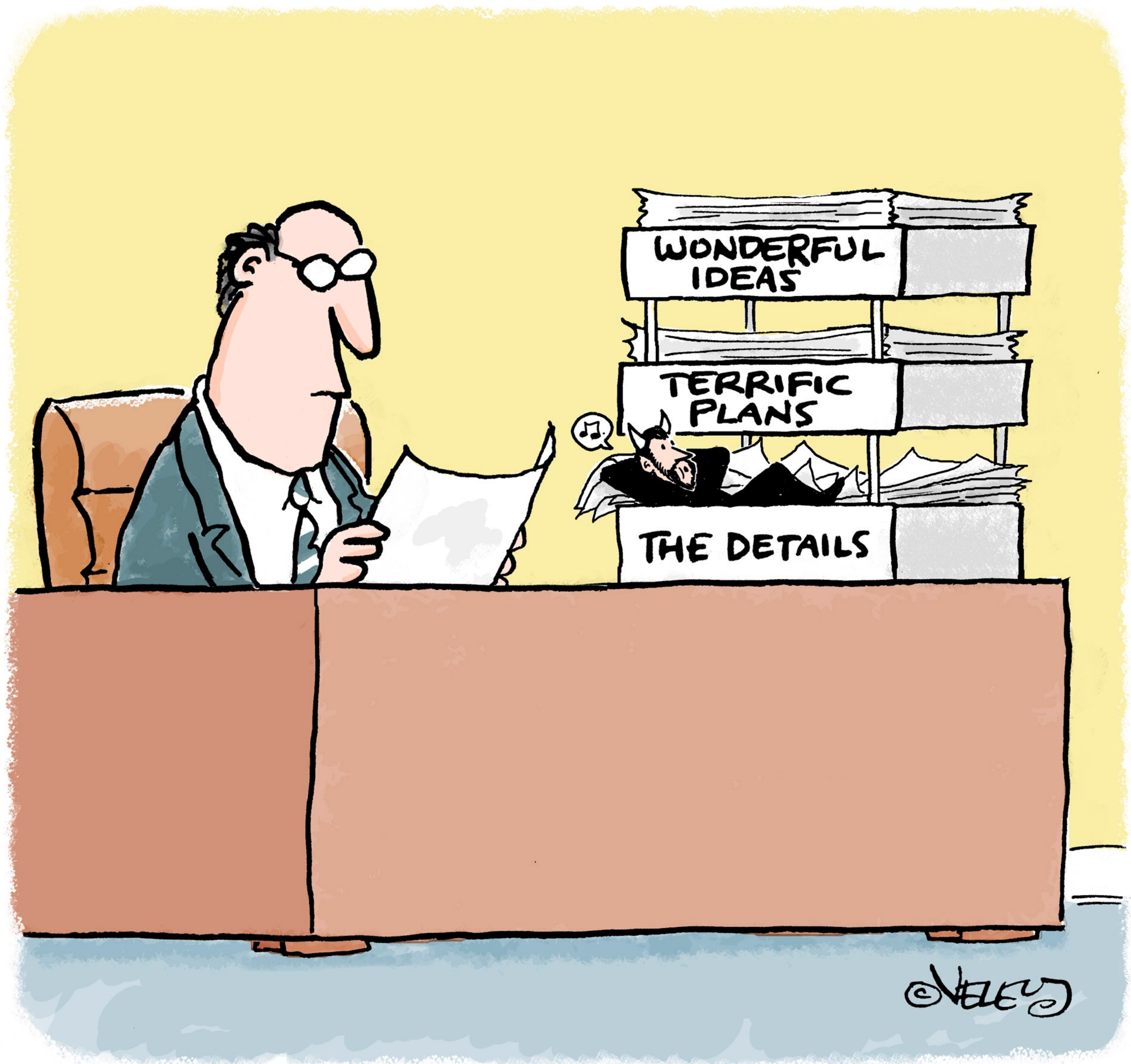
  - Unbalanced training: 1-30 TP, 8k-25k FP
  - Keep TP:FP ratio fixed (1:3), use worst-misclassified FPs.



SSD Architecture

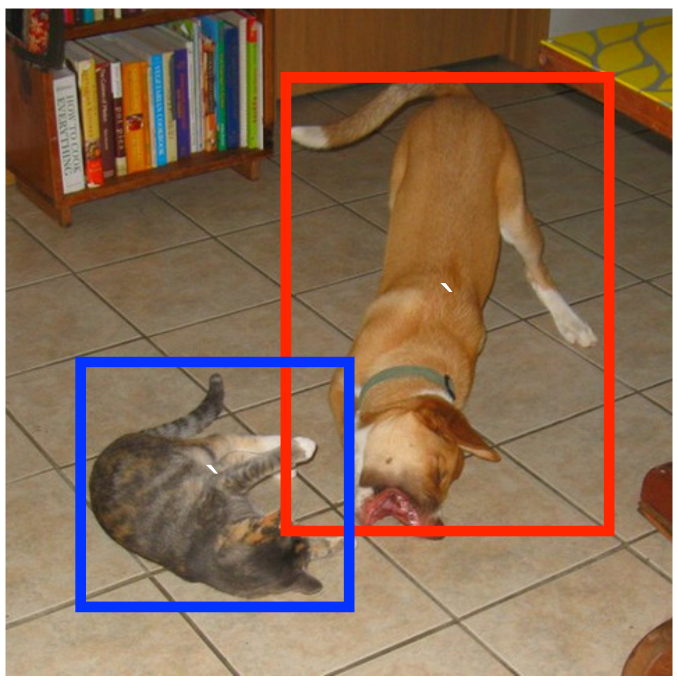


Contribution #3:
The Devil is in the Details



Data Augmentation

Data Augmentation



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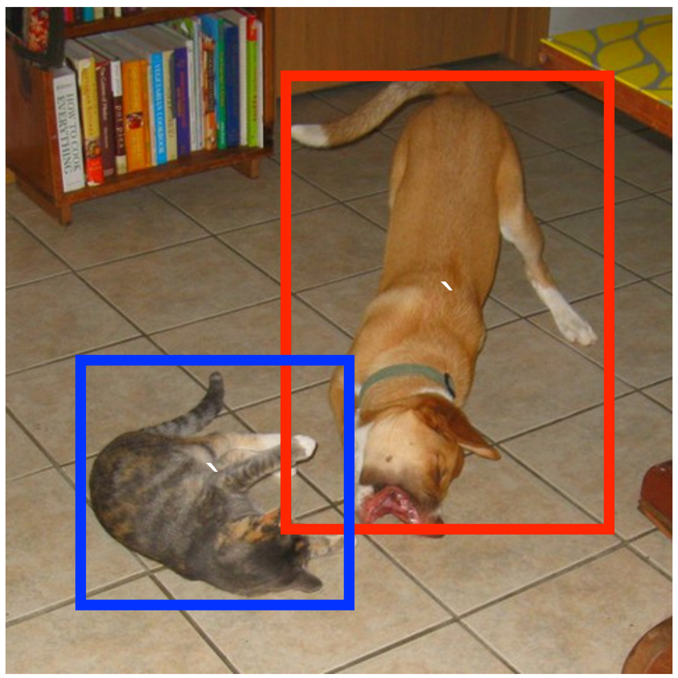

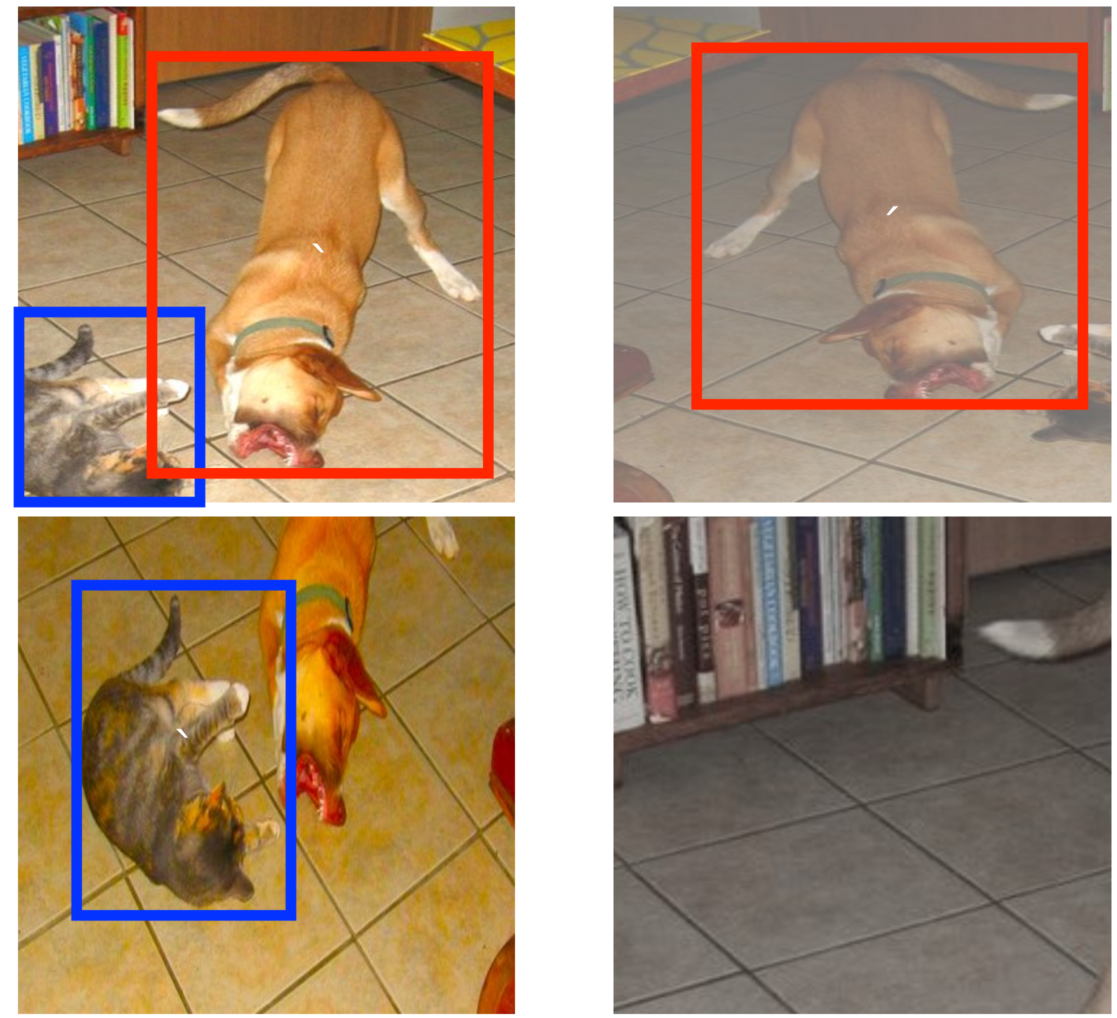

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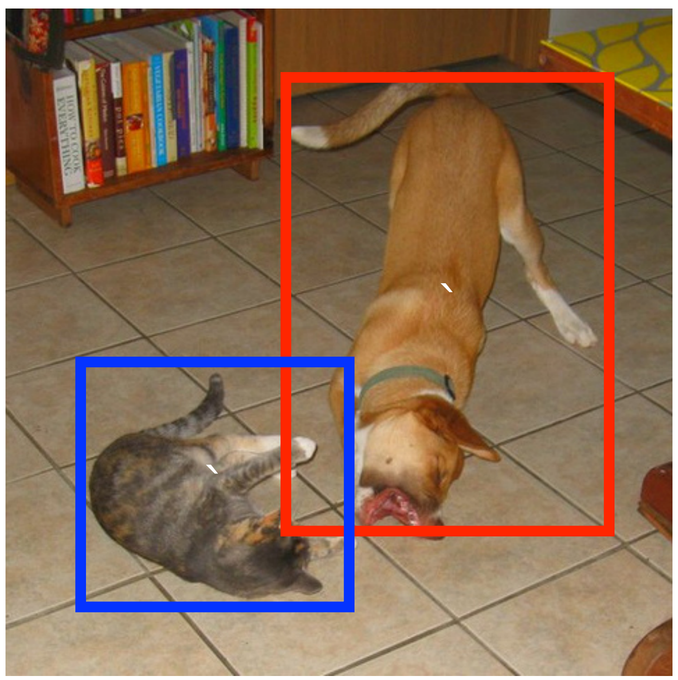

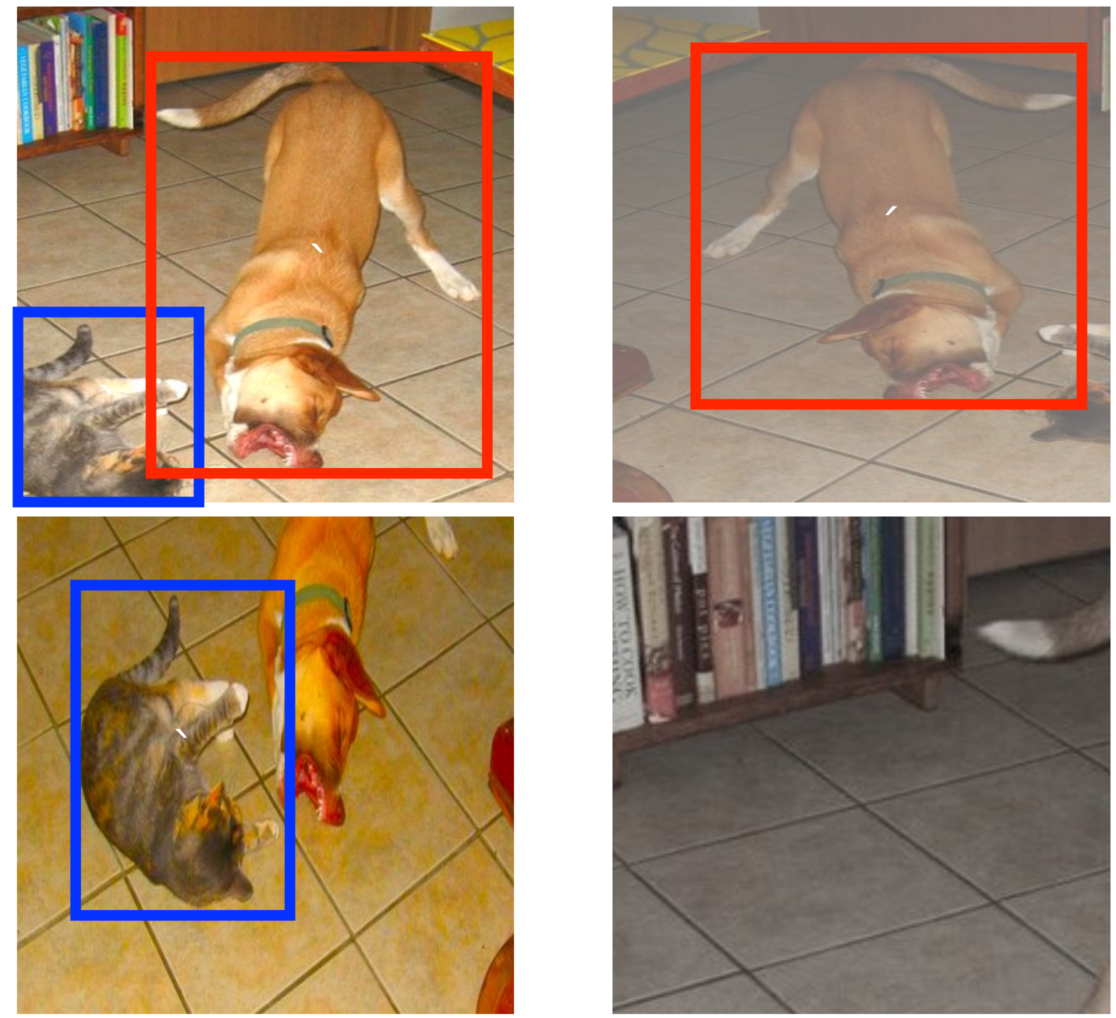

data augmentation	SSD300	
horizontal flip	✔	✔
random crop & color distortion		✔
VOC2007 `test` mAP	65.5	**74.3**

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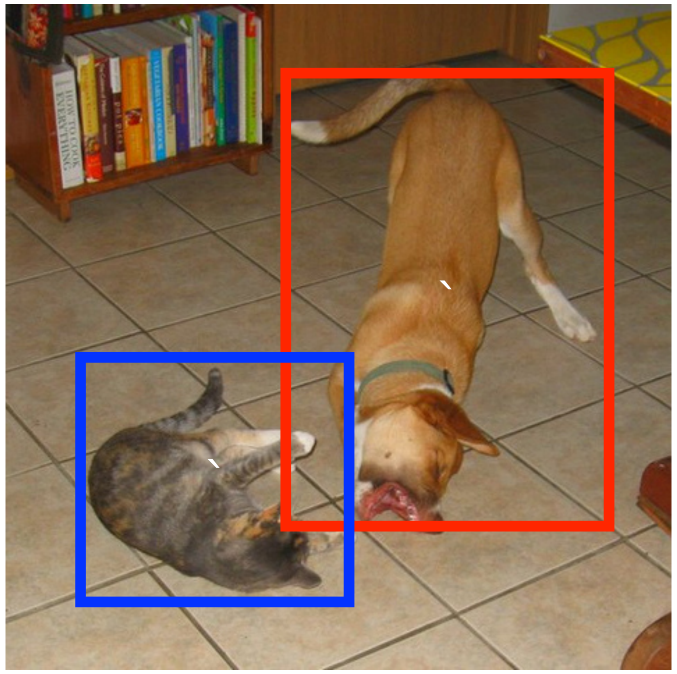

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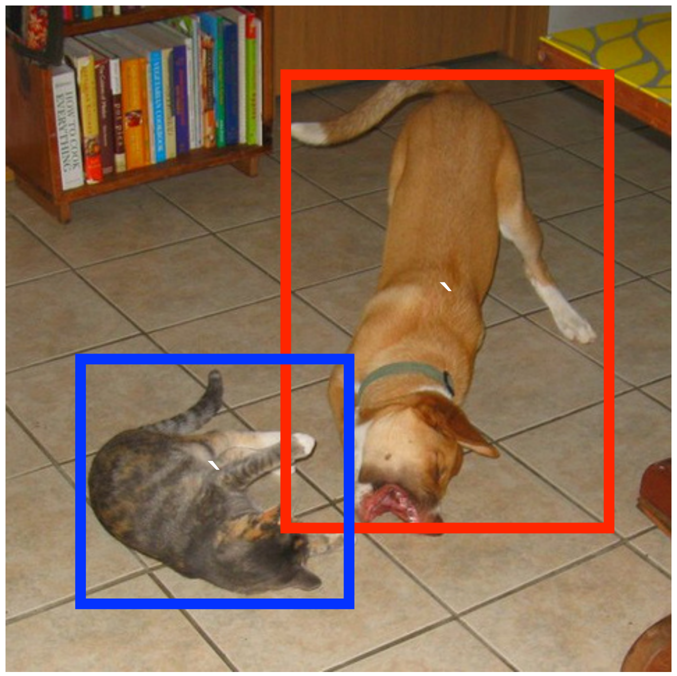
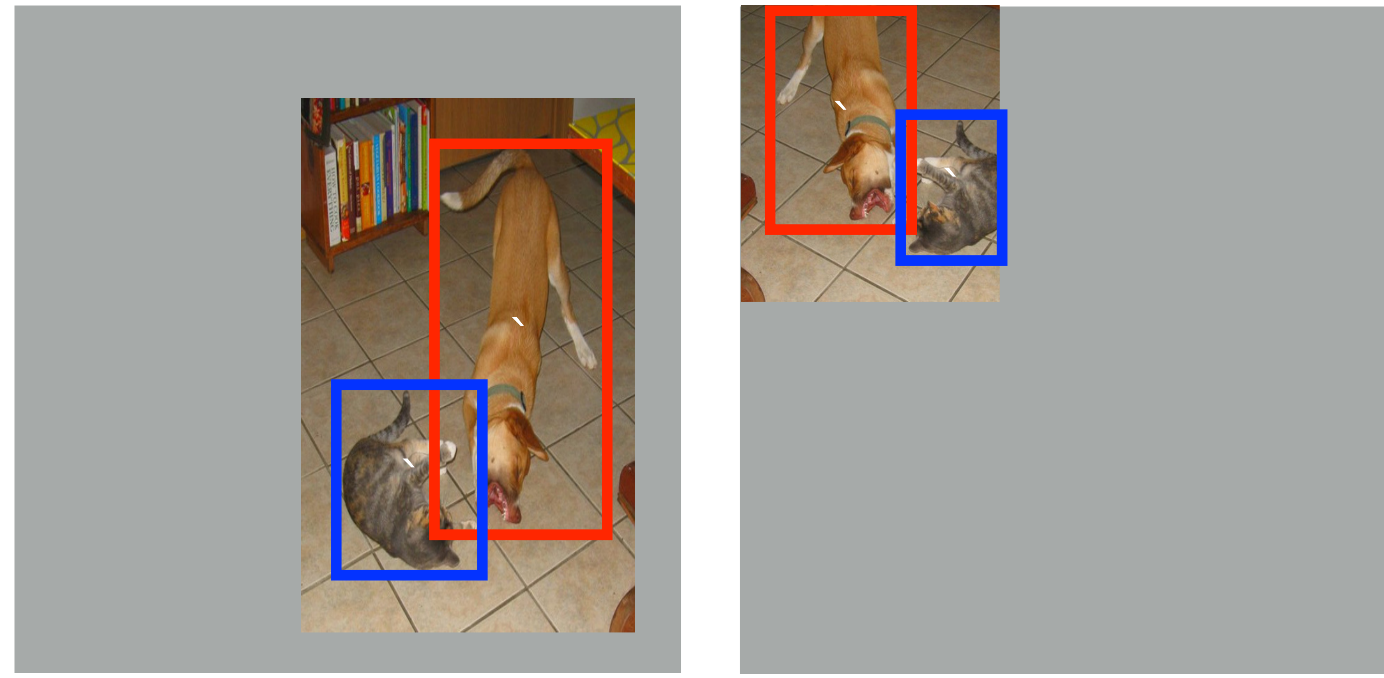
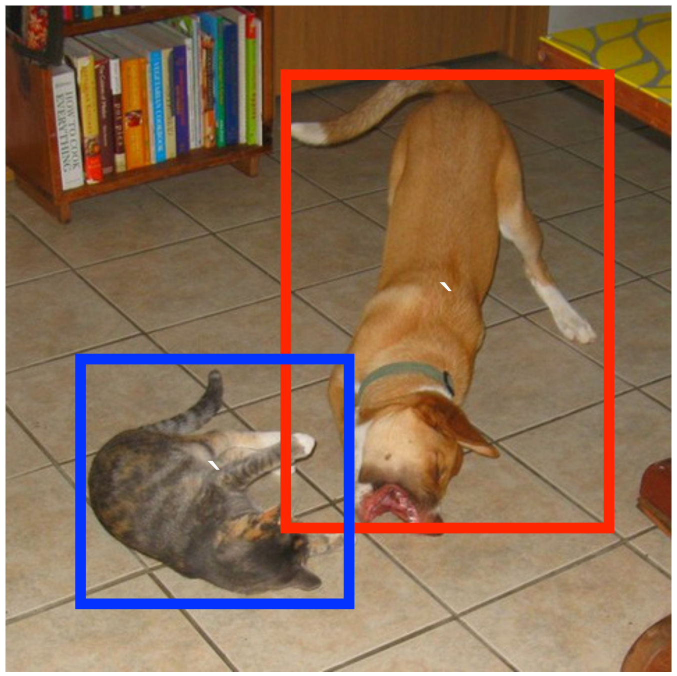
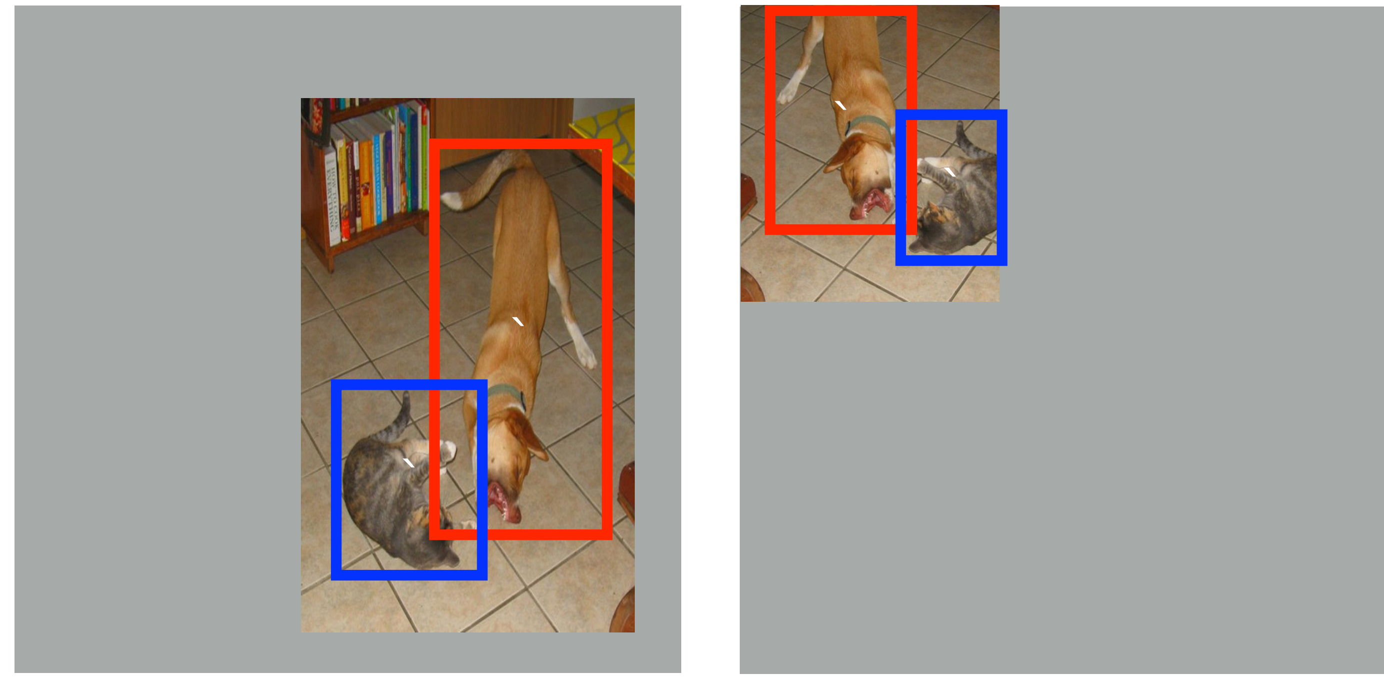




Random expansion creates more **small** training examples

Data Augmentation





Random expansion creates more **small** training examples

data augmentation	SSD300		
horizontal flip	✔	✔	✔
random crop & color distortion		✔	✔
random expansion			✔
VOC2007 `test` mAP	65.5	74.3	**77.2**

Results on VOC2007 test

Method	mAP	FPS	batch size	# Boxes	Input resolution
Faster R-CNN (VGG16)	73.2	7	1	~ 6000	$\sim 1000 \times 600$
Fast YOLO	52.7	155	1	98	448×448
YOLO (VGG16)	66.4	21	1	98	448×448
SSD300	74.3	46	1	8732	300×300
SSD512	76.8	19	1	24564	512×512
SSD300	74.3	59	8	8732	300×300
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Results on More Datasets

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Method	VOC2007 test	VOC2012 test	MS COCO test-dev	ILSVRC2014 val2
Fast R-CNN	70.0	68.4	19.7	N/A
Faster R-CNN	**73.2**	**70.4**	**21.9**	N/A
YOLO	63.4	57.9	N/A	N/A

Results on More Datasets

Method	VOC2007 test	VOC2012 test	MS COCO test-dev	ILSVRC2014 val2
Fast R-CNN	70.0	68.4	19.7	N/A
Faster R-CNN	73.2	70.4	21.9	N/A
YOLO	63.4	57.9	N/A	N/A
SSD300	**74.3**	**72.4**	**23.2**	**43.4**

Results on More Datasets

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Faster R-CNN	73.2	70.4	21.9	N/A
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SSD300	74.3	72.4	23.2	43.4
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Faster R-CNN	73.2	70.4	21.9	N/A
YOLO	63.4	57.9	N/A	N/A
SSD300*	77.2	75.8	25.1	N/A
SSD512*	**79.8**	**78.5**	**28.8**	N/A

COCO Bounding Box precision

COCO Bounding Box precision

mAP @ IoU	0.5	0.75	0.5:0.95
Faster R-CNN	45.3	23.5	24.2
SSD512*	48.5	30.3	28.8
gain	**+3.2**	**+6.8**	**+4.6**

Future Work

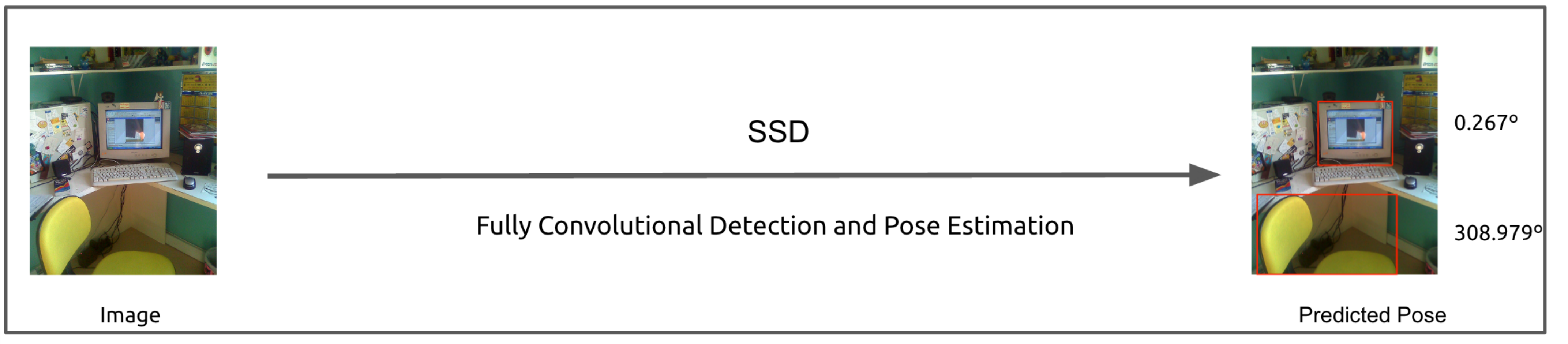
Future Work

- Object detection + pose estimation

Future Work

- Object detection + pose estimation

[Poirson et al, coming out at 3DV, 2016]



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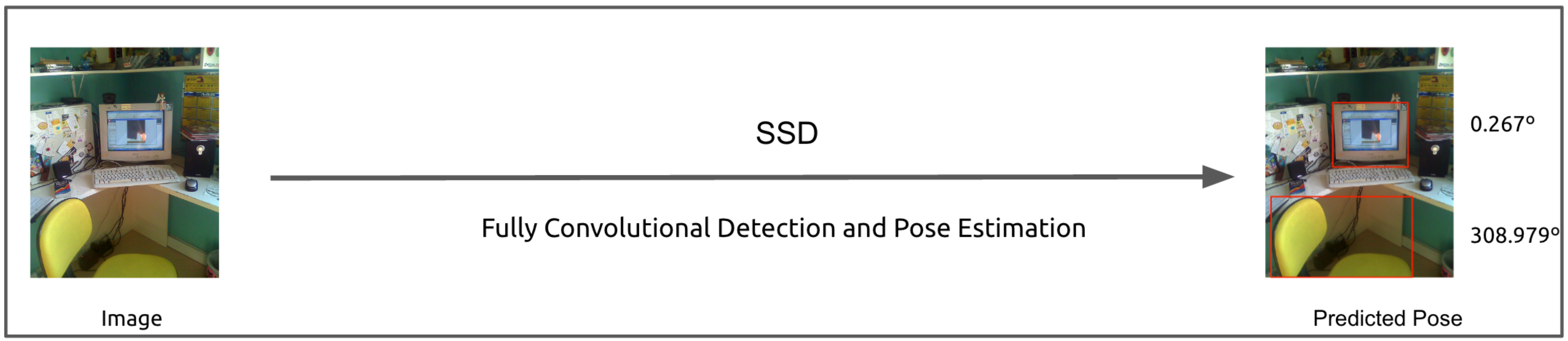

- Single shot 3D bounding box detection

Future Work

- Object detection + pose estimation

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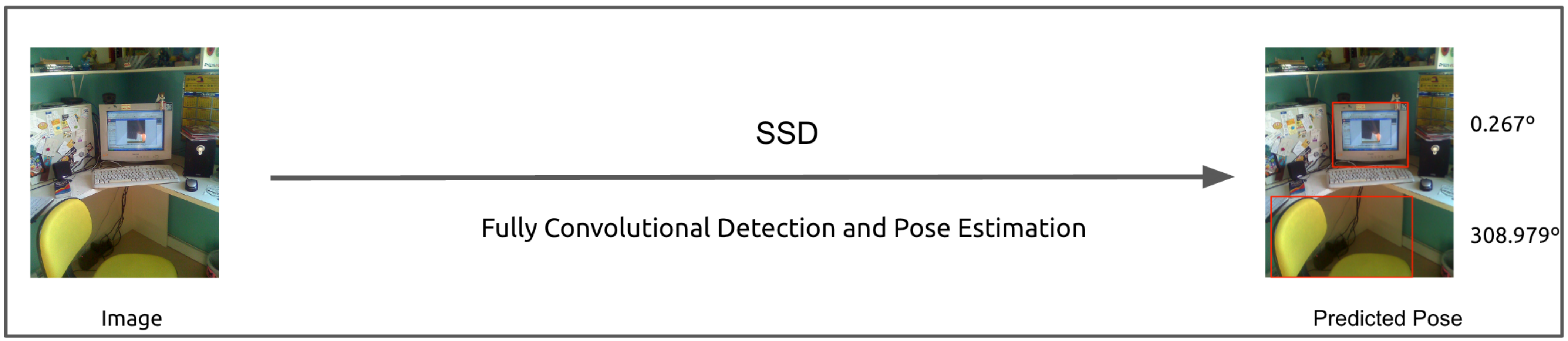

- Single shot 3D bounding box detection
- Joint object detection + tracking model

Check out the code/models

https://github.com/weiliu89/caffe/tree/ssd

Thank you!

Come by our poster O-1A-02