THE UNIVERSITY OF TEXAS AT DALLAS

Semantic Segmentation

CS 4391 Introduction to Computer Vision

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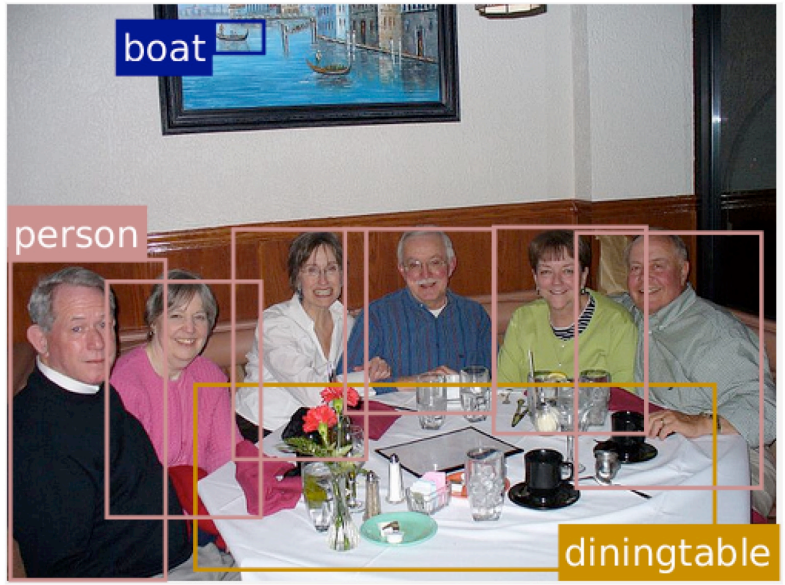
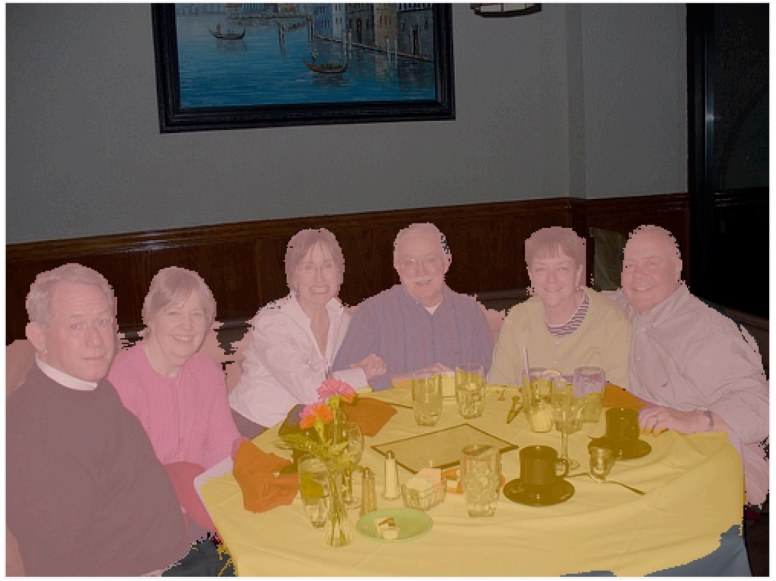
Department of Computer Science

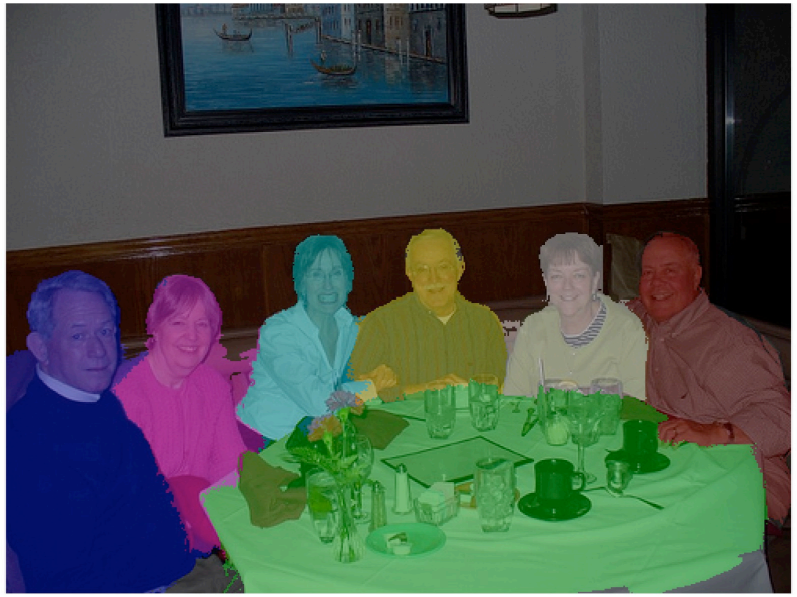
Semantic Scene Understanding



Object Detection



Semantic Segmentation



Instance Segmentation

Semantic Segmentation

Semantic image segmentation is the task of **classifying each pixel in an image from a predefined set of classes**

The pixels belonging to the bed are classified in the class “bed”, the pixels corresponding to the walls are labeled as “wall”, etc.

Problem Formulation

Input

segmented

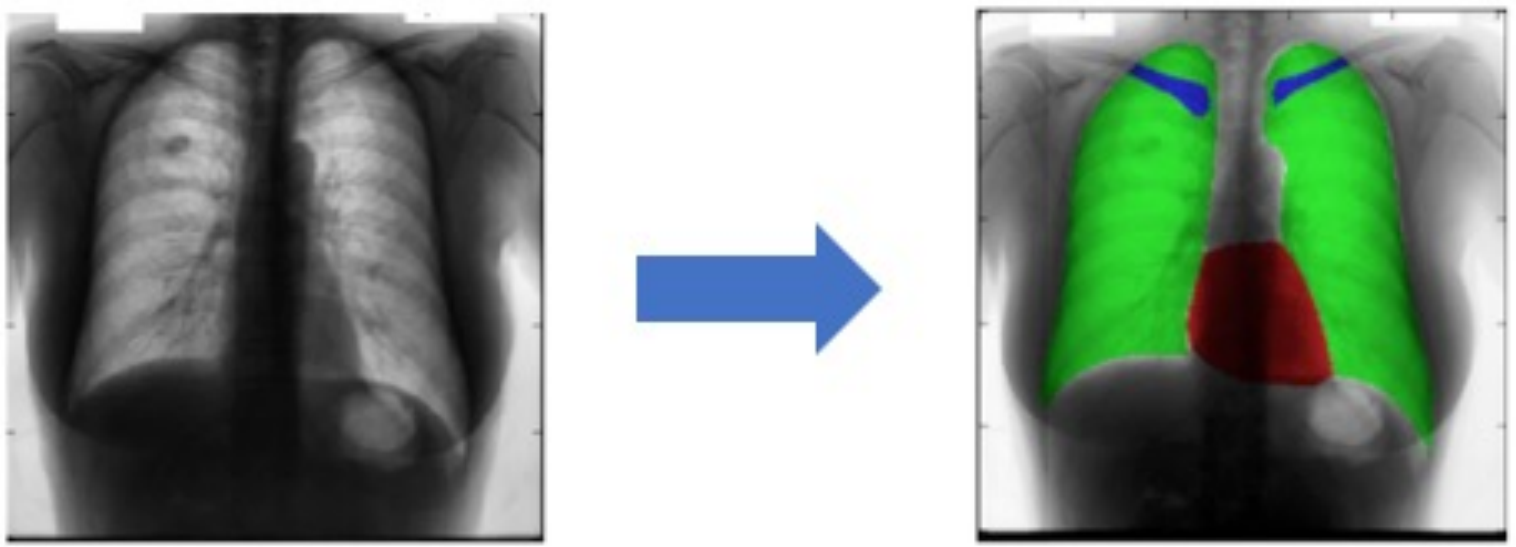
1: Person
2: Purse
3: Plants/Grass
4: Sidewalk
5: Building/Structures

3	3	3	3	3	3	3	3	3	3	3	3	5	5	5	5	5	5
3	3	3	3	3	3	3	3	3	3	3	3	5	5	5	5	5	5
3	3	3	3	3	3	1	1	3	3	3	3	5	5	5	5	5	5
3	3	3	3	3	1	1	1	1	3	3	3	5	5	5	5	5	5
3	3	3	3	3	3	1	1	3	3	3	5	5	5	5	5	5	5
5	5	3	3	3	3	1	1	3	3	5	5	5	5	5	5	5	5
4	4	3	4	1	1	1	1	1	1	4	4	4	5	5	5	5	5
4	4	3	4	1	1	1	1	1	1	4	4	4	4	4	5	5	5
4	4	4	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4
3	3	3	1	1	1	1	1	1	1	1	4	4	4	4	4	4	4
3	3	3	1	2	2	1	1	1	1	1	4	4	4	4	4	4	4
3	3	3	1	2	2	1	1	1	1	1	4	4	4	4	4	4	4

Semantic Labels

Given an image of size W x H x 3, we aim to generate a W x H matrix containing the predicted class labels corresponding to all the pixels.

Applications: Medical images



A chest x-ray with the heart (red), lungs (green), and clavicles (blue) are segmented.

Novikov et al. Fully Convolutional Architectures for Multi-Class Segmentation in Chest Radiographs, 2018

Applications: Autonomous Vehicles

A real-time segmented road scene for autonomous driving

https://www.youtube.com/watch?v=ATlcEDSPWXY

Semantic Segmentation

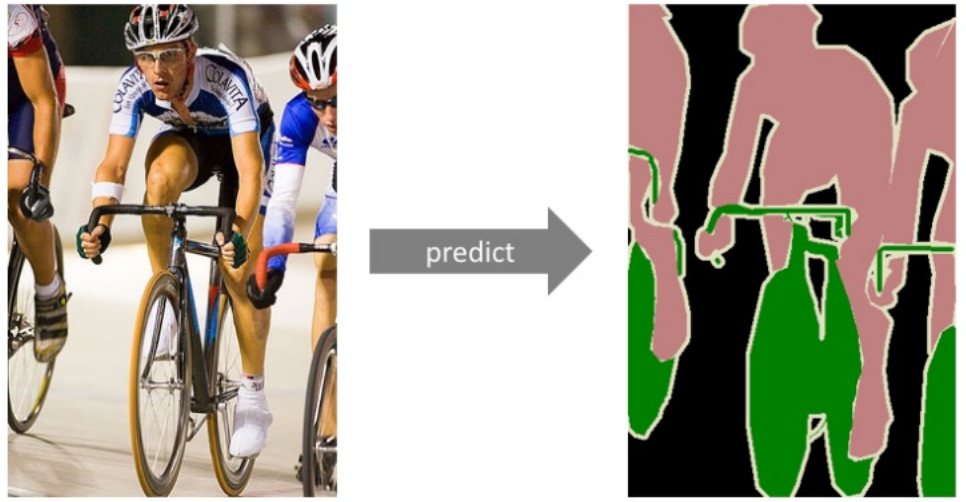
Label pixels into semantic classes

Naïve method

- Classify each pixel independently

Better idea

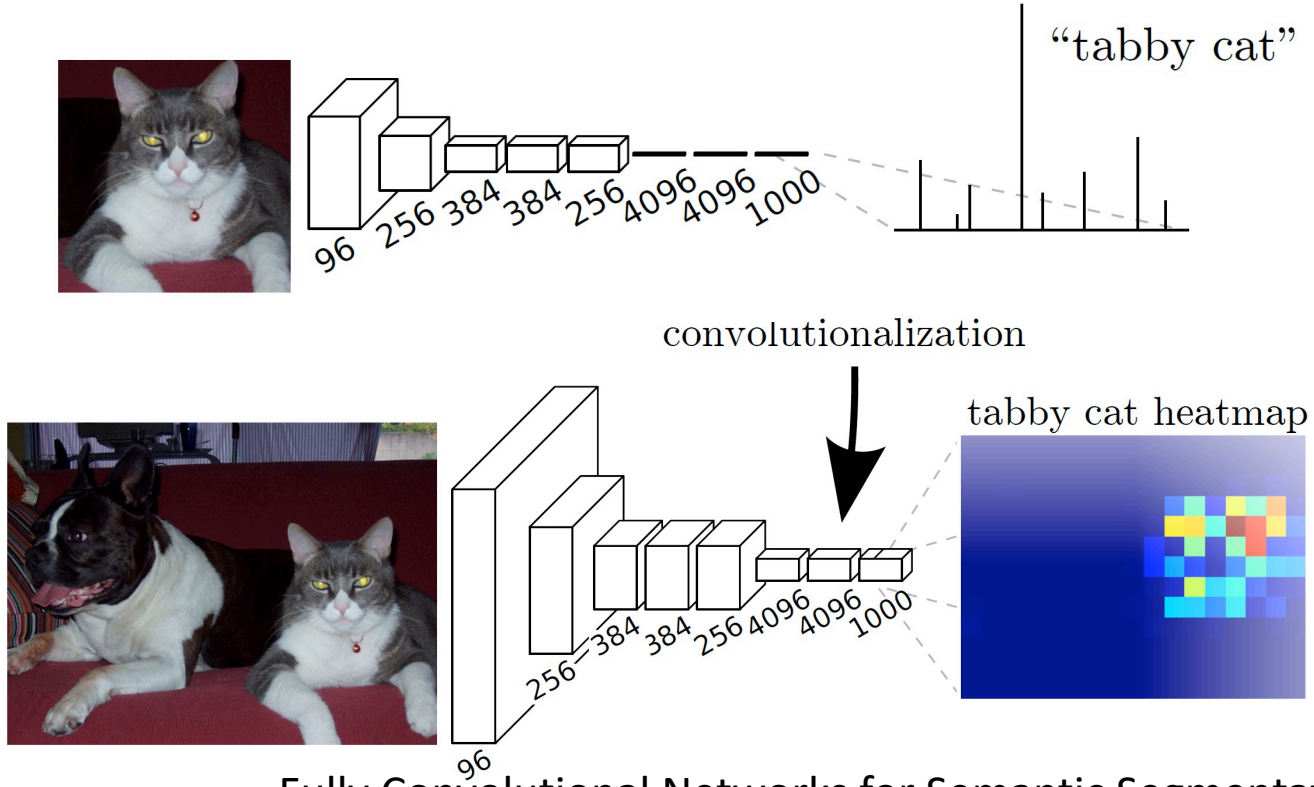
- Using context of pixels



Pixel-wise image classification

Fully Convolutional Networks

Adapt classification networks for dense prediction



- These FC layers can also be viewed as convolutions with kernels that cover their entire input regions
- Transforming FC layers into Conv layers enables a classification net to output a heatmap

Fully Convolutional Networks for Semantic Segmentation. Long et al., CVPR, 2015

Fully Convolutional Networks

Convert AlexNet

[224x224x3] INPUT
[55x55x96] CONV1: 96 11x11 filters at stride 4, pad 0
[27x27x96] MAX POOL1: 3x3 filters at stride 2
[27x27x96] NORM1: Normalization layer
[27x27x256] CONV2: 256 5x5 filters at stride 1, pad 2
[13x13x256] MAX POOL2: 3x3 filters at stride 2
[13x13x256] NORM2: Normalization layer
[13x13x384] CONV3: 384 3x3 filters at stride 1, pad 1
[13x13x384] CONV4: 384 3x3 filters at stride 1, pad 1
[13x13x256] CONV5: 256 3x3 filters at stride 1, pad 1
[6x6x256] MAX POOL3: 3x3 filters at stride 2
[4096] FC6: 4096 neurons
[4096] FC7: 4096 neurons
[1000] FC8: 1000 neurons (class scores)

```
layer {
  name: "fc6"
  type: "Convolution"
  bottom: "pool5"
  top: "fc6"
  convolution_param {
    num_output: 4096
    pad: 0
    kernel_size: 6
    group: 1
    stride: 1
  }
}
```

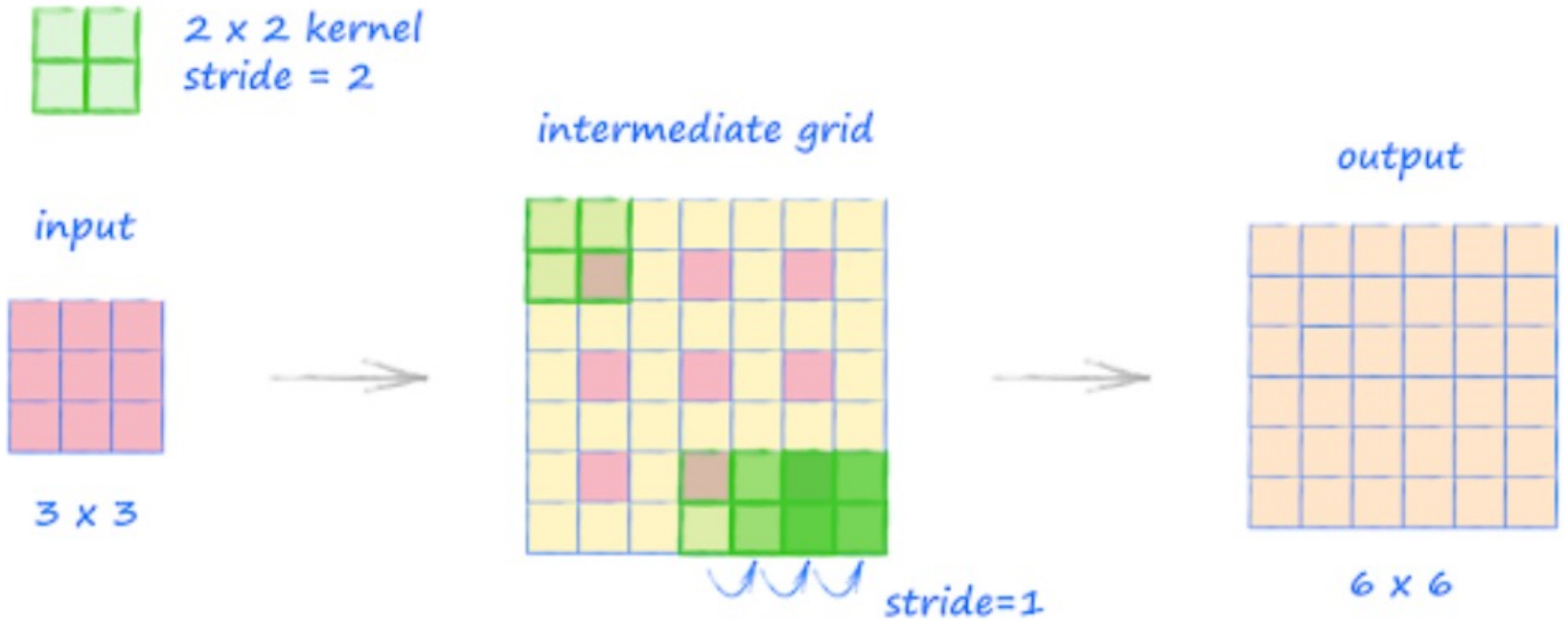
```
layer {
  name: "fc7"
  type: "Convolution"
  bottom: "fc6"
  top: "fc7"
  convolution_param {
    num_output: 4096
    pad: 0
    kernel_size: 1
    group: 1
    stride: 1
  }
}
```

```
layer {
  name: "score_fr"
  type: "Convolution"
  bottom: "fc7"
  top: "score_fr"
  param {
    lr_mult: 1
    decay_mult: 1
  }
  param {
    lr_mult: 2
    decay_mult: 0
  }
  convolution_param {
    num_output: 21
    pad: 0
    kernel_size: 1
  }
}
```

Fully Convolutional Networks for Semantic Segmentation. Long et al., CVPR, 2015

Fully Convolutional Networks

Deconvolution for up-sampling




```
layer {
  name: "upscore"
  type: "Deconvolution"
  bottom: "score_fr"
  top: "upscore"
  param {
    lr_mult: 0
  }
  convolution_param {
    num_output: 21
    bias_term: false
    kernel_size: 63
    stride: 32
  }
}
```

```
Pytorch: nn.ConvTranspose2d(in_channels, out_channels, kernel_size=2, stride=2)
```

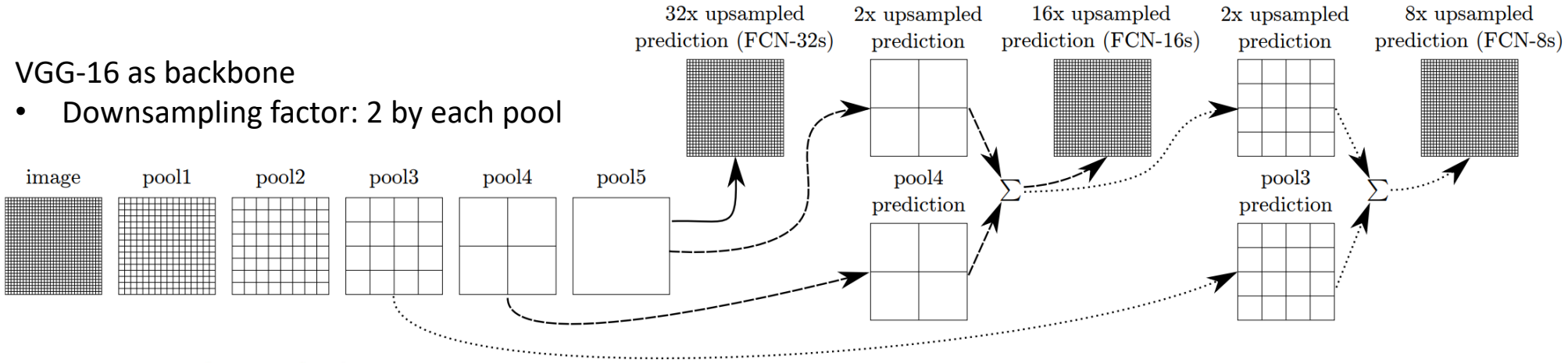
source

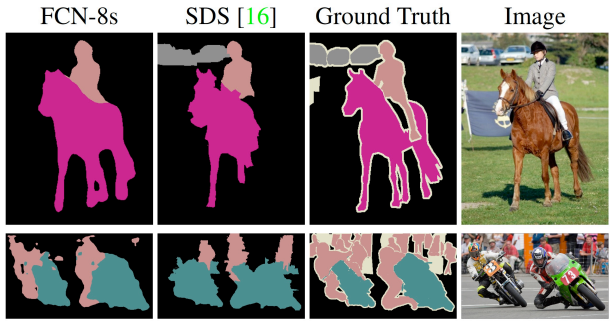
Fully Convolutional Networks

Combine predictions with different resolutions

VGG-16 as backbone

- Downsampling factor: 2 by each pool

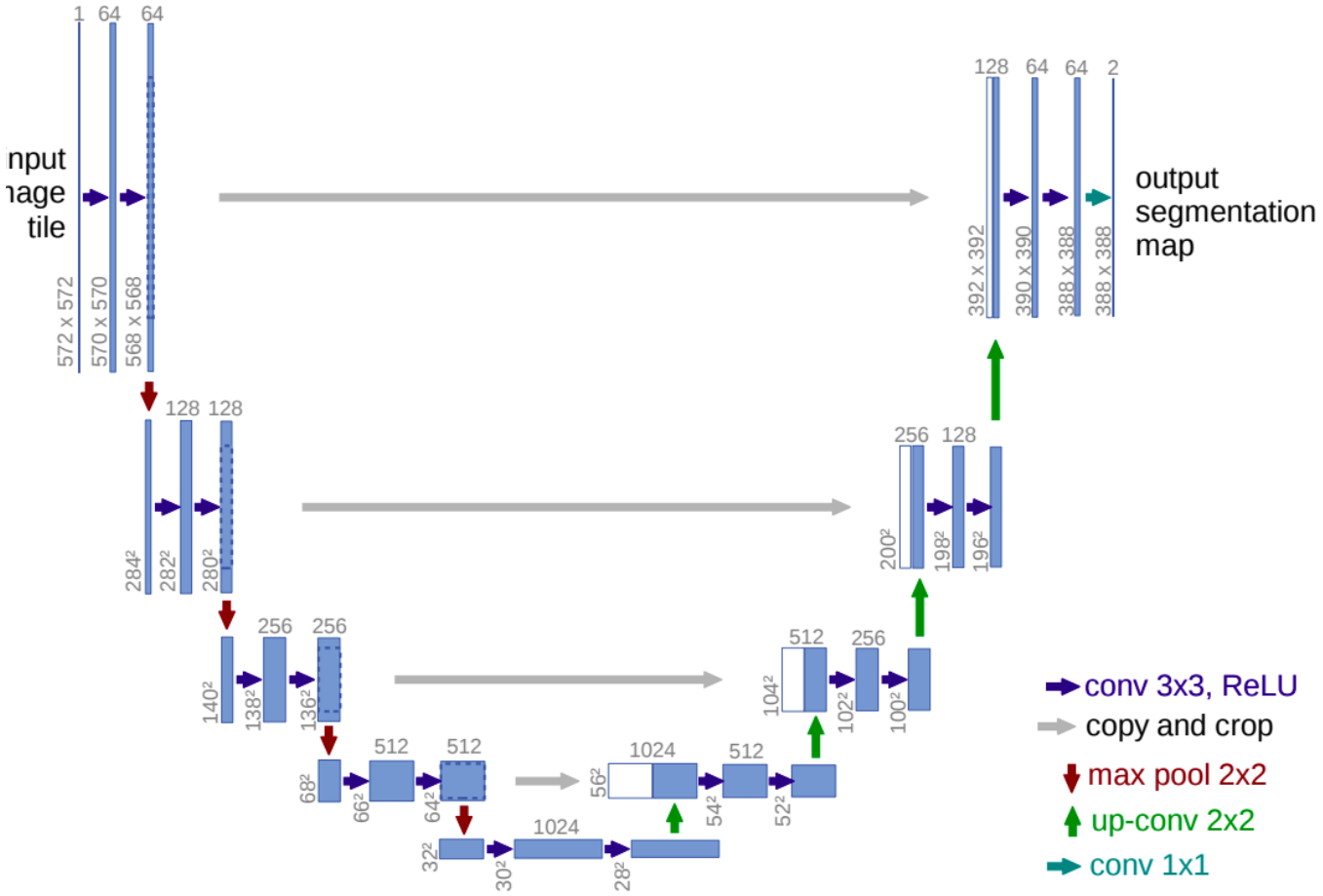




	pixel acc.	mean acc.	mean IU	f.w. IU
FCN-32s-fixed	83.0	59.7	45.4	72.0
FCN-32s	89.1	73.3	59.4	81.4
FCN-16s	90.0	75.7	62.4	83.0
FCN-8s	**90.3**	**75.9**	**62.7**	**83.2**

Fully Convolutional Networks for Semantic Segmentation. Long et al., CVPR, 2015

U-Net



Convolution

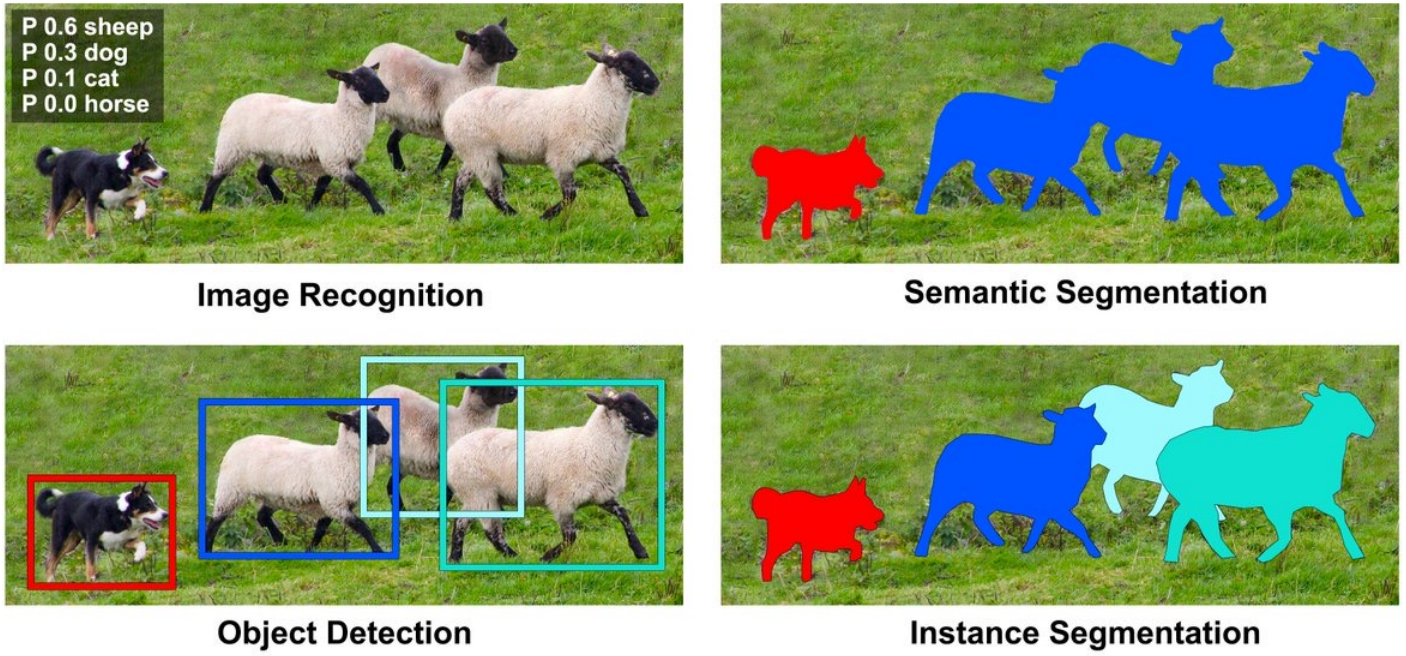
Deconvolution

U-Net: Convolutional Networks for Biomedical Image Segmentation, Ronneberger et al., MICCAI 2015

Instance Segmentation

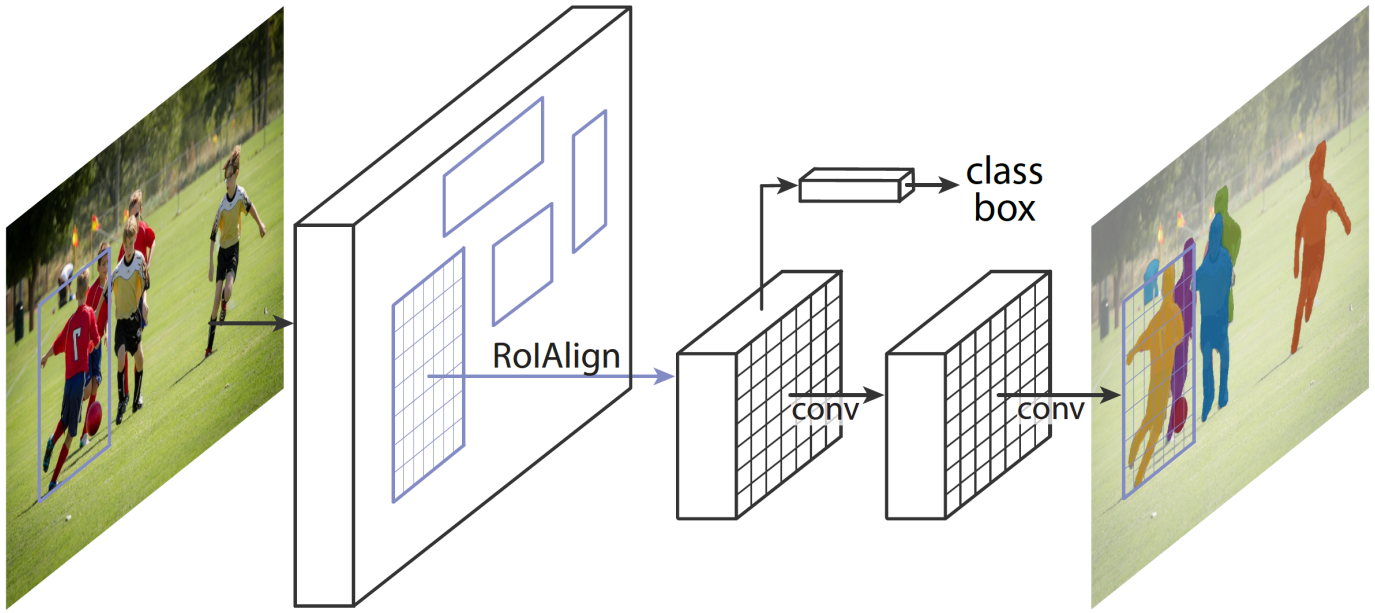
Separate object instances in the same class

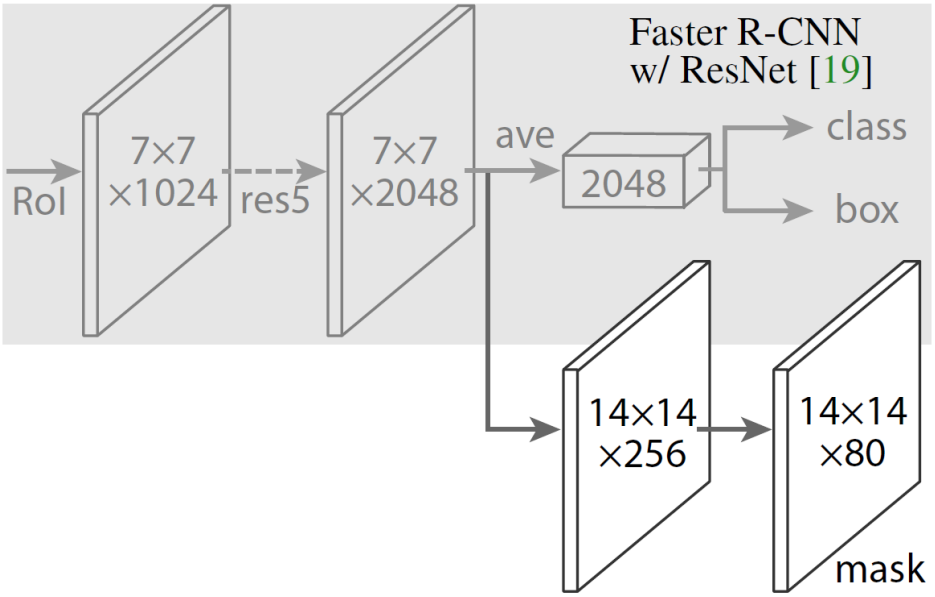
Detection + segmentation



https://ai-pool.com/d/could-you-explain-me-how-instance-segmentation-works

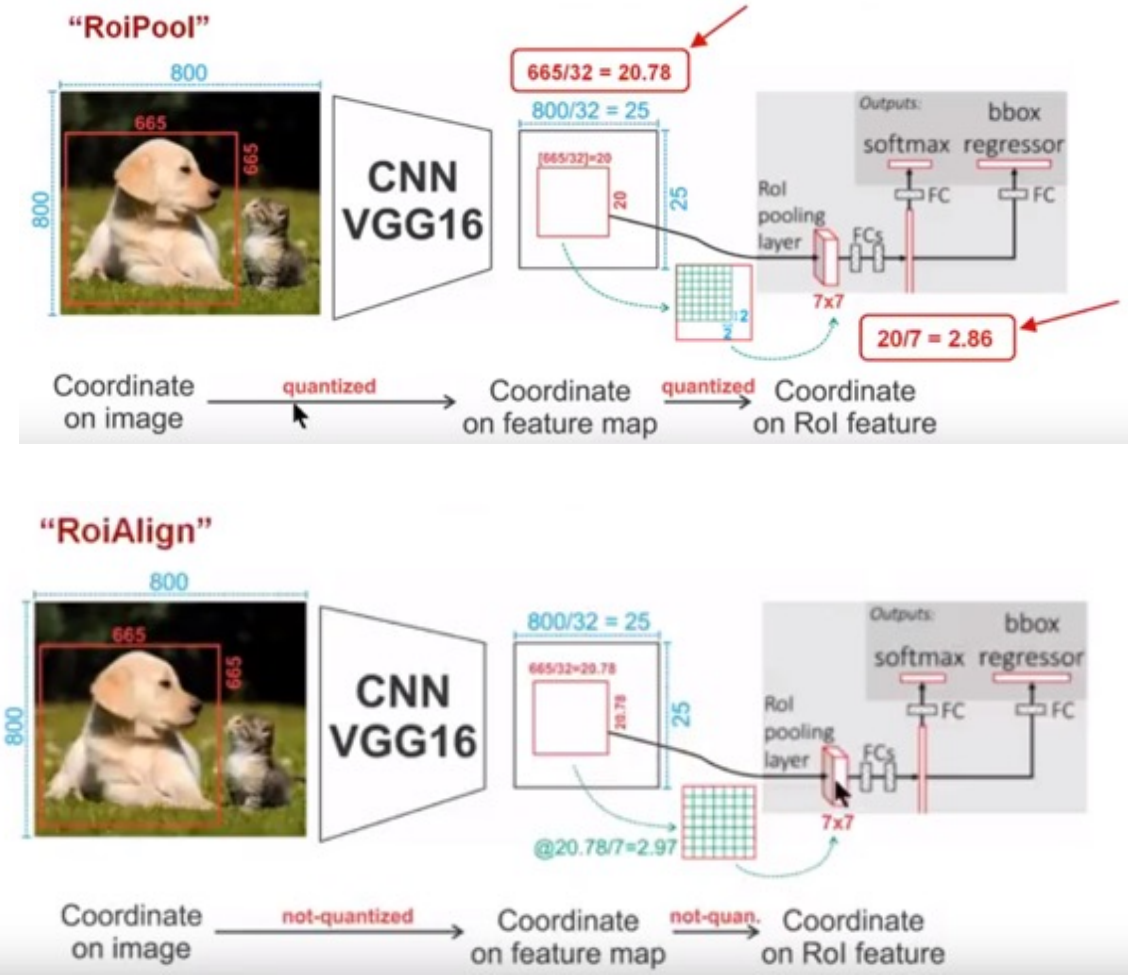
Mask R-CNN





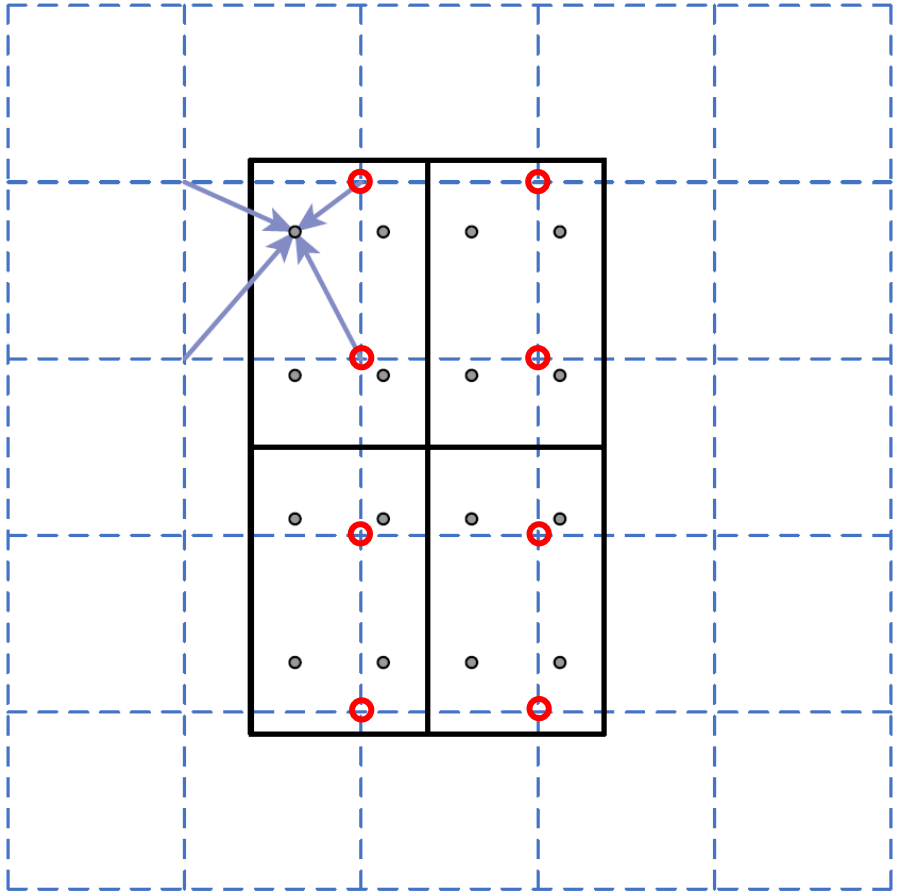
Mask R-CNN. He et al., ICCV, 2017

RoI Pooling vs. RoI Align



Credit: Ardian Umam

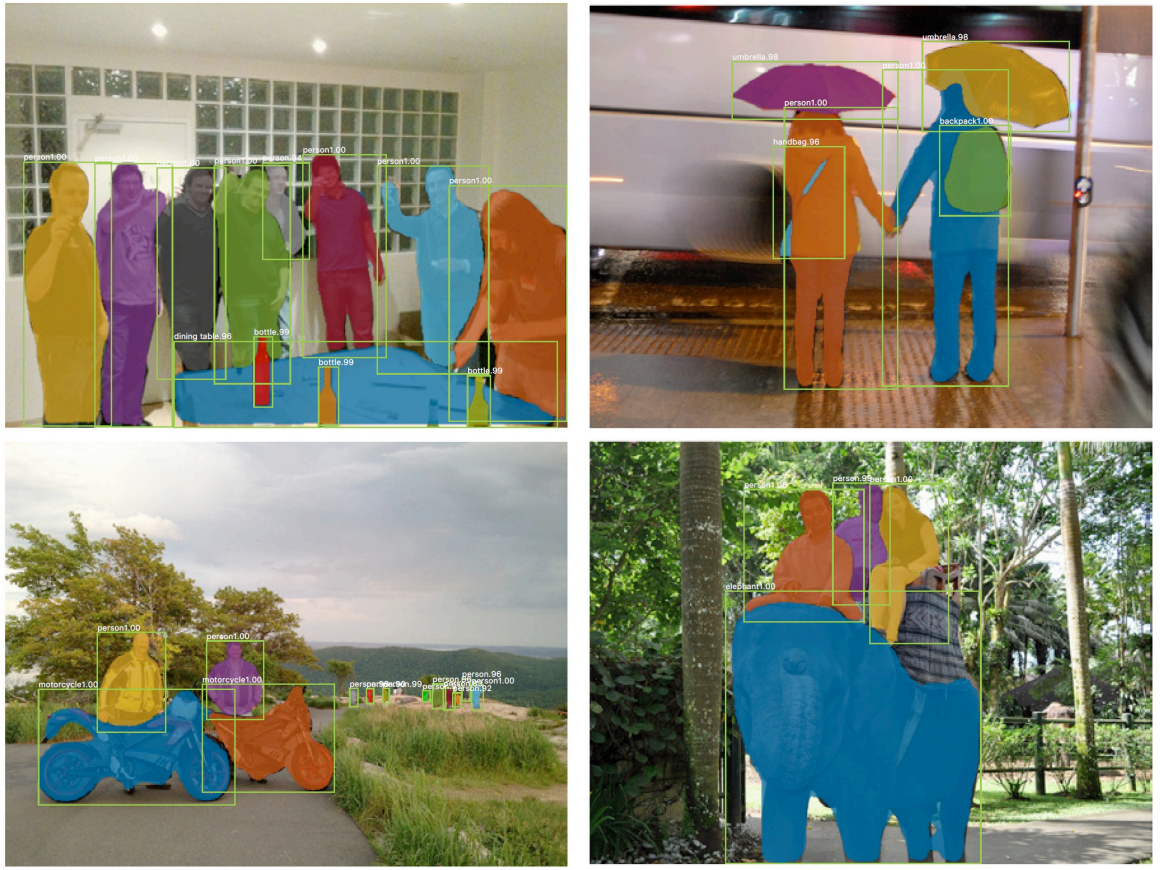
Bilinear interpolation for non-integer positions in RoI align



BI formula see wiki

Mask R-CNN

	align?	bilinear?	agg.	AP	AP_{50}	AP_{75}
RoIPool [12]			max	26.9	48.8	26.4
RoIWarp [10]		✓	max	27.2	49.2	27.1
		✓	ave	27.1	48.9	27.1
RoIAlign	✓	✓	max	**30.2**	**51.0**	**31.8**
	✓	✓	ave	**30.3**	**51.2**	**31.5**



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

Computer Vision

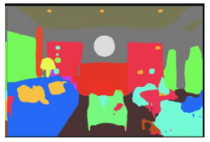
Semantic Segmentation

Edit

3673 papers with code • 97 benchmarks • 255 datasets

Semantic segmentation, or image segmentation, is the task of clustering parts of an image together which belong to the same object class. It is a form of pixel-level prediction because each pixel in an image is classified according to a category. Some example benchmarks for this task are Cityscapes, PASCAL VOC and ADE20K. Models are usually evaluated with the Mean Intersection-Over-Union (Mean IoU) and Pixel Accuracy metrics.

(Image credit: CSAILVision)



Benchmarks

Add a Result

These leaderboards are used to track progress in Semantic Segmentation

Trend	Dataset	Best Model	Paper	Code	Compare
	ADE20K	InternImage-H (M3I Pre-training)			See all
	Cityscapes test	InternImage-H			See all
	ADE20K val	BEiT-3			See all
	Cityscapes val	InternImage-H			See all
	NYU Depth v2	CMX (B5)			See all
	PASCAL Context	InternImage-H			See all
	PASCAL VOC 2012 test	DeepLabv3+ (Xception-65-JFT)			See all
	S3DIS	WindowNorm+StratifiedTransformer			See all
	DensePASS	Trans4PASS+ (multi-scale)			See all
	S3DIS Area5	PTv2			See all

Show all 97 benchmarks

Libraries

Use these libraries to find Semantic Segmentation models and implementations

PaddlePaddle/PaddleSeg	52 papers	6,625 ★
osmr/imgclsmob	30 papers	2,776 ★
rwightman/pytorch-image-models	27 papers	24,242 ★
open-mmlab/mmsegmentation	19 papers	5,431 ★

See all 31 libraries.

Content

Summary

Semantic segmentation

- Label pixels into object classes

Instance segmentation

- Separate object instances in the same class
- Detection + segmentation inside each box

Further Reading

FCN, 2015 https://arxiv.org/abs/1411.4038

Unet, 2015 https://arxiv.org/abs/1505.04597

Mask R-CNN, 2017 https://arxiv.org/abs/1703.06870

DeepLab, 2015 https://arxiv.org/abs/1606.00915

A semantic segmentation overview
https://www.jeremyjordan.me/semantic-segmentation/