

Image Segmentation

Computer Vision

Assignment 5

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Overview

- Task 1: implement Mean-Shift to segment image (40 pts).
- Task 2: implement simplified SegNet on multi-digit MNIST dataset (60 pts).

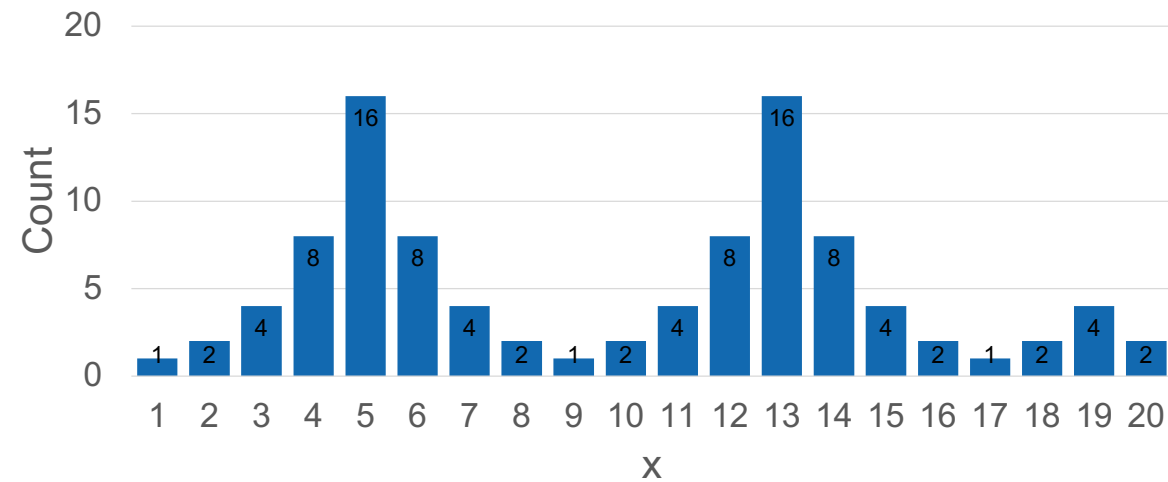
Mean-Shift

- Input image



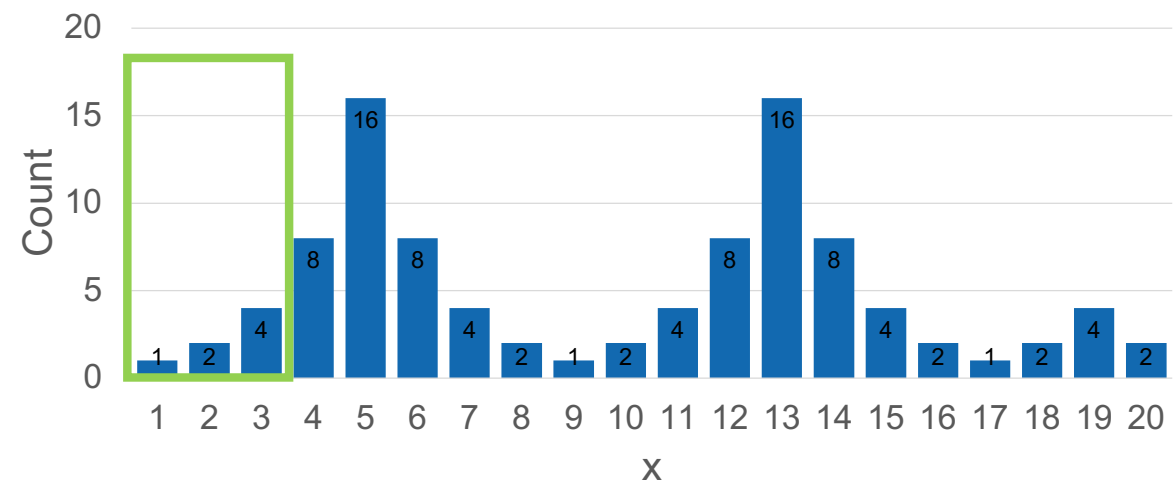
- Goal – segment the image in CIELAB color space (preprocessing already provided in code)

Mean-Shift Algorithm



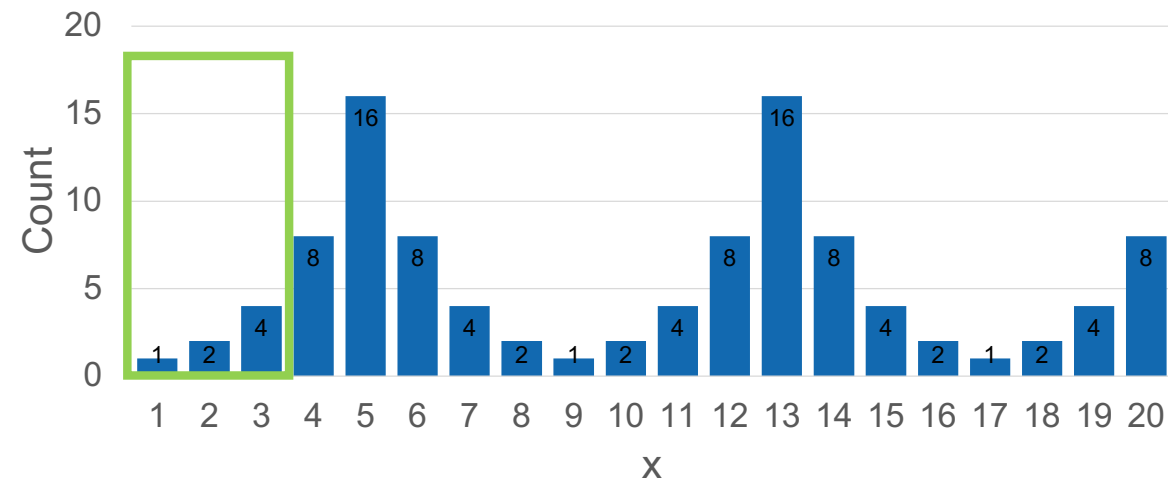
$$x' = \sum_{x \in W} xH(x)$$

Mean-Shift Algorithm



$$W = [1, 3] \quad \bar{x} = 2$$

Mean-Shift Algorithm



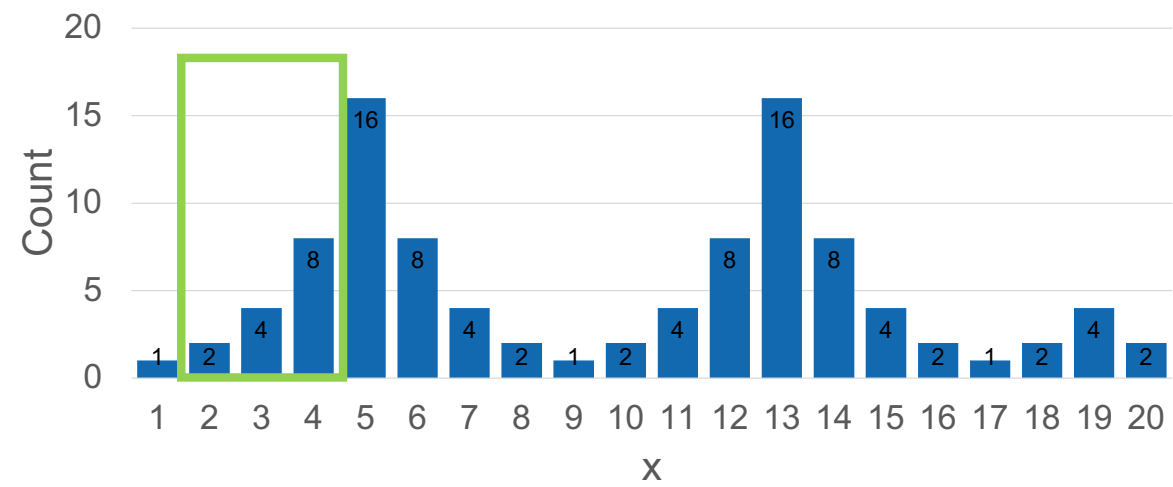
$$W = [1, 3] \quad \bar{x} = 2$$

2 to 2.4 → move right

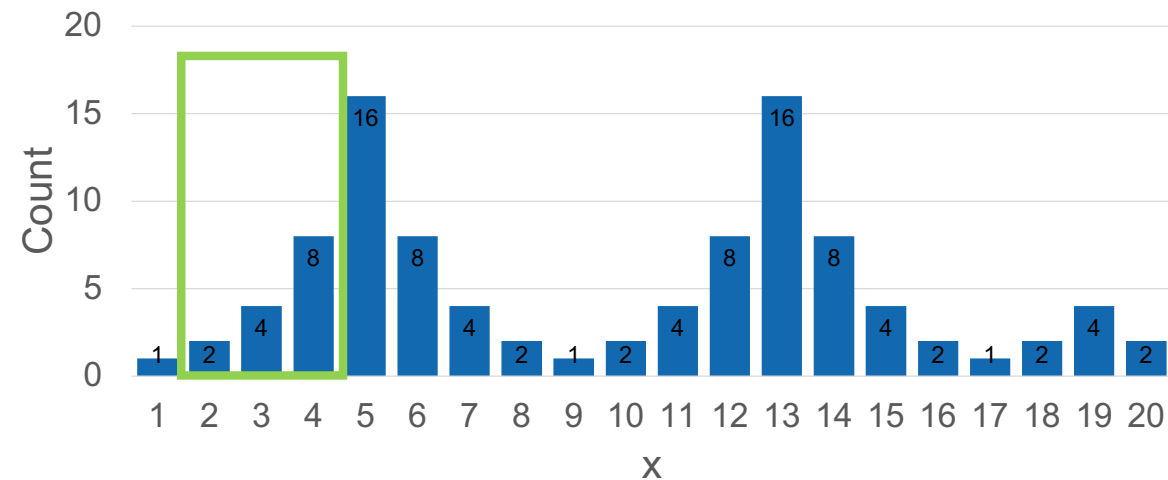
$$x' = \sum_{x \in W} xH(x)$$

$$H(1) = \frac{1}{7}, H(2) = \frac{2}{7}, H(3) = \frac{4}{7} \quad x' = \frac{17}{7} \approx 2.4$$

Mean-Shift Algorithm



Mean-Shift Algorithm



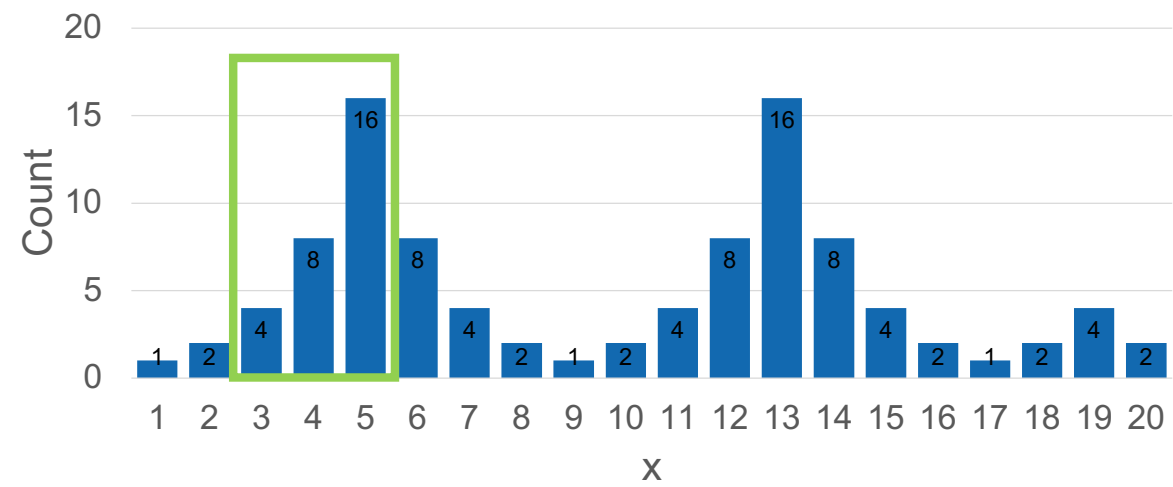
$$W = [2, 4] \quad \bar{x} = 3$$

3 to 3.4 → move right

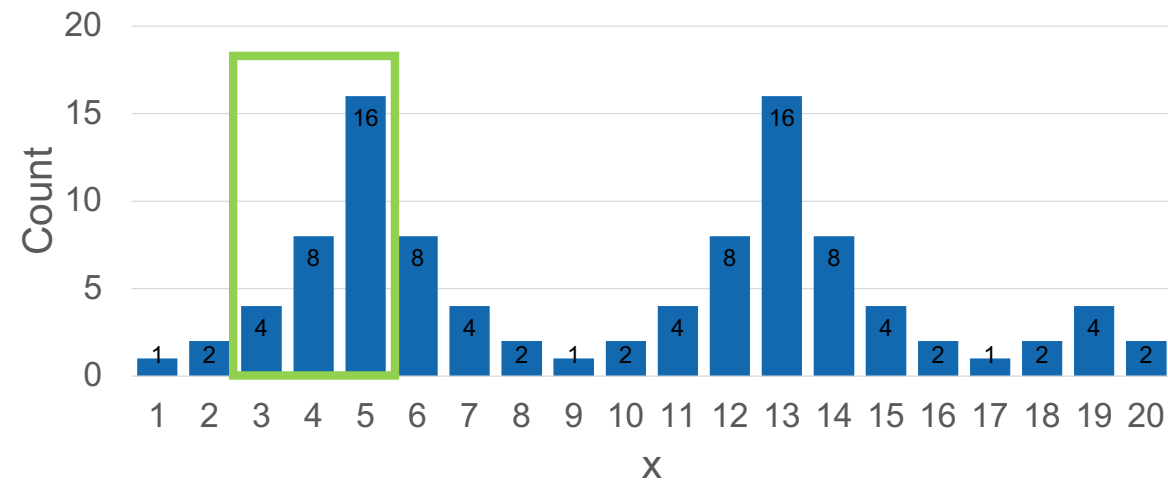
$$x' = \sum_{x \in W} xH(x)$$

$$H(2) = \frac{1}{7}, H(3) = \frac{2}{7}, H(4) = \frac{4}{7} \quad x' = \frac{24}{7} \approx 3.4$$

Mean-Shift Algorithm



Mean-Shift Algorithm



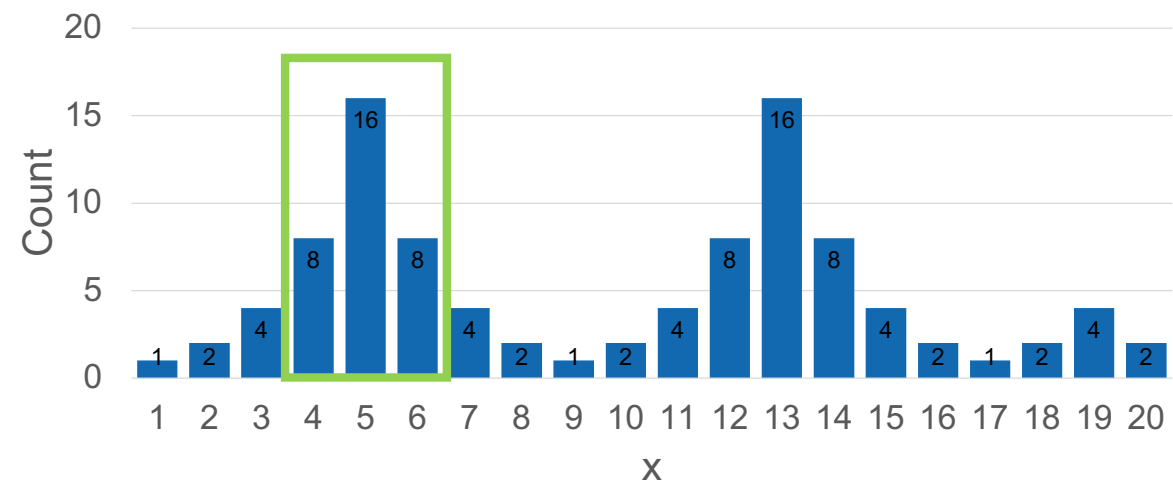
$$W = [3, 5] \quad \bar{x} = 4$$

4 to 4.4 → move right

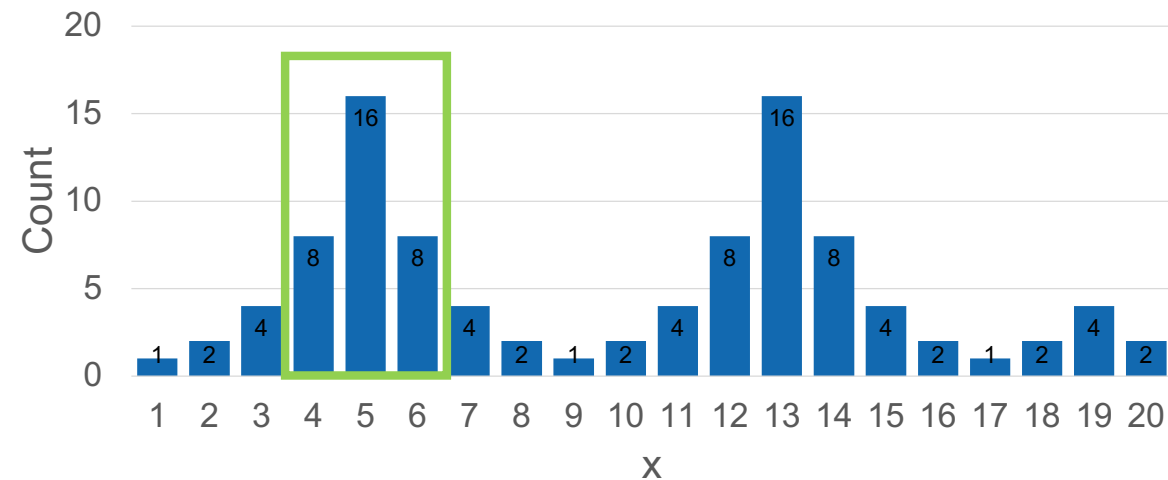
$$x' = \sum_{x \in W} xH(x)$$

$$H(3) = \frac{1}{7}, H(4) = \frac{2}{7}, H(5) = \frac{4}{7} \quad x' = \frac{24}{7} \approx 4.4$$

Mean-Shift Algorithm



Mean-Shift Algorithm



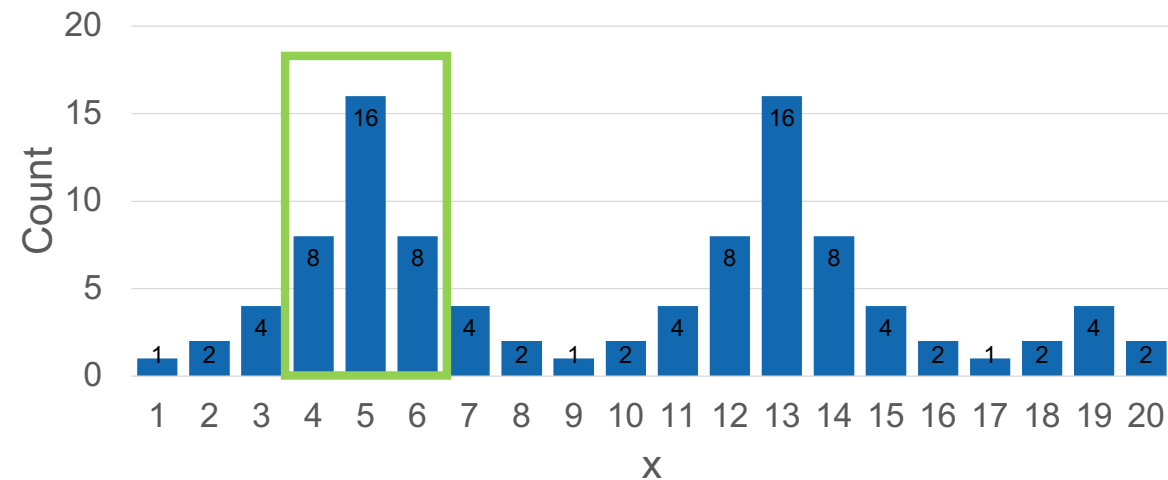
$$W = [4, 6] \quad \bar{x} = 5$$

5 to 5 → stop!

$$x' = \sum_{x \in W} xH(x)$$

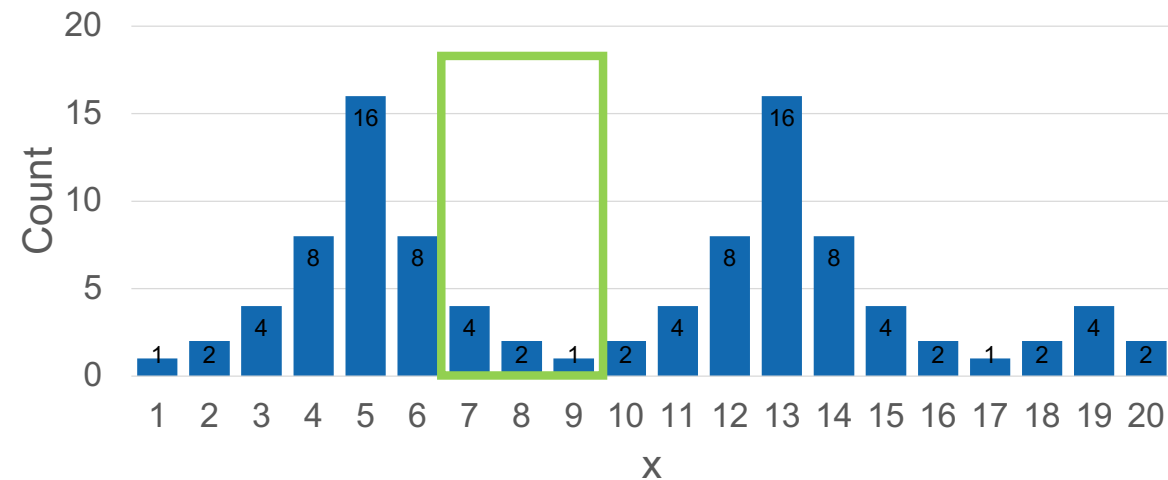
$$H(4) = \frac{1}{4}, H(5) = \frac{1}{2}, H(6) = \frac{1}{4} \quad x' = 5$$

Mean-Shift Algorithm



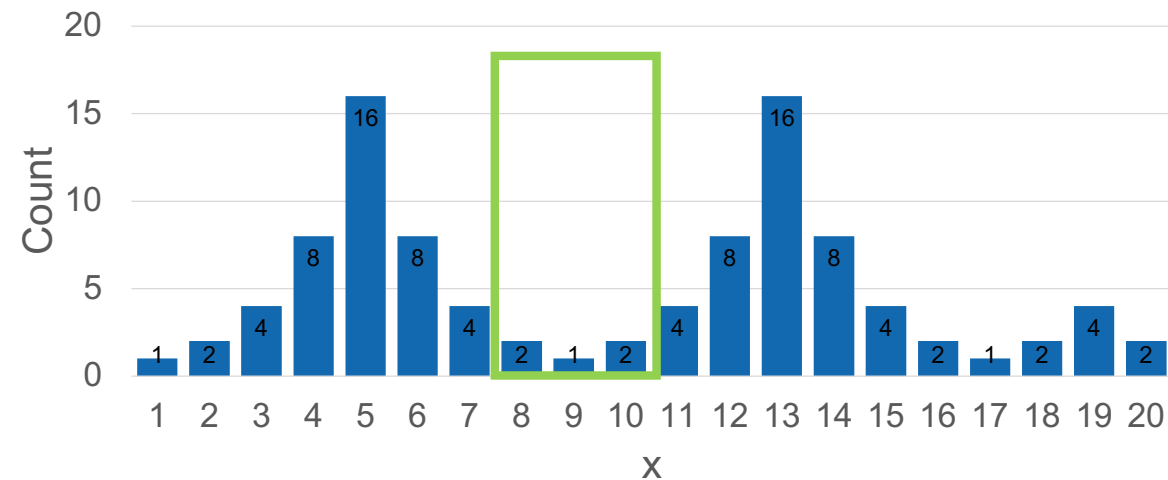
x from 1 to 5 are grouped together because they are all shifted to the same mean

Mean-Shift Algorithm



Similarly, from the other side of the mode, the window will also move to $x=5$, which clusters those x values together.

Mean-Shift Algorithm



If you unfortunately start from
here, mean-shift will get stuck

Mean-Shift

- In each step, for each point:
 - Compute the distances from this point to all points (including current point) within a radius. In this assignment we set this radius to positive infinity so that you can have an easier implementation
 - Compute weight of every point as a Gaussian kernel function of distance, with bandwidth=2.5
 - Compute weighted mean of all points (including current point), then update current point with this weighted mean
- Experiment with different bandwidth and report findings

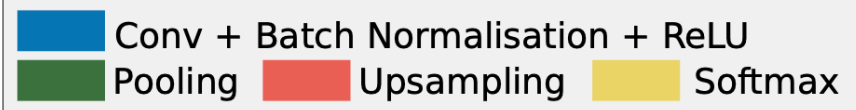
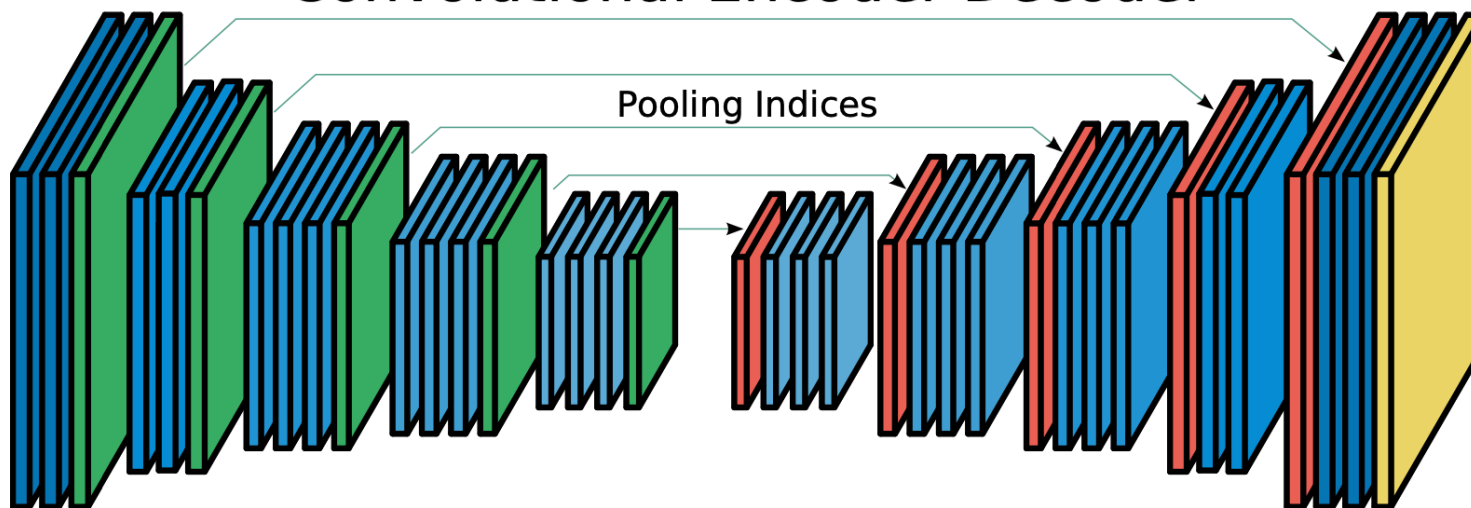
SegNet

Input

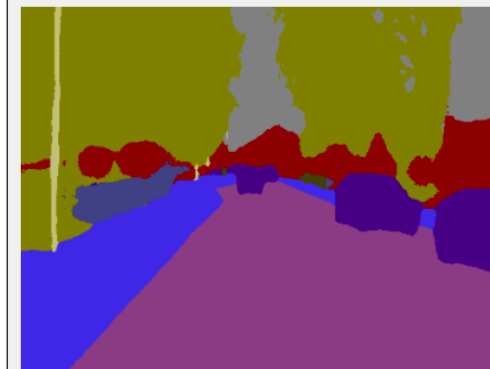


RGB Image

Convolutional Encoder-Decoder

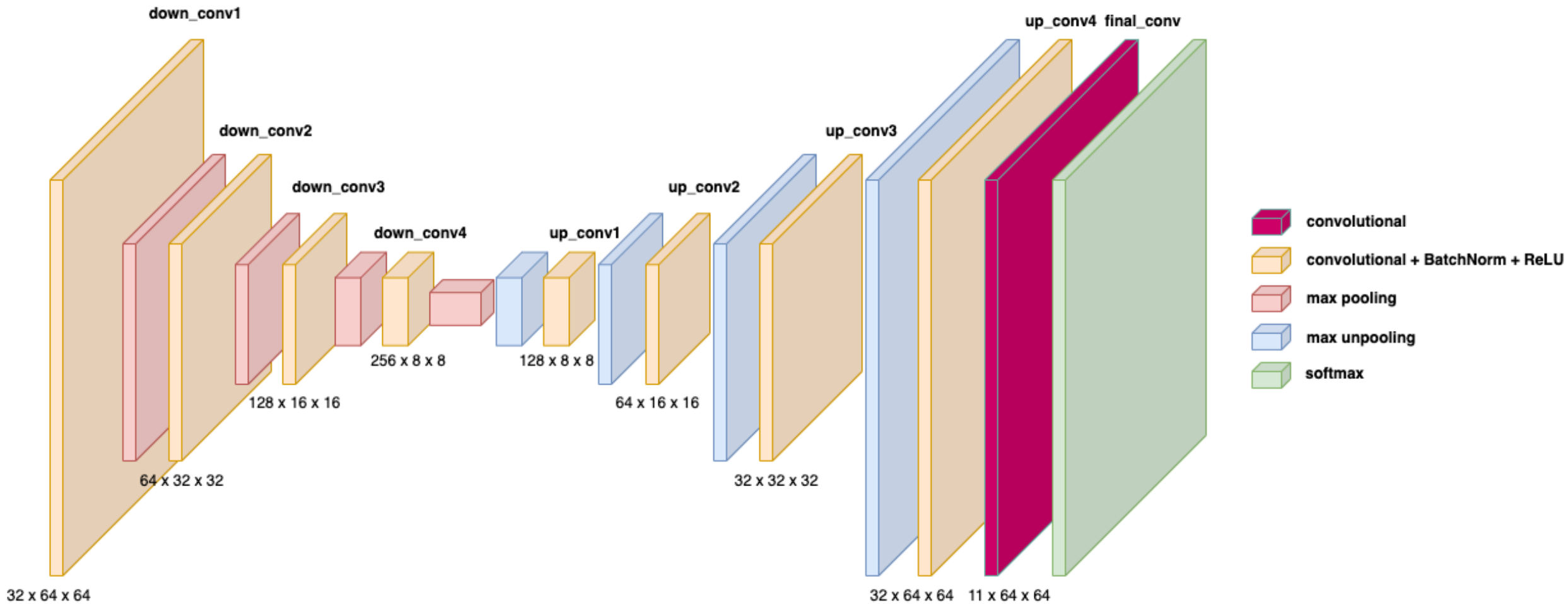


Output



Segmentation

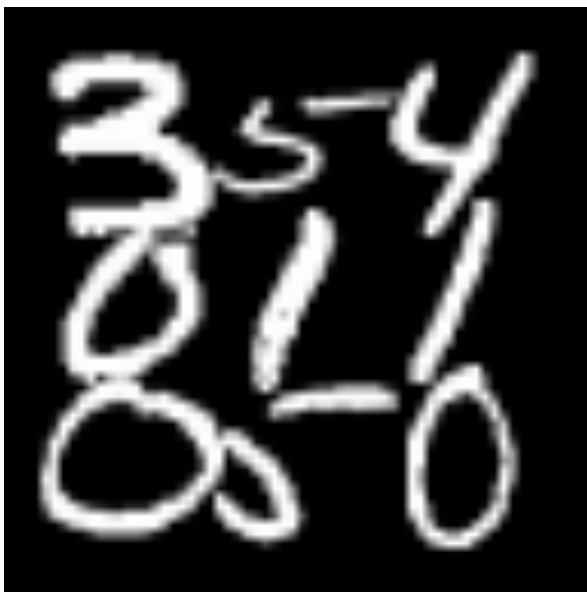
SegNet – Simplified Version



For illustration purpose only. Please check the code skeleton for specific network numbers

SegNet

- Dataset – multi-digit MNIST



Input Image (64x64)



GT Labels

Basic Modules

- Conv2d, BatchNorm2d, MaxPool2d and MaxUnpool2d

Basic Modules – BatchNorm2d

<https://pytorch.org/docs/stable/generated/torch.nn.BatchNorm2d.html>

```
CLASS torch.nn.BatchNorm2d(num_features, eps=1e-05, momentum=0.1, affine=True,  
    track_running_stats=True, device=None, dtype=None) [SOURCE]
```

Applies Batch Normalization over a 4D input (a mini-batch of 2D inputs with additional channel dimension) as described in the paper [Batch Normalization: Accelerating Deep Network Training by Reducing Internal Covariate Shift](#).

$$y = \frac{x - \mathbf{E}[x]}{\sqrt{\mathbf{Var}[x] + \epsilon}} * \gamma + \beta$$

The mean and standard-deviation are calculated per-dimension over the mini-batches and γ and β are learnable parameter vectors of size C (where C is the input size). By default, the elements of γ are set to 1 and the elements of β are set to 0. The standard-deviation is calculated via the biased estimator, equivalent to `torch.var(input, unbiased=False)`.

Also by default, during training this layer keeps running estimates of its computed mean and variance, which are then used for normalization during evaluation. The running estimates are kept with a default `momentum` of 0.1.

If `track_running_stats` is set to `False`, this layer then does not keep running estimates, and batch statistics are instead used during evaluation time as well.

Basic Modules – MaxUnpool2d

<https://pytorch.org/docs/stable/generated/torch.nn.MaxUnpool2d.html>

CLASS `torch.nn.MaxUnpool2d(kernel_size, stride=None, padding=0)` [\[SOURCE\]](#)

Computes a partial inverse of `MaxPool2d`.

`MaxPool2d` is not fully invertible, since the non-maximal values are lost.

`MaxUnpool2d` takes in as input the output of `MaxPool2d` including the indices of the maximal values and computes a partial inverse in which all non-maximal values are set to zero.

Loss – Per-pixel Cross-Entropy Loss

```
class CrossEntropy2D(nn.Module):
    def __init__(self, ignore_index, reduction='mean', weight=None):
        """Initialize the module

        Args:
            ignore_index: specify which the label index to ignore.
            reduction (str): reduction method. See torch.nn.functional.cross_entropy for details.
            output_dir (str): output directory to save the checkpoint
            weight: weight for samples. See torch.nn.functional.cross_entropy for details.
        """
        super(CrossEntropy2D, self).__init__()
        self.weight = weight
        self.ignore_index = ignore_index
        self.reduction = reduction

    def forward(self, output, target, resize_scores=True):
        """Forward pass of the loss function

        Args:
            output (torch.nn.Tensor): output logits, i.e. network predictions w.o. softmax activation.
            target (torch.nn.Tensor): ground truth labels.
            resize_scores (bool): if set to True, when target and output have different widths or heights,
                upsample output bilinearly to match target resolution. Otherwise, downsample
                target using nearest neighbor to match input.

        Returns:
            loss (torch.nn.Tensor): loss between output and target.
        """
        _assert_no_grad(target)

        b, c, h, w = output.size()
        tb, th, tw = target.size()

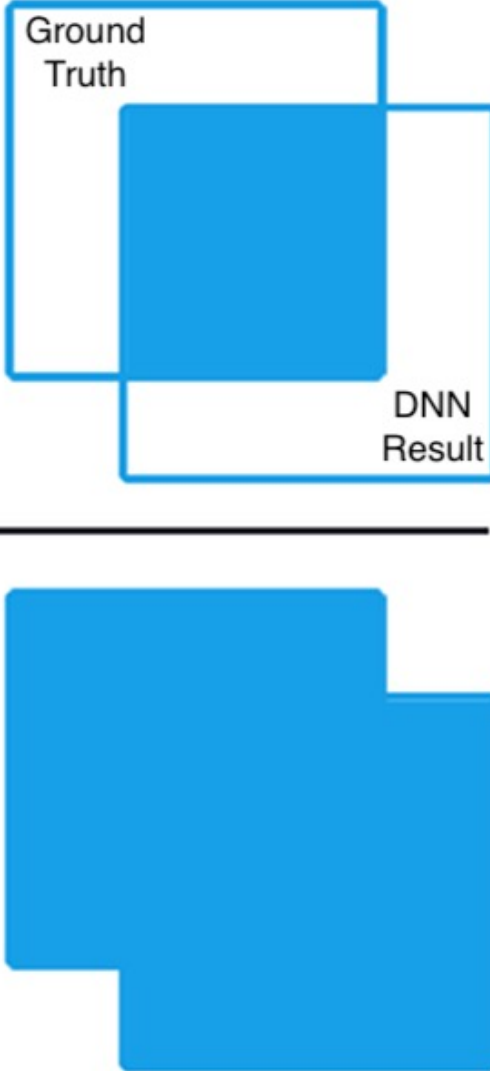
        assert(b == tb)

        # Handle inconsistent size between input and target
        if resize_scores:
            if h != th or w != tw: # upsample logits
                output = nn.functional.interpolate(output, size=(th, tw), mode="bilinear", align_corners=False)
            else:
                if h != th or w != tw: # downsample labels
                    target = nn.functional.interpolate(target.view(b, 1, th, tw).float(), size=(h, w), mode="nearest").view(b, h, w).long()

        loss = nn.functional.cross_entropy(
            output, target, weight=self.weight, ignore_index=self.ignore_index, reduction=self.reduction
        )

        return loss
```

Evaluation Metric – Intersection Over Union

$$\text{IoU} = \frac{\text{Area of Overlap}}{\text{Area of Union}}$$


The diagram illustrates the Intersection Over Union (IoU) metric. It shows two overlapping rectangles: a 'Ground Truth' rectangle (top-left) and a 'DNN Result' rectangle (bottom-right). The intersection of the two rectangles is shaded blue. Below the rectangles, the union of the two rectangles is also shaded blue, representing the total area covered by both.

- Due: November 24, 2023, at 11:59 AM (noon)
- If you have any inquiries regarding the assignment, kindly post them on Moodle.