

Project

hello

```
addpath('./functions');  
addpath('./data');
```

Mandatory Part: Methodology

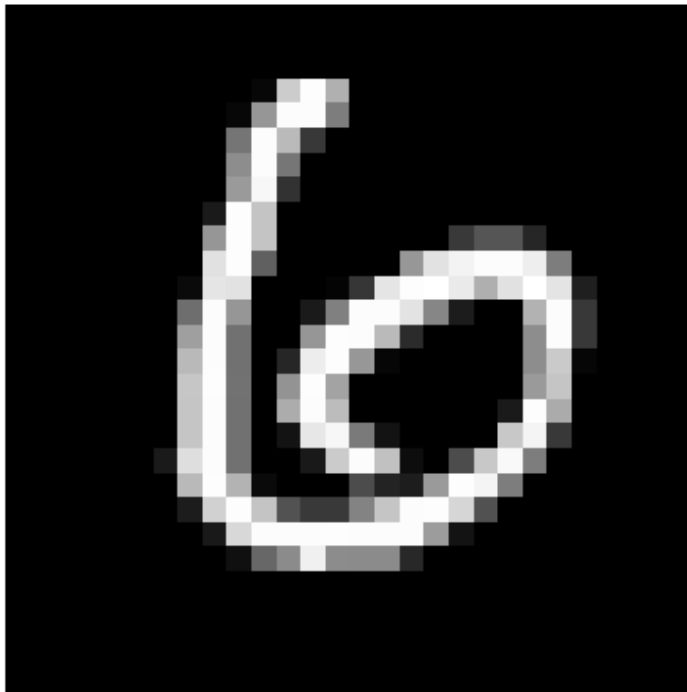
Loading the MNIST Dataset

Load the dataset

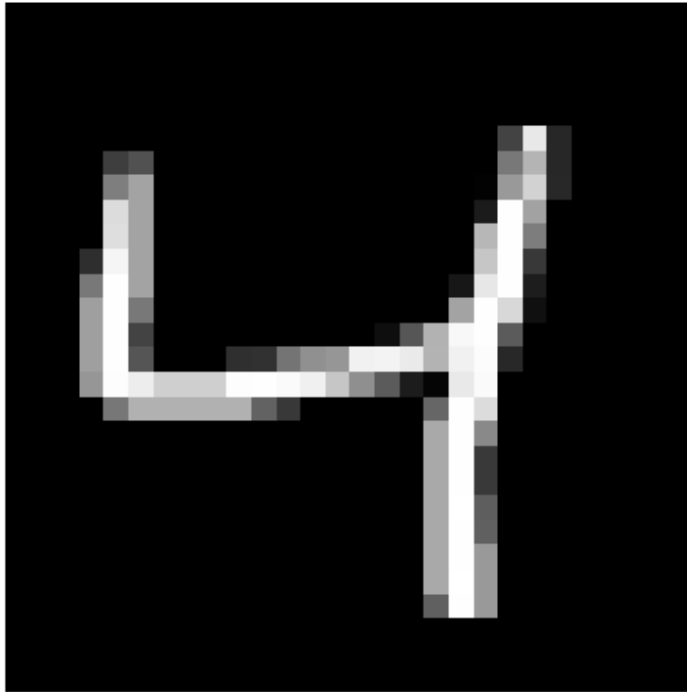
```
d = load('mnist.mat')  
  
d = struct with fields:  
    testX: [10000x784 uint8]  
    testY: [7 2 1 0 4 1 4 9 5 9 0 6 9 0 1 5 9 7 3 4 9 6 6 5 4 0 7 4 0 1 3 1 3 4 7 2 7 1 2 1 1 7 4 2 3 5 1  
    trainY: [5 0 4 1 9 2 1 3 1 4 3 5 3 6 1 7 2 8 6 9 4 0 9 1 1 2 4 3 2 7 3 8 6 9 0 5 6 0 7 6 1 8 7 9 3 9 8  
    trainX: [60000x784 uint8]
```

Visualize images:

```
show_digit(d.testX, 12)
```

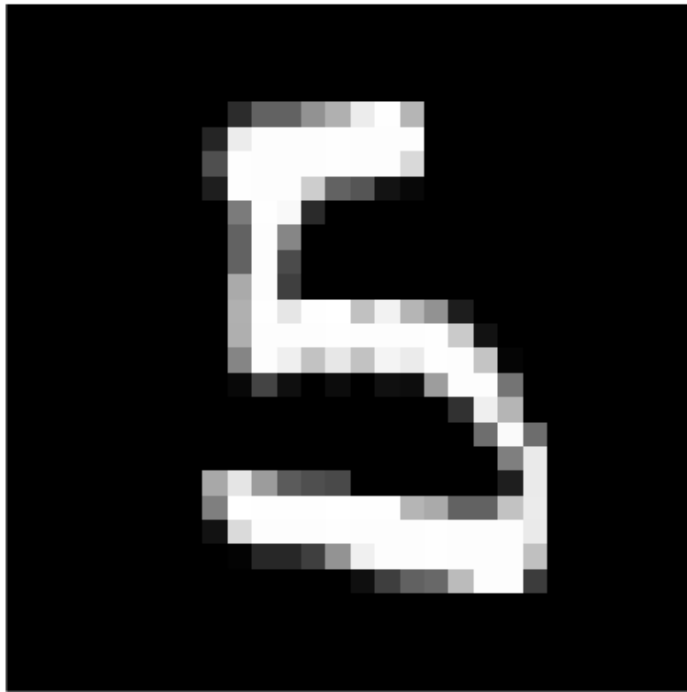


```
show_digit(d.trainX, 3)
```



Splitting the training part into training and test sets.

```
train_perc = 0.8;
% Handle images
x_train = d.trainX(1:int32(size(d.trainX, 1) * train_perc), :);
x_test = d.trainX(int32(size(d.trainX, 1) * train_perc)+1:end, :);
x_train = reshape(x_train, [28, 28, 1, size(x_train, 2)]);
x_test = reshape(x_test, [28, 28, 1, size(x_test, 2)]);
x_train = permute(x_train, [2 1 3 4]);
x_test = permute(x_test, [2 1 3 4]);
imshow(x_test(:, :, :, 5))
```



```
% Handle labels
y_train = d.trainY(1:int32(length(d.trainY) * train_perc));
y_test = d.trainY(int32(length(d.trainY) * train_perc)+1:end);
y_train = categorical(y_train);
y_test = categorical(y_test);

% Normalize images between 0 and 1
x_train = x_train ./ 255;
x_test = x_test ./ 255;
```

FCN

Model Definition

"The [segnetLayers](#) function creates a U-Net to perform semantic segmentation and the beauty of this type of a network is that it is made up primarily of convolution, relu and batchNormalization layers. Thus, one can pass arbitrary sized inputs during the inference/prediction stage.

This is because a convolutionLayer contains filters of some size (say 3x3) which can be applied on any input irrespective of its size(as mentioned it works well on 200x200 or 1000x1000). The reason why the size needs to be same during training stage is because training happens in batches and each batch must have same size in all dimensions, i.e. [H W C] dimensions need to be the same for all images during training. But during prediction you are free to pass in an input size smaller or greater than the size used during training."

```
fcn_layers = fcn_model()
```

```

fcnn_layers =
    10x1 Layer array with layers:

    1  ''  Image Input          28x28x1 images
    2  ''  Convolution          128 5x5 convolutions with stride [1 1] and padding 'same'
    3  ''  ReLU                  ReLU
    4  ''  Max Pooling           2x2 max pooling with stride [2 2] and padding [0 0 0 0]
    5  ''  Convolution           64 5x5 convolutions with stride [1 1] and padding [0 0 0 0]
    6  ''  ReLU                  ReLU
    7  ''  Max Pooling           2x2 max pooling with stride [2 2] and padding [0 0 0 0]
    8  ''  Convolution           10 5x5 convolutions with stride [1 1] and padding [0 0 0 0]
    9  ''  Softmax               softmax
    10 ''  Pixel Classification Layer Cross-entropy loss

```

```
% analyzeNetwork(fcnn_layers)
```

Training

Setup the optimizer and train the network.

```

num_epochs = 2;
% Setup Optimizer
% NOTE: For such a simple dataset, the learning rate drop is not actually
% required (nor actually happening), but I'll keep it for future
% references.
% NOTE: Also ValidationPatience is kinda useless here, but it turns out
% handy in future projects...
% NOTE: Momentum is not available with the Adam optimizer
optimizer = trainingOptions('adam', ...
    'InitialLearnRate', 2e-3, ...
    'LearnRateSchedule', 'piecewise', ...
    'LearnRateDropPeriod', 3, ...
    'LearnRateDropFactor', 0.5, ...
    'MaxEpochs', num_epochs, ...
    'MiniBatchSize', 128, ...
    'Plots','training-progress', ...
    'ValidationData', {x_test, y_test}, ...
    'ValidationPatience', 10);

% Train the network
fcnn_net = trainNetwork(x_train, y_train, fcnn_layers, optimizer);

```

Training on single CPU.

Epoch	Iteration	Time Elapsed (hh:mm:ss)	Mini-batch Accuracy	Validation Accuracy	Mini-batch Loss	Validation Loss	Ba
1	1	00:00:15	18.75%	14.70%	2.2887	2.2677	
1	50	00:00:34	93.75%	94.18%	0.2318	0.1983	
1	100	00:00:52	95.31%	96.16%	0.1553	0.1208	
1	150	00:01:11	97.66%	96.99%	0.0898	0.0985	
1	200	00:01:30	97.66%	97.76%	0.0607	0.0727	
1	250	00:01:49	97.66%	97.28%	0.0983	0.0899	
1	300	00:02:08	96.88%	98.00%	0.0882	0.0626	
1	350	00:02:27	97.66%	98.04%	0.0795	0.0667	
2	400	00:02:46	97.66%	98.49%	0.0572	0.0513	

2	450	00:03:05	99.22%	98.55%	0.0340	0.0480
2	500	00:03:26	99.22%	98.28%	0.0269	0.0558
2	550	00:03:45	97.66%	98.41%	0.0982	0.0533
2	600	00:04:05	98.44%	98.37%	0.0525	0.0524
2	650	00:04:24	99.22%	98.62%	0.0218	0.0471
2	700	00:04:43	100.00%	98.52%	0.0134	0.0469
2	750	00:05:03	98.44%	98.37%	0.0356	0.0541

=====

Training finished: Max epochs completed.

```
save('./data/fcn_net.mat', 'fcn_net');
```

Save or releod network.

```
load('./data/fcn_net.mat', 'fcn_net');
```

Evaluation

```
acc_count = nnz(fcn_net.classify(x_test)' == y_test);
acc = acc_count / size(y_test, 2);
disp(['INFO. Network accuracy: ' num2str(acc * 100) '%%'])
```

INFO. Network accuracy: 98.3667%%

Scale Space

Load Test Image

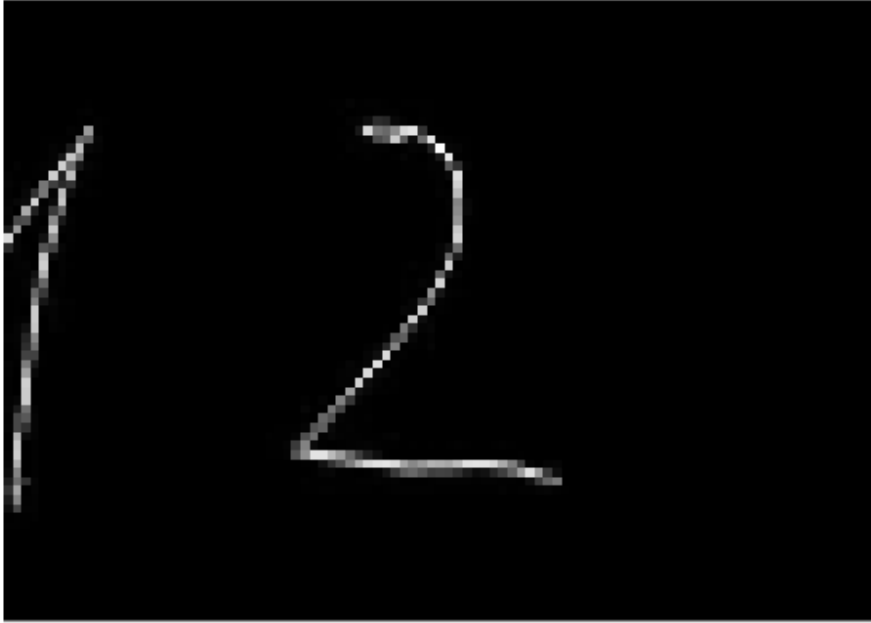
```
as_grayscale = true;
img = read_image('./data/handwritten.png', as_grayscale);
img = imcomplement(img); % Invert black and white
% img = img ./ max(img, [], 'all'); % Normalize b/w 0 and 1

img_patch = img(782:918, 645:838); % Consider just a portion, for testing
imshow(img_patch)
```

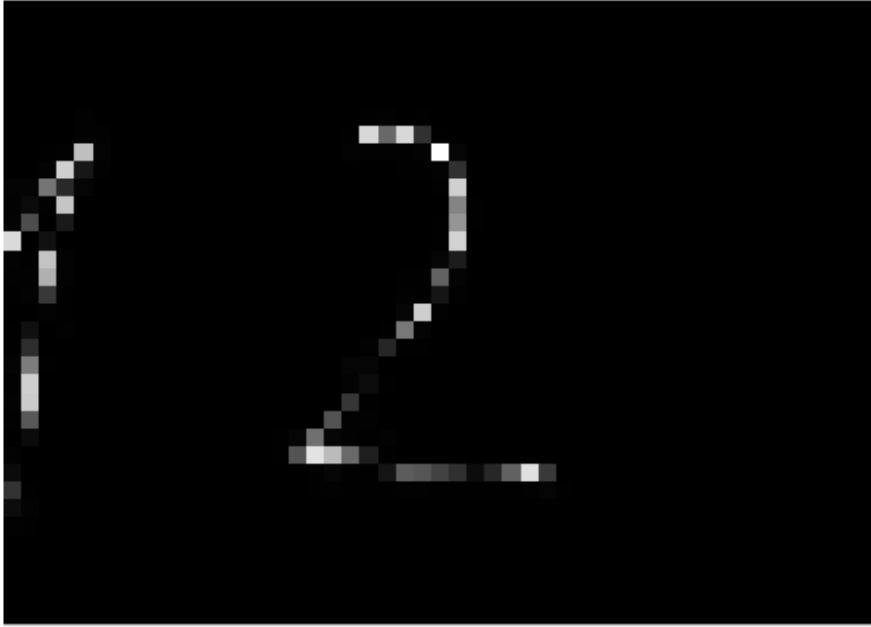


Downscaling (no smoothing)

```
down_factor = 2;  
img_down = img_patch(1:down_factor:end, 1:down_factor:end);  
imshow(img_down)
```

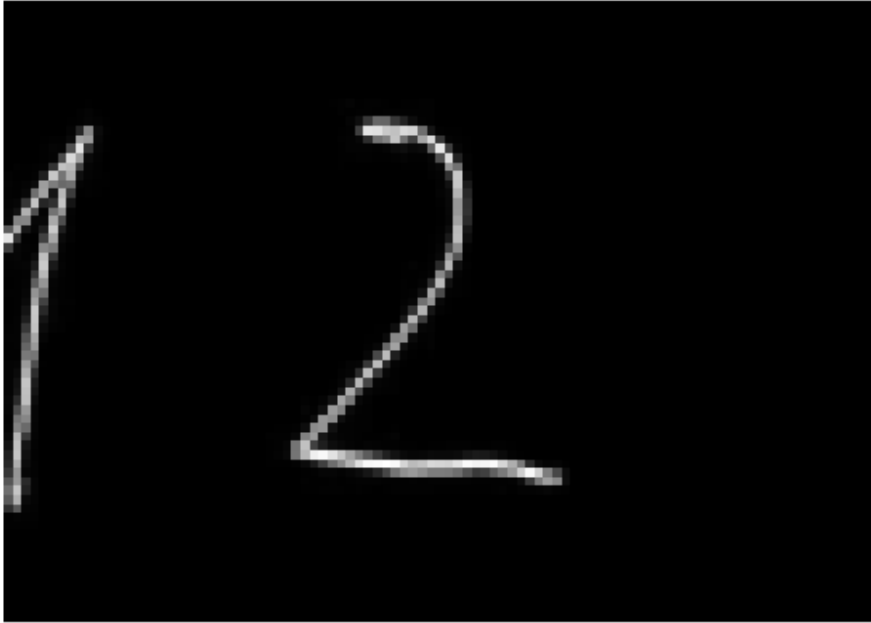


```
down_factor = 4;  
img_down = img_patch(1:down_factor:end, 1:down_factor:end);  
imshow(img_down)
```



Smoothing and Downscaling

```
down_factor = 2;
img_smooth = gaussian_filter(img_patch, 0.8);
img_down = img_smooth(1:down_factor:end, 1:down_factor:end);
img_down = img_down ./ max(img_down, [], 'all'); % Normalize b/w 0 and 1
size(img);
size(img_down);
imshow(img_down)
```

```
img_down = downscale(img_down, down_factor, down_factor * 0.8);  
imshow(img_down)
```



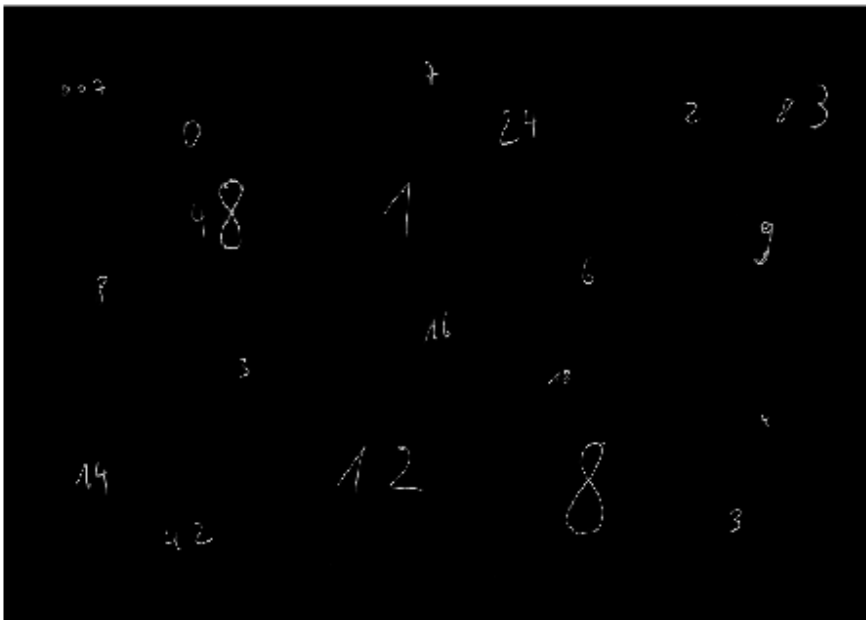
Get Boxes from Image

Reload test image

```
as_grayscale = true;
img = read_image('./data/handwritten.png', as_grayscale);
img = imcomplement(img); % Invert black and white
img = img ./ max(img, [], 'all'); % Normalize b/w 0 and 1
size(img)
```

```
ans = 1x2
      1131      1600
```

```
imshow(img)
```



Loop over image dimensions and get boxes and the actual image patches (to be used as input to the `semanticseg()` function). No padding. Always starting from top left corner.

If there is no overlapping, then when utilizing IoU, we would need to **combine** the patches with the same classification in a bigger patch. For now, add some overlapping such that some more patches are generated.

```
box_size = 28;
stride = int32(box_size / 2);
[bboxes, boxes] = get_bboxes(img, box_size, stride);
size(bboxes), size(boxes)
```

```
ans = 1x2
```

```

      8927      4
ans = 1x4
      28      28      1      8927

```

Non-Maximum Suppression (NMS)

The NMS happens in two steps:

1. Remove all patches with a low confidence score, i.e. with a low maximum probability
2. (If no overlapping patches, form the boxes with the same classification)
3. Use Intersect Over Union (IoU) to get the most accurate box

TODO: Where do I store the patches? Cell array?

```

% First get the patches by running the FCN
[~, box_class_probs] = semanticseg(boxes, fcn_net);

```

Step 1:

Get rid of boxes with a low confidence score, i.e. class prob

```

% Get the max prob from the 10 prob scores and the associated labels
[box_confidence, labels] = max(box_class_probs, [], 2);
confidence_threshold = 0.8;
bboxes_best = bboxes(box_confidence > confidence_threshold, :);
labels = labels(box_confidence > confidence_threshold);
box_scores = box_confidence(box_confidence > confidence_threshold);

```

Step 2:

Identify the best bounding boxes via the MATLAB predefined function.

```

iou_threshold = 0.3;
[selected_boxes, selected_scores, selected_labels, index] = selectStrongestBboxMultiClass(
size(selected_boxes)

```

```

ans = 1x2
      84      4

```

```

size(selected_labels)

```

```

ans = 1x2
      84      1

```

Wrapping NMS into a function

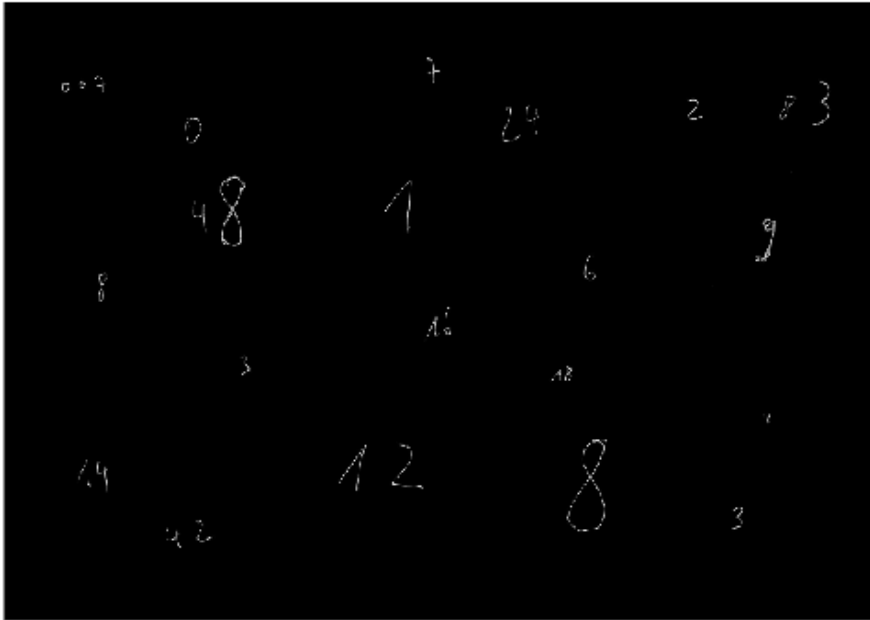
```

as_grayscale = true;
img = read_image('./data/handwritten.png', as_grayscale);
img = imcomplement(img); % Invert black and white
img = img ./ max(img, [], 'all'); % Normalize b/w 0 and 1
size(img)

```

```
ans = 1x2
      1131      1600
```

```
imshow(img)
```



```
box_size = 28;
stride = 11;
confidence_threshold = 0.5;
iou_threshold = 0.5;
[boxes, scores, labels] = semanticseg_scalelevel(img, fcn_net, ...
                                                  box_size, stride, ...
                                                  confidence_threshold, ...
                                                  iou_threshold);
disp(['INFO. Number of boxes found: ' num2str(size(boxes, 1))])
```

```
INFO. Number of boxes found: 316
```

```
plot_bboxes(img, boxes, labels, scores)
```



Scaling and NMS

Must happen at the same scale level

```
box_size = 28;

down_factor = 2;
stride = 15;
confidence_threshold = 0.8;
iou_threshold = 0.6;
std = 0.8;

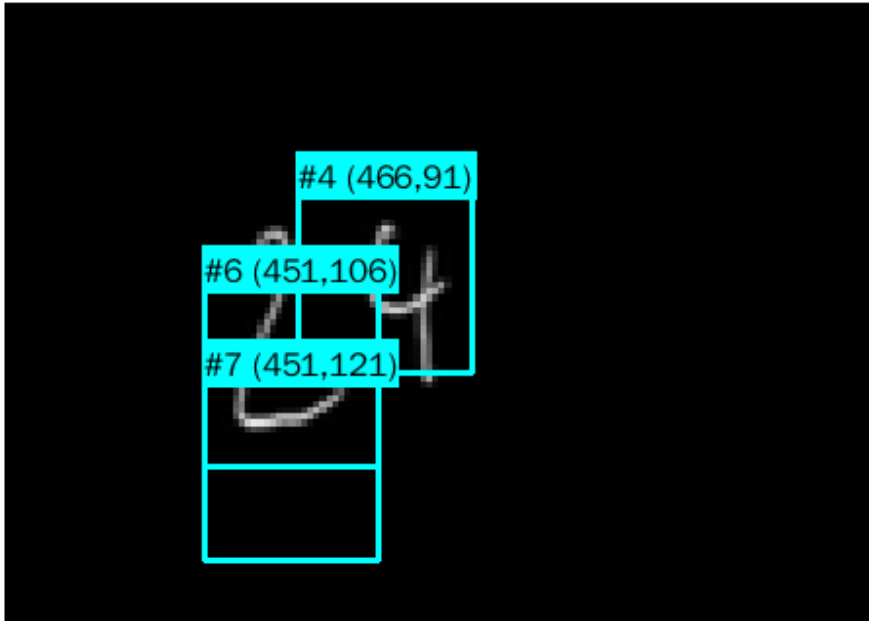
img_down = downscale(img, down_factor, std);
size(img_down)
```

```
ans = 1x2
    566    800
```

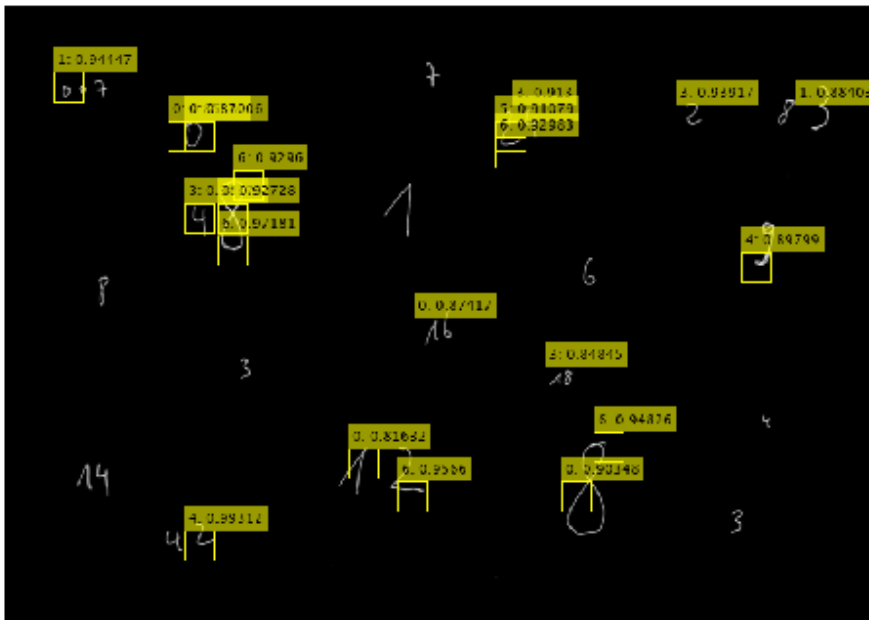
```
[boxes, scores, labels] = nms(img_down, fcn_net, box_size, stride, confidence_threshold, iou_threshold);
disp(['INFO. Number of boxes found: ' num2str(size(boxes, 1))])
```

```
INFO. Number of boxes found: 20
```

```
plot_bboxes(img_down, boxes, labels)
```



```
plot_bboxes(img_down, boxes, labels, scores)
```



```
find(labels == 0)
```

```
ans =
```

```
0x1 empty double column vector
```

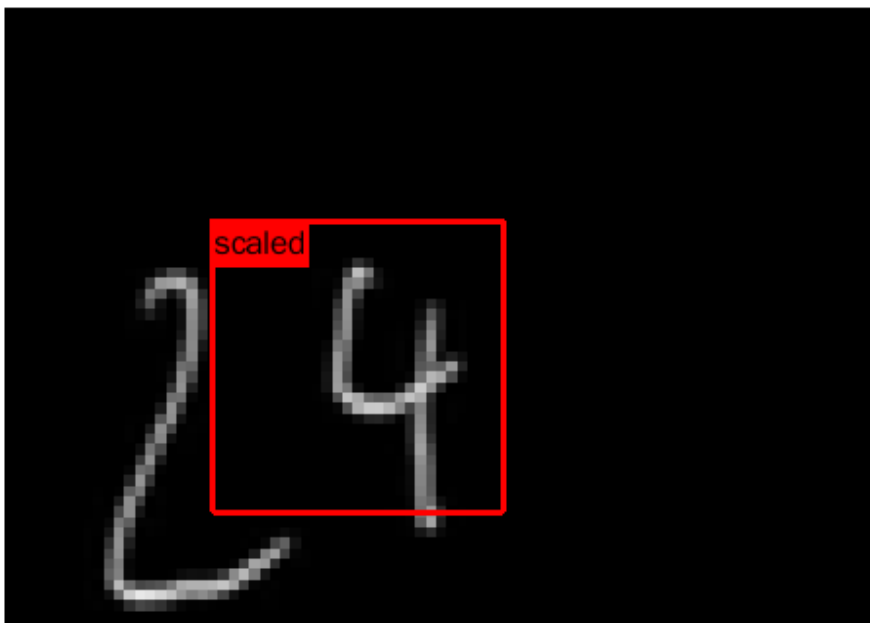
NMS across Scale Levels

Get all bounding boxes at different scale levels. First check that the bbox definition scales with the scale level: **it does**.

```
box_size = 28;
down_factor = 2;
std = 0.8;

img_down = downscale(img, down_factor, std);
boxes = zeros(2, 4);
boxes(1, :) = [466, 91, box_size, box_size];
boxes(2, :) = boxes(1, :) * down_factor;

figure, imshow(img_down);
hold on;
showShape('rectangle', round(boxes(1, :)), 'Label', 'scaled', 'Color', 'red');
hold off;
```



```
figure, imshow(img);
```

```

hold on;
showShape('rectangle', round(boxes(2, :)), 'Label', 'orig', 'Color', 'cyan');
hold off;

```



```

% Fixed parameters at all scale levels
box_size = 28;
std = 0.8;
confidence_threshold = 0.7;
iou_threshold = 0.3;
% Scale levels and changing parameters
downscale_levels = [1, 2, 3, 4, 5, 6, 7, 8, 1/2, 1/3];
strides = [5, 5, 5, 5, 5, 5, 3, 5, 11, 15];
bboxes = [];
scores = [];
labels = [];
for n = 1:length(downsacle_levels)
    t = downscale_levels(n);
    confidence_threshold = confidence_threshold - t * 0.01;
    stride = strides(n);
    img_down = downscale(img, t, std);
    [b, s, l] = semanticseg_scalelevel(img_down, ...
                                       fcn_net, box_size, stride, ...
                                       confidence_threshold, iou_threshold);
    disp(['INFO. Number of boxes found at level ' num2str(t) ': ' num2str(size(b, 1))])
    if size(b, 1) > 0

```



```

        if n == 1
            bboxes = round(b * t);
            scores = s;
            labels = l;
        else
            bboxes = vertcat(bboxes, round(b * t));
            scores = vertcat(scores, s);
            labels = vertcat(labels, l);
        end
    end
end
end

```

```

num bboxes: 49
INFO. Number of boxes found at level 1: 49
num bboxes: 31
INFO. Number of boxes found at level 2: 31
num bboxes: 6
INFO. Number of boxes found at level 3: 6
num bboxes: 1
INFO. Number of boxes found at level 4: 1
num bboxes: 0
INFO. Number of boxes found at level 5: 0
num bboxes: 0
INFO. Number of boxes found at level 6: 0
num bboxes: 0
INFO. Number of boxes found at level 7: 0
num bboxes: 1
INFO. Number of boxes found at level 8: 1
num bboxes: 4
INFO. Number of boxes found at level 0.5: 4
num bboxes: 0
INFO. Number of boxes found at level 0.33333: 0

```

```

disp(['INFO. Total boxes found: ' num2str(size(bboxes, 1))])

```

```

INFO. Total boxes found: 92

```

Use IoU as NMS once we found all boxes at all desired levels.

```

iou_threshold = 0.8;
[final_boxes, final_scores, final_labels, ~] = ...
    selectStrongestBboxMulticlass(bboxes, scores, labels, ...,
    'OverlapThreshold', 1- iou_threshold);
disp(['INFO. Final boxes found: ' num2str(size(final_boxes, 1))])

```

```

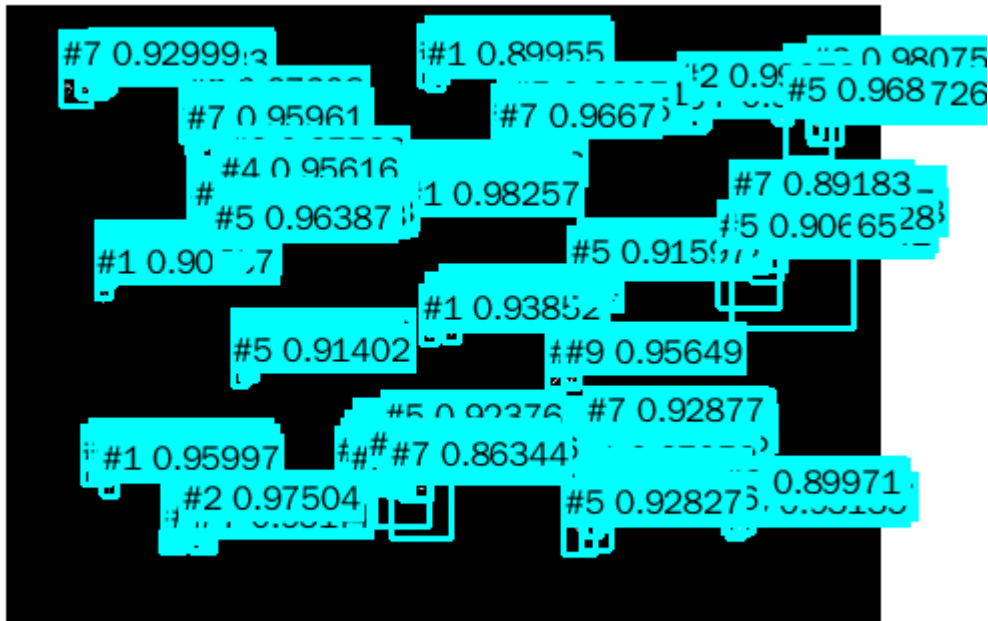
INFO. Final boxes found: 152

```

```

plot_bboxes(img, final_boxes, final_labels, final_scores)

```



The function `bboxOverlapRatio()` returns a matrix of IoU ratios. If applied on the boxes, it will give us the IoU of all the **pairs** of boxes. Naturally, the main diagonal will be all 1s since each pair perfectly overlaps with itself, whereas the overall matrix will be symmetrical. That's why we only consider the bottom half of it through the `tril(..., -1)` function.

```
iou_threshold = 0.2;
size(bboxes, 1)
```

```
ans = 92
```

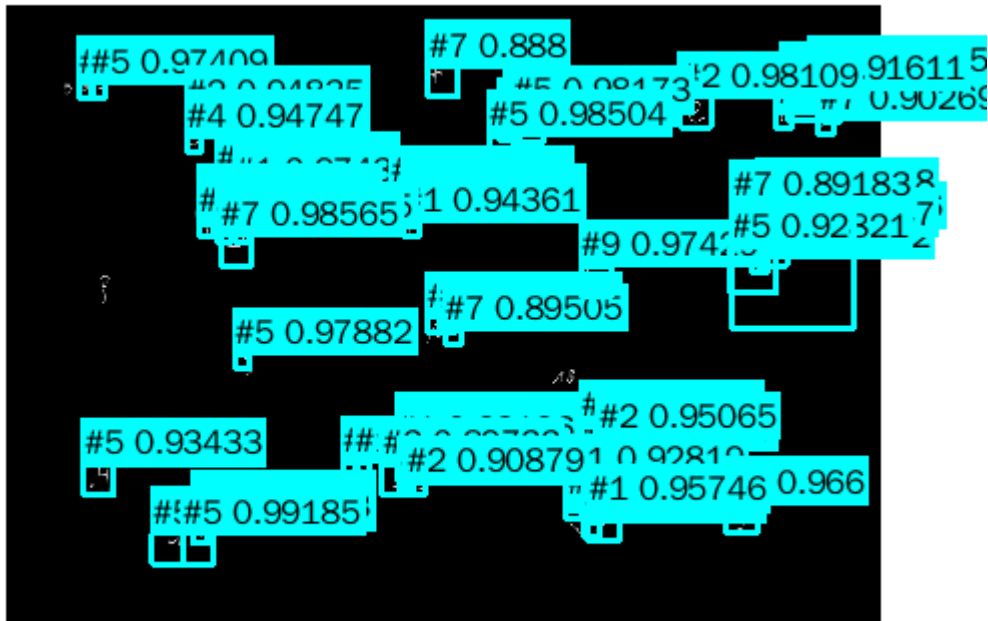
```
[final_boxes, final_scores, final_labels] = nms(bboxes, ...
        scores, labels, iou_threshold);
```

```
num bboxes: 60
```

```
size(final_boxes, 1)
```

```
ans = 60
```

```
plot_bboxes(img, final_boxes, final_labels, final_scores)
```



Wrapping all together in a single function

```
% Fixed parameters at all scale levels
box_size = 28;
std = 0.8;
confidence_threshold = 0.9;
iou_level_threshold = 0.3;
iou_final_threshold = 0.02;
% Scale levels and changing parameters
downscale_levels = [1, 2, 3, 4, 5, 6, 1/1.5, 1/2, 1/3];
strides = [15, 11, 11, 7, 7, 7, 7, 11, 11];

[final_boxes, final_scores, final_labels] = semanticseg_img(...
    img, fcn_net, box_size, strides, downscale_levels, ...
    confidence_threshold, iou_level_threshold, iou_final_threshold)
```

```
INFO. Number of boxes found at level 1: 32
INFO. Number of boxes found at level 2: 13
INFO. Number of boxes found at level 3: 3
INFO. Number of boxes found at level 4: 1
INFO. Number of boxes found at level 5: 0
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 51
INFO. Number of boxes found at level 0.5: 4
INFO. Number of boxes found at level 0.33333: 0
INFO. Total boxes found: 47
final_boxes = 47x4
    331    241    28    28
```

901	241	28	28
691	361	28	28
391	391	28	28
421	421	28	28
391	436	28	28
1366	451	28	28
1051	466	28	28
166	481	28	28
166	511	28	28

⋮

`final_scores = 47x1 single column vector`

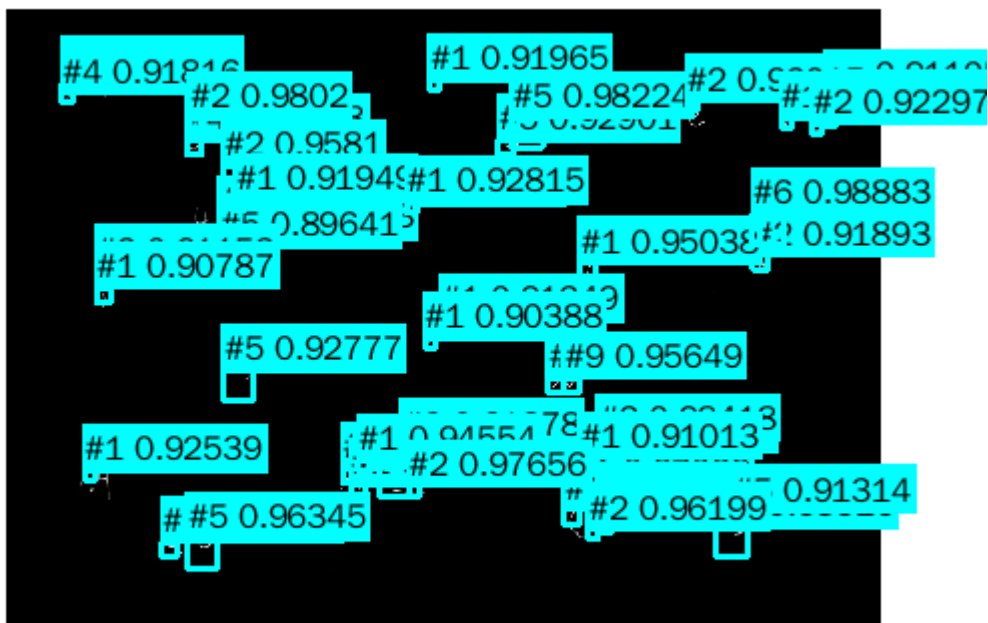
0.9696
0.9290
0.9505
0.9861
0.9954
0.8964
0.9189
0.9504
0.9115
0.9079

⋮

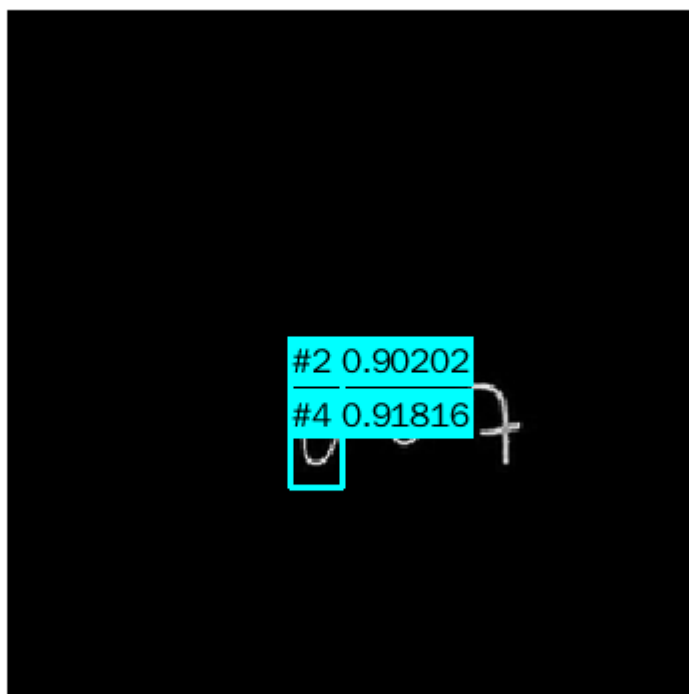
`final_labels = 47x1`

4
5
1
1
1
5
2
1
2
1
⋮
⋮

```
plot_bboxes(img, final_boxes, final_labels, final_scores)
```



```
plot_bboxes(img(1:250, 1:250), final_boxes, final_labels, final_scores)
```



Mandatory Part: Evaluation

Load gold annotations

```
anno = load('anno.mat').anno;  
anno.bbox_annotations
```

```
ans = 4×10 table
```

...

	digit_0	digit_1	digit_2
1	4×4 double	[502,374,22,23;852,324...	[393,212,53,61;489,217...
2	4×4 double	[464,426,25,22;849,330...	[406,207,54,62;515,203...
3	3×4 double	5×4 double	4×4 double
4	[134,106,35,48;191,105...	4×4 double	3×4 double

```
anno.image_filenames
```

```
ans = 4×1 cell  
'computer_generated.png'  
'computer_generated_rotated.png'  
'handwritten.png'  
'handwritten_rotated.png'
```

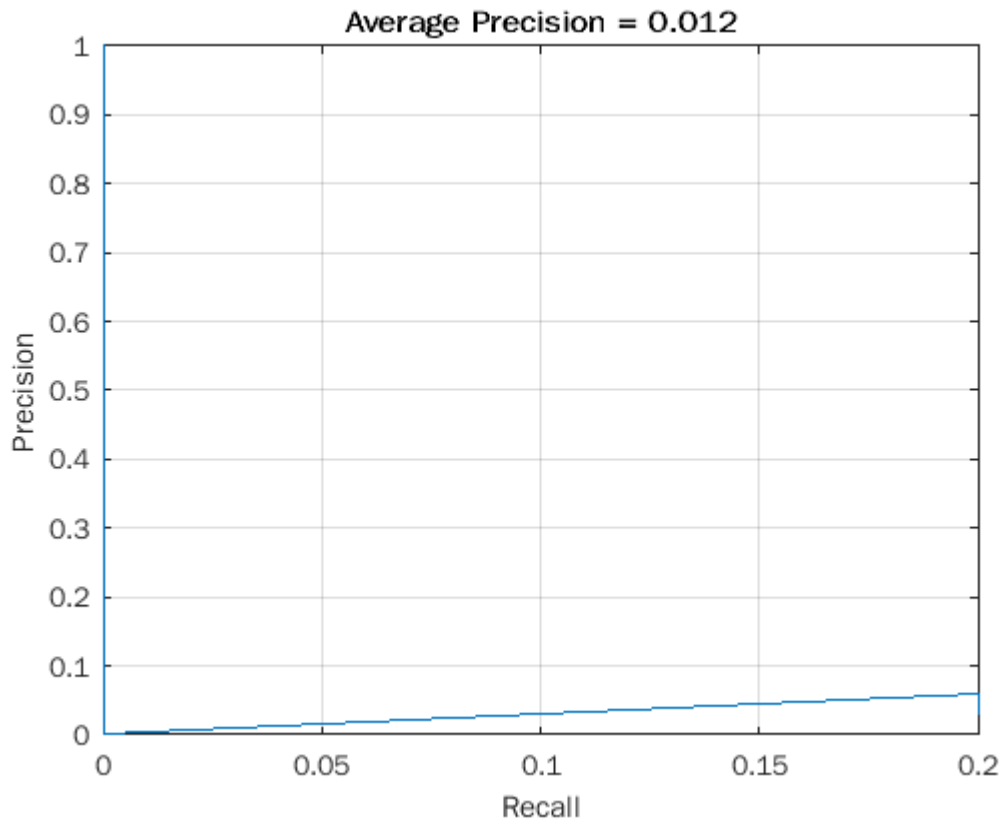
```
digit_annotations = anno.bbox_annotations(3, :)
```

```
digit_annotations = 1×10 table
```

...

	digit_0	digit_1	digit_2	digit_3	digit_4	digit_5
1	3×4 double	5×4 double	4×4 double	3×4 double	5×4 double	[]

```
[average_precision, recall, precision] = eval_semanticseg(...  
    digit_annotations, final_boxes, final_scores, final_labels);  
% plot(cell2mat(recall), cell2mat(precision))  
average_precision;  
recall;  
precision;  
digit = 2;  
ap = average_precision(digit);  
r = (cell2mat(recall(digit, :)));  
p = (cell2mat(precision(digit, :)));  
figure, plot(r, p)  
grid on  
title(sprintf('Average Precision = %.3f', ap))  
xlabel('Recall')  
ylabel('Precision')
```



```

as_grayscale = true;
% Fixed parameters at all scale levels
box_size = 28;
std = 0.8;
confidence_threshold = 0.8;
iou_level_threshold = 0.5;
iou_final_threshold = 0.5;
% Scale levels and changing parameters
downscale_levels = [1, 2, 3, 4, 5, 6, 1/1.5, 1/2, 1/3, 1/4];
strides = [15, 15, 11, 11, 11, 11, 11, 7, 11, 15];

for n = [1, 3] % 1:length(anno.image_filenames)
    disp(['Semantic Segmentation on image: ' string(anno.image_filenames(n))])
    % Load image and normalize it
    img = read_image('./data/' + string(anno.image_filenames(n)), as_grayscale);
    img = imcomplement(img); % Invert black and white
    img = img ./ max(img, [], 'all'); % Normalize b/w 0 and 1
    % Run Semantic Segmentation
    [final_boxes, final_scores, final_labels] = semanticseg_img(...
        img, fcn_net, box_size, strides, downscale_levels, ...
        confidence_threshold, iou_level_threshold, iou_final_threshold);
    % Evaluate system
    digit_annotations = anno.bbox_annotations(n, :);
    [average_precision, recall, precision] = eval_semanticseg(digit_annotations, ...
        final_boxes, final_scores, final_labels);

```

```

% Plotting
average_precision, recall, precision
disp(['Average mAP across digits: ' num2str(mean(average_precision))])
figure, plot_bboxes(img, final_boxes, final_labels, final_scores)
title(sprintf('BBoxes for %s', string(anno.image_filenames(n))));
for digit = 1:10
    ap = average_precision(digit);
    r = (cell2mat(recall(digit, :)));
    p = (cell2mat(precision(digit, :)));
    figure, plot(r, p)
    grid on
    title(sprintf('Average Precision for digit %d: %.3f', digit, ap))
    xlabel('Recall')
    ylabel('Precision')
end
end

```

```

"Semantic Segmentation on image: " "computer_generated.png"
INFO. Number of boxes found at level 1: 41
INFO. Number of boxes found at level 2: 27
INFO. Number of boxes found at level 3: 23
INFO. Number of boxes found at level 4: 21
INFO. Number of boxes found at level 5: 11
INFO. Number of boxes found at level 6: 4
INFO. Number of boxes found at level 0.66667: 56
INFO. Number of boxes found at level 0.5: 10
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 193
INFO. Total boxes found: 168
average_precision = 10x1
    0.2500
    0.5000
    0.5000
         0
         0
    0.3333
         0
    0.0738
         0
         0
recall = 10x1 cell

```

	1
1	[0;0;0.2...
2	32x1 double
3	46x1 double
4	0
5	0
6	33x1 double
7	[0;0;0;0...
8	43x1 double

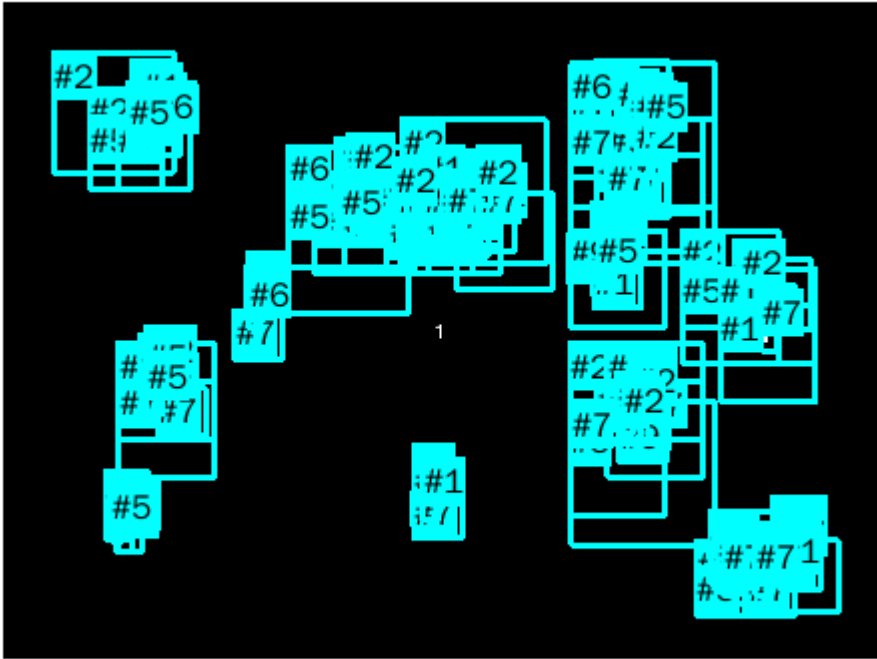
	1
9	0
10	[0;0;0;0...

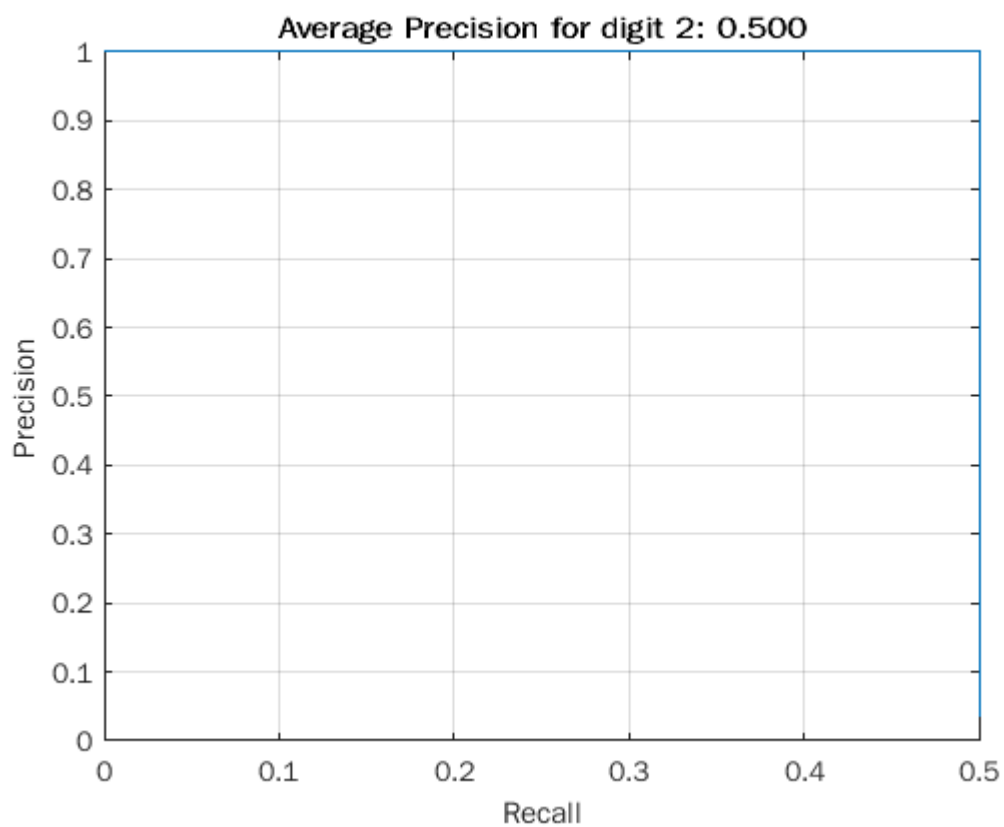
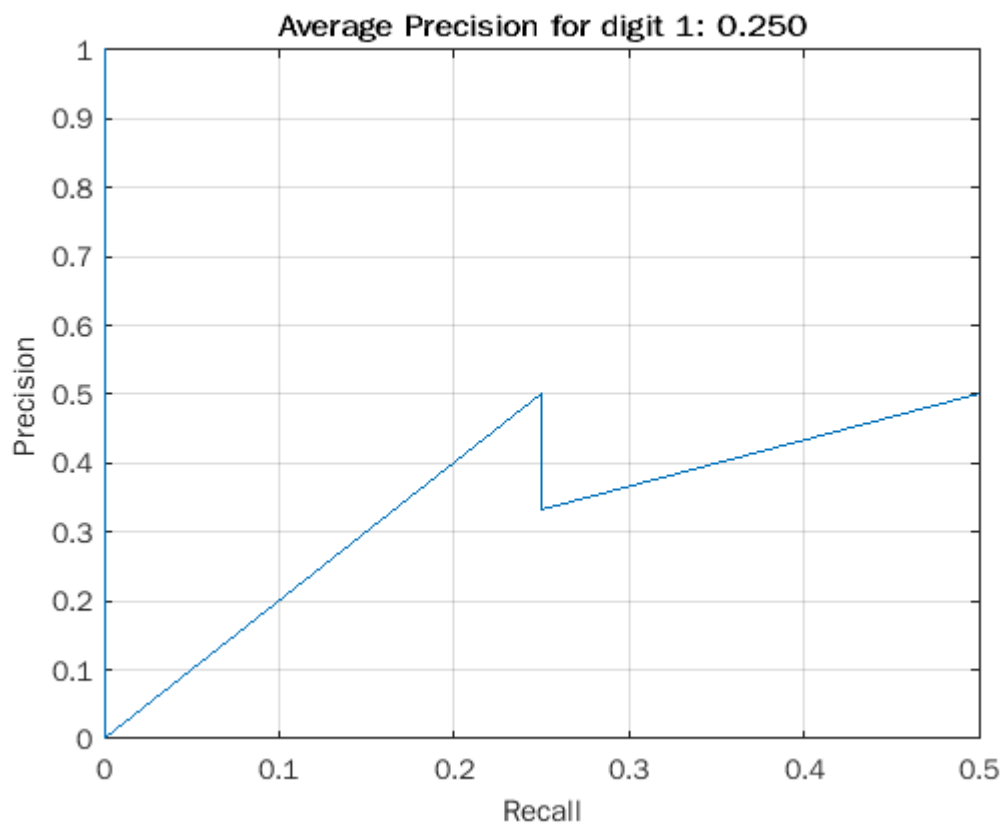
```
precision = 10x1 cell
```

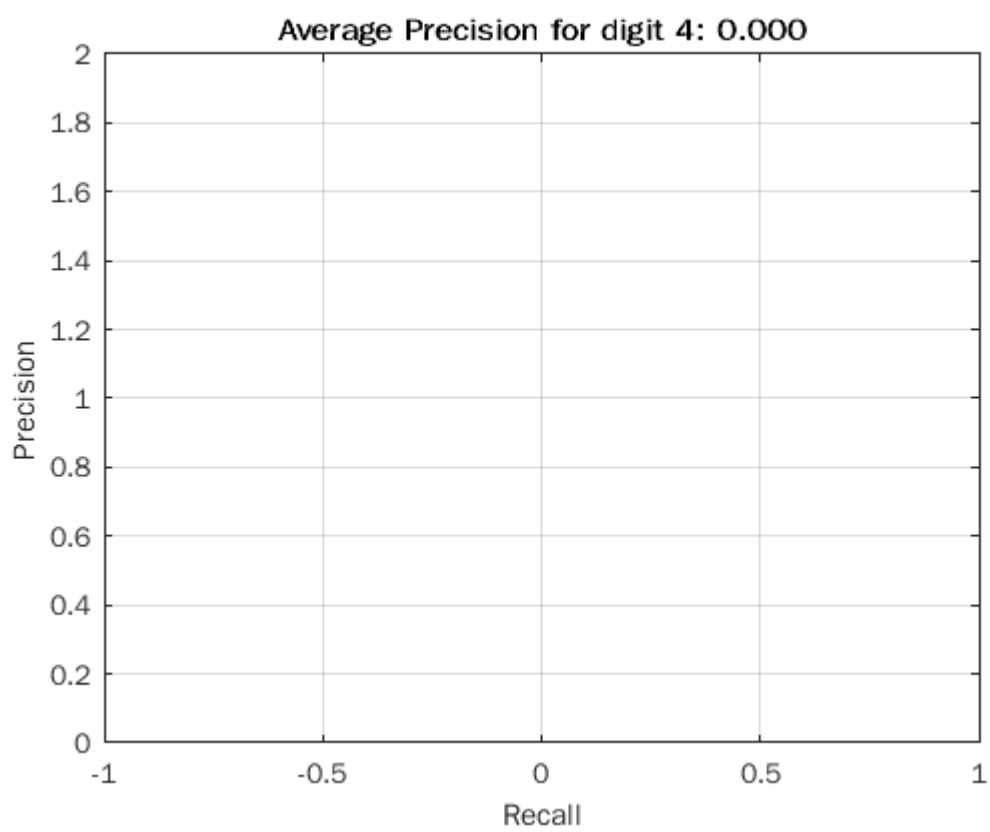
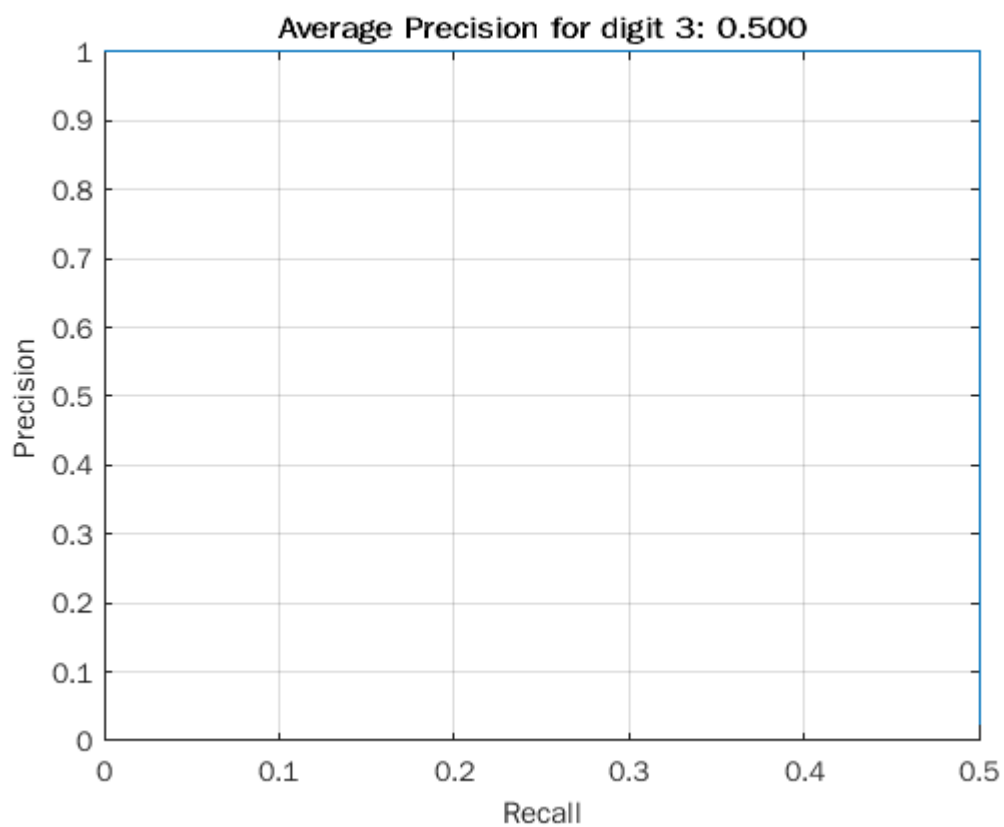
	1
1	[1;0;0.5...
2	32x1 double
3	46x1 double
4	1
5	1
6	33x1 double
7	[1;0;0;0...
8	43x1 double
9	1
10	[1;0;0;0...

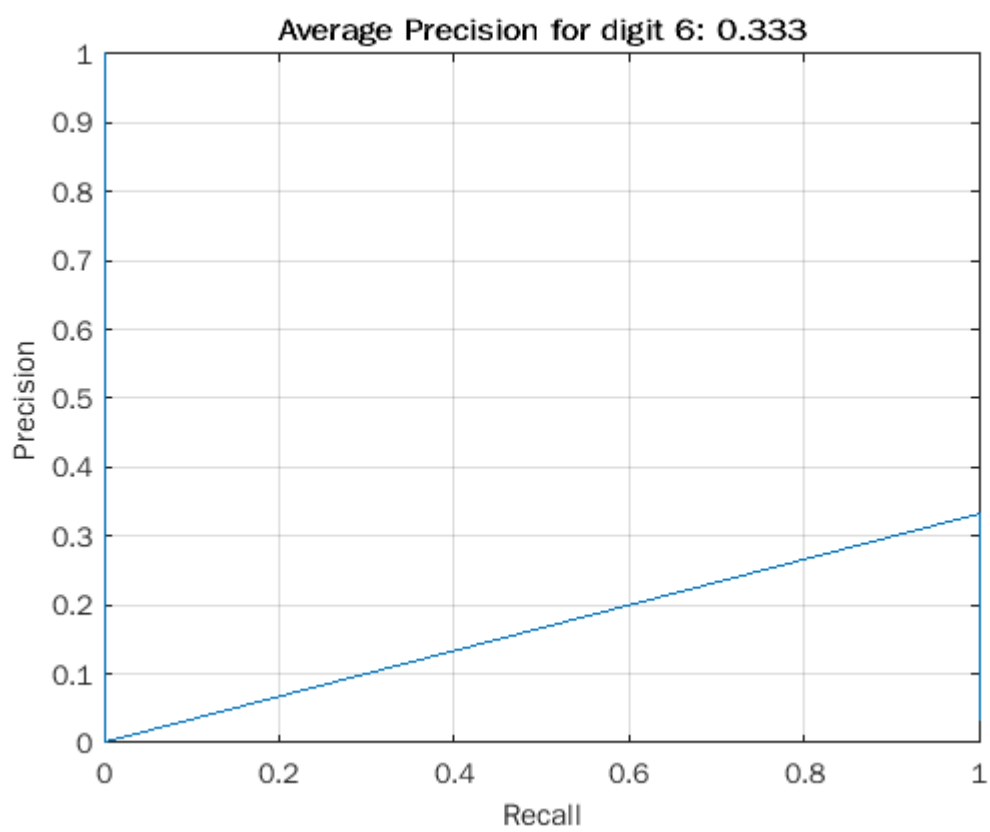
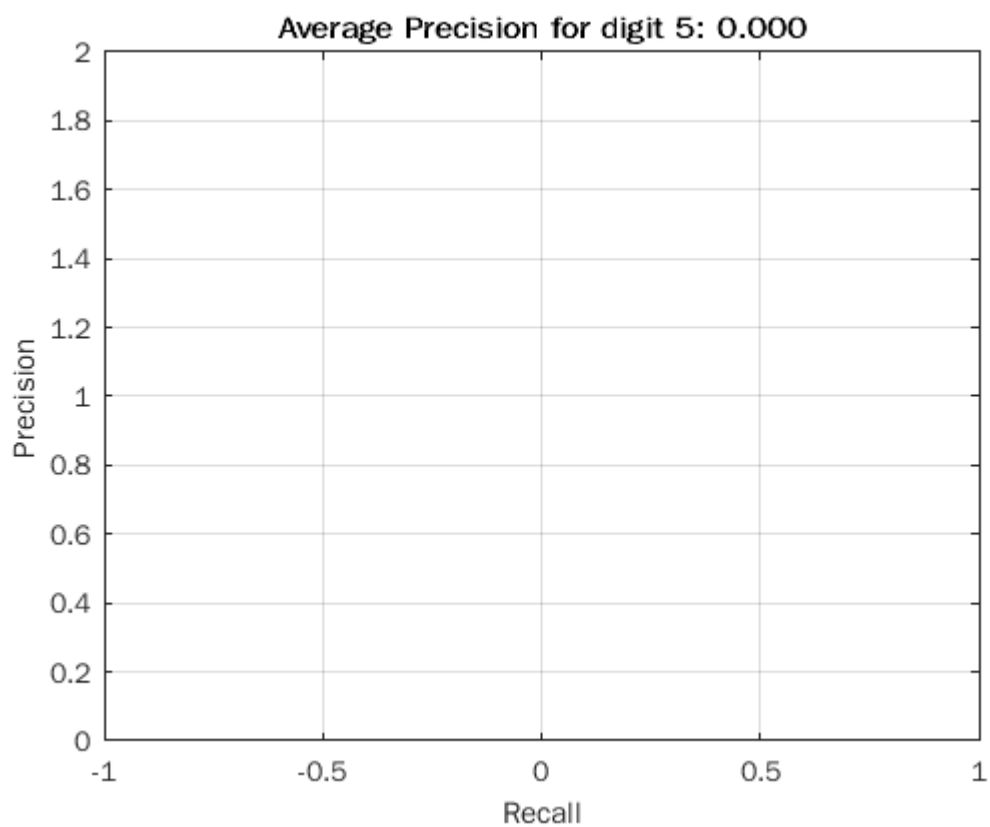
```
Average mAP across digits: 0.16571
```

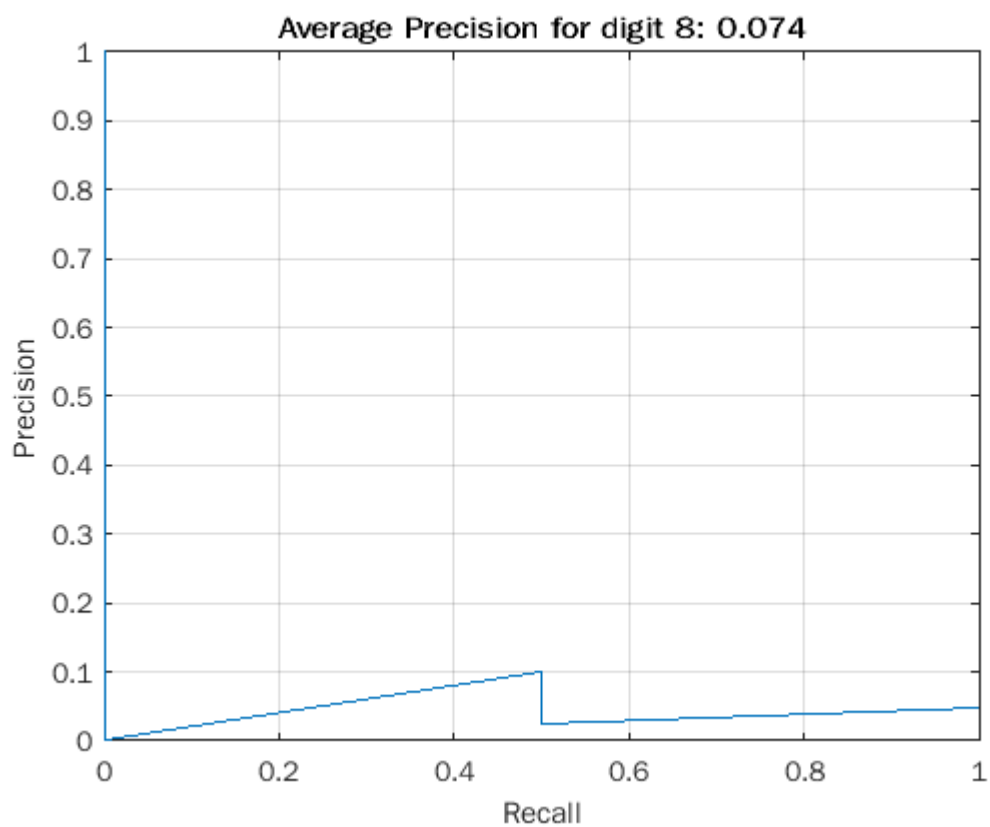
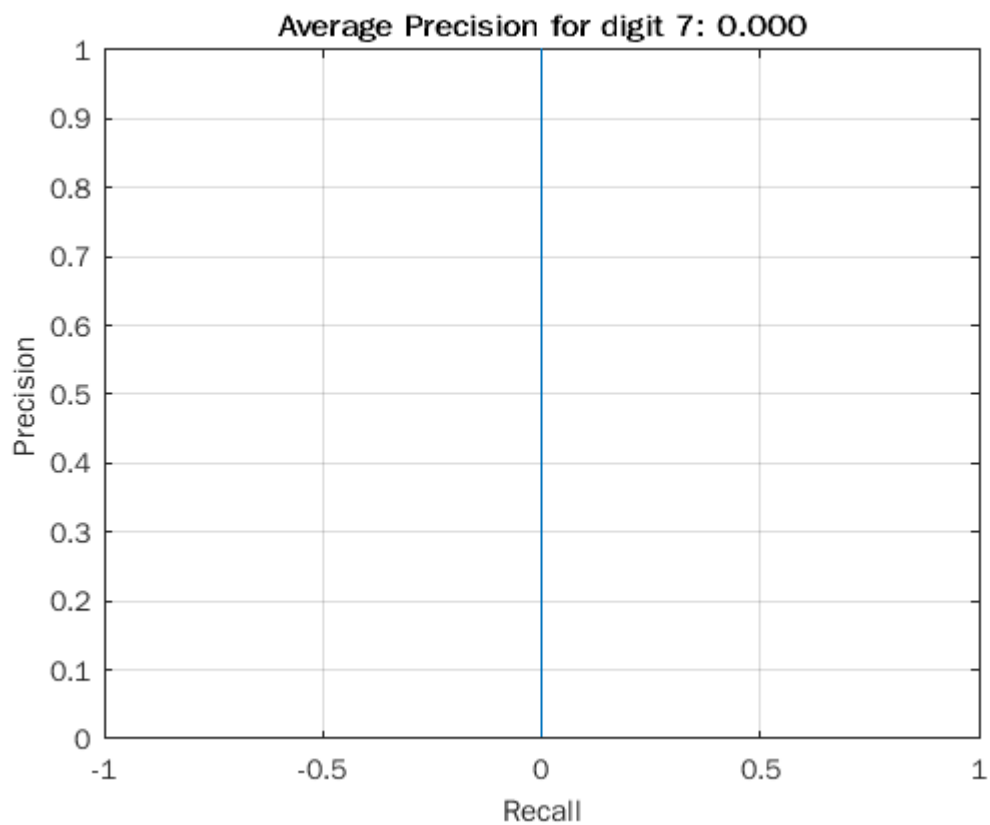
BBoxes for computer_generated.png

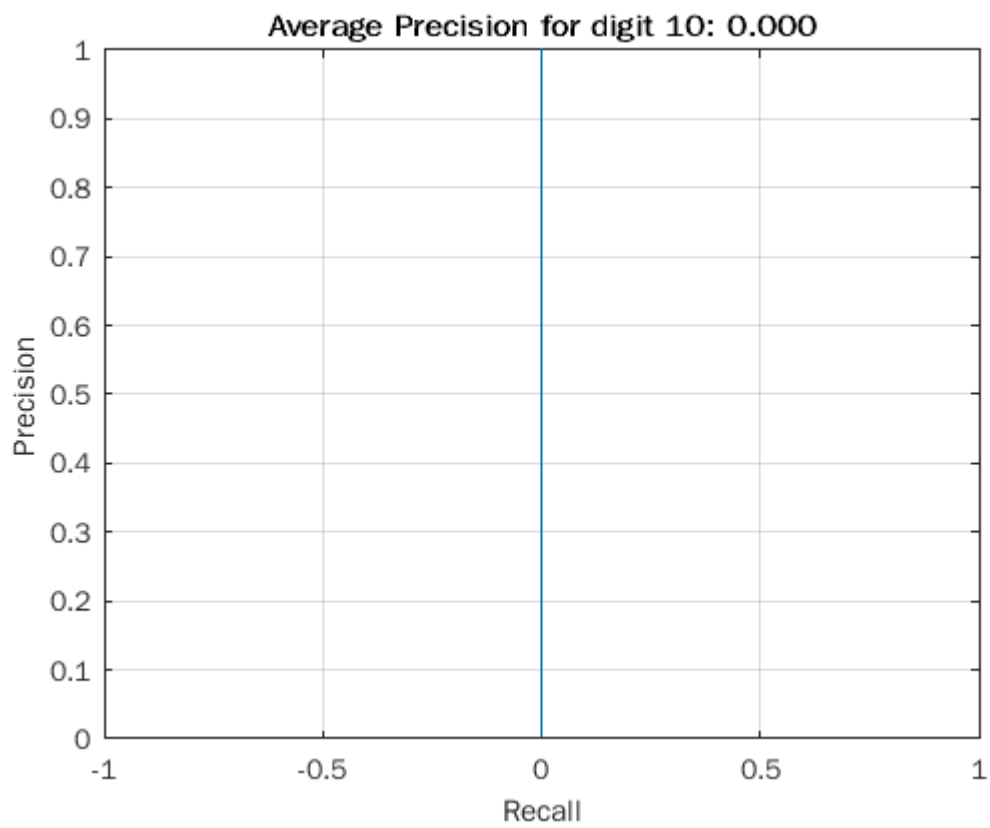
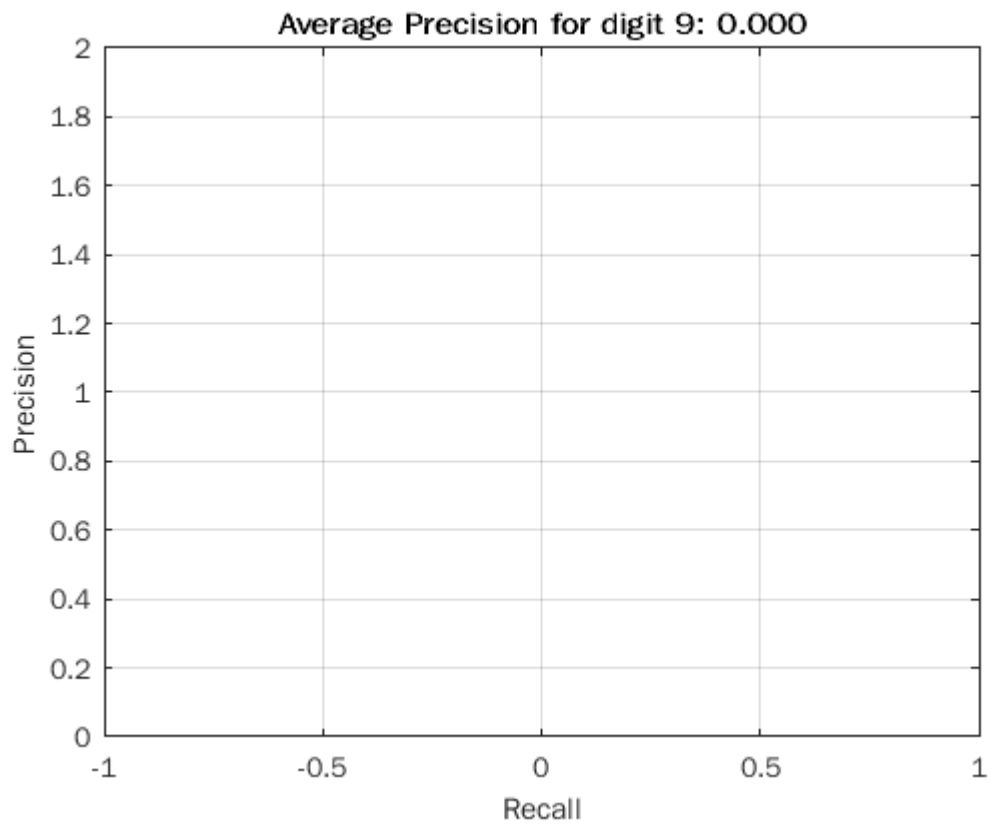












"Semantic Segmentation on image: " "handwritten.png"
INFO. Number of boxes found at level 1: 50
INFO. Number of boxes found at level 2: 17
INFO. Number of boxes found at level 3: 9

```

INFO. Number of boxes found at level 4: 4
INFO. Number of boxes found at level 5: 0
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 87
INFO. Number of boxes found at level 0.5: 13
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 180
INFO. Total boxes found: 170

```

```
average_precision = 10x1
```

```

0
0.0262
0.0278
0
0.0667
0
0
0
0
0
0

```

```
recall = 10x1 cell
```

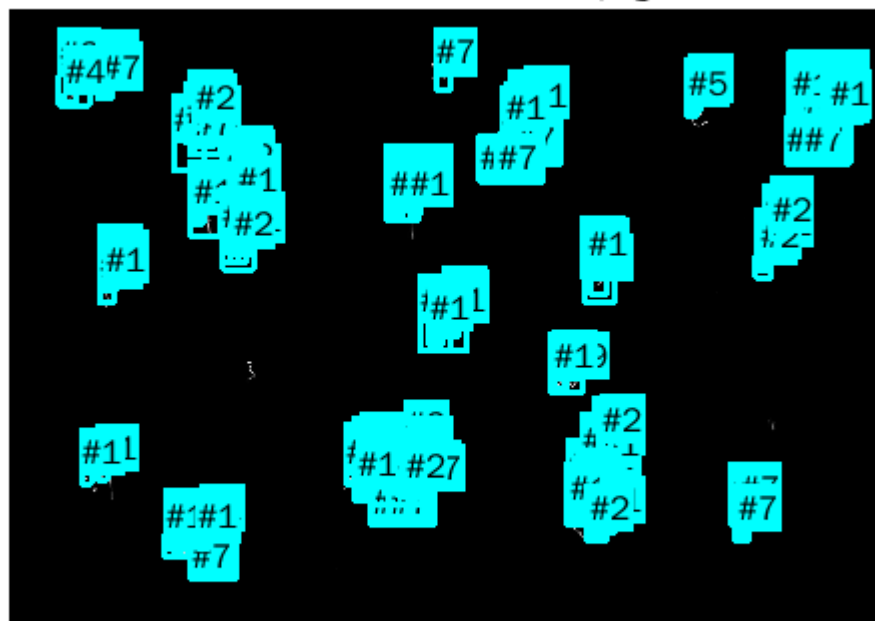
	1
1	[0;0]
2	89x1 double
3	33x1 double
4	0
5	[0;0;0;0...
6	0
7	[0;0;0]
8	24x1 double
9	0
10	[0;0;0]

```
precision = 10x1 cell
```

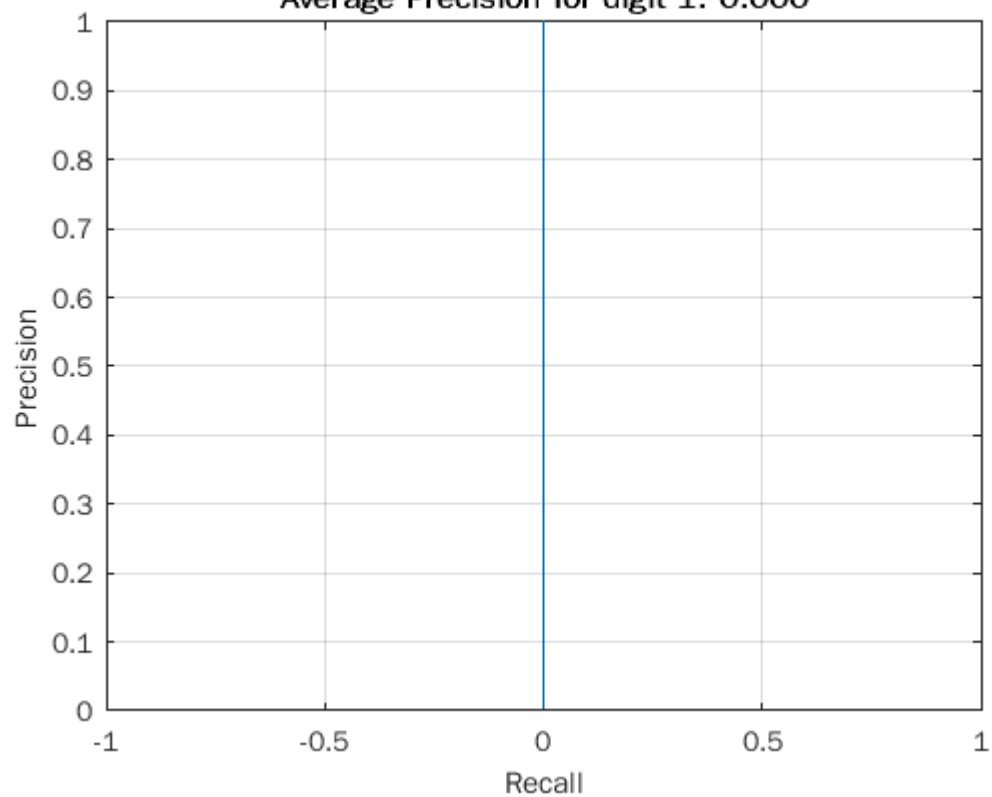
	1
1	[1;0]
2	89x1 double
3	33x1 double
4	1
5	[1;0;0;0...
6	1
7	[1;0;0]
8	24x1 double
9	1
10	[1;0;0]

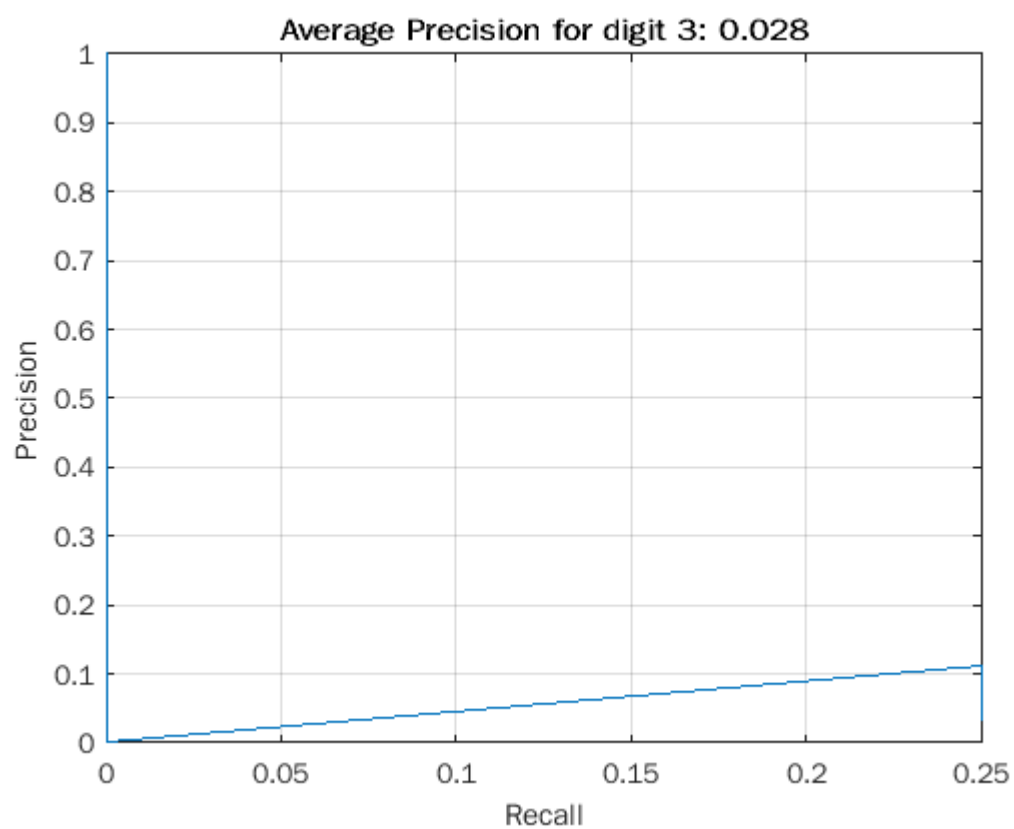
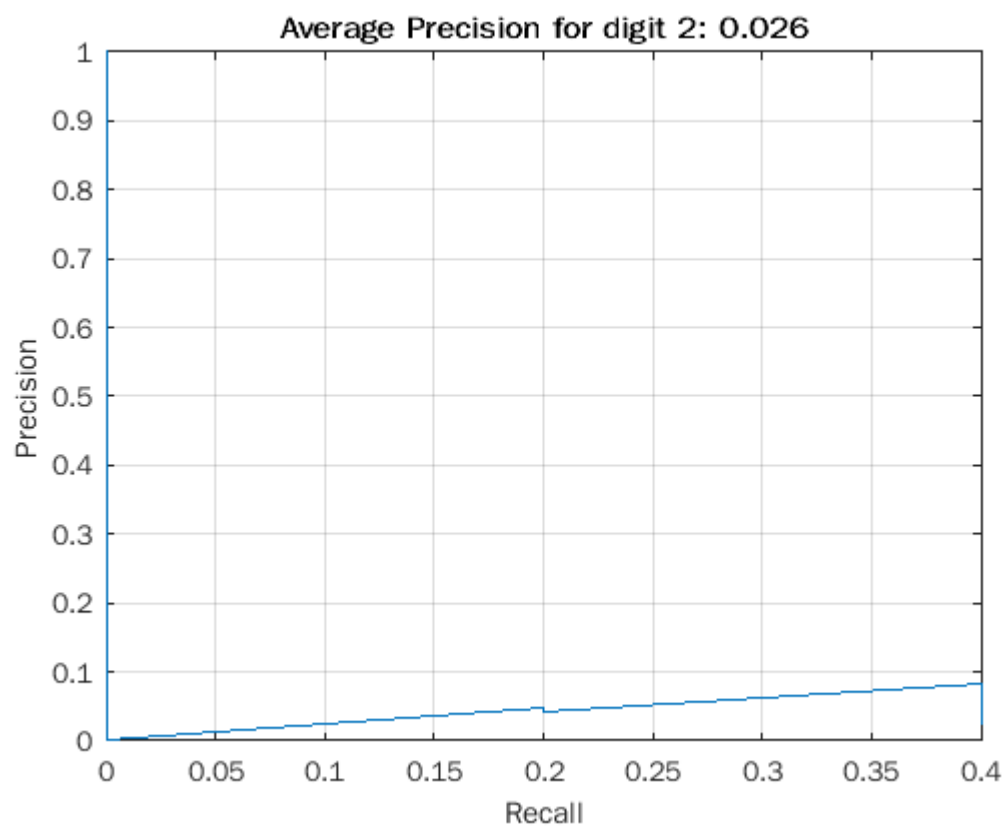
```
Average mAP across digits: 0.012063
```

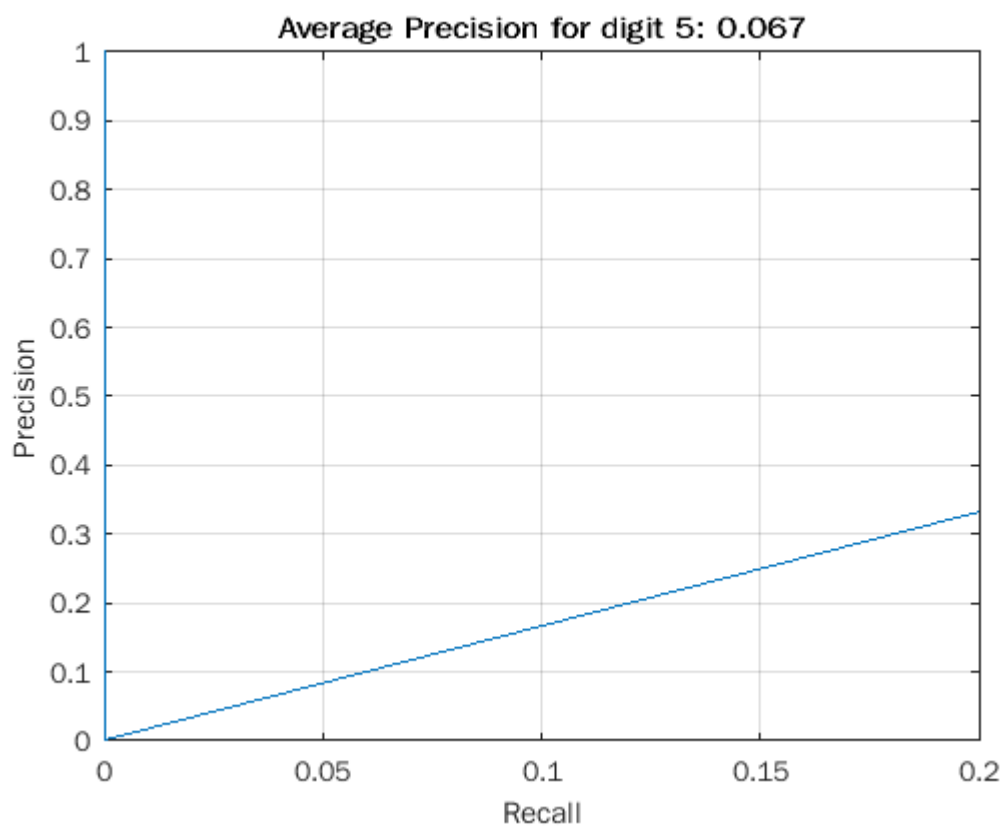
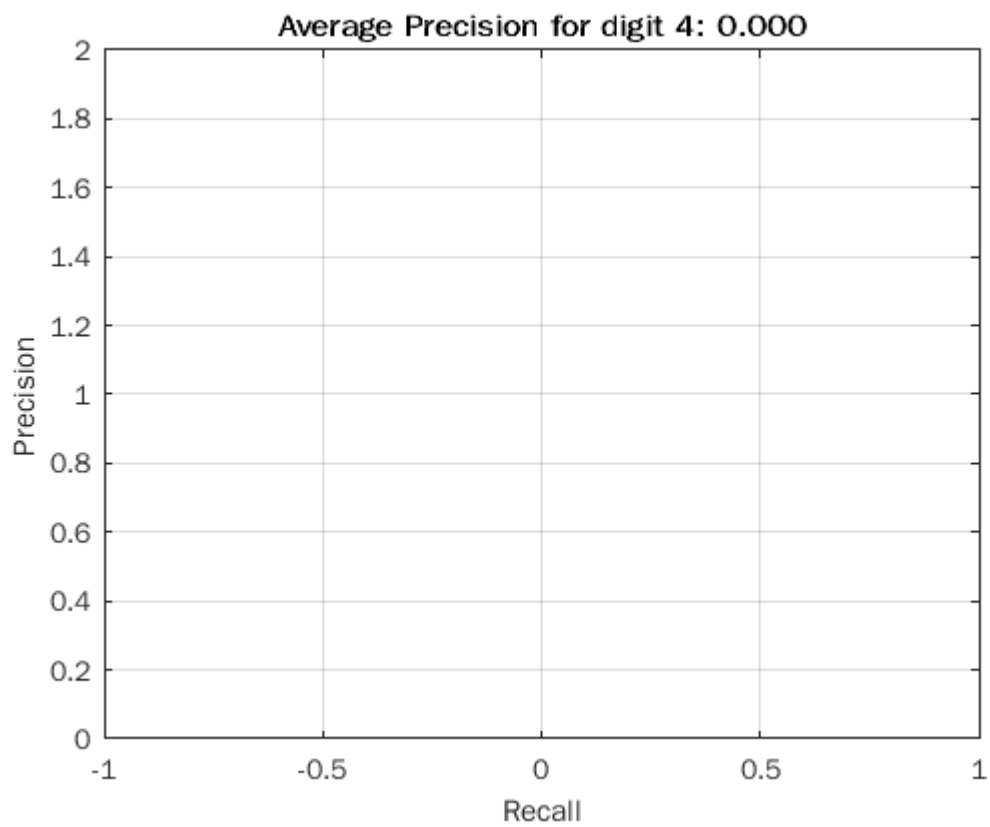
BBoxes for handwritten.png

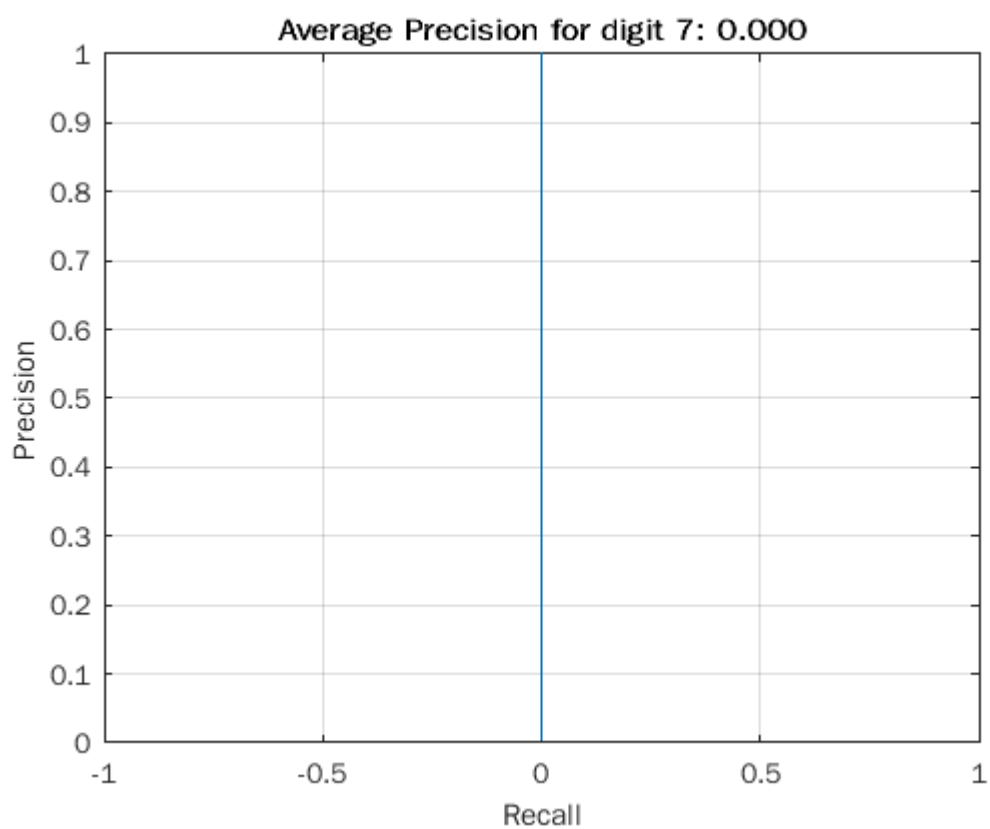
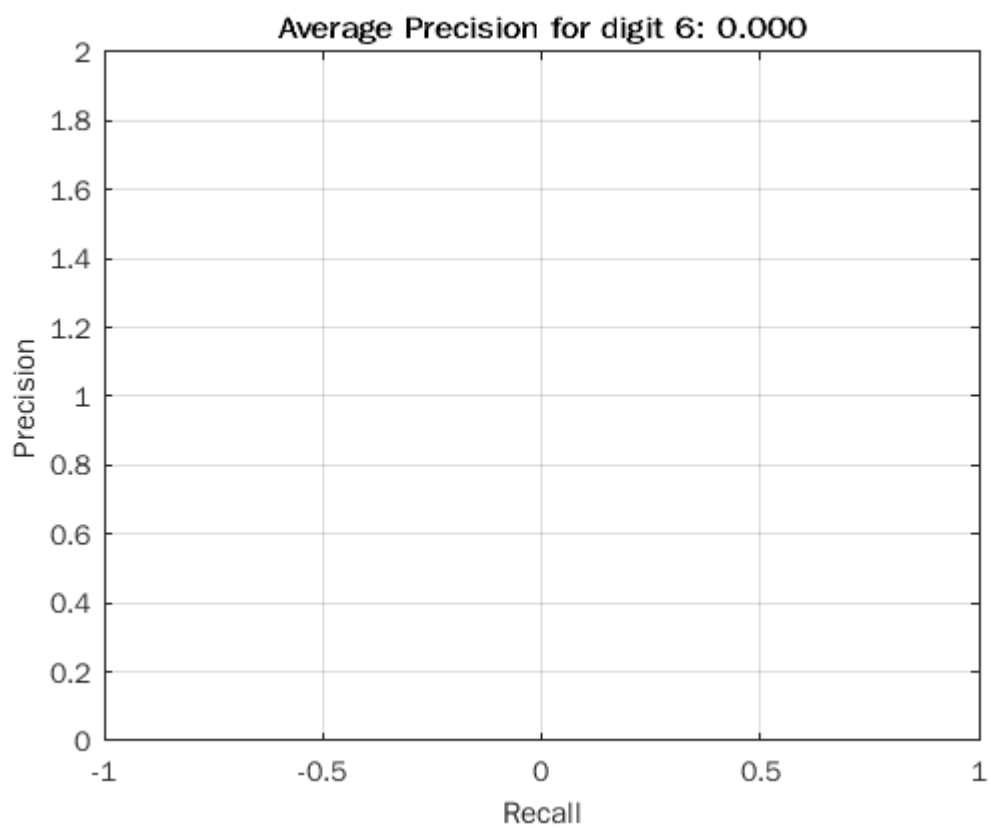


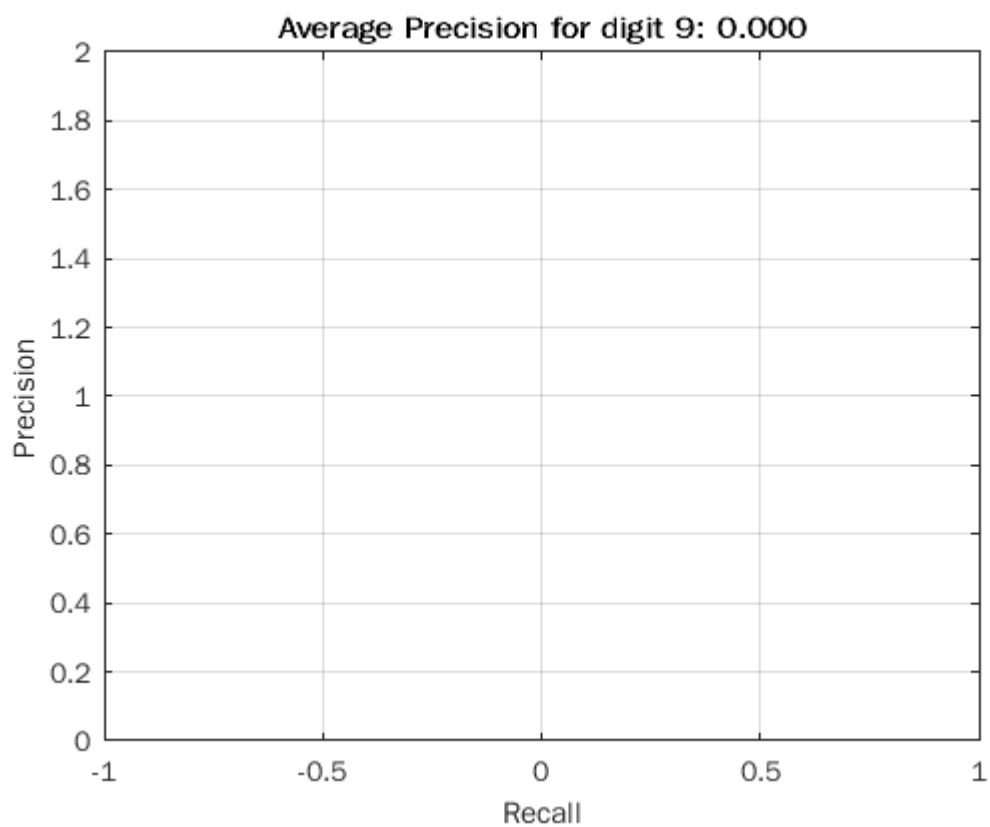
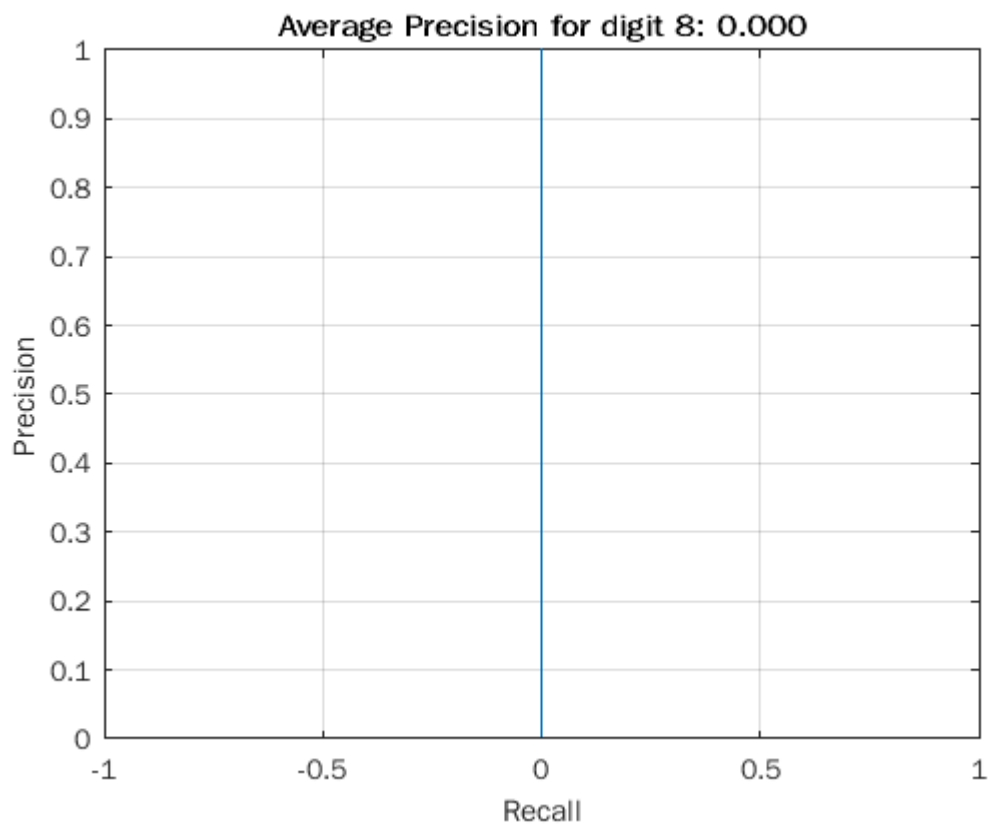
Average Precision for digit 1: 0.000

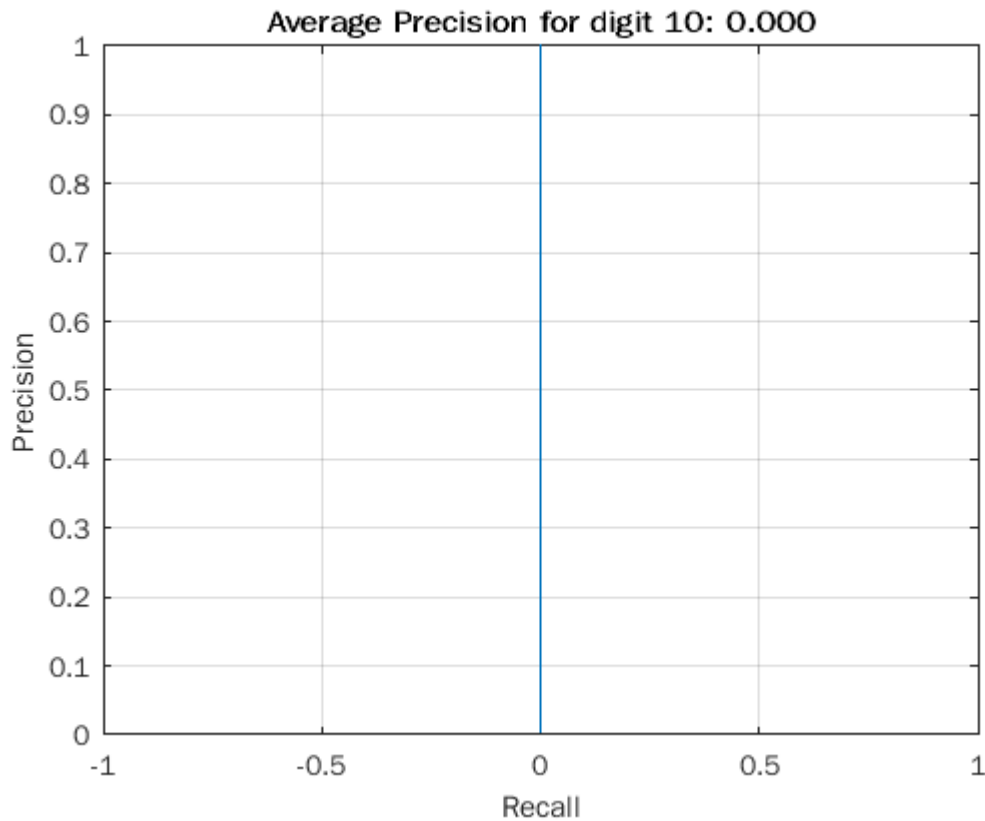












```

as_grayscale = true;
% Fixed parameters at all scale levels
box_size = 28;
std = 0.8;
confidence_threshold = 0.9;
% iou_level_threshold = 0.5;
% iou_final_threshold = 0.5;
% Scale levels and changing parameters
downscale_levels = [1, 2, 3, 4, 5, 6, 1/1.5, 1/2, 1/3, 1/4];
% strides = [15, 15, 11, 11, 11, 11, 11, 7, 11, 15];

best_ap = 0.64;
for iou_level_threshold = [0.3, 0.4, 0.5]
    for iou_final_threshold = [0.3, 0.4, 0.5]
        for stride_size = [5, 11, 15]
            disp('=====')
            disp(['iou_level_threshold: ' num2str(iou_level_threshold)])
            disp(['iou_final_threshold: ' num2str(iou_final_threshold)])
            disp(['stride_size: ' num2str(stride_size)])
            strides = stride_size * ones(10, 1);
            strides(7:10) = [15, 15, 15, 15];

            ap = [0, 0];
            for n = [1, 3] % 1:length(anno.image_filenames)
                disp(['Semantic Segmentation on image: ' string(anno.image_filenames(n))])
            end
        end
    end
end

```



```

INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 314
INFO. Total boxes found: 103
Average mAP across digits: 0.5625
=====
iou_level_threshold: 0.3
iou_final_threshold: 0.3
stride_size: 11
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 41
INFO. Number of boxes found at level 2: 29
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 12
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 117
INFO. Total boxes found: 70
Average mAP across digits: 0.44583
=====
iou_level_threshold: 0.3
iou_final_threshold: 0.3
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 20
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 72
INFO. Total boxes found: 47
Average mAP across digits: 0.15583
=====
iou_level_threshold: 0.3
iou_final_threshold: 0.4
stride_size: 5
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 114
INFO. Number of boxes found at level 2: 84
INFO. Number of boxes found at level 3: 46
INFO. Number of boxes found at level 4: 32
INFO. Number of boxes found at level 5: 13
INFO. Number of boxes found at level 6: 9
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 314
INFO. Total boxes found: 145
Average mAP across digits: 0.63667
=====
iou_level_threshold: 0.3
iou_final_threshold: 0.4
stride_size: 11
  "Semantic Segmentation on image: "      "computer_generated.png"

```

```

INFO. Number of boxes found at level 1: 41
INFO. Number of boxes found at level 2: 29
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 12
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 117
INFO. Total boxes found: 74
Average mAP across digits: 0.44464
=====
iou_level_threshold: 0.3
iou_final_threshold: 0.4
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 20
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 72
INFO. Total boxes found: 61
Average mAP across digits: 0.15298
=====
iou_level_threshold: 0.3
iou_final_threshold: 0.5
stride_size: 5
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 114
INFO. Number of boxes found at level 2: 84
INFO. Number of boxes found at level 3: 46
INFO. Number of boxes found at level 4: 32
INFO. Number of boxes found at level 5: 13
INFO. Number of boxes found at level 6: 9
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 314
INFO. Total boxes found: 203
Average mAP across digits: 0.64528
average_precision = 10x1
  0.2917
  0.5000
  0.2111
  1.0000
  1.0000
  1.0000
  1.0000
  0.4500
  1.0000
  0
recall = 10x1 cell

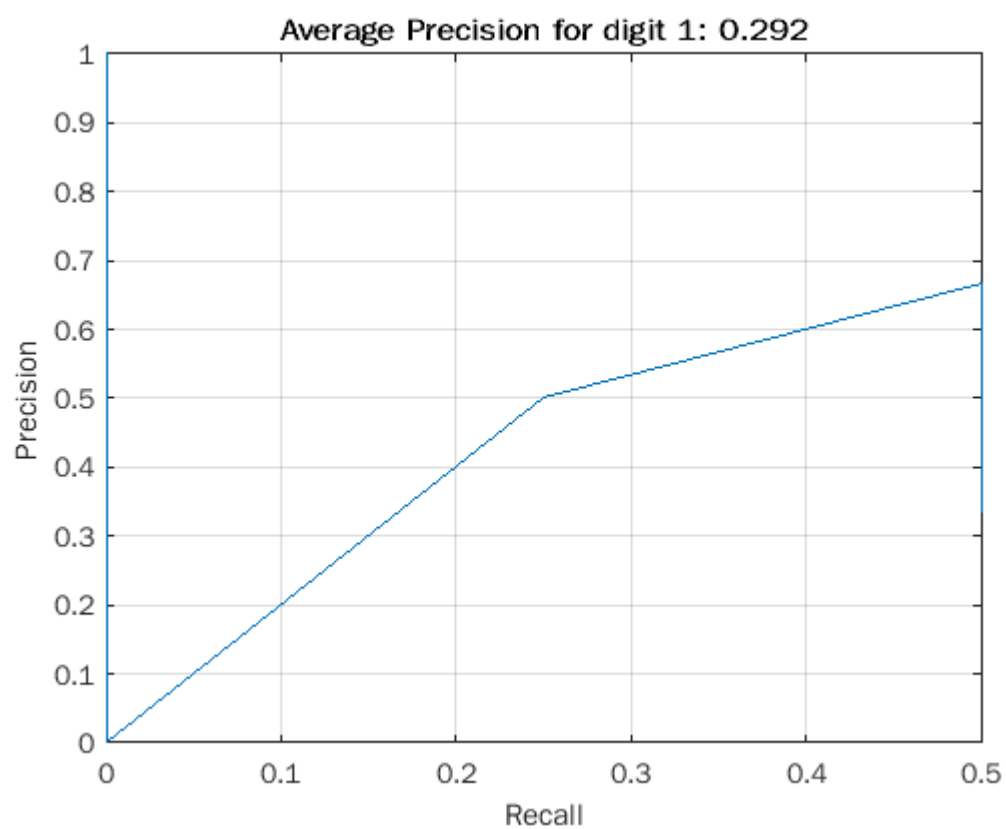
```

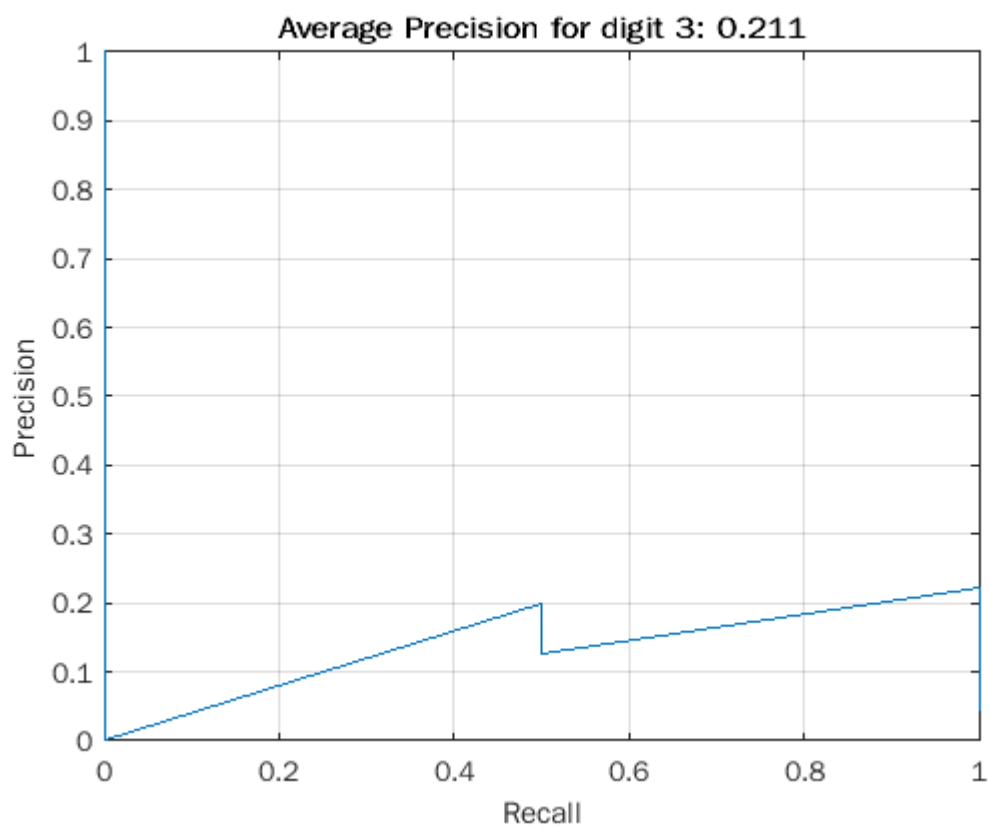
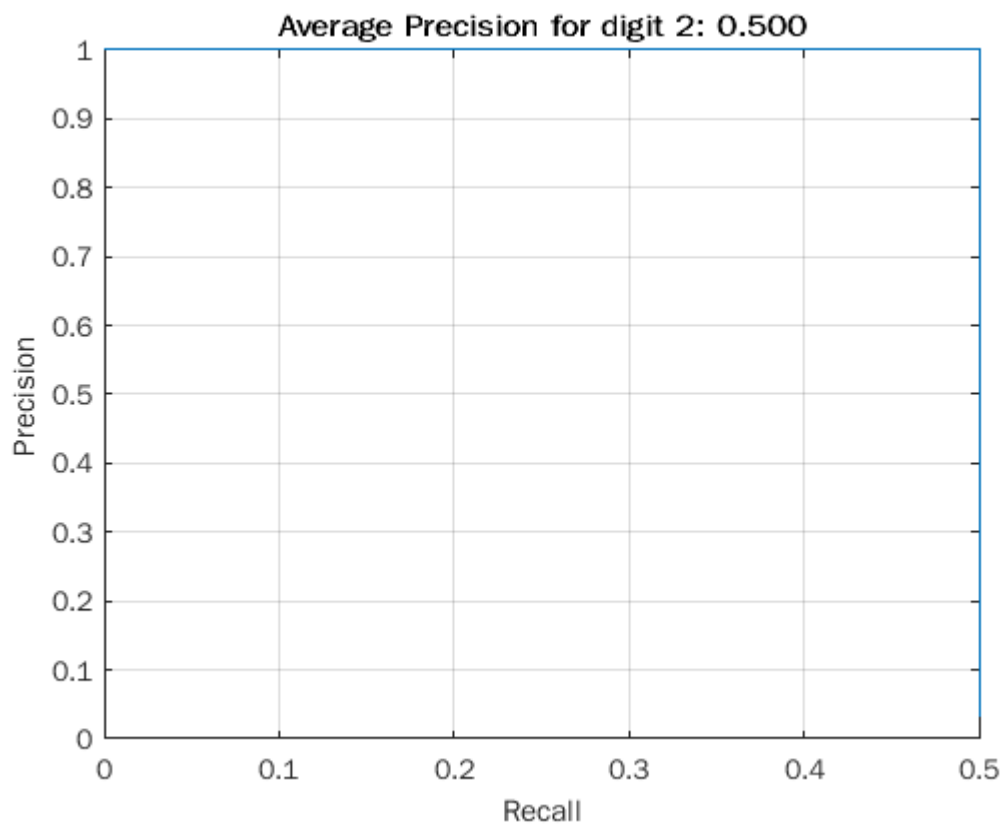

	1
1	[0;0;0.2...
2	33×1 double
3	48×1 double
4	[0;0.500...
5	[0;1;1;1...
6	46×1 double
7	[0;1;1;1...
8	42×1 double
9	[0;1;1]
10	15×1 double

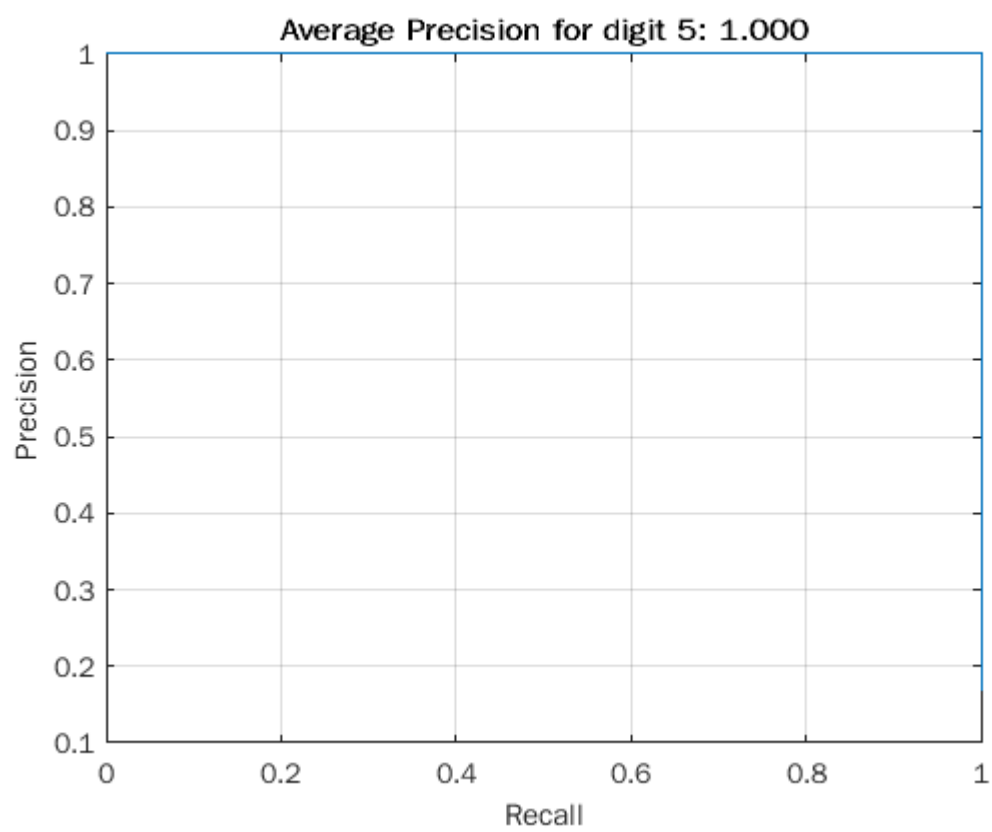
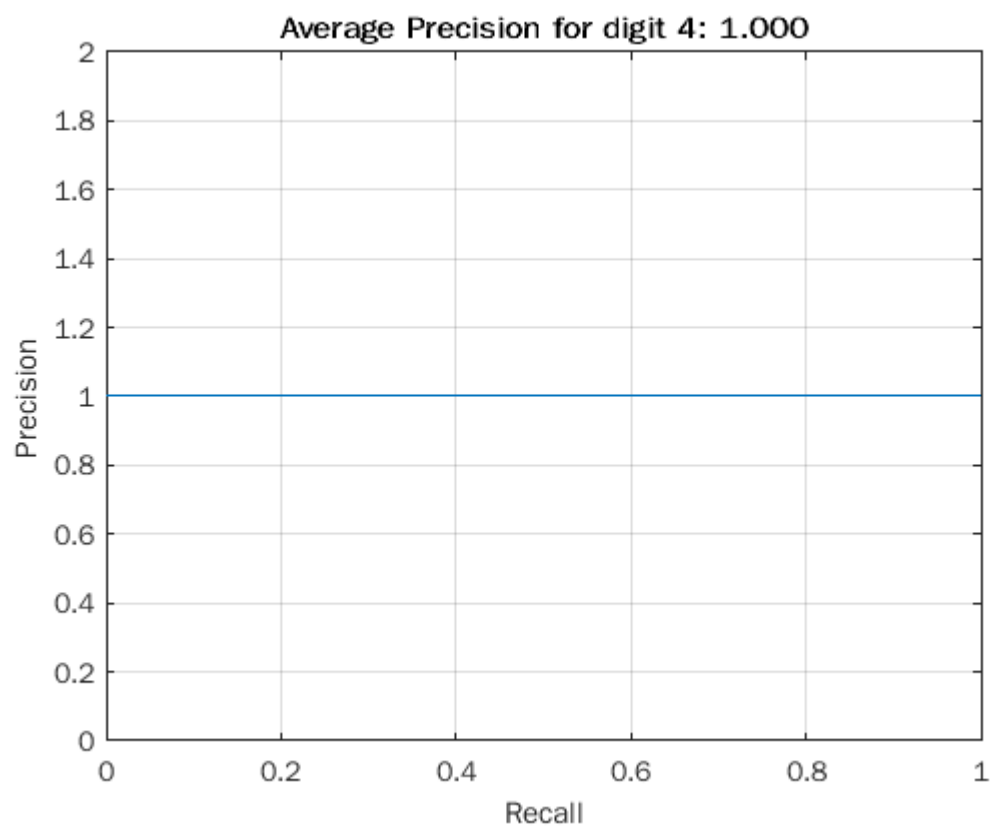
precision = 10×1 cell

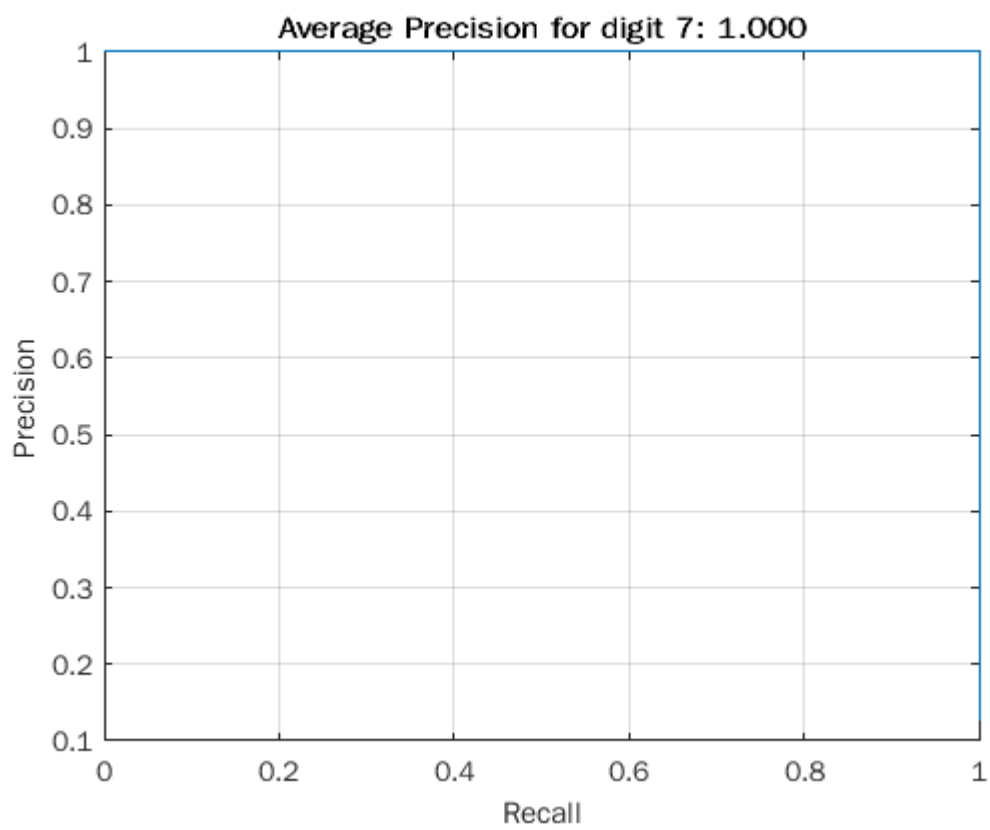
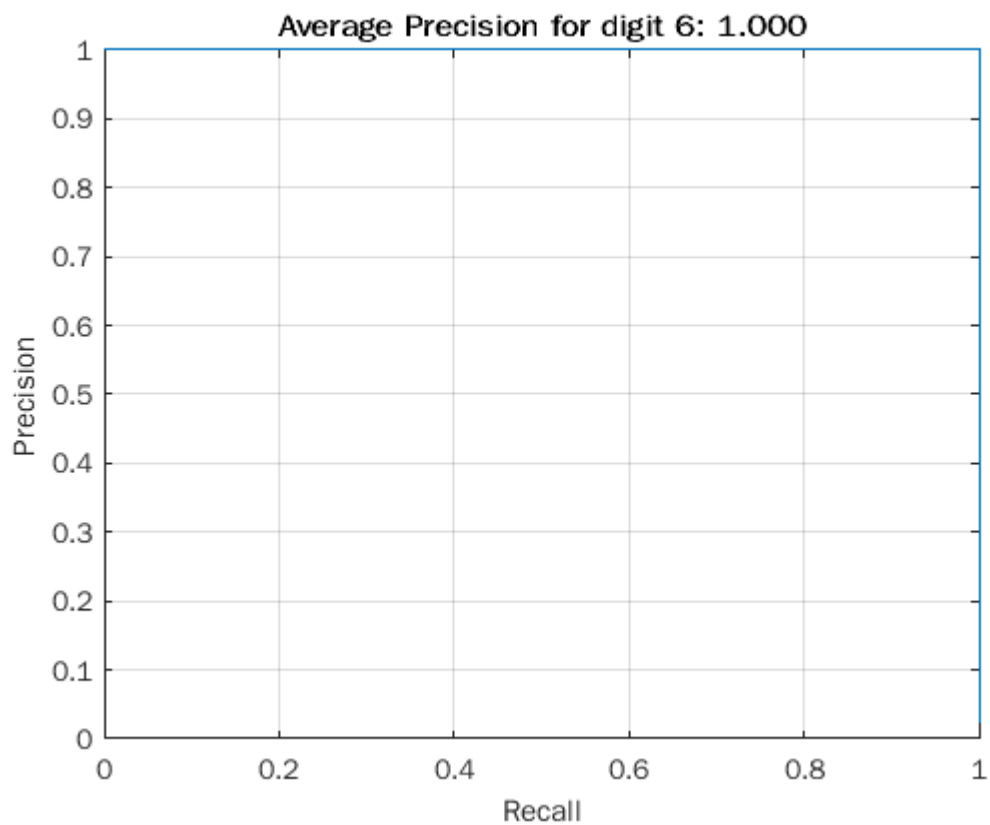
	1
1	[1;0;0.5...
2	33×1 double
3	48×1 double
4	[1;1;1]
5	[1;1;0.5...
6	46×1 double
7	[1;1;0.5...
8	42×1 double
9	[1;1;0.5...
10	15×1 double

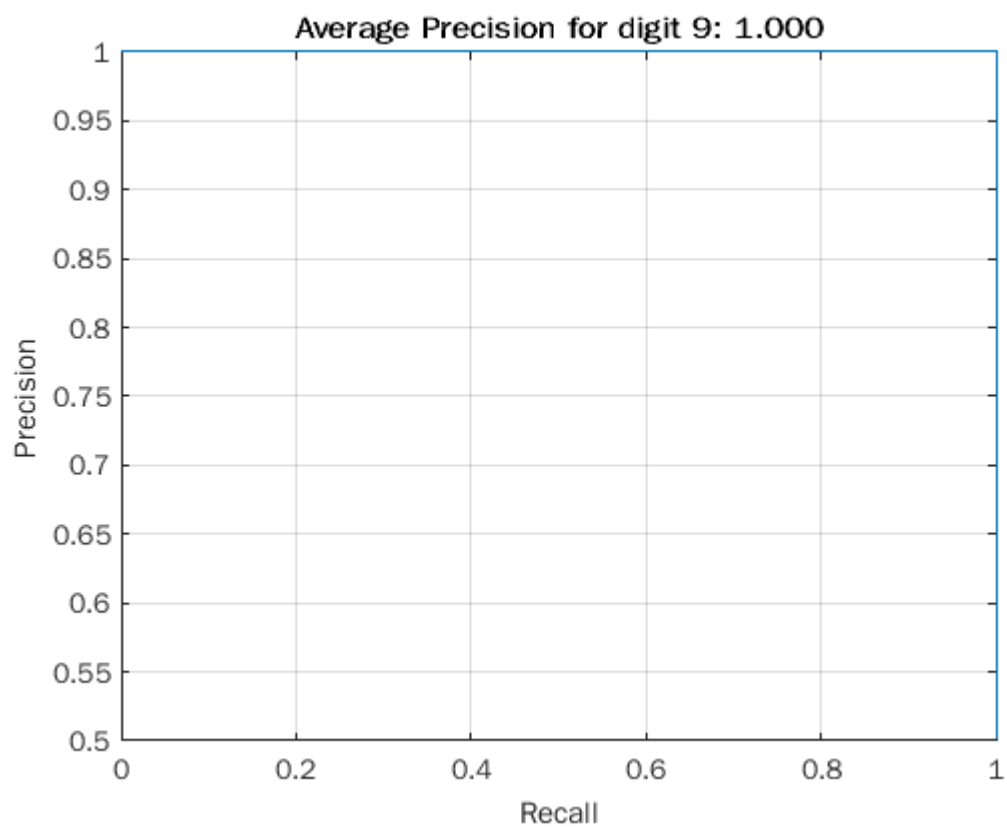
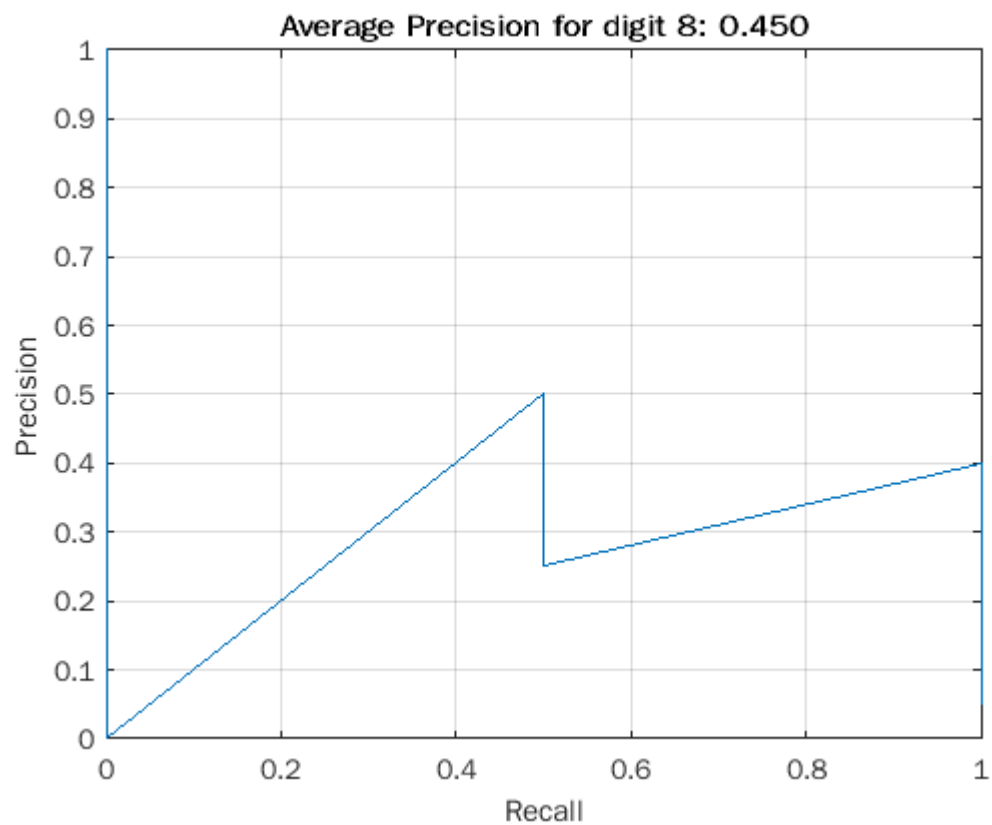
BBoxes for computer_generated.png

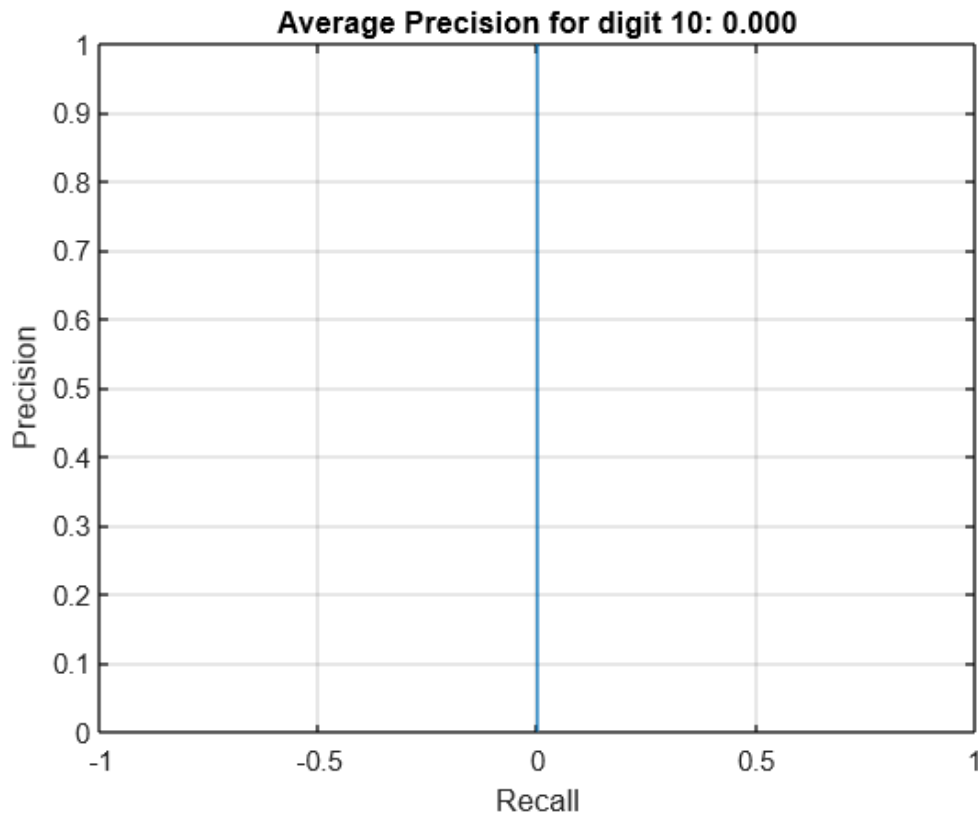












```

"Semantic Segmentation on image: "      "handwritten.png"
INFO. Number of boxes found at level 1: 138
INFO. Number of boxes found at level 2: 63
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 5
INFO. Number of boxes found at level 5: 0
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 15
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 228
INFO. Total boxes found: 205
Average mAP across digits: 0.12361
=====
iou_level_threshold: 0.3
iou_final_threshold: 0.5
stride_size: 11
"Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 41
INFO. Number of boxes found at level 2: 29
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 12
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 117
INFO. Total boxes found: 108
Average mAP across digits: 0.51407
=====
iou_level_threshold: 0.3

```

```

iou_final_threshold: 0.5
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 20
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 72
INFO. Total boxes found: 71
Average mAP across digits: 0.15139
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.3
stride_size: 5
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 121
INFO. Number of boxes found at level 2: 94
INFO. Number of boxes found at level 3: 49
INFO. Number of boxes found at level 4: 34
INFO. Number of boxes found at level 5: 13
INFO. Number of boxes found at level 6: 9
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 336
INFO. Total boxes found: 108
Average mAP across digits: 0.5625
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.3
stride_size: 11
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 41
INFO. Number of boxes found at level 2: 29
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 12
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 117
INFO. Total boxes found: 70
Average mAP across digits: 0.44583
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.3
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 22
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16

```



```

INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 74
INFO. Total boxes found: 47
Average mAP across digits: 0.15583
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.4
stride_size: 5
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 121
INFO. Number of boxes found at level 2: 94
INFO. Number of boxes found at level 3: 49
INFO. Number of boxes found at level 4: 34
INFO. Number of boxes found at level 5: 13
INFO. Number of boxes found at level 6: 9
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 336
INFO. Total boxes found: 149
Average mAP across digits: 0.64222
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.4
stride_size: 11
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 41
INFO. Number of boxes found at level 2: 29
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 12
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 117
INFO. Total boxes found: 74
Average mAP across digits: 0.44464
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.4
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 22
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 74
INFO. Total boxes found: 63
Average mAP across digits: 0.15298
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.5
stride_size: 5

```

```

    "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 121
INFO. Number of boxes found at level 2: 94
INFO. Number of boxes found at level 3: 49
INFO. Number of boxes found at level 4: 34
INFO. Number of boxes found at level 5: 13
INFO. Number of boxes found at level 6: 9
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 336
INFO. Total boxes found: 213
Average mAP across digits: 0.64528
    "Semantic Segmentation on image: "      "handwritten.png"
INFO. Number of boxes found at level 1: 158
INFO. Number of boxes found at level 2: 63
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 5
INFO. Number of boxes found at level 5: 0
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 17
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 250
INFO. Total boxes found: 226
Average mAP across digits: 0.12295
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.5
stride_size: 11
    "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 41
INFO. Number of boxes found at level 2: 29
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 12
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 117
INFO. Total boxes found: 108
Average mAP across digits: 0.51407
=====
iou_level_threshold: 0.4
iou_final_threshold: 0.5
stride_size: 15
    "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 22
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 74
INFO. Total boxes found: 73
Average mAP across digits: 0.15139

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=====
iou_level_threshold: 0.5
iou_final_threshold: 0.3
stride_size: 5
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 132
INFO. Number of boxes found at level 2: 98
INFO. Number of boxes found at level 3: 52
INFO. Number of boxes found at level 4: 36
INFO. Number of boxes found at level 5: 14
INFO. Number of boxes found at level 6: 10
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 358
INFO. Total boxes found: 106
Average mAP across digits: 0.5625
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.3
stride_size: 11
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 47
INFO. Number of boxes found at level 2: 30
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 13
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 125
INFO. Total boxes found: 71
Average mAP across digits: 0.44583
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.3
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 22
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 74
INFO. Total boxes found: 47
Average mAP across digits: 0.15583
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.4
stride_size: 5
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 132
INFO. Number of boxes found at level 2: 98
INFO. Number of boxes found at level 3: 52
INFO. Number of boxes found at level 4: 36
INFO. Number of boxes found at level 5: 14

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INFO. Number of boxes found at level 6: 10
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 358
INFO. Total boxes found: 151
Average mAP across digits: 0.64222
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.4
stride_size: 11
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 47
INFO. Number of boxes found at level 2: 30
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 13
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 125
INFO. Total boxes found: 75
Average mAP across digits: 0.45131
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.4
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 22
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 74
INFO. Total boxes found: 63
Average mAP across digits: 0.15298
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.5
stride_size: 5
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 132
INFO. Number of boxes found at level 2: 98
INFO. Number of boxes found at level 3: 52
INFO. Number of boxes found at level 4: 36
INFO. Number of boxes found at level 5: 14
INFO. Number of boxes found at level 6: 10
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 358
INFO. Total boxes found: 227
Average mAP across digits: 0.64528
  "Semantic Segmentation on image: "      "handwritten.png"

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INFO. Number of boxes found at level 1: 170
INFO. Number of boxes found at level 2: 65
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 5
INFO. Number of boxes found at level 5: 0
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 17
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 264
INFO. Total boxes found: 240
Average mAP across digits: 0.1228
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.5
stride_size: 11
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 47
INFO. Number of boxes found at level 2: 30
INFO. Number of boxes found at level 3: 14
INFO. Number of boxes found at level 4: 13
INFO. Number of boxes found at level 5: 4
INFO. Number of boxes found at level 6: 1
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 125
INFO. Total boxes found: 116
Average mAP across digits: 0.51407
=====
iou_level_threshold: 0.5
iou_final_threshold: 0.5
stride_size: 15
  "Semantic Segmentation on image: "      "computer_generated.png"
INFO. Number of boxes found at level 1: 22
INFO. Number of boxes found at level 2: 20
INFO. Number of boxes found at level 3: 7
INFO. Number of boxes found at level 4: 6
INFO. Number of boxes found at level 5: 3
INFO. Number of boxes found at level 6: 0
INFO. Number of boxes found at level 0.66667: 16
INFO. Number of boxes found at level 0.5: 0
INFO. Number of boxes found at level 0.33333: 0
INFO. Number of boxes found at level 0.25: 0
INFO. Bboxes found in scale space: 74
INFO. Total boxes found: 73
Average mAP across digits: 0.15139

```

Advanced Part

Dataset Augmentation

Evaluation