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1 1

10 x 10 image, 1 channel = 10 x 10 x 1 = 100 dimensional vector

2 2

$$\sqrt{(1-3)^2 + (2-2)^2 + (3-1)^2} = \sqrt{4+0+4} = 2\sqrt{2}$$

3 3

3.1 a

Correctly Classified 25% of the time, **Error Rate** = 75%.

3.2 b

The most frequent label (label A) should be always returned. This results in the smallest error possible, of 50% (error = 1 - frequency).

4 4

4.1 a

The point (0.5, 0.5) lies in the region enclosed by Class 2. Thus, this point has a label of 2.

4.2 b

$$\|(0.5, 0.5) - (1.5, 0.5)\| = \|(-1, 0)\| = 1$$
$$\|(0.5, 1.5) - (1.5, 0.5)\| = \|(-1, 1)\| = \sqrt{2}$$

Label will be the label of the nearest neighbor (0.5, 0.5), or Class 2

4.3 c

$$\|(0.5, 0.5) - (2, 2)\| = \|(1.5, 1.5)\| = \sqrt{1.5^2 + 1.5^2} = \sqrt{4.5}$$
$$\|(0.5, 1.5) - (2, 2)\| = \|(1.5, .5)\| = \sqrt{2.5}$$

Label will be the label of the nearest neighbor (0.5, 1.5), or Class 1

4.4 d

Class 3 will never be predicted because there does not exist any points in the training set that are within the boundary enclosed by Class 3

4.5   e

With a training set of just two points, the decision boundary is simply a perpendicular line passing through the midpoint of the two training points. That is, a horizontal line passing through (0.5, 1), or the line y=1. This means that all points in the half-square above y=1 are classified as class 1, and the half-square below y=1 are classified as class 2. All Class 1 and Class 2 test labels are correctly classified, but all Class 3 test points are incorrectly classified (consisting of 50% of the points). Thus, the error rate would be 50%.

5   5

Based on the image, we find the distances to the query point from each point:

$\sqrt{1.5^2 + 1.5^2} = \sqrt{4.5}$	$\sqrt{1.5^2 + 0.5^2} = \sqrt{2.5}$	$\sqrt{1.5^2 + 2.5^2} = \sqrt{8.5}$
$\sqrt{0.5^2 + 1.5^2} = \sqrt{2.5}$	$\sqrt{0.5^2 + 0.5^2} = \sqrt{0.5}$	$\sqrt{0.5^2 + 2.5^2} = \sqrt{6.5}$
$\sqrt{2.5^2 + 1.5^2} = \sqrt{8.5}$	$\sqrt{2.5^2 + 0.5^2} = \sqrt{6.5}$	$\sqrt{2.5^2 + 2.5^2} = \sqrt{12.5}$
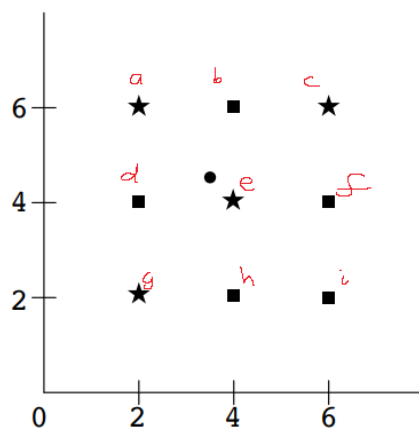
Order of closest points: [{e}, {d, b}, {a}, {h, f}, {c, g}, {i}]

5.1   a

1-NN: {(e, star)}. The majority label is **star**.

5.2   b

3-NN: {(e, star), (d, square), (b, square)}. The majority label is **square**.

5.3   c

5-NN: {(e, star), (d, square), (b, square), (a, star), (h/f, square)}. The majority label is **square**. Even though the 5th nearest neighbor has two options, the classification outcome is the same since all possible candidate points have the same label (square).

6   6

Each fold is 10,000/4 = 2,500, but the training sets are (k-1) folds, so each training set is 2500*3=7500 data values.

7 7

Point	Label	Predicted Label	Correct
Point 1	+	{+}	Yes
Point 2	+	{+}	Yes
Point 3	-	{+}	No
Point 4	+	{-}	No

LOOCV error for 1-NN: 50%.

Point	Label	Predicted Label	Correct
Point 1	+	$\{+,-,+\} \rightarrow +$	Yes
Point 2	+	$\{+,-,+\} \rightarrow +$	Yes
Point 3	-	$\{+,+,+\} \rightarrow +$	No
Point 4	+	$\{-,+,+\} \rightarrow +$	Yes

LOOCV error for 3-NN: 25%

8 8

8.1 a
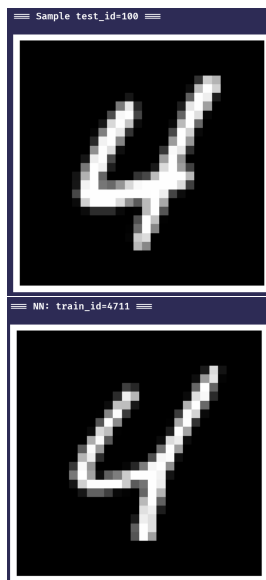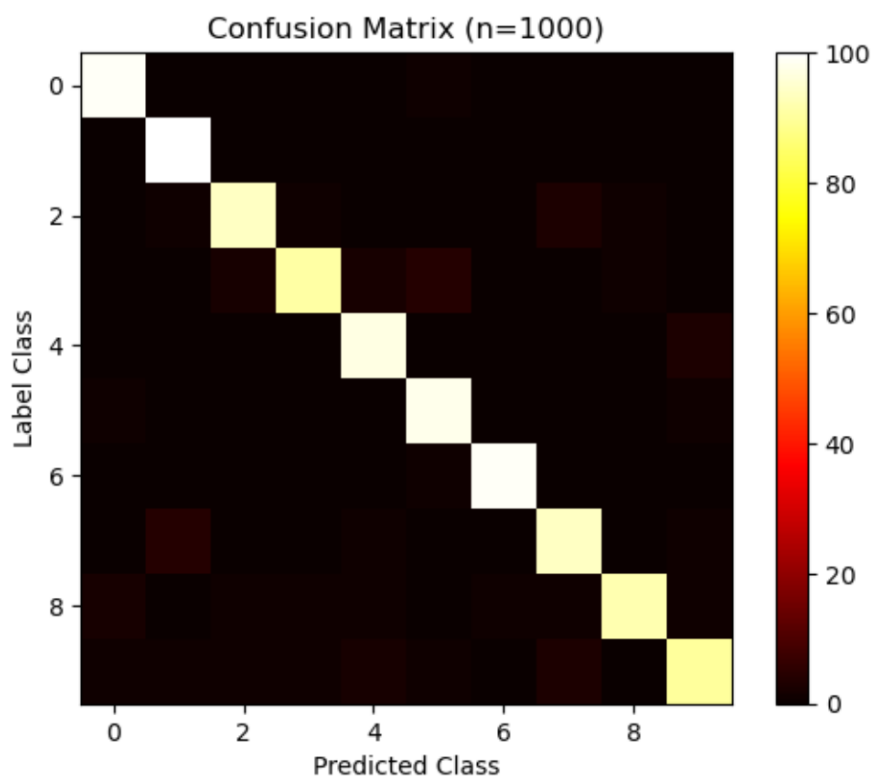

Because both the images have the same label, it is correctly classified.

8.2   b

```
[[ 99.    0.    0.    0.    0.    1.    0.    0.    0.    0.]
 [  0.  100.    0.    0.    0.    0.    0.    0.    0.    0.]
 [  0.    1.   94.    1.    0.    0.    0.    3.    1.    0.]
 [  0.    0.    2.   91.    2.    4.    0.    0.    1.    0.]
 [  0.    0.    0.    0.   97.    0.    0.    0.    0.    3.]
 [  1.    0.    0.    0.    0.   98.    0.    0.    0.    1.]
 [  0.    0.    0.    0.    0.    1.   99.    0.    0.    0.]
 [  0.    4.    0.    0.    1.    0.    0.   94.    0.    1.]
 [  2.    0.    1.    1.    1.    0.    1.    1.   92.    1.]
 [  1.    1.    1.    1.    2.    1.    0.    3.    0.   90.]]

<matplotlib.colorbar.Colorbar at 0×2daa16f33a0>
```
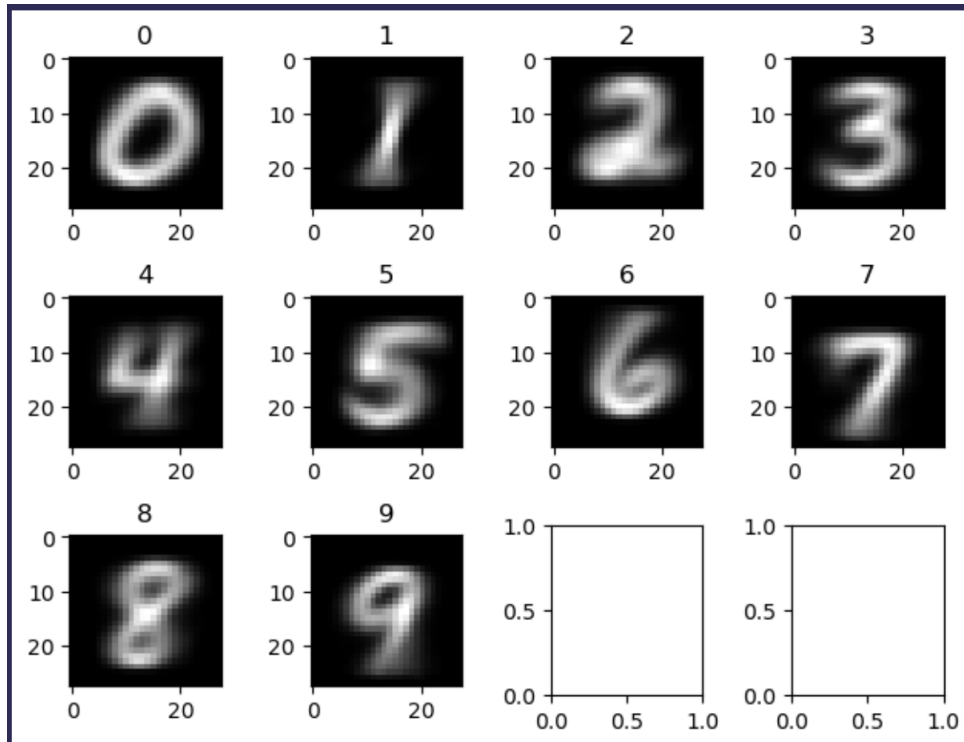

Confusion Matrix (n=1000)

Digit	Error	Digit	Error
0	1/100	1	0/100
2	6/100	3	9/100
4	3/100	5	2/100
6	1/100	7	6/100
8	8/100	9	10/100

Digit 9 was the most mis-classified, digit 1 was the least mis-classified.

8.3   c

9   9

9.1   a

L1 Norm Error: 0.2167
L2 Norm Error: 0.2333

9.2   b

L1 Norm:

	NO	DH	SL
NO	14	0	2
DH	9	9	0
SL	1	1	24

L2 Norm:

	NO	DH	SL
NO	12	1	3
DH	9	9	0
SL	1	0	25