

## Load Data

```
clear
clf
clc

[train_images,test_images,train_labels,test_labels] = load_MNIST();
```

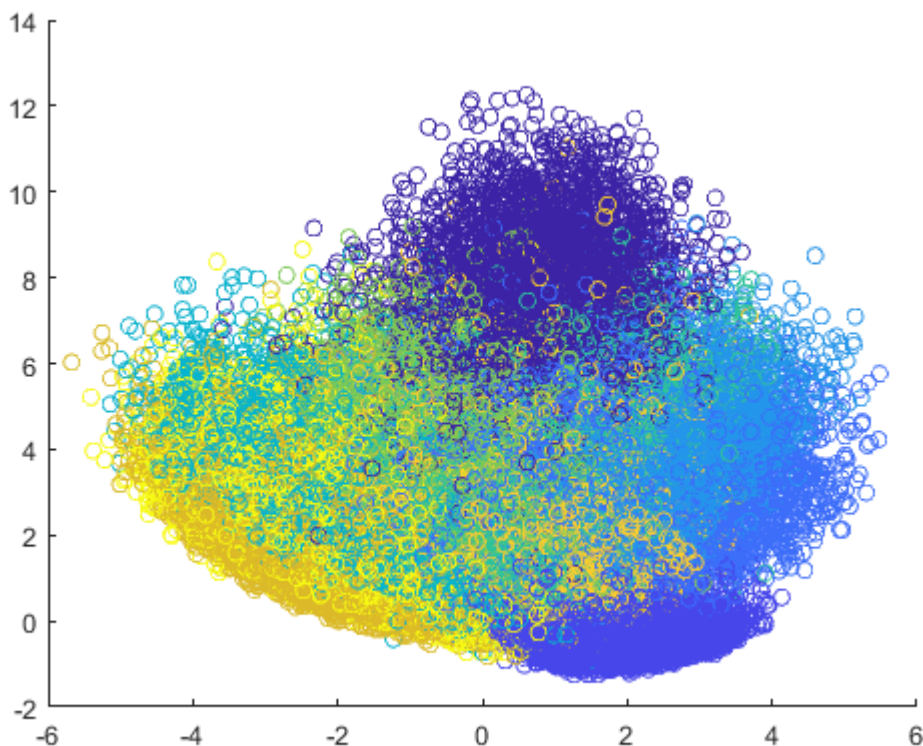
## PCA

```
all_images = [train_images test_images];

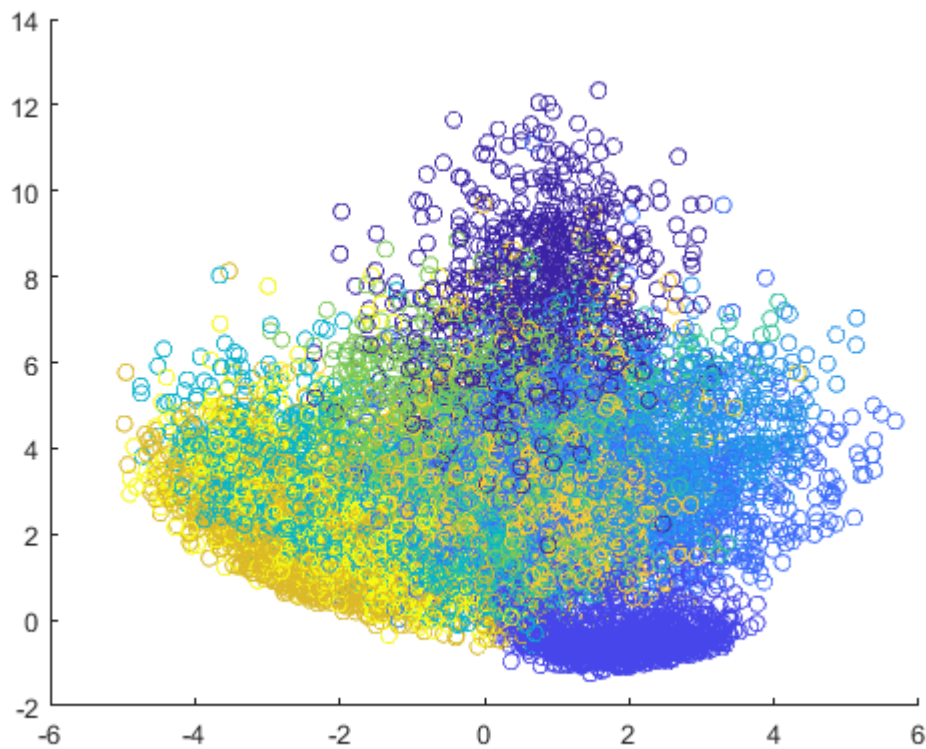
[train_pca,test_pca] = pcaManual(all_images,train_images,test_images)
```

```
train_pca = 2×60000
    1.3085    1.2055   -1.4755    2.4504   -2.7936   -0.8095    0.7037    1.2791 ...
    3.4705    6.9538    2.7597   -0.1343    1.4565    3.7204    0.1264    4.9655
test_pca = 2×10000
   -2.8311    3.8353    1.7737   -0.3628   -2.7539    1.9940   -2.0968   -1.2786 ...
    1.6422    3.0915   -0.7185    7.8480    3.7038   -1.0153    1.9364    1.7228
```

```
% Plot the data
scatter(train_pca(1,:),train_pca(2,:),[],train_labels)
```



```
scatter(test_pca(1,:),test_pca(2,:),[],test_labels)
```



## Nearest Class Centroid Classifier

$$\|\mathbf{x}_i^{(k)} - \boldsymbol{\mu}_k\|_2^2,$$

```
%PCA  
class_labels = nearestClassCentroidClassifier(train_labels, train_pca, test_pca);  
plotconfusionMatrixManualMNIST(test_pca, test_labels, class_labels)
```

Confusion Matrix											
Output Class	1	2	3	4	5	6	7	8	9	10	
	785 7.8%	0 0.0%	125 1.3%	72 0.7%	9 0.1%	121 1.2%	195 1.9%	2 0.0%	94 0.9%	19 0.2%	55.2% 44.8%
	0 0.0%	1115 11.2%	92 0.9%	60 0.6%	31 0.3%	52 0.5%	41 0.4%	74 0.7%	72 0.7%	37 0.4%	70.8% 29.2%
	30 0.3%	1 0.0%	82 0.8%	70 0.7%	0 0.0%	95 0.9%	49 0.5%	1 0.0%	78 0.8%	2 0.0%	20.1% 79.9%
	9 0.1%	7 0.1%	332 3.3%	581 5.8%	0 0.0%	105 1.1%	30 0.3%	2 0.0%	159 1.6%	0 0.0%	47.4% 52.6%
	8 0.1%	0 0.0%	14 0.1%	5 0.1%	481 4.8%	41 0.4%	82 0.8%	282 2.8%	43 0.4%	438 4.4%	34.5% 65.5%
	15 0.1%	0 0.0%	42 0.4%	20 0.2%	0 0.0%	30 0.3%	36 0.4%	1 0.0%	49 0.5%	2 0.0%	15.4% 84.6%
	122 1.2%	1 0.0%	167 1.7%	39 0.4%	26 0.3%	194 1.9%	357 3.6%	23 0.2%	151 1.5%	23 0.2%	32.4% 67.6%
	0 0.0%	2 0.0%	28 0.3%	18 0.2%	344 3.4%	47 0.5%	22 0.2%	552 5.5%	24 0.2%	388 3.9%	38.7% 61.3%
	11 0.1%	9 0.1%	140 1.4%	144 1.4%	14 0.1%	182 1.8%	132 1.3%	22 0.2%	289 2.9%	12 0.1%	30.3% 69.7%
	0 0.0%	0 0.0%	10 0.1%	1 0.0%	77 0.8%	25 0.3%	14 0.1%	69 0.7%	15 0.1%	88 0.9%	29.4% 70.6%
	80.1% 19.9%	98.2% 1.8%	7.9% 92.1%	57.5% 42.5%	49.0% 51.0%	3.4% 96.6%	37.3% 62.7%	53.7% 46.3%	29.7% 70.3%	8.7% 91.3%	43.6% 56.4%
Target Class											
1 2 3 4 5 6 7 8 9 10											

Overall precision: 43.6%

Elapsed time is 2.232273 seconds.

```
%Real Data
class_labels = nearestClassCentroidClassifier(train_labels, train_images, test_images);
plotconfusionMatrixManualMNIST(test_images, test_labels, class_labels)
```

### Confusion Matrix

Output Class	0	1	2	3	4	5	6	7	8	9	10
0	878 8.8%	0 0.0%	19 0.2%	4 0.0%	1 0.0%	11 0.1%	18 0.2%	2 0.0%	14 0.1%	15 0.1%	91.3% 8.7%
1	0 0.0%	1092 10.9%	71 0.7%	24 0.2%	22 0.2%	63 0.6%	27 0.3%	59 0.6%	39 0.4%	22 0.2%	77.0% 23.0%
2	7 0.1%	10 0.1%	781 7.8%	25 0.3%	2 0.0%	2 0.0%	22 0.2%	22 0.2%	11 0.1%	7 0.1%	87.9% 12.1%
3	2 0.0%	3 0.0%	33 0.3%	814 8.1%	0 0.0%	118 1.2%	0 0.0%	1 0.0%	83 0.8%	10 0.1%	76.5% 23.5%
4	2 0.0%	0 0.0%	31 0.3%	1 0.0%	811 8.1%	21 0.2%	31 0.3%	20 0.2%	12 0.1%	83 0.8%	80.1% 19.9%
5	58 0.6%	7 0.1%	3 0.0%	49 0.5%	3 0.0%	612 6.1%	32 0.3%	2 0.0%	36 0.4%	12 0.1%	75.2% 24.8%
6	25 0.3%	3 0.0%	23 0.2%	8 0.1%	16 0.2%	27 0.3%	827 8.3%	0 0.0%	13 0.1%	1 0.0%	87.7% 12.3%
7	1 0.0%	0 0.0%	18 0.2%	15 0.1%	1 0.0%	10 0.1%	0 0.0%	856 8.6%	10 0.1%	27 0.3%	91.3% 8.7%
8	7 0.1%	20 0.2%	50 0.5%	58 0.6%	10 0.1%	13 0.1%	1 0.0%	13 0.1%	718 7.2%	18 0.2%	79.1% 20.9%
9	0 0.0%	0 0.0%	3 0.0%	12 0.1%	116 1.2%	15 0.1%	0 0.0%	53 0.5%	38 0.4%	814 8.1%	77.5% 22.5%
10	89.6% 10.4%	96.2% 3.8%	75.7% 24.3%	80.6% 19.4%	82.6% 17.4%	68.6% 31.4%	86.3% 13.7%	83.3% 16.7%	73.7% 26.3%	80.7% 19.3%	82.0% 18.0%

Overall precision: 82.03%

Elapsed time is 1.473488 seconds.

## Nearest Sub-Class Centroid Classifier 2 PCA

```
%Pca
tic
class_labels = NearestSubClassCentroidClassifier(train_labels, train_pca, test_pca, 2);
plotconfusionMatrixManualMNIST(test_pca, test_labels, class_labels')
```

Overall precision: 42.86%

toc

Elapsed time is 2.737199 seconds.

## Nearest Sub-Class Centroid Classifier 2

```
%Real Data
tic
class_labels = NearestSubClassCentroidClassifier(train_labels, train_images, test_images, 2);
plotconfusionMatrixManualMNIST(test_images, test_labels, class_labels')
```

**Confusion Matrix**

1	866 8.7%	0 0.0%	12 0.1%	5 0.1%	1 0.0%	10 0.1%	24 0.2%	2 0.0%	14 0.1%	12 0.1%	91.5% 8.5%
2	1 0.0%	1115 11.2%	25 0.3%	23 0.2%	17 0.2%	8 0.1%	7 0.1%	53 0.5%	10 0.1%	13 0.1%	87.7% 12.3%
3	2 0.0%	4 0.0%	863 8.6%	18 0.2%	2 0.0%	2 0.0%	5 0.1%	17 0.2%	6 0.1%	2 0.0%	93.7% 6.3%
4	4 0.0%	2 0.0%	24 0.2%	853 8.5%	0 0.0%	66 0.7%	1 0.0%	0 0.0%	55 0.5%	9 0.1%	84.1% 15.9%
5	1 0.0%	1 0.0%	22 0.2%	1 0.0%	807 8.1%	10 0.1%	20 0.2%	13 0.1%	15 0.1%	69 0.7%	84.2% 15.8%
6	63 0.6%	1 0.0%	7 0.1%	33 0.3%	5 0.1%	717 7.2%	14 0.1%	1 0.0%	41 0.4%	6 0.1%	80.7% 19.3%
7	26 0.3%	4 0.0%	11 0.1%	3 0.0%	25 0.3%	19 0.2%	884 8.8%	0 0.0%	4 0.0%	3 0.0%	90.3% 9.7%
8	1 0.0%	0 0.0%	19 0.2%	12 0.1%	5 0.1%	5 0.1%	0 0.0%	876 8.8%	8 0.1%	52 0.5%	89.6% 10.4%
9	12 0.1%	8 0.1%	43 0.4%	48 0.5%	6 0.1%	28 0.3%	3 0.0%	9 0.1%	792 7.9%	10 0.1%	82.6% 17.4%
10	4 0.0%	0 0.0%	6 0.1%	14 0.1%	114 1.1%	27 0.3%	0 0.0%	57 0.6%	29 0.3%	833 8.3%	76.8% 23.2%
	88.4% 11.6%	98.2% 1.8%	83.6% 16.4%	84.5% 15.5%	82.2% 17.8%	80.4% 19.6%	92.3% 7.7%	85.2% 14.8%	81.3% 18.7%	82.6% 17.4%	86.1% 13.9%
	1	2	3	4	5	6	7	8	9	10	
	<b>Target Class</b>										

Overall precision: 86.06%

```
toc
```

Elapsed time is 105.196861 seconds.

## Nearest Sub-Class Centroid Classifier 3 PCA

```
%Pca
```

```
class_labels = NearestSubClassCentroidClassifier(train_labels, train_pca, test_pca, 3);
plotconfusionMatrixManualMNIST(test_pca, test_labels, class_labels')
```

**Confusion Matrix**

1	669 6.7%	0 0.0%	122 1.2%	34 0.3%	2 0.0%	102 1.0%	151 1.5%	0 0.0%	98 1.0%	12 0.1%	56.2% 43.8%
2	0 0.0%	1092 10.9%	53 0.5%	29 0.3%	16 0.2%	33 0.3%	22 0.2%	49 0.5%	25 0.3%	22 0.2%	81.4% 18.6%
3	60 0.6%	4 0.0%	293 2.9%	172 1.7%	2 0.0%	136 1.4%	102 1.0%	8 0.1%	155 1.6%	7 0.1%	31.2% 68.8%
4	10 0.1%	3 0.0%	172 1.7%	457 4.6%	4 0.0%	156 1.6%	35 0.4%	6 0.1%	158 1.6%	2 0.0%	45.6% 54.4%
5	3 0.0%	0 0.0%	32 0.3%	11 0.1%	350 3.5%	55 0.5%	43 0.4%	201 2.0%	38 0.4%	278 2.8%	34.6% 65.4%
6	54 0.5%	9 0.1%	93 0.9%	100 1.0%	38 0.4%	143 1.4%	143 1.4%	28 0.3%	113 1.1%	21 0.2%	19.3% 80.7%
7	150 1.5%	2 0.0%	97 1.0%	39 0.4%	14 0.1%	96 1.0%	283 2.8%	6 0.1%	109 1.1%	13 0.1%	35.0% 65.0%
8	0 0.0%	8 0.1%	13 0.1%	13 0.1%	333 3.3%	34 0.3%	7 0.1%	478 4.8%	14 0.1%	417 4.2%	36.3% 63.7%
9	29 0.3%	17 0.2%	153 1.5%	150 1.5%	14 0.1%	123 1.2%	128 1.3%	19 0.2%	254 2.5%	13 0.1%	28.2% 71.8%
10	5 0.1%	0 0.0%	4 0.0%	5 0.1%	209 2.1%	14 0.1%	44 0.4%	233 2.3%	10 0.1%	224 2.2%	29.9% 70.1%
	68.3% 31.7%	96.2% 3.8%	28.4% 71.6%	45.2% 54.8%	35.6% 64.4%	16.0% 84.0%	29.5% 70.5%	46.5% 53.5%	26.1% 73.9%	22.2% 77.8%	42.4% 57.6%
	1	2	3	4	5	6	7	8	9	10	
	<b>Target Class</b>										

Overall precision: 42.43%

## Nearest Sub-Class Centroid Classifier 3

```
%Real Data
class_labels = NearestSubClassCentroidClassifier(train_labels, train_images, test_images, 3);
plotconfusionMatrixManualMNIST(test_images, test_labels, class_labels')
```



Output Class	1	2	3	4	5	6	7	8	9	10	
	917 9.2%	0 0.0%	19 0.2%	4 0.0%	1 0.0%	9 0.1%	21 0.2%	1 0.0%	12 0.1%	10 0.1%	92.3% 7.7%
	1 0.0%	1120 11.2%	19 0.2%	5 0.1%	15 0.1%	5 0.1%	6 0.1%	50 0.5%	4 0.0%	12 0.1%	90.5% 9.5%
	1 0.0%	2 0.0%	898 9.0%	16 0.2%	5 0.1%	3 0.0%	5 0.1%	15 0.1%	4 0.0%	1 0.0%	94.5% 5.5%
	4 0.0%	1 0.0%	21 0.2%	887 8.9%	2 0.0%	57 0.6%	1 0.0%	0 0.0%	60 0.6%	16 0.2%	84.6% 15.4%
	0 0.0%	1 0.0%	12 0.1%	2 0.0%	838 8.4%	5 0.1%	14 0.1%	16 0.2%	11 0.1%	63 0.6%	87.1% 12.9%
	28 0.3%	1 0.0%	6 0.1%	33 0.3%	7 0.1%	738 7.4%	16 0.2%	3 0.0%	42 0.4%	6 0.1%	83.9% 16.1%
	20 0.2%	4 0.0%	2 0.0%	2 0.0%	20 0.2%	23 0.2%	893 8.9%	0 0.0%	3 0.0%	3 0.0%	92.1% 7.9%
	1 0.0%	0 0.0%	20 0.2%	12 0.1%	3 0.0%	4 0.0%	0 0.0%	882 8.8%	10 0.1%	48 0.5%	90.0% 10.0%
	8 0.1%	6 0.1%	33 0.3%	44 0.4%	3 0.0%	28 0.3%	2 0.0%	5 0.1%	803 8.0%	8 0.1%	85.4% 14.6%
0 0.0%	0 0.0%	2 0.0%	5 0.1%	88 0.9%	20 0.2%	0 0.0%	56 0.6%	25 0.3%	842 8.4%	81.1% 18.9%	
	93.6% 6.4%	98.7% 1.3%	87.0% 13.0%	87.8% 12.2%	85.3% 14.7%	82.7% 17.3%	93.2% 6.8%	85.8% 14.2%	82.4% 17.6%	83.4% 16.6%	88.2% 11.8%
	1	2	3	4	5	6	7	8	9	10	
	Target Class										

Overall precision: 88.18%

## Nearest Sub-Class Centroid Classifier 5 PCA

```
%Pca
class_labels = NearestSubClassCentroidClassifier(train_labels, train_pca, test_pca, 5);
```

Warning: Failed to converge in 100 iterations during replicate 4.

```
plotconfusionMatrixManualMNIST(test_pca, test_labels, class_labels')
```

Output Class	0	1	2	3	4	5	6	7	8	9	10
0	597 6.0%	0 0.0%	70 0.7%	16 0.2%	2 0.0%	57 0.6%	117 1.2%	1 0.0%	69 0.7%	12 0.1%	63.4% 36.6%
1	0 0.0%	1098 11.0%	65 0.7%	29 0.3%	11 0.1%	33 0.3%	24 0.2%	43 0.4%	35 0.4%	21 0.2%	80.8% 19.2%
2	39 0.4%	7 0.1%	247 2.5%	173 1.7%	10 0.1%	79 0.8%	58 0.6%	15 0.1%	113 1.1%	8 0.1%	33.0% 67.0%
3	26 0.3%	3 0.0%	178 1.8%	454 4.5%	10 0.1%	164 1.6%	56 0.6%	10 0.1%	161 1.6%	5 0.1%	42.5% 57.5%
4	6 0.1%	1 0.0%	20 0.2%	6 0.1%	429 4.3%	41 0.4%	61 0.6%	283 2.8%	31 0.3%	342 3.4%	35.2% 64.8%
5	116 1.2%	9 0.1%	142 1.4%	129 1.3%	16 0.2%	178 1.8%	127 1.3%	11 0.1%	134 1.3%	16 0.2%	20.3% 79.7%
6	103 1.0%	4 0.0%	119 1.2%	48 0.5%	19 0.2%	112 1.1%	226 2.3%	21 0.2%	142 1.4%	23 0.2%	27.7% 72.3%
7	0 0.0%	7 0.1%	8 0.1%	15 0.1%	238 2.4%	31 0.3%	14 0.1%	459 4.6%	18 0.2%	314 3.1%	41.6% 58.4%
8	70 0.7%	5 0.1%	166 1.7%	135 1.4%	10 0.1%	170 1.7%	184 1.8%	14 0.1%	247 2.5%	10 0.1%	24.4% 75.6%
9	23 0.2%	1 0.0%	17 0.2%	5 0.1%	237 2.4%	27 0.3%	91 0.9%	171 1.7%	24 0.2%	258 2.6%	30.2% 69.8%
10	60.9% 39.1%	96.7% 3.3%	23.9% 76.1%	45.0% 55.0%	43.7% 56.3%	20.0% 80.0%	23.6% 76.4%	44.6% 55.4%	25.4% 74.6%	25.6% 74.4%	41.9% 58.1%

Overall precision: 41.93%

## Nearest Sub-Class Centroid Classifier 5

%Real Data

```
class_labels = NearestSubClassCentroidClassifier(train_labels, train_images, test_images, 5);
```

```
Warning: Failed to converge in 100 iterations during replicate 4.
Warning: Failed to converge in 100 iterations during replicate 7.
Warning: Failed to converge in 100 iterations during replicate 14.
Warning: Failed to converge in 100 iterations during replicate 15.
Warning: Failed to converge in 100 iterations during replicate 1.
Warning: Failed to converge in 100 iterations during replicate 10.
Warning: Failed to converge in 100 iterations during replicate 12.
Warning: Failed to converge in 100 iterations during replicate 8.
Warning: Failed to converge in 100 iterations during replicate 12.
Warning: Failed to converge in 100 iterations during replicate 15.
```



Warning: Failed to converge in 100 iterations during replicate 7.

```
plotconfusionMatrixManualMNIST(test_images, test_labels, class_labels')
```

Confusion Matrix											
Output Class	1	2	3	4	5	6	7	8	9	10	
	930 9.3%	0 0.0%	15 0.1%	2 0.0%	0 0.0%	9 0.1%	10 0.1%	0 0.0%	6 0.1%	8 0.1%	94.9% 5.1%
	1 0.0%	1120 11.2%	10 0.1%	3 0.0%	13 0.1%	6 0.1%	5 0.1%	31 0.3%	2 0.0%	8 0.1%	93.4% 6.6%
	4 0.0%	3 0.0%	924 9.2%	14 0.1%	5 0.1%	2 0.0%	5 0.1%	19 0.2%	3 0.0%	3 0.0%	94.1% 5.9%
	1 0.0%	0 0.0%	23 0.2%	901 9.0%	2 0.0%	34 0.3%	1 0.0%	2 0.0%	50 0.5%	12 0.1%	87.8% 12.2%
	0 0.0%	1 0.0%	5 0.1%	2 0.0%	871 8.7%	7 0.1%	9 0.1%	18 0.2%	9 0.1%	52 0.5%	89.4% 10.6%
	22 0.2%	1 0.0%	5 0.1%	36 0.4%	2 0.0%	769 7.7%	12 0.1%	1 0.0%	36 0.4%	5 0.1%	86.5% 13.5%
	16 0.2%	4 0.0%	3 0.0%	0 0.0%	21 0.2%	17 0.2%	913 9.1%	0 0.0%	3 0.0%	2 0.0%	93.3% 6.7%
	1 0.0%	0 0.0%	15 0.1%	11 0.1%	4 0.0%	4 0.0%	0 0.0%	898 9.0%	10 0.1%	37 0.4%	91.6% 8.4%
	5 0.1%	6 0.1%	30 0.3%	34 0.3%	3 0.0%	32 0.3%	2 0.0%	3 0.0%	838 8.4%	7 0.1%	87.3% 12.7%
	0 0.0%	0 0.0%	2 0.0%	7 0.1%	61 0.6%	12 0.1%	1 0.0%	56 0.6%	17 0.2%	875 8.8%	84.9% 15.1%
Target Class											
											10

Overall precision: 90.39%

## Nearest Neighbor classifier PCA

```
%Pca  
class_labels = NearestNeighborClassifier(train_labels, train_pca, test_pca);  
plotconfusionMatrixManualMNIST(test_pca, test_labels, class_labels)
```

Output Class	1	2	3	4	5	6	7	8	9	10	
	592 5.9%	0 0.0%	88 0.9%	25 0.3%	3 0.0%	80 0.8%	115 1.1%	1 0.0%	68 0.7%	11 0.1%	60.2% 39.8%
	1 0.0%	979 9.8%	25 0.3%	17 0.2%	10 0.1%	11 0.1%	11 0.1%	22 0.2%	19 0.2%	10 0.1%	88.6% 11.4%
	95 0.9%	26 0.3%	275 2.8%	191 1.9%	18 0.2%	153 1.5%	127 1.3%	21 0.2%	148 1.5%	20 0.2%	25.6% 74.4%
	29 0.3%	20 0.2%	191 1.9%	394 3.9%	14 0.1%	125 1.3%	75 0.8%	16 0.2%	153 1.5%	12 0.1%	38.3% 61.7%
	3 0.0%	10 0.1%	25 0.3%	11 0.1%	323 3.2%	47 0.5%	57 0.6%	218 2.2%	37 0.4%	260 2.6%	32.6% 67.4%
	75 0.8%	15 0.1%	132 1.3%	117 1.2%	36 0.4%	140 1.4%	139 1.4%	39 0.4%	146 1.5%	29 0.3%	16.1% 83.9%
	123 1.2%	16 0.2%	120 1.2%	82 0.8%	46 0.5%	136 1.4%	243 2.4%	21 0.2%	168 1.7%	36 0.4%	24.5% 75.5%
	1 0.0%	27 0.3%	12 0.1%	13 0.1%	241 2.4%	30 0.3%	17 0.2%	405 4.0%	26 0.3%	293 2.9%	38.0% 62.0%
	51 0.5%	27 0.3%	149 1.5%	153 1.5%	21 0.2%	142 1.4%	140 1.4%	18 0.2%	189 1.9%	15 0.1%	20.9% 79.1%
10 0.1%	15 0.1%	15 0.1%	7 0.1%	270 2.7%	28 0.3%	34 0.3%	267 2.7%	20 0.2%	323 3.2%	32.7% 67.3%	
	60.4% 39.6%	86.3% 13.7%	26.6% 73.4%	39.0% 61.0%	32.9% 67.1%	15.7% 84.3%	25.4% 74.6%	39.4% 60.6%	19.4% 80.6%	32.0% 68.0%	38.6% 61.4%
	1	2	3	4	5	6	7	8	9	10	
	Target Class										

Overall precision: 38.63%

## Nearest Neighbor classifier

```
%Real data
class_labels = NearestNeighborClassifier(train_labels, train_images, test_images);
plotconfusionMatrixManualMNIST(test_images, test_labels, class_labels)
```

### Confusion Matrix

Output Class	0	1	2	3	4	5	6	7	8	9	10
0	973 9.7%	0 0.0%	7 0.1%	0 0.0%	0 0.0%	1 0.0%	4 0.0%	0 0.0%	6 0.1%	2 0.0%	98.0% 2.0%
1	1 0.0%	1129 11.3%	6 0.1%	1 0.0%	7 0.1%	1 0.0%	2 0.0%	14 0.1%	1 0.0%	5 0.1%	96.7% 3.3%
2	1 0.0%	3 0.0%	992 9.9%	2 0.0%	0 0.0%	0 0.0%	0 0.0%	6 0.1%	3 0.0%	1 0.0%	98.4% 1.6%
3	0 0.0%	0 0.0%	5 0.1%	970 9.7%	0 0.0%	12 0.1%	0 0.0%	2 0.0%	14 0.1%	6 0.1%	96.1% 3.9%
4	0 0.0%	1 0.0%	1 0.0%	1 0.0%	944 9.4%	2 0.0%	3 0.0%	4 0.0%	5 0.1%	10 0.1%	97.2% 2.8%
5	1 0.0%	1 0.0%	0 0.0%	19 0.2%	0 0.0%	860 8.6%	5 0.1%	0 0.0%	13 0.1%	5 0.1%	95.1% 4.9%
6	3 0.0%	1 0.0%	2 0.0%	0 0.0%	3 0.0%	5 0.1%	944 9.4%	0 0.0%	3 0.0%	1 0.0%	98.1% 1.9%
7	1 0.0%	0 0.0%	16 0.2%	7 0.1%	5 0.1%	1 0.0%	0 0.0%	992 9.9%	4 0.0%	11 0.1%	95.7% 4.3%
8	0 0.0%	0 0.0%	3 0.0%	7 0.1%	1 0.0%	6 0.1%	0 0.0%	0 0.0%	920 9.2%	1 0.0%	98.1% 1.9%
9	0 0.0%	0 0.0%	0 0.0%	3 0.0%	22 0.2%	4 0.0%	0 0.0%	10 0.1%	5 0.1%	967 9.7%	95.6% 4.4%
10	99.3% 0.7%	99.5% 0.5%	96.1% 3.9%	96.0% 4.0%	96.1% 3.9%	96.4% 3.6%	98.5% 1.5%	96.5% 3.5%	94.5% 5.5%	95.8% 4.2%	96.9% 3.1%

Overall precision: 96.91%

## Perceptron with backpropagation PCA

```
nDOT      = 10^(-3);
max_runs  = 600;
```

```
result = perceptron_with_back(train_pca,train_labels,nDOT,max_runs)
```

```

bincounts = 1x10
           5923           6742           5958           6131           5842           5421 ...
result = 3x10
-359.2890    0.8940   -44.5520   -45.3670   -28.9250   -31.1820   -48.5990   -22.6510 ...
    1.1294    23.8632    4.0255    22.3541   -20.5899    3.0369    21.9451   -12.5246
    42.4111   -80.9825   -49.8554    9.3143    7.5514   -1.7157   -71.1062   -23.7302

```

```
plots_perceptronForMNISTPcaVersion(test_pca,test_labels,result);
```

**Confusion Matrix**

1	245 2.5%	90 0.9%	201 2.0%	167 1.7%	100 1.0%	262 2.6%	211 2.1%	140 1.4%	324 3.2%	83 0.8%	13.4% 86.6%
2	0 0.0%	1016 10.2%	20 0.2%	3 0.0%	10 0.1%	5 0.1%	3 0.0%	30 0.3%	4 0.0%	16 0.2%	91.8% 8.2%
3	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	NaN% NaN%
4	632 6.3%	29 0.3%	695 7.0%	800 8.0%	1 0.0%	432 4.3%	283 2.8%	6 0.1%	479 4.8%	10 0.1%	23.8% 76.2%
5	103 1.0%	0 0.0%	116 1.2%	40 0.4%	871 8.7%	193 1.9%	461 4.6%	852 8.5%	167 1.7%	899 9.0%	23.5% 76.5%
6	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	NaN% NaN%
7	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	NaN% NaN%
8	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	1 0.0%	0.0% 100%
9	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	NaN% NaN%
10	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	NaN% NaN%
	25.0% 75.0%	89.5% 10.5%	0.0% 100%	79.2% 20.8%	88.7% 11.3%	0.0% 100%	0.0% 100%	0.0% 100%	0.0% 100%	0.0% 100%	29.3% 70.7%
	1	2	3	4	5	6	7	8	9	10	

**Target Class**

Overall accuracy: 84.306%

## Perceptron with backpropagation

```
%Real data
result = perceptron_with_back(train_pca,train_labels,nDOT,max_runs)

plots_perceptronForMNIST(test_images,test_labels,result)
```

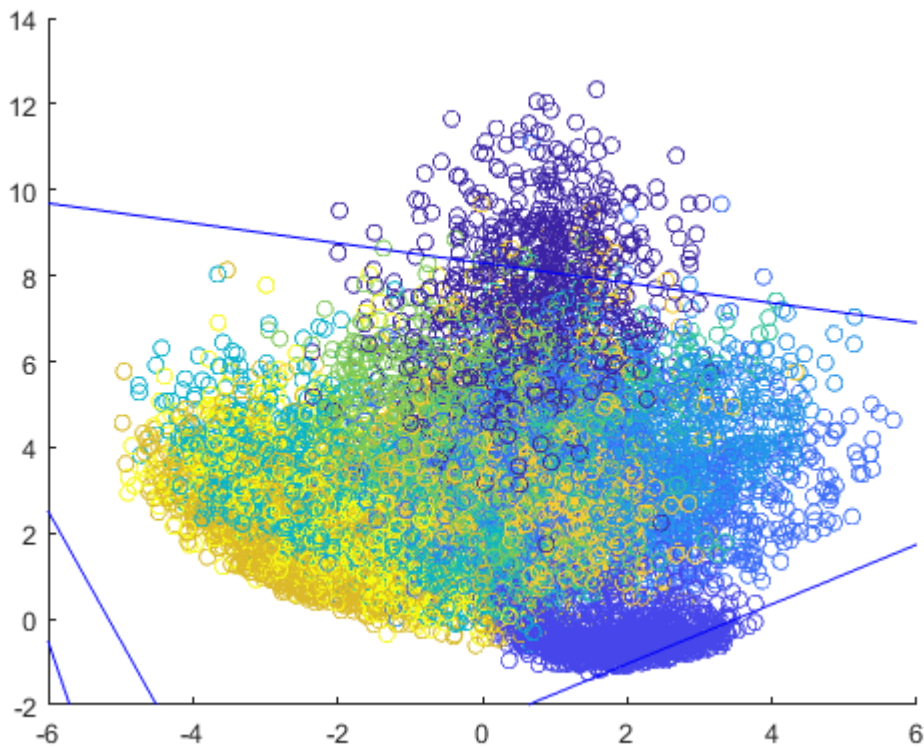
## Perceptron LMS PCA

```
w = Perceptron_LMS(train_labels, train_pca)
```

```
w = 3×10
```

-1.2569	-0.3519	-0.8518	-0.8361	-0.7689	-0.8651	-0.8851	-0.6564 ...
0.0352	0.1005	0.0640	0.0991	-0.1179	0.0261	-0.0003	-0.1271
0.1516	-0.1445	0.0153	0.0112	-0.0093	0.0147	0.0276	-0.0421

```
figure
scatter(test_pca(1,:),test_pca(2,:),[],test_labels)
hold on
for i = 1:size(w,2)
    plotpc(w(2:end,i)',w(1,i));
end
hold off
```



```
plots_perceptronForMNISTPcaVersion(test_pca,test_labels,w);
```

Confusion Matrix										
Output Class	1	2	3	4	5	6	7	8	9	10
	980 9.8%	991 9.9%	1032 10.3%	1010 10.1%	982 9.8%	892 8.9%	958 9.6%	1028 10.3%	974 9.7%	1009 10.1%
	0 0.0%	144 1.4%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
										11.2% 88.8%
Target Class										

Overall accuracy: 90.393%

## Perceptron LMS

```
w = Perceptron_LMS(train_labels, train_images)
```

```
w = 785x10
-0.6844 -0.5173 -0.9003 -0.9598 -0.5824 -0.6228 -0.8610 -0.7169 ...
-0.0000 -0.0000 -0.0000 -0.0000 -0.0000 0.0000 0.0000 0.0000
0.0000 -0.0000 0.0000 -0.0000 0.0000 -0.0000 0.0000 0.0000
0.0000 -0.0000 -0.0000 0.0000 0.0000 -0.0000 0.0000 -0.0000
0.0000 -0.0000 0.0000 0.0000 0.0000 0.0000 -0.0000 -0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 -0.0000 -0.0000
-0.0000 -0.0000 0.0000 -0.0000 -0.0000 -0.0000 0.0000 0.0000
0.0000 0.0000 -0.0000 0.0000 -0.0000 -0.0000 0.0000 -0.0000
-30.3232 10.1744 9.1996 -13.5964 12.4488 0.3666 -0.7510 4.1085
7.7375 -2.0091 -2.3198 2.3146 -2.5973 0.2275 0.1750 -2.0915
```



⋮

```
plots_perceptronForMNIST(test_images,test_labels,w)
```

**Confusion Matrix**

1	970 9.7%	97 1.0%	329 3.3%	335 3.4%	272 2.7%	422 4.2%	172 1.7%	254 2.5%	429 4.3%	411 4.1%	26.3% 73.7%
2	0 0.0%	1035 10.3%	20 0.2%	0 0.0%	6 0.1%	7 0.1%	5 0.1%	15 0.1%	12 0.1%	1 0.0%	94.0% 6.0%
3	0 0.0%	1 0.0%	630 6.3%	7 0.1%	3 0.0%	3 0.0%	7 0.1%	1 0.0%	4 0.0%	0 0.0%	96.0% 4.0%
4	0 0.0%	0 0.0%	12 0.1%	651 6.5%	0 0.0%	18 0.2%	0 0.0%	3 0.0%	3 0.0%	2 0.0%	94.5% 5.5%
5	0 0.0%	0 0.0%	4 0.0%	0 0.0%	684 6.8%	3 0.0%	6 0.1%	6 0.1%	3 0.0%	15 0.1%	94.9% 5.1%
6	4 0.0%	0 0.0%	0 0.0%	1 0.0%	0 0.0%	407 4.1%	7 0.1%	0 0.0%	32 0.3%	0 0.0%	90.2% 9.8%
7	4 0.0%	2 0.0%	24 0.2%	1 0.0%	2 0.0%	9 0.1%	761 7.6%	0 0.0%	6 0.1%	0 0.0%	94.1% 5.9%
8	1 0.0%	0 0.0%	2 0.0%	8 0.1%	1 0.0%	6 0.1%	0 0.0%	732 7.3%	3 0.0%	33 0.3%	93.1% 6.9%
9	1 0.0%	0 0.0%	10 0.1%	5 0.1%	1 0.0%	11 0.1%	0 0.0%	0 0.0%	480 4.8%	0 0.0%	94.5% 5.5%
10	0 0.0%	0 0.0%	1 0.0%	2 0.0%	13 0.1%	6 0.1%	0 0.0%	17 0.2%	2 0.0%	547 5.5%	93.0% 7.0%
	99.0% 1.0%	91.2% 8.8%	61.0% 39.0%	64.5% 35.5%	69.7% 30.3%	45.6% 54.4%	79.4% 20.6%	71.2% 28.8%	49.3% 50.7%	54.2% 45.8%	69.0% 31.0%
	1	2	3	4	5	6	7	8	9	10	
	<b>Target Class</b>										

**Output Class**

Overall accuracy: 96.348%