ISTANBUL TECHNICAL UNIVERSITY

COMPUTER ENGINERING DEPARTMENT

BLG 527E MACHINE LEARNING

CRN: 13817

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Homework #3

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Running Code

hw3.py file can be run with Python 2.7 interpreter. hw3.py can be run directly without any command line arguments or it can be run with input files as command line arguments. If no parameters are given default input file names will be used.

```
hw3.py <train_file_name> <test_file_name>
```

It took about 40 seconds to run. It is tested on both Ubuntu 16.04 and Windows 10 environment. Following Python modules needs to be installed to run hw3.py;

```
pip install numpy
pip install scipy
pip install pandas
pip install sklearn
```

Answers

Q1) optdigits.tra input data set randomly spiltted into 90% train and 10% validation sets for determine the best hyper-parameters. Output for the following 3 methods: knn, linear discrimination, multilayer perceptron:

```
Optimum KNN k is 3 with validation accuracy: 98.20%
Optimum LDA component number is 2 with validation accuracy: 95.47%
Optimum MLP layering is (100,) layer number is 1 with validation accuracy: 97.88%
Optimum decision tree minimum impurity decrease is 0.00 with validation accuracy: 88.64%


**** KNN ****
KNN Training accuracy: 99.27
KNN Test accuracy: 97.83
KNN Training accuracy for each class:
[1.0, 0.975, 0.997, 0.995, 0.992, 0.997, 0.995, 0.99, 0.995, 0.992]
KNN Test accuracy for each class:
[1.0, 0.923, 1.0, 0.968, 0.994, 0.994, 0.995, 0.994, 0.97, 0.951]
```

```
KNN Training confusion matrix:
[[374   0   0   0   1   0   1   0   0   0]
 [  0 387   1   0   0   0   0   1   0   0]
 [  0   0 380   0   0   0   0   0   0   0]
 [  0   1   0 386   0   1   0   0   1   0]
 [  0   0   0   0 385   0   1   1   0   0]
 [  0   1   0   0   0 373   0   0   0   2]
 [  0   2   0   0   0   0 375   0   0   0]
 [  0   0   0   1   1   0   0 385   0   0]
 [  0   6   0   0   0   0   0   0 373   1]
 [  0   0   0   1   1   0   0   2   1 377]]

KNN Test confusion matrix:
[[178   0   0   0   0   0   0   0   0   0]
 [  0 180   0   0   0   0   1   0   1   0]
 [  0   4 173   0   0   0   0   0   0   0]
 [  0   0   0 181   0   0   0   1   1   0]
 [  0   2   0   0 178   0   0   0   1   0]
 [  0   0   0   1   1 179   0   0   0   1]
 [  0   0   0   0   0   0 181   0   0   0]
 [  0   0   0   0   0   0   0 172   1   6]
 [  0   9   0   1   0   0   0   0 162   2]
 [  0   0   0   4   0   1   0   0   1 174]]

KNN Training time: 1.424000
KNN Test time: 0.764000
```

**** LDA ****

LDA Training accuracy: 96.26

LDA Test accuracy: 93.88

LDA Training accuracy for each class:

[0.992, 0.936, 0.978, 0.967, 0.982, 0.983, 0.979, 0.992, 0.918, 0.905]

LDA Test accuracy for each class:

[1.0, 0.897, 0.966, 0.955, 0.983, 0.927, 1.0, 0.988, 0.882, 0.814]

LDA Training confusion matrix:

```
[[374   0   0   0   1   0   1   0   0   0]
 [  0 364   6   0   0   0   0   1  13   5]
 [  0   1 364   3   0   0   1   1   8   2]
 [  0   1   1 376   0   2   0   0   2   7]
 [  0   4   0   0 373   0   5   0   4   1]
 [  1   0   0   1   0 356   0   0   0  18]
 [  0   1   1   0   1   0 374   0   0   0]
 [  0   1   0   4   0   0   0 379   0   3]
 [  1  13   0   0   2   2   1   0 359   2]
 [  1   4   0   5   3   2   0   1   5 361]]
```

LDA Test confusion matrix:

```
[[174   0   0   0   0   2   0   0   1   1]
 [  0 166   5   0   0   0   0   0   5   6]
 [  0   0 168   7   0   0   0   0   1   1]
 [  0   0   1 171   0   3   0   0   5   3]
 [  0   2   0   0 175   0   0   1   2   1]
 [  0   0   0   0   0 179   0   0   0   3]
 [  0   2   0   0   1   0 178   0   0   0]
 [  0   0   0   0   1   3   0 163   2  10]
 [  0  12   0   0   0   5   0   1 142  14]
 [  0   3   0   1   1   1   0   0   3 171]]
```

LDA Training time: 0.027000

LDA Test time: 0.001000

**** MLP ****

MLP Training accuracy: 99.97

MLP Test accuracy: 96.38

MLP Training accuracy for each class:

[1.0, 0.997, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0]

MLP Test accuracy for each class:

[0.989, 0.947, 0.989, 0.994, 0.973, 0.923, 0.978, 0.982, 0.952, 0.921]

MLP Training confusion matrix:

```
[[376   0   0   0   0   0   0   0   0   0]
 [  0 389   0   0   0   0   0   0   0   0]
 [  0   0 380   0   0   0   0   0   0   0]
 [  0   0   0 389   0   0   0   0   0   0]
 [  0   0   0   0 387   0   0   0   0   0]
 [  0   0   0   0   0 376   0   0   0   0]
 [  0   0   0   0   0   0 377   0   0   0]
 [  0   0   0   0   0   0   0 387   0   0]
 [  0   1   0   0   0   0   0   0 379   0]
 [  0   0   0   0   0   0   0   0   0 382]]
```

MLP Test confusion matrix:

```
[[176   0   0   0   0   2   0   0   0   0]
 [  0 180   0   0   0   0   0   0   2   0]
 [  0   1 172   0   0   0   2   2   0   0]
 [  1   0   1 172   0   4   1   0   2   2]
 [  0   1   0   0 179   0   0   0   1   0]
 [  0   0   1   0   0 179   1   0   0   1]
 [  1   1   0   0   2   0 176   0   1   0]
 [  0   0   0   0   2   5   0 165   1   6]
 [  0   7   0   0   1   2   0   1 157   6]
 [  0   0   0   1   0   2   0   0   1 176]]
```

MLP Training time: 2.174000

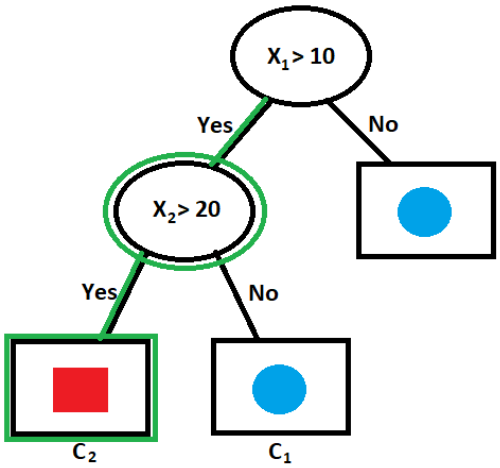
MLP Test time: 0.004000

Q2) MLP gives best training accuracy but also it is the slowest one. KNN gives best test accuracy. LDA is the fastest one among them but it has less training and test accuracy. It can be seen from confusion matrices that class 1 and class 9 are confused with each other the most.

	KNN	LDA	MLP
Training confusion matrix	[[374 0 0 0 1 0 1 0 0 0] [0 387 1 0 0 0 0 1 0 0] [0 0 380 0 0 0 0 0 0 0] [0 1 0 386 0 1 0 0 1 0] [0 0 0 0 385 0 1 1 0 0] [0 1 0 0 0 373 0 0 0 2] [0 2 0 0 0 0 375 0 0 0] [0 0 0 1 1 0 0 385 0 0] [0 6 0 0 0 0 0 0 373 1] [0 0 0 1 1 0 0 2 1 377]]	[[374 0 0 0 1 0 1 0 0 0] [0 364 6 0 0 0 0 1 13 5] [0 1 364 3 0 0 1 1 8 2] [0 1 1 376 0 2 0 0 2 7] [0 4 0 0 373 0 5 0 4 1] [1 0 0 1 0 356 0 0 0 18] [0 1 1 0 1 0 374 0 0 0] [0 1 0 4 0 0 0 379 0 3] [1 13 0 0 2 2 1 0 359 2] [1 4 0 5 3 2 0 1 5 361]]	[[376 0 0 0 0 0 0 0 0 0] [0 389 0 0 0 0 0 0 0 0] [0 0 380 0 0 0 0 0 0 0] [0 0 0 389 0 0 0 0 0 0] [0 0 0 0 387 0 0 0 0 0] [0 0 0 0 0 376 0 0 0 0] [0 0 0 0 0 0 377 0 0 0] [0 0 0 0 0 0 0 387 0 0] [0 1 0 0 0 0 0 0 379 0] [0 0 0 0 0 0 0 0 0 382]]
Training accuracy	99.27 %	96.26 %	99.97 %
Training accuracy for each class	[1.0, 0.975, 0.997, 0.995, 0.992, 0.997, 0.995, 0.99, 0.995, 0.992]	[0.992, 0.936, 0.978, 0.967, 0.982, 0.983, 0.979, 0.992, 0.918, 0.905]	[1.0, 0.997, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0]
Training time	1.424 s	0.027 s	2.174 s
Test confusion matrix	[[178 0 0 0 0 0 0 0 0 0] [0 180 0 0 0 0 1 0 1 0] [0 4 173 0 0 0 0 0 0 0] [0 0 0 181 0 0 0 1 1 0] [0 2 0 0 178 0 0 0 1 0] [0 0 0 1 1 179 0 0 0 1] [0 0 0 0 0 0 181 0 0 0] [0 0 0 0 0 0 0 172 1 6] [0 9 0 1 0 0 0 0 162 2] [0 0 0 4 0 1 0 0 1 174]]	[[174 0 0 0 0 2 0 0 1 1] [0 166 5 0 0 0 0 0 5 6] [0 0 168 7 0 0 0 0 1 1] [0 0 1 171 0 3 0 0 5 3] [0 2 0 0 175 0 0 1 2 1] [0 0 0 0 0 179 0 0 0 3] [0 2 0 0 1 0 178 0 0 0] [0 0 0 0 1 3 0 163 2 10] [0 12 0 0 0 5 0 1 142 14] [0 3 0 1 1 1 0 0 3 171]]	[[176 0 0 0 0 2 0 0 0 0] [0 180 0 0 0 0 0 0 2 0] [0 1 172 0 0 0 2 2 0 0] [1 0 1 172 0 4 1 0 2 2] [0 1 0 0 179 0 0 0 1 0] [0 0 1 0 0 179 1 0 0 1] [1 1 0 0 2 0 176 0 1 0] [0 0 0 0 2 5 0 165 1 6] [0 7 0 0 1 2 0 1 157 6] [0 0 0 1 0 2 0 0 1 176]]
Test accuracy	97.83 %	93.88 %	96.38 %
Test accuracy for each class	[1.0, 0.923, 1.0, 0.968, 0.994, 0.994, 0.995, 0.994, 0.97, 0.951]	[1.0, 0.897, 0.966, 0.955, 0.983, 0.927, 1.0, 0.988, 0.882, 0.814]	[0.989, 0.947, 0.989, 0.994, 0.973, 0.923, 0.978, 0.982, 0.952, 0.921]
Test time	0.764 s	0.001 s	0.004 s

Q3-a) Given the decision tree for w10=10 and w20=20, data point $[25,23]^T$ belongs to class C_2.

$X_1 = 25$, $X_2 = 23$



Q3-b)

```
**** Decision Tree ****
Decision Tree Training accuracy: 100.00
Decision Tree Test accuracy: 87.20
Decision Tree Training accuracy for each class:
[1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0]
Decision Tree Test accuracy for each class:
[0.96, 0.814, 0.902, 0.837, 0.818, 0.892, 0.934, 0.929, 0.818, 0.836]
Decision Tree Training confusion matrix:
[[376   0   0   0   0   0   0   0   0   0]
 [  0 389   0   0   0   0   0   0   0   0]
 [  0   0 380   0   0   0   0   0   0   0]
 [  0   0   0 389   0   0   0   0   0   0]
 [  0   0   0   0 387   0   0   0   0   0]
 [  0   0   0   0   0 376   0   0   0   0]
 [  0   0   0   0   0   0 377   0   0   0]
 [  0   0   0   0   0   0   0 387   0   0]
 [  0   0   0   0   0   0   0   0 380   0]
 [  0   0   0   0   0   0   0   0   0 382]]
Decision Tree Test confusion matrix:
[[168   0   0   0   3   1   1   0   3   2]
 [  0 158   6   2   6   0   1   0   7   2]
 [  1   8 148   7   0   1   1   3   7   1]
 [  4   4   2 154   1   2   0   7   3   6]
 [  0   3   0   0 171   1   4   0   1   1]
 [  0   2   0   3   0 166   5   1   1   4]
 [  0   1   1   0   1   1 171   0   6   0]
 [  0   0   1   0  19   2   0 144   3  10]
 [  1  16   6   3   3   3   0   0 139   3]
 [  1   2   0  15   5   9   0   0   0 148]]

Decision Tree Training time: 0.046000
Decision Tree Test time: 0.001000
```