Project3

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1 Project 3 Report

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CS458

1.1 P3-1. Revisit Text Documents Classification

(a) Load the following 4 categories from the 20 newsgroups dataset: categories = [‘rec.autos’, ‘talk.religion.misc’, ‘comp.graphics’, ‘sci.space’].

(b) Build classifiers using the following methods: + Support Vector Machine (sklearn.svm.LinearSVC) + Naive Bayes classifiers (sklearn.naive_bayes.MultinomialNB) + K-nearest neighbors (sklearn.neighbors.KNeighborsClassifier) + Random forest (sklearn.ensemble.RandomForestClassifier) + AdaBoost classifier (sklearn.ensemble.AdaBoostClassifier)

Optimize the hyperparameters of these methods and compare the results of these methods.

[1]:
```
import numpy as np
from sklearn import datasets, model_selection, metrics
from sklearn.feature_extraction.text import TfidfTransformer, TfidfVectorizer
from sklearn.pipeline import Pipeline

from sklearn.svm import LinearSVC
from sklearn.naive_bayes import MultinomialNB
from sklearn.neighbors import KNeighborsClassifier
from sklearn.ensemble import RandomForestClassifier, AdaBoostClassifier

# (a) load newsgroups
ng_train = datasets.fetch_20newsgroups(subset='train', categories=['rec.autos',␣
↪'talk.religion.misc', 'comp.graphics', 'sci.space'], remove=('headers',␣
↪'footers', 'quotes'))
ng_test = datasets.fetch_20newsgroups(subset='test', categories=['rec.autos',␣
↪'talk.religion.misc', 'comp.graphics', 'sci.space'], remove=('headers',␣
↪'footers', 'quotes'))

y1 = ng_train.target
```

```python
y2 = ng_test.target

# (b) classifiers

max_depth_range = [None, 2, 5, 10]
min_samples_leaf_range = [1, 5, 10]
min_sample_split_range = [2, 10, 20]
min_leaf_nodes_range = [None, 5, 10, 20]

param_grid = {"clf__criterion": ['gini'],
              "clf__max_depth": [10],
              "clf__min_samples_leaf": [1, 5, 10],
              "clf__min_samples_split": [20],
              "clf__max_leaf_nodes": [None, 5, 10, 20]
              }

pipe_rf = Pipeline([('vect', TfidfVectorizer()),
                    ('tfidf', TfidfTransformer()),
                    ('clf', RandomForestClassifier())])

Results_SVC_Penalty = {
  "l1" : 0,
  "l2" : 0
}

Results_Bayes_Alpha = {
  0.001 : 0,
  0.01 : 0,
  0.1 : 0
}

Results_KNN_Neighbors = {
  5 : 0,
  10 : 0,
  15 : 0
}

Results_Ada_LearningRate = {
  0.001 : 0,
  0.01 : 0,
  0.1 : 0,
  1.0 : 0
}

Results_Forest_Multiple = dict()

def trainMe(clf, Results, hyperparameter):
```

```
  print(f"Testing {str(clf)}")
  clf.fit(x1, y1)
  pred = clf.predict(x2)
  score = metrics.accuracy_score(y2, pred)
  Results[hyperparameter] = score

def runTests():
  # Support Vector Machine (LinearSVC)
  for hp in Results_SVC_Penalty:
    trainMe(LinearSVC(penalty=hp, tol=1e-3, dual=False), Results_SVC_Penalty,␣
 ↪hp)

  # Naive Bayes (MultinomialNB)
  for hp in Results_Bayes_Alpha:
    trainMe(MultinomialNB(alpha=hp), Results_Bayes_Alpha, hp)

  # K-nearest Neighbors (KNeighborsClassifier)
  for hp in Results_KNN_Neighbors:
    trainMe(KNeighborsClassifier(n_neighbors=hp), Results_KNN_Neighbors, hp)

  # Random forest (RandomForestClassifier)
  print("Testing RandomForestClassifier(*)")
  grid = model_selection.GridSearchCV(estimator=pipe_rf, param_grid=param_grid,␣
 ↪scoring='accuracy', refit=True, verbose=True)
  grid.fit(ng_train.data, ng_train.target)
  means = grid.cv_results_["mean_test_score"]
  for mean, params in zip(means, grid.cv_results_["params"]):
    Results_Forest_Multiple.update({str(params) : mean})

  # AdaBoost (AdaBoostClassifier)
  for hp in Results_Ada_LearningRate:
    trainMe(AdaBoostClassifier(learning_rate=hp), Results_Ada_LearningRate, hp)

def printDictReallyNice(d):
  for k,v in d.items():
    print(k, ' : ', v)

vectorizer = TfidfVectorizer(sublinear_tf=True, max_df=0.5,␣
 ↪stop_words='english',)
x1 = vectorizer.fit_transform(ng_train.data)
x2 = vectorizer.transform(ng_test.data)

runTests()
print("\nFormat = Hyperparameter : Accuracy")
print(f'\nSupport Vector Machine\nHyperparameter: Penalty')
printDictReallyNice(Results_SVC_Penalty)
print(f'\nNaive Bayes\nHyperparameter: Smoothing (alpha)')
```

```python
printDictReallyNice(Results_Bayes_Alpha)
print(f'\nK-nearest Neighbors\nHyperparameter: Number of Neighbors')
printDictReallyNice(Results_KNN_Neighbors)
print(f'\nRandom Forest\nHyperparameter: Max Depth, Min Samples Leaf, Min␣
 ↪Samples Split, Min Leaf Nodes')
printDictReallyNice(Results_Forest_Multiple)
print(f'\nAdaBoost Classifier\nHyperparameter: Learning Rate')
printDictReallyNice(Results_Ada_LearningRate)
```

```
Testing LinearSVC(dual=False, penalty='l1', tol=0.001)
Testing LinearSVC(dual=False, tol=0.001)
Testing MultinomialNB(alpha=0.001)
Testing MultinomialNB(alpha=0.01)
Testing MultinomialNB(alpha=0.1)
Testing KNeighborsClassifier()
Testing KNeighborsClassifier(n_neighbors=10)
Testing KNeighborsClassifier(n_neighbors=15)
Testing RandomForestClassifier(*)
Fitting 5 folds for each of 12 candidates, totalling 60 fits
Testing AdaBoostClassifier(learning_rate=0.001)
Testing AdaBoostClassifier(learning_rate=0.01)
Testing AdaBoostClassifier(learning_rate=0.1)
Testing AdaBoostClassifier()

Format = Hyperparameter : Accuracy

Support Vector Machine
Hyperparameter: Penalty
l1  :  0.8251748251748252
l2  :  0.8748251748251749

Naive Bayes
Hyperparameter: Smoothing (alpha)
0.001  :  0.8699300699300699
0.01  :  0.8748251748251749
0.1  :  0.8818181818181818

K-nearest Neighbors
Hyperparameter: Number of Neighbors
5  :  0.28601398601398603
10  :  0.2748251748251748
15  :  0.26713286713286716

Random Forest
Hyperparameter: Max Depth, Min Samples Leaf, Min Samples Split, Min Leaf Nodes
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': None,
'clf__min_samples_leaf': 1, 'clf__min_samples_split': 20}  :  0.7490724779096871
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': None,
```

```
'clf__min_samples_leaf': 5, 'clf__min_samples_split': 20}  :  0.7532650295440994
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': None,
'clf__min_samples_leaf': 10, 'clf__min_samples_split': 20}  :
0.7369664444083048
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 5,
'clf__min_samples_leaf': 1, 'clf__min_samples_split': 20}  :  0.6713167452702337
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 5,
'clf__min_samples_leaf': 5, 'clf__min_samples_split': 20}  :  0.6917970401691332
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 5,
'clf__min_samples_leaf': 10, 'clf__min_samples_split': 20}  :
0.6824936304006071
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 10,
'clf__min_samples_leaf': 1, 'clf__min_samples_split': 20}  :  0.727197918360709
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 10,
'clf__min_samples_leaf': 5, 'clf__min_samples_split': 20}  :  0.7323217867403914
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 10,
'clf__min_samples_leaf': 10, 'clf__min_samples_split': 20}  :
0.7323315444245677
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 20,
'clf__min_samples_leaf': 1, 'clf__min_samples_split': 20}  :  0.7388355830216295
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 20,
'clf__min_samples_leaf': 5, 'clf__min_samples_split': 20}  :  0.7430270504689109
{'clf__criterion': 'gini', 'clf__max_depth': 10, 'clf__max_leaf_nodes': 20,
'clf__min_samples_leaf': 10, 'clf__min_samples_split': 20}  :
0.7337095462676858

AdaBoost Classifier
Hyperparameter: Learning Rate
0.001  :  0.4342657342657343
0.01  :  0.4783216783216783
0.1  :  0.6601398601398601
1.0  :  0.6573426573426573
```

SVM, Naive Bayes, and KNN were not too sensitive in regards to the chosen hyperparameters. The Random Forest preferred a higher maximum number of leaf nodes, but was around 73% for most runs. AdaBoost, while not very accurate, saw a significant boost when increasing the "learning rate" value towards one.

1.2 P3-2. Recognizing hand-written digits

(a) Develop a multi-layer perceptron classifier to recognize images of hand-written digits.

(b) Optimize the hyperparameters of your neural network to maximize the classification accuracy. Show the confusion matrix of your neural network. Discuss and compare your results with the results using a support vector classifier (see https://scikit-learn.org/stable/auto_examples/classification/plot_digits_classification.html#sphx-glr-auto-examples-classification-plot-digits-classification-py).

[2]:

```python
from sklearn import datasets, metrics
from sklearn.neural_network import MLPClassifier
from sklearn.svm import SVC
from sklearn.model_selection import train_test_split

# (a) build classifier
digits = datasets.load_digits()
x1, x2, y1, y2 = train_test_split(digits.data, digits.target, test_size=0.5)
good_clf = None

class Neural:
  def __init__(self, a):
    self.alpha = a
    self.clf = MLPClassifier(alpha=a)
    self.score = 0

  def update(self, s):
    self.score = s

Results_MLP_Alpha = {
  0.0001 : Neural(0.0001),
  0.001 : Neural(0.001),
  0.01 : Neural(0.01),
  0.1 : Neural(0.1)
}

Results_SVC_Gamma = {
  0.0001 : 0,
  0.001 : 0,
  0.01 : 0,
  0.1 : 0
}

def trainMe(clf, Results, hyperparameter):
  print(f"Testing {str(clf)}")
  clf.fit(x1, y1)
  pred = clf.predict(x2)
  score = metrics.accuracy_score(y2, pred)
  try:
    Results[hyperparameter].score = score
  except AttributeError:
    Results[hyperparameter] = score

def runTests():
  global good_clf

  # MLPClassifier
```

```python
  max_score = 0
  for hp in Results_MLP_Alpha:
    trainMe(Results_MLP_Alpha[hp].clf, Results_MLP_Alpha, hp)
    if Results_MLP_Alpha[hp].score > max_score:
      max_score = Results_MLP_Alpha[hp].score
      good_clf = Results_MLP_Alpha[hp].clf

  # SVC
  for hp in Results_SVC_Gamma:
    trainMe(SVC(gamma=hp, tol=1e-3), Results_SVC_Gamma, hp)

def printDictReallyNice(d):
  for k,v in d.items():
    try:
      print(k, ' : ', v.score)
    except AttributeError:
      print(k, ' : ', v)

runTests()
print("\nFormat = Hyperparameter : Accuracy")
print(f'\nMulti-layer Perceptron\nHyperparameter: Regularization (alpha)')
printDictReallyNice(Results_MLP_Alpha)
print(f'\nSupport Vector Machine\nHyperparameter: Gamma')
printDictReallyNice(Results_SVC_Gamma)
print()
print(f"Using {str(good_clf)} as best NN...\n")
print(" -- Confusion Matrix of Neural Network --")
print(metrics.confusion_matrix(y2, good_clf.predict(x2)))
```

```
Testing MLPClassifier()
Testing MLPClassifier(alpha=0.001)
Testing MLPClassifier(alpha=0.01)
Testing MLPClassifier(alpha=0.1)
Testing SVC(gamma=0.0001)
Testing SVC(gamma=0.001)
Testing SVC(gamma=0.01)
Testing SVC(gamma=0.1)

Format = Hyperparameter : Accuracy

Multi-layer Perceptron
Hyperparameter: Regularization (alpha)
0.0001  :  0.9710789766407119
0.001  :  0.9655172413793104
0.01  :  0.967741935483871
0.1  :  0.9666295884315906

Support Vector Machine
```

```
Hyperparameter: Gamma
0.0001  :  0.9655172413793104
0.001  :  0.9888765294771968
0.01  :  0.7063403781979978
0.1  :  0.08898776418242492

Using MLPClassifier() as best NN…

 -- Confusion Matrix of Neural Network --
[[88  0  0  0  1  0  0  0  0  0]
 [ 1 77  1  1  0  0  0  0  0  0]
 [ 0  0 97  0  0  0  0  0  0  0]
 [ 0  0  0 83  0  3  0  0  0  0]
 [ 1  1  0  0 91  0  0  0  1  0]
 [ 0  1  0  0  0 99  0  0  0  0]
 [ 0  0  0  0  2  0 92  0  0  0]
 [ 0  0  0  0  2  0  0 85  0  0]
 [ 0  5  0  0  0  2  0  0 75  0]
 [ 0  0  0  0  0  0  0  3  1 86]]
```

The multi-layer perceptron is clearly the better classifier for this situation. Accuracy hovers around 96% even after adjusting hyperparameter for regularization. Meanwhile, the Support Vector Machine is accurate at lower gamma values but loses accuracy significantly at higher values.

1.3 P3-3. Nonlinear Support Vector Machine

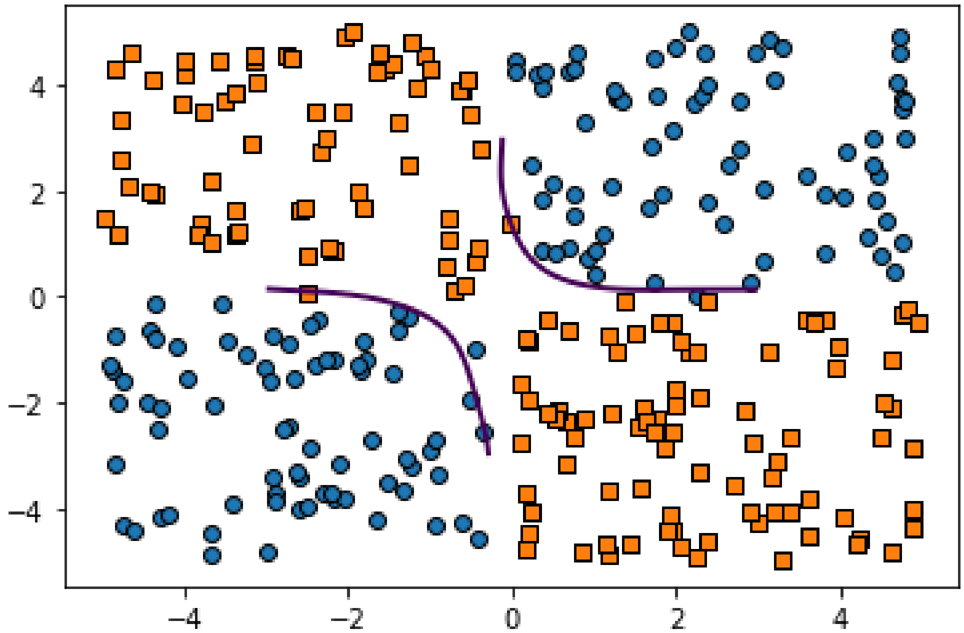
(a) Randomly generate the following 2-class data points.

(b) Develop a nonlinear SVM binary classifier (sklearn.svm.NuSVC).

(c) Plot these data points and the corresponding decision boundaries, which is similar to the figure in the slide 131 in Chapter 4.

[3]:
```python
import numpy as np
from sklearn.svm import NuSVC
import matplotlib.pyplot as plt

# (a) generate 2-class data points
np.random.seed(0)
x = np.random.rand(300,2) * 10 - 5
y = np.logical_xor(x[:,0]>0, x[:,1]>0)

# (b) develop nonlinear SVM binary classifier
clf = NuSVC(gamma='auto')
clf.fit(x,y)

# (c) plot the decision boundaries
xx, yy = np.meshgrid(np.linspace(-3, 3, 500), np.linspace(-3, 3, 500))
z = clf.decision_function(np.c_[xx.ravel(),yy.ravel()])
```

```
z = z.reshape(xx.shape)

cont = plt.contour(xx, yy, z, linewidths=2, levels=[0])
plt.scatter(x[y == 0,0], x[y == 0,1], marker='o', cmap=plt.cm.bwr,␣
 ↪edgecolors='k')
plt.scatter(x[y == 1,0], x[y == 1,1], marker='s', cmap=plt.cm.bwr,␣
 ↪edgecolors='k')
plt.show()
```



The graph shows that the classifier is fairly acccurate in its decision boundaries. Only a few points are misclassified.