Models and Ensembling Methods

Import dependencies ¶

In [1]:
```
import numpy
from gensim.models import word2vec
from gensim.models import KeyedVectors
import pandas
from nltk import WordPunctTokenizer
from sklearn.preprocessing import label_binarize
import sqlite3
from sklearn.multiclass import OneVsRestClassifier
from matplotlib import pyplot as plt
import seaborn as sns
from sklearn.metrics import precision_recall_curve # The average precision sco
re in multi-label settings
from sklearn.metrics import average_precision_score
from sklearn.metrics import f1_score
from sklearn.metrics import matthews_corrcoef
from sklearn.metrics import precision_recall_fscore_support
from sklearn import svm # Support Vector Machine
from itertools import cycle
from sklearn.linear_model import LogisticRegression
from sklearn.naive_bayes import GaussianNB
from sklearn import tree
from sklearn.model_selection import train_test_split
from sklearn.model_selection import cross_validate
from sklearn.metrics import precision_score, recall_score, roc_auc_score
from sklearn.metrics import make_scorer
from sklearn.ensemble import StackingClassifier
```

```
unable to import 'smart_open.gcs', disabling that module
```

Read in the data

Load raw train and test data

Load in the data from the database

In [2]:
```
dbconn = sqlite3.connect('./data/cleanedtraintest_v2.db')
train_data_df = pandas.read_sql_query('SELECT category, content_cleaned FROM t
rain_data', dbconn)
test_data_df = pandas.read_sql_query('SELECT category, content_cleaned FROM te
st_data', dbconn)
dbconn.commit()
dbconn.close()
```

Check the if the data was loaded correctly

In [3]:
```
train_data_df
```

Out[3]:

	category	content_cleaned
0	3	wall street seeing green
1	3	private investment firm carlyle group reputati...
2	3	soaring crude prices plus economy outlook earn...
3	3	authorities halted oil main pipeline southern ...
4	3	tearaway world oil prices toppling records str...
...	...	...
119995	1	pakistani president pervez musharraf said stay...
119996	2	red sox general manager theo epstein acknowled...
119997	2	miami dolphins put courtship lsu coach nick sa...
119998	2	pittsburgh ny giants time line steelers record...
119999	2	vince carter traded toronto raptors new jersey...

120000 rows × 2 columns

In [4]:
```
test_data_df
```

Out[4]:

	category	content_cleaned
0	3	unions representing workers turner newall say ...
1	4	toronto canada rocketeers competing million an...
2	4	company founded chemistry researcher universit...
3	4	barely dawn mike fitzpatrick starts shift blur...
4	4	southern california agency went emissions bovi...
...	...	...
7595	1	ukrainian presidential candidate viktor yushch...
7596	2	supply attractive pitching options dwindling d...
7597	2	like roger clemens almost exactly eight years ...
7598	3	singapore doctors united states warned painkil...
7599	3	ebay plans buy apartment home rental service m...

7600 rows × 2 columns

Train & Test data where x is the predictor features, y is the predicted feature

In [5]:
```
N_CLASSES = 4

x_train = train_data_df.content_cleaned
y_train = label_binarize(train_data_df.category, classes=[1, 2, 3, 4])

x_test = test_data_df.content_cleaned
y_test = label_binarize(test_data_df.category, classes=[1, 2, 3, 4])
```

Load word2vec data

Load word2vec feature arrays from .npz files

load dict of arrays

In [6]:
```
w2v_train_features_array_dict = numpy.load(
    './data/word2vec-train-features-120000-min5dim300.npz')
w2v_test_features_array_dict = numpy.load(
    './data/word2vec-test-features-120000-min5dim300.npz')
# extract the first array from train
data = w2v_train_features_array_dict['arr_0']
# print the array
print(data)
# extract the first array from test
data = w2v_test_features_array_dict['arr_0']
# print the array
print(data)
```

```
[[-0.43092448  0.50092196  0.08331972 ...  1.3914201   1.2953259
  -1.8574607 ]
 [-0.10783155 -0.35169265  0.90062636 ... -0.38979718  0.13664657
   0.5066641 ]
 [-1.0086536  -0.29255652 -0.7550053  ... -0.18521406  0.7896786
  -0.23576818]
 ...
 [-0.02566049  0.23409443 -0.8595321  ... -0.05427613 -0.89297265
  -0.09055152]
 [-0.6081659   0.42683512 -0.9105423  ... -0.06156884 -0.40654626
   0.07195716]
 [-1.0819023  -0.04211196 -0.16453283 ... -0.40625843 -0.13644677
  -0.0066904 ]]
[[-0.02657197 -1.0014614  -0.035705   ...  0.48677683  0.3947945
  -0.9894788 ]
 [-0.54866743 -1.3801866   0.66031504 ... -0.4012159   0.6803215
   0.92033225]
 [ 0.11171789  0.3781767  -0.26057357 ... -0.5006595   0.13674003
   0.10530389]
 ...
 [-0.46190766  0.7501185  -0.20256642 ... -0.32613838  0.09363924
   0.46578252]
 [-0.023529   -0.33200815 -0.63418424 ... -0.46149412  0.39634904
  -0.46027517]
 [-0.25388533 -0.6177681   0.9628809  ... -0.66557425 -0.1068292
  -0.64577085]]
```

Load word2vec model trained key vectors

In [7]:
```
w2v_model_train = KeyedVectors.load(
    './data/custom-trained-word2vec-120000-min5dim300.kv')
```

Get the word2vec data back into usable form

In [8]:
```
wpt = WordPunctTokenizer()
tokenized_corpus_train = [wpt.tokenize(document) for document in x_train]
tokenized_corpus_test = [wpt.tokenize(document) for document in x_test]

del(x_train)
del(x_test)
```

In [9]:
```
def average_word_vectors(words, model, vocabulary, num_features):

 feature_vector = numpy.zeros((num_features,), dtype="float32")
 nwords = 0.

 for word in words:
    if word in vocabulary:
      nwords = nwords + 1.
      feature_vector = numpy.add(feature_vector, model[word])

 if nwords:
    feature_vector = numpy.divide(feature_vector, nwords)

 return feature_vector

def averaged_word_vectorizer(corpus, model, num_features):
 vocabulary = set(model.wv.index2word)
 features = [average_word_vectors(tokenized_sentence, model, vocabulary, num_f
eatures)
            for tokenized_sentence in corpus]
 return numpy.array(features)
```

Obtain document level embeddings

In [10]:
```
FEATURE_SIZE = 300

w2v_feature_array_train = averaged_word_vectorizer(corpus=tokenized_corpus_tra
in,
    model=w2v_model_train, num_features=FEATURE_SIZE)
w2v_feature_array_test = averaged_word_vectorizer(corpus=tokenized_corpus_test
,
    model=w2v_model_train, num_features=FEATURE_SIZE)

x_train_w2v = pandas.DataFrame(w2v_feature_array_train)
x_test_w2v = pandas.DataFrame(w2v_feature_array_test)
```

Build Models

SVM Model Building Function

In [11]:
```
def run_svm(x_train, y_train):
    classifier = OneVsRestClassifier(svm.LinearSVC(random_state=1))
    classifier.fit(x_train, y_train)
    return classifier
```

Logistic Regression Model Building Function

In [12]:
```
def run_logreg(x_train, y_train):
    classifier = OneVsRestClassifier(LogisticRegression(random_state=1))
    classifier.fit(x_train, y_train)
    return classifier
```

Naive Bayes Function

In [13]:
```
def run_nb(x_train, y_train):
    classifier = OneVsRestClassifier(GaussianNB())
    classifier.fit(x_train, y_train)
    return classifier
```

Decision Trees Function

In [14]:
```
def run_dectree(x_train, y_train):
    classifier = OneVsRestClassifier(tree.DecisionTreeClassifier())
    classifier.fit(x_train, y_train)
    return classifier
```

Functions to calculate scores and to plot them

Calculate, then plot the Precision, Recall, Average Precision, F1

In [15]:
```
def prf1_calc(classifier, algo_name, n_classes, x_test, y_test):
    # Get the decision function from the classifier
    if algo_name == 'SVM':
        y_score = classifier.decision_function(x_test)
    else:
        y_score = classifier.predict_proba(x_test)
    y_pred = classifier.predict(x_test)

    # The average precision score in multi-label settings
    # For each class
    precision = dict()
    recall = dict()
    average_f1 = dict()
    average_precision = dict()
    mcc = dict()
    for i in range(n_classes):
        precision[i], recall[i], _ = precision_recall_curve(y_test[:, i],
                                                            y_score[:, i])
        average_precision[i] = average_precision_score(y_test[:, i], y_score
[:, i])
        average_f1[i] = f1_score(y_test[:, i], y_pred[:, i])
        mcc[i] = matthews_corrcoef(y_test[:, i], y_pred[:, i])

    # A "micro-average": quantifying score on all classes jointly
    precision["micro"], recall["micro"], _ = precision_recall_curve(y_test.rav
el(),
        y_score.ravel())
    average_precision["micro"] = average_precision_score(y_test, y_score,
                                                         average="micro")
    average_f1['micro'] = f1_score(y_test, y_pred, average='micro')
    mcc['micro'] = sum(mcc.values())/4

    # Plot the data
    prf1_plot(precision, recall, average_precision, algo_name, n_classes)

    # Return all metrics
    results = pandas.DataFrame()

    for k in average_precision.keys():
        results.at[algo_name, f'P-R {k}'] = numpy.round(average_precision[k],
3)
        results.at[algo_name, f'F1 {k}'] = numpy.round(average_f1[k], 3)
        results.at[algo_name, f'MCC {k}'] = numpy.round(mcc[k], 3)

    return results

# Function to Plot Precision, Recall, F1
def prf1_plot(precision, recall, average_precision, algo_name, n_classes):
    print(algo_name)
    print('Average precision score, micro-averaged over all classes: {0:0.2f}'
        .format(average_precision["micro"]))

    # Plot the micro-averaged Precision-Recall curve
    plt.figure()
    plt.step(recall['micro'], precision['micro'], where='post')
```

```
    plt.xlabel('Recall')
    plt.ylabel('Precision')
    plt.ylim([0.0, 1.05])
    plt.xlim([0.0, 1.0])
    plt.title(
        'Average precision score, micro-averaged over all classes: AP={0:0.2f}
'
        .format(average_precision["micro"]))

    # Plot Precision-Recall curve for each class and iso-f1 curves
    # setup plot details
    colors = cycle(['navy', 'turquoise', 'darkorange', 'cornflowerblue', 'tea
l'])

    plt.figure(figsize=(7, 8))
    f_scores = numpy.linspace(0.2, 0.8, num=4)
    lines = []
    labels = []
    for f_score in f_scores:
        x = numpy.linspace(0.01, 1)
        y = f_score * x / (2 * x - f_score)
        l, = plt.plot(x[y >= 0], y[y >= 0], color='gray', alpha=0.2)
        plt.annotate('f1={0:0.1f}'.format(f_score), xy=(0.9, y[45] + 0.02))

    lines.append(l)
    labels.append('iso-f1 curves')
    l, = plt.plot(recall["micro"], precision["micro"], color='gold', lw=2)
    lines.append(l)
    labels.append('micro-average Precision-recall (area = {0:0.2f})'
                  ''.format(average_precision["micro"]))

    for i, color in zip(range(n_classes), colors):
        l, = plt.plot(recall[i], precision[i], color=color, lw=2)
        lines.append(l)
        labels.append('Precision-recall for class {0} (area = {1:0.2f})'
                      ''.format(i, average_precision[i]))

    fig = plt.gcf()
    fig.subplots_adjust(bottom=0.25)
    plt.xlim([0.0, 1.0])
    plt.ylim([0.0, 1.05])
    plt.xlabel('Recall')
    plt.ylabel('Precision')
    plt.title('Extension of Precision-Recall curve to multi-class')
    plt.legend(lines, labels, loc=(0, -.5), prop=dict(size=14))

    plt.show()
```

Run the Models

In [16]:
```
# Run SVM Model
svm_model = run_svm(x_train_w2v, y_train)
```

In [17]:
```
# Run Logistic Regression Model
logreg_model = run_logreg(x_train_w2v, y_train)
```

In [18]:
```
# Run Naive Bayes Classifier
nb_model = run_nb(x_train_w2v, y_train)
```

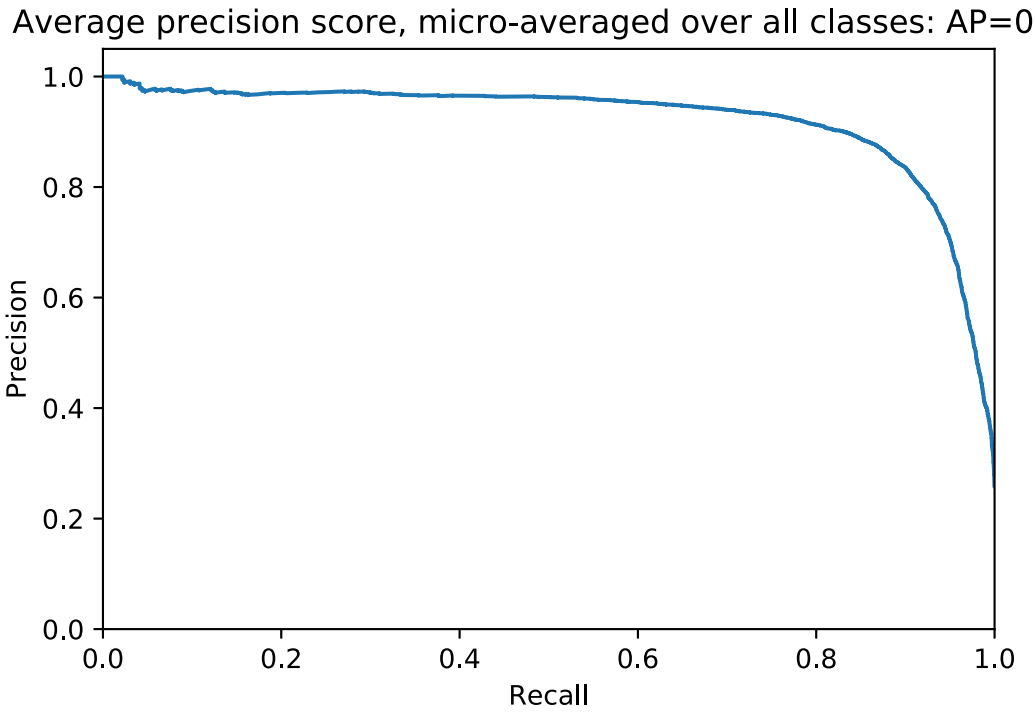
In [19]:
```
# Run Decision Trees Classifier
dectree_model = run_dectree(x_train_w2v, y_train)
```

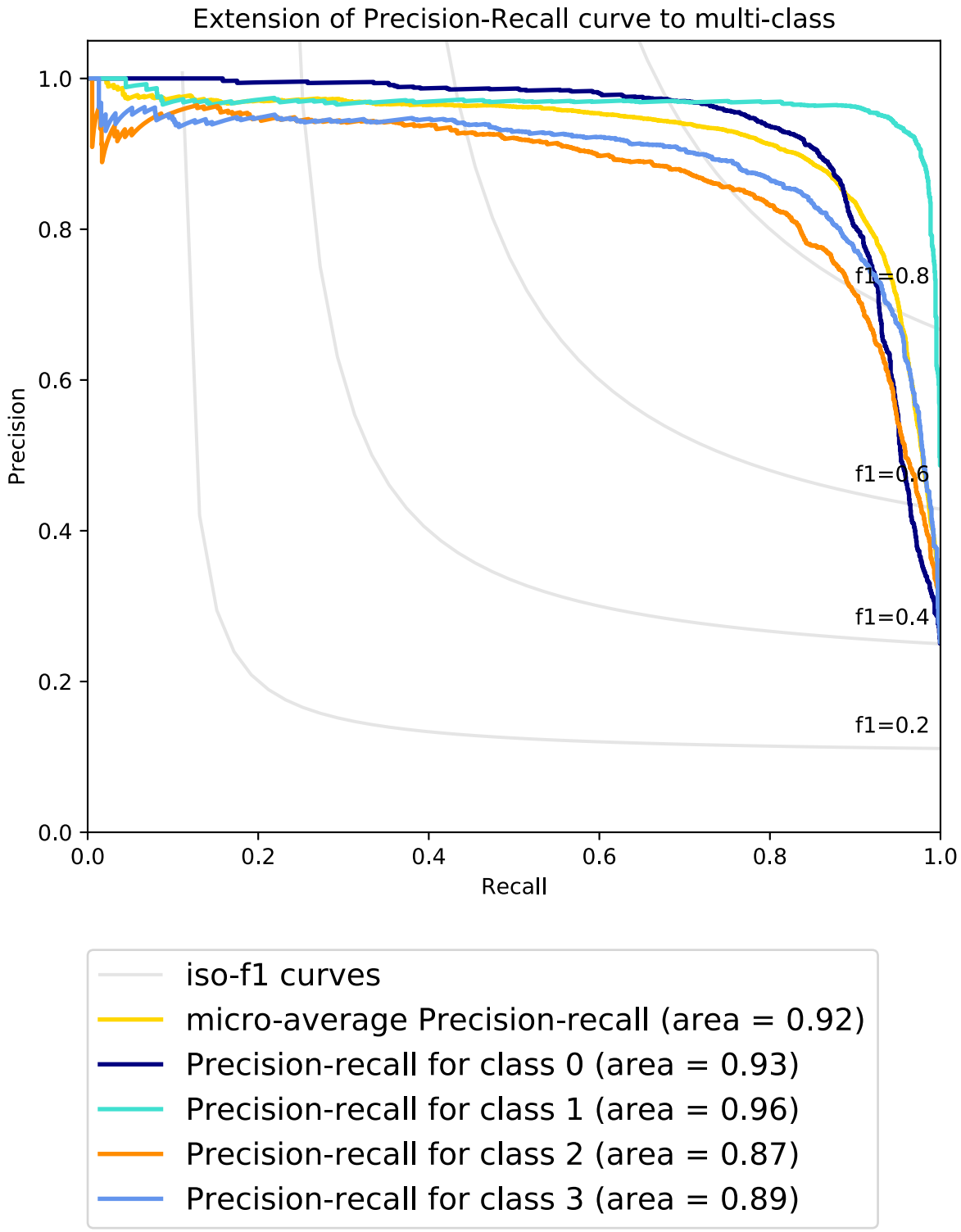
Get the scores

In [20]:
```
# Initialize the dataframe to keep track of the scores
scores = pandas.DataFrame()
```

In [21]:
```
# Precision, Recall, Avg. Precision for SVM
scores = scores.append(prf1_calc(svm_model, 'SVM', N_CLASSES, x_test_w2v, y_te
st))
```

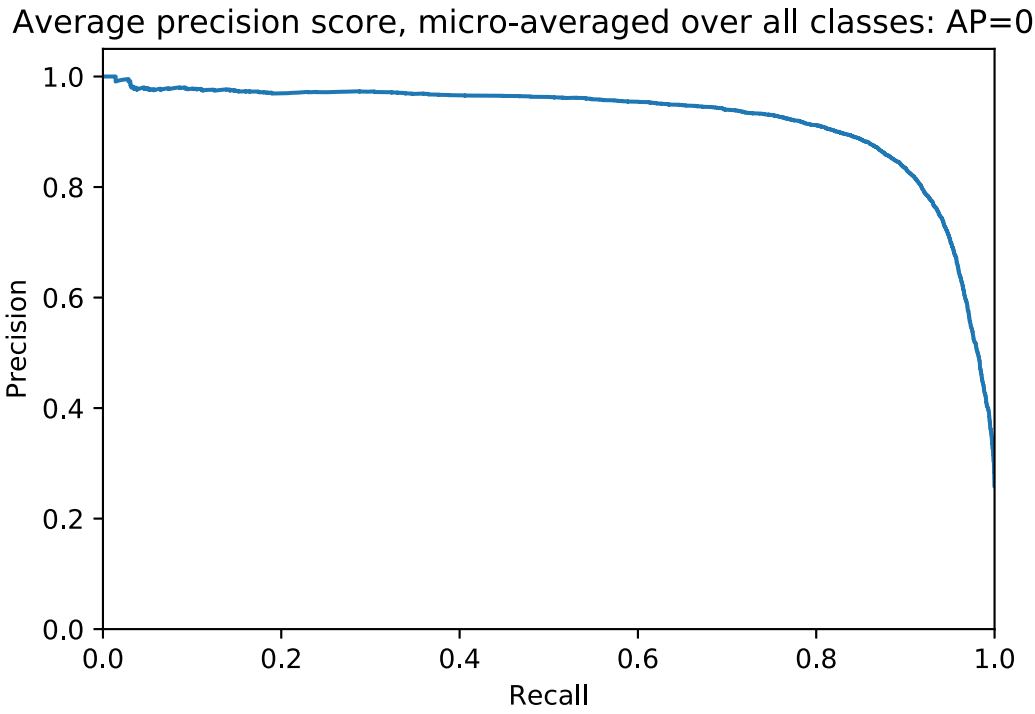
```
SVM
Average precision score, micro-averaged over all classes: 0.92
```

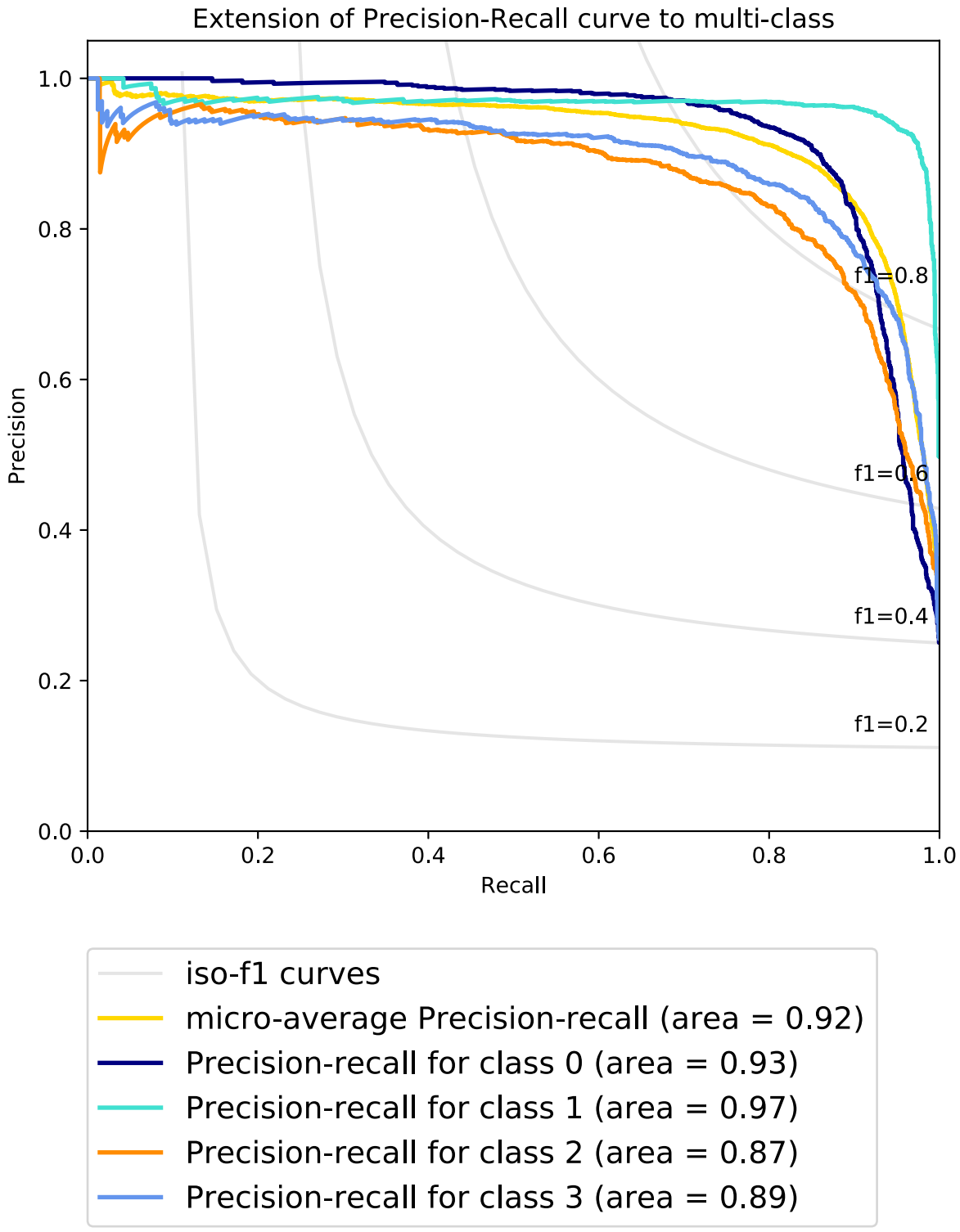



Extension of Precision-Recall curve to multi-class
Precision
Recall
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
f1=0.8
f1=0.6
f1=0.4
f1=0.2
iso-f1 curves
micro-average Precision-recall (area = 0.92)
Precision-recall for class 0 (area = 0.93)
Precision-recall for class 1 (area = 0.96)
Precision-recall for class 2 (area = 0.87)
Precision-recall for class 3 (area = 0.89)

In [22]:
```
# Precision, Recall, Avg. Precision for LOG REG
scores = scores.append(prf1_calc(logreg_model, 'LOGREG', N_CLASSES, x_test_w2v
, y_test))
```

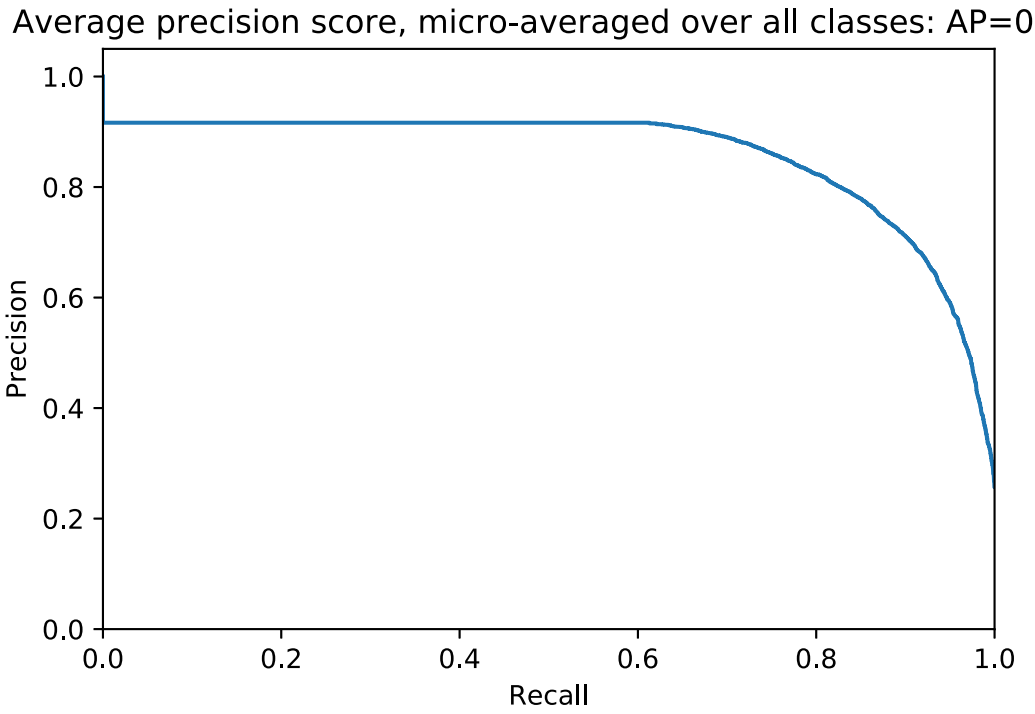
```
LOGREG
Average precision score, micro-averaged over all classes: 0.92
```

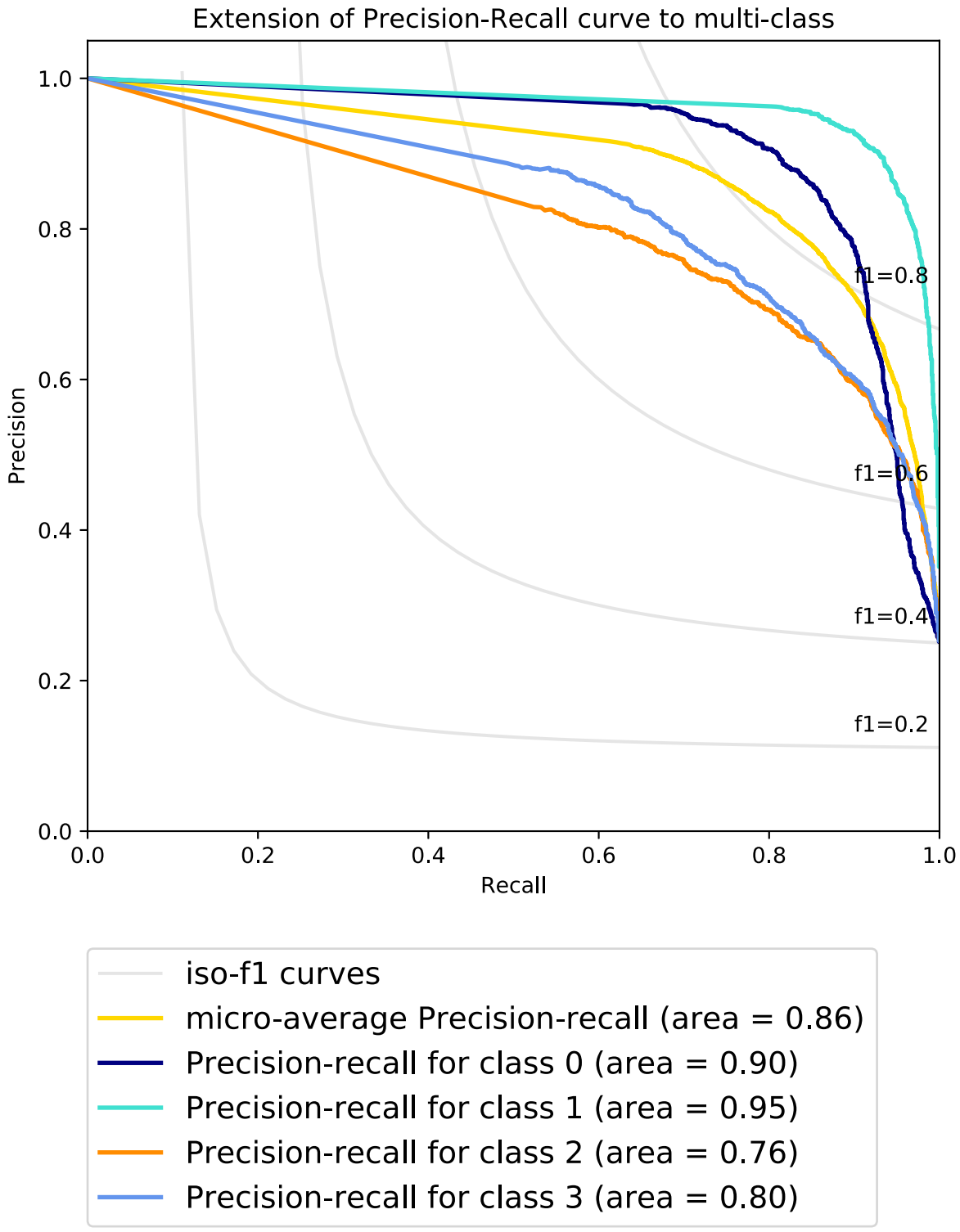



Extension of Precision-Recall curve to multi-class
Precision
Recall
0.0
0.2
0.4
0.6
0.8
1.0
f1=0.8
f1=0.6
f1=0.4
f1=0.2
iso-f1 curves
micro-average Precision-recall (area = 0.92)
Precision-recall for class 0 (area = 0.93)
Precision-recall for class 1 (area = 0.97)
Precision-recall for class 2 (area = 0.87)
Precision-recall for class 3 (area = 0.89)

In [23]:
```
# Precision, Recall, Avg. Precision for Naive Bayes
scores = scores.append(prf1_calc(nb_model, 'NB', N_CLASSES, x_test_w2v, y_test
))
```

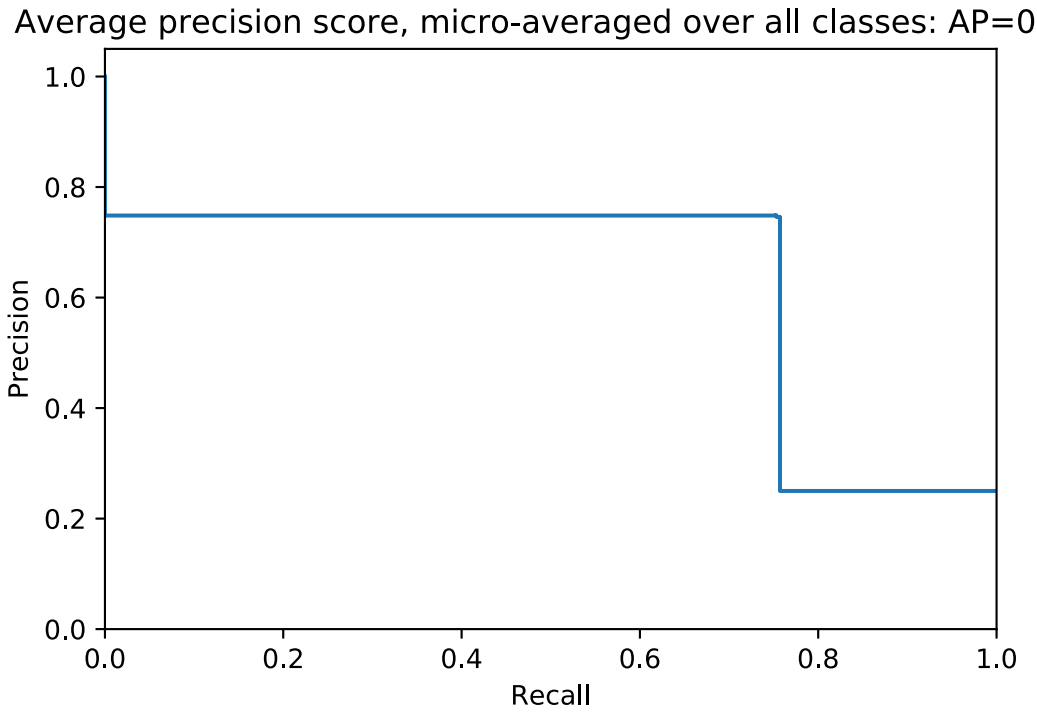
```
NB
Average precision score, micro-averaged over all classes: 0.86
```

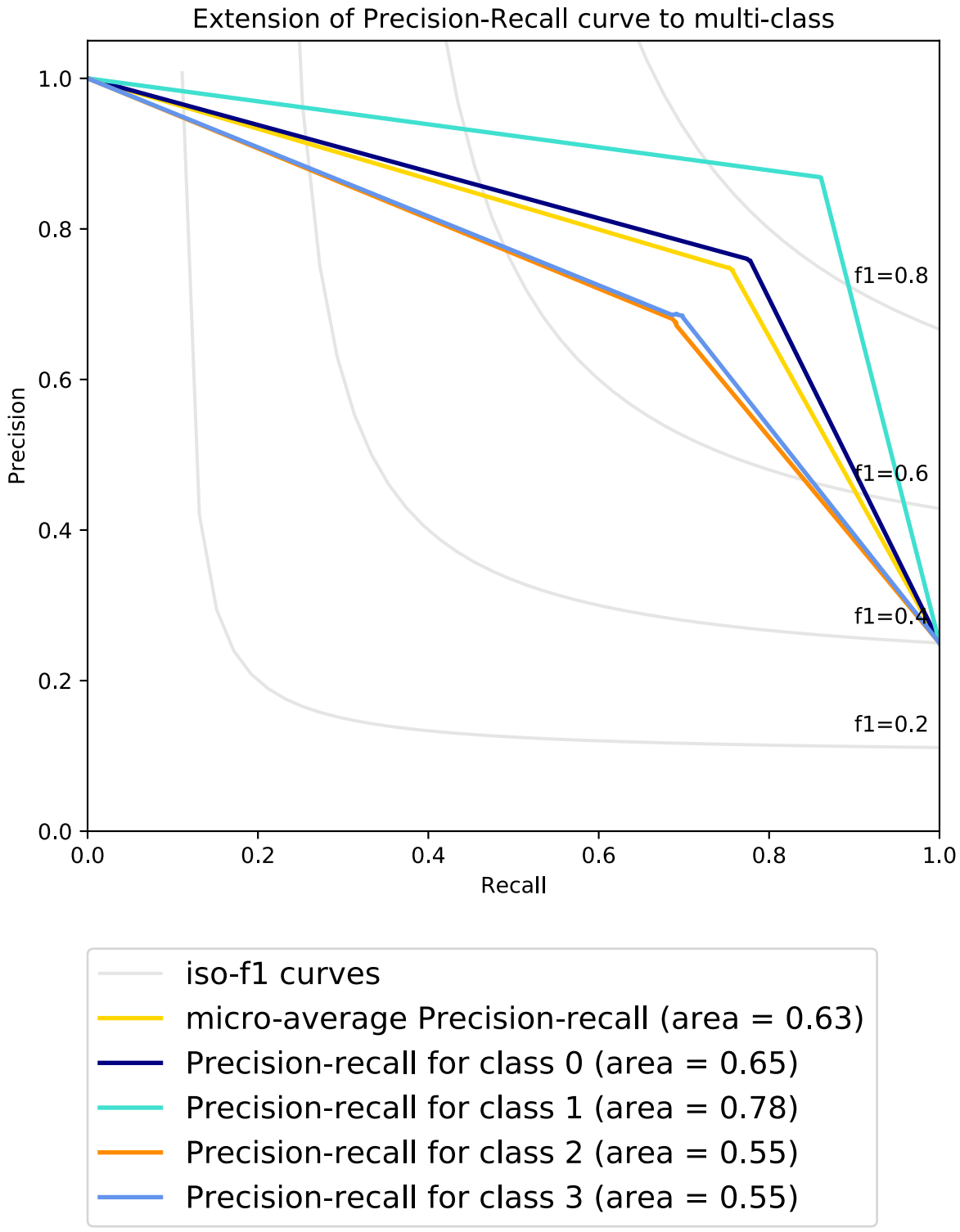



Extension of Precision-Recall curve to multi-class
Precision
Recall
0.0
0.2
0.4
0.6
0.8
1.0
f1=0.8
f1=0.6
f1=0.4
f1=0.2
iso-f1 curves
micro-average Precision-recall (area = 0.86)
Precision-recall for class 0 (area = 0.90)
Precision-recall for class 1 (area = 0.95)
Precision-recall for class 2 (area = 0.76)
Precision-recall for class 3 (area = 0.80)

In [24]:
```
# Precision, Recall, Avg. Precision for Decision Trees
scores = scores.append(prf1_calc(dectree_model, 'DT', N_CLASSES, x_test_w2v, y
_test))
```

```
DT
Average precision score, micro-averaged over all classes: 0.63
```




Extension of Precision-Recall curve to multi-class
Precision
Recall
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
f1=0.8
f1=0.6
f1=0.4
f1=0.2
iso-f1 curves
micro-average Precision-recall (area = 0.63)
Precision-recall for class 0 (area = 0.65)
Precision-recall for class 1 (area = 0.78)
Precision-recall for class 2 (area = 0.55)
Precision-recall for class 3 (area = 0.55)

In [25]:
```
clf = OneVsRestClassifier(GaussianNB())
scoring = {'precision': make_scorer(precision_score, average='micro'),
           'recall': make_scorer(recall_score, average='micro'),
           'f1': make_scorer(f1_score, average='micro'),
           'roc_auc': make_scorer(roc_auc_score, average='micro'),
           # 'mcc': make_scorer(matthews_corrcoef) <- cannot support multi-lab
el
          }
metrics = cross_validate(
    clf,
    x_train_w2v,
    y_train,
    cv=5,
    scoring = scoring,
    return_train_score=False,
    n_jobs=-1
)
sorted(metrics.keys())
```

Out[25]:
```
['fit_time',
 'score_time',
 'test_f1',
 'test_precision',
 'test_recall',
 'test_roc_auc']
```

In [27]:
```
metrics
```

Out[27]:
```
{'fit_time': array([ 9.4257288 , 12.11315131, 12.24181008,  9.48158455, 11.79
636312]),
 'score_time': array([5.18003964, 4.63967133, 4.5987978 , 5.2253058 , 4.89950
895]),
 'test_precision': array([0.75722522, 0.77106389, 0.7667393 , 0.77066706, 0.7
6570792]),
 'test_recall': array([0.85916667, 0.87091667, 0.86504167, 0.87708333, 0.8596
6667]),
 'test_f1': array([0.80498136, 0.81795414, 0.8129295 , 0.82043887, 0.8099715
4]),
 'test_roc_auc': array([0.88367361, 0.89236111, 0.88865972, 0.89504167, 0.885
99306])}
```

In [28]:
```
#metrics
cv_result_entries = []
```

In [29]:
```
for metric_key in metrics.keys():
        for fold_index, metric_score in enumerate(metrics[metric_key]):
            cv_result_entries.append(('NB', fold_index, metric_key, metric_sco
re))
```

In [35]:
```
gnb = OneVsRestClassifier(GaussianNB())
sv = OneVsRestClassifier(svm.LinearSVC(random_state=1))
lreg = OneVsRestClassifier(LogisticRegression(random_state=1))
dtree = OneVsRestClassifier(tree.DecisionTreeClassifier())

model_list = [gnb, sv, lreg, dtree]
model_namelist = ['Gaussian Naive Bayes', 'SVM/Linear SVC', 'Logistic Regressi
on', 'Decision Tree']
```

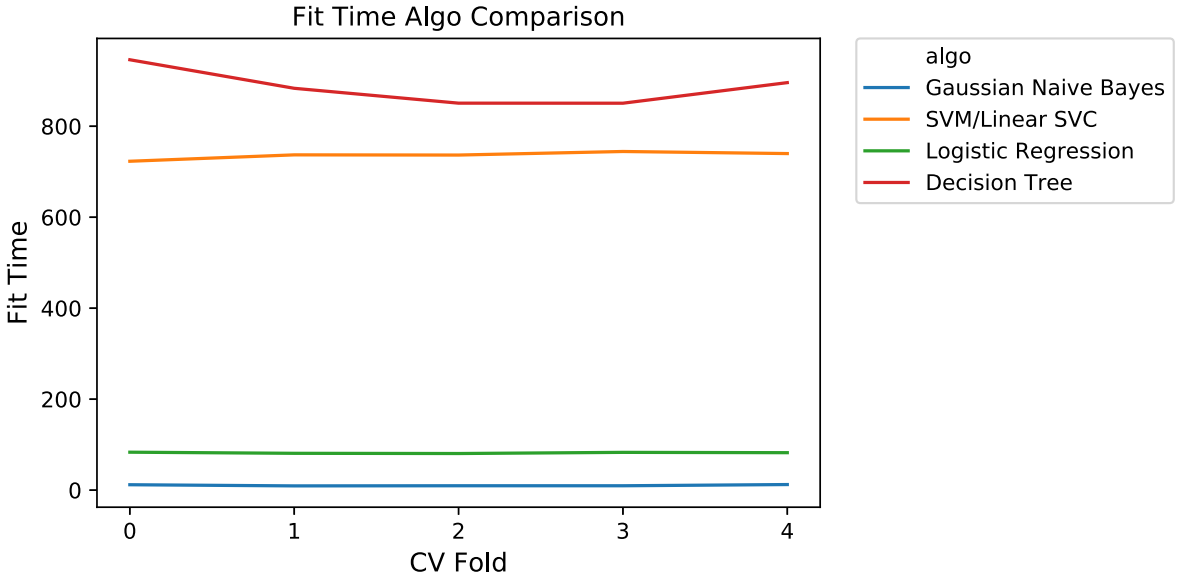
In [36]:
```
scoring = {'precision': make_scorer(precision_score, average='micro'),
           'recall': make_scorer(recall_score, average='micro'),
           'f1': make_scorer(f1_score, average='micro'),
           'roc_auc': make_scorer(roc_auc_score, average='micro'),
           # 'mcc': make_scorer(matthews_corrcoef) <- cannot support multi-lab
el
          }

cv_result_entries = []
i = 0
```

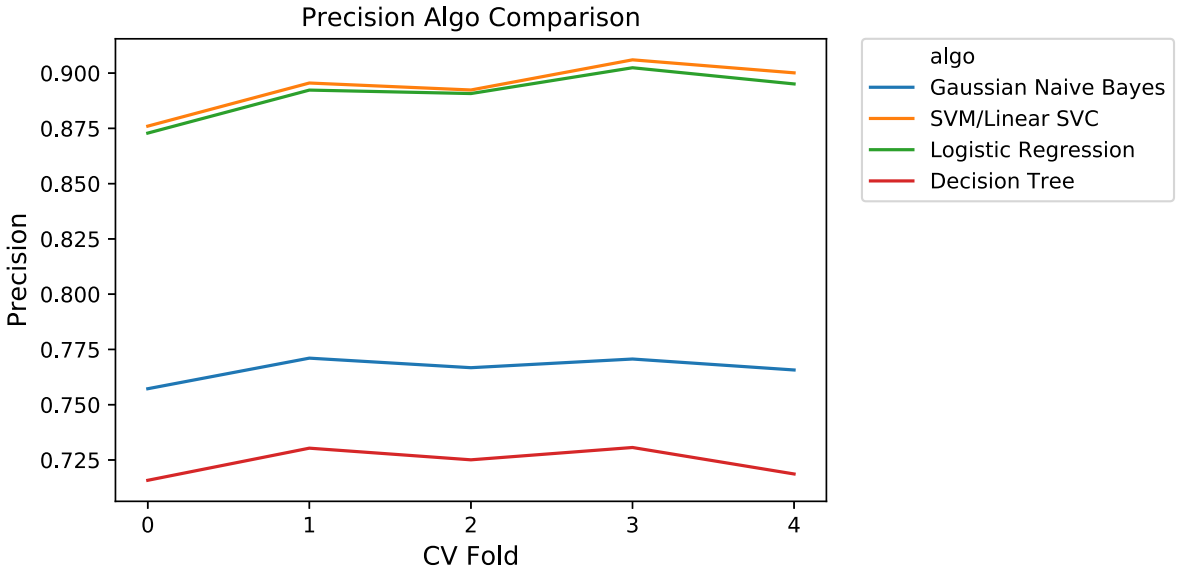
In [37]:
```
for mod in model_list:
    metrics = cross_validate(
        mod,
        x_train_w2v,
        y_train,
        cv=5,
        scoring = scoring,
        return_train_score=False,
        n_jobs=-1
    )
    for key in metrics.keys():
        for fold_index, score in enumerate(metrics[key]):
            cv_result_entries.append((model_namelist[i], fold_index, key, scor
e))
    i += 1
```

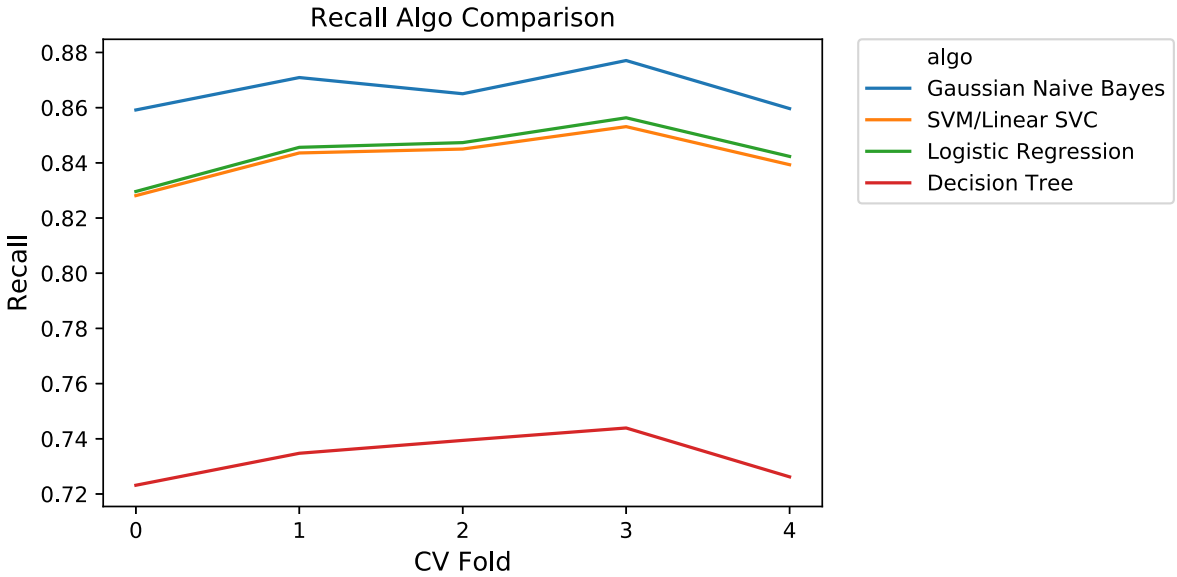
In [38]:
```
cv_result_entries = pandas.DataFrame(cv_result_entries)
```

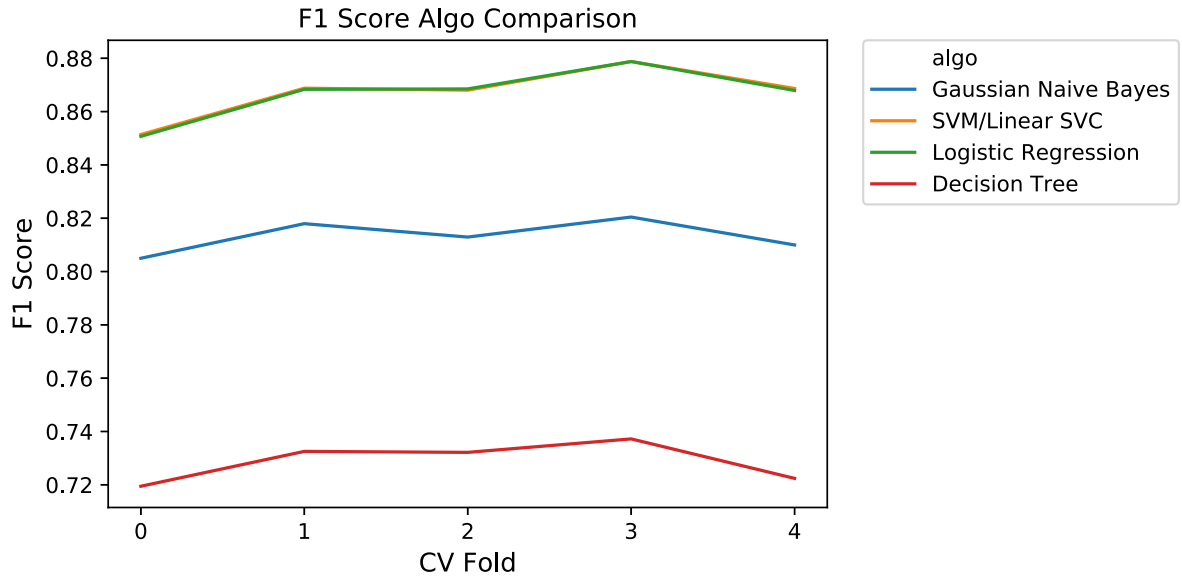
In [39]:
```
cv_result_entries.to_csv('cv-results.csv',sep = ',')
```

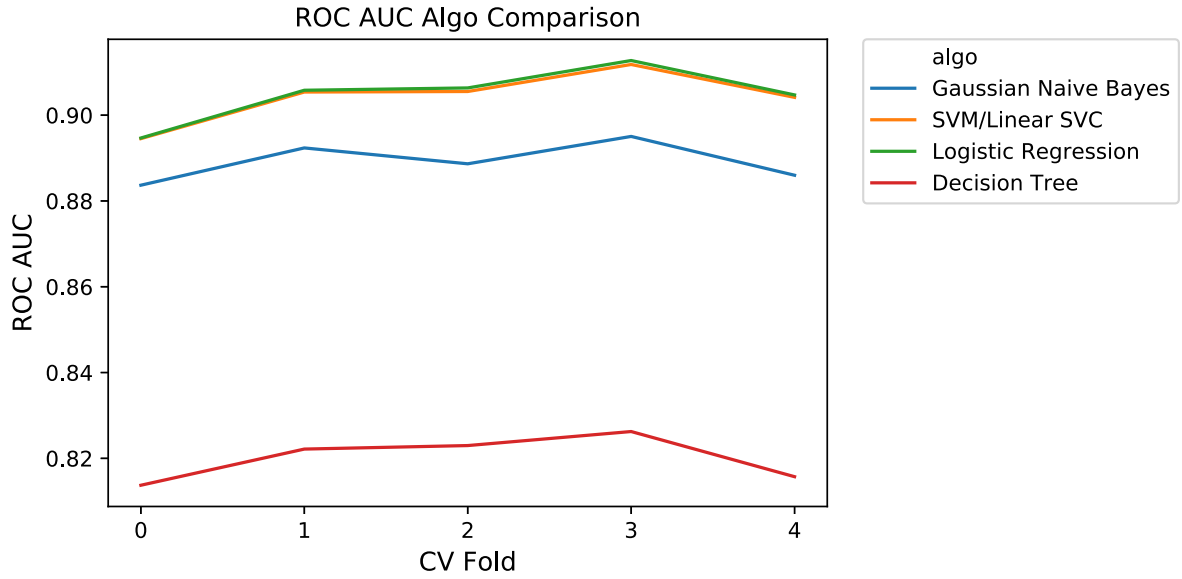
In [75]:
```
for metric_name, metric in zip(['fit_time',
                                'test_precision',
                                'test_recall',
                                'test_f1',
                                'test_roc_auc'],
                               ['Fit Time',
                                'Precision',
                                'Recall',
                                'F1 Score',
                                'ROC AUC']):
    sns.lineplot(x='cv fold', y='value', hue='algo',
        data=cv_results_df[cv_results_df.metric.eq(f'{metric_name}')])
    plt.title(f'{metric} Algo Comparison', fontsize=12)
    plt.xlabel('CV Fold', fontsize=12)
    plt.ylabel(f'{metric}', fontsize=12)
    plt.xticks([0, 1, 2, 3, 4])
    plt.legend(bbox_to_anchor=(1.05, 1), loc=2, borderaxespad=0.)
    plt.show()
```


Fit Time Algo Comparison
Fit Time
CV Fold
algo
Gaussian Naive Bayes
SVM/Linear SVC
Logistic Regression
Decision Tree


Precision Algo Comparison
Precision
CV Fold
algo
Gaussian Naive Bayes
SVM/Linear SVC
Logistic Regression
Decision Tree


Recall Algo Comparison
Recall
CV Fold
algo
Gaussian Naive Bayes
SVM/Linear SVC
Logistic Regression
Decision Tree





Import dependencies

In [87]:
```
# STACKING
x_train_w2v_sample = x_train_w2v.sample(
    n = 4000, replace = False, random_state = 123
)
y_train_sample = train_data_df.category.sample(
    n = 4000, replace = False, random_state = 123
)
y_train_sample = label_binarize(y_train_sample, classes=[1,2,3,4])

estimators = [
              ('nb', GaussianNB()),
              ('svm', svm.LinearSVC())
             ]

sclf = OneVsRestClassifier(StackingClassifier(
    estimators=estimators, final_estimator=LogisticRegression())
)

metrics = cross_validate(
    sclf,
    x_train_w2v_sample,
    y_train_sample,
    cv=5,
    scoring = scoring,
    return_train_score=False,
    n_jobs=-1
)
```

In [91]:
```
res = []
for key in metrics.keys():
    for fold_index, score in enumerate(metrics[key]):
        res.append(('Stacking', fold_index, key, score))
```

In [94]:
```
res_df = pandas.DataFrame.from_dict(res)
```

In [96]:
```
res_df.columns = ['algo', 'cv fold', 'metric', 'value']
```

In [97]:
```
cv_results_inc_ens = pandas.concat([cv_results_df, res_df])
```

BOOSTING

In [98]:
```
from sklearn.ensemble import BaggingClassifier

sclf = OneVsRestClassifier(BaggingClassifier(
    base_estimator=LogisticRegression())
)

metrics = cross_validate(
    sclf,
    x_train_w2v_sample,
    y_train_sample,
    cv=5,
    scoring = scoring,
    return_train_score=False,
    n_jobs=-1
)
```

In [99]:
```
res = []
for key in metrics.keys():
    for fold_index, score in enumerate(metrics[key]):
        res.append(('Bagging', fold_index, key, score))
```

In [100]:
```
res_df = pandas.DataFrame.from_dict(res)
res_df.columns = ['algo', 'cv fold', 'metric', 'value']
cv_results_inc_ens = pandas.concat([cv_results_inc_ens, res_df])
```