Jeremey_code

July 31, 2021

1 DS 5110 Group Project

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Original data: https://www.kaggle.com/reddit/reddit-comments-may-2015

1.1 Includes & Spark Setup

[1]:
```
import pandas as pd
from matplotlib import pyplot as plt

import time

from pyspark import StorageLevel

from pyspark.mllib.evaluation import BinaryClassificationMetrics,␣
 ↪MulticlassMetrics

from pyspark.ml import Pipeline, PipelineModel
from pyspark.ml.classification import LogisticRegression,␣
 ↪RandomForestClassifier, RandomForestClassificationModel
from pyspark.ml.evaluation import BinaryClassificationEvaluator,␣
 ↪MulticlassClassificationEvaluator
from pyspark.ml.feature import *
from pyspark.ml.tuning import CrossValidator, CrossValidatorModel,␣
 ↪ParamGridBuilder

from pyspark.sql import SparkSession, SQLContext
from pyspark.sql.functions import col, countDistinct, lower, size, split, udf,␣
 ↪when
from pyspark.sql.types import ArrayType, FloatType, IntegerType,  StringType,␣
 ↪StructType
```

[2]:
```
#from pyspark import SparkContext
spark = SparkSession.builder.getOrCreate()
sc=spark.sparkContext
```

1.2 Code Control

[3]:
```
# EDA is a little slow so runEDA = 1 to run
runEDA=1
```

[4]:
```
# train, test, holdout
# key code control b/c we have been experiencing memory issues with a 50/50␣
 ↪train/test split
trainPct=0.1
testPct=0.1
holdoutPct=0.8
```

[5]:
```
# persisting trainDF should speed training but we have been experiencing memory␣
 ↪issues
persistTrainDF=0
```

[6]:
```
# Over-ride parallelism: We have been expreiencing memory issues. Set to␣
 ↪anything other than 0 to override.
# Otherwise, set to the desired over-ride integer value
overrideParallelism=1
```

[7]:
```
# loadCVmodel: If blank, then do not load and instead run CV
# otherwise, provide name of cv model to load
#loadCVmodel=""
loadCVmodel="lrModel20210730-005848"

loadCVmodelSens="lrModelSens20210730-093722"
```

[8]:
```
# NOT IMPLEMENTED!!! It may be that to efficient load RF, we need to also embed␣
 ↪in CV
"""
# loadRFmodel: If blank, then do not load and instead run RF baseline model
# otherwise, provide name of RF model to load
#loadCVmodel=""
loadRFmodel="rfModel20210730-211517"
"""
```

[8]:
```
'\n# loadRFmodel: If blank, then do not load and instead run RF baseline
model\n# otherwise, provide name of RF model to
load\n#loadCVmodel=""\nloadRFmodel="rfModel20210730-211517"\n'
```

1.3 Data Import and Pre-Processing

1.3.1 Data Import

[9]:
```
# Import the reddit data
full_path = '/project/ds5559/r-slash-group8/sample.csv'

df = spark.read.csv(full_path,  inferSchema=True, header = True)
```

[10]:
```
# Import the Bad Word data
schema = StructType().add("badWord",StringType(),True)
dfBW=spark.read.format("csv").schema(schema).load('bad_words.csv')
#  dfBW.show(5)  # not showing since words are quite vulgar

# Also create in list format
listBW=list(dfBW.select('badWord').toPandas()['badWord'])
# listBW
```

[11]:
```
# Create a regex with all the bad words
# if there is an issue, try \\\\b instead; just \b probably has issues
listBW=list(map(lambda line: "\\b" + line + "\\b",listBW))
delim='|'
strBW=delim.join(listBW)
```

1.3.2 Filtering

[12]:
```
# Drop unneeded cols from dataframe
df=df.
 ↪drop('_c0','created_utc','subreddit_id','link_id','name','score_hidden','author_flair_css_c
 ↪'gilded', \
        'author_flair_text','id','archived','retrieved_on',␣
 ↪'edited','controversiality','parent_id','score')

# convert integer cols (ups, downs, and gilded) to integers
# Note: we could have done this by defining a schema before the csv read
df=df.withColumn("ups",df.ups.cast(IntegerType()))
df=df.withColumn("downs",df.downs.cast(IntegerType()))
#df=df.withColumn("gilded",df.gilded.cast(IntegerType()))  # Removed gilded␣
 ↪since not used in this analysis

# Confirm new schema
df.printSchema()
df.show(5)
```

```
root
 |-- ups: integer (nullable = true)
 |-- subreddit: string (nullable = true)
 |-- removal_reason: string (nullable = true)
 |-- downs: integer (nullable = true)
 |-- author: string (nullable = true)
 |-- body: string (nullable = true)
 |-- distinguished: string (nullable = true)

+----+---------+--------------+-----+------------+--------------------+---------
----+
| ups|subreddit|removal_reason|downs|      author|
body|distinguished|
+----+---------+--------------+-----+------------+--------------------+---------
----+
|   4|soccer_jp|            NA|    0|       rx109|                  |
null|
|null|     null|          null| null|        null|                null|
null|
|   0|     null|          null| null|        null|                null|
null|
|   4|      nba|            NA|    0|   WyaOfWade|gg this one's ove…|
NA|
|   0| politics|            NA|    0|Wicked_Truth|Are you really im…|
NA|
+----+---------+--------------+-----+------------+--------------------+---------
----+
only showing top 5 rows
```

[13]:
```
# Count the number of rows before removing NA
df.count()
# There are 15,317,725 rows
```

[13]:
```
15317725
```

[14]:
```
# Remove rows where up, down, or body is null. We  do this since inference of␣
↪these values is not applicable
df=df.filter(df['ups'].isNotNull())
df=df.filter(df['downs'].isNotNull())
df=df.filter(df['body'].isNotNull())

df.show(5)
```

```
+---+---------+--------------+-----+--------------+--------------------+--------
-----+
|ups|subreddit|removal_reason|downs|        author|
body|distinguished|
+---+---------+--------------+-----+--------------+--------------------+--------
-----+
|  4|soccer_jp|            NA|    0|         rx109|                  |
null|
|  4|      nba|             NA|    0|     WyaOfWade|gg this one's ove…|
NA|
|  0| politics|             NA|    0|  Wicked_Truth|Are you really im…|
NA|
|  3|AskReddit|             NA|    0|      jesse9o3|No one has a Euro…|
NA|
|  3|AskReddit|             NA|    0|beltfedshooter|"That the kid ""…|
NA|
+---+---------+--------------+-----+--------------+--------------------+--------
-----+
only showing top 5 rows
```

[15]:
```python
# Remove rows where the author was '[deleted]'
df=df.filter(df['author']!='[deleted]')

# Remove author "0"
df=df.filter(df['author']!='0')


# Remove rows where the author was 'AutoModerator'
# see https://www.reddit.com/wiki/automoderator
df=df.filter(df['author']!='AutoModerator')
```

[16]:
```python
# Count the number of rows AFTER removing NA
df.count()
# There now 9,226,090 rows
```

[16]:
```
9226090
```

1.3.3 Binning & Feature Engineering

[17]:
```python
# Lowercase all body text
df=df.withColumn('body',lower(col('body')))
```

[18]:
```python
# Even though we dropped the column, adding score back into dataframe by␣
 ↪computing it
df=df.withColumn('score',df['ups']-df['downs'])
df=df.withColumn("score",df.score.cast(IntegerType()))
df.show(5)
```

```
+---+---------+--------------+-----+--------------+--------------------+--------
-----+-----+
|ups|subreddit|removal_reason|downs|        author|
body|distinguished|score|
+---+---------+--------------+-----+--------------+--------------------+--------
-----+-----+
|  4|soccer_jp|            NA|    0|         rx109|                  |
null|    4|
|  4|      nba|            NA|    0|     WyaOfWade|gg this one's ove…|
NA|    4|
|  0| politics|            NA|    0|  Wicked_Truth|are you really im…|
NA|    0|
|  3|AskReddit|            NA|    0|      jesse9o3|no one has a euro…|
NA|    3|
|  3|AskReddit|            NA|    0|beltfedshooter|"that the kid ""…|
NA|    3|
+---+---------+--------------+-----+--------------+------------------+--------
-----+-----+
only showing top 5 rows
```

[19]:
```
# Determine a scoreSentiment as either postive, neutral, or negative.
# This will be our response variable

# Drop scoreSentiment if it already exists
df=df.drop('scoreSentiment')

# Set up bucketizer
splits = [-float("inf"), -0.1,0.1, float("inf")]
bkt = Bucketizer(splits=splits, inputCol="score", outputCol="scoreSentiment")

# Transform to add scoreSentiment: 0=negative; 1=neutral; 2=positive.
df=bkt.transform(df)

# !!! Cannot shift to -1,0,1 since LR must start with 0 !!!
# To make things more clear, shift to -1=negative; 0=neutral; 1=positive
#df=df.withColumn("scoreSentiment", \
#                  when(df['scoreSentiment']==0,-1) \
#                  .when(df['scoreSentiment']==1,0) \
#                  .otherwise(1)
#                 )

df.show(2)
```

```
+---+---------+--------------+-----+---------+--------------------+-------------
+-----+--------------+
|ups|subreddit|removal_reason|downs|   author|
body|distinguished|score|scoreSentiment|
+---+---------+--------------+-----+---------+--------------------+-------------
+-----+--------------+
|  4|soccer_jp|            NA|    0|    rx109|                  |         null|
4|           2.0|
|  4|      nba|            NA|    0|WyaOfWade|gg this one's ove…|
NA|    4|           2.0|
+---+---------+-------------+-----+---------+-------------------+-------------
+-----+--------------+
only showing top 2 rows
```

[20]:
```
# Flag comments containing bad words
df=df.withColumn('bwFlag',col('body').rlike(strBW))
```

[21]:
```
# Append bodyWordCount
df=df.withColumn("bodyWordCount", size(split(df['body'], ' ')))
#df.show(5)
```

[22]:
```
# Though not the cleanest thing to do from a data sci perspective, we
# are going to drop the neutral sentiment rows so we can do binomial
# rather than multinomial regression; neutral currently "1"
df=df.filter(df['scoreSentiment']!=1)
# Shift positive from 2 to 1
df=df.withColumn("scoreSentiment", \
                 when(df['scoreSentiment']==2,1) \
                 .when(df['scoreSentiment']==0,0) \
                 .otherwise(-1)
                )
# we should never have the otherwise case!!!
```

[23]:
```
# Cross-validator explicity wants response to be called "label"
# so copying scoreSentiment to label in all DFs
df=df.withColumn("label", df["scoreSentiment"])
```

1.4 Data Splitting & Sampling

[24]:
```
seed=314
trainDF,testDF, holdoutDF=df.randomSplit([trainPct,testPct,holdoutPct],seed)
```

1.5 EDA

[25]:
```
if runEDA:
    # How many comments have bad words?
    # Confirm the flagging worked by looking at how many comments contain bad␣
 ↪words vs good
    # NOTE: This has a rather long runtime!!!
    df.groupby('bwFlag').agg({"bwFlag":"count"}).show()
    #df.filter(df['bwFlag']==True).show(5,False)
```

```
+------+-------------+
|bwFlag|count(bwFlag)|
+------+-------------+
|  true|       392771|
| false|      8433257|
+-------+-------------+
```

```
[26]: if runEDA:
          # How many authors are there?
          df.select(countDistinct('author')).show()
          # There are 1,216,598 authors
```

```
+----------------------+
|count(DISTINCT author)|
+----------------------+
|               1216598|
+----------------------+
```

```
[27]: if runEDA:
          # Show the top 10 authors with sum of ups and downs
          df.groupby('author').agg({"author":"count","ups":"sum","downs":
       ↪"sum","score":"sum"}).sort(col('count(author)').desc()).show(10)
```

```
+--------------------+----------+----------+-------------+--------+
|              author|sum(score)|sum(downs)|count(author)|sum(ups)|
+--------------------+----------+----------+-------------+--------+
|       TheNitromeFan|     10445|         0|         3997|   10445|
|         TweetPoster|      7090|         0|         3452|    7090|
|         autowikibot|      6420|         0|         3188|    6420|
|          PoliticBot|      3159|         0|         3138|    3159|
|TweetsInCommentsBot|      9965|         0|         2999|    9965|
|      atomicimploder|      7363|         0|         2616|    7363|
|        Removedpixel|      5333|         0|         2264|    5333|
|           TrollaBot|      2640|         0|         2212|    2640|
|           havoc_bot|      2120|         0|         2101|    2120|
|      MTGCardFetcher|      3089|         0|         2053|    3089|
+--------------------+----------+----------+-------------+--------+
only showing top 10 rows
```

Odd that the preceding authors have no down but this is correct

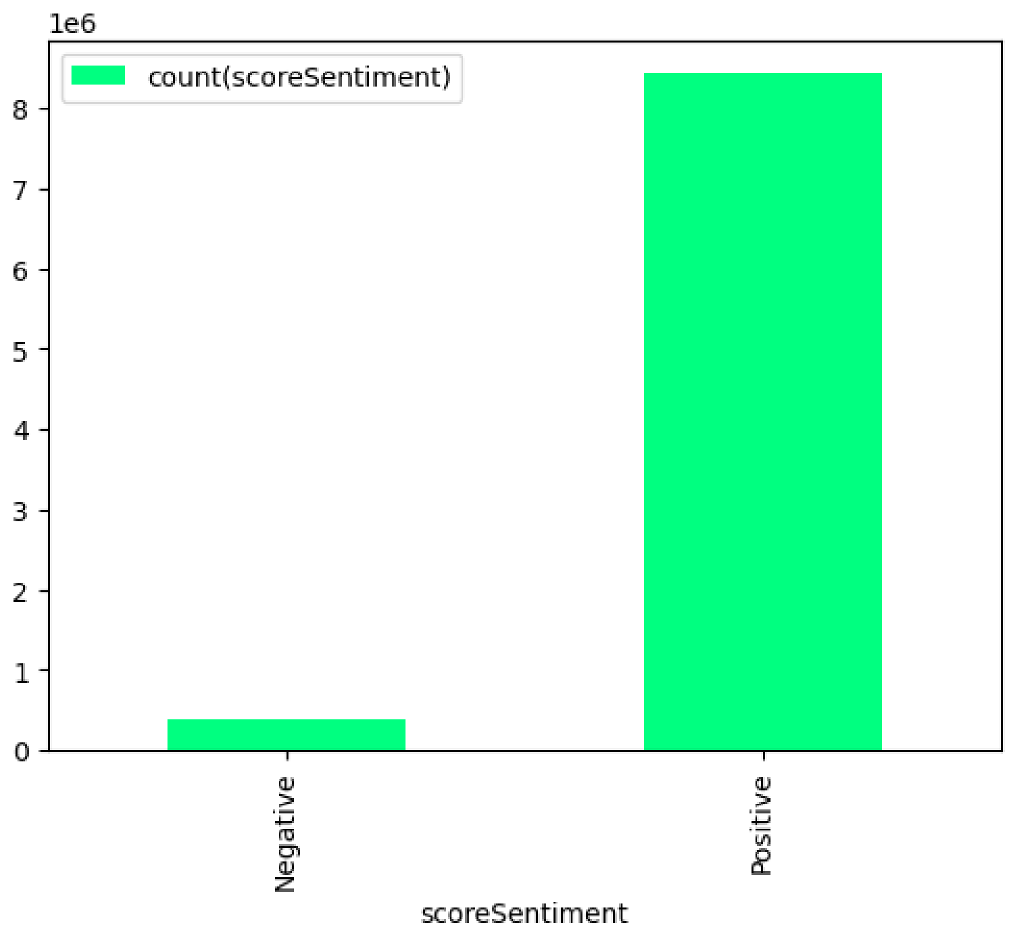
```
[28]: if runEDA:
          # Show authors with the lowest scores
          df.groupby('author').agg({"score":"sum","ups":"sum","downs":"sum"}).
       ↪sort(col('sum(score)').asc()).show(10)
```

```
+-----------------+----------+----------+--------+
|           author|sum(score)|sum(downs)|sum(ups)|
+-----------------+----------+----------+--------+
|     ItWillBeMine|     -6839|         0|   -6839|
|        blaghart|     -4233|         0|   -4233|
|       Shanondoa|     -3555|         0|   -3555|
|    bad_driverman|     -3053|         0|   -3053|
|      RSneedsEoC|     -2192|         0|   -2192|
|    b00gymonster1|     -2050|         0|   -2050|
|      frankenham|     -2024|         0|   -2024|
|    SaddharKadham|     -1485|         0|   -1485|
|letters_numbers-|     -1412|         0|   -1412|
|      djroomba322|     -1392|         0|   -1392|
+----------------+----------+----------+--------+
only showing top 10 rows
```

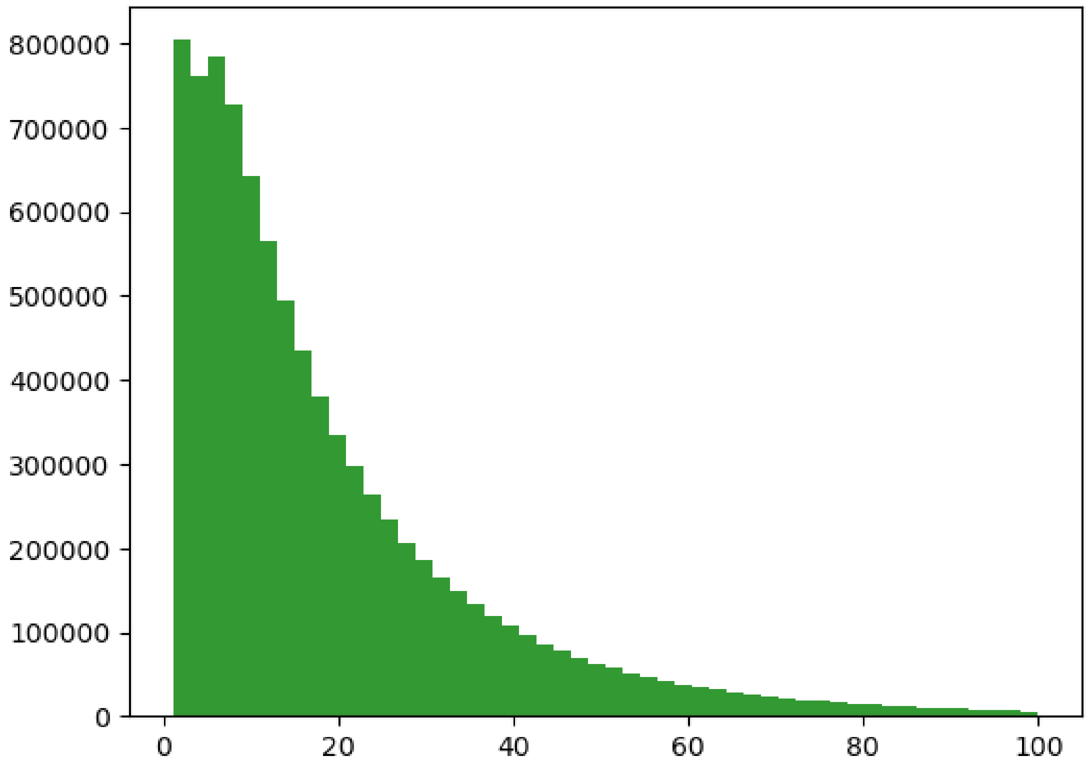
[29]:
```
if runEDA:
    # Get a summary of score sentiment by label
    sentDF=df.groupby('scoreSentiment').agg({"scoreSentiment":"count"}).
 ↪sort(col('scoreSentiment').asc())
    sentDF.show()
```

```
+--------------+---------------------+
|scoreSentiment|count(scoreSentiment)|
+--------------+---------------------+
|             0|               394008|
|             1|              8432020|
+--------------+---------------------+
```

[30]:
```
if runEDA:
    # convert to pandas DF
    sentDF_pandas=sentDF.toPandas()
    sentDF_pandas['scoreSentiment'] = sentDF_pandas['scoreSentiment'].
 ↪astype(str)
    sentDF_pandas['scoreSentiment']=sentDF_pandas['scoreSentiment'].
 ↪replace(['0'],'Negative')
    sentDF_pandas['scoreSentiment']=sentDF_pandas['scoreSentiment'].
 ↪replace(['1'],'Positive')
    sentDF_pandas.plot(kind='bar', x='scoreSentiment',␣
 ↪y='count(scoreSentiment)', colormap='winter_r')

    plt.show()

    #sentDF.registerTempTable("sentiment_table")
    #display(SQLContext(sc).sql("select * from sentiment_table"))
    #sentDF.select('scoreSentiment').display()
```



[31]:
```
if runEDA:
    # Generate historgram of body word count
    # There are a small (relative) number of long comments but most are under␣
↪100 words
    maxWords=100
    bwcDF=df.filter(col('bodyWordCount')<=maxWords).select('bodyWordCount')
    bwcDF_pandas=bwcDF.toPandas()

    fig = plt.figure()
    ax = fig.add_subplot(111)

    numBins = 50
    ax.hist(bwcDF_pandas,numBins,color='green',alpha=0.8)
    plt.show()
```



1.6 Model: Predict Sentiment from body

1.6.1 Set up pipeline

[32]:
```
# Create TF (Term Frequency) feature
tok = Tokenizer(inputCol="body", outputCol="words")
htf = HashingTF(inputCol="words", outputCol="tf")  # numFeatures will be a␣
 ↪hyper-parameter

#testing
tmpDF=tok.transform(df)
tmpDF=htf.transform(tmpDF)
tmpDF.select('words','tf').show(2)
```

```
+--------------------+--------------------+
|               words|                  tf|
+--------------------+--------------------+
|                [ ]|(262144,[85691],[…|
|[gg, this, one's,…|(262144,[5674,905…|
+--------------------+--------------------+
only showing top 2 rows
```

[33]:
```
# Create w2v (word to vec) feature

# the comment string needs to be turned into a vector for w2v to work
# unfortunately, VectorAssember does not work on string so we need a UDF

# Create UDF (note: split(anything,0) simply means don't split)
str_to_vec=spark.udf.register("str_to_vec",
                             lambda row:row.split("#",0),
                             ArrayType(StringType()))

# set up the tranformation
rva=SQLTransformer(statement="SELECT *, str_to_vec(body) bodyVec FROM __THIS__")

w2v = Word2Vec(inputCol='bodyVec', outputCol='w2v')  # not setting minCount

# testing
"""
tmpDF=rva.transform(df)
model=w2v.fit(tmpDF)
tmpDF=model.transform(tmpDF)
tmpDF.show(2)
"""
```

[33]:
```
'\ntmpDF=rva.transform(df)\nmodel=w2v.fit(tmpDF)\ntmpDF=model.transform(tmpDF)\n
tmpDF.show(2)\n'
```

[34]:
```
# Assemble predictors
va=VectorAssembler(inputCols=['tf','w2v','bwFlag','bodyWordCount'],outputCol='features')
```

[35]:
```
# Set up the regression model; regParam & elasticNetParam will be␣
 ↪hyper-parameters
# CrossVal currently requires the labelCol to be precisely called 'label'
#lr = LogisticRegression(labelCol='scoreSentiment',maxIter=10)
lr = LogisticRegression(labelCol='label',maxIter=10)
```

[36]:
```
# Build the pipeline
#pipeline=Pipeline(stages=[bkt,tok,htf,rva,w2v,va,lr])  # took out bkt since␣
 ↪this is pre-EDA
pipeline=Pipeline(stages=[tok,htf,rva,w2v,va,lr])
```

1.6.2 Set up hyperparameter tuning & Cross-Validation

[37]:
```
# Set up the parameter grid

"""
# This version works and homes in on elasticNetParam=0
paramGrid = ParamGridBuilder() \
    .addGrid(htf.numFeatures, [200]) \
    .addGrid(lr.regParam, [0.1]) \
    .addGrid(lr.elasticNetParam, [0.0, 0.5, 1.0]) \
    .build()
"""

paramGrid = ParamGridBuilder() \
    .addGrid(htf.numFeatures, [200]) \
    .addGrid(lr.regParam, [0.1, 0.01]) \
    .addGrid(lr.elasticNetParam, [0.0, 0.5, 1.0]) \
    .build()

# This paramGrid for testing
"""
paramGrid = ParamGridBuilder() \
    .addGrid(htf.numFeatures, [200]) \
    .addGrid(lr.regParam, [0.3]) \
    .addGrid(lr.elasticNetParam, [0.5]) \
    .build()
"""
```

[37]:
```
'\nparamGrid = ParamGridBuilder()     .addGrid(htf.numFeatures, [200])
.addGrid(lr.regParam, [0.3])     .addGrid(lr.elasticNetParam, [0.5])
.build()\n'
```

[38]:
```
# Too inspect paramGrid, uncomment next 4 lines
"""
print('-'*30)
#print('paramGrid', paramGrid, '\n')
#print('len(paramGrid): {}'.format(len(paramGrid)))
print('-'*30)
"""
```

[38]:
```
"\nprint('-'*30)\n#print('paramGrid', paramGrid, '\n')\n#print('len(paramGrid):
{}'.format(len(paramGrid)))\nprint('-'*30)\n"
```

[39]:
```
# Treat the Pipeline as an Estimator, wrapping it in a CrossValidator instance.
# Using the pipeline as the estimator slows things down but is necessary if␣
↪tuning featurziers.  If not, set the
# model specification as the estimator with estimator=lr (I think; though not␣
↪sure if that means lr needs to be removed from pipeline)
numFolds=5
crossval = CrossValidator(estimator=pipeline,
                          estimatorParamMaps=paramGrid,
                          ␣
↪evaluator=BinaryClassificationEvaluator(labelCol='label'),
                          numFolds=numFolds,
                                        collectSubModels=True)
```

1.6.3 Train the benchmark model (only based on badwords & word count)

[40]:
```
# Set up featuresRF
vaRF=VectorAssembler(inputCols=['bwFlag','bodyWordCount'],outputCol='featuresRF')

# Define the RF classifier
rf = RandomForestClassifier(labelCol="label", featuresCol="featuresRF",␣
 ↪numTrees=10)

# Create the pipeline
rfPipeline = Pipeline(stages=[vaRF,rf])

# Fit the model using the training data
rfModel = rfPipeline.fit(trainDF)

# save the rf model with a timestamp
timestr = time.strftime("%Y%m%d-%H%M%S")
rfModel.save("rfModel"+timestr)

print("RF model fitting complete")
```

```
RF model fitting complete
```

[41]:
```
# Generate predictions
predictionRF = rfModel.transform(testDF)
print ("RF prediction complete")
```

```
RF prediction complete
```

[42]:
```
rfEvaluator = MulticlassClassificationEvaluator(labelCol="label",␣
 ↪predictionCol="prediction", metricName="accuracy")
rfAccuracy = rfEvaluator.evaluate(predictionRF)
```

[43]:
```
print("Test Accuracy for RF:", rfAccuracy)
```

```
Test Accuracy for RF: 0.9552675049687026
```

1.6.4 Train the Advanced Model

[44]:
```
# Determine parallelism
# This resource: see https://databricks.com/session/
 ↪model-parallelism-in-spark-ml-cross-validation
# says that best practice is parallelism = (# cores)/(# partitions) but␣
 ↪generally not more than 10
numPartitions=trainDF.rdd.getNumPartitions()
```

```
numCores=sc.defaultParallelism
parallelism=int(round(numCores/numPartitions,0))
# also see https://stackoverflow.com/questions/42171499/
 ↪get-current-number-of-partitions-of-a-dataframe

# constrain to between 1 and 10
if parallelism<1:
    parallelism=1
elif parallelism > 10:
    parallelism=10

# ---------------------------------------------------------------------------

"""
# Another thing we can do is treat cores as fixed and repartition to get a␣
 ↪target parallelism
# while avoiding memory issues that occur when != cores/partitions
# in the future: verify cores/partitions is correct; might want to do something␣
 ↪to avoid having
# too few partitions
parallelism=2
targetNumPartitions=int(round(numCores/parallelism,0))
if (targetNumPartitions>=1):
    if (targetNumPartitions<numPartitions):
        trainDF = trainDF.coalesce(targetNumPartitions) # no shuffling but can␣
 ↪only be used for decreasing numPartitions
    else:
        trainDF = trainDF.repartition(targetNumPartitions)  # this involves␣
 ↪shuffling to less efficient
"""

# ---------------------------------------------------------------------------



# However, elsewhere, you typically see that partitions should be 2x to 4x the␣
 ↪number of cores!
# So, we could just override (note: 4 yielded memory errors)
if overrideParallelism:
    parallelism=overrideParallelism
```

[45]:
```
# print out parallelism
parallelism
```

[45]:
```
1
```

[46]:
```
# Cache trainDF to speed up cross validation; we could use .select(colnames...)␣
↪to use less memory
# Cache & persist failed with 96GB and down to 50/50 train test split
# yeah! worked with 25/25/50 train/test/holdout split with 96GB allocated!!!
if persistTrainDF:
    #trainDF=trainDF.cache()
    trainDF=trainDF.persist(StorageLevel.MEMORY_AND_DISK)
    trainDF.count()  # call count to actually cache the data
```

[47]:
```
if len(loadCVmodel)==0:
    # Run cross-validation, and choose the best set of parameters. Print the␣
↪training time.
    import time
    t0 = time.time()
    if parallelism<=1:
        cvModel = crossval.fit(trainDF) # train models (no parallelism)
    else:
        cvModel = crossval.setParallelism(parallelism).fit(trainDF) # train␣
↪models in parallel
    print("train time:", time.time() - t0)
    print('-'*30)
    # Took 3580 secs (~1hr) to run single params set with 50/50 split, 5 fold␣
↪on 8 cores with 32 GB memmory & no parallelism & no cache/persist
    # 10/10/90 train/test/holdout without parallelism took 3352 secs for 6␣
↪model variations (10 mins per model)

    # save the model with a timestamp
    timestr = time.strftime("%Y%m%d-%H%M%S")
    cvModel.save("lrModel"+timestr)
    pipeline.save("lrPipeline"+timestr)
else:
    # Load the model and the pipeline  (should these be preceded by "val")
    cvModel = CrossValidatorModel.load(loadCVmodel)
    #val sameModel = PipelineModel.load("/path-to-my-pipeline/
↪spark-log-reg-transfer-pipeline")
```

[48]:
```
# release the cache
if persistTrainDF:
    trainDF.unpersist()
```

[49]:
```
cvModel.bestModel.stages[-1].extractParamMap()
# best model has the following:
# elasticNetParam = 0
# regParam = 0.01
```

[49]:
```
{Param(parent='LogisticRegression_4446ecd1f38f', name='aggregationDepth',
doc='suggested depth for treeAggregate (>= 2).'): 2,
 Param(parent='LogisticRegression_4446ecd1f38f', name='elasticNetParam',
doc='the ElasticNet mixing parameter, in range [0, 1]. For alpha = 0, the
penalty is an L2 penalty. For alpha = 1, it is an L1 penalty.'): 0.0,
 Param(parent='LogisticRegression_4446ecd1f38f', name='family', doc='The name of
family which is a description of the label distribution to be used in the model.
Supported options: auto, binomial, multinomial'): 'auto',
 Param(parent='LogisticRegression_4446ecd1f38f', name='featuresCol',
doc='features column name.'): 'features',
 Param(parent='LogisticRegression_4446ecd1f38f', name='fitIntercept',
doc='whether to fit an intercept term.'): True,
 Param(parent='LogisticRegression_4446ecd1f38f', name='labelCol', doc='label
column name.'): 'label',
 Param(parent='LogisticRegression_4446ecd1f38f', name='maxIter', doc='max number
of iterations (>= 0).'): 10,
 Param(parent='LogisticRegression_4446ecd1f38f', name='predictionCol',
doc='prediction column name.'): 'prediction',
 Param(parent='LogisticRegression_4446ecd1f38f', name='probabilityCol',
doc='Column name for predicted class conditional probabilities. Note: Not all
models output well-calibrated probability estimates! These probabilities should
be treated as confidences, not precise probabilities.'): 'probability',
 Param(parent='LogisticRegression_4446ecd1f38f', name='rawPredictionCol',
doc='raw prediction (a.k.a. confidence) column name.'): 'rawPrediction',
 Param(parent='LogisticRegression_4446ecd1f38f', name='regParam',
doc='regularization parameter (>= 0).'): 0.01,
 Param(parent='LogisticRegression_4446ecd1f38f', name='standardization',
doc='whether to standardize the training features before fitting the model.'):
True,
 Param(parent='LogisticRegression_4446ecd1f38f', name='threshold',
doc='Threshold in binary classification prediction, in range [0, 1]. If
threshold and thresholds are both set, they must match.e.g. if threshold is p,
then thresholds must be equal to [1-p, p].'): 0.5,
 Param(parent='LogisticRegression_4446ecd1f38f', name='tol', doc='the
convergence tolerance for iterative algorithms (>= 0).'): 1e-06}
```

1.7 Model Evaluation

[50]:
```python
# Create the necessary evaluators
evaluator=BinaryClassificationEvaluator(labelCol='label')
mcEvaluator = MulticlassClassificationEvaluator(metricName="accuracy")
```

[51]:
```python
# Generate predictions
predict_train=cvModel.transform(trainDF)
predict_test=cvModel.transform(testDF)
```

[52]:
```
#predict_test.show(3)
# besides initial df cols and those created by pipeline, we ahve label,␣
↪rawPrediction, probability, and prediction
```

1.7.1 Accuracy

[53]:
```
print("Train Accuracy:", mcEvaluator.evaluate(predict_train))
print("Test Accuracy:", mcEvaluator.evaluate(predict_test))
```

```
Train Accuracy: 0.9549860734338707
Test Accuracy: 0.9552607024095798
```

1.7.2 precision, recall, F1 score

Source: https://stackoverflow.com/questions/60772315/how-to-evaluate-a-classifier-with-pyspark-2-4-5

[54]:
```
weightedPrecision = mcEvaluator.evaluate(predict_test, {mcEvaluator.metricName:␣
↪"weightedPrecision"})
print("Test precision is {}".format(weightedPrecision))

weightedRecall = mcEvaluator.evaluate(predict_test, {mcEvaluator.metricName:␣
↪"weightedRecall"})
print("Test recall is {}".format(weightedRecall))

f1 = mcEvaluator.evaluate(predict_test, {mcEvaluator.metricName: "f1"})
print("Test f1 is {}".format(f1))
```

```
Test precision is 0.9214841866897692
Test recall is 0.9552607024095798
Test f1 is 0.9334140348304236
```

[55]:
```
weightedPrecision = mcEvaluator.evaluate(predict_train, {mcEvaluator.metricName:
↪ "weightedPrecision"})
print("Train precision is {}".format(weightedPrecision))

weightedRecall = mcEvaluator.evaluate(predict_train, {mcEvaluator.metricName:␣
↪"weightedRecall"})
print("Train recall is {}".format(weightedRecall))

f1 = mcEvaluator.evaluate(predict_train, {mcEvaluator.metricName: "f1"})
print("Train f1 is {}".format(f1))
```

```
Train precision is 0.9232611846478553
Train recall is 0.9549860734338705
Train f1 is 0.9330062499313787
```

1.7.3 Confusion Matrix

Source: https://stackoverflow.com/questions/58404845/confusion-matrix-to-get-precsion-recall-f1score

Confusion matrix references that may be helpful if the above does not work:

https://gist.github.com/ispmarin/05feacd8be5e2901cf2b35453a148060

https://shihaojran.com/distributed-machine-learning-using-pyspark/

[56]:
```
#important: need to cast to float type, and order by prediction, else it won't␣
↪work
preds_and_labels = predict_test.select(['prediction','label']).
↪withColumn('label', col('label').cast(FloatType())).orderBy('prediction')

#select only prediction and label columns
preds_and_labels = preds_and_labels.select(['prediction','label'])

metrics = MulticlassMetrics(preds_and_labels.rdd.map(tuple))
print("Confustion matrix for test:")
print(metrics.confusionMatrix().toArray())
```

```
Confustion matrix for test:
[[2.00000e+00 3.94530e+04]
 [8.00000e+00 8.42558e+05]]
```

[57]:
```
#important: need to cast to float type, and order by prediction, else it won't␣
↪work
preds_and_labels = predict_train.select(['prediction','label']).
↪withColumn('label', col('label').cast(FloatType())).orderBy('prediction')

#select only prediction and label columns
preds_and_labels = preds_and_labels.select(['prediction','label'])

metrics = MulticlassMetrics(preds_and_labels.rdd.map(tuple))
print("Confustion matrix for train:")
print(metrics.confusionMatrix().toArray())
```

```
Confustion matrix for train:
[[2.00000e+00 3.97020e+04]
 [6.00000e+00 8.42417e+05]]
```

1.7.4 AUC

[58]:
```
evalTrain=evaluator.evaluate(predict_train)
evalTest=evaluator.evaluate(predict_test)
```

[59]:
```
print("The area under ROC for train set after CV  is {}".format(evalTrain))
print("The area under ROC for test set after CV  is {}".format(evalTest))

# source: https://dhiraj-p-rai.medium.com/
 ↪logistic-regression-in-spark-ml-8a95b5f5434c
```

```
The area under ROC for train set after CV  is 0.6010342168729936
The area under ROC for test set after CV  is 0.5955954005433566
```

1.8 Sensitivity Analysis

[60]:
```
# My attempt to access submodels so don't need to fit again for sensitivity
# There is very little documentation for this online.  subModels appears to be
# a folds x models 2D list of pipelines. However, not sure how to extract a␣
 ↪single model
#cvModel.subModels
#cvModel.subModels[1][1].stages[-1].extractParamMap()
```

[61]:
```
# Our best model has elasticNetParam=0 and regParam=0.01.  So, we can do␣
 ↪sensitivity analysis
# by comparing to regParam=0.1 (we have this in subModels but I could not out␣
 ↪how to access)
paramGrid_sens = ParamGridBuilder() \
    .addGrid(htf.numFeatures, [200]) \
    .addGrid(lr.regParam, [0.1]) \
    .addGrid(lr.elasticNetParam, [0.0]) \
    .build()
```

[62]:
```
# Treat the Pipeline as an Estimator, wrapping it in a CrossValidator instance.
# Using the pipeline as the estimator slows things down but is necessary if␣
 ↪tuning featurziers.  If not, set the
# model specification as the estimator with estimator=lr (I think; though not␣
 ↪sure if that means lr needs to be removed from pipeline)
numFolds=5
crossval_sens = CrossValidator(estimator=pipeline,
                          estimatorParamMaps=paramGrid_sens,
                          ␣
 ↪evaluator=BinaryClassificationEvaluator(labelCol='label'),
                          numFolds=numFolds,
                          collectSubModels=False)
```

[63]:
```
if len(loadCVmodelSens)==0:
    cvModel_sens = crossval_sens.fit(trainDF) # train models (no parallelism)
    print ("Sensitivity fit complete")
else:
    cvModel_sens = CrossValidatorModel.load(loadCVmodelSens)
```

```
[64]: # save the sensitivity model if it was just fitted
      if len(loadCVmodelSens)==0:
          # save the model with a timestamp
          timestr = time.strftime("%Y%m%d-%H%M%S")
          cvModel_sens.save("lrModelSens"+timestr)
```

```
[65]: # Generate predictions
      predict_train_sens=cvModel_sens.transform(trainDF)
      predict_test_sens=cvModel_sens.transform(testDF)
      print ("Sensitivity prediction generation complete")
```

```
Sensitivity prediction generation complete
```

```
[66]: evaluator=BinaryClassificationEvaluator(labelCol='label')
      evalTrain=evaluator.evaluate(predict_train_sens)
      evalTest=evaluator.evaluate(predict_test_sens)
      print ("Sensitivity evaluate complete")
```

```
Sensitivity evaluate complete
```

```
[67]: print("The area under ROC for train set after CV  is {}".format(evalTrain))
      print("The area under ROC for test set after CV  is {}".format(evalTest))

      # source: https://dhiraj-p-rai.medium.com/
       ↪logistic-regression-in-spark-ml-8a95b5f5434c
```

```
The area under ROC for train set after CV  is 0.599735723234755
The area under ROC for test set after CV  is 0.5950043808385443
```

1.9 Save notebook as PDF document

```
[ ]: # Save notebook as PDF document
     !jupyter nbconvert --to pdf `pwd`/*.ipynb
```

```
[ ]:
```