COS424 Assignment 1: Email Classification

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Abstract

Spam has plagued the inboxes of email users for decades now, and new companies and technologies have risen to fight the influx of "the use of electronic messaging systems to send unsolicited messages (spam), especially advertising, as well as sending messages repeatedly on the same site." In this assignment, we address the problem of classifying emails into spam or ham (not spam) using two different feature sets, and a variety of different classifiers. The datasets used are the training and testing partitions of the TREC 2007 spam track overview dataset. We find that logistic regression in conjunction with bag-of-words features achieves the highest accuracy. but when examining different classifiers in a more refined and smaller feature space, a linear support vector machine achieves the best performance.

1 Introduction

According to a report on workplace productivity by McKinsey, workers spend up to 28% of their time checking their email. While most companies have a rigorous spam filter or secure email gateway in place (such as Proofpoint or Gmail), it is still a fruitful exercise in machine learning to examine classifier and feature extraction in the spam space.

We first use the given "vanilla" feature extraction strict, modified to threshold 100, to extract bag-of-word features from our dataset. Using cross-validation, we obtain a validation score for each of the following three models – Naive Bayes, Logistic Regression, and AdaBoost. Picking the highest validation score, we re-train the model on the full training set, and obtain the final test accuracy upon the testing set originally given.

Next, as more of an experiment, we use custom features extracted with more meaning than simple bag-of-words features. Splitting the training set into a simple training / validation partition, we train the following models on the sub-training set – Random Forests, SVM (Gaussian), SVM (Sigmoid), SVM (Linear), Deep Neural Network, and Logistic Regression. We take the model with the highest accuracy on the untouched validation set, and then re-train said model on the full training set. Finally, we evaluate this model on the testing set to obtain an unbiased test accuracy.

1.1 Data processing

The TREC 2007 dataset was downloaded from the COS424 Piazza website on February 13th, 2015, with the folder already partitioned into a 90/10 training and testing split. Using the `email_process.py` script that was written for us (with a small modification of dictionary threshold 200 lowered to 100), we extracted enough word counts for each training and testing emai to form a dataframe with the 45000 examples, and 15228 features per email.

For the custom features, we)insert stuff from Daway's explanation here)

1.2 Classification methods

We use three different classification methods from the SciKitLearn Python libraries for the vanilla feature set (all parameterizations are the default unless specified)

1. *Naive Bayes* (NB): Using the default parameters of MultinomialNB()
2. *Logistic regression with ℓ_2 penalty* (LOG): built on liblinear library
3. *AdaBoost* (AdB): using 50 decision trees as weak learners

For the custom feature set, we use six different classification methods in R:

1. *Random Forest* (RF): default params of randomForest
2. *Support Vector Machine (Gaussian)* (SVMG): default params
3. *Support Vector Machine (sigmoid)* (SVMS): default params
4. *Support Vector Machine (linear)* (SVML): default params
5. *Deep Neural Network* (DNN): 100 epochs, tanh activation, 3 layers of 50 nodes, 50% drop-out for each layer, 20% of inputs dropped

1.3 Evaluation

In the vanilla feature space, we used 5-fold cross validation on the full training set to obtain a full generalization error for each of the three models. This is a simple accuracy metric – we sum the total number of errors each model incurred on each validation fold, and subtract it from 1. The k-fold cross validation gives us a prediction for each training sample when it is unseen, allowing us to use that total error as a metric to choose between models. In other words, we have the metric A_q for model q:

$$A_q = 1 - \frac{\sum_{i=1}^{5}(FP_{fi} + FN_{fi})}{N}$$

where FP_{fi} is the number of false positives obtained from training on all folds but fold i, and predicting on fold i (likewise for the false negatives FN_{fi}.

For our experimental custom feature set, we simply set aside 20% of the training set as a validation set, to avoid the cost of training the same model k times in the cross validation. Here, we also obtain some more in-depth metrics rather than just the validation accuracy: we also use the precision, recall, F_1-score, and log loss metrics, defined as

$$\text{precision} = \frac{TP}{TP + FP}$$

$$\text{recall} = \frac{TP}{TP + FN}$$

$$F_1 = 2 \cdot \frac{\text{precision} \cdot \text{recall}}{\text{precision} + \text{recall}}$$

$$\text{log-loss} = -\frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{M} y_{i,j}\log(p_{i,j})$$

where for the log-loss, there are N samples, M classes (2 in our case), $y_{i,j}$ is 1 if sample i is in class j, and 0 otherwise, and $p_{i,j}$ is the model's probabilistic estimate of sample i belonging in class j.

2 Results

2.1 Evaluation results

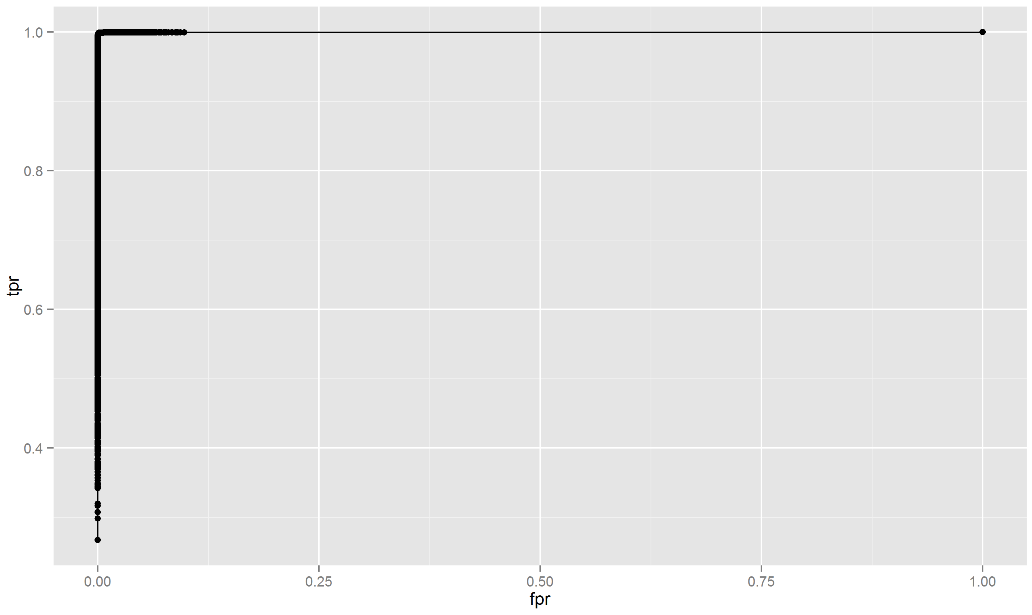
2.1.1 Vanilla Features

For our vanilla features and three models, we include the number of misclassified samples in each validation fold (indexing from f0 to f4 instead of f1 to f5), the average number of misclassifications per fold, as well as the total number of misclassifications, which is easily manipulated into the generalization error (and accuracy). While it's clear that the total validation accuracy is extremely

	f0	f1	f2	f3	f4	average	total	gen_acc
NB	29	18	21	38	25	26.2	131	0.997089
LOG	12	9	9	15	10	11.0	55	0.998778
AdB	13	19	15	26	21	18.8	94	0.997911

high for all three methods, it is clear that the Logistic Regression model obtains the highest accuracy with respect to the entire validation process.

Taking the logistic regression as our "best model", we re-train it on the full training set and then evaluate it in an unbiased fashion on the test set. Doing so gives us an accuracy that is comparable to the generalization accuracy obtained during the validation phase – **99.762%**. Given this extraordinarily high test accuracy, we should expect to see a relatively strange ROC curve, one that spikes up immediately as the threshold moves down from 99.99...% to 0%. This tells us that we are near



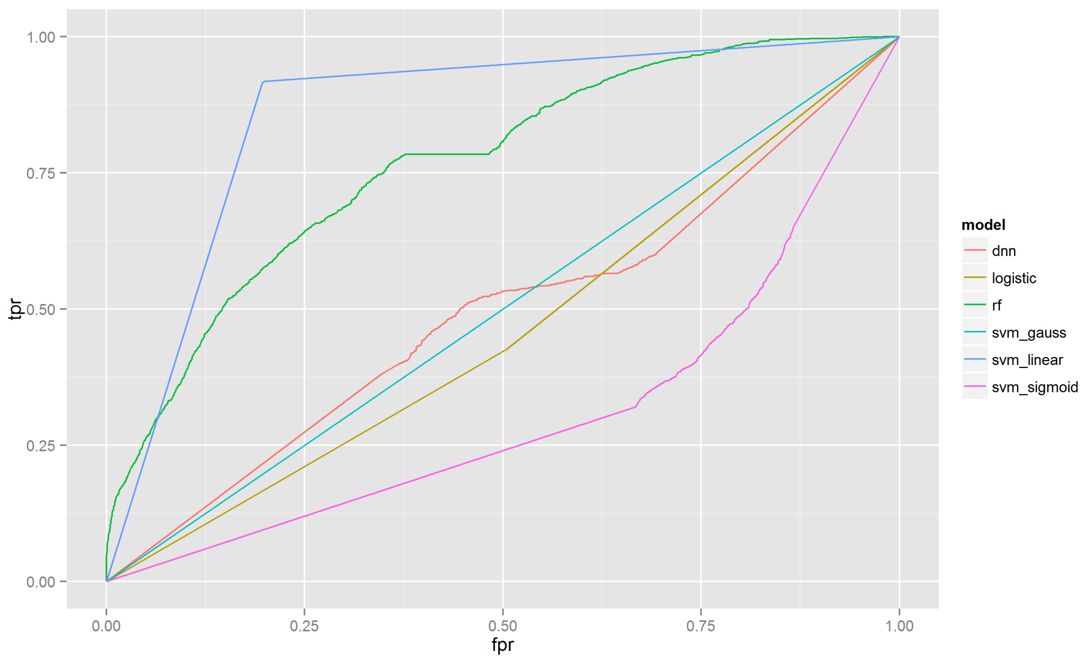
our perfectly desired $(0, 1)$ point. This makes sense, because when we have a very high threshold, everything is classified as negative, and, as with all ROC curves, the first point is at $(0, 0$. But because the classifier is so strong, its predicted probabilities are very close to 0 and 1, so the threshold only needs to be relaxed a small amount before the true positive rate shoots up. The ROC curves of such successful classifiers are almost misleading – with the points overlaid on the curve, we see that the fpr value simply jumps from 0.09 to 1 as the threshold goes to 0.

2.1.2 Custom Features

Because the more refined feature space is defined by only 63 features, the classifiers are working with less data and should be expected to have lower validation and testing scores. The idea here is that with much lower space, time, and computational costs, we might be able to achieve decent performance.

	validation accuracy	log loss	precision	recall	F_1
RF	0.5796667	0.3951222	0.8917411	0.1781494	0.2969708
SVM_gauss	0.4983333	0.1532875	0.4983333	1.0000000	0.6651835
SVM_sigmoid	0.3371111	3.6592386	0.3623350	0.4345596	0.3951744
SVM_linear	0.8593333	0.6662509	0.8217070	0.9166109	0.8665683
DNN	0.5195556	0.8806850	0.5176342	0.5268673	0.4307182
Logistic	0.4610000	10.2988752	0.4563246	0.4263099	0.4493372

It is clear that the linear support vector machine blew all of the other models out of the water, with a much higher validation accuracy, precision, recall, and F_1 score. Since we have more models and computational capacity here, we also provide the ROC curves of every model on the validation set:



2.2 Computational speed

The variability in the time for training and testing these linear classifiers was substantial (Table **??**). In particular, we found that the KNN classifier, which does not perform training, takes the largest amount of time because of the all-by-all comparison that occurs during test phase. AdaBoost takes the second longest, but here the time is spent on training the weak classifiers and the weights of the linear combination of those weak classifiers. The fastest classifiers include the NB classifier, the perceptron, and the hinge loss classifier, followed by the linear SVM and then the decision tree and random forest classifiers.

3 Discussion and Conclusion

In this work, we compared ten different classifiers to predict the newsgroup for a particular newsgroup post using bag-of-words features. We found that, considering precision, recall, and time, the decision tree and random forest classifiers showed superior performance on this task. The effect of feature selection was mostly on the time, although the improvement in performance was substantial for the random forest classifier on this task.

There are a number of directions to go that would improve these results. First, we could expand our data set using available data from these and other related newsgroups. Second, we could consider more sophisticated features for the newsgroup posts than dictionary word counts; bi-grams, post length, or punctuation may be useful in this classification task. Third, we could use the most promising models in a more problem-tailored way. In particular, because the random forest classifier showed such promise in this task, we could consider applying it to this problem using multi class class labels instead of one-versus-rest class labels, and reducing the dimension of the feature space using supervised latent Dirichlet allocation based methods [**?**, **?**].