

Credit Approval Analysis using Machine Learning

Vipul Munot
Indiana University
MS in Data Science
Indiana, Bloomington
vipmunot@iu.edu

Rahul Sampat
Indiana University
MS in Data Science
Indiana, Bloomington
rrsambat@uemail.iu.edu

DATA SETS:

For this project, we are using the following 3 data sets from the UCI machine learning repository:

1) German Credit Data:

This is a binary classification problem, where based on the given set of attributes, a person is labelled as a good(1)/bad(2) credit risk. There are a total of 1000 instances with 20 attributes and a label.

URL: [https://archive.ics.uci.edu/ml/datasets/Statlog+\(German+Credit+Data\)](https://archive.ics.uci.edu/ml/datasets/Statlog+(German+Credit+Data))

Below is the attribute description:

Attribute	Type	Description	Example
Attribute 1	Qualitative	Status of existing checking account	A11 : ... < 0 DM A12 : 0 <= ... < 200 DM A13 : ... >= 200 DM / salary assignments for at least 1 year A14 : no checking account
Attribute 2	Numerical	Duration in month	6, 48 etc
Attribute 3	Qualitative	Credit history	A30 : no credits taken/ all credits paid back duly A31 : all credits at this bank paid back duly A32 : existing credits paid back duly till now A33 : delay in paying off in the past A34 : critical account/ other credits existing (not at this bank)
Attribute 4	Qualitative	Purpose	A40 : car (new) A41 : car (used) A42 : furniture/equipment A43 : radio/television A44 : domestic appliances A45 : repairs A46 : education A47 : (vacation - does not exist?) A48 : retraining A49 : business A410 : others
Attribute 5	Numerical	Credit amount	1169, 5951 etc.
Attribute 6	Qualitative	Savings account/bonds	A61 : ... < 100 DM A62 : 100 <= ... < 500 DM A63 : 500 <= ... < 1000 DM

			A64 : .. >= 1000 DM A65 : unknown/ no savings account
Attribute 7	Qualitative	Present employment since	A71 : unemployed A72 : ... < 1 year A73 : 1 <= ... < 4 years A74 : 4 <= ... < 7 years A75 : .. >= 7 years
Attribute 8	Numerical	Installment rate in percentage of disposable income	1,2,3,4 etc.
Attribute 9	Qualitative	Personal status and sex	A91 : male : divorced/separated A92 : female : divorced/separated/married A93 : male : single A94 : male : married/widowed A95 : female : single
Attribute 10	Qualitative	Other debtors / guarantors	A101 : none A102 : co-applicant A103 : guarantor
Attribute 11	Numerical	Present residence since	1,2,3,4 etc.
Attribute 12	Qualitative	Property	A121 : real estate A122 : if not A121 : building society savings agreement/ life insurance A123 : if not A121/A122 : car or other, not in attribute 6 A124 : unknown / no property
Attribute 13	Numerical	Age in years	22, 49 etc.
Attribute 14	Qualitative	Other installment plans	A141 : bank A142 : stores A143 : none
Attribute 15	Qualitative	Housing	A151 : rent A152 : own A153 : for free
Attribute 16	Numerical	Number of existing credits at this bank	1,2,3 etc.
Attribute 17	Qualitative	Job	A171 : unemployed/ unskilled - non-resident A172 : unskilled - resident A173 : skilled employee / official A174 : management/ self-employed/highly qualified employee/ officer
Attribute 18	Numerical	Number of people being liable to provide maintenance for	1,2
Attribute 19	Qualitative	Telephone	A191 : none

			A192 : yes, registered under the customer's name
Attribute 20	Qualitative	Foreign Worker	A201 : yes A202 : no
Label	Binary	Indicates good/bad risk	1 = Good, 2 = Bad

Note: For this dataset, it is worse to class a customer as good when they are bad (5), than it is to class a customer as bad when they are good (1).

2) Credit Approval Data Set:

This data set concerns credit card applications.

This is a binary classification problem, where based on the given set of attributes, a person is labelled as a + (positive)/ - (negative) candidate for issuing a credit card. There are a total of 690 instances with 15 attributes and a label.

This dataset is interesting because there is a good mix of attributes -- continuous, nominal with small numbers of values, and nominal with larger numbers of values. There are also a few missing values.

URL: <https://archive.ics.uci.edu/ml/datasets/Credit+Approval>

Below is the attribute description:

Attribute	Type/Set of values
A1	b,a.
A2	Continuous
A3	Continuous
A4	u, y, l, t
A5	g, p, gg
A6	c, d, cc, i, j, k, m, r, q, w, x, e, aa, ff.
A7	v, h, bb, j, n, z, dd, ff, o.
A8	Continuous
A9	t, f.
A10	t, f.
A11	Continuous
A12	t,f
A13	g,p,s
A14	Continuous
A15	Continuous
A16	+,-

Missing Attribute Values:

37 cases (5%) have one or more missing values.

Class Distribution:

+: 307 (44.5%)

-: 383 (55.5%)

3) Default of Credit Card Clients Data Set:

This research aimed at the case of customers default payments in Taiwan.

From the perspective of risk management, the result of predictive accuracy of the estimated probability of default will be more valuable than the binary result of classification - credible or not credible clients.

This research employed a binary variable, default payment (Yes = 1, No = 0), as the response variable. There are a total of 30000 instances with 23 attributes and a label.

URL: <https://archive.ics.uci.edu/ml/datasets/default+of+credit+card+clients>

Below is the attribute description:

Attribute	Description	Examples
X1	Amount of the given credit (NT dollar)	It includes both the individual consumer credit and his/her family (supplementary) credit.
X2	Gender	(1 = male; 2 = female).
X3	Education	(1 = graduate school; 2 = university; 3 = high school; 4 = others)
X4	Marital status	(1 = married; 2 = single; 3 = others)
X5	Age	Year
X6 - X11	History of past payment. We tracked the past monthly payment records (from April to September, 2005)	X6 = the repayment status in September, 2005; X7 = the repayment status in August, 2005; . . .; X11 = the repayment status in April, 2005. The measurement scale for the repayment status is: -1 = pay duly; 1 = payment delay for one month; 2 = payment delay for two months; ...and so on;
X12-X17	Amount of bill statement (NT dollar)	X12 = amount of bill statement in September, 2005; X13 = amount of bill statement in August, 2005; X17 = amount of bill statement in April, 2005.
X18-X23	Amount of previous payment (NT dollar).	X18 = amount paid in September, 2005; X19 = amount paid in August, 2005; . . .; X23 = amount paid in April, 2005
Y	Label	Default payment (Yes = 1, No = 0),

METHOD:

Data Splitting:

We used 90-10% train-test split of data.

Machine Learning Techniques:

We self implemented 2 algorithms and used scikit libraries for 5 algorithms, on all the 3 datasets above:

Self Implemented:

- a) Naïve Bayes
- b) kNN

Using Scikit Libraries:

- a) Naive Bayes
- b) Random Forest
- c) Logistic Regression
- d) Support Vector Machines
- e) K Nearest Neighbors

Parameter Settings for Sci-kit Packages:

We tried out various parameter tuning settings to find out the best ones, based on a greedy approach, ie. changing one parameter at a time, for each of the algorithm on each of the data set separately. You may see the output of these parameter setting by executing final.py file provided. Below are the best parameter settings for each of the algorithms on each dataset:

a) Random Forest

In Random Forest, we hyper tuned the parameters according to area under ROC curve and the accuracy. The parameters we tuned are max_depth, max_features, n_estimators, random_state and min_samples_leaf. Following are the final parameters settings we used to maximize the accuracy

Dataset: German Dataset

```
RandomForestClassifier(bootstrap=True, class_weight=None, criterion='gini', max_depth=800,
max_features='auto', max_leaf_nodes=None, min_impurity_split=1e-07, min_samples_leaf=50,
min_samples_split=2, min_weight_fraction_leaf=0.0, n_estimators=600, n_jobs=-1,
oob_score=False, random_state=None, verbose=0, warm_start=False)
```

Dataset: Credit Approval Data Set

```
RandomForestClassifier(bootstrap=True, class_weight=None, criterion='gini', max_depth=300,
max_features='auto', max_leaf_nodes=None, min_impurity_split=1e-07,
min_samples_leaf=1, min_samples_split=2, min_weight_fraction_leaf=0.0, n_estimators=800,
n_jobs=-1, oob_score=False, random_state=100, verbose=0, warm_start=False)
```

Dataset: Default of Credit Card Clients Data Set

```
RandomForestClassifier(bootstrap=True, class_weight=None, criterion='gini', max_depth=100,
max_features='auto', max_leaf_nodes=None, min_impurity_split=1e-07, min_samples_leaf=50,
min_samples_split=2, min_weight_fraction_leaf=0.0, n_estimators=600, n_jobs=-1,
oob_score=False, random_state=None, verbose=0, warm_start=False)
```

b) Logistic Regression

In Logistic Regression, we hyper tuned the parameters according to area under ROC curve and the accuracy. The parameters we tuned are penalty, solver, C, class_weight, max_iter and random_state. Following are the final parameters settings we used to maximize the accuracy.

Dataset: German Dataset

LogisticRegression(C=0.5, class_weight=None, dual=False, fit_intercept=True, intercept_scaling=1, max_iter=100, multi_class='ovr', n_jobs=-1, penalty='l2', random_state=500, solver='liblinear', tol=0.0001, verbose=0, warm_start=False)

Dataset: Credit Approval Data Set

LogisticRegression(C=1, class_weight=None, dual=False, fit_intercept=True, intercept_scaling=1, max_iter=100, multi_class='ovr', n_jobs=-1, penalty='l2', random_state=None, solver='liblinear', tol=0.0001, verbose=0, warm_start=False)

Dataset: Default of Credit Card Clients Data Set

LogisticRegression(C=1, class_weight=None, dual=False, fit_intercept=True, intercept_scaling=1, max_iter=100, multi_class='ovr', n_jobs=-1, penalty='l2', random_state=None, solver='liblinear', tol=0.0001, verbose=0, warm_start=False)

c) kNN:

In k Nearest Neighbors, we hyper tuned the parameters according to area under ROC curve and the accuracy. The parameters we tuned are n_neighbors, weights and algorithm. Following are the final parameters settings we used to maximize the accuracy.

Dataset: German Dataset

KNeighborsClassifier(algorithm='auto', leaf_size=30, metric='minkowski', metric_params=None, n_jobs=-1, n_neighbors=5, p=2, weights='uniform')

Dataset: Credit Approval Data Set

KNeighborsClassifier(algorithm='ball_tree', leaf_size=30, metric='minkowski', metric_params=None, n_jobs=-1, n_neighbors=10, p=2, weights='uniform')

Dataset: Credit Approval Data Set

KNeighborsClassifier(algorithm='auto', leaf_size=30, metric='minkowski', metric_params=None, n_jobs=-1, n_neighbors=50, p=2, weights='uniform')

d) Linear SVC:

In Linear Support Vector Machine, we hyper tuned the parameters according to area under ROC curve and the accuracy. The parameters we tuned are dual, C, class_weight, penalty and random_state. Following are the final parameters settings we used to maximize the accuracy.

Dataset: German Dataset

LinearSVC(C=1, class_weight=None, dual=False, fit_intercept=True, intercept_scaling=1, loss='squared_hinge', max_iter=1000, multi_class='ovr', penalty='l1', random_state=1000, tol=0.0001, verbose=0)

Dataset: Credit Approval Data Set

LinearSVC(C=1, class_weight=None, dual=False, fit_intercept=True, intercept_scaling=1, loss='squared_hinge', max_iter=500, multi_class='ovr', penalty='l2', random_state=1000, tol=0.0001, verbose=0)

Dataset: Credit Approval Data Set

LinearSVC(C=1, class_weight=None, dual=False, fit_intercept=True, intercept_scaling=1, loss='squared_hinge', max_iter=10, multi_class='ovr', penalty='l1', random_state=1000, tol=0.0001, verbose=0)

e) Naïve Bayes:

There are no parameter to be set for NB.

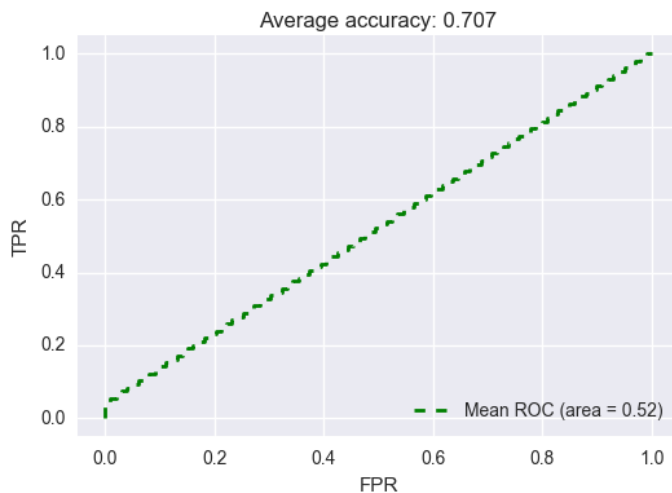
Dataset: German Dataset/ Credit Approval Data Set/ Credit Approval Data Set

GaussianNB()

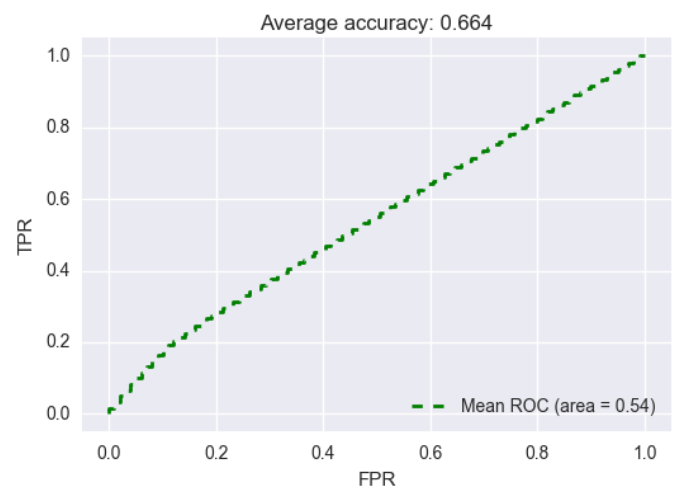
ROC Curves:

The average ROC (over 10-fold cross validation) for different algorithms over different datasets are as follows:

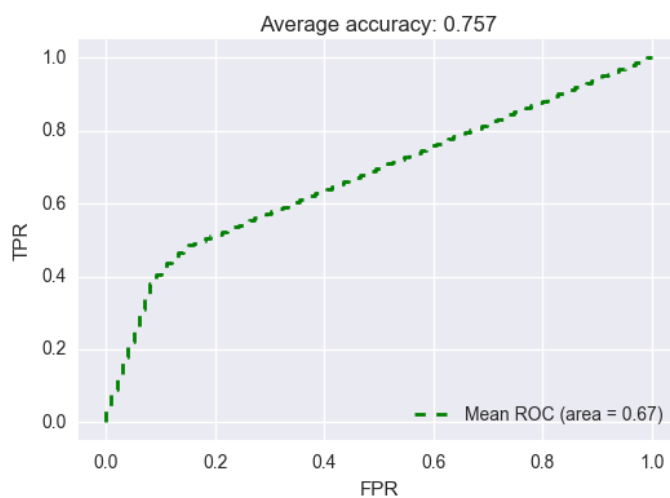
1) German Dataset:



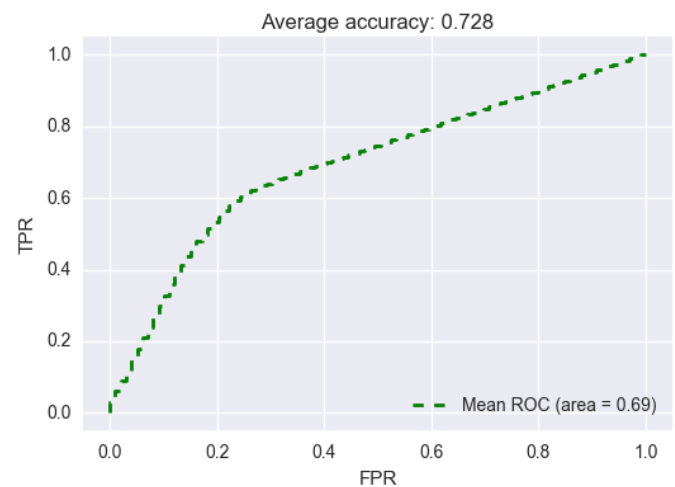
Random Forest



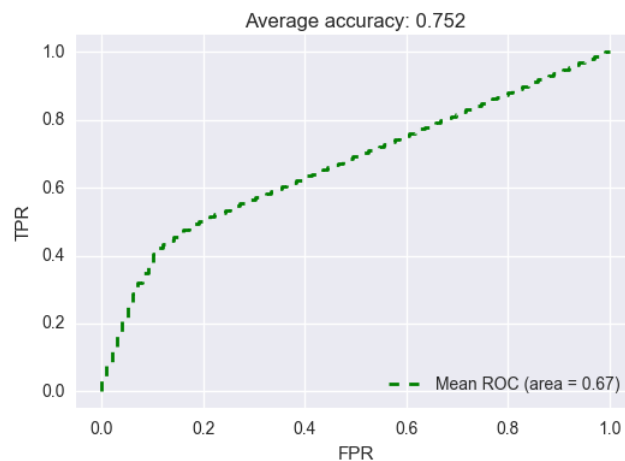
kNN



Logistic Regression

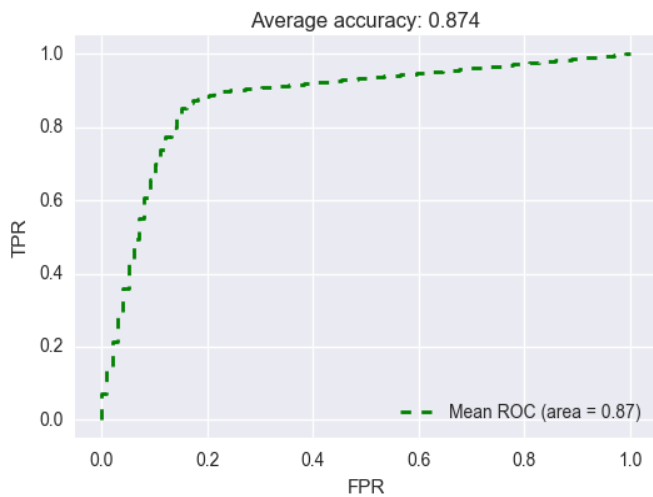


Naïve Bayes

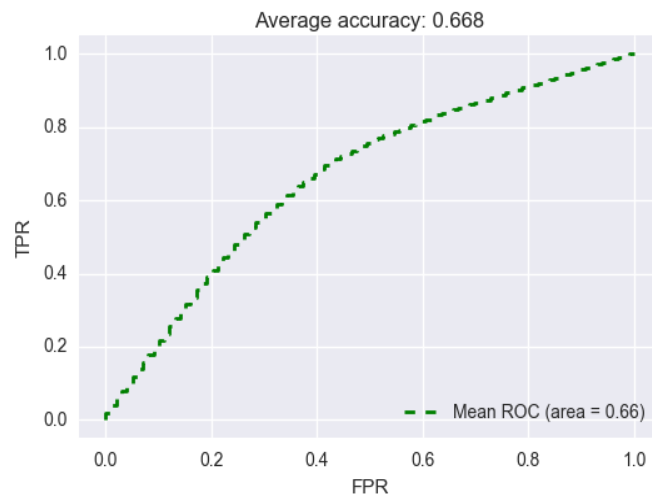


SVM

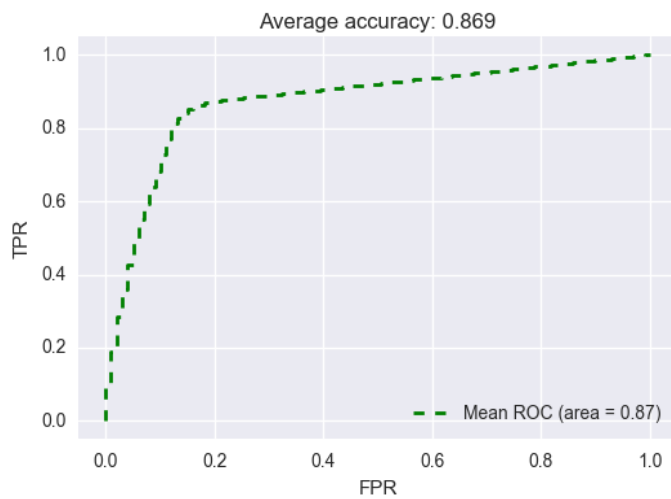
2) Credit Approval Data Set:



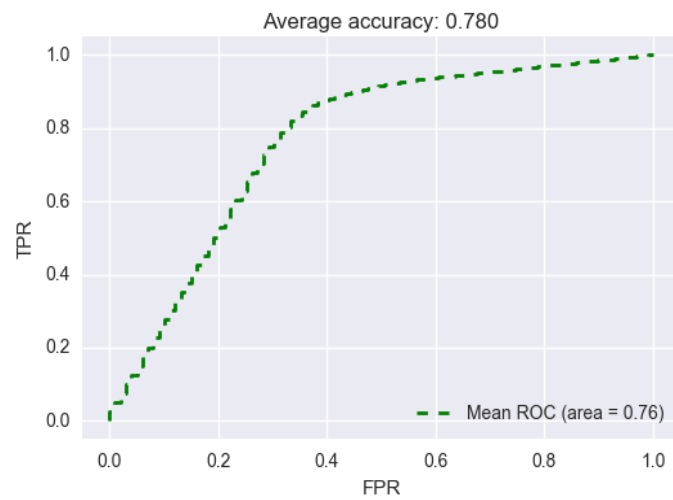
Random Forest



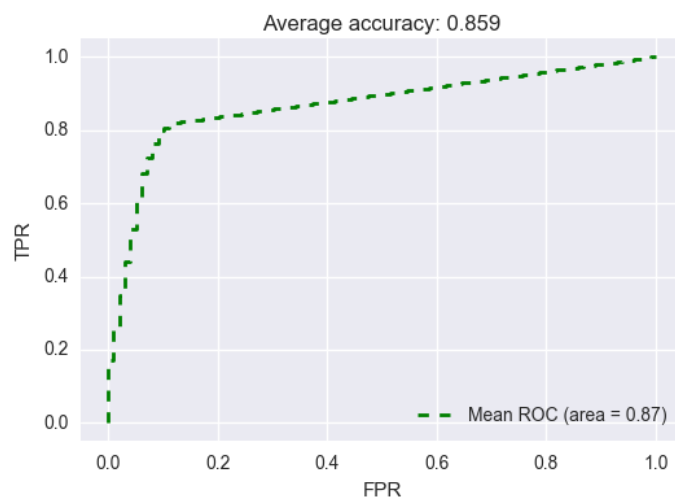
kNN



Logistic Regression

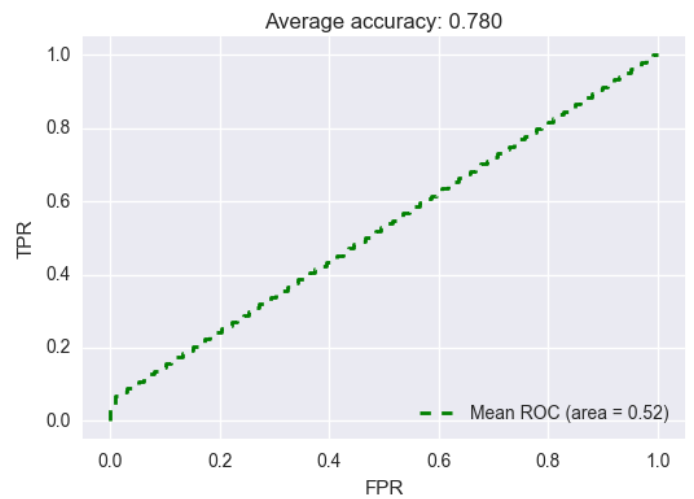
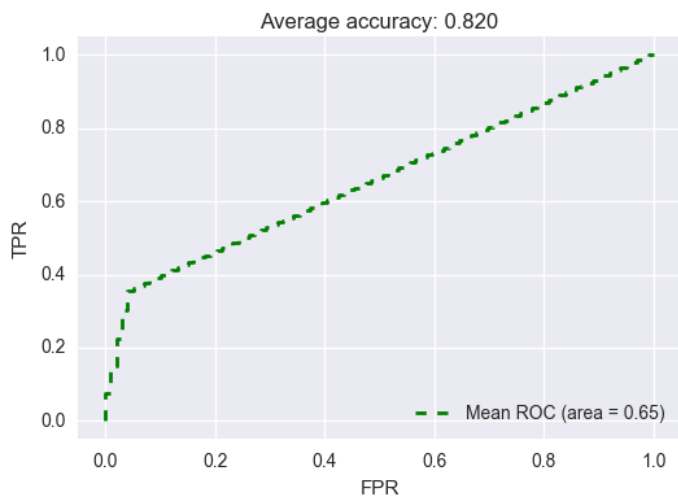


Naïve Bayes



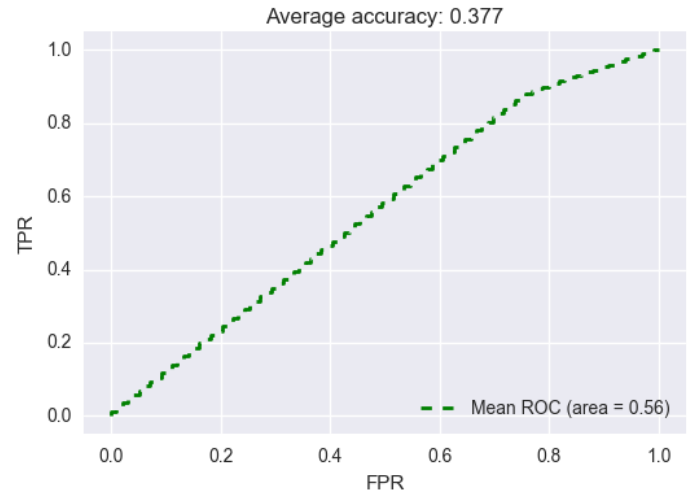
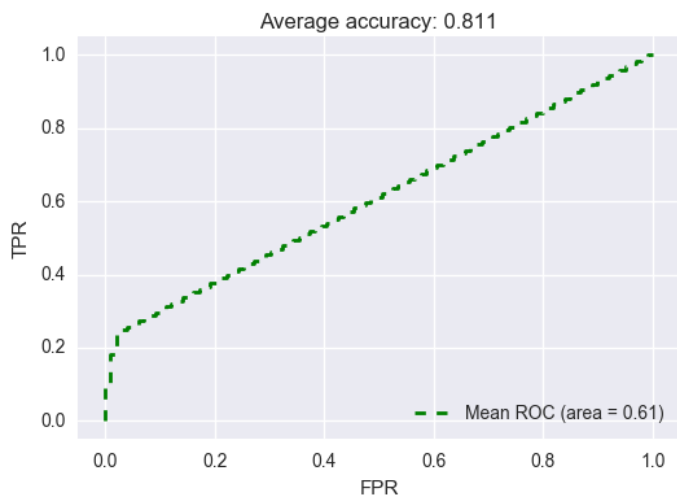
SVM

3) Default of Credit Card Clients Data Set:



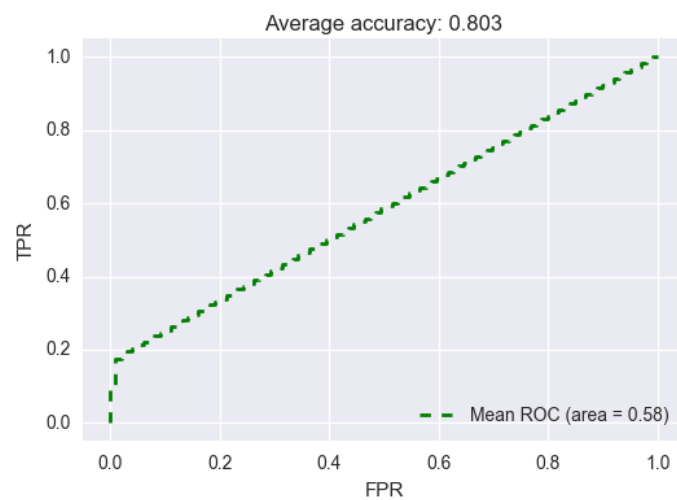
Random Forest

kNN



Logistic Regression

Naïve Bayes



SVM

Confusion Matrices:

Below are the confusion matrices using self implemented and scikit libraires with 0.1-test/0.9-train data split:

1) Self-Implemented:

a) Naïve Bayes:

German Dataset:

Confusion Matrix

Model Results

Actual\Model	1	2	Actual Count
1	55	21	76
2	10	21	31

('Naive Bayes Accuracy', 71.02803738317758)

CRX Dataset:

Confusion Matrix

Model Results

Actual\Model	+	-	Actual Count
+	23	9	32
-	8	33	41

('Naive Bayes Accuracy', 76.71232876712328)

Default Dataset:

Confusion Matrix

Model Results

Actual\Model	1	0	Actual Count
1	275	415	690
0	362	1941	2303

('Naive Bayes Accuracy', 74.0394253257601)

b) kNN:

German Dataset:

Accuracy_score: 68.95%

CRX Dataset:

Accuracy_score: 65.94%

Default Dataset:

Accuracy_score: 75.5%

2) Scikit:

a) German Dataset:

Random Forest

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	282	5
Actual No	18	695

Accuracy : 70%
True Positive Rate: 98.25%
False Positive Rate: 2.52%

Logistic

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	163	80
Actual No	137	620

Accuracy 75.7 %
True Positive Rate: 67.07%
False Positive Rate: 18.09%

Naïve Bayes

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	118	146
Actual No	182	554

Accuracy 72.8%
True Positive Rate: 44.69%
False Positive Rate: 24.72%

kNN

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	231	107
Actual No	169	593

Accuracy 66.4%
True Positive Rate: 68.3%
False Positive Rate: 10.42%

SVM

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	163	82
Actual No	137	618

Accuracy 75.2%
True Positive Rate: 66.53%
False Positive Rate: 18.14%

b) Credit Approval (CRX) Dataset:**Random Forest**

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	37	40
Actual No	346	267

Accuracy 87.4%

True Positive Rate: 48.05%

False Positive Rate: 56.44%

Logistic

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	56	32
Actual No	327	275

Accuracy 86.9%

True Positive Rate: 63.63%

False Positive Rate: 54.31%

Naïve Bayes

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	35	112
Actual No	348	195

Accuracy 78%

True Positive Rate: 23.80%

False Positive Rate: 64.08%

kNN

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	107	119
Actual No	276	188

Accuracy 66.8%

True Positive Rate: 47.34%

False Positive Rate: 59.48%

SVM

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	73	27
Actual No	310	280

Accuracy 85.9%

True Positive Rate: 66.53%

False Positive Rate: 18.14%

c) Default Dataset:

Random Forest

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	4266	1124
Actual No	2370	22240

Accuracy 82%
True Positive Rate: 79.14%
False Positive Rate: 9.63%

Logistic

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	5043	638
Actual No	1593	22726

Accuracy 81.1%
True Positive Rate: 88.76%
False Positive Rate: 6.55%

Naïve Bayes

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	771	17889
Actual No	5865	5475

Accuracy 37.7%
True Positive Rate: 4.13%
False Positive Rate: 51.71%

kNN

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	6220	410
Actual No	416	22954

Accuracy 78%
True Positive Rate: 93.81%
False Positive Rate: 1.78%

SVM

Confusion Matrix

	Predicted Yes	Predicted No
Actual Yes	5455	438
Actual No	1181	22926

Accuracy 80.3%
True Positive Rate: 92.56%
False Positive Rate: 4.89%

WEKA ANALYSIS:

a) German Dataset:

Random Forest:

Choose RandomForest -P 100 -I 100 -num-slots 1 -K 0 -M 1.0 -V 0.001 -S 1

Test options

☐ Use training set
☐ Supplied test set Set...
☒ Cross-validation Folds 10
☐ Percentage split % 66
More options...

(Nom) attribute_20

Start Stop

Result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest

Classifier output

attribute_13
attribute_14
attribute_15
attribute_16
attribute_17
attribute_18
attribute_19
attribute_20

Test mode: 10-fold cross-validation

=== Classifier model (full training set) ===

RandomForest

Bagging with 100 iterations and base learner

weka.classifiers.trees.RandomTree -K 0 -M 1.0 -V 0.001 -S 1 -do-not-check-capabilities

Time taken to build model: 0.07 seconds

=== Stratified cross-validation ===

=== Summary ===

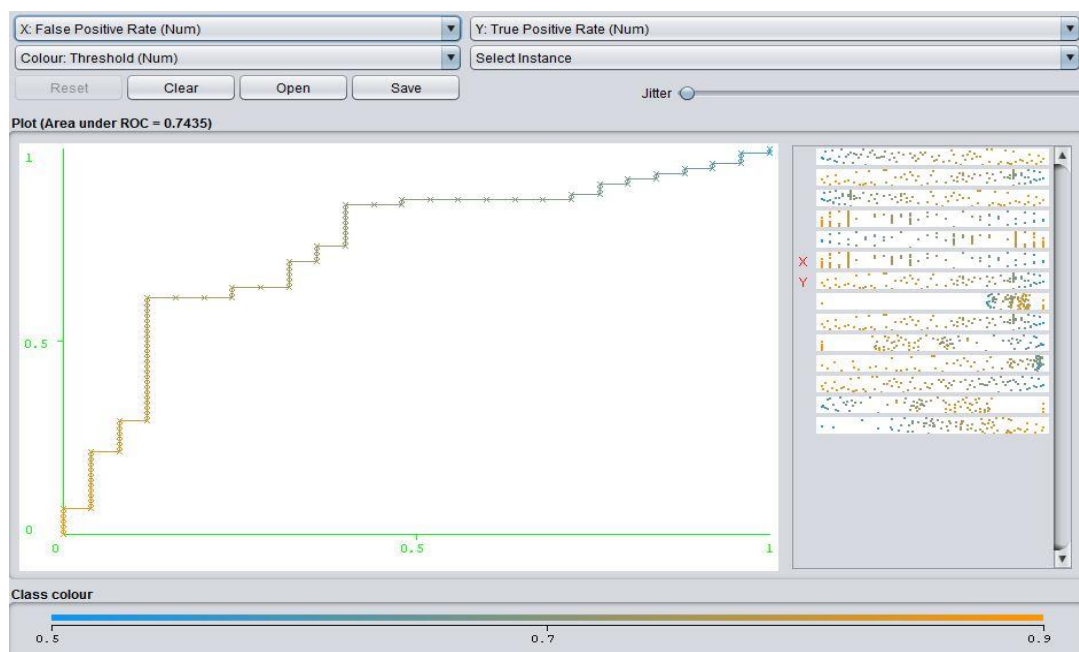
Correctly Classified Instances	74	74	%
Incorrectly Classified Instances	26	26	%
Kappa statistic	-0.0196		
Mean absolute error	0.3504		
Root mean squared error	0.4133		
Relative absolute error	92.6349 %		
Root relative squared error	95.2889 %		
Total Number of Instances	100		

=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.987	1.000	0.747	0.987	0.851	-0.058	0.743	0.887	1
	0.000	0.013	0.000	0.000	0.000	-0.058	0.743	0.445	2
Weighted Avg.	0.740	0.753	0.561	0.740	0.638	-0.058	0.743	0.776	

=== Confusion Matrix ===

a	b	<-- classified as	
74	1	a = 1	
25	0	b = 2	



Logistic Regression:

Choose **Logistic** - R 1.0E-8 - M -1 - num-decimal-places 4

Test options

☐ Use training set
☐ Supplied test set
☒ Cross-validation Folds
☐ Percentage split %

Nom) attribute_20

result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic

Classifier output

```

attribute_19=A142      0.0005
attribute_19=A143      0.5344
attribute_14=A151      1.7716
attribute_14=A152     13.0565
attribute_14=A153      0.0036
attribute_15=1         6.0107
attribute_15=2         0.0394
attribute_15=3     845362.7785
attribute_15=4         4.5913
attribute_16=A171     55729846.9404
attribute_16=A172      1.2893
attribute_16=A173      0.6185
attribute_16=A174      0.4536
attribute_17=2         5.6997
attribute_18=A192      0.2197
attribute_19=A202      21.0085
  
```

Time taken to build model: 2.89 seconds

=== Stratified cross-validation ===

=== Summary ===

Correctly Classified Instances	66	66	%
Incorrectly Classified Instances	34	34	%
Kappa statistic	0.236		
Mean absolute error	0.3161		
Root mean squared error	0.5403		
Relative absolute error	83.5681 %		
Root relative squared error	124.5825 %		
Total Number of Instances	100		

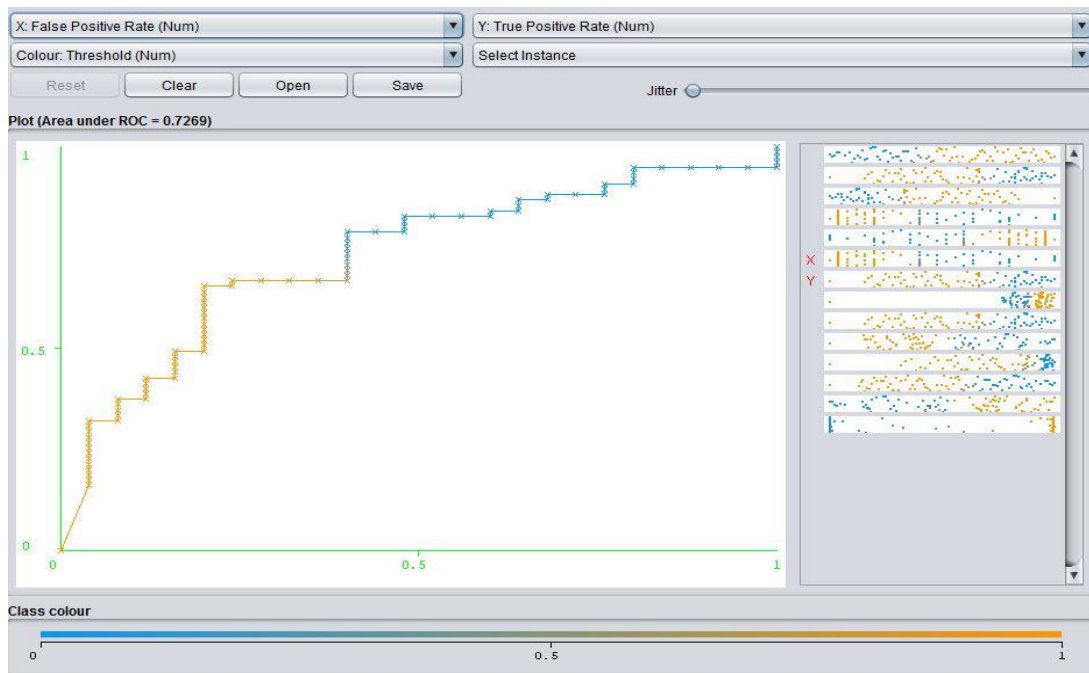
=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.680	0.400	0.836	0.680	0.750	0.249	0.727	0.882	1
	0.600	0.320	0.385	0.600	0.469	0.249	0.726	0.416	2
Weighted Avg.	0.660	0.380	0.723	0.660	0.680	0.249	0.727	0.765	

=== Confusion Matrix ===

```

a b  <-- classified as
51 24 | a = 1
10 15 | b = 2
  
```



kNN:

Choose **IBk -K 1 -W 0 -A "weka.core.neighboursearch.LinearNNSearch -A "weka.core.EuclideanDistance -R first-last"**

Test options

☐ Use training set
☐ Supplied test set
☒ Cross-validation Folds
☐ Percentage split %

(Nom) attribute_20

result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest
- 15:43:11 - functions.SMO
- 15:48:40 - lazy.IBk

Classifier output

attribute_11
attribute_12
attribute_13
attribute_14
attribute_15
attribute_16
attribute_17
attribute_18
attribute_19
attribute_20

Test mode: 10-fold cross-validation

=== Classifier model (full training set) ===

IB1 instance-based classifier
using 1 nearest neighbour(s) for classification

Time taken to build model: 0 seconds

=== Stratified cross-validation ===

=== Summary ===

Correctly Classified Instances	74	74	%
Incorrectly Classified Instances	26	26	%
Kappa statistic	0.2239		
Mean absolute error	0.3227		
Root mean squared error	0.512		
Relative absolute error	85.3138 %		
Root relative squared error	118.0521 %		
Total Number of Instances	100		

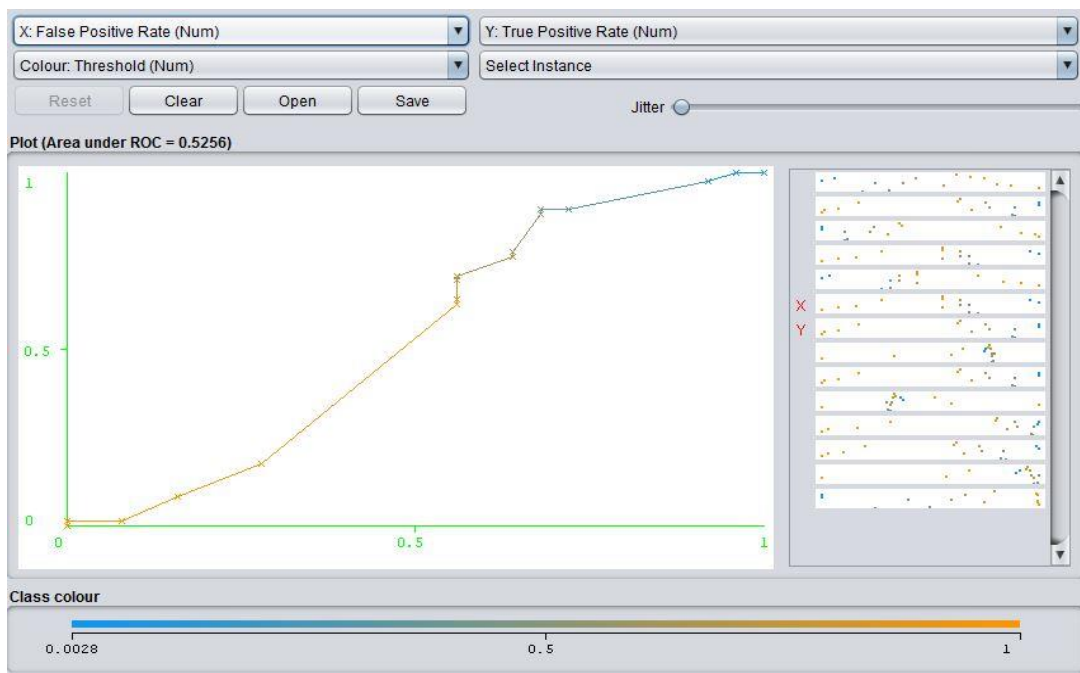
=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.880	0.680	0.795	0.880	0.835	0.231	0.526	0.755	1
	0.320	0.120	0.471	0.320	0.381	0.231	0.526	0.344	2
Weighted Avg.	0.740	0.540	0.714	0.740	0.722	0.231	0.526	0.652	

=== Confusion Matrix ===

a b <-- classified as

66	9	a = 1
17	8	b = 2



Naïve Bayes:

Choose **NaiveBayes**

Test options

☐ Use training set
☐ Supplied test set
☒ Cross-validation Folds
☐ Percentage split %

(Nom) attribute_20

Result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes

Classifier output

```
attribute_17
1      63.0  23.0
2      14.0   4.0
[total] 77.0  27.0

attribute_18
A191   47.0  14.0
A192   30.0  13.0
[total] 77.0  27.0

attribute_19
A201   74.0  26.0
A202    3.0   1.0
[total] 77.0  27.0

Time taken to build model: 0 seconds

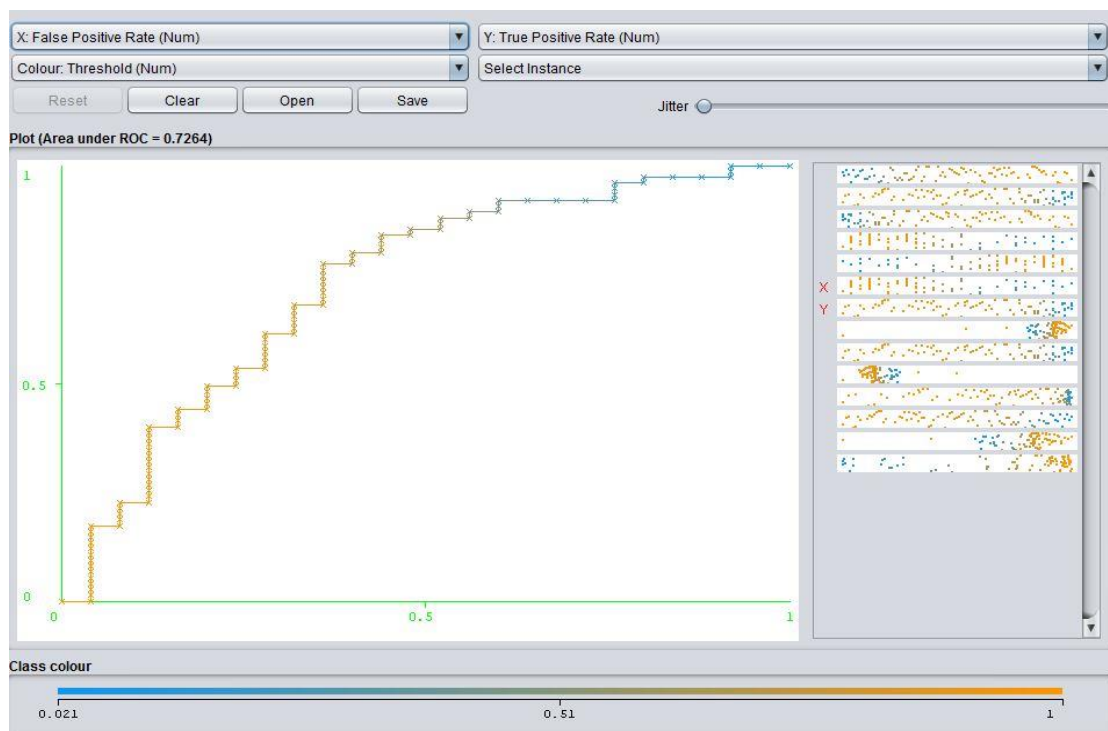
=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances      78      78  %
Incorrectly Classified Instances    22      22  %
Kappa statistic                    0.3803
Mean absolute error                 0.2635
Root mean squared error             0.4158
Relative absolute error             69.6628 %
Root relative squared error         95.8754 %
Total Number of Instances          100

=== Detailed Accuracy By Class ===
```

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.880	0.520	0.835	0.880	0.857	0.383	0.726	0.853	1
	0.480	0.120	0.571	0.480	0.522	0.383	0.726	0.527	2
Weighted Avg.	0.780	0.420	0.769	0.780	0.773	0.383	0.726	0.772	

```
=== Confusion Matrix ===
  a  b  <-- classified as
66  9  | a = 1
13 12 | b = 2
```



Support Vector Machine (Poly):

Choose **SMO** - C 1.0 - L 0.001 - P 1.0E-12 - N 0 - V -1 -W 1 -K "weka.classifiers.functions.supportVector.PolyKernel" - E 1.0 - C 250007 - calibrator "weka.classifiers.functions.Logistic" - R 1.0E-8 - M -1 - num-decimal-places 4"

Test options

☐ Use training set
☐ Supplied test set
☒ Cross-validation Folds **10**
☐ Percentage split % **66**
[More options...](#)

(Nom) attribute_20

[Start](#) [Stop](#)

Result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest
- 15:43:11 - functions.SMO**

Classifier output

```
+ 0.015 * (normalized) attribute_14=A153
+ -0.0047 * (normalized) attribute_15=1
+ 0.3969 * (normalized) attribute_15=2
+ -0.3922 * (normalized) attribute_15=3
+ -0.0601 * (normalized) attribute_16=A171
+ 0.2409 * (normalized) attribute_16=A172
+ 0.0612 * (normalized) attribute_16=A173
+ -0.242 * (normalized) attribute_16=A174
+ 0.3363 * (normalized) attribute_17=2
+ -0.0015 * (normalized) attribute_18=A192
+ -0.2956 * (normalized) attribute_19=A202
- 0.8275
```

Number of kernel evaluations: 4189 (96.918% cached)

Time taken to build model: 0.22 seconds

=== Stratified cross-validation ===
 === Summary ===

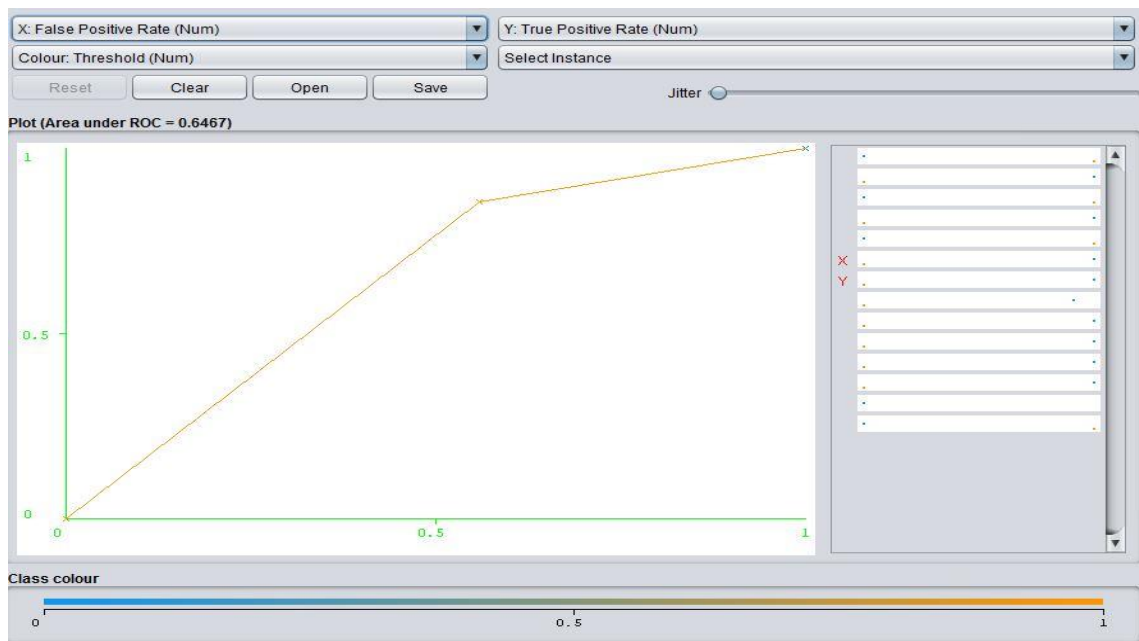
Correctly Classified Instances	75	75	%
Incorrectly Classified Instances	25	25	%
Kappa statistic	0.3056		
Mean absolute error	0.25		
Root mean squared error	0.5		
Relative absolute error	66.092	%	
Root relative squared error	115.285	%	
Total Number of Instances	100		

=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	FRC Area	Class
	0.853	0.560	0.821	0.853	0.837	0.307	0.647	0.810	1
	0.440	0.147	0.500	0.440	0.468	0.307	0.647	0.360	2
Weighted Avg.	0.750	0.457	0.740	0.750	0.744	0.307	0.647	0.698	

=== Confusion Matrix ===

```
a b <-- classified as
64 11 | a = 1
14 11 | b = 2
```



b) Credit Approval Data Set:

Random Forest:

Choose **RandomForest** -P 100 -I 100 -num-slots 1 -K 0 -M 1.0 -V 0.001 -S 1

est options

☐ Use training set
☐ Supplied test set
☒ Cross-validation Folds
☐ Percentage split %

Nom) attribute_15

result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest
- 15:43:11 - functions.SMO
- 15:48:40 - lazy.IBK
- 15:55:16 - lazy.IBK
- 15:58:11 - bayes.BayesNet
- 15:58:36 - bayes.NaiveBayes
- 15:58:55 - bayes.NaiveBayes
- 16:00:12 - bayes.NaiveBayes
- 16:02:45 - functions.SMO
- 16:04:37 - functions.Logistic
- 16:06:31 - functions.Logistic
- 16:06:53 - trees.RandomForest

Classifier output

```
attribute_8
attribute_9
attribute_10
attribute_11
attribute_12
attribute_13
attribute_14
attribute_15

Test mode: 10-fold cross-validation

=== Classifier model (full training set) ===

RandomForest

Bagging with 100 iterations and base learner

weka.classifiers.trees.RandomTree -K 0 -M 1.0 -V 0.001 -S 1 -do-not-check-capabilities

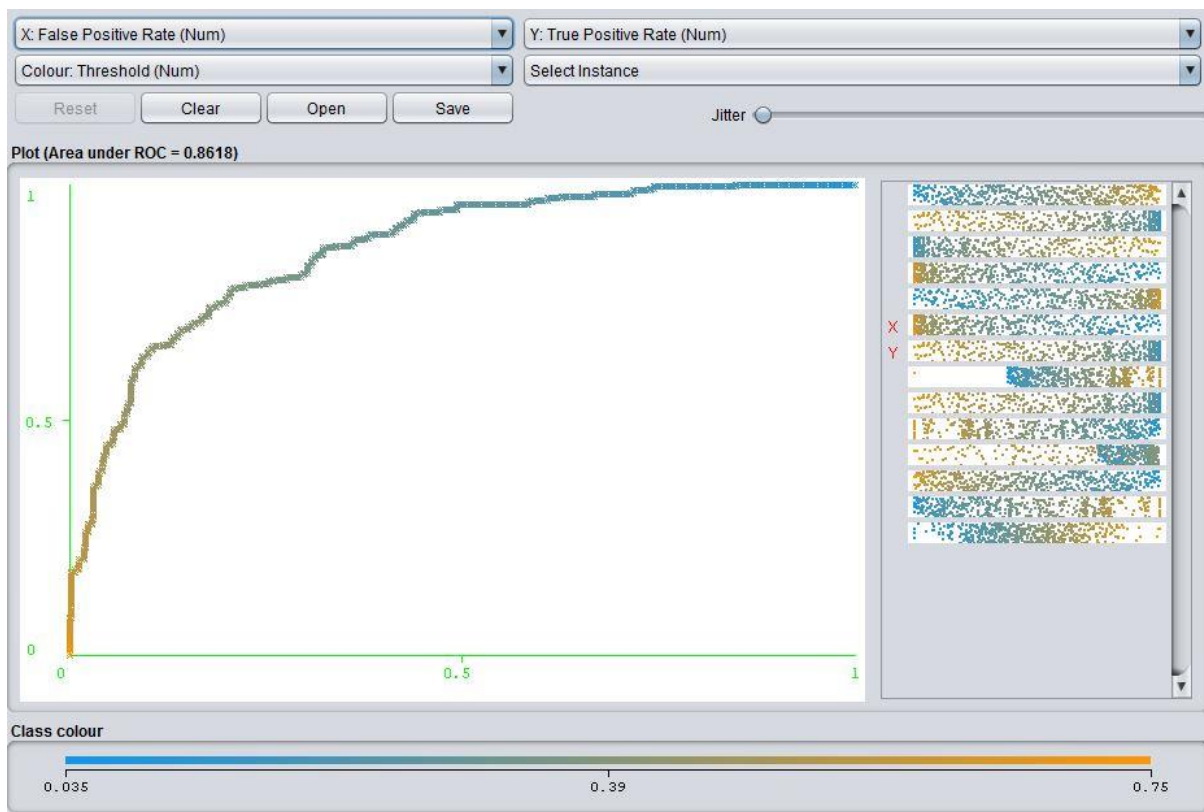
Time taken to build model: 0.66 seconds

=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances      456           73.43 %
Incorrectly Classified Instances    165           26.57 %
Kappa statistic                    0.367
Mean absolute error                 0.3857
Root mean squared error             0.4192
Relative absolute error             81.5728 %
Root relative squared error         86.2233 %
Total Number of Instances          621

=== Detailed Accuracy By Class ===
               TP Rate  FP Rate  Precision  Recall   F-Measure  MCC      ROC Area  PRC Area  Class
               0.357    0.031    0.876     0.357    0.507     0.436    0.862    0.797    +
               0.969    0.643    0.708     0.969    0.818     0.436    0.862    0.909    -
Weighted Avg.   0.734    0.408    0.773     0.734    0.699     0.436    0.862    0.866

=== Confusion Matrix ===
  a  b  <-- classified as
85 153 | a = +
12 371 | b = -
```



Logistic Regression:

Choose **Logistic -R 1.0E-8 -M 1 -num-decimal-places 4**

test options

☐ Use training set
☐ Supplied test set
☒ Cross-validation Folds
☐ Percentage split %

(Nom) attribute_15

Result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest
- 15:43:11 - functions.SMO
- 15:48:40 - lazy.IBk
- 15:55:16 - lazy.IBk
- 15:58:11 - bayes.BayesNet
- 15:58:36 - bayes.NaiveBayes
- 15:58:55 - bayes.NaiveBayes
- 16:00:12 - bayes.NaiveBayes
- 16:02:45 - functions.SMO
- 16:04:37 - functions.Logistic

Classifier output

```
attribute_14=8000      33383.5215
attribute_14=8851      33383.5227
attribute_14=9800      33383.5202
attribute_14=10000      1
attribute_14=10561      33383.5198
attribute_14=11177      4.866091071663078E12
attribute_14=11202      33383.5171
attribute_14=13212      33383.5158
attribute_14=15000      33383.5143
attribute_14=15108      1
attribute_14=18027      33383.5127
attribute_14=26726      33383.5099
attribute_14=31285      1
attribute_14=50000      1
attribute_14=51100      33383.5059
attribute_14=100000      33383.4905
```

Time taken to build model: 3.77 seconds

=== Stratified cross-validation ===
=== Summary ===

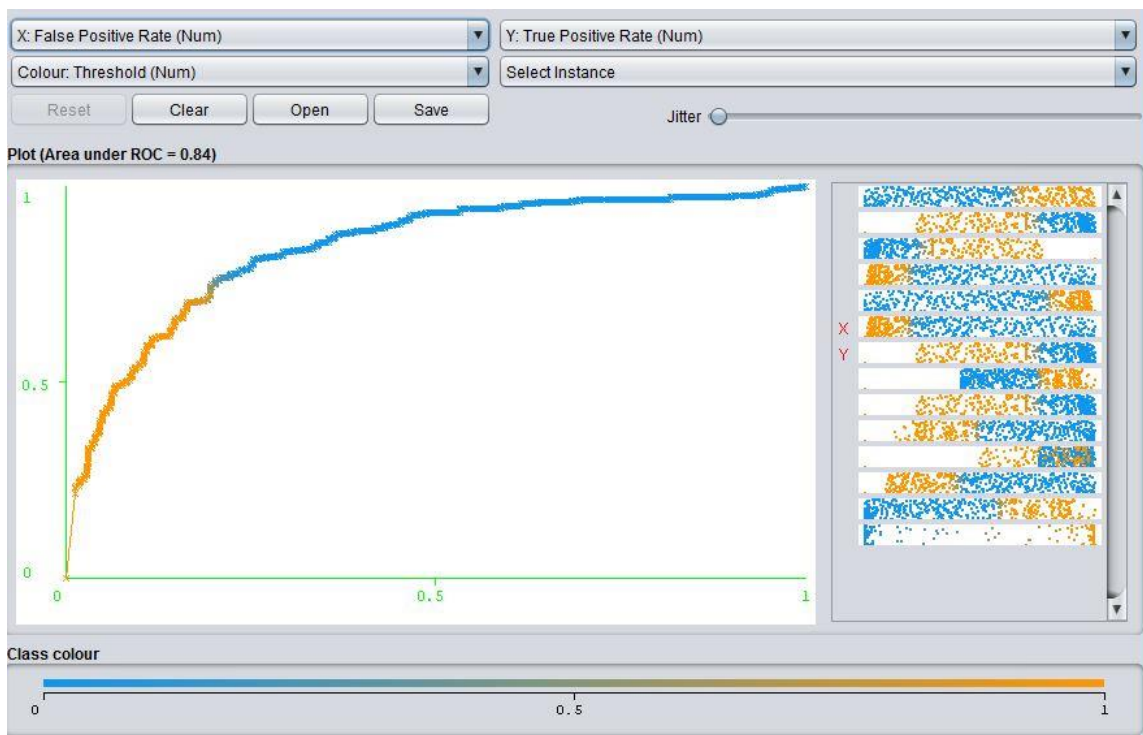
Correctly Classified Instances	484	77.9388 %
Incorrectly Classified Instances	137	22.0612 %
Kappa statistic	0.5388	
Mean absolute error	0.2235	
Root mean squared error	0.4587	
Relative absolute error	47.2771 %	
Root relative squared error	94.3366 %	
Total Number of Instances	621	

=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.744	0.198	0.700	0.744	0.721	0.540	0.840	0.767	+
	0.802	0.256	0.834	0.802	0.818	0.540	0.841	0.873	-
Weighted Avg.	0.779	0.234	0.783	0.779	0.781	0.540	0.841	0.832	

=== Confusion Matrix ===

a	b	<-- classified as
177	61	a = +
76	307	b = -



kNN:

Choose **IBk** -K 1 -W 0 -A "weka.core.neighboursearch.LinearNNSearch -A "weka.core.EuclideanDistance -R first-last"

Test options

☐ Use training set

☐ Supplied test set

☒ Cross-validation Folds

☐ Percentage split %

Nom) attribute_15

Classifier output

```

attribute_6
attribute_7
attribute_8
attribute_9
attribute_10
attribute_11
attribute_12
attribute_13
attribute_14
attribute_15
Test mode: 10-fold cross-validation

=== Classifier model (full training set) ===

IB1 instance-based classifier
using 1 nearest neighbour(s) for classification

Time taken to build model: 0 seconds

=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances      512           82.4477 %
Incorrectly Classified Instances    109           17.5523 %
Kappa statistic                    0.6313
Mean absolute error                 0.1938
Root mean squared error             0.3762
Relative absolute error             40.9959 %
Root relative squared error         77.3806 %
Total Number of Instances          621

=== Detailed Accuracy By Class ===

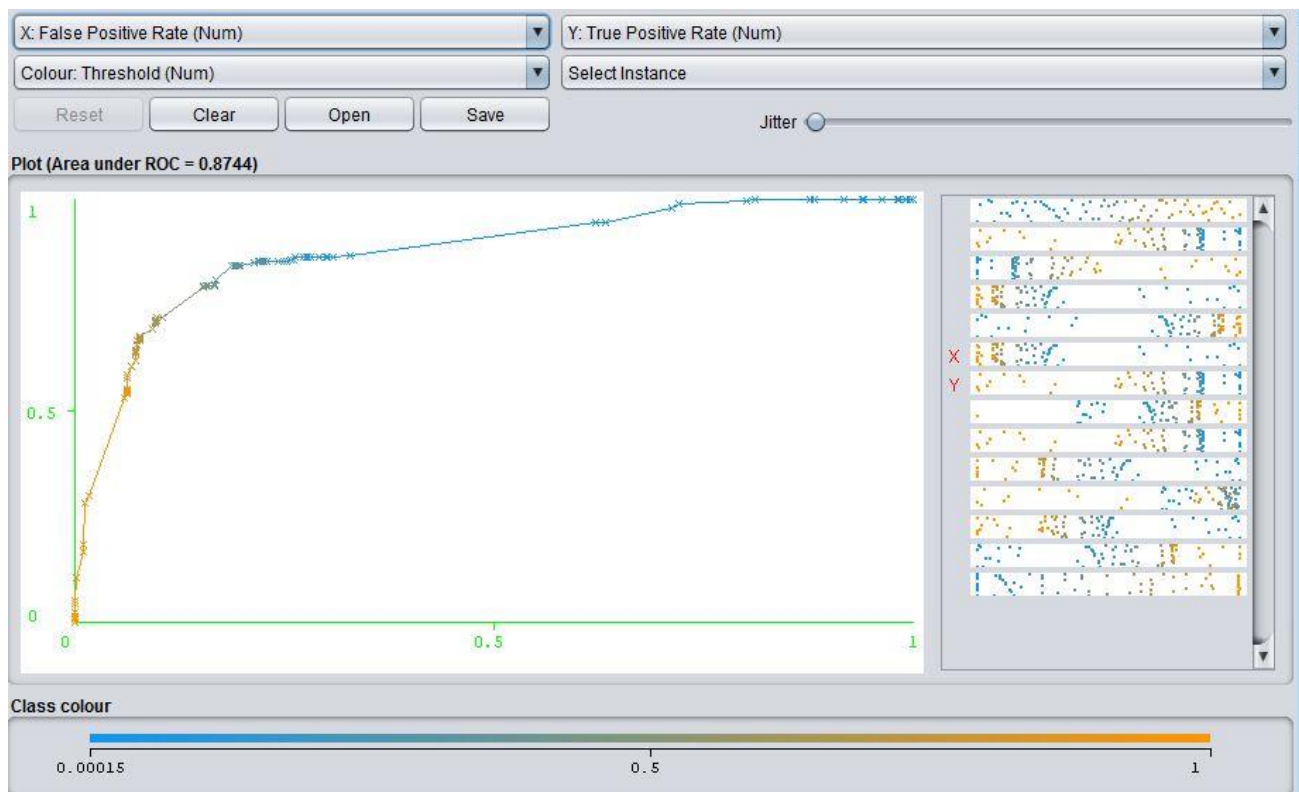
          TP Rate  FP Rate  Precision  Recall  F-Measure  MCC   ROC Area  PRC Area  Class
          0.790    0.154    0.761    0.790    0.775    0.632    0.874    0.808    +
          0.846    0.210    0.866    0.846    0.856    0.632    0.875    0.902    -
Weighted Avg.   0.824    0.189    0.826    0.824    0.825    0.632    0.875    0.866

=== Confusion Matrix ===
      a  b  <-- classified as
188  50 | a = +
 59 324 | b = -

```

Result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest
- 15:43:11 - functions.SMO
- 15:48:40 - lazy.IBk
- 15:55:16 - lazy.IBk



Naïve Bayes:

Choose **NaiveBayes**

Test options

☐ Use training set

☒ Supplied test set Set...

☐ Cross-validation Folds: 10

☐ Percentage split %: 66

More options...

(Nom) attribute_15

Start Stop

Result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest
- 15:43:11 - functions.SMO
- 15:48:40 - lazy.IBk
- 15:55:16 - lazy.IBk
- 15:58:11 - bayes.BayesNet
- 15:58:36 - bayes.NaiveBayes
- 15:58:55 - bayes.NaiveBayes**

Classifier output

```

11177      2.0  1.0
11202      2.0  1.0
13212      2.0  1.0
15000      2.0  1.0
15108      1.0  1.0
18027      2.0  1.0
26726      2.0  1.0
31285      1.0  1.0
50000      1.0  1.0
51100      2.0  1.0
100000     2.0  1.0
[total]    478.0 623.0

Time taken to build model: 0 seconds

=== Evaluation on test set ===

Time taken to test model on supplied test set: 0 seconds

=== Summary ===

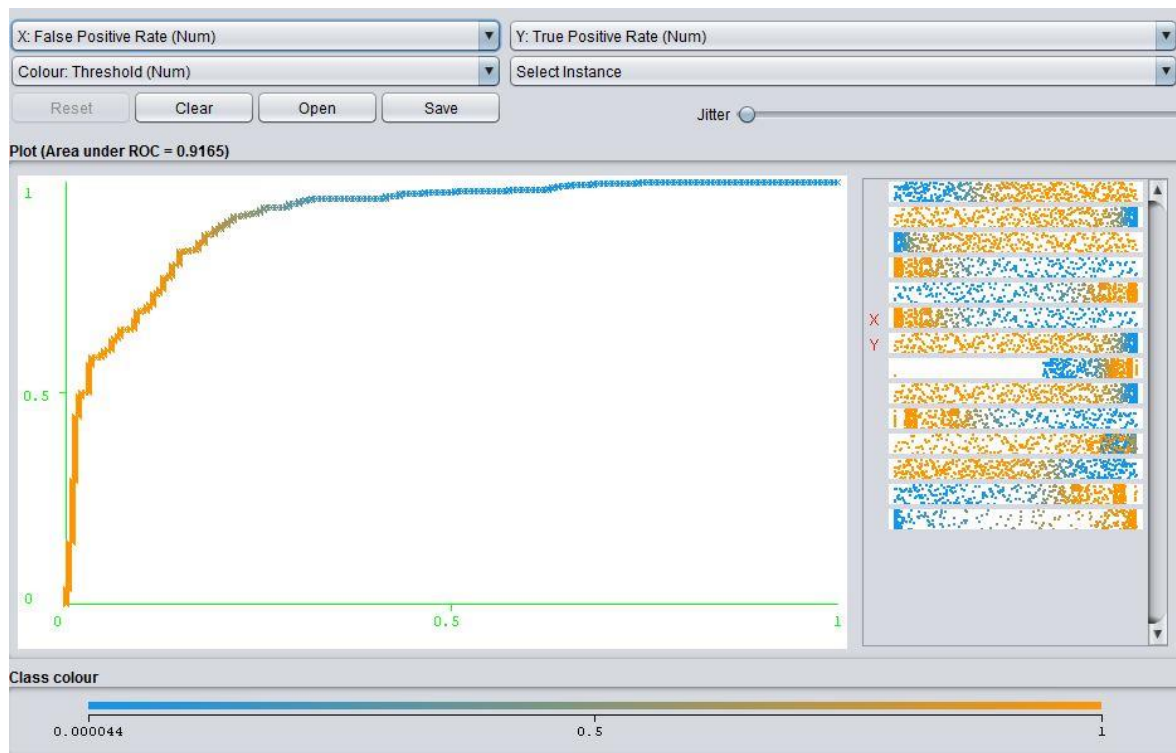
Correctly Classified Instances      48          69.5652 %
Incorrectly Classified Instances    21          30.4348 %
Kappa statistic                     0
Mean absolute error                 0.3072
Root mean squared error             0.4783
Relative absolute error              49.8459 %
Root relative squared error         77.5932 %
Total Number of Instances          69

=== Detailed Accuracy By Class ===

          TP Rate  FP Rate  Precision  Recall   F-Measure  MCC      ROC Area  PRC Area  Class
          0.696    0.000    1.000     0.696   0.821     0.000    ?        1.000    +
          0.000    0.304    0.000     0.000   0.000     0.000    ?        ?        -
Weighted Avg.  0.696    0.000    1.000     0.696   0.821     0.000    0.000    1.000

=== Confusion Matrix ===
  a  b  <-- classified as
 48 21 | a = +
  0  0 | b = -

```



Support Vector Machine (Poly):

Choose **SMO -C 1.0 -L 0.001 -P 1.0E-12 -N 0 -V -1 -W 1 -K "weka.classifiers.functions.supportVector.PolyKernel -E 1.0 -C 25000"** -calibrator "weka.classifiers.functions.Logistic -R 1.0E-

test options

☐ Use training set

☐ Supplied test set

☒ Cross-validation Folds

☐ Percentage split %

(Nom) attribute_15

Classifier output

```

+ -0.0595 * (normalized) attribute_14=5860
+ -0.0973 * (normalized) attribute_14=6700
+ -0.1476 * (normalized) attribute_14=7544
+ -0.2581 * (normalized) attribute_14=8851
+ -0.1297 * (normalized) attribute_14=10561
+ -0.1539 * (normalized) attribute_14=11177
+ -0.0307 * (normalized) attribute_14=11202
+ -0.1094 * (normalized) attribute_14=13212
+ -0.0567 * (normalized) attribute_14=15000
+ -0.1995 * (normalized) attribute_14=18027
+ -0.2029 * (normalized) attribute_14=100000
+ 0.3617

```

Number of kernel evaluations: 134760 (94.722% cached)

Time taken to build model: 0.98 seconds

=== Stratified cross-validation ===

=== Summary ===

Correctly Classified Instances	536	86.3124 %
Incorrectly Classified Instances	85	13.6876 %
Kappa statistic	0.7112	
Mean absolute error	0.1369	
Root mean squared error	0.37	
Relative absolute error	28.9472 %	
Root relative squared error	76.0954 %	
Total Number of Instances	621	

=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.828	0.115	0.817	0.828	0.823	0.711	0.856	0.743	+
	0.885	0.172	0.892	0.885	0.889	0.711	0.856	0.860	-
Weighted Avg.	0.863	0.150	0.863	0.863	0.863	0.711	0.856	0.815	

=== Confusion Matrix ===

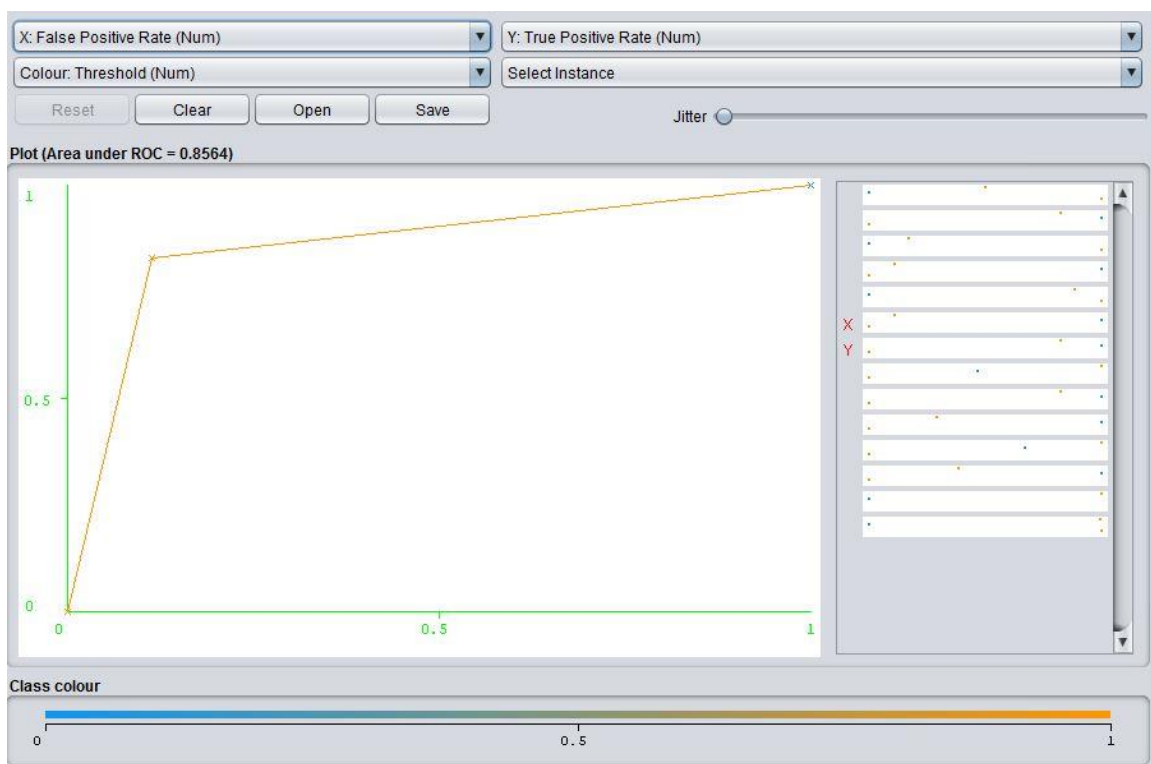
```

a  b  <-- classified as
197 41 | a = +
44 339 | b = -

```

Result list (right-click for options)

- 14:47:34 - bayes.NaiveBayes
- 15:09:14 - trees.RandomForest
- 15:12:45 - functions.Logistic
- 15:15:56 - functions.Logistic
- 15:31:23 - functions.Logistic
- 15:32:13 - bayes.NaiveBayes
- 15:32:42 - bayes.NaiveBayes
- 15:34:58 - functions.Logistic
- 15:39:01 - trees.RandomForest
- 15:43:11 - functions.SMO
- 15:48:40 - lazy.IBK
- 15:55:16 - lazy.IBK
- 15:58:11 - bayes.BayesNet
- 15:58:36 - bayes.NaiveBayes
- 15:58:55 - bayes.NaiveBayes
- 16:00:12 - bayes.NaiveBayes
- 16:02:45 - functions.SMO



c) Default of Credit Card Clients Data Set:

Naïve Bayes:

Choose **NaiveBayes**

Test options

☐ Use training set

☐ Supplied test set

☒ Cross-validation Folds

☐ Percentage split %

(Nom) defaultpaymentnextmonth

Result list (right-click for options)

16:32:36 - bayes.NaiveBayes

Classifier output

279706	2.0	1.0
280000	2.0	1.0
287982	1.0	2.0
290000	2.0	1.0
308000	2.0	1.0
345293	1.0	1.0
351282	2.0	1.0
372495	1.0	1.0
377000	2.0	1.0
403500	2.0	1.0
422000	2.0	1.0
443001	2.0	1.0
527143	2.0	1.0
528666	1.0	1.0
[total]	27971.0	12907.0

Time taken to build model: 0.07 seconds

=== Stratified cross-validation ===

=== Summary ===

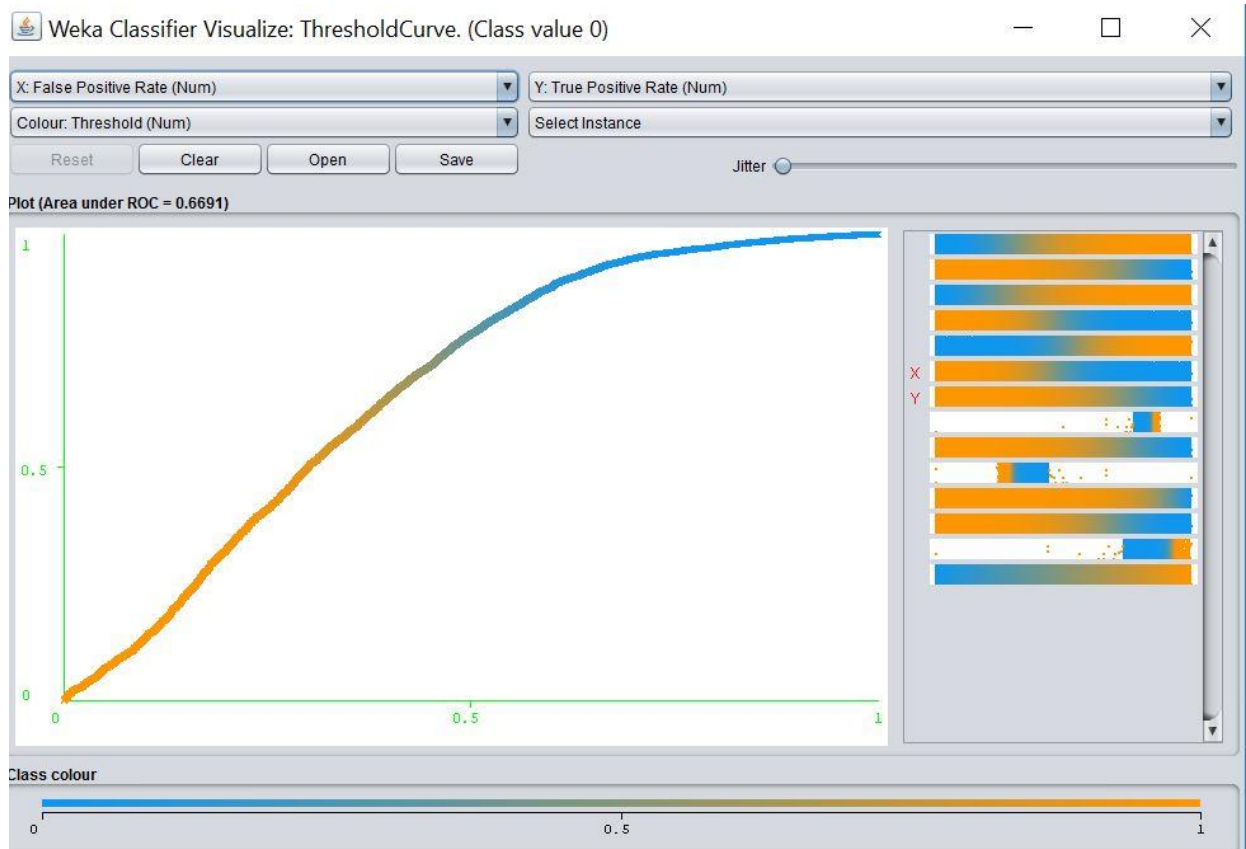
Correctly Classified Instances	18540	68.6667 %
Incorrectly Classified Instances	8460	31.3333 %
Kappa statistic	0.2288	
Mean absolute error	0.331	
Root mean squared error	0.4972	
Relative absolute error	96.1297 %	
Root relative squared error	119.824 %	
Total Number of Instances	27000	

=== Detailed Accuracy By Class ===

	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0.728	0.458	0.849	0.728	0.783	0.238	0.669	0.842	0
	0.542	0.272	0.361	0.542	0.434	0.238	0.669	0.452	1
Weighted Avg.	0.687	0.417	0.741	0.687	0.706	0.238	0.669	0.755	

=== Confusion Matrix ===

	a	b	
15303	5729		a = 0
2731	3237		b = 1



ACCURACY SUMMARY:

All the accuracies are based on 10-fold cross validation with 90-10 train-test split.

Model/Accuracies	Scikit	Weka	Self
German:			
Naïve Bayes	72.8%	78%	71.02%
kNN	66.4%	74%	68.95%
SVM	75.2%	75%	-
Logistic Regression	75.7 %	66%	-
Random Forest	70%	74%	-
CRX:			
Naïve Bayes	78%	69.56%	76.71%
kNN	66.8%	82.44%	65.94%
SVM	85.9%	86.43%	-
Logistic Regression	86.9%	77.93%	-
Random Forest	87.4%	73.43%	-
Default of Credit Card:			
Naïve Bayes	37.7%	68.66%	74.03%
kNN	78%	NC	75.5%
SVM	80.3%	NC	-
Logistic Regression	82%	NC	-
Random Forest	81.1%	NC	-

NC: Not computable. Due to the size of the data set, it takes too long to compute and exceeds the heap size as well.

Based on the accuracy table above, we can say that our implementation using Scikit libraries outperform or atleast perform equally well as Weka, but Weka works much better with kNN.

Also, our implementation of kNN and Naïve Bayes performs close to Scikit Libraries.

ANALYSIS:

Naïve Bayes vs kNN vs Logistic Regression vs SVM vs Random Forest

We performed a 10-fold cross validation on each of the data set by splitting them randomly into 90-10 train-test ratio.

1) Performance on the given datasets:

a) German Data Set:

Accuracy-wise SVM and logistic regression almost perform similar to each other, while Naïve Bayes stands just behind them (for Scikit Learn), whereas Naïve Bayes performs the best on Weka. As per our understanding, this is because this is a linearly separable dataset ie. class label is binary (0 and 1).

Naïve Bayes performs well, since very few features are actually dependent on each other and hence the Naïve Bayes assumption of feature independence benefits the algorithm in this case. Although its performance is brought down a bit due to some continuous values.

But the important point to note here, which was also mentioned in the dataset description is that for this dataset, it is worse to class a customer as good when they are bad (5), than it is to class a customer as bad when they are good (1).

In other words, the cost of False Positives(FP) is much higher than the cost of False Negatives(FN)
Cost (FP) >>> Cost(FN)

In that sense, Random Forest performs the best with the least FPR rate of 2.52% and might be preferred over other higher accuracy algorithms like SVM and Linear Regression, for such a task.

b) Credit Approval Data Set (CRX):

Accuracy-wise SVM, Logistic Regression and Random Forest perform pretty well with average accuracy of 85%+. This is again due to its binary nature. Although, we would need a bigger dataset to confirm if all the three of these algorithms can perform well on such a data set.

Naïve Bayes also gives a pretty decent performance of ~77%, because of less no of continuous features and their distinct values. Although discretizing these continuous features could have given a drastic boost to its performance.

Using Scikit and our implementation, kNN doesn't perform well, but performs surprisingly well on Weka.

Since it is again a Credit Approval Dataset, where based on the features we need to determine if a credit card application for a particular person can be approved or not, its cost(FP) >> cost(FN)
In that sense, SVM performs the best and might be the best fit for such kind of datasets.

c) Default of Credit Card Clients Data Set:

Again, Accuracy-wise kNN, SVM, Logistic Regression and Random Forest perform pretty well with average accuracy of 80%+. This is again due to its binary nature. Even if not too big, it would be considered to be a decent sized data set, as opposed to the previous ones, and hence kNN takes a lot of time to compute as it needs to find the distance between each test and train points.

Also, this is credit defaulter dataset, where based on the features we need predict if a person is going to be a defaulter or not. So in this case, the False Negatives (a person who is going to be a defaulter, but is incorrectly predicted as a non-defaulter) are the most harmful.

Hence, we need to minimize the false negatives for this dataset.

On that basis, kNN and SVM perform the best and are followed by logistic regression. Even though Random Forest gives highest accuracy, it almost gives thrice or atleast twice as much FN's as them. Hence, we would prefer kNN or SVM over Random Forest for such data set.

Sci-kit based Naïve Bayes gives a low performance of ~37%, probably because of a very high number of no of continuous features and their distinct values, but our implemented Naïve Bayes performs pretty well with an accuracy of 74%. We almost thought there is some bug in our code, but then felt assured by testing the same on Weka on getting an accuracy of ~69%. Also, discretizing these continuous features could have given a pretty good boost to its performance. Our implementation of kNN performs almost on par with the Scikit based kNN. Also, we couldn't finish the testing of this dataset on Weka due to its size, which lead to HeapOutOfMemoryException for all the algorithms except Naïve Bayes.

2) Miscellaneous Observations:

Overall, Logistic and SVM have better area under ROC curve and higher accuracy. Others perform similar way but the area under ROC curve aren't as good as these algorithm.

Class label is binary (1 and 2) so all the classifiers perform good on the dataset. All three algorithms have an average accuracy of 80%+ for the datasets.

All the algorithms except kNN have more than 80% accuracy. Even the area under ROC curve is more or less than the same. kNN doesn't work better may be because of the k may not be optimal.

The major difference in the third dataset's accuracy and area under ROC curve may be due to dataset size difference.

Our implementations for all dataset performs at par with scikit learn libraries.

REFERENCES:

<http://scikit-learn.org/stable/>

<https://archive.ics.uci.edu/ml/datasets.html>

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