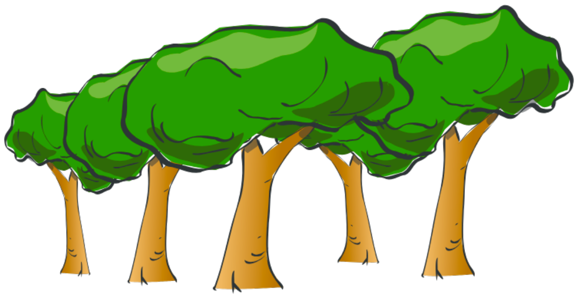
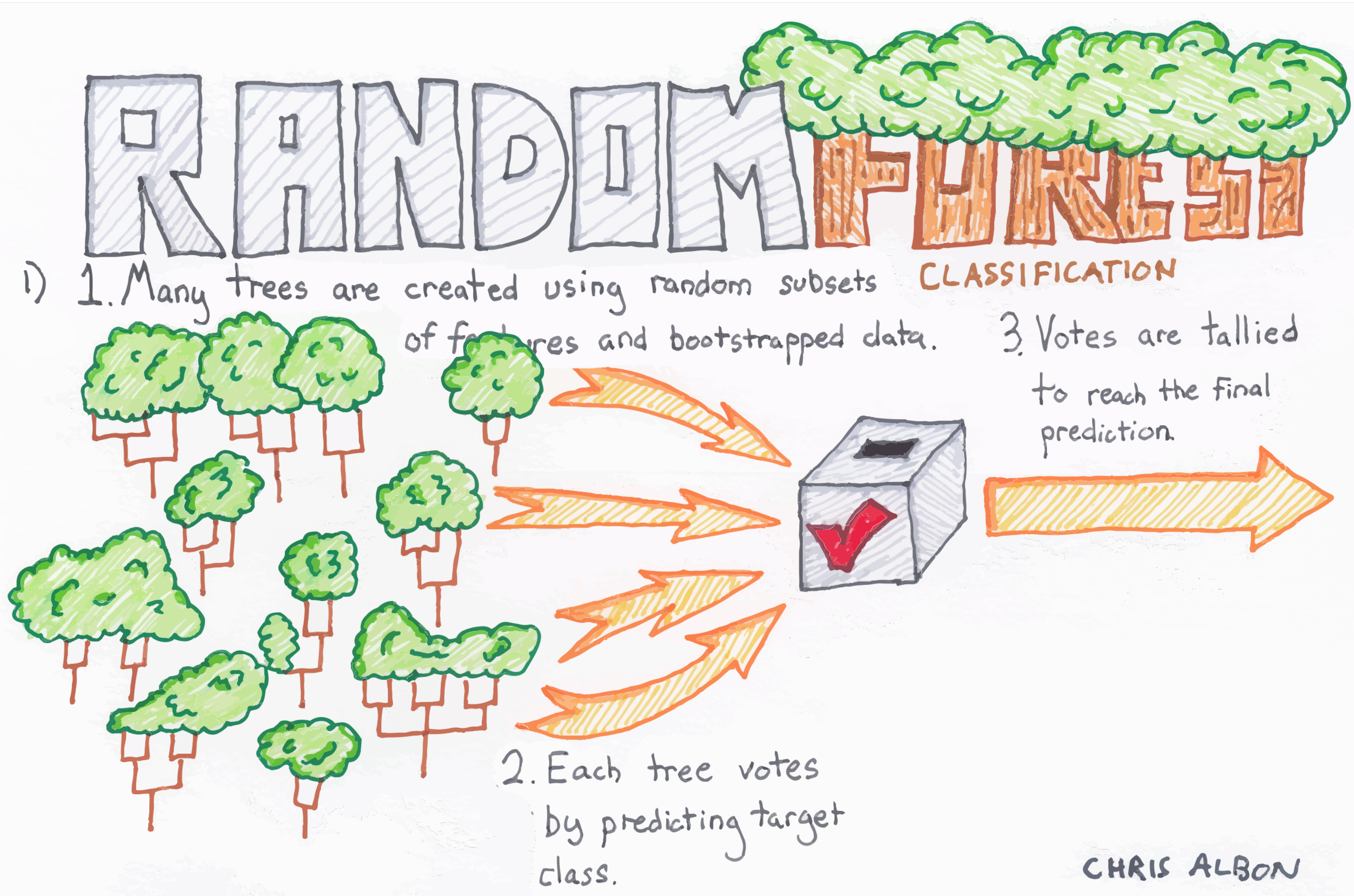
What's better than a tree?

Random Forest



- Can often improve performance of decision tree classifiers using a set of decision trees (a forest)
- Each tree trained on a random subset of training data
- Classify a data instance using all trees
- Combine answers to make classification
  - E.g., vote for most common class


RANDOM FOREST
CLASSIFICATION
1) 1. Many trees are created using random subsets
of f ures and bootstrapped data.
2. Each tree votes
by predicting target
class.
3. Votes are tallied
to reach the final
prediction.
CHRIS ALBON

cf. Wisdom of the Crowd

- Statistician Francis Galton observed a 1906 contest to guess an ox's weight at a country fair. 800 people entered. He noted that their average guess (1,197lb) was very close to the actual weight (1,198lb)
- When getting human annotations training data for machine learning, standard practice is get ≥ 3 annotations and take majority vote

cf. *abbreviation (short for Latin: confer/conferatur) refer reader to other material to make a comparison*

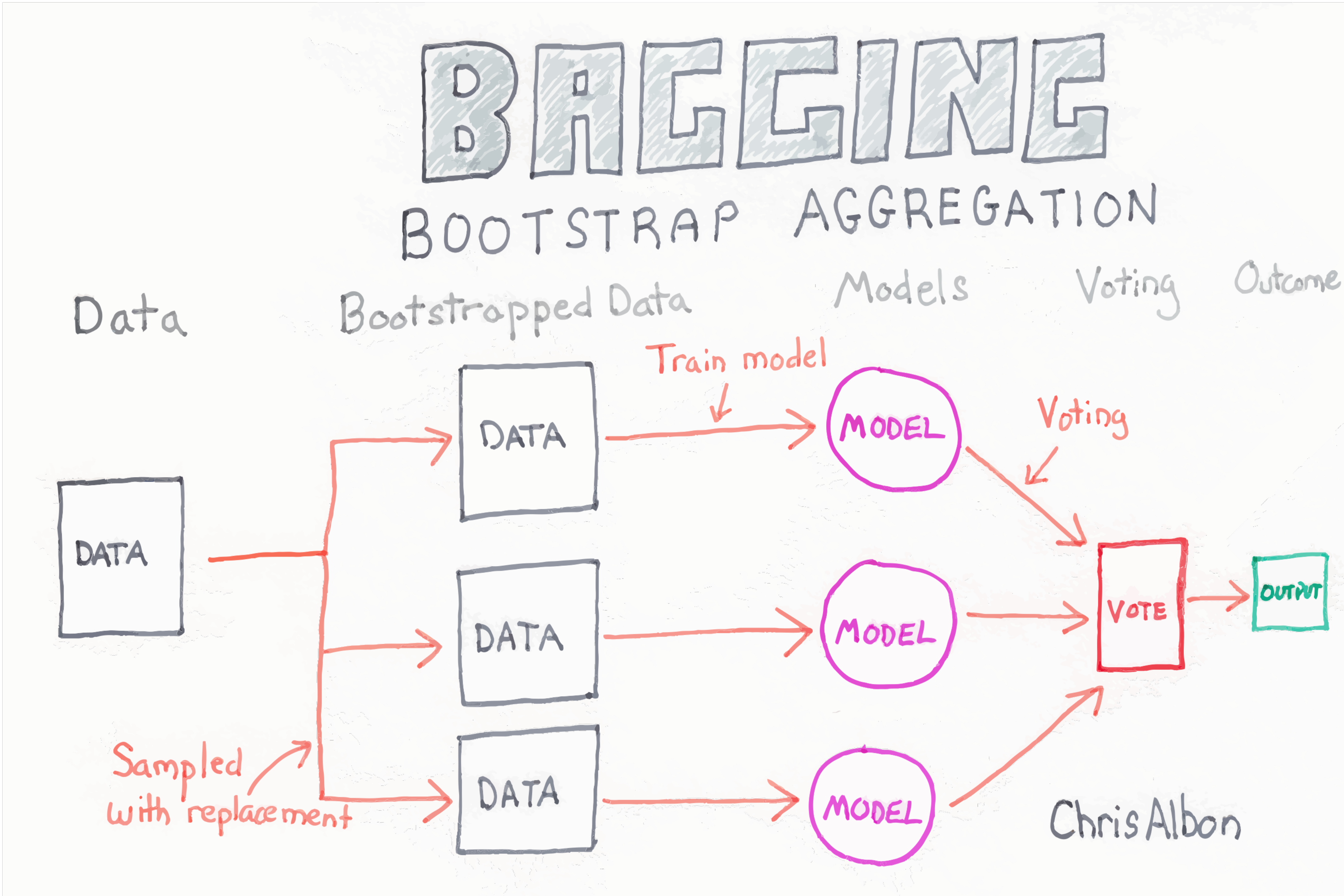
Random Forests Benefits

- Decision trees not the strongest modeling approach
- Random forests make them much stronger
- => more **robust** than a single decision tree
  - Limit overfitting to given dataset
  - Reduce errors due to training data bias
  - Stable performance if some noise added to training data

Bagging

- Idea can be used on any classifier!
- Improve classification by combining classify-cations of randomly selected training subsets
- Bagging = ***Bootstrap aggregating***

  ensemble meta-algorithm that can improve stability & accuracy of algorithms for statistical classification and regression
- Helps avoid overfitting
- AKA ensembling


BAGGING
BOOTSTRAP AGGREGATION
Data
Bootstrapped Data
Models
Voting
Outcome
Train model
Voting
DATA
DATA
DATA
DATA
MODEL
MODEL
MODEL
VOTE
OUTPUT
Sampled with replacement
Chris Albon

Choosing training data subsets

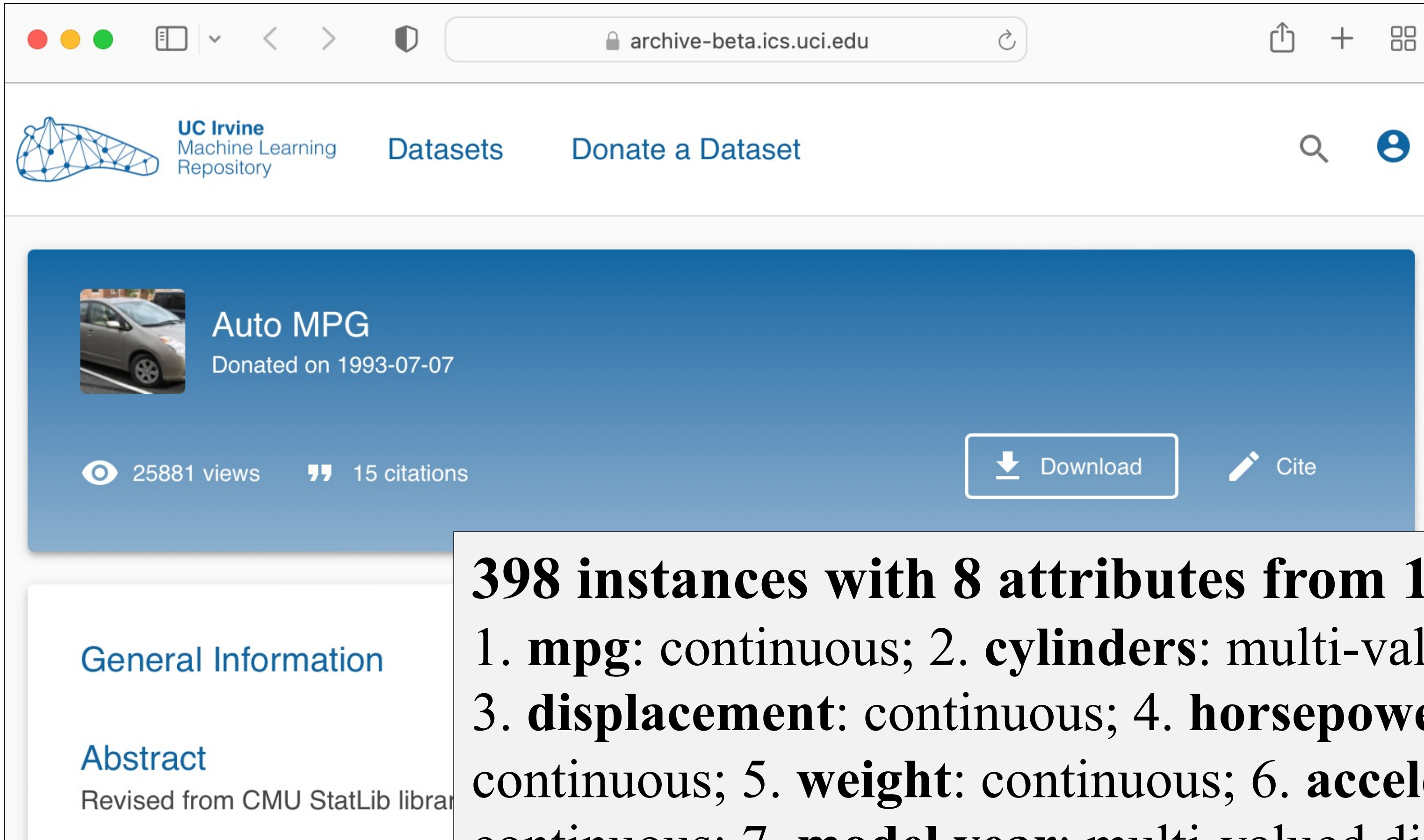
- **Classic bagging**: select random subset of training instances **with replacement**
- **Pasting**: select random subset of training instances (i.e., without replacement)
- **Random Subspaces**: use all training instances, but with a random subset of features
- **Random Patches**: random subset of instances and random subset of features
- **Best?** depends on problem, training data, algorithm

Examples

- Two examples using Weka
  - UCI Auto mpg prediction dataset
  - UCI Adult income prediction dataset
- RandomForest improves over J48 for the smaller dataset, but not for the larger
- Takeaway: more data is always best

UCI Auto MGP Dataset

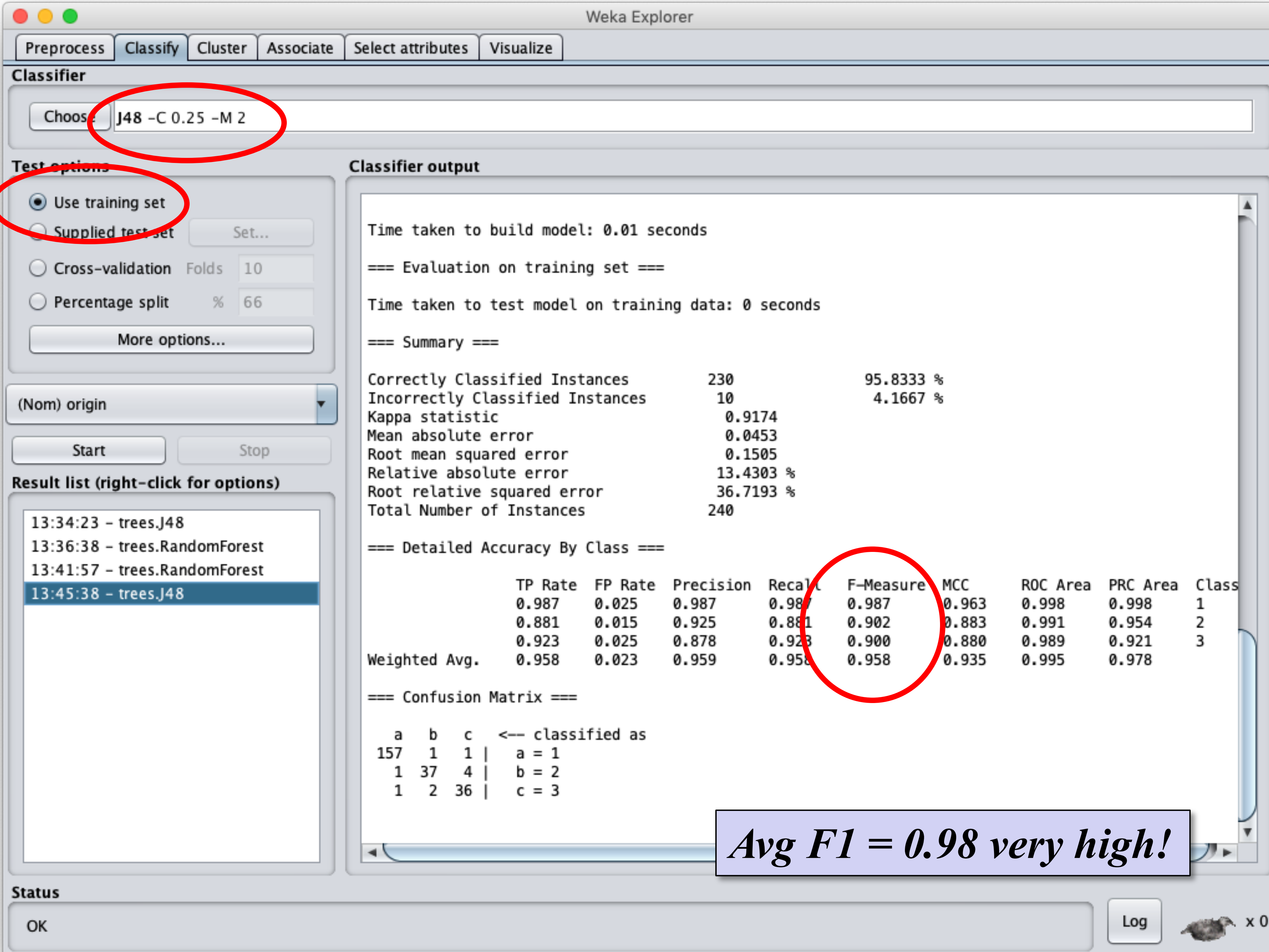
kaggle

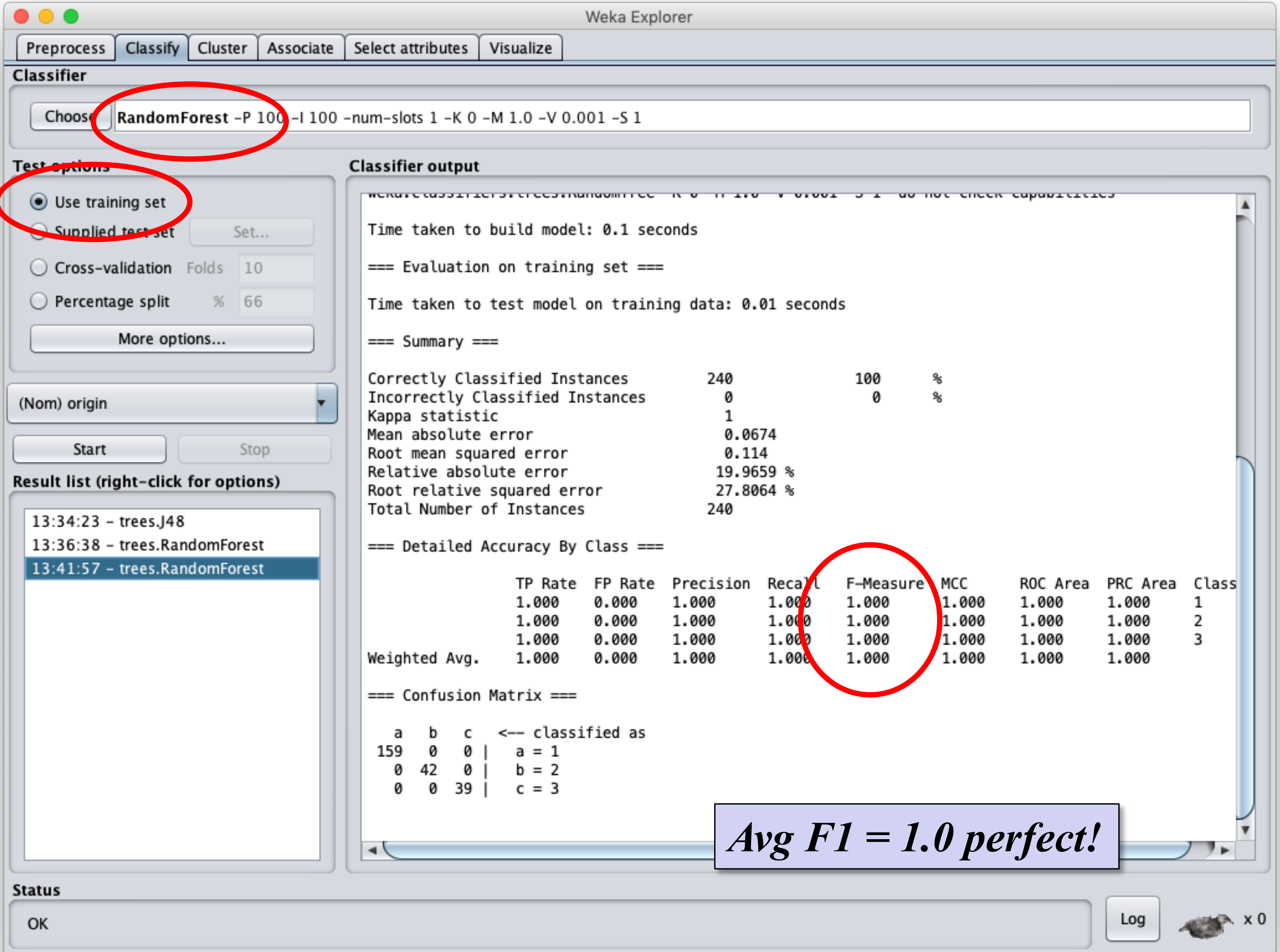


398 instances with 8 attributes from 1983:
1. **mpg**: continuous; 2. **cylinders**: multi-valued discrete; 3. **displacement**: continuous; 4. **horsepower**: continuous; 5. **weight**: continuous; 6. **acceleration**: continuous; 7. **model year**: multi-valued discrete; 8. **origin**: multi-valued discrete; 9. **car name**: string (unique for each instance)

Predict MPG from other 7 attributes

Arff training data (240); test data (132)


Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
Choose
J48 -C 0.25 -M 2
Test options
Use training set
Supplied test set
Set...
Cross-validation Folds 10
Percentage split % 66
More options...
(Nom) origin
Start
Stop
Result list (right-click for options)
13:34:23 - trees.J48
13:36:38 - trees.RandomForest
13:41:57 - trees.RandomForest
13:45:38 - trees.J48
Classifier output
Time taken to build model: 0.01 seconds
=== Evaluation on training set ===
Time taken to test model on training data: 0 seconds
=== Summary ===
Correctly Classified Instances 230 95.8333 %
Incorrectly Classified Instances 10 4.1667 %
Kappa statistic 0.9174
Mean absolute error 0.0453
Root mean squared error 0.1505
Relative absolute error 13.4303 %
Root relative squared error 36.7193 %
Total Number of Instances 240
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
0.987 0.025 0.987 0.987 0.987 0.963 0.998 0.998 1
0.881 0.015 0.925 0.881 0.902 0.883 0.991 0.954 2
0.923 0.025 0.878 0.923 0.900 0.880 0.989 0.921 3
Weighted Avg. 0.958 0.023 0.959 0.958 0.958 0.935 0.995 0.978
=== Confusion Matrix ===
a b c <-- classified as
157 1 1 | a = 1
1 37 4 | b = 2
1 2 36 | c = 3
Avg F1 = 0.98 very high!
Status
OK
Log
x 0

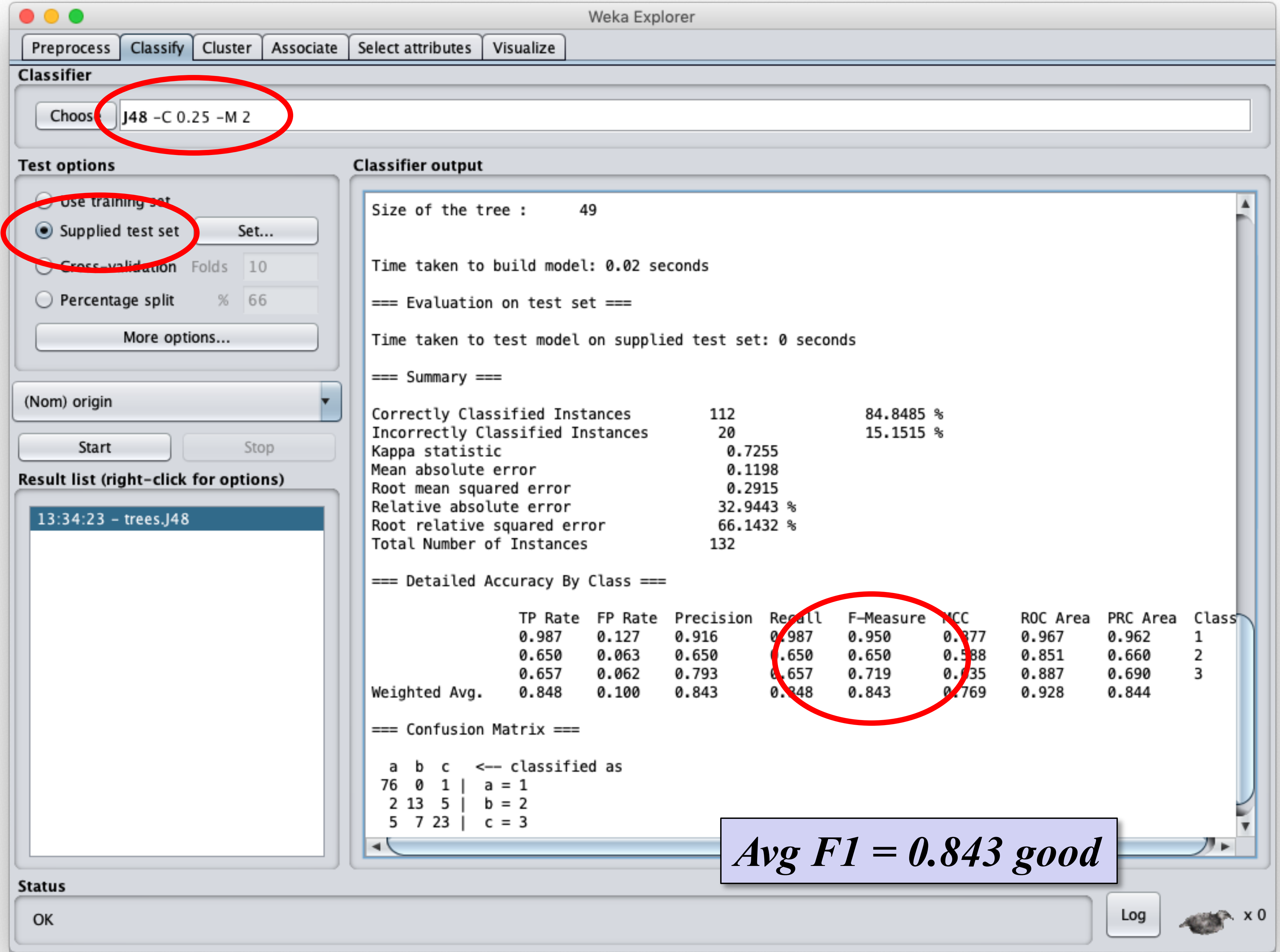

Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
Choose
RandomForest -P 100 -I 100 -num-slots 1 -K 0 -M 1.0 -V 0.001 -S 1
Test options
Use training set
Supplied test set
Set...
Cross-validation Folds 10
Percentage split % 66
More options...
(Nom) origin
Start
Stop
Result list (right-click for options)
13:34:23 - trees.J48
13:36:38 - trees.RandomForest
13:41:57 - trees.RandomForest
Classifier output
Time taken to build model: 0.1 seconds
=== Evaluation on training set ===
Time taken to test model on training data: 0.01 seconds
=== Summary ===
Correctly Classified Instances 240 100 %
Incorrectly Classified Instances 0 0 %
Kappa statistic 1
Mean absolute error 0.0674
Root mean squared error 0.114
Relative absolute error 19.9659 %
Root relative squared error 27.8064 %
Total Number of Instances 240
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
1.000 0.000 1.000 1.000 1.000 1.000 1.000 1.000 1
1.000 0.000 1.000 1.000 1.000 1.000 1.000 1.000 2
1.000 0.000 1.000 1.000 1.000 1.000 1.000 1.000 3
Weighted Avg. 1.000 0.000 1.000 1.000 1.000 1.000 1.000 1.000
=== Confusion Matrix ===
a b c <-- classified as
159 0 0 | a = 1
0 42 0 | b = 2
0 0 39 | c = 3
Avg F1 = 1.0 perfect!
Status
OK
Log
x 0

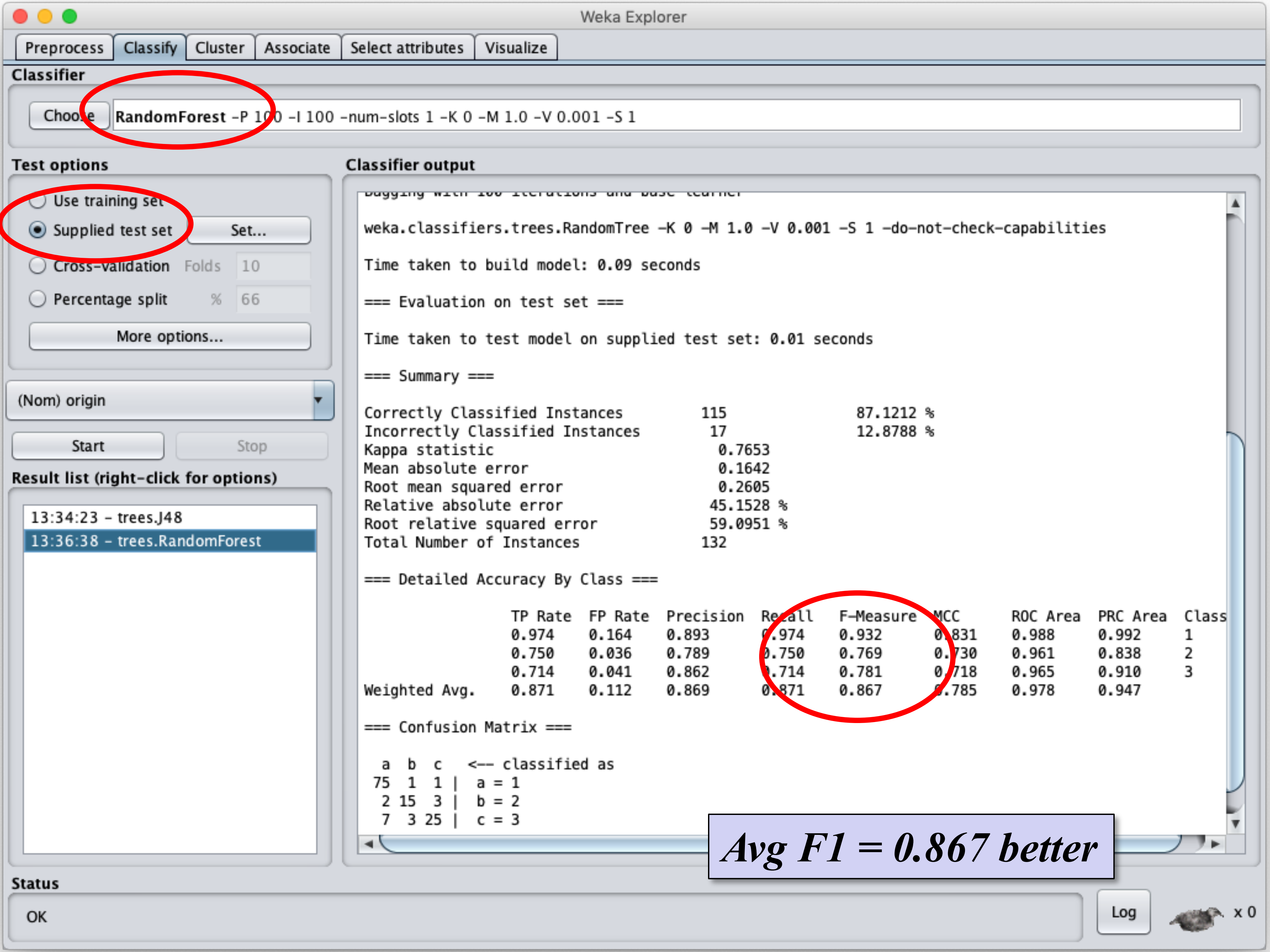
100% … Wait, What ?

- Results are too good to be true!
  - Something must be wrong
- ML results tend to be asymptotic
  - Asymptotic lines approach a curve but never touch
- Closer you get to F1=1.0, the harder it is to improve
- What did we do wrong?

Results are too good

- Relatively small dataset allows construction of a DT model that does very well
- Using Random Forest still got perfect results!
- We trained and tested on the same data!
- Very poor methodology since it overfits to this particular training set
- This training dataset has a separate test data set
  - We can also try 10-fold cross validation


Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
Choose
J48 -C 0.25 -M 2
Test options
Use training set
Supplied test set
Set...
Cross-validation
Folds
10
Percentage split
%
66
More options...
(Nom) origin
Start
Stop
Result list (right-click for options)
13:34:23 - trees.J48
Classifier output
Size of the tree : 49
Time taken to build model: 0.02 seconds
=== Evaluation on test set ===
Time taken to test model on supplied test set: 0 seconds
=== Summary ===
Correctly Classified Instances 112 84.8485 %
Incorrectly Classified Instances 20 15.1515 %
Kappa statistic 0.7255
Mean absolute error 0.1198
Root mean squared error 0.2915
Relative absolute error 32.9443 %
Root relative squared error 66.1432 %
Total Number of Instances 132
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
0.987 0.127 0.916 0.987 0.950 0.967 0.962 1
0.650 0.063 0.650 0.650 0.650 0.851 0.660 2
0.657 0.062 0.793 0.657 0.719 0.887 0.690 3
Weighted Avg. 0.848 0.100 0.843 0.848 0.843 0.769 0.928 0.844
=== Confusion Matrix ===
a b c <-- classified as
76 0 1 | a = 1
2 13 5 | b = 2
5 7 23 | c = 3
Avg F1 = 0.843 good
Status
OK
Log
x 0

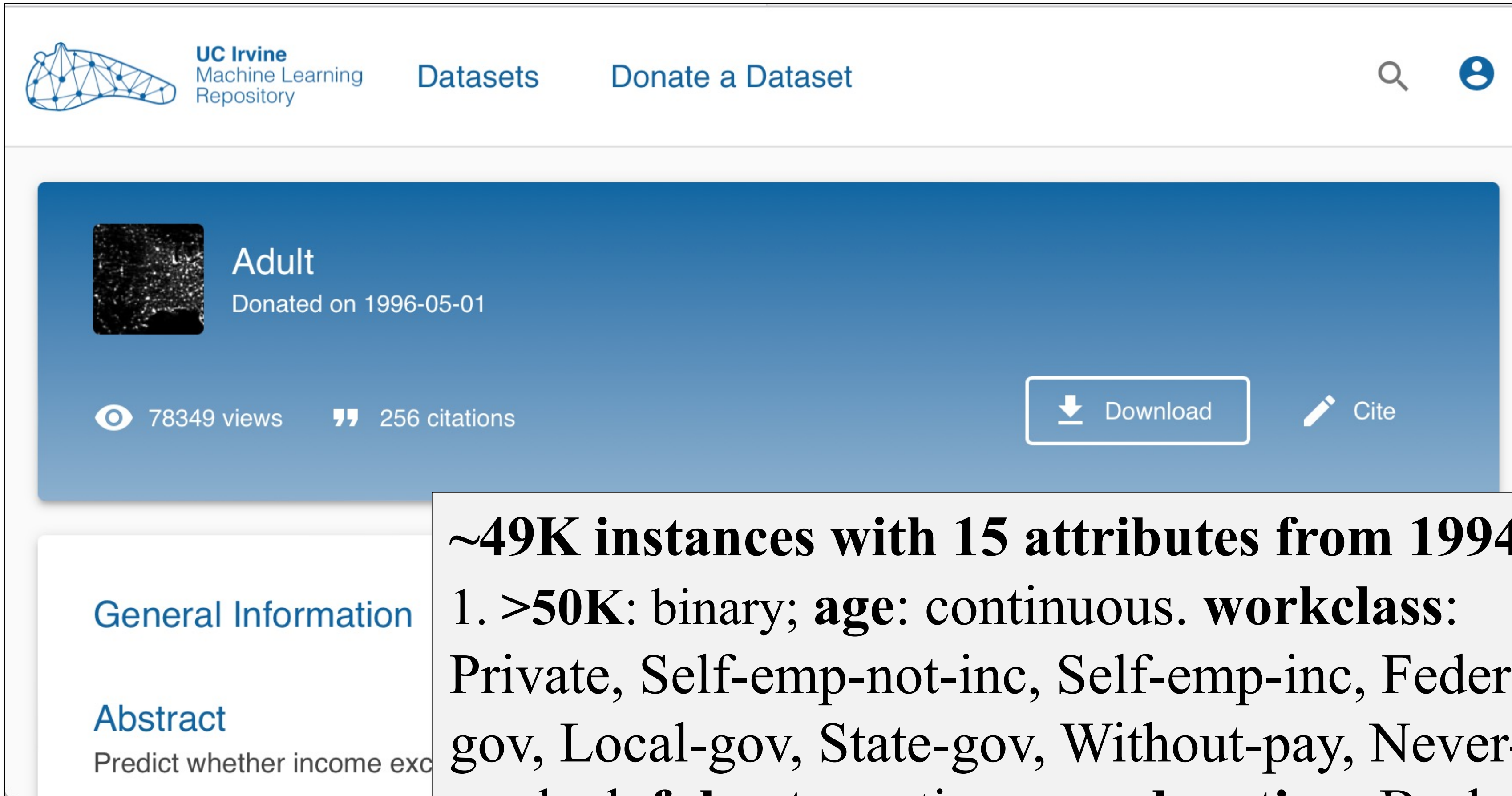

Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
Choose
RandomForest -P 100 -I 100 -num-slots 1 -K 0 -M 1.0 -V 0.001 -S 1
Test options
Use training set
Supplied test set
Set...
Cross-validation
Folds
10
Percentage split
%
66
More options...
(Nom) origin
Start
Stop
Result list (right-click for options)
13:34:23 - trees.J48
13:36:38 - trees.RandomForest
Classifier output
weka.classifiers.trees.RandomTree -K 0 -M 1.0 -V 0.001 -S 1 -do-not-check-capabilities
Time taken to build model: 0.09 seconds
=== Evaluation on test set ===
Time taken to test model on supplied test set: 0.01 seconds
=== Summary ===
Correctly Classified Instances 115 87.1212 %
Incorrectly Classified Instances 17 12.8788 %
Kappa statistic 0.7653
Mean absolute error 0.1642
Root mean squared error 0.2605
Relative absolute error 45.1528 %
Root relative squared error 59.0951 %
Total Number of Instances 132
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
0.974 0.164 0.893 0.974 0.932 0.831 0.988 0.992 1
0.750 0.036 0.789 0.750 0.769 0.730 0.961 0.838 2
0.714 0.041 0.862 0.714 0.781 0.718 0.965 0.910 3
Weighted Avg. 0.871 0.112 0.869 0.871 0.867 0.785 0.978 0.947
=== Confusion Matrix ===
a b c <-- classified as
75 1 1 | a = 1
2 15 3 | b = 2
7 3 25 | c = 3
Avg F1 = 0.867 better
Status
OK
Log
x 0

New AUTO MPG Results

- Using an independent test set shows more realistic balanced F1 score of **.843**
- Using Random Forest raises this to **.867**
- While the increase is not large, it is probably statistically significant
- F1 scores this high are difficult to increase dramatically
  - Human scores for many tasks are often in this range (i.e., 0.8 – 0.9)

UCI Adult Census Income Dataset

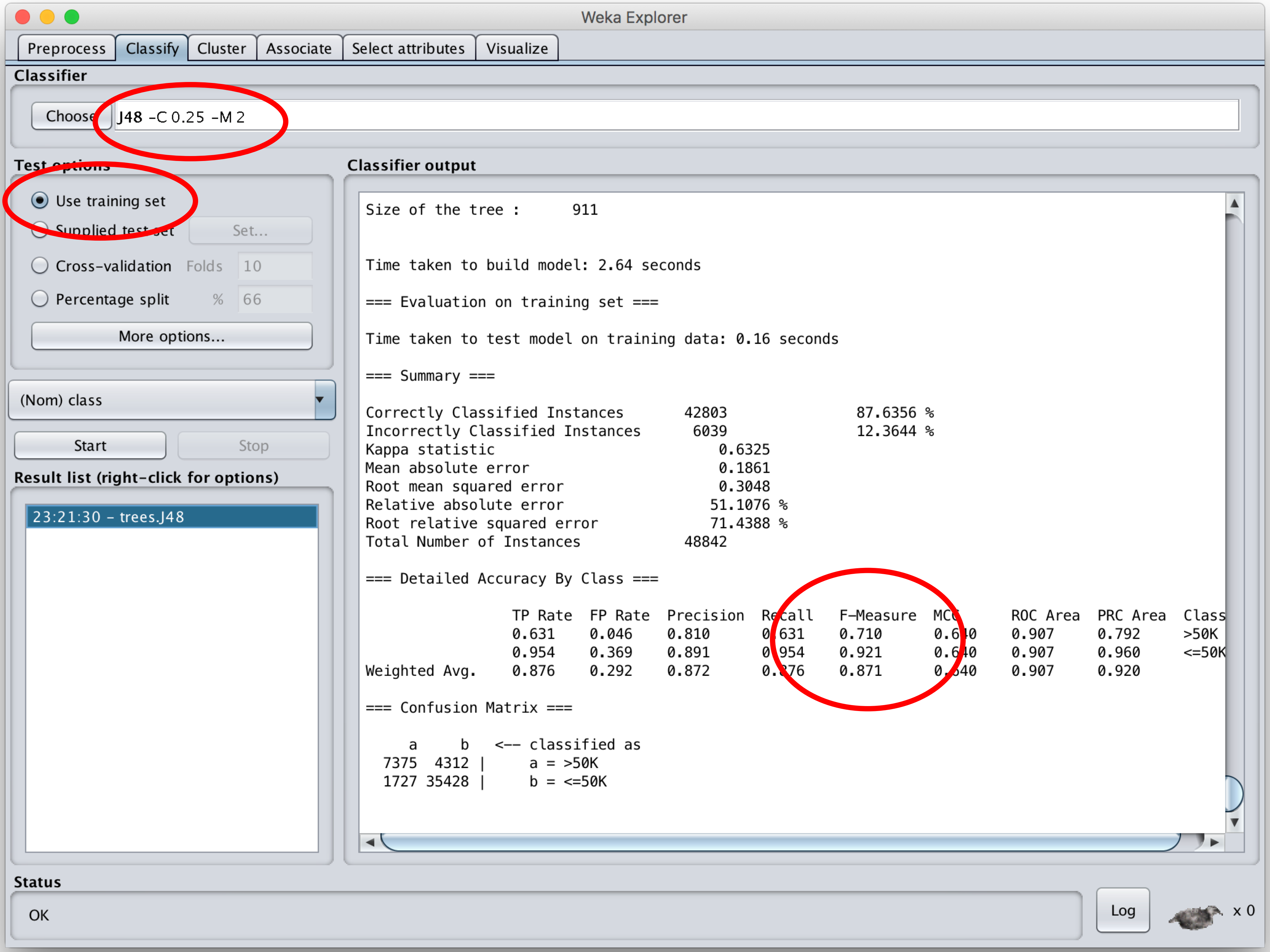
kaggle

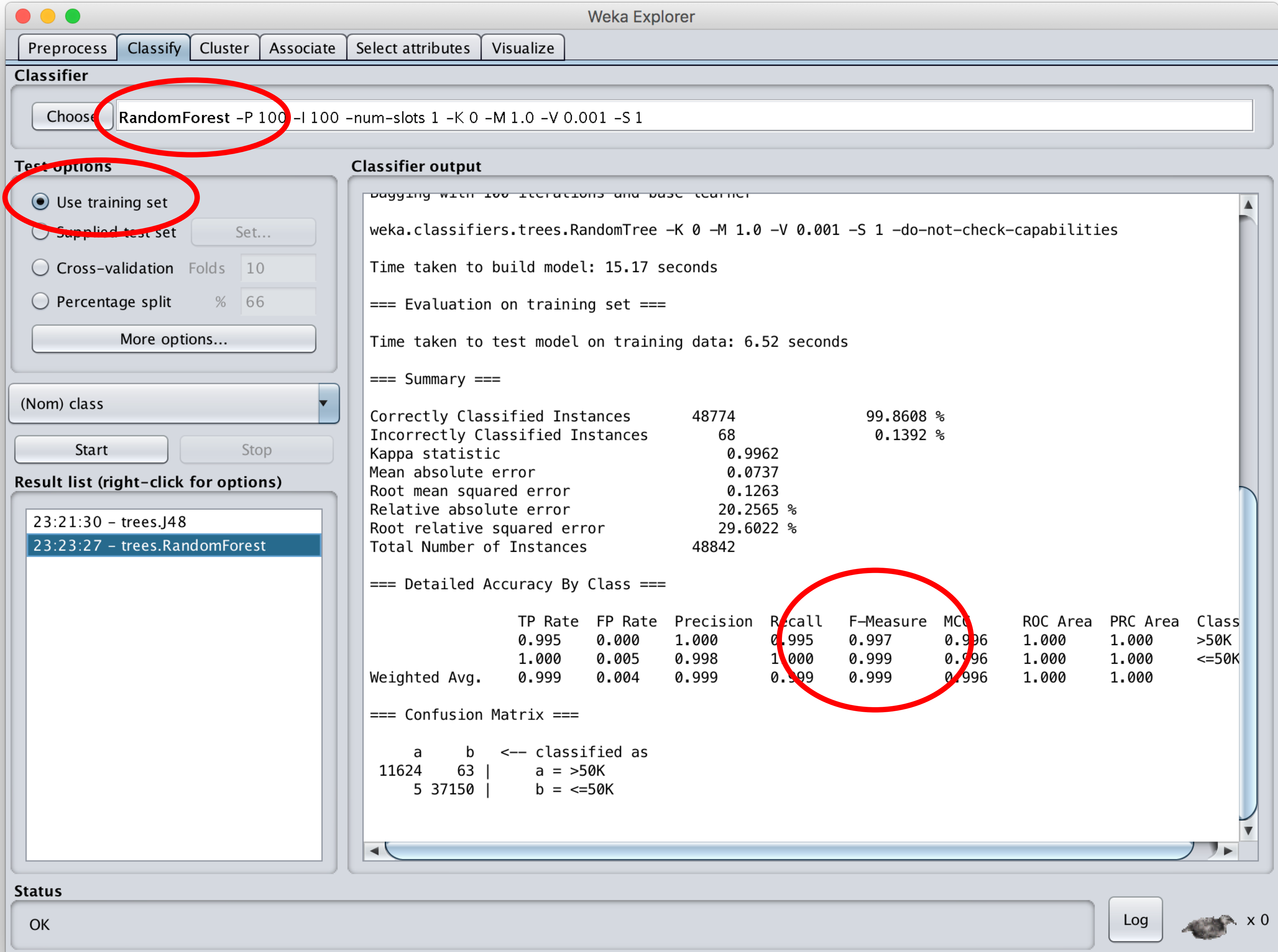


~49K instances with 15 attributes from 1994:
1. **>50K**: binary; **age**: continuous. **workclass**: Private, Self-emp-not-inc, Self-emp-inc, Federal-gov, Local-gov, State-gov, Without-pay, Never-worked. **fnlwgt**: continuous. **education**: Bachelors, Some-college, 11th, HS-grad, Prof-school, …

Predict income >50k from 15 attributes

Arff data


Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
Choose
J48 -C 0.25 -M 2
Test options
Use training set
Supplied test set
Set...
Cross-validation Folds 10
Percentage split % 66
More options...
(Nom) class
Start
Stop
Result list (right-click for options)
23:21:30 - trees.J48
Classifier output
Size of the tree : 911
Time taken to build model: 2.64 seconds
=== Evaluation on training set ===
Time taken to test model on training data: 0.16 seconds
=== Summary ===
Correctly Classified Instances 42803 87.6356 %
Incorrectly Classified Instances 6039 12.3644 %
Kappa statistic 0.6325
Mean absolute error 0.1861
Root mean squared error 0.3048
Relative absolute error 51.1076 %
Root relative squared error 71.4388 %
Total Number of Instances 48842
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
0.631 0.046 0.810 0.631 0.710 0.640 0.907 0.792 >50K
0.954 0.369 0.891 0.954 0.921 0.640 0.907 0.960 <=50K
Weighted Avg. 0.876 0.292 0.872 0.876 0.871 0.640 0.907 0.920
=== Confusion Matrix ===
a b <-- classified as
7375 4312 | a = >50K
1727 35428 | b = <=50K
Status
OK
Log
x 0

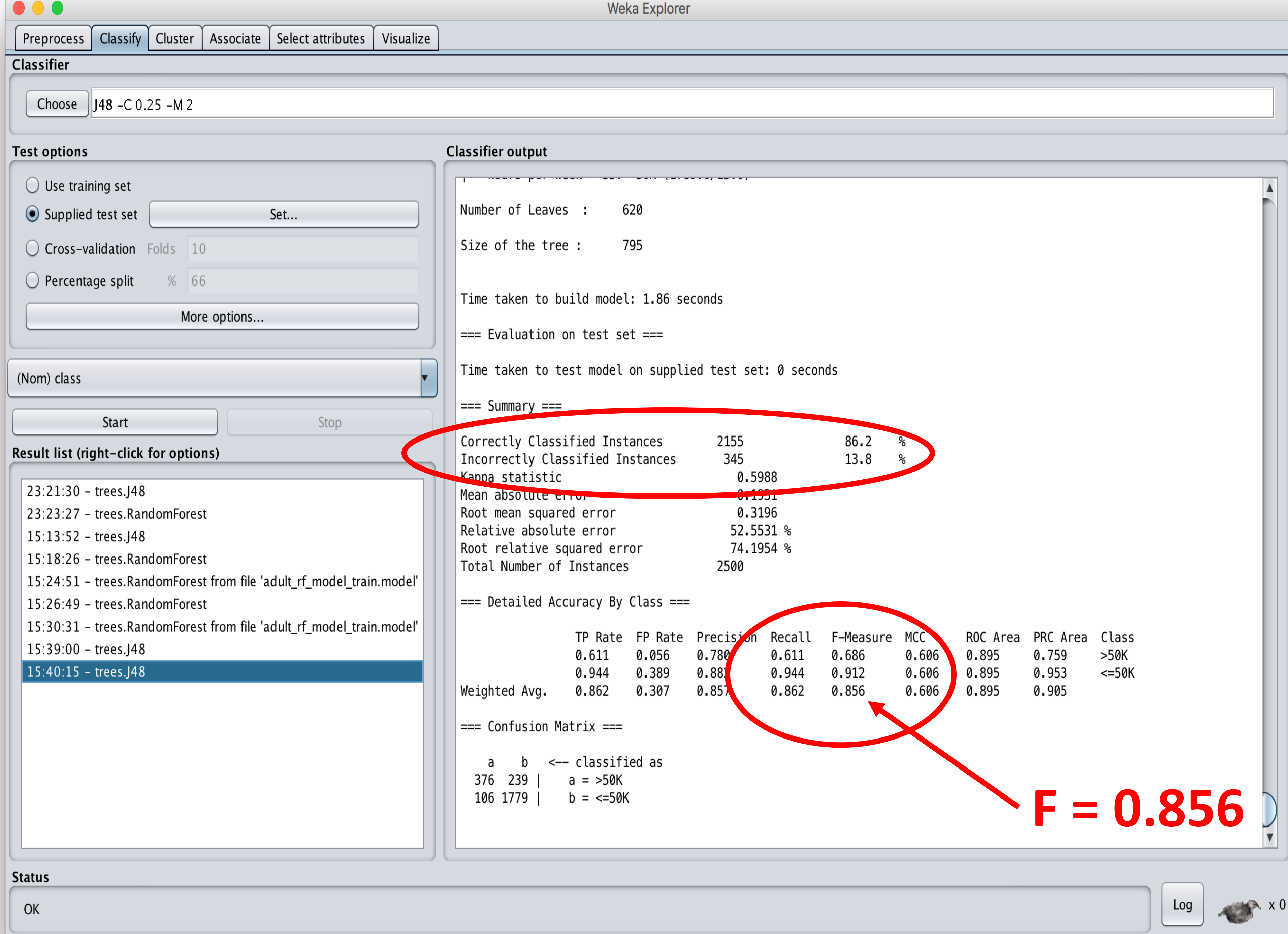

Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
Choose
RandomForest -P 100 -I 100 -num-slots 1 -K 0 -M 1.0 -V 0.001 -S 1
Test options
Use training set
Supplied test set
Set...
Cross-validation Folds 10
Percentage split % 66
More options...
(Nom) class
Start
Stop
Result list (right-click for options)
23:21:30 - trees.J48
23:23:27 - trees.RandomForest
Classifier output
weka.classifiers.trees.RandomTree -K 0 -M 1.0 -V 0.001 -S 1 -do-not-check-capabilities
Time taken to build model: 15.17 seconds
=== Evaluation on training set ===
Time taken to test model on training data: 6.52 seconds
=== Summary ===
Correctly Classified Instances 48774 99.8608 %
Incorrectly Classified Instances 68 0.1392 %
Kappa statistic 0.9962
Mean absolute error 0.0737
Root mean squared error 0.1263
Relative absolute error 20.2565 %
Root relative squared error 29.6022 %
Total Number of Instances 48842
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
0.995 0.000 1.000 0.995 0.997 0.996 1.000 1.000 >50K
1.000 0.005 0.998 1.000 0.999 0.996 1.000 1.000 <=50K
Weighted Avg. 0.999 0.004 0.999 0.999 0.999 0.996 1.000 1.000
=== Confusion Matrix ===
a b <-- classified as
11624 63 | a = >50K
5 37150 | b = <=50K
Status
OK
Log
x 0

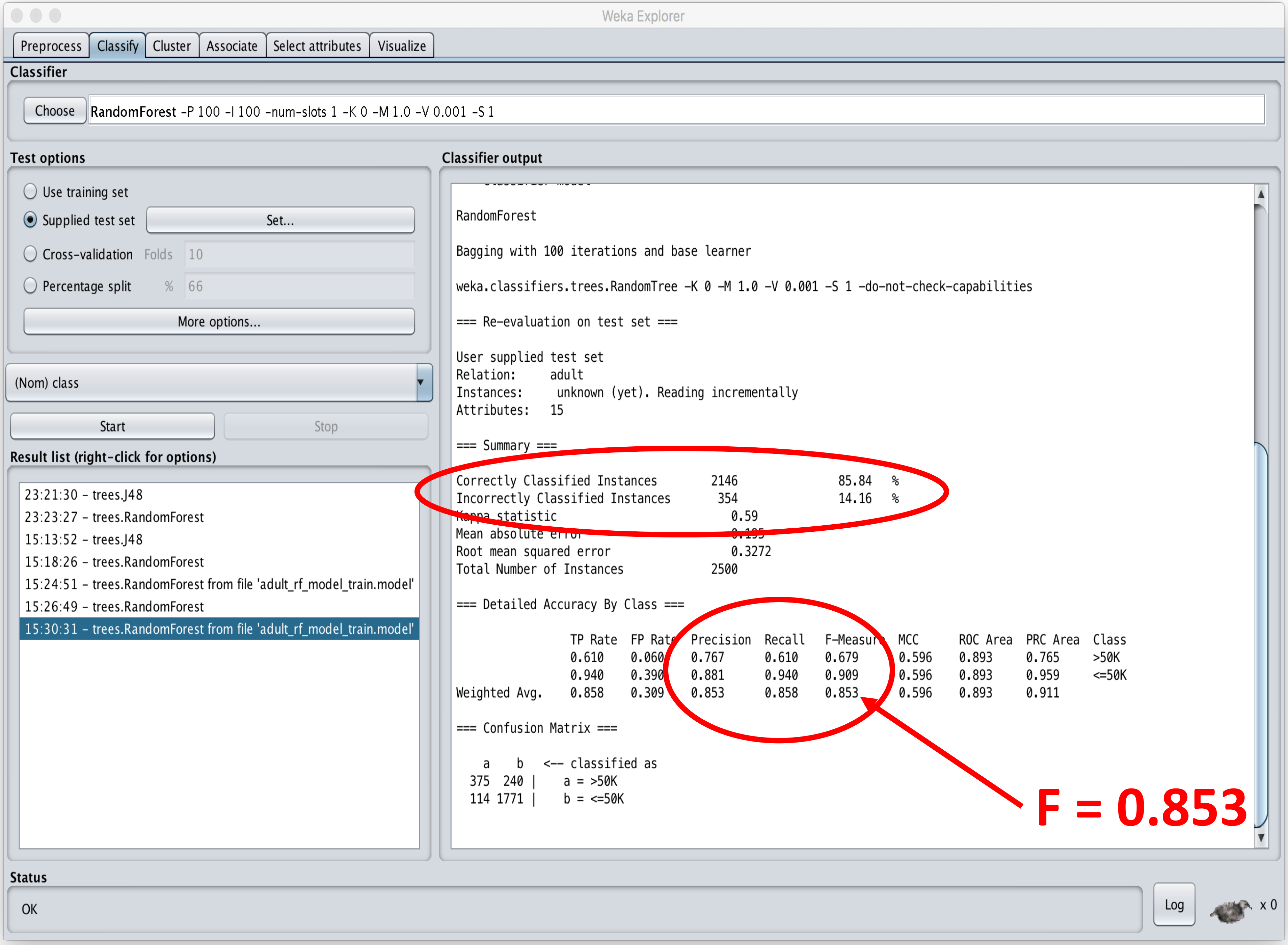
Result

- Significant increase on F1 scores when both trained and evaluated on training set
- This is considered to be poor methodology since it overfits to the particular training set

Create train and test collection

- Train has ~95% of data, test 5%
- Trained models for J48 and random forest using train dataset
- Tested on test data set
- Results were that random forest was (at best) about the same as J48
- Large dataset reduced problem of overfitting, so random forest did not help


Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
Choose
J48 -C 0.25 -M 2
Test options
Use training set
Supplied test set
Set...
Cross-validation Folds 10
Percentage split % 66
More options...
(Nom) class
Start
Stop
Result list (right-click for options)
23:21:30 - trees.J48
23:23:27 - trees.RandomForest
15:13:52 - trees.J48
15:18:26 - trees.RandomForest
15:24:51 - trees.RandomForest from file 'adult_rf_model_train.model'
15:26:49 - trees.RandomForest
15:30:31 - trees.RandomForest from file 'adult_rf_model_train.model'
15:39:00 - trees.J48
15:40:15 - trees.J48
Classifier output
Number of Leaves : 620
Size of the tree : 795
Time taken to build model: 1.86 seconds
=== Evaluation on test set ===
Time taken to test model on supplied test set: 0 seconds
=== Summary ===
Correctly Classified Instances 2155 86.2 %
Incorrectly Classified Instances 345 13.8 %
Kappa statistic 0.5988
Root mean squared error 0.3196
Relative absolute error 52.5531 %
Root relative squared error 74.1954 %
Total Number of Instances 2500
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
0.611 0.056 0.780 0.611 0.686 0.606 0.895 0.759 >50K
0.944 0.389 0.881 0.944 0.912 0.606 0.895 0.953 <=50K
Weighted Avg. 0.862 0.307 0.857 0.862 0.856 0.606 0.895 0.905
=== Confusion Matrix ===
a b <-- classified as
376 239 | a = >50K
106 1779 | b = <=50K
F = 0.856
Status
OK
Log
x 0



Weka Explorer
Preprocess
Classify
Cluster
Associate
Select attributes
Visualize
Classifier
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) class
Start
Stop
Result list (right-click for options)
23:21:30 - trees.J48
23:23:27 - trees.RandomForest
15:13:52 - trees.J48
15:18:26 - trees.RandomForest
15:24:51 - trees.RandomForest from file 'adult_rf_model_train.model'
15:26:49 - trees.RandomForest
15:30:31 - trees.RandomForest from file 'adult_rf_model_train.model'
Classifier output
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
=== Re-evaluation on test set ===
User supplied test set
Relation: adult
Instances: unknown (yet). Reading incrementally
Attributes: 15
=== Summary ===
Correctly Classified Instances 2146 85.84 %
Incorrectly Classified Instances 354 14.16 %
Kappa statistic 0.59
Mean absolute error
Root mean squared error 0.3272
Total Number of Instances 2500
=== Detailed Accuracy By Class ===
TP Rate FP Rate Precision Recall F-Measure MCC ROC Area PRC Area Class
0.610 0.060 0.767 0.610 0.679 0.596 0.893 0.765 >50K
0.940 0.390 0.881 0.940 0.909 0.596 0.893 0.959 <=50K
Weighted Avg. 0.858 0.309 0.853 0.858 0.853 0.596 0.893 0.911
=== Confusion Matrix ===
a b <-- classified as
375 240 | a = >50K
114 1771 | b = <=50K
F = 0.853
Status
OK
Log
x 0

Conclusions

- Bagging helps, especially if training data adequate, but not as large as it should be
  - With lots of data, overfitting less of a problem, so bagging may not help
- While we explore it using decision trees, it can be applied to any classifier
  - Scikit-learn has a general module for bagging
- In general, using any of several **ensemble** approaches to classification often helpful
- Training neural networks uses a different approach (dropout) to control overfittting

~~Conclusions~~

- Wait, there's more…
- A classification problem can change over time
  - E.g.: recognizing a spam message from its content and metadata
- We showed that an ensemble approach can detect a change in the nature of spam
  - Which tells us its time to retrain with new data
  - D. Chinavle, P. Kolari, T. Oates, and T. Finin, Ensembles in Adversarial Classification for Spam, ACM CIKM, 2009. link

Recognizing Concept Drift

- Build ensemble of five models to classify spam comments left on a blog at time T1
- Note the relative level of agreement
- Detect when one of the models starts to diverge from the others with at time T2
  - Time to get new data and retrain
  - Examining disagreements can be enlightening
- Used temporal data spanning several years to prove effectiveness
  - E.g., spam focus shift from *viagra* to *weight loss*