

Extending Classifiers for Incomplete Data

A dissertation submitted in partial fulfilment of
the requirements for the degree of
BACHELOR OF ENGINEERING in Computer Science

in

The Queen's University of Belfast

by

Christopher McKee

10 May 2017

SCHOOL OF ELECTRONICS, ELECTRICAL ENGINEERING and COMPUTER SCIENCE

CSC3002 – COMPUTER SCIENCE PROJECT

Dissertation Cover Sheet

A signed and completed cover sheet must accompany the submission of the Software Engineering dissertation submitted for assessment.

Work submitted without a cover sheet will **NOT** be marked.

Student Name:

Student Number:

Project Title:

Supervisor:

Declaration of Academic Integrity

Before signing the declaration below please check that the submission:

1. Has a full bibliography attached laid out according to the guidelines specified in the Student Project Handbook
2. Contains full acknowledgement of all secondary sources used (paper-based and electronic)
3. Does not exceed the specified page limit
4. Is clearly presented and proof-read
5. Is submitted on, or before, the specified or agreed due date. Late submissions will only be accepted in exceptional circumstances or where a deferment has been granted in advance.

I declare that I have read both the University and the School of Electronics, Electrical Engineering and Computer Science guidelines on plagiarism - <http://www.qub.ac.uk/schools/eeecs/Education/StudentStudyInformation/Plagiarism/> - and that the attached submission is my own original work. No part of it has been submitted for any other assignment and I have acknowledged in my notes and bibliography all written and electronic sources used.

Student's signature

Date of submission

Acknowledgements

I would like to thank my project supervisor, Dr. Cassio Polpo de Campos, for all of his guidance and support during this project.

I'd also like to thank Queens University Belfast for assigning me a project that was of great interest to me, and also for the usage of their facilities during this time.

I'd also like to thank my family for their support, and more importantly the refreshments which they prepared.

Abstract

Data used in the real world has a tendency to be incomplete, with values missing due to problems ranging from clerical error to data corruption. This dissertation is concerned with investigating the effects of repeatedly filling in missing values in training data, and especially by doing so using probabilistic methods. The accuracy of using models trained this way is then compared with models trained against the original data set, including the missing values. Results obtained using the implemented method are inconclusive, and would need to be examined further in a subsequent study.

Contents

List of Tables	3
List of Figures	5
1 Introduction	6
2 Design and Implementation	8
2.1 Design	8
2.2 Implementation	9
2.2.1 Weka Architecture	9
2.2.2 weka.core	10
2.2.3 AbstractClassifier	10
2.2.4 SingleClassifierEnhancer	12
2.2.5 IterativeClassifier	12
2.2.6 Weka Interfaces	13
2.2.7 StateAnalyser	13
2.2.8 ProjectClassifier	14
2.2.9 Testing	16

3 Experiments	17
3.1 Results	18
3.1.1 Naive Bayes	18
3.1.2 Bayesian Network	19
3.1.3 J48 Decision Tree	20
4 Conclusion	22
5 Bibliography	23
A Experimental Data Sets	24
B Experimental Results	26
C Hidden Variables	39
C.1 Implementation	39
C.2 Experiments	40
C.2.1 Naive Bayes	40
C.2.2 Bayesian Network	50
C.2.3 J48 Decision Tree	59
C.3 Conclusions	68
D User Guide	69
D.0.1 CLI	69
D.0.2 GUI	70
E JavaDoc	73

List of Tables

A.1	Experimental Data Sets	24
B.1	Naive Bayes Percent Incorrect	27
B.2	Naive Bayes Mean Absolute Error	28
B.3	Naive Bayes Root Mean Squared Error	29
B.4	Naive Bayes Mean Entropy Gain	30
B.5	Bayesian Network Percent Incorrect	31
B.6	Bayesian Network Mean Absolute Error	32
B.7	Bayesian Network Root Mean Squared Error	33
B.8	Bayesian Network Mean Entropy Gain	34
B.9	J48 Decision Tree Percent Incorrect	35
B.10	J48 Decision Tree Mean Absolute Error	36
B.11	J48 Root Mean Squared Error	37
B.12	J48 Decision Tree Mean Entropy Gain	38
C.1	Naive Bayes Percent Incorrect - Three Hidden Variables	42
C.2	Naive Bayes Percent Incorrect - Five Hidden Variables	43
C.3	Naive Bayes Mean Absolute Error - Three Hidden Variables	44

C.4	Naive Bayes Mean Absolute Error - Five Hidden Variables	45
C.5	Naive Bayes Root Mean Squared Error - Three Hidden Variables	46
C.6	Naive Bayes Root Mean Squared Error - Five Hidden Variables	47
C.7	Naive Bayes Mean Entropy Gain - Three Hidden Variables	48
C.8	Naive Bayes Mean Entropy Gain - Five Hidden Variables	49
C.9	Bayesian Network Percent Incorrect - Three Hidden Variables	51
C.10	Bayesian Network Percent Incorrect - Five Hidden Variables	52
C.11	Bayesian Network Mean Absolute Error - Three Hidden Variables	53
C.12	Bayesian Network Mean Absolute Error - Five Hidden Variables	54
C.13	Bayesian Network Root Mean Squared Error - Three Hidden Variables	55
C.14	Bayesian Network Root Mean Squared Error - Five Hidden Variables	56
C.15	Bayesian Network Mean Entropy Gain - Three Hidden Variables	57
C.16	Bayesian Network Mean Entropy Gain - Five Hidden Variables	58
C.17	J48 Decision Tree Percent Incorrect - Three Hidden Variables	60
C.18	J48 Decision Tree Percent Incorrect - Five Hidden Variables	61
C.19	J48 Decision Tree Mean Absolute Error - Three Hidden Variables	62
C.20	J48 Decision Tree Mean Absolute Error - Five Hidden Variables	63
C.21	J48 Root Mean Squared Error - Three Hidden Variables	64
C.22	J48 Root Mean Squared Error - Five Hidden Variables	65
C.23	J48 Decision Tree Mean Entropy Gain - Three Hidden Variables	66
C.24	J48 Decision Tree Mean Entropy Gain - Five Hidden Variables	67

List of Figures

D.1	Weka Main Menu	70
D.2	Weka Package Manager	71
D.3	Weka Classifier Selector	71
D.4	Project Classifier Configuration GUI	72

Chapter 1

Introduction

The reliability of a machine learning model is heavily dependent on the data which was used to train it. Training data sets with missing values are therefore an interesting problem since there is no way of knowing what any given missing value could have been, and so the only two useful approaches involve either making statistical approximations of missing values or ignoring any record which contains missing data. Both mentioned approaches have positives as well as negatives, and may produce false outcomes. Ignoring a record prevents the use of unreliable data, but also may lead to valuable data in the other, non-missing attributes of the same record being discounted. The process of attempting to fill in a missing value is known as *imputation*. This has no guarantee of being correct, but it may be worth the risk to gain value from the other complete attributes. It is therefore extremely important that any imputation is carried out with care, and it must be very likely to be correct.

All implemented code for this project, as well as some additional utility material, can be found in the Git repository [1]. It aims to investigate the usage of machine learning techniques on incomplete sets of discrete data. It will attempt to impute any missing values in the training data, by iteratively building and applying models until no further change is observed. It is expected that predicted missing values will trend towards the mean, leading to more reliable classification when this trained model is then applied to target data. Given sufficient time, it is also intended that this approach can be used to infer 'hidden variables', similarly to how neural networks produce hidden layers to create relationships between data [2]. This will be achieved by adding a new attribute to a data set, and initially filling it full of random valid data. We will then repeatedly build, apply and rebuild models to classify this attribute until it stops changing, in an identical manner to how missing data is imputed in the training set. New data will be added to the training data set by this method, and this project aims to determine whether or not these hidden variables lead to a greater classification accuracy.

The goal of this project is to study the effects of iteratively building common classifiers and comparing the performance of classifiers built this way against the performance of the same classifier, but without attempting to impute missing training data. The main aims of the software to be developed will therefore be:

- A Weka plugin will be developed. This should integrate smoothly into any version of Weka > 3.7.1, and will be made freely available.
- The classifier developed within the plugin should be usable from both the CLI and GUI.
- Running experiments using the plugin should be easy, and have well explained documentation.
- Allow any Weka classifier which is valid to use for a given data set to be used within the newly implemented classifier, and for this to be easily configurable.
- Run a number of experiments to compare the performance of the iteratively trained classifier against some control cases on the same data sets.

Chapter 2

Design and Implementation

2.1 Design

This body of work is mainly interested in popular classification algorithms, and in trying to use them in a slightly unusual way. It therefore makes sense to extend a package in which these are already implemented, and in which they are easily accessible. The Weka project [3] suits this purpose since it has well maintained, efficient implementations of most machine learning algorithms, handles file I/O, and has both command line and graphical user interfaces. Since Weka is written in Java, it follows that the plugin should also be written in Java.

It also follows that any files which are used for testing should be in either .csv, or .arff format. The former is commonly used in data processing while the latter is a proprietary Weka format which is very similar, but differs in that it contains additional data at the top of the file pertaining to the data set. Both are supported by Weka, and therefore either is usable.

Since the project relies upon the idea that predictions for missing training data values should converge, it is assumed that the developed classifier will initially only work on nominal data sets. This is because nominal data sets should eventually settle on concrete values (at least when imputed using probabilistic techniques), whilst numeric values are not guaranteed to ever settle on a particular value at all. It is more likely that numeric predictions would just change less and less between iterations, until the changes were minuscule. While it would be possible to implement a solution which stops iterating once a numeric data set only changes to a certain degree, as a proof of concept it is sensible to stick to nominal data.

It is intended that the implemented algorithm will work as follows:

1. Take a given training set, and make a copy of it
2. Fill the copy set with random, viable values
3. Use the produced data set to train a new model
4. Use the newly trained model to impute values into a new copy of the training set
5. Repeat 3 and 4 until identical data sets are produced by two consecutive iterations
6. Use the model built by the final iteration for classification of a test set

2.2 Implementation

As an existing piece of software is being extended, much of the work to implement the various classifiers to be tested is already done. The main aim of this work is to integrate successfully into Weka as a plugin, and to interface with it as necessary. This plugin will be provided as a zip file containing the implemented algorithm which can be loaded by Weka using its package manager.

2.2.1 Weka Architecture

Weka is a Java package, with a source code layout which looks somewhat like this if unused packages are omitted:

```
weka
├── associations
├── attributeSelection
├── classifiers
│   ├── AbstractClassifier
│   ├── IterativeClassifier
│   └── SingleClassifierEnhancer
├── clusterers
├── core
│   ├── Attribute
│   ├── Capabilities
│   ├── Instance
│   ├── Instances
│   ├── Option
│   └── Utils
├── datagenerators
└── estimators
```

```
|
|_ experiment
|_ filters
|_ gui
|_ knowledgeflow
```

Each of these sub-packages is reasonably self explanatory. This project is mostly concerned with classifications, and thus code implemented for it lives in the *weka.classifiers* package, although there are some dependencies on *weka.core* since it contains much of the shared code for Weka. Provided that the rest of the project works as intended and the documentation is followed, there is no need to modify or discuss the other packages.

2.2.2 weka.core

From *weka.core*, the following classes are used:

- **Attribute** - An Attribute in Weka refers to a single column in a data set. This object is mostly responsible for tracking the column's data type (e.g. nominal, numeric, etc), and other related information common to the entire column.
- **Instance** - An Instance is the representation of a single row of data, roughly analogous to a row in a CSV file. Each Instance belongs to a particular Instances object. Each attribute value is stored as a Java double, which is then used in connection with an Attribute object to determine the actual value of an attribute.
- **Instances** - An Instances object in Weka is used to represent a complete data set. It is roughly equivalent to the object representation of an ARFF file. It is comprised of a list of Instance objects, a list of Attribute objects and some other metadata such as the class attribute for the data set and its name.
- **Option** - An Option object represents a particular command line parameter, and the way in which it should be handled. This also contains a description to be printed in the help dialog if incorrect parameters are passed to the CLI.

2.2.3 AbstractClassifier

AbstractClassifier is the class from which all classifiers which make nominal or numeric predictions in Weka are derived from. It provides a number of helpful implementations to prevent

code duplication in classifiers, and to ease implementation. A pseudocode description of some notable methods can be seen below:

```
abstract class AbstractClassifier {
    forName(classifierName, options) {
        return an instance of classifier <classifierName>
            with options <option>
    }

    runClassifier(classifier, options) {
        run any classifier by passing options to it
    }

    classifyInstance(instance) {
        returns the class which the instance is most
            likely to belong to as a double in Weka's
            internal representation
    }

    distributionForInstance(instance) {
        return a list of probabilities for each
            possible class value for a given instance
    }

    listOptions() {
        return all of the command line options which
            a classifier accepts to configure how it will run
    }

    getOptions() {
        return the list of options which a classifier
            is currently set up to run with
    }

    setOptions(options) {
        sets the command line options for a
            classifier to options
    }

    getCapabilities() {
        returns a list of the attribute and class attribute
            types which are supported by this classifier
    }
}
```

There are a number of other utility and stub methods within this abstract class which may prove useful for other people in other cases, but have been omitted from the description above.

2.2.4 SingleClassifierEnhancer

SingleClassifierEnhancer is a concrete class which extends from *AbstractClassifier*, and from which the implemented *ProjectClassifier* extends. Extending from this class gives us a couple of benefits:

- *SingleClassifierEnhancer* is designed for 'meta' classifiers, or those which wrap another classifier. It already contains an internal classifier and handles passing options to it. This can easily be extended to copy this classifier multiple times with the same options.
- The internal classifier is already displayed nicely in the Weka GUI. This allows it to be configured via a menu, as shown in figure D.4.
- It already handles some edge cases, such as calling the *preExecution()* and *postExecution()* methods of the internal classifier, which handles any specific setup and cleanup needed. These are small edge cases that would be easy to forget about, so extending in this way improves reliability by removing some of the mental overhead of the implementation.

2.2.5 IterativeClassifier

IterativeClassifier is an Interface which is provided by Weka for 'classifiers which build models of increasing complexity'. It provides three method signatures:

```
public initializeClassifier() {
    do setup for the classifier
}

public next() {
    increase in complexity by one step by retraining the model
    return false if finished, or true if another step can be taken
}

public done() {
    stop increasing complexity and do any necessary cleanup
}
```


These methods generally come together in the following pattern in a classifier which implements the interface:

```
public buildClassifier(instances) {  
    // some code here  
    initializeClassifier(instances)  
    while(next()) {}  
    done()  
    // some other code here  
}
```

This means that building the classifier continues until it no longer makes sense to keep doing so, or no gain is achieved. This suits the project's use case, and therefore the interface makes sense to use.

2.2.6 Weka Interfaces

Calling a Weka classifier from the command line (assuming that the Weka jar file is already on the classpath) is reasonably straightforward. The target classifier is firstly called by its full path e.g. `java weka.classifiers.trees.J48`. Anything which comes after this point is passed to the classifier as an Option object. These are used as parameters to configure the behaviour of a particular classifier, and each class which extends from *AbstractClassifier* generally implements its own specific set of Options through a combination of private variables and specifically named methods. The GUI works in much the same way, except that it provides windows with dropdown menus and text fields to allow classifiers and their Options to be configured.

For example, imagine a given classifier had a private variable named *m_Example*. In order to expose this to the GUI and CLI it would require getter and setter methods, as well as an *exampleTipText()* method to display help text. Code specifying how to handle this Option would also need to be added to the *getOptions()*, *setOptions()* and *listOptions()* methods.

2.2.7 StateAnalyser

The *StateAnalyser* class has been designed to track the progress of the *ProjectClassifier* as it is being trained. It contains references to the two most recent training sets which have been produced by the *next()* method, and records the number of differences between them. All of the methods described below are just utility methods for working with or comparing the training sets which have been produced.

```

private convertToMatrix(instances) {
    create a matrix
    for each row in the data set {
        turn it into an array of floats
        add that array to the matrix
    }
    return matrix
}

public getNumberDifferences() {
    if at least two training sets recorded {
        convert the two most recent training sets to matrices
        for each row in both matrices {
            if the two rows differ, increment the difference counter
        }

        return the number of different rows;
    }

    else
        return a negative number to indicate an invalid test;
}

public getNumberIterations() {
    return number of recorded sets
}

```

2.2.8 ProjectClassifier

The *ProjectClassifier* class is the implementation of the algorithm described in section 2.1. This extends from *SingleClassifierEnhancer* and implements the *IterativeClassifier* interface. It maintains an internal array of classifiers, one for each of the attributes in a data set, and uses these to impute values into the training set as well as to classify test data. It also maintains three copies of training set while building:

- *original* - a copy of the training set
- *last* - the last data set produced by imputing missing values, which can be used for re-training during the next iteration
- *current* - the data set which is currently having its missing values filled in

```

public buildClassifier(instances) {
    record the index of the original class attribute
    take a reference copy of the training set (original)
    find the location of missing data in the training set
    set up the classifier for the first run
    repeat until no change is observed between current and last
    perform any cleanup needed
}

public findMissingAttributes(instances) {
    for each instance in a training set {
        record any values which are missing for later use
    }
}

public initializeClassifier(instances) {
    create new tracker object
    create one classifier object per attribute in the data set
    take two modifiable copies of the training data set (last/current)
    replace any missing data in last using random values
}

public replaceMissingValues(instances) {
    for any each piece of missing data {
        input a random possible value
    }
}

public next() {
    replace last with current
    replace current with a new copy of the training data
    retrain classifiers against last
    for each recorded missing value {
        use trained classifiers to impute missing values in current
    }
    add current to the tracker object
    if (there are no differences between current and last)
        stop iterating
    else
        iterate again
}

public done() {
    do option specific cleanup
}

```

```

public retrainClassifiers(instances) {
    for each attribute in the training set {
        retrain a classifier against that attribute
    }
}

```

ProjectClassifier also accepts some options, which can be used to configure how it runs:

- **maxIterations** (-M number) - Some classifiers may not converge in the way in which we expect, or they may take a very long time to reach this point. This flag allows for a maximum number of training iterations to be set in order to ensure experiments finish in a timely fashion.
- **supervised** (-S) - It may be interesting to observe the difference between classifiers which are trained against a training set where the class attribute is trained iteratively along with the rest of the data set against a training set where missing class attribute values are not imputed until the classifier rest of the classifier has converged. This flag allows for the latter case to be tested.
- **randomData** (-R) - As a control set during experiments, it makes sense to fill a training set with random data and determine whether or not the implemented algorithm outperforms classifiers which are trained against this. This allows this experiment to be performed.
- **hiddenVariables** (-N) - See appendix C.

2.2.9 Testing

Unit tests were written for both the *StateAnalyser* and *ProjectClassifier* classes using JUnit 3 since Weka's unit tests are written using this version. While JUnit 4 and 5 are both available, it seems sensible to use the same version for both as there are large changes in how tests are defined and written between versions. These tests allowed for reasonably quick iteration, and in the case of the *ProjectClassifier* class provided useful debugging information.

Unfortunately more rigorous testing could not be performed due to the nature of this work. Since this is an experimental implementation, the expected results are unknown and are therefore only testable through experimentation as described in section 3.

Chapter 3

Experiments

The algorithm described in the previous section will be used in experiments with a number of internal classifiers in order to assess their performance when trained iteratively. These results will be compared with the results of using the internal classifier in a number of control cases, to determine if the implemented algorithm described has proven beneficial. Each case will be tested against 51 different sets of nominal data taken from the UCI Machine Learning Repository [4], each of which has had approximately 10% of its values removed at random in order to simulate the effects of having missing data. For each data set, 5 folds will be used for cross validation and this will be repeated 10 times. Additional information about the data sets can be found in appendix A.

For each classifier which we are testing we will use the following test cases, where *TestClassifier* represents the current classifier under test:

1. *ProjectClassifier -S with TestClassifier* - Iteratively trains the target classifier by imputing missing values, retraining against the newly completed data set and then imputing again until convergence or max iterations reached. The class attribute is not guessed.
2. *ProjectClassifier with TestClassifier* - Same as previous case, except that the initial class attribute is also iteratively imputed.
3. *TestClassifier* - 'Vanilla' classifier, run without attempting to remove missing values before classification.
4. *TestClassifier (missing data filled in with mode)* - Same as previous case, except every missing value will be replaced using the mode before it is run.

5. *ProjectClassifier -R with TestClassifier* - Similar to previous case, except missing values will be replaced using random possible values before classification. Only one iteration will be performed.

Each of these tests will henceforth be referred to as Case 1, 2, 3, 4 and 5 respectively. Cases 4 and 5 are being treated as control cases, since they are not very sophisticated techniques. For each of the tables discussed below, the index of each column refers to the number of each case.

Some adaptations may need to be made for certain classifiers, but this is the general structure of each experiment. For each of these classifiers the percentage of incorrect classifications, mean absolute error (MAE), root mean squared error (RMSE), and mean entropy gain (MEG) will be compared using a paired T test with a statistical significance threshold of 0.05. It is generally expected that Case 1, the iteratively trained classifier, will perform better than all other cases with the possible exception of Case 3.

3.1 Results

Tables referenced below can be found in appendix B, since they are too large to be included in-line.

3.1.1 Naive Bayes

No adaptations needed to be made for the Naive Bayes classification method since it converged to a stable model as expected, and did so within a reasonable period of time.

Naive Bayes Percent Incorrect results are shown in Table B.1. As expected, Case 1 generally performed better than Cases 2, 4 and 5. It seems logical that Cases 4 and 5 would perform the worst, since these methods generally just involved filling in missing data with the mode and random data respectively. Case 1 generally performed worse than Case 3, producing statistically even results in 30 tests and statistically worse results in 19 tests.

Naive Bayes MAE results are shown in Table B.2. Cases 1, 2 and 3 proved approximately equal according to this test, with no real significant difference between results. Case 1 performed much better than Cases 4 or 5, showing better results in 37 and 45 tests respectively. This is an expected result, since Cases 4 and 5 are effectively control cases.

Naive Bayes RMSE results are shown in Table B.3. Using this metric for measurement, Case 1 performed significantly better than both Cases 2 and 4, with better results shown in 41 and 28 data sets respectively. Interestingly, it performed about as well as Case 5, performing significantly better in 17 tests, approximately about as well in 16 tests, and significantly worse in 18 tests. This could be due to the fact that using random data is unlikely to lead to strong predictions being made, while iteratively imputing missing values will tend to result in either increasingly bad or increasingly good predictions being made. Again, Case 3 performed significantly better than Case 1.

Naive Bayes MEG results are shown in Table B.4. Case 1 performed significantly worse than Case 2 according to this metric, performing worse in 42/51 data sets. It is assumed that this is due to the iterative imputation of the class attribute in Case 2, which probably leads to lower entropy gains since it will produce a smaller range of values. For a very similar reason, Case 1 performs significantly better than Case 3. Since it's iteratively imputing all but one attribute in the training set, a smaller range of values are probably produced during classification. Cases 1, 4 and 5 perform about as well as each other, since Cases 4 and 5 are essentially just making random guesses.

It would seem that the implemented algorithm does not provide any significant gains when using the Naive Bayes classifier according to the classification accuracy and RMSE tests, although there was some promise shown in the MAE and MEG tests. While significant decreases in entropy gain were observed, it was both less accurate as a classifier and more strongly wrong.

3.1.2 Bayesian Network

For testing, a Tree Augmented Naive Bayes (TAN) Bayesian Network using MDL for scoring was used as the internal classifier for the ProjectClassifier, although some small adaptations to the experiment were needed for testing performance. In some cases, most frequently with small data sets, an iteratively trained Bayesian Network did not converge as expected. This led to it running for longer than it would be practical to test for, with no guarantee that it would ever finish iterating. In order to produce results, training was limited to 5000 iterations.

Bayesian Network Percent Incorrect results are shown in Table B.5. Case 1 did not perform particularly well according to this metric, with results that were approximately equivalent to the results from Case 5, and were slightly worse than the results seen in Case 4. Since Case 1 significantly outperformed Case 2 (with more accurate or similarly accurate results shown in 49/51 tests) and Case 3 performed as well or better than Case 1 in 38/51 tests, this may show

that the more a Bayesian Network is trained iteratively the less accurate it becomes.

Bayesian Network Mean Absolute Error results are shown in Table B.6. Case 1 produced much better results than either control case, doing as well or better than Case 4 in 45/51 tests, and as well or better than Case 5 in 50/51 tests. Case 2 provided very similar results to Case 1, with neither method proving significantly better or worse according to this metric. Case 1 performed better than Case 3 in 27/51 tests, as well as Case 3 in 5/51 tests, and worse than Case 3 in 19/51 tests. This does not allow any clear conclusion to be drawn, since while Case 1 did perform better in more cases, it was not enough to be significant.

Bayesian Network RMSE results are displayed in Table B.7. Using this measure, it was determined that Cases 4 and 5 both outperformed Case 1. Case 4 produced better results in 32/51 tests, while Case 5 produced better results in 27/51 tests and similar results in 14/51 tests. Case 3 produced a similar result, with better results in 31/51 test cases. The only case which Case 1 performed better than was Case 2, which it did in 37/51 tests. This would appear to indicate that further training using this classifier leads to stronger predictions which are less accurate.

Bayesian Network MEG results are shown in Table B.8. Case 1 again showed smaller entropy gains than Cases 3, 4 and 5 in at least 60% of cases. Case 2 again showed even smaller entropy gains, probably due to the increased iteration removing variation.

It would seem that the implemented algorithm does not provide any significant gains to classification accuracy when using a TAN Bayesian Network. Again, entropy gain significantly decreased due to the repeated training and imputation cycles, but the classifications became more inaccurate, and judging by the RMSE results they were more likely to be very inaccurate. The MAE results show some promise though.

3.1.3 J48 Decision Tree

When testing the J48 decision tree, adaptations were needed. The J48 failed to converge as expected in most cases, although this was most common and also most time consuming with very large data sets. Through experimentation it was determined that iteratively training the J48 classifier caused it to reach a certain state of stability around which it would fluctuate by changing a handful of rows between iterations, usually after around 15-20 rounds of training and re-imputing. It therefore made sense to limit training to 30 iterations to allow experiments to be run in a reasonable period of time while also providing some 10-15 extra iterations to allow for even more volatile data sets to reach relative stability.

J48 Percent Incorrect results are shown in Table B.9. Case 1 performed as well as or better than Cases 2, 4 and 5 in almost all tests, which was the expected result for the control cases. Case 1 was again outperformed by Case 3, performing worse in 16/51 tests and even in 26/51.

J48 Mean Absolute Error results can be found in Table B.10. Interestingly, using this metric Case 1 performed much better than Cases 3, 4 or 5, with better results in 38/51, 37/51 and 47/51 data sets respectively. This result was not seen while using Naive Bayes or Bayesian Networks as the classifier. This could be due to the fact that J48 was capped at 30 iterations to reduce experiment time and this may suggest that there is an optimal number of iterations for this method. Case 2 also was significantly more accurate than Case 1 in 21/51 tests, and approximately the same in 26/51.

J48 RMSE results are shown in Table B.11. Case 1 again performed much better than either Case 4 or 5, which was expected since these were the control cases. It also performed as well as or better than Case 2 in all 51 data sets. Case 1 was heavily outperformed by Case 3 using RMSE as the metric for comparison, since the results for Case 3 were as good or better in 44/51 data sets.

J48 MEG results are shown in Table B.12. Case 1 significantly outperformed Case 3 using this measure, as it rewards a reduction in entropy. Since the iterative training will naturally lead to decreased variety in the results shown, this result is expected. Case 1 generally produced a smaller reduction in entropy than Case 2, since it was not also iteratively training the class attribute. Case 1 performed worse than Case 4 in 29/51 tests, which is also interesting.

The results gained from the above experiments are inconclusive, While the J48 classifier became less accurate when trained iteratively and appeared to make larger errors according to the RMSE test, the MAE result is an interesting case and be explored further.

Chapter 4

Conclusion

This body of work has implemented a novel method of training models for use in classifying nominal data sets, and has experimented with using this method together with a number of established classification techniques. Through these experiments it has been shown that the implemented method of iteratively imputing and retraining classifiers generally leads to a better result when measuring mean absolute error, but also causes lower classification accuracy and a worse root mean squared error value. Despite these broad trends, no concrete conclusion has been reached and there is potential for further experimentation in another body of work, including experimentation with other classifiers and experimentation with the maximum iteration limit.

As a project, all objectives have been fulfilled. A functional, distributable Weka plugin has been developed which integrates into the system through its package manager and passes all unit tests imposed by the system. It is usable from both the CLI and GUI, and allows for easy configuration of its parameters and the parameters of its internal classifiers. It has also been used for experiments as intended, and some minor insights have been gleaned from these.

Chapter 5

Bibliography

- [1] C. McKee and C. P. de Campos, “Gitlab repository,” <https://gitlab.eecs.qub.ac.uk/cassiope/cdc04>, 2017.
- [2] D. S. Touretzky and D. A. Pomerleau, “What’s hidden in the hidden layers?” *BYTE*, vol. 14, no. 8, pp. 227–233, Aug. 1989. [Online]. Available: <http://dl.acm.org/citation.cfm?id=77174.77190>
- [3] E. Frank, M. A. Hall, and I. H. Witten, *The WEKA Workbench*, 4th ed. Morgan Kaufmann, 2016.
- [4] M. Lichman, “UCI machine learning repository,” <http://archive.ics.uci.edu/ml>, 2013.
- [5] D. J. Harris, “What does the hidden layer in a neural network compute?” <https://stats.stackexchange.com/a/63163>, 2013.

Appendix A

Experimental Data Sets

Figure A.1 shows some information about the data which was used for the experiments in Section 3. All of the data sets used for testing contain only nominal data, although the categories vary in size between attributes. There is also a fairly large range of data set shapes and sizes, which should provide a range of results to prevent false positives.

Table A.1: Experimental Data Sets

Dataset Title	Num. Attributes	Num. Instances
audiology	70	226
autos	26	205
balance-scale	5	625
breast-cancer	10	286
bridges-version1	11	107
car	7	1728
cmc	10	1473
colic	23	368
cylinder-bands	33	540
dermatology	35	366
diabetes	9	768
ecoli	6	336
flags	29	194
glass	8	214
haberman	4	306
hayes-roth-train	5	132
heart-h	12	294
heart-statlog	10	270
hepatitis	20	155

hypothyroid	28	3772
ionosphere	34	351
iris	5	150
kr-vs-kp	37	3196
labor	17	57
letter	17	20000
liver-disorders	7	345
lung-cancer	57	32
lymph	18	148
molecular-biology-promoters	58	106
mushroom	22	8124
nursery	9	12960
optdigits	38	5620
page-blocks	11	5473
pendigits	17	10992
postoperative-patient-data	9	90
primary-tumor	18	339
segment	17	2310
shuttle-landing-control	7	15
sick	28	3772
solar-flare-2	12	1066
sonar	61	208
soybean	36	683
spambase	8	4601
tae	6	151
tic-tac-toe	10	958
trains	27	10
vehicle	19	846
vote	17	435
vowel	14	990
waveform-5000	41	5000
zoo	17	101

Appendix B

Experimental Results

This appendix contains the results for the experiments carried out in section 3.

Table B.1: Naive Bayes Percent Incorrect

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	36.33	38.44 ○	37.28 ○	50.09 ○	43.50 ○
autos	10.33	9.78 ●	10.22	9.62 ●	9.61 ●
balance-scale	26.54	25.96 ●	26.26 ●	28.49 ○	25.98 ●
breast-cancer	27.67	27.63	27.14	27.41	27.33
bridges-version1	35.44	33.67 ●	35.45	36.00	38.04 ○
car	19.26	19.67 ○	19.46	23.23 ○	21.39 ○
cmc	51.80	52.27 ○	50.69 ●	50.24 ●	51.24 ●
colic	21.45	21.94	20.92 ●	19.94 ●	21.72
cylinder-bands	32.26	33.12 ○	31.79 ●	32.69	32.92
dermatology	3.19	3.04	2.95	3.58	3.31
diabetes	28.12	28.90 ○	27.79	27.52	28.41
ecoli	33.61	33.52	32.67 ●	34.53 ○	32.44 ●
flags	37.83	37.60	38.46	40.51 ○	39.77 ○
glass	45.98	44.97	46.42	46.58	46.02
haberman	28.30	28.12	27.71	27.27 ●	27.31 ●
hayes-roth-train	51.28	52.26	47.16 ●	49.23	50.26
heart-h	17.98	18.05	18.39	19.23 ○	18.24
heart-statlog	27.15	27.15	27.10	27.51	27.03
hepatitis	18.98	19.05	19.06	19.20	19.35
hypothyroid	9.14	12.42 ○	8.74 ●	8.38 ●	7.76 ●
ionosphere	27.11	30.89 ○	24.93 ●	23.94 ●	25.97 ●
iris	21.29	21.59	21.51	23.54 ○	22.26
kr-vs-kp	14.69	16.55 ○	14.01 ●	16.69 ○	16.31 ○
labor	5.40	5.00	4.80	5.20	7.00 ○
letter	60.44	61.98 ○	59.84 ●	62.59 ○	60.33 ●
liver-disorders	38.00	39.84 ○	37.31	39.17	37.99
lung-cancer	49.89	47.90	53.02	45.55	53.19
lymph	16.60	16.30	15.65 ●	16.49	16.65
molecular-biology-promoters	9.73	10.18	8.56	14.00 ○	10.39
mushroom	5.06	6.86 ○	5.06	7.89 ○	8.06 ○
nursery	16.01	16.08	15.87	16.51 ○	15.63 ●
optdigits	13.60	14.06 ○	13.10 ●	16.32 ○	14.55 ○
page-blocks	16.82	19.30 ○	16.82	14.00 ●	9.17 ●
pendigits	21.97	22.49 ○	21.21 ●	26.14 ○	23.08 ○
postoperative-patient-data	30.69	31.41	29.98	30.36	33.26 ○
primary-tumor	54.72	55.26	54.13	54.94	56.04 ○
segment	28.72	30.80 ○	28.12 ●	33.04 ○	31.49 ○
shuttle-landing-control	44.00	42.67	46.67	36.67 ●	45.33
sick	9.64	10.26 ○	9.81 ○	8.84 ●	7.98 ●
solar-flare-2	28.23	28.22	28.16	28.39	28.21
sonar	24.86	26.31 ○	24.14 ●	25.33	24.60
soybean	9.62	10.51 ○	9.77	11.28 ○	11.91 ○
spambase	24.61	24.85 ○	24.51 ●	24.14 ●	24.57
tae	49.72	50.00	48.92	51.64 ○	51.37 ○
tic-tac-toe	30.03	30.21	29.49 ●	29.23 ●	29.33 ●
trains	33.00	33.00	31.00	39.00	33.00
vehicle	55.02	56.60 ○	53.71 ●	55.79 ○	54.53
vote	9.47	9.57 ○	9.47	9.34	9.64
vowel	70.35	71.30 ○	69.27 ●	72.30 ○	69.72
waveform-5000	22.34	22.65 ○	22.44	23.63 ○	23.04 ○
zoo	8.99	9.86 ○	8.78	11.33 ○	11.16 ○
Average	27.71	28.24	27.37	28.52	28.18

○, ● statistically significant improvement or degradation

Table B.2: Naive Bayes Mean Absolute Error

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03 ○	0.03 ○	0.04 ○	0.04 ○
autos	0.10	0.10 ●	0.10 ●	0.10	0.10
balance-scale	0.25	0.25 ●	0.27 ○	0.28 ○	0.29 ○
breast-cancer	0.33	0.32 ●	0.32	0.32	0.34 ○
bridges-version1	0.15	0.14 ●	0.15 ○	0.15 ○	0.16 ○
car	0.13	0.13 ●	0.13 ○	0.14 ○	0.17 ○
cmc	0.38	0.38 ●	0.38 ○	0.39 ○	0.39 ○
colic	0.23	0.24 ○	0.23 ●	0.22 ●	0.25 ○
cylinder-bands	0.35	0.35 ○	0.34	0.35	0.37 ○
dermatology	0.01	0.01 ●	0.01 ●	0.02 ○	0.02 ○
diabetes	0.33	0.33 ○	0.33 ○	0.33 ○	0.35 ○
ecoli	0.10	0.10 ●	0.10 ○	0.11 ○	0.11 ○
flags	0.10	0.10	0.10 ○	0.11 ○	0.11 ○
glass	0.16	0.16 ●	0.16 ○	0.16 ○	0.17 ○
haberman	0.37	0.36 ●	0.37	0.37 ●	0.39 ○
hayes-roth-train	0.31	0.31	0.31	0.31 ○	0.32 ○
heart-h	0.09	0.09 ●	0.09 ○	0.10 ○	0.11 ○
heart-statlog	0.30	0.29	0.30 ○	0.31 ○	0.31 ○
hepatitis	0.21	0.21	0.21 ○	0.21 ○	0.23 ○
hypothyroid	0.07	0.08 ○	0.07 ●	0.07 ●	0.10 ○
ionosphere	0.28	0.31 ○	0.26 ●	0.26 ●	0.28
iris	0.18	0.17 ●	0.18	0.21 ○	0.20 ○
kr-vs-kp	0.23	0.24 ○	0.23 ●	0.25 ○	0.29 ○
labor	0.08	0.08	0.08	0.09 ○	0.11 ○
letter	0.05	0.05 ●	0.05 ●	0.06 ○	0.06 ○
liver-disorders	0.46	0.46	0.46	0.46	0.47 ○
lung-cancer	0.34	0.33	0.36 ○	0.31 ●	0.35
lymph	0.10	0.10 ○	0.10	0.11 ○	0.11 ○
molecular-biology-promoters	0.11	0.12 ○	0.11	0.15 ○	0.13 ○
mushroom	0.05	0.07 ○	0.05 ●	0.08 ○	0.08 ○
nursery	0.09	0.09 ●	0.10 ○	0.13 ○	0.14 ○
optdigits	0.03	0.03 ○	0.03 ●	0.04 ○	0.04 ○
page-blocks	0.08	0.09 ○	0.08 ●	0.07 ●	0.10 ○
pendigits	0.05	0.05 ●	0.05 ●	0.07 ○	0.06 ○
postoperative-patient-data	0.28	0.28 ○	0.28 ○	0.27 ●	0.30 ○
primary-tumor	0.06	0.06 ●	0.06	0.06 ○	0.06 ○
segment	0.09	0.10 ○	0.09 ●	0.11 ○	0.11 ○
shuttle-landing-control	0.46	0.45	0.46	0.44 ●	0.47 ○
sick	0.12	0.12 ○	0.12 ○	0.11 ●	0.16 ○
solar-flare-2	0.11	0.11 ●	0.11 ○	0.12 ○	0.13 ○
sonar	0.25	0.26 ○	0.25 ●	0.26 ○	0.25 ●
soybean	0.01	0.01 ○	0.01	0.01 ○	0.02 ○
spambase	0.27	0.27 ○	0.27 ○	0.28 ○	0.29 ○
tae	0.40	0.40	0.40 ○	0.41 ○	0.41 ○
tic-tac-toe	0.36	0.36 ●	0.37 ○	0.37 ○	0.39 ○
trains	0.32	0.35	0.33	0.35	0.33
vehicle	0.29	0.29 ○	0.28 ●	0.29 ○	0.29
vote	0.10	0.10 ○	0.10 ●	0.10 ○	0.10 ○
vowel	0.14	0.14 ○	0.14 ●	0.15 ○	0.14 ○
waveform-5000	0.16	0.16 ○	0.16 ●	0.17 ○	0.17 ○
zoo	0.03	0.03	0.03	0.04 ○	0.04 ○
Average	0.19	0.19	0.19	0.20	0.20

○, ● statistically significant improvement or degradation

Table B.3: Naive Bayes Root Mean Squared Error

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.16	0.16 ○	0.16 ○	0.17 ○	0.16 ○
autos	0.29	0.28 ●	0.28 ●	0.27 ●	0.28 ●
balance-scale	0.34	0.34 ○	0.34 ○	0.36 ○	0.35 ○
breast-cancer	0.45	0.45 ○	0.45 ●	0.44 ●	0.44 ●
bridges-version1	0.28	0.29	0.28	0.29 ○	0.29 ○
car	0.24	0.24 ○	0.25 ○	0.26 ○	0.27 ○
cmc	0.46	0.47 ○	0.46 ●	0.45 ●	0.45 ●
colic	0.42	0.43 ○	0.41 ●	0.41 ●	0.41 ●
cylinder-bands	0.47	0.49 ○	0.47 ●	0.47 ●	0.46 ●
dermatology	0.08	0.08	0.08 ●	0.09 ○	0.09 ○
diabetes	0.43	0.44 ○	0.43 ●	0.42 ●	0.42 ●
ecoli	0.23	0.23 ○	0.23 ●	0.23 ○	0.23
flags	0.26	0.27 ○	0.26	0.27 ○	0.27
glass	0.29	0.29 ○	0.29 ●	0.29	0.29
haberman	0.44	0.44	0.44 ●	0.44 ○	0.44
hayes-roth-train	0.39	0.39 ○	0.38 ●	0.39 ○	0.39 ○
heart-h	0.23	0.23 ○	0.23 ●	0.23 ○	0.23
heart-statlog	0.43	0.44 ○	0.43 ●	0.42 ●	0.42 ●
hepatitis	0.39	0.39 ○	0.39	0.39	0.38 ●
hypothyroid	0.19	0.22 ○	0.18 ●	0.18 ●	0.19 ○
ionosphere	0.45	0.50 ○	0.44 ●	0.43 ●	0.44 ●
iris	0.32	0.32	0.32	0.34 ○	0.32 ○
kr-vs-kp	0.32	0.34 ○	0.32 ●	0.34 ○	0.35 ○
labor	0.18	0.18	0.17 ●	0.19	0.20 ○
letter	0.17	0.17 ○	0.17 ●	0.17 ○	0.17 ●
liver-disorders	0.48	0.49 ○	0.48 ●	0.48 ○	0.48
lung-cancer	0.51	0.50	0.52	0.48 ●	0.52
lymph	0.24	0.24 ○	0.23 ●	0.24	0.24
molecular-biology-promoters	0.24	0.26 ○	0.24	0.31 ○	0.26 ○
mushroom	0.20	0.25 ○	0.20 ●	0.26 ○	0.26 ○
nursery	0.21	0.21 ○	0.21 ○	0.23 ○	0.23 ○
optdigits	0.15	0.15 ○	0.14 ●	0.16 ○	0.15
page-blocks	0.22	0.24 ○	0.21 ●	0.20 ●	0.19 ●
pendigits	0.18	0.18 ○	0.18 ●	0.20 ○	0.18 ○
postoperative-patient-data	0.39	0.40 ○	0.39	0.39	0.40
primary-tumor	0.18	0.18 ○	0.18 ●	0.18 ○	0.18 ○
segment	0.25	0.25 ○	0.24 ●	0.26 ○	0.25
shuttle-landing-control	0.49	0.49	0.49	0.48 ●	0.50
sick	0.26	0.27 ○	0.26 ●	0.25 ●	0.25 ●
solar-flare-2	0.24	0.25 ○	0.24 ●	0.25 ○	0.25
sonar	0.45	0.46 ○	0.44 ●	0.45 ○	0.43 ●
soybean	0.09	0.10 ○	0.09	0.10 ○	0.10 ○
spambase	0.43	0.43 ○	0.42 ●	0.42 ●	0.41 ●
tae	0.46	0.46 ○	0.46 ●	0.46	0.46
tic-tac-toe	0.44	0.44 ○	0.43 ●	0.44 ○	0.44
trains	0.40	0.42	0.41	0.43	0.42
vehicle	0.45	0.46 ○	0.44 ●	0.44 ●	0.43 ●
vote	0.29	0.30 ○	0.29 ●	0.29 ●	0.29 ●
vowel	0.27	0.28 ○	0.27 ●	0.28 ○	0.27 ●
waveform-5000	0.35	0.35 ○	0.35 ●	0.35 ○	0.35 ●
zoo	0.13	0.13	0.12	0.14 ○	0.14 ○
Average	0.31	0.32	0.31	0.32	0.31

○, ● statistically significant improvement or degradation

Table B.4: Naive Bayes Mean Entropy Gain

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-1.07	-1.31 ●	-1.30 ●	-2.14 ●	-0.49 ○
autos	-0.10	-0.12 ●	-0.04 ○	0.11 ○	0.17 ○
balance-scale	0.42	0.41 ●	0.39 ●	0.32 ●	0.35 ●
breast-cancer	-0.04	-0.07 ●	-0.02 ○	-0.00 ○	0.03 ○
bridges-version1	0.73	0.68 ●	0.75 ○	0.67 ●	0.72
car	0.65	0.65 ●	0.63 ●	0.57 ●	0.45 ●
cmc	0.01	-0.08 ●	0.04 ○	0.04 ○	0.08 ○
colic	-0.32	-0.43 ●	-0.22 ○	-0.17 ○	0.01 ○
cylinder-bands	-0.02	-0.16 ●	0.02 ○	0.04 ○	0.07 ○
dermatology	2.32	2.32	2.33 ○	2.29 ●	2.30 ●
diabetes	0.14	0.12 ●	0.16 ○	0.16 ○	0.17 ○
ecoli	0.98	0.96 ●	1.00 ○	0.96	0.95 ●
flags	0.27	0.12 ●	0.31 ○	0.27	0.45 ○
glass	0.53	0.48 ●	0.55 ○	0.53	0.50
haberman	-0.00	-0.01	0.01 ○	-0.01 ●	0.01 ○
hayes-roth-train	0.13	0.08 ●	0.14 ○	0.10 ●	0.07 ●
heart-h	0.27	0.25 ●	0.31 ○	0.30 ○	0.27
heart-statlog	0.17	0.14 ●	0.20 ○	0.22 ○	0.23 ○
hepatitis	-0.16	-0.21 ●	-0.14 ○	-0.09 ○	0.03 ○
hypothyroid	0.09	-0.12 ●	0.10 ○	0.09 ○	0.01 ●
ionosphere	-0.26	-0.65 ●	-0.18 ○	-0.08 ○	-0.08 ○
iris	0.89	0.89	0.89	0.76 ●	0.87 ●
kr-vs-kp	0.52	0.49 ●	0.53 ○	0.48 ●	0.43 ●
labor	0.68	0.71 ○	0.71 ○	0.70	0.70
letter	1.69	1.50 ●	1.75 ○	1.58 ●	1.76 ○
liver-disorders	0.05	0.01 ●	0.06 ○	0.03 ●	0.05
lung-cancer	-1.45	-1.58	-1.40	-1.21 ○	-1.12 ○
lymph	0.66	0.63 ●	0.70 ○	0.72 ○	0.67
molecular-biology-promoters	0.63	0.59	0.66 ○	0.43 ●	0.61
mushroom	0.71	0.51 ●	0.76 ○	0.57 ●	0.61 ●
nursery	1.20	1.20 ●	1.19 ●	1.00 ●	0.98 ●
optdigits	2.41	2.36 ●	2.46 ○	2.37 ●	2.57 ○
page-blocks	0.05	-0.11 ●	0.07 ○	0.11 ○	0.09 ○
pendigits	2.10	2.06 ●	2.13 ○	2.00 ●	2.19 ○
postoperative-patient-data	-0.16	-0.20 ●	-0.14 ○	-0.17	-0.12
primary-tumor	0.79	0.74 ●	0.84 ○	0.71 ●	0.82 ○
segment	1.27	1.16 ●	1.32 ○	1.25 ●	1.41 ○
shuttle-landing-control	0.00	0.01	0.00	0.04 ○	-0.03
sick	0.02	-0.01 ●	0.02 ○	0.04 ○	0.02 ○
solar-flare-2	1.38	1.35 ●	1.40 ○	1.28 ●	1.34 ●
sonar	-0.43	-0.59 ●	-0.37 ○	-0.33 ○	-0.16 ○
soybean	3.23	3.14 ●	3.25 ○	3.23	3.21 ●
spambase	0.11	0.06 ●	0.14 ○	0.17 ○	0.22 ○
tae	0.02	0.01 ●	0.05 ○	0.03	0.06 ○
tic-tac-toe	0.13	0.13 ●	0.14 ○	0.12 ●	0.13 ●
trains	0.08	-0.14	0.07	0.01	-0.00
vehicle	-1.15	-1.54 ●	-1.00 ○	-0.68 ○	-0.60 ○
vote	0.14	0.08 ●	0.18 ○	0.28 ○	0.34 ○
vowel	0.80	0.58 ●	0.85 ○	0.63 ●	0.80
waveform-5000	0.51	0.46 ●	0.54 ○	0.60 ○	0.66 ○
zoo	2.16	2.16	2.18 ○	2.06 ●	2.09 ●
Average	0.47	0.39	0.49	0.45	0.53

○, ● statistically significant improvement or degradation

Table B.5: Bayesian Network Percent Incorrect

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	37.73	38.68 ○	41.04 ○	50.09 ○	41.78 ○
autos	10.06	9.23 ●	10.83	9.62	9.29 ●
balance-scale	30.55	30.14	28.49 ●	28.49 ●	29.90
breast-cancer	27.48	27.71	29.46 ○	27.41	27.59
bridges-version1	35.45	34.22	38.89 ○	36.00	38.32 ○
car	20.09	20.56 ○	15.41 ●	23.23 ○	21.45 ○
cmc	52.33	52.66 ○	49.26 ●	50.24 ●	52.12
colic	20.00	21.48 ○	19.84	19.94	21.54 ○
cylinder-bands	34.00	33.67	28.38 ●	32.69 ●	34.31
dermatology	4.60	4.75	6.10 ○	3.58 ●	4.84
diabetes	28.72	29.12	27.28 ●	27.52 ●	28.88
ecoli	35.80	35.54	33.03 ●	34.53 ●	34.63 ●
flags	38.75	38.74	42.66 ○	40.51 ○	39.48
glass	47.75	47.65	42.56 ●	46.58	47.03
haberman	31.22	30.37	31.03	27.27 ●	29.26 ●
hayes-roth-train	50.69	53.61 ○	46.97 ●	49.23	51.37
heart-h	18.20	18.55	20.18 ○	19.23 ○	19.15
heart-statlog	26.42	26.42	26.62	27.51 ○	26.50
hepatitis	19.06	18.98	20.20	19.20	20.07 ○
hypothyroid	9.55	10.63 ○	8.15 ●	8.38 ●	7.75 ●
ionosphere	26.38	30.54 ○	19.62 ●	23.94 ●	24.96 ●
iris	26.89	26.75	19.66 ●	23.54 ●	23.31 ●
kr-vs-kp	16.01	17.52 ○	11.73 ●	16.69 ○	17.27 ○
labor	5.60	5.20	8.00 ○	5.20	7.60 ○
letter	61.73	63.06 ○	56.25 ●	62.59 ○	61.68
liver-disorders	38.26	39.94 ○	37.99	39.17	38.72
lung-cancer	50.64	49.99	57.43 ○	45.55	50.90
lymph	15.70	16.58	16.14	16.49	17.30 ○
molecular-biology-promoters	13.11	11.75	23.31 ○	14.00	13.98
mushroom	5.74	6.93 ○	0.57 ●	7.89 ○	7.92 ○
nursery	17.12	18.40 ○	15.16 ●	16.51 ●	16.69 ●
optdigits	16.98	17.33 ○	10.67 ●	16.32 ●	15.99 ●
page-blocks	14.87	16.45 ○	9.23 ●	14.00 ●	10.21 ●
pendigits	29.42	29.88 ○	18.20 ●	26.14 ●	26.59 ●
postoperative-patient-data	30.95	33.40 ○	33.61 ○	30.36	33.62 ○
primary-tumor	55.23	56.20 ○	57.97 ○	54.94	56.91 ○
segment	38.08	36.91 ●	26.16 ●	33.04 ●	32.92 ●
shuttle-landing-control	45.33	46.67	40.00 ●	36.67 ●	41.33
sick	8.81	9.25 ○	7.47 ●	8.84	7.64 ●
solar-flare-2	29.38	29.20	28.22 ●	28.39 ●	29.18
sonar	25.33	25.91	23.43	25.33	24.56
soybean	10.43	11.10 ○	11.23 ○	11.28 ○	12.88 ○
spambase	26.10	25.99	22.76 ●	24.14 ●	25.85
tae	52.85	52.20	53.69	51.64	51.36
tic-tac-toe	30.40	30.45	27.29 ●	29.23 ●	30.12
trains	29.00	32.00	20.00 ●	39.00 ○	32.00
vehicle	55.43	57.54 ○	42.62 ●	55.79	54.90
vote	9.08	9.44 ○	6.78 ●	9.34 ○	9.41
vowel	72.03	73.17 ○	63.98 ●	72.30	71.61
waveform-5000	23.28	23.63 ○	24.25 ○	23.63 ○	23.68 ○
zoo	12.71	13.16	13.50	11.33	12.51
Average	28.85	29.40	26.93	28.52	28.80

○, ● statistically significant improvement or degradation

Table B.6: Bayesian Network Mean Absolute Error

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03	0.04 ○	0.04 ○	0.04 ○
autos	0.10	0.10	0.11 ○	0.10	0.10
balance-scale	0.26	0.26 ●	0.26 ●	0.28 ○	0.29 ○
breast-cancer	0.32	0.32 ●	0.35 ○	0.32	0.33 ○
bridges-version1	0.14	0.14 ●	0.16 ○	0.15 ○	0.16 ○
car	0.12	0.12 ○	0.12	0.14 ○	0.17 ○
cmc	0.39	0.38 ●	0.38	0.39	0.40 ○
colic	0.22	0.23 ○	0.23 ○	0.22	0.25 ○
cylinder-bands	0.35	0.35 ○	0.32 ●	0.35	0.37 ○
dermatology	0.02	0.02	0.03 ○	0.02 ●	0.02 ○
diabetes	0.33	0.33 ○	0.34 ○	0.33 ○	0.35 ○
ecoli	0.10	0.10 ●	0.11 ○	0.11 ○	0.12 ○
flags	0.10	0.10	0.11 ○	0.11 ○	0.11 ○
glass	0.16	0.16 ●	0.16	0.16 ○	0.17 ○
haberman	0.38	0.37 ●	0.38	0.37 ●	0.40 ○
hayes-roth-train	0.31	0.31	0.30 ●	0.31 ○	0.32 ○
heart-h	0.09	0.09 ●	0.11 ○	0.10 ○	0.11 ○
heart-statlog	0.30	0.30	0.33 ○	0.31 ○	0.32 ○
hepatitis	0.20	0.20 ●	0.23 ○	0.21 ○	0.23 ○
hypothyroid	0.07	0.07	0.06 ●	0.07 ●	0.10 ○
ionosphere	0.27	0.30 ○	0.22 ●	0.26	0.27
iris	0.20	0.20	0.22 ○	0.21 ○	0.21 ○
kr-vs-kp	0.23	0.24 ○	0.18 ●	0.25 ○	0.30 ○
labor	0.08	0.08	0.11 ○	0.09 ○	0.12 ○
letter	0.06	0.06 ●	0.05 ●	0.06 ○	0.06 ○
liver-disorders	0.46	0.46	0.44 ●	0.46	0.47 ○
lung-cancer	0.34	0.33	0.39 ○	0.31 ●	0.34
lymph	0.10	0.10 ○	0.10 ○	0.11 ○	0.11 ○
molecular-biology-promoters	0.14	0.13	0.24 ○	0.15 ○	0.15 ○
mushroom	0.06	0.07 ○	0.01 ●	0.08 ○	0.08 ○
nursery	0.09	0.10 ○	0.10 ○	0.13 ○	0.14 ○
optdigits	0.04	0.04 ○	0.03 ●	0.04 ○	0.04 ○
page-blocks	0.08	0.08 ○	0.06 ●	0.07 ●	0.10 ○
pendigits	0.07	0.07	0.05 ●	0.07 ○	0.07 ○
postoperative-patient-data	0.27	0.28 ○	0.28 ○	0.27	0.30 ○
primary-tumor	0.06	0.06 ●	0.06 ○	0.06 ○	0.06 ○
segment	0.11	0.11 ●	0.10 ●	0.11 ●	0.11 ●
shuttle-landing-control	0.44	0.44	0.45 ○	0.44	0.44
sick	0.10	0.11 ○	0.10 ●	0.11 ○	0.15 ○
solar-flare-2	0.11	0.11 ●	0.12 ○	0.12 ○	0.13 ○
sonar	0.26	0.26	0.27	0.26	0.26
soybean	0.01	0.01 ○	0.01 ○	0.01 ○	0.02 ○
spambase	0.28	0.28	0.30 ○	0.28 ○	0.29 ○
tae	0.40	0.40	0.42 ○	0.41 ○	0.41 ○
tic-tac-toe	0.36	0.36 ●	0.36 ●	0.37 ○	0.39 ○
trains	0.30	0.34	0.23 ●	0.35 ○	0.34
vehicle	0.29	0.29 ○	0.25 ●	0.29 ○	0.29 ○
vote	0.10	0.10 ○	0.08 ●	0.10 ○	0.10 ○
vowel	0.14	0.14	0.13 ●	0.15 ○	0.14 ○
waveform-5000	0.16	0.17 ○	0.19 ○	0.17 ○	0.17 ○
zoo	0.04	0.04	0.05 ○	0.04	0.05 ○
Average	0.19	0.19	0.19	0.20	0.21

○, ● statistically significant improvement or degradation

Table B.7: Bayesian Network Root Mean Squared Error

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.16	0.16 ○	0.16 ○	0.17 ○	0.16 ○
autos	0.28	0.28	0.30 ○	0.27 ●	0.27 ●
balance-scale	0.35	0.35 ○	0.35 ○	0.36 ○	0.36 ○
breast-cancer	0.45	0.46 ○	0.45	0.44 ●	0.44 ●
bridges-version1	0.29	0.29	0.30 ○	0.29	0.29 ○
car	0.27	0.27 ○	0.23 ●	0.26 ●	0.27
cmc	0.46	0.47 ○	0.45 ●	0.45 ●	0.46 ●
colic	0.42	0.43 ○	0.40 ●	0.41 ●	0.41 ●
cylinder-bands	0.48	0.50 ○	0.45 ●	0.47 ●	0.47 ●
dermatology	0.10	0.10	0.12 ○	0.09 ●	0.11
diabetes	0.43	0.44 ○	0.42 ●	0.42 ●	0.43 ●
ecoli	0.24	0.25 ○	0.23 ●	0.23 ●	0.24 ●
flags	0.27	0.27	0.28 ○	0.27	0.27
glass	0.30	0.30 ○	0.29 ●	0.29 ●	0.29 ●
haberman	0.45	0.45	0.45	0.44 ●	0.45 ●
hayes-roth-train	0.39	0.40 ○	0.38 ●	0.39 ○	0.39
heart-h	0.24	0.24	0.24 ○	0.23 ●	0.23
heart-statlog	0.43	0.44 ○	0.42 ●	0.42 ●	0.43 ●
hepatitis	0.39	0.39	0.39	0.39 ●	0.38 ●
hypothyroid	0.19	0.20 ○	0.18 ●	0.18 ●	0.19 ○
ionosphere	0.45	0.50 ○	0.39 ●	0.43 ●	0.43 ●
iris	0.36	0.36 ○	0.33 ●	0.34 ●	0.34 ●
kr-vs-kp	0.33	0.35 ○	0.29 ●	0.34 ○	0.36 ○
labor	0.18	0.18	0.22 ○	0.19	0.22 ○
letter	0.17	0.18 ○	0.16 ●	0.17 ○	0.17 ●
liver-disorders	0.48	0.49 ○	0.48 ●	0.48 ○	0.48
lung-cancer	0.52	0.52	0.56 ○	0.48 ●	0.52
lymph	0.23	0.24 ○	0.24	0.24	0.24
molecular-biology-promoters	0.30	0.29	0.43 ○	0.31	0.31
mushroom	0.22	0.25 ○	0.07 ●	0.26 ○	0.26 ○
nursery	0.23	0.25 ○	0.21 ●	0.23 ○	0.24 ○
optdigits	0.16	0.17 ○	0.13 ●	0.16 ●	0.16 ●
page-blocks	0.21	0.23 ○	0.17 ●	0.20 ●	0.19 ●
pendigits	0.21	0.21 ○	0.16 ●	0.20 ●	0.20 ●
postoperative-patient-data	0.39	0.40 ○	0.41 ○	0.39	0.40 ○
primary-tumor	0.18	0.19 ○	0.18 ○	0.18 ●	0.18
segment	0.28	0.28	0.23 ●	0.26 ●	0.25 ●
shuttle-landing-control	0.48	0.48	0.49 ○	0.48	0.49
sick	0.25	0.26 ○	0.23 ●	0.25 ●	0.24 ●
solar-flare-2	0.26	0.26 ○	0.25 ●	0.25 ●	0.25 ●
sonar	0.45	0.46 ○	0.42 ●	0.45	0.44 ●
soybean	0.10	0.10 ○	0.09	0.10 ○	0.10 ○
spambase	0.44	0.44 ○	0.39 ●	0.42 ●	0.42 ●
tae	0.47	0.47 ○	0.47 ○	0.46 ●	0.46 ●
tic-tac-toe	0.44	0.44 ○	0.43 ●	0.44 ●	0.44 ●
trains	0.39	0.43	0.29 ●	0.43	0.43
vehicle	0.45	0.46 ○	0.37 ●	0.44 ●	0.44 ●
vote	0.29	0.29 ○	0.23 ●	0.29	0.29
vowel	0.28	0.29 ○	0.27 ●	0.28 ●	0.27 ●
waveform-5000	0.36	0.36 ○	0.34 ●	0.35 ●	0.35 ●
zoo	0.15	0.15	0.15	0.14 ●	0.15
Average	0.32	0.33	0.31	0.32	0.32

○, ● statistically significant improvement or degradation

Table B.8: Bayesian Network Mean Entropy Gain

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-1.00	-1.07 ●	-1.86 ●	-2.14 ●	-0.12 ○
autos	-0.14	-0.14	0.20 ○	0.11 ○	0.17 ○
balance-scale	0.37	0.37 ●	0.37	0.32 ●	0.33 ●
breast-cancer	-0.07	-0.10 ●	-0.02 ○	-0.00 ○	0.01 ○
bridges-version1	0.55	0.47 ●	0.61 ○	0.67 ○	0.65 ○
car	0.26	0.24 ●	0.67 ○	0.57 ○	0.44 ○
cmc	-0.02	-0.12 ●	0.09 ○	0.04 ○	0.05 ○
colic	-0.34	-0.45 ●	0.00 ○	-0.17 ○	0.00 ○
cylinder-bands	-0.05	-0.19 ●	0.08 ○	0.04 ○	0.05 ○
dermatology	2.26	2.26	2.15 ●	2.29 ○	2.25
diabetes	0.13	0.10 ●	0.17 ○	0.16 ○	0.15 ○
ecoli	0.78	0.74 ●	0.97 ○	0.96 ○	0.87 ○
flags	0.04	-0.08 ●	-0.09 ●	0.27 ○	0.25 ○
glass	0.43	0.36 ●	0.49	0.53 ○	0.46
haberman	-0.05	-0.05	-0.03	-0.01 ○	-0.02 ○
hayes-roth-train	0.12	0.07 ●	0.15 ○	0.10 ●	0.08 ●
heart-h	0.23	0.22	0.26	0.30 ○	0.25
heart-statlog	0.14	0.10 ●	0.21 ○	0.22 ○	0.20 ○
hepatitis	-0.20	-0.24 ●	-0.14	-0.09 ○	0.01 ○
hypothyroid	0.07	0.02 ●	0.10 ○	0.09 ○	0.01 ●
ionosphere	-0.24	-0.65 ●	0.01 ○	-0.08 ○	-0.06 ○
iris	0.63	0.60 ●	0.79 ○	0.76 ○	0.78 ○
kr-vs-kp	0.51	0.47 ●	0.60 ○	0.48 ●	0.42 ●
labor	0.66	0.68 ○	0.65	0.70 ○	0.65
letter	1.55	1.36 ●	2.03 ○	1.58 ○	1.67 ○
liver-disorders	0.04	0.01 ●	0.06	0.03 ●	0.04
lung-cancer	-2.01	-2.02	-1.97	-1.21 ○	-1.63 ○
lymph	0.71	0.67 ●	0.62 ●	0.72	0.68
molecular-biology-promoters	0.39	0.43	-0.28 ●	0.43	0.39
mushroom	0.64	0.46 ●	0.97 ○	0.57 ●	0.59 ●
nursery	0.81	0.48 ●	1.14 ○	1.00 ○	0.89 ○
optdigits	2.14	2.10 ●	2.78 ○	2.37 ○	2.47 ○
page-blocks	0.04	-0.12 ●	0.24 ○	0.11 ○	0.09 ○
pendigits	1.62	1.56 ●	2.49 ○	2.00 ○	2.03 ○
postoperative-patient-data	-0.20	-0.23 ●	-0.24	-0.17 ○	-0.18
primary-tumor	0.56	0.49 ●	0.62 ○	0.71 ○	0.66 ○
segment	0.76	0.76	1.81 ○	1.25 ○	1.33 ○
shuttle-landing-control	0.04	0.03	-0.01 ●	0.04	-0.00
sick	0.02	-0.01 ●	0.08 ○	0.04 ○	0.03 ○
solar-flare-2	1.19	1.15 ●	1.32 ○	1.28 ○	1.26 ○
sonar	-0.51	-0.67 ●	0.09 ○	-0.33 ○	-0.22 ○
soybean	3.17	3.08 ●	3.31 ○	3.23 ○	3.14 ●
spambase	0.06	0.01 ●	0.28 ○	0.17 ○	0.18 ○
tae	-0.02	-0.04 ●	-0.02	0.03 ○	0.05 ○
tic-tac-toe	0.11	0.10 ●	0.16 ○	0.12	0.12
trains	-0.17	-0.58 ●	0.32 ○	0.01	-0.26
vehicle	-1.17	-1.51 ●	0.51 ○	-0.68 ○	-0.60 ○
vote	0.12	0.06 ●	0.66 ○	0.28 ○	0.32 ○
vowel	0.57	0.34 ●	1.00 ○	0.63 ○	0.69 ○
waveform-5000	0.40	0.34 ●	0.78 ○	0.60 ○	0.61 ○
zoo	1.95	1.91	1.94	2.06 ○	1.96
Average	0.35	0.27	0.53	0.45	0.47

○, ● statistically significant improvement or degradation

Table B.9: J48 Decision Tree Percent Incorrect

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	29.13	31.13 ○	32.94 ○	35.33 ○	36.43 ○
autos	13.68	14.78	13.02	14.68	12.59
balance-scale	28.72	29.47 ○	29.02	29.56 ○	29.10
breast-cancer	25.70	26.91 ○	26.80 ○	26.68	28.09 ○
bridges-version1	43.54	45.20	41.77	45.89	44.09
car	16.03	15.95	16.73 ○	20.18 ○	17.85 ○
cmc	49.48	49.07	50.17 ○	50.40	51.20 ○
colic	18.03	18.18	17.32 ●	18.98 ○	18.52
cylinder-bands	34.06	34.01	34.84	35.73 ○	35.38
dermatology	10.97	12.26	10.04	13.33 ○	13.97 ○
diabetes	29.29	29.00	28.61	27.73 ●	28.77
ecoli	35.34	34.72	34.92	37.23 ○	34.46
flags	40.07	42.00 ○	41.94	44.77 ○	42.50
glass	41.32	40.66	38.89 ●	41.35	42.51
haberman	27.56	26.90 ●	26.57 ●	26.57 ●	26.57 ●
hayes-roth-train	37.26	37.78	37.95	42.43 ○	41.13 ○
heart-h	21.09	21.81	22.94 ○	23.77 ○	21.81
heart-statlog	32.01	30.36 ●	32.32	30.04 ●	32.17
hepatitis	22.84	22.02	22.10	23.28	22.39
hypothyroid	7.76	7.73	7.73	7.73	7.73
ionosphere	20.67	18.76 ●	19.37	21.55	22.19
iris	25.87	26.59	20.50 ●	22.24 ●	23.71
kr-vs-kp	5.97	6.05	6.09	5.88	7.79 ○
labor	23.60	26.20	27.80 ○	21.40	21.80
letter	49.11	49.10	47.39 ●	51.04 ○	49.21
liver-disorders	39.83	40.06	40.16	38.54	41.57 ○
lung-cancer	59.79	62.11	67.29 ○	55.14	65.87
lymph	20.02	20.34	21.75	23.36 ○	21.01
molecular-biology-promoters	21.19	21.59	20.22	26.85 ○	23.67
mushroom	2.22	3.47 ○	0.86 ●	0.57 ●	1.33 ●
nursery	12.00	12.22 ○	12.58 ○	14.34 ○	13.15 ○
optdigits	17.18	17.09	13.90 ●	23.70 ○	17.69 ○
page-blocks	7.27	7.30 ○	7.25	7.27	7.28
pendigits	15.72	15.79	11.80 ●	16.89 ○	13.67 ●
postoperative-patient-data	29.84	29.24	29.24	29.24	29.35
primary-tumor	61.77	61.54	60.68	61.71	62.96
segment	26.45	26.61	21.77 ●	25.39 ●	24.26 ●
shuttle-landing-control	41.33	42.00	40.00	41.33	43.33
sick	6.20	6.19	6.19	6.19	6.21
solar-flare-2	30.14	30.30	28.17 ●	29.45 ●	29.04 ●
sonar	32.41	33.22	30.93	32.63	32.86
soybean	18.86	18.09	16.24 ●	18.71	20.59 ○
spambase	22.43	22.36	21.79 ●	22.36	21.84 ●
tae	49.35	49.85	48.07 ●	51.07	52.30 ○
tic-tac-toe	22.47	22.08	21.55	21.98	23.79 ○
trains	1.00	10.00 ○	0.00	0.00	8.00
vehicle	40.13	40.98 ○	38.88 ●	42.76 ○	41.39
vote	8.67	8.44	6.34 ●	7.03 ●	7.49 ●
vowel	49.88	50.02	52.36 ○	54.88 ○	53.20 ○
waveform-5000	27.95	27.44 ●	25.72 ●	32.41 ○	29.50 ○
zoo	15.94	18.01 ○	15.39	18.76 ○	18.10
Average	26.85	27.31	26.41	27.85	27.87

○, ● statistically significant improvement or degradation

Table B.10: J48 Decision Tree Mean Absolute Error

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03	0.04 ○	0.04 ○	0.04 ○
autos	0.19	0.19	0.19	0.21 ○	0.21 ○
balance-scale	0.26	0.26	0.29 ○	0.28 ○	0.30 ○
breast-cancer	0.37	0.37	0.38 ○	0.37	0.40 ○
bridges-version1	0.16	0.17	0.17 ○	0.18 ○	0.19 ○
car	0.09	0.09	0.12 ○	0.12 ○	0.14 ○
cmc	0.39	0.38 ●	0.40 ○	0.39 ○	0.40 ○
colic	0.26	0.25 ●	0.28 ○	0.27 ○	0.30 ○
cylinder-bands	0.37	0.37	0.40 ○	0.39 ○	0.40 ○
dermatology	0.05	0.06 ○	0.07 ○	0.07 ○	0.09 ○
diabetes	0.36	0.35 ●	0.38 ○	0.36 ○	0.38 ○
ecoli	0.10	0.10	0.11 ○	0.11 ○	0.12 ○
flags	0.12	0.12	0.13 ○	0.13 ○	0.13 ○
glass	0.14	0.14	0.15 ○	0.15 ○	0.16 ○
haberman	0.39	0.38 ●	0.39	0.38 ●	0.40 ○
hayes-roth-train	0.24	0.23 ●	0.26 ○	0.27 ○	0.28 ○
heart-h	0.11	0.11	0.12 ○	0.13 ○	0.14 ○
heart-statlog	0.37	0.36	0.40 ○	0.38	0.39 ○
hepatitis	0.29	0.27 ●	0.29	0.28	0.30
hypothyroid	0.07	0.07 ●	0.07	0.07 ●	0.11 ○
ionosphere	0.25	0.23 ●	0.27 ○	0.26 ○	0.28 ○
iris	0.20	0.20	0.22 ○	0.23 ○	0.24 ○
kr-vs-kp	0.09	0.09 ●	0.14 ○	0.13 ○	0.19 ○
labor	0.25	0.26	0.32 ○	0.22	0.27
letter	0.05	0.04 ●	0.05 ○	0.05 ○	0.05 ○
liver-disorders	0.45	0.45	0.46 ○	0.46 ○	0.47 ○
lung-cancer	0.39	0.40	0.44 ○	0.37	0.44 ○
lymph	0.13	0.13	0.15 ○	0.14 ○	0.15 ○
molecular-biology-promoters	0.25	0.25	0.27	0.30 ○	0.29 ○
mushroom	0.05	0.05 ○	0.03 ●	0.05 ○	0.09 ○
nursery	0.06	0.06 ○	0.09 ○	0.10 ○	0.12 ○
optdigits	0.05	0.05 ●	0.05 ○	0.06 ○	0.06 ○
page-blocks	0.05	0.05 ●	0.05 ○	0.05 ○	0.08 ○
pendigits	0.05	0.05 ●	0.05 ○	0.06 ○	0.06 ○
postoperative-patient-data	0.28	0.28 ●	0.28	0.28 ●	0.30 ○
primary-tumor	0.06	0.06	0.07 ○	0.06	0.07 ○
segment	0.10	0.09 ●	0.10 ○	0.11 ○	0.12 ○
shuttle-landing-control	0.49	0.49	0.49	0.49	0.49
sick	0.12	0.11 ●	0.12	0.11 ●	0.16 ○
solar-flare-2	0.12	0.12 ●	0.13 ○	0.13 ○	0.14 ○
sonar	0.34	0.35	0.35	0.34	0.35
soybean	0.02	0.02 ●	0.03 ○	0.03 ○	0.04 ○
spambase	0.31	0.30 ●	0.32 ○	0.33 ○	0.33 ○
tae	0.40	0.39 ●	0.40 ○	0.41 ○	0.41 ○
tic-tac-toe	0.28	0.28	0.30 ○	0.28	0.32 ○
trains	0.01	0.09 ○	0.00	0.00	0.09 ○
vehicle	0.23	0.23	0.25 ○	0.25 ○	0.25 ○
vote	0.11	0.10	0.11	0.13 ○	0.15 ○
vowel	0.10	0.10	0.12 ○	0.11 ○	0.11 ○
waveform-5000	0.21	0.21 ●	0.22 ○	0.24 ○	0.24 ○
zoo	0.06	0.07	0.07	0.07 ○	0.08 ○
Average	0.19	0.19	0.21	0.20	0.22

○, ● statistically significant improvement or degradation

Table B.11: J48 Root Mean Squared Error

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.13	0.14 ○	0.14 ○	0.15 ○	0.15 ○
autos	0.33	0.35	0.33	0.35	0.32
balance-scale	0.37	0.38 ○	0.37	0.38 ○	0.38
breast-cancer	0.44	0.45	0.44	0.45	0.45 ○
bridges-version1	0.32	0.33 ○	0.31	0.33 ○	0.33 ○
car	0.23	0.23	0.23 ○	0.26 ○	0.25 ○
cmc	0.46	0.46	0.45 ●	0.46 ○	0.46
colic	0.38	0.39	0.37 ●	0.40 ○	0.39
cylinder-bands	0.49	0.50	0.48 ●	0.53 ○	0.50
dermatology	0.17	0.18 ○	0.16	0.19 ○	0.19 ○
diabetes	0.44	0.45 ○	0.44 ●	0.44	0.44
ecoli	0.24	0.24 ○	0.23	0.24 ○	0.24
flags	0.27	0.28	0.27	0.30 ○	0.28
glass	0.29	0.29	0.28 ●	0.30 ○	0.29
haberman	0.45	0.44	0.44 ●	0.44	0.44
hayes-roth-train	0.36	0.36	0.36	0.38 ○	0.37 ○
heart-h	0.25	0.25	0.26 ○	0.27 ○	0.25
heart-statlog	0.47	0.47	0.47	0.47	0.47
hepatitis	0.43	0.42	0.41 ●	0.44	0.42
hypothyroid	0.19	0.19	0.19	0.19	0.20 ○
ionosphere	0.40	0.38	0.38	0.43 ○	0.42 ○
iris	0.33	0.33	0.32 ●	0.34 ○	0.33
kr-vs-kp	0.21	0.21	0.22 ○	0.24 ○	0.26 ○
labor	0.40	0.41	0.45 ○	0.40	0.39
letter	0.15	0.16 ○	0.15 ●	0.16 ○	0.16 ○
liver-disorders	0.49	0.50 ○	0.49	0.50	0.50
lung-cancer	0.56	0.56	0.57	0.55	0.59 ○
lymph	0.28	0.29	0.29	0.31 ○	0.29
molecular-biology-promoters	0.41	0.41	0.40	0.47 ○	0.43
mushroom	0.14	0.15 ○	0.09 ●	0.10 ●	0.13 ●
nursery	0.18	0.18 ○	0.19 ○	0.22 ○	0.20 ○
optdigits	0.16	0.16	0.15 ●	0.20 ○	0.17 ○
page-blocks	0.16	0.16	0.16 ○	0.16 ○	0.16 ○
pendigits	0.15	0.15	0.14 ●	0.17 ○	0.15
postoperative-patient-data	0.38	0.38	0.38	0.38	0.38
primary-tumor	0.20	0.20	0.19 ●	0.20 ○	0.20
segment	0.22	0.23	0.21 ●	0.24 ○	0.23
shuttle-landing-control	0.50	0.50	0.50	0.50	0.51
sick	0.24	0.24	0.24	0.24	0.25 ○
solar-flare-2	0.25	0.25 ○	0.25 ●	0.26 ○	0.26 ○
sonar	0.51	0.52	0.48 ●	0.54 ○	0.51
soybean	0.12	0.12	0.11 ●	0.13 ○	0.13 ○
spambase	0.39	0.40 ○	0.39 ●	0.41 ○	0.39
tae	0.46	0.46	0.45 ●	0.47 ○	0.46
tic-tac-toe	0.41	0.41	0.39 ●	0.41	0.42
trains	0.01	0.09 ○	0.00	0.00	0.10 ○
vehicle	0.36	0.36 ○	0.35 ●	0.39 ○	0.37 ○
vote	0.24	0.24	0.23 ●	0.25	0.24
vowel	0.24	0.25	0.24	0.27 ○	0.25 ○
waveform-5000	0.38	0.37	0.35 ●	0.43 ○	0.38 ○
zoo	0.19	0.19	0.18 ●	0.20 ○	0.20
Average	0.31	0.31	0.31	0.32	0.32

○, ● statistically significant improvement or degradation

Table B.12: J48 Decision Tree Mean Entropy Gain

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-111.99	-117.88	-87.04 ○	-158.79 ●	-132.51 ●
autos	-17.82	-18.41	-3.68 ○	-21.39	-10.74
balance-scale	-2.57	-2.22	0.25 ○	-2.59	-0.13 ○
breast-cancer	-13.39	-10.55	-1.20 ○	-16.63	-10.55
bridges-version1	-151.55	-162.36	-77.69 ○	-133.17	-133.59
car	-17.59	-17.81	-1.06 ○	-39.71 ●	-13.41 ○
cmc	-24.22	-20.66	-0.50 ○	-31.94 ●	-15.37 ○
colic	-19.82	-20.17	-0.69 ○	-36.02 ●	-15.21
cylinder-bands	-48.29	-54.02	-1.51 ○	-101.43 ●	-45.65
dermatology	-19.57	-28.30 ●	-0.63 ○	-55.02 ●	-25.22
diabetes	-2.86	-4.58	0.11 ○	-2.54	-1.14
ecoli	-38.97	-39.01	-21.92 ○	-51.93 ●	-21.36 ○
flags	-176.53	-191.86	-59.40 ○	-262.88 ●	-194.28
glass	-85.34	-95.00	-20.88 ○	-134.49 ●	-66.81 ○
haberman	-1.60	-0.01	0.00	-0.00	-0.00
hayes-roth-train	-26.51	-26.47	0.32 ○	-24.76	-6.18 ○
heart-h	-24.50	-22.09	-0.60 ○	-21.34	-11.60 ○
heart-statlog	-17.59	-24.89 ●	0.08 ○	-24.89	-13.21
hepatitis	-34.79	-43.30	-5.45 ○	-56.53	-27.84
hypothyroid	-0.25	-0.00	-0.00	-0.00	-0.06
ionosphere	-37.49	-31.33	-2.47 ○	-86.84 ●	-43.67
iris	-17.69	-18.53	0.06 ○	-14.53	0.79 ○
kr-vs-kp	-0.18	-0.03	0.73 ○	-4.54 ●	-1.74 ●
labor	-59.74	-46.92	-14.96 ○	-78.97	-38.26
letter	-49.47	-50.59 ●	-2.75 ○	-123.96 ●	-42.88 ○
liver-disorders	-7.41	-8.49	-0.34 ○	-7.05	-1.76 ○
lung-cancer	-363.37	-347.14	-285.77	-349.74	-427.12
lymph	-59.55	-57.39	-14.26 ○	-98.35 ●	-58.21
molecular-biology-promoters	-90.56	-102.45	-10.05 ○	-120.80 ●	-86.50
mushroom	0.91	0.90 ●	0.94 ○	0.12 ●	0.83 ●
nursery	-4.78	-5.08	1.23 ○	-8.25 ●	-1.33 ○
optdigits	-46.57	-47.29	-5.72 ○	-172.03 ●	-48.23
page-blocks	-0.44	-0.52	-0.10 ○	-1.16 ●	0.08 ○
pendigits	-10.10	-10.69 ●	1.74 ○	-52.19 ●	-5.57 ○
postoperative-patient-data	-1.28	-0.01	-0.01	-0.01	-1.28
primary-tumor	-297.02	-284.90	-120.47 ○	-366.49 ●	-315.85
segment	-11.43	-12.00	0.95 ○	-51.51 ●	-6.16 ○
shuttle-landing-control	-0.01	-0.03	-0.00	-0.01	-21.46
sick	0.00	-0.00	0.00	-0.00	-0.02 ●
solar-flare-2	-20.25	-23.66	-1.14 ○	-45.09 ●	-21.53
sonar	-132.17	-130.59	-26.02 ○	-213.09 ●	-120.45
soybean	-24.16	-22.74	-4.49 ○	-112.98 ●	-36.20 ●
spambase	-0.12	-0.41 ●	0.28 ○	0.15 ○	0.27 ○
tae	-16.71	-9.90	0.09 ○	-18.33	-5.29 ○
tic-tac-toe	-30.09	-29.23	0.12 ○	-34.08	-23.32 ○
trains	0.99	-42.09 ●	1.01	1.01	-42.08 ●
vehicle	-36.01	-35.91	-3.43 ○	-125.50 ●	-40.04
vote	-5.11	-6.47	-0.43 ○	-19.92 ●	-5.95
vowel	-103.51	-103.65	-15.15 ○	-292.68 ●	-121.50 ●
waveform-5000	-49.76	-46.96	-0.12 ○	-165.15 ●	-55.58 ●
zoo	-45.13	-40.46	-19.36 ○	-111.23 ●	-50.10
Average	-46.16	-47.34	-15.71	-75.48	-46.37

○, ● statistically significant improvement or degradation

Appendix C

Hidden Variables

In neural networks, many hidden layers generally exist between the input and output layer and each is trained to determine particular characteristics of an input, either from the actual input or from a preceding layer [5]. This appendix attempts to apply a similar concept to the iterative training method described in Section 2.1 by adding additional attributes to the training set before the algorithm begins, and investigating the effect of these on classification accuracy.

C.1 Implementation

The implemented *ProjectClassifier* class from Section 2.2.8 accepts an optional parameter (-N followed by a number), which represents the number of 'hidden variables' which will be added to the test data set during training. It is hoped that each of these hidden variables will correspond to some trend within the training data. In order to simplify the scope of the experiments, the added attributes will each be binary attributes where a 1 represents the presence of the unknown trend, while a 0 will represent its absence.

The training algorithm then becomes the following:

1. Add x additional attributes to the training set, where x is the specified number of hidden variables
2. Fill each of these added columns with random data by adding either a 1 or a 0
3. Train the model normally
4. Once the data set has converged, remove the added columns

This should cause the model to behave slightly differently during classification than if it had been trained without the hidden attributes.

C.2 Experiments

The experiments described here follow much the same format as those described in section 3, with only slight alterations. Exactly the same test cases and data sets are used as those described there, except hidden variables are added to Cases 1 and 2. Experiments will be carried out with three and five added hidden variables, and these will then be compared with relevant results found with 0 hidden variables earlier in the work.

C.2.1 Naive Bayes

The results for the Naive Bayes classifier with various numbers of hidden variables can be seen in figures C.1 - C.8.

From the percent incorrect results (figures B.1, C.1 and C.2), it can be seen that increasing the number of hidden variables decreased the accuracy of the classifier quite significantly. With no hidden variables, Case 1 was roughly as accurate as Case 3 in 30 tests, and less accurate in 19. With three hidden variables it was as accurate in 19 tests and less accurate in 28 cases, and with 5 hidden variables it was even in 17 tests and performed significantly worse in 32 cases. At five hidden variables Case 1 was roughly as accurate as Case 4, and actually less accurate than Case 5.

The Naive Bayes MAE results (figures B.2, C.3 and C.4) show a similar trend. While Case 1 outperformed Cases 3 and 5 with 0 hidden variables, increasing the number of hidden variables caused Case 1 to perform less well relative to these classifiers. Case 1 still performed better than Case 4 in all three experiments.

The Naive Bayes RMSE results (figures B.3, C.5 and C.6) show that adding hidden variables during training appears to significantly lower RMSE. Case 1 was outperformed by the other cases in all three experiments, and the number of tests in which they were outperformed increased from 36 to 41 when three hidden variables were added. This is probably because the iterative training method will generally lead to very strong predictions one way or the other, and adding additional random data to this is likely to cause more extreme predictions.

From the Naive Bayes MEG results in figures B.4, C.7 and C.8, it can be seen that adding additional hidden variables caused large reductions in entropy. With three added hidden variables Case 1 showed larger entropy reductions than Cases 4 and 5, with large increases in the number of tests in which this was observed. A similar trend was observed when five hidden variables were added. This is probably due to so the amount of additional data being added to the system (X hidden variables $\times Y$ rows of data). It is assumed that this causes the iterative training to find and favour certain trends, and therefore reduce the entropy of the whole data set.

Table C.1: Naive Bayes Percent Incorrect - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	37.44	38.34 ○	37.28	50.09 ○	37.28
autos	9.89	9.94	10.22	9.62	10.22
balance-scale	25.78	26.03	26.26	28.49 ○	26.26
breast-cancer	27.33	27.52	27.14	27.41	27.14
bridges-version1	34.68	34.57	35.45	36.00	35.45
car	19.51	19.75	19.46	23.23 ○	19.46
cmc	51.92	52.39 ○	50.69 ●	50.24 ●	50.69 ●
colic	22.65	22.22	20.92 ●	19.94 ●	20.92 ●
cylinder-bands	32.93	32.73	31.79 ●	32.69	31.79 ●
dermatology	3.10	3.16	2.95	3.58	2.95
diabetes	29.18	28.88	27.79 ●	27.52 ●	27.79 ●
ecoli	33.39	32.96	32.67 ●	34.53 ○	32.67 ●
flags	36.86	37.05	38.46 ○	40.51 ○	38.46 ○
glass	47.78	45.17 ●	46.42	46.58	46.42
haberman	28.34	27.93	27.71	27.27 ●	27.71
hayes-roth-train	53.76	55.09	47.16 ●	49.23 ●	47.16 ●
heart-h	17.75	18.13 ○	18.39 ○	19.23 ○	18.39 ○
heart-statlog	26.74	27.03	27.10	27.51	27.10
hepatitis	18.84	18.99	19.06	19.20	19.06
hypothyroid	11.07	12.42 ○	8.74 ●	8.38 ●	8.74 ●
ionosphere	31.46	30.99 ●	24.93 ●	23.94 ●	24.93 ●
iris	21.89	21.43 ●	21.51	23.54 ○	21.51
kr-vs-kp	16.53	16.50	14.01 ●	16.69	14.01 ●
labor	5.40	5.00	4.80	5.20	4.80
letter	62.20	62.01 ●	59.84 ●	62.59 ○	59.84 ●
liver-disorders	39.38	40.30	37.31 ●	39.17	37.31 ●
lung-cancer	47.87	51.21	53.02 ○	45.55	53.02 ○
lymph	16.23	16.23	15.65	16.49	15.65
molecular-biology-promoters	9.95	9.53	8.56	14.00 ○	8.56
mushroom	6.89	6.86	5.06 ●	7.89 ○	5.06 ●
nursery	16.11	16.06	15.87 ●	16.51 ○	15.87 ●
optdigits	14.03	14.05	13.10 ●	16.32 ○	13.10 ●
page-blocks	27.29	19.30 ●	16.82 ●	14.00 ●	16.82 ●
pendigits	23.03	22.49 ●	21.21 ●	26.14 ○	21.21 ●
postoperative-patient-data	31.16	32.42	29.98	30.36	29.98
primary-tumor	55.55	55.16	54.13 ●	54.94	54.13 ●
segment	30.06	30.79 ○	28.12 ●	33.04 ○	28.12 ●
shuttle-landing-control	41.33	44.67	46.67 ○	36.67	46.67 ○
sick	10.73	10.23 ●	9.81 ●	8.84 ●	9.81 ●
solar-flare-2	28.29	28.33	28.16	28.39	28.16
sonar	26.16	25.85	24.14 ●	25.33	24.14 ●
soybean	10.44	10.34	9.77 ●	11.28 ○	9.77 ●
spambase	25.42	24.84 ●	24.51 ●	24.14 ●	24.51 ●
tae	51.29	49.86	48.92 ●	51.64	48.92 ●
tic-tac-toe	29.98	30.07	29.49 ●	29.23 ●	29.49 ●
trains	36.00	33.00	31.00	39.00	31.00
vehicle	56.72	56.82	53.71 ●	55.79 ●	53.71 ●
vote	9.57	9.57	9.47 ●	9.34	9.47 ●
vowel	71.54	71.71	69.27 ●	72.30	69.27 ●
waveform-5000	22.62	22.65	22.44 ●	23.63 ○	22.44 ●
zoo	9.11	9.12	8.78	11.33 ○	8.78

○, ● statistically significant improvement or degradation

Table C.2: Naive Bayes Percent Incorrect - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	38.18	38.44	37.28 ●	50.09 ○	37.28 ●
autos	9.94	9.94	10.22	9.62	10.22
balance-scale	26.08	26.27	26.26	28.49 ○	26.26
breast-cancer	27.86	27.67	27.14 ●	27.41	27.14 ●
bridges-version1	34.85	33.87	35.45	36.00	35.45
car	19.51	19.71	19.46	23.23 ○	19.46
cmc	52.00	52.32	50.69 ●	50.24 ●	50.69 ●
colic	22.74	22.25 ●	20.92 ●	19.94 ●	20.92 ●
cylinder-bands	33.08	32.89	31.79 ●	32.69	31.79 ●
dermatology	3.19	3.04	2.95	3.58	2.95
diabetes	29.15	28.90	27.79 ●	27.52 ●	27.79 ●
ecoli	32.90	33.35	32.67	34.53 ○	32.67
flags	37.22	37.26	38.46 ○	40.51 ○	38.46 ○
glass	48.25	44.82 ●	46.42 ●	46.58	46.42 ●
haberman	28.53	28.12	27.71 ●	27.27 ●	27.71 ●
hayes-roth-train	55.26	52.65	47.16 ●	49.23 ●	47.16 ●
heart-h	17.82	18.09	18.39 ○	19.23 ○	18.39 ○
heart-statlog	26.87	27.03	27.10	27.51	27.10
hepatitis	18.98	18.70	19.06	19.20	19.06
hypothyroid	13.06	12.31	8.74 ●	8.38 ●	8.74 ●
ionosphere	32.03	30.92 ●	24.93 ●	23.94 ●	24.93 ●
iris	21.90	21.74	21.51	23.54 ○	21.51
kr-vs-kp	16.82	16.53 ●	14.01 ●	16.69	14.01 ●
labor	5.00	5.00	4.80	5.20	4.80
letter	62.56	62.00 ●	59.84 ●	62.59	59.84 ●
liver-disorders	39.77	40.37	37.31 ●	39.17	37.31 ●
lung-cancer	49.79	49.54	53.02	45.55	53.02
lymph	15.95	16.23	15.65	16.49	15.65
molecular-biology-promoters	9.85	9.95	8.56	14.00 ○	8.56
mushroom	7.04	6.86 ●	5.06 ●	7.89 ○	5.06 ●
nursery	16.07	16.06	15.87 ●	16.51 ○	15.87 ●
optdigits	14.06	14.05	13.10 ●	16.32 ○	13.10 ●
page-blocks	34.97	19.25 ●	16.82 ●	14.00 ●	16.82 ●
pendigits	23.29	22.49 ●	21.21 ●	26.14 ○	21.21 ●
postoperative-patient-data	32.90	32.76	29.98 ●	30.36 ●	29.98 ●
primary-tumor	55.36	55.52	54.13 ●	54.94	54.13 ●
segment	30.05	30.75 ○	28.12 ●	33.04 ○	28.12 ●
shuttle-landing-control	44.00	45.33	46.67	36.67 ●	46.67
sick	10.94	10.23 ●	9.81 ●	8.84 ●	9.81 ●
solar-flare-2	28.40	28.21	28.16	28.39	28.16
sonar	26.37	26.26	24.14 ●	25.33	24.14 ●
soybean	10.39	10.62	9.77 ●	11.28 ○	9.77 ●
spambase	25.44	24.85 ●	24.51 ●	24.14 ●	24.51 ●
tae	50.50	49.64	48.92 ●	51.64	48.92 ●
tic-tac-toe	29.97	30.21	29.49 ●	29.23 ●	29.49 ●
trains	34.00	33.00	31.00	39.00	31.00
vehicle	56.94	56.72	53.71 ●	55.79 ●	53.71 ●
vote	9.57	9.57	9.47 ●	9.34	9.47 ●
vowel	71.90	71.27 ●	69.27 ●	72.30	69.27 ●
waveform-5000	22.66	22.63	22.44 ●	23.63 ○	22.44 ●
zoo	8.69	9.44 ○	8.78	11.33 ○	8.78

○, ● statistically significant improvement or degradation

Table C.3: Naive Bayes Mean Absolute Error - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03 ○	0.03 ○	0.04 ○	0.03 ○
autos	0.10	0.10	0.10	0.10	0.10
balance-scale	0.25	0.25 ○	0.27 ○	0.28 ○	0.27 ○
breast-cancer	0.32	0.32	0.32 ○	0.32	0.32 ○
bridges-version1	0.14	0.14	0.15 ○	0.15 ○	0.15 ○
car	0.13	0.13 ●	0.13 ○	0.14 ○	0.13 ○
cmc	0.38	0.38 ●	0.38 ○	0.39 ○	0.38 ○
colic	0.24	0.24 ●	0.23 ●	0.22 ●	0.23 ●
cylinder-bands	0.35	0.35 ●	0.34 ●	0.35	0.34 ●
dermatology	0.01	0.01	0.01	0.02 ○	0.01
diabetes	0.33	0.33 ●	0.33	0.33 ○	0.33
ecoli	0.10	0.10 ●	0.10 ○	0.11 ○	0.10 ○
flags	0.10	0.10	0.10 ○	0.11 ○	0.10 ○
glass	0.16	0.16 ●	0.16	0.16 ○	0.16
haberman	0.37	0.36 ●	0.37 ○	0.37	0.37 ○
hayes-roth-train	0.31	0.31	0.31	0.31	0.31
heart-h	0.09	0.09	0.09 ○	0.10 ○	0.09 ○
heart-statlog	0.29	0.29 ○	0.30 ○	0.31 ○	0.30 ○
hepatitis	0.21	0.21 ●	0.21 ○	0.21	0.21 ○
hypothyroid	0.08	0.08 ○	0.07 ●	0.07 ●	0.07 ●
ionosphere	0.31	0.31 ●	0.26 ●	0.26 ●	0.26 ●
iris	0.18	0.17 ●	0.18	0.21 ○	0.18
kr-vs-kp	0.24	0.24	0.23 ●	0.25 ○	0.23 ●
labor	0.08	0.08	0.08	0.09 ○	0.08
letter	0.06	0.05 ●	0.05 ●	0.06 ○	0.05 ●
liver-disorders	0.46	0.46	0.46	0.46	0.46
lung-cancer	0.33	0.34	0.36 ○	0.31	0.36 ○
lymph	0.10	0.10	0.10 ●	0.11	0.10 ●
molecular-biology-promoters	0.12	0.12	0.11 ●	0.15 ○	0.11 ●
mushroom	0.07	0.07 ●	0.05 ●	0.08 ○	0.05 ●
nursery	0.09	0.09 ●	0.10 ○	0.13 ○	0.10 ○
optdigits	0.03	0.03	0.03 ●	0.04 ○	0.03 ●
page-blocks	0.12	0.09 ●	0.08 ●	0.07 ●	0.08 ●
pendigits	0.05	0.05 ●	0.05 ●	0.07 ○	0.05 ●
postoperative-patient-data	0.28	0.28	0.28	0.27 ●	0.28
primary-tumor	0.06	0.06 ●	0.06 ○	0.06 ○	0.06 ○
segment	0.10	0.10 ○	0.09 ●	0.11 ○	0.09 ●
shuttle-landing-control	0.45	0.46	0.46	0.44 ●	0.46
sick	0.12	0.12 ●	0.12 ●	0.11 ●	0.12 ●
solar-flare-2	0.11	0.11 ●	0.11 ○	0.12 ○	0.11 ○
sonar	0.26	0.26	0.25 ●	0.26	0.25 ●
soybean	0.01	0.01	0.01 ●	0.01 ○	0.01 ●
spambase	0.27	0.27 ●	0.27 ●	0.28 ○	0.27 ●
tae	0.40	0.40	0.40 ○	0.41 ○	0.40 ○
tic-tac-toe	0.36	0.36 ●	0.37 ○	0.37 ○	0.37 ○
trains	0.34	0.34	0.33	0.35	0.33
vehicle	0.29	0.29	0.28 ●	0.29	0.28 ●
vote	0.10	0.10	0.10 ●	0.10	0.10 ●
vowel	0.14	0.14	0.14 ●	0.15 ○	0.14 ●
waveform-5000	0.16	0.16 ●	0.16 ●	0.17 ○	0.16 ●
zoo	0.03	0.03 ○	0.03 ○	0.04 ○	0.03 ○

○, ● statistically significant improvement or degradation

Table C.4: Naive Bayes Mean Absolute Error - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03 ○	0.03 ○	0.04 ○	0.03 ○
autos	0.10	0.10	0.10	0.10	0.10
balance-scale	0.25	0.25	0.27 ○	0.28 ○	0.27 ○
breast-cancer	0.32	0.32	0.32	0.32	0.32
bridges-version1	0.14	0.14	0.15 ○	0.15 ○	0.15 ○
car	0.13	0.13 ●	0.13 ○	0.14 ○	0.13 ○
cmc	0.38	0.38 ●	0.38 ○	0.39 ○	0.38 ○
colic	0.24	0.24 ●	0.23 ●	0.22 ●	0.23 ●
cylinder-bands	0.35	0.35 ●	0.34 ●	0.35 ●	0.34 ●
dermatology	0.01	0.01	0.01	0.02 ○	0.01
diabetes	0.33	0.33 ●	0.33	0.33 ○	0.33
ecoli	0.10	0.10 ●	0.10 ○	0.11 ○	0.10 ○
flags	0.10	0.10	0.10 ○	0.11 ○	0.10 ○
glass	0.16	0.16 ●	0.16	0.16 ○	0.16
haberman	0.37	0.36 ●	0.37 ○	0.37	0.37 ○
hayes-roth-train	0.31	0.31 ●	0.31 ●	0.31	0.31 ●
heart-h	0.09	0.09	0.09 ○	0.10 ○	0.09 ○
heart-statlog	0.29	0.29	0.30 ○	0.31 ○	0.30 ○
hepatitis	0.21	0.21 ●	0.21	0.21	0.21
hypothyroid	0.09	0.08	0.07 ●	0.07 ●	0.07 ●
ionosphere	0.32	0.31 ●	0.26 ●	0.26 ●	0.26 ●
iris	0.18	0.17 ●	0.18	0.21 ○	0.18
kr-vs-kp	0.24	0.24 ●	0.23 ●	0.25 ○	0.23 ●
labor	0.08	0.08	0.08	0.09 ○	0.08
letter	0.06	0.05 ●	0.05 ●	0.06 ○	0.05 ●
liver-disorders	0.46	0.46 ●	0.46	0.46	0.46
lung-cancer	0.33	0.33	0.36 ○	0.31	0.36 ○
lymph	0.10	0.10	0.10 ●	0.11 ○	0.10 ●
molecular-biology-promoters	0.12	0.13	0.11 ●	0.15 ○	0.11 ●
mushroom	0.07	0.07 ●	0.05 ●	0.08 ○	0.05 ●
nursery	0.09	0.09 ●	0.10 ○	0.13 ○	0.10 ○
optdigits	0.03	0.03	0.03 ●	0.04 ○	0.03 ●
page-blocks	0.14	0.09 ●	0.08 ●	0.07 ●	0.08 ●
pendigits	0.05	0.05 ●	0.05 ●	0.07 ○	0.05 ●
postoperative-patient-data	0.28	0.28	0.28 ●	0.27 ●	0.28 ●
primary-tumor	0.06	0.06 ●	0.06	0.06 ○	0.06
segment	0.10	0.10 ○	0.09 ●	0.11 ○	0.09 ●
shuttle-landing-control	0.45	0.46	0.46 ○	0.44 ●	0.46 ○
sick	0.13	0.12 ●	0.12 ●	0.11 ●	0.12 ●
solar-flare-2	0.11	0.11 ●	0.11 ○	0.12 ○	0.11 ○
sonar	0.26	0.26	0.25 ●	0.26	0.25 ●
soybean	0.01	0.01	0.01 ●	0.01 ○	0.01 ●
spambase	0.27	0.27 ●	0.27 ●	0.28 ○	0.27 ●
tae	0.40	0.40	0.40 ○	0.41 ○	0.40 ○
tic-tac-toe	0.36	0.36 ●	0.37 ○	0.37 ○	0.37 ○
trains	0.33	0.34	0.33	0.35	0.33
vehicle	0.29	0.29	0.28 ●	0.29	0.28 ●
vote	0.10	0.10	0.10 ●	0.10	0.10 ●
vowel	0.14	0.14 ●	0.14 ●	0.15 ○	0.14 ●
waveform-5000	0.16	0.16 ●	0.16 ●	0.17 ○	0.16 ●
zoo	0.03	0.03 ○	0.03 ○	0.04 ○	0.03 ○

○, ● statistically significant improvement or degradation

Table C.5: Naive Bayes Root Mean Squared Error - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.16	0.16	0.16 ●	0.17 ○	0.16 ●
autos	0.28	0.28	0.28	0.27 ●	0.28
balance-scale	0.34	0.34 ○	0.34 ○	0.36 ○	0.34 ○
breast-cancer	0.45	0.45	0.45 ●	0.44 ●	0.45 ●
bridges-version1	0.29	0.29	0.28 ●	0.29 ○	0.28 ●
car	0.24	0.24	0.25 ○	0.26 ○	0.25 ○
cmc	0.47	0.47	0.46 ●	0.45 ●	0.46 ●
colic	0.44	0.43 ●	0.41 ●	0.41 ●	0.41 ●
cylinder-bands	0.50	0.49 ●	0.47 ●	0.47 ●	0.47 ●
dermatology	0.08	0.08	0.08	0.09 ○	0.08
diabetes	0.44	0.44	0.43 ●	0.42 ●	0.43 ●
ecoli	0.23	0.23	0.23 ●	0.23	0.23 ●
flags	0.27	0.27	0.26 ●	0.27	0.26 ●
glass	0.29	0.29 ●	0.29 ●	0.29 ●	0.29 ●
haberman	0.44	0.44 ●	0.44 ●	0.44	0.44 ●
hayes-roth-train	0.39	0.40	0.38 ●	0.39	0.38 ●
heart-h	0.23	0.23	0.23 ●	0.23	0.23 ●
heart-statlog	0.43	0.44 ○	0.43 ●	0.42 ●	0.43 ●
hepatitis	0.39	0.39	0.39 ●	0.39 ●	0.39 ●
hypothyroid	0.20	0.22 ○	0.18 ●	0.18 ●	0.18 ●
ionosphere	0.50	0.50 ●	0.44 ●	0.43 ●	0.44 ●
iris	0.32	0.32 ●	0.32 ●	0.34 ○	0.32 ●
kr-vs-kp	0.34	0.34 ○	0.32 ●	0.34	0.32 ●
labor	0.18	0.17	0.17	0.19 ○	0.17
letter	0.18	0.17 ●	0.17 ●	0.17 ●	0.17 ●
liver-disorders	0.49	0.49	0.48 ●	0.48 ●	0.48 ●
lung-cancer	0.50	0.52	0.52 ○	0.48 ●	0.52 ○
lymph	0.24	0.24	0.23 ●	0.24 ●	0.23 ●
molecular-biology-promoters	0.25	0.26	0.24 ●	0.31 ○	0.24 ●
mushroom	0.25	0.25	0.20 ●	0.26 ○	0.20 ●
nursery	0.21	0.21	0.21 ○	0.23 ○	0.21 ○
optdigits	0.15	0.15 ○	0.14 ●	0.16 ○	0.14 ●
page-blocks	0.28	0.24 ●	0.21 ●	0.20 ●	0.21 ●
pendigits	0.19	0.18 ●	0.18 ●	0.20 ○	0.18 ●
postoperative-patient-data	0.40	0.40 ○	0.39 ●	0.39	0.39 ●
primary-tumor	0.18	0.18	0.18 ●	0.18 ○	0.18 ●
segment	0.25	0.25 ○	0.24 ●	0.26 ○	0.24 ●
shuttle-landing-control	0.49	0.50	0.49	0.48 ●	0.49
sick	0.27	0.27 ●	0.26 ●	0.25 ●	0.26 ●
solar-flare-2	0.25	0.25 ○	0.24 ●	0.25 ○	0.24 ●
sonar	0.46	0.46	0.44 ●	0.45 ●	0.44 ●
soybean	0.10	0.10	0.09 ●	0.10 ○	0.09 ●
spambase	0.43	0.43 ●	0.42 ●	0.42 ●	0.42 ●
tae	0.46	0.46	0.46 ●	0.46	0.46 ●
tic-tac-toe	0.44	0.44	0.43 ●	0.44	0.43 ●
trains	0.43	0.43	0.41	0.43	0.41
vehicle	0.46	0.46 ○	0.44 ●	0.44 ●	0.44 ●
vote	0.30	0.30	0.29 ●	0.29 ●	0.29 ●
vowel	0.28	0.28 ○	0.27 ●	0.28 ●	0.27 ●
waveform-5000	0.35	0.35 ●	0.35 ●	0.35 ●	0.35 ●
zoo	0.12	0.13 ○	0.12	0.14 ○	0.12

○, ● statistically significant improvement or degradation

Table C.6: Naive Bayes Root Mean Squared Error - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.16	0.16 ○	0.16 ●	0.17 ○	0.16 ●
autos	0.28	0.28	0.28	0.27 ●	0.28
balance-scale	0.34	0.34 ○	0.34 ○	0.36 ○	0.34 ○
breast-cancer	0.45	0.45	0.45 ●	0.44 ●	0.45 ●
bridges-version1	0.29	0.29	0.28 ●	0.29 ○	0.28 ●
car	0.24	0.24	0.25 ○	0.26 ○	0.25 ○
cmc	0.47	0.47	0.46 ●	0.45 ●	0.46 ●
colic	0.44	0.43 ●	0.41 ●	0.41 ●	0.41 ●
cylinder-bands	0.50	0.49 ●	0.47 ●	0.47 ●	0.47 ●
dermatology	0.08	0.08	0.08	0.09 ○	0.08
diabetes	0.44	0.44	0.43 ●	0.42 ●	0.43 ●
ecoli	0.23	0.23	0.23 ●	0.23	0.23 ●
flags	0.27	0.27	0.26	0.27	0.26
glass	0.29	0.29 ●	0.29 ●	0.29 ●	0.29 ●
haberman	0.44	0.44	0.44 ●	0.44	0.44 ●
hayes-roth-train	0.40	0.39	0.38 ●	0.39	0.38 ●
heart-h	0.23	0.23 ○	0.23 ●	0.23	0.23 ●
heart-statlog	0.44	0.44	0.43 ●	0.42 ●	0.43 ●
hepatitis	0.39	0.39	0.39 ●	0.39 ●	0.39 ●
hypothyroid	0.22	0.22	0.18 ●	0.18 ●	0.18 ●
ionosphere	0.51	0.50 ●	0.44 ●	0.43 ●	0.44 ●
iris	0.32	0.32 ●	0.32 ●	0.34 ○	0.32 ●
kr-vs-kp	0.34	0.34 ●	0.32 ●	0.34	0.32 ●
labor	0.17	0.17	0.17	0.19 ○	0.17
letter	0.18	0.17 ●	0.17 ●	0.17 ●	0.17 ●
liver-disorders	0.49	0.49	0.48 ●	0.48 ●	0.48 ●
lung-cancer	0.50	0.50	0.52 ○	0.48	0.52 ○
lymph	0.24	0.25 ○	0.23 ●	0.24 ●	0.23 ●
molecular-biology-promoters	0.25	0.26	0.24 ●	0.31 ○	0.24 ●
mushroom	0.25	0.25 ●	0.20 ●	0.26 ○	0.20 ●
nursery	0.21	0.21	0.21 ○	0.23 ○	0.21 ○
optdigits	0.15	0.15	0.14 ●	0.16 ○	0.14 ●
page-blocks	0.31	0.24 ●	0.21 ●	0.20 ●	0.21 ●
pendigits	0.19	0.18 ●	0.18 ●	0.20 ○	0.18 ●
postoperative-patient-data	0.40	0.40	0.39 ●	0.39 ●	0.39 ●
primary-tumor	0.18	0.18	0.18 ●	0.18 ○	0.18 ●
segment	0.25	0.25 ○	0.24 ●	0.26 ○	0.24 ●
shuttle-landing-control	0.49	0.49	0.49	0.48 ●	0.49
sick	0.28	0.27 ●	0.26 ●	0.25 ●	0.26 ●
solar-flare-2	0.25	0.25	0.24 ●	0.25 ○	0.24 ●
sonar	0.46	0.46	0.44 ●	0.45 ●	0.44 ●
soybean	0.10	0.10	0.09 ●	0.10	0.09 ●
spambase	0.43	0.43 ●	0.42 ●	0.42 ●	0.42 ●
tae	0.46	0.46	0.46 ●	0.46	0.46 ●
tic-tac-toe	0.44	0.44	0.43 ●	0.44	0.43 ●
trains	0.42	0.42	0.41	0.43	0.41
vehicle	0.46	0.46	0.44 ●	0.44 ●	0.44 ●
vote	0.30	0.30	0.29 ●	0.29 ●	0.29 ●
vowel	0.28	0.28 ○	0.27 ●	0.28 ●	0.27 ●
waveform-5000	0.35	0.35 ●	0.35 ●	0.35 ●	0.35 ●
zoo	0.12	0.12 ○	0.12 ○	0.14 ○	0.12 ○

○, ● statistically significant improvement or degradation

Table C.7: Naive Bayes Mean Entropy Gain - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-1.33	-1.30 ○	-1.30	-2.14 ●	-1.30
autos	-0.12	-0.13	-0.04 ○	0.11 ○	-0.04 ○
balance-scale	0.42	0.41	0.39 ●	0.32 ●	0.39 ●
breast-cancer	-0.06	-0.07 ●	-0.02 ○	-0.00 ○	-0.02 ○
bridges-version1	0.67	0.67	0.75 ○	0.67	0.75 ○
car	0.65	0.65	0.63 ●	0.57 ●	0.63 ●
cmc	-0.07	-0.08 ●	0.04 ○	0.04 ○	0.04 ○
colic	-0.44	-0.44 ○	-0.22 ○	-0.17 ○	-0.22 ○
cylinder-bands	-0.17	-0.16 ○	0.02 ○	0.04 ○	0.02 ○
dermatology	2.32	2.32	2.33	2.29 ●	2.33
diabetes	0.12	0.12	0.16 ○	0.16 ○	0.16 ○
ecoli	0.96	0.96	1.00 ○	0.96	1.00 ○
flags	0.12	0.12	0.31 ○	0.27 ○	0.31 ○
glass	0.47	0.48	0.55 ○	0.53 ○	0.55 ○
haberman	-0.01	-0.01 ○	0.01 ○	-0.01	0.01 ○
hayes-roth-train	0.08	0.07	0.14 ○	0.10	0.14 ○
heart-h	0.26	0.25	0.31 ○	0.30 ○	0.31 ○
heart-statlog	0.15	0.14 ●	0.20 ○	0.22 ○	0.20 ○
hepatitis	-0.21	-0.21	-0.14 ○	-0.09 ○	-0.14 ○
hypothyroid	0.04	-0.12 ●	0.10 ○	0.09 ○	0.10 ○
ionosphere	-0.68	-0.65 ○	-0.18 ○	-0.08 ○	-0.18 ○
iris	0.88	0.89 ○	0.89 ○	0.76 ●	0.89 ○
kr-vs-kp	0.49	0.49 ●	0.53 ○	0.48 ●	0.53 ○
labor	0.70	0.72 ○	0.71	0.70	0.71
letter	1.49	1.49 ○	1.75 ○	1.58 ○	1.75 ○
liver-disorders	0.01	0.01	0.06 ○	0.03 ○	0.06 ○
lung-cancer	-1.66	-1.55	-1.40 ○	-1.21 ○	-1.40 ○
lymph	0.62	0.62	0.70 ○	0.72 ○	0.70 ○
molecular-biology-promoters	0.62	0.61	0.66 ○	0.43 ●	0.66 ○
mushroom	0.52	0.51	0.76 ○	0.57 ○	0.76 ○
nursery	1.20	1.20	1.19 ●	1.00 ●	1.19 ●
optdigits	2.37	2.36 ●	2.46 ○	2.37	2.46 ○
page-blocks	-0.30	-0.11 ○	0.07 ○	0.11 ○	0.07 ○
pendigits	2.05	2.06 ○	2.13 ○	2.00 ●	2.13 ○
postoperative-patient-data	-0.18	-0.20 ●	-0.14 ○	-0.17	-0.14 ○
primary-tumor	0.73	0.74	0.84 ○	0.71	0.84 ○
segment	1.17	1.16 ●	1.32 ○	1.25 ○	1.32 ○
shuttle-landing-control	0.02	-0.01	0.00	0.04 ○	0.00
sick	-0.02	-0.01 ○	0.02 ○	0.04 ○	0.02 ○
solar-flare-2	1.35	1.35	1.40 ○	1.28 ●	1.40 ○
sonar	-0.59	-0.59	-0.37 ○	-0.33 ○	-0.37 ○
soybean	3.14	3.13 ●	3.25 ○	3.23 ○	3.25 ○
spambase	0.06	0.06 ○	0.14 ○	0.17 ○	0.14 ○
tae	0.00	0.01	0.05 ○	0.03 ○	0.05 ○
tic-tac-toe	0.13	0.13	0.14 ○	0.12 ●	0.14 ○
trains	-0.07	-0.06	0.07 ○	0.01	0.07 ○
vehicle	-1.53	-1.54 ●	-1.00 ○	-0.68 ○	-1.00 ○
vote	0.08	0.08	0.18 ○	0.28 ○	0.18 ○
vowel	0.60	0.57 ●	0.85 ○	0.63 ○	0.85 ○
waveform-5000	0.46	0.46 ○	0.54 ○	0.60 ○	0.54 ○
zoo	2.19	2.15 ●	2.18	2.06 ●	2.18

○, ● statistically significant improvement or degradation

Table C.8: Naive Bayes Mean Entropy Gain - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-1.36	-1.30 ○	-1.30 ○	-2.14 ●	-1.30 ○
autos	-0.13	-0.13	-0.04 ○	0.11 ○	-0.04 ○
balance-scale	0.42	0.42	0.39 ●	0.32 ●	0.39 ●
breast-cancer	-0.07	-0.07	-0.02 ○	-0.00 ○	-0.02 ○
bridges-version1	0.67	0.67	0.75 ○	0.67	0.75 ○
car	0.64	0.65	0.63 ●	0.57 ●	0.63 ●
cmc	-0.07	-0.08 ●	0.04 ○	0.04 ○	0.04 ○
colic	-0.45	-0.43 ○	-0.22 ○	-0.17 ○	-0.22 ○
cylinder-bands	-0.18	-0.16 ○	0.02 ○	0.04 ○	0.02 ○
dermatology	2.32	2.32	2.33 ○	2.29 ●	2.33 ○
diabetes	0.12	0.12	0.16 ○	0.16 ○	0.16 ○
ecoli	0.97	0.96	1.00 ○	0.96	1.00 ○
flags	0.12	0.12	0.31 ○	0.27 ○	0.31 ○
glass	0.45	0.48 ○	0.55 ○	0.53 ○	0.55 ○
haberman	-0.01	-0.01	0.01 ○	-0.01	0.01 ○
hayes-roth-train	0.07	0.08	0.14 ○	0.10 ○	0.14 ○
heart-h	0.26	0.25 ●	0.31 ○	0.30 ○	0.31 ○
heart-statlog	0.14	0.14	0.20 ○	0.22 ○	0.20 ○
hepatitis	-0.21	-0.21	-0.14 ○	-0.09 ○	-0.14 ○
hypothyroid	-0.10	-0.11	0.10 ○	0.09 ○	0.10 ○
ionosphere	-0.75	-0.65 ○	-0.18 ○	-0.08 ○	-0.18 ○
iris	0.87	0.89 ○	0.89 ○	0.76 ●	0.89 ○
kr-vs-kp	0.49	0.49	0.53 ○	0.48	0.53 ○
labor	0.71	0.71	0.71	0.70	0.71
letter	1.47	1.49 ○	1.75 ○	1.58 ○	1.75 ○
liver-disorders	0.01	0.01	0.06 ○	0.03 ○	0.06 ○
lung-cancer	-1.63	-1.54	-1.40	-1.21 ○	-1.40
lymph	0.64	0.61	0.70 ○	0.72 ○	0.70 ○
molecular-biology-promoters	0.60	0.59	0.66 ○	0.43 ●	0.66 ○
mushroom	0.50	0.51 ○	0.76 ○	0.57 ○	0.76 ○
nursery	1.20	1.20	1.19 ●	1.00 ●	1.19 ●
optdigits	2.37	2.36 ●	2.46 ○	2.37	2.46 ○
page-blocks	-0.45	-0.11 ○	0.07 ○	0.11 ○	0.07 ○
pendigits	2.05	2.06 ○	2.13 ○	2.00 ●	2.13 ○
postoperative-patient-data	-0.19	-0.19	-0.14 ○	-0.17	-0.14 ○
primary-tumor	0.73	0.74	0.84 ○	0.71	0.84 ○
segment	1.17	1.16 ●	1.32 ○	1.25 ○	1.32 ○
shuttle-landing-control	0.01	0.00	0.00	0.04 ○	0.00
sick	-0.02	-0.01 ○	0.02 ○	0.04 ○	0.02 ○
solar-flare-2	1.35	1.35	1.40 ○	1.28 ●	1.40 ○
sonar	-0.58	-0.60 ●	-0.37 ○	-0.33 ○	-0.37 ○
soybean	3.13	3.13	3.25 ○	3.23 ○	3.25 ○
spambase	0.06	0.06 ○	0.14 ○	0.17 ○	0.14 ○
tae	0.01	0.01	0.05 ○	0.03	0.05 ○
tic-tac-toe	0.12	0.13	0.14 ○	0.12	0.14 ○
trains	-0.05	-0.08	0.07	0.01	0.07
vehicle	-1.54	-1.54	-1.00 ○	-0.68 ○	-1.00 ○
vote	0.08	0.08	0.18 ○	0.28 ○	0.18 ○
vowel	0.59	0.57 ●	0.85 ○	0.63 ○	0.85 ○
waveform-5000	0.45	0.46 ○	0.54 ○	0.60 ○	0.54 ○
zoo	2.20	2.16 ●	2.18	2.06 ●	2.18

○, ● statistically significant improvement or degradation

C.2.2 Bayesian Network

The results for a TAN Bayesian Network with various numbers of hidden variables can be seen in figures C.9 - C.16.

The Bayesian Network Percent Incorrect results can be seen in figures B.5, C.9 and C.10. With zero hidden variables, Case 1 performed slightly worse than Case 4, and roughly as well as Case 5. Once the number of hidden variables was increased to three, Case 1 started to perform much worse than both Cases 4 and 5. This trend continued when five hidden variables were added. Interestingly the performance of Case 1 relative to Case 3 was reasonably stable throughout. The number of tests in which they performed better or worse than each other was approximately the same in all three experiments, with Case 3 performing better in roughly twice as many tests.

The Bayesian Network MAE results (figures B.6, C.11 and C.12) again show Case 1 and Case 3 performing roughly as well as each other with all numbers of hidden variables. Case 1 does perform slightly better than Case 3, but not significantly so. The most interesting part of these results is the comparison between Case 1 and Case 5. With zero hidden variables Case 1 performs better in 44/51 tests, but with three and five hidden variables this drops to 22/51 tests.

The Bayesian Network RMSE results can be seen in figures B.7, C.13 and C.14. These figures show Case 1 performing significantly worse as hidden variables are added, especially relative to the control cases. Case 1 again performs approximately the same relative to Case 3 at any number of hidden variables, with Case 3 seeming to be roughly 2.5 times better.

The Bayesian Network MEG results are shown in figures B.8, C.15 and C.16. Adding hidden variables again caused large entropy reductions, and adding more hidden variables led to larger reductions.

Table C.9: Bayesian Network Percent Incorrect - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	37.68	38.23	41.04 ○	50.09 ○	37.87
autos	9.28	9.34	10.83 ○	9.62	9.67
balance-scale	29.40	29.61	28.49 ●	28.49 ●	30.05
breast-cancer	27.52	27.36	29.46 ○	27.41	27.40
bridges-version1	34.66	36.77 ○	38.89 ○	36.00	36.91 ○
car	21.16	21.41	15.41 ●	23.23 ○	21.24
cmc	52.46	52.96 ○	49.26 ●	50.24 ●	50.61 ●
colic	21.11	21.42	19.84 ●	19.94 ●	20.03 ●
cylinder-bands	33.71	33.73	28.38 ●	32.69 ●	33.20
dermatology	4.69	4.75	6.10 ○	3.58 ●	3.43 ●
diabetes	29.30	29.49	27.28 ●	27.52 ●	27.94 ●
ecoli	35.47	34.66 ●	33.03 ●	34.53 ●	34.14 ●
flags	37.56	38.86 ○	42.66 ○	40.51 ○	38.81
glass	49.56	49.12	42.56 ●	46.58 ●	47.03 ●
haberman	29.48	30.00	31.03 ○	27.27 ●	28.48 ●
hayes-roth-train	54.88	55.59	46.97 ●	49.23 ●	49.30 ●
heart-h	18.81	18.47	20.18 ○	19.23	17.79 ●
heart-statlog	26.90	26.74	26.62	27.51	26.02
hepatitis	18.84	18.63	20.20	19.20	19.13
hypothyroid	10.59	10.84	8.15 ●	8.38 ●	8.61 ●
ionosphere	30.67	32.00 ○	19.62 ●	23.94 ●	23.66 ●
iris	26.30	26.37	19.66 ●	23.54 ●	21.27 ●
kr-vs-kp	17.31	17.43	11.73 ●	16.69 ●	15.22 ●
labor	5.60	5.20	8.00 ○	5.20	5.00
letter	63.01	63.20 ○	56.25 ●	62.59 ●	61.77 ●
liver-disorders	40.60	41.09	37.99 ●	39.17	38.07 ●
lung-cancer	50.23	53.10	57.43 ○	45.55	55.90 ○
lymph	16.07	16.96	16.14	16.49	16.37
molecular-biology-promoters	11.88	12.59	23.31 ○	14.00 ○	11.11
mushroom	6.90	7.11 ○	0.57 ●	7.89 ○	4.16 ●
nursery	18.62	19.07 ○	15.16 ●	16.51 ●	16.47 ●
optdigits	17.39	17.55 ○	10.67 ●	16.32 ●	15.19 ●
page-blocks	17.54	23.49 ○	9.23 ●	14.00 ●	14.18 ●
pendigits	29.71	29.30 ●	18.20 ●	26.14 ●	24.65 ●
postoperative-patient-data	31.30	32.04	33.61 ○	30.36	30.93
primary-tumor	55.52	55.68	57.97 ○	54.94	54.68 ●
segment	38.36	39.05	26.16 ●	33.04 ●	30.88 ●
shuttle-landing-control	46.67	44.67	40.00 ●	36.67 ●	44.00
sick	9.19	9.28	7.47 ●	8.84 ●	9.52 ○
solar-flare-2	28.68	28.72	28.22	28.39	28.41
sonar	25.39	25.86	23.43 ●	25.33	24.09 ●
soybean	11.09	11.42	11.23	11.28	9.46 ●
spambase	26.17	25.86	22.76 ●	24.14 ●	25.17 ●
tae	52.15	51.85	53.69	51.64	49.43 ●
tic-tac-toe	30.31	30.37	27.29 ●	29.23 ●	30.08
trains	36.00	32.00	20.00 ●	39.00	37.00
vehicle	57.05	57.32	42.62 ●	55.79 ●	53.53 ●
vote	9.59	9.57	6.78 ●	9.34 ●	9.80 ○
vowel	72.66	73.35	63.98 ●	72.30	71.36 ●
waveform-5000	23.91	24.08	24.25	23.63	23.33 ●
zoo	12.06	13.06	13.50	11.33	11.99

○, ● statistically significant improvement or degradation

Table C.10: Bayesian Network Percent Incorrect - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	37.68	38.23	41.04 ○	50.09 ○	37.87
autos	9.28	9.34	10.83 ○	9.62	9.67
balance-scale	29.40	29.61	28.49 ●	28.49 ●	30.05
breast-cancer	27.52	27.36	29.46 ○	27.41	27.40
bridges-version1	34.66	36.77 ○	38.89 ○	36.00	36.91 ○
car	21.16	21.41	15.41 ●	23.23 ○	21.24
cmc	52.46	52.96 ○	49.26 ●	50.24 ●	50.61 ●
colic	21.11	21.42	19.84 ●	19.94 ●	20.03 ●
cylinder-bands	33.71	33.73	28.38 ●	32.69 ●	33.20
dermatology	4.69	4.75	6.10 ○	3.58 ●	3.43 ●
diabetes	29.30	29.49	27.28 ●	27.52 ●	27.94 ●
ecoli	35.47	34.66 ●	33.03 ●	34.53 ●	34.14 ●
flags	37.56	38.86 ○	42.66 ○	40.51 ○	38.81
glass	49.56	49.12	42.56 ●	46.58 ●	47.03 ●
haberman	29.48	30.00	31.03 ○	27.27 ●	28.48 ●
hayes-roth-train	54.88	55.59	46.97 ●	49.23 ●	49.30 ●
heart-h	18.81	18.47	20.18 ○	19.23	17.79 ●
heart-statlog	26.90	26.74	26.62	27.51	26.02
hepatitis	18.84	18.63	20.20	19.20	19.13
hypothyroid	10.59	10.84	8.15 ●	8.38 ●	8.61 ●
ionosphere	30.67	32.00 ○	19.62 ●	23.94 ●	23.66 ●
iris	26.30	26.37	19.66 ●	23.54 ●	21.27 ●
kr-vs-kp	17.31	17.43	11.73 ●	16.69 ●	15.22 ●
labor	5.60	5.20	8.00 ○	5.20	5.00
letter	63.01	63.20 ○	56.25 ●	62.59 ●	61.77 ●
liver-disorders	40.60	41.09	37.99 ●	39.17	38.07 ●
lung-cancer	50.23	53.10	57.43 ○	45.55	55.90 ○
lymph	16.07	16.96	16.14	16.49	16.37
molecular-biology-promoters	11.88	12.59	23.31 ○	14.00 ○	11.11
mushroom	6.90	7.11 ○	0.57 ●	7.89 ○	4.16 ●
nursery	18.62	19.07 ○	15.16 ●	16.51 ●	16.47 ●
optdigits	17.39	17.55 ○	10.67 ●	16.32 ●	15.19 ●
page-blocks	17.54	23.49 ○	9.23 ●	14.00 ●	14.18 ●
pendigits	29.71	29.30 ●	18.20 ●	26.14 ●	24.65 ●
postoperative-patient-data	31.30	32.04	33.61 ○	30.36	30.93
primary-tumor	55.52	55.68	57.97 ○	54.94	54.68 ●
segment	38.36	39.05	26.16 ●	33.04 ●	30.88 ●
shuttle-landing-control	46.67	44.67	40.00 ●	36.67 ●	44.00
sick	9.19	9.28	7.47 ●	8.84 ●	9.52 ○
solar-flare-2	28.68	28.72	28.22	28.39	28.41
sonar	25.39	25.86	23.43 ●	25.33	24.09 ●
soybean	11.09	11.42	11.23	11.28	9.46 ●
spambase	26.17	25.86	22.76 ●	24.14 ●	25.17 ●
tae	52.15	51.85	53.69	51.64	49.43 ●
tic-tac-toe	30.31	30.37	27.29 ●	29.23 ●	30.08
trains	36.00	32.00	20.00 ●	39.00	37.00
vehicle	57.05	57.32	42.62 ●	55.79 ●	53.53 ●
vote	9.59	9.57	6.78 ●	9.34 ●	9.80 ○
vowel	72.66	73.35	63.98 ●	72.30	71.36 ●
waveform-5000	23.91	24.08	24.25	23.63	23.33 ●
zoo	12.06	13.06	13.50	11.33	11.99

○, ● statistically significant improvement or degradation

Table C.11: Bayesian Network Mean Absolute Error - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03	0.04 ○	0.04 ○	0.03 ○
autos	0.10	0.10	0.11 ○	0.10	0.10
balance-scale	0.26	0.26	0.26 ●	0.28 ○	0.27 ○
breast-cancer	0.32	0.32	0.35 ○	0.32	0.33 ○
bridges-version1	0.14	0.15 ○	0.16 ○	0.15 ○	0.15 ○
car	0.12	0.12	0.12	0.14 ○	0.14 ○
cmc	0.38	0.38	0.38 ○	0.39 ○	0.39 ○
colic	0.23	0.23	0.23	0.22 ●	0.22 ●
cylinder-bands	0.35	0.35 ○	0.32 ●	0.35 ●	0.34 ●
dermatology	0.02	0.02	0.03 ○	0.02 ●	0.02 ●
diabetes	0.33	0.33	0.34 ○	0.33	0.33
ecoli	0.10	0.10	0.11 ○	0.11 ○	0.10 ○
flags	0.10	0.10 ○	0.11 ○	0.11 ○	0.10 ○
glass	0.16	0.16	0.16	0.16 ○	0.16 ○
haberman	0.37	0.37	0.38 ○	0.37	0.38 ○
hayes-roth-train	0.31	0.31	0.30 ●	0.31	0.31 ●
heart-h	0.09	0.09	0.11 ○	0.10 ○	0.09 ○
heart-statlog	0.30	0.30	0.33 ○	0.31 ○	0.31 ○
hepatitis	0.20	0.20	0.23 ○	0.21 ○	0.21 ○
hypothyroid	0.07	0.07	0.06 ●	0.07 ●	0.07 ●
ionosphere	0.31	0.32 ○	0.22 ●	0.26 ●	0.26 ●
iris	0.20	0.20 ○	0.22 ○	0.21 ○	0.19
kr-vs-kp	0.24	0.24	0.18 ●	0.25 ○	0.23 ●
labor	0.08	0.08	0.11 ○	0.09 ○	0.08
letter	0.06	0.06	0.05 ●	0.06 ○	0.06 ○
liver-disorders	0.46	0.46	0.44 ●	0.46	0.46
lung-cancer	0.33	0.35	0.39 ○	0.31	0.37 ○
lymph	0.10	0.10	0.10	0.11 ○	0.10
molecular-biology-promoters	0.14	0.14	0.24 ○	0.15 ○	0.13
mushroom	0.07	0.07 ○	0.01 ●	0.08 ○	0.04 ●
nursery	0.11	0.11	0.10 ●	0.13 ○	0.11
optdigits	0.04	0.04 ○	0.03 ●	0.04 ○	0.03 ●
page-blocks	0.09	0.10 ○	0.06 ●	0.07 ●	0.08 ●
pendigits	0.07	0.07	0.05 ●	0.07 ○	0.06 ●
postoperative-patient-data	0.28	0.28	0.28	0.27 ●	0.28
primary-tumor	0.06	0.06	0.06 ○	0.06 ○	0.06 ○
segment	0.12	0.12	0.10 ●	0.11 ●	0.10 ●
shuttle-landing-control	0.44	0.43	0.45 ○	0.44 ○	0.43 ●
sick	0.11	0.11	0.10 ●	0.11 ○	0.12 ○
solar-flare-2	0.11	0.11 ○	0.12 ○	0.12 ○	0.11 ○
sonar	0.26	0.26	0.27	0.26	0.26
soybean	0.01	0.01	0.01 ○	0.01 ○	0.01 ●
spambase	0.28	0.27	0.30 ○	0.28 ○	0.28 ○
tae	0.40	0.40	0.42 ○	0.41 ○	0.40 ○
tic-tac-toe	0.36	0.36	0.36	0.37 ○	0.38 ○
trains	0.37	0.34	0.23 ●	0.35	0.34
vehicle	0.29	0.29	0.25 ●	0.29 ●	0.28 ●
vote	0.10	0.10	0.08 ●	0.10 ○	0.10
vowel	0.14	0.14	0.13 ●	0.15 ○	0.14 ○
waveform-5000	0.17	0.17	0.19 ○	0.17 ○	0.17 ●
zoo	0.04	0.04 ○	0.05 ○	0.04	0.04

○, ● statistically significant improvement or degradation

Table C.12: Bayesian Network Mean Absolute Error - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03	0.04 ○	0.04 ○	0.03 ○
autos	0.10	0.10	0.11 ○	0.10	0.10
balance-scale	0.26	0.26	0.26 ●	0.28 ○	0.27 ○
breast-cancer	0.32	0.32	0.35 ○	0.32	0.33 ○
bridges-version1	0.14	0.15 ○	0.16 ○	0.15 ○	0.15 ○
car	0.12	0.12	0.12	0.14 ○	0.14 ○
cmc	0.38	0.38	0.38 ○	0.39 ○	0.39 ○
colic	0.23	0.23	0.23	0.22 ●	0.22 ●
cylinder-bands	0.35	0.35 ○	0.32 ●	0.35 ●	0.34 ●
dermatology	0.02	0.02	0.03 ○	0.02 ●	0.02 ●
diabetes	0.33	0.33	0.34 ○	0.33	0.33
ecoli	0.10	0.10	0.11 ○	0.11 ○	0.10 ○
flags	0.10	0.10 ○	0.11 ○	0.11 ○	0.10 ○
glass	0.16	0.16	0.16	0.16 ○	0.16 ○
haberman	0.37	0.37	0.38 ○	0.37	0.38 ○
hayes-roth-train	0.31	0.31	0.30 ●	0.31	0.31 ●
heart-h	0.09	0.09	0.11 ○	0.10 ○	0.09 ○
heart-statlog	0.30	0.30	0.33 ○	0.31 ○	0.31 ○
hepatitis	0.20	0.20	0.23 ○	0.21 ○	0.21 ○
hypothyroid	0.07	0.07	0.06 ●	0.07 ●	0.07 ●
ionosphere	0.31	0.32 ○	0.22 ●	0.26 ●	0.26 ●
iris	0.20	0.20 ○	0.22 ○	0.21 ○	0.19
kr-vs-kp	0.24	0.24	0.18 ●	0.25 ○	0.23 ●
labor	0.08	0.08	0.11 ○	0.09 ○	0.08
letter	0.06	0.06	0.05 ●	0.06 ○	0.06 ○
liver-disorders	0.46	0.46	0.44 ●	0.46	0.46
lung-cancer	0.33	0.35	0.39 ○	0.31	0.37 ○
lymph	0.10	0.10	0.10	0.11 ○	0.10
molecular-biology-promoters	0.14	0.14	0.24 ○	0.15 ○	0.13
mushroom	0.07	0.07 ○	0.01 ●	0.08 ○	0.04 ●
nursery	0.11	0.11	0.10 ●	0.13 ○	0.11
optdigits	0.04	0.04 ○	0.03 ●	0.04 ○	0.03 ●
page-blocks	0.09	0.10 ○	0.06 ●	0.07 ●	0.08 ●
pendigits	0.07	0.07	0.05 ●	0.07 ○	0.06 ●
postoperative-patient-data	0.28	0.28	0.28	0.27 ●	0.28
primary-tumor	0.06	0.06	0.06 ○	0.06 ○	0.06 ○
segment	0.12	0.12	0.10 ●	0.11 ●	0.10 ●
shuttle-landing-control	0.44	0.43	0.45 ○	0.44 ○	0.43 ●
sick	0.11	0.11	0.10 ●	0.11 ○	0.12 ○
solar-flare-2	0.11	0.11 ○	0.12 ○	0.12 ○	0.11 ○
sonar	0.26	0.26	0.27	0.26	0.26
soybean	0.01	0.01	0.01 ○	0.01 ○	0.01 ●
spambase	0.28	0.27	0.30 ○	0.28 ○	0.28 ○
tae	0.40	0.40	0.42 ○	0.41 ○	0.40 ○
tic-tac-toe	0.36	0.36	0.36	0.37 ○	0.38 ○
trains	0.37	0.34	0.23 ●	0.35	0.34
vehicle	0.29	0.29	0.25 ●	0.29 ●	0.28 ●
vote	0.10	0.10	0.08 ●	0.10 ○	0.10
vowel	0.14	0.14	0.13 ●	0.15 ○	0.14 ○
waveform-5000	0.17	0.17	0.19 ○	0.17 ○	0.17 ●
zoo	0.04	0.04 ○	0.05 ○	0.04	0.04

○, ● statistically significant improvement or degradation

Table C.13: Bayesian Network Root Mean Squared Error - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.16	0.16	0.16 ○	0.17 ○	0.15 ●
autos	0.28	0.28	0.30 ○	0.27	0.28
balance-scale	0.35	0.35	0.35	0.36 ○	0.35
breast-cancer	0.46	0.46	0.45	0.44 ●	0.45 ●
bridges-version1	0.29	0.30 ○	0.30 ○	0.29	0.29
car	0.27	0.27	0.23 ●	0.26 ●	0.26 ●
cmc	0.47	0.47	0.45 ●	0.45 ●	0.46 ●
colic	0.42	0.43	0.40 ●	0.41 ●	0.41 ●
cylinder-bands	0.50	0.50 ○	0.45 ●	0.47 ●	0.47 ●
dermatology	0.10	0.10	0.12 ○	0.09 ●	0.09 ●
diabetes	0.44	0.44	0.42 ●	0.42 ●	0.43 ●
ecoli	0.24	0.24	0.23 ●	0.23 ●	0.23 ●
flags	0.27	0.27	0.28 ○	0.27	0.27
glass	0.30	0.30	0.29 ●	0.29 ●	0.29 ●
haberman	0.45	0.45	0.45	0.44 ●	0.45
hayes-roth-train	0.40	0.40	0.38 ●	0.39 ●	0.39 ●
heart-h	0.24	0.24	0.24 ○	0.23 ●	0.23 ●
heart-statlog	0.44	0.44	0.42 ●	0.42 ●	0.42 ●
hepatitis	0.39	0.39	0.39	0.39 ●	0.40
hypothyroid	0.20	0.20	0.18 ●	0.18 ●	0.18 ●
ionosphere	0.50	0.51 ○	0.39 ●	0.43 ●	0.43 ●
iris	0.35	0.36 ○	0.33 ●	0.34 ●	0.33 ●
kr-vs-kp	0.34	0.34 ○	0.29 ●	0.34 ●	0.33 ●
labor	0.18	0.18	0.22 ○	0.19	0.17
letter	0.18	0.18	0.16 ●	0.17 ●	0.17 ●
liver-disorders	0.49	0.49	0.48 ●	0.48 ●	0.48 ●
lung-cancer	0.51	0.53	0.56 ○	0.48 ●	0.54 ○
lymph	0.24	0.25 ○	0.24	0.24 ●	0.24 ●
molecular-biology-promoters	0.30	0.30	0.43 ○	0.31	0.29
mushroom	0.25	0.25 ○	0.07 ●	0.26 ○	0.18 ●
nursery	0.24	0.24	0.21 ●	0.23 ●	0.22 ●
optdigits	0.17	0.17 ○	0.13 ●	0.16 ●	0.15 ●
page-blocks	0.24	0.26 ○	0.17 ●	0.20 ●	0.21 ●
pendigits	0.21	0.21	0.16 ●	0.20 ●	0.19 ●
postoperative-patient-data	0.40	0.40	0.41 ○	0.39	0.39 ●
primary-tumor	0.18	0.18	0.18	0.18 ●	0.18 ●
segment	0.29	0.29	0.23 ●	0.26 ●	0.25 ●
shuttle-landing-control	0.48	0.48	0.49 ○	0.48	0.48
sick	0.26	0.26	0.23 ●	0.25 ●	0.26
solar-flare-2	0.26	0.26 ○	0.25 ●	0.25 ●	0.25 ●
sonar	0.46	0.46	0.42 ●	0.45 ●	0.44 ●
soybean	0.10	0.10	0.09 ●	0.10	0.09 ●
spambase	0.44	0.44	0.39 ●	0.42 ●	0.42 ●
tae	0.47	0.47	0.47 ○	0.46 ●	0.46 ●
tic-tac-toe	0.44	0.44	0.43 ●	0.44 ●	0.44 ●
trains	0.47	0.43	0.29 ●	0.43	0.43
vehicle	0.46	0.46	0.37 ●	0.44 ●	0.43 ●
vote	0.29	0.29	0.23 ●	0.29 ●	0.29
vowel	0.28	0.29 ○	0.27 ●	0.28 ●	0.27 ●
waveform-5000	0.36	0.36	0.34 ●	0.35 ●	0.35 ●
zoo	0.15	0.16 ○	0.15	0.14 ●	0.14

○, ● statistically significant improvement or degradation

Table C.14: Bayesian Network Root Mean Squared Error - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.16	0.16	0.16 ○	0.17 ○	0.15 ●
autos	0.28	0.28	0.30 ○	0.27	0.28
balance-scale	0.35	0.35	0.35	0.36 ○	0.35
breast-cancer	0.46	0.46	0.45	0.44 ●	0.45 ●
bridges-version1	0.29	0.30 ○	0.30 ○	0.29	0.29
car	0.27	0.27	0.23 ●	0.26 ●	0.26 ●
cmc	0.47	0.47	0.45 ●	0.45 ●	0.46 ●
colic	0.42	0.43	0.40 ●	0.41 ●	0.41 ●
cylinder-bands	0.50	0.50 ○	0.45 ●	0.47 ●	0.47 ●
dermatology	0.10	0.10	0.12 ○	0.09 ●	0.09 ●
diabetes	0.44	0.44	0.42 ●	0.42 ●	0.43 ●
ecoli	0.24	0.24	0.23 ●	0.23 ●	0.23 ●
flags	0.27	0.27	0.28 ○	0.27	0.27
glass	0.30	0.30	0.29 ●	0.29 ●	0.29 ●
haberman	0.45	0.45	0.45	0.44 ●	0.45
hayes-roth-train	0.40	0.40	0.38 ●	0.39 ●	0.39 ●
heart-h	0.24	0.24	0.24 ○	0.23 ●	0.23 ●
heart-statlog	0.44	0.44	0.42 ●	0.42 ●	0.42 ●
hepatitis	0.39	0.39	0.39	0.39 ●	0.40
hypothyroid	0.20	0.20	0.18 ●	0.18 ●	0.18 ●
ionosphere	0.50	0.51 ○	0.39 ●	0.43 ●	0.43 ●
iris	0.35	0.36 ○	0.33 ●	0.34 ●	0.33 ●
kr-vs-kp	0.34	0.34 ○	0.29 ●	0.34 ●	0.33 ●
labor	0.18	0.18	0.22 ○	0.19	0.17
letter	0.18	0.18	0.16 ●	0.17 ●	0.17 ●
liver-disorders	0.49	0.49	0.48 ●	0.48 ●	0.48 ●
lung-cancer	0.51	0.53	0.56 ○	0.48 ●	0.54 ○
lymph	0.24	0.25 ○	0.24	0.24 ●	0.24 ●
molecular-biology-promoters	0.30	0.30	0.43 ○	0.31	0.29
mushroom	0.25	0.25 ○	0.07 ●	0.26 ○	0.18 ●
nursery	0.24	0.24	0.21 ●	0.23 ●	0.22 ●
optdigits	0.17	0.17 ○	0.13 ●	0.16 ●	0.15 ●
page-blocks	0.24	0.26 ○	0.17 ●	0.20 ●	0.21 ●
pendigits	0.21	0.21	0.16 ●	0.20 ●	0.19 ●
postoperative-patient-data	0.40	0.40	0.41 ○	0.39	0.39 ●
primary-tumor	0.18	0.18	0.18	0.18 ●	0.18 ●
segment	0.29	0.29	0.23 ●	0.26 ●	0.25 ●
shuttle-landing-control	0.48	0.48	0.49 ○	0.48	0.48
sick	0.26	0.26	0.23 ●	0.25 ●	0.26
solar-flare-2	0.26	0.26 ○	0.25 ●	0.25 ●	0.25 ●
sonar	0.46	0.46	0.42 ●	0.45 ●	0.44 ●
soybean	0.10	0.10	0.09 ●	0.10	0.09 ●
spambase	0.44	0.44	0.39 ●	0.42 ●	0.42 ●
tae	0.47	0.47	0.47 ○	0.46 ●	0.46 ●
tic-tac-toe	0.44	0.44	0.43 ●	0.44 ●	0.44 ●
trains	0.47	0.43	0.29 ●	0.43	0.43
vehicle	0.46	0.46	0.37 ●	0.44 ●	0.43 ●
vote	0.29	0.29	0.23 ●	0.29 ●	0.29
vowel	0.28	0.29 ○	0.27 ●	0.28 ●	0.27 ●
waveform-5000	0.36	0.36	0.34 ●	0.35 ●	0.35 ●
zoo	0.15	0.16 ○	0.15	0.14 ●	0.14

○, ● statistically significant improvement or degradation

Table C.15: Bayesian Network Mean Entropy Gain - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-1.01	-1.00	-1.86 ●	-2.14 ●	-0.61 ○
autos	-0.12	-0.13	0.20 ○	0.11 ○	0.02 ○
balance-scale	0.36	0.36	0.37 ○	0.32 ●	0.35 ●
breast-cancer	-0.09	-0.09	-0.02 ○	-0.00 ○	-0.05 ○
bridges-version1	0.47	0.43	0.61 ○	0.67 ○	0.60 ○
car	0.25	0.25	0.67 ○	0.57 ○	0.60 ○
cmc	-0.11	-0.11	0.09 ○	0.04 ○	0.03 ○
colic	-0.43	-0.44	0.00 ○	-0.17 ○	-0.21 ○
cylinder-bands	-0.17	-0.20 ●	0.08 ○	0.04 ○	0.02 ○
dermatology	2.25	2.25	2.15 ●	2.29 ○	2.30 ○
diabetes	0.11	0.10	0.17 ○	0.16 ○	0.16 ○
ecoli	0.75	0.78	0.97 ○	0.96 ○	0.93 ○
flags	-0.08	-0.05	-0.09	0.27 ○	0.18 ○
glass	0.37	0.37	0.49 ○	0.53 ○	0.49 ○
haberman	-0.04	-0.04	-0.03	-0.01 ○	-0.02 ○
hayes-roth-train	0.07	0.06	0.15 ○	0.10 ○	0.13 ○
heart-h	0.22	0.23	0.26 ○	0.30 ○	0.29 ○
heart-statlog	0.11	0.11	0.21 ○	0.22 ○	0.20 ○
hepatitis	-0.25	-0.25	-0.14 ○	-0.09 ○	-0.18 ○
hypothyroid	0.04	0.02	0.10 ○	0.09 ○	0.09 ○
ionosphere	-0.64	-0.76 ●	0.01 ○	-0.08 ○	-0.09 ○
iris	0.64	0.61	0.79 ○	0.76 ○	0.79 ○
kr-vs-kp	0.48	0.47 ●	0.60 ○	0.48 ○	0.52 ○
labor	0.68	0.70 ○	0.65	0.70	0.72 ○
letter	1.38	1.37	2.03 ○	1.58 ○	1.68 ○
liver-disorders	0.02	0.01	0.06 ○	0.03 ○	0.05 ○
lung-cancer	-2.13	-2.08	-1.97	-1.21 ○	-1.94
lymph	0.68	0.64	0.62	0.72 ○	0.71 ○
molecular-biology-promoters	0.41	0.38	-0.28 ●	0.43	0.49 ○
mushroom	0.48	0.47 ●	0.97 ○	0.57 ○	0.80 ○
nursery	0.76	0.78	1.14 ○	1.00 ○	1.08 ○
optdigits	2.10	2.09 ●	2.78 ○	2.37 ○	2.41 ○
page-blocks	-0.14	-0.27 ●	0.24 ○	0.11 ○	0.09 ○
pendigits	1.56	1.57	2.49 ○	2.00 ○	2.04 ○
postoperative-patient-data	-0.22	-0.23	-0.24	-0.17 ○	-0.17 ○
primary-tumor	0.51	0.51	0.62 ○	0.71 ○	0.70 ○
segment	0.64	0.65	1.81 ○	1.25 ○	1.30 ○
shuttle-landing-control	0.04	0.05	-0.01 ●	0.04	0.05
sick	-0.00	-0.00	0.08 ○	0.04 ○	0.02 ○
solar-flare-2	1.21	1.17 ●	1.32 ○	1.28 ○	1.33 ○
sonar	-0.68	-0.68	0.09 ○	-0.33 ○	-0.30 ○
soybean	3.10	3.09	3.31 ○	3.23 ○	3.27 ○
spambase	0.02	0.01 ●	0.28 ○	0.17 ○	0.15 ○
tae	-0.02	-0.03	-0.02	0.03 ○	0.03 ○
tic-tac-toe	0.11	0.11	0.16 ○	0.12 ○	0.13 ○
trains	-0.73	-0.37 ○	0.32 ○	0.01 ○	-0.11 ○
vehicle	-1.48	-1.49	0.51 ○	-0.68 ○	-0.79 ○
vote	0.05	0.05	0.66 ○	0.28 ○	0.18 ○
vowel	0.38	0.30 ●	1.00 ○	0.63 ○	0.69 ○
waveform-5000	0.31	0.32	0.78 ○	0.60 ○	0.55 ○
zoo	1.96	1.88 ●	1.94	2.06 ○	2.04 ○

○, ● statistically significant improvement or degradation

Table C.16: Bayesian Network Mean Entropy Gain - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-1.01	-1.00	-1.86 ●	-2.14 ●	-0.61 ○
autos	-0.12	-0.13	0.20 ○	0.11 ○	0.02 ○
balance-scale	0.36	0.36	0.37 ○	0.32 ●	0.35 ●
breast-cancer	-0.09	-0.09	-0.02 ○	-0.00 ○	-0.05 ○
bridges-version1	0.47	0.43	0.61 ○	0.67 ○	0.60 ○
car	0.25	0.25	0.67 ○	0.57 ○	0.60 ○
cmc	-0.11	-0.11	0.09 ○	0.04 ○	0.03 ○
colic	-0.43	-0.44	0.00 ○	-0.17 ○	-0.21 ○
cylinder-bands	-0.17	-0.20 ●	0.08 ○	0.04 ○	0.02 ○
dermatology	2.25	2.25	2.15 ●	2.29 ○	2.30 ○
diabetes	0.11	0.10	0.17 ○	0.16 ○	0.16 ○
ecoli	0.75	0.78	0.97 ○	0.96 ○	0.93 ○
flags	-0.08	-0.05	-0.09	0.27 ○	0.18 ○
glass	0.37	0.37	0.49 ○	0.53 ○	0.49 ○
haberman	-0.04	-0.04	-0.03	-0.01 ○	-0.02 ○
hayes-roth-train	0.07	0.06	0.15 ○	0.10 ○	0.13 ○
heart-h	0.22	0.23	0.26 ○	0.30 ○	0.29 ○
heart-statlog	0.11	0.11	0.21 ○	0.22 ○	0.20 ○
hepatitis	-0.25	-0.25	-0.14 ○	-0.09 ○	-0.18 ○
hypothyroid	0.04	0.02	0.10 ○	0.09 ○	0.09 ○
ionosphere	-0.64	-0.76 ●	0.01 ○	-0.08 ○	-0.09 ○
iris	0.64	0.61	0.79 ○	0.76 ○	0.79 ○
kr-vs-kp	0.48	0.47 ●	0.60 ○	0.48 ○	0.52 ○
labor	0.68	0.70 ○	0.65	0.70	0.72 ○
letter	1.38	1.37	2.03 ○	1.58 ○	1.68 ○
liver-disorders	0.02	0.01	0.06 ○	0.03 ○	0.05 ○
lung-cancer	-2.13	-2.08	-1.97	-1.21 ○	-1.94
lymph	0.68	0.64	0.62	0.72 ○	0.71 ○
molecular-biology-promoters	0.41	0.38	-0.28 ●	0.43	0.49 ○
mushroom	0.48	0.47 ●	0.97 ○	0.57 ○	0.80 ○
nursery	0.76	0.78	1.14 ○	1.00 ○	1.08 ○
optdigits	2.10	2.09 ●	2.78 ○	2.37 ○	2.41 ○
page-blocks	-0.14	-0.27 ●	0.24 ○	0.11 ○	0.09 ○
pendigits	1.56	1.57	2.49 ○	2.00 ○	2.04 ○
postoperative-patient-data	-0.22	-0.23	-0.24	-0.17 ○	-0.17 ○
primary-tumor	0.51	0.51	0.62 ○	0.71 ○	0.70 ○
segment	0.64	0.65	1.81 ○	1.25 ○	1.30 ○
shuttle-landing-control	0.04	0.05	-0.01 ●	0.04	0.05
sick	-0.00	-0.00	0.08 ○	0.04 ○	0.02 ○
solar-flare-2	1.21	1.17 ●	1.32 ○	1.28 ○	1.33 ○
sonar	-0.68	-0.68	0.09 ○	-0.33 ○	-0.30 ○
soybean	3.10	3.09	3.31 ○	3.23 ○	3.27 ○
spambase	0.02	0.01 ●	0.28 ○	0.17 ○	0.15 ○
tae	-0.02	-0.03	-0.02	0.03 ○	0.03 ○
tic-tac-toe	0.11	0.11	0.16 ○	0.12 ○	0.13 ○
trains	-0.73	-0.37 ○	0.32 ○	0.01 ○	-0.11 ○
vehicle	-1.48	-1.49	0.51 ○	-0.68 ○	-0.79 ○
vote	0.05	0.05	0.66 ○	0.28 ○	0.18 ○
vowel	0.38	0.30 ●	1.00 ○	0.63 ○	0.69 ○
waveform-5000	0.31	0.32	0.78 ○	0.60 ○	0.55 ○
zoo	1.96	1.88 ●	1.94	2.06 ○	2.04 ○

○, ● statistically significant improvement or degradation

C.2.3 J48 Decision Tree

J48 Decision Tree results for various numbers of hidden variables can be seen in figures C.17 - C.24. As in section 3.1.3, the maximum number of iterations was set to 30 in order to obtain results in a reasonable time.

The J48 Percent Incorrect results can be seen in figures B.9, C.17 and C.18. As more hidden variables were added, Case 1 became less accurate relative to Case 3. At zero hidden variables it was more accurate in 9/51 cases, while with 5 hidden variables this had decreased to 4/51. It also remained better than Case 4 in all three experiments, although became worse relative to Case 5 as more hidden variables were added.

The J48 MAE results are shown in B.10, C.19 and C.20. Adding hidden variables seemed to have a much smaller effect on this metric when using J48 rather than the other classifiers. Only small changes were observed, probably due to the much lower cap on the max iterations. Case 1 began to perform slightly better than Case 3 as hidden variables were added, while it also began to perform slightly worse relative to Cases 4 and 5.

The J48 RMSE results (figures B.11, C.21 and C.22) show that adding more hidden variables with this classifier caused the RMSE to increase on average. Case 1 initially performed better than Case 5 in 21/51 cases, while with five hidden variables added in only performed better in 4/51. The decrease in relative performance was less pronounced between Case 3 and Case 4, although decreases were still observed in both cases.

The J48 MEG results can be seen in B.12, C.23 and C.24. Case 1 saw large entropy reductions relative to Cases 3 and 5 as more hidden variables were added. Case 1 also saw large entropy *gains* relative to Case 4. This is probably due to how J48 decision trees are built; imputing the most common value for missing values will heavily influence how the tree splits, and therefore decrease the entropy of the system.

Table C.17: J48 Decision Tree Percent Incorrect - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	30.27	30.48	32.94 ○	35.33 ○	32.94 ○
autos	13.84	14.12	13.02	14.68	13.02
balance-scale	28.88	28.81	29.02	29.56	29.02
breast-cancer	25.97	27.26 ○	26.80 ○	26.68	26.80 ○
bridges-version1	43.00	44.01	41.77	45.89 ○	41.77
car	16.25	16.52	16.73 ○	20.18 ○	16.73 ○
cmc	49.71	50.30	50.17	50.40	50.17
colic	18.74	17.91 ●	17.32 ●	18.98	17.32 ●
cylinder-bands	34.53	34.14	34.84	35.73	34.84
dermatology	11.00	11.63	10.04	13.33 ○	10.04
diabetes	28.94	28.87	28.61	27.73 ●	28.61
ecoli	34.69	34.53	34.92	37.23 ○	34.92
flags	41.71	42.19	41.94	44.77 ○	41.94
glass	41.70	42.73	38.89 ●	41.35	38.89 ●
haberman	27.08	26.57	26.57	26.57	26.57
hayes-roth-train	40.97	41.15	37.95 ●	42.43	37.95 ●
heart-h	21.69	21.28	22.94 ○	23.77 ○	22.94 ○
heart-statlog	31.00	30.00	32.32	30.04	32.32
hepatitis	23.33	21.75	22.10	23.28	22.10
hypothyroid	7.73	7.76	7.73	7.73	7.73
ionosphere	20.92	19.21 ●	19.37 ●	21.55	19.37 ●
iris	24.61	25.76	20.50 ●	22.24 ●	20.50 ●
kr-vs-kp	5.99	5.93	6.09	5.88	6.09
labor	23.60	26.00	27.80 ○	21.40	27.80 ○
letter	49.51	49.39	47.39 ●	51.04 ○	47.39 ●
liver-disorders	39.27	39.84	40.16	38.54	40.16
lung-cancer	58.40	56.15	67.29 ○	55.14	67.29 ○
lymph	20.47	20.03	21.75	23.36 ○	21.75
molecular-biology-promoters	21.91	21.11	20.22	26.85 ○	20.22
mushroom	2.20	3.56 ○	0.86 ●	0.57 ●	0.86 ●
nursery	12.32	12.48 ○	12.58 ○	14.34 ○	12.58 ○
optdigits	17.22	17.25	13.90 ●	23.70 ○	13.90 ●
page-blocks	7.30	7.23	7.25	7.27	7.25
pendigits	15.90	15.92	11.80 ●	16.89 ○	11.80 ●
postoperative-patient-data	29.61	29.35	29.24	29.24	29.24
primary-tumor	62.48	63.10	60.68 ●	61.71	60.68 ●
segment	26.84	26.79	21.77 ●	25.39 ●	21.77 ●
shuttle-landing-control	42.00	42.00	40.00	41.33	40.00
sick	6.20	6.25	6.19	6.19	6.19
solar-flare-2	30.35	30.02	28.17 ●	29.45 ●	28.17 ●
sonar	33.83	33.20	30.93 ●	32.63	30.93 ●
soybean	18.22	18.28	16.24 ●	18.71	16.24 ●
spambase	22.31	22.72 ○	21.79 ●	22.36	21.79 ●
tae	51.06	52.79	48.07 ●	51.07	48.07 ●
tic-tac-toe	21.97	22.35	21.55	21.98	21.55
trains	2.00	9.00	0.00	0.00	0.00
vehicle	40.60	40.90	38.88 ●	42.76 ○	38.88 ●
vote	8.31	8.49	6.34 ●	7.03 ●	6.34 ●
vowel	50.98	50.63	52.36 ○	54.88 ○	52.36 ○
waveform-5000	27.60	27.58	25.72 ●	32.41 ○	25.72 ●
zoo	16.26	17.61	15.39	18.76 ○	15.39

○, ● statistically significant improvement or degradation

Table C.18: J48 Decision Tree Percent Incorrect - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	30.39	30.37	32.94 ○	35.33 ○	32.94 ○
autos	13.30	14.44	13.02	14.68	13.02
balance-scale	29.11	29.60	29.02	29.56	29.02
breast-cancer	26.50	27.36	26.80	26.68	26.80
bridges-version1	42.44	44.02	41.77	45.89 ○	41.77
car	16.38	16.55	16.73	20.18 ○	16.73
cmc	50.50	49.60	50.17	50.40	50.17
colic	18.22	18.68	17.32 ●	18.98	17.32 ●
cylinder-bands	33.26	33.44	34.84	35.73 ○	34.84
dermatology	11.06	11.75	10.04	13.33 ○	10.04
diabetes	30.00	29.46	28.61 ●	27.73 ●	28.61 ●
ecoli	34.40	35.19	34.92	37.23 ○	34.92
flags	41.15	41.64	41.94	44.77 ○	41.94
glass	41.41	41.42	38.89 ●	41.35	38.89 ●
haberman	26.57	26.75	26.57	26.57	26.57
hayes-roth-train	41.14	42.24	37.95 ●	42.43	37.95 ●
heart-h	21.84	22.30	22.94	23.77 ○	22.94
heart-statlog	31.25	31.33	32.32	30.04	32.32
hepatitis	23.06	21.59	22.10	23.28	22.10
hypothyroid	7.73	7.74	7.73	7.73	7.73
ionosphere	20.19	19.78	19.37	21.55	19.37
iris	23.70	23.70	20.50 ●	22.24	20.50 ●
kr-vs-kp	6.05	6.06	6.09	5.88	6.09
labor	26.60	24.80	27.80	21.40 ●	27.80
letter	49.51	49.41	47.39 ●	51.04 ○	47.39 ●
liver-disorders	40.29	39.14	40.16	38.54 ●	40.16
lung-cancer	58.23	53.31	67.29 ○	55.14	67.29 ○
lymph	20.62	20.67	21.75	23.36 ○	21.75
molecular-biology-promoters	20.36	21.81	20.22	26.85 ○	20.22
mushroom	2.14	3.60 ○	0.86 ●	0.57 ●	0.86 ●
nursery	12.35	12.61 ○	12.58 ○	14.34 ○	12.58 ○
optdigits	17.07	17.18	13.90 ●	23.70 ○	13.90 ●
page-blocks	7.17	7.32	7.25	7.27	7.25
pendigits	15.92	16.05	11.80 ●	16.89 ○	11.80 ●
postoperative-patient-data	29.24	29.61	29.24	29.24	29.24
primary-tumor	61.65	62.10	60.68	61.71	60.68
segment	26.88	27.00	21.77 ●	25.39 ●	21.77 ●
shuttle-landing-control	42.00	42.00	40.00	41.33	40.00
sick	6.19	6.32	6.19	6.19	6.19
solar-flare-2	30.25	29.73	28.17 ●	29.45 ●	28.17 ●
sonar	32.45	31.76	30.93	32.63	30.93
soybean	18.14	18.25	16.24 ●	18.71	16.24 ●
spambase	22.08	22.60 ○	21.79 ●	22.36 ○	21.79 ●
tae	51.13	51.57	48.07 ●	51.07	48.07 ●
tic-tac-toe	22.10	22.22	21.55	21.98	21.55
trains	2.00	3.00	0.00	0.00	0.00
vehicle	40.60	40.30	38.88 ●	42.76 ○	38.88 ●
vote	8.44	8.31	6.34 ●	7.03 ●	6.34 ●
vowel	50.87	51.51	52.36 ○	54.88 ○	52.36 ○
waveform-5000	27.54	27.48	25.72 ●	32.41 ○	25.72 ●
zoo	18.35	18.56	15.39 ●	18.76	15.39 ●

○, ● statistically significant improvement or degradation

Table C.19: J48 Decision Tree Mean Absolute Error - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03	0.04 ○	0.04 ○	0.04 ○
autos	0.19	0.19	0.19	0.21 ○	0.19
balance-scale	0.27	0.27	0.29 ○	0.28 ○	0.29 ○
breast-cancer	0.36	0.37 ○	0.38 ○	0.37	0.38 ○
bridges-version1	0.17	0.17	0.17 ○	0.18 ○	0.17 ○
car	0.09	0.10	0.12 ○	0.12 ○	0.12 ○
cmc	0.39	0.39	0.40 ○	0.39 ○	0.40 ○
colic	0.26	0.25 ●	0.28 ○	0.27 ○	0.28 ○
cylinder-bands	0.37	0.37	0.40 ○	0.39	0.40 ○
dermatology	0.05	0.05	0.07 ○	0.07 ○	0.07 ○
diabetes	0.36	0.36	0.38 ○	0.36 ○	0.38 ○
ecoli	0.11	0.11	0.11 ○	0.11 ○	0.11 ○
flags	0.12	0.12	0.13 ○	0.13 ○	0.13 ○
glass	0.15	0.15	0.15 ○	0.15	0.15 ○
haberman	0.38	0.38 ○	0.39 ○	0.38 ●	0.39 ○
hayes-roth-train	0.26	0.26	0.26 ○	0.27 ○	0.26 ○
heart-h	0.11	0.11	0.12 ○	0.13 ○	0.12 ○
heart-statlog	0.37	0.37	0.40 ○	0.38	0.40 ○
hepatitis	0.28	0.27	0.29	0.28	0.29
hypothyroid	0.07	0.07	0.07 ○	0.07 ●	0.07 ○
ionosphere	0.25	0.24	0.27 ○	0.26 ○	0.27 ○
iris	0.21	0.21	0.22 ○	0.23 ○	0.22 ○
kr-vs-kp	0.09	0.09 ●	0.14 ○	0.13 ○	0.14 ○
labor	0.25	0.26	0.32 ○	0.22 ●	0.32 ○
letter	0.05	0.05 ●	0.05 ○	0.05 ○	0.05 ○
liver-disorders	0.45	0.45	0.46 ○	0.46	0.46 ○
lung-cancer	0.39	0.38	0.44 ○	0.37	0.44 ○
lymph	0.13	0.13	0.15 ○	0.14 ○	0.15 ○
molecular-biology-promoters	0.26	0.25	0.27	0.30 ○	0.27
mushroom	0.05	0.05 ○	0.03 ●	0.05 ○	0.03 ●
nursery	0.06	0.06	0.09 ○	0.10 ○	0.09 ○
optdigits	0.05	0.05	0.05 ○	0.06 ○	0.05 ○
page-blocks	0.05	0.05 ○	0.05 ○	0.05 ○	0.05 ○
pendigits	0.05	0.05 ●	0.05 ○	0.06 ○	0.05 ○
postoperative-patient-data	0.28	0.28	0.28	0.28	0.28
primary-tumor	0.07	0.07	0.07 ○	0.06	0.07 ○
segment	0.10	0.10 ●	0.10 ○	0.11 ○	0.10 ○
shuttle-landing-control	0.49	0.49	0.49	0.49	0.49
sick	0.11	0.11	0.12 ○	0.11	0.12 ○
solar-flare-2	0.12	0.12 ●	0.13 ○	0.13 ○	0.13 ○
sonar	0.35	0.35	0.35	0.34	0.35
soybean	0.02	0.03	0.03 ○	0.03 ○	0.03 ○
spambase	0.31	0.32 ○	0.32 ○	0.33 ○	0.32 ○
tae	0.40	0.41	0.40	0.41 ○	0.40
tic-tac-toe	0.28	0.28	0.30 ○	0.28	0.30 ○
trains	0.02	0.08	0.00	0.00	0.00
vehicle	0.23	0.23	0.25 ○	0.25 ○	0.25 ○
vote	0.10	0.11	0.11	0.13 ○	0.11
vowel	0.10	0.10	0.12 ○	0.11 ○	0.12 ○
waveform-5000	0.21	0.21	0.22 ○	0.24 ○	0.22 ○
zoo	0.06	0.07	0.07	0.07 ○	0.07

○, ● statistically significant improvement or degradation

Table C.20: J48 Decision Tree Mean Absolute Error - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.03	0.03	0.04 ○	0.04 ○	0.04 ○
autos	0.18	0.19	0.19	0.21 ○	0.19
balance-scale	0.27	0.27	0.29 ○	0.28 ○	0.29 ○
breast-cancer	0.37	0.37	0.38 ○	0.37	0.38 ○
bridges-version1	0.16	0.17	0.17 ○	0.18 ○	0.17 ○
car	0.10	0.10	0.12 ○	0.12 ○	0.12 ○
cmc	0.39	0.39	0.40 ○	0.39 ○	0.40 ○
colic	0.26	0.26	0.28 ○	0.27 ○	0.28 ○
cylinder-bands	0.37	0.37	0.40 ○	0.39 ○	0.40 ○
dermatology	0.05	0.05	0.07 ○	0.07 ○	0.07 ○
diabetes	0.37	0.36	0.38 ○	0.36	0.38 ○
ecoli	0.11	0.11	0.11 ○	0.11 ○	0.11 ○
flags	0.12	0.12	0.13 ○	0.13 ○	0.13 ○
glass	0.15	0.15	0.15	0.15	0.15
haberman	0.38	0.38	0.39 ○	0.38 ●	0.39 ○
hayes-roth-train	0.26	0.26	0.26	0.27 ○	0.26
heart-h	0.11	0.11	0.12 ○	0.13 ○	0.12 ○
heart-statlog	0.37	0.37	0.40 ○	0.38	0.40 ○
hepatitis	0.28	0.27	0.29	0.28	0.29
hypothyroid	0.07	0.07 ○	0.07 ○	0.07	0.07 ○
ionosphere	0.24	0.24	0.27 ○	0.26 ○	0.27 ○
iris	0.20	0.21	0.22 ○	0.23 ○	0.22 ○
kr-vs-kp	0.09	0.09 ●	0.14 ○	0.13 ○	0.14 ○
labor	0.27	0.25	0.32 ○	0.22 ●	0.32 ○
letter	0.05	0.05 ●	0.05 ○	0.05 ○	0.05 ○
liver-disorders	0.45	0.45	0.46 ○	0.46	0.46 ○
lung-cancer	0.39	0.36	0.44 ○	0.37	0.44 ○
lymph	0.13	0.13	0.15 ○	0.14 ○	0.15 ○
molecular-biology-promoters	0.24	0.26	0.27 ○	0.30 ○	0.27 ○
mushroom	0.05	0.05 ○	0.03 ●	0.05 ○	0.03 ●
nursery	0.06	0.06 ○	0.09 ○	0.10 ○	0.09 ○
optdigits	0.05	0.05	0.05 ○	0.06 ○	0.05 ○
page-blocks	0.05	0.05 ○	0.05 ○	0.05 ○	0.05 ○
pendigits	0.05	0.05 ●	0.05 ○	0.06 ○	0.05 ○
postoperative-patient-data	0.28	0.28	0.28 ○	0.28	0.28 ○
primary-tumor	0.06	0.06	0.07 ○	0.06	0.07 ○
segment	0.10	0.10	0.10 ○	0.11 ○	0.10 ○
shuttle-landing-control	0.49	0.49	0.49	0.49	0.49
sick	0.11	0.11	0.12 ○	0.11 ●	0.12 ○
solar-flare-2	0.12	0.12	0.13 ○	0.13 ○	0.13 ○
sonar	0.34	0.34	0.35	0.34	0.35
soybean	0.02	0.03	0.03 ○	0.03 ○	0.03 ○
spambase	0.31	0.32 ○	0.32 ○	0.33 ○	0.32 ○
tae	0.41	0.40	0.40	0.41 ○	0.40
tic-tac-toe	0.28	0.29	0.30 ○	0.28	0.30 ○
trains	0.02	0.03	0.00	0.00	0.00
vehicle	0.23	0.23	0.25 ○	0.25 ○	0.25 ○
vote	0.11	0.10	0.11	0.13 ○	0.11
vowel	0.10	0.11	0.12 ○	0.11 ○	0.12 ○
waveform-5000	0.21	0.21	0.22 ○	0.24 ○	0.22 ○
zoo	0.07	0.07	0.07	0.07	0.07

○, ● statistically significant improvement or degradation

Table C.21: J48 Root Mean Squared Error - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.14	0.14	0.14 ○	0.15 ○	0.14 ○
autos	0.33	0.34	0.33	0.35 ○	0.33
balance-scale	0.37	0.38	0.37	0.38	0.37
breast-cancer	0.44	0.45 ○	0.44	0.45	0.44
bridges-version1	0.32	0.33	0.31 ●	0.33 ○	0.31 ●
car	0.23	0.23	0.23 ○	0.26 ○	0.23 ○
cmc	0.46	0.46	0.45 ●	0.46 ○	0.45 ●
colic	0.39	0.38 ●	0.37 ●	0.40 ○	0.37 ●
cylinder-bands	0.50	0.50	0.48 ●	0.53 ○	0.48 ●
dermatology	0.17	0.17	0.16	0.19 ○	0.16
diabetes	0.44	0.44	0.44 ●	0.44	0.44 ●
ecoli	0.24	0.24	0.23 ●	0.24 ○	0.23 ●
flags	0.28	0.28	0.27 ●	0.30 ○	0.27 ●
glass	0.29	0.29	0.28 ●	0.30 ○	0.28 ●
haberman	0.44	0.44	0.44	0.44	0.44
hayes-roth-train	0.37	0.37	0.36 ●	0.38 ○	0.36 ●
heart-h	0.25	0.25	0.26	0.27 ○	0.26
heart-statlog	0.47	0.46	0.47	0.47	0.47
hepatitis	0.43	0.42	0.41 ●	0.44	0.41 ●
hypothyroid	0.19	0.19	0.19 ●	0.19 ○	0.19 ●
ionosphere	0.40	0.39	0.38 ●	0.43 ○	0.38 ●
iris	0.33	0.33	0.32 ●	0.34 ○	0.32 ●
kr-vs-kp	0.21	0.21	0.22 ○	0.24 ○	0.22 ○
labor	0.41	0.42	0.45 ○	0.40	0.45 ○
letter	0.16	0.16	0.15 ●	0.16 ○	0.15 ●
liver-disorders	0.50	0.50	0.49 ●	0.50	0.49 ●
lung-cancer	0.55	0.54	0.57	0.55	0.57
lymph	0.29	0.28	0.29	0.31 ○	0.29
molecular-biology-promoters	0.42	0.41	0.40	0.47 ○	0.40
mushroom	0.14	0.15 ○	0.09 ●	0.10 ●	0.09 ●
nursery	0.18	0.18 ○	0.19 ○	0.22 ○	0.19 ○
optdigits	0.16	0.16	0.15 ●	0.20 ○	0.15 ●
page-blocks	0.16	0.16	0.16 ○	0.16 ○	0.16 ○
pendigits	0.15	0.15	0.14 ●	0.17 ○	0.14 ●
postoperative-patient-data	0.38	0.38	0.38	0.38	0.38
primary-tumor	0.20	0.20	0.19 ●	0.20 ○	0.19 ●
segment	0.23	0.23	0.21 ●	0.24 ○	0.21 ●
shuttle-landing-control	0.50	0.50	0.50	0.50	0.50
sick	0.24	0.24	0.24	0.24	0.24
solar-flare-2	0.25	0.25	0.25 ●	0.26 ○	0.25 ●
sonar	0.53	0.52	0.48 ●	0.54	0.48 ●
soybean	0.12	0.12	0.11 ●	0.13 ○	0.11 ●
spambase	0.40	0.40 ○	0.39 ●	0.41 ○	0.39 ●
tae	0.46	0.47	0.45 ●	0.47	0.45 ●
tic-tac-toe	0.40	0.41	0.39 ●	0.41 ○	0.39 ●
trains	0.02	0.08	0.00	0.00	0.00
vehicle	0.36	0.36	0.35 ●	0.39 ○	0.35 ●
vote	0.24	0.25 ○	0.23 ●	0.25 ○	0.23 ●
vowel	0.25	0.25	0.24 ●	0.27 ○	0.24 ●
waveform-5000	0.38	0.38	0.35 ●	0.43 ○	0.35 ●
zoo	0.18	0.19	0.18	0.20 ○	0.18

○, ● statistically significant improvement or degradation

Table C.22: J48 Root Mean Squared Error - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	0.14	0.14	0.14 ○	0.15 ○	0.14 ○
autos	0.34	0.34	0.33	0.35	0.33
balance-scale	0.37	0.38	0.37	0.38	0.37
breast-cancer	0.45	0.45	0.44	0.45	0.44
bridges-version1	0.32	0.32	0.31	0.33 ○	0.31
car	0.23	0.23	0.23 ○	0.26 ○	0.23 ○
cmc	0.46	0.46 ●	0.45 ●	0.46	0.45 ●
colic	0.39	0.39	0.37 ●	0.40 ○	0.37 ●
cylinder-bands	0.49	0.50	0.48 ●	0.53 ○	0.48 ●
dermatology	0.17	0.17	0.16	0.19 ○	0.16
diabetes	0.45	0.44 ●	0.44 ●	0.44 ●	0.44 ●
ecoli	0.24	0.24 ○	0.23 ●	0.24 ○	0.23 ●
flags	0.28	0.28	0.27	0.30 ○	0.27
glass	0.29	0.29	0.28 ●	0.30 ○	0.28 ●
haberman	0.44	0.44	0.44 ●	0.44 ○	0.44 ●
hayes-roth-train	0.37	0.37	0.36 ●	0.38 ○	0.36 ●
heart-h	0.25	0.26	0.26	0.27 ○	0.26
heart-statlog	0.47	0.47	0.47	0.47	0.47
hepatitis	0.43	0.42	0.41 ●	0.44	0.41 ●
hypothyroid	0.19	0.19	0.19	0.19	0.19
ionosphere	0.39	0.40	0.38 ●	0.43 ○	0.38 ●
iris	0.32	0.33	0.32	0.34 ○	0.32
kr-vs-kp	0.21	0.21	0.22 ○	0.24 ○	0.22 ○
labor	0.43	0.41	0.45	0.40	0.45
letter	0.16	0.16	0.15 ●	0.16 ○	0.15 ●
liver-disorders	0.50	0.49	0.49 ●	0.50	0.49 ●
lung-cancer	0.55	0.53	0.57	0.55	0.57
lymph	0.29	0.28	0.29	0.31 ○	0.29
molecular-biology-promoters	0.40	0.42	0.40	0.47 ○	0.40
mushroom	0.14	0.15 ○	0.09 ●	0.10 ●	0.09 ●
nursery	0.18	0.18 ○	0.19 ○	0.22 ○	0.19 ○
optdigits	0.16	0.16	0.15 ●	0.20 ○	0.15 ●
page-blocks	0.16	0.16 ○	0.16	0.16 ○	0.16
pendigits	0.15	0.15 ○	0.14 ●	0.17 ○	0.14 ●
postoperative-patient-data	0.38	0.38	0.38	0.38	0.38
primary-tumor	0.20	0.20	0.19 ●	0.20 ○	0.19 ●
segment	0.23	0.23	0.21 ●	0.24 ○	0.21 ●
shuttle-landing-control	0.50	0.50	0.50	0.50	0.50
sick	0.24	0.24	0.24 ●	0.24 ○	0.24 ●
solar-flare-2	0.25	0.25	0.25 ●	0.26 ○	0.25 ●
sonar	0.51	0.51	0.48 ●	0.54 ○	0.48 ●
soybean	0.12	0.12	0.11 ●	0.13 ○	0.11 ●
spambase	0.40	0.40 ○	0.39 ●	0.41 ○	0.39 ●
tae	0.47	0.46	0.45 ●	0.47	0.45 ●
tic-tac-toe	0.40	0.41	0.39 ●	0.41 ○	0.39 ●
trains	0.02	0.03	0.00	0.00	0.00
vehicle	0.36	0.36	0.35 ●	0.39 ○	0.35 ●
vote	0.24	0.24	0.23 ●	0.25	0.23 ●
vowel	0.25	0.25	0.24 ●	0.27 ○	0.24 ●
waveform-5000	0.37	0.37	0.35 ●	0.43 ○	0.35 ●
zoo	0.20	0.20	0.18 ●	0.20	0.18 ●

○, ● statistically significant improvement or degradation

Table C.23: J48 Decision Tree Mean Entropy Gain - Three Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-108.27	-111.93	-87.04 ○	-158.79 ●	-87.04 ○
autos	-13.12	-17.24	-3.68 ○	-21.39	-3.68 ○
balance-scale	-1.44	-2.01	0.25 ○	-2.59	0.25 ○
breast-cancer	-11.36	-12.58	-1.20 ○	-16.63	-1.20 ○
bridges-version1	-134.90	-145.54	-77.69 ○	-133.17	-77.69 ○
car	-15.90	-16.45	-1.06 ○	-39.71 ●	-1.06 ○
cmc	-22.03	-21.96	-0.50 ○	-31.94 ●	-0.50 ○
colic	-27.45	-20.50 ○	-0.69 ○	-36.02 ●	-0.69 ○
cylinder-bands	-53.56	-54.23	-1.51 ○	-101.43 ●	-1.51 ○
dermatology	-21.83	-23.49	-0.63 ○	-55.02 ●	-0.63 ○
diabetes	-4.72	-1.45 ○	0.11 ○	-2.54	0.11 ○
ecoli	-36.23	-35.86	-21.92 ○	-51.93 ●	-21.92 ○
flags	-179.68	-185.81	-59.40 ○	-262.88 ●	-59.40 ○
glass	-79.32	-79.87	-20.88 ○	-134.49 ●	-20.88 ○
haberman	-0.01	-0.00	0.00	-0.00	0.00
hayes-roth-train	-23.77	-21.93	0.32 ○	-24.76	0.32 ○
heart-h	-20.45	-23.32	-0.60 ○	-21.34	-0.60 ○
heart-statlog	-20.16	-13.23	0.08 ○	-24.89	0.08 ○
hepatitis	-32.65	-32.56	-5.45 ○	-56.53 ●	-5.45 ○
hypothyroid	-0.00	0.01	-0.00 ○	-0.00 ●	-0.00 ○
ionosphere	-39.49	-36.41	-2.47 ○	-86.84 ●	-2.47 ○
iris	-15.26	-13.70	0.06 ○	-14.53	0.06 ○
kr-vs-kp	0.01	-0.03	0.73 ○	-4.54 ●	0.73 ○
labor	-42.63	-64.07	-14.96	-78.97 ●	-14.96
letter	-48.05	-46.34 ○	-2.75 ○	-123.96 ●	-2.75 ○
liver-disorders	-2.12	-2.82	-0.34	-7.05 ●	-0.34
lung-cancer	-304.56	-282.51	-285.77	-349.74	-285.77
lymph	-61.28	-63.72	-14.26 ○	-98.35 ●	-14.26 ○
molecular-biology-promoters	-96.84	-87.74	-10.05 ○	-120.80	-10.05 ○
mushroom	0.91	0.90 ●	0.94 ○	0.12 ●	0.94 ○
nursery	-3.53	-3.26	1.23 ○	-8.25 ●	1.23 ○
optdigits	-46.04	-45.95	-5.72 ○	-172.03 ●	-5.72 ○
page-blocks	-0.42	-0.44	-0.10 ○	-1.16 ●	-0.10 ○
pendigits	-9.69	-9.74	1.74 ○	-52.19 ●	1.74 ○
postoperative-patient-data	-5.38	-1.27	-0.01	-0.01	-0.01
primary-tumor	-295.99	-280.61	-120.47 ○	-366.49 ●	-120.47 ○
segment	-10.11	-11.44	0.95 ○	-51.51 ●	0.95 ○
shuttle-landing-control	-0.03	-0.03	-0.00	-0.01	-0.00
sick	-0.09	-0.12	0.00	-0.00	0.00
solar-flare-2	-22.42	-20.61	-1.14 ○	-45.09 ●	-1.14 ○
sonar	-148.45	-139.16	-26.02 ○	-213.09 ●	-26.02 ○
soybean	-23.97	-25.22	-4.49 ○	-112.98 ●	-4.49 ○
spambase	0.06	0.09	0.28 ○	0.15	0.28 ○
tae	-15.98	-22.25	0.09 ○	-18.33	0.09 ○
tic-tac-toe	-28.11	-28.61	0.12 ○	-34.08 ●	0.12 ○
trains	0.97	-42.07 ●	1.01	1.01	1.01
vehicle	-34.63	-36.74	-3.43 ○	-125.50 ●	-3.43 ○
vote	-1.82	-4.57 ●	-0.43	-19.92 ●	-0.43
vowel	-99.00	-97.54	-15.15 ○	-292.68 ●	-15.15 ○
waveform-5000	-49.15	-47.75	-0.12 ○	-165.15 ●	-0.12 ○
zoo	-39.30	-46.47	-19.36 ○	-111.23 ●	-19.36 ○

○, ● statistically significant improvement or degradation

Table C.24: J48 Decision Tree Mean Entropy Gain - Five Hidden Variables

Dataset	(1)	(2)	(3)	(4)	(5)
audiology	-105.03	-110.89	-87.04 ○	-158.79 ●	-87.04 ○
autos	-18.34	-17.84	-3.68 ○	-21.39	-3.68 ○
balance-scale	-1.26	-1.45	0.25 ○	-2.59	0.25 ○
breast-cancer	-12.60	-15.42	-1.20 ○	-16.63	-1.20 ○
bridges-version1	-148.10	-107.96 ○	-77.69 ○	-133.17	-77.69 ○
car	-16.04	-15.51	-1.06 ○	-39.71 ●	-1.06 ○
cmc	-22.04	-18.29	-0.50 ○	-31.94 ●	-0.50 ○
colic	-22.84	-21.19	-0.69 ○	-36.02 ●	-0.69 ○
cylinder-bands	-51.38	-49.18	-1.51 ○	-101.43 ●	-1.51 ○
dermatology	-19.87	-23.44	-0.63 ○	-55.02 ●	-0.63 ○
diabetes	-2.87	-1.77	0.11 ○	-2.54	0.11 ○
ecoli	-32.71	-33.77	-21.92 ○	-51.93 ●	-21.92 ○
flags	-176.06	-184.33	-59.40 ○	-262.88 ●	-59.40 ○
glass	-75.58	-66.34	-20.88 ○	-134.49 ●	-20.88 ○
haberman	-0.00	-0.00	0.00 ○	-0.00 ●	0.00 ○
hayes-roth-train	-18.23	-17.24	0.32 ○	-24.76	0.32 ○
heart-h	-20.47	-20.90	-0.60 ○	-21.34	-0.60 ○
heart-statlog	-18.45	-18.48	0.08 ○	-24.89	0.08 ○
hepatitis	-43.57	-31.08	-5.45 ○	-56.53	-5.45 ○
hypothyroid	0.00	0.00	-0.00	-0.00	-0.00
ionosphere	-34.09	-36.48	-2.47 ○	-86.84 ●	-2.47 ○
iris	-16.90	-16.13	0.06 ○	-14.53	0.06 ○
kr-vs-kp	0.04	0.08	0.73 ○	-4.54 ●	0.73 ○
labor	-49.10	-44.76	-14.96 ○	-78.97	-14.96 ○
letter	-45.92	-45.06	-2.75 ○	-123.96 ●	-2.75 ○
liver-disorders	-3.54	-2.46	-0.34 ○	-7.05	-0.34 ○
lung-cancer	-351.02	-315.18	-285.77	-349.74	-285.77
lymph	-62.13	-51.21	-14.26 ○	-98.35 ●	-14.26 ○
molecular-biology-promoters	-88.35	-98.66	-10.05 ○	-120.80 ●	-10.05 ○
mushroom	0.91	0.90 ●	0.94 ○	0.12 ●	0.94 ○
nursery	-2.22	-2.39	1.23 ○	-8.25 ●	1.23 ○
optdigits	-45.50	-45.83	-5.72 ○	-172.03 ●	-5.72 ○
page-blocks	-0.44	-0.35	-0.10 ○	-1.16 ●	-0.10 ○
pendigits	-9.20	-9.41	1.74 ○	-52.19 ●	1.74 ○
postoperative-patient-data	-4.03	-2.70	-0.01	-0.01	-0.01
primary-tumor	-288.14	-269.52	-120.47 ○	-366.49 ●	-120.47 ○
segment	-10.68	-9.55	0.95 ○	-51.51 ●	0.95 ○
shuttle-landing-control	-0.02	-0.03	-0.00	-0.01	-0.00
sick	-0.00	-0.18	0.00 ○	-0.00 ●	0.00 ○
solar-flare-2	-19.83	-18.59	-1.14 ○	-45.09 ●	-1.14 ○
sonar	-135.92	-118.66	-26.02 ○	-213.09 ●	-26.02 ○
soybean	-20.99	-22.94	-4.49 ○	-112.98 ●	-4.49 ○
spambase	0.16	0.12	0.28	0.15	0.28
tae	-16.80	-6.08 ○	0.09 ○	-18.33	0.09 ○
tic-tac-toe	-21.80	-20.57	0.12 ○	-34.08 ●	0.12 ○
trains	0.97	-9.78	1.01	1.01	1.01
vehicle	-31.99	-34.90	-3.43 ○	-125.50 ●	-3.43 ○
vote	-4.28	-4.28	-0.43 ○	-19.92 ●	-0.43 ○
vowel	-97.20	-101.43	-15.15 ○	-292.68 ●	-15.15 ○
waveform-5000	-45.64	-45.07	-0.12 ○	-165.15 ●	-0.12 ○
zoo	-61.66	-49.83	-19.36 ○	-111.23 ●	-19.36 ○

○, ● statistically significant improvement or degradation

C.3 Conclusions

Adding hidden variables did not appear to be particularly helpful for the iterative training method which was implemented in this work. While adding more hidden variables did further reduce the entropy gains of the classifier, it also decreased classifier accuracy in every test case, and also generally increased root mean squared error. While this method may prove useful for other classifiers that were not tested, it does not appear useful for those that were.

Appendix D

User Guide

The developed plugin is fully usable from either the command line, or the GUI. It's also possible to mix and match the two, for example it would be fine to install the plugin using the CLI and then use it with the GUI. This section is mainly split into two subsections for clarity.

D.0.1 CLI

Provided that the installed *weka.jar* file is on the classpath, the following examples should be reproducible on any system. If the *weka.jar* file is not on the class path, then the `-cp` flag must also be appended to the command. For example:

```
java weka.classifiers.bayes.NaiveBayes -t training.arff
```

would have to become

```
java -cp /home/path/to/jar/weka.jar weka.classifiers.bayes.NaiveBayes  
-t training.arff
```

The plugin can be installed using Weka's package manager using the following command, assuming that the *cdc04* zip file is in the current directory:

```
java weka.core.WekaPackageManager -install-package cdc04.zip
```

An example of using the classifier from the command line would be:

```
java weka.Run ProjectClassifier -t audiology.arff
-W weka.classifiers.bayes.NaiveBayes -S -M 30 -- -O
```

Any parameters which follow the - - are passed to the target classifier. If there is any doubt about flags or parameters, use the help flag (-h).

D.0.2 GUI

Once Weka is running the plugin can be imported using the package manager which can be found in the menu shown in Figure D.1.

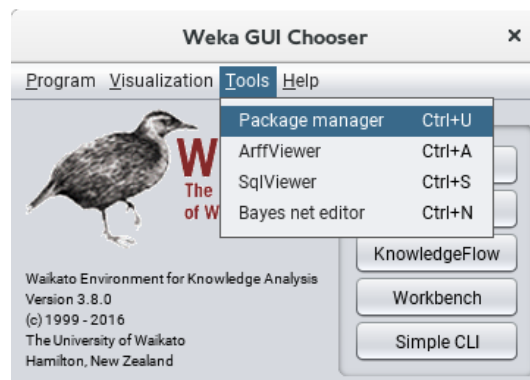


Figure D.1: Weka Main Menu

This will bring up the screen shown in D.2. The plugin can be installed by clicking the *File/Url* button in the top right corner, and then adding the *cdc04.zip* file.

Once the plugin has been installed, it can then be used throughout Weka. For example in the explorer it can be found under *Weka / Classifiers / Meta* as shown in Figure D.3.

This can then be configured using the interface shown in Figure D.4. Clicking the name of the internal classifier will allow it to be configured using its own, similar window.

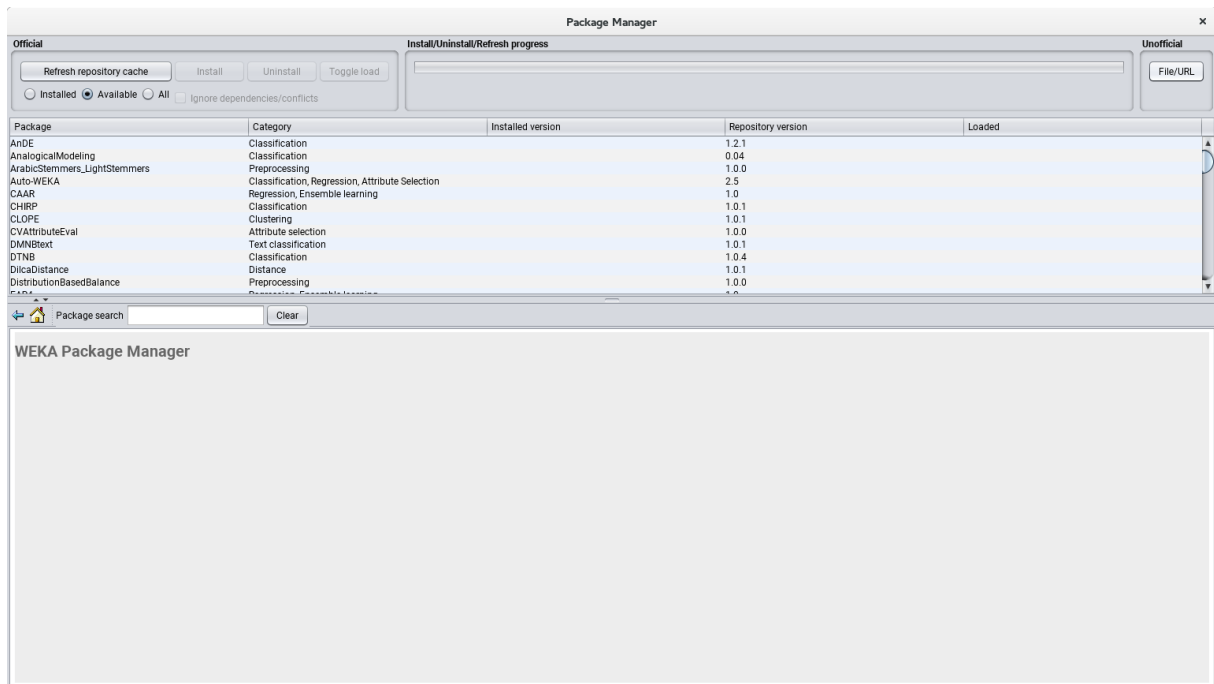


Figure D.2: Weka Package Manager

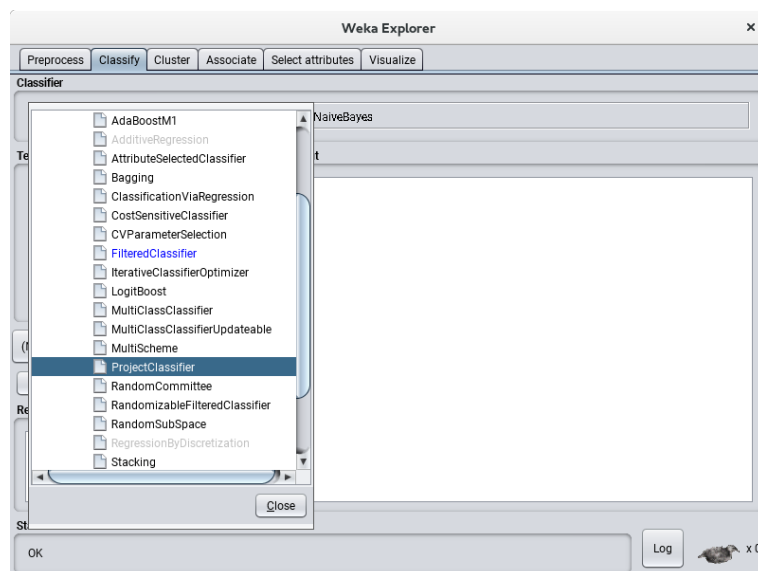


Figure D.3: Weka Classifier Selector

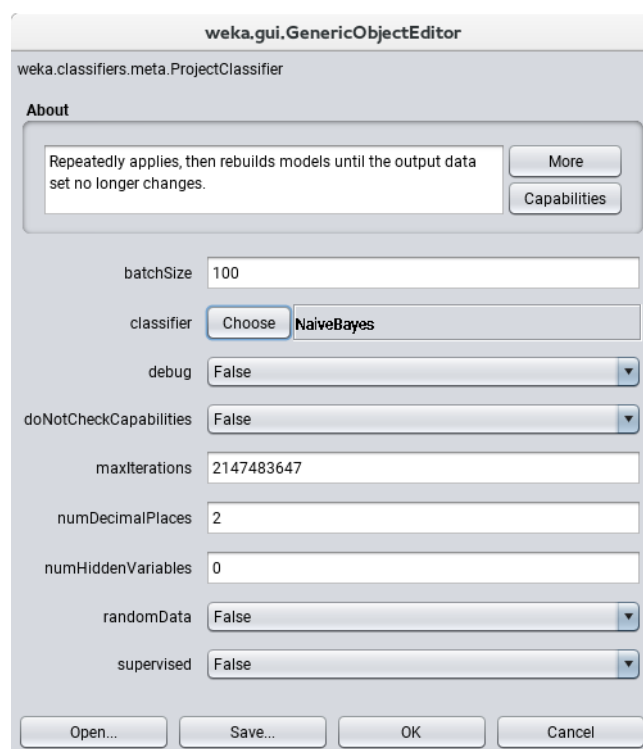


Figure D.4: Project Classifier Configuration GUI

Appendix E

JavaDoc

CDC04 TeXDoclet

Christopher McKee

10 May 2017

Contents

Class Hierarchy	2
1 Package cdc04	3
1.1 Class StateAnalyser	3
1.1.1 Declaration	3
1.1.2 Constructor summary	3
1.1.3 Method summary	3
1.1.4 Constructors	3
1.1.5 Methods	4
2 Package weka.classifiers.meta	5
2.1 Class ProjectClassifier	5
2.1.1 Declaration	5
2.1.2 Constructor summary	6
2.1.3 Method summary	6
2.1.4 Constructors	6
2.1.5 Methods	7
2.1.6 Members inherited from class SingleClassifierEnhancer	13
2.1.7 Members inherited from class AbstractClassifier	13

Class Hierarchy

Classes

- `java.lang.Object`
 - `cdc04.StateAnalyser` (in [1.1](#), page [3](#))
 - `weka.classifiers.AbstractClassifier`
 - `weka.classifiers.SingleClassifierEnhancer`
 - `weka.classifiers.meta.ProjectClassifier` (in [2.1](#), page [5](#))

Chapter 1

Package cdc04

<i>Package Contents</i>	<i>Page</i>
Classes	
StateAnalyser	3
Class written to record a series of Weka instances, and to determine differences between them.	

1.1 Class StateAnalyser

Class written to record a series of Weka instances, and to determine differences between them.

1.1.1 Declaration

```
public class StateAnalyser
    extends java.lang.Object implements java.io.Serializable
```

1.1.2 Constructor summary

StateAnalyser() Constructs a new instance with no recorded instances

1.1.3 Method summary

addInstances(Instances) Adds an Instances object to be tracked
getNumberDifferences() Returns an integer representation of the number of rows which have changed between the previous two iterations of the classifier A negative return values shows that the number of differences could not be calculated, since there are not at least two iterations present.
getNumberIterations() Returns the number of instances which are currently contained in the tracker for analysis

1.1.4 Constructors

- **StateAnalyser**

```
public StateAnalyser()
```

- **Description**

Constructs a new instance with no recorded instances

1.1.5 Methods

- **addInstances**

```
public void addInstances(weka.core.Instances toAdd)
```

- **Description**

Adds an Instances object to be tracked

- **Parameters**

- * toAdd – Instances object to be added

- **getNumberDifferences**

```
public int getNumberDifferences()
```

- **Description**

Returns an integer representation of the number of rows which have changed between the previous two iterations of the classifier. A negative return value shows that the number of differences could not be calculated, since there are not at least two iterations present.

- **Returns** – int representing number of differences between previous two iterations

- **getNumberIterations**

```
public int getNumberIterations()
```

- **Description**

Returns the number of instances which are currently contained in the tracker for analysis

- **Returns** – the current number of recorded instances

Chapter 2

Package weka.classifiers.meta

<i>Package Contents</i>	<i>Page</i>
Classes	
ProjectClassifier	5
A classifier which is iteratively trained, imputing missing values into copies of the training data until no further change is observed.	

2.1 Class ProjectClassifier

A classifier which is iteratively trained, imputing missing values into copies of the training data until no further change is observed. Builds one learner per attribute, and therefore can take quite a while to run. Valid options are:

`-W classifier`

Full path to the target classifier to use, e.g. `weka.classifiers.trees.J48`

`-S`

Defines whether or not the classifier will impute a value for the class attribute as it trains.

`-R`

If set, the classifiers will be trained with any missing arguments filled in by random data. The classifier will then only iterate once.

`-M integer`

Sets the maximum number of times that a particular classifier will iterate before determining that it is trained.

Options after `-` are passed to the currently selected classifier.

2.1.1 Declaration

```
public class ProjectClassifier
```

extends `weka.classifiers.SingleClassifierEnhancer` **implements** `weka.classifiers.IterativeClassifier`

2.1.2 Constructor summary

ProjectClassifier() Constructor

2.1.3 Method summary

buildClassifier(Instances) Builds a set of classifiers based on the training data.
classifierOptionsTipText() Tip text to be displayed in the GUI for this property
classifyInstance(Instance) Classifies an instance.
defaultClassifierString() String describing default classifier.
distributionForInstance(Instance) Returns class probabilities for an instance.
done() Method called when iteration has terminated.
getCapabilities() Returns default capabilities of the classifier.
getClassifierOptions() Gets classifier options
getMaxIterations() Get the value of `m_MaxIterations`
getNumHiddenVariables()
getOptions() Gets the current settings of the Classifier.
getRandomData() Get the value of `m_RandomData`
getSupervised() Get the value of `m_Supervised`
globalInfo() Global information about the class
initializeClassifier(Instances) Makes copies of the training data which can be mutated, and initialise the array of Classifier objects
listOptions() Returns an enumeration describing the available options.
main(String[]) Main method for testing this class.
maxIterationsTipText() Tip text to be displayed in the GUI for this property
next() Retrains each of the classifiers, then attempts to impute missing data in a copy of the training data.
numHiddenVariablesTipText()
randomDataTipText() Tip text to be displayed in the GUI for this property
setClassifierOptions(String[]) Sets classifier options
setMaxIterations(int) Set the value of `m_MaxIterations`.
setNumHiddenVariables(int)
setOptions(String[]) Parses a given list of options.
setRandomData(boolean) Set the value of `m_RandomData`
setSupervised(boolean) Set the value of `m_Supervised`
supervisedTipText() Tip text to be displayed in the GUI for this property

2.1.4 Constructors

- **ProjectClassifier**

public ProjectClassifier()

- **Description**
Constructor

2.1.5 Methods

- **buildClassifier**

```
public void buildClassifier(weka.core.Instances instances)
    throws java.lang.Exception
```

- **Description**

Builds a set of classifiers based on the training data. These are iteratively trained on copies of the data.

- **Parameters**

- * **instances** – the Instances object which comprises the training data

- **Throws**

- * **java.lang.Exception** – exception thrown is raised to a Weka error handler

- **classifierOptionsTipText**

```
public java.lang.String classifierOptionsTipText()
```

- **Description**

Tip text to be displayed in the GUI for this property

- **Returns** – tip text to be displayed in the GUI

- **classifyInstance**

```
public double classifyInstance(weka.core.Instance instance)
    throws java.lang.Exception
```

- **Description**

Classifies an instance.

- **Parameters**

- * **instance** – the instance to classify

- **Returns** – the classification for the instance

- **Throws**

- * **java.lang.Exception** – if instance can't be classified successfully

- **defaultClassifierString**

```
protected java.lang.String defaultClassifierString()
```

- **Description**

String describing default classifier.

- **distributionForInstance**

```
public double [] distributionForInstance(weka.core.Instance  
instance) throws java.lang.Exception
```

- **Description**

Returns class probabilities for an instance.

- **Parameters**

- * **instance** – the instance to calculate the class probabilities for

- **Returns** – the class probabilities

- **Throws**

- * **java.lang.Exception** – if distribution can't be computed successfully

- **done**

```
public void done() throws java.lang.Exception
```

- **Description**

Method called when iteration has terminated. Imputes class values if `m_Supervised` is set.

- **getCapabilities**

```
public weka.core.Capabilities getCapabilities()
```

- **Description**

Returns default capabilities of the classifier.

- **Returns** – the capabilities of this classifier

- **getClassifierOptions**

```
public java.lang.String [] getClassifierOptions()
```

- **Description**

Gets classifier options

- **Returns** – array of String objects to be passed to each classifier

- **getMaxIterations**

```
public int getMaxIterations()
```

- **Description**

Get the value of m_MaxIterations

- **Returns** – value of m_MaxIterations

- **getNumHiddenVariables**

```
public int getNumHiddenVariables()
```

- **getOptions**

```
public java.lang.String [] getOptions()
```

- **Description**

Gets the current settings of the Classifier.

- **Returns** – an array of strings suitable for passing to setOptions

- **getRandomData**

```
public boolean getRandomData()
```

- **Description**

Get the value of m_RandomData

- **Returns** – value of m_RandomData

- **getSupervised**

```
public boolean getSupervised()
```

- **Description**

Get the value of m_Supervised

- **Returns** – value of m_Supervised

- **globalInfo**

```
public java.lang.String globalInfo()
```

- **Description**

Global information about the class

- **Returns** – information about the classifier which is displayed in the CLI/GUI

- **initializeClassifier**

```
public void initializeClassifier(weka.core.Instances instances)
    throws java.lang.Exception
```

– **Description**

Makes copies of the training data which can be mutated, and initialise the array of Classifier objects

– **Parameters**

* **instances** – the training data

• **listOptions**

```
public java.util Enumeration listOptions()
```

– **Description**

Returns an enumeration describing the available options.

– **Returns** – an enumeration of all the available options.

• **main**

```
public static void main(java.lang.String[] args)
```

– **Description**

Main method for testing this class.

– **Parameters**

* **args** – the options

• **maxIterationsTipText**

```
public java.lang.String maxIterationsTipText()
```

– **Description**

Tip text to be displayed in the GUI for this property

– **Returns** – tip text to be displayed in the GUI

• **next**

```
public boolean next() throws java.lang.Exception
```

– **Description**

Retrains each of the classifiers, then attempts to impute missing data in a copy of the training data. Does not iterate again if the results of current iteration match the results of the previous iteration, or the max number of iterations has been reached.

- **Returns** – true if another iteration should be performed, otherwise false.

- **numHiddenVariablesTipText**

```
public java.lang.String numHiddenVariablesTipText()
```

- **randomDataTipText**

```
public java.lang.String randomDataTipText()
```

- **Description**
Tip text to be displayed in the GUI for this property
- **Returns** – tip text to be displayed in the GUI

- **setClassifierOptions**

```
public void setClassifierOptions(java.lang.String[]  
    classifierOptions)
```

- **Description**
Sets classifier options
- **Parameters**
* **classifierOptions** – array of String objects to be passed to each classifier

- **setMaxIterations**

```
public void setMaxIterations(int maxIterations)
```

- **Description**
Set the value of m_MaxIterations. Defaults to Integer.MAX_VALUE if value less than 0 is supplied.
- **Parameters**
* **maxIterations** – new value of m_MaxIterations

- **setNumHiddenVariables**

```
public void setNumHiddenVariables(int numHiddenVariables)
```

- **setOptions**

```
public void setOptions(java.lang.String[] options) throws java.  
    lang.Exception
```

- **Description**

Parses a given list of options. Valid options are:

-W classifier

Full path to the target classifier to use, e.g. weka.classifiers.trees.J48

-S

Defines whether or not the classifier will impute a value for the class attribute as it trains.

-R

If set, the classifiers will be trained with any missing arguments filled in by random data. The classifier will then only iterate once.

-M integer

Sets the maximum number of times that a particular classifier will iterate before determining that it is trained.

Options after – are passed to the currently selected classifier.

- **Parameters**

- * `options` – The list of options as an array of Strings

- **Throws**

- * `java.lang.Exception` – if an option is not supported

- **setRandomData**

```
public void setRandomData(boolean randomData)
```

- **Description**

Set the value of `m_RandomData`

- **Parameters**

- * `randomData` – new value of `m_RandomData`

- **setSupervised**

```
public void setSupervised(boolean supervised)
```

- **Description**

Set the value of `m_Supervised`

- **Parameters**

- * `supervised` – the new value of `m_Supervised`

- **supervisedTipText**

```
public java.lang.String supervisedTipText()
```

- **Description**

Tip text to be displayed in the GUI for this property

- **Returns** – tip text to be displayed in the GUI

2.1.6 Members inherited from class SingleClassifierEnhancer

weka.classifiers.SingleClassifierEnhancer

- public String classifierTipText()
- protected String defaultClassifierOptions()
- protected String defaultClassifierString()
- public Capabilities getCapabilities()
- public Classifier getClassifier()
- protected String getClassifierSpec()
- public String getOptions()
- public Enumeration listOptions()
- protected m_Classifier
- public void postExecution() throws java.lang.Exception
- public void preExecution() throws java.lang.Exception
- public void setClassifier(Classifier arg0)
- public void setOptions(java.lang.String[] arg0) throws java.lang.Exception

2.1.7 Members inherited from class AbstractClassifier

weka.classifiers.AbstractClassifier

- public static BATCH_SIZE_DEFAULT
- public String batchSizeTipText()
- public double classifyInstance(weka.core.Instance arg0) throws java.lang.Exception
- public String debugTipText()
- public double distributionForInstance(weka.core.Instance arg0) throws java.lang.Exception
- public double distributionsForInstances(weka.core.Instances arg0) throws java.lang.Exception
- public String doNotCheckCapabilitiesTipText()
- public static Classifier forName(java.lang.String arg0, java.lang.String[] arg1) throws java.lang.Exception
- public String getBatchSize()
- public Capabilities getCapabilities()
- public boolean getDebug()
- public boolean getDoNotCheckCapabilities()
- public int getNumDecimalPlaces()
- public String getOptions()
- public String getRevision()
- public boolean implementsMoreEfficientBatchPrediction()
- public Enumeration listOptions()
- protected m_BatchSize
- protected m_Debug
- protected m_DoNotCheckCapabilities
- protected m_numDecimalPlaces
- public static Classifier makeCopies(Classifier arg0, int arg1) throws java.lang.Exception
- public static Classifier makeCopy(Classifier arg0) throws java.lang.Exception
- public static NUM_DECIMAL_PLACES_DEFAULT
- public String numDecimalPlacesTipText()
- public void postExecution() throws java.lang.Exception
- public void preExecution() throws java.lang.Exception
- public void run(java.lang.Object arg0, java.lang.String[] arg1) throws java.lang.Exception
- public static void runClassifier(Classifier arg0, java.lang.String[] arg1)
- public void setBatchSize(java.lang.String arg0)
- public void setDebug(boolean arg0)
- public void setDoNotCheckCapabilities(boolean arg0)
- public void setNumDecimalPlaces(int arg0)
- public void setOptions(java.lang.String[] arg0) throws java.lang.Exception