Introduction to Neural Computing and Applications (INCA) Open Examination

Exam Number: Y1403115

Section A

1 Architecture Discussion

1.1 Problem

The problem is a two class classification problem - occupancy detection based on sensor readings. The data includes sensor readings for temperature, humidity, light and carbon dioxide. An additional feature, humidity ratio, was derived from the original recorded variables. Each point in the data set is also timestamped. In [1] the time stamp was used to derive two additional features - week status(WS) and number of seconds from midnight(NSM).

A certain amount of noise is expected in the recorded data so a suitable architecture should have good generalisation. Since data was measured in a controlled environment we expect the range of training variables to roughly match the range of expected new data.

1.2 Architectures

There are several neural network architectures suitable for this kind of classification problem. We will consider Multilayer perceptron and Radial basis function network.

1.2.1 Multilayer Perceptron (MLP)

MLP is a feedforward neural network with multiple neurons composed in multiple layers. All neurons are the same, in the case of classification, and they compute a weighted sum of inputs and an activation function (sigmoid or tanh). There is an input layer, which distributes the inputs, one or more hidden layers and an output layer. Each layer feeds into the next one. This type of neural network uses an error correcting learning rule and a backpropagation training algorithm. Backpropagation consists of two stages - a forward pass, where outputs are computed, and a backward pass, where weights are adjusted according to the error in outputs. In the backward pass the output layer weights are adjusted according to the local gradient of the error function and the hidden layer weights are adjusted according to the local gradients of the nodes in the subsequent layer.

1.2.2 MLP Advantages and disadvantages

The multilayer perceptron is suitable for non-linearly separable classification problems. Once a good approximate solution is found, generalisation can be easily improved by adjusting the stopping criteria of the training algorithm, or by using regularisation. MLP is a global approximator (because it splits the entire pattern space using lines), which can be an advantage, if we expect abnormal data points in unseen data and want to try to classify them.

On the other hand, determining the number of hidden layers and the number of neurons in each layer may require a lot of experimentation. Also, the training algorithm uses local gradients and can often get stuck in a local minimum of the error function.

1.2.3   Radial Basis Function Network (RBFN)

RBFN is a feedforward neural network, consisting of an input layer, a single hidden layer, and an output layer. The input layer distributes inputs to the hidden layer. Each neuron in the hidden layer computes a radially symmetric basis activation function (typically a Gaussian) from the inputs. The output layer neurons compute a weighted sum of the outputs of the hidden layer. Each neuron in the hidden layer has two associated parameters - a point in the feature space, which is called a center, and a spread. It computes its response to a given input based on the euclidean distance between the data point and its center. Training is typically done in two stages - center selection and weight estimation (weights are computed in a single matrix vector calculation). RBFNs can also be trained in a supervised manner (like MLP) or by selecting centres at each data point and using regularisation, but these approaches are much slower.

1.2.4   RBFN Advantages and Disadvantages

There is just one hidden layer so only its size needs to be determined experimentally. When using unsupervised center selection, weights can be computed in a single calculation. In comparison to MLP, in RBFN there are far less parameters that need to be varied, when searching for an architecture. The RBFN is a local approximator. This is an advantage when we expect new data to be in a similar range to the training data or when abnormal inputs need to be classified into one class.

When data is not tightly clustered, the network might need a very large hidden layer. It is difficult to determine center locations. Also, supervised center selection and regularisation training approaches are very slow.

1.2.5   Choice of network architecture

Comparing the two architectures described above, we choose an RBFN network architecture. Compared to the MLP, the RBFN has a simpler training process. Furthermore, using our knowledge of the problem, we can see that the range of data we have should roughly match the expected range of unseen data, because the deployment environment is controlled. This means a local classifier would be more suitable than a global classifier. When using an RBFN, there are far less training parameters that have to be discovered experimentally.

2   Creation and Application

2.1   Data

Three data sets are provided for training, validation and testing. The test sets are merged together in chronological order of the timestamps. This composite data set has 20,560 data points. The features used are Temperature, Humidity, Light, CO2, and Humidity Ratio and all of them are real valued. The target outputs are binary. Humidity Ratio is not a sensor reading but it has been derived from Humidity measurements [1]. Timestamps are not used as input features.

In figure 1 the MATLAB *gplotmatrix* function is used to plot all input variables against each

other and to create histograms of each variable along the diagonal (classes are color coded). Several observations can be made based on this plot. The plots of Light against all other features show a clear separation of the two classes, which shows that Light is probably an important feature. On the other hand, the histogram of Light is bimodal and it is clear that the examples around the second peak are much less than around the first, which means they are under-represented and might not be properly incorporated in the model. Looking at CO_2 we see that its distribution is skewed, which also might cause problems for our model. The distributions of the rest of the variables look normal.
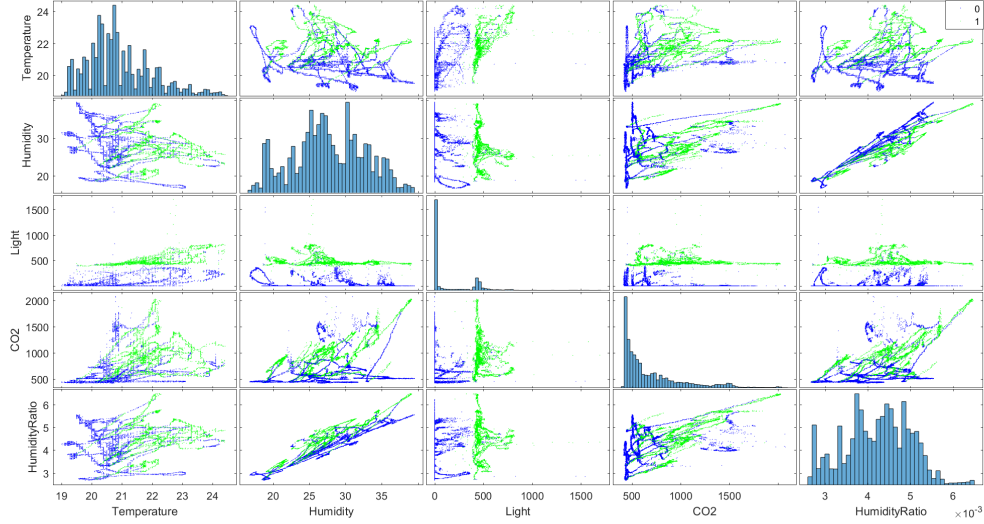

Figure 1: Plot matrix

There seems to be a big correlation between Humidity and HumidityRatio, which makes sense since the latter is derived from the first one. It might be a good idea to discard HumidityRatio. However to make sure that we are really removing unimportant features and to be able to measure their contribution to the dataset we use Principal component analysis (PCA). PCA does two things. It orthogonalises input components to remove correlation between them. It can also be used to measure the contribution of each component to the total variance of the data set and can help make a decision to remove the ones, which have little contribution. Since PCA is sensitive to big variances in the data, we first preprocess the data to have a variance of 1 (using Matlab *mapstd* function) and then we apply PCA (Matlab *pca* function). PCA gives us the eigenvectors and eigenvalues of the covariance matrix of the data. The eigenvectors are the transformed inputs (principal components) and the eigenvalues tell us how much each component contributes to the overall variance. Looking at figure 2 we can see that the eigenvalue for the fifth principal component is only 0.001 and in terms of percentage, the contribution of this component to overall variance is 0.03%. This means that the fifth principal component hardly has any contribution to the variance of the data. Removing it might make network training more efficient and would not affect the separability of the data. The forth principal component has a much greater contribution to overall variance (6.3%) so we decide keep it. The threshold for eigenvalues of principal components has to be between the value of the forth and the fifth. We decide to set it at 0.02 in order to the discard the fifth component.

Furthermore, from figure 3 we see that the distributions of the remaining 4 principal components are nearly normal, which means we do not have to worry about potential problems arising from the skewed CO_2 distribution or the asymmetric bimodal distribution of Light.
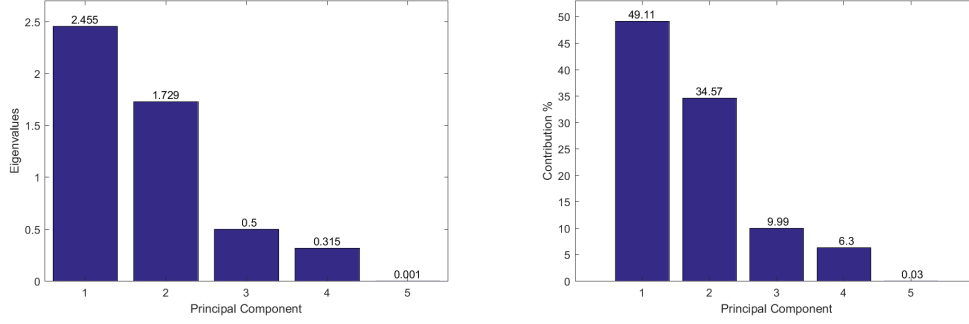
3

Figure 2: Eigenvalues and percent contribution to overall variance of each principal components
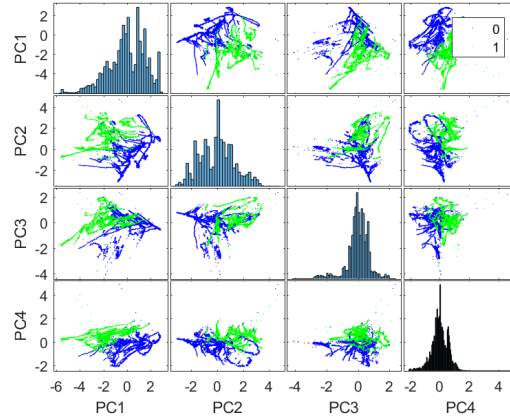

Figure 3: Plot matrix of principal components

To summarise, preprocessing of the input data consist of normalising variances of features to 1. And applying a transformation using principal component analysis, removing principal components with eigenvalues less than 0.02. We use the Matlab functions $x1, trans1 = mapstd(x)$ and $x2, trans2 = processpca(x1, 0.02)$. The transformation settings $trans1$ and $trans2$(including transformation matrices) are provided in the appendix in table 5 and table 6.

2.2 Network

2.2.1 Inputs

Inputs are preprocessed before they are presented to the network. The data set is then randomly split into a training set and a test set with ratio 75%/25%.

2.2.2 Input Layer

The input layer distributes inputs (after preprocessing) to each neuron in the hidden layer. The size of the input layer is therefore the size of the input vector $N = 4$ (after PCA). It is fully connected to the hidden layer.

2.2.3 Hidden Layer

There is a single hidden layer and it is fully connected to the output layer. The optimal size of the hidden layer was found by experimentations. The activation function of each neuron is an isotropic Gaussian:
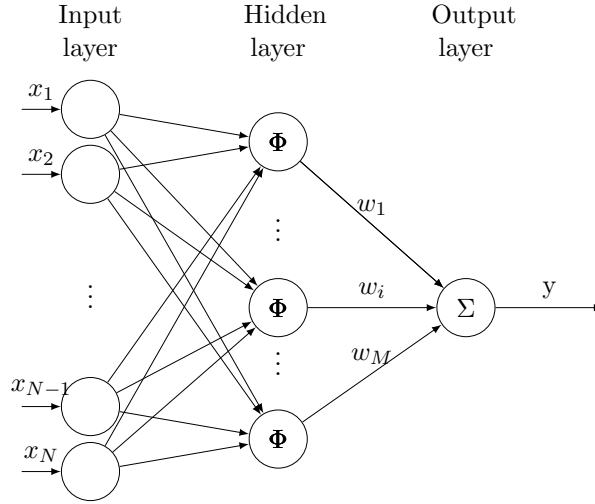
4

Figure 4: RBFN architecture diagram.

$$\Phi_i(\boldsymbol{x}) = \exp\left(-\frac{1}{2\sigma^2}||\boldsymbol{x} - \boldsymbol{c_i}||^2\right) \quad \text{where} \quad \sigma^2 = \frac{1}{2}(\epsilon \times d_{max})^2 \tag{1}$$

Where m is the number of hidden neurons (number of centres), d_{max} is the maximum distance between centres, ϵ is a parameter used to vary the spread of the Gaussian ($0 < \epsilon < 2$), and $\boldsymbol{c_i}$ is the center vector of neuron i. The centres for each hidden layer neuron are found using a k-means clustering algorithm. The number of centres (c_i) and spread parameter ϵ were found through experimentation.

2.2.4 Output Layer

The output layer calculates a weighted sum of hidden layer outputs:

$$y(\boldsymbol{x}) = \sum_{i=1}^{m} w_i \Phi_i(\boldsymbol{x}) \tag{2}$$

In order to obtain hard classification output, a threshold is applied to $y(\boldsymbol{x})$ - if $y > 0.5$ output is 1, else output is 0. The outputs use a boolean encoding, where 1 signifies occupancy.

2.2.5 Best found architecture

The best architecture found through experimentation uses the k-means algorithm to find center locations. The experimentally discovered parameter values are $m = 20, \epsilon = 0.8$. The network architecture and parameters are given below in table 1.

2.2.6 Implementation

The RBF network was implemented in Matlab, following the solution from practical sessions. The code is given in the appendix (RBFN.m). For performing experiments(rerunning network several times with different parameters) an additional script was used. It is also provided in the appendix (runRBFN.m)

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Network type	Radial basis function network
Data features/inputs	Temperature, Humidity, Light, CO2, HumidityRatio
Data preprocessing	Normalize standard deviation to 1
	Principal component analysis (PCA)
PCA variance threshold	0.02
Data train/test set split	Random 75%/25%
Hidden layer activation function (RBF)	$\Phi_i(\boldsymbol{x}) = \exp\left(-\frac{1}{(\epsilon \times d_{max})^2}\|\boldsymbol{x} - \boldsymbol{c_i}\|^2\right)$
Hidden layer size (m)	20
RBF spread σ^2	$\frac{1}{2}(0.8 \times d_{max})^2$
Output layer activation function	Linear: $y(\boldsymbol{x}) = \sum_{i=1}^{m} w_i \Phi_i(\boldsymbol{x})$
Output layer size	1
Training algorithm	1. Unsupervised center selection
	2. One step weight calculation using matrix pseudo inverse
Centre selection algorithm	k-means clustering
Performance function	Mean Squared Error (MSE)

Table 1: Best found RBFN architecture.

2.3 Training

Three types of RBFN training algorithms were considered - regularisation with number of hidden neurons equal to the number of data points, supervised center selection, and unsupervised center selection. Unsupervised center selection was chosen out of the three based on its performance in terms of speed.

Unsupervised center selection is a two step training algorithm. The first step is selecting the center points for each hidden neuron. The second step is calculating the output layer weights based on the outputs of the hidden layer, minimising an error function (MSE in this case). After having selected the center points and preprocessed the data, the training algorithm goes through the following steps (assume center points are in a matrix c, preprocessed training data is in a matrix x, the target data is stored in a binary vector D and the predefined number of centres is m):

1 Calculate the euclidean distance from each of the centres (columns of c) to each of the data points (columns in x) and store them in a matrix *distance*. Calculate the distances from every centre to every centre and store them in a matrix dc.

2 Find the maximum center to center distance and store it in d_{max}. d_{max} is then used to calculate the spread of all radial basis functions in the hidden layer: $\sigma^2 = \frac{1}{2}(\epsilon \times d_{max})^2$, where ϵ is a user defined parameter.

3 Calculate a matrix of responses from each basis function to each data point. Using equation 1 this calculation would be:

$$F = \Phi_i(\boldsymbol{x}) = \exp\left(-\frac{m}{(\epsilon \times d_{max})^2}distances^2\right) \tag{3}$$

4 Calculate the weights of the output layer W using the pseudo inverse of F, F^+ and the target data D: $W = F^+D$.

For the center selection step, of the training algorithm, two options were considered - random center selection and k-means clustering. For the k-means clustering approach the Matlab kmeans function was used. It uses k-means++ algorithm [2] for generating initial center locations and then runs the k-means clustering algorithm [3] to iteratively search for the true center locations. In order to decide between random center selection and k-means, an experiment was performed. The experiment compared two networks, structurally the same as the one in table 1, but with number of centres $m = 10, 15, 20, 25$ and $\epsilon = 1$. The two networks use the two different center selection algorithms(random vs k-means). They were ran 10 times for each parameter combination and mean performance values were recorded. The results are given below in table 2

Number of centres (m)	10	15	20	25
Random center selection Test MSE mean	0.0735	0.0785	0.0832	0.0649
Random center selection Test MSE Std	0.0306	0.0523	0.0499	0.0304
K-means Test MSE mean	0.0331	0.0237	0.0190	0.0187
K-means Test MSE Std	0.0032	0.0044	0.0043	0.0041

Table 2: Performance results for random centre selection and k-means

Clearly the performance (in terms of MSE) of k-means is much better than random center selection. So this is the algorithm we will use.

2.4 Evaluation

We have already discussed decisions about the network structure, training algorithm, and data preprocessing and splitting into training and test sets. The rest of the parameters were discovered experimentally. These are the number of centres (size of hidden layer) and basis function spread parameter ϵ.

2.4.1 Metrics

MSE was used as a metric of performance. However, MSE on its own was not sufficient. Its value keeps decreasing as we increase the number of nodes in the network and too many nodes could lead to poor generalisation. This is why in addition to MSE, we look at the percentage of errors in each of the two classes to help us evaluate performance. Ideally the model should be unbiased and should make an approximately equal amount of errors in both classes. If the model develops a bias against a particular class this means that we are probably either overfitting or not capturing the structure of the data.

2.4.2 Experimentation for determining final network

Initially, we fix ϵ and vary only the number of centres m, searching for networks with low MSE and approximately equal percentage of errors in both classes. We set the spread parameter $\epsilon = 1$ and run for different hidden layer sizes $m = 5, 10, 15, 20, 25, 30, 40, 50, 60$. For each value of m we train and evaluate the network 10 times and record the mean value of MSE, mean percentage of errors, and mean absolute difference of errors for both the training and test sets. Results are plotted in figure 5.

From figure 5a we can confirm out expectations that the MSE decreases when increasing the number of hidden nodes. After getting to 20 nodes, the MSE starts decreasing at a smaller rate. Looking at figure 5b we see that after around 20 hidden nodes, the mean absolute difference in errors doesn't change very much and the total number of errors decreases at a very small rate.
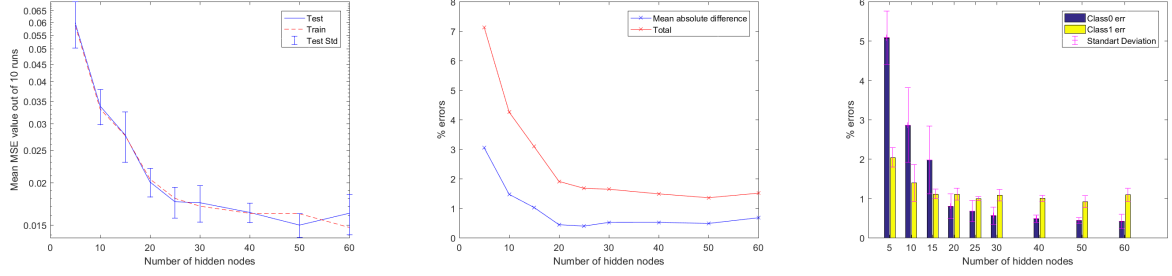
(a) Mean MSE of Test and Train sets.

(b) Mean absolute difference of errors in class 0 and class 1 and mean percentage of errors in both classes, measured on test set.

(c) Bar plot of mean percentage of errors in class 0 and class 1 measured on test set.

Figure 5: Performance of RBFN with parameters $m = 5, 15, 20, 25, 30, 40, 50, 60$ and $\epsilon = 1$, ran 10 times for each parameter combination.

These two plots give us an understanding of how error decreases as we increasing number of neurons, but tells us little about how much we are overfitting the data. From 5c we can see that after we get past 25 hidden nodes, the errors in class 1 remain the same, while the errors in class 0 decrease. After that point the network is developing a bias against class 0. This might mean that we are overfitting. On the other hand, when we use fewer than 20 nodes the bias of the network is against the other class. This probably means we don't have enough neurons to capture the structure of the data. We decide to use 20 hidden nodes in the hidden layer. We perform more experiments to determine the spread coefficient ϵ, while keeping $m = 20$. The results are shown in figure 6.
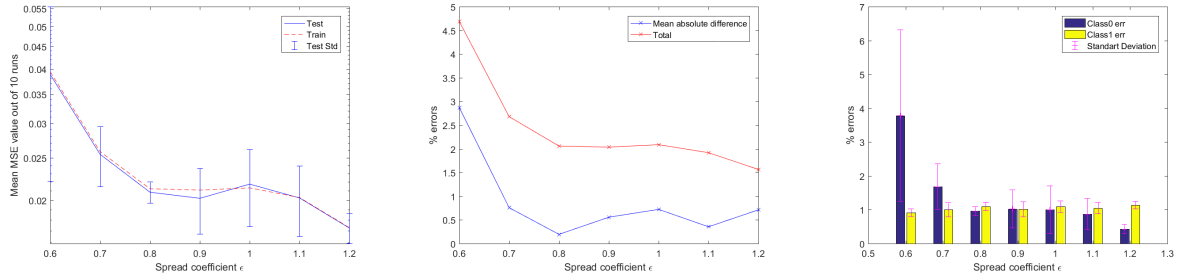
(a) Mean MSE of Test and Train sets.

(b) Mean absolute difference of errors in class 0 and class 1 and mean percentage of errors in both classes, measured on test set.

(c) Bar plot of mean percentage of errors in class 0 and class 1 measured on test set.

Figure 6: Performance of RBFN with parameters $m = 20$ and $\epsilon = 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2$, ran 10 times for each parameter combination.

Looking at figure 6a we see that MSE reaches a local minimum around $\epsilon = 0.9$ and and at this point the test set MSE is lower than the training set MSE. After $\epsilon = 1$ it starts decreasing, which indicates we might be overfitting. Looking at 6b, we see that at $\epsilon = 0.8$ we get very low mean absolute difference in errors between the two classes. Furthermore, looking at 6c we see that at the same point the mean percentage of errors for both classes is around 1% with a very small standard deviation. We choose $\epsilon = 0.8$ for our final architecture, as it achieves a low MSE, a balance between errors in the two classes, and a low variance in percentage of errors.

2.5 Results

The final chosen architecture achieves an average MSE of 0.025. In tables 3 and 4 are shown the mean results for the training and test sets out of 20 runs of the architecture. We can see that the distribution of errors in the two classes is not as balanced as when we were performing experiments. This could mean that the experiments performed were insufficient.

mse	std mse	err0	std err0	err1	std err1	err diff	std err diff
0.025075	0.0065629	1.5438	0.90081	1.0428	0.19202	0.68385	0.82889

Table 3: Mean test results for $m = 20$, $\epsilon = 0.8$ out of 20 runs.

mse	std mse	err0	std err0	err1	std err1	err diff	std err diff
0.025452	0.0062647	1.6051	0.85912	1.0639	0.10549	0.67672	0.80653

Table 4: Mean train results for $m = 20$, $\epsilon = 0.8$ out of 20 runs.

Figure 7 shows the confusion matrix, ROC plot, and error histograms for a single run of the network.

(a) Confusion matrix.   *(b) ROC plot.*   *(c) Error histogram.*
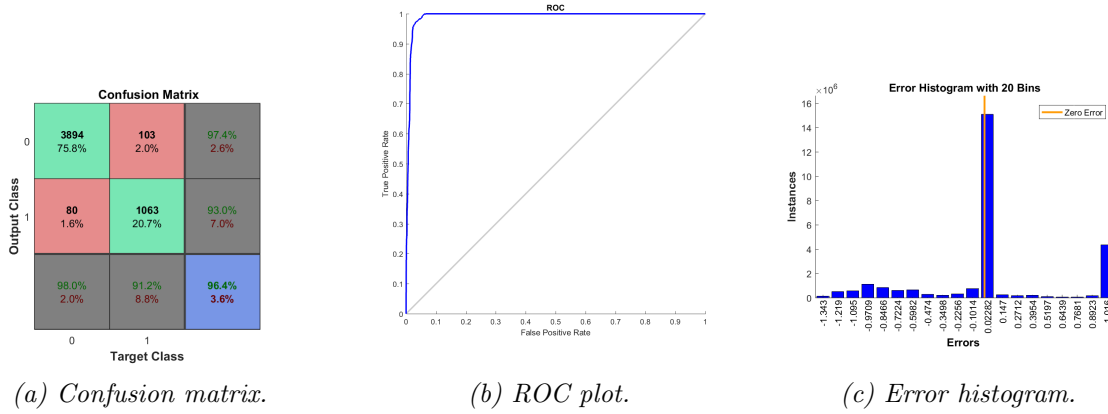
Figure 7: Performance of RBFN with parameters $m = 20$ and $\epsilon = 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2$, ran 10 times for each parameter combination.

From the confusion matrix we can see that the network achieves 96.4% accuracy with a relatively equal distribution of errors in both classes. The shape of the ROC plot indicates a good classifier. However, the error histogram shows that there are a lot of errors at the far right of the plot. These errors indicate that the network was not even close to classifying some of the data points correctly. These might be points, located near a class boundary and thus misclassified due to noise, or outliers, which are not in range of any of the RBF spreads. We can also notice that the network shows a relatively small MSE even with a very small hidden layer. This could mean that the data we have is not representative of the problem. Comparing the performance of the RBFN to that of the models proposed in [1] we see that we get approximately the same accuracy as those models, which use the same input variables (Temperature, Humidity, Light, CO_2 and Humidity Ratio).

Section B

3 Building energy consumption prediction

The problem of predicting energy consumption of a building can be very important for expense managment or for places where energy consumption goes up in colder months, while energy production goes down and a balance has to be established. A neural network can be used to solve this kind of problem. The chosen network is a Multilayer Perceptron. A similar problem solved with neural networks can be seen in [4].

3.1 Technical features of architecture

MLP is a feedforward, multilayer architecture consisting of one input, one output, and one or more hidden layers. The input layer distributes the inputs. Each neuron in the hidden layers computes a weighted sum of inputs, applies an activation function and produces an output. Each layer is fully connected to the next one. The output layer produces the outputs. The MLP uses an error correction learning rule, by which it minimises an error function, defined by the difference of its output and the desired output (typically the error function is mean squared error). The activation functions for all hidden layer neurons are either hyperbolic tangent or sigmoid functions. In the case of regression, the output layer has a linear activation function. The training algorithm for MLP is backpropagation. It consists of a forward pass, in which the network computes it's output and a backward pass, in which the weights are adjusted. Weight changes at each layer are computed based on the local gradient of the next layer. The MLP partitions the feature space into regions (using straight lines in the 2D case and hyper planes in higher dimensions).

3.2 Suitability of the architecture for your application

The multilayer perceptron is a universal approximator. Given the right architecture and enough data it can approximate any function. The training process is slow and has to be done before the network is deployed which is a drawback. MLP also requires a large amount of training data, which needs to be representative of the problem. However, once deployed the network can produce outputs very quickly. MLP is suitable for this particular problem because there is already a lot of historical energy consumption data available to train the network. It might be susceptible to changes in building, depending on the data used as inputs. Data about lots of different buildings might be required in order to achieve good generalisation.

3.3 Source of data, and how the network might be trained

As mentioned already, there is plenty of historical data to train the network. Since the problem is time series prediction we will be using past energy consumption as inputs. Energy consumption is often dependent on the time of year, the first three input variables will be the energy consumption for the month before, this month and next month from last year (if we are predicting for July 2017, inputs are energy consumption for June, July, August 2016). We also take the average temperature from the weather forecast for these three past months as an input. Another sensible input value would be the energy efficiency score of the building (this might be country specific).

The network will be trained using backpropagation. The desired values are obtained from historical data from past years. The activation function of hidden layer neurons will be sigmoid. Normalizing input variables to the range 0-1, so they match the dynamic range of the activation

function, will speed up convergence. The input data will be split into training, validation and test sets (50/25/25). During training, the error on the validation set will be monitored and used as a stopping criteria. Number and size of the hidden layers need to be determined experimentally. Regularisation can be used in the training, if desired accuracy is not achieved.

3.4 How the network would handle significant changes to building or environment

The energy consumption inputs of the network depend on the building, they were measured in. Changes in building might affect the performance of the network significantly. The data we use for training should cover the range of buildings and climate zones, where we want the network to be deployed afterwards. Alternatively, the network can be retrained on redeployment.

The energy efficiency input, as mentioned above, might be country specific and might have different ranges, or categories. We can overcome this by normalising the values for different scoring systems to the range 0-1. However, these systems might differ in their criteria for determining energy efficiency (energy efficiency might mean one thing in the UK and another in the US, further research required on this). If this is the case, the network will not generalise well in different countries. If none of these approaches gives sensible results, more domain knowledge of the problem might be required, to select more suitable inputs.

4 Abnormality detection in the operation of HVAC systems

Early detection of faults in an HVAC system could significantly decrease maintenance costs in a building. Research in abnormality detection of HVAC sensor data has previously shown good results [5] and neural networks have already been used for abnormality detection in other domains [6]. We decide to apply the neural network architecture proposed in [6] to the problem of abnormality detection in HVAC systems.

4.1 Technical features of the architecture

Binary Correlation Matrix Memories(CMMs) are single layer neural networks, which use the Hebbian learning rule. They consist of a single weight matrix that stores correlations between input and output patterns. Learning is achieved by computing the outer product of the binary input and output and adding it to the outer products of all other stored patterns to form the weight matrix. Recall of a stored pattern is done by multiplying the weight matrix and the input. The result from a recall is real valued. In order to obtain the associated binary output pattern, the output needs to be thresholded. A Wilshaw threshold is chosen for this architecture - each value in the recalled vector is compared to the number of bits that are set to 1 in the input. The thresholded value is set to 1 if the recalled was greater and to 0 otherwise. Also, real valued inputs need to be encoded. For this we use a binning procedure (we choose bins for certain ranges of the input and associate a binary pattern to that bin). After all inputs have been binned, they are concatenated to form the input to the CMM.

4.2 Suitability of the architecture for your application

A hardware implementation of a CMM can be very efficient. Store and recall are both very fast operations. This means that we can monitor HVAC systems operation in real time and discover abnormal behaviour as soon as it occurs. This makes the chosen architecture very suitable for the particular problem.

4.3 Source of data, and how the network might be trained

The source of data will be sensors, part of the building management system, which monitor different aspects of the HVAC system operation. The sensor measurements that can be used as inputs are energy consumption, airflow, and supply water temperature. Sensors could be placed in every room in the building in order to localise faults more efficiently. Sensor readings are taken at discrete time intervals to form our training input vectors. A significant amount of data might be required in order to achieve good generalisation and performance. Normal operation of the HVAC system can be monitored for 24 hours for 4 days of the year in different weather conditions. The network can be trained by applying the described binning and concatenation method to different input vectors and storing them in the CMM. Detecting abnormalities is done by recalling patterns in real time and comparing how similar they are to known patterns using for example a k-nearest neighbour algorithm. The tolerated level of similarity can be adjusted by using a smaller threshold at the outputs during recall and requires either domain knowledge or experimentation.

4.4 How the network would handle significant changes to building or environment

The CMMs susceptibility to change of building or environment depends on the training examples. Given enough training data for different buildings in different environmental conditions the network will show good generalisation. On the other hand, the network can be trained over time by storing input patterns of normal operation, which raise false alarms.

References

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[3] S. P. Lloyd, "Least squares quantization in pcm," *IEEE Transactions on Information Theory*, vol. 28, pp. 129–137, 1982.

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[6] J. Austin, T. Jackson, V. J. Hodge, and G. Brewer, "Aura-alert: The use of binary associative memories for condition monitoring applications," in *CM 2010 The Seventh International Conference on Condition Monitoring and Machinery Failure Prevention Technologies*, pp. 699–711, June 2010.

Appendices

A Data import script

```matlab
1      [dataTable, ~, ~, ~] = getDataTable();
2    x = dataTable{:,{'Temperature','Humidity','Light','CO2','
          HumidityRatio'}}';
3    t = dataTable{:, {'Occupancy'}}';
4
5  function [table1, tableTest1, tableTrain, tableTest2] =
       getDataTable()
6    datatest1 = getDataset('data\datatest.txt');
7    datatraining = getDataset('data\datatraining.txt');
8    datatest2 = getDataset('data\datatest2.txt');
9
10    dates = [datatest1.Date; datatraining.Date; datatest2.Date];
11    temp = [datatest1.Temperature; datatraining.Temperature;
          datatest2.Temperature];
12    hum = [datatest1.Humidity; datatraining.Humidity; datatest2.
          Humidity];
13    light = [datatest1.Light; datatraining.Light; datatest2.Light];
14    co2 = [datatest1.CO2; datatraining.CO2; datatest2.CO2];
15    humr = [datatest1.HumidityRatio; datatraining.HumidityRatio;
          datatest2.HumidityRatio];
16    occ = [datatest1.Occupancy; datatraining.Occupancy; datatest2.
          Occupancy];
17
18    tableTest1 = table(datatest1.Date, datatest1.Temperature,
          datatest1.Humidity,...
19       datatest1.Light, datatest1.CO2, datatest1.HumidityRatio,
              datatest1.Occupancy,...
20       'VariableNames', {'Date','Temperature','Humidity','Light','
          CO2','HumidityRatio','Occupancy'});
21
22    tableTest2 = table(datatraining.Date, datatraining.Temperature,
          datatraining.Humidity,...
23       datatraining.Light, datatraining.CO2, datatraining.
              HumidityRatio, datatraining.Occupancy,...
24       'VariableNames', {'Date','Temperature','Humidity','Light','
          CO2','HumidityRatio','Occupancy'});
25
26    tableTrain = table(datatest2.Date, datatest2.Temperature,
          datatest2.Humidity,...
27       datatest2.Light, datatest2.CO2, datatest2.HumidityRatio,
              datatest2.Occupancy,...
28       'VariableNames', {'Date','Temperature','Humidity','Light','
          CO2','HumidityRatio','Occupancy'});
29
```

```matlab
30        table1 = table(dates, temp, hum, light, co2, humr, occ, ...
31            'VariableNames', {'Date','Temperature','Humidity','Light','
               CO2','HumidityRatio','Occupancy'});
32 end
33
34
35 function datatraining = getDataset(filename, startRow, endRow)
36 %IMPORTFILE Import numeric data from a text file as a matrix.
37 %   DATATRAINING = IMPORTFILE(FILENAME) Reads data from text file
       FILENAME
38 %   for the default selection.
39 %
40 %   DATATRAINING = IMPORTFILE(FILENAME, STARTROW, ENDROW) Reads data
       from
41 %   rows STARTROW through ENDROW of text file FILENAME.
42 %
43 % Example:
44 %   datatraining = importfile('datatraining.txt', 2, 8144);
45 %
46 %    See also TEXTSCAN.
47
48 % Auto-generated by MATLAB on 2017/03/17 14:26:37
49
50 %% Initialize variables.
51 delimiter = ',';
52 if nargin<=2
53     startRow = 2;
54     endRow = inf;
55 end
56
57 %% Format for each line of text:
58 %   column2: datetimes (%{yyyy-MM-dd HH:mm:ss}D)
59 %       column3: double (%f)
60 %   column4: double (%f)
61 %       column5: double (%f)
62 %   column6: double (%f)
63 %       column7: double (%f)
64 %   column8: double (%f)
65 % For more information, see the TEXTSCAN documentation.
66 formatSpec = '%*q%{yyyy-MM-dd HH:mm:ss}D%f%f%f%f%f%f%[^\n\r]';
67
68 %% Open the text file.
69 fileID = fopen(filename,'r');
70
71 %% Read columns of data according to the format.
72 % This call is based on the structure of the file used to generate
       this
73 % code. If an error occurs for a different file, try regenerating
       the code
74 % from the Import Tool.
```

```matlab
75  dataArray = textscan(fileID, formatSpec, endRow(1)-startRow(1)+1, '
        Delimiter', delimiter, 'EmptyValue' ,NaN,'HeaderLines', startRow
        (1)-1, 'ReturnOnError', false, 'EndOfLine', '\r\n');
76  for block=2:length(startRow)
77      frewind(fileID);
78      dataArrayBlock = textscan(fileID, formatSpec, endRow(block)-
            startRow(block)+1, 'Delimiter', delimiter, 'EmptyValue' ,NaN,
            'HeaderLines', startRow(block)-1, 'ReturnOnError', false, '
            EndOfLine', '\r\n');
79      for col=1:length(dataArray)
80          dataArray{col} = [dataArray{col};dataArrayBlock{col}];
81      end
82  end
83
84  %% Close the text file.
85  fclose(fileID);
86
87  %% Post processing for unimportable data.
88  % No unimportable data rules were applied during the import, so no
        post
89  % processing code is included. To generate code which works for
90  % unimportable data, select unimportable cells in a file and
        regenerate the
91  % script.
92
93  %% Create output variable
94  datatraining = table(dataArray{1:end-1}, 'VariableNames', {'Date','
        Temperature','Humidity','Light','CO2','HumidityRatio','Occupancy'
        });
95
96  % For code requiring serial dates (datenum) instead of datetime,
        uncomment
97  % the following line(s) below to return the imported dates as
        datenum(s).
98
99  % datatraining.Temperature=datenum(datatraining.Temperature);
100
101 end
```

B Network creation script

```matlab
1  %% Set parameters of the RBF network
2  % 1. Center selection algorithm - kmeans = 1 for kmeans algorithm;
      random
3  % center selection otherwise
4  % 2. Number of centers/hidden nodes -
5  % 3. Scaling coefficient for the standard deviation of each hidden
      layer
6  % neuron - if coefficient = 1, use maximum distance between centers.
7  % 4. Input data matrix
8  % 5. Target class vector
9  use_kmeans = use_kmeans;
10 m1 = m1;          % number of centres
11 std_coef = std_coef;
12 x = x;
13 t = t;
14
15 %% Train and evaluate Network
16 % 1. Preprocess inputs
17 x1 = mapstd(x);
18 x2 = processpca(x1, 0.02);
19 inputs = x2;
20
21
22 % 2. Split Data into training and test sets
23 N = size(x,2); % Calculate number of data points
24 training_set_part = 75;
25 perm_idx = randperm(N);
26 X1 = inputs(:, perm_idx(1:(N*training_set_part/100)));
27 D1 = t(:, perm_idx(1:(N*training_set_part/100)));
28 X2 = inputs(:, perm_idx((N*training_set_part/100)+1:end));
29 D2 = t(:, perm_idx((N*training_set_part/100)+1:end));
30
31
32 % 3. Select centers using either Kmeans algorithm or randomly select
       points from data set.
33 if use_kmeans
34     [~,c] = kmeans(X1',m1);      % find m1 points as centres
35     c = c';
36 else
37     N = size(X1,2);              % calculate number of data points
38     sample = randsample(N,m1);   % generate m1 random numbers
39     c = X1(:,sample');           % sample m1 points from N as centres
40 end;
41
42
43 % 4. Calculate the distance from each of these centres to all of
      these data points.
```

```matlab
44  % Use the function pdist() to generate a matrix of distances, then
        select that part of
45  % the matrix containing the distances required.
46  N = size(X1,2);  % calculate number of data points
47  points = [X1 c]; % append the centres to the data
48  dist = squareform(pdist(points')); % calculate the distance matrix,
        from
49                                      % every point or centre to
50                                      % every other point or centre
51  distance = dist(1:N,N+1:N+m1); % extract the section with distances
52                                  % from points to centres
53  dc = dist(N+1:end,N+1:end); % extract the section with distances
54                              % from centre to centre
55
56
57  % 5. Find the maximum centre to centre distance times a coeeficient
        to use as the
58  % standard deviation of the basis functions.
59  % The matrix  dc  will contain the distance from every centre (in
        rows) to every other centre (in
60  % columns).
61  dmax = std_coef * max(max(dc)); % find the maximum of these
62
63  % 6. Calculate the matrix F composed of the individual basis
        functions responses to each
64  % data point.
65  % Take 'dmax' as an estimate of the standard deviation of the RBF
66  % nodes.
67  % The response from each RBF node to each data point depends on the
        distance
68  % between the node centre and the data point. The operation dist.^2
        squares all these
69  % distances. The calculation of F is the exp() function applied to
        each element of the matrix.
70  F = exp((-m1/(dmax*dmax))*(distance.^2)); % using these distances,
        calculate the
71                                             % response from each
                                                      centre
72
73
74  % 7. Using the pseudo-inverse of F and the target data, find the
        weights.
75  pF = pinv(F); % calculate the pseudoinverse of F
76  W = pF * D1'; % use pF instead of F-1 to calculate the weights
77                % required to give the outputs D
78
79
80  % 8. Check how well the network classifies the training data
81  % Compare the calculated and desired outputs. Apply a threshold on
        the
```

```matlab
82  % output to turn the low responses into a no classification.
83  Dcalc = F*W;                % calculated outputs based on F and W
84  Dclass = Dcalc > 0.5;      % and compare to find the bigger output
85  MSE1 = sum((D1 - Dcalc').^2)/numel(D1);
86
87
88  % 9. Evaluate performance on a separate set of data.
89  % Use the same basis functions (same number, centres, standard
90  % deviation) and weights, but recalculate the distances and
          therefore F.
91  % Calculate F but using the same centres
92  % and dmax. This means calculating a new distance matrix for X2
93  N = size(X2,2);             % calculate number of data points
94  points = [X2 c];            % append the centres to the data
95  dist = squareform(pdist(points')); % calculate the distance matrix,
          from
96                                       % every point or centre to
97                                       % every other point or centre
98  dist = dist(1:N,N+1:N+m1); % extract the section with distances
99                              % from points to centres
100
101
102 % 10. Once you have the distance matrix, calculate the new F matrix
          using the same expression, and
103 % then calculate classes using the same W as before:
104 F2 = exp((-m1/(dmax*dmax))*(dist.*dist)); % using new distances,
          calculate F2
105 Dcalc = F2*W;               % calculated outputs based on F2 and W
106 Dthresh = Dcalc > 0.5;     % and compare
107 MSE2 = sum((D2 - Dcalc').^2)/numel(D2);
```

C   Network experimentation script

```matlab
use_kmeans = 1;
nodes = [20];
std_coefitients = [0.8];
reps = 1;

% Create structure to hold mean training results
s = length(nodes) * length(std_coefitients);
mtrr.mse = zeros(1, s);
mtrr.std_mse = zeros(1, s);
mtrr.err0 = zeros(1, s);
mtrr.std_err0 = zeros(1, s);
mtrr.err1 = zeros(1, s);
mtrr.std_err1 = zeros(1, s);
mtrr.err_diff = zeros(1, s);
mtrr.std_err_diff = zeros(1, s);
mtrr.nodes = nodes;
mtrr.reps = reps;
mtrr.std_coefitients = std_coefitients;

% Create structure to hold mean test results
mtr.mse = zeros(1, s);
mtr.std_mse = zeros(1, s);
mtr.err0 = zeros(1, s);
mtr.std_err0 = zeros(1, s);
mtr.err1 = zeros(1, s);
mtr.std_err1 = zeros(1, s);
mtr.err_diff = zeros(1, s);
mtr.std_err_diff = zeros(1, s);
mtr.nodes = nodes;
mtr.reps = reps;
mtr.std_coefitients = std_coefitients;

% Create structure to hold intermediate training results
train_res.mse = zeros(1, reps);
train_res.err0 = zeros(1, reps);
train_res.err1 = zeros(1, reps);
train_res.err_diff = zeros(1, reps);

% Create structure to hold intermediate test results
test_res.mse = zeros(1, reps);
test_res.err0 = zeros(1, reps);
test_res.err1 = zeros(1, reps);
test_res.err_diff = zeros(1, reps);

count = 1;

for m1 = nodes
```

```matlab
for std_coef = std_coefitients

    fprintf('Hidden Nodes = %i; std coefficient = %5.3f\n', m1,
        std_coef)

    for i=1:reps

        rbnet % Create, train and evalueate network

        temp = D1-Dclass';
        train_res.mse(i) = MSE1;
        train_res.err0(i) = sum(temp(temp>0))*100/numel(temp);
        train_res.err1(i) = abs(sum(temp(temp<0)))*100/numel(temp);
        train_res.err_diff(i) = abs(train_res.err0(i) - train_res.
            err1(i));

        temp = D2-Dthresh';
        test_res.mse(i) = MSE2;
        test_res.err0(i) = sum(temp(temp>0))*100/numel(temp);
        test_res.err1(i) = abs(sum(temp(temp<0)))*100/numel(temp);
        test_res.err_diff(i) = abs(test_res.err0(i) - test_res.err1(
            i));

        plotconfusion(D1, Dclass', 'Training', D2, Dthresh', 'Test')
            ;
        fprintf('MSE1 = %6.4f; MSE2 = %6.4f; Err0 = %4.2f; Err1 =
            %4.2f \n', MSE1, MSE2, test_res.err0(i), test_res.err1(i)
            );

    end;

    mtrr.mse(count) = mean(train_res.mse);
    mtrr.std_mse(count) = std(train_res.mse);
    mtrr.err0(count) = mean(train_res.err0);
    mtrr.std_err0(count) = std(train_res.err0);
    mtrr.err1(count) = mean(train_res.err1);
    mtrr.std_err1(count) = std(train_res.err1);
    mtrr.err_diff(count) = mean(train_res.err_diff);
    mtrr.std_err_diff(count) = std(train_res.err_diff);

    mtr.mse(count) = mean(test_res.mse);
    mtr.std_mse(count) = std(test_res.mse);
    mtr.err0(count) = mean(test_res.err0);
    mtr.std_err0(count) = std(test_res.err0);
    mtr.err1(count) = mean(test_res.err1);
    mtr.std_err1(count) = std(test_res.err1);
    mtr.err_diff(count) = mean(test_res.err_diff);
    mtr.std_err_diff(count) = std(test_res.err_diff);

    count = count+1;
```

```matlab
92  end ;
93  end ;
94  clear temp s count
```

D   Transformation settings

xmean	xstd	xrows	yrows	ymean	ystd	gain	xoffset	nochange
20.9062	1.0553	5	5	0	1	0.94758	20.9062	0
27.6559	4.9822					0.20072	27.6559	
130.7566	210.4309					0.0047522	130.7566	
690.5533	311.2013					0.0032134	690.5533	
0.0042283	0.00076787					1302.3054	0.0042283	

Table 5: mapstd transformation settings

properties	transform					inverseTransform			
name = processpca	-0.37955	-0.39547	-0.40712	-0.49929	-0.53339	-0.37955	0.52236	0.21998	-0.69077
xrows = 5	0.52236	-0.58823	0.4643	0.10901	-0.392	-0.39547	-0.58823	0.1784	0.065158
maxfrac = 0.02	0.21998	0.1784	0.37132	-0.85446	0.22761	-0.40712	0.4643	0.37132	0.6934
yrows = 4	-0.69077	0.065158	0.6934	0.091391	-0.17156	-0.49929	0.10901	-0.85446	0.091391
nochange = 0						-0.53339	-0.392	0.22761	-0.17156

Table 6: processpca transformation settings

E   Results from experimentation

mse	std mse	err0	std err0	err1	std err1	err diff	std err diff	nodes
0.059716	0.0093742	5.0856	0.67757	2.0409	0.24889	3.0447	0.74965	5
0.033823	0.0040718	2.8619	0.94546	1.393	0.46739	1.4689	1.1801	10
0.027771	0.0047367	1.9767	0.86396	1.1128	0.12229	1.0233	0.64423	15
0.020121	0.0019786	0.79767	0.30993	1.1089	0.15014	0.43969	0.22506	20
0.017575	0.0018574	0.67899	0.27136	0.99416	0.048918	0.393	0.081413	25
0.017462	0.0021756	0.56226	0.22001	1.0798	0.14909	0.51751	0.28567	30
0.016336	0.0010998	0.48249	0.093888	1.0019	0.07632	0.51946	0.13605	40
0.01498	0.0012328	0.4358	0.069967	0.91829	0.14697	0.48249	0.18813	50
0.016253	0.0022396	0.41634	0.18093	1.0914	0.16341	0.6751	0.19107	60

Table 7: Test results for $m = 5, 15, 20, 25, 30, 40, 50, 60$ and $\epsilon = 1$, 10 runs

mse	std mse	err0	std err0	err1	std err1	err diff	std err diff	nodes
0.058733	0.0091118	5.0564	0.63631	1.9514	0.24993	3.1051	0.74387	5
0.033152	0.0038992	2.7808	0.81748	1.3437	0.35573	1.4371	0.93089	10
0.027671	0.0057495	2.0104	0.9814	1.0837	0.14054	1.0499	0.78676	15
0.020522	0.0023281	0.90856	0.408	1.1291	0.076455	0.47471	0.10834	20
0.017991	0.001829	0.65499	0.3314	1.0772	0.035316	0.51686	0.055958	25
0.017054	0.0012634	0.52529	0.16249	1.035	0.094582	0.50973	0.18991	30
0.016236	0.00054387	0.46498	0.073118	1.0156	0.064793	0.55058	0.10566	40
0.016195	0.0012942	0.48768	0.094859	1.0875	0.092021	0.59987	0.14418	50
0.014741	0.00090728	0.40856	0.094127	0.98184	0.056304	0.57328	0.098266	60

Table 8: Train results for $m = 5, 15, 20, 25, 30, 40, 50, 60$ and $\epsilon = 1$, 10 runs

mse	std mse	err0	std err0	err1	std err1	err diff	std err diff	std coef
0.038798	0.016715	3.7802	2.532	0.90856	0.11046	2.8716	2.589	0.6
0.025469	0.0039952	1.6809	0.67949	0.99805	0.20344	0.75681	0.70723	0.7
0.020859	0.0011533	0.95914	0.12939	1.0992	0.12245	0.19455	0.18204	0.8
0.0202	0.0034591	1.0214	0.55894	1.0136	0.22342	0.55642	0.43554	0.9
0.021771	0.0043611	0.99805	0.70792	1.0895	0.16786	0.72179	0.32869	1
0.020238	0.0037262	0.86965	0.46231	1.0486	0.16872	0.35409	0.23162	1.1
0.017267	0.0013571	0.42607	0.13555	1.1381	0.11129	0.71206	0.1527	1.2

Table 9: Test results for $m = 20$ and $\epsilon = 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2$, 10 runs

mse	std mse	err0	std err0	err1	std err1	err diff	std err diff	std coef
0.039359	0.016031	3.8301	2.5963	0.93061	0.19077	2.8995	2.7467	0.6
0.025842	0.0046411	1.7354	0.80573	1.0467	0.13525	0.79507	0.7904	0.7
0.021243	0.0018937	0.98249	0.18012	1.1226	0.07359	0.17899	0.1276	0.8
0.021095	0.0042415	1.0311	0.57676	1.085	0.066911	0.50519	0.29447	0.9
0.021342	0.0055074	1.0266	0.79916	1.0447	0.072438	0.70687	0.37628	1
0.020281	0.0027321	0.7847	0.46976	1.1336	0.082926	0.51881	0.28693	1.1
0.017302	0.00069705	0.38975	0.10109	1.1537	0.047405	0.76394	0.10585	1.2

Table 10: Train results for $m = 20$ and $\epsilon = 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2$, 10 runs