

# The Comparisons of Neural Networks and Regression Techniques

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(Dated: Saturday 9<sup>th</sup> November, 2019)

A numerical study regarding both a classification problem and a regression problem is presented. The classification problem aimed to reproduce the results from two data mining methods from the study of (Yeh & Lien)[3]. The data set was a credit card data set with 23 predictors and 30,000 data points and a binary output: whether or not the individuals would default their next credit card bill. The data was analyzed by neural networks (NN) and logistic regression (LOGR) and evaluated by error rates, area ratios in cumulative gain charts, and estimation of real probability of default. The NN obtained better results than LOGR, which was shown by lower error rates and higher area ratios in cumulative gain charts. The results from (Yeh & Lien) were partly reproduced. The area ratios and cumulative gain charts were reproduced by a good accuracy. The NN obtained very similar area ratios, whereas LOGR obtained a slightly lower area ratio for the training data (0.37 vs. 0.41). This study did not achieve as low error rates or very similar estimations of actual probability of default.

The regression problem was a generated noisy data set of Franke's function with 40,000 data points, 2 predictors and 1 output. The aim was achieve the best  $R^2$  score, by applying a neural network and a linear regression method, namely Ridge regression (RR). NN achieved an  $R^2$  score of 0.48, which was only slightly better than RR, which achieved an  $R^2$  score of 0.47. The NN converged slowly and did require several hundred epochs before it obtained a higher  $R^2$  score than RR, which was a considerably slower algorithm.

## I. INTRODUCTION

Machine learning is a very central topic in the modern world. There is a high value in information that can be extracted from the vast amount of data that exists. Supervised learning is the case where an algorithm is learning from the data at hand and there are two main groups of problems. The first one is *classification* problems, where the outputs can be categorized in discrete groups, such as yes/no, 0-9 or blue/red/yellow/green. The second type of problem is *regression* problems, where the outputs take continuous values, such as the speed of a car or the surface of the seafloor. The aim of the research presented, is to apply artificial neural networks on both a classification and a regression problem. For both problems, the neural networks will be compared with an additional method.

As a classification problem, a credit card data set from Taiwan 2006 will be studied. The data set is obtained from the *UCI Machine Learning Repository*[3]. The credit card data contains 30,000 data points, 23 predictors and 1 set of binary outputs: whether or not the individuals would default their credit card bill the next month. A previous study performed has been conducted on this subject[3], where six different data mining methods were performed on the credit card data set. In the research presented, two of those methods (logistic regression and artificial neural networks) will be implemented with the aim of reproducing the results of (Yeh & Lien)[3].

For the regression problem, a generated data set of Franke's function will be studied. Franke's function takes two input values  $x, y$  and produces a single and continuous output value  $f(x, y)$ . It is essentially a 3D surface consisting of a sum of three Gaussian peaks and one dip. The data set of Franke's function will include an additional noise as an irreducible error. This data set will be fitted by applying both a neural network and a linear regression model, namely Ridge regression.

The intention of this research is to explore the strengths and weaknesses of all four models. It is especially a goal to identify the neural networks' predictive ability as opposed to the other two methods: which model performs best in the classification case and in the regression case?

In the next section, the necessary theory behind the models will be introduced. The longer and more mathematical derivations are added in the appendices as additional theory for the interested reader. The method section will in detail describe the algorithms for the models and the parameters used. In the result and discussion sections, the results of this research will be presented and examined. Finally, the conclusion will summarize the key insights and conclusions found in the study presented, as well as suggestions for further research in this subject. For reproducibility or further research, the codes and algorithms, figures and results, may also be found in my GitHub repository.

## II. THEORY

The aim of a regression problem is to predict outputs which can take continuous values, unlike a classification problem, where the outputs take discrete variables. In the research presented, both regression and classification data sets will be studied, therefore the theory section is split in these two parts.

### A. Classification

There are many machine learning options which can be applied to classification problems. (Yeh & Lien, 2009)[3] applied six different methods on a credit card data set from Taiwan with 23 predictors and 25,000 data points.

The conclusion of (Yeh & Lien)[3] was that artificial neural networks

1. showed the best performance based on  $R^2$  scores, intercept and slope of linear regressions between predicted probability vs. actual probability.
2. produced a predictive default probability which is the only one that could be used to represent real probability of default.
3. should be employed to score clients instead of other data mining techniques, such as logistic regression.

This research aims to reproduce the results from two of the methods from (Yeh & Lien)[3]: *logistic regression* (LOGR) and *artificial neural networks* (ANNs).

It is necessary with methods to evaluate the performance of the models. (Yeh & Lien, 2009)[3] applied three different measurement of performance

1. Error rates in predictions.
2. Area ratio in cumulative gain curves.
3.  $R^2$ -score of the linear regression of real probability vs. predictive probability. The latter was estimated by using the novel approach, called Sorting Smoothing Method.

In this research, all three measurements will be reproduced, it is therefore necessary to explain the methodology behind these methods. The first and most simple metric is the error rate. It is given by

$$Err = 1 - A \quad (1)$$

$$= \frac{1}{n} \sum_{i=1}^n I(\hat{y}_i, y_i), \quad (2)$$

where  $A$  is the accuracy score,  $n$  is the number of data points and the indicator function is given as

$$I(\hat{y}_i, y_i) = \begin{cases} 1 & \hat{y}_i = y_i \\ 0 & \hat{y}_i \neq y_i \end{cases} \quad (3)$$

The error rate is simply a measure of what fraction of the predicted outputs  $\hat{y}_i$  are not equal to the correct outputs  $y_i$ . This evaluation can provide an insight about the predictive abilities of the two models, but not an actual probability of default on the individual level.

The second method which will be used, is the area ratio in cumulative gain curves. As explained in the report from [3], the horizontal axis represents the total number of data and the vertical axis represents the cumulative number of target data. There are three curves in this diagram: the theoretical best curve  $C_{best}$ , a diagonal baseline curve  $C_{base}$  and the model curve  $C_{model}$ . The area ratio is defined as

$$\text{Area ratio} = \frac{\text{area between } C_{model} \text{ and } C_{base}}{\text{area between } C_{best} \text{ and } C_{base}}. \quad (4)$$

The higher the area ratio is, the better the model. The last method to evaluate the methods is to estimate the real probability of default. This will be done by the Sorting Smoothing Method (SSM) and will be done by the same method as described in (Yeh & Lien)[3]. The approach is to use the continuous outputs from the model. These values are called the *predictive probabilities* and will be values in the range  $[0, 1]$ . These data points can be ordered from minimum to maximum. The *estimated probabilities* can be calculated by

$$P_i = \frac{1}{2n+1} \sum_{j=i-n}^{i+n} Y_j, \quad (5)$$

where  $Y_i$  is the binary value of the default in the same order as the sorted predictive probabilities. Lastly the estimated probability will be plotted vs. the predictive probability. This scatter plot will be fitted with a linear regression of a 1st order polynomial

$$y = ax + b, \quad (6)$$

where a good model will have  $a \approx 1$  and  $b \approx 0$ . These linear fits will also be evaluated with  $R^2$  scores (which will be explained in the linear regression part of the theory section). A good model will have a higher  $R^2$  score.

In the next two subsections, both logistic regression and neural networks for classification problem will be explained. The choice of cost function for the classification problem will be cross entropy. According to (Nielsen)[2], cross entropy is a better choice of cost function, provided that the output neurons are Sigmoid neurons. This cost function also avoids a learning slowdown which occurs in the case of a quadratic cost function.

### 1. Logistic Regression

Logistic regression (LOGR) is a statistical model that aims to predict discrete outputs. The method for logistic regression which will be applied is the stochastic gradient descent (SGD) with mini-batches. This is a method which is solved iteratively, with an initial guess for the parameter vector  $\beta$ . In appendix A in section VII there is a long derivation for gradient descent with cross entropy as a cost function. The derivation of SGD with mini-batches is also shown in section VII. The numerical algorithm for gradient descent is given by

$$\beta_{opt}^t = \beta_{opt}^{t-1} - \gamma X^T(p - y). \quad (7)$$

The general iterative procedure for SGD with mini-batches is

$$\beta_{opt}^t = \beta_{opt}^{t-1} - \gamma \sum_{i \in B_k} \frac{\partial}{\partial \beta} c_i(x_i, \beta). \quad (8)$$

where  $B_k$  denotes one mini-batch, which is a subset of all the data points. The cost function  $c_i$  can for instance be the cross entropy which is derived in section VII and shown above in equation 38.

## 2. Neural Network

A feed forward neural network (FFNN) is a neural network where the information only moves forward from one layer to next layer. There are no loops or information going backwards. It essentially works by applying SGD between each neighboring layers, and it must have at least one hidden layer to differ from the regular logistic regression. It can obtain a high predictability with several hidden layers.

The input layer has a given number of features which is equivalent to the given number of nodes in the hidden layers. The output could have a fixed number of outputs (e.g. 10 in the case of digit recognition). When these numbers are fixed, the neural network can be trained with training data.

Between each pair of layers (including the input and output layer) there are a set of weights and biases. In the case of a fully connected FFNN, all inputs are linked to all nodes in the next layers, thus fully connected. The feed forward algorithm works by applying

$$a^l = f(z^l) = f(W^l y^{l-1} + b^l). \quad (9)$$

where  $y^l, b^l \in \mathbb{R}^n$  and  $y^{l-1} \in \mathbb{R}^m$  are column vectors and  $W^l \in \mathbb{R}^{n \times m}$  is a matrix. The output in layer  $l$  is given by the previous layer  $l-1$ , then this can be used as input in the next layer. This process can be repeated until the output in the last layer is found.  $f$  is the activation function, which often is the Sigmoid function

$$\sigma(x) = \frac{1}{1 + e^{-x}}, \quad (10)$$

$$\frac{d}{dx} \sigma(x) = \sigma(x)(1 - \sigma(x)). \quad (11)$$

The Sigmoid function works element-wise on the  $x$  if it is a vector. And whichever values  $x$  contain,  $f(x)$  maps those values in the range  $[0, 1]$ . The activation function can also be the hyperbolic tangent

$$\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}, \quad (12)$$

$$\frac{d}{dx} \tanh(x) = 1 - \tanh(x)^2. \quad (13)$$

The hyperbolic tangent maps the input  $x$  to an output value in the range  $[-1, 1]$ . There are more options for activation functions, but only these will be used in the research presented. The choice of activation function should correspond with the way that the data is preprocessed. For instance, the input data could be processed with a so-called MinMaxScaler, in which all the data is in a certain range,

e.g.  $[0, 1]$ . With this scaling, the Sigmoid function is relevant.

The goal of the FFNN is to train the network so that it can accurately predict the correct output for new data points which it has never before seen. That is done tweaking the weights and biases, which again is done by the *backpropagation algorithm*. This algorithm can be summarized with four equations

$$\delta^L = \nabla_a C \odot \sigma'(z^L), \quad (14)$$

$$\delta^l = \left([w^{l+1}]^T \delta^{l+1}\right) \odot \sigma'(z^l), \quad (15)$$

$$\frac{\partial C}{\partial b_j^l} = \delta_j^l, \quad (16)$$

$$\frac{\partial C}{\partial w_{jk}^l} = a_k^{l-1} \delta_j^l. \quad (17)$$

$L$  denotes the output layer and  $l$  denotes all the other layers. Before these equations can be evaluated, all  $z^l$  and  $a^l$  must be evaluated through the feed forward algorithm described in equation 9. The weights and biases are updated by

$$w_{jk, new}^l = w_{jk, old}^l - \eta \frac{\partial C}{\partial w_{jk}^l}, \quad (18)$$

$$b_{j, new}^l = b_{j, old}^l - \eta \frac{\partial C}{\partial b_j^l}, \quad (19)$$

where  $\eta$  is the learning rate.

The choice of cost function will be cross entropy with L2 regularization,

$$C = -\frac{1}{n} \sum_j [y_j \ln a_j^L + (1 - y_j) \ln (1 - a_j^L)] + \frac{\lambda}{2n} \sum_w w^2. \quad (20)$$

In the case of the backpropagation algorithm, it is convenient to use SGD, which is achieved by using mini batches. Consider that the number of data points in one batch is  $m$ , and hence the number of mini batches is  $M = n/m$ . During one epoch, there is an inner loop with  $M$  iterations. Each time, a random data sample of size  $m$  is picked. Further, the backpropagation algorithm is applied on that mini batch to yield a small step for all weights and biases, given by equations 18 and 19.

When the inner loop is finished, all the biases are updated by taking the average step of which all mini batches yielded

$$b_{j, new}^l = b_{j, old}^l - \frac{\eta}{M} \sum_{batches} \frac{\partial C}{\partial b_j^l}. \quad (21)$$

For the weights, the same is done, taking the average step from all the mini batches. Additionally, the L2 regularization from equation 20 now enters the term which updates the weights

$$w_{jk, new}^l = w_{jk, old}^l \left(1 - \frac{\eta \lambda}{n}\right) - \frac{\eta}{M} \sum_{batches} \frac{\partial C}{\partial w_{jk}^l}. \quad (22)$$

## B. Regression

The aim of regression is to compare the predictive abilities of neural networks (NN) and linear regressions (LINR). The data that will be used is a data set with two predictors  $x_1$  and  $x_2$  and a single output. This data will be generated by using the Franke function, with both  $x_1, x_2 \in [0, 1]$  and the output  $y = f(x_1, x_2)$  is a sum of four Gaussian distributions with different centers, standard deviations and heights.

The cost function in the case of regression problems, will be the mean squared error (MSE) as the goal is to provide a model that can as best as possible model the underlying function. When a prediction  $\hat{y}$  is provided, the MSE is defined as

$$MSE = \frac{1}{N} \sum_{i=1}^N (y_i - \hat{y}_i)^2. \quad (23)$$

After each model has provided a prediction, a possible evaluation method is the  $R^2$  score, which is defined by

$$RSS = \sum_{i=1}^N (y_i - \hat{y}_i)^2, \quad (24)$$

$$TSS = \sum_{i=1}^N (y_i - \bar{y})^2, \quad (25)$$

$$R^2 = 1 - \frac{RSS}{TSS}. \quad (26)$$

### 1. Linear Regression

Concerning LINR, a previous study on the Franke function has been conducted[1], with design matrices consisting of polynomial terms of  $x_1$  and  $x_2$ . The conclusions of this study were that Ridge regression provided the most accurate results, and therefore this method will be re-applied in the research presented. The parameters that may be varied in Ridge regression in this case, are the regularization parameter and the polynomial degree of the design matrix.

### 2. Neural Network

The neural network will be trained by using only the two predictors  $x_1$  and  $x_2$  and a single output. The method that the network can be trained is nearly the same as in the classification case, presented earlier in this section. However, the cost function is now the MSE. The activation functions between each hidden layer can still be e.g. the sigmoid function, tanh, etc, but between the last hidden layer and the output layer, the activation function must be a linear function, because this model is going to predict a linear regression problem.

## III. METHOD

### A. Classification

The data set which was analysed was credit card data from Taiwan with 23 different attributes and 30,000 data points [3]. The classification problem was to predict customers' default payments. In the research presented, two methods are presented: *logistic regression* (LOGR) and *artificial neural networks* (NN).

#### 1. Processing and Description of the Data Set

The credit card data set contained 23 predictors. The outputs where one column of binary outputs, *default payment next month* where 1 means yes and 0 means no.

The processing of the data set was done with the aim of scaling the data and removing outliers.

The outliers were removed by simply deleting entire rows containing at least one value which were not defined in the data set. In total, 399 rows were deleted, resulting in 29601 unique data points.

Among the 23 predictors, some of the columns were categorical and some were continuous. The categorical columns: *gender*, *marital status* and *education* were one-hot encoded and placed first in the processed data set. These columns resulted in 9 one-hot encoded columns containing values 0 or 1:

- 0, SEX: Gender (1=male)
- 1, SEX: Gender (1=female)
- 2, EDUCATION: (1=graduate school)
- 3, EDUCATION: (1=university)
- 4, EDUCATION: (1=high school)
- 5, EDUCATION: (1=others)
- 6, MARRIAGE: Marital status (1=married)
- 7, MARRIAGE: Marital status (1=single)
- 8, MARRIAGE: Marital status (1=others)

Further, column 6-11 in the original data set contained integer values in the range  $[-2, 9]$ . Where  $\{-2, -1, 0\}$  were three different categories that all describes that the bill has been paid (-2: credit card was inactive in period, -1: the due amount and balance paid fully, 0: the minimum due amount paid) whereas the integers  $[1, 9]$  described payment delay in months. Therefore, the first three values  $\{-2, -1, 0\}$  were interpreted as the same category (bill paid) and one-hot encoded, resulting in 12 new columns. The latter values (1-9) were treated as continuous variables because these described something of the same unit, which in this case was *payment delay in months*. Thus the next 12 columns were

- 9, PAY\_0: Repayment status (1=paid), Sep. 05
- 10, PAY\_2: Repayment status (1=paid), Aug. 05
- 11, PAY\_3: Repayment status (1=paid), July 05
- 12, PAY\_4: Repayment status (1=paid), June 05
- 13, PAY\_5: Repayment status (1=paid), May 05
- 14, PAY\_6: Repayment status (1=paid), Apr. 05
- 15, PAY\_0: Repayment status (1=not paid), Sep. 05
- 16, PAY\_2: Repayment status (1=not paid), Aug. 05
- 17, PAY\_3: Repayment status (1=not paid), July 05
- 18, PAY\_4: Repayment status (1=not paid), June 05

- 19, PAY\_5: Repayment status (1=not paid), May 05
- 20, PAY\_6: Repayment status (1=not paid), Apr. 05

The data set was split into a training set and test set of 80% and 20% of the data set, respectively. The training set was upscaled so that the number of rows with output  $y_i = 0$  equal the number of row with output  $y_i = 1$ . This was not done for the test set.

Lastly, the entire data set was scaled by using a MinMaxScaler. Every continuous columns (and also the categorical columns), now contained values within the range  $[0, 1]$ . The remaining columns were

- 21, LIMIT\_BAL: Am. of given credit in NT dollars
- 22, AGE: Age of credit card holder
- 23, PAY\_0: Payment delay in Sep. 05
- 24, PAY\_2: Payment delay in Aug. 05
- 25, PAY\_3: Payment delay in July 05
- 26, PAY\_4: Payment delay in June 05
- 27, PAY\_5: Payment delay in May 05
- 28, PAY\_6: Payment delay in Apr. 05
- 29, BILL\_AMT1: Am. of bill statement in Sep. 05
- 30, BILL\_AMT2: Am. of bill statement in Aug. 05
- 31, BILL\_AMT3: Am. of bill statement in July 05
- 32, BILL\_AMT4: Am. of bill statement in June 05
- 33, BILL\_AMT5: Am. of bill statement in May 05
- 34, BILL\_AMT6: Am. of bill statement in Apr. 05
- 35, PAY\_AMT1: Am. of prev. payment in Sep. 05
- 36, PAY\_AMT2: Am. of prev. payment in Aug. 05
- 37, PAY\_AMT3: Am. of prev. payment in July 05
- 38, PAY\_AMT4: Am. of prev. payment in June 05
- 39, PAY\_AMT5: Am. of prev. payment in May 05
- 40, PAY\_AMT6: Am. of prev. payment in Apr. 05

The scaling parameters were obtained from the training set, and both sets were scaled according to the training set. Now, an important note is that the training set contained no information from the test set, but the test set is scaled according to the training set. In total, the processed data set contained 41 predictors and 29601 unique data points.

### 2. Logistic Regression

The logistic regression method that was applied and implemented in Python was *stochastic gradient descent* (SGD) with mini-batches. This was an iterative algorithm and the general structure of the algorithm was

1. Random weights and bias was initialized
2. Loop over epochs/max no. of iterations
3. Loop over n mini batches, where one random mini batches is chosen each time

(a) Evaluate p:  $p = \frac{1}{1 + \exp\{-X_i\beta + b\}}$

(b) Adjust bias:  $b^{new} = b^{old} - ave(p_i - y_i)$

(c) Adjust weights  $\beta^{new} = \beta^{old} - \gamma X_i^T(p - y)$

The weights are updated according to the cost function *cross entropy*. The parameter  $\gamma$  was the learning rate. This was set to be  $1/(t + 10)$  where  $t \in [0, epochs)$ . This resulted in the learning rate becoming smaller throughout the epochs.

The SGD algorithm was trained with the training data and tested with both the training data and the test data.

Considering that the learning rate is decreasing as the epochs evolve, high number of epochs can be tested. The number of epochs was tested by trial and error with values from 100 to 3000 in order to produce the best results. Finally, a constant number of 1000 epochs was set.

The evaluation of the model consisted of obtaining the error rates and area ratios for both the test set and training set. Additionally, for the test set, the cumulative gain curve was plotted. Finally, and the estimated probability was plotted vs. predictive probability as a scatter plot along with the corresponding linear regression.

### 3. Neural Network

A feed forward neural network was implemented by utilizing the back propagation algorithm. The NN was trained by using Sigmoid as activation functions between each hidden layer and by using cross entropy with L2 regularization as cost function. The mini batch size were set to 100.

Another parameter to consider, was the number of epochs. By setting aside 10 % of the training data to validation data, the accuracy of the validation data was monitored. This analysis found that the accuracy in the validation data did not increase after around 10 epochs. Therefore, for the remaining analyses the number of epochs was kept fixed at 10, and the validation data was included as training data.

The layers were varied by trial and error, and one combination that seemed to provide stable and good results was a layer setup of [41, 100, 75, 50, 34, 1], including the input and output layer. This setup was created by using a fairly high complexity to begin with (100 nodes in the first hidden layer), and then following roughly the 2/3 rule of slowly decreasing the number of nodes.

The L2 regularization parameter,  $\lambda$  and the learning rate,  $\eta$  were two parameters to be determined. In order to find the best combination, there was performed a grid search: the neural network was trained for all combinations of

$$\log_{10}(\eta) \in \{0, -1, -2, -3\} \quad (27)$$

$$\log_{10}(\lambda) \in \{-1, -2, -3, -4, -5, -6\} \quad (28)$$

For each trained neural network, the area ratio was determined both for the training set and the test set, and the parameters that resulted in the highest area ratio, were recorded. A heat map for the area ratios in the test data was plotted.

For the best combination of parameters for both the training and test set, both the area ratio and error rate were recorded. The cumulative gain curve of the test set was plotted, and the estimated probability vs. predictive probability was plotted as a scatter plot along with the corresponding linear regression.

## B. Regression

### 1. Generating a data set

The matrices  $X_{train} \in \mathbb{R}^{30,000 \times 2}$  and  $X_{test} \in \mathbb{R}^{10,000 \times 2}$  was initialized. The two columns in these matrices correspond to  $x_1$  and  $x_2$ , which were generated by using a uniform distribution in the range  $[0, 1]$ . The output vectors  $y_{train}$  and  $y_{test}$  was initialized by computing the Franke function with the values in  $X_{train}$  and  $X_{test}$ , respectively. There was an additional noise added to the y vectors with a standard deviation of 0.3 and a variance of 0.09.

### 2. Linear Regression

Ridge regression was applied to the training set. The matrix  $X_{train}$  were modified by using polynomial design matrices, with various polynomial degrees. The regression was performed by using 5-fold cross validation on the training data to obtain a stable estimate of the  $R^2$  score.

The Ridge regression now has two parameters that can be adjusted, the polynomial degree of the design matrix and the L2 regularization parameter. In order to find the best set of parameters, the  $R^2$  score was evaluated (by 5-fold cross validation) for grid of various polynomial degrees and regularization parameters. The polynomial degrees were varied in the range  $[7, 15]$ . The regularization parameters were varied in the range  $[10^{-5}, 10^{-13}]$ . The results were plotted as a heat map over  $R^2$  scores.

### 3. Neural Network: Regression

The neural network was set up by redefining the cost function from cross entropy to mean squared error (MSE). Now the number of hidden layers and nodes per hidden layer were experimented with by trial and error. One setup that provided stable and good results were two hidden layers with 100 and 60 nodes respectively.

There are many options for activation functions, but because this is a linear regression problem, the activation function for the output layer must be a linear function. The activation function for the output layer was set to be a linear activation function  $f(a) = a$ , which is equivalent to no activation function at all.

For the hidden layers however, there are many options. In order to see how the neural network evolved during the epochs, five different activation functions (Sigmoid,  $\tanh$ , ReLU, ReLU6 and Leaky ReLU) were tried. The time evolution of neural networks on a Franke function data set (without noise) were animated. By studying these animations (<https://github.com/simehaa/MachineLearning/tree/master/NeuralNetworks/animations>), ReLU and ReLU6 were the most unstable activation functions for this problem or this setup. Sigmoid did not quite capture the curves of the Franke function, whereas both  $\tanh$  and leaky ReLU seemed to provide quite good results. Finally, the ac-

tivation function for the two hidden layers was chosen to be  $\tanh$ .

Now, there are three parameters of the neural network which must be found in order to obtain the best regression: the number of epochs, learning rate and L2 regularization parameter. The learning rate and regularization parameter was found by using a grid search of various combinations with

- Learning rates  $\in \{0.01, 1e-3\}$ .
- Regularization parameters  $\in \{0.1, 0.01, 1e-3, 1e-4\}$ .

The optimal number of epochs was determined by plotting the cost function (MSE) of the test set vs. the epoch number. For all different combinations of learning rates and regularization parameters, the neural networks were trained for a total of 500 epochs. When the NN is not very trained, the model suffers from a high bias, but this is a value that decreases as the model becomes better. At the same time, the variance in the model increases over time. It can be shown that  $MSE = Bias^2 + Var + \sigma^2$ , where  $\sigma^2$  is some irreducible error: essentially the noise in the data set. Since the goal is to minimize MSE, one must minimize the sum of  $Bias^2$  and  $Var$ : this is called the Bias-Variance trade-off. When plotting MSE vs. epochs, the aim was to identify if overfitting would occur, which could happen if the NN starts to model the noise in the training data. This would lead to an increased variance, and hence MSE in the test data.

For the grid search of parameters, the  $R^2$  score was recorded for each NN and plotted as a heat map. The best  $R^2$  scores obtained from Ridge regression and neural networks were compared.

## IV. RESULTS

### A. Classification

Table I shows the obtained error rates for both logistic regression and neural networks on the credit card data set.

TABLE I. Logistic regression and a neural network model performed on the credit card data set. Error rates and area ratios from previous research conducted by (Yeh & Lien)[3] are included for comparison.

Method	Error rate		Area ratio	
	Training	Test	Training	Test
Logistic regression with SGD	0.29	0.22	0.37	0.44
Logistic regression (Yeh & Lien)	0.20	0.18	0.41	0.44
Neural network	0.29	0.21	0.55	0.54
Neural network (Yeh & Lien)	0.19	0.17	0.55	0.54

Figure 1 and 2 shows the cumulative gain curves of the test set for LOGR and NN, respectively.

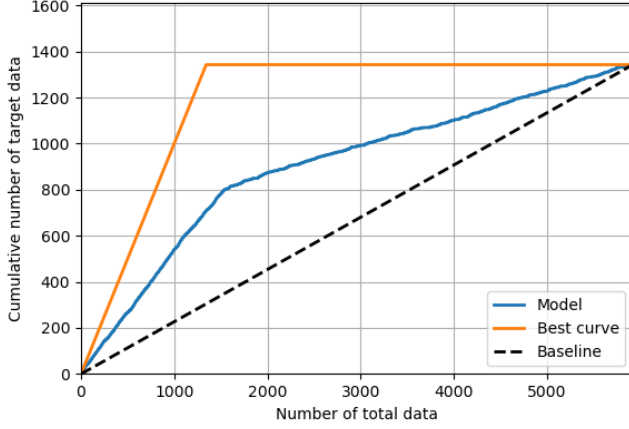


FIG. 1. ROC curve of logistic regression model, performed with SGD with 1200 epochs and decreasing learning rate. This figure represents the test set.

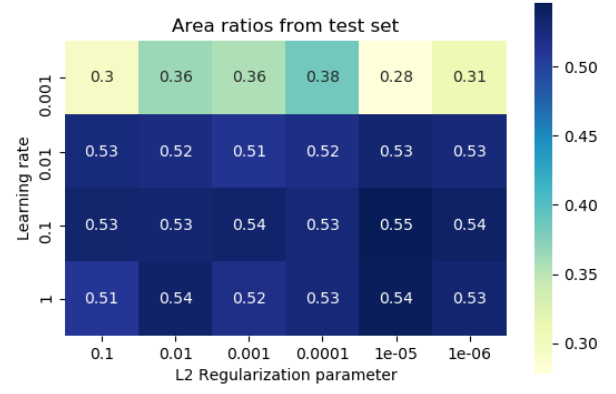


FIG. 3. Heat map over area ratios for test set for various combinations of regularization parameters and learning rates.

Figure 4 and 5 shows the estimated actual probability vs. the predicted probability for logistic regression and neural network. The estimated actual probability was calculated by using the Sorting Smoothing Method with  $n = 50$ . Additionally a linear regression line is included, which was calculated by ordinary least squares method.

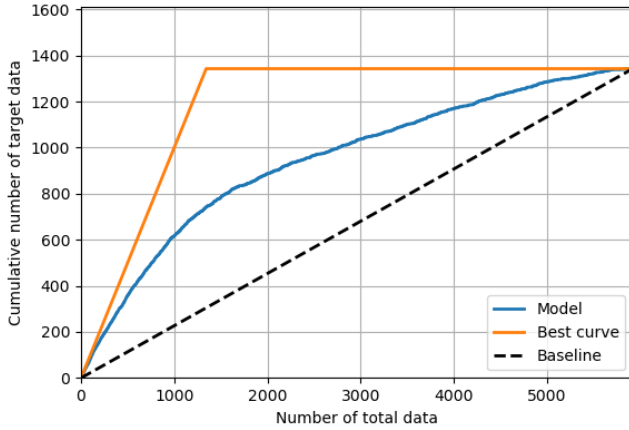


FIG. 2. ROC curve of neural network model. This figure represents the test set. In the training of the network, the learning rate used was  $\eta = 0.1$  and the regularization parameter was  $= 10^{-5}$ .

Figure 3 shows a heat map over area ratios of the test set, obtained for a grid of various L2 regularization parameters and learning rates. Only the heat map of the test set is included, because the training set gave very similar results.

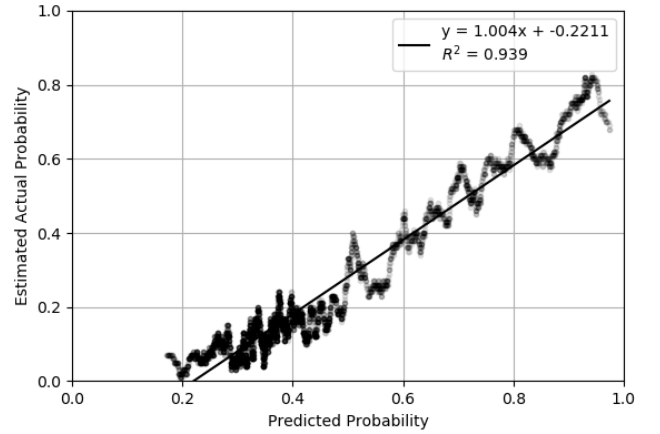


FIG. 4. The estimated actual probability (calculated by SSM) vs. the predictive probability for the test set and logistic regression. The figure also show a line fit, obtained by using the ordinary least squares method and the regression  $R^2$  score.

Figure 5 was created by using the test set and the neural network with the optimal parameters (those which obtained the best area ratio): learning rate  $\eta = 0.1$  and L2 regularization  $\lambda = 1e - 5$ . The activation functions and hidden layers were the same as before.

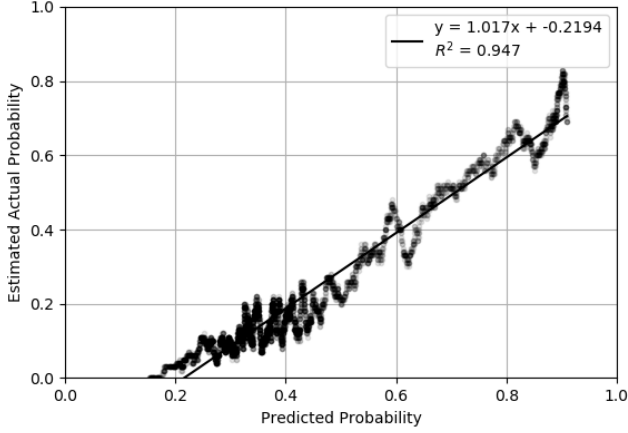


FIG. 5. The estimated actual probability (calculated by SSM) vs. the predictive probability for the test set and neural networks. The figure also show a line fit, obtained by using the ordinary least squares method and the regression  $R^2$  score.

Table II shows a summary of the linear regressions applied in figure 4 and 5, as well as the results from (Yeh & Lien)[3] for comparison.

TABLE II. Summary of the linear regression on estimated real probability vs. predictive probability. The data is the test set of the credit card data set. Results from previous research conducted by (Yeh & Lien)[3] are included for comparison.

Method	Regr. Coefficient	Regr. Intercept	Regr. $R^2$
Logistic regression	1.004	-0.2211	0.939
Logistic regression (Yeh & Lien)	1.233	-0.0523	0.794
Neural network	1.017	-0.2194	0.947
Neural network (Yeh & Lien)	0.998	0.0145	0.965

### B. Regression

Table III shows the obtained  $R^2$  scores from the best combinations of parameters for the two methods (regularization parameters for both methods, polynomial degree for Ridge regression and learning rate for the neural network).

TABLE III. Linear regression and neural networks performed on the Franke function data set. The best  $R^2$  scores of the parameters of the respective models are shown.

Method	$R^2$ -Score	Regularization Parameter	Learning rate	Polynomial degree
Ridge regression	0.89	$1E-13$	—	13
Neural network	0.88	0.01	0.1	—

Figure 6 and 7 shows heat maps over  $R^2$  scores for Ridge regression and neural networks, respectively.

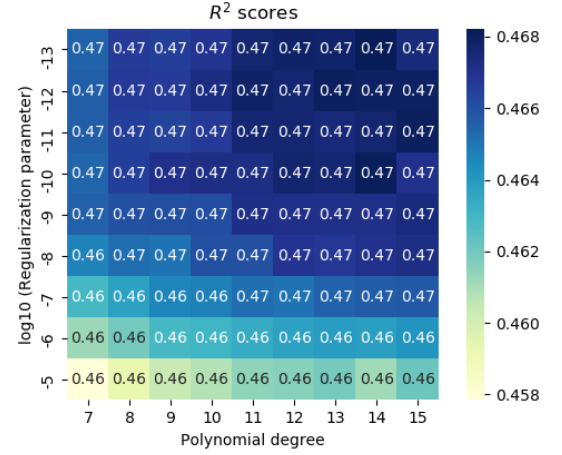


FIG. 6. Heat map over various  $R^2$  scores obtained by using 5-fold CV and Ridge regression.

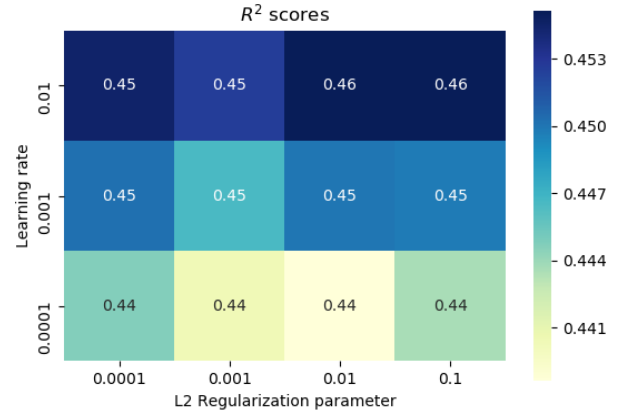


FIG. 7. Heat map over various  $R^2$  scores obtained by using a neural network with 2 hidden layers with 100 and 6 nodes respectively, and 300 epochs.

Figure 8 shows the MSE for the various neural networks vs. epoch number. The minimum MSEs are also indicated with red dots.



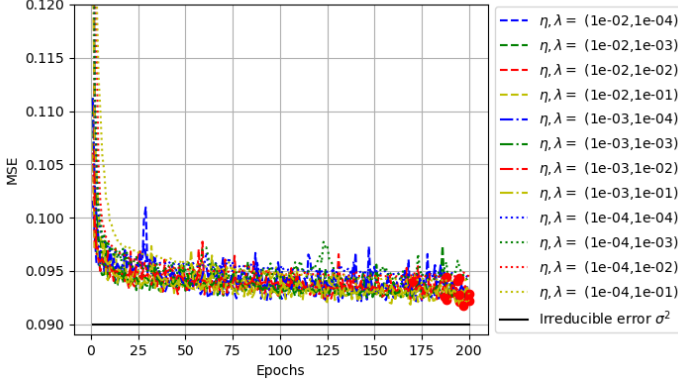


FIG. 8.

## V. DISCUSSION

### A. Classification

Table I shows the achieved error rates and area ratios obtained from both logistic regression and from neural networks. For simplicity, this research's results will be presented in plain text and the results from (Yeh Lien) will be presented in parentheses. Regarding the training error rates, LOGR achieved 0.29 (0.20) and NN achieved 0.29 (0.19). This is a significant worse result than that of (Yeh Lien). The test error rates were also worse, but closer: LOGR 0.22 (0.18) and NN 0.21 (0.17).

The area ratios were quite similar, except for the training area ratio of LOGR which was 0.37 (0.41). The other area ratios were equal by two digit significance, except for the test set area ratio of NN which was slightly better with a value of 0.55 (0.54). The area ratios obtained from (Yeh Lien) were reproduced with a good precision, except for LOGR's training area ratio. The error rates were not as good as the results from (Yeh Lien).

Figure 1 and 2 shows the ROC curves for the test set for both methods, LOGR and NN. These appear quite similar as to the results of (Yeh Lien), and as discussed above, the area ratios are also very close to those results.

Figure 4 and 5 shows the estimated probability (by the sorting smoothing method) vs. the predictive probability (from the models). The interesting part of these figures is the linear fit. A good model would result in a line with a slope close to 1 and an intercept close to 0. Another measure of a good model is a high  $R^2$  score. These parameters are also shown in table II.

The logistic regression model had a very good slope (1.004) which was much closer to 1 than the previous research (1.233). The intercept on the other hand had a value of  $-0.2211$  which is lower than expected. The  $R^2$  score of (0.939) was also much better than the previous research.

The neural network obtain a worse slope (1.017) than the previous research (0.998), by a small margin. Also this model had a much lower intercept ( $-0.2194$ ) than the previous research ( $-0.0523$ ). Lastly, the  $R^2$  score (0.947) was

surprisingly close to that of logistic regression and slightly worse than what (Yeh & Lien) obtained for neural networks (0.965). A observable feature for both LOGR and NN, was that the intercept was  $\approx -0.2$  which is quite a lot lower than 0 in this situation. It is unknown why this error occurred, but it is seemingly a systematic error. One reason could be that the models could not identify features (or collections of features) with a very low chance of not defaulting their credit card bill. In other words, a large majority of the individuals very at a low-to-moderate risk of defaulting.

A last note regarding the comparison of this study and the study conducted by (Yeh & Lien) is that logistic regression obtained worse error rates, but a better  $R^2$  score of the linear regression. Error rates and area ratios in cumulative gain curves are popular methods of evaluation in machine learning. The last method however, which attempted to estimate the real probability of default, might be a less relevant method of evaluation for these models. The reason why they chose this method or the theory behind it, is not explained by (Yeh & Lien)[3].

Out of the two classification models, it is NN that performs best, because it achieves slightly better error rates and quite remarkably better area ratios. The reason behind this result is the fact that NN applies higher complexity with the introduction of several hidden layers that each performs SGD. Logistic regression on the other hand, only has one weight per feature in addition to the bias, and can only model some very clear relationships between the input layer and output layer. It is hard to imagine exactly how NN achieves a better result, but through the hidden layers, it can model more complex relationships between the various features themselves. It can, over the course of learning, model complex patterns which turns out to result in a better prediction.

### B. Regression

Table III shows the best  $R^2$  scores obtained from both Ridge regression and neural networks. RR achieves a score of  $R^2 = 0.47$ , which is not a very high score, but this can be explained by the noise in the data set. NN achieves a score of  $R^2 = 0.48$ , which is only better than RR by a very small margin. Therefore NN was better than RR in the regression problem, in terms of the result. There are of course more aspects to this comparison.

One aspect to consider is time. Ridge regression has a considerably shorter execution time, and it is also much faster to implement. A model is ready after just a few matrix-matrix multiplications (MMM) and one matrix inversion. The Neural networks on the other hand requires very many matrix-matrix multiplications, many CPU expensive functions such as  $\tanh$  and generally a large number of computations for each epoch. In addition to that, it requires several hundred epochs in order to beat RR.

The other, and last aspect, to consider is the payoff between execution time vs. rewards. The time difference has already been discussed. The rewards however, are a result which is only slightly better. Depending on the required

precision desired, it might be considered an overkill to apply neural networks to a regression problem like the noisy Franke function. The payoff is small, and the cost is a much slower execution time.

### C. Comparison of the Methods

Neural network performed well on the classification problem. It obtained better results than logistic regression with stochastic gradient descent. This is consistent with some of the final remarks of (Yeh & Lien), which also found that neural networks performed better. Some of the results from (Yeh & Lien) were reproduced and some were not. The cumulative gain charts and area ratios were reproduced, but the error rates were slightly worse for both neural networks and logistic regression, especially the training error.

The regression problem was best solved by the neural network, but only by a small margin and at the cost of a much slower execution time. Therefore, it is very often the case that regression problems are most easily solved by applying linear regression methods, such as Ridge regression. Linear regression methods also contains fewer tuning parameters than neural networks. A final argument for linear regression methods, is that the theory behind them are much easier to understand, and hence are the results much easier to analyze.

In the research presented, there have been some limitations to the methods applied. Therefore, some suggestions for future improvements will be presented. Regarding the logistic regression, it is possible to modify the parameters in order to attempt to achieve better results. One could try various sizes of the mini batches, which in this research was kept constant at 100. Another possibility is to vary the learning rate, which can also be proportional to the gradient i.e. if the change in the weights are small, apply an accordingly small learning rate in the next epoch. Lastly, the number of epochs can be varied together along with the learning rate i.e. use more epochs with smaller learning rates.

Regarding the neural networks, both in the classification and regression problem, there are a high number of possibilities. Firstly, the number of hidden layers and the number of nodes per hidden layer can be varied infinitely. With computing power availability, one could go deeper and apply more hidden layers. Another important feature to explore, is which activation functions to use per hidden layers. In this research the Sigmoid function was used in classification and tanh was used in regression, but there are many more options, e.g. ReLU. It would also be interesting to explore decreasing learning rates and different types of regularization parameters, as these two parameters can improve the results remarkably.

## VI. CONCLUSION

The classification problem in the study presented, aimed to reproduce the results from two data mining methods from

the study of (Yeh & Lien)[3]. The data set was a credit card data set with 23 predictors and 30,000 data points, which was analyzed by neural networks (NN) and logistic regression (LOGR). The NN obtained better results than LOGR, which was shown by lower error rates and higher area ratios in cumulative gain charts. The results from (Yeh & Lien) were partly reproduced, because this research did not achieve as low error rates nor very similar estimations of actual probability of default. The area ratios and cumulative gain charts were reproduced by a good accuracy. The NN obtained almost identical area ratios, whereas LOGR obtained a slightly lower area ratio for the training data (0.37 vs. 0.41).

As a regression problem, a noisy data set of Franke function was analyzed by NN and Ridge regression (RR). NN achieved an  $R^2$  score of 0.48, whereas RR achieved and  $R^2$  score of 0.47. By considering the similarity in this result, and <https://physics.bu.edu/~pankajm/MLnotebooks.html> the execution time of neural networks, it might be more beneficial to apply linear regression methods instead of neural networks for regression problems.

Neural networks has been shown to be flexible in the sense that it can be applied to both classification and regression problems, but it is seemingly most outstanding and powerful when applied on classification problems.

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- [2] Nielsen, M. A. (2018). Neural networks and deep learning.
- [3] Yeh, I.-C. and hui Lien, C. (2009). The comparisons of data mining techniques for the predictive accuracy of probability of default of credit card clients. *Expert Systems with Applications*, 36(2):2473–2480.

## VII. APPENDIX A: DERIVATION OF THE ALGORITHM FOR SGD WITH MINI-BATCHES

Consider a dataset  $\mathcal{D} = \{(x_i, y_i)\}$  of independent and identically distributed (iid.) events and  $y_i \in \{0, 1\}$ . The probability of a certain output value is given by the logistic (also called logit or Sigmoid) function

$$p(y_i = 1|x_i, \beta) = \frac{\exp(\beta^T x_i)}{1 + \exp(\beta^T x_i)}, \quad (29)$$

where  $x_i$  is a row in the design matrix (under the assumption that  $x_{i,0} = 1$ , which yields the bias term  $\beta_0$ ). The next step is to use the maximum likelihood estimation principle (MLE)

$$P(\mathcal{D}|\beta) = \prod_{i=1}^n [P(y_i = 1|x_i, \beta)]^{y_i} [1 - P(y_i = 1|x_i, \beta)]^{1-y_i}. \quad (30)$$

A typical choice of cost function in logistic regression is the cross entropy, which can easily be found given MLE in equation 30. The negative log-likelihood of  $P$ , is the cross entropy,

$$\begin{aligned} C(\beta) &= -\log P(\mathcal{D}|\beta) \\ &= \sum_{i=1}^n y_i [\log P(y_i = 1|x_i, \beta)] + (1 - y_i) \log [1 - P(y_i = 1|x_i, \beta)]. \end{aligned} \quad (31)$$

$$(32)$$

The cost function must be minimized, it is therefore convenient to find the gradient of  $C(\beta)$  wrt.  $\beta$ . The linearized expression for this gradient is

$$\frac{\partial C(\beta)}{\partial \beta} = -X^T(y - p), \quad (33)$$

where  $X \in \mathbb{R}^{n \times p}$  is the design matrix,  $y \in \mathbb{R}^n$  is the output vector and  $p \in \mathbb{R}^n$  is the probability vector given by equation 29. The second derivative is given by

$$\frac{\partial^2 C(\beta)}{\partial \beta \partial \beta^T} = X^T W X, \quad (34)$$

with  $W \in \mathbb{R}^{n \times n}$  being a diagonal matrix where the diagonal elements are

$$W_{i,i} = P(y_i|x_i, \beta) [1 - P(y_i|x_i, \beta)]. \quad (35)$$

Computationally, the optimal  $\beta$  can be found iteratively by

$$\beta_{opt}^t = \beta_{opt}^{t-1} - \frac{\partial C(\beta)}{\partial \beta} / \frac{\partial^2 C(\beta)}{\partial \beta \partial \beta^T} \quad (36)$$

$$= \beta_{opt}^{t-1} - (X^T W X)^{-1} X^T (p - y). \quad (37)$$

After each iteration,  $W$  and  $p$  must be updated by using the new  $\beta_{opt}^t$ .  $H = (X^T W X)^{-1}$  is the Hessian matrix, and it requires a lot of computational power, therefore  $H$  is normally replaced by a scalar  $\gamma$  which is referred to as the *learning rate*. The iterative algorithm for gradient descent is given by

$$\beta_{opt}^t = \beta_{opt}^{t-1} - \gamma X^T (p - y). \quad (38)$$

In the research presented, a stochastic gradient descent (SGD) with mini-batches will be applied. When the cost-function can be written as a sum over the  $n$  data points - which is the case for cross entropy, then the gradient wrt.  $\beta$  is on the form

$$\frac{\partial}{\partial \beta} C(\beta) = \sum_{i=1}^n \nabla_{\beta} c_i(\mathbf{x}_i, \beta). \quad (39)$$

The data set can also be split into  $m$  mini-batches, each with the size of  $M = n/m$  data points. Now, instead of summing over all the data points, sum over the mini-batches  $B_k$ . The sum over the mini-batches should be done  $m$  (no. of mini-batches) times, where  $k \in \{1, 2, 3, \dots, m\}$  is picked randomly each time.

$$\frac{\partial}{\partial \beta} C(\beta) = \sum_{i \in B_k} \frac{\partial}{\partial \beta} c_i(\mathbf{x}_i, \beta). \quad (40)$$