

# Software Fault Detection

*Report submitted in fulfillment of the requirements  
for BTech Project*

**Third Year B.Tech.**

*by*

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May 2021



Dedicated to

*Our parents, teachers, and the  
almighty god.....*

# Declaration

We certify that

1. The work contained in this report is original and has been done by ourselves and the general supervision of our supervisor.
2. The work has not been submitted for any project.
3. Whenever we have used materials (data, theoretical analysis, results) from other sources, we have given due credit to them by citing them in the text of the thesis and giving their details in the references.
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Place: IIT (BHU) Varanasi  
Date: 1/5/2021

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# Certificate

*This is to certify that the work contained in this report entitled ” **Software Fault Detection**” being submitted by **Bavanya(18075034) and Swati S Malik(18075060)**, carried out in the Department of Computer Science and Engineering, Indian Institute of Technology (BHU) Varanasi, is a bona fide work of my supervision.*

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Date:1/5/2021

# Abstract

Effective detection of software faults is an important activity of software development process. Software plays a vital role, it tells a computer how to function. Without software, most computers would be useless. For example, a web browser is a software application that allows users to access the internet. . An operating system (OS) is also a software program that serves as the interface between other applications and the hardware on a computer or mobile device. So software are very important in this modern world of computers. So defect detection is an important activity during software development process. For a software development project, it is highly desirable to reduce software defects. The main goal of building program patterns is to find software defects. We implemented deep learning models with different feature extraction techniques to detect the defects in dataset.

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# Chapter 1

## Introduction

### 1.1 Software

Software is a set of instructions, data, or programs used to operate a computer and execute specific tasks. Software tells a computer how to function. Without software, most computers would be useless. For example, a web browser is a software application that allows users to access the internet. . An operating system (OS) is also a software program that serves as the interface between other applications and the hardware on a computer or mobile device. So software are very important in this modern world of computers.

### 1.2 Software Fault Detection

Effective detection of software faults is an important activity of software development process. Defect detection is an important activity during software development process. For a software development project, it is highly desirable to reduce software defects. The main goal of building program patterns is to find software defects.[1]

The main difficulty of detecting software fault is finding faults in a large and complex software system.

## 1.3 Unsupervised Anomaly Detection

Anomaly detection is the method of identifying data points in the dataset which are unexpected compared to the rest of the data points.

In case the dataset available for software fault prediction of a project is unlabelled, the fault detection problem can be handled as an Anomaly detection problem where all the faulty data points will be treated as anomalies. This approach is based on the assumption that the percentage of faulty data points is very less in the entire dataset that they can be considered as anomalies.

## 1.4 Cross Version Fault Prediction

Metrics are extracted from a software project's specific version's source code and immediate next version's source code. Now specific version's data collected are collectively taken as the training data for training the model and the immediate next version's data collected as the collective testing data.

## 1.5 Project Overview

Initially we have explored Software fault detection of an unlabelled dataset as an Anomaly detection problem and later we have build different deep learning architectures for predicting faulty data points in the software fault prediction dataset.

### 1.5.1 Different Techniques Used:

- Isolation Forest
- Artificial Neural Network
- Convolution Neural Network
- Recurrent Neural Network

## 1.6. Organisation of the Report

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- Long Short Term Memory
- Gated Recurrent Unit

### 1.5.2 Goal of Software Fault Prediction

- The main goal of software fault prediction is to use the underlying properties of the source code of a software project to predict faults before the actual testing process begins. This will help in prioritizing the work in the testing process.

## 1.6 Organisation of the Report

The chapter 2 of the report explains the dataset features and the work done. Chapter 3 discusses the preprocessing, oversampling, postprocessing methods and evaluation metrics used in detail with their working explained. In chapter 4, we give clear explanation of the models and architectures experimented for the project. In chapter 5, we display the results and the plots of the training curves to visualize the performance of the models for software fault prediction and analyse and compare the results. In chapter 6, we finally conclude and discuss the future directions of this project.

# Chapter 2

## Dataset and work done

### 2.1 Dataset

The datasets for training and testing the models are taken from the PROMISE repository which consists of 41 different versions of projects. The datasets are taken from 11 open source projects. Data is collected from three or more versions from each of the open source projects.

We used former version of a project as the training data of our models and tested the models' predictions on the latter version for the deep learning regression models developed. For anomaly detection, we have taken csv files of all versions and concatenated them to a single dataset, removed the labels and split the training and testing data to 4:1 ratio for the isolation forest model.

The target variable of datasets taken for anomaly prediction had binary values i.e 0 or 1 where 1 meant that a specific data point was flawed and 0 meant that it was unflawed. Whereas, for the deep learning regression problem we took that the datasets which had the target value as the number of faults corresponding to each data point.



## 2.2. Description of Dataset

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## 2.2 Description of Dataset

The following matrices are proposed by Chidamber and Kemerer, Henderson-Sellers, Martins, QMOOD and Tang et al. The features in the datasets taken are:

**Table 2.1** Dataset Features

Abbreviation	Dataset Features
CBO	Coupling between objects
RFC	Response for a class
LCOM	Lack of cohesion in methods
NOC	Number of children
DIT	Depth of inheritance
WMC	Weighted methods per class
Ca	Afferent couplings
Ce	Efferent Couplings
NPM	Number of public methods
DAM	Data Access Metric
MOA	Measure of Aggregation
MFA	Measure of Functional Abstraction
CAM	Cohesion Among Methods of Class
AMC	Average Method Complexity
LOC	Line of Code
CBM	Coupling Between Methods
IC	Inheritance Coupling

**Table 2.2** Explanation of the features

Abbreviation	Explanation
CBO	counts the number of other classes to which a class is coupled with.
RFC	counts the number of external and internal classes.
LCOM	measures dissimilarity of methods in a class.
NOC	counts the number of descendants of a class.
DIT	measures number of ancestor classes.
WMC	counts the number of methods in a class weighted by complexity.
Ca	counts how many other classes use a given class.
Ce	counts the number of classes. a class is dependent upon.
NPM	counts the number of public methods in a class.
DAM	the number of private methods divided by the total number of methods.
MOA	counts the number of abstract data types in a class.
MFA	the number of inherited methods divided by total number of methods accessible by its member functions.
CAM	based upon the parameters in a method.
AMC	counts average size of method in a class.
LOC	counts the number of lines of source code.
CBM	counts the newly added func- tions with which inherited based methods are coupled.
IC	it is based upon inheritance-based coupling.

## 2.3 Work done

This section gives the overview of the work done and includes all the concepts and work done in the experiments. Indetailed explanation about each concept and term used the following subsections will be given the following next two chapters.

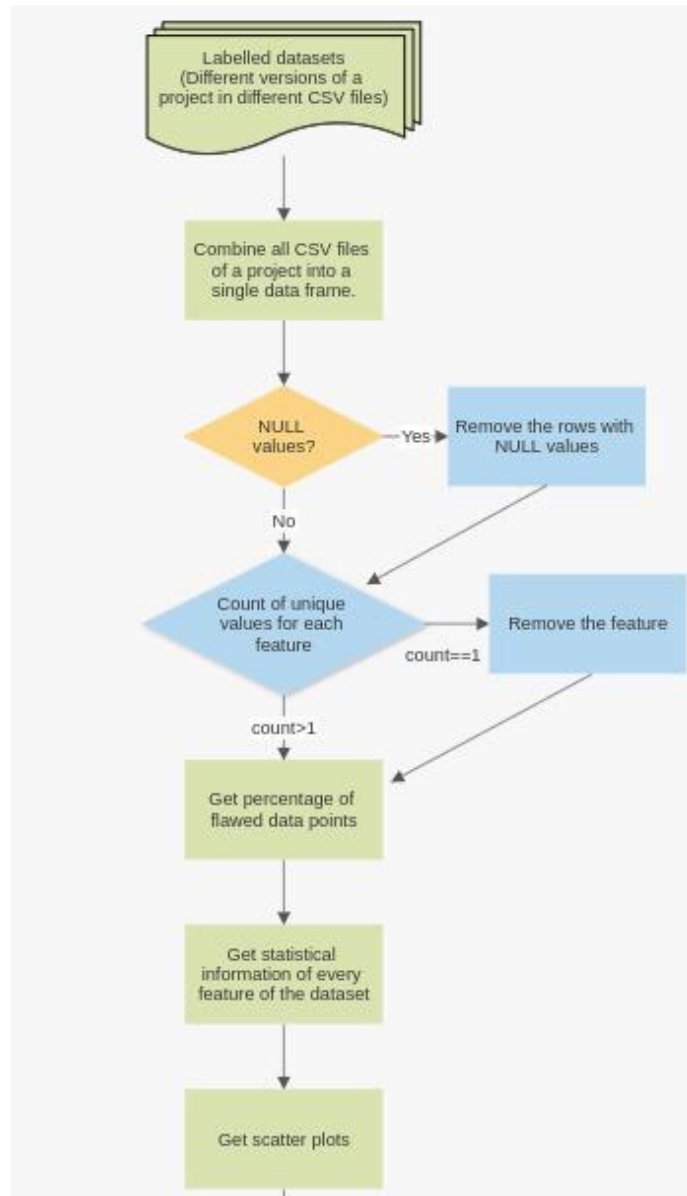
### 2.3.1 Anomaly Detection

Data files of all the versions of a project are concatenated into a single dataframe and features without unique values are trimmed. The data did not include any null values to handle and the percentage of faulty datapoints was found to be 4.7090517241379315 %. Applying normalization will result in the outliers not being too distinctive from the rest of the data points, so feature scaling was not applied on the dataset. Scatter plots and distribution plots were obtained of the dataset for each feature and analysed. From the plots, the distinctive behaviour of the defective data points was clearly perceivable. The data set was visualized in 3D and 2D space using t-SNE. We noticed that the data points were not distinctive in 2D or 3D space. So, we went with the earlier finalized features and didn't opt for further feature selection. We removed the labels from our data to treat the problem as unsupervised and split the training and testing data to 4:1 ratio. We used `IsolationForest()` function from sklearn package for building the model. To evaluate the performance of the model built, we calculated the metrics in confusion matrix and calculated the model accuracy which came out to be 87.70576131687243 %.

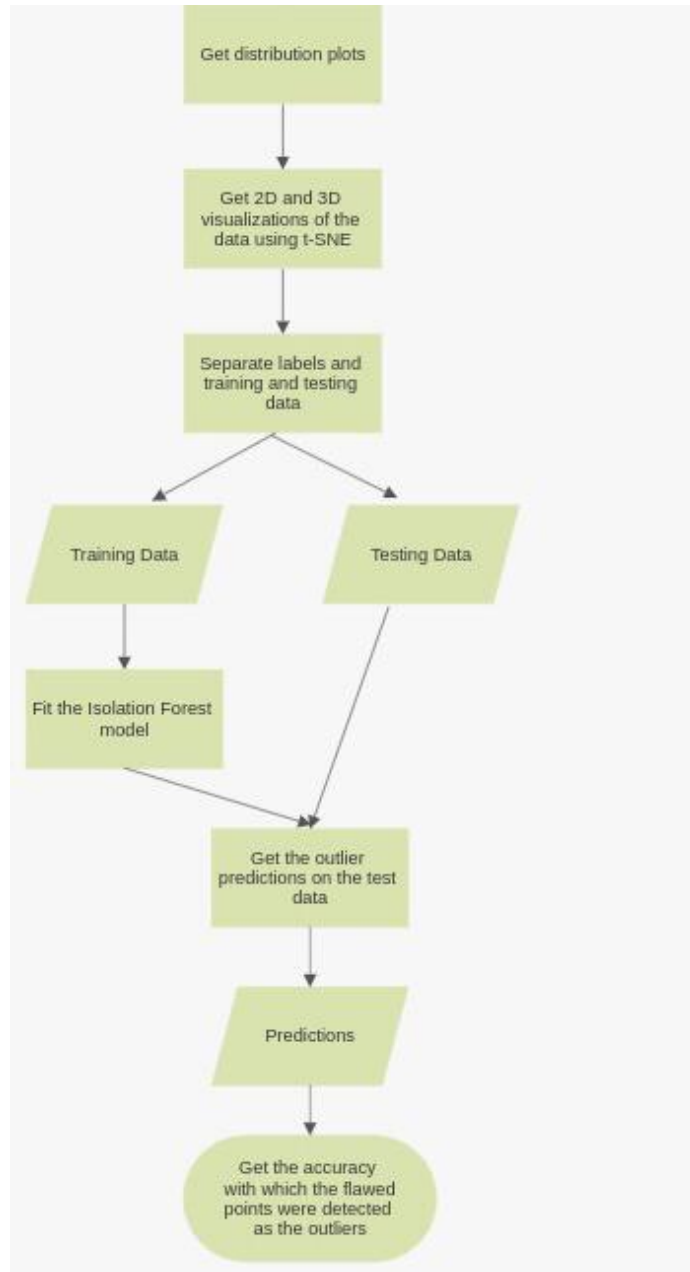
The detailed flow chart of the entire experiment is given:

### 2.3.2 Regression using Deep Learning

Exploratory data analysis has been done on the two versions of the project which were taken for training and testing the model. The analysis included checking the presence of null data points, making sure all the features had unique values for the datasets, checking the datatypes of the features and visualizing the scatter plot and frequency distribution of the data for each feature. As per the analysis done, no data cleaning or feature filtration was needed. A specific version ant-1.3 was taken to train the data and ant-1.4 version was taken for testing the models built. Min Max scaling was applied and models' performance were checked with and without differ-



**Figure 2.1** Flowchart of the anomaly detection experiment



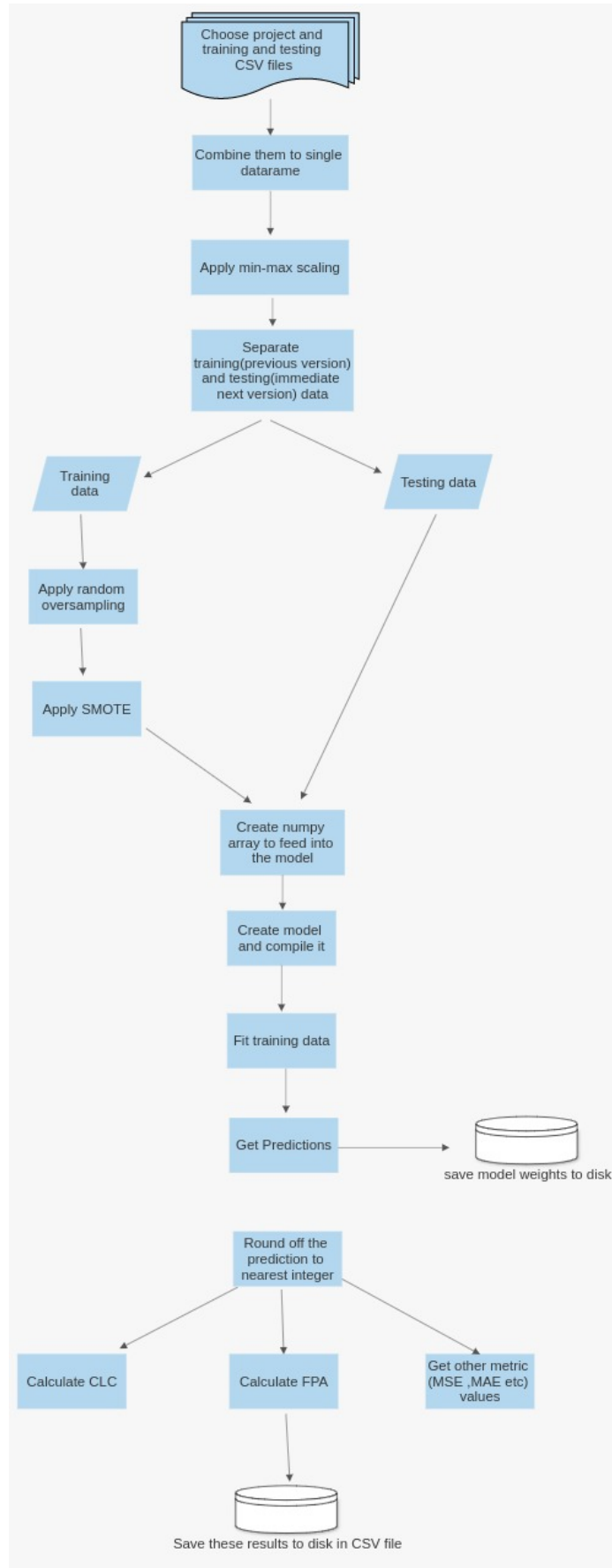
**Figure 2.2** Flowchart continuation

### 2.3. Work done

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ent two feature reduction techniques: SVD and PCA with each taking two different number of components hyperparameter values. Since the data points in the training and testing datasets were very few and might be inadequate for the deep learning models to learn efficiently, we used `RandomOverSampler()` and `SMOTE()` functions from `imblearn` package to increase the size of the data and balance it. The models were developed using `tensorflow keras` in python. We obtained the training and testing time of the models using the `time()` function from `time` package. The predictions obtained were round off to the nearest integer using `np rint()` from `numpy` package because the target value to be predicted was a strict integer. Following the decision in the paper *Ridge and Lasso Regression Models for Cross-Version Defect Prediction* by Xiaoxing Yang and Wushao Wen we have considered `FPA`(Fault-percentile-average) and `CLC`(Cumulative lift chart (also the area under `CLC`)) as our main model evaluation metrics. At the end of each experiment we have automated the saving of the model weights and results in `csv`.

The detailed flow chart of the experiments done for regression using deep learning is given:

**Figure 2.3** Flowchart of the anomaly detection experiment

# Chapter 3

## Feature Engineering and metrics

The feature engineering concepts used in the experiments i.e preprocessing, post-processing and oversampling and the metrics considered for the model evaluation are discussed here. Each section is related to each of the two experiments conducted. Each concept used in the respective type of experiment is explained in each sub section of the sections.

### 3.1 Anomaly detection

Extensive exploratory data analysis and preprocessing was performed on the datasets before developing the Isolation forest model. The concepts used for anomaly detection were:

#### 3.1.1 t-SNE(t-distributed stochastic neighbor embedding)

t-SNE is used to visualize high dimensional data. The similarities between the data points are converted to joint probabilities and the Kullback-Leibler divergence between these joint probabilities of the low-dimensional embedding and the high-dimensional data is minimized. The similarities between the pairs of instances in the high dimensional space and low dimensional space are optimized using a cost

function.

## **3.2 Deep leaning regression**

Deep learning models are built to predict the number of faults corresponding to a datapoint in the testing dataset. Since the predictions are strictly greater than zero we have used ReLU Activation function after the output layer in the models and post processing is performed after that to convert the predictions to whole numbers. Different concepts used in the feature engineering in these experiments are:

### **3.2.1 Min Max Scaling**

Min Max scaling is done to rescale a feature or observation value to a distribution value between 0 and 1. The formula followed is:

$$X_{\text{new}} = \frac{X_i - \min(X)}{\max(x) - \min(X)}$$

**Figure 3.1** Min Max scaling formula

### **3.2.2 SVD(Singular Value Decomposition)**

The singular value decomposition (SVD) is a factorization of a real or complex matrix that generalizes the eigendecomposition of a square normal matrix to any. matrix via an extension of the polar decomposition.

### **3.2.3 PCA(Principal Component Analysis)**

Principal Component Analysis, or PCA, is a dimensionality-reduction method that is often used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller one that still contains most of the information in the large set. Reducing the number of variables of a data set naturally comes at the expense



### 3.2. Deep leaning regression

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of accuracy, but the trick in dimensionality reduction is to trade a little accuracy for simplicity.

#### 3.2.4 Over Sampling

Oversampling in data analysis are techniques used to adjust the class distribution of a data set. The bias in the training dataset can influence many machine learning algorithms, leading some to ignore the minority class entirely. To address this problem, oversampling is carried out on the dataset. Random Oversampling involves supplementing the training data with multiple copies of some of the minority classes. Oversampling can be done more than once.

#### Synthetic Minority Over-sampling Technique(SMOT)

The most common technique to oversample a dataset used in a typical classification problem is SMOTE: Synthetic Minority Over-sampling Technique. To illustrate how this technique works consider some training data which has  $s$  samples, and  $f$  features in the feature space of the data. Note that these features, for simplicity, are continuous. As an example, consider a dataset of birds for classification. The feature space for the minority class for which we want to oversample could be beak length, wingspan, and weight (all continuous). To then oversample, take a sample from the dataset, and consider its  $k$  nearest neighbors (in feature space). To create a synthetic data point, take the vector between one of those  $k$  neighbors, and the current data point. Multiply this vector by a random number  $x$  which lies between 0, and 1. Add this to the current data point to create the new, synthetic data point.[2]

#### 3.2.5 FPA(Fault-percentile-average)

Considering  $m$  modules  $f_1, f_2, \dots, f_m$  listed in increasing order of predicted defect number,  $s_i$  as the actual defect number in the module  $f_i$ , and  $s = s_1 + s_2 + \dots + s_m$

as the total number of defects in all the modules, the proportion of actual defects in the top  $t$  predicted modules (i.e., top  $t$  modules predicted to have most defects) to the whole defects is  $\frac{1}{s} \sum_{i=m-t+1}^m s_i$ . Then FPA is defined as follows:

$$\frac{1}{m} \sum_{t=1}^m \frac{1}{s} \sum_{i=m-t+1}^m s_i$$

#### 3.2.6 CLC(Cumulative lift chart (also the area under CLC))

CLC uses percentages of modules as x-axis and percentages of defects as y-axis. The area under CLC is always used for comparison, and the area is simply denoted as CLC in this paper. Considering  $m$  modules  $f_1, f_2, \dots, f_m$ , listed in increasing order of predicted defect number,  $s_i$  as the actual defect number in the module  $f_i$ , and  $s = s_1 + s_2 + \dots + s_m$  as the total number of defects in all the modules, the area under the curve should be computed as the sum of areas of trapezoid composed of two adjacent points and the axes in the CLC. Using CLC to denote the area under the curve in rest of the paper, it can be computed as follows:[3]

$$\begin{aligned} CLC &= \sum_{t=1}^m trapezoid_t \\ &= \left(\frac{1}{m}\right)\left(\frac{1}{2}\right)\left(\left(0 + \frac{s_m}{s} + \dots\right.\right. \\ &\quad \left.\left.+ \left(\frac{s_m + \dots + s_2}{s} + \frac{s_m + \dots + s_1}{s}\right)\right)\right) \end{aligned}$$

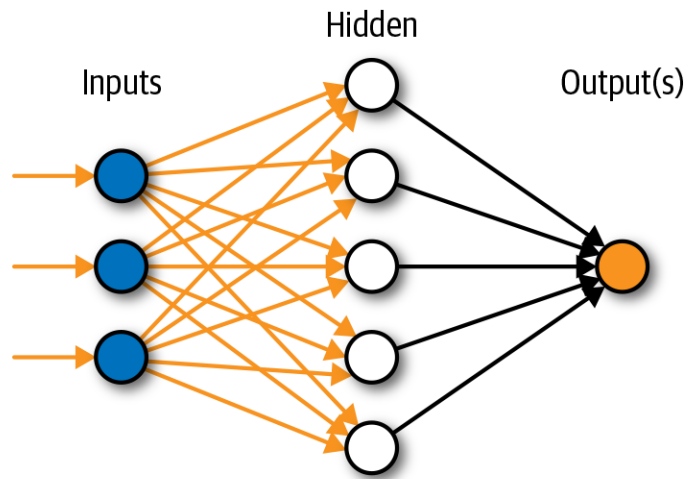
# Chapter 4

## Models

### 4.1 Artificial Neural Network(ANN)

Artificial Neural Networks are a special type of machine learning algorithms that are modeled after the human brain. That is, just like how the neurons in our nervous system are able to learn from the past data, similarly, the ANN is able to learn from the data and provide responses in the form of predictions or classifications. ANNs are nonlinear statistical models which display a complex relationship between the inputs and outputs to discover a new pattern.[4] In a neural network, there are three essential layers –

- **Input Layer**- It is the first layer of an ANN that receives the input information in the form of various texts, numbers, audio files, image pixels, etc.
- **Hidden Layer** - In the middle of the ANN model are the hidden layers. There can be a single hidden layer, as in the case of a perceptron or multiple hidden layers. These hidden layers perform various types of mathematical computation on the input data and recognize the patterns that are part of.
- **Outer Layer** -In the output layer, we obtain the result that we obtain through rigorous computations performed by the middle layer.

**Artificial Neural Network****Figure 4.1** ANN**4.2 Recurrent neural network(RNN)**

A recurrent neural network is a class of artificial neural networks where connections between nodes form a directed graph along a temporal sequence. This allows it to exhibit temporal dynamic behavior. It is derived from feedforward neural networks, RNNs can use their internal state (memory) to process variable length sequences of inputs. The term “recurrent neural network” is used indiscriminately to refer to two broad classes of networks with a similar general structure, where one is finite impulse and the other is infinite impulse. Both classes of networks exhibit temporal dynamic behavior. Both finite impulse and infinite impulse recurrent networks can have additional stored states, and the storage can be under direct control by the neural network. The storage can also be replaced by another network or graph, if that incorporates time delays or has feedback loops.[5]

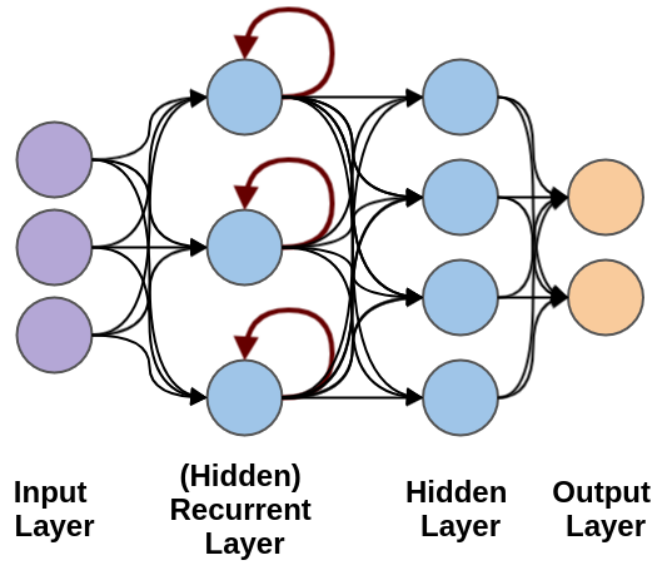
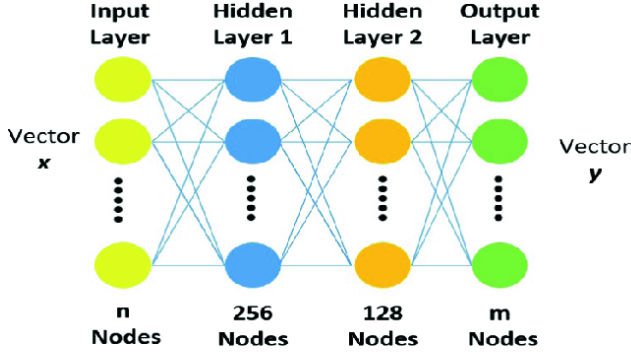


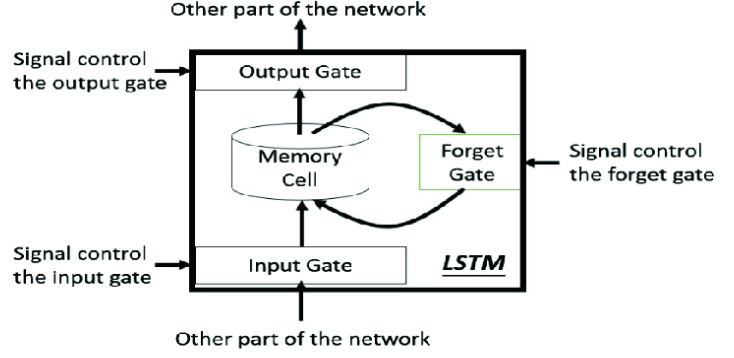
Figure 4.2 Recurrent neural network

### 4.3 Long short-term memory (LSTM)

Long Short-Term Memory (LSTM) networks are a type of recurrent neural network capable of learning order dependence in sequence prediction problems. LSTMs have the ability to preserve long-term memory and have a slightly more complex structure. At each time step, the LSTM cell takes in 3 different pieces of information – the current input data, the short-term memory from the previous cell (similar to hidden states in RNNs) and lastly the long-term memory. The short-term memory is commonly referred to as the hidden state, and the long-term memory is usually known as the cell state. The cell then uses gates to regulate the information to be kept or discarded at each time step before passing on the long-term and short-term information to the next cell. These gates are called the Input Gate, the Forget Gate, and the Output Gate.[6]



(a) LSTM Network Architecture



(b) Internal Structure of LSTM Unit

Figure 4.3 LSTM

## 4.4 Gated Recurrent Unit(GRU)

A Gated Recurrent Unit is a variant of the RNN architecture, and uses gating mechanisms to control and manage the flow of information between cells in the neural network. The structure of the GRU allows it to adaptively capture dependencies from large sequences of data without discarding information from earlier parts of the sequence. This is achieved through its gating units, similar to the ones in LSTMs, which solve the vanishing gradient problem of traditional RNNs. These gates are responsible for regulating the information to be kept or discarded at each time step. The GRU cell contains only two gates: the Update gate and the Reset gate. These gates in the GRU are trained to selectively filter out any irrelevant information while keeping what's useful. These gates are essentially vectors containing values between 0 to 1 which will be multiplied with the input data and/or hidden state. A 0 value in the gate vectors indicates that the corresponding data in the input or hidden state is unimportant and will, therefore, return as a zero. On the other hand, a 1 value in the gate vector means that the corresponding data is important and will be used.

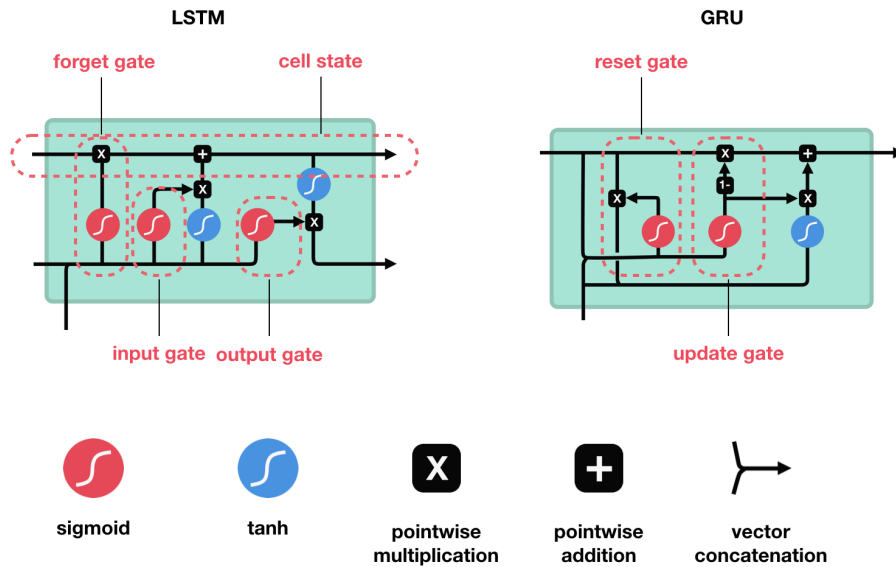


Figure 4.4 LSTM vs GRU

## 4.5 Convolutional Neural Network (CNN)

In deep learning, a convolutional neural network (CNN, or ConvNet) is a class of deep neural network, most commonly applied to analyze visual imagery. We track sizes of communities across time. As the community labels are changing, we keep track of size changes by cluster memberships. CNNs are regularized versions of multilayer perceptrons. Multilayer perceptrons usually mean fully connected networks, that is, each neuron in one layer is connected to all neurons in the next layer. A convolutional neural network consists of an input layer, hidden layers and an output layer. In any feed-forward neural network, any middle layers are called hidden because their inputs and outputs are masked by the activation function and final convolution. In a convolutional neural network, the hidden layers include layers that perform convolutions.

[7]

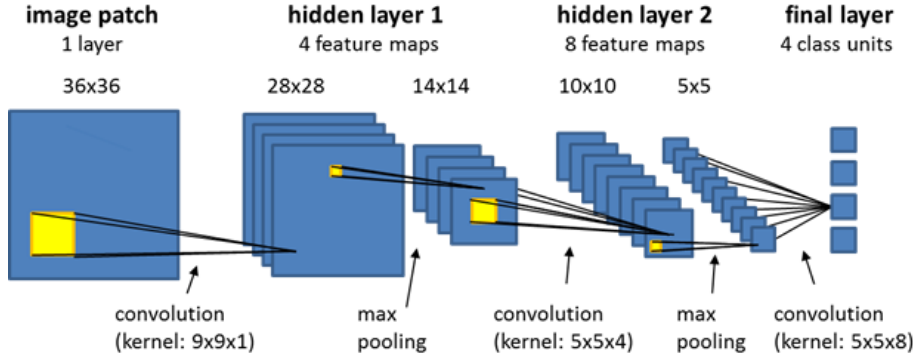


Figure 4.5 CNN

## 4.6 Isolation Forest

Isolation forest is an unsupervised learning algorithm for anomaly detection that works on the principle of isolating anomalies, instead of the most common techniques of profiling normal points. An anomaly is an observation or event that deviates so much from other events to arouse suspicion it was generated by a different mean. Anomalies in a big dataset may follow very complicated patterns, which are difficult to detect “by eye” in the great majority of cases. In order to isolate a data point (outlier), the algorithm recursively generates partitions on the sample by randomly selecting an attribute and then randomly selecting a split value for the attribute, between the minimum and maximum values allowed for that attribute. [8]

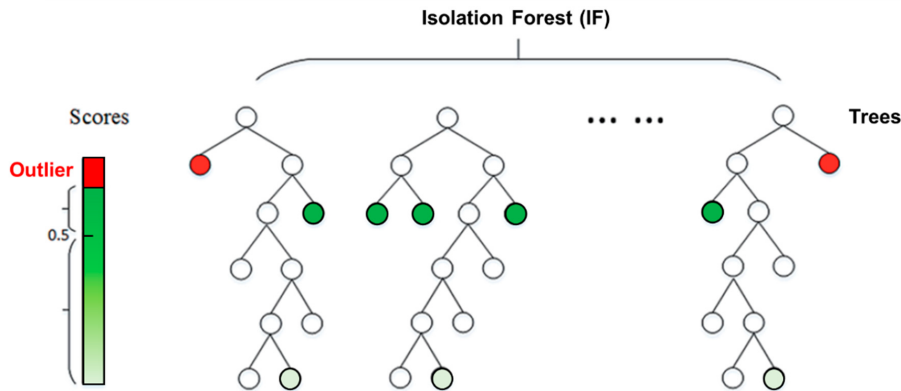


Figure 4.6 Isolation Forest

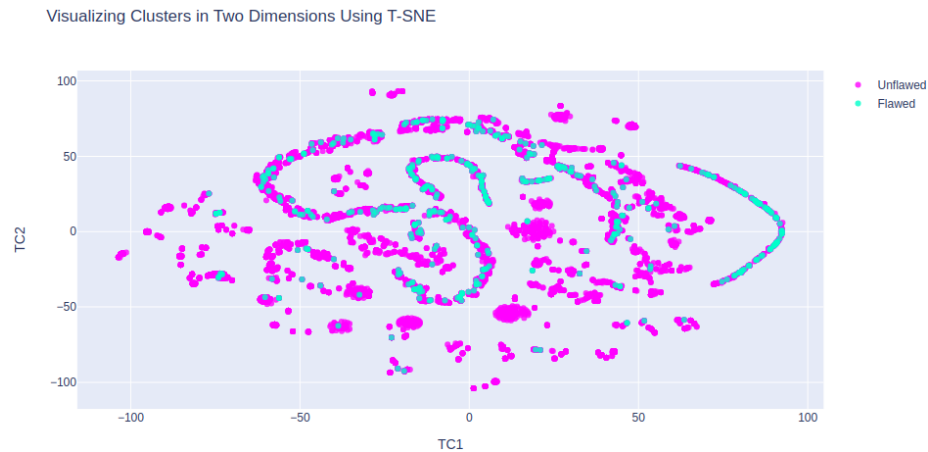


# Chapter 5

## Results

### 5.1 Anomaly detection

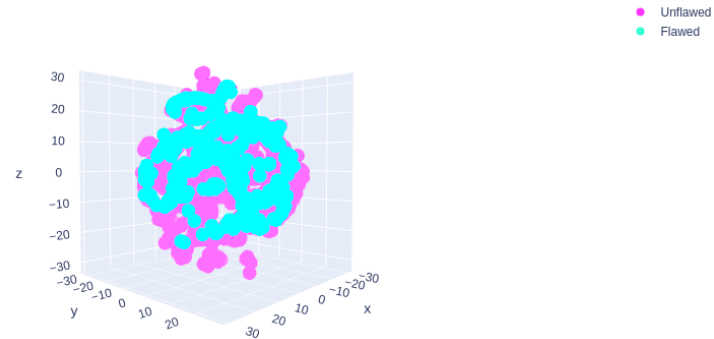
Using Isolation Forest we have performed anomaly detection to detect the faulty datapoints in the datasets. The 2D and 3D visualizations from t-SNE are as follows:



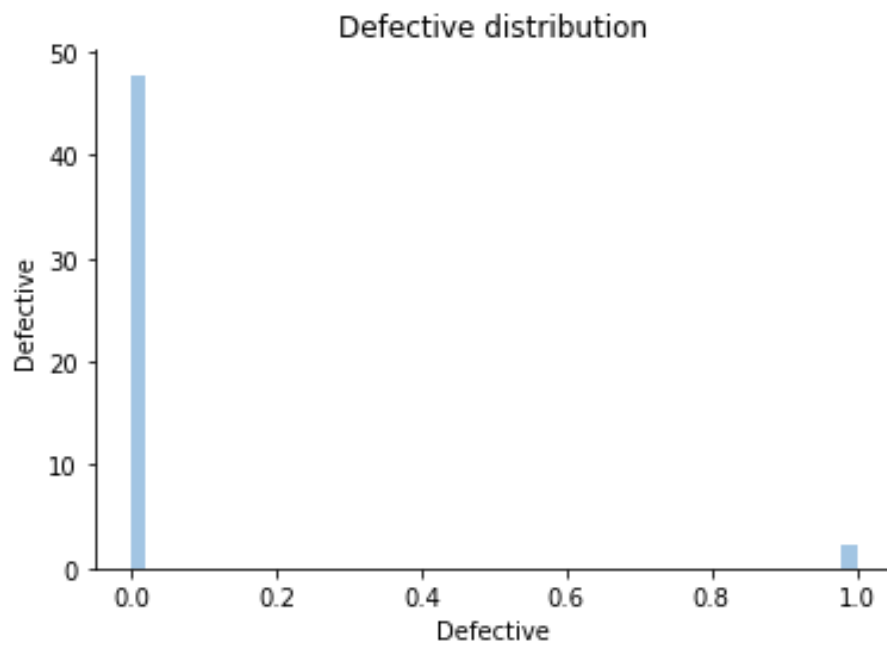
**Figure 5.1** 2D visualization

From the visualizations, it became clear that extensive feature reduction would not help in detecting the faulty datapoints. So, we proceeded without any feature selection. The datasets taken were initially labelled, so we found out the percentage of the faulty datapoints which came out to be 4.71 % and plotted the distribution of the labels before removing the labels. The plot obtained is:

Visualizing Clusters in Three Dimensions Using T-SNE



**Figure 5.2** 3D visualization



**Figure 5.3** Distribution of labels

## 5.2. Deep Learning Regression

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After applying the Isolation Forest model, we have obtained the Accuracy of the model by obtaining true positive, true negative and all samples count in the predictions. The formula for accuracy used is:

$$\frac{TruePositive + TrueNegative}{AllSamples}$$

## 5.2 Deep Learning Regression

We performed 32 experiments without any feature selection and with three different feature selection techniques:

- Singular value Decomposition with 10 and 15 components
- Principal component analysis with 10 and 15 components
- Information Gain

and each of SVD and PCA with two different number of components: 10 and 15. Min Max scaling preprocessing was performed on the datasets before running all the models. The predictions obtained by all the models were rounded off to nearest integers. We used MSE as the loss function for all the models We have developed 9 different models and tried 3 different architectures of LSTM, 3 different architectures of RNN and single architecture each of GRU, ANN and CNN.

### 5.2.1 ANN

The schematics of the ANN model designed is visualized as follows:

The performance results are as follows:

Observing the results, we can see that the FPA and CLC is obtained to be NAN for two of the experiments. This situation is encountered when all the predictions i.e the number of bugs in the testing data come out to be zero after rounding off. This

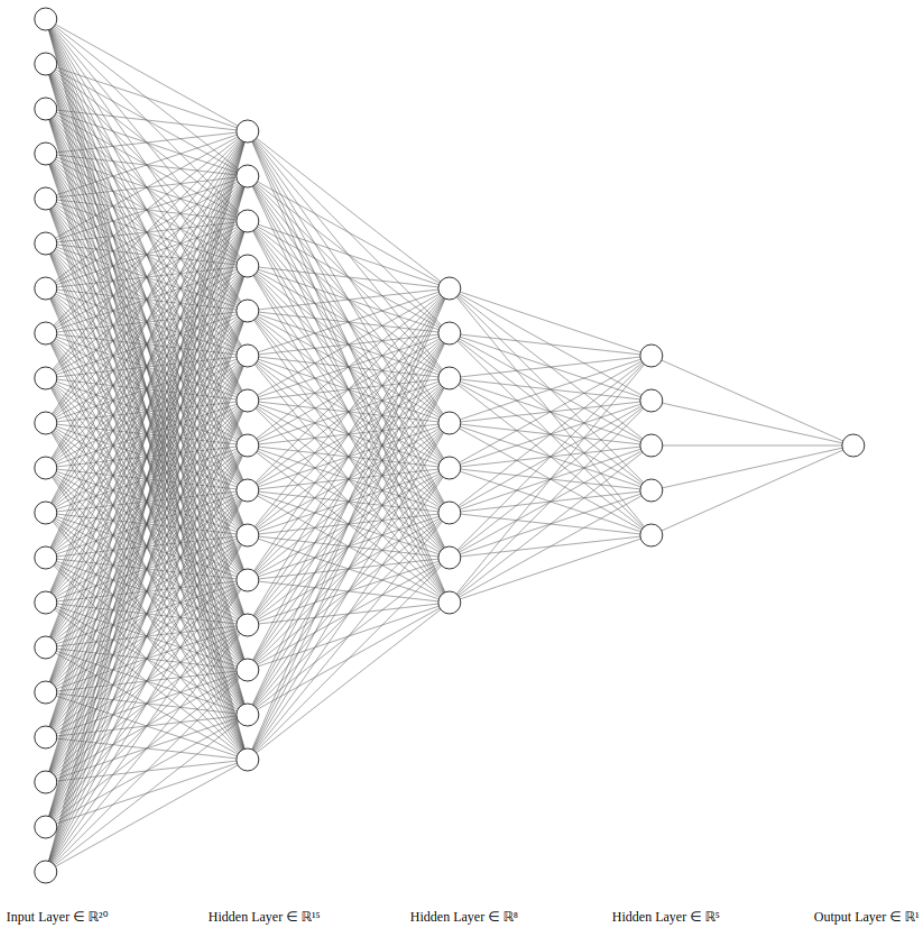


Figure 5.4 ANN Architecture

Table 5.1 ANN Model results						
Feature Selection	No. of components	FPA	CLC	Train Loss at last epoch(MSE)	Test Loss(MSE)	
N/A	N/A	<b>0.47545615</b>	<b>0.48384327</b>	<b>0.555</b>	<b>1.1668</b>	
SVD	10	0.47456595	0.48294193	0.385	0.907	
SVD	15	NAN	NAN	3.5	0.3652	
PCA	10	NAN	NAN	3.5	0.3652	
PCA	15	0.4627341	0.47109878	0.2115	0.8144	

## 5.2. Deep Learning Regression

is an unwanted result. We also see that the best FPA and CLC are obtained when no feature selection technique is applied.

### 5.2.2 GRU

The schematics of the GRU model designed is visualized as follows:

Layer (type)	Output Shape	Param #
gru (GRU)	(None, 1, 100)	36600
gru_1 (GRU)	(None, 1, 80)	43680
gru_2 (GRU)	(None, 60)	25560
dense (Dense)	(None, 1)	61
Total params: 105,901		
Trainable params: 105,901		
Non-trainable params: 0		

**Figure 5.5** GRU Architecture

Oversampling and SMOTE were applied to all the experiments involving the GRU model also. The performance results are as follows:

**Table 5.2** GRU Model results

Feature Selection	No. of components	FPA	CLC	Train Loss at last epoch(MSE)	Test Loss(MSE)
N/A	N/A	0.48528624	0.49368343	0.9214	1.3261
SVD	10	0.48289812	0.49128413	0.7384	1.0185
SVD	15	0.47688892	0.4852823	0.6949	1.2748
<b>PCA</b>	<b>10</b>	<b>0.49431464</b>	<b>0.5027083</b>	<b>0.7483</b>	<b>1.1861</b>
PCA	15	0.4928466	0.5012389	0.7455	1.1761

Observing the results, we see that the best FPA and CLC are obtained when PCA is applied and 10 components were taken for training the model and the least FPA and CLC are obtained when SVD is applied and 15 components were taken for training the model.

### 5.2.3 CNN

The schematics of the CNN model designed is visualized as follows:

Layer (type)	Output Shape	Param #
conv2d_3 (Conv2D)	(None, 1, 20, 64)	128
conv2d_4 (Conv2D)	(None, 1, 20, 32)	2080
conv2d_5 (Conv2D)	(None, 1, 20, 16)	528
flatten_1 (Flatten)	(None, 320)	0
dense_2 (Dense)	(None, 8)	2568
dense_3 (Dense)	(None, 1)	9
Total params: 5,313		
Trainable params: 5,313		
Non-trainable params: 0		

Figure 5.6 CNN Architecture

6 Experiments were conducted taking CNN model and we ran one of the experiments without applying any oversampling and smote with PCA taking 10 components. Rest of the 5 experiments were applying on oversampled and SMOTE balanced data with different feature selection techniques. The performance results are as follows:

Table 5.3 CNN Experiments Details

Model Number	Feature Selection	No. of components	Oversampling and SMOTE
1	N/A	N/A	yes
2	SVD	10	yes
3	SVD	15	yes
4	<b>PCA</b>	<b>10</b>	<b>yes</b>
5	PCA	10	no
6	PCA	15	yes

Table 5.4 CNN Model results

Model Number	FPA	CLC	Train Loss at last epoch(MSE)	Test Loss(MSE)
1	0.484641	0.4930281	0.5649	1.1203
2	0.4716726	0.4800206	0.094	0.7005
3	NAN	NAN	3.5	0.3652
4	<b>0.498646</b>	<b>0.507073</b>	<b>0.1769</b>	<b>0.7597</b>
5	0.473417	0.481844	0.2426	0.4125
6	0.478746	0.487105	0.1106	0.743

Observing the results, we obtained undesired NAN values for FPA and CLC when we applied SVD and obtained 15 components. The best results were obtained when we ran the model with oversampled and SMOTE balanced data after applying PCA

## 5.2. Deep Learning Regression

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and obtaining 10 components.

### 5.2.4 LSTM

Three different architectures were tried and they are as follows:

- Architecture 1: Three LSTM layers with decreasing output features and single dense layer at the end.
- Architecture 2: Five LSTM layers with decreasing output features and single dense layer at the end.
- Architecture 3: Seven LSTM layers with decreasing output features and single dense layer at the end.

The summaries of the three LSTM architectures tried as as follows:

Layer (type)	Output Shape	Param #
lstm (LSTM)	(None, 1, 100)	48400
lstm_1 (LSTM)	(None, 1, 80)	57920
lstm_2 (LSTM)	(None, 60)	33840
dense (Dense)	(None, 1)	61
Total params: 140,221		
Trainable params: 140,221		
Non-trainable params: 0		

**Figure 5.7** LSTM Architecture 1

Oversampling and SMOTE were applied to all the experiments involving the three LSTM models also. Info gain was taken as a feature selection criteria in one of the experiments. Considering the info gain, 9 features were selected. They are: CBO, RFC, Ce, LCOM3, LOC, DAM, MOA, MFA and CAM. The explanation of the following features are given in chapter 2.

The performance results are as follows:

Layer (type)	Output Shape	Param #
lstm_4 (LSTM)	(None, 1, 100)	46400
lstm_5 (LSTM)	(None, 1, 80)	57920
lstm_6 (LSTM)	(None, 1, 60)	33840
lstm_7 (LSTM)	(None, 1, 40)	16160
lstm_8 (LSTM)	(None, 20)	4880
dense (Dense)	(None, 1)	21
Total params: 159,221		
Trainable params: 159,221		
Non-trainable params: 0		

Figure 5.8 LSTM Architecture 2

Layer (type)	Output Shape	Param #
lstm (LSTM)	(None, 1, 140)	87360
lstm_1 (LSTM)	(None, 1, 120)	125280
lstm_2 (LSTM)	(None, 1, 100)	88400
lstm_3 (LSTM)	(None, 1, 80)	57920
lstm_4 (LSTM)	(None, 1, 60)	33840
lstm_5 (LSTM)	(None, 1, 40)	16160
lstm_6 (LSTM)	(None, 20)	4880
dense (Dense)	(None, 1)	21
Total params: 413,861		
Trainable params: 413,861		
Non-trainable params: 0		

Figure 5.9 LSTM Architecture 3

Table 5.5 LSTM Experiments Details

Model Number	Architecture Number	Feature Selection	No. of components
1	1	N/A	N/A
2	1	SVD	15
3	1	SVD	10
4	1	Info_gain	9 Features selected
5	1	PCA	15
6	1	PCA	10
7	2	<b>PCA</b>	<b>15</b>
8	3	PCA	15



## 5.2. Deep Learning Regression

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**Table 5.6** LSTM Model results

Model Number	FPA	CLC	Train Loss at last epoch(MSE)	Test Loss(MSE)
1	0.4891348	0.49753347	0.9225	1.3541
2	0.4854812	0.4938745	0.8029	1.2402
3	0.48686993	0.49526507	0.7701	1.2719
4	0.48584172	0.494218	0.9962	1.421
5	0.49402896	0.5024241	0.7275	1.2536
6	0.4832134	0.4916067	0.7384	1.1761
7	<b>0.504664</b>	<b>0.5130555</b>	<b>0.741</b>	<b>1.2263</b>
8	0.4919156	0.5003081	0.7219	1.3139

From the table, we can observe that the best result was obtained from the LSTM model with architecture 2 when PCA was applied on the data and 15 components were obtained. The second best result was obtained from the architecture 1 of the LSTM models when PCA was obtained and 15 components were taken.

### 5.2.5 RNN

Three different architectures were tried and they are as follows:

- Architecture 1: Three RNN layers with decreasing output features and single dense layer at the end.
- Architecture 2: Five RNN layers with decreasing output features and single dense layer at the end.
- Architecture 3: Three RNN layers with decreasing output features and single dense layer at the end. This architecture is slightly less complex than the 1st RNN architecture.

The summaries of the three RNN architectures tried as as follows:

8 experiments were performed on the RNN models of which in one experiment, we have not oversampled and SMOTE balanced the data.

The performance results are as follows:

From the table, we can observe that the best result was obtained when SVD was applied on oversampled and SMOTE balanced data and 10 components were selected.

Layer (type)	Output Shape	Param #
=====	=====	=====
simple_rnn (SimpleRNN)	(None, 1, 100)	12100
simple_rnn_1 (SimpleRNN)	(None, 1, 80)	14480
simple_rnn_2 (SimpleRNN)	(None, 60)	8460
dense (Dense)	(None, 1)	61
=====	=====	=====
Total params: 35,101		
Trainable params: 35,101		
Non-trainable params: 0		

Figure 5.10 RNN Architecture 1

Layer (type)	Output Shape	Param #
=====	=====	=====
simple_rnn (SimpleRNN)	(None, 1, 100)	11100
simple_rnn_1 (SimpleRNN)	(None, 1, 80)	14480
simple_rnn_2 (SimpleRNN)	(None, 1, 60)	8460
simple_rnn_3 (SimpleRNN)	(None, 1, 40)	4040
simple_rnn_4 (SimpleRNN)	(None, 20)	1220
dense (Dense)	(None, 1)	21
=====	=====	=====
Total params: 39,321		
Trainable params: 39,321		
Non-trainable params: 0		

Figure 5.11 RNN Architecture 2

Layer (type)	Output Shape	Param #
=====	=====	=====
simple_rnn (SimpleRNN)	(None, 1, 100)	11100
simple_rnn_1 (SimpleRNN)	(None, 1, 60)	9660
simple_rnn_2 (SimpleRNN)	(None, 20)	1620
dense (Dense)	(None, 1)	21
=====	=====	=====
Total params: 22,401		
Trainable params: 22,401		
Non-trainable params: 0		

Figure 5.12 RNN Architecture 3

## 5.2. Deep Learning Regression

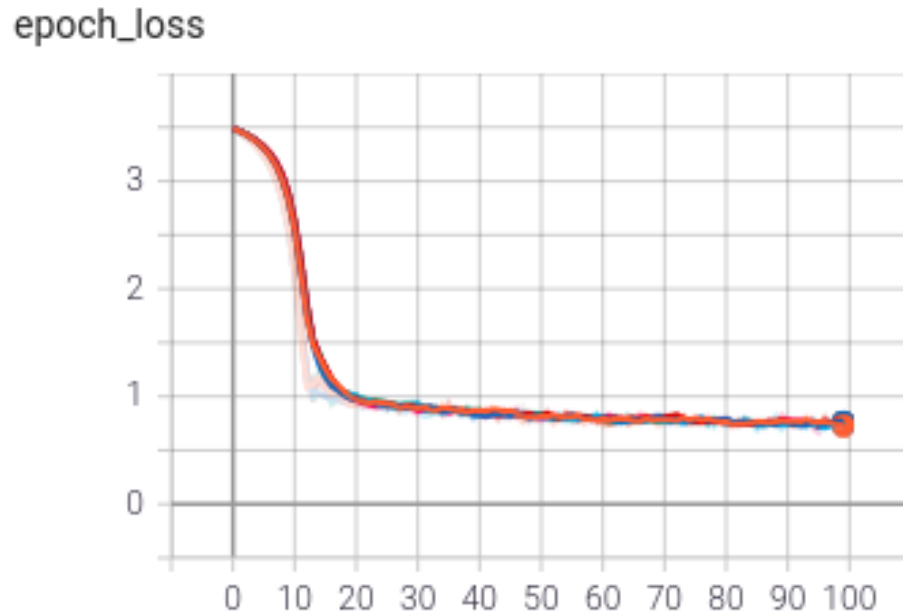
**Table 5.7** RNN Experiments Details

Model Number	Architecture Number	Feature Selection	No. of components	Oversampling and SMOTE
1	1	N/A	N/A	yes
2	<b>1</b>	<b>SVD</b>	<b>10</b>	<b>yes</b>
3	1	SVD	10	no
4	1	SVD	15	yes
5	1	PCA	10	yes
6	1	PCA	15	yes
7	2	SVD	10	yes
8	3	SVD	10	yes

**Table 5.8** RNN Model results

Model Number	FPA	CLC	Train Loss at last epoch(MSE)	Test Loss(MSE)
1	0.49177	0.50014	0.8385	1.3362
2	<b>0.50518</b>	<b>0.51357</b>	<b>0.6928</b>	<b>1.2263</b>
3	0.49487	0.5033	0.3527	0.3634
4	0.48322	0.49161	0.5944	1.0027
5	0.48304	0.49143	0.7491	1.1926
6	0.49248	0.50087	0.5342	0.9949
7	0.49188	0.50027	0.644	1.1513
8	0.47143	0.479826	0.6852	1.156

The training curve of the best performing model among the 32 experiments is plotted using tensorboard and it is visualized as follows:



**Figure 5.13** Training curve

# Chapter 6

## Conclusions and Discussion

### 6.1 Conclusion

In conclusion we see that the best performing model among all the models and different architectures is the first architecture from RNN models when SVD is applied for selecting 10 components from the dataset features after oversampling and smote balancing the data. Also a clear observation is that the ANN model performed the least compared to the other models. The remaining 4 models gave results almost close to each other. We also see that in some cases, we got NAN values for FPA and CLC but the test loss in those cases is the second least and the train loss was the highest among all the experiments. Hence taking FPA and CLC as the criteria for evaluating the model performance was better.

### 6.2 Future scope

For even more improved results, attention layers can be introduced in the model architectures. Even after taking such complex architectures the results were very close to each other and the dataset was small because of taking cross versions so we had to perform oversampling and SMOTE balancing. It is possible that due to

## 6.2. Future scope

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limited data of cross versions for the training of the deep learning models, the results were saturated. Different classical Machine learning techniques could be applied on the same data and checked for better results.

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