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Authenticating Raspberry Pi Devices

HARDWARE AUTHENTICATION OF DEVICES USING POLYNOMIAL REGRESSION AND CLASSIFICATION

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Contents

1 Introduction

The Internet of Things (IoT) is a widely understood new area of Computer Science, however possible methods of authentication of such devices are yet to be fully explored. The industry standard for verifying the authenticity of devices up until now has been to create an encryption certificate for said device and use this to ensure that devices are who they say they are. Imagine a smart home with sensors and smart devices in every room. You may have a fridge with sensors to read how much food you have available, thermometers in every room, or smart bulbs adjusting their colour temperature depending on your mood. For some of these devices, the processing power simply will not be available to run complex encryption algorithms to keep the data transfers secure. The alternative then, may be to look at other methods of verifying devices.

When it comes to the IoT, we are likely to have many very small devices in the future all transmitting data that will be personal to the owner and need to be kept private. This poses a few new problems when it comes to authentication. “As is often the case, IoT technology has moved more quickly than the mechanisms available to safeguard the devices and their users.” (Rouse, 2018). As developments are made into creating cheaper, more useful devices, perhaps not enough is being done to ensure that all avenues of information security for these devices are being explored. Additionally, as the demand for these small devices grows, pressure will be put on manufacturers to find solutions to these important security questions.

In this project I will be exploring how IoT devices can be authenticated not using an encryption certificate, but by using the hardware features of such devices. Having the ability to bypass the need to generate encryption certificates will allow the use of lower powered devices by reducing the amount of processing power required. Machine Learning is still a relatively new field in the area of Computer Science and its applications are still being researched. I will be looking at using Machine Learning methods to analyse and classify devices so that they may be authenticated as being who they say they are. This project is an exploratory study to see if classification based on hardware characteristics, and does not intend to provide working code for classification in real world environments.

2 Related Studies

This project was inspired by a paper by Jonathan Branstett (2016), looking at device authentication techniques using device hardware features. The aim of his paper was to verify if authentication based on hardware features was possible, and the types of variables that may be measured for best results. I aimed to build upon this work by looking at the real-world application of hardware feature device authentication and how practical it may be. Jonathan laid much of the groundwork for this project and provided the basis of the Java server and client code that I have extended.

Other related studies are described below.

Park, Kim and Lim (2015) designed a framework to manage mutual authentication of devices based on Public Key Identification (PKI). They present a lighter certificate that could be used by smaller devices in such infrastructure. However, this assumes that the devices have enough computing capability to perform public key cryptography which is not always the case (Shin, Yeh and

Kim, 2012). This issue can be bypassed either by providing more computational capabilities to devices or by using authentication scheme lighter than PKI. This project aims to substantially reduce the amount of processing power required to authenticate devices by offloading calculations to a central server. As Moore's law plateaus, we are no longer going to be seeing the same growth in computational power in the next decade that we have seen in the past. New approaches need to be tried to be able to get the most out of the technology that we have available now.

However, there are some studies to show that low powered encryption is possible. Shin, Yeh and Kim (2012) proposed an authentication scheme that avoid the use of public key cryptography and therefore does not need any additional device to improve the computing capabilities. They defined a light protocol only based on the use of hash functions, random number generators, bitwise operations (XOR) and a group key using the device serial number and a defined bit sequences called digital DNA to authenticate the devices.

2.1 Comparisons with Branstett's paper

Within Branstett's paper polynomial regression was used to identify each device; If the known coefficients were exactly the same as those for the current device, the device would be authenticated. The fundamental difference between Branstett's project and my own was that Branstett was programming multiple identities into his Raspberry Pi, and having each identity transmit its data to the server. Each identity would have slightly different hardware characteristics, simulating different virtual devices within the Raspberry Pi. Through execution of the program, data about the device's RAM usage, CPU utilisation, and more were sent to the server device. See appendix 8.3. Each data point would have two values associated with it, which could be normalised to the same magnitude as the other data points. Coefficients could then be calculated from this data. The server would then compare the known coefficients of each identity to the calculated coefficients and output its authenticity.

Within my project however, I wanted to take a slightly different approach. I wanted my project to be able to authenticate the Raspberry Pi itself, and not the virtual devices within the Pi. This threw up the issue of comparing the coefficients, since they would change based on how much of the device's resources are used up in the current task, so the same device could have two entirely different coefficients at different times of day. I needed a classification model to predict the identity of the device, checking if the data is within an acceptable range to be positively classified. Despite these differences, a large proportion of the Java code in my project could be easily modified from Branstett's work.

3 Setup

3.1 Exploratory Analysis

For exploratory data analysis, the choice was easy to use Python as the main language for implementation of our Machine Learning regression and classification algorithms, and I ended up using Python code for the project itself. Although the ability to implement the needed techniques

was available in Java using the Apache Commons libraries, the breadth of knowledge and support online for Python, along with its user-friendly implementation of ML algorithms, outweighed the usefulness of using one language for the whole project. Within Python notebooks I could also easily visualise progress. As a result of this choice, I ended up using both Java and Python in the final project. This was less of an issue than initially expected, and as I grew more confident using both languages concurrently, I was able to integrate Python into the project without many problems.

The SciKit-Learn and Pandas libraries provided the algorithms used for regression and classification, and dataset management respectively. The wealth of support online for these libraries served the project greatly and was a valuable resource in fixing errors. The full list of libraries is included in the appendix. I used IBM Watson notebooks to host our code for the analysis stages.

3.2 Data Collection

Continuing the concept that the Raspberry Pi in this project would represent a low powered IoT device, I wanted to offload as much processing as possible to the more highly powered server. The data collection for this project was already fairly thoroughly developed. Branstett's Java code laid the groundwork for transmitting and collecting this data for further analysis. For use in this project, I stripped down the project developed by Branstett to include just the essential data collection elements of the code. Since I would be implementing my own data analysis and classification algorithms in Python, I did not need to include the previously written coefficient generation and comparisons in Java.

The method for data collection was therefore as follows:

1. The client transmits to the server the device name.
2. The client measures hardware data using the specified formatter.
3. The client stores this raw data in a Java list, with each entry representing a different hardware feature.
4. This list is then sent to the server over LAN.
5. The server receives this data and cleans it before saving it to a CSV file.

At this stage the Java code would execute the Python script, and display its output to the console. The formatters used were set up so that different amounts of constant and variable data were collected in each run of the program. For example, I used the following formatters, with each percentage relating to the amount of variable data being collected in each run:

- 80%
- 70%
- 60%
- 50%

The full list of variables used for each formatter can be found in section 8.3 of the appendix.

- For each run of the program, the client measures metrics about itself and communicates these to the server. Both client and server run Java code to measure and receive the data.
- The client will measure data about itself 54 times, with processes running in the background. This is so that data can be measured over a period of time and a consistent dataset can be measured.
- Each data point measured has an X and Y value. For example, CPU usage vs time, or free memory vs total memory.

3.2.1 Client

Two Raspberry Pi devices were used for this project, one on loan from the City, University of London Computer Science offices, and the other at home. These were used to test the validity of my classification algorithms since I wanted to be able to tell devices apart from one another. The Raspberry Pi device used from home was the Raspberry Pi 4. This device is relatively highly powered for a computer of its size and cost, and allowed me a degree of flexibility when developing the code to run on the client. I was able to use the IntelliJ Idea Java IDE to develop my client code directly on the device rather than develop on the server and transfer across Jar files. Comparatively, the Pi used from City was the model 3 which was less powerful and did not support the IDE. For this device I transferred across the Jar file generated on the home device. Within this report I refer to these two devices as CityPi and HomePi respectively.

Raspberry Pi devices were used for this project primarily since they supported easy and accurate measurements of hardware data using the 'vcgencmd' command. This command allowed a range of data to be collected easily through the terminal, and examples of such data can be found in the appendix. Additionally, Raspberry Pi devices are low cost and easily configurable to this specific project due to their Linux operating system.

3.2.2 Server

The server in this project was a Windows 10 desktop computer which ran the server-side Java code. In the final project, all processing and results were calculated server-side, so that the least amount of processing was allocated to the client.

3.2.2.1 Development

In the early stages of the project, I wrote the code for the client and compiled it to a Jar file, and then transferred this across to the Raspberry Pi. This iterative method of development grew to be very time consuming and it meant that I was not able to make small changes to my code easily. I soon realised that since the HomePi was powerful enough, I was able to install IntelliJ Idea onto the device and edit code on-the-go. This saved me a great deal of time when I needed to make small changes since they would be implemented instantly.

I was not able to implement the same method with the CityPi however, since the RAM available was not enough to run the operating system and the IDE. Therefore, when I had a working client Jar file that functioned on my HomePi, I was able to transfer this across to the CityPi. The fact that I was able to run an IDE on at least one of the Pis was a great help in terms of speeding up the development of my program.

3.2.2.2 Access

I needed to be able to log into the devices remotely, especially since the CityPi was situated in London. I explored two different solutions to be able to access the Raspberry Pi on the go. Firstly, I used TeamViewer to access the Pis. This was effective in the sense of giving a fluid and easy to use UI, however I found the client to be resource heavy, which affected the performance of the CityPi. Secondly, I used RealVNC. This comes preinstalled on the devices and is streamlined to give reliable performance. The switch to this software helped the performance of both Pi devices and made it easier to implement my code.

Unfortunately, I did encounter issues when it came to transmitting data across the internet. The implementation of peer to peer data transfer was beyond the scope of this project, and therefore I was limited to recording data over LAN. Despite this, I was able to record data from both devices and generate an accurate model based on that data, described below.

4 Research

The initial stage of this process was exploratory. There was a strong need to understand the data I had available and the possible pathways I could take to implement this authentication method. Therefore, research played a large role in determining the path that this project would take. During the course of the project, I used many online notebooks as I experimented using different approaches to analyse the data. I was able to share these notebooks easily and gain feedback on the results I was producing with the help of Dr Komninos.

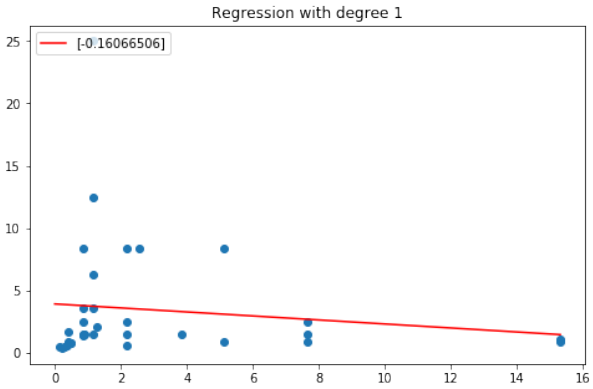
The decision was made early on to use polynomial regression to generate one or two coefficients that could represent the large amounts of data that were being generated through communication with the devices. Each data file generated through running the program and authenticating the device ended up being between 280KB and 330KB in size, so it was essential to be able to condense this down into a few identifying numbers. Thankfully this approach produced coefficients that could be used to accurately differentiate between the devices.

4.1 Formatters

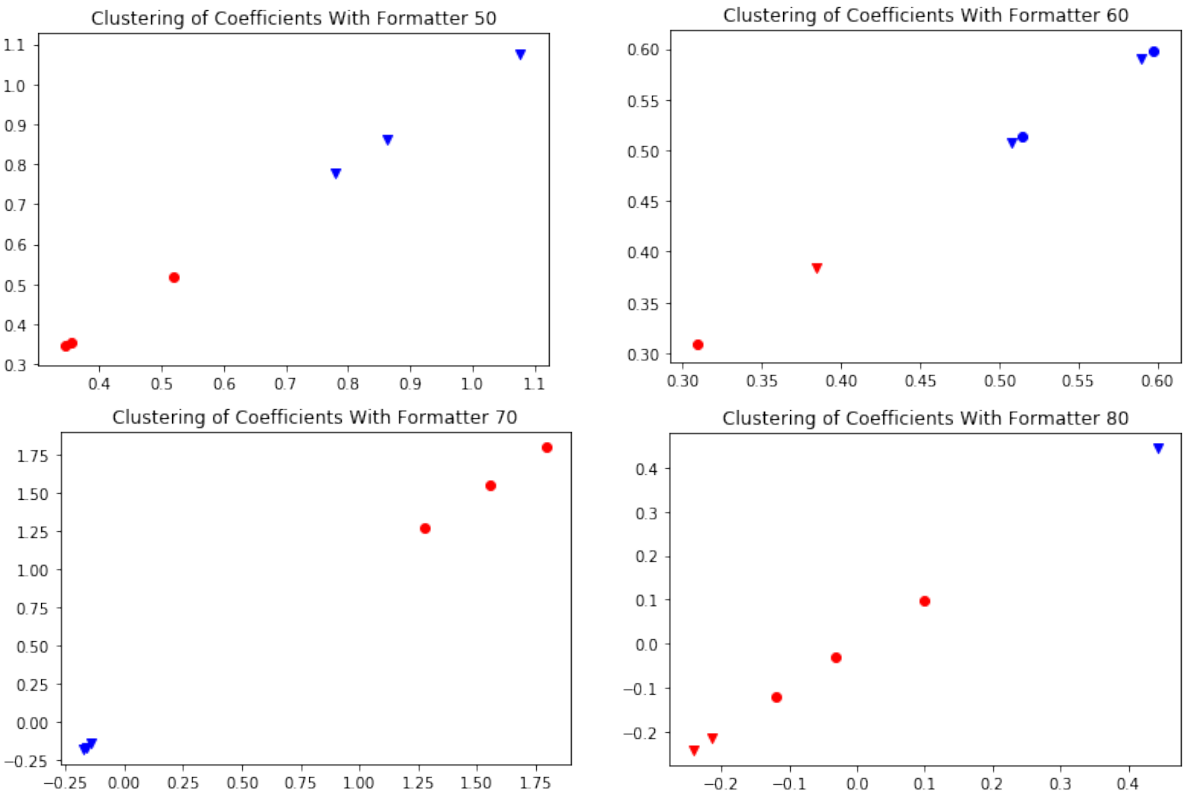
Collecting data using the different formatters in the program was essential to this exploratory research stage. I collected 3 datasets from each Pi, at different times of day and with different background processes running. I then repeated this for each formatter. This gave me a moderate

amount of data for each formatter, and I was then able to compare which formatter was going to give me the best classification results.

The graphs below show the results I produced through comparing the different formatters. Each point represents 1 coefficient generated from each dataset through linear regression. As shown below. Each data point here is one measurement from the client device, weighted to be within a consistent magnitude.

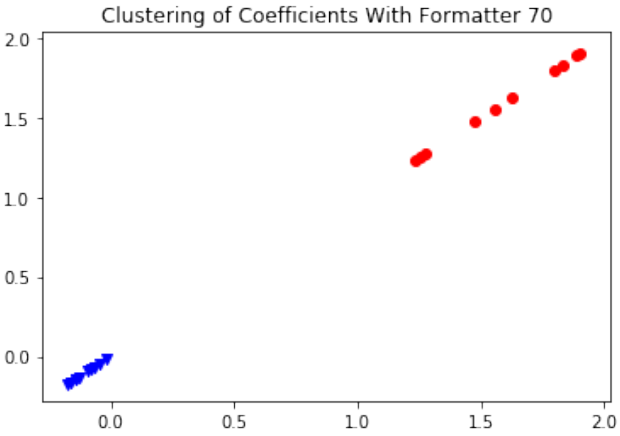


The graphs below show one coefficient from each dataset plotted on an X = Y one dimensional graph to make it easier to read. The colours represent the clustering groups calculated through k-means clustering, and the different markers represent the actual device each point belongs to. The full parameters can be found in section 8.4.5 of the appendix.

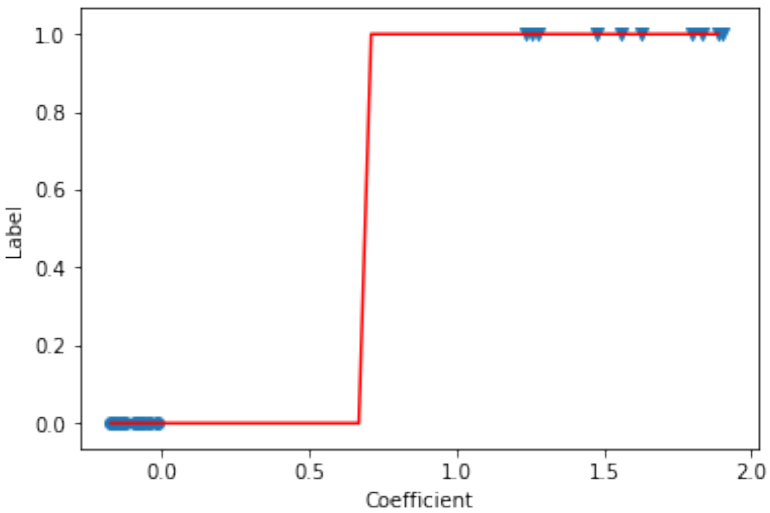


We can see from these graphs that both the 50% formatter and the 70% formatter correctly clustered the data into each device. Despite this, the 70% formatter graph shows a very clear separation between the two devices, which will make it easier to classify the two devices when we have a very large dataset.

The 80% and 60% formatters did not provide a clear separation between the two devices, with 17% accuracy and 34% accuracy respectively. The below graph shows just how easily the K-Means clustering Algorithm was able to separate the devices when using the 70% formatter and a dataset of 20 samples.



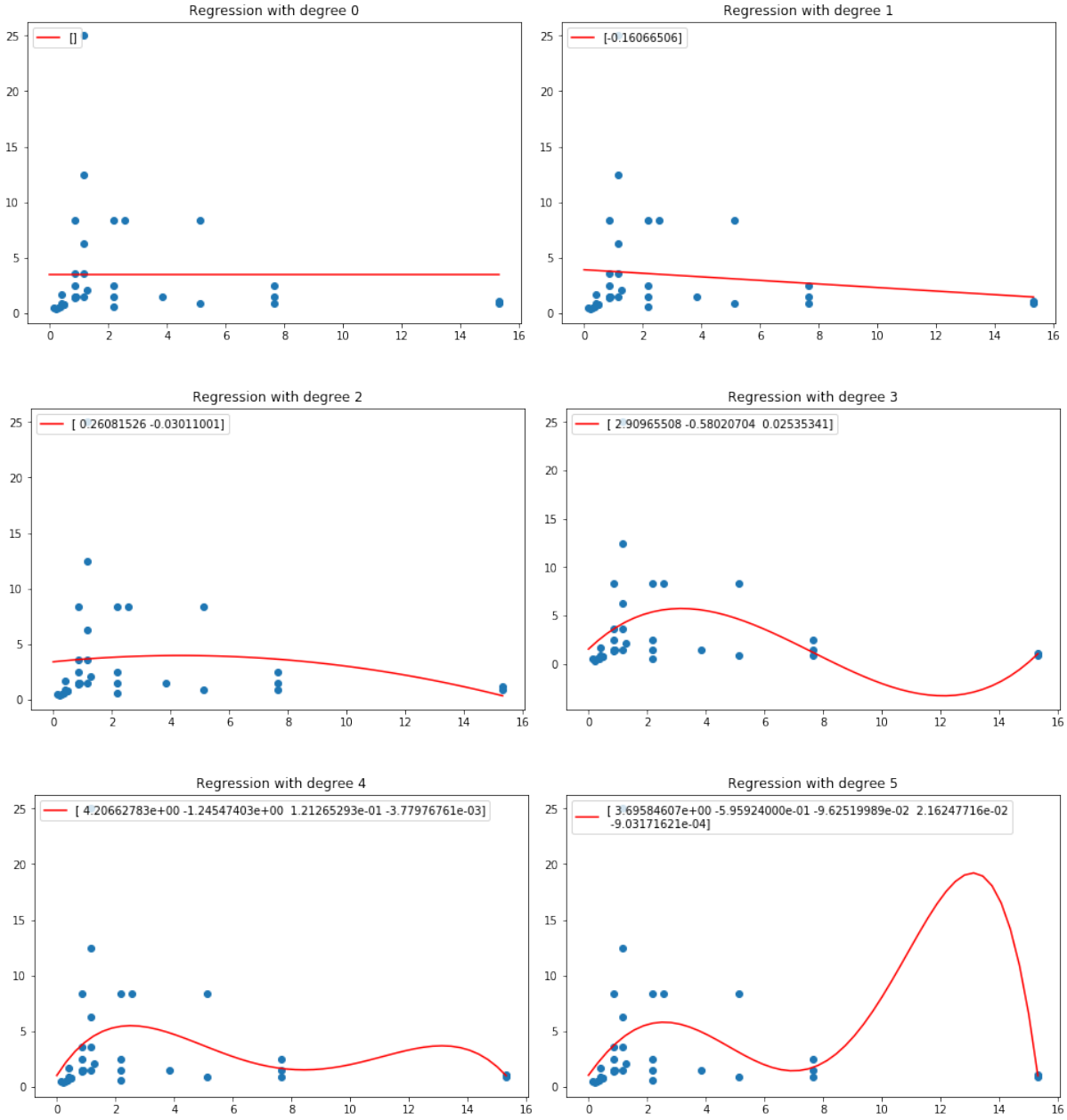
I started the project classifying the devices using one coefficient to represent each dataset generated. This worked initially, however one of the drawbacks to using a one coefficient to classify my data was that edge cases generated from each device would be at risk of being classified incorrectly. The graph below shows how the SVM classifier with a degree of 1 performed on our one-dimensional graph, trained with 70% data, scored on 30% data, and displayed using the entire dataset as the input.



We can see that it performs well, much like the clustering graphs above it, and classifies the devices with 100% accuracy. The issue with this approach is that if we were to measure data from a device under heavy load, the data collected may land much closer to the other device's coefficients, and therefore be incorrectly classified. To prevent this, I also explored the use of two coefficients as described below.

4.2 Polynomial Regression

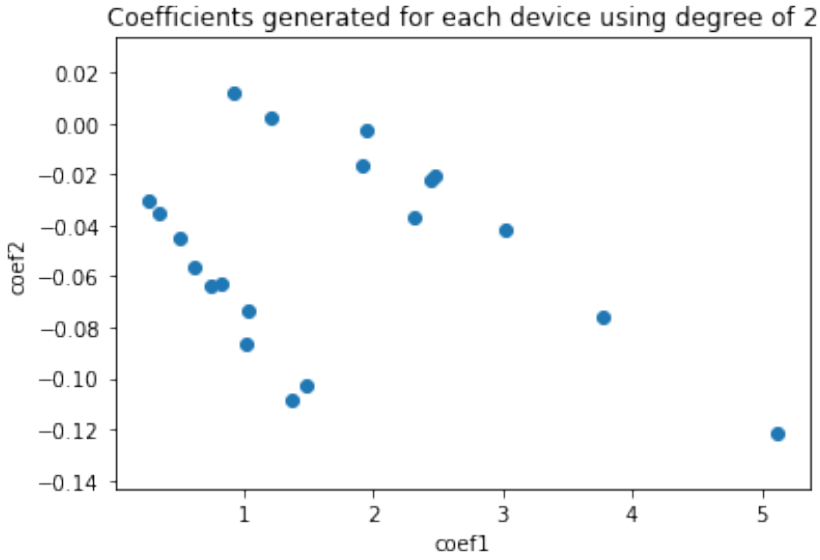
Here we can see different degrees of regression algorithms performed on the same dataset. Each dataset is run through a weighting algorithm to reduce the range within which we are working. The axis here are arbitrary, since each point is representing different information about the device.



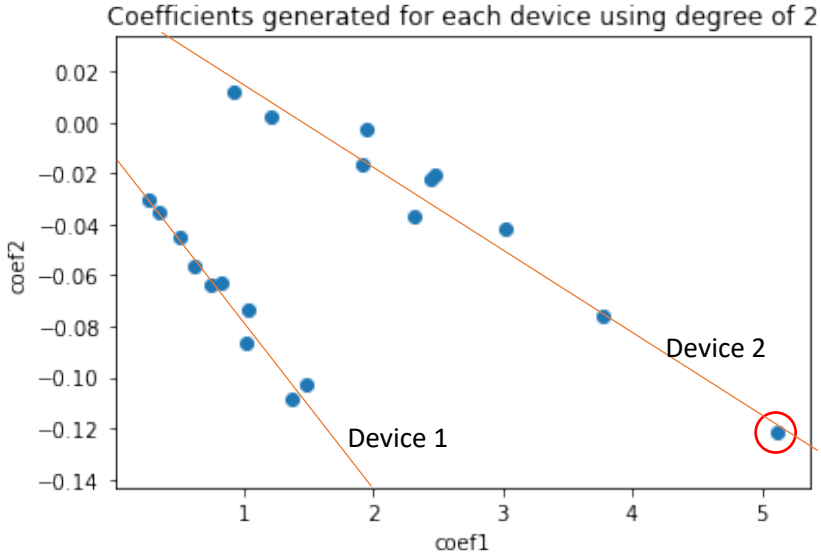
Degrees from 3 onward show that the data is being overfitted. Because of this, I decided to run the regression algorithm with degree 2.

Since at this stage I knew that I was going to be focusing on the 70% constant formatter, I generated 20 datasets using this system and ran my analysis on this relatively large dataset. For each

dataset generated, I ran polynomial regression with a degree of 2. The graph below shows all the datasets from both devices plotted on a graph using each coefficient as the x and y values.



We can see very clearly from this graph that if I were to have used just one coefficient to identify each dataset, there would have been a significant amount of overlap between devices and I would have not been able to classify the devices with any acceptable degree of accuracy. However, since I used two coefficients there is a very clear separation between devices.



The 2-coefficient approach also meant that edge cases were far less likely to be able to skew the results of my classifier. We can see that in the graph above there is one data point highlighted in red which may seem like an outlier, however since it falls within the acceptable range of coefficients for each device, it would still be classified correctly.

4.3 Exploring Classifiers

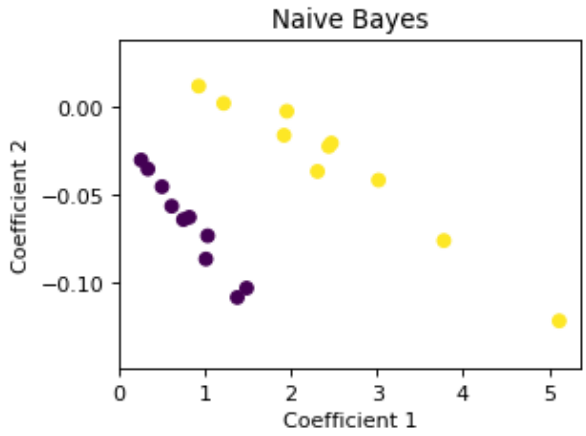
When it came to deciding which classification algorithms I would be testing within this project, it became clear that there were many different options that would produce the results that I was looking for. For this project, I decided to review four of the main classification algorithms, Naïve Bayes, Random Forest, Logistic Regression, and Support Vector Machine (Chen, 2011). For a dataset such as the one used in this project with only 20 samples and clear separation between the devices, many algorithms would perform similarly. Chen is clear to point out that for larger datasets, it is not always the most accurate classifier that should be chosen. Factors such as speed, ability to interpret results, and the ability to explain the process behind each classifier are important.

I also found that for the classifiers below, their accuracy would vary greatly on each run of the program. This is because the python code was randomly splitting the data into training and testing sets with a ratio of 70:30. The randomness in generating the classifiers then caused the reported accuracy of each classifier to vary by up to 10% on each run of the program. In the deliverable classifier used in the final project, the entire 20 sample dataset was used to train the classifier so that the greatest accuracy could be achieved on the unseen data from the Pis.

The parameters of each classifier can be found in section 8.3 along with the metrics in 8.4. Each classifier tested is trained on 70% data, and predicts the outcome of the entire dataset. We can see from the below that each classifier scored a perfect 1.00 on the test set. If we had used a larger dataset with which to test our classifiers we would have been able to see larger variance in results. Since the data collected to train our classifier can quite easily be separated into each device, we get similar results from each classifier. There is also no overlap between devices within our data, so a clean linear line can be drawn between the two groups.

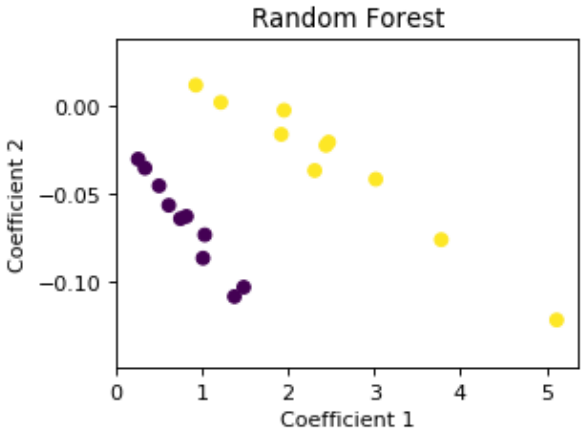
4.3.1 Naïve Bayes

Score: 1.00



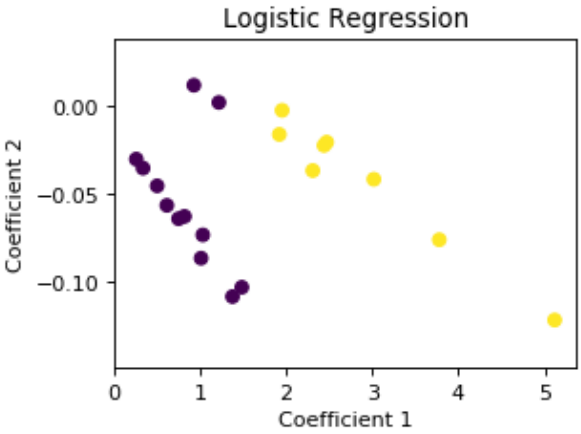
4.3.2 Random Forest

Score: 1.00



4.3.3 Logistic Regression

Score: 0.90



4.3.4 Support Vector Machine

Score: 1.00

Decision Function:

[-0.97984064 -1.02751492 -1.00024654 -1.15130345 -1.36028516 -1.12546558

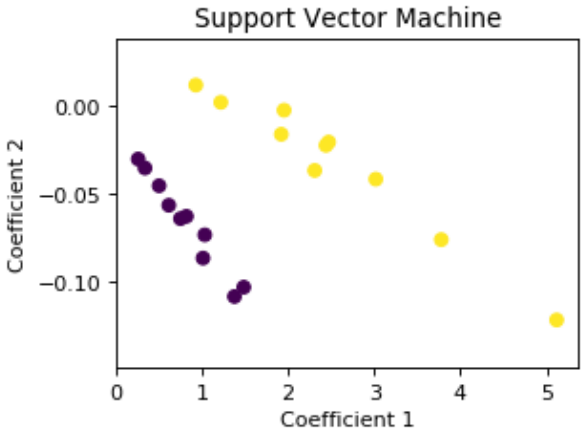
-1.15608185 -1.02797916 -1.40736279 -0.99950887 2.53097575 2.71135733

 1.15265689 0.99977084 1.67923071 2.05057578 2.21804555 3.40709608

 2.30799621 1.66141698]

Hinge Loss Value: 0.0010439825203261532

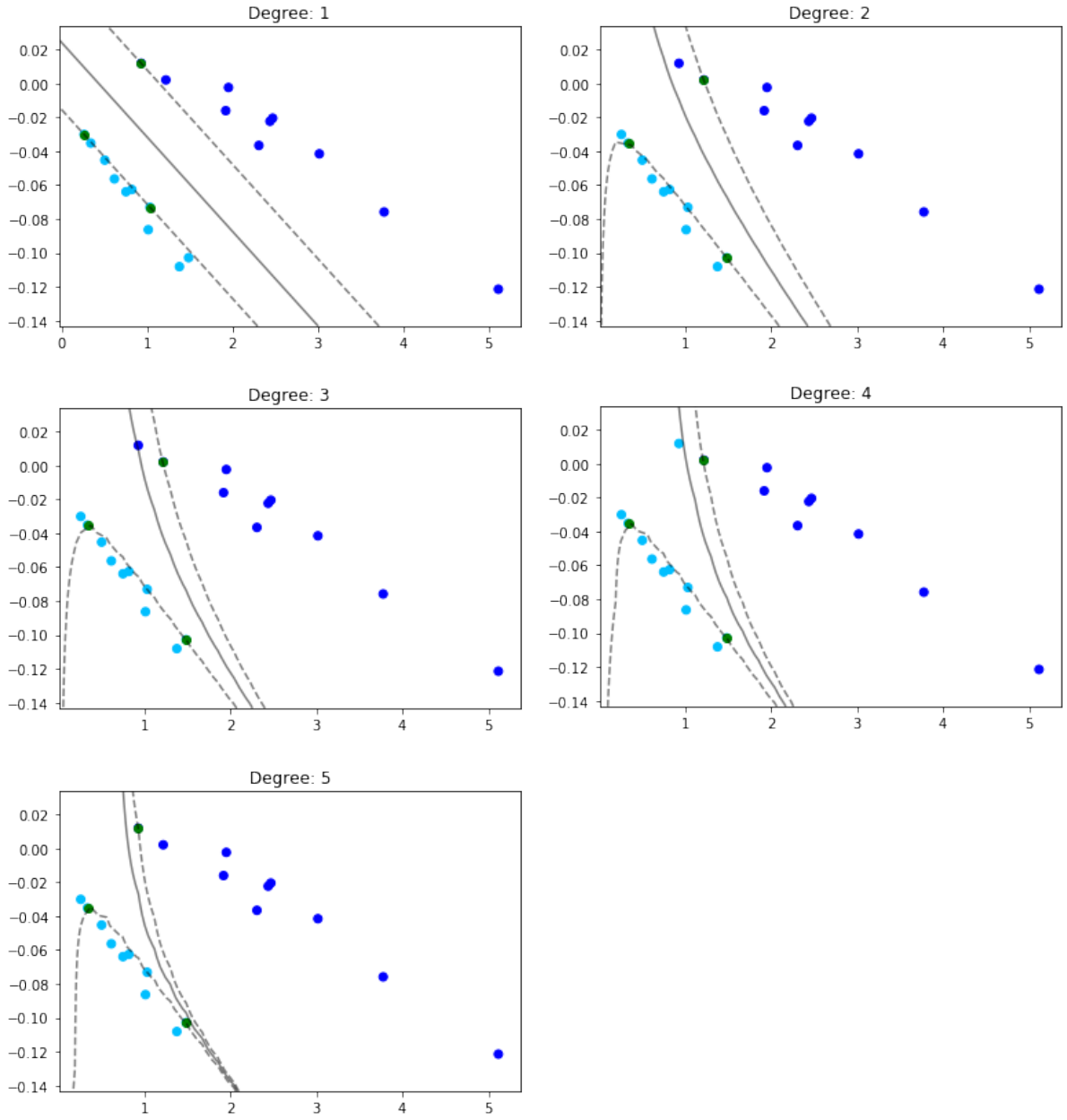
The hinge loss value of this classifier is calculated by using the SciKit-learn library 'metrics' with the decision function of this classifier. Therefore, the hinge loss value for this classifier was calculated to be 0.0010 (2 sf) which shows us that the classifier was able to correctly classify our unseen data to a good level of accuracy. The hinge loss value is not quite 0 since some points within our data to the top left of the graph were close to the boundary and caused uncertainty.



The full metrics data for the classifiers used can be found in section 8.4. As seen in this data, many of our classifiers perform without fault on the small dataset provided. The SVM classifier performed with an accuracy of 100% when tested in Python using SciKit-Learn, however just 90% accuracy when testing within Weka using cross validation using 10 folds. I wanted to be able to explore the use of the SVM and see if changing the degree of the classifier would help to produce a more accurate result. SVM was also explored further since its boundary can be easily visualised and compared within the python code. I believe that in a real-world application of this authentication technique, other classifiers would perform just as well as an SVM. These classifiers need to be tested on a much larger dataset in order to clearly see which would be the best selection.

4.4 Support Vector Machine Degrees

I wanted to be able to explore the accuracy of the different degrees of the SVM classifier to see if any increase in performance could be obtained.



From the above classifications we can see that anything above the degree of 1 would give us overfitting of our test set. The coefficients follow a linear line, and therefore the best classifier to match that would be the SVM with a degree of 1. Underfitting was not an issue with our dataset, as the simplest scenario with our classifier would be a straight line.

Now that we have a model with a reliable classifier, we just need to export this model to a .joblib file and load it into the python script each time we would like to authenticate a new device.

5 Device Authentication

Authentication in this project is comprised of two main steps: Data collection, and data analysis. Java code based off of Branstett's paper was used for collection, and python code was used for the analysis and prediction using our classification model.

5.1 Data Collection

1. The client Jar file and the server Jar file are initiated using the respective .bat files on each device.

2. A connection is established between the client and the server. This is made over LAN and using the server IP address. (Or wan later on…)

3. The client sends the server it's device name. Within the scope of this project, this is limited to CityPi or HomePi. This is the name that will be compared to the predicted name of the device using our model.

4. The client starts to send over data about the device. 54 rows of data are sent over, measuring variables described by the 70% constant data formatter.

5. Once 54 rows are received, the server breaks connection with the client.

6. The server then formats the data received, storing it in a .csv file within the project folder. This formatting includes converting data to the same filetype, and ensuring each row is represented on a new line.

5.2 Data Analysis

The server then calls the authenticate.py script:

1. The .csv file containing the client data is loaded in and stored in a Data class.

2. The data is weighted, duplicates are removed, and the two coefficients generated.

3. The AuthenticationModel.joblib classifier is loaded and used to predict the identity of the device using its generated coefficients. The classification is outputted to the console.

4. Java detects this output and compares the claimed identity of the device against the predicted identity.

6 Conclusion

6.1 Limitations

- This project was not designed to be a deployable, and the reason for this is mainly that the classification model would have to be entirely retrained for each new situation. The classifier used to predict the identity of the current device is trained on many sets of labelled data – in our case 20 – to be able to distinguish two devices. In order for this to be accurate over a period of time, measurements need to be made over the duration of a day of normal use for the device. In practice, outliers and data collected while performing unusual operations and under stress should still be correctly classified by the model since it will fall under the device's line of best fit (See section 4.2).
- The connection between the server and client is set up to be established over a LAN connection. The code will need to be modified and networks set up to allow traffic over WAN. Despite this, most IoT devices are connected over the same connection as one another so this method of authentication could likely work on many existing networks.
- As with any classification model, there is a degree of uncertainty with its predictions. Although our model scored 100% accuracy on the data we had available, that's not to say it would be 100% accurate all the time. Therefore, it's important to keep in mind that a classification model for device authentication should not be used on anything critical before extensive testing is carried out.

6.2 Application

This project has shown that a device authentication model based on classification of hardware features offers many benefits to an IoT network. The ability to offload data processing to the server allows for much lower powered devices to be used in networks, however there is still work to be done to measure how accurate the models can be in a real world scenario. The techniques used in this project could therefore be applied to non-critical infrastructure, such as a home network with many low powered devices. The idea explored in this paper could be expanded further, for example could we use data collected by listening to the network using an application such as Wireshark in addition to the authentication data sent to the server. This would even further reduce the need for processing power since the client devices could be authenticated during their normal operations.

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8 Appendix

8.1 Java Code

Credit to Jonathan Branstett. The following code has been modified to suit this project.

8.1.1 Client.java

```
package deviceRecognition;

import deviceRecognition.devices.*;
import deviceRecognition.formatter.*;

import java.io.IOException;
import java.io.ObjectOutputStream;
import java.io.OutputStream;
import java.net.Socket;
/**
 * @author Jonathan Branstett
 */
public class Client {

   static String ip = "192.168.0.20";
   static int port = 6789;
```

```
public static void main(String[] args) {
   try {
      test_successRate_client();
   } catch (Exception e) {
      System.out.println(e.getMessage());
   }
}

/**
 * This method collects data about the device on which it is run 54 times.
 * This data is then transferred to the server.
 *
 * @throws IOException
 * @throws NoSuchFieldException
 * @throws IllegalAccessException
 */
private static void test_successRate_client()
      throws IOException, NoSuchFieldException, IllegalAccessException {
   final String[] NAMES = {"device1", "device2", "device3"};
   final Device[] DEVICES = {
         new Device(), new Device1_empty(), new Device1_full(),
         new Device1_approx(), new Device1_var0(), new Device(),
         new Device2(), new Device2_empty(), new Device2_full(),
         new Device2_approx(), new Device2_var0(), new Device2(),
         new Device3(), new Device3_empty(), new Device3_full(),
         new Device3_approx(), new Device3_var0(), new Device3()
   };

   Socket s;
   OutputStream os;
   ObjectOutputStream oos;
   Device d;
   Formatter f;
   Point[] pts;

   System.out.println("Starting write");

   Socket sname = new Socket(ip, port);
   OutputStream osname = sname.getOutputStream();
   oos = new ObjectOutputStream(osname);
   oos.writeObject("HomePi");

   int j = 0;
   while (j < 100) {
      for (String name : NAMES) {
         for (int i = 0; i < DEVICES.length; i++) {
            s = new Socket(ip, port);
```

```
                os = s.getOutputStream();
                oos = new ObjectOutputStream(os);
                oos.writeObject(name);
                d = DEVICES[i];
                f = new Formatter70(1E15, 1, 0, 8);
                pts = f.formatData(d, false, false);
                oos.writeObject(pts);
                oos.close();
                os.close();
                s.close();
              }
            }
            j++;
          }
        }
      }
```

8.1.2 Server.java

```
package deviceRecognition;

import java.io.*;
import java.net.ServerSocket;
import java.net.Socket;
/**
 * @author Jonathan Branstett
 */

public class Server {

   static int port = 6789;
   static String filePath = "Pi.csv";
   static String deviceName;
   static String authenticatedName;

   public static void main(String[] args) {
      try {
         prepareFile();
         processData();
         authenticate();
      } catch (Exception e) {
         System.out.println(e.getMessage());
      }
   }
```

```
/**
 * Overwrite the existing data file with a blank file.
 */
public static void prepareFile() {

   try {

      FileWriter wrPts = new FileWriter(filePath);

      wrPts.write("");

      wrPts.close();

   } catch (Exception e) {
      System.out.println(e.getMessage());
   }

}


/**
 * This method receives the data from the client and appends it to the data file.
 *
 * @throws IOException
 * @throws ClassNotFoundException
 */
private static void processData()
      throws IOException, ClassNotFoundException {

   ServerSocket ss = new ServerSocket(port);
   Socket sname = ss.accept();
   InputStream isname = sname.getInputStream();
   ObjectInputStream oisname = new ObjectInputStream(isname);
   deviceName = (String) oisname.readObject();

   System.out.println(deviceName);

   int i = 0;
   while (i < 54) {
      Socket s = ss.accept();
      InputStream is = s.getInputStream();
      ObjectInputStream ois = new ObjectInputStream(is);
      String name = (String) ois.readObject();
      System.out.println("received message from " + deviceName);
      Point[] pts = (Point[]) ois.readObject();

      Save.savePts(pts, filePath);
```

```
            System.out.println();
            is.close();
            s.close();

            i++;
        }

        ss.close();
    }


    /**
     * This method calls the python file which authenticates the device using the data collected.
     * It then reads the output of the python code and outputs the authenticity of the device.
     *
     * @throws IOException
     */

    public static void authenticate() throws IOException{

        String s;

        String pyfilepath = "C:\\...\\Device Recognition";


        // run the Python file using the cmd:
        Process p = Runtime.getRuntime().exec("cmd /c \"cd " + pyfilepath + " && python
authenticate.py\"");

        BufferedReader stdInput = new BufferedReader(new
                InputStreamReader(p.getInputStream()));

        BufferedReader stdError = new BufferedReader(new
                InputStreamReader(p.getErrorStream()));

        String lastOutput = "";

        // read the output from the command
        while ((s = stdInput.readLine()) != null) {
            System.out.println(s);
            lastOutput = s;
        }

        authenticatedName = lastOutput.split(" ")[1];

        // read any errors from the attempted command
        while ((s = stdError.readLine()) != null) {
            System.out.println(s);
```

```
        }

        System.out.println(deviceName + " vs " + authenticatedName);

        if (deviceName.equals(authenticatedName)) {
            System.out.println("Device Authenticated");
        }

        System.exit(0);

    }
}
```

8.1.3 Point.java

```
package deviceRecognition;

import org.apache.commons.math3.fitting.WeightedObservedPoint;

/**
 * @author Jonathan Branstett
 */
public class Point extends WeightedObservedPoint{
    private final String xLabel;
    private final String yLabel;
    /**
     * @param weight the weight of the point.
     * @param xLabel the name of the field used as x coordinate
     * @param xValue the value of the x coordinate
     * @param yLabel the name of the field used as y coordinate
     * @param yValue the value of the y coordinate
     */
    public Point(double weight, String xLabel, double xValue,
                 String yLabel, double yValue) {
        super(weight,xValue,yValue);
        this.xLabel = xLabel;
        this.yLabel = yLabel;
    }
    public String getXLabel() {
        return xLabel;
    }
    public String getYLabel() {
        return yLabel;
    }
    @Override
    public String toString() {
```

```
        return "w=" + this.getWeight() + " "
                + "x=" + this.getX() + " "
                + "y=" + this.getY() + " "
                + "(" + this.getXLabel() + " " + " + this.getYLabel() + ")";
    }
}
```

8.1.4 Save.java

```
package deviceRecognition;

import java.io.*;
import java.math.BigDecimal;
/**
 * The class to perform the saving function
 *
 * @author Jonathan Branstett
 */
public class Save {

    static boolean firstRun = true;

    public static void savePts(Point[] pts, String filePath) {

        try {

            PrintStream wr = new PrintStream(new FileOutputStream(filePath, true));

            if (firstRun) {
                firstRun = false;
                for (Point pt : pts) {
                    wr.print(pt.getXLabel() + ",");
                    wr.print(pt.getYLabel() + ",");
                }
                wr.println();
            }

            for (Point pt : pts) {

                BigDecimal Xnum = new BigDecimal(pt.getX());
                String x = Xnum.toPlainString();

                BigDecimal Ynum = new BigDecimal(pt.getY());
                String y = Ynum.toPlainString();

                wr.print(x + ",");
```

```
            wr.print(y + ",");
        }

        wr.println();

        wr.close();

      } catch (Exception e) {
        System.out.println(e.getMessage());
      }
   }
}
```

8.1.5 Device.java

```
package deviceRecognition.devices;
import com.sun.management.OperatingSystemMXBean;
import java.io.BufferedReader;
import java.io.IOException;
import java.io.InputStreamReader;
import java.lang.management.ManagementFactory;
import java.lang.reflect.Field;
import java.util.logging.Level;
import java.util.logging.Logger;
/**
 * The Device class is used to collect data on the Raspberry PI. All data are made public so they can
 * be called by the Formatter classes using reflection.
 *
 * @author Jonathan Branstett
 */
public class Device {
   // Data collected using Java OperatingSystemMXBean class
   public String architecture;
   public int availableProcessors;
   public long committedVirtualMemorySize;
   public long freePhysicalMemorySize;
   public long freeSwapSpaceSize;
   public String osName;
   public String osVersion;
   public double processCpuLoad; //recent CPU usage for the JVM process
   public long processCpuTime; //CPU time used by the JVM process
   public double systemCpuLoad; //recent CPU usage in the system
   public double systemLoadAverage; //System load average for the last minute
   public long totalPhysicalMemorySize;
   public long totalSwapSpaceSize;
   //Data collected using the Raspberry PI vcgencmd command
```

```
public double clock_arm;
public double clock_core;
public double clock_h264;
public double clock_isp;
public double clock_v3d;
public double clock_uart;
public double clock_pwm;
public double clock_emmc;
public double clock_pixel;
public double clock_vec;
public double clock_hdmi;
public double clock_dpi;
public double volts_core;
public double volts_sdram_c;
public double volts_sdram_i;
public double volts_sdram_p;
public double temperature;
public boolean isCodecEnabled_H264;
public boolean isCodecEnabled_MPG2;
public boolean isCodecEnabled_WVC1;
public boolean isCodecEnabled_MPG4;
public boolean isCodecEnabled_MJPG;
public boolean isCodecEnabled_WMV9;
public double memorySize_arm;
public double memorySize_gpu;
public String firmwareVersion;
// SD card data collected using the OS commands
public String cid; // Card ID (contains all of the following data)
public String manfid; // Manufacturer ID
public String oemid; // OEM/Application ID
public String sdName; // Product name
public String hwrev; // Product revision
public String fwrev; // Product revision
public String sdSerial; // Serial number
public String date; // Manufacture Date Code
//Other data collected using the OS commands
public double bogoMips;
public String hardware; // Raspberry PI model
public String revision; // Raspberry PI revision
public String mac1; // ethernet MAC address
public String mac2; // Wi-Fi MAC address
public String cpuSerial;
/*
 * Private attributes needed for collection purposes.
 * Because these are unique instances provided by Java, they are defined as attributes of the
 * class so we only have to get them once.
 */
protected final OperatingSystemMXBean os;
```

```
protected final Runtime r;
/**
 * Construct a collector and collect data. The collect method can be called again later to update
 * the given instance with new values.
 */
public Device() {
   this.os = ManagementFactory.getPlatformMXBean(OperatingSystemMXBean.class);
   this.r = Runtime.getRuntime();
}
/**
 * Updates the fields of the class with new measurements.
 */
public void collect() {
   //Collect data using Java OperatingSystemMXBean class
   this.architecture = os.getArch();
   this.availableProcessors = os.getAvailableProcessors();
   this.committedVirtualMemorySize = os.getCommittedVirtualMemorySize();
   this.freePhysicalMemorySize = os.getFreePhysicalMemorySize();
   this.freeSwapSpaceSize = os.getFreeSwapSpaceSize();
   this.osName = os.getName();
   this.processCpuLoad = os.getProcessCpuLoad();
   this.processCpuTime = os.getProcessCpuTime();
   this.systemCpuLoad = os.getSystemCpuLoad();
   this.systemLoadAverage = os.getSystemLoadAverage();
   this.totalPhysicalMemorySize = os.getTotalPhysicalMemorySize();
   this.totalSwapSpaceSize = os.getTotalSwapSpaceSize();
   this.osVersion = os.getVersion();
   /*
    * When retrieving values using the OS terminal, the output is given as a String so we first
    * need to select the part containing the value we are interested in (split) and then convert it
    * into the right type (parse)
    */
   //Collect data using Raspberry PI vcgencmd command
   this.clock_arm = Double.parseDouble(run("vcgencmd measure_clock arm").split("=")[1]);
   this.clock_h264 = Double.parseDouble(run("vcgencmd measure_clock h264").split("=")[1]);
   this.clock_isp = Double.parseDouble(run("vcgencmd measure_clock isp").split("=")[1]);
   this.clock_v3d = Double.parseDouble(run("vcgencmd measure_clock v3d").split("=")[1]);
   this.clock_uart = Double.parseDouble(run("vcgencmd measure_clock uart").split("=")[1]);
   this.clock_pwm = Double.parseDouble(run("vcgencmd measure_clock pwm").split("=")[1]);
   this.clock_emmc = Double.parseDouble(run("vcgencmd measure_clock emmc").split("=")[1]);
   this.clock_pixel = Double.parseDouble(run("vcgencmd measure_clock pixel").split("=")[1]);
   this.clock_vec = Double.parseDouble(run("vcgencmd measure_clock vec").split("=")[1]);
   this.clock_hdmi = Double.parseDouble(run("vcgencmd measure_clock hdmi").split("=")[1]);
   this.clock_dpi = Double.parseDouble(run("vcgencmd measure_clock dpi").split("=")[1]);
   this.temperature = Double.parseDouble(run("vcgencmd measure_temp").split("[=']")[1]);
   this.volts_core = Double.parseDouble(run("vcgencmd measure_volts core").split("[=V]")[1]);

   this.volts_sdram_c = Double.parseDouble(
```

```
            run("vcgencmd measure_volts sdram_c").split("[=V]")[1]
    );
    this.volts_sdram_i = Double.parseDouble(
            run("vcgencmd measure_volts sdram_i").split("[=V]")[1]
    );
    this.volts_sdram_p = Double.parseDouble(
            run("vcgencmd measure_volts sdram_p").split("[=V]")[1]
    );
    this.memorySize_arm = Double.parseDouble(
            run("vcgencmd get_mem arm").split("[=M]")[1]
    );
    this.memorySize_gpu = Double.parseDouble(
            run("vcgencmd get_mem gpu").split("[=M]")[1]
    );
    this.isCodecEnabled_H264 = run("vcgencmd codec_enabled H264")
            .split("=")[1].equals("enabled");
    this.isCodecEnabled_MPG2 = run("vcgencmd codec_enabled MPG2")
            .split("=")[1].equals("enabled");
    this.isCodecEnabled_WVC1 = run("vcgencmd codec_enabled WVC1")
            .split("=")[1].equals("enabled");
    this.isCodecEnabled_MPG4 = run("vcgencmd codec_enabled MPG4")
            .split("=")[1].equals("enabled");
    this.isCodecEnabled_MJPG = run("vcgencmd codec_enabled MJPG")
            .split("=")[1].equals("enabled");
    this.isCodecEnabled_WMV9 = run("vcgencmd codec_enabled WMV9")
            .split("=")[1].equals("enabled");
    this.firmwareVersion = run("vcgencmd version").split(" ")[8];
    /*
     * Collect data using OS commands
     */
    this.cid = run("cat /sys/block/mmcblk0/device/cid");
    this.manfid = run("cat /sys/block/mmcblk0/device/manfid").split("x")[1];
    this.oemid = run("cat /sys/block/mmcblk0/device/oemid").split("x")[1];
    this.sdName = run("cat /sys/block/mmcblk0/device/name");
    this.hwrev = run("cat /sys/block/mmcblk0/device/hwrev").split("x")[1];
    this.fwrev = run("cat /sys/block/mmcblk0/device/fwrev").split("x")[1];
    this.sdSerial = run("cat /sys/block/mmcblk0/device/serial").split("x")[1];
    this.date = run("cat /sys/block/mmcblk0/device/date");
    this.hardware = run("grep Hardware /proc/cpuinfo").split(": ")[1];
    this.revision = run("grep Revision /proc/cpuinfo").split(": ")[1];
    this.cpuSerial = run("grep Serial /proc/cpuinfo").split(": ")[1];
    this.mac1 = run("cat /sys/class/net/eth0/address");
    this.mac2 = run("cat /sys/class/net/wlan0/address");
    this.bogoMips = Double.parseDouble(run("grep BogoMIPS /proc/cpuinfo").split("[ \n]")[1]);
}

@Override
public String toString() {
```

```
        Field[] fields = this.getClass().getFields();
        String s = this.getClass().getName() + " Object {\n";
        for (Field f : fields) {
            s += "\t";
            try {
                s += f.getName() + ": " + f.get(this) + "\n";
            } catch (IllegalAccessException ex) {
                Logger.getLogger(Device.class.getName()).log(Level.SEVERE, null, ex);
            }
        }
        s += "}";
        return s;
    }
    /**
     * Run an OS command.
     * @param command The command to execute in the Runtime
     * @return The output of the command as a String
     */
    private String run(String command) {
        String result = "";
        try {
            boolean isFirstLine = true;
            String line;
            Process p = this.r.exec(command);
            BufferedReader br = new BufferedReader(new InputStreamReader(p.getInputStream()));
            while ((line = br.readLine()) != null) {
                // If there are more than one line to output we add a new line to the output String
                if (!isFirstLine) {
                    result = result.concat("\n");
                }
                result = result.concat(line);
                isFirstLine = false;
            }
            p.waitFor();
            p.destroy();
        } catch (IOException | InterruptedException ex) {
            Logger.getLogger(Device.class.getName()).log(Level.SEVERE, null, ex);
        }
        return result;
    }
}
```

8.1.6 Formatter.java

```
package deviceRecognition.formatter;
```

```
import deviceRecognition.Point;
import deviceRecognition.devices.Device;
import java.lang.reflect.Field;
import java.util.ArrayList;
/**
 * The Formatter class is used to convert the data retrieved by a Device in a format that can be
 * used by the linear regression. This abstract class provides the basic methods to format the data
 * and subclasses represents the different set of values to be used
 *
 * @author Jonathan Branstett
 */
public abstract class Formatter {
   // Lower bound for the exponent
   protected int expFrom;
   // Upper bound for exponent
   protected int expTo;
   // Name of fields for the constant data to use in the regression
   protected String[] namesCons;
   // Name of fields for the variable data to use in the regression
   protected String[] namesVar;
   // Weight given to constant data for the linear regression
   protected double weightCons;
   // Weight given to variable data for the linear regression
   protected double weightVar;
   /**
    * Construct a Formatter with the given parameters
    *
    * @param cWeight weight for constant data
    * @param vWeight weight for variable data
    * @param expFrom lower bound for exponents. If this value is equal to the upper bound, the
    * original data values will be used
    * @param expTo upper bounds for exponents. If the value is equal to the lower bound, the
    * original data values will be used
    */
   public Formatter(double cWeight, double vWeight, int expFrom, int expTo) {
      this.weightCons = cWeight;
      this.weightVar = vWeight;
      this.expFrom = expFrom;
      this.expTo = expTo;
   }
   /**
    * Format data to create Point objects from them.
    *
    * @param dev The device containing the data to format.
    * @param noVar If set to true, the Formatter will ignore variable data.
    * @param mixed If set to true, the Point objects will mix constant and variable coordinates. If
    * set to false, the Point objects will contain two constant or two variable coordinates.
    * @return array of Point objects.
```

```
     * @throws java.lang.NoSuchFieldException
     * @throws java.lang.IllegalAccessException
     */
    public Point[] formatData(Device dev, boolean noVar, boolean mixed)
            throws NoSuchFieldException, IllegalAccessException {
        dev.collect();
        // Creating list for constants
        ArrayList<String> constantNames = new ArrayList<>();
        ArrayList<Double> constantValues = new ArrayList<>();
        for (String name : this.namesCons) {
            Field f = dev.getClass().getField(name);
            if (f.getType().getSimpleName().equals("String")) {
                int[] info = this.getStringInfo(f);
                double[] subValues = this.formatString((String) f.get(dev), info[0], info[1]);
                for (double val : subValues) {
                    constantNames.add(name);
                    if (this.expFrom != this.expTo) {
                        val = modifyExponentInRange(val, this.expFrom, this.expTo);
                    }
                    constantValues.add(val);
                }
            } else {
                constantNames.add(name);
                double val = this.formatField(dev, f);
                if (this.expFrom != this.expTo) {
                    val = modifyExponentInRange(val, this.expFrom, this.expTo);
                }
                constantValues.add(val);
            }
        }
        if (noVar) {
            int pointsNbr = constantNames.size() / 2;
            Point[] points = new Point[pointsNbr];
            for (int i = 0; i < pointsNbr; i++) {
                points[i] = new Point(
                        this.weightCons,
                        constantNames.get(i * 2),
                        constantValues.get(i * 2),
                        constantNames.get(i * 2 + 1),
                        constantValues.get(i * 2 + 1)
                );
            }
            return points;
        } else {
        //Creating list for variables
            ArrayList<String> varNames = new ArrayList<>();
            ArrayList<Double> varValues = new ArrayList<>();
            for (String name : this.namesVar) {
```

```
    Field f = dev.getClass().getField(name);
    if (f.getType().getSimpleName().equals("String")) {
       int[] info = this.getStringInfo(f);
       double[] subValues = this.formatString((String) f.get(dev), info[0], info[1]);
       for (double val : subValues) {
          varNames.add(name);
          if (this.expFrom != this.expTo) {
             val = modifyExponentInRange(val, this.expFrom, this.expTo);
          }
          varValues.add(val);
       }
    } else {
       varNames.add(name);
       double val = this.formatField(dev, f);
       if (this.expFrom != this.expTo) {
          val = modifyExponentInRange(val, this.expFrom, this.expTo);
       }
       varValues.add(val);
    }
 }
 if (mixed) {
    int pointsNbr = (constantNames.size() + varNames.size()) / 2;
    int limit = Math.min(constantNames.size(), varNames.size());
    Point[] points = new Point[pointsNbr];
    for (int i = 0; i < pointsNbr; i++) {
       if (i < limit) {
          points[i] = new Point(
                this.weightVar,
                constantNames.get(i),
                constantValues.get(i),
                varNames.get(i),
                varValues.get(i)
          );
       } else if (varNames.size() == limit) {
          points[i] = new Point(
                this.weightCons,
                constantNames.get(i * 2 - limit),
                constantValues.get(i * 2 - limit),
                constantNames.get(i * 2 - limit + 1),
                constantValues.get(i * 2 - limit + 1)
          );
       } else {
          points[i] = new Point(
                this.weightVar,
                varNames.get(i * 2 - limit),
                varValues.get(i * 2 - limit),
                varNames.get(i * 2 - limit + 1),
                varValues.get(i * 2 - limit + 1)
```

```
                );
            }
        }
        return points;
    } else {
        int constantPointsNbr = constantNames.size() / 2;
        int variablePointsNbr = varNames.size() / 2;
        int pointsNbr = constantPointsNbr + variablePointsNbr;
        Point[] points = new Point[pointsNbr];
        for (int i = 0; i < constantPointsNbr; i++) {
            points[i] = new Point(
                    this.weightCons,
                    constantNames.get(i * 2),
                    constantValues.get(i * 2),
                    constantNames.get(i * 2 + 1),
                    constantValues.get(i * 2 + 1)
            );
        }
        for (int i = 0; i < variablePointsNbr; i++) {
            points[i + constantPointsNbr] = new Point(
                    this.weightVar,
                    varNames.get(i * 2),
                    varValues.get(i * 2),
                    varNames.get(i * 2 + 1),
                    varValues.get(i * 2 + 1)
            );
        }
        return points;
    }
  }
}

/**
 * Return the content of the Field casted as a double
 *
 * @param dev The Device owning the Field
 * @param f The Field whose value needs to be casted as double
 * @return The double value representing the content of the Field
 * @throws IllegalAccessException
 */
private double formatField(Device dev, Field f) throws IllegalAccessException {
  switch (f.getType().getSimpleName()) {
    case "int":
      return (int) f.get(dev);
    case "long":
      return (long) f.get(dev);
    case "boolean":
      return (boolean) f.get(dev) ? 1 : 0;
```

```
            default:
                return (double) f.get(dev);
        }
    }
    /**
     * Split Strings that are too long to be converted into smaller substrings
     * that will be converted.
     *
     * @param data The String to be converted
     * @param radix The radix to use during the conversion. Must be 36 for alphanumerical Strings
     * (A-Za-z0-9) or 16 for hexadecimal (0-9a-f)
     * @param size The size of the substrings that will be extracted from the given String. The last
     * substring will be smaller if there are not enoughcharacters.
     * @return An array of double which are the values gotten from the converted substrings.
     */
    private double[] formatString(String data, int radix, int size) {
        data = data.replaceAll("[^A-Za-z0-9]", "");
        if (data.length() > size) {
            int nb = (data.length() - 1) / size + 1;
            double[] l = new double[nb];
            for (int i = 0; i < nb; i++) {
                int limit = (i + 1) * size < data.length() ? (i + 1) * size : data.length();
                l[i] = Long.parseLong(data.substring(i * size, limit), radix);
            }
            return l;
        } else {
            return new double[]{Long.parseLong(data, radix)};
        }
    }
    /**
     * Get the information needed to convert the String of a given Field into a double. These
     * information are the radix and size of substrings.
     *
     * @param f The Field to get information from.
     * @return An int array with two values: the radix to use as index 0 and the size of substrings to
     * use as 1.
     */
    private int[] getStringInfo(Field f) {
        int[] info = new int[2]; // [Radix, Substrings size]
        switch (f.getName()) {
// Alphanum Strings
            case "hardware":
                info[0] = 36;
                info[1] = 4;
                break;
            case "architecture":
            case "osName":
            case "osVersion":
```

```
            case "sdName":
               info[0] = 36;
               info[1] = 6;
               break;
// Hexadecimal Strings
            case "sdSerial":
            case "cpuSerial":
               info[0] = 16;
               info[1] = 4;
               break;
            case "mac1":
            case "mac2":
            case "revision":
               info[0] = 16;
               info[1] = 6;
               break;
            case "firmwareVersion":
               info[0] = 16;
               info[1] = 7;
               break;
            case "cid":
            case "manfid":
            case "oemid":
            case "hwrev":
            case "fwrev":
               info[0] = 16;
               info[1] = 8;
               break;
// Decimal Strings
            case "date":
               info[0] = 11;
               info[1] = 10;
               break;
            default:
               info[0] = 0;
               info[1] = 0;
         }
         return info;
      }
      /**
       * Modify a double exponent in order to be in the given range
       * @param val The double value to modify
       * @param from The lower bound for the exponent
       * @param to The upper bound for the exponent
       * @return The value with its exponent changed
       */
      private double modifyExponentInRange(double val, int from, int to) {
         if (val != 0) {
```

```
            int exp = (int) Math.floor(Math.log10(Math.abs(val)));
            int newExp = Math.floorMod(exp - from, to - from) + from;
            return val * Math.pow(10, newExp - exp);
        } else {
            return val;
        }
    }
}
```

8.1.7 Formatter50.java

```
package deviceRecognition.formatter;

/**
 * The Formatter50 class is used to convert the data retrieved by a Device in a format that can be
 * used by the linear regression. It formats data using a set of values with a ratio of 50/50
 *
 * @author Jonathan Branstett
 */
public class Formatter50 extends Formatter {
    /**
     * Construct a Formatter with the given parameters
     * @param cWeight weight for constant data
     * @param vWeight weight for variable data
     * @param expFrom lower bound for exponents. If this value is equal to the upper bound, the
     * original data values will be used
     * @param expTo upper bounds for exponents. If the value is equal to the lower bound, the
     * original data values will be used
     */
    public Formatter50(
            double cWeight, double vWeight, int expFrom, int expTo
    ) {
        super(cWeight, vWeight, expFrom, expTo);
        this.namesCons = new String[]{
                "memorySize_arm", "memorySize_gpu", "cpuSerial",
                "firmwareVersion", "cid", "mac1", "mac2", "hardware"
        };
        this.namesVar = new String[]{
                "freePhysicalMemorySize", "freeSwapSpaceSize",
                "systemLoadAverage", "temperature", "volts_core",
                "volts_sdram_c", "volts_sdram_i", "volts_sdram_p",
                "clock_arm", "clock_core", "clock_h264", "clock_isp",
                "clock_v3d", "clock_uart", "clock_pwm", "clock_emmc",
                "clock_pixel", "clock_vec", "clock_hdmi", "clock_dpi",
                "processCpuLoad", "systemCpuLoad"
        };
```

```
    }
}
```

8.1.8 Formatter60.java

```
package deviceRecognition.formatter;
/**
 * The Formatter60 class is used to convert the data retrieved by a Device in a format that can be
 * used by the linear regression. It formats data using a set of values with a ratio of 60/40
 *
 * @author Jonathan Branstett
 */
public class Formatter60 extends Formatter {
    /**
     * Construct a Formatter with the given parameters
     * @param cWeight weight for constant data
     * @param vWeight weight for variable data
     * @param expFrom lower bound for exponents. If this value is equal to the upper bound, the
     * original data values will be used
     * @param expTo upper bounds for exponents. If the value is equal to the lower bound, the
     * original data values will be used
     */
    public Formatter60(
            double cWeight, double vWeight, int expFrom, int expTo
    ) {
        super(cWeight, vWeight, expFrom, expTo);
        this.namesCons = new String[]{
                "memorySize_arm", "memorySize_gpu", "cpuSerial",
                "firmwareVersion", "cid", "mac1", "mac2"
        };
        this.namesVar = new String[]{
                "freePhysicalMemorySize", "freeSwapSpaceSize",
                "systemLoadAverage", "temperature", "volts_core",
                "volts_sdram_c", "volts_sdram_i", "volts_sdram_p",
                "clock_arm", "clock_uart", "processCpuLoad",
                "systemCpuLoad"
        };
    }
}
```

8.1.9 Formatter70.java

```
package deviceRecognition.formatter;
```

```
/**
 * The Formatter70 class is used to convert the data retrieved by a Device in a format that can be
 * used by the linear regression. It formats data using a set of values with a ratio of 70/30
 *
 * @author Jonathan Branstett
 */
public class Formatter70 extends Formatter {
   /**
    * Construct a Formatter with the given parameters
    * @param cWeight weight for constant data
    * @param vWeight weight for variable data
    * @param expFrom lower bound for exponents. If this value is equal to the upper bound, the
    * original data values will be used
    * @param expTo upper bounds for exponents. If the value is equal to the lower bound, the
    * original data values will be used
    */
   public Formatter70(double cWeight, double vWeight, int expFrom, int expTo) {
      super(cWeight, vWeight, expFrom, expTo);
      this.namesCons = new String[]{
            "memorySize_arm", "memorySize_gpu", "cpuSerial",
            "firmwareVersion", "cid", "mac1", "mac2", "hardware"
      };
      this.namesVar = new String[]{
            "freePhysicalMemorySize", "freeSwapSpaceSize",
            "systemLoadAverage", "temperature", "volts_core",
            "volts_sdram_c", "clock_arm", "clock_uart"
      };
   }
}
```

8.1.10 Formatter80.java

```
package deviceRecognition.formatter;

/**
 * The Formatter80 class is used to convert the data retrieved by a Device in a format that can be
 * used by the linear regression. It formats data using a set of values with a ratio of 80/20
 *
 * @author Jonathan Branstett
 */
public class Formatter80 extends Formatter {
   /**
    * Construct a Formatter with the given parameters
    * @param cWeight weight for constant data
    * @param vWeight weight for variable data
    * @param expFrom lower bound for exponents. If this value is equal to the upper bound, the
```

```
     * original data values will be used
     * @param expTo upper bounds for exponents. If the value is equal to the lower bound, the
     * original data values will be used
     */
    public Formatter80(
            double cWeight, double vWeight, int expFrom, int expTo
    ) {
        super(cWeight, vWeight, expFrom, expTo);
        this.namesCons = new String[]{
                "memorySize_arm", "memorySize_gpu", "cpuSerial",
                "firmwareVersion", "cid", "mac1", "mac2", "hardware"
        };
        this.namesVar = new String[]{
                "freePhysicalMemorySize", "freeSwapSpaceSize",
                "volts_core", "clock_arm"
        };
    }
}
```

8.1.11 Device.java

```
package deviceRecognition.devices;
import com.sun.management.OperatingSystemMXBean;
import java.io.BufferedReader;
import java.io.IOException;
import java.io.InputStreamReader;
import java.lang.management.ManagementFactory;
import java.lang.reflect.Field;
import java.util.logging.Level;
import java.util.logging.Logger;
/**
 * The Device class is used to collect data on the Raspberry PI. All data are made public so they can
 * be called by the Formatter classes using reflection.
 *
 * @author Jonathan Branstett
 */
public class Device {
    // Data collected using Java OperatingSystemMXBean class
    public String architecture;
    public int availableProcessors;
    public long committedVirtualMemorySize;
    public long freePhysicalMemorySize;
    public long freeSwapSpaceSize;
    public String osName;
    public String osVersion;
    public double processCpuLoad; //recent CPU usage for the JVM process
```

```
public long processCpuTime; //CPU time used by the JVM process
public double systemCpuLoad; //recent CPU usage in the system
public double systemLoadAverage; //System load average for the last minute
public long totalPhysicalMemorySize;
public long totalSwapSpaceSize;
//Data collected using the Raspberry PI vcgencmd command
public double clock_arm;
public double clock_core;
public double clock_h264;
public double clock_isp;
public double clock_v3d;
public double clock_uart;
public double clock_pwm;
public double clock_emmc;
public double clock_pixel;
public double clock_vec;
public double clock_hdmi;
public double clock_dpi;
public double volts_core;
public double volts_sdram_c;
public double volts_sdram_i;
public double volts_sdram_p;
public double temperature;
public boolean isCodecEnabled_H264;
public boolean isCodecEnabled_MPG2;
public boolean isCodecEnabled_WVC1;
public boolean isCodecEnabled_MPG4;
public boolean isCodecEnabled_MJPG;
public boolean isCodecEnabled_WMV9;
public double memorySize_arm;
public double memorySize_gpu;
public String firmwareVersion;
// SD card data collected using the OS commands
public String cid; // Card ID (contains all of the following data)
public String manfid; // Manufacturer ID
public String oemid; // OEM/Application ID
public String sdName; // Product name
public String hwrev; // Product revision
public String fwrev; // Product revision
public String sdSerial; // Serial number
public String date; // Manufacture Date Code
//Other data collected using the OS commands
public double bogoMips;
public String hardware; // Raspberry PI model
public String revision; // Raspberry PI revision
public String mac1; // ethernet MAC address
public String mac2; // Wi-Fi MAC address
public String cpuSerial;
```

```
/*
 * Private attributes needed for collection purposes.
 * Because these are unique instances provided by Java, they are defined as attributes of the
 * class so we only have to get them once.
 */
protected final OperatingSystemMXBean os;
protected final Runtime r;
/**
 * Construct a collector and collect data. The collect method can be called again later to update
 * the given instance with new values.
 */
public Device() {
   this.os = ManagementFactory.getPlatformMXBean(OperatingSystemMXBean.class);
   this.r = Runtime.getRuntime();
}
/**
 * Updates the fields of the class with new measurements.
 */
public void collect() {
   //Collect data using Java OperatingSystemMXBean class
   this.architecture = os.getArch();
   this.availableProcessors = os.getAvailableProcessors();
   this.committedVirtualMemorySize = os.getCommittedVirtualMemorySize();
   this.freePhysicalMemorySize = os.getFreePhysicalMemorySize();
   this.freeSwapSpaceSize = os.getFreeSwapSpaceSize();
   this.osName = os.getName();
   this.processCpuLoad = os.getProcessCpuLoad();
   this.processCpuTime = os.getProcessCpuTime();
   this.systemCpuLoad = os.getSystemCpuLoad();
   this.systemLoadAverage = os.getSystemLoadAverage();
   this.totalPhysicalMemorySize = os.getTotalPhysicalMemorySize();
   this.totalSwapSpaceSize = os.getTotalSwapSpaceSize();
   this.osVersion = os.getVersion();
   /*
    * When retrieving values using the OS terminal, the output is given as a String so we first
    * need to select the part containing the value we are interested in (split) and then convert it
    * into the right type (parse)
    */
   //Collect data using Raspberry PI vcgencmd command
   this.clock_arm = Double.parseDouble(run("vcgencmd measure_clock arm").split("=")[1]);
   this.clock_h264 = Double.parseDouble(run("vcgencmd measure_clock h264").split("=")[1]);
   this.clock_isp = Double.parseDouble(run("vcgencmd measure_clock isp").split("=")[1]);
   this.clock_v3d = Double.parseDouble(run("vcgencmd measure_clock v3d").split("=")[1]);
   this.clock_uart = Double.parseDouble(run("vcgencmd measure_clock uart").split("=")[1]);
   this.clock_pwm = Double.parseDouble(run("vcgencmd measure_clock pwm").split("=")[1]);
   this.clock_emmc = Double.parseDouble(run("vcgencmd measure_clock emmc").split("=")[1]);
   this.clock_pixel = Double.parseDouble(run("vcgencmd measure_clock pixel").split("=")[1]);
   this.clock_vec = Double.parseDouble(run("vcgencmd measure_clock vec").split("=")[1]);
```

```
this.clock_hdmi = Double.parseDouble(run("vcgencmd measure_clock hdmi").split("=")[1]);
this.clock_dpi = Double.parseDouble(run("vcgencmd measure_clock dpi").split("=")[1]);
this.temperature = Double.parseDouble(run("vcgencmd measure_temp").split("[=']")[1]);
this.volts_core = Double.parseDouble(run("vcgencmd measure_volts core").split("[=V]")[1]);

this.volts_sdram_c = Double.parseDouble(
      run("vcgencmd measure_volts sdram_c").split("[=V]")[1]
);
this.volts_sdram_i = Double.parseDouble(
      run("vcgencmd measure_volts sdram_i").split("[=V]")[1]
);
this.volts_sdram_p = Double.parseDouble(
      run("vcgencmd measure_volts sdram_p").split("[=V]")[1]
);
this.memorySize_arm = Double.parseDouble(
      run("vcgencmd get_mem arm").split("[=M]")[1]
);
this.memorySize_gpu = Double.parseDouble(
      run("vcgencmd get_mem gpu").split("[=M]")[1]
);
this.isCodecEnabled_H264 = run("vcgencmd codec_enabled H264")
      .split("=")[1].equals("enabled");
this.isCodecEnabled_MPG2 = run("vcgencmd codec_enabled MPG2")
      .split("=")[1].equals("enabled");
this.isCodecEnabled_WVC1 = run("vcgencmd codec_enabled WVC1")
      .split("=")[1].equals("enabled");
this.isCodecEnabled_MPG4 = run("vcgencmd codec_enabled MPG4")
      .split("=")[1].equals("enabled");
this.isCodecEnabled_MJPG = run("vcgencmd codec_enabled MJPG")
      .split("=")[1].equals("enabled");
this.isCodecEnabled_WMV9 = run("vcgencmd codec_enabled WMV9")
      .split("=")[1].equals("enabled");
this.firmwareVersion = run("vcgencmd version").split(" ")[8];
/*
 * Collect data using OS commands
 */
this.cid = run("cat /sys/block/mmcblk0/device/cid");
this.manfid = run("cat /sys/block/mmcblk0/device/manfid").split("x")[1];
this.oemid = run("cat /sys/block/mmcblk0/device/oemid").split("x")[1];
this.sdName = run("cat /sys/block/mmcblk0/device/name");
this.hwrev = run("cat /sys/block/mmcblk0/device/hwrev").split("x")[1];
this.fwrev = run("cat /sys/block/mmcblk0/device/fwrev").split("x")[1];
this.sdSerial = run("cat /sys/block/mmcblk0/device/serial").split("x")[1];
this.date = run("cat /sys/block/mmcblk0/device/date");
this.hardware = run("grep Hardware /proc/cpuinfo").split(": ")[1];
this.revision = run("grep Revision /proc/cpuinfo").split(": ")[1];
this.cpuSerial = run("grep Serial /proc/cpuinfo").split(": ")[1];
this.mac1 = run("cat /sys/class/net/eth0/address");
```

```
        this.mac2 = run("cat /sys/class/net/wlan0/address");
        this.bogoMips = Double.parseDouble(run("grep BogoMIPS /proc/cpuinfo").split("[ \n]")[1]);
    }

    @Override
    public String toString() {
        Field[] fields = this.getClass().getFields();
        String s = this.getClass().getName() + " Object {\n";
        for (Field f : fields) {
            s += "\t";
            try {
                s += f.getName() + ": " + f.get(this) + "\n";
            } catch (IllegalAccessException ex) {
                Logger.getLogger(Device.class.getName()).log(Level.SEVERE, null, ex);
            }
        }
        s += "}";
        return s;
    }
    /**
     * Run an OS command.
     * @param command The command to execute in the Runtime
     * @return The output of the command as a String
     */
    private String run(String command) {
        String result = "";
        try {
            boolean isFirstLine = true;
            String line;
            Process p = this.r.exec(command);
            BufferedReader br = new BufferedReader(new InputStreamReader(p.getInputStream()));
            while ((line = br.readLine()) != null) {
                // If there are more than one line to output we add a new line to the output String
                if (!isFirstLine) {
                    result = result.concat("\n");
                }
                result = result.concat(line);
                isFirstLine = false;
            }
            p.waitFor();
            p.destroy();
        } catch (IOException | InterruptedException ex) {
            Logger.getLogger(Device.class.getName()).log(Level.SEVERE, null, ex);
        }
        return result;
    }
}
```

8.2 Python Code

Include all python code here

```
import numpy as np
from sklearn import linear_model, utils, cluster
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.svm import SVC
from sklearn.linear_model import Ridge
from sklearn.preprocessing import PolynomialFeatures
from sklearn.pipeline import make_pipeline
from joblib import dump, load

def __iter__(self): return 0

print("Libraries Loaded Successfully")

# The Data class provides an organised structure to store the data and the analysis performed on said data.
# This class allows easy access to the coefficients and the polynomial regression model for each dataset.
class Data:

    def __init__(self, df):
        self.df = formatDF(df)
        self.combinedDF = combineDF(self.df)
        self.weightedDF = weightedDF(self.combinedDF)

    def getModel(self, degree):
        return calculateModel(self.weightedDF, degree)
```

```
    def getCoefs(self, degree):
        return self.getModel(degree).steps[1][1].coef_[1:degree+1]

# This method performs preliminary cleaning on the dataset.
def formatDF(df):

    df = df.drop_duplicates()
    df = df.loc[:, ~df.columns.str.contains('^Unnamed')]

    return df

# This method formats the dataset from having multiple columns into a dataset that has just two columns.
def combineDF(df):

    dfCombined = pd.DataFrame()

    for i in range(int(df.shape[1]/2)):

        col1 = df.iloc[:,i*2]
        col2 = df.iloc[:,(i*2)+1]

        dfCombined = dfCombined.append(pd.DataFrame.from_dict({'0':col1, '1':col2}), ignore_index=True)

    dfCombined.dropna(inplace=True)

    return dfCombined

# This dataset weights the datapoints depending on their uniqueness.
def weightedDF(df):
```

```
    df['0'] = uniqueModelX = utils.class_weight.compute_class_weight('balanced', df['0'], df['0'])

    df['1'] = uniqueModelY = utils.class_weight.compute_class_weight('balanced', df['1'], df['1'])

    df.drop_duplicates(inplace=True)

    df.reset_index(inplace=True, drop=True)

    return df

# This method calculates the polynomial regression model for each dataset using Ridge regression.
def calculateModel(data, degree):

    model = make_pipeline(PolynomialFeatures(degree=degree), Ridge())
    model.fit(data['0'].values.reshape(-1,1), data['1'])

    return model

#This method loads in the data file generated by the Java code.
def loadData():

    global dataList

    dataList = {}

    dataList['Pi'] = Data(pd.read_csv('Pi.csv'))

    print('CSV file loaded')
```

```
'''
From this point the data analysis starts.
1. Data is loaded in
2. The coefficients are calculated and printed to the console
3. The classification model is loaded in
4. The identity of the device is predicted and printed
'''

loadData()

coefs = dataList.get("Pi").getCoefs(2)

piDF = pd.DataFrame(columns=['coef1', 'coef2'], data=list([coefs]))

print(piDF.head())

clf = load('AuthenticationModel.joblib')

y_pred = clf.predict(piDF)

if y_pred == 1:
   classification = "CityPi"
else:
   classification = "HomePi"

print("Classification: " + classification)
```

8.3 Formatter Variables

8.3.1 Formatter 50

Constant:
"memorySize_arm", "memorySize_gpu", "cpuSerial",
"firmwareVersion", "cid", "mac1", "mac2", "hardware"

Variable:
"freePhysicalMemorySize", "freeSwapSpaceSize",
"systemLoadAverage", "temperature", "volts_core",
"volts_sdram_c", "volts_sdram_i", "volts_sdram_p",
"clock_arm", "clock_core", "clock_h264", "clock_isp",
"clock_v3d", "clock_uart", "clock_pwm", "clock_emmc",
"clock_pixel", "clock_vec", "clock_hdmi", "clock_dpi",
"processCpuLoad", "systemCpuLoad"

8.3.2 Formatter 60

Constant:
"memorySize_arm", "memorySize_gpu", "cpuSerial",
"firmwareVersion", "cid", "mac1", "mac2"

Variable:
"freePhysicalMemorySize", "freeSwapSpaceSize",
"systemLoadAverage", "temperature", "volts_core",
"volts_sdram_c", "volts_sdram_i", "volts_sdram_p",
"clock_arm", "clock_uart", "processCpuLoad",
"systemCpuLoad"

8.3.3 Formatter 70

Constant:
"memorySize_arm", "memorySize_gpu", "cpuSerial",
"firmwareVersion", "cid", "mac1", "mac2", "hardware"

Variable:

"freePhysicalMemorySize", "freeSwapSpaceSize",

"systemLoadAverage", "temperature", "volts_core",

"volts_sdram_c", "clock_arm", "clock_uart"

8.3.4 Formatter 80

Constant:

"memorySize_arm", "memorySize_gpu", "cpuSerial",

"firmwareVersion", "cid", "mac1", "mac2", "hardware"

Variable:

"freePhysicalMemorySize", "freeSwapSpaceSize",

"volts_core", "clock_arm"

8.4 Classification Metrics

The classifiers below were trained with 20 data points, using cross validation. The below data was calculated using the Weka metrics tool. (Eibe Frank, 2016)

	Support Vector Machine	Logistic Regression	Naïve Bayes	Random Forest
Correctly Classified Instances	90%	100%	100%	95%
Incorrectly Classified Instances	10%	0%	0%	5%
Kappa statistic	0.8	1	1	0.9
Mean absolute error	0.1	0	0.1011	0.136
Root mean squared error	0.3162	0.0001	0.1587	0.2213
Relative absolute error	20%	0.0027%	20.226%	27.2%
Root relative squared error	63.2456%	0.0122%	31.745%	44.2538%

8.4.1 Support Vector Machine

8.4.1.1 Metrics

Class	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area
0	1.000	0.200	0.833	1.000	0.909	0.816	0.900	0.833
1	0.800	0.000	1.000	0.800	0.889	0.816	0.900	0.900
Weighted Avg.	0.900	0.100	0.917	0.900	0.899	0.816	0.900	0.867

8.4.1.2 Parameters

C	1.0
class_weight	None
dual	False
fit_intercept	True
intercept_scaling	1
max_iter	100
multi_class	multinomial
n_jobs	None
penalty	l2
random_state	0
solver	lbfgs
tol	0.0001
verbose	0
warm_start	False

8.4.2 Logistic Regression

8.4.2.1 Metrics

Class	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area
0	1.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000
1	1.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000
Weighted Avg.	1.000	0.00	1.000	1.000	1.000	1.000	1.000	1.000

8.4.2.2 Parameters

bootstrap	True
class_weight	None
criterion	gini
max_depth	2
max_features	auto
max_leaf_nodes	None
min_impurity_decrease	0.0
min_impurity_split	None
min_samples_leaf	1
min_samples_split	2
min_weight_fraction_leaf	0.0
n_estimators	100
n_jobs	None
oob_score	False
random_state	0
Verbose	0
warm_start	False

8.4.3 Naïve Bayes

8.4.3.1 Metrics

Class	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area
0	1.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000
1	1.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000
Weighted Avg.	1.000	0.00	1.000	1.000	1.000	1.000	1.000	1.000

8.4.3.2 Parameters

C	10000000000.0
cache_size	200
class_weight	None
coef0	0.0

decision_function_shape	ovr
degree	1
gamma	auto
kernel	poly
max_iter	-1
probability	False
random_state	None
shrinking	True
tol	0.001
verbose	False

8.4.4 Random Forest

8.4.4.1 Metrics

Class	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area
0	1.000	0.100	0.909	1.000	0.952	0.905	0.995	0.991
1	0.900	0.000	1.000	0.900	0.947	0.905	0.995	0.991
Weighted Avg.	0.950	0.050	0.955	0.950	0.950	0.905	0.995	0.991

8.4.4.2 Parameters

priors	None
var_smoothing	1e-09

8.4.5 K-Means Clustering

8.4.5.1 Parameters

algorithm:	auto
copy_x:	True
init:	k-means++
max_iter:	300
n_clusters:	2
n_init:	10
n_jobs:	None
random_state:	None
precompute_distances:	auto
tol:	0.0001
verbose:	0