**Malware Categorization using Machine Learning**

A dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Science in Computer Science

In

**The Queen’s University of Belfast**

By

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# Declaration

# Acknowledgements

I’d like to thank:

* My project supervisor **Philip O’Kane**, for his guidance, expertise and patience throughout the course of this dissertation.
* The online community at **VirusShare** for their help in providing me with access to their online malware repositories used in this dissertation.
* My family for their time and support over the course of this final year dissertation.

# Abstract

An important factor in risk assessment is categorisation of malware and its behaviour. It should be noted, a high number of new malware types does not necessarily imply high risk, as malware such as adware does not constitute a high risk. However, a low number of new signature variants does not indicate a low risk, as the new malware signature may relate to a rootkit. Malware programs are often categorised based on Propagation, infection mechanism, Self-Defence (concealment/evasion) or Payload (Criminal Software functionality).

When malware is correctly categorised, it enables an assessment of the risk associated with particular types of malware attacks, thereby enabling Security Operation Centres (SOC) to focus on the highest current threat. Many SOCs have adapted malware categorisation according to type, family and strain is a difficult task and may be impossible to achieve fully. The result is that 66 different AV scanners (VirusTotal) often produce different results, adding to the confusion and impact the ability to assess malware attacks. Therefore this investigates new methods of malware classification that will improve the ability to determine risk assessment of malware. A dynamic runtime dataset (PE file execution) will be mined using unsupervised/clustering algorithms to identify new methods of malware categorisation based on API call structure, which hopefully provides insight to malware risk assessment.

The project will involve:

* Study current publications about dynamic malware analysis techniques
* Establish a run-time environment that can be used to create a programme execution trace dataset (such as cuckoo)
* Write a parser to extract features from the dataset. A literature review is required to determine those features that may yield the best machine learning features.
* Use machine learning clustering algorithms to categorise malware into a cluster that correlates its: risk, family, structure, etc.
* The data mining should be repeated for multiple malware family/categories to determine the optimal category definition.
* Develop and implement an algorithm for measuring agreement/different between existing labels and the new label sets (novel labelling).

The project code repository can be found on the Queen’s University EEECS GitLab [1].

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# 1.0 Introduction and Problem Area

## 1.1 Introduction

Malware: any malicious program or code that is harmful to computers.

With an expected, 20 Billion Internet-connected devices to come online by 2020 [2], protection against and identification of Malware is becoming more important by the day. The average cost of a malware attack on a company is $2.4million and the cost in time of a malware attack is 50 days [3].

It’s clear that Malware is becoming even more varied, with the NHS Ransomware attack spanning off multiple clones of the WannaCry virus, G Data Software estimates that in 2017 alone there were 7.41 million new malware specimens [4].

The cost and rate at which malware is growing make this field one of the most important in the Computer Science industry. Current methods of analysing malware are not proving useful for this ever-changing field. Static Analysis is prevalent, but the major downside is that it doesn’t protect against zero-day attacks or new strains. Even polymorphic code can fool malware detectors that rely upon Static Analysis.

Machine Learning algorithms using dynamic analysis provide a viable alternative to this limitation, by basing their result on the behaviour of the specimen, the model theoretically can predict not only whether it is benign or malicious but could also be used to classify what family of malware the specimen belongs to.

The goal of this report it to provide an in-depth look into how we could use machine learning in the future to classify malware. The report will look into different methods of malware analysis techniques, it will then document the process of setting up a Cuckoo Sandbox environment that will allow us to analyse the behaviour of the specimen. This dataset will be used with a machine learning algorithm to predict what type of malware (or benign) a specimen is. This process will be repeated to determine the optimal category definition.

## 1.2 Malware Types

As this dissertation will focus on identifying malicious files, an enhanced overview of different types of Malware is required, in this section is a descriptive overview of the main types of Malware that are active today. Later on, in this dissertation will be an overview of the specific malicious families that will be tested.

### 1.2.1 Trojan

A Trojan Horse, commonly referred to as a Trojan, is a virus that is often disguised as legitimate software. It’s called a Trojan due to the method of attack used by the Greeks in the Trojan war, the Greeks gifted a huge wooden horse that concealed an army. This parallels the attack method used by the Trojan Virus, the payload that would do the damage is hidden in a legitimate program [5].

A cybercriminal would often use social engineering to spread a Trojan Virus. Usually, a victim would have to click on a fake link or email that would redirect the user to a webpage often designed in the style of the legitimate counterpart. Once the user downloads and launches the file, the Trojan may execute [6].



Figure 1. Example of Flash Player Trojan Webpage

In Figure 1above you can see a webpage that looks identical to the Adobe Flashplayer download page, however in this example, the webpage is from a website called flesh-updates-max.com, this would be set up by the cybercriminal. This attack method would catch out most unsuspecting users.

The Trojan horse, when on your system can do many things, most would be designed not to alert the user to the Trojan Horses presence. For example, Trojans can work as spyware when they’re working like this, they would capture the user's credit card details, passwords and other information that could be valuable to sell on or exploit. Another way a Trojan Horse can cause damage is by using your computer as part of a botnet, this can cause damage to other users, particularly when performing a Distributed Denial of Service attack. The DDoS attack would work with other computers and devices on the botnet to overload a target's network. The target of this attack could be anyone from a single person up to a multinational company, recent examples of this attack are the Boxing Day attacks on online game services such as Xbox Live and PlayStation Network. Being part of a botnet can put the user in great trouble as cyber-attacks are often detected through the originators IP address [6] [7].

### 1.2.2 Worm

A Worm is a virus that works by copying multiple instances of itself and infecting other computers within the network. The key indicator to a system becoming infected by a Worm is the when System Resources start to consume a large number of resources, this slows down the system. The reasoning for this is that the worm will often infect parts of the operating system itself meaning that to an untrained eye all that would be seen is a system resource being used excessively [8].

The Morris worm is often credited as becoming the first widespread use of a Worm virus. Created accidentally by Robert Tappan Morris in November 1988, it was meant to be research into understanding how a Worm could spread quickly. When a Worm looks for a new system, it sees if there is or was a Worm previously on that system, System Administrators realised they could respond to the Worm’s requests with a simple “Yes” and the Worm would not try to infect the system. Morris programmed the worm to infect, even if a “Yes” was issued one in seven times. This is the reason why the Worm infected so many computers, around 10% of the internet is often suggested. This is an example of how quickly a Worm can infect systems as well as how a Worm can use vulnerabilities in system functions to propagate [9].

The most common infection method of a Worm is via a software vulnerability. For example, the Morris Worm mentioned above used a vulnerability in the Unix Sendmail program as well as weak passwords on systems as it’s attack vector [10].



Figure 2. "Self-Retweeting Tweet"

Less sinister Worms, like the “Self Retweeting Tweet” in Figure 2, used Cross-Site Scripting on Twitter as an attack vector. This exploited a vulnerability in where Twitter would display the *<Script>* HTML tag as code rather than text. This resulted in a JavaScript code snippet being run that searches for the retweet button and presses it. As the JavaScript code was embedded in the Tweet, this would be executed whenever it appeared on a user’s feed. Although this was not used for a serious offence, it highlighted that this form of Worm could be used in a more serious manner, performing any browser function or even downloading files as a user without them knowing [11].

Worms can often be used as transportation methods for other types of Malware, for example, the WannaCry Ransomware attack used a Worm as its primary transportation method [12]. By exploiting a vulnerability in the way Windows handles the SMB Protocol it was able to propagate across wide networks.

### 1.2.3 Ransomware

Ransomware is any type of Malware that attempts to stop a user from using their system and demands payment in exchange for the release of this system [13].

There are various ways this can be achieved [13] [14]:

**Locker Ransomware** or **“Law Enforcement” Ransomware** often forces the user into paying out a fee to use their computer. WinLock, created circa 2007, would lock the user out of their computer by displaying pornographic images in full screen, the method of paying this fee was via SMS text message.

Another variant of this type of Ransomware is Reveton which would fool victims into thinking their computer had been took over by the FBI or Interpol and the only way to get access back was to pay via a prepaid card.



*Figure 3. Reveton Malware Screen*

This payment could range from $100 to $3000. It was successful as the average user would not know what to make of the message and would genuinely believe they are being investigated.

**“Scareware”** Ransomware used the simple tactic of telling users their computer is infected.

A common example is to pose as a legitimate software company and tell the user there is a fee for getting rid of the malicious files.



*Figure 4. Example of Scareware Ransomware*

If the user decides against protection the ransomware is offering then they are bombarded with pop-ups until they decide to pay. Usually the files are safe, however, it gets the user through the annoyance of pop-ups and the inability to use their computer.

**Encrypting Ransomware** uses an encryption technique to lock the user out of their files. It then demands money for the unlock of these files.



*Figure 5. Screenshot of WannaCry virus and background*

An example of this type of malware is the WannaCry attack. When infected, the WannaCry virus would work through all the user’s files encrypting them with a hybrid of RSA and AES encryption [15]. This meant that a user’s files were encrypted and irretrievable without a decryption key. A message would then be displayed, telling the user that their files were encrypted and that they had to pay a fee to get them unlocked, seen in Figure 5. Handily, the creators of WannaCry were willing to help by providing the encryption key for $300 in BitCoin. Due to BitCoin’s anonymity, it meant the creator was difficult to track down [12]. The damage from this Ransomware was insurmountable, with companies having to decide whether the data was worth the risk of losing or they should risk paying the fee in BitCoin without the solid promise of a decryption key being provided.

### 1.2.4 Keylogger

A keylogger is any tool or function that captures a user’s input and then sends it or stores it unbeknownst to the user. With a bad actor behind a Keylogger, it can be used to syphon off users passwords, credit card details, and other personal information. A fake phishing email could be used as a primary point of infection with the user clicking on a malicious link that downloads the executable file and runs it [16].



Figure 6. Example KeyLogger Interfaces

There are consumer-facing Keyloggers that can be bought on a monthly subscription. One keylogger shown in Figure 6 can be used to automatically record KeyStrokes, Websites Visited, as well as the Microphone and Webcam [17]. Keyloggers may also be used as part of physical hardware, as one news outlet has reported, Keyloggers are being used by at least one student to record exam and test questions typed into an unsuspecting teachers’ computer. These devices can be bought for as low as $40 and look exactly like a normal USB thumb drive. Sometimes they can be installed into the keyboard itself [18]. This attack vector is the most open to consumers with products being directed towards the curious.

## 1.3 Machine Learning

### 1.3.1 Supervised Learning

### 1.3.2 Unsupervised Learning

## 1.4 Analysis

This project will require analysis of the Malware Files to compile the Dataset used for Machine Learning. There are two main types of analysis, Dynamic and Static, these are then tied together and utilised in an open source product called Cuckoo.

### 1.4.1 Dynamic Analysis

### 1.4.2 Static Analysis

### 1.4.3 Cuckoo Environment

The Cuckoo Environment is an open source automated tool that runs both static and dynamic analysis on samples passed to it. It works through either a command line interface on the Cuckoo server or via the use of the Cuckoo Web UI, for this dissertation we will be looking at the Cuckoo Web UI.



Figure 7. Cuckoo Web UI

The Cuckoo Web UI provides a graphical user interface that the user can use to submit samples as well as check and download the report generated once analysis has been completed. As well as this, a REST API is also provided that allows for the remote submission of samples as well as the downloading of reports as above [19].

The Cuckoo Environment carries out Dynamic Analysis and Static Analysis with the use of a Virtual Machine. This Virtual Machine is created by the user and allows for customization to suit the users needs, for example, if the user wants to diagnose only Java files the Virtual Machine would have a basic copy of Windows 7 with just Python and Java Run Time Environment installed. In the section 3.1.1 Cuckoo Environment more detail will be provided on the design considerations on the Virtual Machine needed for this project.

# 2.0 Solution Description and System Requirements

## 2.1 Solution Description

## 2.2 System Requirements

# 3.0 Design

In this section, a general

## 3.1 Architectural Design

## 3.2 User Interaction

ldld

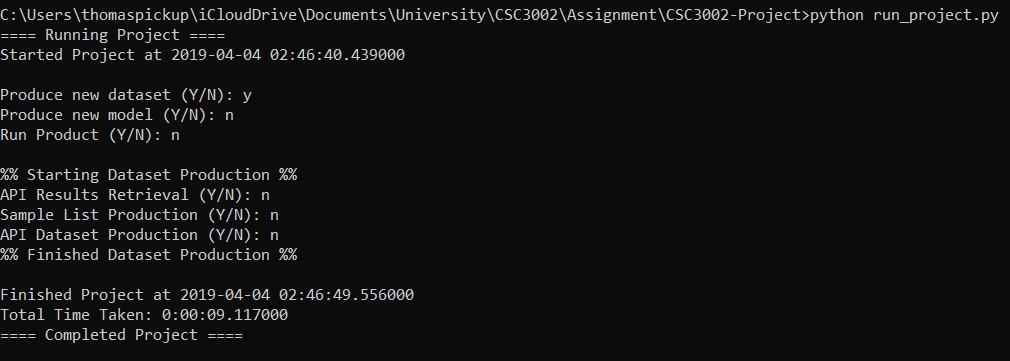


Figure 8. Design of User Interaction

## 3.3 Software System Design

There are three main parts to the system that will be developed. The first part is a cuckoo environment, this will take in an executable file and run it, making a report of the API Calls amongst other pieces of information. The next part of the system is a parser, this will take in the JSON file that has been created by the cuckoo environment and will extract features from this creating the training dataset. The final part of the system is the actual Machine Learning mind. It will be trained using the dataset created previously and will be able to take in a set of API Calls and predict the family of malware the executable belongs to.

### 3.1.1 Cuckoo Environment

The first part is the Cuckoo environment that will perform dynamic analysis on the specimens, this will output a JSON report.



Figure 9. Example of Cuckoo Environment

The environment will consist of a

The Windows 7 virtual machine will be used to run the specimen file. This will allow the Cuckoo Host to perform dynamic analysis, looking at what that file is doing when activated. After it has finished executing, the Cuckoo host will generate the JSON report.



Figure 10. An example of the JSON reports collection.

Out of this report, we are interested in the API Calls. API stands for Application Programming Interface, these are functions in DLL files that an executable would run to perform various system tasks.



Figure 11. Example of API Call in JSON File

In the JSON report, we can see a whole host of details about what the process, in this case, a malicious file called “stats.exe” is trying to do on the computer. In this case, it is running an API called NTAllocateVirtualMemory.

From there will we will parse the collection of JSON files into one. From there we will be able to apply a machine learning algorithm.

### 3.1.2 Parser

The job of the Parser is to essentially make sense of the JSON files generated by the Cuckoo Environment, it will work in two parts

### 3.1.3 Machine Learning

## 3.4 Key Design Decisions

### 3.4.1 Malware Chosen for Analysis

In Section 1.2 Malware Types is a brief overview of the most prominent malware types that are affecting users today.

#### 3.4.1.1 Benign Files

#### 3.4.1.2 CryptoRansom

#### 3.4.1.3 InstallCore

#### 3.4.1.4 Mediyes



Figure 12. Example of Install Core Installation Screen

djdjdj

#### 3.4.1.5 Generic WinPE

#### 3.4.1.6 Zeus / ZBot

[20] [21]

### 3.4.2 Machine Learning Algorithm

The Machine Learning Algorithm is one of the most important design decisions.

# 4.0 Implementation

## 4.1 Use of Supporting Tools

For this project, I needed to use plenty of Supporting Tools and Languages to develop this project. Below is listed the tools and languages that were used in the making of this project as well as the development environment used to create the code.

### 4.1.1 Languages Used

For the development of this project, there was a need for both a scripting language to automate the different subsystems as well as a language aimed towards data science. For this purpose, Python and R were chosen.

I decided on Python as the scripting language because of its ease of use as well as the fact that it was built with scripting in mind. For the Machine Learning portion of the project, I chose R, this is because of its advantages when manipulating large datasets as well as the inbuilt libraries that are provided with R (4.4 Use of Software Libraries).

As a note, Python also contains great support from pre-existing libraries to be used for Machine Learning, however my experience with R in the CSC3060: Artificial Intelligence and Data Analytics module during my final year gave R a slight advantage over Python.

### 4.1.2 Development Environment

The project was developed on a Windows System that leverages Microsoft and Canonical’s recent partnership to run Ubuntu as a subsystem on Windows 10 [19]. This allowed for Cuckoo to be installed as part of this Ubuntu without the need for a separate Virtual Machine to become the Cuckoo Host. As the

For the development of the code, the Atom text editor was used. It is a text editor created by GitHub that has built-in support for Python Syntax highlighting. As it was developed by GitHub it also has enhanced support for the Git Version Control System [20]. It was chosen for its simple layout as well as powerful enhancements.

### 4.1.3 Version Control

During the course of the practical part of the dissertation, the Queen’s EEECS Gitlab service was used to host a Git Repository containing the code used for this project. A private Github Repository was also used as a secondary backup location.

The use of Git meant that both myself and the supervisor could access the project’s codebase at any time. By using the commit system to upload incremental changes, it gave an itemised report of the features and changes that had been made, down to the line of code. This meant that in the event of a bug or issue, it was easy to investigate where and when the bug was created. In the event of a catastrophic failure, a full rollback could be carried out by using the Git system.

## 4.2 Use of Software Libraries

### 4.2.1 Python Libraries

#### 4.2.1.1 os

#### 4.2.1.2 datetime

#### 4.2.1.3 json

#### 4.2.1.4 csv

#### 4.2.1.5 sys

#### 4.2.1.6 shutil.copyfile

#### 4.2.1.7 hashlib

### 4.2.2 R Libraries

#### 4.2.2.1 caret

[21]

#### 4.2.2.2 e1071

[22]

#### 4.2.2.3 Boruta

[23]

## 4.3 Key Implementation Decisions

## 4.4 Important Functions and Algorithms

## 4.5 Description of How Each Component Was Implemented

# 5.0 Testing

## 5.1 Testing Approach

## 5.2 Testing Results

# 6.0 System Evaluation and Experimental Results

## 6.1 Evaluation of Results

## 6.2 Conclusion

# 7.0 Appendices

## 7.1 Malware Used to Train Model

CryptoRansom: 462

Install Core: 464

Mediyes: 71

WinPE: 183

Zeus: 466

CryptoRansom

00f5da8b1b4539508a418bda650f68b0

0bb4967a86f8e4188b7ab808fb87d53f

0acd3589927dae70f36a2ac5be5935e2

00d7bcafe9e33ede2af6cf91cc33e176

0a4158f22b7fcd9e6f7f310a54ae5730

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0c705be975d203c5316bc9886b90cbc0

0cb9b2330524bc422b38e716d8ee9fdf

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Install Core

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