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Literature Review on MSc Project

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Declaration

I declare that this assignment is all my own work and that I have acknowledged all quotations from published or unpublished work of other people. I also declare that I have read the statements on plagiarism in Section 1 of the Regulations Governing Examination and Assessment Offences, and in accordance with these regulations I submit this project report as my own work.

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Abstract

The first ransomware reviewed to public at 1989 kown as AIDS[16] and then since 2005 the ransomware attack has escalated rapidly with the help of cryptography algorithm. [17] GPcode is one of the most famous ransomware family and first version *a* appeared in late 2004.In the year of 2006 version ac appeared and RSA was introduced in the GBcode and the key size after version *ad* has grown very large to defend its encrypted files. [19, 18] For a single year in 2016, 98 new ransomware families was discovered and it is 2 times more than the ransomware family in 2015.[14] Current studies about detecting ransomware have provided effective system to capture ransomware but the successful ransomware attack is still one of the most significant threat to individuals and organisations.[20] And recovery method is highly rely on user's backup.[12] The main objective of the project is to provide a detection-recovery hybrid system model and discuss its benefits and limitations. Propose a multiple regression model which evaluate the effectiveness of features and a precise threshold which gives best prediction with low false-positive rate.

Chapter 1: **Introduction**

The very first ransomware known as AIDS Trojan was implemented by Joseph Popp in 1989, after the victims computer been affected AIDS hides directories and encrypts the name of all files on drive C: making system unusable then pop up a dialog and like many current ransomware it asks user to pay to a company called PC Cybrog Corporation to renew users license. With the development of information technology and network infrastructure more capable the attacker behind extortion software no longer confine to individual user but also commercial companies or other organizations, however, the goal of these attackers are mostly the same, asking for a payment.[16]

To prevent ransomware from attacker on the delivery stage has always been a defensive problem, no matter how hard the security practitioner work the adversary always have 0days that never reviewed infiltrate victims device and taint the system, before the malicious code being activated it remain stealth until further instruction therefore a dynamic analysis system is important and necessary to capture malicious behavior once the malicious code being enabled.

Ransomware behaves in a different way from traditional malware and such differences are the keys to learn its behaviour. Chapter 4 of this paper will discuss how these behaviours been used to against itself.

Not only personal computer, lots of commercial service has became victim of ransomware these days. For example Sony, NHS[2] and many public service has been attacked by WannaCry and Shamoon Wiper, caused delay of public service and even financial loss. The system roll-back and recover from back-up image takes long time and effort, to recover from ransomware attack normally require victim to wait for the attacker to release the sevret key. 23 days average time to resolve a ransomware attack[20] is a long time for an ordinary user to wait and if a system which is capable of decrypting and detecting ransomware at the same time exists, than the damaged system will recover instantly causing less damage. Current studies about detecting ransomware have provided effective system to capture ransomware but the successful ransomware attack is still one of the most significant threat to individuals and organisation, during 2017 the ransomware attack was twice as much as it was in 2016[20] and caused millions of lost. The recover mechanism provided by Mattias Wecksten, et al. highly rely on users back up which is not realistic for all users keep backup.[6] By study PayBreak[3](A run time recovery system based on study on WannaCry) I realised it is possible to combine detection and removal mechanism to stop malicious application from damaging the system.

PayBreak is a novel proactive ransomware defensive software against WannaCry. In the paper they hook the encryption function that custom made for the WannaCry and keep the session keys in a safe place then decrypt files after encryption.

The paper is structured as follows. In Chapter 3 I will briefly introduce background information and explain the history and different classes of ransomware. Chapter 4 consists of two parts, the review on previous literature about detecting ransomware and recover from ransomware attack. In Chapter 5, detailed information about the hybrid system will be presented. Limitations and benefits are discussed in Chapter 6. Conclude the paper in Chapter7.

In summary, the main objectives of the project are:

1. To get an overview of current literature and technology.
2. To illustrate the importance and necessity of reducing the ransomware threat.

3. Provide a regression model using different features
4. Provide analysis for the experiment on the regression model
5. Provide a ransomware detection-recovery model
6. Discussion of the system model

Chapter 2: **Preliminary Literature Review**

UNVEIL[1, 15], a novel dynamic analysis system for ransomware detection and behaviour modeling was proposed in 2016, it is capable of detecting both file locker and screen locker using two distinct components. UNVEIL has a filesystem monitoring component which monitoring data buffers, I/O requests, process information and screenshots of desktop before, during and after execution of the malicious software. The data buffer, I/O request and process information is use to compute entropy of a I/O trace, the theory is based on Shannon entropy, a file after encryption or compression will have a higher entropy comparing to file before encryption. By sorting I/O access request on each file the literature believes that a repetitive pattern can be observed on malicious process, in a successful malicious attack, an victim file typically been encrypted and overwritten, for some variant of ransomware the victim file would be delete or duplicated at some point during the malicious process. These operation pattern raise flag of malicious activity on filesystem and along with entropy computation UNVEIL has demonstrated it is a high precision ransomware detecting system. Not only file locker, UNVEIL is able to detect screen locker by taking screenshots of desktop and compute the similarity of the screenshots before and after the execution, if the difference has exceeded the threshold set by UNVEIL then search ransomware-related text on the image, UNVEIL claims to have highest 100% precision for entire dataset.

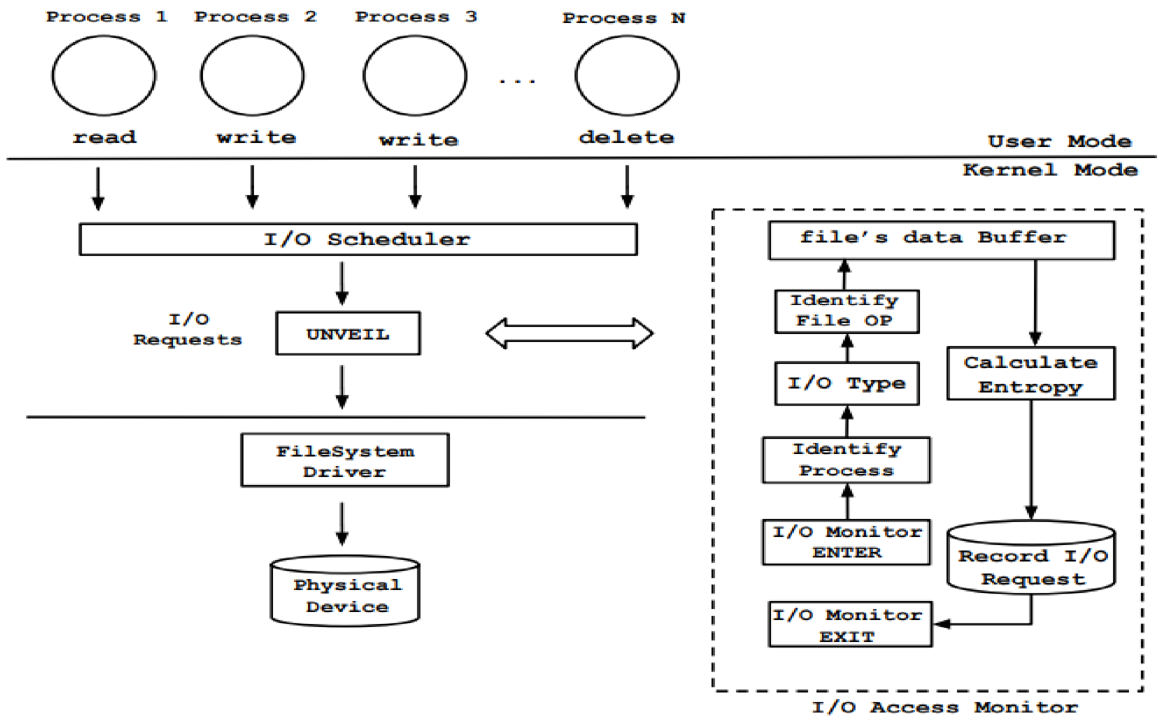


Fig. 1: UNVEIL design overview

The other research team proposed a similar system that dynamically analysis and detect ransomware samples by using same indicators and algorithm (Shannon Entropy), the project is called CryptoDrop[5]. The primary focus of this paper is also the behaviour of ransomwares but the difference is in this research the develop team uses few more indicators to identify malicious process. Recall the UNVEIL computes the entropy of each I/O trace and file read/write patterns to identify file locker and screenshots for desktop locker, CryptoDrop introduced three primary indicators and two secondary indicators and by union these indicators to dynamically identify ransomware. The three primary indicators are file type changes, similarity measurement and Shannon entropy. These indicators each measure an aspect of a files transformation, if all three indicators has been met then a file is likely to have a ransomware-related transformation. The analysis on file operation is more detailed compare to UNVEIL because UNVEIL observe read/write operation patterns but these pattern is likely to be evaded or a innocent process doing harmless operations. For example the attacker could pad user file with low entropy bytes to lower the post encryption entropy and a normal user process is merging file content to original one. CryptoDrop records type change of files and bulk modifications to raise red flag, but a update of software will have the same suspicious activity therefore second indicator is used to prevent this false-positive from happening, by using similarity-preserving hash function to compare a file before and after modification to observe any suspicious activities, one characteristic of a good encryption algorithm is that the cipher text should not review any information from plaint text, although updating file could broadly change the content, the difference will not be as huge as a encryption process and dissimilarity of new file to original file give the system enough reason to suspect the process. Research shows that English text has fairly low entropy because it is easy to predict, after encryption or compression the entropy will be higher because the text contains more higher information per character, thus, if the file has been modified by a process and has higher entropy this entropy indicator will later help to classify the malware sample. File deletion gives little less information on file transformation because not all ransomware delete or unlink user files and benign may create temporary file and delete it but mass deletion of file is indicates some degree of malicious activities. File type funneling occurs when application reads unusual large amount of files as it writes, it is normal for example a Microsoft Word allow user to attach pictures, audios and others document but only output a single document but for a success ransomware attack, the malicious application will output as much file as it reads for a board range of data type. The CryptoDrop state that none of its benign sample has triggered all three primary indicators while vast majority of ransomware does. CryptoDrop claim to have 100% detection rate same as UNVEIL.

Unlike previous researches using controlled environment to analysis malicious application, Daniel Nieuwenhuizen[4] from MWR Lab proposed a machine learning approach to detect and classify ransomware, in the research the author has stated that ransomware detection requires a decision making algorithm which is the result of supervised-machine training and such training process need three crucial components: application samples dataset (both malicious and benign), behavioural indicator which can be quantified for example file entropy trace and a classification which defines training and prediction algorithm, although the research does not show large number of experiment data, it shows the ability of predict a 0day ransomware.

An earlier research[12, 7, 13] proposed a ransomware detection and dynamic analysis system which implemented machine learning component to classify ransomware and ordinary applications, their machine learning component consists a feature selection phase which select the most discriminating features to pass into the Regularized Logistic Regression classifier. The live detection component gathers samples from network from both legitimate website and malicious source such as phishing emails, EldeRan then extract features from these sample and by the help of the classifier the program will output whether the application is malicious. The classification features EldeRan uses is mainly focused on system operations and static information while UNVEIL and CryptoDrop primary focus is the information that carried by the file.

1. Windows API calls (i.e., the traces of invocations of native functions and Windows API calls).
2. Registry Key Operations (in particular, the read, open, write, and delete operations).
3. File System Operations (in particular, the read, open, write, and delete operations).
4. the set of file operations performed per File Extension.

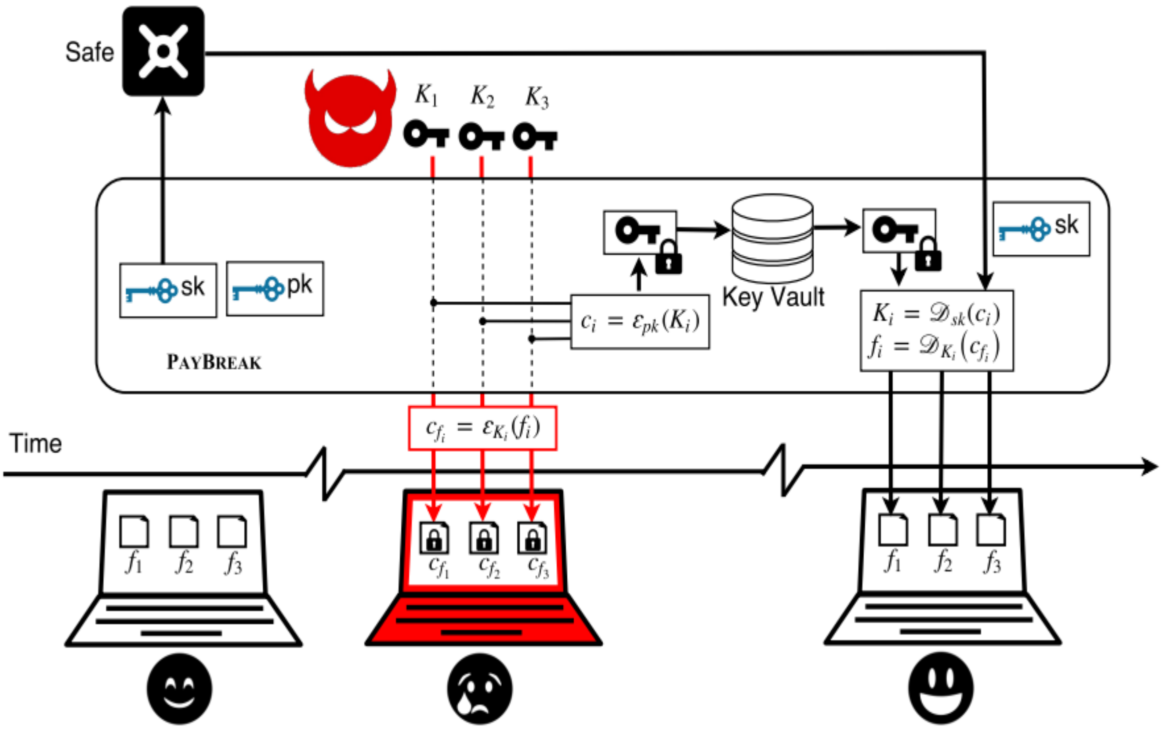
5. Directory Operations (the set of operations performed on directories, in particular the enumeration and creation).

6. Dropped Files (i.e., the set of files that are dropped by an application during installation).

7. Strings (the strings embedded in the binary).

Mattias Wecksten, et al.[6] has proposed a method to recover from crypto ransomware infection by renaming a system process vssadmin.exe (which is necessary for Windows system recovery) and recover after a successful ransomware attack, this method requires victim maintain a proper backup scheme therefore to minimize the damage but if the data is updated in a short time frame with high frequency then this method will only recover the system but not preventing data lost fully the result of recovery is highly rely on users behaviour.

Take a recent example of ransomware attack: WannaCry[15, 8] which caused the hospital in the UK paralysed for a short period and over 100,000 personal device been affected. PayBreak[3] was designed to recover from the damage caused by this crypto-based ransomware, WannaCry uses self-compiled AES-128-CBC cryptography system to generate keys to encrypt infected files. The idea of this program is to monitor the keyGen() and the victim filesystem, record the key generated and corresponding file and keep this record in an vault and this key-file pair will be used to recover file after the attack. It does not rely on users backup and the author also stated that it is unrealistic for all user to use backups. And given the significant growth of ransomware attacks to personal computer[14, 20], I believe that to reduce the lost of property ransomware needs to be detected, terminated and recovered more ef-



ficiently.
Fig.2: PayBreak's process flow

By reviewing literature, I realise that many effective systems have been developed to detect and analysis ransomware while recovering system has very little improvement. PayBreak has demonstrated the ability to defeat most ransomware families but as process flow diagram shown, the decrypting mechanism will not work until ransomware finish encryption and if malware is specifically aiming to evade or overwrite PayBreaks executable file then the decryption will not work after the encryption. Thus I believe that detection system running simultaneously is necessary, stopping malicious code before it finishes attack system potentially reduce the recover time and gives another layer of protection to defend the system for a successful attack which managed to infiltrate the system.

The indicators CryptoDrop[5] has introduced to detect ransomware demonstrated strong ability to detect ransomware activity and merging these indicators with other features used by other similar[1, 15] or machine-learning based system[12, 7] in one model could potentially benefits the outcome of ransomware detection, therefore an experiment will be conduct in the proposed paper to identify any improvement or deterioration.

Families	# Samples	Previously defeated	Defeated by PAYBREAK	Defeated	Library	Algorithm
Almalocker	1	✓ [1]	✓	✓	CryptoAPI	RSA+AES-128-CBC
Cerber	14	✓ [4]	✓	✓	CryptoAPI	RSA+RC4-256
Chimera	1	✗	✓	✓	CryptoAPI	RSA+AES-256-ECB
CryptoFortress	2	✗	✓	✓	CryptoAPI	RSA+AES-256-ECB
CryptoLocker	33	✗	✓	✓	CryptoAPI	RSA+AES-256-CBC
CryptoWall	7	✗	✓	✓	CryptoAPI	RSA+AES-256-CBC
CrypWall	4	✗	✓	✓	CryptoAPI	RSA+AES-256-CBC
GPcode	2	✓ [38]	✓	✓	CryptoAPI	RSA+AES-256-ECB
Locky	7	✗	✓	✓	CryptoAPI	RSA+AES-128-CTR
SamSam	4	✗	✓	✓	CryptoAPI	RSA+AES-128-CBC
Thor Locky	1	✗	✓	✓	CryptoAPI	RSA+AES-128-CTR
Tox	9	✗	✓	✓	Crypto++	RSA+3DES-128-CBC
DXXD	2	✓ [5]	✗	✓	Unknown	XOR with Constant Key [5]
MarsJokes	1	✓ [12]	✗	✓	Unknown	ECC+AES-256-ECB [12]
PokemonGo	1	✓ [9]	✗	✓	.NET Crypto	AES with Constant Key [9]
Troldesh	5	✓ [13]	✗	✓	Unknown	RSA+AES-256-CBC [13]
VirLock	4	✓ [15]	✗	✓	Unknown	XOR with Constant Key [15]
Androm	2	✗	✗	✗	Unknown	RSA+AES-256-CBC [11]
Razy	3	✗	✗	✗	.NET Crypto	AES-128[9]
TeslaCrypt	4	✗	✗	✗	Unknown	ECC+AES-256-CBC [16]
20	107	8	12	17		

Fig.3: Ransomware samples

2.1 Methodology

Many approaches have been proposed recent year that aiming to analysis and detect malicious software. The primary research method for the system model is literature review and extract component which can be implemented in the system model. The thesis will first review various types of detection study such as dynamic-behaviour analysis and machine learning based behaviour analysis(Dynamic and static). I obtain available literature through on-line resources(search engine, IEEE) and public research projects. Tools which help to finish the experiment part of the project, for example, file generators, file change monitor from GitHub.

Based on the understanding of previous literature, a multiple regression model will be developed to help modeling the hybrid system, in this stage of study, ransomware dataset is needed for the regression model but variables for the model are missing from the datasets(i.e file entropy value before and after attack), therefore experiment on ransomware sample will be necessary in order to obtain the mean entropy of each ransomware family.

The dataset obtained has 582 samples of ransomware and 942 benign applications, 10 ransomware families, 7 sets of features and total of 30970 features. The 7 sets of features are:

1. API API invocations
2. DROP Extensions of the dropped files
3. REG Registry key operations
4. FILES File operations
5. FILES_EXT Extension of the files involved in file operations.
6. DIR File directory operations
7. STR Embedded strings

This project is mainly focus on file system operations therefore the STR set and REG set will be ignored, and other features such as API:closesocket and API:Http* will be dropped from the dataset. Shannons entropy will be added to the dataset as a new feature, entropy value indicates the information carried by the file, compression and encryption operation on raw file will make the resulting file has higher entropy than before. The entropy e of a file can be computed as:

$$e = -\sum_{i=0}^{255} P_B(i) log_2 P_B(i)$$

$$P_B(i) = \frac{B_i}{total\,bytes}$$

Bi it the number of byte value i in the byte array, this will produces e from range 0 to 8, because the maximum information a byte can carry is 8-bits. The dataset will be processed and visualized in R-studio because it has powerful regression library and provide easy manipulation to dataset. The summary() function returns useful information such as F-statistic and T-value for optimizing the regression model. The regression model denotes as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_k x_k + u$$

Where Xi is the selected features(i.e entropy, number of file deleted). The experiment will be carried out in Windows system on top of an open source malware analysis Cuckoo Sandbox, generating random files with extensions which the most common to user in a designated directory then calculate the average entropy before and after attack as the new feature to the ransomware sample. Due to the scope and time frame of the project monitoring entire file system is not feasible. The program will be written in JAVA.

Chapter 3: **Ransomware**

Ransomware is a piece of malicious software that once infiltrated and installed in personal computer, it takes full control of the device then threat user with damaging files, denial of access to data or operating system. Ransom payment is demanded by the attacker in exchange of unlock the victim device(s), however the promises are not always fulfilled. A traditional malicious software typically would remain stealth after its been delivered to victims system and even when it is triggered, the code itself is designated to draw less attention from system and victim in order to steal information such as bank details, keystrokes of password or using victims device as Bitcoin mining machine. In contrast, the goal of ransomware need it to behave in an opposite way, the malicious code will notify user directly that user being hacked.

3.1 How Ransomware get installed

3.2 Types of Ransomware

Chapter 4: **Defending Ransomware**

4.1 Detecting Ransomware

4.1.1 Dynamic behaviour analysis

4.1.2 Machine learning approach

4.2 Recover from Ransomware

Chapter 5: **A hybrid system model**

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5.1.1 Machine learning based detection module

Multiple Regression Model

Analysis of the features

Experiment and Optimisation

Result

5.1.2 Recover component

5.2 System requirements

5.3 Execution flow

Chapter 6: **Discussion**

6.1 Benefit

6.2 Limitations

Chapter 7: **Conclusion**

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