Honeypot-powered Malware Reverse Engineering

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Abstract

Honeypots, i.e. networked computer systems specially designed and crafted to mimic the normal operations of other systems while capturing and storing information about the interactions with the world outside, are a crucial technology into the study of cyber threats and attacks that propagate and occur through networks. Among them, high interaction honeypots are considered the most efficient because the attacker (whether automated or not) perceives realistic interactions with the target machine. In the case of automated attacks, propagated by malwares, currently available honeypots alone are not specialized enough to allow the analysis of their behaviors and effects on the target system. The research presented in this paper shows how high interaction honeypots can be enhanced by powering them with specific features that improve the reverse engineering activities needed to effectively analyze captured malicious entities.

1 Introduction

Nowadays, an ever growing number of systems and devices interoperate and cooperate over the Internet which has become a huge and very complex open distributed system. Being open is one of the features that brought Internet to the role it plays into the current IT scenario. However, this expose the interconnected services and devices to the risk of being the target of Internet-enabled malicious entities also known as malwares. A challenging goal of the research efforts directed in the Cyber Security field is the devising of effective techniques and tools able to face and defeat the attacks coming from such entities. Hence, it is crucial to analyze and understand a malware behavior in order to identify the vulnerabilities it exploits and to take the suitable countermeasures. Malware activities are often detected a lot of time after the victim system has been violated and then it is very difficult to trace back the actions that have been executed. A malware usually modifies file sys-
tems, starts processes, initiates network connections and steals information. All this actions need time to be understood starting just from a binary file, which is often the only tangible record of the malicious code and which need to be analyzed once it has recovered from the victim filesystem.

A honeypot [12] is a decoy system which aims at looking like a real networked resource to the world outside. It manifests a low or absent protection level so as to draw attackers' attention and to gather information about their behavior while they gain access to and interact with it. Most of the honeypots currently used are classified as having low interaction [8, 10], which means that they host only emulated services. With such a type of honeypots, it is hard to study malware propagation in details because emulating a service behavior is not a simple task and most of these fake services offer only a, somewhat limited, support to network traffic analysis, command execution tracking and file modification tracing. Such type of honeypots are the most diffused, however smartly crafted malwares and skilled attackers are able to recognize them and avoid of being caught or analyzed [13].

On the other side, high interaction honeypots are based on real operating systems. This factor lets the malware or the attacker manifest his behavior completely without being stopped by the lack of unimplemented features which can be present in low interaction honeypots. High interaction honeypots are clearly more difficult to handle because the attack surface becomes very large along the fact that it is nearly impossible to predict the attacker or malware intentions with no previous knowledge.

We argue that enhancing high interaction honeypots by adding reverse engineering instrumentation features will result in a great empowering of malware analysis processes. This paper illustrates the design and the features of HERESy (Honeypot Embedded Reverse Engineering System), a modular high interaction honeypot system whose components work at various levels: file system, network and process execution tracing. HERESy is able to create on-demand an isolated environment for each attacker or malware that accesses it by purposely exploiting the notion of container [14]. For each isolated instance, the system tracks all the attack lifecycle. The attacker or the malware tries to connect to a particular service, if the targeted service is handled by our system, then a proxy intercepts the request and builds on the fly a container redirecting all the traffic to this instance. From this point on all the actions performed by the attacker are tracked and saved on the HERESy logging and storage system.

The rest of this paper is organized as follows. Section 2 presents the architecture of HERESy, the roles of its components and how they work together. Section 3 shows a practical example of a malware being captured by the system and subsequently analyzed. Section 4 draws the conclusions and the future work.

2 HEREsy Architecture

As pointed out in the previous section, the HERESy architecture, depicted in the diagram of Fig. 1, is composed by several modules, each of which is in charge of performing a specific hijacking task on the isolated running containers [14]. The proxy module plays the role of container factory: it builds up on-demand a specialized container on the basis of the protocol over which the potentially malicious remote entity tries to access the system and then it redirects all the subsequent incoming traffic to it. At this point, HERESy begins the hijack: file system modifications are tracked by the filesystem module which exploits versioning control technologies; traffic analysis is performed by the network sniffing module; extraneous binaries, in case they are downloaded by malwares or attackers, are detected by the process execution tracing module. Fig. 2 depicts an activity diagram that models the HERESy execution workflow which handles connections attempts.

2.1 Proxy module

Once a connection attempt reaches the system, if the proxy has been configured to handle the requested service, a fresh new container is built on the fly and all the attacker’s traffic is redirected to it. Each attacker will run and operate inside its own isolated
environment. When the attacker leaves, the environment is destroyed after all the relevant data have been suitably stored. To speed up the build operation, and hence to improve the HERESy responsiveness, an environment for each service is always up and maintained ready to be used.

### 2.2 Filesystem module

One of the main problem with malicious code is that more than often it modifies the content of file system resources. It is possible to track these modifications by writing custom file systems or by hijacking function library calls. However, the former is an hard task to accomplish because of the low level machinery around the host operating system, the latter can be ineffective because, if the malware calls into the kernel bypassing the libraries, interception does not occur at all. The solution devised by HERESy consists in exploiting versioning control software on the existing virtual file system layer. File system resources are shared between the host HERESy system and the current attacked environment. By using file system notification mechanism \[7\], each time a modification, creation or deletion happens, the system triggers the versioning control software which tracks the updates. This technique allows to explore the file system history going backward and forward in time. This indeed is crucial for tracing back the malware behavior from the viewpoint of the action made on the file system. The file system module of the current version of HERESy uses of GIT as a versioning control software and the Linux *inotify* API to handle events \[7\] (see Fig. 2). Previous experiments used FUSE \[1\] as a file system layer, however the integration with docker was hard to achieve. Another project relaying on GIT in a similar way is *gitfs*, a FUSE file system which automatically converts all the changes made into commits \[2\].
2.3 Network module

Traffic generated by attackers or malicious software is of course fundamental to track where the malicious activities starts and where they try to propagate. For each environment a complete network traffic dump is performed, so a clean data representation of the network flow is given to the threat analyst. The system spawns a daemon for each sandbox environment which is built up. The module relays on the libcap library and saves the attacker generated traffic into the classical pcap format. So using the berkeley packet filtering [9] we are able to select just the traffic generated by the target container.

2.4 Process execution module

For each kind of environment all the binaries are hashed and the signatures are saved into the core system memory. Each time a malicious software or the attacker executes a binary, the command is logged. Also, the module performs the binary hash and if the calculated signature is not present into the white list, the module starts tracking the process using the dynamic binary instrumentation [6], so it dumps instructions and memory accesses saving the entire hostile program execution flow.

Figure 4 shows the process execution tracing step. We use for the hashing process SHA512 which is considered strong enough to avoid collisions, so it becomes difficult for an attacker to generate a binary which has the same hash to trick the system.

In practice, we used both CRIU [11] and DynamoRIO [3] in order to trace the process execution and to dump its resources. The following strategy has been employed to alternate our dynamoRIO based tool with CRIU: the process is first run inside the dynamoRIO based tool, which detects whether the process is hostile or not on the basis of the signatures of the executable images used by the process; in the case of a not trusted process, the tool begins to dump all the executed instructions and if detects a memory write it asks CRIU to dump all the process resources and waits for its termination; CRIU receives dump requests by means of a daemon which listen on a socket for messages coming from the dynamoRIO based tool; once CRIU completes its task, it notifies the dynamoRIO tool which then restarts its process instrumentation activities. Each time the hostile process accesses the memory, the tool switching, above described, occurs again.

Currently, we are trying to improve this technique in order to disarm debug-aware malwares which once detect they are into a honeypot try to evade the system, for example by killing themselves.
3 Experiments

HERESy has been tested by distributing it inside a /16 network (i.e. a campus network). Thousands of attacks targeting various protocols have been detected. Among them, the most targeted were FTP, SSH, TELNET, HTTP and SMB. Independently from the kind of attack, the system is able to recognize and log all the spawned commands. If the executed binaries belong to the attacked environment, their execution is just logged, otherwise, i.e. the process is recognized alien, the dynamic binary instrumentation module begins tracing it. All the instructions executed are saved in a separate log for each traced process. Furthermore, an experimental process dumper takes periodic snapshots saving all the information regarding file descriptors, memory, registers, and so on. All the file system accesses, which concern modifications, are saved on a versioning basis. All this workflow allowed to observe almost completely the behavior of various malwares and permitted to accelerate the reverse engineering process. The vast majority of the captured attacks comes from the BRIC area, most of them targeting embedded systems, many others have as target common platforms like x86_64 and others were equipped of multi-platform droppers written in common script languages such as bash, Python, etc. The deployment of HERESy instances in various machines inside this big network permitted to observe that the behavior of some malware is also iterative, in the sense that an attack on a low IP address inside the same network reached high IP number addresses just some minutes later. So, we observed basically that this kind of malware tries to reproduce itself enumerating many IP addresses and searching for the same vulnerability.

3.1 A simple malware

During the testing phase of HERESy, we captured a series of malwares. In this section, we will describe the most simple of them. We analyzed the his behavior by extracting the data captured by HERESy. The malware entered the honeypot through a brute force attack to the SSH protocol. Once it guessed the password, it reproduced itself on a specific location of the file system. So we tracked the copy of the malicious binary inside our file system replica. Then, the network module sniffed all the connections to a malicious FTP server performed by the malware and controlled by an attacker. By looking at the memory dump of the malware, we found out a behavior that it was not observed during the very first static analysis phase. The malware had various encrypted strings representing well known document extensions. Observing the memory into his various modifications states revealed those strings and looking at the dumped code accessing this memory block we observed the intention to search and upload the files matching such extensions. When the malware ends its execution it deletes itself and his copies from the files system, however the HERESy instrumentation allowed us to save these binaries and the other replicas. The behavior of the captured malware is sketched in the activity diagram of Fig. 5.
3.2 Real Time Monitoring

To observe the behavior of HERESy we developed a centralized system to gain and transmit information about its operation. Each module (except the networking module) sends updates about new connections, command executed and file modifications to a daemon which in turns acts as a web server. Our clients connects to this daemon through WebSockets [15] and monitors in real time all the actions performed by attackers/malwares inside the isolated environments. Using this strategy we can observe the overall system status and also it come useful to debug its behavior. So we deploy multiple instances of the HERESy architecture inside our huge network using our cloud or machine which are up for the purpose and we are constantly aware of the threats which menace our institutional infrastructures. The information generated by the modules is also stored into a NoSQL database [4] in order to allow to query off-line the system and make statistics about the attacks received every day. The employed database is ElasticSearch [5] because of its good performances. We observed that it is able to execute a thousand of writes per seconds without a significant impact on performance of the machine used for storage purposes.

4 Conclusions

In this paper we presented HERESy, a honeypot software system born to support and enhance the effectiveness of malware reverse engineering activities. HERESy is able to create on-demand high-interaction isolated environment which are exploited to capture malware behavior and store the byproducts of its activity. HERESy features have proven to be useful tools for easing and powering malware analysis tasks.

Future improvements, which are already in experimentation, are adding support for process memory dump at specific points of execution and the possibility to navigate through these snapshots in order to restore a particular status of the malicious process inside the environment. Another characteristic on which we are currently working on is a procedure to automatically generate signatures for new malwares and communicate these to IDS in order for them to automatically recognize and block future attacks. During the HERESy development and the subsequent testing phase we captured a huge number of malwares and we studied their behavior using the above cited instruments. The main features of HERESy, i.e. the ability of dumping file system modifications and the network and process tracking, greatly relieved our work on threat analysis.

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