Are current antivirus programs able to detect complex metamorphic malware? An empirical evaluation.

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Abstract. In this paper, we present the design of a metamorphic engine representing a type of hurdle that antivirus systems need to get over in their fight against malware. First we describe the two steps of the engine replication process : obfuscation and modeling. Then, we apply this engine to a real worm to evaluate current antivirus products detection capacities. This assessment leads to a classification of detection tools, based on their observable behavior, in two main categories: the first one, relying on static detection techniques, presents low detection rates obtained by heuristic analysis. The second one, composed of dynamic detection programs, focuses only on elementary suspicious actions. Consequently, no products appear to reliably detect the candidate malware after application of the metamorphic engine. Through this evaluation of antivirus products, we hope to help defenders understand and defend against the threat represented by this class of malware.

1 Introduction

Malware is a generic term used to describe all kinds of software presenting malicious behavior. In terms of security of computer users, malicious software is considered as major threat. Many detection programs are based on form detection relying on byte signature to identify a specific malware. To circumvent these detection tools, attackers have developed specific counter-measures, giving birth to more and more advanced code mutation techniques. Among all these techniques such as encryption and polymorphism, metamorphism is certainly the most advanced one. Metamorphism consists in canceling as much as possible any fixed element that would represent a potential detection pattern according to byte signature matching. Here, we consider metamorphism as a special class of self-replicating program.

From a theoretical point of view, few results exist concerning the detection complexity of code mutation techniques, even if these notions have already been

evoked in F. Cohen's seminal works [10]. Recently, D. Spinellis has proved [24] that the detection of bounded-length polymorphic viruses is an NP-complete problem. Then, E. Filiol has formalized metamorphism by the means of formal grammars and languages [16] to extract three classes of detection complexity according to the corresponding grammar class identified by N. Chomsky [7, 8]: polynomial complexity for class 3 grammars, NP-complexity for class 1 and 2 grammars, and undecidablility for class 0 grammars.

From a practical point of view, very few metamorphic malware are known to exist thanks to the difficulty of writing such complex programs. The most advanced metamorphic virus known is MetaPHOR [13], for which 14 000 lines of assembly instructions (90% of the code) are dedicated to the metamorphic engine. Despite this complexity, this virus only uses simple instructions rewriting rules to change its forms. Thus, it was shown that this malware belongs to class 3 grammars and can then easily be detected [16].

In this paper, we focus on metamorphic malware detection. More precisely, it was suggested in [16] that a metamorphic malware presents few limitations from an execution context point of view, whereas any antivirus tool is bounded by severe time constraints. To take advantage of this time constraint, a new class of obfuscator denoted τ-obfuscator was introduced in [3] to delay code analysis for a predefined time τ. Our work aims at evaluating current antivirus products confronted by possible future threats that metamorphic malware could represent by taking advantage of the time-answer constraint from a detection point of view.

The contributions of this paper are the following:

- We propose a design of a metamorphic engine corresponding to a future possible threat that antivirus tools must deal with.
- We practically evaluate current malware detection products confronted by the well known worm MyDoom [14] after application of the metamorphic engine.

This paper is organized as follows. In section 2 we introduce metamorphic malware detection and its link with code obfuscation. In section 3 we present the description of our metamorphic engine. In section 4 we evaluate detection tools with the application of the metamorphic engine to a real worm.

2 Metamorphism and obfuscation

Metamorphic malware and code obfuscation techniques are narrow linked subjects. Indeed, as mentioned in [9], a metamorphic code can be viewed as an obfuscated program. So, detecting such a program leads to the ablility to deobfuscate it. Before describing our metamorphic engine approach, we briefly introduce these two fundamental notions of obfuscation and metamorphism.

Barak et al. informally defined an obfuscator $\mathcal{O}$ as a probabilistic compiler taking in input a program P, and producing a new program $\mathcal{O}(P)$ with the

same functionality as P but being unintelligible [2]. Starting with this informal definition, they proposed a formal one based on oracle access to program. Then, they proved that no obfuscator exists according to this definition. Recently, another formalization of obfuscation, based on the notion of oracle programs led to the same impossibility result [3]. Despite these theoretical results, practical obfuscation has been intensively investigated to protect intellectual property and especially concerning high level languages such as .NET and JAVA [11, 12]. Indeed, with such languages, the resulting code contains all the information allowing us to easily retrieve the original program such as names, structures, data types, etc.

Concerning malware, obfuscation schemes were used to change the syntactic structure of the code to escape simple form detection techniques such as pattern matching. Metamorphic malware traditionally used basic obfuscation transformations modifying either data flow (rewriting rules, registers exchange) or control flow (branch insertions) to avoid pattern detection [5]. The choice of such basic obfuscations transformations was clearly evoked in [21] as follows: *"... a metamorphic virus must be able to disassemble and reverse itself. Thus a metamorphic virus cannot utilize [...] techniques that make it harder or impossible for its code to be disassembled or reverse engineered by itself."* In agreement with this point of view, many static detection approaches based on de-obfuscation techniques (such as data flow analysis [1], slicing [26]) were developed [6, 29, 23]. However, more complex obfuscation schemes based on control flow modifications such as [5], could thwart these static detection techniques. Being aware of static detection limitations, an increasing number of antivirus products consider behavioral detection, which can be divided in two classes [18]. The first one is represented by dynamic detectors relying on sequences of observable events such as system call traces. The second one is composed of static verifiers relying on instruction meta-structures (graphs, temporal logic formula). In all cases, a behavioral description comprises temporal aspects. In [19], the coverage of behavioral detection engines was assessed with the introduction of functional polymorphic engines. Briefly, a functional polymorphic engine was defined as a malware embedding a non deterministic compiler to dynamically produce functional variants from a high level malware description. In this paper, we focus on the temporal constraint aspect by investigating the new threat that τ-obfuscation-based metamorphic malware could represent on antivirus products.

3 Metamorphic engine description

From a high level point of view, a metamorphic engine offers a self-replicating property which has to produce a syntactically different but semantically equivalent mutated form. A generic description of metamorphic binary-transformation is given in [28]. Here, we present our metamorphic engine self replication process, which acts in two steps:

1. In the first step, known as the obfuscation step, the engine changes its form to escape detection algorithms. The main purpose of this step is to avoid static detection approaches such as [9, 6, 4]
2. In the second step, the already obfuscated engine reverses its own obfuscation transformations to come back to its original form. This step, known as the modeling step, allows the engine to re-obfuscate itself. It is worth mentioning here that the reverse engine in charge of the engine modeling is itself obfuscated otherwise it could be easily detected by pattern matching.

This section presents the design of our metamorphic engine. More precisely, in 3.1, we focus on the obfuscation step. In 3.2, we describe the engine information needed to ensure its modeling. In 3.3, we describe the whole replication process. Finally, in 3.4, we explain how to produce a metamorphic binary starting from the sources of an original program.

3.1 Obfuscation step

This section presents the obfuscation step in the self-replication process of our metamorphic engine. The obfuscation process has to work on both the code and the data in a program at the same time .

Code obfuscation The general code obfuscation scheme detailed hereafter is inspired from [5]. Let P be a program composed of n consecutive instructions $(I_1, \dots I_n)$. This program P is split in k consecutive blocks $P = (P_1, \dots, P_k)$. Each of these blocks contains a random number of instructions. Let σ be a random permutation over the set $[1, n]$ used to randomize P_i blocks. For each P_i block, we define a new block $P'_{\sigma(i)}$ with its transition. This approach is illustrated in figure 1. On the left hand, we have an original program P composed of ten instructions whose control flow is represented with arrows. The boxes illustrate the random splitting of P in five blocks. On the right hand, the new program P' is obtained by permutating P_i blocks according to σ.

It is easy to see that whatever the *Control Flow Graph* (CFG) of program P looks like, the execution remains the same if after executing the last instruction of block $P'_{\sigma(i)}$, the first instruction of $P'_{\sigma(i+1)}$ is reached. These transitions, represented with dashed arrows in figure 1, are the key points of the obfuscation scheme. For instance, considering the block containing instructions I_1, I_2 and I_3, the execution of instruction I_3 must lead to I_4 as illustrated in P and P'.

As the splitting is randomly generated, no syntactic pattern can be directly extracted, according to this approach. Moreover, it was proved in [5] that the static detection of metamorphic malware employing such a technique in a multi path assumption, is an NP-complete problem. In static analysis, the multi path assumption translates the difficulty of branch target evaluation. Indeed, considering a branch instruction, represented as follows, "`if` (*condition*) {*branch1*} `else` {*branch2*}", the *condition* evaluation can be highly complicated by the use of opaque predicates as detailed in [11]. Informally, a predicate is said to be opaque if it has a property which is known to the obfuscator, but which is

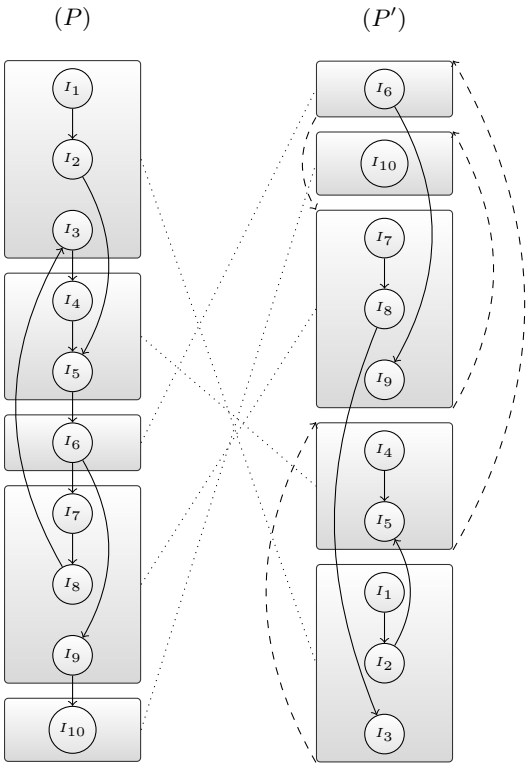

Fig. 1. Illustration of the obfuscation scheme. Original program P on the left and the obfuscated program P' on the right.

difficult for the deobfuscator to deduce. Thus, if a program cannot determine the *condition* value, then it has to consider the two branches as possibly executable paths. However, the creation of opaque predicates which are difficult to resolve is a hard task [11]. It is also the case from a metamorphic malware point of view. Instead of focusing on opaque predicate creation, we deliberately choose to take advantage of the malware time detection constraint evoked in [16] and [3].

In other words, each block P' transition is τ-obfuscated by dynamically computing the target destination. Several approaches were detailed in [3] to τ-obfuscate programs. In order to facilitate time measurement, we decided to use an obfuscated loop which computes the destination address. So, for the rest of the article, the τ delaying time is measured thanks to the number of iterations in the transitions loops. Here, we only present a sketch of our τ obfuscation design for two reasons. First, from an ethical point of view, giving a complete description of the implementation could lead an attacker to directly write such a metamorphic engine, which is a non affordable risk. Second, according to the experiment result, τ-obfuscation seems to have no impact on current detection tools. So, τ-obfuscation does not appear to be the key component of the meta-

morphic engine. To achieve τ-obfuscation, the key idea consists in choosing a random function f for each transition. Then the target address is determined by the number of compositions of this function f. Of course, this simple loop is obfuscated using classical techniques such as rewriting rules to avoid any patterns.

Data obfuscation A simple way to protect data is encryption as used in polymorphic malware, for example. In this case, the malware execution begins with a (polymorphic) decryption routine acting on the rest of the code and data. After this decryption, all the code and data represent a possible detection pattern. Thus, a practical detection ([25] pages 451-458) consists in emulating the decryption routine to come back to classical pattern matching detection techniques on the decrypted program.

To avoid such a detection, a better approach consists in decrypting data just before they are used and re-encrypting them just after. By data we mean a block of data which cannot be divided without a loss of semantics (for instance, a string, a switch table, a structure,etc.). This technique known as on-the-fly encryption is commonly used in malware protection (DarkParanoid [20] and W32/Elkern [15]). More precisely, let f be a function taking as parameter a data block, denoted D. Our original program P computes the function $f(D)$. Let E be a symmetric encryption scheme. We modify the original program P to get the program P' defined as follows: P' contains (in its binary representation) an encryption key K and the encrypted data $C = E_K(D)$. Then, during its execution, P' starts with the decryption of the encrypted data C. After that, P' computes f with the previous decrypted data D. Finally, P' re-encrypts this data D with the same key K. So, without the knowledge of the key K, the protection of D is guaranteed by the robustness of the encryption scheme.

The data obfuscation process consists in randomizing the key value and its position in such a way that only the piece of code which previously had access to this key has access to the new one. The new program contains the new encryption K' and the new encrypted data $C' = E_{K'}(D)$. In this case, the decryption key can only be discovered by disassembling the code. Thus, the robustness of data obfuscation directly relies on the robustness of the previous code obfuscation guaranteed by τ-obfuscation.

3.2 Modeling Step : the necessity of extra information

This section presents the modeling step in the self replication process of the metamorphic engine. From now on, we consider that the metamorphic engine M is already obfuscated, as presented in section 1. The obfuscated metamorphic engine is denoted M' in the rest of the section.

From its entry point, M' must be able to extract its structure in memory in order to re-obfuscate itself. Without any particular information on the way it was produced, M' would have to disassemble itself as any other external program would have to. In this case, the engine would be confronted with the difficulty

of reversing its own obfuscation scheme. So, to easily reverse its own code, M' must embed extra information allowing its de-obfuscation without simplifying the detection.

According to the obfuscation scheme presented in 3.1, coming back to M means recovering the original sequence of code blocks $(M_1, \ldots, M_n)$ and the original data blocks. More precisely, the extra information to be embedded is composed of:

1. the description of the original sequence of code blocks $(P_1, \ldots, P_n)$;
2. the description of data blocks with their corresponding encryption key;
3. the description of memory references.

With these three elements, the metamorphic engine M' is able to come back to its exact original (de-obfuscated) form M. We shall explain the necessity of references. At binary level, each logical element in a program (a block of data, an instruction, an import table entry,etc.) is represented by its address. As these addresses change during each mutation according to the previous obfuscation scheme, the metamorphic engine must be able to find and update these references according to the new position of the corresponding element. Unfortunately, the exact determination of references in a binary program is difficult.

To illustrate this problem, let us consider the following assembly instruction: `cmp eax, 0402000h`. This instruction compares the value contained in the `eax` register with the hexadecimal value `402000`. Considering the metamorphic engine (or any disassembler), the problem consists in determining the semantics of this value. In other words, is it an address or not? Now, let us consider the two following programs described in C language: both of them declared a constant value `MY_FLAG` in line 1 and a global string `Global1` in line 2. The `main` function only declares a variable in line 6, whose value is supposed to be defined later in the `main` function. The key point is the `if` statement line 8 which compares `var1` with `MY_FLAG` in the first source and with `Global1` in the second source.

```
1 #define MY_FLAG 0x402000
2 char    Global1[]="string";
3
4 main()
5 {
6     int var1;
7     ...
8     if (var1==MY_FLAG) {...}
9 }
```

```
1 #define MY_FLAG 0x402000
2 char    Global1[]="string";
3
4 main()
5 {
6     char* var1;
7     ...
8     if (var1==Global1) {...}
9 }
```

Fig. 2. Example of references determination problem.

Considering the particular case where the compilation process places the `Global1` string at address `402000` in the two resulting binaries, line 8 corresponds to the previous assembly instruction. It is worth mentioning that this extreme

academic case is not very probable, but clearly illustrates the problem of the references. Concerning our metamorphic approach, code and data are randomly dispersed throughout the program during the replication. So, considering the previous example, the address of `Global1` will be different after replication. And then, to be correct, in the statement `cmp eax, 402000h`, the hexadecimal value must be updated by the new address of `Global1` only in the second program's binary.

3.3 Metamorphic engine replication with no constant kernel

At this stage we have illustrated :

1. how to obfuscate a program to guarantee that it cannot be disassembled under a predefined time τ in 3.1;
2. which information is mandatory to create a program able to reverse this previous obfuscation scheme in 3.2;

We now have to describe how the metamorphic engine can link these two steps to achieve its self-replication. Figure 3 illustrates this replication process. For the purpose of simplicity, we only present how the description of the original code blocks sequence is used in the replication process.

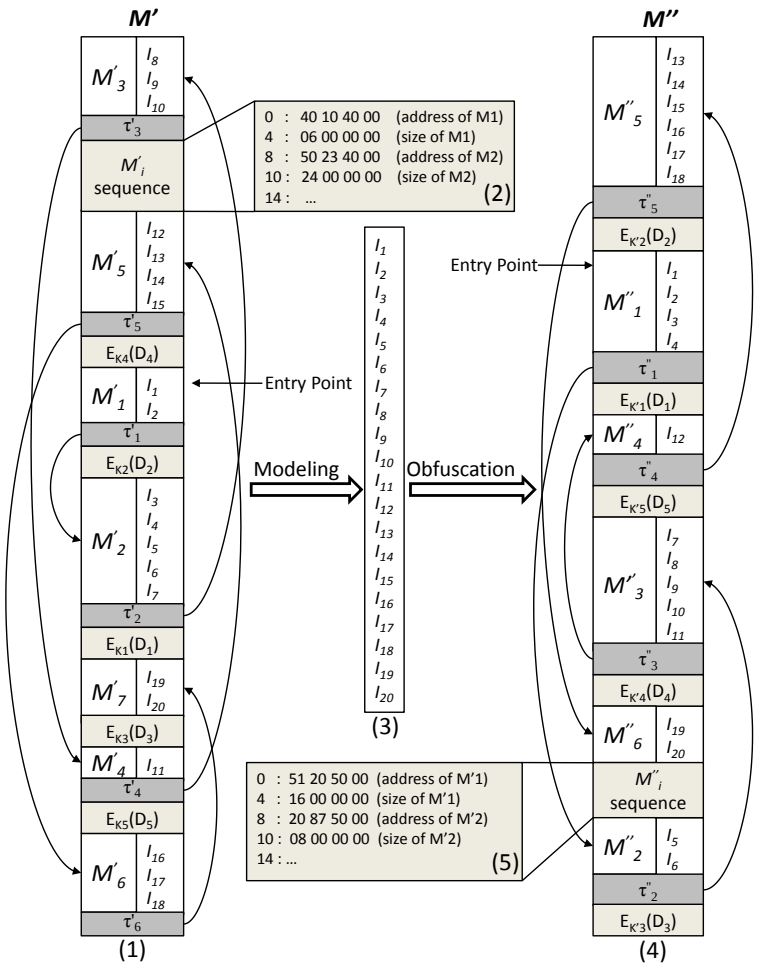

Fig. 3. Illustration of the replication process of the metamorphic engine.

Let M' be an already-obfuscated version of the metamorphic engine M, as described in section 3.1. M' embeds its own rebuilding information, as presented in section 3.2. More precisely, M' is here composed of 20 instructions $(I_1, \ldots, I_{20})$ distributed in 7 blocks $(M'_1, \ldots, M'_7)$ as represented in (1). Each instruction index represents its execution order, I_1 stands for the first executed one whereas I_{20} is the last instruction. Each block M'_i contains a random number of instructions and a random position in the program M'. At the end of each block, another one denoted τ'_i represents the τ-obfuscated branch whose destination is highlighted by pointed arrows. As previously mentioned, the destination of this block cannot be determined before the τ'_i duration.

Without loss of generality, let us assume that the rebuilding information is used by instruction I_4 to start the modeling step. Then, this instruction has a reference to the first block description represented in (2). This description gives the position and the size of each M'_i block. So, M' can disassemble M'_1, then M'_2 until the last block M'_7. From now, M' has its own instructions sequence $(I_1, \ldots, I_{20})$ in memory as illustrated in (3). The re-obfuscation starts here, as described in 3.1 whose results is illustrated in (4): new code blocks are randomly generated $(M''_1, \ldots, M''_6)$ with their corresponding τ-obfuscated transitions $(\tau''_1, \ldots, \tau''_6)$. The original code block sequence $(M''_1, \ldots, M''_6)$ is inserted in a new data block represented in (5). The key point consists in updating the reference to this rebuilding information in instruction I_4, to be sure that this instruction will use the new code blocks description. Moreover, the entry point of M'' is defined in its header to point to the position of I_1 instruction in M''.

From a detection point of view, rebuilding information presents no constant part nor constant position between the two mutated programs. Thus, we assume that reaching rebuilding information means to be able to disassemble any obfuscated program until identifying the part of the program using this information. In this case, any disassembler would be confronted with the robustness of the code obfuscation scheme.[4] And then detection is delayed during the amount of time defined by τ-obfuscation.

3.4 Embedding the metamorphic engine in another program

We have illustrated how the metamorphic engine can reproduce itself according to its rebuilding information. However, the remaining question is the origin of this information. In other words, how can we get the first obfuscated metamorphic binary? First, our metamorphic engine works at binary level taking advantage of the dissembling difficulty in x86 architecture. Second, the purpose of the engine is to be generic, in order to transform high level language programs to make them metamorphic. Here we only focus on programs written in C language. Thus, we have to modify the compilation process to build the first metamorphic binary in the same way the metamorphic engine does. This is achieved by inserting an obfuscator in the compilation process as illustrated in figure 4 step (2).

The compilation process starts normally by taking two inputs programs, the metamorphic engine and the to-be-obfuscated program. First, the compiler produces the corresponding assembly sources. Second, the obfuscator transforms these sources, as presented in 3.1. The obfuscated assembly sources now contain all the rebuilding information for the whole program. Then, the assembler produces object files which will be linked with additional libraries to obtain the final metamorphic binary just like any classical assembling process.

[4] The question of heuristic detection of the permuted code is not mentioned here.

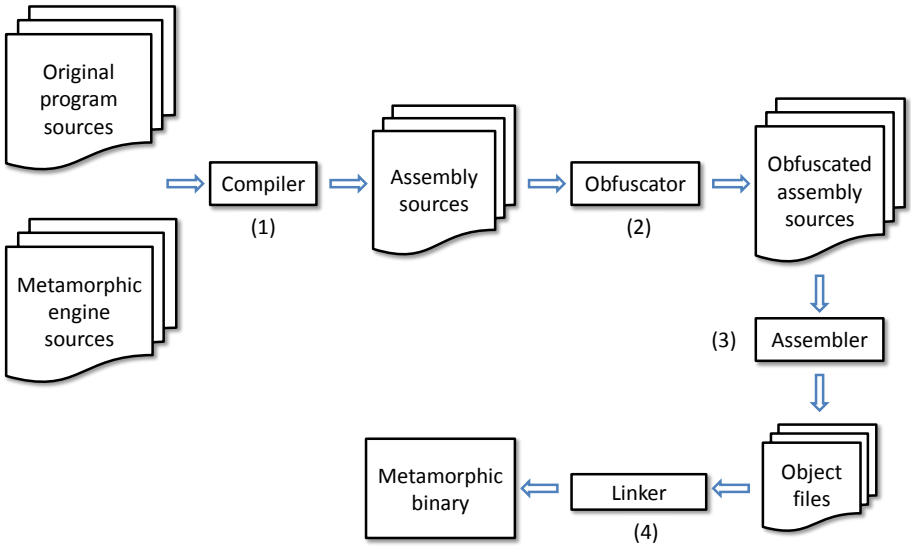

Fig. 4. Illustration of the production of the first metamorphic binary from the metamorphic engine and an original program.

4 Malware detectors evaluation

This section aims at empirically evaluating the impact of our metamorphic engine approach on the state of the art detection tools. In 4.1, we present the way we transform the well known worm MyDoom into a metamorphic one. In 4.2, we describe the evaluation platform. In 4.3, we present the results of our experiments.

4.1 Building a metamorphic version of MyDoom

All our experiments are based on the well known worm MyDoom.A [14] discovered in January 2004. The choice of this malware was motivated by two major reasons:

1. the worm sources [27] are available in C language, which allow us to directly use our metamorphic engine;
2. according to its virulence (number of emails generated), MyDoom is considered as the most serious worm attack ever known [25].

Briefly, MyDoom is a worm propagating through a peer-to-peer client and by emails. Its payload is composed of two parts: first, the worm tries a *Denial Of Service* (DOS) on a specific web site. Second, MyDoom embeds an encrypted *Dynamic Link Library* (DLL) which represents a backdoor listening on a TCP port ranging between 3127 and 3198 . This DLL can be viewed as a standalone

malware, loaded by the Windows `Explorer.exe` process, and waiting for malicious commands. Thus, we have two malware candidates for detection purpose: MyDoom, and its backdoor. In the original sources of MyDoom, the `CopyFile` function is in charge of the worm replication. To use our metamorphic engine, we have modified the sources of MyDoom to replace all the `CopyFile` calls to the replication entry point of the metamorphic engine. Concerning the backdoor, its detection could make MyDoom suspicious according to heuristics detection techniques. As a non-replicating program the backdoor does not use the metamorphic engine but has to be obfuscated as the worm is.

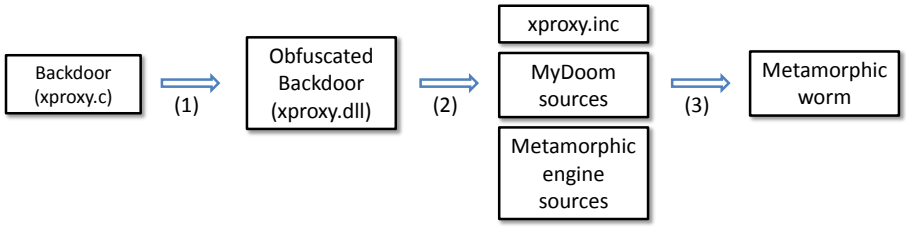

Fig. 5. Illustration of the incorporation of the obfuscated backdoor (xproxy) in the metamorphic worm (MyDoom).

The generation of the metamorphic worm is illustrated in figure 5: first the backdoor is obfuscated as explained in figure 3.1 to obtain the obfuscated backdoor (`xproxy.dll`) in step (1). Then, the backdoor binary has to be encrypted as the worm normally does. This encrypted binary is then translated as a table of hexadecimal values in a source file (`xproxy.inc`). This step is denoted in (2). Finally, the metamorphic worm is produced as illustrated in 4 from the previous `xproxy.inc` file, the metamorphic engine and MyDoom sources in step (3).

4.2 Evaluation platform

To observe the malware's behavior in a safe and protected environment, a target platform was installed. The adopted solution consisted in using virtual machines for two reasons: first, to prevent any infection of the real operating system from the malware. On this subject, we verified beforehand that MyDoom did not try to detect any virtualisation environment. Indeed, malwares are used to changing their behavior in case of virtualisation. Second, virtual machines allowed us to easily come back to a clean state independently of detection success by restoring the safe machine image. The evaluation platform was composed of two components, namely the guest and the host machine.

Guest Machine : VMWare workstation was chosen as the emulating environment. Windows XP Pro SP3 was installed with up-to-date hot fixes to represent

a personal user configuration. To observe the worm propagation, a mail client and a peer-to-peer one were configured. An ISP account was also defined with different parameters and especially the SMTP server address. This guest machine configuration was cloned according to the number of antivirus to be tested. An antivirus program was installed on each configuration.

Host Machine : A bridge was installed between the two machines to establish a network communication between them. A fake SMTP server listening on TCP port 25 was in charge of collecting the worm's mail. All the guest traffic was oriented toward the bridge to reach the host machine.

In order to validate the metamorphic engine replication, and to bring representative results, each sample of malware used in the followings experiments was produced as follows:

1. a metamorphic worm obtained, as illustrated in 5, was installed on a guest machine containing no activated detection product. The parameters of the metamorphic engine were configured according to the experiments (code block sizes and τ iteration values).
2. this worm was then executed on the guest machine until two mutated worms were obtained. These two worms were collected from the peer-to-peer client and from emails by the host machine.
3. the virtual environment was finally restored to a clean state and this process was renewed (step 2) with the previously collected malware until the desired sample of worms was obtained.

4.3 Experiment results

To be as general as possible, we started with 15 of the most used antivirus software regardless of their detection techniques (heuristic, behavioral blockers, state automata [17]). In terms of license several products present ambiguities concerning black box evaluations : *"You shall not use this Software in automatic, semi-automatic or manual tools designed to create virus signatures, virus detection routines, any other data or code for detecting malicious code or data."* To be as neutral as possible, all the results are given anonymously denoted by AV1 to AV15. All detection software were used with their default configuration parameters.

Concerning the metamorphic engine parameters, τ-obfuscation was initialized to a single iteration and the code blocks size was set to contain from 1 to 5 instructions. For detection purpose, each worm was installed on a guest machine and submitted to on demand detection. Then, non detected malware were executed until mail and peer-to-peer propagations.

Two samples of malware differing only in their replications were submitted to antivirus products: the first one used direct replication API calls (`CopyFile`), whereas the second one used the metamorphic engine replication functionality. The interest of such a distinction lies in the difficulty of determining the self

replication of the metamorphic engine whereas it is quite simple to identify a direct copy. The detection results concerning the two submitted samples of malware are presented in table 1 with their corresponding observed detection technique.

Software	Obfuscated worms	Metamorphic worms	Observed detection technique
AV1	100/100 detected as generic Trojan	0/100	behavior monitoring
AV2	100/100 blocked for suspicious files actions (self copies) and registry actions (residency)	0/100	behavior monitoring
AV3	40/100 blocked for suspicious files actions	40/100 blocked for suspicious files actions	file blocker
AV4	100/100 blocked for registry modifications (residency)	100/100 blocked for registry modifications (residency)	registry blocker
AV5	100/100 blocked for suspicious actions	100/100 blocked for suspicious actions	actions blocker
AV6	10/100 detected as "Heur_PE virus"	10/100 detected as "Heur_PE virus"	heuristic form-analysis
AV7	0/100	0/100	no detection
⋮	⋮	⋮	⋮
AV15	0/100	0/100	no detection

Table 1. Detection results obtained on 15 antivirus products with 100 obfuscated worms (first column) and 100 metamorphic ones (second column).

According to table 1, which presents the observed results obtained from the two submitted worms samples, four classes of detection techniques can be extracted:

1. behavioral monitoring software represented by AV1 and AV2;
2. behavioral blocker products represented by AV3, AV4 and AV5;
3. heuristic-based detection tools represented by AV6;
4. form-based detection software unable to detect any obfuscated worm or metamorphic ones (AV7 to AV15);

The first three detection classes are detailed hereafter.

Behavioral monitoring results. This class of detectors includes two software (AV1 and AV2) able to detect all the obfuscated worms but no metamorphic ones. This result tends to illustrate that AV1 and AV2 considered self-copying as a key component for detection purposes. However, the self replication problem is a well-known undecidable one, as F.Cohen proved [10]. Our results show that direct replication by calling the `CopyFile` function was detected but not the metamorphic engine replication process illustrated in 3. AV1 gave no more information to help understand the precise detection technique used. It seems that sensible events (files creations, file and registry modifications, self copying, etc.) were correlated to identifying a generic class of malware (here trojans). AV2 detected two suspicious behaviors before blocking any obfuscated worms: the first

one concerned suspicious file actions such as copying itself and the second one was the attempt of residency through registry modifications.

Behavioral blocker results. All these software (AV3, AV4 and AV5) required a user decision concerning each detected suspicious action. AV3 blocked each file containing an executable program disguised by harmless file extension. This happened during mail creation with a probability of 40% set in the source code. More precisely, in this case, the worm packed itself in a temporary directory with a `.tmp` extension before encoding this copy as a mail attachment. Consequently, all of these temporary files were detected as suspicious by AV3. AV4 blocked all the malware attempts to become resident by registry modifications. Finally, AV5 monitored several behavior with different level of risks and gave the following warnings for all the metamorphic worms:

1. modifying your computer so that another computer can access it;
2. copying an "executable" file to a sensitive area of your system;
3. registering itself in your "Windows System Startup" list;
4. copying another program to an area of your computer that shares files with other computers;
5. connecting to the Internet in a suspicious manner to send out emails.

Here, it is worth mentioning that this product was not able to detect the self replication of the metamorphic engine. Indeed expressions "an executable" in 2 and "another program" in 4 confirmed the self replication detection difficulty as for AV1 and AV2. Moreover, it was verified that AV5 could detect self replication on the obfuscated versions of MyDoom. However, in all cases a warning was generated for any program copy as well as a self copying. Moreover, these different warnings were not correlated to identify a specific malware behavior. Behavioral blocking is a proactive detection technique preventing any malicious action before execution. Each of these action relies on a single system call. So, τ-obfuscation is usless on this class of detectors.

Heuristic-based detection results. AV6 detected all the malware according to their binary files and not during their executions. More precisely, all the malware were detected under the label "Heur_PE virus" which suggests that heuristics were used for detection purpose. To validate this heuritic-based detection assumption, we created 3 samples of malware with different τ values (1, 500, and 1 000 000 iterations). Each of these samples was composed of 4 groups of 100 malware with different code block sizes. Figure 6 gives the corresponding detections rates.

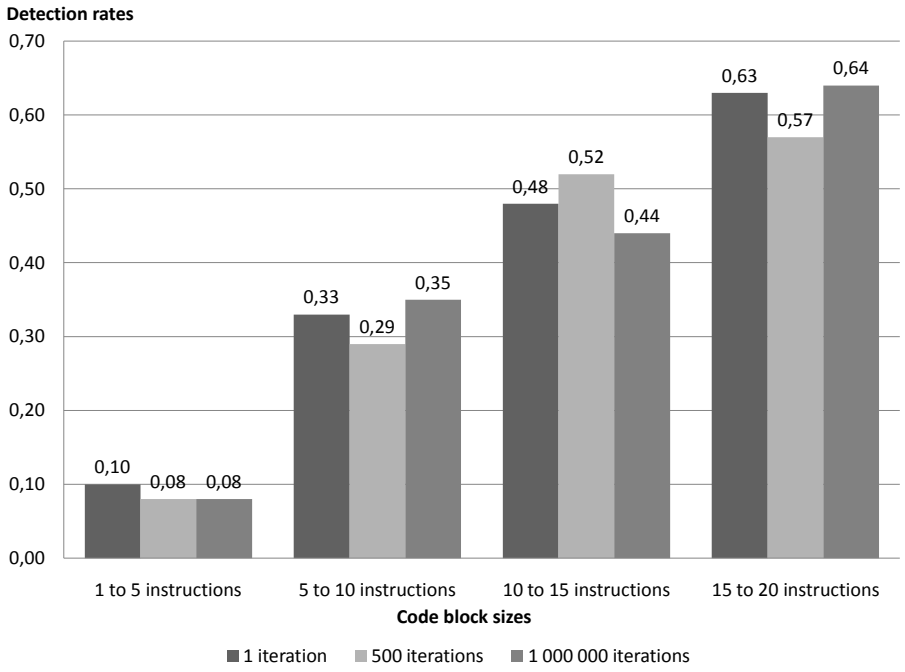

Fig. 6. Detection rates of AV6 according to code block sizes and τ values.

According to these results, the detections rates seem proportional to the code block sizes. Moreover, τ-obfuscation appears to have no impact on detection. This confirms that AV6 used heuritics-based detection approach to recognize these metamorphic malware. No information was given by the product on these specific heuristic detection techniques.

4.4 Discussion on the experiments results

The previous experiments emphasize the two main representative dynamic detection techniques used in current dynamic industrial malware detectors: behavioral monitoring and behavioral blocking. AV1 and AV5 produce two interesting results, each one representing a different class of dynamic detection techniques. Indeed, AV1 is able to correlate some suspicious actions to identify generic malware behavior. Unfortunately, complex self-replications such as metamorphic ones are not detected, leading to a 100% false negatives results when confronted with our experimental metamorphic worms. AV6 can detect all elementary suspicious actions which could describe the behavior of the worm MyDoom. Unfortunately, these events are not correlated to identify the generic worm behavior. Finally, in all cases, it appears to be too immature to evaluate the impact of τ-obfuscation on the current state of the art dynamic detection products. Behavioral detections seems too early to detect complex metamorphic malware.

5 Conclusion

In this paper, we have proposed an approach of a generic metamorphic engine based on advanced code transformation techniques. Describing the process of the metamorphic engine self-replication, we have illustrated the difficulty of detecting it. From a static point of view, the obfuscation scheme was designed to avoid any syntactic signature which could represent a possible detection pattern. Moreover, classical static analysis techniques based on data flow propagation or slicing are limited by the robustness of code obfuscation.

To evaluate the threat represented by self-replicating metamorphic malware, we applied our metamorphic engine to a representative worm to assess current industrial antivirus products detection capabilities. The results show that no tested detection tool is able to reliably detect this class of malware as a worm. Concerning static detection products, only one seems able to detect samples of malware according to some heuristics. Concerning dynamic detection tools, two techniques seem to be used : behavioral monitoring and behavioral blocking. Unfortunately, our experiments found some worrying limitations in these detection techniques. Indeed, behavioral monitoring fails to identify the replication process of the proposed metamorphic engine, leading to false positive results. Behavioral blocking, which consists in suspending some suspicious actions, relies on the user decision to achieve system security and appears unable to detect a global malicious behavior. Consequently, behavioral detection seems an early detection strategy, which is not yet effective against τ-obfuscation.

Finally, this work aimed at focusing on the threats that metamorphic malware could represent. By considering the practical case where no user can decide on the malicious aspect of an action, the question is about the automatic detection of such τ-obfuscated threats. As underlined in [22], we believe that alert correlation would offer interesting perspectives in malware detection, as has already been done concerning intrusion detection. From now, our work will be aimed at dynamically detecting this type of malware.

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