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Indicators of compromise in memory forensics

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Abstract

Utilizing memory forensics during incident response provides valuable cyber threat intelligence. By both providing mechanisms to verify current compromise using known indicators and to discover additional indicators, memory forensics can be leveraged to identify, track, isolate and remediate more efficiently.

1.0 Introduction

There has been a recent increase in the availability of intelligence related to malware. New IP addresses, hostnames, MD5 hashes, mutex values, and other attacker artifacts are shared often. Historically, there exist many host-based and network-based standard methods to utilize these artifacts, such as intrusion detection/prevention systems, firewalls, anti-virus, and file whitelisting. While these solutions provide various benefits, they can fall short of confirming an infection.

Consider antivirus for example. In an article published June 11th, 2012, MIT Technology Review boldly proclaimed "The Antivirus Era Is Over". Mikko Hypponen, Chief Research Officer of F-Secure, wrote that it was "a spectacular failure of our company, and for the antivirus industry in general" (Hypponen, 2012) that they had possessed samples of Flame, one of the most complex pieces of malware ever discovered, for at least two years without examining it closely and developing detection mechanisms. (Hypponen, 2012) Later, in the same article, Mr. Hypponen states, "The truth is, consumer-grade antivirus products can't protect against targeted malware created by well-resourced nation-states with bulging budgets. They can protect you against run-of-the-mill malware: banking trojans, keystroke loggers, and e-mail worms. But targeted attacks like these go to great lengths to avoid antivirus products on purpose. And the zero-day exploits used in these attacks are unknown to antivirus companies by definition." (Hypponen, 2012)

SC Magazine's Tom Cross states, "Although basic controls like anti-virus will always have a place in the security arsenal, they are not up to the task of defending networks against sophisticated, targeted attacks." (Cross, 2012) "It is going to take human analysts to recognize the subtle and often unpredictable patterns of evidence that sophisticated attacks leave behind. Therefore, the best strategies are going to focus on arming incident responders with the tools that they need to monitor their environments and actively hunt for active attack activity." (Cross, 2012)

"So what's the next-generation solution? The future of security lies in shifting toward behavior-oriented scanning, says Dennis Pollutro, president and founder of cloud

security vendor Taasera. While "there will always be a place for signatures," security products have to begin identifying malware by what it's doing, rather than what it looks like, he says." (Rashid, 2012)

"Several things have to happen before the malware infection results in damage or data theft on the compromised computer, which gives defenders a "couple hundred processes" to monitor for, Pollutro adds. Threat intelligence allows administrators to recognize patterns of behavior, such as creating directories on a file system or communicating with an IP address that had previously been flagged as suspicious." (Rashid, 2012)

Malware can be identified by seeking out common TTP's (tools, techniques, and procedures) used during development and infection. These relationships help analyst gain a better understanding of the adversary and develop attacker profiles. From the profiles we can draw inferences to better adapt and respond to attacks.

Categorization techniques vary among researchers. David French, Senior Malware Researcher at CERT suggests a malware-centric approach. "To express such relationships between files, we use the concept of a "malware family", which is loosely defined as "a set of files related by objective criteria derived from the files themselves." Using this definition, we can apply different criteria to different sets of files to form a family." (French, 2012)

Michael Cloppert, a senior member of Lockheed Martin's Computer Incident Response Team suggests taking a more adversary-centric approach. "The best way to behaviorally describe an adversary is by how he or she does his job…that "job" is compromising data, and therefore we describe our attacker in terms of the anatomy of their attacks." (Cloppert, 2009). "We as analysts seek the most static of all indicators [those closest to the adversary] but often must settle for indicators further from the adversary until those key elements reveal themselves." (Cloppert, 2009)

According to Greg Hoglund, Founder of HBGary, "It makes no sense to separate the human from the malware and TTP's. They are two ends of the same spectrum. This is not a black and white science; it works because humans aren't perfect. It works because

humans are creatures of habit and tend to use what they know. They use the same tools every day and don't rewrite their malware every morning. They don't have perfect OPSEC. They put their digital footprints out on the Internet long ago – and it's usually just a few clicks away from discovery. There is a reflection of the threat actor behind every intrusion. To discount this is to discount forensic science." (Hoglund, 2011)

According to The MITRE Corporation, "to be proactive, cyber defenders need to fundamentally change the nature of the game by stopping the adversary's advance, preferably before the exploit stage of the attack [which] requires defenders to evolve from a defensive strategy based primarily on after-the-fact incident investigation and response to one driven by cyber threat intelligence." (The MITRE Corporation, 2012)

Identification of singular characteristics of malware helps to automate future identification tasks. Often malware from the same family share these characteristics, which helps analysts, identify related files. These characteristics can be used by analysts to organize malware within repositories, root out additional infections present on the network, or identify new variants of malware.

Memory forensics allows analysts to "reconstruct the state of the original system, including what applications were running, what files those applications were accessing, which network connections were active, and many other artifacts" (Michael Ligh, 2010). Many free tools are available to analyst for local memory imaging as well as several enterprise solutions for remote imaging. While memory forensics shouldn't be considered a replacement for any other security technology, it is most certainly a valuable tool and should be considered, as is stated in the Malware Analyst's Cookbook, "extremely important to incident response" (Michael Ligh, 2010).This paper discusses analyzing malware. It does not describe designing a safe and effective malware analysis environment. If you are new to malware analysis and wish to perform any of the examples within this paper please spend some time researching how to do so safely.

2.0 Scope and Assumptions

The research discussed herein focuses on the creation of signatures to help speed up memory analysis during incident response. Because they are not meant to be used as host-based indicators deployed uniformly there is a greater tolerance for false positives. If, instead, the task was to develop signatures to deploy to all client machines then there would be a much greater need to tune each rule since, in that case, any false positive could have an immediate impact on the client experience. For this research, the resulting signatures will be run by the analyst, for the analyst, to expedite the identification, containment, and eradication of threats.

We will touch on many topics related to malware analysis and memory forensics. To limit the scope of this research, specific malware analysis techniques will not be discussed. We will rely on various publicly available materials from which to understand our topic. If malware analysis is of interest to the reader, they are encouraged to see the reference section for the articles cited and the appendix for a list of additional resources.

There are many tools mentioned throughout this paper. Detailing each tool is out of scope, but links to the tools mentioned will be included within the appendix for reference.

3.0 Finding Indicators

Indicators can come from a variety of sources. There are numerous blogs dedicated to malware reversing and analysis. "Malwaremustdie", "Joe Security LLC", and "Hooked on Mnemonics worked for me" to name a few (see Appendix 1). There are also many security companies that publish some of their own internal findings publicly. Organizations such as Mandiant, Fireeye, and Dell Secureworks are great sources of detailed reports that include indicators.

Another option is to acquire malware samples for analysis. Enterprising and ambitious analysts could mine the internet for malware themselves. There are a variety of sites (See Appendix 1) that note active malware sources that can be downloaded manually or scrapped via script (such as maltrieve - See Appendix 1) to automate

collection. Alternatively, one could setup a honeypot (such as Dionea - See Appendix 1) to glean current samples from the internet by allowing attackers access to seemingly vulnerable services.

Another approach is to turn to the numerous websites that provide users access to malware. Sites such as virusshare.com, malwr.com, malware.lu, offensivecomputing.net, and contagiodump offer access to millions of samples (See Appendix 1).

3.1 YARA

To help aid in scanning memory samples for indicators of compromise, we will use a tool called YARA. "YARA is a tool aimed at helping malware researchers to identify and classify malware samples. With YARA you can create descriptions of malware families based on textual or binary patterns contained on samples of those families. Each description consists of a set of strings and a Boolean expression which determines its logic." (YARA in a nutshell, 2013)

YARA provides a mechanism to match indicators such as strings and hexadecimal within memory samples.

3.2 Indicators Defined

Michael Cloppert wrote a phenomenal blog post in 2009 on the computer forensic blog on SANS called *Security Intelligence: Attacking the Kill Chain.* In it he describes classifying indicators into one of three categories: atomic, computed, and behavioral. Michael's description of each is shown here:

"Atomic indicators are pieces of data that are indicators of adversary activity on their own. Examples include IP addresses, email addresses, a static string in a Covert Command-and-control (C2) channel, or fully-qualified domain names (FQDN's). Atomic indicators can be problematic, as they may or may not exclusively represent activity by an adversary." (Cloppert, 2009)

"Computed indicators are those which are, well, computed. The most common

amongst these indicators are hashes of malicious files, but can also include specific data in decoded custom C2 protocols, etc. Your more complicated IDS signatures may fall into this category." (Cloppert, 2009)

"Behavioral indicators are those which combine other indicators — including other behaviors - to form a profile." (Cloppert, 2009)

As an example of a complex behavioral indicator, consider the following. An adversary is identified that tends to rely on "spear phished" email attachments. The emails tend to come from a specific range of IP space. When the attachment is executed, the dropper malware gains persistence by writing to specific registry keys and then installs a PoisonIvy variant. From there the attacker uses Windows Credential Editor to move laterally within the network. Once interesting data has been identified, Winrar is used to zip up the files and exfiltrate them to a set of IPs. These indicators could have been identified during separate incident response engagements, and may has little significance alone, but when viewed together build behavioral indicators that can be assigned to specific attacker profiles. We will discuss identifying atomic and computed indicators in depth here, and will leave the creation of behavior indicators to the reader.

Indeed, the identification of atomic and computed artifacts is the easiest step in malware analysis. Sources of unique strings, IP addresses, registry keys, file locations, etc. related to malware are numerous. The task of determining the relevance of each accumulated artifact and its contribution to the attacker profile falls upon the analyst team.

3.2.1 Avoiding poor indicators

As we have been discussing, not all indicators are equal. Some artifacts are easily changed by the attacker. For example, consider GhostRat – a popular RAT (remote access tool) used in many recently documented attacks. According to Norton, "the most stable indicator of GhostRat is its network communication. It is well documented and quite distinctive, as it always begins with a "magic word" which in its default configuration is "Gh0st"" (Norman, 2012). However, because the source code for Gh0stRAT is freely available, modifying this "magic word" is simple.

```
7hero, Adobe, B1X6Z, BEiLa, BeiJi, ByShe, FKJP3, FLYNN, FWAPR, FWKJG,
GWRAT, Gh0st, GOLDt, HEART, HTTPS, HXWAN, Heart, IM007, ITore, KOBBX,
KrisR, LUCKK, LURK0, LYRAT, Level, Lover, Lyyyy, MYFYB, MoZhe, MyRat,
OXXMM, PCRat, QWPOT, Spidern, Tyjhu, URATU, W0LFKO, Wangz, Winds, World,
X6RAT, XDAPR, Xjjhj, ag0ft, attac, cb1st, https, whmhl, xhjyk
```

Figure 1

Several known values of Gh0stRAT's "Magic word" -- Source: http://download01.norman.no/documents/ThemanyfacesofGh0stRat.pdf

4.0 Writing indicator-based YARA rules

Consider the differences between host-based signatures, such as those used by anti-virus, and incident response rules used for YARA. Because many anti-virus platforms have real-time functionality, they must constantly monitor the file system and memory for both static and heuristic based signatures. Thus, system performance is impacted by the simple addition of anti-virus, regardless of the quality of its signatures. If the signatures written for the anti-virus platform are vague, the resulting additional overhead on the system impacts the user experience at best by simply slowing down processing and, at worse, incorrectly identifying files as malicious, quarantining them, and denying the user access until a patch can be deployed.

YARA signatures, specifically those focused on memory forensics, involve only a snapshot of memory, frozen in time and independent of the host machine, thus there is no real-time performance impact to consider. Also, because incident response engagements typically involve a small number of systems, performing matches for less precise characteristics is tolerated and, in some cases, preferred.

To that end, as we create YARA signatures we will test them against a corpus of malware to assess the false positive rate. We will ask ourselves if, in some cases, defining signatures based upon characteristics that might be considered poor form for anti-virus platforms is more tolerated for memory analysis.

4.2 Python and IDA

To help speed up the process of creating YARA rules based on disassembled malware, we turn to IDA Pro and Python. Within idc.py, the Python plugin for IDA, the o_* constants allow for the identification of variable memory addresses within malware. These addresses require the use of wildcards within YARA. A very useful script to automate the substitution of the variable memory addresses with '??' was written by Case Barnes of Accuvant (Barnes, 2012). His script relies on the following operands, o_mem, o_phase, o_displ, o_far, o_near, which are defined within idc.py:

```
o_void     =  idaapi.o_void      #  No Operand                           ----------
o_reg      =  idaapi.o_reg       #  General Register (al,ax,es,ds...)    reg
o_mem      =  idaapi.o_mem       #  Direct Memory Reference  (DATA)      addr
o_phrase   =  idaapi.o_phrase    #  Memory Ref [Base Reg + Index Reg]    phrase
o_displ    =  idaapi.o_displ     #  Memory Reg [Base Reg + Index Reg + Displacement] phrase+addr
o_imm      =  idaapi.o_imm       #  Immediate Value                      value
o_far      =  idaapi.o_far       #  Immediate Far Address  (CODE)        addr
o_near     =  idaapi.o_near      #  Immediate Near Address (CODE)        addr
o_idpspec0 =  idaapi.o_idpspec0  #  IDP specific type
o_idpspec1 =  idaapi.o_idpspec1  #  IDP specific type
o_idpspec2 = idaapi.o_idpspec2  #  IDP specific type
o_idpspec3 = idaapi.o_idpspec3  #  IDP specific type
o_idpspec4 = idaapi.o_idpspec4  #  IDP specific type
o_idpspec5 = idaapi.o_idpspec5  #  IDP specific type
o_last     = idaapi.o_last      #  first unused type
```

Figure 2

Operands within idc.py – Source: Author created

5.0 Demonstrations

To test our ability to identify indicators in one piece of malware, and then use them to create signatures to identify the same or similar malware across multiple memory dumps, we will turn to three pieces of malware; Stabuniq, X0rb0t, and a sample from APT1. Each sample will be assessed for indicators, and then YARA will be used to scan across several memory images to verify the effectiveness of the rule.

5.1 Stabuniq

Stabuniq is not considered APT, but due to its availability and interesting characteristics it is an excellent example for our purpose.

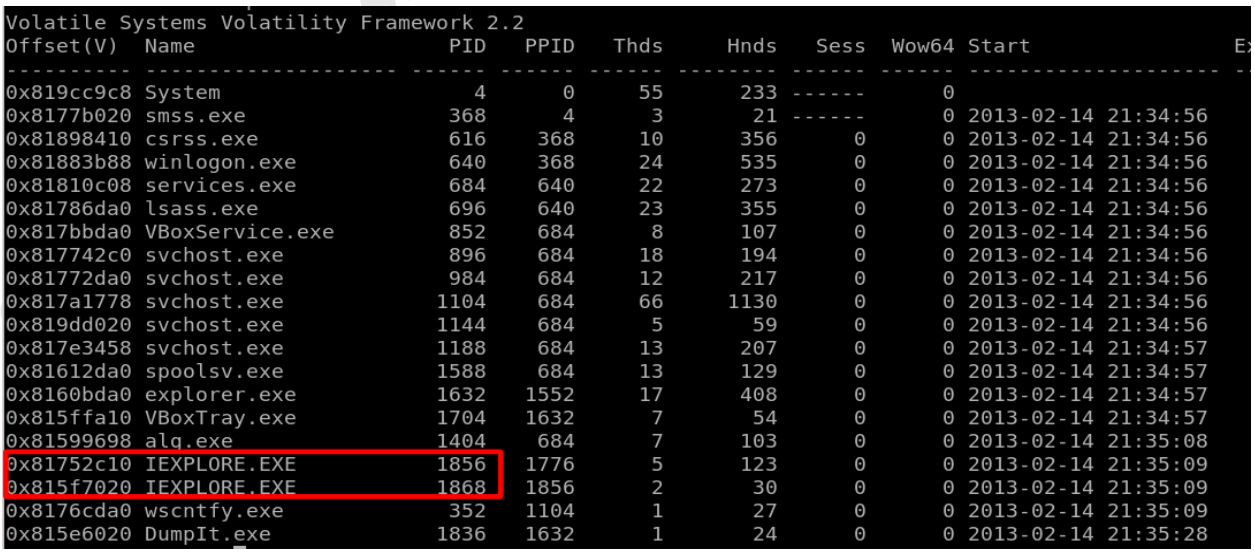
I will refer to indicators identified within two public analysis posts:

1. http://quequero.org/2013/01/stabuniq-financial-infostealer-trojan-analysis/
2. http://www.symantec.com/connect/blogs/trojanstabuniq-found-financial-institution-servers

According to Symantec, Stabuniq was first spotted in 2011 on servers belonging to financial institutions, banking firms, and credit unions. (Gutierrez, 2012) Symantec published an analysis in December 2012. During that same month, Mila Parkor of Contagio Malware Dump posted links to samples of the malware (see Appendix 1).

The initial executable contains a second executable that is decoded and dropped at runtime. Because our approach cares only about what eventually ends up in memory, the initial binary is of little interest. Therefore, to identify pertinent indicators, we must review the final executable dropped on the system.

After the malware has been run and the subsequent memory image acquired, similar artifacts to those noted within the online analysis can be seen using Volatility. To follow along, we must identify the injected process PID:



```
Volatile Systems Volatility Framework 2.2
Offset(V)  Name                    PID   PPID   Thds     Hnds   Sess  Wow64 Start                 Ex
---------- -------------------- ------ ------ ------ -------- ------ ------ ------------------- --
0x819cc9c8 System                    4      0     55      233 ------      0
0x8177b020 smss.exe                368      4      3       21 ------      0 2013-02-14 21:34:56
0x81898410 csrss.exe               616    368     10      356      0      0 2013-02-14 21:34:56
0x81883b88 winlogon.exe            640    368     24      535      0      0 2013-02-14 21:34:56
0x81810c08 services.exe            684    640     22      273      0      0 2013-02-14 21:34:56
0x81786da0 lsass.exe               696    640     23      355      0      0 2013-02-14 21:34:56
0x817bbda0 VBoxService.exe         852    684      8      107      0      0 2013-02-14 21:34:56
0x817742c0 svchost.exe             896    684     18      194      0      0 2013-02-14 21:34:56
0x81772da0 svchost.exe             984    684     12      217      0      0 2013-02-14 21:34:56
0x817a1778 svchost.exe            1104    684     66     1130      0      0 2013-02-14 21:34:56
0x819dd020 svchost.exe            1144    684      5       59      0      0 2013-02-14 21:34:56
0x817e3458 svchost.exe            1188    684     13      207      0      0 2013-02-14 21:34:57
0x81612da0 spoolsv.exe            1588    684     13      129      0      0 2013-02-14 21:34:57
0x8160bda0 explorer.exe           1632   1552     17      408      0      0 2013-02-14 21:34:57
0x815ffa10 VBoxTray.exe           1704   1632      7       54      0      0 2013-02-14 21:34:57
0x81599698 alg.exe                1404    684      7      103      0      0 2013-02-14 21:35:08
0x81752c10 IEXPLORE.EXE           1856   1776      5      123      0      0 2013-02-14 21:35:09
0x815f7020 IEXPLORE.EXE           1868   1856      2       30      0      0 2013-02-14 21:35:09
0x8176cda0 wscntfy.exe             352   1104      1       27      0      0 2013-02-14 21:35:09
0x815e6020 DumpIt.exe             1836   1632      1       24      0      0 2013-02-14 21:35:28
```

Figure 3

Injected processes -- Source: Author created

The malware uses StabililtyMutexString as its mutex. We can confirm that by using the Volatility mutantscan plugin.

```
Volatile Systems Volatility Framework 2.2
Offset(P)  #Ptr #Hnd Signal Thread           CID Name
---------- ---- ---- ------ ---------- --------- ----
0x017abd68    2    1      1 0x00000000          WindowsUpdateTracingMutex
0x017b0908    1    1      1 0x00000000
0x017d8578    3    2      1 0x00000000          StabilityMutexString
0x017db1d8    1    1      1 0x00000000
0x017de240    1    1      1 0x00000000
0x017e8480    1    1      1 0x00000000
0x017e8b00    1    1      1 0x00000000
0x017f7dd8    1    1      1 0x00000000
0x01802718    1    1      1 0x00000000
```

Figure 4

Output from Volatility's mutantscan plugin -- Source: author created

To create a YARA rule to identify this sample by this mutex, we must consider how the data looks within memory. One way to see is to use volshell to display the contents of memory:

```
Volatile Systems Volatility Framework 2.2
Current context: process System, pid=4, ppid=0 DTB=0x311000
Welcome to volshell! Current memory image is:
file:///opt/cuckoo/shares/Windows-XP/WINDOWSXP-stabuniq.raw
To get help, type 'hh()'
>>> cc(pid1856)
Traceback (most recent call last):
  File "<console>", line 1, in <module>
NameError: name 'pid1856' is not defined
>>> cc(pid=1856)
Current context: process IEXPLORE.EXE, pid=1856, ppid=1776 DTB=0x6b40260
>>> db(0x001518b6)
0x001518b6  53 00 74 00 61 00 62 00 69 00 6c 00 69 00 74 00   S.t.a.b.i.l.i.t.
0x001518c6  79 00 4d 00 75 00 74 00 65 00 78 00 53 00 74 00   y.M.u.t.e.x.S.t.
0x001518d6  72 00 69 00 6e 00 67 00 00 00 00 00 00 00 00 00   r.i.n.g.........
0x001518e6  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x001518f6  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00151906  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00151916  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
0x00151926  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00   ................
>>>
```

Figure 5

The mutex as stored in process memory -- Source: author created

As you can see above, the string is encoded with two bytes per character. The 'wide' YARA modifier must be used:

```
rule Stabuniq_strings

{
        strings:
                $mutex = "StabilityMutexString" wide
        condition:
                $mutex
}
```

Figure 6

YARA rule to match Stabuniq's mutex - Source: author created

The signature is checked and verified to match:

```
Stabuniq_strings [] /usr/share/memory_dumps/public/WINDOWSXP-stabuniq.raw
```

Figure 7

Results shows match - Source: author created

Because the mutex name is likely easy to change, we return to the quequero.org analysis for a preferred indicator. The analysis also mentions the segment of code used to re-injecting Internet Explorer. Perhaps this function would be more difficult for the malware author to change and thus make a better signature.

```
.text:0040802B                  call    dword ptr [eax+0ACh] ;
GetProcessVersion
.text:00408031                  mov     [ebp+var_8], eax
.text:00408034                  cmp     [ebp+var_8], 0
.text:00408038                  jnz     short loc_408071
.text:0040803A                  mov     [ebp+var_4], offset injectedThread
...
.text:00408068                  mov     ecx, [ebp+arg_0]
.text:0040806B                  push    ecx
.text:0040806C                  call    createRemoteIEThread
.text:00408071
.text:00408071 loc_408071:                              ; CODE XREF:
threadReinjectIE+30↑j
.text:00408071                  push    1000
.text:00408076                  mov     edx, [ebp+arg_0]
.text:00408079                  call    dword ptr [edx+0A8h] ; Sleep
.text:0040807F                  jmp     short loc_40800E
```

Figure 8

Interesting code block from Stabuniq - Source: http://quequero.org/2013/01/stabuniq-financial-infostealer-trojan-analysis/

Using the Python script mentioned above, we use this bit of code to create a YARA rule:

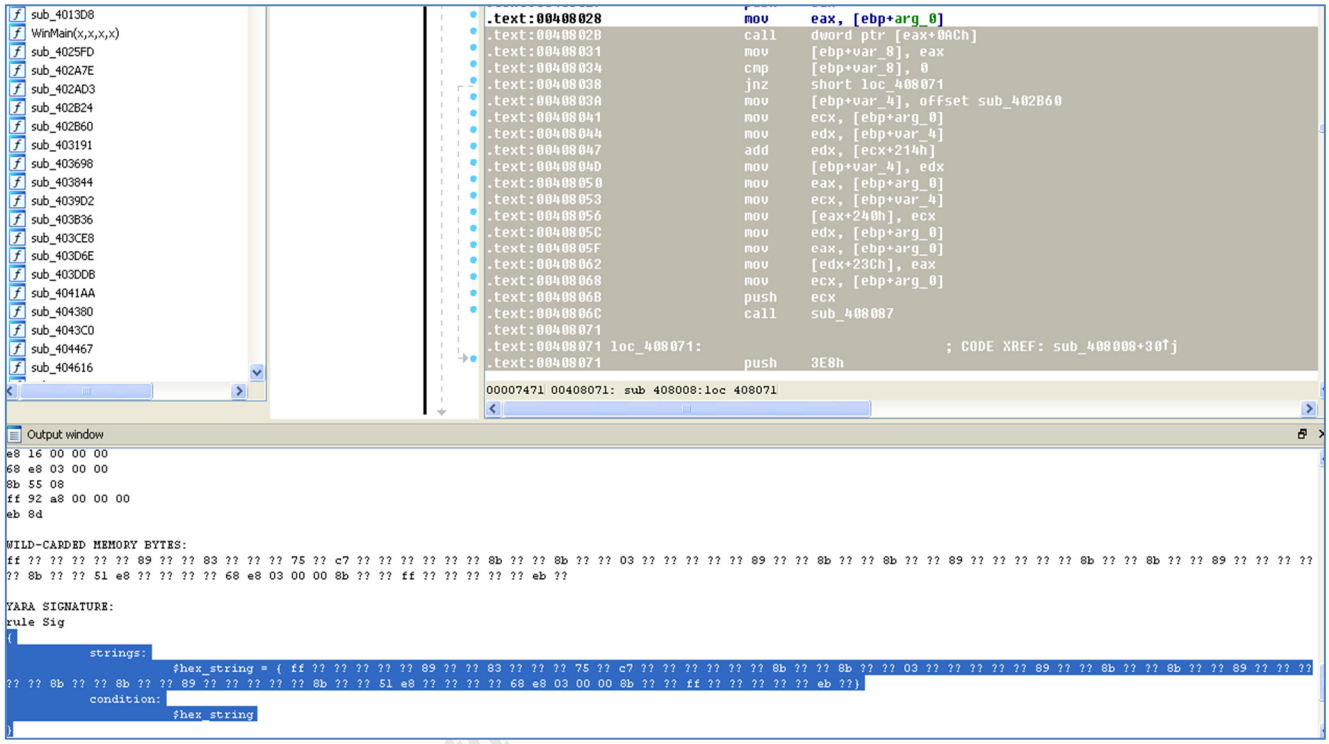


Figure 9

Using Python to create YARA rule - Source: Author created

While process could certainly be done manually, the script automatically inserts wildcards where needed to adjust for memory addressing.

To validate the rule, I will use various publicly available memory images, including all those linked to from the Volatility website. I will also include various known-infected memory images acquired during research. These memory images are shown below:

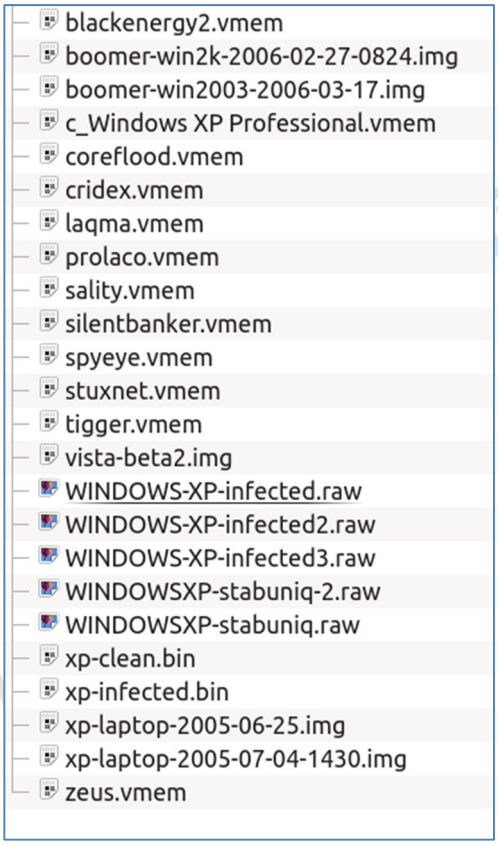


Figure 10

Sample memory images - Source: author created

The results are shown here:

```
Stabuniq [] /usr/share/memory_dumps/public//WINDOWSXP-stabuniq.raw
Stabuniq [] /usr/share/memory_dumps/public//WINDOWSXP-stabuniq-2.raw
```

Figure 11

Stabuniq YARA signature matched - Source: author created

As you can see, the rule matched the two Stabuniq-infected memory dumps, but none of the other dumps in the folder. To further test the resilience of the rule, we can extract the malware from memory by using Volatility's malfind command:

```
Process: IEXPLORE.EXE Pid: 1856 Address: 0x160000
Vad Tag: VadS Protection: PAGE_EXECUTE_READWRITE
Flags: CommitCharge: 7, MemCommit: 1, PrivateMemory: 1, Protection: 6

0x00160000  55 8b ec 83 ec 14 53 56 57 e8 00 00 00 00 5b 81   U.....SVW.....[.
0x00160010  eb 6e 2b 40 00 89 5d fc 8b 45 08 8b 4d fc 89 88   .n+@..]..E..M...
0x00160020  14 02 00 00 c7 45 f4 00 00 00 00 8b 55 f4 6b d2   .....E......U.k.
0x00160030  28 8b 45 08 33 c9 66 8b 8c 10 32 12 00 00 85 c9   (.E.3.f...2.....

0x160000 55              PUSH EBP
0x160001 8bec            MOV EBP, ESP
0x160003 83ec14          SUB ESP, 0x14
0x160006 53              PUSH EBX
0x160007 56              PUSH ESI
0x160008 57              PUSH EDI
0x160009 e800000000      CALL 0x16000e
0x16000e 5b              POP EBX
0x16000f 81eb6e2b4000    SUB EBX, 0x402b6e
0x160015 895dfc          MOV [EBP-0x4], EBX
0x160018 8b4508          MOV EAX, [EBP+0x8]
0x16001b 8b4dfc          MOV ECX, [EBP-0x4]
0x16001e 898814020000    MOV [EAX+0x214], ECX
0x160024 c745f400000000  MOV DWORD [EBP-0xc], 0x0
0x16002b 8b55f4          MOV EDX, [EBP-0xc]
0x16002e 6bd228          IMUL EDX, EDX, 0x28
0x160031 8b4508          MOV EAX, [EBP+0x8]
0x160034 33c9            XOR ECX, ECX
0x160036 668b8c1032120000 MOV CX, [EAX+EDX+0x1232]
0x16003e 85c9            TEST ECX, ECX
```

Figure 12

IEXPLORE.EXE injected process #1 - Source: author created

```
Process: IEXPLORE.EXE Pid: 1868 Address: 0x160000
Vad Tag: VadS Protection: PAGE_EXECUTE_READWRITE
Flags: CommitCharge: 7, MemCommit: 1, PrivateMemory: 1, Protection: 6

0x00160000  55 8b ec 83 ec 14 53 56 57 e8 00 00 00 00 5b 81   U.....SVW.....[.
0x00160010  eb 6e 2b 40 00 89 5d fc 8b 45 08 8b 4d fc 89 88   .n+@..]..E..M...
0x00160020  14 02 00 00 c7 45 f4 00 00 00 00 8b 55 f4 6b d2   .....E......U.k.
0x00160030  28 8b 45 08 33 c9 66 8b 8c 10 32 12 00 00 85 c9   (.E.3.f...2.....

0x160000 55              PUSH EBP
0x160001 8bec            MOV EBP, ESP
0x160003 83ec14          SUB ESP, 0x14
0x160006 53              PUSH EBX
0x160007 56              PUSH ESI
0x160008 57              PUSH EDI
0x160009 e800000000      CALL 0x16000e
0x16000e 5b              POP EBX
0x16000f 81eb6e2b4000    SUB EBX, 0x402b6e
0x160015 895dfc          MOV [EBP-0x4], EBX
0x160018 8b4508          MOV EAX, [EBP+0x8]
0x16001b 8b4dfc          MOV ECX, [EBP-0x4]
0x16001e 898814020000    MOV [EAX+0x214], ECX
0x160024 c745f400000000  MOV DWORD [EBP-0xc], 0x0
0x16002b 8b55f4          MOV EDX, [EBP-0xc]
0x16002e 6bd228          IMUL EDX, EDX, 0x28
0x160031 8b4508          MOV EAX, [EBP+0x8]
0x160034 33c9            XOR ECX, ECX
0x160036 668b8c1032120000 MOV CX, [EAX+EDX+0x1232]
0x16003e 85c9            TEST ECX, ECX
```

Figure 13

IEXPLORE.EXE injected process #2 - Source: author created

If we now run the same scan against the dumped binaries we see the same results:

```
Stabuniq [] /usr/share/malware//process.0x815f7020.0x160000.dmp
Stabuniq [] /usr/share/malware//process.0x81752c10.0x160000.dmp
```

Figure 14

Stabuniq YARA rule matched - Source: author created

As a final verification, we can use Virus Share's malware corpus. Scanning 131073 samples returns zero results.

5.2 X0rb0t

Next, we take a look at one of the public analysis posted by Malware.lu called X0rb0t. The analysis can be found here:

1. http://code.google.com/p/malware-lu/wiki/en_x0rb0t_analysis

This malware sample uses XOR for encoding. Let's focus on that function to create a YARA rule to test.

The function is shown below:

```
.text:00406CDE    cmp     [ebp+var_C], 7
.text:00406CE2    jnb     short loc_406CFF
.text:00406CE4    mov     eax, [ebp+Str]
.text:00406CE7    add     eax, [ebp+var_8]
.text:00406CEA    mov     ecx, [ebp+var_C]
.text:00406CED    mov     dl, [eax]
.text:00406CEF    xor     dl, byte_40EE60[ecx]
.text:00406CF5    mov     eax, [ebp+Str]
.text:00406CF8    add     eax, [ebp+var_8]
.text:00406CFB    mov     [eax], dl
.text:00406CFD    jmp     short loc_406CD5
```

Figure 15

Related xor function - Source: author created

and the resulting YARA rule:

```
DISASSEMBLY:
jnb     short loc_406CFF
mov     eax, [ebp+Str]
add     eax, [ebp+var_8]
mov     ecx, [ebp+var_C]
mov     dl, [eax]
xor     dl, byte_40EE60[ecx]
mov     eax, [ebp+Str]
add     eax, [ebp+var_8]
mov     [eax], dl
jmp     short loc_406CD5

BYTES:
73 1b 8b 45 fc 03 45 f8 8b 4d f4 8a 10 32 91 60 ee 40 00 8b 45 fc 03 45 f8 88 10 eb d6

BYTES PER LINE:
73 1b
8b 45 fc
03 45 f8
8b 4d f4
8a 10
32 91 60 ee 40 00
8b 45 fc
03 45 f8
88 10
eb d6

WILD-CARDED MEMORY BYTES:
73 ?? 8b ?? ?? 03 ?? ?? 8b ?? ?? 8a ?? 32 ?? ?? ?? ?? ?? 8b ?? ?? 03 ?? ?? 88 ?? eb ??

YARA SIGNATURE:
rule Sig
{
            strings:
                        $hex_string = { 73 ?? 8b ?? ?? 03 ?? ?? 8b ?? ?? 8a ?? 32 ?? ?? ?? ?? ?? 8b ?? ?? 03 ?? ?? 88
            condition:
                        $hex_string
}
```

Figure 16

Output of Python script in IDA - Source: author created

When tested against the same set of memory dumps as was used for Stabuniq, with the addition of a memory dump from an x0rb0t infection, the Yara rule matches only the known x0rb0t-infected dump:

```
X0rb0t [] /usr/share/memory dumps/public//WINDOWSXP-x0rb0t.raw
```

Figure 17

X0rbot YARA rule matched - Source: author created

When run against a corpus of 131073 files, the rule matches 8 times. Taking a closer look at one of the matches (503783a11080777a35b6349099fb3c3d) revels that the same function is utilized within both samples.

Below, on the right is the segment from x0rb0t, and the left the same code segment from 503783a11080777a35b6349099fb3c3d:

```
.text:0040112B          cmp     [ebp+var_C], 6
.text:0040112F          jnb     short loc_40114C
.text:00401131          mov     eax, [ebp+var_4]
.text:00401134          add     eax, [ebp+var_8]
.text:00401137          mov     ecx, [ebp+var_C]
.text:0040113A          mov     dl, [eax]
.text:0040113C          xor     dl, byte_4030B8[ecx]
.text:00401142          mov     eax, [ebp+var_4]
.text:00401145          add     eax, [ebp+var_8]
.text:00401148          mov     [eax], dl
.text:0040114A          jmp     short loc_401122
```

```
.text:00406CDE          cmp     [ebp+var_C], 7
.text:00406CE2          jnb     short loc_406CFF
.text:00406CE4          mov     eax, [ebp+Str]
.text:00406CE7          add     eax, [ebp+var_8]
.text:00406CEA          mov     ecx, [ebp+var_C]
.text:00406CED          mov     dl, [eax]
.text:00406CEF          xor     dl, byte_40EE60[ecx]
.text:00406CF5          mov     eax, [ebp+Str]
.text:00406CF8          add     eax, [ebp+var_8]
.text:00406CFB          mov     [eax], dl
.text:00406CFD          jmp     short loc_406CD5
```

Figure 18

Output of Python script in IDA - Source: author created

As expected, the same instructions are present in both binaries.

5.3 APT1

Soon after Mandiant released their report on APT1 (See appendix 1), Alienvault released several YARA signatures to identify malware seemingly associated with that group. Both the YARA signatures and the malware samples are easily found online (See Appendix 1). To test the effectiveness of utilizing the YARA rules to identify APT1 activity within memory, a sample from the set is selected (8934aeed5d213fe29e858eee616a6ec7), executed, and the memory from the compromised host dumped to disk.

To start, we test the Alienvault YARA rule against the malicious binary to verify the rule works:

```
./yara -ms ./apt-test.yar /usr/share/malware/APT1/021b4ce5c4d9eb45ed016fe7d87abe745ea961b712
a08ea4c6b1b81d791f1eca
EclipseSunCloudRAT [info="CommentCrew-threat-apt1",author="AlienVault Labs"] /usr/share/malware/APT1/021b4ce5c4d9eb45ed016fe7d87a
be745ea961b712a08ea4c6b1b81d791f1eca
0x20a44:$f: /csre/aafrmap
0x210a2:$e: Snlu-oe
0x2109b:$d: XaM
0x210c2:$c: ElpeCin_.d
0x210b0:$a: ElpeA
```

Figure 19

The known malicious bilary matches the rule – Source: Author created

The Alienvault rule matches the malware as expected. Now, the malicious binary is executed on a test system, and the memory from the test system acquired. The same YARA rule is then used to scan the memory dump:

```
                                                                    . vol.py -f /opt/cuckoo/shares/Windows-XP/WINDOWS
XP-20130228-192408.raw --profile=WinXPSP2x86 yarascan -y            ./Downloads/yara-1.6/apt-test.yar
Volatile Systems Volatility Framework 2.2
Rule: EclipseSunCloudRAT
Owner: Process 021b4ce5c4d9eb4 Pid 748
0x00422244  2f 75 63 5f 73 65 72 76 65 72 2f 64 61 74 61 2f   /uc_server/data/
0x00422254  66 6f 72 75 6d 2e 61 73 70 00 00 00 50 4f 53 54   forum.asp...POST
0x00422264  00 00 00 00 6d 75 6c 74 69 70 61 72 74 2f 66 6f   ....multipart/fo
0x00422274  72 6d 2d 64 61 74 61 3b 20 62 6f 75 6e 64 61 72   rm-data;.boundar
Rule: EclipseSunCloudRAT
Owner: Process 021b4ce5c4d9eb4 Pid 748
0x0042289b  58 69 61 6f 4d 45 5c 53 75 6e 43 6c 6f 75 64 2d   XiaoME\SunCloud-
0x004228ab  43 6f 64 65 5c 45 63 6c 69 70 73 65 5f 41 5c 52   Code\Eclipse_A\R
0x004228bb  65 6c 65 61 73 65 5c 45 63 6c 69 70 73 65 5f 43   elease\Eclipse_C
0x004228cb  6c 69 65 6e 74 5f 42 2e 70 64 62 00 00 00 00 00   lient_B.pdb.....
Rule: EclipseSunCloudRAT
Owner: Process 021b4ce5c4d9eb4 Pid 748
0x004228a2  53 75 6e 43 6c 6f 75 64 2d 43 6f 64 65 5c 45 63   SunCloud-Code\Ec
0x004228b2  6c 69 70 73 65 5f 41 5c 52 65 6c 65 61 73 65 5c   lipse_A\Release\
0x004228c2  45 63 6c 69 70 73 65 5f 43 6c 69 65 6e 74 5f 42   Eclipse_Client_B
0x004228d2  2e 70 64 62 00 00 00 00 00 00 00 00 00 00 00 00   .pdb............
Rule: EclipseSunCloudRAT
Owner: Process 021b4ce5c4d9eb4 Pid 748
0x004228b0  45 63 6c 69 70 73 65 5f 41 5c 52 65 6c 65 61 73   Eclipse_A\Releas
0x004228c0  65 5c 45 63 6c 69 70 73 65 5f 43 6c 69 65 6e 74   e\Eclipse_Client
0x004228d0  5f 42 2e 70 64 62 00 00 00 00 00 00 00 00 00 00   _B.pdb..........
0x004228e0  00 00 00 00 14 aa 42 00 b8 2a 42 00 00 00 00 00   ......B..*B.....
Rule: EclipseSunCloudRAT
Owner: Process 021b4ce5c4d9eb4 Pid 748
0x004228c2  45 63 6c 69 70 73 65 5f 43 6c 69 65 6e 74 5f 42   Eclipse_Client_B
0x004228d2  2e 70 64 62 00 00 00 00 00 00 00 00 00 00 00 00   .pdb............
0x004228e2  00 00 14 aa 42 00 b8 2a 42 00 00 00 00 00 00 00   ....B..*B.......
0x004228f2  00 00 00 00 00 00 14 50 42 00 00 29 42 00 00 00   .......PB..)B...
```

Figure 20

The Alienvault YARA rule matches the memory dump – Source: Author created

With very little effort we were able to take publically available indicators contained within YARA rules and make them actionable against the test machine. The same techniques can be utilized to identify compromised systems across production environments during incident response.

Conclusion

Incident response is evolving. Malware authors are constantly coming up with new ways to compromise systems. They have the ability to adapt quickly and often circumvent our slower moving, often signature-based, archaic security solutions. As such, we must begin to consider how we can achieve similar agility in the way we respond. Perhaps the best way to meet today's threats is to stop relying solely on these legacy tools and begin to focus more on the analyst, our human capital, to piece together

malware artifacts.

The research conducted during the writing of this paper set out to identify how memory forensics can be leveraged to aid incident response. We began by discussing the limitations of standard security platforms. Next, we discussed how behavioral indicators can be created based on the tools, techniques, and procedures utilized by attackers. Then, we discussed how we might find data to be used as indicators, how YARA can be used to aid us, and how we might label and group our identified artifacts. Finally, we took a quick look at two pieces of malware and how we can use readily available analysis data to identify them using YARA.

With the techniques discussed here, an analyst can begin to accumulate and utilize indicators from both publicly disclosed sources and private research. These indicators can then grouped together to form behavioral indicators to move our overall intelligence closer to the adversary. Volatility provides analysts an unprecedented capability to analyze memory images and acquire intelligence. Finally, YARA can be leveraged to identify those indicators across binary data and memory images, allowing for rapid response capabilities.

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Appendix A

Blogs, companies, and tools mentioned within this paper:

http://malwaremustdie.blogspot.jp/ - Malware Must Die!

http://joe4security.blogspot.ch - Joe Security LLC

http://hooked-on-mnemonics.blogspot.com - Hooked on Mnemonics worked for me

http://www.mandiant.com/ - Mandiant

http://www.fireeye.com/ - FireEye

http://www.secureworks.com/cyber-threat-intelligence/blog - Dell Secureworks

https://github.com/technoskald/maltrieve - Maltrieve

http://dionaea.carnivore.it – Malware honeypot

http://virusshare.com/ - Virus Share

http://malwr.com/ - Malwr

http://offensivecomputing.net/ - Offensive Computing / Open Malware

http://contagiodump.blogspot.com/ - Contagio Malware Dump

http://code.google.com/p/yara-project/ - YARA Project

https://www.mandiant.com/blog/mandiant-exposes-apt1-chinas-cyber-espionage-units-releases-3000-indicators/ - Mandiant's APT1 Report

http://www.threatexpert.com/ Threat Expert automated threat analysis

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SANS Canberra 2014	Canberra, Australia	Jun 30, 2014 - Jul 12, 2014	Live Event
SANS London Summer 2014	London, United Kingdom	Jul 14, 2014 - Jul 21, 2014	Live Event
SANS vLive - FOR508: Advanced Computer Forensic Analysis and Incident Response	FOR508 - 201407,	Jul 21, 2014 - Aug 27, 2014	vLive
Mentor Session - FOR 508	Saint Louis, MO	Aug 06, 2014 - Oct 08, 2014	Mentor
SANS Virginia Beach 2014	Virginia Beach, VA	Aug 18, 2014 - Aug 29, 2014	Live Event
SANS Chicago 2014	Chicago, IL	Aug 24, 2014 - Aug 29, 2014	Live Event
SANS Bangalore 2014	Bangalore, India	Sep 15, 2014 - Sep 27, 2014	Live Event
SANS DFIR Prague 2014	Prague, Czech Republic	Sep 29, 2014 - Oct 11, 2014	Live Event
SOS: SANS October Singapore 2014	Singapore, Singapore	Oct 07, 2014 - Oct 18, 2014	Live Event
SANS vLive - FOR508: Advanced Computer Forensic Analysis and Incident Response	FOR508 - 201410,	Oct 14, 2014 - Nov 20, 2014	vLive
Community SANS Paris @ HSC - FOR508 (in French)	Paris, France	Nov 03, 2014 - Nov 07, 2014	Community SANS
SANS London 2014	London, United Kingdom	Nov 15, 2014 - Nov 24, 2014	Live Event
SANS OnDemand	Online	Anytime	Self Paced
SANS SelfStudy	Books & MP3s Only	Anytime	Self Paced