J Comput Virol (2010) 6:181–195
DOI 10.1007/s11416-008-0096-y

EICAR 2008 EXTENDED VERSION

Measuring virtual machine detection in malware using DSD tracer

Boris Lau · **Vanja Svajcer**

Received: 20 January 2008 / Revised: 6 June 2008 / Accepted: 27 June 2008 / Published online: 5 August 2008

Abstract Most methods for detecting that a process is running inside a virtual environment such as VMWare or Microsoft Virtual PC are well known and the paper briefly discusses the most common methods measured during the research. The measurements are conducted over a representative set of malicious files, with special regards to packer code. The results are broken down with respect to malware category, families and various commercial and non-commercial packers and presented in a graphical and tabular format. The extent of virtual machine detection problem is estimated based on the results of the research. The main subject of the paper is measurement of actual usage of Virtual machine detection methods in current malware. The research uses DSD Tracer, a dynamic-static tracing system based on an instrumented Bochs virtual machine. The system employs tracing to produce traces of execution that can be scripted or used as a basis for disassembly/emulation in IDA Pro when combined with a customised version of IDAEmul (emulator). The paper gives an overview of design and usage of DSD Tracer.

1 Introduction

Virtual machine technology is not new. The concept was originally developed by IBM in the late fifties and early sixties to allow sharing of resources on large and fast mainframe computers of the day.

With the increase of interest in virtualization and usage of virtual machines in production environment the virtualization technology has attracted a lot of attention from the virus writers and computer security research community.

It is a well-known fact that virtualization technology was adopted in its early stage by security researchers and anti-virus laboratories. Virtual machines provide a powerful malware analysis environment and are widely used in IT security community. Anti-virus researchers were one of the early adopters of the technology as early as 1999.

Soon after the initial adoption period, it became clear that many anti-virus companies are using virtualisation in the analysis process. For this reason malware writers invested a significant amount of time in analysis of various virtualization implementations with the objective to find methods that will allow malware to detect the presence of virtual machine. If the virtual machine was detected, malware could simply behave like a legitimate program or more commonly, refuse to run inside the virtual environment. If automated logic was used to decide if a program is malicious based solely on its behaviour, the malware would be able to avoid detection by anti-virus software—the detection signatures would not be created and the sample would be archived (or discarded) as non-malicious.

As a result of the virus writer's and security researcher's efforts, several methods of detection have been developed.

Although it is well known that many malware samples are VM-aware, we have not been able to find any research that attempts to measure the proportion of VM-aware malware in the set of all known malware samples. This proportion is very important when investigating the feasibility of developing a large scale automated analysis system.

If the proportion of VM-aware samples is very small ($<0.1\%$) we may be able to ignore it and manually analyze samples that do not produce results when run inside a virtual

---

B. Lau (✉) · V. Svajcer
Sophoslabs, Sophos Plc, The Pentagon,
Abingdon Science Park, Abingdon OX14 3YP, UK
e-mail: boris.lau@sophos.com

V. Svajcer
e-mail: vanja.svajcer@sophos.com

environment. If the proportion is higher than that, an effort has to be made to account for development of an environment able to successfully analyze VM-aware malware. For example, a multi-stage automated system could be developed. In the first stage the sample is moved to virtual environment and run inside the guest OS providing a relatively quick check using a simplified hardware configuration (full analysis network running inside one physical machine). Only if the virtualized analysis system does not produce conclusive result the sample is moved to the next phase - a system based on real hardware.

1.1 Virtualization and security research

Despite the fact that there are several detection methods, virtualisation is often used in computer security research. Here are just some of the most common use cases.

1.1.1 Software vulnerability research

Vulnerability research is in many ways similar to product testing. A vulnerability researcher may use virtual machines to create environment to test security of an application on several operating systems or test the security of the operating system itself.

Since virtual machines can be configured to create virtual network environment within the host operating system, security researchers often use them to perform black box analysis by creating unexpected application input (often using automated tools), which may expose vulnerabilities in the application or the operating system.

Furthermore, the researchers often install system debuggers which help them investigate the state of the system once an error condition is triggered by the unexpected input to the application.

Virtual machines can be used for testing of exploits and vulnerability payloads, including ones supplied with popular exploit development frameworks such as Metasploit.

1.1.2 Malware analysis

With the number of new potential malware samples discovered every day approaching 10.000 and constantly increasing it is very important for anti-malware researchers to be able to analyze incoming samples as quickly as possible.

Virus researchers were one of the first to recognize benefits of software virtualization for their work. Virtual machines allow creation of many different operating system environments which can be saved in a known state and restored in a matter of seconds.

With every new malware sample analyzed the analyst has to restore known clean state of the system in order to observe side-effects of malware infection.

The side-effects include file system changes, registry changes, network communication such as opening a socket to listen on a port for remote connections by the attacker or connecting to a web site to download and run additional malware components or potentially unwanted applications (PUAs).

Virtual machines allow creation of isolated networks that simulate standard network services (DNS, SMTP, POP3, HTTP, IRC, IM, P2P) expected to be online if a machine is connected to internet and redirect network traffic generated by the infected machine to a safe destination which will not expose any real machines on the internet.

In addition to manual analysis methods virtual machines are commonly used in automated analysis systems with dedicated clusters analyzing thousands of potential samples every day.

1.1.3 Honeypots

The detection of malware in a real world situation often depends on the moment when a security company receives the first sample of the threat. It is very important to obtain the new sample as soon as it appears in the wild.

Self replicating malware samples are often acquired using honeypots, systems that provide value to the owner by attracting unauthorized traffic.

Virtualization technology can be deployed to provide a secure environment with configuration identical to the machines targeted by malware. This non-production environment is exposed to the network and any access the system can be considered unauthorized.

From the attacker's position, the virtualized machine appears identical to a real machine and the malware will attempt to infect it. As soon as the infection is detected by the honeypot management system (which can be manual or automated) the new sample will be isolated and the detection added to the set of signatures used by the product.

2 Virtual machine detection methods

As already mentioned, it is a well known fact that virtual machines are used for malware analysis. For that reason, several malware families include detection of virtual machine environment. Commonly, when a virtual machine environment is detected the malware adopts its behaviour to its environment, most commonly stopping the execution or launching a specially crafted payload designed to be run if the presence of a virtual machine is detected.

Most notably, family of Zlob (Puper, DNSChanger) Trojans contain code to detect if they are being executed inside Virtual PC and VMWare. If the virtual machine is detected the Trojan attempts to remove itself from the system.

Big families of IRC bots such as Agobot and Sdbot also contain detection of virtual machines. If virtualization is detected the main bot functionality will not be exhibited and the bot will terminate its execution.

With the increasing usage of virtualization in a production environment a decrease in the number of malware which does not work in a virtual machine environment is expected.

Some of the executable packers also check for the presence of virtual machine. For example Themida is a very well known packer that does not unpack the underlying code if it is running under VMware.

In the following section we documented some well known examples of code used by malware to detect presence of a virtualised environment. Here, we only describe common methods we used to measure the overall detection of virtual machines. A fully comprehensive coverage of other virtual machine detection methods is provided by several existing papers [12].

2.1.1 Detection of running under MS virtual PC using VPC communication channel

This method relies on the communication channel between a virtual machine guest and Virtual Machine Manager (VMM). The code sets up ebx and eax registers with required values and emits an invalid instruction code 0x0f,0x3f which causes an exception if the code is not running under a Microsoft virtual machine. If no exception is triggered, the code is running under a Microsoft Virtual Machine.

The invalid instruction 0x0f,0x3f provides a method of communication between the guest OS and the Virtual PC VMM. Bytes 3 and 4 can contain several other values, each representing a call to a different VMM service although the values used in the following code snippet are by far the most common ones (0x07 and 0x0b) observed in Virtual PC (VPC) aware malware.

```
DWORD __forceinline
IsInsideVPC_exceptionFilter
    (LPEXCEPTION_POINTER ep)
 {
  PCONTEXT ctx = ep->ContextRecord;
  ctx->Ebx = -1; // Not running VPC
  ctx->Eip += 4; // skip past the "call
    VPC" opcodes
  return EXCEPTION_CONTINUE_EXECUTION;

  // we can safely resume execution
        since we skipped faulty
 }      instruction

// High level language friendly version
        of IsInsideVPC()
bool IsInsideVPC()
 {
  bool rc = false;
  __try
   {
    _asm push ebx
    _asm mov ebx, 0 // It will stay ZERO
        if VPC is running
    _asm mov eax, 1 // VPC function
        number
    // call VPC
    _asm __emit 0Fh
    _asm __emit 3Fh
    _asm __emit 07h
    _asm __emit 0Bh
    _asm test ebx, ebx
    _asm setz [rc]
    _asm pop ebx
   }

  // The except block shouldn't get
        triggered if VPC is running!!

  __except(IsInsideVPC_exceptionFilter
           (GetExceptionInformation()))
  {
  }
 return rc;
}
```

Invalid instruction VPC communication channel detection

2.1.2 Detection of running under Vmware using VMWare control API

This technique uses VMWare "backdoor" communication using port 0x5658 (VX) to detect the presence of Vmware [23]. In a real machine, communication with any port using in and out instructions of the processor in user mode (ring3) will cause an exception. However, if an application is running under Vmware, reading from port 0x5658 with VMWare magic value (0x564D5868—VMXh) in register eax and function number in ebx will start communication with the VMM.

In case of Agobot and most of the other programs that check for the presence of VMWare, it is simply sufficient to check for the presence of the expected VMWare magic number in register ebx after the in instruction was executed.

This method can be disabled if the following undocumented options are added to the virtual machine configuration file [24,25]. These settings prevent Agobot, Zlob and several other malware families from detecting the VMWare presence.

```
isolation.tools.getPtrLocation.disable = "TRUE"
isolation.tools.setPtrLocation.disable = "TRUE"
isolation.tools.setVersion.disable = "TRUE"
isolation.tools.getVersion.disable = "TRUE"
monitor_control.disable_directexec = "TRUE"
monitor_control.disable_chksimd = "TRUE"
monitor_control.disable_ntreloc = "TRUE"
monitor_control.disable_selfmod = "TRUE"
monitor_control.disable_reloc = "TRUE"
monitor_control.disable_btinout = "TRUE"
monitor_control.disable_btmemspace = "TRUE"
monitor_control.disable_btpriv = "TRUE"
monitor_control.disable_btseg = "TRUE"
```

Anti-VMWare prevention virtual machine initialization settings

```
/* executes VMware backdoor I/O
    function call */

#define VMWARE_MAGIC 0x564D5868 //
    Backdoor magic number
#define VMWARE_PORT 0x5658 // Backdoor
            port number
#define VMCMD_GET_VERSION 0x0a // Get
             version number

int VMBackDoor(unsigned long *reg_a,
    unsigned long *reg_b, unsigned
long *reg_c, unsigned long *reg_d)
 {
  unsigned long a, b, c, d;
  b=reg_b?*reg_b:0;
  c=reg_c?*reg_c:0;
  xtry {
  __asm {

    push eax
    push ebx
    push ecx
    push edx
    mov eax, VMWARE_MAGIC
    mov ebx, b
    mov ecx, c
    mov edx, VMWARE_PORT
    in eax, dx
    mov a, eax
    mov b, ebx
    mov c, ecx
    mov d, edx
    pop edx
    pop ecx
    pop ebx
    pop eax
   }
 } xcatch(...) {}

if(reg_a) *reg_a=a; if(reg_b) *reg_b=b;
if(reg_c) *reg_c=c; if(reg_d) *reg_d=d;

return a;
}

/* Check VMware version only */

int VMGetVersion()
 {
  unsigned long version, magic, command;
  command=VMCMD_GET_VERSION;
  VMBackDoor(&version, &magic, &command,
                    NULL);
  if(magic==VMWARE_MAGIC) return
        version;
  else return 0;
 }

/* Check if running inside VMWare */

int IsVMWare()
 {
  int version=VMGetVersion();
  if(version) return true; else return
    false;
 }
```

VMWare detection using VMWare communication channel

2.1.3 Redpill (using SIDT, SGDT or SLDT)

At the heart of this detection method is the SIDT x86 instruction (encoded as 0F01[addr]), which stores the contents of the interrupt descriptor table register (IDTR) in a memory location. SIDT is one of the few instructions that can be executed in the non privileged mode (ring3) but it returns the contents of the sensitive register, used internally by operating system. SxxT are only one type of instructions of x86 instruction set that can be used to detect that the application is running inside a virtual machine (Vmware or Virtual PC). It is important to note that developers of VMWare and Virtual PC could have probably used dynamic translation to translate SIDT instruction to a safe format that returns the same results in a virtual environment as in real environment but they made a decision not to do it. This is why this method (in some systems) can be reliably used to detect virtual machines.

It was first observed by Joanna Rutkowska that because there is only one IDTR register, but there are at least two OS running concurrently (i.e. the host and the guest OS), VMM needs to shadow the guest's IDTR in a safe place, so that it will not conflict with host's one. On VMWare with a single processor, the relocated address of IDT was at address 0xffXXXXXX, while on Virtual PC it is 0xe8XXXXXX.

However, this assumption is not correct if the system is fully emulated or there is more than one hardware CPU installed, which is the case with most modern multi-core processors. In a multi processor system every processor uses its own interrupt descriptor table (IDT) and has its own register (IDTR) to point to the IDT. Often, the IDT memory address for the second CPU is in the region 0xf7XXXXXX, which means that the method used by Redpill [20] and Scoopy Doo [21,22] detection programs can often show incorrect results.

```
int detect_vm () {

/* setup memory areas for returned IDTR
    content and the assembly */

unsigned char m[2+4], sidtc[] = ``\x0f
    \x01\x0d\00\x00\x00\x00\xc3";

/* patch assembly with the pointer to
    buffer allocated for IDTR */

*((unsigned*)&sidtc[3]) = (unsigned)m;

/* call the code to retrieve IDTR */

((void(*)())&sidtc)();

/* if MSB of the IDTR is larger than
    0xd0 assume virtual machine */

return (m[5]>0xd0) ? 1 : 0;
}
```

Redpill detection method

The Redpill's method checks the first byte of the IDTR and compares it with 0xd0. If the byte greater than 0xd0 the program assumes that it is running inside a virtual machine. In case of a dual processor system this approach will generate false positive detection in 50% of the time [19].

A more reliable method may be to use sldt instruction since LDTR registers for individual processors running Windows seem to be initialised to point to the same memory location and the false positive rate is minimised.

2.1.4 SMSW VMWare detection

An alternative method of checking for the presence of VMWare has been found in several samples of an IRC backdoor Troj/Zyklo (Backdoor.Zyklobot). The method uses the SMSW (Store Machine Specific Word) instruction. The instruction is supposed to return 16-bit result and if the 32 bit register is used to store the result, the higher 16 bits are undefined, according to the Intel's Instruction Set Reference.

In an experiment [27] conducted by Danny Quist of Offensive computing, it has been observed that on Intel processors, the return value of top 16 bits is consistently 0x8001, while on virtualized CPU in VMWare the target register contains the value preserved before the instruction was executed. This fact was used in the SMSW method. First the target register is initialized with a "magic" value and the SMSW is executed. If after the execution of the instruction the target register still contains the magic value, the program is deemed to be running inside VMWare.

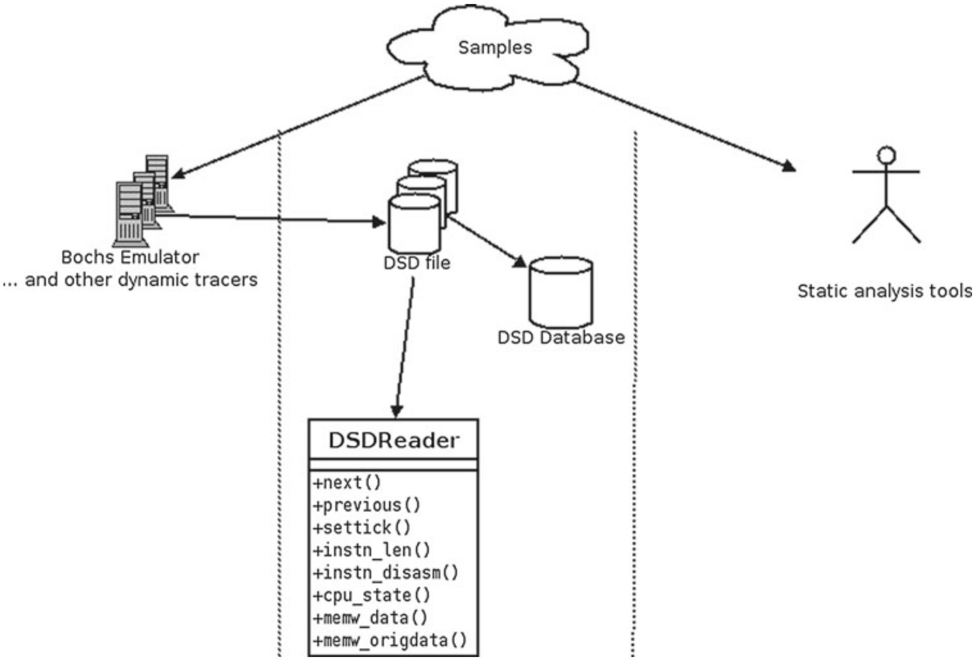
```
int mswCheck(void)
 {
  int rc = 0;
  unsigned int reax = 0;

  __asm
    {
     mov eax, 0xCCCCCCCC; // This is the
        magic value
     smsw eax;
     mov DWORD PTR [reax], eax;
    }

  printf("MSW: %2.2x%2.2x%2.2x%2.2x\n",
         (reax >> 24) & 0xFF, (reax >>
         16) & 0xFF, (reax >> 8) & 0xFF,
         reax & 0xFF);

// If the high order bits are still
    0xCC, then we are in a VMWare
    session
// with emulation turned off.

  if ( (( (reax >> 24) & 0xFF) == 0xcc)
    && (( (reax >> 16) & 0xFF) == 0xcc))
   rc = 1;
  else
   rc = 0;
  return rc;
 }
```

This code has been observed in few other malware families, indicating a code reuse.

2.1.5 Other detection methods

Presence of a virtual machine can also be detected by checking other operating system objects such as:

Fig. 1 Architecture of DSD-Tracer



- System services (for presence of VMWare Tools service)
- Virtual network card MAC specific addresses
- System BIOS (for Virtual machine specific BIOS emulation)
- System hardware devices (both VMWare and Virtual PC virtualize a specific set of devices)
- File system
- System CPU (CPUID instruction, returns ConnectixCPU if the system is a VPC machine)
- Registry keys referencing VMWare or Connectix (Microsoft Virtual PC).

3 Methodology of our study with DSD-Tracer

In our study, we utilized DSD-Tracer, a malware analysis framework developed in house for our own research. We aimed to use DSD-Tracer to identify the families of obfuscation packers which employ VM-aware detection techniques, while detection of other non-obfuscated virtualization aware malware was implemented using a set of static analysis rules and dynamic rules applied to the output of Sophos virus engine built-in emulator.

DSD-Tracer is a framework that integrates dynamic and static analysis. Detailed discussion of DSD-Tracer is outside of the scope of this paper. Interested parties can refer to [1] for detailed discussion of the framework. In the following section we will briefly discuss our methodology and advantages of employing DSD-Tracer as our tool for analysing samples (Fig. 1).

3.1.1 Dynamic component

DSD-Tracer provides a detailed trace of the executable in dynamic state, including the following information:

- Instructions decoded before its execution.
- All CPU registers.
- Reads/writes to virtual/physical memory.
- Interrupts/exceptions generated.

At the core of the dynamic component is an instrumented virtual machine which aims to capture every instruction run by the sample. The specification of the framework enables tools to communicate low level information about samples.

There are existing studies on automated replication systems; some previous studies for using VM to automate analysis (such as TTAnalyze [3], Cobra [4], CWSandbox [5], see references) focused on using VM to obtain high-level information as opposed to low level assembly traces.

DSD-Tracer collects low-level information about the running sample. We argue this ability for collecting low-level information is essential for our investigation since techniques for detecting virtual machine (e.g. the invalid instruction execution to detect Virtual PC which only requires one instruction) can be observed at only low level.

3.1.2 Static component

Serialized dynamic information can be accessed via a well defined interface. The interface module was written in C++ which is wrapped into a high-level language module using

SWIG module (supporting Perl, PHP, Python, Tcl, Ruby, PHP, etc.)

The following summarise the interface used to access the serialized dynamic information:

```
class dsd_reader {
 public:
 dsd_reader(char *logname);
 ~dsd_reader();
 tick cputick();
 tick min_cputick();
 tick max_cputick();
 dsd_reader* next();
 dsd_reader* previous();
 dsd_reader* set_tick(tick t);

 //check if certain block exists
 dsd_block* read_block();
 //dsd_block* read_block(const char*
    type);
 dsd_block* read_block(block_type type);

  // return current instructions
  address instn_laddr();
  unsigned instn_len();
  byte* instn_buf(); //return array of
    null-terminated bytes
  char* instn_disasm();

  // return details about memory write
  address memw_laddr();
  address memw_paddr();
  unsigned memw_len();
  byte* memw_data();
  byte* memw_origdata();

  //return cpu states
  Bit32u cpu_eax();
  Bit32u cpu_ebx();
  Bit32u cpu_ecx();
  Bit32u cpu_edx();
  Bit32u cpu_ebp();
  Bit32u cpu_esi();
  Bit32u cpu_edi();
  Bit32u cpu_esp();
};
```

An example of C++ interface declaration

We have taken advantage of this interface and written a Python script to detect known techniques for detecting VM detailed in previous paragraphs. The script takes the trace, steps through each CPU tick and performs matching to see if the trace matches one of the previously discussed VM detection techniques.

3.1.3 Automatic replication harness

In order to handle large number of samples to obtain reliable statistics, manual generation of dynamic traces and analysis is impractical (Fig. 2).

We have implemented a web-based automatic replication harness which allows feeding large number of samples, and automatically performs required analysis to detect if the sample has employed known VM detection techniques (in addition to various code-coverage analysis, data-I/O analysis as shown in above screenshot).

The result of our analysis was obtained by the web-based interface which displays the proportion and category of detected VM-aware techniques.

3.2 Case study: DSD-Tracer on Themida

To give insight into the complexity of analyzing packers that employ virtualization detection techniques, we will use Themida packer as an example. Themida [15] is a complex packer that employs various armouring techniques, metamorphic/junk instructions insertions and virtualization detection.

3.2.1 Complexity of Themida

The complexity of Themida can be illustrated by the following Data I/O graph produced from a trace of DSD-Tracer of the Themida unpacking (Fig. 3).

The red line shows the IP, blue line shows the write address, green is the read address. This graph illustrates a few things:

1. The multiple layers of encryption employed by Themida.
2. The large red blob in the middle is the embedded Virtual Machine code by Themida—the virtual machine itself employs excessive junk jumps which cause the large spread of the IP.

Analyzing Themida through traditional debugger/static technique is very labor intensive.

3.2.2 Static analysis of the dsddump sample

One of the frequently used too in DSD-Tracer is “dsddump”. Since DSD-Tracer recorded all memory I/O operations of the original executable, we can simply replay all the recorded memory-io and produce a “dump” of the packed sample in static environment. Advantage of such method compare to dumping directly from memory includes ability to

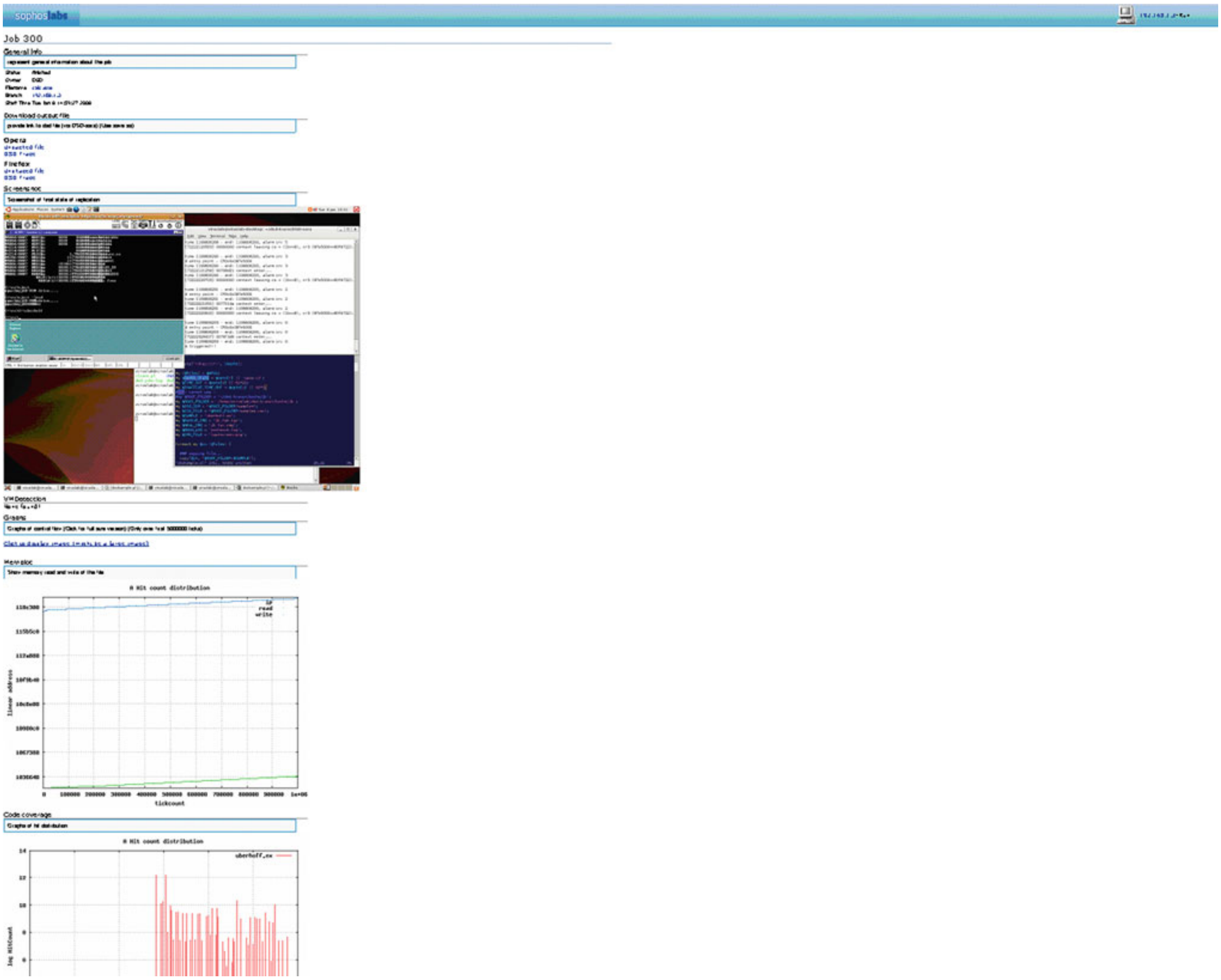


Fig. 2 Screenshot of our post-analysis results

circumvent various page-level anti-dumping techniques as well as ability to inspect the "dump" at different time slices.

If we look at the information extracted from the replication harness.

Both the CPU tick (relative to the start of the process) and the virtual address of the technique is recorded.

Now we can refer to the de-obfuscated "dsddump" sample. We can investigate the virtual address at which the VM-aware technique occurred (Fig. 4).

This allows us to cross verified the VM-aware technique used between samples. For example, the following is a side by side comparison for the VMX backdoor technique used between two samples (Fig. 5).

Note the:

1. The junk jump instruction in front of the technique. The junk jumps are modified between different samples.
2. Simple algebraic instruction is used to build up the required register values to avoid static detection and looks polymorphic. However, we found that these algebraic operations are relatively constant between the samples and might not be generated at the time of packing.

In summary, DSD-Tracer provides us with an effective and accurate way of analysing packers without requiring manually trace through the sample.

3.3 Justification for using DSD-Tracer

3.3.1 Coverage of packed samples

In malware research, a large number of samples are packed. At least 20% of samples from Sophos sample set are packed with known packers, although this percentage is on decrease.

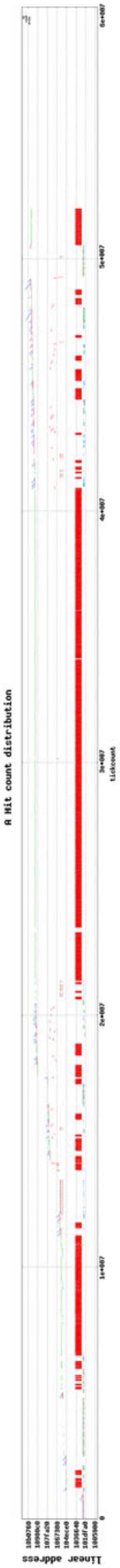


Fig. 3 Data I/O graph from a trace of DSD-Tracer (Themida unpacking)

Such packed samples prevent static analysis techniques from discovering that the sample is VM-aware. Unpacking the sample does not help towards our goal since one of our major goals was to investigate VM-aware techniques which are embedded within the packer, and unpacking the sample will strip the sample of such property.

By using DSD-Tracer, we record a trace of dynamically executed samples, and recognize a Virtual Machine detection technique even if it is hidden deep inside the packer and cannot be seen by static analysis techniques.

This ability is demonstrated by the previously discussed case-study of Themida.

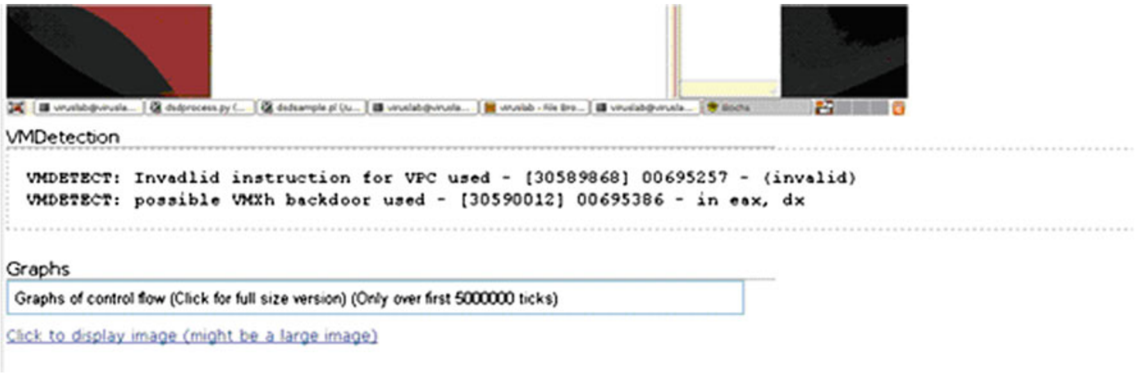
3.3.2 Low-level accuracy

There are existing tools for obtaining low level assembly information through emulation, including the Norman Sandbox Analyzer [7]. It constructs an ad-hoc subset of CPU/OS functionality, which means there are often flaws which malware can detect easily (e.g. “Detecting Norman by IDT” [8] [av07]). Nevertheless, these are valuable tools to cross-verify trace information in the framework. ida-x86emu [9] is an x86 emulator written as an IDA plug-in , with limited OS-level emulation. Note that most of these tools are designed with different goals—Norman Sandbox analyzer is a real-time analysis tool with efficiency in mind, while ida-x86emu is a tool aimed at assisting unpacking in IDA as opposed to being a full emulator - so accuracy of emulation might not be the most important goal of these tools.

3.3.3 Circumventing armour techniques

DSD-Tracer uses an instrumented Virtual Machine for which the “debugger” runs below Ring0 (using x86 terminology here) and so it had been labelled as Ring-1 debugger. Ring -1 debuggers provide a more accurate simulation environment since no modification is required to the OS-level. It can monitor the debugee without affecting any of the host OS environment or the CPU state (e.g. debugging registers).

There are alternative solutions which also allow kernel mode debugging, such as VMware workstation, or QEmu kernel mode debugger. However, we have chosen Bochs as our final choice due to the fact that in Bochs, the CPU is fully emulated (as oppose to some other VM such as QEMU [10], KQEMU and VMware which, for efficiency purposes, execute some instructions natively on the machine). It does not employ any dynamic binary translation technique, which greatly simplifies implementing the VM at CPU execution level. This property makes Bochs relatively accurate and robust compare to other VMs.


VMDetection

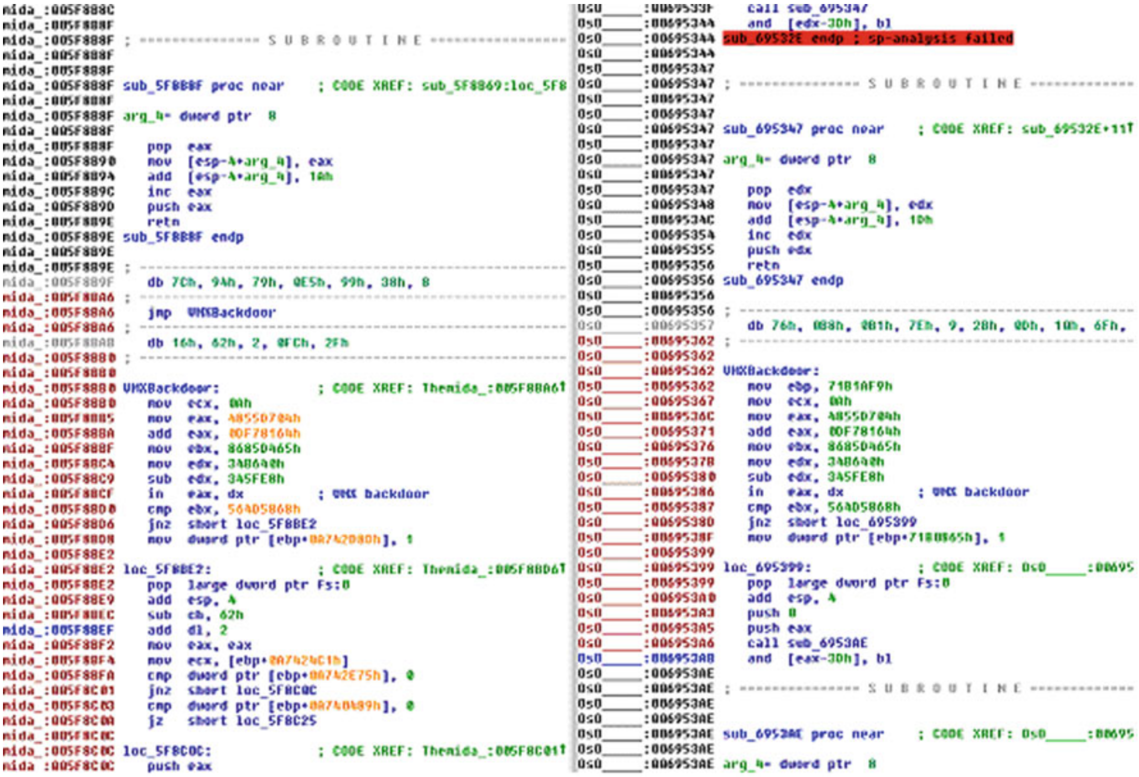
```
VMDETECT: Invadlid instruction for VPC used - [30589868] 00695257 - (invalid)
VMDETECT: possible VMXh backdoor used - [30590012] 00695386 - in eax, dx
```

Graphs

Graphs of control flow (Click for full size version) (Only over first 5000000 ticks)

Click to display image (might be a large image)

Fig. 4 Screenshot of DSD presenting where VM aware technique is used


```
mida_:005F888C
mida_:005F888F
mida_:005F888F ; =============== S U B R O U T I N E ===============
mida_:005F888F
mida_:005F888F
mida_:005F888F sub_5F888F proc near      ; CODE XREF: sub_5F8869:loc_5F8
mida_:005F888F
mida_:005F888F arg_4= dword ptr  8
mida_:005F888F
mida_:005F888F    pop   eax
mida_:005F8890    mov   [esp-4+arg_4], eax
mida_:005F8894    add   [esp-4+arg_4], 1Ah
mida_:005F889C    inc   eax
mida_:005F889D    push eax
mida_:005F889E    retn
mida_:005F889E sub_5F888F endp
mida_:005F889E
mida_:005F889E ; ---------------------------------------------------
mida_:005F889F    db 7Ch, 94h, 79h, 0E5h, 99h, 38h, 8
mida_:005F88A6 ; ---------------------------------------------------
mida_:005F88A6    jmp   VMXBackdoor
mida_:005F88A6 ; ---------------------------------------------------
mida_:005F88A8    db 16h, 62h, 2, 0FCh, 2Fh
mida_:005F88B0 ; ---------------------------------------------------
mida_:005F88B0
mida_:005F88B0 VMXBackdoor:              ; CODE XREF: Themida_:005F88A6↑
mida_:005F88B0    mov   ecx, 0Ah
mida_:005F88B5    mov   eax, 4855D704h
mida_:005F88BA    add   eax, 0OF78164h
mida_:005F88BF    mov   ebx, 8685D465h
mida_:005F88C4    mov   edx, 3A8640h
mida_:005F88C9    sub   edx, 345FE8h
mida_:005F88CF    in    eax, dx           ; VMX backdoor
mida_:005F88D0    cmp   ebx, 564D5868h
mida_:005F88D6    jnz   short loc_5F88E2
mida_:005F88D8    mov   dword ptr [ebp+0A742080h], 1
mida_:005F88E2
mida_:005F88E2 loc_5F88E2:               ; CODE XREF: Themida_:005F88D6↑
mida_:005F88E2    pop   large dword ptr Fs:0
mida_:005F88E9    add   esp, 4
mida_:005F88EC    sub   ch, 62h
mida_:005F88EF    add   dl, 2
mida_:005F88F2    mov   eax, eax
mida_:005F88F4    mov   ecx, [ebp+0A7424C1h]
mida_:005F88FA    cmp   dword ptr [ebp+0A742E75h], 0
mida_:005F8901    jnz   short loc_5F890C
mida_:005F8903    cmp   dword ptr [ebp+0A740489h], 0
mida_:005F890A    jz    short loc_5F8925
mida_:005F890C
mida_:005F890C loc_5F890C:               ; CODE XREF: Themida_:005F8901↑
mida_:005F890C    push eax
```

```
0s0_____:0069533F    call sub_695347
0s0_____:00695344    and  [edx-3Dh], bl
0s0_____:00695344 sub_69532E endp ; sp-analysis failed
0s0_____:00695344
0s0_____:00695347
0s0_____:00695347 ; =============== S U B R O U T I N E =============
0s0_____:00695347
0s0_____:00695347
0s0_____:00695347 sub_695347 proc near     ; CODE XREF: sub_69532E+11↑
0s0_____:00695347
0s0_____:00695347 arg_4= dword ptr  8
0s0_____:00695347
0s0_____:00695347    pop   edx
0s0_____:00695348    mov   [esp-4+arg_4], edx
0s0_____:0069534C    add   [esp-4+arg_4], 10h
0s0_____:00695354    inc   edx
0s0_____:00695355    push edx
0s0_____:00695356    retn
0s0_____:00695356 sub_695347 endp
0s0_____:00695356
0s0_____:00695356 ; ---------------------------------------------
0s0_____:00695357    db 76h, 0B8h, 0B1h, 7Eh, 9, 28h, 0Dh, 10h, 6Fh,
0s0_____:00695362 ; ---------------------------------------------
0s0_____:00695362
0s0_____:00695362 VMXBackdoor:
0s0_____:00695362    mov   ebp, 71B1AF9h
0s0_____:00695367    mov   ecx, 0Ah
0s0_____:0069536C    mov   eax, 4855D704h
0s0_____:00695371    add   eax, 0OF78164h
0s0_____:00695376    mov   ebx, 8685D465h
0s0_____:0069537B    mov   edx, 3A8640h
0s0_____:00695380    sub   edx, 345FE8h
0s0_____:00695386    in    eax, dx          ; VMX backdoor
0s0_____:00695387    cmp   ebx, 564D5868h
0s0_____:0069538D    jnz   short loc_695399
0s0_____:0069538F    mov   dword ptr [ebp+718B865h], 1
0s0_____:00695399
0s0_____:00695399 loc_695399:              ; CODE XREF: 0s0_____:00695
0s0_____:00695399    pop   large dword ptr Fs:0
0s0_____:006953A0    add   esp, 4
0s0_____:006953A3    push 0
0s0_____:006953A5    push eax
0s0_____:006953A6    call sub_6953AE
0s0_____:006953AB    and   [eax-3Dh], bl
0s0_____:006953AE
0s0_____:006953AE ; =============== S U B R O U T I N E =============
0s0_____:006953AE
0s0_____:006953AE
0s0_____:006953AE sub_6953AE proc near     ; CODE XREF: 0s0_____:00695
0s0_____:006953AE
0s0_____:006953AE arg_4= dword ptr  8
```

Fig. 5 Comparision of 2 Themida samples using VM aware techniques

3.4 Mitigating factors in using DSD-Tracer

While DSD-Tracer does provide some advantage for our research, we have to also be aware of certain caveats in using it. Below detailed some of our concerns while employing DSD-Tracer, and describe measures to minimize the impact of such factors.

Bochs as a Virtual Machine

DSD-Tracer currently employs Bochs as the analysis environment at the core of the dynamic stage. There are known techniques for detecting Bochs—most easily on the emulated device characteristic.

In our evaluation of suitability for Bochs as analysis environment, we had tried to establish if any malware employs known technique in detecting Bochs. However, from our research, we had not been able to find any samples which tried to detect the existence of Bochs machine.

In the original description of DSD-Tracer in [1], it is proposed that multiple dynamic analysis trace generated on different environment can be cross-verified against each other to make VM-aware techniques (and in general, armoring technique) almost impossible, since armoring techniques would display a divergence between the 2 traces. We have implemented a proof of concept version of such framework which will be discussed in the following section.

3.4.1 Scalability

Due to the large amount of information handled by DSD-Tracer, the current throughput of our experimental setup of DSD-Tracer is close to 4 samples/hour. Our main aim of research for using DSD-Tracer is to establish the amount of packed samples which employ VM-aware techniques.

To best-employ our limited bandwidth with our DSD-Tracer replication harness, we have taken random samples from each known (as several custom) packers so we can accurately establish if a family of packer contain VM-aware techniques or not. We took 5 samples from each of the commonly used sets of packed, while for packers with smaller population we have taken 2.

Some packers, such as Themida, have Virtual Machine detection as an optional feature. It is not necessary true that the samples we chose from our collection to represent the packer will have such option enabled. However, we argue that it is likely that malware authors would more often than not enable such features since:

1. Malware running in a virtualized environment is often less valuable than one on real environment
2. Malware researchers make use of virtualization as their analysis environment is a well known fact, and hence malware authors are likely to enable such option.

We have done a brief research on the percentage of samples which had VM technique turned on for Themida, we found more than 85% of them contain VM-aware techniques.

3.5 Proof of concept experiment for DSD-Tracer on VMware

One of the core-idea of DSD-Tracer is the ability to cross-verified multiple dynamic analysis trace generated on different environment to make VM-aware techniques (and in general, armoring technique) almost impossible, since armoring techniques would display a divergence between the 2 traces.

In the following section we shall describe our attempt to implement another implementation of DSD-Tracer of which we could verify against the trace generated from Bochs.

We have also implemented a prototype version of the DSD-Tracer running on VMware Workstation 6 using its GDB debugging stub and implementing a customized GDB client on the host environment which will single step and record the trace.

The setup was quite simple. Following instruction from [6], the vmx file needed to be configured with following lines:

```
debugStub.listen.guest32 = "TRUE"
debugStub.listen.guest32.remote = "TRUE"
```

In addition, we would like to enable the "invisible breakpoint" [17] option that does not use the usual software breakpoints affecting the guest memory. Invisible breakpoints allow VMware to maintain a set of internal breakpoints similar to hardware breakpoints.

```
debugStub.hideBreakpoints=1
```

One advantage of such "invisible breakpoints" is that they operate on virtual addresses. They work on all page tables—even if the process has not yet been created. This is a very convenient mechanism which allows us to set a breakpoint at the entry point of the process.

With the above options enabled we can connect a GDB client to port 8832 and it will act as a kernel mode debugger on the host, using the following command in gdb:

```
target remote localhost:8832
```

As a simple experiment, we can use the following simple GDB script to print out the assembly execution trace from the client. Note that we would only target the Ring 3 instructions from the specific process we are investigating.

```
target remote localhost:8832
# default disassembly flavour for gdb is
 att set disassembly-flavour intel
# set breakpoint at the entry point
 (remember to use invisible breakpoint)

b *0x4010000
continue

# list of contextswap breakpoints
    (at win2k KiSwap Context)
b *0x80403b96
b *0x80403c6c

# internal function for getting Process
    ID from PEB
# Note it might not be able to read the
    necessary memory when in Ring 0,
# thus will return -1 if it fail. See
    below

define getpid
# cannot get pid in ring 0
set $pidnow = -1
# PEB->PID
set $pidnow = *0x7ffde020
end
```

```
# get current pid
set $pid = *0x7ffde020 # PEB.pid at
    Win2k
printf "current pid = %i\n", $pid
while 1
set $switchcount = 0
getpid
while ($pid != $pidnow)
printf "waiting to be switched (pid =
    %i)...\n", $pidnow
continue

set $switchcount = $switchcount + 1
if ($switchcount > 1000)
printf "switched too many times! quit
    ...\n"
quit
end
getpid
end

# only print disassembly if not in r0
if ($cs != 8)
# print one instruction
x/i $pc
end
si
end
quit
```

To avoid error in memory read while running the script, it will require a patch on the GDB client to handle memory read errors without stopping the script. This can be done by patching the source of GDB client with patches based on [18] (the above script assumed a simplified version of the patch that all errors are ignored).

Using this setup, we are able to demonstrate detection on the VMX backdoor technique, by showing the differences between the traces generated from Bochs and VMware. We are able to locate the exact instruction at which the VM-detection have occurred.

A problem with our proof of concept is that the throughput of this experimental setup is very low. It takes approximately 6 hours to run a proof of concept sample on VMware workstation with single stepping GDB client, this is mainly due to 2 reasons:

1. overhead in communication between the GDB client on the host and GDB stub in the VMware.
2. when investigating SIDT VM-aware technique, we noticed that the returned IDT value shows that acceleration was disabled. It seems that turning on debugging stub would implicitly disable acceleration, which is a side effect of our investigation.

Note that since QEMU also has the GDB stub support, it is possible to implement the above technique in QEMU as well.

This proof of concept, DSD-Tracer on VMware demonstrates our technique of cross-verifying traces against each other to detect armoring techniques. However, improvements are needed to be made if we are to employ it on a large sample set.

4 Results

Our research attempted to measure the proportion of VM-aware files in the malware set using a combination of static and dynamic analysis methods. During the process we were aware of the limitation of both approaches with regards to the modern malware that often employs obfuscation methods to make analysis more difficult and in many ways our measurement will amount to approximation where our target to come up with “worst case” numbers.

For example, if we found that a significant number of family members are VM-aware we used the full number of family members as the worst case. With this approach we hope we have taken in account the number of malicious files and families that were not detected due to obfuscation and insufficiencies of our testing methods.

4.1 VM detection in packers

DSD-Tracer test has been run on a set of around 400 samples packed by 193 different generic and custom packers classified by out database. We have taken 5 random samples from each of the commonly used sets of packed, while for packers with smaller population we have taken 2. More than one sample of each packer is taken to eliminate uncertainties around determination of the VM detection in the packer code. Only if two or more of the tested samples were found to exhibit VM detection we attributed the detection to packer code, otherwise we would attribute the detection to the underlying malware. Overall, our tests have shown only one major packer that actively used VM detection code—Themida accounting for 1.03% samples in our test set.

One border line case we found is ExeCryptor (accounted for 0.15% of our testset). ExeCryptor provides an option for making the packed executable compatible with Virtual environment (Fig. 6).

☑ Dynamic Import
☑ Delay DLL loading
☐ VMWare/VirtualPC/wine compatible

Fig. 6 Execryptor VMWare compatibility protection option

However, when we tried to investigate further, we found:

- We have taken a number of ExeCryptor samples from our test set, and verify that they all behaved the same between virtual and real environment.
- We created our own ExeCrytor executables with and without the VM compatibility option but could not spot any differences in execution path between the samples in DSD-Tracer.
- Static analysis concludes that it does not contains any known techniques for detecting Virtual environment.

Therefore we have decided to exclude ExeCrytor from our list of packers which detects Virtual environment.

Nevertheless, we found several samples of various custom packers that also exhibited this VM detection behaviour. Since we know that these custom packers were specifically created to obfuscate malware we can conclude that there is a higher probability of VM detection code in custom packers than in the generic packers. We do not have the names for these packers as they are detected under Sophos generic custom packer detection name EncPk. When VM-aware custom packers are taken in account, the overall VM detection rate in packer code raises to 1.15%.

4.2 VM detection in malware families

This part of testing was conducted using a combination of purely static analysis (disassembly) rules and dynamic (Sophos virus engine emulation) rules. The rules were run over a set consisting of around 2 million known malicious files. The rules are also tested on a large set of known clean files to make sure that none of the rules trigger too many false positive detections.

Some rules, for example SIDT scanning static rule generated too many false positive detections. We use these rules to identify a list of possible candidates which uses VM-aware techniques, and then use slower and more detail static analysis technique via IDA scripting to disassemble the sample and determine if the technique was used (Table 1).

Table 1 Virtual machine detection method breakdown

Method	Number	Percentage (%)	FP rate
VMWare backdoor	4,524	0.232	Low
SIDT, SLDT	8,668	0.444	Medium_to_high
Redpill copy	68	0.003	None
VPCDet-A	2,630	0.135	Low
VMWare string	3,216	0.165	Medium
VMsmsw	4		None
Overall		0.978	

Rules based testing (excluding packers) shows that a little bit less of 1% of samples may be VM-aware. To get overall percentage, we should add the percentage of files that use VM-aware packers.

In terms of family breakdown there are a lot of smaller families implementing VM detection methods, the largest of them comprise of Dorf (not all samples), Zlob (again only downloading component) and Agobot and various IRCBot variants (Table 2).

Another significant contribution comes from a family of dialers Dial/FlashL, although the full behaviour will still be exhibited regardless of the fact that a VM was detected. Dial/FlashL will however report the presence of a virtual machine in its infection report using HTTP post request to its home website.

4.3 Overall numbers

If we add numbers from the previous two sections, we get a good approximation of the overall number of VM-aware malicious files.

4.4 Some interesting observations

Of the samples using the VMWare backdoor detection method, 50% of them also contain detection of Virtual PC using the VPC illegal instruction detection method. However, of the samples using the VPC illegal instruction detection method 93% of them also contain VMWare detection method.

This possibly reflects the opinion among virus writers that VMWare is considered to be used most commonly used for anti-virus research, which may be true. Another possibility is that it may reflect the fact that VMWare appeared earlier in the market.

Table 2 Virtual machine detection with significant families

Noticable family	VMware backdoor	VMware SIDT	VPC invalid instructions
Agobot	Y		
DelpDldr		Y	
Dorf	Y		Y
DwnLd		Y	
IRCBot	Y		
SmallDn	Y		Y
Torpig	Y		Y
Virtum		Y	
Zlob	Y		Y
Customized packers (EncPk)	Y		Y

Fig. 7 VMWare backdoor detections in 2007

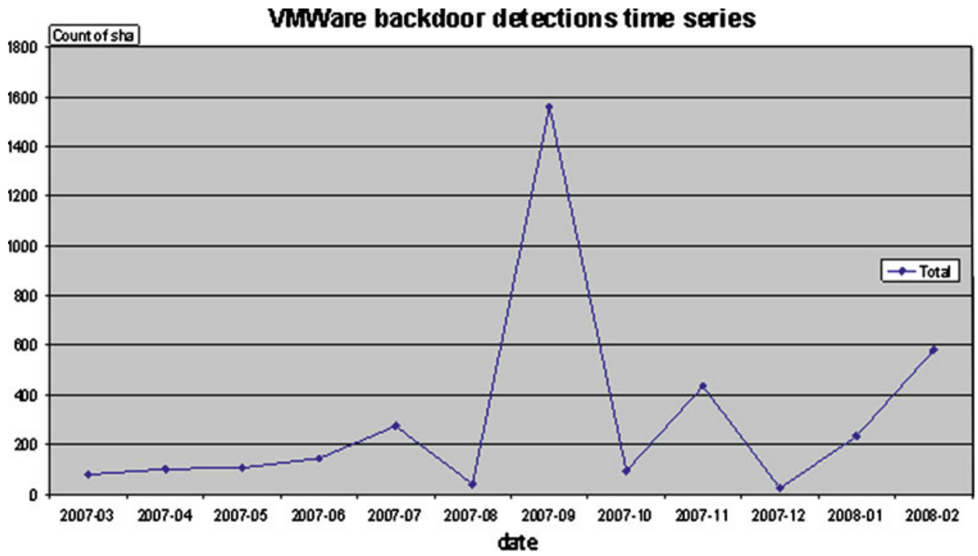
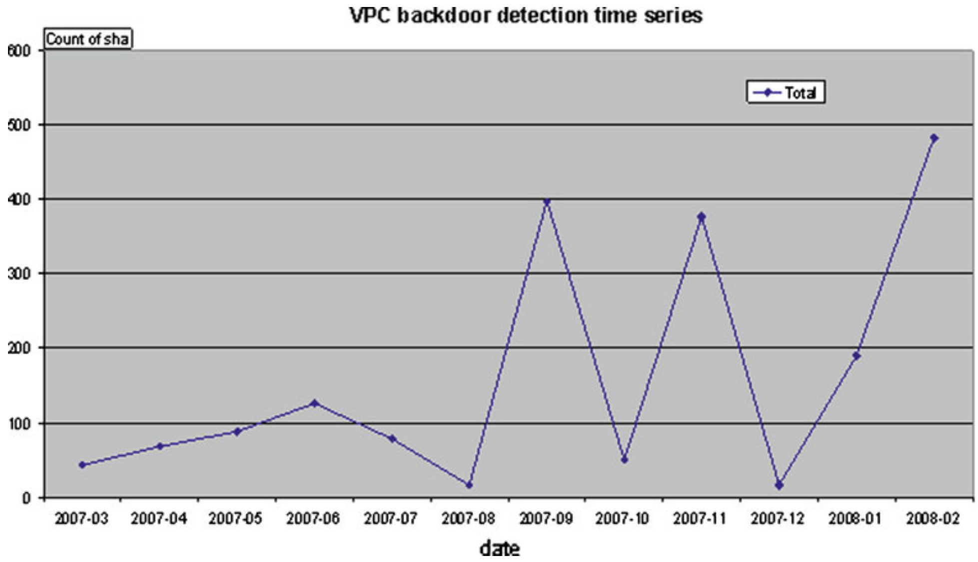


Fig. 8 VPC backdoor detections in 2007



In our research we have also attempted to find out if there is a growing or decreasing trend in VM detections by measuring a number of files that arrived to Sophos every month versus detections of particular VM detection rules. While a sharp increase attributed to VM-aware Dorf variants is clearly visible in September 2007, both detections of VMWare and VPC backdoor detections give overall inconclusive results (Figs. 7 and 8).

5 Conclusion

Measuring proportion of VM-aware malware is not an easy task. When measuring this proportion, one cannot simply rely on static analysis methods, since they can be easily circumvented with obfuscated and encrypted code. Dynamic analysis using DSD-Tracer is slow and it would take to long to measure over a statistically representative set of samples (e.g. to achieve low margin of error and high level of certainty).

We think that the combination of static and dynamic method gives a good approximation that allows the reader to make decisions based on the content of the paper. We have developed DSD-Tracer—a system that can reliably, with time constraint, measure several virtual machine detection methods in a program.

Finally, we measured that the overall proportion of VM-aware samples is 2.13%. This number is not as high as sometimes claimed, but still represents a significant number that must be taken in account while conducting analysis using virtual machines. It also shows that measures to minimise the possibility of VM detection have to be taken when designing VM-based automated analysis systems.

References

1. Lau, B.: DSD-Tracer: experimentation and implementation. In: Virus Bulletin 2007 Conference proceedings (2007)
2. Moser, A., Kruegel, C., Kirda, E.: Exploring Multiple Execution Paths for Malware Analysis (2006)
3. Bayer, U.: TTAnalyze: a tool for analyzing Malware. Master's Thesis, Technical University of Vienna (2005)
4. Vasudevan, A., Yerraballi, R.: Cobra: fine-grained Malware analysis using stealth localized-executions. In: IEEE and Signature Generation of Exploits on Commodity Software (2006)
5. Willems, A., Holz, C., Freiling, T., Felix A.: Toward Automated Dynamic Malware Analysis Using CWSandbox. http://www.cwsandbox.org/ (2007)
6. Simplified Wrapper and Interface Generator. http://www.swig.org/ (2000)
7. Natvig, K.: Norman sandbox white paper. http://download.norman.no/whitepapers/whitepaper_Norman_SandBox.pdf (2003)
8. Vidstrom, A.: Evading the Norman SandBox Analyzer. BugTraq bulletin (2007)
9. Eagle, C.: Attacking Packed Code with IDA Pro. http://ida-x86emu.sourceforge.net, Black-hat Asia (2006)
10. Bellard, F.: QEMU Emulator User Documentation # GDB usage. http://fabrice.bellard.free.fr/qemu/qemu-doc.html#SEC46 (2005)
11. Ormandy, T.: An empirical study into the security exposure to hosts of hostile virtualized environments, CanSecWest (2007)
12. Ferrie, P.: Attacks on virtual machine emulators (2007)
13. Xu M., et al.: ReTrace: Collecting execution trace with virtual machine deterministic replay (2007)
14. Herrod, S.: The amazing VM record/replay feature in VMware Workstation 6. http://blogs.vmware.com/sherrod/2007/04/the_amazing_vm_.html (2007)
15. Technology, O.: Themida overview. http://www.oreans.com/themida.php (2007)
16. Malyugin, V.: Application debugging with Record/Replay. http://stackframe.blogspot.com/2007/09/application-debugging-with-recordreplay.html (2007)
17. Malyugin, V.: VMware forum thread. http://communities.vmware.com/thread/104296 (2007)
18. Callanan, S.: Terminate-on-error patch for GDBcli. http://sourceware.org/ml/gdb-patches/2005-08/msg00120.html (2005)
19. Schneider, O.: Redpill getting colorless? http://blog.assarbad.net/wp-content/uploads/2007/04/redpill_getting_colorless.pdf (2007)
20. Rutkowska, J.: Red Pill. http://invisiblethings.org/papers/redpill.html (2004)
21. Klein, T.: Jerry. http://www.trapkit.de/research/vmm/jerry/index.html (2005)
22. Klein, T.: Scoopy Doo. http://www.trapkit.de/research/vmm/scoopydoo/index.html (2005)
23. Kato, K.: VMWare Back. http://chitchat.at.infoseek.co.jp/vmware/backdoor.html (2003)
24. Liston, T., Skoudis, E.: On the cutting edge: thwarting virtual machine detection. http://handlers.sans.org/tliston/ThwartingVMDetection_Liston_Skoudis.pdf (2006)
25. O'Dea, H.: Trapping worms in a virtual net. In: Virus Bulletin 2004 Conference Proceedings (2004)
26. Intel.: Intel architecture software developer's manual, vol 2: instruction set reference manual. http://developer.intel.com/design/pentiumii/manuals/243191.htm (2003)
27. Quist, D.: Vmdetect. http://www.offensivecomputing.net/dc14/vmdetect.cpp (2006)