Virtual Deobfuscator

Removing virtualization obfuscations from malware – a DARPA Cyber Fast Track funded effort

Approved for Public Release, Distribution Unlimited

Overview

- What is virtualization obfuscations?
- Why we care
- What has been done?
- Solution
- Future work
- Source code/Questions

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What is Virtualization Obfuscation

- Software protection
- Translation of a binary into randomly generated bytecode
- Bytecode is a new instruction set targeted typically for RISC based architecture VM which runs on x86
- Original binary is lost

Why we care

- Superior anti-reverse engineering technique
- Malware is using this technology to avoid detection and analysis
- Analysis
  - Static:
    - Disassemblers fail on new bytecode
  - Dynamic:
    - Difficult due to finding the boundaries between interpreter and translated original program
    - Vast numbers of instructions

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Pain and Joy

- Slogging
  - Understand logic of bytecode
  - Custom disassembler
- Architecture specific?
  - <Sigh>
  - No ‘break once break everywhere’
- Automation would be nice…

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What has been done

- Rotalume – Sharif
  - Dynamic approach
- Unpacking Virtualization Obfuscators – R. Rolles
  - A static approach
- University of Arizona (Kevin Coogan, Gen Lu Gen, and Saumya K. Debray)
  - Dynamic approach

Virtual Deobfuscator

- Developed in Python
- Uses a run trace
- Filters out VM interpreters logic
  - RISC pipeline
- Result: Bytcode interpretation (syntax and semantics)
- Architecture agnostic
- Recursive clustering
- PeepHole Optimization

Virtual Deobfuscator Flow

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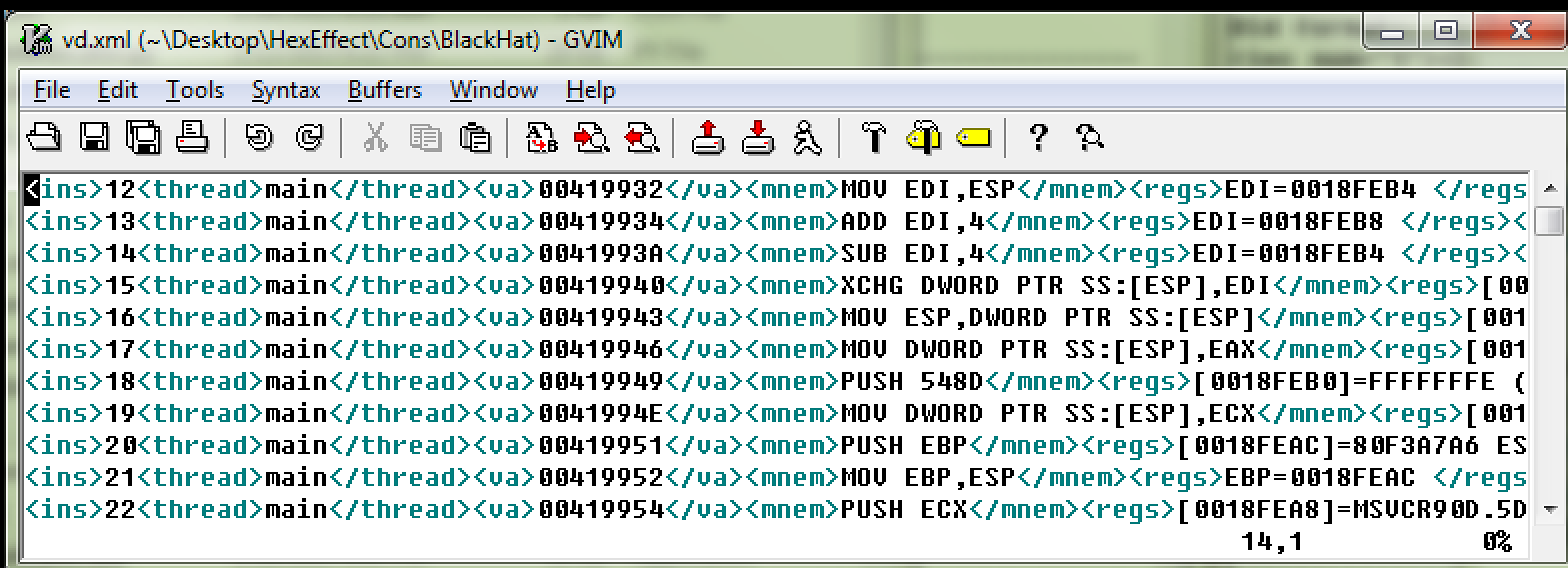
Parser

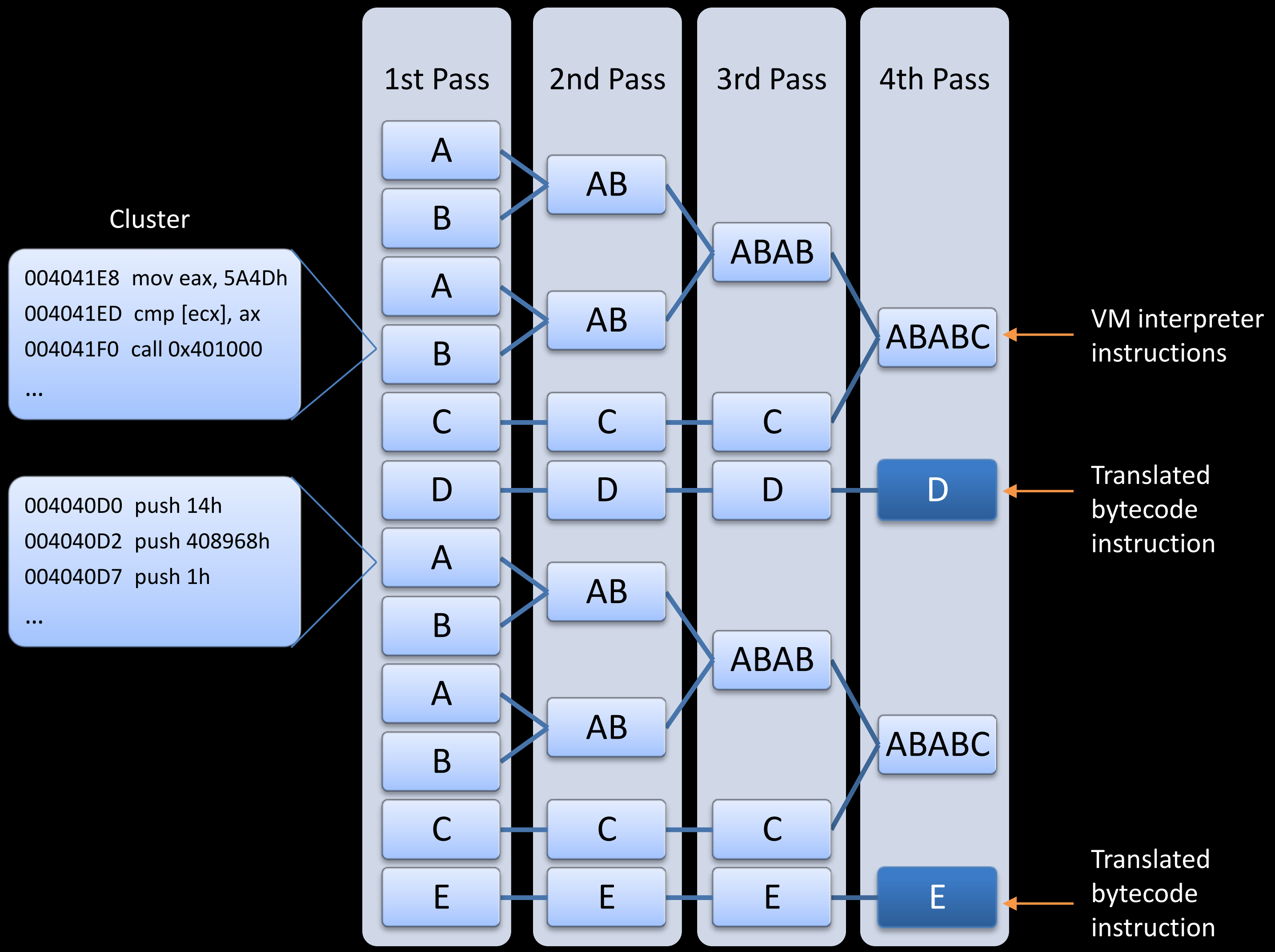
- Parse run traces into a XML based database
  - OllyDbg 2.0
  - OllyDbg 1.0
  - Immunity
  - WinDbg
  - Source code available – so you can add your own
    - Hypervisor, hardware emulator, etc

Parser

- Creates a file called vd.xml
- > python VirtualDeobfuscator.py -i file.txt -d 1 -t verify.txt



Clustering



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Clustering

- Parse run trace
- Create clusters by grouping snippets of assembly instructions
- Create new clusters based off pattern matching
- Assign each cluster a notational name that reflects depth of cluster (i.e. A, B, AB, etc)
- Loop until no more clusters

c2_______#8

- '**c**' - the processing round ("a", "b", "c", etc.) *[c = round 3]*
- '**2**' - ascending integer, unique per round *[ID = 2]*
- '______' shows depth
- '**#8**' - number of instructions in a cluster *[size = 8]*
- Example: **c2_______#8**
  - c = round 3, '2' = second cluster, '_____' = depth, '#8' = contains 8 ins

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Cluster Sample

- > VirtualDeobfuscator.py -c -d 1

```
Loop 1
  Loop 2
      if (only)
      {
            _asm { mov eax, 0xDEADBEEF }
            only = false;
      }
```

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Console output...what's all that about

C:\Windows\system32\cmd.exe

```
C:\Users\Jason\Desktop\HexEffect\Cons\BlackHat>python VirtualDeobfu
y -c -d 1

---------------------------------------------------------------------
|                    Virtual Deobfuscator ver 0.4                   |
|                              HexEffect                            |
---------------------------------------------------------------------


Loading packages...
- running with lxml.etree

read_xml
- reading vd.xml...................................................
* Writing new cluster
   - orig_cluster.txt

Building frequency graph from: [a_cluster.txt]
Writing frequency graph
   - a_freq.txt
Compressing basic blocks..
Writing window/new cluster table
   - a_window_sz.txt
Writing compression backtrace
   - a_bt_win_sz.txt
Create clustering...
Backtrace - Verification of new cluster
   - a_backtrace.txt

* Writing new cluster
   - a_cluster.txt

Building frequency graph from: [b_cluster.txt]
Writing frequency graph
   - b_freq.txt

Greedy round b:-------------------------------
Create greedy clustering............................................
* Writing new cluster
   - b_cluster.txt
Writing greedy backtrace
   - b_bt_greedy.txt
Greedy backtrace - Verification of new cluster
   - b_backtrace.txt
Create Complete Backtrace
- [round 1]
- reading backtrace file: b_backtrace.txt
- reading backtrace file: a_backtrace.txt
- writing all_backtrace.txt
Writing backtrace for validation: validate.txt
- reading backtrace file: all_backtrace.txt........................
.................
```

Clustering Loop sample

.... (start up code)
004113D3 JMP SHORT 004113DE
c1_______#11 ← Clusters
c2_______#8
f1__________________#47
c1_______#11
a21_#2
c2_______#8
a21_#2
00411411 MOV EAX,DEADBEEF ;EAX=DEADBEEF → Sweet!
f1__________________#47
a16_#2
00411427 MOV ESI,ESP ;ESI=0018FE34
... (wrap up code)

Clustering Sample – Code Virtualizer

OR AX, 0xC0A1 ; ax = DEAD – Original Code

```
--------------------------------------------------------------------------------
...
42D6BC NOP
42D6BD JMP 0049E22D
49E22D PUSH OFFSET 0049D34B
49E232 JMP 00499130
k7________________________________#3508

499B7D MOV AX,WORD PTR SS:[ESP]
499B81 PUSH EAX
499B82 JMP 0049AC87
49AC87 PUSH ESP
49AC88 POP EAX
49AC89 JMP 0049D056
49D056 ADD EAX,4
49D05B ADD EAX,2
49D060 XCHG DWORD PTR SS:[ESP],EAX
49D063 POP ESP
49D064 OR WORD PTR SS:[ESP],AX
49D068 PUSHFD
49D069 JMP 004993DE
k8________________________________#3196
....
```

A lot of instructions folded up in k7 cluster. This cluster likely represents the interpreter's loading of the emulator, loading of bytecode, simulated CPU pipeline (prefetch, decode, execute). 3,508 ins worth.

Starting area for unique translation

GOLDEN! AX becomes DEAD

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Step 1: A Deeper Dive - Internals

- Create Frequency Graph - freq_graph[]

cluster line numbers
4113D3 - [13]
4113D5 - [44, 77, 115, 148] ←
4113D8 - [45, 78, 116, 149]
4113DB - [46, 79, 117, 150]
4113DE - [14, 47, 80, 118, 151] ←

This ins @ 4113d5 occurs on lines 44, 77, etc it is the beginning of a basic block

A new basic block begins

```
004113D5 loc_4113D5:                           ;
004113D5                 mov     eax, [ebp+var_20]
004113D8                 add     eax, 1
004113DB                 mov     [ebp+var_20], eax
004113DE
004113DE loc_4113DE:                           ;
004113DE                 cmp     [ebp+var_20], 4
```

Step 2: Compress Basic Blocks

- Window size - window[] - A table of window sizes for each cluster with an cluster id
- Only done once

cluster	line numbers
4113D3 -	[13]
4113D5 -	[44, 77, 115, 148]
4113D8 -	[45, 78, 116, 149]
4113DB -	[46, 79, 117, 150]
4113DE -	[14, 47, 80, 118, 151]

cluster		window size	new cluster id
4113A1	-	[(1,	4113A1)]
4113A3	-	[(1,	4113A3)]
....			
4113D3	-	[(1,	4113D3)]
4113D5	-	[(3,	a16_#3)]

Our new cluster with size 3

Step 3: Greedy Clustering

- Greedy refs cluster list, then iterates through this list looking for more matches
- Recursive

4113A0
a_a1_#2 <- a_a1_#2 + a_a2_#3 match - will become new cluster b1___#5
a_a2_#3
a_a1_#2 <- a_a1_#2 + a_a2_#3 match - will become cluster b1___#5
a_a2_#3
a_a1_#2 <- no match, but could be another match for a1,a3
a_a3_#8

Step 4: Back tracing

- Optional – Testing purposes
  - Verify clustering is working

```
b2_______#22   a333_#5 a169_#17
b3_________#6   a179_#4 a263_#2
b4_______#10   a747_#7 a162_#3
b5_________#7   a55_#2 a456_#
```

← Round B

```
a55_#2     419C46 419C48
a456_#5  41C2E0 41C2E2 41C2E5 41C2E8 41C2EA
a601_#4  41CCE3 41CCE4 41CCE5 41CCE7
a78_#2    419D09 419D0B
```

← Round A

Step 5: Last Clustering Step

- New Clusters - new_cluster_lst[]

line number		new cluster id
13	-	004113D3
14	-	b1___#7
15	-	b2___#4

VA if no cluster created

Cluster ID

- From here repeat the steps until no more clusters

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Step 6: Final Step

- Final_assembly.txt

 4113D3 JMP SHORT 004113DE
c1______#11
f1_______________#47
a21_#2
411411 MOV EAX,DEADBEEF ← What we are interested in
f1_______________#4

- Last Cluster file (round_cluster.txt)

4113D3
c1______#11
f1_______________#47
a21_#2
411411
f1_______________#4

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More on Formatting

```
k2_____________________________________________#3265     [15, 990] 15 (5807)
e32______________#101                                    [16, 224] 16 (9072)
e56__________#76                                         (9173)
e57______________#101                                    (9249)
f34______________#173                                    [19, 205] 19 (9350)
g18___________________#343                               [20, 35] 20  (9523)
f37______________#173                                    (9866)
f38______________#179                                    (10039)
e64__________#79                                         (10218)
k3________________________________________#2919          [24, 47] 24  (10297)
```

[15, 990] 15 (5807)

- (5807) → run trace line number
- 15 → current file line number of final_assembly.txt
- [15, 990] → line numbers of where this cluster is duplicated on

Chunking

- Grouping of instructions based on cluster
- Found in DIR ‘chunk_cluster’
- f34______________#173_19.asm (19 is line num)
  - Not intended to be assembled (.asm) for color syntax in vi
- Can compare same clusters

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Chunking Sections (-s size)

k2____#3265 [15, 990] 15 (5807)
e32____________#101 [16, 224] 16 (9072)
e56_________#76
e57____________#101
f34____________#173
g18_________________#343
f37____________#173
f38____________#179
e64_________#79
k3____#2919 [24, 47] 24 (10297)

New section file called 23.txt created

VirtualDeobfuscator.py -c -d 1 -s 1300

So why create all these sections?

That is where our instructions of interest are at. After peephole optimization phase, we will have the interpreted instructions of the original program, and then we are laughing!

Final Tally

- BAC – Blood Alcohol Calculator (77 instructions)
- Protected with VMProtect and Code Virtualizer
- ~255,000 ins
- Sections = 40,000 ins
- Virtual Deobfuscator reduced run trace by 85%
  - ~90% reduction for VMProtect
- Why so much?
  - Code obfuscations! <sigh>

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Code Obfuscations

```
MOV EBP,76732756    ;EBP=76732756
AND EBP,45421A6A    ;EBP=44420242
ADD EBP,39C01533    ;EBP=7E021775
JMP 0041B02B
AND EBP,41EA266F    ;EBP=40020665
XOR EBP,40020661    ;EBP=00000004
```

```
PUSH 100F
MOV DWORD PTR SS:[ESP],EAX
```

```
POP ECX
PUSH ECX
```

And many more…

Repackage Binary

- NASM (The Netwide Assembler) http://www.nasm.us/
- Used to assemble ‘chunk_sections’ files
- Look for _nasm.asm (14_nasm.asm)
- Massaging run trace
  - Assembler needs either 'h' or '0x' added to hex numbers
  - Memory refs: e.g. MOV EDX,DWORD PTR DS:[EAX*4+__pioinfo]
  - I skip over control flow breaks such as (jmp, jxx, call, rets)
  - NASM does not support LODS, MOVS, etc (instead use LODSB)
  - I removed keywords such as OFFSET, PTR, SS:, DS:
  - ST(0), ST(1) - NASM chooses to call them st0, st1 etc
- > nasm -f win32 final_assembly_nasm.asm

PeepHole

- After binary repackaging, disassemble in IDA Pro
- Python plugin (VD_peephole.py) to remove code obfuscations
- Generates another ‘optimized’ assembly file
  - Run nasm again on the optimized file for analysis in IDA Pro or whatever disassembler you prefer

PeepHole (VD_peephole.py)

- Example of 5 instructions VM protected
  - ADD ESP, 4
  - LEA EAX, [drinks]
  - PUSH EAX
  - PUSH "%d"
  - SCANF
- Equated to 3,329 instructions
- After machine code deobfuscation – 359 instructions
- From here it was easy to hand remove code to see final equivalent instructions

Malware Analysis

- Win32.Klone.af – uses VMProtect along with NSPack
- Able to reduce the .vmp0 section to 50 instructions
- Quickly determined:
  - Decrypt the compressed section of .nsp1 (to later be decompressed into dynamic memory)
  - Setup of local variables for VirtualAlloc
  - Setup dynamic memory for VirtualAlloc
  - Call VirtualAlloc
  - Finalize the resource section in .nsp1, so that NSPacker can decompress the newly decrypted compressed area of the malware

Future Work

- Machine code deobfuscation
  - This capability could filter out categories of obfuscation patterns never seen before
- Profiler
  - identify hot-spots
  - aid for quick program understanding
  - fixing bugs or to optimize code
  - clustering method could be a similar concept in lumping code and data flow into a more abstract representation of the actual program run trace

Where to get it

- Available from
  - http://www.hexeffect.com/virtual_deob.html
- POC: Jason Raber
  - jason.raber@hexeffect.com
  - Phone: 937-430-1365
- **The views expressed are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government." This is in accordance with DoDI 5230.29, January 8, 2009.**

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