DOC – ANSWERING THE HIDDEN “CALL” OF A VIRUS

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SUMMARY

DOC is a prototype to demonstrate a method for detecting obfuscated calls and returns in binaries. Malicious programs use such obfuscations to hide information about the system calls they make. DOC statically identifies several types of obfuscations, promising to speed up the process of determining whether a program is malicious.

INTRODUCTION

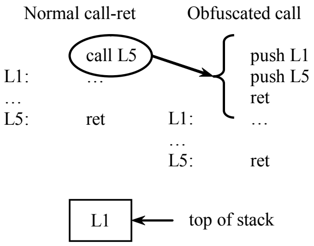
One of the first steps in determining whether a program is malicious is to identify the system calls it makes. If the program performs certain collections of file operations, registry operations, or network operations, it may be good reason to consider it potentially malicious.

The set (sometimes, the sequence) of system calls a program makes we refer to as its behavior. The behavior of a program may be determined by either static analysis or by dynamic analysis. In static analysis, a program is analyzed (by humans and/or tools) without running or simulating it. In dynamic analysis, a program’s behavior is observed, often by trapping the calls or sniffing network activity.

Malware writers have developed obfuscation techniques that make it difficult to statically identify the calls made by their program. These programs effectively make a *call* without actually using the call instruction (Szor, Ferrie 2001, Virus Bulletin Conference). Doing so increases the difficulty of analyzing a program not least because it defeats the methods typical disassemblers use to identify procedure entry and exit points.

AV companies, therefore, rely on dynamic methods for determining a program’s behavior. For instance, Symantec’s Bloodhound technology executes a program in a sandbox (or an emulator), traps the calls made by the program, and then determines whether it is malicious.

While dynamic analyses are helpful and often necessary, they are often cumbersome, time-consuming and fallible. Malware authors already know many methods for defeating detection through dynamic analysis, including detecting the dynamic analysis method, introducing delay loops to bypass stopping heuristics, and executing their malicious behaviour in only particular circumstances. For these reasons alone static analysis is still a critical component of AV strategies, but methods for overcoming obfuscation obstacles are extremely desirable.



```
L1:      call L5
...      ...
L5:      ret
```

```
         push L1
         push L5
         ret
L1:      ...
...
L5:      ret
```

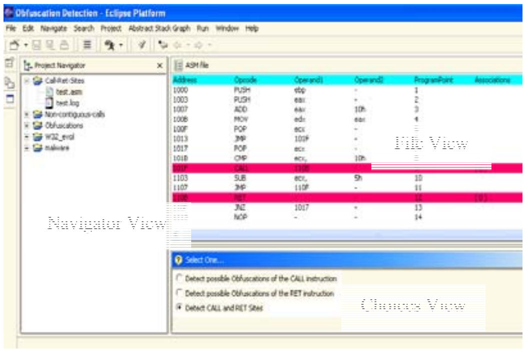
Figure 1. Call obfuscation

In this paper we present the results of using a new tool called DOC (Detector of Obfuscated Calls) to analyze W32.Evol. DOC statically identifies several types of obfuscations related to the *call* and *return* instructions. Technical details of the method used by DOC has been described elsewhere (Lakhotia and Kumar 2004, *Fourth IEEE International Workshop on Source Code Analysis and Manipulation-SCAM’2004*). We will review call/return obfuscations, describe DOC and how it was applied to W32.Evol, and close by summarizing some of the successes and limitations of the approach.

CALL/RETN OBFUSCATIONS

Figure 1 shows a classic example of call obfuscation used by viruses, most notably W32.Evol and Netsky.Z. In the left column is a normal *call* instruction. In the right column is code containing a sequence of two *push* instructions and a *retn* instruction. These three instructions do exactly the same work as the *call* instruction. They are semantically equivalent.

Other related obfuscations include the substitution of *retn* instructions and the use of non-contiguous function bodies. For instance a *retn* may be replaced with a *pop ip* instruction. Non-contiguous procedure bodies can be created by intertwining a procedure’s code with the code of other procedures, thus making it difficult to match a *call* instruction to its corresponding *retn* instructions.



Address	Opcode	Operand1	Operand2	ProgramPoint	Associations
1000	PUSH	ebp	-	1	
1003	PUSH	eax	-	2	
1007	ADD	eax	10h	3	
100B	MOV	edx	eax	4	
100F	POP	ecx	-	5	
1013	JMP	101F	-	6	
1017	POP	ecx	-	7	
101B	CMP	ecx,	10h	8	
101F	CALL	1100	-	[illegible]	[illegible]
1103	SUB	ecx,	5h	10	
1107	JMP	110F	-	11	
1100	RET		-	12	[illegible]
[illegible]	JNZ	1017	-	13	
[illegible]	NOP	-	-	14	

○ Detect possible Obfuscations of the CALL instruction
○ Detect possible Obfuscations of the RET instruction
● Detect CALL and RET Sites

Figure 2. DOC User Interface

Such obfuscations take away important cues that are used during both automated and manual analysis. While a determined, experienced programmer can discover the obfuscations; the time spent in making the discovery can be precious when the malware is actively spreading.

Substituting *call* instructions, in particular, breaks most automated methods for detecting a virus since these methods depend on recognizing *call* instructions to (a) identify the kernel functions used by the program and (b) to identify procedures in the code. As is shown later, IDA Pro, a disassembler used very widely in the industry, gives incorrect and misleading results in the presence of call/return obfuscations.

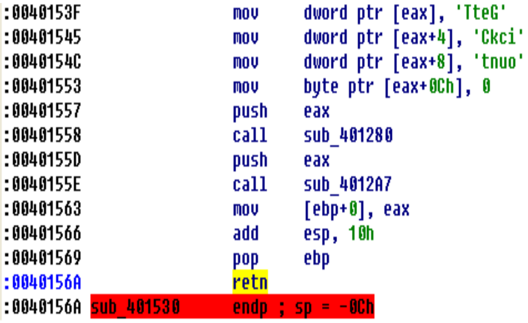
ABOUT DOC

DOC is implemented Java as a plug-in to the Eclipse Platform (www.eclipse.org). Figure 2 shows a screenshot DOC when opening an assembly file (.asm extension). DOC provides the ability to open any number of projects at the same time. The navigator view is used to browse and open files in a project. The files are displayed in the file view.

DOC takes as input an assembly file or a disassembled binary obtained from a disassembler such as IDAPro. A user may choose any of the following three analyses:

- Match *call-ret* instructions
- Detect obfuscated calls
- Detect obfuscated returns

DOC returns its results by highlighting and annotating the assembly. The annotations contain links to related code when there are multiple occurrences of the same type of obfuscation.



```
:0040153F                 mov     dword ptr [eax], 'TteG'
:00401545                 mov     dword ptr [eax+4], 'Ckci'
:0040154C                 mov     dword ptr [eax+8], 'tnuo'
:00401553                 mov     byte ptr [eax+0Ch], 0
:00401557                 push    eax
:00401558                 call    sub_401280
:0040155D                 push    eax
:0040155E                 call    sub_4012A7
:00401563                 mov     [ebp+0], eax
:00401566                 add     esp, 10h
:00401569                 pop     ebp
:0040156A                 retn
:0040156A sub_401530      endp ; sp = -0Ch
```

Figure 3. W32.Evol code with Multiple Obfuscations

INSIDE DOC

DOC uses abstract interpretation, a technique commonly used in static analysis. In this technique a program is interpreted using abstract values, instead of real values. The key challenge in using abstract interpretation is in choosing the right abstraction.

DOC creates an abstraction of the stack and its contents. A specific instance of a *real stack* is represented as an *abstract stack*. Further, the set of all possible abstract stacks for all possible executions of a program is represented as an *abstract stack graph*. Though the set of all abstract stacks (or real stacks) for all possible executions of a program may be infinite, the abstract stack graph is finite.

The abstract stack graph for a given assembly program is constructed by interpreting each instruction of the program. The operations performed by the instruction on a real stack are instead performed on an abstract stack graph. Each instruction is interpreted at most once.

Once the abstract interpretation terminates, the abstract stack graph contains an abstraction of all possible stacks at each statement. DOC analyzes the abstract stack to match *call-ret* instructions, detect obfuscated calls, and detect obfuscated returns.

W32.EVOL – REVEALING THE HIDDEN

Our efforts at statically analyzing W32.Evol, in fact, led us to developing DOC. It all started a few years ago as a result of our first attempt at developing an AV scanner based on formal, static analysis. We had implemented behavior-based analyzer using model checking. Our analyzer failed miserably when we exposed it to W32.Evol.

```
0040153F mov dword ptr ds:[eax], 54746547 ;'TteG'

00401545 mov dword ptr ds:[eax+4], 436B6369 ;'Ckci'

0040154C mov dword ptr ds:[eax+8], 746E756F ;'tnuo'

00401553 mov byte ptr ds:[eax+c], 0;  '\0'

00401557 push eax; ptr to "GetTickCount".

00401558 call 00401280; gets base address of kernel32.dll base.

0040155D push eax;

0040155E call 004012A7; obfuscated call to GetProcAddress()

00401563 mov dword ptr ss:[ebp], eax; addr of GetTickCount().

00401566 add esp, 10

00401569 pop ebp

0040156A retn; transfer control to GetTickCount().
```

Figure 4. Annotated code of Figure 3

A closer analysis revealed that the virus was obfuscating all system calls, and our analyzer assumed that IDA Pro would correctly detect system calls in disassembled code. It failed and, as is so common in developing new technologies, the failures provided the impetus to explore new methods. Here we describe some of the causes for disassembly failure and show how DOC can detect these.

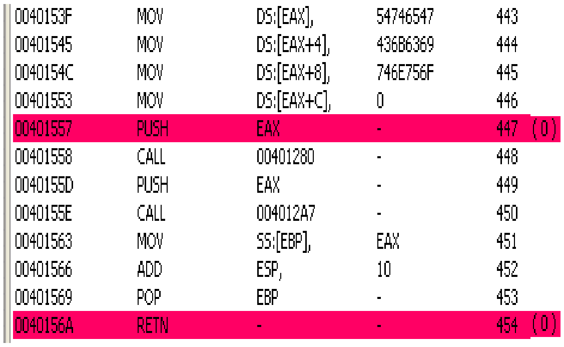
Call/Ret Obfuscation in W32.Evol

The common sequence of instructions to make a system call, say *GetTickcount*, on a Windows environment is as follows:

```
push   add1   ; "kernel32.dll"
push   add2   ; "GetTickCount"
call   GetProcAddress
call   [eax]  ; "call GetTickCount"
```

Here addr1 and addr2, respectively, are pointers to strings "kernel32.dll" and "GetTickCount" located in the data segment. The addresses of these strings are pushed on the stack. The kernel32.dll function GetProcAddress is called, which returns the address of the function "GetTickCount" in the *eax* register. The program then does an indirect call to the address in *eax*, effectively making a call to *GetTickCount*.

Disassemblers, such as IDA Pro, can detect such patterns of call and aid in detecting system calls. Figure 3 shows a code fragment from W32.Evol for calling the function *GetTickCount*. This code has multiple obfuscations, none of which are detected by IDA Pro. The reasons for this are instructive.



```
0040153F   MOV    DS:[EAX],     54746547   443
00401545   MOV    DS:[EAX+4],   436B6369   444
0040154C   MOV    DS:[EAX+8],   746E756F   445
00401553   MOV    DS:[EAX+C],   0          446
00401557   PUSH   EAX           -          447 (0)
00401558   CALL   00401280      -          448
0040155D   PUSH   EAX           -          449
0040155E   CALL   004012A7      -          450
00401563   MOV    SS:[EBP],     EAX        451
00401566   ADD    ESP,          10         452
00401569   POP    EBP           -          453
0040156A   RETN   -             -          454 (0)
```

Figure 5. Using DOC to detect obfuscated *call*.

IDAPro assumes that the *retn* instruction at address 0040156A actually returns from the procedure. Thus, it deems this statement as ending the procedure that has entry at address 00401530. IDA Pro indicates the end of a procedure by introducing the dummy directive *endp*. Thus it deduces that the *retn* statement matches "*call* 00401530" instructions.

The *retn* instruction, it turns out, is performing a call. The value returned from *GetProcAddress* is moved to the stack, and the stack pointer modified such that when the *retn* instruction is executed, it transfers control to *GetTickCount*. This can be verified by manually analyzing the virus in a debugger such as OllyDbg. Figure 4 presents the code of Figure 3 with annotations created by such a manual analysis.

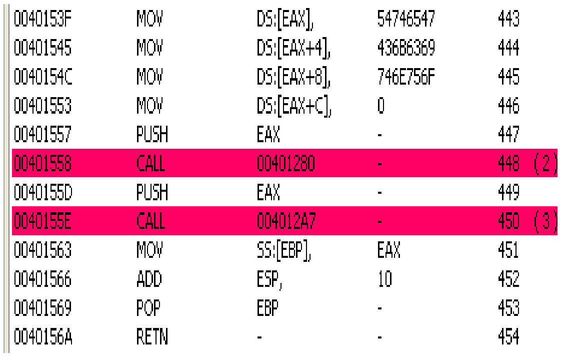
Detecting call obfuscations

Figure 5 shows a portion of the code where DOC detects the obfuscated *call* to the kernel function *GetTickCount()*. The *push* instruction at address 00401557 and the *retn* instruction at address 0040156A are instrumental in obfuscating the *call* to *GetTickCount()*. This is indicated by highlighting these instructions in red. The annotation "(0)" at the end of these instructions indicates that the two belong to the same call obfuscation.

W32.Evol uses similar code to make system calls in 25 locations. IDA Pro misses all of these calls, where as DOC highlights every such *retn* instruction as making a call.

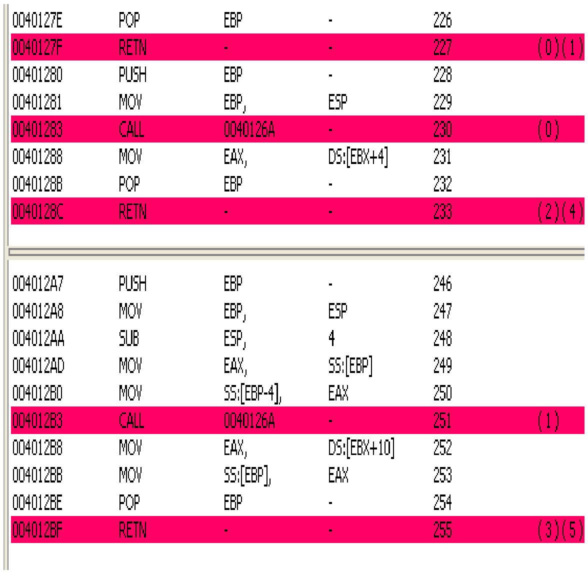
Matching call-retn instructions

Figure 6 shows the same code as Figure 3, but it also shows of the results of running DOC's analysis for matching *call-retn* instructions. The two call instructions at addresses 00401558 and 0040155E are highlighted and are annotated "(2)" and "(3)", respectively. These numbers are arc



```
0040153F   MOV    DS:[EAX],     54746547   443
00401545   MOV    DS:[EAX+4],   436B6369   444
0040154C   MOV    DS:[EAX+8],   746E756F   445
00401553   MOV    DS:[EAX+C],   0          446
00401557   PUSH   EAX           -          447
00401558   CALL   00401280      -          448  ( 2 )
0040155D   PUSH   EAX           -          449
0040155E   CALL   004012A7      -          450  ( 3 )
00401563   MOV    SS:[EBP],     EAX        451
00401566   ADD    ESP,          10         452
00401569   POP    EBP           -          453
0040156A   RETN   -             -          454
```

Figure 6. Using DOCs to detect valid calls.



```
0040127E   POP    EBP           -            226
0040127F   RETN   -             -            227          (0)(1)
00401280   PUSH   EBP           -            228
00401281   MOV    EBP,          ESP          229
00401283   CALL   0040126A      -            230          (0)
00401288   MOV    EAX,          DS:[EBX+4]   231
0040128B   POP    EBP           -            232
0040128C   RETN   -             -            233          (2)(4)

004012A7   PUSH   EBP           -            246
004012A8   MOV    EBP,          ESP          247
004012AA   SUB    ESP,          4            248
004012AD   MOV    EAX,          SS:[EBP]     249
004012B0   MOV    SS:[EBP-4],   EAX          250
004012B3   CALL   0040126A      -            251          (1)
004012B8   MOV    EAX,          DS:[EBX+10]  252
004012BB   MOV    SS:[EBP],     EAX          253
004012BE   POP    EBP           -            254
004012BF   RETN   -             -            255          (3)(5)
```

Figure 7. Using DOC to detect valid *call-ret* sites.

labels in the effective call graph. Figure 7 shows return sites corresponding to these statements. These statements are annotated with the numbers “(2)” and “(3)”, which are matched to the call sites so labeled. This figure also shows *retn* statements matching call sites annotated as “(0)” and “(1)”. As is expected, one *retn* statement may match multiple call sites.

DOC correctly found matching *retn* statements for all 33 *call* statements of W32.Evol. In several instances the procedure code was not contiguous.

CONCLUSIONS

DOC is efficient, being linear in both space and time. And it is demonstrably effective in finding the sort of *call/retn* obfuscations found inW32.Evol. We believe its techniques can be an important part of an AV researcher’s toolkit, and can significantly speed up analysis of obfuscated binaries. DOC has limitations. It is restricted solely to detecting call obfuscations, and cannot handle some of these, including manual stack manipulation. Efforts to overcome some of these limitations are in progress in our laboratory.