A SCAFFOLDED METAMORPHIC CTF FOR REVERSE ENGINEERING

Motivation

Scaffolded

Metamorphic

Extensible

Levels being added via internships and course projects

Build script and program template
- Script produces random data per user
- Combined with program template to produce unique program per-user

Deployable

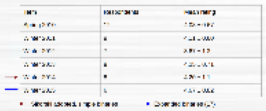
Integrated web site
- Distributing binaries
- Submission and validation of per-student solutions

BitBucket repository for source and website for instructors

Evaluation

CS 492/592: Malware

Q13. Quality and usefulness of homework assignments



Status and future

25 levels at http://malware.oregonctf.org => gseX

MetaCTF for web security (based on natas)

MetaCTF for CS 201 (Bryant & O'Halloran's 3rd ed)

CTFs for high-school classes and camps
- Saturday Academy CyberAcademy (juniors, seniors)
  - 15 levels of natas, 8 levels of microcorruption
- Divergent-themed CTF and Urban Race (sophomores)

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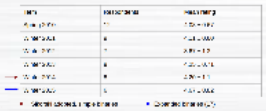

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Capture-the-Flag (CTF) competitions

Increasingly popular vehicle for sharpening security skills
- iCTF, PlaidCTF, CSAW, DEFCON

Goal is to evaluate rather than teach
- Challenges often open-ended, unguided, and esoteric
- Limited pedagogy
- Can be frustrating for beginners

CTFs for Instruction

Goal is to teach rather than just evaluate
- Develop skills, competence, and confidence rapidly

Examples
- Integrated into courses
- Scaffolded CTFs
  - picoCTF (PHP, Python Eval, ROP, Overflow)
  - natas @ overthewire.org (web exploitation)
  - microcorruption.com (memory exploitation)

MetaCTF

Jeopardy-style CTF for reverse engineering
- Scaffolded for quick progression and skill development
- Metamorphic to reduce cheating and allow reuse
- Extensible and configurable to support customization
- Easily deployed

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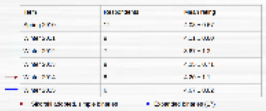

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Scaffolded

Level Design

Integrated with textbook
- Focus on a specific topic

Guided, direct instruction approach

Uniform level operation
- Find password to force binary to print "Good Job."

Basic static and dynamic analysis

Find password stored in read-only data section
- readelf, objdump

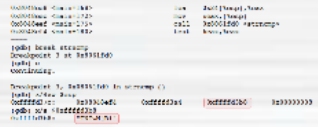
Find password via library tracing
- ltrace

Advanced static analysis

Disassembly
- Decode embedded ASCII
- Decode jump table for switch
- Disable debuggers

Advanced dynamic analysis

Debugging
- Code statically compiled
- Password procedurally generated
- Use breakpoints to find password



Malware functionality

Reverse techniques malware uses
- Follow process spawning
- Undo simple encoding (Base64, XOR)

Employ techniques malware does
- Hijacking dynamic library loading
- Hijacking import address tables (procedure link tables)

Bypassing adversarial protections

Anti-disassembly
- Obfuscated control-flow instructions
- Fake conditionals, impossible disassembly

Anti-debugging
- Debugger detection (ptrace, INT 3, timing)
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Packers
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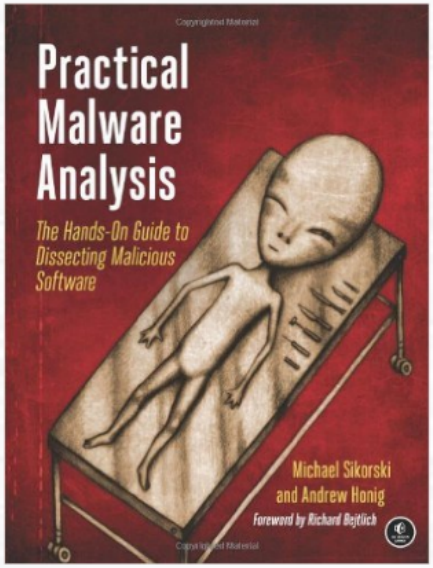

Basic static and dynamic analysis

Find password stored in read-only data section

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Advanced static analysis

Disassembly

- Decode embedded ASCII

```
80484b4:        movb    $0x1,0x804a11d
804851e:        movb    $0x31,0x14(%esp)
8048523:        movb    $0x4e,0x15(%esp)
8048528:        movb    $0x54,0x16(%esp)
804852d:        movb    $0x49,0x17(%esp)
8048532:        movb    $0x77,0x18(%esp)
8048537:        movb    $0x4e,0x19(%esp)
804853c:        movb    $0x6a,0x1a(%esp)
8048541:        movb    $0x42,0x1b(%esp)
```

- Disable debuggers

```
void detectTrace(void) __attribute__((constructor));
void detectTrace (void) {
    if(ptrace(PTRACE_TRACEME, 0, 1, 0) < 0) {
        printf("Sorry, we have disallowed debuggers on this assignment.\n");
        exit(1);
    };
};
```

- Decode jump table for switch

```
movl 28(%esp), %eax
subl $10647, %eax
cmpl $4, %eax
ja .L3
movl .L5(,%eax,4), %eax
jmp *%eax

.L4:  movl $.LC3, (%esp)
      call puts
      jmp .L8
.L6:  movl $.LC3, (%esp)
      call puts
      jmp .L8
.L7:  movl $.LC4, (%esp)
      call puts
      jmp .L8
.L3:  movl  $.LC3, (%esp)
      call  puts
.L8:  movl  $0, %eax
      leave
      ret
```

```
.L5:
      .long .L4
      .long .L6
      .long .L7
      .long .L6
      .long .L4

.LC3:
      .string    "Try again."
.LC4:
      .string    "Good Job."
```

Advanced dynamic analysis

Debugging

- Code statically compiled
- Password procedurally generated
- Use breakpoints to find password

```
0x8048ee8 <main+168>                    lea    0x24(%esp),%eax
0x8048eec <main+172>                    mov    %eax,(%esp)
0x8048eef <main+175>                    call   0x8061fd0 <strncmp>
0x8048ef4 <main+180>                    test   %eax,%eax
----
(gdb) break strncmp
Breakpoint 3 at 0x8061fd0
(gdb) c
Continuing.

Breakpoint 3, 0x08061fd0 in strncmp ()
(gdb) x/4xw $esp
0xffffd37c:     0x08048ef4      0xffffd3a4      0xffffd3b8      0x00000008
(gdb) x/s $0xffffd3b8
0xffffd3b8:     "TNIwNjBi"
```

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```
mask_output[cnt] = enc_table[(mod+rand())%64];
…
printf("%d %d %d\n",rand(),rand(),rand());
printf("Hint: %s\n",mask_output);
```

```
mashimaro <~> % export LD_PRELOAD=rand.so
mashimaro <~> % ./Ch11MalBeh_LdPreload
…
Enter the password: foo
0 0 0
Hint: i2abIun48
Try again.
mashimaro <~> % export LD_PRELOAD=
mashimaro <~> % ./Ch11MalBeh_LdPreload
…
Enter the password: i2abIun48
1350490027 1025202362 1189641421
Hint: J8DOZtxkl
Good Job.
mashimaro <~> %
```

Malware functionality

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- Undo simple encoding (Base64, XOR)

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(Adapted from Narnia at overthewire.org)

```
void print_good() {
    printf("Good Job.\n");
    exit(0);
}
main() {
      …
    *ip = i;
    printf("Address %x will contain %x\n",ip,i);
    sleep(1);
    printf("Try again.\n");
      …
}
```

```
(gdb) disassemble 0x80483f0
Dump of assembler code for function sleep@plt:
   0x080483f0 <+0>:   jmp    *0x4e548014
   0x080483f6 <+6>:   push   $0x10
   0x080483fb <+11>:  jmp    0x80483c0
End of assembler dump.
(gdb) p (void *) &print_good
$1 = (void *) 0x4e54686d <print_good>
```

```
…
Enter the password: 4e548014 04e54686d
Address 4e548014 will contain 4e54686d
Good Job.
mashimaro <~> %
```

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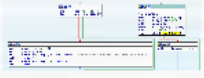

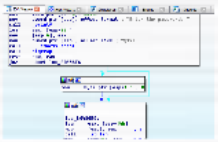

```
main:                                   ; DATA XREF: _start+17↑o
                push    ebp
                mov     ebp, esp
                and     esp, 0FFFFFFF0h
                sub     esp, 20h
                call    print_msg
                push    eax
                cmp     eax, eax
                jz      short near ptr loc_804859C+1

loc_804859C:                            ; CODE XREF: .text:0804859A↑j
                addps   xmm0, xmm7
                inc     esp
                and     al, 1Ch
                in      eax, dx
                retn
```

```
main:                                   ; DATA XREF: _start+17↑o
                push    ebp
                mov     ebp, esp
                and     esp, 0FFFFFFF0h
                sub     esp, 20h
                call    print_msg
                push    eax
                cmp     eax, eax
                jz      short loc_804859D
; ---------------------------------------------------------------------------
                db  0Fh
; ---------------------------------------------------------------------------

loc_804859D:                            ; CODE XREF: .text:0804859A↑j
                pop     eax
                mov     dword ptr [esp+1Ch], 24C3EDh
                mov     dword ptr [esp], offset aEnterThePasswo ; "Enter the password: "
                call    _printf
```

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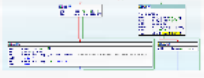

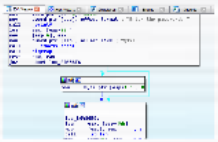

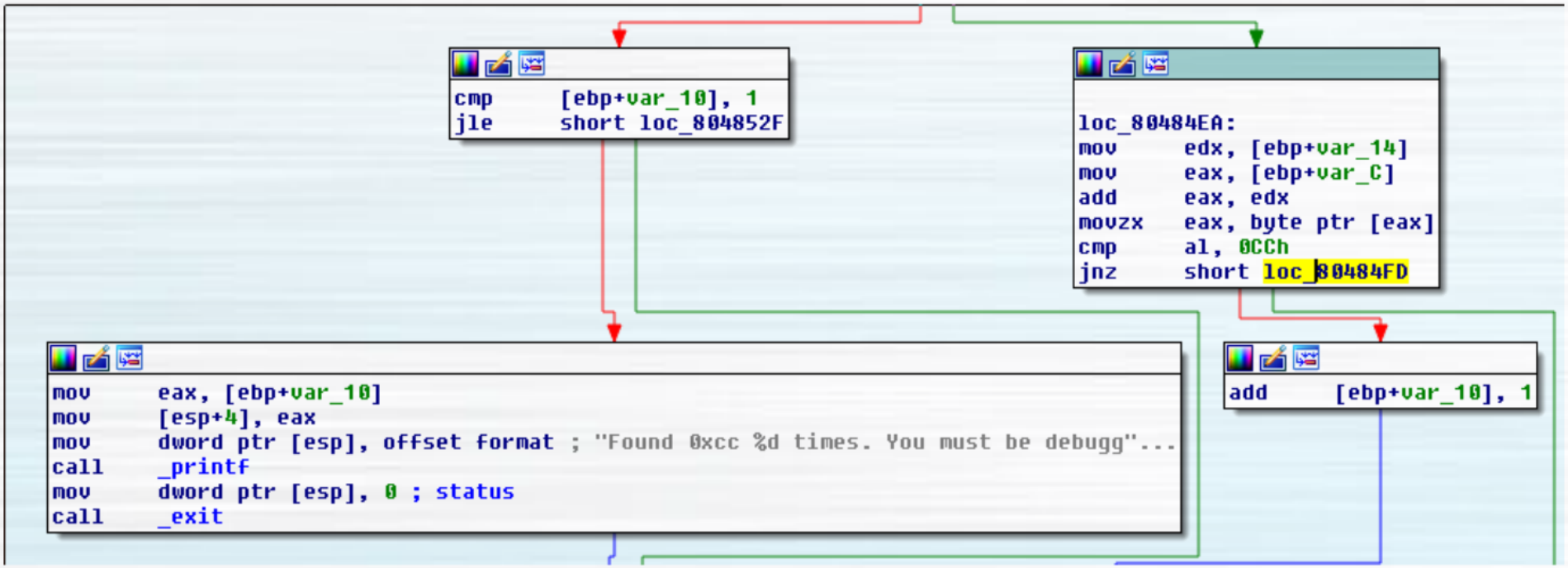
cmp [ebp+var_10], 1
jle short loc_804852F
loc_80484EA:
mov edx, [ebp+var_14]
mov eax, [ebp+var_C]
add eax, edx
movzx eax, byte ptr [eax]
cmp al, 0CCh
jnz short loc_80484FD
mov eax, [ebp+var_10]
mov [esp+4], eax
mov dword ptr [esp], offset format ; "Found 0xcc %d times. You must be debugg"...
call _printf
mov dword ptr [esp], 0 ; status
call _exit
add [ebp+var_10], 1

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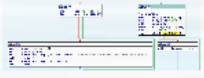

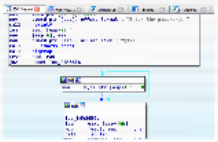

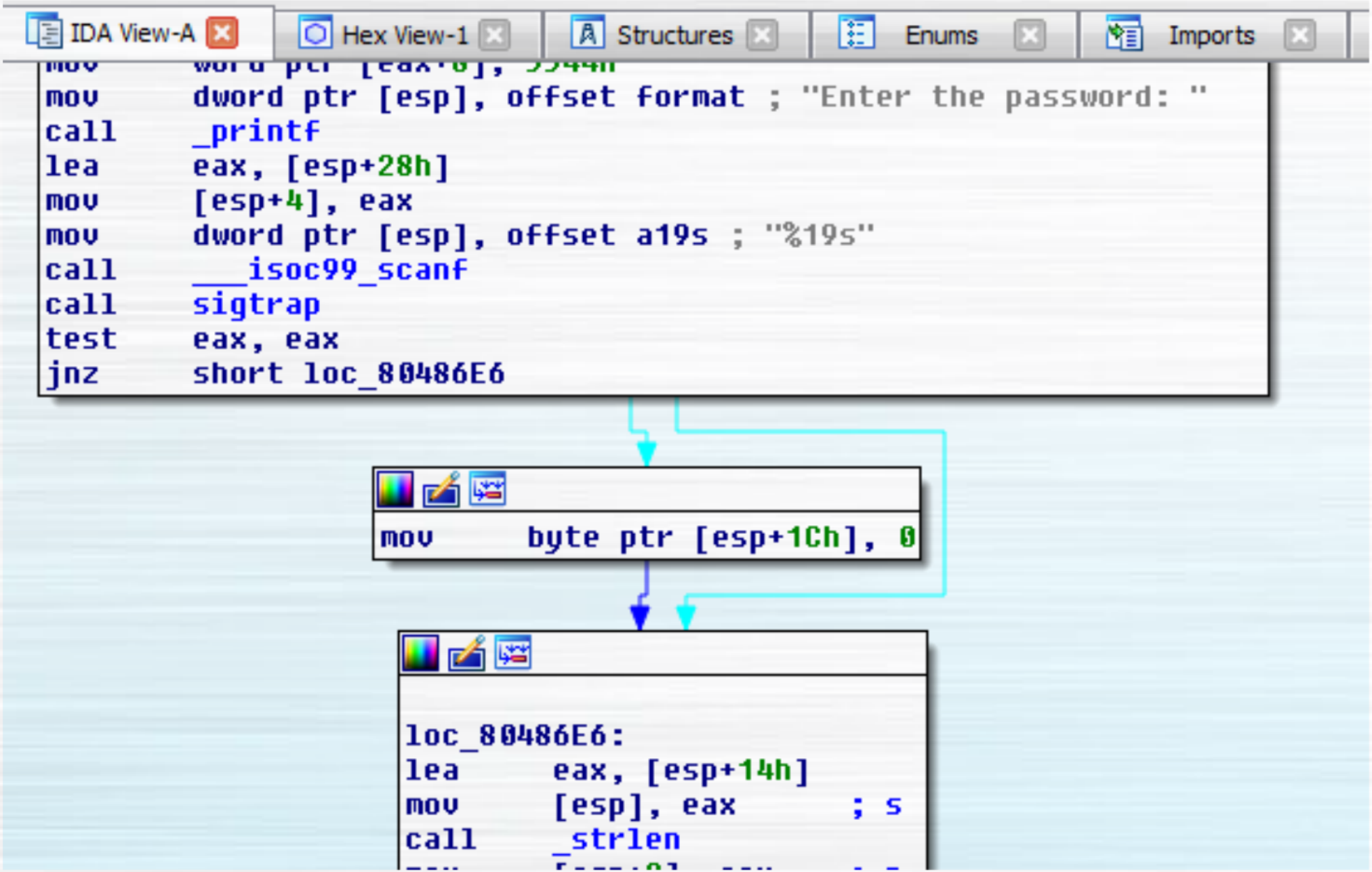
IDA View-A
Hex View-1
Structures
Enums
Imports
mov dword ptr [esp], offset format ; "Enter the password: "
call _printf
lea eax, [esp+28h]
mov [esp+4], eax
mov dword ptr [esp], offset a19s ; "%19s"
call ___isoc99_scanf
call sigtrap
test eax, eax
jnz short loc_80486E6
mov byte ptr [esp+1Ch], 0
loc_80486E6:
lea eax, [esp+14h]
mov [esp], eax ; s
call _strlen

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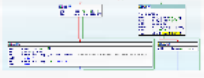
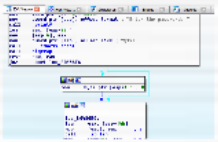




Metamorphic

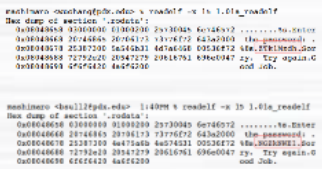
Unique per-student binaries

Data and code of binaries polymorphic and metamorphic

- Reduce cheating
- Allow re-use across schools
- Allow re-use over multiple offerings

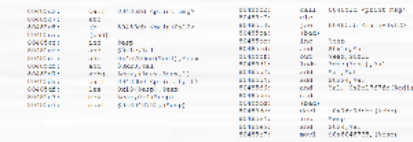
Data

Ch01StatA_Readelf



Code

Ch15AntiDis_FakeMetaConds



Code location

Ch11MalBeh_HijackPLT

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Data

Ch01StatA_Readelf

```
mashimaro <wuchang@pdx.edu> % readelf -x 15 1.01a_readelf
Hex dump of section '.rodata':
  0x08048658 03000000 01000200 25730045 6e746572 ........%s.Enter
  0x08048668 20746865 20706173 73776f72 643a2000  the password: .
  0x08048678 25387300 5a546b31 4d7a6468 00536f72 %8s.ZTk1Mzdh.Sor
  0x08048688 72792e20 20547279 20616761 696e0047 ry.  Try again.G
  0x08048698 6f6f6420 4a6f6200                   ood Job.
```

```
mashimaro <bsull2@pdx.edu>  1:40PM % readelf -x 15 1.01a_readelf
Hex dump of section '.rodata':
  0x08048658 03000000 01000200 25730045 6e746572 ........%s.Enter
  0x08048668 20746865 20706173 73776f72 643a2000  the password: .
  0x08048678 25387300 4e475a6b 4e574531 00536f72 %8s.NGZkNWE1.Sor
  0x08048688 72792e20 20547279 20616761 696e0047 ry.  Try again.G
  0x08048698 6f6f6420 4a6f6200                   ood Job.
```

Code

Ch15AntiDis_FakeMetaConds

```
80485c2:       call   804852d <print_msg>
80485c7:       stc
80485c8:       jb     80485cb <main+0x12>
80485ca:       (bad)
80485cc:       inc    %esp
80485cd:       and    $0x1c,%al
80485cf:       adc    0x4c700cc(%edi),%ebx
80485d5:       and    $0x20,%al
80485d7:       xchg   %eax,(%eax,%ecx,1)
80485da:       call   80483b0 <printf@plt>
80485df:       lea    0x18(%esp),%eax
80485e3:       mov    %eax,0x4(%esp)
80485e7:       movl   $0x8048735,(%esp)
```

```
80485c2:       call   804852d <print_msg>
80485c7:       clc
80485c8:       jae    80485cb <main+0x12>
80485ca:       (bad)
80485cc:       inc    %esp
80485cd:       and    $0x1c,%al
80485cf:       out    %eax,$0x11
80485d1:       lods   %ds:(%esi),%al
80485d2:       add    %al,%bh
80485d4:       add    $0x24,%al
80485d6:       and    %al,-0x2e17f7fc(%edi)
80485dc:       std
80485dd:       (bad)
80485de:       decl   -0x76e7dbbc(%ebp)
80485e4:       inc    %esp
80485e5:       and    $0x4,%al
80485e7:       movl   $0x8048735,(%esp)
```

Code location

Ch11MalBeh_HijackPLT

```
4e7a476d <print_good>:
4e7a476d:       push   %ebp
4e7a476e:       mov    %esp,%ebp
4e7a4770:       sub    $0x18,%esp
4e7a4773:       movl   $0x4e7a4960,(%esp)

080483f0 <sleep@plt>:
 80483f0:       jmp    *0x4e7a6014
```

```
4e545a6d <print_good>:
4e545a6d:       push   %ebp
4e545a6e:       mov    %esp,%ebp
4e545a70:       sub    $0x18,%esp
4e545a73:       movl   $0x4e545c60,(%esp)

080483f0 <sleep@plt>:
 80483f0:       jmp    *0x4e547014
```

Extensible

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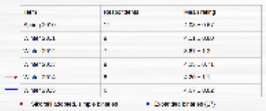
CS 492/592: Malware

Q13. Quality and usefulness of homework assignments



Status and future

25 levels at http://malware.oregonctf.org => gseX

MetaCTF for web security (based on natas)

MetaCTF for CS 201 (Bryant & O'Halloran's 3rd ed)

CTFs for high-school classes and camps
- Saturday Academy CyberAcademy (juniors, seniors)
  - 15 levels of natas, 8 levels of microcorruption
- Divergent-themed CTF and Urban Race (sophomores)

Evaluation

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Term	Respondents	Mean rating
Spring 2010	12	4.08 ± 0.67
Winter 2011	9	4.11 ± 0.60
Winter 2012	7	3.67 ± 1.2
Winter 2013	8	4.25 ± 0.71
Winter 2014	8	4.20 ± 1.1
Winter 2015	6	4.67 ± 0.82

Sikorski adopted, simple binaries

Expanded binaries (17)

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A SCAFFOLDED METAMORPHIC CTF FOR REVERSE ENGINEERING

Motivation

Scaffolded

Metamorphic

Extensible

Levels being added via internships and course projects

Build script and program template
- Script produces random data per user
- Combined with program template to produce unique program per-user

Deployable

Integrated web site
- Distributing binaries
- Submission and validation of per-student solutions

BitBucket repository for source and website for instructors

Evaluation

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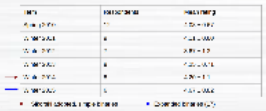

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