Control Hijacking

Basic Control Hijacking Attacks

Acknowledgments: Lecture slides are from the Computer Security course taught by Dan Boneh at Stanford University. When slides are obtained from other sources, a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.
Control hijacking attacks

• Attacker’s goal:
  – Take over target machine (e.g. web server)
    • Execute arbitrary code on target by hijacking application control flow

• Examples.
  – Buffer overflow attacks
  – Integer overflow attacks
  – Format string vulnerabilities
Example 1: buffer overflows

- Extremely common bug in C/C++ programs.
  - First major exploit: 1988 Internet Worm. fingerd.

Source: web.nvd.nist.gov
What is needed

- Understanding C functions, the stack, and the heap.
- Know how system calls are made
- The exec() system call

Attacker needs to know which CPU and OS used on the target machine:
- Our examples are for x86 running Linux or Windows
- Details vary slightly between CPUs and OSs:
  - Little endian vs. big endian (x86 vs. Motorola)
  - Stack Frame structure (Unix vs. Windows)
Linux process memory layout

- **user stack**
- **shared libraries**
- **run time heap**
- **unused**

- %esp
- brk
- Loaded from exec

Addresses:
- 0x08048000
- 0xC0000000
- 0x40000000
- 0x08048000
- 0

Dan Boneh
What are buffer overflows?

Suppose a web server contains a function:

```
void func(char *str) {
    char buf[128];
    strcpy(buf, str);
    do-something(buf);
}
```

When `func()` is called stack looks like:

- **Argument:** `str`
- **Return address**
- **Stack frame pointer**
- **Array:** `char buf[128]`
What are buffer overflows?

What if `*str` is 136 bytes long?

After `strcpy`:

```c
void func(char *str) {
    char buf[128];
    strcpy(buf, str);
    do-something(buf);
}
```

Problem: no length checking in `strcpy`
Basic stack exploit

Suppose `*str` is such that after `strcpy` stack looks like:

Program P: `exec("/bin/sh")`
(exact shell code by Aleph One)

When `func()` exits, the user gets shell!

Note: attack code P runs in stack.
The NOP slide

Problem: how does attacker determine ret-address?

Solution: NOP slide

• Guess approximate stack state when \texttt{func()} is called
• Insert many NOPs before program P:
  \begin{verbatim}
nop, xor eax, eax, inc ax
  \end{verbatim}
Details and examples

• Some complications:
  – Program P should not contain the ‘\0’ character.
  – Overflow should not crash program before func() exits.

• (in)Famous remote stack smashing overflows:
  – Overflow in Windows animated cursors (ANI).
    LoadAniIcon()
  – Buffer overflow in Symantec virus detection (May 2016)
    overflow when parsing PE headers … kernel vuln.
Many unsafe libc functions

\texttt{strcpy} (char *dest, const char *src)
\texttt{strcat} (char *dest, const char *src)
\texttt{gets} (char *s)
\texttt{scanf} (const char *format, ...) and many more.

- "Safe" libc versions \texttt{strncpy()}, \texttt{strncat()} are misleading
  - e.g. \texttt{strncpy()} may leave string unterminated.

- Windows C run time (CRT):
  - \texttt{strcpy_s (*dest, DestSize, *src)}: ensures proper termination
Buffer overflow opportunities

• Exception handlers: (Windows SEH attacks)
  – Overwrite the address of an exception handler in stack frame.

• Function pointers: (e.g. PHP 4.0.2, MS MediaPlayer Bitmaps)
  – Overflowing buf will override function pointer.

• Longjmp buffers: longjmp(pos) (e.g. Perl 5.003)
  – Overflowing buf next to pos overrides value of pos.
Heap exploits: corrupting virtual tables

- Compiler generated function pointers (e.g., C++ code)

Object T

- After overflow of buf:

buf[256] vtable

ptr data

vtable

method #1

method #2

method #3

NOP slide shell code

ptr data

Object T
An example: exploiting the browser heap

Attacker’s goal is to infect browsers visiting the web site

• How: send javascript to browser that exploits a heap overflow
A reliable exploit?

Problem: attacker does not know where browser places shellcode on the heap
Heap Spraying

Idea:

1. Use Javascript to spray heap with shellcode (and NOP slides).
2. Then point vtable ptr anywhere in spray area.
Javascript heap spraying

```javascript
var nop = unescape(“%u9090%u9090”)
while (nop.length < 0x100000)  nop += nop;

var shellcode = unescape("%u4343%u4343%...");

var x = new Array ()
for (i=0;  i<1000;  i++) {
    x[i] = nop + shellcode;
}
```

Pointing function-ptr almost anywhere in heap will cause shellcode to execute.
Ad-hoc heap overflow mitigations

- Better browser architecture:
  - Store JavaScript strings in a separate heap from browser heap

- OpenBSD and Windows 8 heap overflow protection:
  - Nozzle [RLZ’08]: detect sprays by prevalence of code on heap

- Prevents cross-page overflows
Finding overflows by fuzzing

• To find overflow:
  – Run web server on local machine
  – Use AFL to issue malformed requests (ending with “$$$$$$”)
    • Fuzzers: automated tools for this (in a few lectures)
  – If web server crashes,
    search core dump for “$$$$$$” to find overflow location

• Construct exploit (not easy given latest defenses in next lecture)
Control Hijacking
More Control Hijacking Attacks
More Hijacking Opportunities

• **Integer overflows:** (e.g. MS DirectX MIDI Lib)

• **Double free:** double free space on heap
  – Can cause memory mgr to write data to specific location
  – Examples: CVS server

• **Use after free:** using memory after it is freed

• **Format string vulnerabilities**
Integer Overflows (see Phrack 60)

Problem: what happens when int exceeds max value?

int m; (32 bits) short s; (16 bits) char c; (8 bits)

c = 0x80 + 0x80 = 128 + 128 => c = 0
s = 0xff80 + 0x80 => s = 0
m = 0xffffffff80 + 0x80 => m = 0

Can this be exploited?
An example

```c
void func( char *buf1, *buf2, unsigned int len1, len2) {
    char temp[256];
    if (len1 + len2 > 256) {return -1}  // length check
    memcpy(temp, buf1, len1);          // cat buffers
    memcpy(temp+len1, buf2, len2);     // do stuff
    do-something(temp);
}
```

What if \( \text{len1} = 0x80, \text{len2} = 0xffffffff80 \) ?
\[ \Rightarrow \text{len1} + \text{len2} = 0 \]
Second \( \text{memcpy}() \) will overflow heap !!
Integer overflow exploit stats

Source: NVD/CVE
Format string bugs
Format string problem

```c
int func(char *user) {
    fprintf(stderr, user);
}
```

Problem: what if `*user = "%s%s%s%s%s%s%s%s"` ??

- Most likely program will crash: DoS.
- If not, program will print memory contents. Privacy?
- Full exploit using `user = "%n"

Correct form: `fprintf(stdout, "%s", user);`
Vulnerable functions

Any function using a format string.

Printing:
  printf, fprintf, sprintf, ...
  vprintf, vfprintf, vsprintf, ...

Logging:
  syslog, err, warn
Exploit

• Dumping arbitrary memory:
  – Walk up stack until desired pointer is found.
  – `printf( "%08x.%08x.%08x.%08x|%s|" )`

• Writing to arbitrary memory:
  – `printf( "hello %n", &temp)  -- writes ‘6’ into temp.`
  – `printf( "%08x.%08x.%08x.%08x.%n")`
printf ("a has value %d, b has value %d, c is at address: %08x\n", a, b, &c);
Format String (con’t)

Print the contents at the address 0x10014808 using format-string vulnerability

printf ("%10\x01\x48\x08 %x %x %x %x %s");
Use after free exploits
High impact security vulns. in Chrome 2015 - 2020 (C++)

70% due to memory management bugs
IE11 Example: CVE-2014-0282 (simplified)

(form id="form">
   <textarea id="c1" name="a1" ></textarea>
   <input id="c2" type="text" name="a2" value="val">
</form>

<script>
   function changer() {
      document.getElementById("form").innerHTML = "";
      CollectGarbage();       // erase c1 and c2 fields
   }

   document.getElementById("c1").onpropertychange = changer;
   document.getElementById("form").reset();
</script>

Loop on form elements:
c1.DoReset()
c2.DoReset()
What just happened?

c1.doReset() causes changer() to be called and free object c2
What just happened?

c1.doReset() causes \textit{changer()} to be called and free object c2

Suppose attacker allocates a string of same size as vtable

When c2.DoReset() is called, attacker gets shell
The exploit

<script>
    function changer() {
        document.getElementById("form").innerHTML = "";
        CollectGarbage();

        --- allocate string object to occupy vtable location ---
    }

    document.getElementById("c1").onpropertychange = changer;
    document.getElementById("form").reset();
</script>

Lesson: use after free can be a serious security vulnerability!!
Next lecture ...

DEFENSES
THE END
References on heap spraying


[3] Interpreter Exploitation: Pointer inference and JIT spraying, by Dion Blazakis
Acknowledgments/References

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