# Control Hijacking Attacks

Buffer overflows and
format string bugs

1

## Buffer overflows

- Extremely common bug.
  - First major exploit: 1988 Internet Worm. fingerd.
- 15 years later: ≈ 50% of all CERT advisories:
  - 1998: 9 out of 13
  - 2001: 14 out of 37
  - 2003: 13 out of 28
- Often lead to total compromise of host.
- Developing buffer overflow attacks:
  - Locate buffer overflow within an application.
  - Design an exploit.

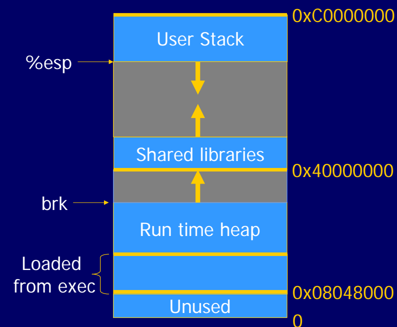
2

## What is needed

- Understanding C functions and the stack.
- Some familiarity with machine code.
- Know how systems calls are made.
- The exec() system call.
- Attacker needs to know which CPU and OS are running on the target machine.
  - Our examples are for x86 running Linux.
  - Details vary slightly between CPUs and OSs:
    - Little endian vs. big endian (x86 vs. Motorola)
    - Stack Frame structure (Linux vs. Windows)
    - Stack growth direction.

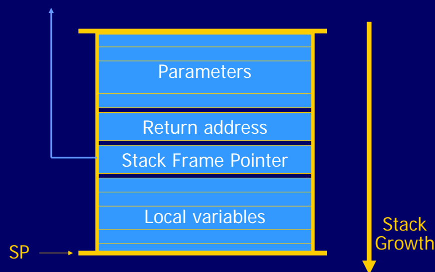
3

## Linux process memory layout




4

## Stack Frame




5

## 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 the function is invoked the stack looks like:

buf | sfp | ret-addr | str — top of stack

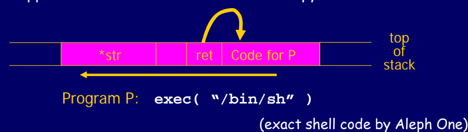
- What if `*str` is 136 bytes long? After `strcpy`:

*str | ret | str — top of stack

6

## Basic stack exploit

- Main problem: no range checking in strcpy().
- 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 will be given a shell !!
- Note: attack code runs *in stack*.
- To determine ret guess position of stack when func() is called.

7

## Some unsafe C lib functions

strcpy (char *dest, const char *src)
strcat (char *dest, const char *src)
gets (char *s)
scanf ( const char *format, … )
printf (conts char *format, … )

⋮

8

## Exploiting buffer overflows

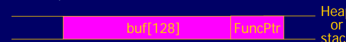
- Suppose web server calls func() with given URL.
  - Attacker sends a 200 byte URL. Gets shell on web server.
- Some complications:
  - Program P should not contain the '\0' character.
  - Overflow should not crash program before func() exists.
- Sample remote buffer overflows of this type:
  - (Old) overflow in MIME type field in MS Outlook.
  - (Old) overflow in Symantec Virus Detection

```
Set test = CreateObject("Symantec.SymVAFileQuery.1")
test.GetPrivateProfileString "file", [long string]
```

9

## Control hijacking opportunities

- Stack smashing attack:
  - Override return address in stack activation record by overflowing a local buffer variable.
- 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.

10

## Other types of overflow attacks

- Integer overflows: (e.g. MS DirectX MIDI Lib) Phrack60

```
void func(int a, char v) {
  char buf[128];
  init(buf);
  buf[3*a+1] = v;
}
```

  - Problem: 3*a+1 can point to `ret-addr' on stack.
- Double free: double free space on heap.
  - Can cause memory mgr to write data to specific locations.
  - Examples: CVS server

11

## Finding buffer overflows

- To find overflow:
  - Run web server on local machine.
  - Issue requests with long tags.
    All long tags end with "$$$$$".
  - If web server crashes,
    search core dump for "$$$$$" to find overflow location.
- Some automated tools exist. (e.g. eEye Retina).
- Then use disassemblers and debuggers (e..g IDA-Pro) to construct exploit.

12

## Preventing overflow attacks

- Main problem:
  - strcpy(), strcat(), sprintf() have no range checking.
  - "Safe" versions strncpy(), strncat() are misleading
    - strncpy() may leave buffer unterminated.
    - strncpy(), strncat() encourage off by 1 bugs.
- Defenses:
  - Type safe languages (Java, ML). Legacy code?
  - Mark stack as non-execute. Random stack location.
  - Static source code analysis.
  - Run time checking: StackGuard, Libsafe, SafeC, (Purify).
  - Many more … (covered later in course)

13

## Marking stack as non-execute

- Basic stack exploit can be prevented by marking stack segment as non-executable.
  - NX-bit on AMD Athlon 64, XD-bit on Intel P4 "Prescott".
    - NX bit in every Page Table Entry (PTE)
  - Support in SP2. Code patches exist for Linux, Solaris.
- Limitations:
  - Does not defend against `return-to-libc' exploit.
    - Overflow sets ret-addr to address of libc function.
  - Does not block more general overflow exploits:
    - Overflow on heap: overflow buffer next to func pointer.
  - Some apps need executable stack (e.g. LISP interpreters).

14

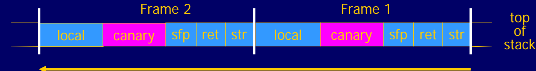
## Static source code analysis

- Statically check source to detect buffer overflows.
  - Several consulting companies.
- Can we automate the review process?
- Several tools exist:
  - Coverity (Engler et al.): Test trust inconsistency.
  - Microsoft program analysis group:
    - PREfix: looks for fixed set of bugs (e.g. null ptr ref)
    - PREfast: local analysis to find idioms for prog errors.
  - Berkeley: Wagner, et al. Test constraint violations.
- Find lots of bugs, but not all.

15

## Run time checking: StackGuard

- Many many run-time checking techniques …
  - Here, only discuss methods relevant to overflow protection.
- Solutions 1: StackGuard (WireX)
  - Run time tests for stack integrity.
  - Embed "canaries" in stack frames and verify their integrity prior to function return.




16

## Canary Types

- Random canary:
  - Choose random string at program startup.
  - Insert canary string into every stack frame.
  - Verify canary before returning from function.
  - To corrupt random canary, attacker must learn current random string.
- Terminator canary:
  Canary = 0, newline, linefeed, EOF
  - String functions will not copy beyond terminator.
  - Hence, attacker cannot use string functions to corrupt stack.

17

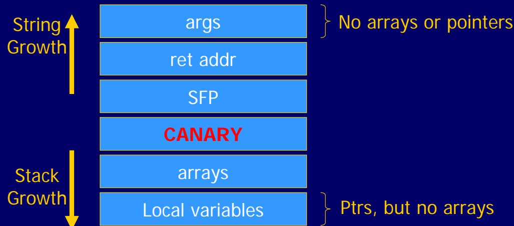
## StackGuard (Cont.)

- StackGuard implemented as a GCC patch.
  - Program must be recompiled.
- Minimal performance effects: 8% for Apache.
- Newer version: PointGuard.
  - Protects function pointers and setjmp buffers by placing canaries next to them.
  - More noticeable performance effects.
- Note: Canaries don't offer fullproof protection.
  - Some stack smashing attacks can leave canaries untouched.

18

## StackGuard variants - ProPolice

- ProPolice (IBM) - gcc 3.4.1. (**-fstack-protector**)
  - Rearrange stack layout to prevent ptr overflow.





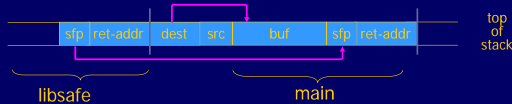

## Windows XP SP2 /GS

- Non executable stack.
- Compiler /GS option:
  - Combination of ProPolice and Random canary.
  - Triggers UnHandledException in case of Canary mismatch to shutdown process.
- Litchfield vulnerability report.
  - Overflow overwrites exception handler.
  - Redirects exception to attack code.



## Run time checking: Libsafe

- Solutions 2: Libsafe (Avaya Labs)
  - Dynamically loaded library.
  - Intercepts calls to strcpy (dest, src)
    - Validates sufficient space in current stack frame: |frame-pointer – dest| > strlen(src)
    - If so, does strcpy. Otherwise, terminates application.






## More methods …

- StackShield
  - At function prologue, copy return address RET and SFP to "safe" location (beginning of data segment)
  - Upon return, check that RET and SFP is equal to copy.
  - Implemented as assembler file processor (GCC)
- Randomization:
  - PaX ASLR: Randomize location of libc.
    - Attacker cannot jump directly to exec function.
  - Instruction Set Randomization (ISR)
    - Attacker cannot execute its own code.



## Format string bugs



## Format string problem

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

Problem: what if user = "%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:

```
int func(char *user) {
   fprintf( stdout, "%s", user);
}
```

## History

- Danger discovered in June 2000.
- Examples:
  - wu-ftpd 2.* : remote root.
  - Linux rpc.statd: remote root
  - IRIX telnetd: remote root
  - BSD chpass: local root

25

## Vulnerable functions

Any function using a format string.

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

Logging:
syslog, err, warn

26

## 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")

27

## Overflow using format string

```
char errmsg[512], outbuf[512];
sprintf (errmsg, "Illegal command: %400s", user);
   …
sprintf( outbuf, errmsg );
```

- What if user = "%500d <nops> <shellcode>"
  - Bypass "%400s" limitation.
  - Will ovreflow outbuf.

28