Buffer Overflow Attacks
and Format String bugs

Buffer overflows

- ◆ Extremely common bug.
  - First major exploit: 1988 Internet Worm. fingerd.
- ◆ 10 years later: over 50% of all CERT advisories:
  - 1997: 16 out of 28 CERT advisories.
  - 1998: 9 out of 13 -"-
  - 1999: 6 out of 12 -"-
- ◆ Often leads to total compromise of host.
  - Fortunately: exploit requires expertise and patience.
  - Two steps: (until one exploit available)
    - Locate buffer overflow within an application.
    - Design an exploit.

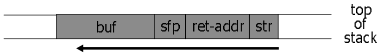
What are buffer overflows?

- ◆ Suppose a web server contains a function:

```
void func(char *str) {
  char buf[128];

  strcpy(buf, str);
  do-something(buf);
}
```

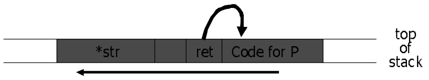
- ◆ When the function is invoked the stack looks like:



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

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.

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, …)

⋮

Exploiting buffer overflows

- ◆ Suppose web server calls func() with given URL.
- ◆ Attacker can create a 200 byte URL to obtain shell on web server.
- ◆ Some complications:
  - Program P should not contain the '\0' character.
  - Overflow should not crash program before func() exists.
- ◆ Sample buffer overflows of this type:
  - Overflow in MIME type field in MS Outlook.
  - Overflow in ISAPI in IIS.

Causing program to exec attack code

- ◆ Stack smashing attack:
  - Override return address in stack activation record by overflowing a local buffer variable.
- ◆ Function pointers: (used in attack on Linux superprobe)

  - Overflowing buf will override function pointer.
- ◆ Longjmp buffers: longjmp(pos) (used in attack on Perl 5.003)
  - Overflowing buf next to pos overrides value of pos.

Finding buffer overflows

- ◆ Hackers find buffer overflows as follows:
  - 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. (eEye Retina, ISIC).

Preventing buf 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).
  - Black box testing (e.g. eEye Retina, ISIC).

Marking stack as non-execute

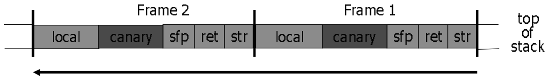
- ◆ Basic stack exploit can be prevented by marking stack segment as non-executable or randomizing stack location.
  - Code patches exist for Linux and Solaris.
- ◆ Problems:
  - Does not block more general overflow exploits:
    - Overflow on heap: overflow buffer next to func pointer.
  - Some apps need executable stack (e.g. LISP interpreters).
- ◆ Patch not shipped by default for Linux and Solaris.

Static source code analysis

- ◆ Statically check source to detect buffer overflows.
  - Several consulting companies.
- ◆ Can we automate the review process?
- ◆ Several tools exist:
  - @stake.com (l0pht.com): SLINT (designed for UNIX)
  - rstcorp: its4. Scans function calls.
  - Berkeley: Wagner, et al. Test constraint violations.
  - Stanford: Engler, et al. Test trust inconsistency.
- ◆ Find lots of bugs, but not all.

Run time checking: StackGuard

- ◆ Many many run-time checking techniques …
- ◆ Solutions 1: StackGuard (WireX)
  - Run time tests for stack integrity.
  - Embed "canaries" in stack frames and verify their integrity prior to function return.



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

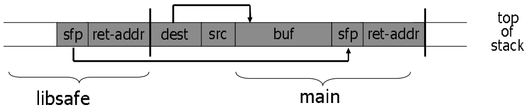
  - String functions will not copy beyond terminator.
  - Hence, attacker cannot use string functions to corrupt stack.

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.

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.



Run time checking: many others …

- ◆ Address obfuscation. (Stony Brook '03)
  - Encrypt return address on stack by XORing with random string. Decrypt just before returning from function.
  - Attacker needs decryption key to set return address to desired value.
- ◆ Randomize location of functions in libc.
  - Attacker cannot jump directly to exec function.

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

⋮

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”)

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.

Timing attacks

Timing attacks

- ◆ Timing attacks extract secret information based on the time a device takes to respond.
- ◆ Applicable to:
  - Smartcards.
  - Cell phones.
  - PCI cards.

Timing attacks: example

- Consider the following pwd checking code:

```
int password-check( char *inp, char *pwd)
    if   (strlen(inp)  !=  strlen(pwd)) return 0;
    for( i=0; i < strlen(pwd); ++i)
        if  ( *inp[i]  !=  *pwd[i]  )
            return 0;
    return 1;
```

- *A simple timing attack will expose the password one character at a time.*

Timing attacks: example

- Alternative code:

```
int password-check( char *inp, char *pwd)  {
    oklen = ( strlen(inp)   ==  strlen(pwd) ) ;
    for( ok=1, i=0;  i < strlen(pwd) ; ++i)
        ok = ok  &  ( inp[i]   ==   pwd[i] ) ;
    return ok & oklen;
}
```

- Timing attack is ineffective … (?)