System Security Overview

Department of Computer Science & Technology
Tsinghua University

2015

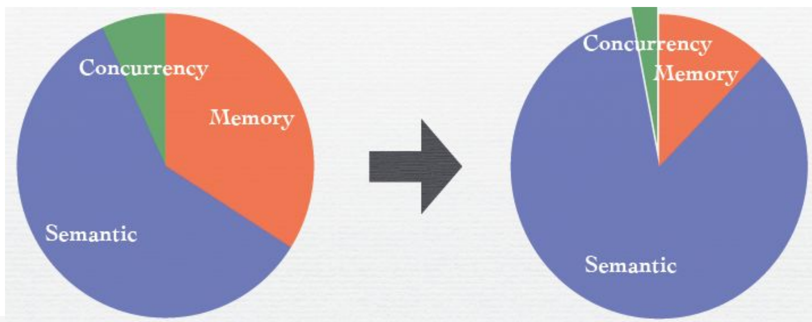
Contents

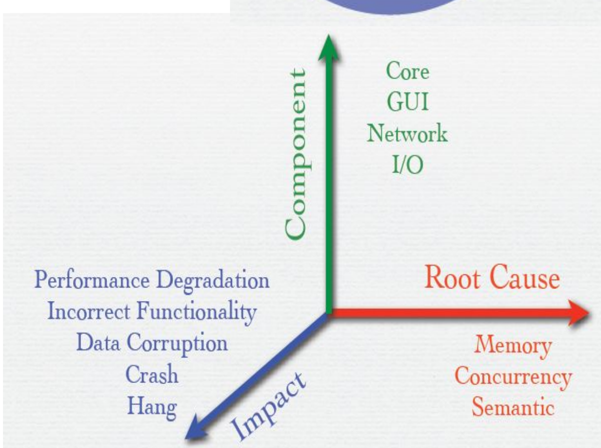
- Software Vulnerabilities
- Program Static/Dynamic Analysis
- security labs

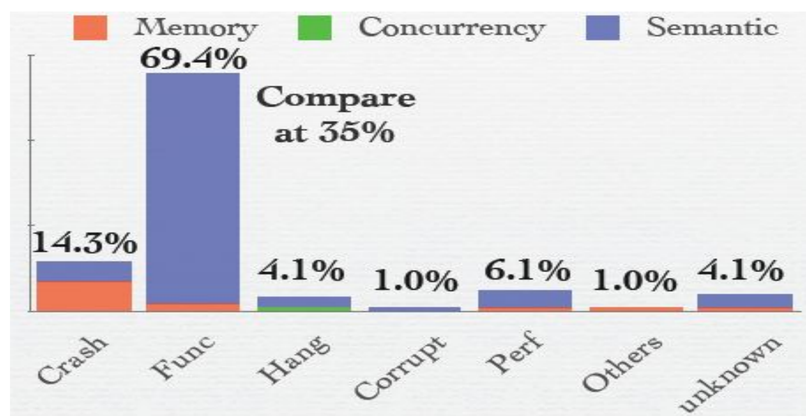
Current Status (1)

对当前软件漏洞的理解

- Sematic Vulnerability 越来越多
- 数据泄漏漏洞的威胁越来越大



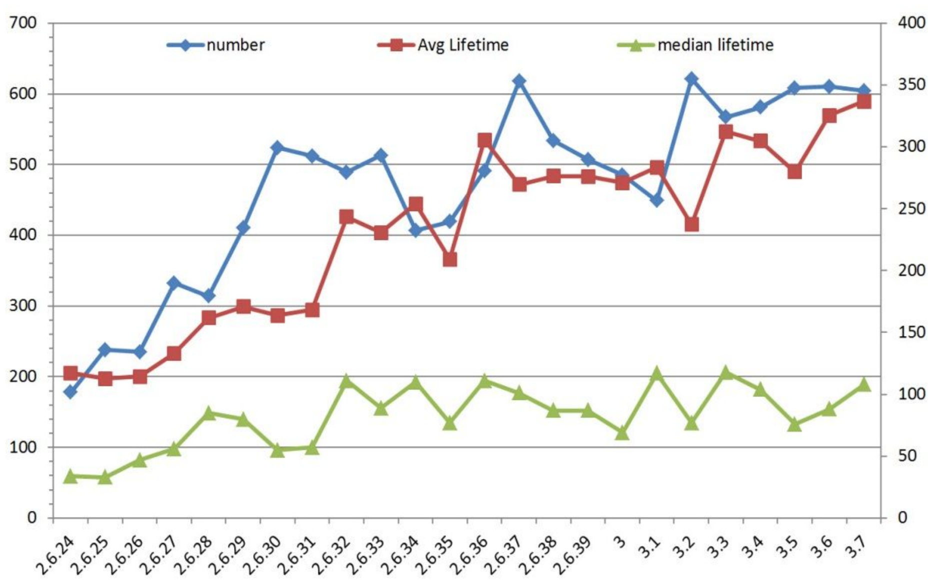


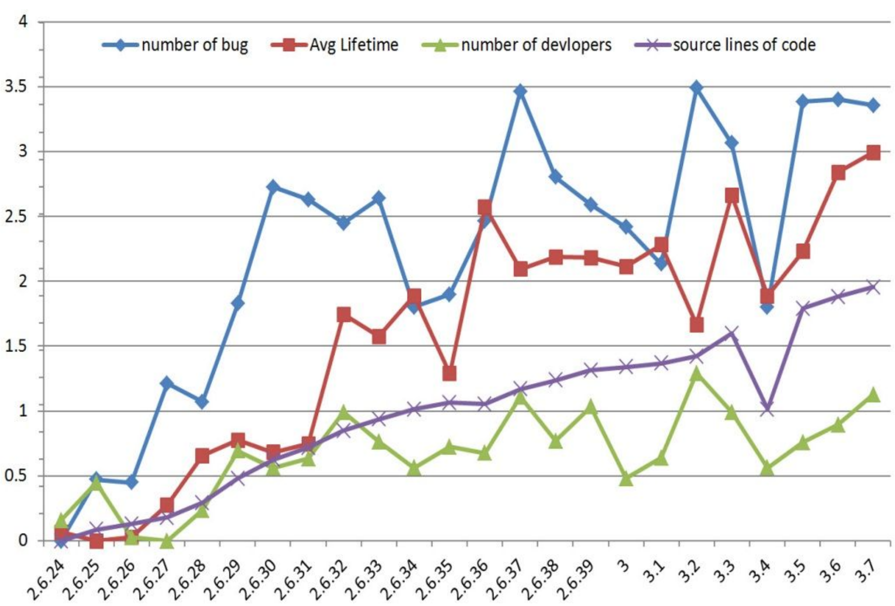


Current Status (2)

对当前Linux Kernel漏洞的理解

- Linux漏洞有扩大化的趋势
- 但发现Linux漏洞难度加大





System Security Technology

安全分析工具

- OVALdi
- Metasploit
- WALA
- Soot
- Droidscope
- KINT
- KLEE
- S2E
- TEMU

系统安全机制

- 权限模型
- Binder -Intent机制
- Content Provider机制
- 应用签名验证机制
- 用户隐私保护机制
- SQLite数据库机制
- SSL机制
- 内核级整数溢出
- 内核级内存溢出
- 内核数据流分析
- 内核驱动缺陷分析

符号执行	数据流分析	动态执行分析	静态控制流分析	Model check

核心分析技术

5

Software Vulnerabilities

- **Input Validation Issues**
- **Buffer Overflows**
- **Format String**
- **Integer Overflow**
- **Race conditions**
- …

Steps in a standard break-in (Getting in)

- Get your foot in the door
  - Steal a password file and run dictionary attack
  - Try to guess a password online
  - Sniff passwords off the network, social engineering
  - Use input vulnerability in network-facing programs (e.g., web server, ftp server, mail server, browser, etc.)
- Use partial access to gain root (admin) access
  - Break some mechanism on the system
  - Often involve exploiting vulnerabilities in some local programs

Steps in a standard break-in (After Getting in)

- Set up some way to return
  - Install login program or web server with back door
- Cover your tracks
  - Disable intrusion detection, virus protection,
  - Install rootkits,
- Perform desired attacks
  - break into other machines
  - taking over the machine
  - Steal useful information (e.g., credit card numbers)

Software Vulnerabilities

- **Input Validation Issues**
- **Buffer Overflows**
- **Format String**
- **Integer Overflow**
- **Race conditions**
- …

Input Validation

- Sources of input
  - Command line arguments
  - Environment variables
  - Function calls from other modules
  - Configuration files
  - Network packets
- Sources of input for web applications
  - Web form input
  - Scripting languages with string input

Weak Input Validation

What are some things that the attacker may try to achieve?

- Crash programs
- Execute arbitrary code
  - setuid or setgid programs
- Obtain sensitive information

Command line

- User can set command line arguments to almost anything
  - Using execve command
  - Do not trust name of the program (it can be sent to any value including NULL)
- Do not check for bad things (blacklisting)
- Check for things that are allowed (whitelisting)
- Check all possible inputs

Simple example

```
void main(int argc, char ** argv) {
  char buf[1024];
  sprintf(buf,”cat %s”,argv[1]);
  system (buf);
}
```

?

Simple example

```
void main(int argc, char ** argv) {
  char buf[1024];
  sprintf(buf,"cat %s",argv[1]);
  system (buf);
}
```

Can easily add things to the command by adding ;

Environment variables

- Users can set the environment variables to anything
  - Using execve
  - Has some interesting consequences
- Examples:
  - LD_LIBRARY_PATH
  - PATH
  - IFS

An example attack

- Assume you have a setuid program that loads dynamic libraries
- UNIX searches the environment variable LD_LIBRARY_PATH for libraries
- A user can set LD_LIBRARY_PATH to /tmp/attack and places his own copy of the libraries here
- Most modern C runtime libraries have fixed this by not using the LD_LIBRARY_PATH variable when the EUID is not the same as the UID or the EGID is not the same as the GID

More fun with environment variables

- A setuid program has a system call: `system(ls);`
- The user sets his PATH to be . (current directory) and places a program ls in this directory
- The user can then execute arbitrary code as the setuid program
- Solution: Reset the PATH variable to be a standard form (i.e., “/bin:/usr/bin”)

Even more fun

- However, you must also reset the IFS variable
  - IFS is the characters that the system considers as white space
- If not, the user may add “s” to the IFS
  - system(ls) becomes system(l)
  - Place a function l in the directory

Software Vulnerabilities

- **Input Validation Issues**
- **Buffer Overflows**
- **Format String**
- **Integer Overflow**
- **Race conditions**
- …

What is Buffer Overflow?

A **buffer overflow**, or **buffer overrun**, is an anomalous condition where a process attempts to store data beyond the boundaries of a fixed-length buffer.

The result is that the extra data overwrites adjacent memory locations. The overwritten data may include other buffers, variables and program flow data, and may result in erratic program behavior, a memory access exception, program termination (a crash), incorrect results or — especially if deliberately caused by a malicious user — a possible breach of system security.

Most common with C/C++ programs

History

- Used in 1988’s Morris Internet Worm
- Alphe One’s “Smashing The Stack For Fun And Profit” in Phrack Issue 49 in 1996 popularizes stack buffer overflows
- Still extremely common today

What is needed to understand Buffer Overflow

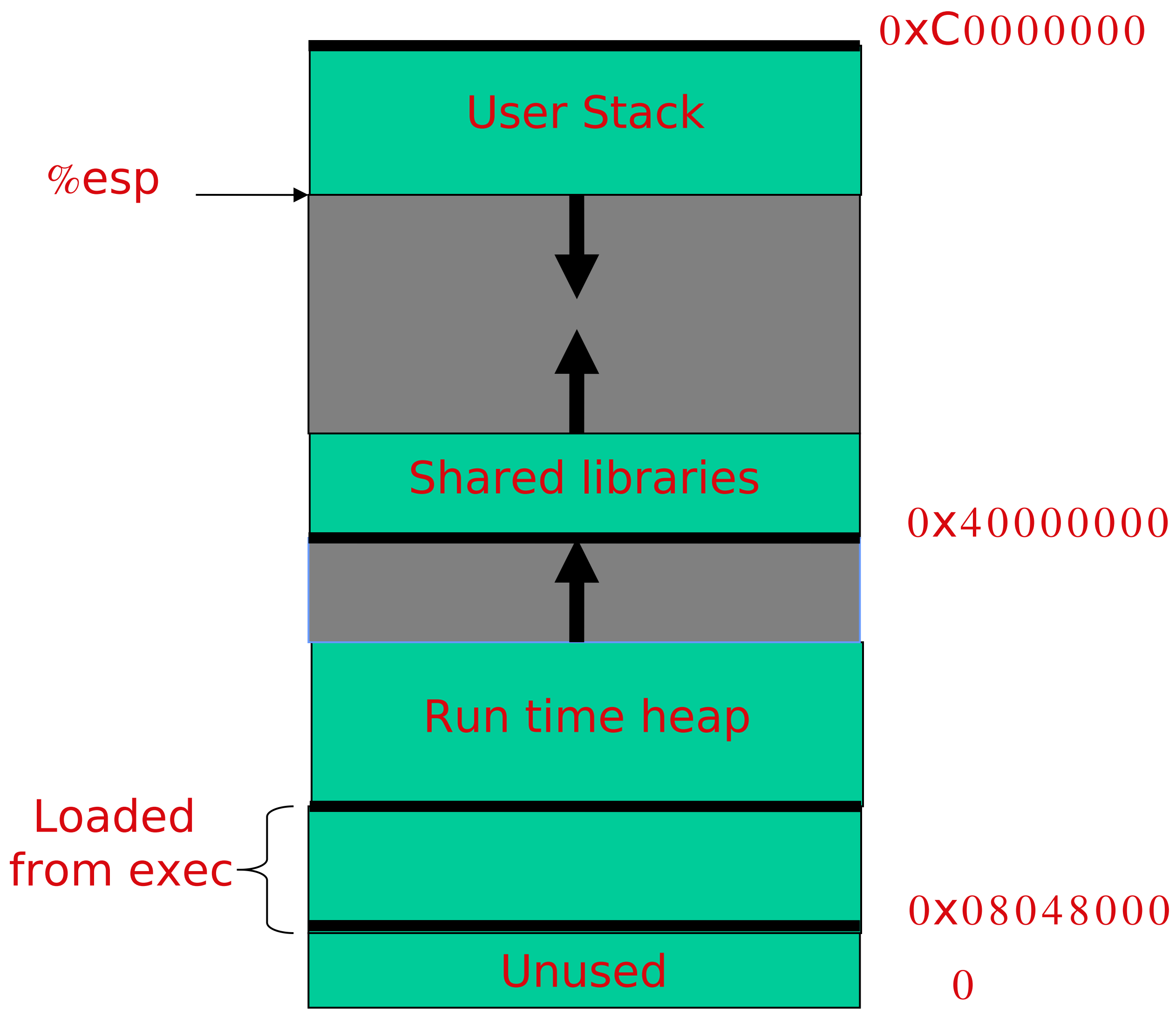
- Understanding C functions and the stack.
- Some familiarity with machine code.
- Know how systems calls are made.
- The exec() system call.

- 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 CPU's and OS:
    - Stack growth direction.
    - big endian vs. little endian.

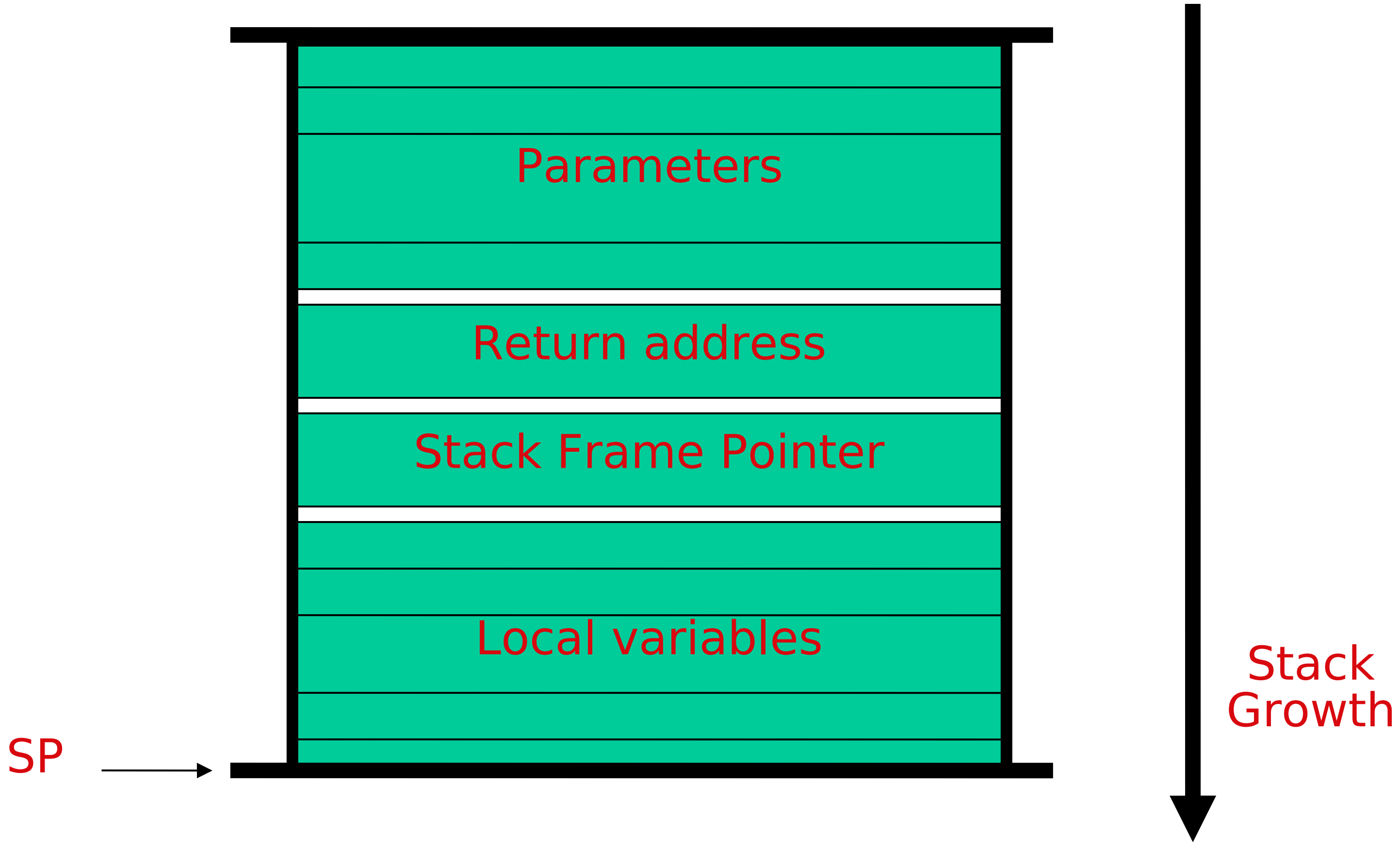
Buffer Overflow

- Stack overflow
  - Shell code
  - Return-to-libc
    - Overflow sets ret-addr to address of libc function
  - Off-by-one
  - Overflow function pointers & longjmp buffers
- Heap overflow

Linux process memory layout



Stack Frame



Parameters
Return address
Stack Frame Pointer
Local variables
SP
Stack
Growth

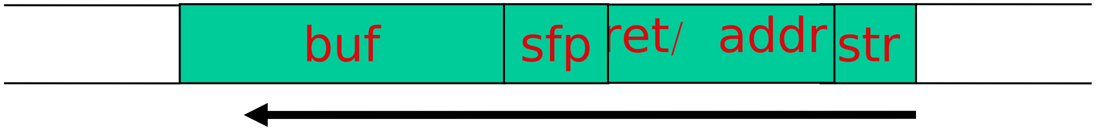
What are buffer overflows?

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`**:

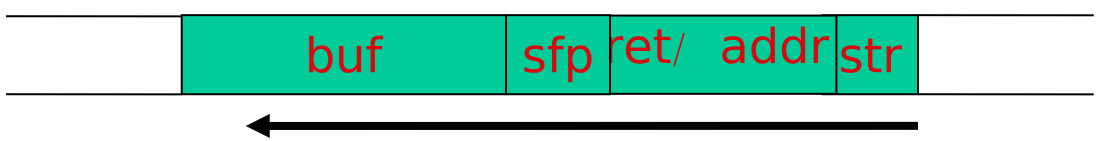
What are buffer overflows?

Suppose a web server contains a function:

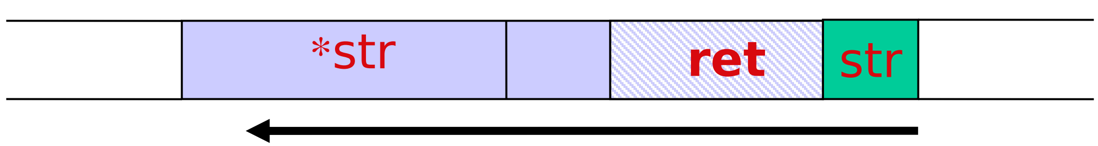
```
void func(char *str) {
    char buf[128];

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

When the function is invoked the stack looks like:



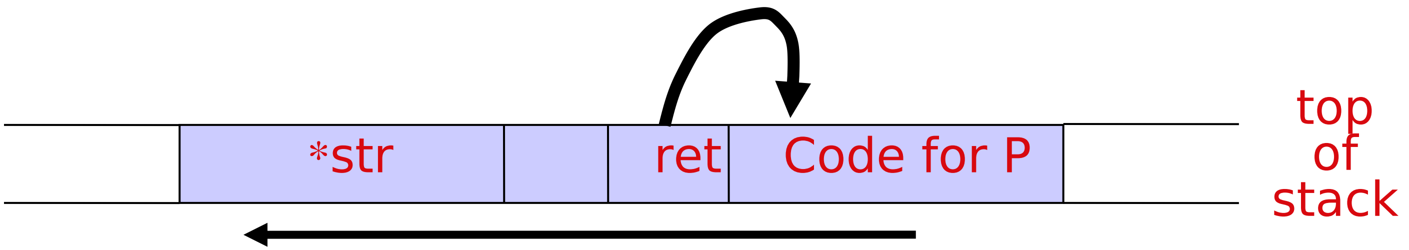
What if **`*str`** is 136 bytes long? After **`strcpy`**:



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, …)
- sprintf (conts char *format, …)

⋮

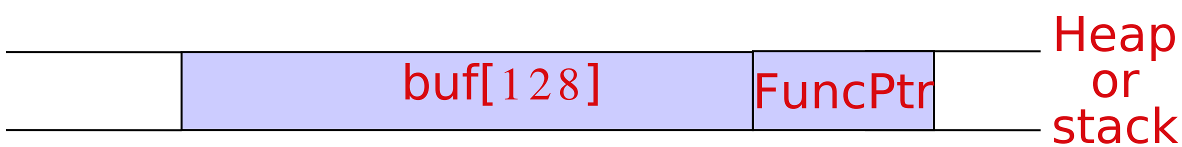
Exploiting buffer overflows

- Suppose web server calls func() with given URL.
- Attacker can create a 200 byte URL to obtain shell on web server.
- Some complications for stack overflows:
  - Program P should not contain the '\0' character.
  - Overflow should not crash program before func() exits.

Other control hijacking opportunities

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

Function pointers: (used in attack on PHP 4.0.2)



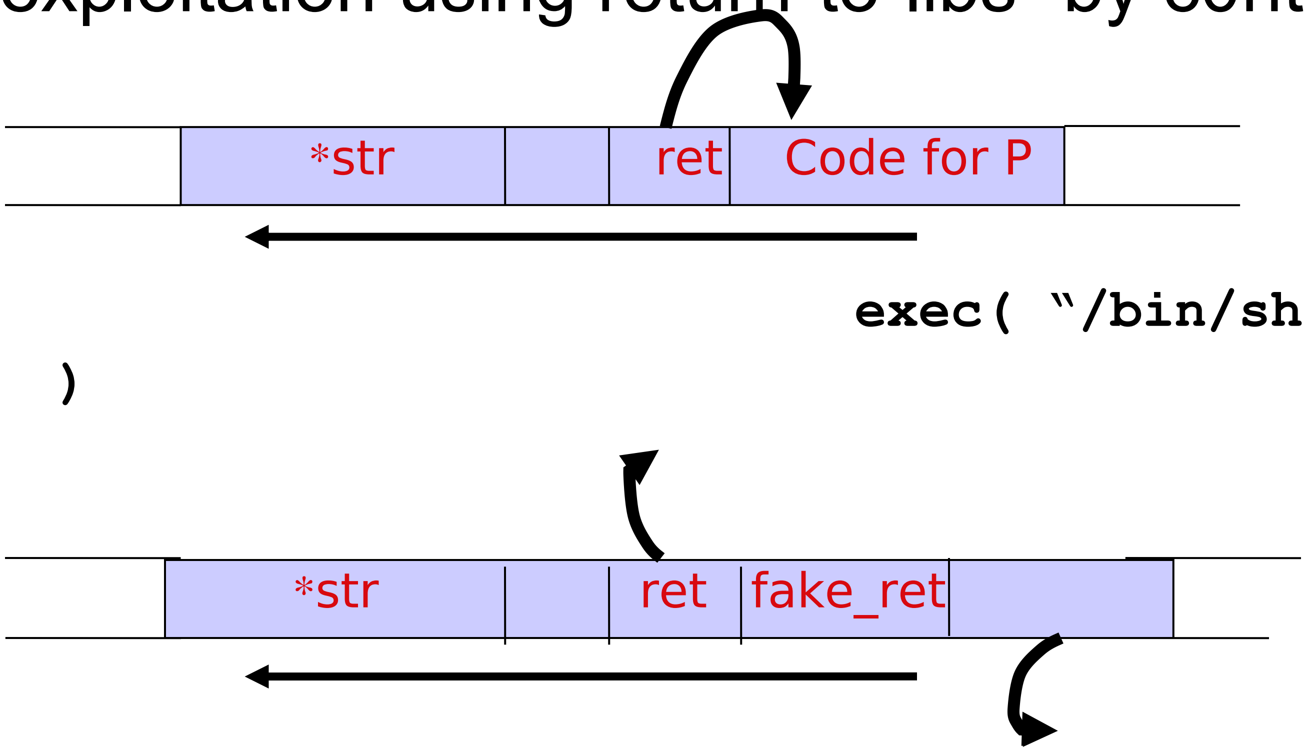
Overflowing buf will override function pointer.

Longjmp buffers: longjmp(pos) (used in attack on Perl 5.003)

Overflowing buf next to pos overrides value of pos.

return-to-libc attack

"Bypassing non-executable-stack during exploitation using return-to-libs" by c0ntex



Off by one buffer overflow

Sample code

```
func  f(char *input) {
  char buf[LEN];
  if (strlen(input) <= LEN) {
     strcpy(buf, input)
  }
}
```

Heap Overflow

- Heap overflow is a general term that refers to overflow in data sections other than the stack
  - buffers that are dynamically allocated, e.g., by malloc
  - statically initialized variables (data section)
  - uninitialized buffers (bss section)

- Heap overflow may overwrite other date allocated on heap
- By exploiting the behavior of memory management routines, may overwrite an arbitrary memory location with a small amount of data.
  - E.g., SimpleHeap_free() does
    - hdr->next->next->prev := hdr->next->prev;

Finding buffer overflows

- Hackers find buffer overflows as follows:
  - Run web server on local machine.
  - **Fuzzing:** 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. ().
- Then use disassemblers and debuggers (e..g IDA-Pro) to construct exploit.

Preventing Buffer Overflow Attacks

- Use type safe languages (Java, ML).
- Use safe library functions
- Static source code analysis.
- Non-executable stack
- Run time checking: StackGuard, Libsafe, SafeC, (Purify).
- Address space layout randomization.
- Detection deviation of program behavior
- Access control to control aftermath of attacks… (covered later in course)

Static source code analysis

- Statically check source code to detect buffer overflows.
  - Several consulting companies.
- Main idea: automate the code 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.

Bugs to Detect in Source Code Analysis

Some examples

- **Crash Causing Defects**
- **Null pointer dereference**
- **Use after free**
- **Double free**
- **Array indexing errors**
- **Mismatched array new/delete**
- **Potential stack overrun**
- **Potential heap overrun**
- **Return pointers to local variables**
- **Logically inconsistent code**
- **Uninitialized variables**
- **Invalid use of negative values**
- **Passing large parameters by value**
- **Underallocations of dynamic data**
- **Memory leaks**
- **File handle leaks**
- **Network resource leaks**
- **Unused values**
- **Unhandled return codes**
- **Use of invalid iterators**

Marking stack as non-execute

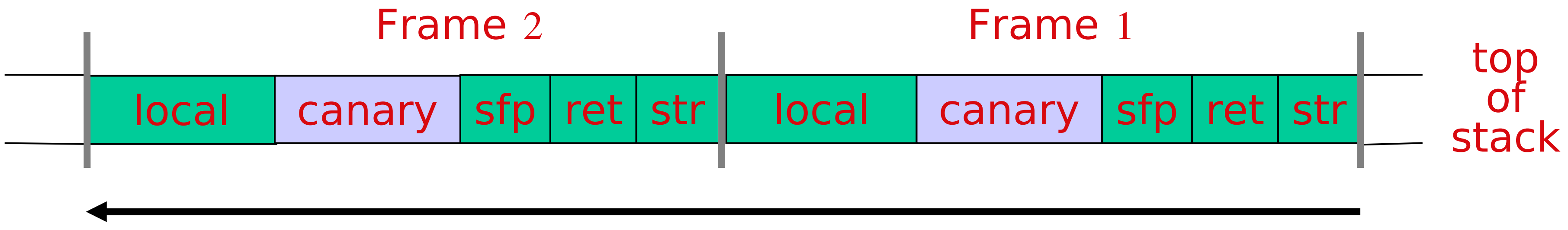
- Basic stack exploit can be prevented by marking stack segment as non-executable.
  - Support in Windows SP2. Code patches exist for Linux, Solaris.
- Problems:
  - Does not defend against `return-to-libc’ exploit.
  - Some apps need executable stack (e.g. LISP interpreters).
  - Does not block more general overflow exploits:
    - Overflow on heap, overflow func pointer.

Run time checking: StackGuard

There are many run-time checking techniques …

StackGuard 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.)

- Protection.
  - Some stack smashing attacks can leave canaries untouched.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 full proof protection.
  - Some stack smashing attacks can leave canaries untouched.

Randomization: Motivations.

- Buffer overflow and return-to-libc exploits need to know the (virtual) address to which pass control
  - Address of attack code in the buffer
  - Address of a standard kernel library routine
- Same address is used on many machines
  - Slammer infected 75,000 MS-SQL servers using same code on every machine
- Idea: introduce artificial diversity
  - Make stack addresses, addresses of library routines, etc. unpredictable and different from machine to machine

Address Space Layout Randomization

- Arranging the positions of key data areas randomly in a process' address space.
  - e.g., the base of the executable and position of libraries (libc), heap, and stack,
  - Effects: for return to libc, needs to know address of the key functions.
  - Attacks:
    - Repetitively guess randomized address
    - Spraying injected attack code
- Vista has this enabled, software packages available for Linux and other UNIX variants

Instruction Set Randomization

- Instruction Set Randomization (ISR)
  - Each program has a *different* and *secret* instruction set
  - Use translator to randomize instructions at load-time
  - Attacker cannot execute its own code.
- What constitutes instruction set depends on the environment.
  - for binary code, it is CPU instruction
  - for interpreted program, it depends on the interpreter

Instruction Set Randomization

- An implementation for x86 using the Bochs emulator
  - network intensive applications doesn’t have too much performance overhead
  - CPU intensive applications have one to two orders of slow-down
- Not yet used in practice

Software Vulnerabilities

- **Input Validation Issues**
- **Buffer Overflows**
- **Format String**
- **Integer Overflow**
- **Race conditions**
- …

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);
}
```

Format string attacks (“%n”)

printf(“%n”, &x) will change the value of the variable x

- in other words, the parameter value on the stack is interpreted as a pointer to an integer value, and the place pointed by the pointer is overwritten

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

Software Vulnerabilities

- **Input Validation Issues**
- **Buffer Overflows**
- **Format String**
- **Integer Overflow**
- **Race conditions**
- …

When casting occurs in C?

When assigning to a diffreent data type

For binary operators +, -, *, /, %, &, |, ^,

- if either operand is an unsigned long, both are cast to an unsigned long
- in all other cases where both operands are 32-bits or less, the arguments are both upcast to int, and the result is an int

For unary operators

- ~ changes type, e.g., ~((unsigned short)0) is int
- ++ and -- does not change type

Where Does Integer Overflow Matter?

Allocating spaces using calculation.

Calculating indexes into arrays

Checking whether an overflow could occur

Direct causes:

- Truncation; Integer casting

Integer Overflow Vulnerabilities Example (from Phrack)

```
int main(int argc, char *argv[]) {
    unsigned short s;  int i;   char buf[80];
    if (argc < 3){ return -1; }
    i = atoi(argv[1]);   s = i;
    if(s >= 80)  {  printf(“No you don't!\n"); return -1; }
    printf("s = %d\n", s);
    memcpy(buf, argv[2], i);
    buf[i] = '\0'; printf("%s\n", buf); return 0;
}
```

Integer Overflow Vulnerabilities Example

Example:

```
const long MAX_LEN = 20K;
Char   buf[MAX_LEN];
short len = strlen(input);
if (len < MAX_LEN)  strcpy(buf, input);
```

Can a buffer overflow attack occur?

If so, how long does input needs to be?

Another Example

```
int ConcatBuffers(char *buf1, char *buf2,    size_t
   len1, size_t len2)
{
    char buf[0xFF];
    if ((len1 + len2) > 0xFF) return -1;
    memcpy(buf, buf1, len1);
    memcpy(buf+len1, buf2, len2);
    return 0;
}
```

Yet Another Example

```
// The function is supposed to return false when
// x+y overflows unsigned short.
// Does the function do it correctly?
bool  IsValidAddition(unsigned short x,
    unsigned short y) {
    if (x+y < x)
        return false;
    return true;
}
```

Software Vulnerabilities

- **Input Validation Issues**
- **Buffer Overflows**
- **Format String**
- **Integer Overflow**
- **Race conditions**
- …

Race Condition

- what's a race condition?

multiple computations operate on some shared resources

- computation: processes, threads, cpus, etc.
- resources: memories, files, I/O devices, etc.

e.g., for the C code (b in memory):

```
b = b + 1;
```

possible instruction sequence on machine:

```
[b] -> r
inc r
r -> [b]
```

Race Condition

consider a multi-core machine with core C1 and core C2

possible assembly code:

```
[b] -> C1
[b] -> C2
C1++
C2++
C1 -> [b]
C2 -> [b]
```

what's the value in b?
other results?

Race Condition

another example on file system. sample code:

```
if (0==access("a.txt", W_OK)){
  fopen ("a.txt", "w");
}
else error ("file not found");
```

safe on a single-core machine?

safe on a multi-core machine? why?

Race Condition

- why race conditions occur?
- how to prevent them?
  - must guarantee exclusive access
  - the simplest idea is locking!
- What's a lock?
  - another shared resources

```
void lock (){
  while (theLock) ;
   theLock = 1;
}

 void unLock (){
    theLock = 0;
}
```

```
 .globl lock
lock:
  movl  $1, %eax
start:
  xchg  %eax, theLock
  cmpl  $0, %eax
  jne   start
  ret
```

Race Condition

- what if one want to deal with process-level locking?
  - difference address space
  - the key idea is that file systems are still global!

- lock files:

```
void lock (){
    while (create ("lock.txt")<0) ;
    }
void unLock (){
    remove ("lock.txt");
}
```

```
// code as above
lock ();
   b = b+1;
unLock ();
```

- **what if the file exists before any application?**
- **what if the attack can remove or create this file?**
- **what if the function "create" is not at atomic?**

Thank you