CSE 484 (Winter 2008)

Software Security: Buffer Overflow Attacks and Beyond

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Thanks to Dan Boneh, Dieter Gollmann, John Manferdelli, John Mitchell, Vitaly Shmatikov, Bennet Yee, and many others for sample slides and materials ...

Goals for Today

- Software security
  - Software lifecycle
  - Buffer overflow attacks
  - Other software security issues
- Turn in Ethics Form
- Project 1 online
- Really impressed with all the activity on the blog!

Software Lifecycle (Simplified)

- Requirements
- Design
- Implementation
- Testing
- Use

Software problems are ubiquitous

Software Bug Halts F-22 Flight

Posted by kdawson on Sunday February 25, @06:35PM
from the **dare-you-to-cross-this-line** dept.

mgh02114 writes

> "The new US stealth fighter, the F-22 Raptor, was deployed for the first time to Asia earlier this month. On Feb. 11, twelve Raptors flying from Hawaii to Japan were forced to turn back when a software glitch crashed all of the F-22s' on-board computers as they crossed the international date line. The delay in arrival in Japan was previously reported, with rumors of problems with the software. CNN television, however, this morning reported that every fighter completely lost all navigation and communications when they crossed the international date line. They reportedly had to turn around and follow their tankers by visual contact back to Hawaii. According to the CNN story, if they had not been with their tankers, or the weather had been bad, this would have been serious. CNN has not put up anything on their website yet."

Software problems are ubiquitous

1985-1987 -- Therac-25 medical accelerator. A radiation therapy device malfunctions and delivers lethal radiation doses at several medical facilities. Based upon a previous design, the Therac-25 was an "improved" therapy system that could deliver two different kinds of radiation: either a low-power electron beam (beta particles) or X-rays. The Therac-25's X-rays were generated by smashing high-power electrons into a metal target positioned between the electron gun and the patient. A second "improvement" was the replacement of the older Therac-20's electromechanical safety interlocks with software control, a decision made because software was perceived to be more reliable.

What engineers didn't know was that both the 20 and the 25 were built upon an operating system that had been kludged together by a programmer with no formal training. Because of a subtle bug called a "race condition," a quick-fingered typist could accidentally configure the Therac-25 so the electron beam would fire in high-power mode but with the metal X-ray target out of position. At least five patients die; others are seriously injured.

http://www.wired.com/software/coolapps/news/2005/11/69355

Software problems are ubiquitous

January 15, 1990 -- AT&T Network Outage. A bug in a new release of the software that controls AT&T's #4ESS long distance switches causes these mammoth computers to crash when they receive a specific message from one of their neighboring machines -- a message that the neighbors send out when they recover from a crash.

One day a switch in New York crashes and reboots, causing its neighboring switches to crash, then their neighbors' neighbors, and so on. Soon, 114 switches are crashing and rebooting every six seconds, leaving an estimated 60 thousand people without long distance service for nine hours. The fix: engineers load the previous software release.

http://www.wired.com/software/coolapps/news/2005/11/69355

Software problems are ubiquitous

- NASA Mars Lander
  - Bug in translation between English and metric units
  - Cost taxpayers $165 million
- Denver Airport baggage system
  - Bug caused baggage carts to become out of "sync," overloaded, etc.
  - Delayed opening for 11 months, at $1 million per day
- Other fatal or potentially fatal bugs
  - US Vicennes tracking software
  - MV-22 Ospray
  - Medtronic Model 8870 Software Application Card

From *Exploiting Software* and http://www.fda.gov/cdrh/recalls/recall-082404b-pressrelease.html

Adversarial Failures

- Software bugs are bad
  - Consequences can be serious
- Even worse when an intelligent adversary wishes to exploit them!
  - Intelligent adversaries: Force bugs into "worst possible" conditions/states
  - Intelligent adversaries: Pick their targets
- Buffer overflows bugs: Big class of bugs
  - Normal conditions: Can sometimes cause systems to fail
  - Adversarial conditions: Attacker able to violate security of your system (control, obtain private information, ...)

A Bit of History: Morris Worm

- Worm was released in 1988 by Robert Morris
  - Graduate student at Cornell, son of NSA chief scientist
  - Convicted under Computer Fraud and Abuse Act, sentenced to 3 years of probation and 400 hours of community service
  - Now an EECS professor at MIT
- Worm was intended to propagate slowly and harmlessly measure the size of the Internet
- Due to a coding error, it created new copies as fast as it could and overloaded infected machines
- $10-100M worth of damage

Morris Worm and Buffer Overflow

- One of the worm's propagation techniques was a buffer overflow attack against a vulnerable version of fingerd on VAX systems
  - By sending special string to finger daemon, worm caused it to execute code creating a new worm copy
  - Unable to determine remote OS version, worm also attacked fingerd on Suns running BSD, causing them to crash (instead of spawning a new copy)

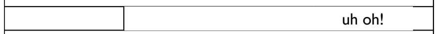
Buffer Overflow These Days

- Very common cause of Internet attacks
  - In 1998, over 50% of advisories published by CERT (computer security incident report team) were caused by buffer overflows
- Morris worm (1988): overflow in fingerd
  - 6,000 machines infected
- CodeRed (2001): overflow in MS-IIS server
  - 300,000 machines infected in 14 hours
- SQL Slammer (2003): overflow in MS-SQL server
  - 75,000 machines infected in **10 minutes** (!!)

Attacks on Memory Buffers

- Buffer is a data storage area inside computer memory (stack or heap)
  - Intended to hold pre-defined amount of data
    - If more data is stuffed into it, it spills into adjacent memory
  - If executable code is supplied as "data", victim's machine may be fooled into executing it – we'll see how
    - Code will self-propagate or give attacker control over machine
- First generation exploits: stack smashing
- Second gen: heaps, function pointers, off-by-one
- Third generation: format strings and heap management structures

Stack Buffers

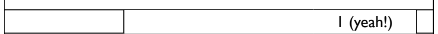


- Suppose Web server contains this function

```
void func(char *str) {
      char buf[126];
      ...
      strcpy(buf,str);
      ...
}
```

- No bounds checking on strcpy()
- If str is longer than 126 bytes
  - Program may crash
  - Attacker may change program behavior

Changing Flags



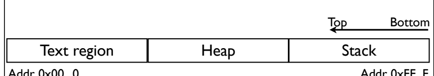
- Suppose Web server contains this function

```
void func(char *str) {
      int authenticated = 0;
      char buf[126];
      ...
      strcpy(buf,str);
      ...
}
```

- Authenticated variable non-zero when user has extra privileges
- Morris worm also overflowed a buffer to overwrite an authenticated flag in in.fingerd

Memory Layout

- Text region: Executable code of the program
- Heap: Dynamically allocated data
- Stack: Local variables, function return addresses; grows and shrinks as functions are called and return



Stack Buffers

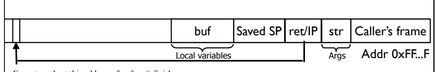
- Suppose Web server contains this function

```
void func(char *str) {
      char buf[126];
      strcpy(buf,str);
}
```

Allocate local buffer (126 bytes reserved on stack)

Copy argument into local buffer

- When this function is invoked, a new frame with local variables is pushed onto the stack



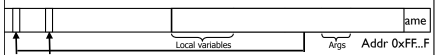
What If Buffer is Overstuffed?

- Memory pointed to by str is copied onto stack…

```
void func(char *str) {
      char buf[126];
      strcpy(buf,str);
}
```

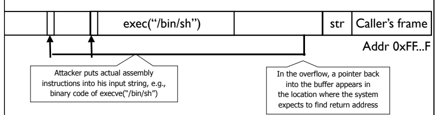
strcpy does NOT check whether the string at *str contains fewer than 126 characters

- If a string longer than 126 bytes is copied into buffer, it will overwrite adjacent stack locations



Executing Attack Code

- Suppose buffer contains attacker-created string
  - For example, *str contains a string received from the network as input to some network service daemon



- When function exits, code in the buffer will be executed, giving attacker a shell
  - Root shell if the victim program is setuid root

Buffer Overflow Issues

- Executable attack code is stored on stack, inside the buffer containing attacker's string
  - Stack memory is supposed to contain only data, but…
- Overflow portion of the buffer must contain correct address of attack code in the RET position
  - The value in the RET position must point to the beginning of attack assembly code in the buffer
    - Otherwise application will crash with segmentation violation
  - Attacker must correctly guess in which stack position his buffer will be when the function is called

Problem: No Range Checking

- strcpy does <u>not</u> check input size
  - strcpy(buf, str) simply copies memory contents into buf starting from *str until "\0" is encountered, ignoring the size of area allocated to buf
- Many C library functions are unsafe
  - strcpy(char *dest, const char *src)
  - strcat(char *dest, const char *src)
  - gets(char *s)
  - scanf(const char *format, …)
  - printf(const char *format, …)

Does Range Checking Help?

- strncpy(char *dest, const char *src, size_t n)
  - If strncpy is used instead of strcpy, no more than n characters will be copied from *src to *dest
    - Programmer has to supply the right value of n
- Potential overflow in htpasswd.c (Apache 1.3):

```
strcpy(record,user);
strcat(record,":");
strcat(record,cpw); …
```

Copies username ("user") into buffer ("record"), then appends ":" and hashed password ("cpw")

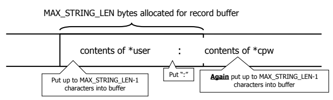
- Published "fix":

```
… strncpy(record,user,MAX_STRING_LEN-1);
  strcat(record,":");
  strncat(record,cpw,MAX_STRING_LEN-1); …
```

Misuse of strncpy in htpasswd "Fix"

- Published "fix" for Apache htpasswd overflow:

```
… strncpy(record,user,MAX_STRING_LEN-1);
  strcat(record,":");
  strncat(record,cpw,MAX_STRING_LEN-1); …
```



Off-By-One Overflow

- Home-brewed range-checking string copy

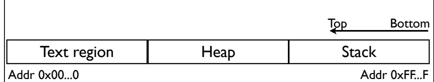
```
void notSoSafeCopy(char *input) {
     char buffer[512]; int i;
     for (i=0; i<=512; i++)
         buffer[i] = input[i];
}
void main(int argc, char *argv[]) {
     if (argc==2)
        notSoSafeCopy(argv[1]);
}
```

This will copy **513** characters into buffer. Oops!

- 1-byte overflow: can't change RET, but can change pointer to <u>previous</u> stack frame
  - On little-endian architecture, make it point into buffer
  - RET for previous function will be read from buffer!

Memory Layout

- Text region: Executable code of the program
- Heap: Dynamically allocated data
- Stack: Local variables, function return addresses; grows and shrinks as functions are called and return

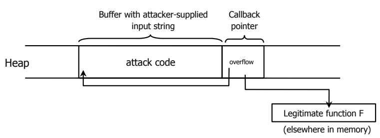


Heap Overflow

- Overflowing buffers on heap can change pointers that point to important data
  - Sometimes can also transfer execution to attack code
  - Can cause program to crash by forcing it to read from an invalid address (segmentation violation)
- Illegitimate privilege elevation: if program with overflow has sysadm/root rights, attacker can use it to write into a normally inaccessible file
  - For example, replace a filename pointer with a pointer into buffer location containing name of a system file
    - Instead of temporary file, write into AUTOEXEC.BAT

Function Pointer Overflow

- C uses function pointers for callbacks: if pointer to F is stored in memory location P, then another function G can call F as (*P)(…)



Format Strings in C

- Proper use of printf format string:

```
… int foo=1234;

  printf("foo = %d in decimal, %X in hex",foo,foo); …
```

  - This will print

```
foo = 1234 in decimal, 4D2 in hex
```

- Sloppy use of printf format string:

```
… char buf[14]="Hello, world!";

  printf(buf);
   // should've used printf("%s", buf); …
```

  - If buffer contains format symbols starting with %, location pointed to by printf's internal stack pointer will be interpreted as an argument of printf. This can be exploited to <u>move printf's internal stack pointer</u>.

Viewing Memory

- %x format symbol tells printf to output data on stack

```
… printf("Here is an int:  %x",i); …
```

- What if printf does <u>not</u> have an argument?

```
… char buf[16]="Here is an int:  %x";

  printf(buf); …
```

  - Stack location pointed to by printf's internal stack pointer will be interpreted as an int. (What if crypto key, password, ...?)
- Or what about:

```
… char buf[16]="Here is a string:  %s";

  printf(buf); …
```

  - Stack location pointed to by printf's internal stack pointer will be interpreted as a pointer to a string

Writing Stack with Format Strings

- %n format symbol tells printf to write the number of characters that have been printed

```
… printf("Overflow this!%n",&myVar); …
```

  - Argument of printf is interpeted as destination address
  - This writes 14 into myVar ("Overflow this!" has 14 characters)
- What if printf does <u>not</u> have an argument?

```
… char buf[16]="Overflow this!%n";
  printf(buf); …
```

  - Stack location pointed to by printf's internal stack pointer will be interpreted as address into which the number of characters will be written.

More Buffer Overflow Targets

- Heap management structures used by malloc()
- URL validation and canonicalization
  - If Web server stores URL in a buffer with overflow, then attacker can gain control by supplying malformed URL
    - Nimda worm propagated itself by utilizing buffer overflow in Microsoft's Internet Information Server
- Some attacks don't even need overflow
  - Naïve security checks may miss URLs that give attacker access to forbidden files
    - For example, http://victim.com/user/../../autoexec.bat may pass naïve check, but give access to system file
    - Defeat checking for "/" in URL by using hex representation: %5c or %255c.