Software Security: 
Buffer Overflow Attacks

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Announcements

• Things Due:
  – **Ethics form**: Due Monday
  – **Homework #1**: Due Thursday

• Office Hours:
  – Now scheduled, see course website
  – Via Zoom – find links on Canvas
  – Mine are Wednesdays (bet for overall class questions, homeworks; TA office hours for labs, homeworks, other overall questions)
Last time...

• Threat models
  – Assets
  – Adversaries
  – Vulnerabilities
  – Threats
  – Risks

• Defenses
  – Adversary’s asymmetric advantage
SOFTWARE SECURITY
Bugs, Vulnerabilities, and Exploits

• Bug
  – Not working quite right

• Vulnerability
  – A malfunction that can be used for an adversary’s goals

• Exploit
  – The mechanical set of operations to make use of a vulnerability
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
Many types of vulnerability
Memory Corruption Bugs

• **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, ...)

• Stack, Heap both possibilities
BUFFER OVERFLOWS
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,
    • 3 years probation and 400 hours of community service

• 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

Buffer overflows remain a common source of vulnerabilities and exploits today!
(Especially in embedded systems.)
Aside: Famous Internet Worms

- Morris worm (1988): overflow in fingerd
  - 6,000 machines infected
  - 300,000 machines infected in 14 hours
- SQL Slammer (2003): overflow in MS-SQL server
  - 75,000 machines infected in 10 minutes (!!!)
- Sasser (2005): overflow in Windows LSASS
  - Around 500,000 machines infected
... And More

• Conficker (2008-09): overflow in Windows RPC
  – Around 10 million machines infected (estimates vary)

• Stuxnet (2009-10): several zero-day overflows + same Windows RPC overflow as Conficker
  – Windows print spooler service
  – Windows LNK shortcut display
  – Windows task scheduler

• Flame (2010-12): same print spooler and LNK overflows as Stuxnet
  – Targeted cyberespionage virus

• These days, worms are uncommon
... And More

• Embedded systems
  – E.g., our automotive work

• Formative and foundational for software security
Attacks on Memory Buffers

• **Buffer** is a pre-defined data storage area inside computer memory (stack or heap)

• Typical situation:
  – A function takes some input that it writes into a **pre-allocated buffer**.
  – The developer **forgets to check** that the size of the input isn’t larger than the size of the buffer.
  – Uh oh.
    • “Normal” bad input: crash
    • “Adversarial” bad input: take control of execution
Stack Buffers

• Suppose Web server contains this function

```c
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
Example: Changing Flags

• Suppose Web server contains this function

```c
void func(char *str) {
    byte auth = 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 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
Suppose Web server contains this function:

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

When this function is invoked, a new frame (activation record) is pushed onto the stack.
What if Buffer is Overstuffed?

- Memory pointed to by `str` is copied onto stack...

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

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

This will be interpreted as return address!

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

• Suppose buffer contains attacker-created string
  – For example, str points to a string received from the network as the URL

• When function exits, code in the buffer will be executed, giving attacker a shell ("shellcode")
  – Root shell if the victim program is setuid root
Buffer Overflows Can Be Tricky...

- 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 (probably) crash with segfault
  - **Attacker must correctly guess in which stack position his/her buffer will be when the function is called**
Problem: No Bounds Checking

• **strcpy** does **not** 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 Bounds 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):

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

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

• Published fix:

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

Canvas -> Quizzes -> April 2
Misuse of strncpy in htpasswd “Fix”

• Published “fix” for Apache htpasswd overflow:

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

MAX_STRING_LEN bytes allocated for record buffer

- Put up to MAX_STRING_LEN-1 characters into buffer
- Again put up to MAX_STRING_LEN-1 characters into buffer
What About This?

• Home-brewed range-checking string copy

```c
void mycopy(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)
        mycopy(argv[1]);
}
```
Breakout Activity

Canvas -> Quizzes -> April 2
Off-By-One Overflow

- Home-brewed range-checking string copy

```c
void mycopy(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)
        mycopy(argv[1]);
}
```

- 1-byte overflow: can’t change RET, but can change pointer to previous stack frame...

This will copy **513** characters into buffer. Oops!
Frame Pointer Overflow