Software Security: Buffer Overflow Defenses

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Admin

• Homework 1: Due Tomorrow 11:45pm
• Lab 1:
  • Online: https://courses.cs.washington.edu/courses/cse484/21sp/assignments/lab1.pdf
  • Try to form groups and do “Environment and Sign-Up” before quiz section
Summary of Printf Risks

• Printf takes a variable number of arguments
  • E.g., printf(“Here’s an int: %d”, 10);

• Assumptions about input can lead to trouble
  • E.g., printf(buf) when buf=“Hello world” versus when buf=“Hello world %d”
  • Can be used to advance printf’s internal stack pointer
  • Can read memory
    • E.g., printf(“%x”) will print in hex format whatever printf’s internal stack pointer is pointing to at the time
  • Can write memory
    • E.g., printf(“Hello%n”); will write “5” to the memory location specified by whatever printf’s internal SP is pointing to at the time
How Can We Attack This?

```c
foo() {
    char buf[...];
    strncpy(buf, readUntrustedInput(), sizeof(buf));
    printf(buf); //vulnerable
}
```

What should the string returned by `readUntrustedInput()` contain??

Go to Canvas Quiz for today!

Different compilers / compiler options / architectures might vary.
Using %n to Overwrite Return Address

In foo()'s stack frame:

Buffer with attacker-supplied input “string”

• "... attackString%n", attack code
• &RET
• SFP
• RET

Number of characters “in” attackString must be equal to ... what?

When %n happens, make sure the location under printf’s stack pointer contains address of RET; %n will write the number of characters in printed so far into RET

Return execution to this address

Why is “in” in quotes? C allows you to concisely specify the “width” to print, causing printf to pad by printing additional blank characters without reading anything else off the stack.

Example: printf("%5d%n", 10) will print three spaces followed by the integer: “ 10”

That is, the %n will write 5, not 2.

Key idea: do this 4 times with the right numbers to overwrite the return address byte-by-byte.

(4x %n to write into &RET, &RET+1, &RET+2, &RET+3)
The exploitation twilight zone

• During an exploitation attempt sometimes you have to ‘let it run’
  • Overflow a buffer
  • Change things
  • Let program run for ‘a bit’
  • Everything triggers!

• Printf exploit a perfect example
Recommended Reading

• It will be hard to do Lab 1 without:
  • **Reading (see course schedule):**
    • Smashing the Stack for Fun and Profit
    • Exploiting Format String Vulnerabilities
  • **Attending section**
Buffer Overflow: Causes and Cures

• Classical memory exploit involves code injection
  • Put malicious code at a predictable location in memory, usually masquerading as data
  • Trick vulnerable program into passing control to it

• Possible defenses:
  1. Prevent execution of untrusted code
  2. Stack “canaries”
  3. Encrypt pointers
  4. Address space layout randomization
  5. Code analysis
  6. ...
Defense: Executable Space Protection

• Mark all writeable memory locations as non-executable
  • Example: Microsoft’s Data Execution Prevention (DEP)
  • This blocks many code injection exploits

• Hardware support
  • AMD “NX” bit (no-execute), Intel “XD” bit (executed disable) (in post-2004 CPUs)
  • Makes memory page non-executable

• Widely deployed
  • Windows XP SP2+ (2004), Linux since 2004 (check distribution), OS X 10.5+ (10.4 for stack but not heap), Android 2.3+
What Does “Executable Space Protection” Not Prevent?

• Can still corrupt stack ...
  • ... or function pointers
  • ... or critical data on the heap

• As long as RET points into existing code, executable space protection will not block control transfer!
  ➔ return-to-libc exploits
return-to-libc

• Overwrite saved ret (IP) with address of any library routine
  • Arrange stack to look like arguments

• Does not look like a huge threat
  • ...

• Canvas in-class activity, April 6!
return-to-libc

• Overwrite saved ret (IP) with address of any library routine
  • Arrange stack to look like arguments

• Does not look like a huge threat
  • ...
  • We can call any function we want!
  • Say, exec 😊

4/8/2021
return-to-libc++

- Insight: Overwritten saved EIP need not point to the *beginning* of a library routine
- **Any** existing instruction in the code image is fine
  - Will execute the sequence starting from this instruction
- What if instruction sequence contains RET?
  - Execution will be transferred... to where?
  - Read the word pointed to by stack pointer (SP)
    - Guess what? Its value is under attacker’s control!
  - Use it as the new value for IP
    - Now control is transferred to an address of attacker’s choice!
  - Increment SP to point to the next word on the stack
Chaining RETs

• Can chain together sequences ending in RET
  • Krahmer, “x86-64 buffer overflow exploits and the borrowed code chunks exploitation technique” (2005)

• What is this good for?

• Answer [Shacham et al.]: everything
  • Turing-complete language
  • Build “gadgets” for load-store, arithmetic, logic, control flow, system calls
  • Attack can perform arbitrary computation using no injected code at all – return-oriented programming
Return-Oriented Programming
Defense: Run-Time Checking: StackGuard

• Embed “canaries” (stack cookies) in stack frames and verify their integrity prior to function return
  – Any overflow of local variables will damage the canary
Defense: Run-Time Checking: StackGuard

- Embed “canaries” (stack cookies) in stack frames and verify their integrity prior to function return
  - Any overflow of local variables will damage the canary

- Choose random canary string on program start
  - Attacker can’t guess what the value of canary will be

- Canary contains: “\0”, newline, linefeed, EOF
  - String functions like strcpy won’t copy beyond “\0”
StackGuard Implementation

- StackGuard requires code recompilation
- Checking canary integrity prior to every function return causes a performance penalty
  - For example, 8% for Apache Web server at one point in time
- Canvas Quiz
Defeating StackGuard

• StackGuard can be defeated
  – A single memory write where the attacker controls both the value and the destination is sufficient

• Suppose program contains \texttt{copy(buf,attacker-input)} and \texttt{copy(dst,buf)}
  – Example: dst is a local pointer variable
  – Attacker controls both buf and dst

\begin{itemize}
  \item \texttt{buf}
  \item \&\texttt{dst}
  \item canary
  \item \texttt{sfp}
  \item \texttt{RET}
\end{itemize}

\begin{itemize}
  \item BadPointer, \texttt{attack code}
  \item \&\texttt{RET}
  \item canary
  \item \texttt{sfp}
  \item \texttt{RET}
\end{itemize}

\begin{itemize}
  \item Overwrite destination of strcpy with RET position
  \item \texttt{strcpy} will copy BadPointer here
  \item Return execution to this address
\end{itemize}
Admin (Reminders)

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