ΥΣ13 - Computer Security

Buffer Overflows

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Context

- General problem : unsanitized user input
- Low level language (eg C): overflow a local array (buffer)
- Write over the stack!
- Overwrite the return address
- Execute adversary-controlled code
  - from the target program, a library, etc
  - or stored in the buffer

Context

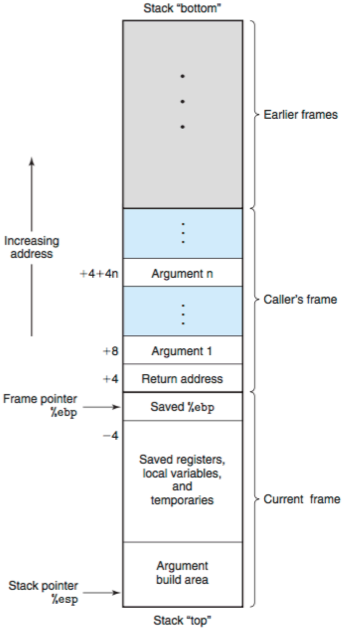
- It's much easier to understand buffer overflows by reproducing one
- Try to reproduce the one we live-coded in the lecture
  - Use the given code & Makefile
- The slides will guide you through the process
- Read also while progressing:
  - Aleph One, Smashing The Stack For Fun And Profit

Outline

- Understand the stack
- Disassemble a test program
- Produce an overflow, watch the return address being overwritten
- Write a shellcode in C
- Write a shellcode in assembly, obtain machine code
- Test the binary, overflow our own buffer
- 1st attack: guess the buffer's address in the target
- 2nd attack: add NOPs for faster guessing

The stack

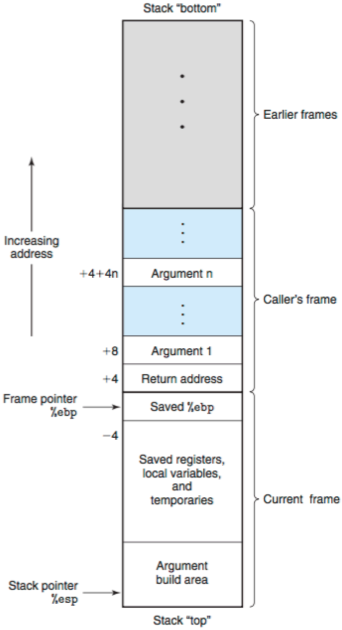
- Grows with every function call (towards lowe
- Caller
  - stores function arguments in reverse order
  - makes call, which stores EIP (return addr.)
- Callee
  - saves old EBP, sets EBP = ESP
  - lowers ESP to make room for local vars (also saves some registers, if needed)
  - Args: EBP+*n*
  - Local vars: EBP-*n*
  - Restore ESP/EBP on exit



The stack

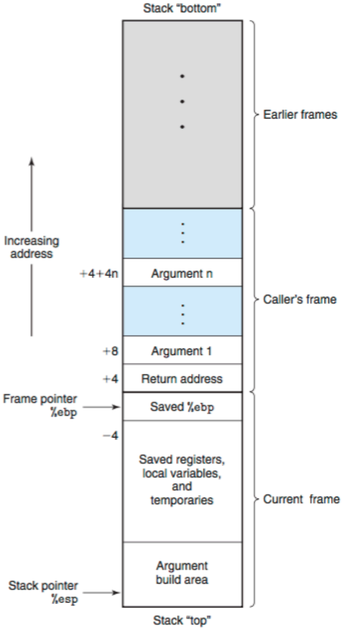
Task

- Compile a simple program (test.c)
  - Makefile (options for simpler assembly)
- Disassemble with gdb
  - GDB tutorial
- Read the assembly of `main,foo` (it's simple!)
  - Understand the stack management procedure in the assembly code
- Modify test.c, observe changes in the code



Buffer overflow

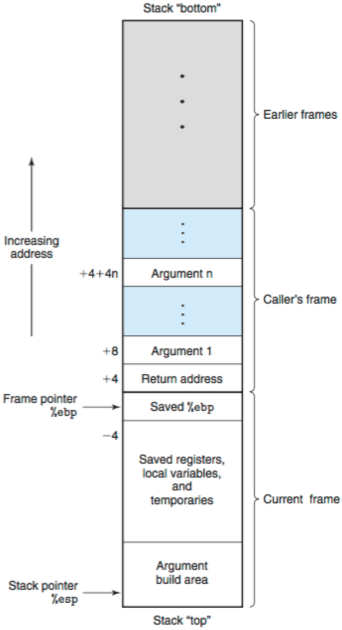
- Input written to a local buffer in the stack
- Large input: continu writing outside the fram
- Overwrite the saved EBP and the return addr
- No segfault: this is our own memory
- Return: follow the overwritten address
  - this will likely segfault!



Buffer overflow

Task : observe a bufffer overflow

- Read and compile target.c
  - use `-fno-stack-protector -zexecstack` see the Makefile!
- Provide large input, observe crash
- Execute step-by-step with gdb
  - Observe the return address (EBP+4) before and after the overflow
  - Observe the crash when the function returns (not during the overflow)



Shellcode

- **Goal**: execute a bash shell
  (provides easy access to all resources)
- Such a malicious code is called shellcode
- **Task**: write a shellcode in C
  - (We'll write in assembly later)
  - Use `execve`
  - Optionally follow by `exit(0)` to always exit cleanly
  - Example: shellcode.c

Shellcode

Task: disassemble the shellcode

- Use gdb to disassemble `execve, _exit`
  - understand the system cals

TODO list for the assembly code:

1. Data needed in memory
   - string ”/bin/sh”
   - The address of array with { ”/bin/sh”, NULL }

Shellcode

Task: disassemble the shellcode

2 To call execve

- EAX <- 0xb (code of execve syscall)
- EBX <- the address of ”/bin/sh”
- ECX <- the address of the array
- EDX <- NULL
- Execute call `*%gs:0x10` (or `int $0x80`)

3 To exit

- EAX <- 0xfc (or 0x1)
- EBX <- 0x0 (exit code)
- Execute call `*%gs:0x10` (or `int $0x80`)

Shellcode

Problem

- We need ”/bin/sh” in memory
- We can put it in the buffer
- But we don’t know its address!

Solution

- `call` pushes EIP in the stack
- So we can jump right before ”/bin/sh” (relative jump!)
- `call` back
- and **pop** the address we need

Shellcode

Solution : assembly

```
jmp label_binsh        // jmp to the call instruction at the end
label_back:
popl   %esi            // the address of /bin/sh is now in %esi!

...main shellcode...

label_binsh:
call label_back        // jump back after pushing EIP
.string ”/bin/sh”      // write ”/bin/bash” in the executable
```

Shellcode

Task: write the assembly shellcode

- Straightforward implementation of the TODO list
  - Using also the jump trick
- Try it yourself, or look at shellcodeasm.c
- **Beware**
  - The machine code should not contain 0s
  - Cause most functions that overflow buffers (strctp, etc) stop at 0s!
  - So: change `movl $0x0 %eax` to `xorl %eax, %eax`, etc

Shellcode

Task: get the machine code

- Disassemble shellcodeasm's `main` with gdb
- Find the address of the shellcode
  - the first `jmp` command
- Fint the length of the shellcode
  - until the end of the /bin/bash string (without the \0)
- Get the machine code with gdb:
  `x/<length>xb <address>`

Shellcode

Task: test the shellcode

- Use shellcodetest.c
- Add the shellcode in binary form
- Direct test
  - directly set a function's return address to the buffer
- Overflow test
  - set the function's return adderss by overflowing our own buffer
  - buffer content

```
<buffer-address>
...
<buffer-address>
<shellcode>
```

Attack 1

- We are almost ready!
  - We have already overflown our own buffer
- **BUT**
  - We had to put `<buffer-address>` in the buffer
  - We don't know the buffer's address in the target
- **Solution**
  - Guess it!
  - Start from ESP in a test program, add an offset
  - Try different offsets until we get lucky

Attack 1

Task : try this attack

- See exploit1.c
- Try different offsets until you get lucky
- Or write a script that does it
- Or cheat by having target.c print it’s buffer address
- Make sure to disable ASLR (see Makefile)

Attack 2

Can we do better?

- Goal: tolerate incorrect guesses of `buffer-address`
- Solution
  - Write NOPs before the shellcode
  - If execution starts there, it will reach the shellcode

```
<buffer-address>
...
<buffer-address>
<shellcode>
NOP
...
NOP
```

Attack 2

Task : try this attack

- See exploit2.c
- Try again different offsets
  - Success should be easier

Counter-measures

Canaries

- Write some value (canary) after the return value
  - CR,LF,0,-1
  - Random
- Buffer overflow still happens
  - but it overwrittes the canary -> detection!
- gcc does this by default
  - Try the attack without `-fno-stack-protector`
- Attacks that don't overwrite the return address stil possible

Counter-measures

Non-executable stack

- Don't allow execution of stack code
- Needs hardware/OS support
- Linux on modern processors does this by default
  - Try the attack without `-zexecstack`
- Return to pre-existing code in the program or a library (eg libc) still possible

Counter-measures

Non-executable stack

- Don’t allow execution of stack code
- Needs hardware/OS support
- Linux on modern processors does this by default
  - Try the attack without `-zexecstack`
- Return to pre-existing code in the program or a library (eg libc) still possible
  - Just use the `system` function

Counter-measures

Bypassing a non-executable stack

- Return to pre-existing code in the program or a library
  - eg. return to the `system` function (return-to-libc)
  - The arguments can be prepared in the stack
- x64 : calling conventions are different
  - The first 6 args are passed in registers (RDI, RSI, RDX, RCX, ...)
  - So we cannot prepare arguments for `system`
  - Solution
    - Find any `pop rdi; ret` instructions in the code (gadget)
    - Put our argument in the stack
    - Return to the gadget to load RDI
    - Many gadgets can be chained (Return Oriented Programming)

Counter-measures

Address space layout randomization (ASLR)

- Randomize the stack's address
- Makes it harder to guess `<buffer-address>`
- Linux does this by default
  - Try the attack with `echo 1 > /proc/sys/kernel/randomize_va_space`
- Needs a sufficiently large range (16-bits not enough)

References

- Aleph One, Smashing The Stack For Fun And Profit
- GDB tutorial : debug/disassemble C programs using gdb
- Dieter Gollmann, Computer Security, Section 10.4
- c0ntex, Bypassing non-executable-stack during exploitation using return-to-libc
- Shacham et al, On the Effectiveness of Address-Space Randomization
- 64-bit Linux Return-Oriented Programming