Buffer Overflow

ICS312
Machine-Level and Systems Programming

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Buffer Overflow

- You likely have heard of the “buffer overflow” method for exploiting a vulnerability of a program
  - e.g., to cause a Web server to do something potentially harmful, such as running code it wasn’t supposed to run
- The way in which this technique works is based on damaging the runtime stack
- Now that we know what the stack looks like, let’s see if we can understand how buffer overflow works
- We use the standard, most simple, example
The Basic Idea

- The goal is to have a program run code it wouldn’t run in a normal/valid/allowed execution
- This is done by overwriting a return address on the stack
- When RET is executed, it pops off a 4-byte value from the stack, interprets it as an address in the text segment, and jumps to it
- If, somehow, these 4 bytes were modified illegally, then the program jumps to any address and starts running code
  - Some function in the program
  - Some library function or system call
  - Some arbitrary code (if one is a bit clever)
- This can be easily done if
  - The original program does unsafe memory operations
  - The attacker has knowledge of the program and of the architecture
  - The attacker is reasonably clever
Corrupting the Stack

Consider the following C program sketch, which takes one command-line argument:

```c
void f(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    f(argv[1]);
}
```

`strcpy` simply goes through the bytes in `str` and copies each byte into `buffer`, until it hits a `\0` character.
The Stack

- The Stack before the call to strcpy()

```c
void f(char *str) {
    char buffer[16];
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}

void main(int argc, char **argv) {
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```
The Stack

The Stack before the call to strcpy()

```
void f(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    f(argv[1]);
}
```
The Stack

- The Stack in the call to strcpy()

```c
void exploitable(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    exploitable(argv[1]);
}
```
Writing into the buffer

- Say that argv[1]="SomeString!\0"
- strcpy() writes it on the stack, in buffer[]

```c
void exploitable(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    exploitable(argv[1]);
}
```
Bad code

- The problem is that the code is buggy
- C being C, you write past the end of the array
- Say the code is part of a Web server, which is compiled and running on some host
- Say that the string passed to f comes from some Web request via the network
- If a string that is too long is passed, then the stack will be corrupted..
Writing into the buffer

- Say that \texttt{argv[1]="SomeOtherStringMuchLonger!!\0"}
- \texttt{strcpy()} writes it on the stack, in buffer[]

- When \texttt{strcpy} returns, it restores ebp for \texttt{f} and returns to \texttt{f}
- \texttt{f} then pops the two parameters for \texttt{strcpy}
- When \texttt{f} returns it
  - removes space for buffer
  - restores the saved EBP to “uchL” (bogus)
- \textbf{jumps to address “onge”}!
So What?

- If an attacker knows the address of some subprogram, he/she can create a string so that bytes 20-23 ("onge" in our example) form the bytes of this address!

- This requires that the attacker know the address of some subprogram to call
  - Can be discovered by “looking” at the program in debug mode (see later in the semester)
  - Only doable for known/standard programs
    - e.g., knowing that a Web server runs Apache, knowing which version it is, knowing the address of some function in that version, then one can perhaps exploit a buffer overflow

- More involved exploit: the overflowing string contains code, and the “fake” return address points to this code
  - One can then run arbitrary code that “looks like a string”
What can we do about it?

- A simple idea: make sure the subprogram doesn’t overwrite activation records willy nilly
  - The activation record should be the subprogram’s “play pen”
- But this would be tricky and costly
  - Some writes to the stack outside the activation record should be allowed (i.e., g passes to f a pointer to one of its local variables)
  - Would have to do an “is this ok?” check for every memory store operation
- Another idea, is to use a stack canary
  - Have the compiler insert hidden local variables with secret values known to the compiler
  - Before doing the ret instruction, check that the canary hasn’t changed!
Stack Canary

- Stack without canary

```c
void f(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    f(argv[1]);
}
```
Stack Canary

- Stack with canary

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void f(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    f(argv[1]);
}
```
**Stack Canary**

- Buffer overflow modifies the canary!

```c
void f(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    f(argv[1]);
}
```
Stack Canary

- The ret instruction BEFORE doing a pop checks the canary

```c
void f(char *str) {
    char buffer[16];
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}

void main(int argc, char **argv) {
    f(argv[1]);
}
```
Stack Canary

The canary has changed, and we branch to code that terminates the program

```c
void f(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main(int argc, char **argv) {
    f(argv[1]);
}
```
In practice

- Most compilers allow you to generate code that does runtime checks
- Check your compiler’s documentation

In gcc, flag `-fstack-protector-all` will make a canary for all functions
  - Safe, but a bit slow.
Conclusion

- Understanding what the stack looks like is necessary to understand how the system can be attacked
- This was the simplest example, and there is more to this
- A course like ICS426 provides more in-depth coverage of such topics