CSci 4271W
Development of Secure Software Systems
Day 2: Memory Safety Introduction

Stephen McCamant
University of Minnesota, Computer Science & Engineering

Outline

- Memory safety and security
- Stack buffer overflow
- Announcements intermission
- Reversing the stack
- Other safety problems

A large class of problems

- First up, a common class of vulnerabilities in C/C++ programs
- Exist because these languages do not enforce safe use of memory
- An attacker who controls program input can make the program do what they want
- Language shifts burden to code, code is incorrect

Ingredient 1: memory unsafety

- Some logical limitations on memory usage are generally not automatically checked in C/C++.
  - Motivated by speed, simplicity, history
- Accessing arrays does not check against the size
- Program must `free` memory when no longer needed, then not use
  - I.e., no garbage collection

Ingredient 2: missing input checks

- Constraints on the *untrusted* input needed for safety are not checked
- Many normal uses of the program will still work fine
  - E.g., input size not too large
- Attacks occur on inputs that are rare or only an attacker would think of
  - Usually would have been OK to reject these

Recipe for safe code

- Safe code needs to ensure that for any value of the untrusted input, nothing unsafe will happen
- From pure security perspective, stopping with an error message is generally safe
- Like other kinds of bugs, easier said than done

Safe interfaces or better checks

- General strategy: use features and libraries with an inherently safer design
  - E.g., C++ `string` class with automatic memory management
- General strategy: add more checks for unsafe or just unexpected conditions
  - Allow fewer inputs → fewer attack opportunities

Auditing and testing

- Reading code looking for security problems is called a *code audit*
  - Often more effective if the reader has fresh eyes
- Many security bugs can be found via testing
  - Especially randomized automatic testing called *fuzzing*

After something goes wrong

- At language level, no guarantees about behavior of memory-unsafe code
  - C *undefined behavior* means literally anything can happen
- On real implementations, most unsafe effects understandable from low-level perspective
  - This is where what you learned in 2021 is relevant
- How an attack succeeds in doing something interesting is more complex

Mitigation: an arms race

- Modern systems also make many changes to the compiler and runtime to try to make attacker's life harder
  - ASLR, DEP, stack canaries, ... more details later
- But for performance and compatibility, usually not complete protections
- Attackers also have fancier techniques to avoid them

Outline

Memory safety and security

Stack buffer overflow

Announcements intermission

Reversing the stack

Other safety problems

Source-level view (1)

```
void func(void) {
    char buffer[50];
    write_200_bytes_into(buffer);
}
```

Source-level view (2)

```
void func(char *attacker_controlled) {
    char buffer[50];
    strcpy(buffer, attacker_controlled);
}
```

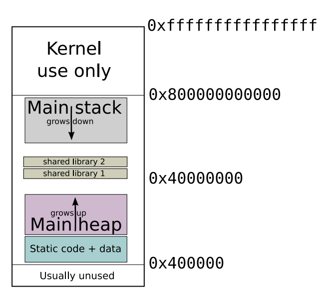
Demo break 1

- Simple palindrome checker:
  - Short input → correct behavior
  - Normal too-long input → crash
  - Malicious too-long input → exploit

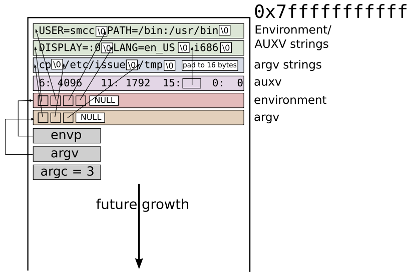
Recall: the stack

- In compiled C code, local variables and other metadata like return addresses are stored in a memory region called *the stack*
- Structured as a stack with one *frame* of data per executing function
- Starts at a numerically large address and grows to smaller addresses

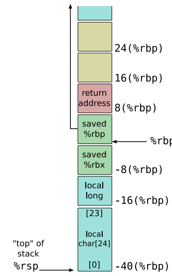
Overall layout (Linux 64-bit)



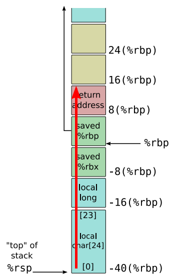
Detail: initial stack



Stack frame layout



Stack frame overflow



Demo break 2

- How did the attacker know how to overwrite the return address?

Outline

Memory safety and security

Stack buffer overflow

Announcements intermission

Reversing the stack

Other safety problems

First lab on Monday

- First lab section will be on Monday morning/noon
- Covering memory safety vulnerabilities and GDB

Outline

Memory safety and security

Stack buffer overflow

Announcements intermission

Reversing the stack

Other safety problems

A possible solution

- Part of what makes this classic attack easy is that the array grows in the direction toward the function's return address
- If we made the stack grow towards higher addresses instead, this wouldn't work in the same way
- Classic puzzler: why isn't this a solution to the problem?

A concrete example

```
void func(char *attacker_controlled) {
    char buffer[50];
    strcpy(buffer, attacker_controlled);
}
```

What might happen in this example, for instance?

Outline

Non-contiguous overflow

- An overflow doesn't have to write to the buffer in sequence
- For instance, the code might compute a single index, and store to it

Heap buffer overflow

- Overwriting a `malloc`ed buffer isn't close to a return address
- But other targets are available:
  - Metadata used to manage the heap, contents of other objects

Use after free

- A common bug is to `free` an object via one pointer and keep using it via another
- Leads to unsafe behavior after the memory is reused for another object

Integer overflow

- Integer types have limited size, and will wrap around if a computation is too large
- Not unsafe itself, but often triggers later bugs
  - E.g., not allocating enough space

Function pointers, etc.

- Other data used for control flow could be targeted for overwriting by an attacker
- Common C case: function pointers
- More obscure C case: `setjmp`/`longjmp` buffers

Virtual dispatch

- When C++ objects have virtual methods, which implementation is called depends on the runtime type
- Under the hood, this is implemented with a table of function pointers called a *vtable*
- An appealing target in attacking C++ code

Non-control data overwrite

- An attacker can also trigger undesired-to-you behavior by modifying other data
- For instance, flags that control other security checks

Format string injection

- The first argument of `printf` is a little language controlling output formatting
- Best practice is for the format string to be a constant
- An attacker who controls a format string can trigger other mischief