CSci 4271W
Development of Secure Software Systems
Day 3: More Memory Safety

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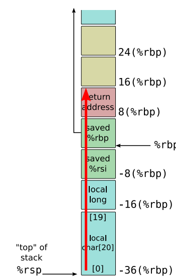
Outline

Source-level view (2)

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

Stack frame overflow



Demo break

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

Outline

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

- Stack buffer overflow, cont'd
- Reversing the stack
- Reversing the stack, discussion
- Other safety problems
- Integer overflow example
- Code auditing

A solution that doesn't help

- 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];
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```
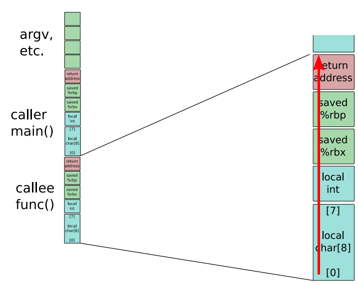

What might happen in this example, for instance?

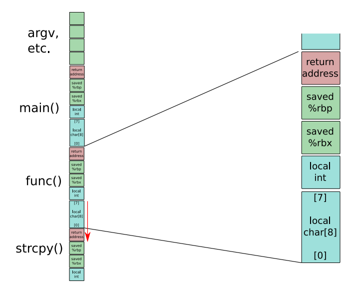
Stack direction orientation

- Higher addresses are "deeper" in the stack, and represent older stack frames (callers) and data (pushed first)
- Lower addresses are closer to the "top" of the stack, representing more-recently pushed frames (callees) and data

Stack frame normal overflow



Reversed overflow



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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

Outline

Stack buffer overflow, cont'd

Reversing the stack

Reversing the stack, discussion

Other safety problems

Integer overflow example

Code auditing

Integer overflow to buffer overflow

- One common pattern: overflow causes an allocation to be too small
- In machine integers, multiplication doesn't always make a value larger

Overflow example

```
struct obj { short ident, x, y, z; long b; double c;};
struct obj *read_objs(int num_objs) {
    unsigned int size = num_objs*(unsigned)sizeof(obj);
    struct obj *objs = malloc(size);
    struct obj *p = objs;
    for (i = 0; i < num_objs; i++) {
        fread(p, sizeof(struct obj), 1, stdin);
        if (p->ident == 0x4442) return 0;
        /* ... */ p++; }
    return objs; }
```

Overflow example questions

1. What's a value of `num_objs` that would trigger an overflow?
   - Think back to 2021 on how multiplication overflows
2. Why is the `p->ident` check relevant to exploitability?

http://www-users.cselabs.umn.edu/classes/Spring-2022/csci4271/slides/02/overflow-eg.c

Outline

Stack buffer overflow, cont'd

Reversing the stack

Reversing the stack, discussion

Other safety problems

Integer overflow example

Code auditing

Auditing is...

- Reading code to find security bugs
- Threat modeling comes first, tells you what kinds of bugs you're looking for
- Bug fixing comes next (might be someone else's job)

Tiers and triage

- You might not have time to do a complete job, so use auditing time strategically
- Which bugs are most likely, and easiest to find?
- Triage into definitely safe, definitively unsafe, hard to tell
  - Hard to tell might be improved even if safe

Threat model and taint

- Vulnerability depends on what an attacker might control
- Another word for attacker-controlled is "tainted"
- Threat model is the best source of tainting information
  - Of course, can always be conservative

Where to look for problems

- If you can't read all the code carefully, search for indicators of common danger spots
  - For format strings, look for `printf`
  - For buffer overflows, look at buffers and copying functions

Ideal: proof

- Given enough time, for each dangerous spot, be able to convince someone:
  - Proof of safety: reasons why a bug could never happen, could turn into assertions
  - Proof of vulnerability: example of tainted input that causes a crash