Buffer Overflow Attacks

David Oswald and Eike Ritter

Changes for 2021 by Ian Batten

Introduction into Computer Security,

Based on a course by Tom Chothia

Introduction

- A simplified, high-level view of buffer overflow attacks
  - x86 architecture
  - overflows on the stack
  - Focus on 32-bit mode, but most things directly apply to 64-bit mode as well

Introduction

- In languages like C, you have to tell the compiler how to manage the memory.
  - This is hard.
- If you get it wrong, then an attacker can usually exploit this bug to make your application run *arbitrary code.*
- Countless worms, attacks against SQL servers, web servers, iPhone jailbreaks, SSH servers, …

What‘s wrong with this code?

```
void getname() {
    char buffer[32];
    gets(buffer);
    printf("Your name is %s.\n", buffer);
}

int main(void) {
    printf("Enter your name:" );
    getname();
    return 0;
}
```

Live-Demo

"Anything that can go wrong, will go wrong"

Triggering a buffer overflow

The x86 Architecture

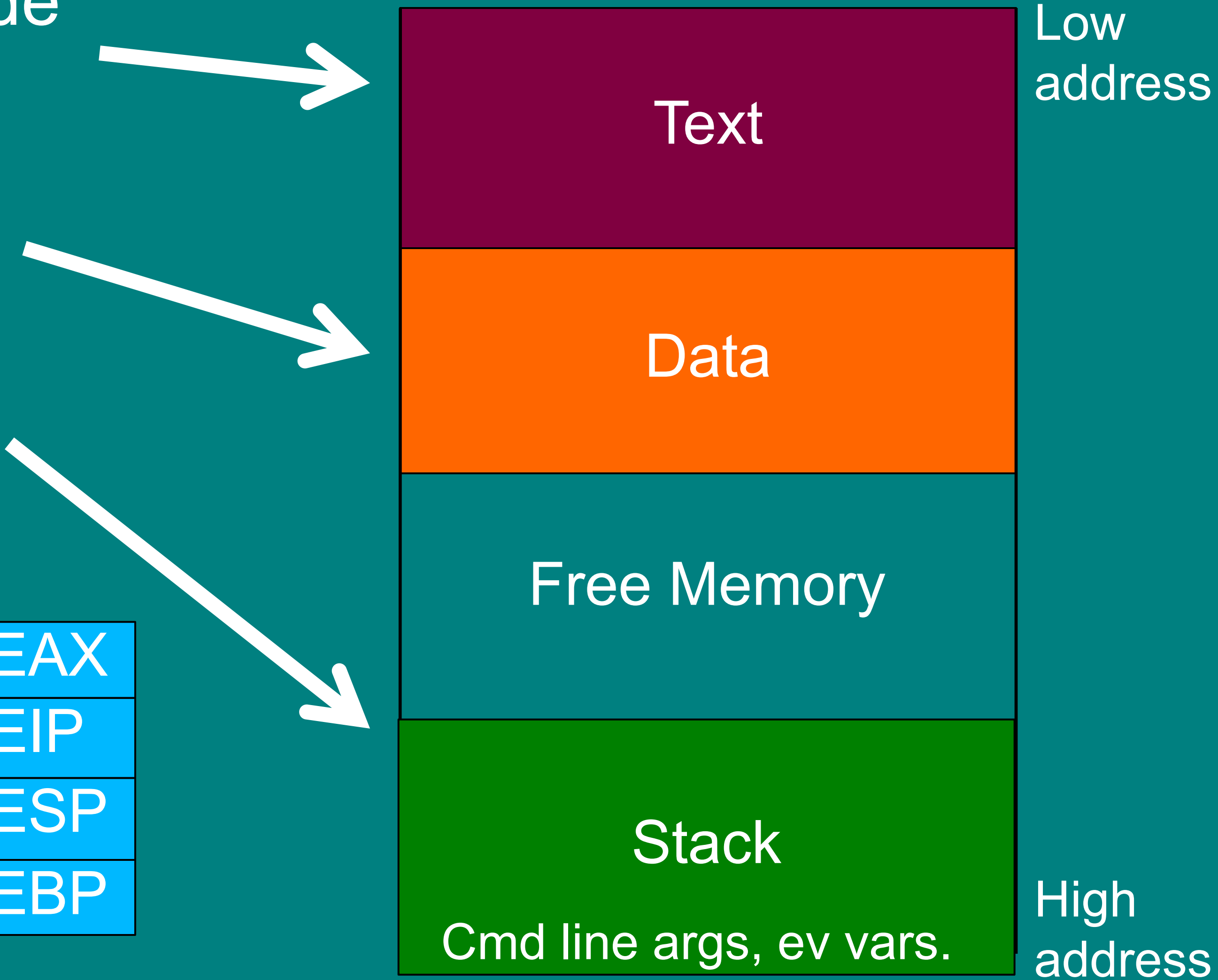
The program code

Static variables,
Strings, etc

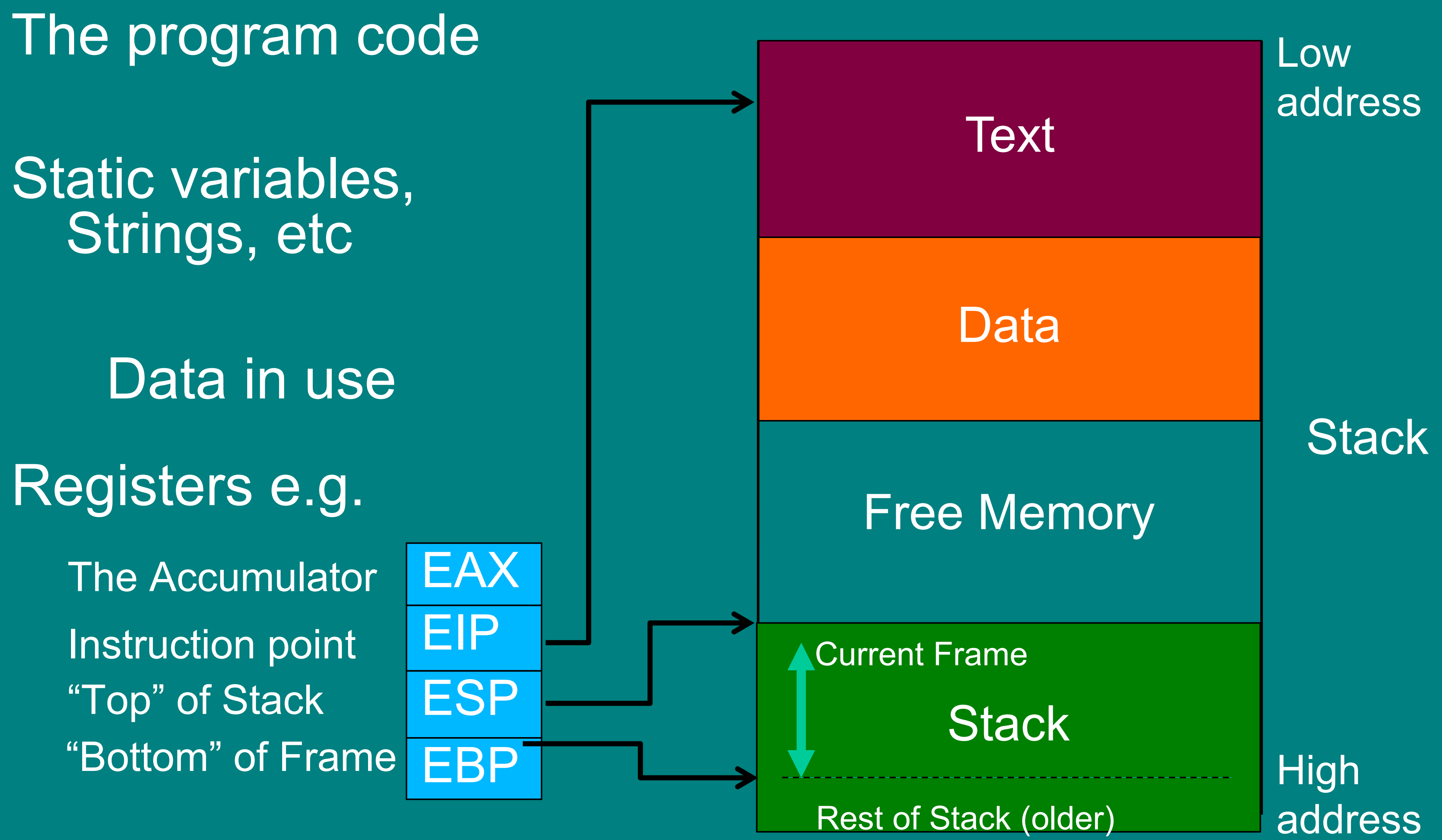
Data in use

Registers e.g.

The Accumulator	EAX
Instruction point	EIP
“Top” of Stack	ESP
“Bottom” of Frame	EBP



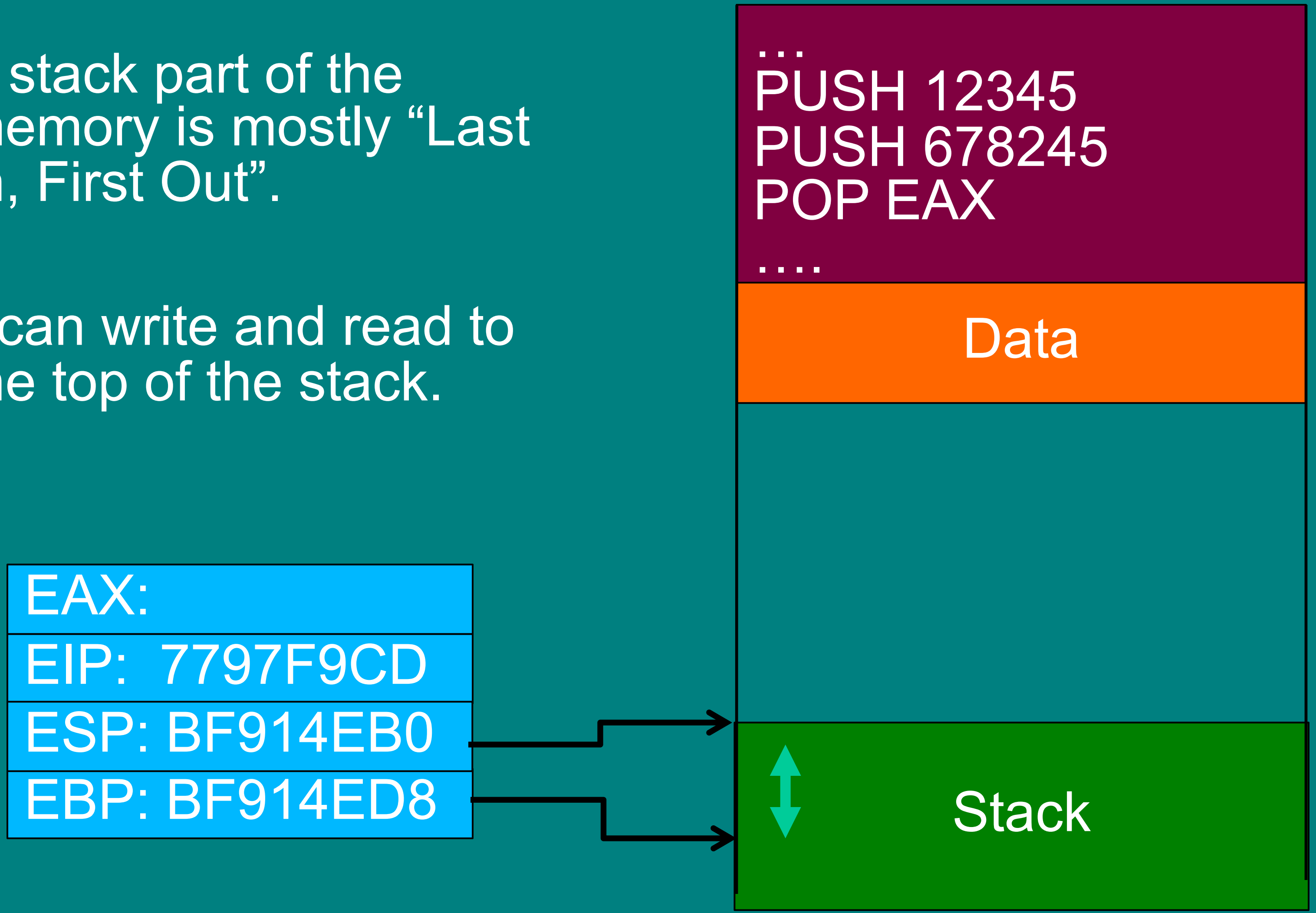
The x86 Architecture



The Stack

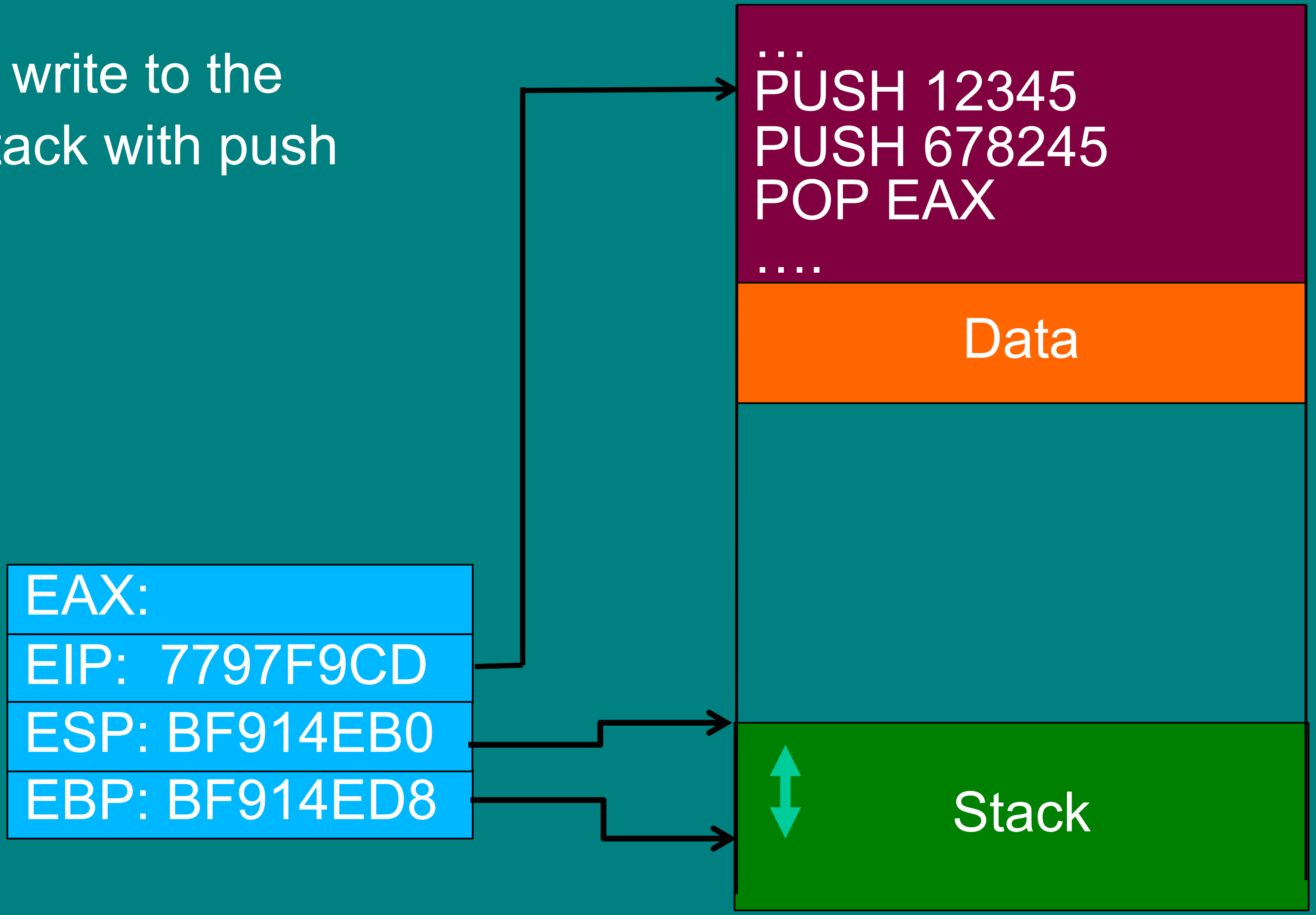
The stack part of the memory is mostly "Last In, First Out".

We can write and read to the top of the stack.



The Stack

You write to the stack with push



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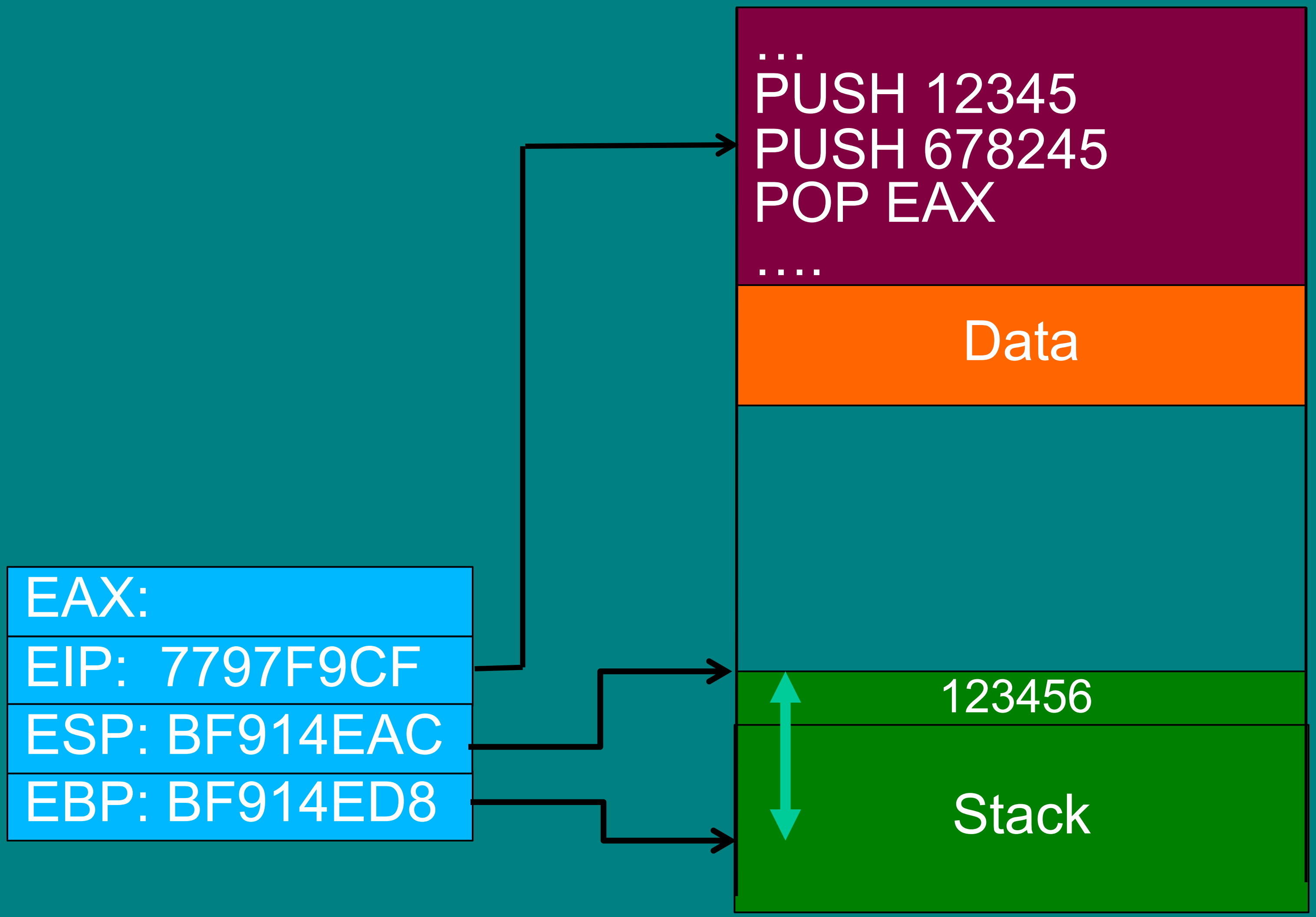
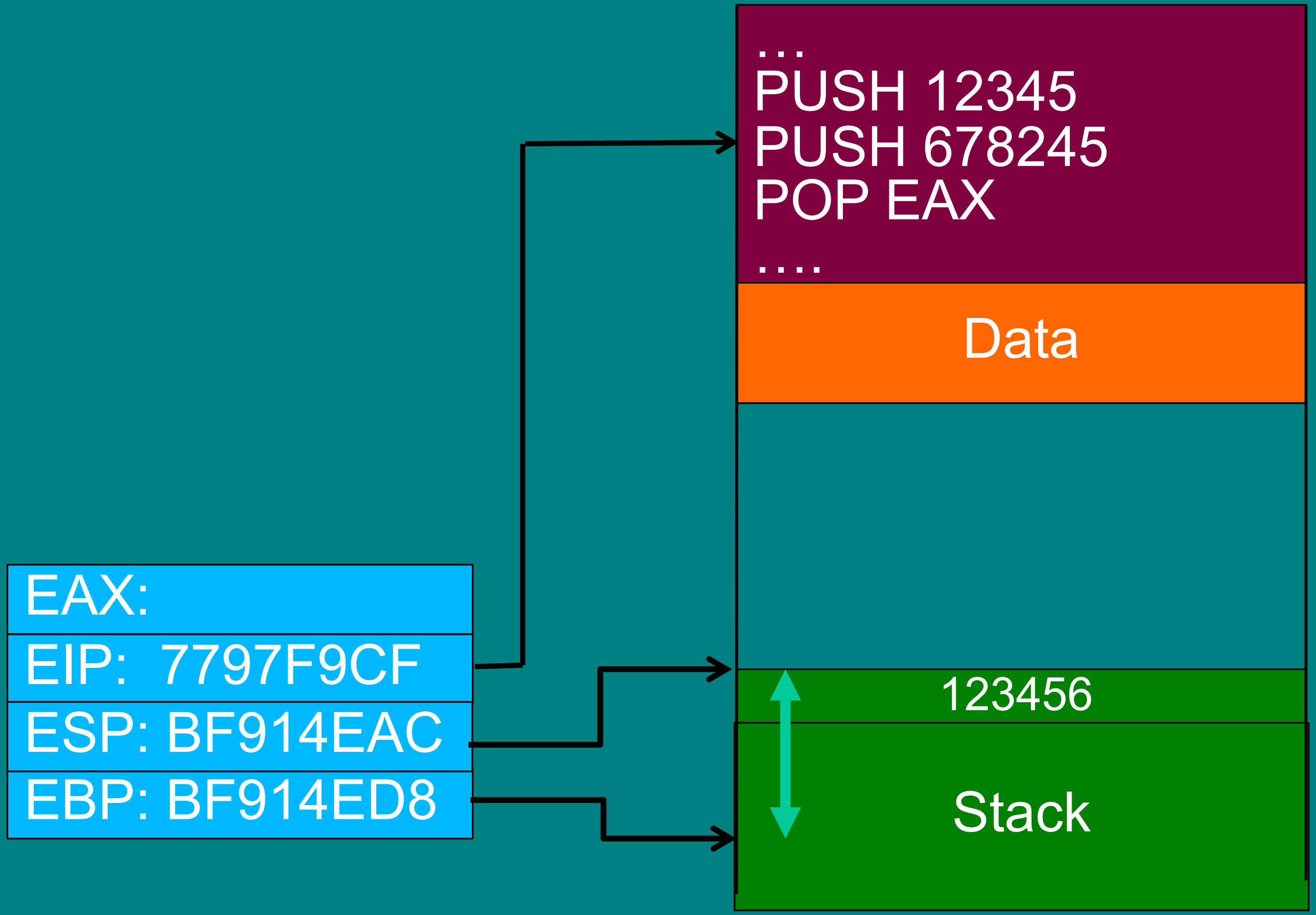


...
PUSH 12345
PUSH 678245
POP EAX
....
Data
123456
Stack
EAX:
EIP: 7797F9CF
ESP: BF914EAC
EBP: BF914ED8

The Stack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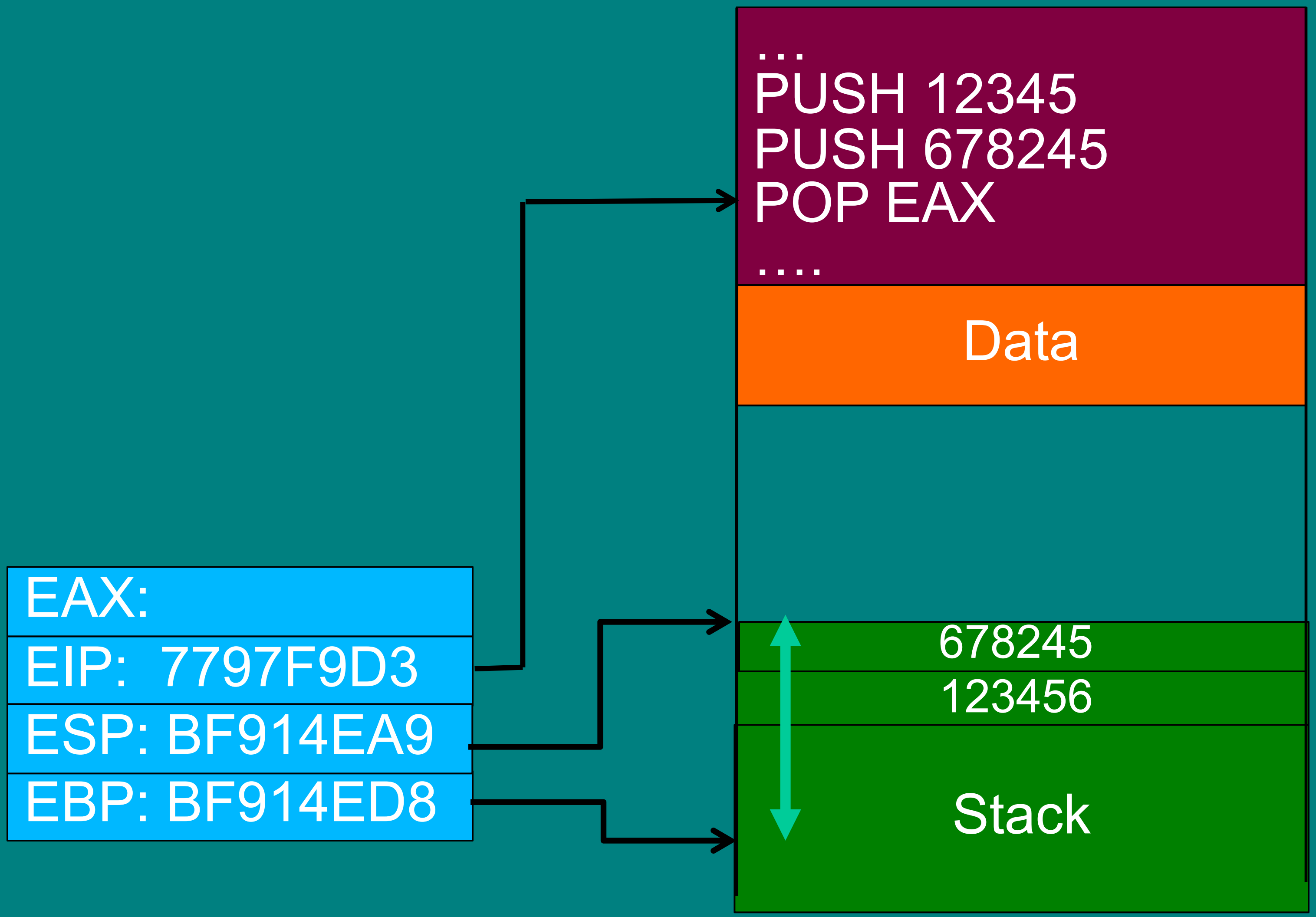
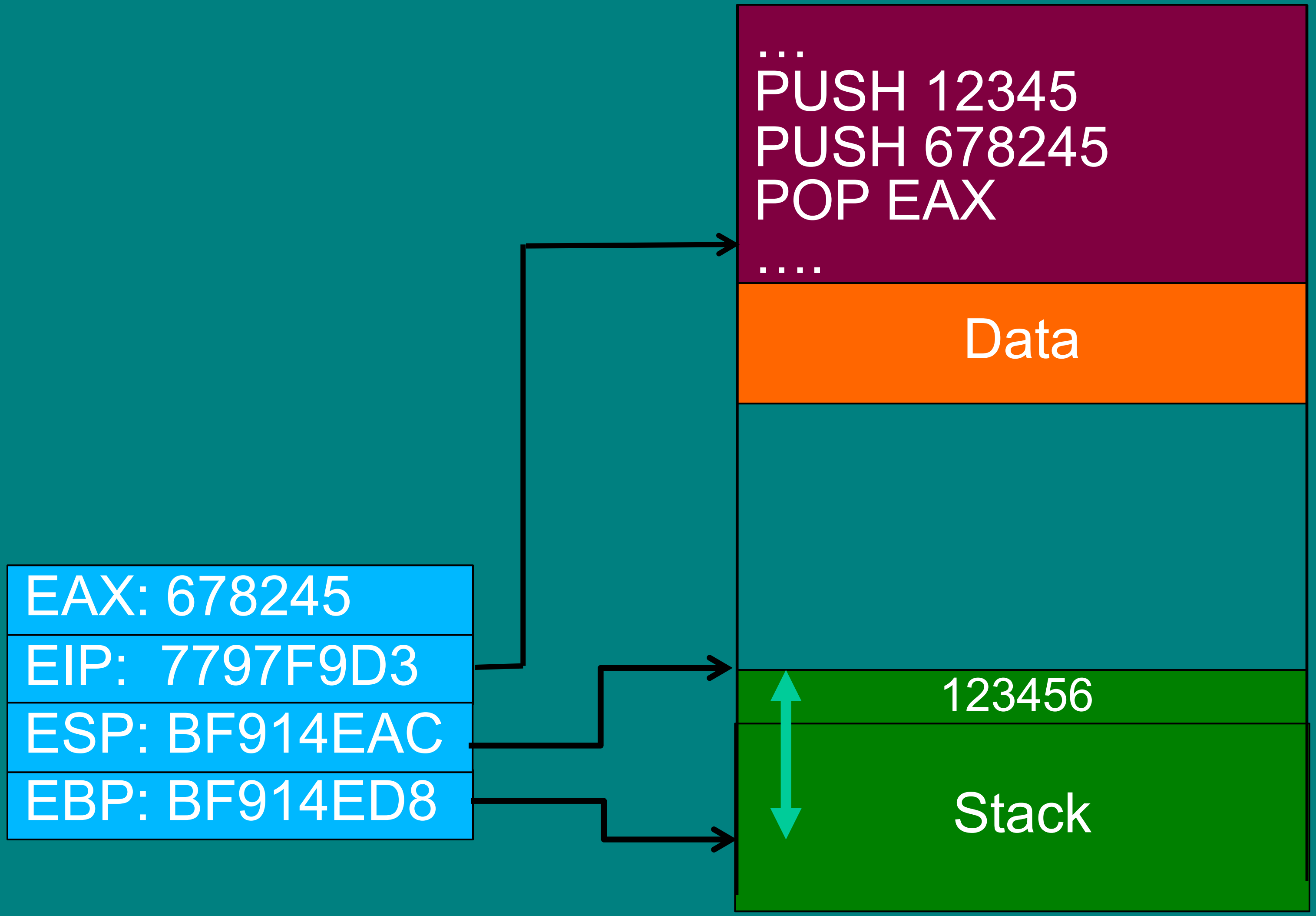


…
PUSH 12345
PUSH 678245
POP EAX
….
Data
EAX:
EIP: 7797F9D3
ESP: BF914EA9
EBP: BF914ED8
678245
123456
Stack

The Stack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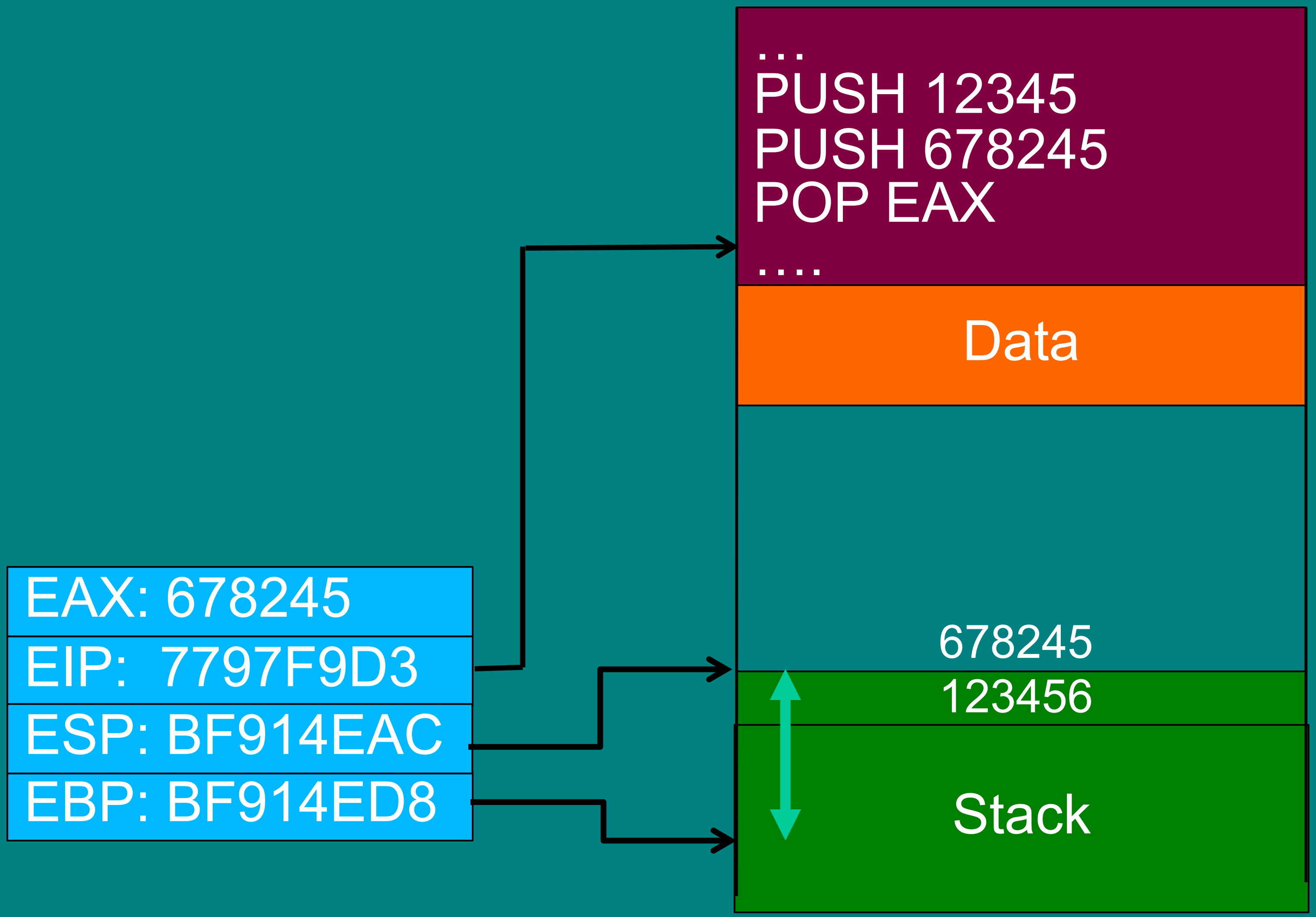
The Stack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EAX: 678245
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Function calls (32-bit)

```
void main () {
  function (1,2);
}
```

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void main () {
   function (1,2);
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```

```
PUSH <2>
PUSH <1>
CALL <function>
```

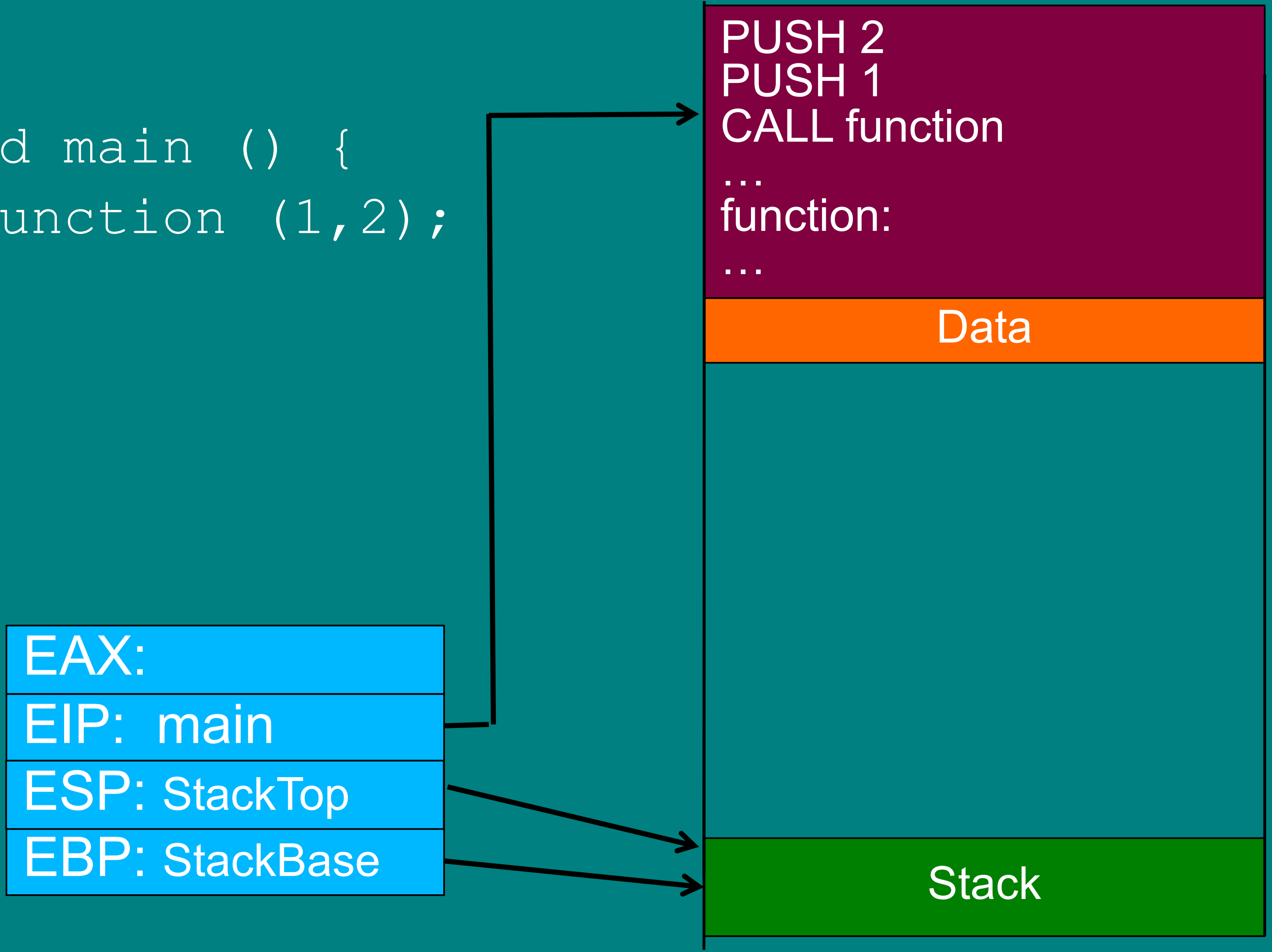
- Arguments 1 & 2 are passed on the stack.
- The CALL instruction puts the address of `function` into EIP and stores the old EIP on the stack.

Stack Pointers

- ESP
  - Points to the TOP of the stack. When you push or pop data onto the stack, it goes here and ESP is then adjusted to reflect the new stack head.
- EBP
  - Points to the BASE of the stack FRAME. When you call a function, this is saved on the stack and EBP now points to the base of the new stack FRAME. All local variables can be found relative to this pointer.

The Stack

```
void main () {
   function (1,2);
}
```



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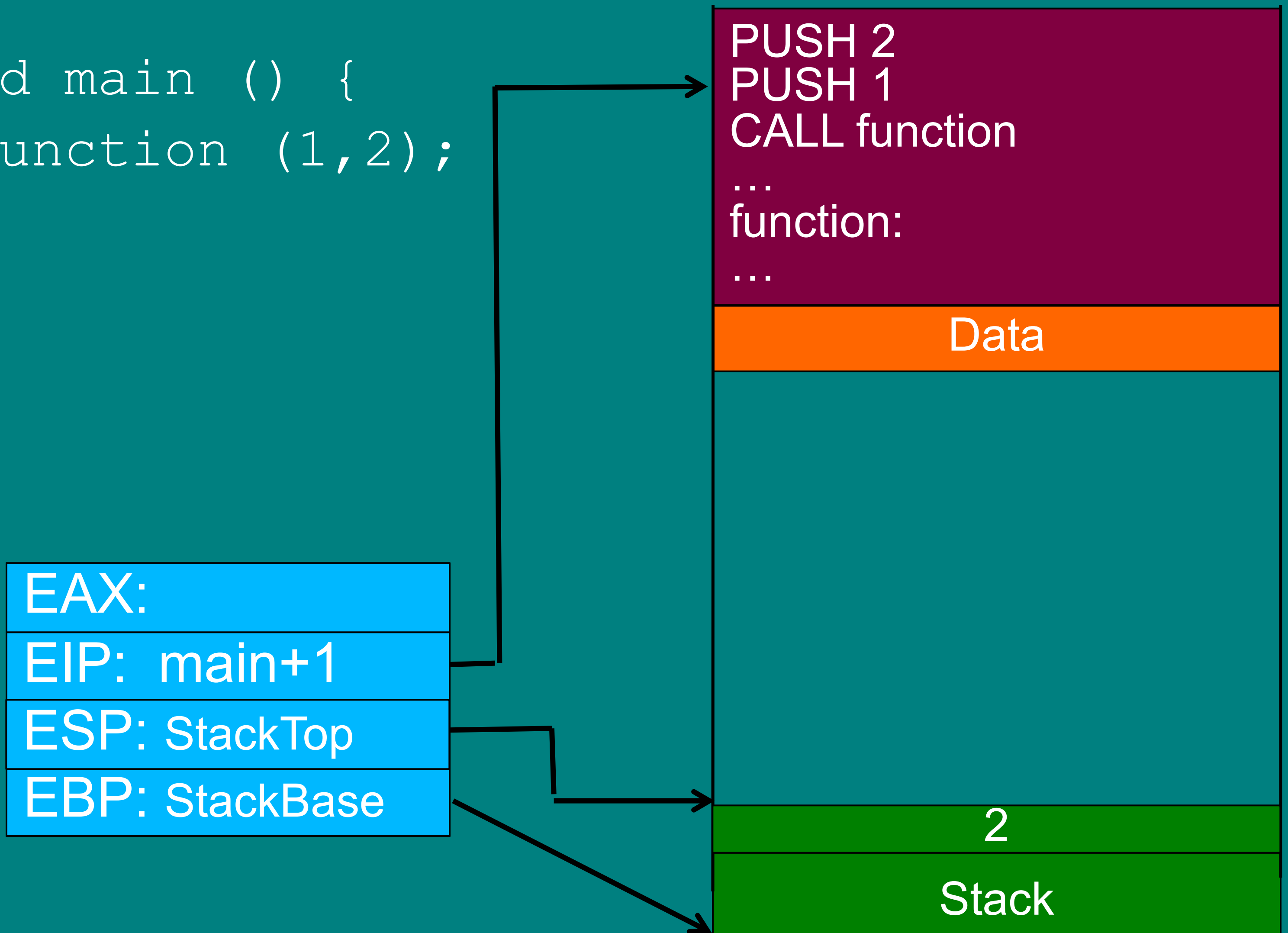

The Stack

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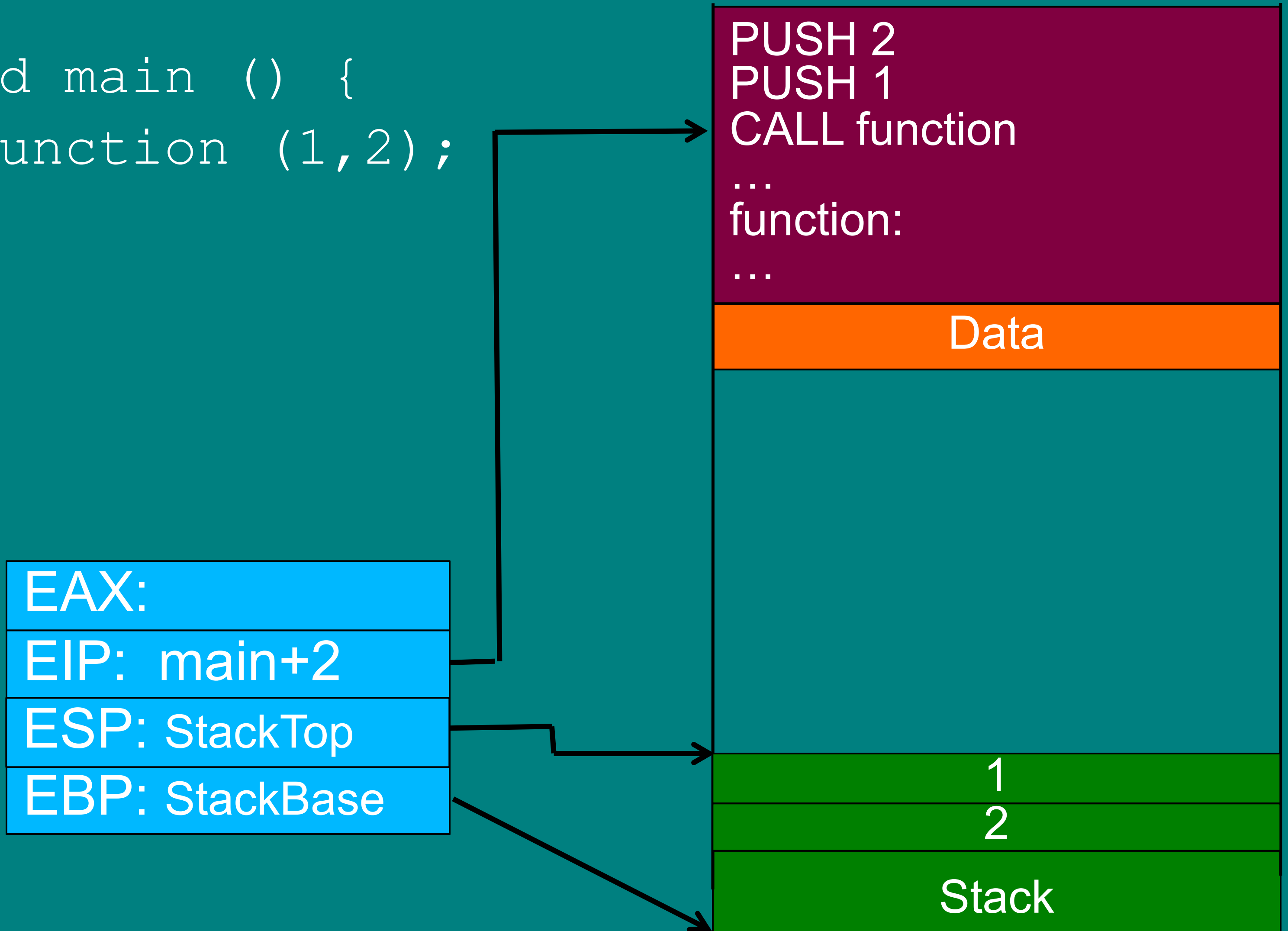

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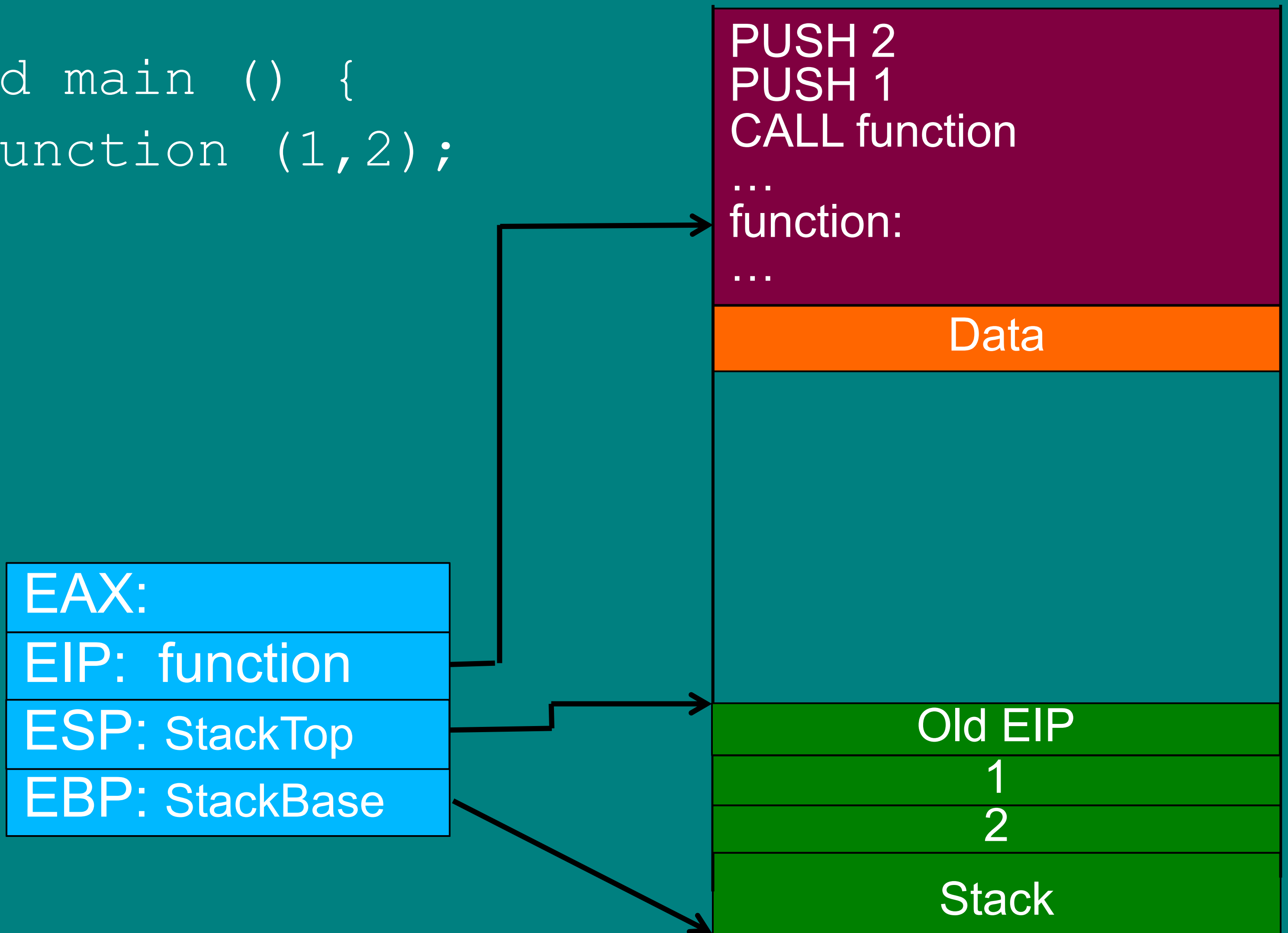

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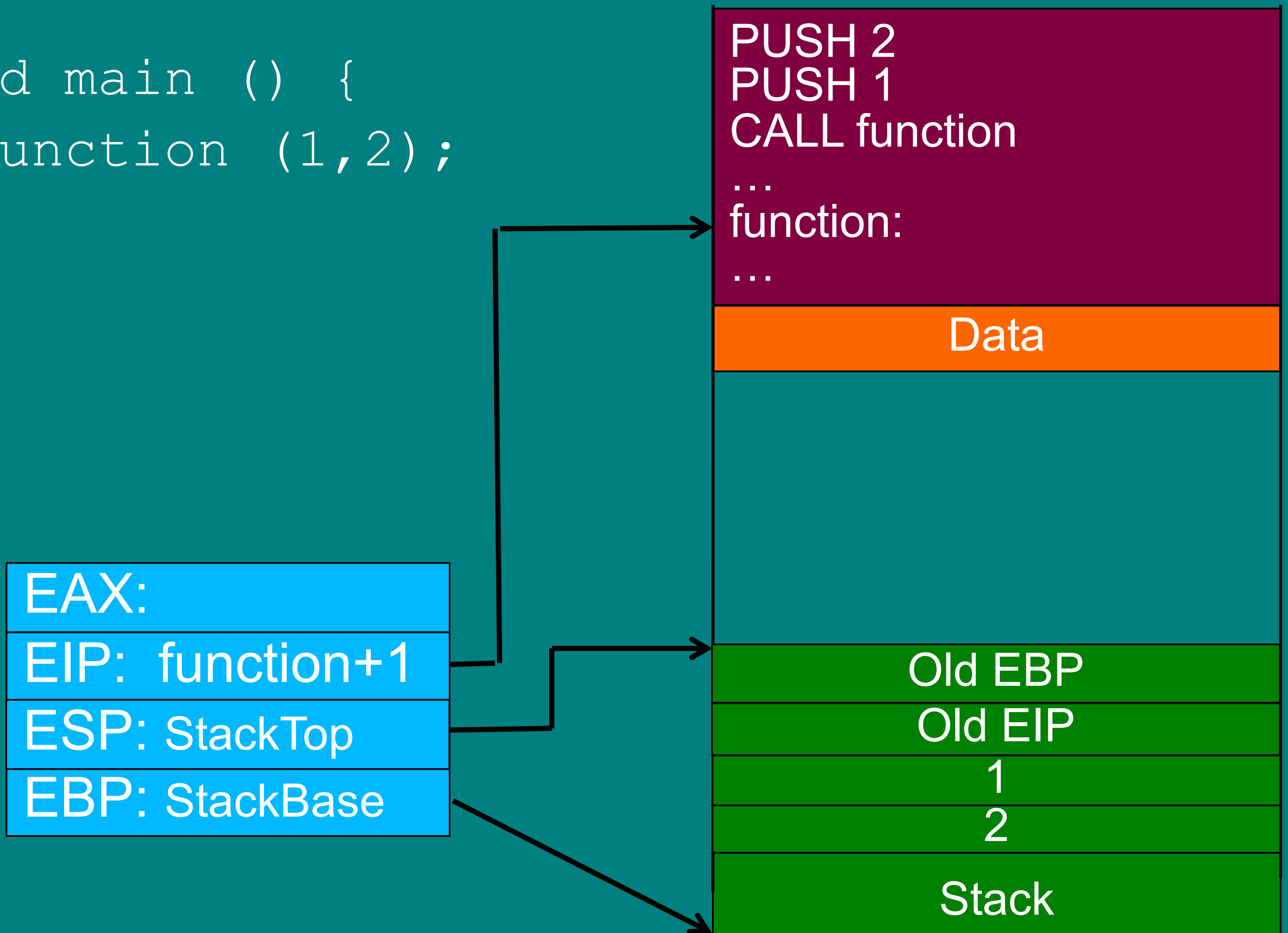

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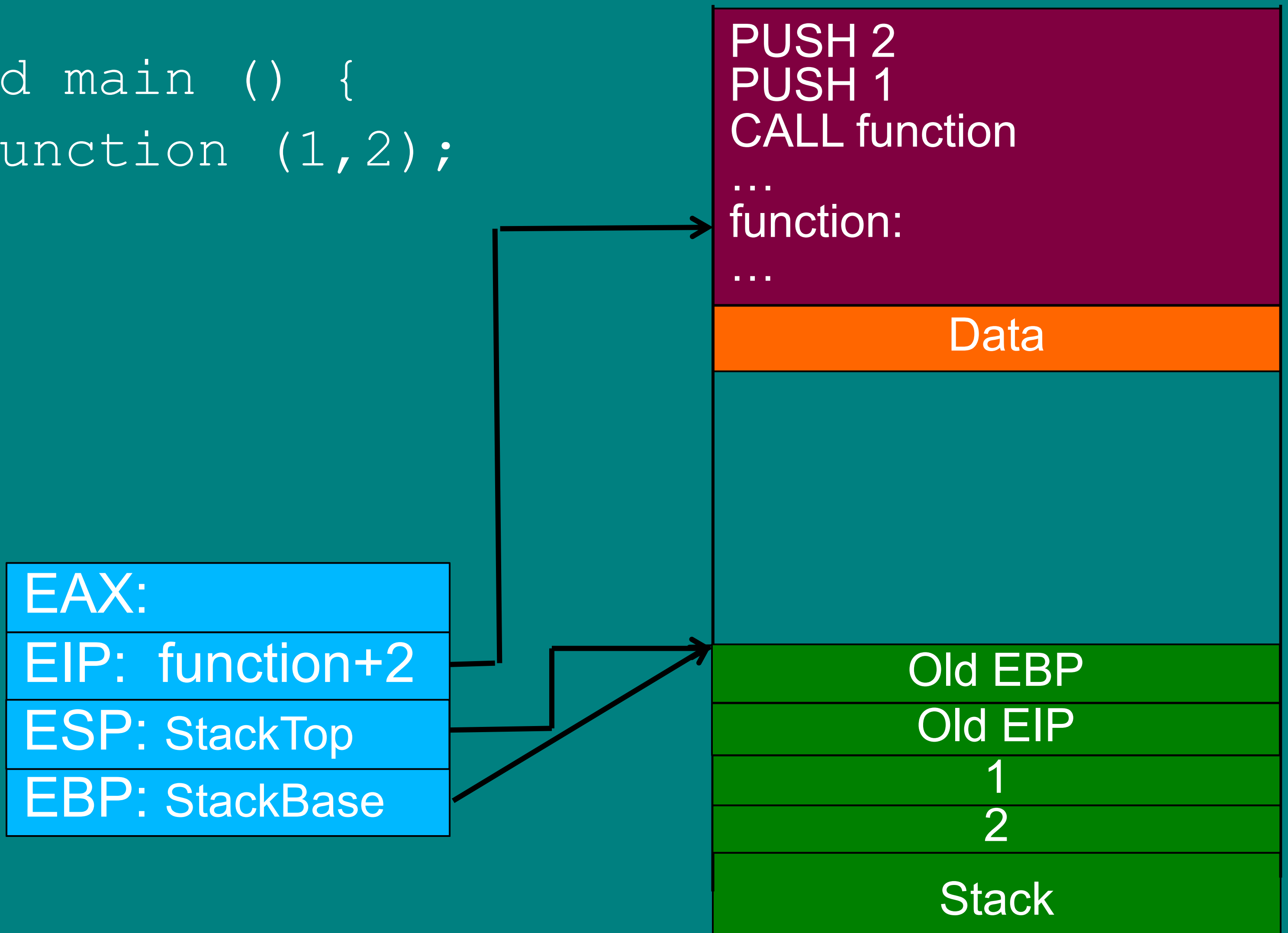
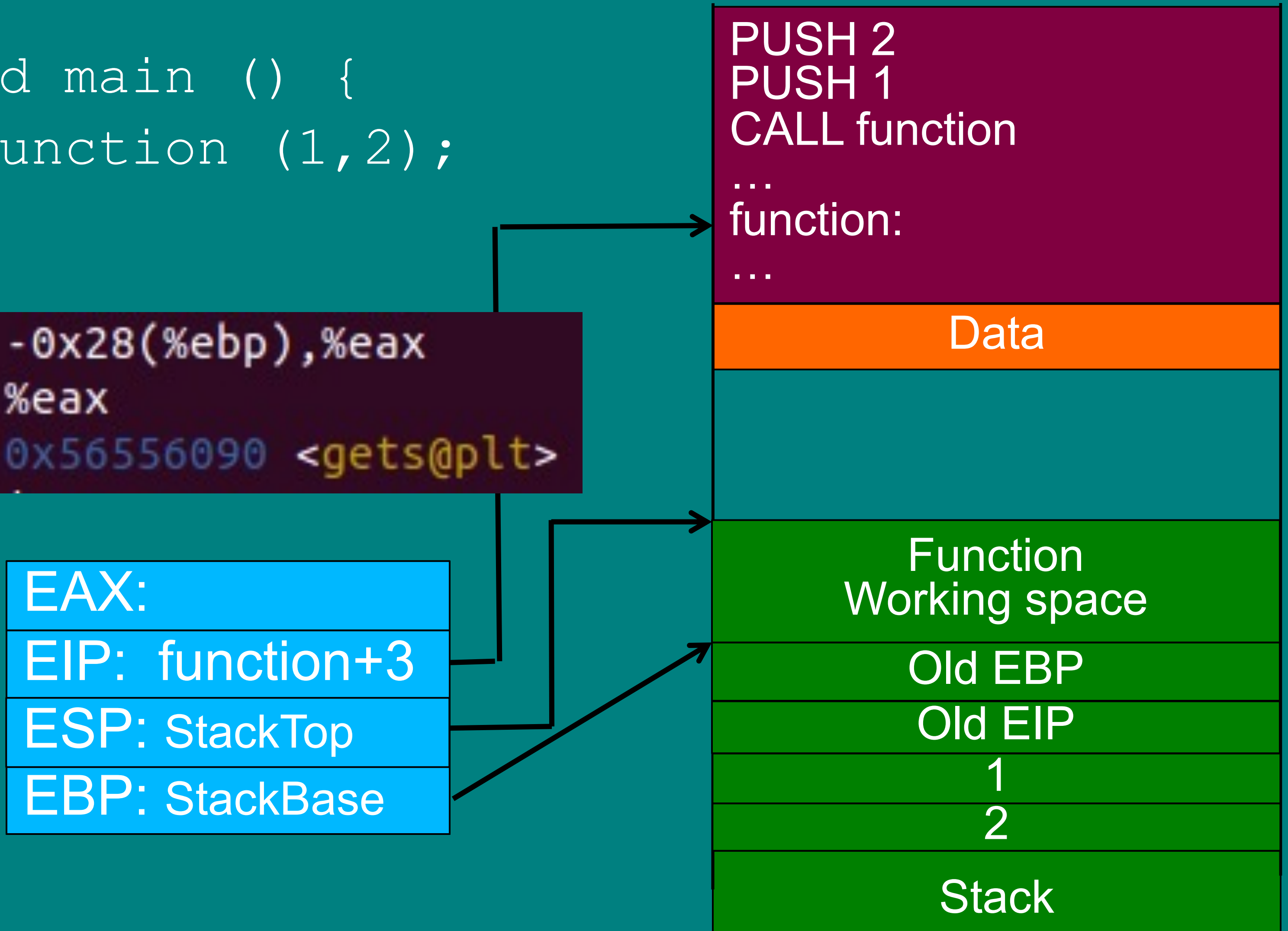


The Stack

```
void main () {
   function (1,2);
}
```

```
<+25>:    lea    -0x28(%ebp),%eax
<+28>:    push   %eax
<+29>:    call   0x56556090 <gets@plt>
```



All local variables in the current context are located relative to EBP

The Stack

```
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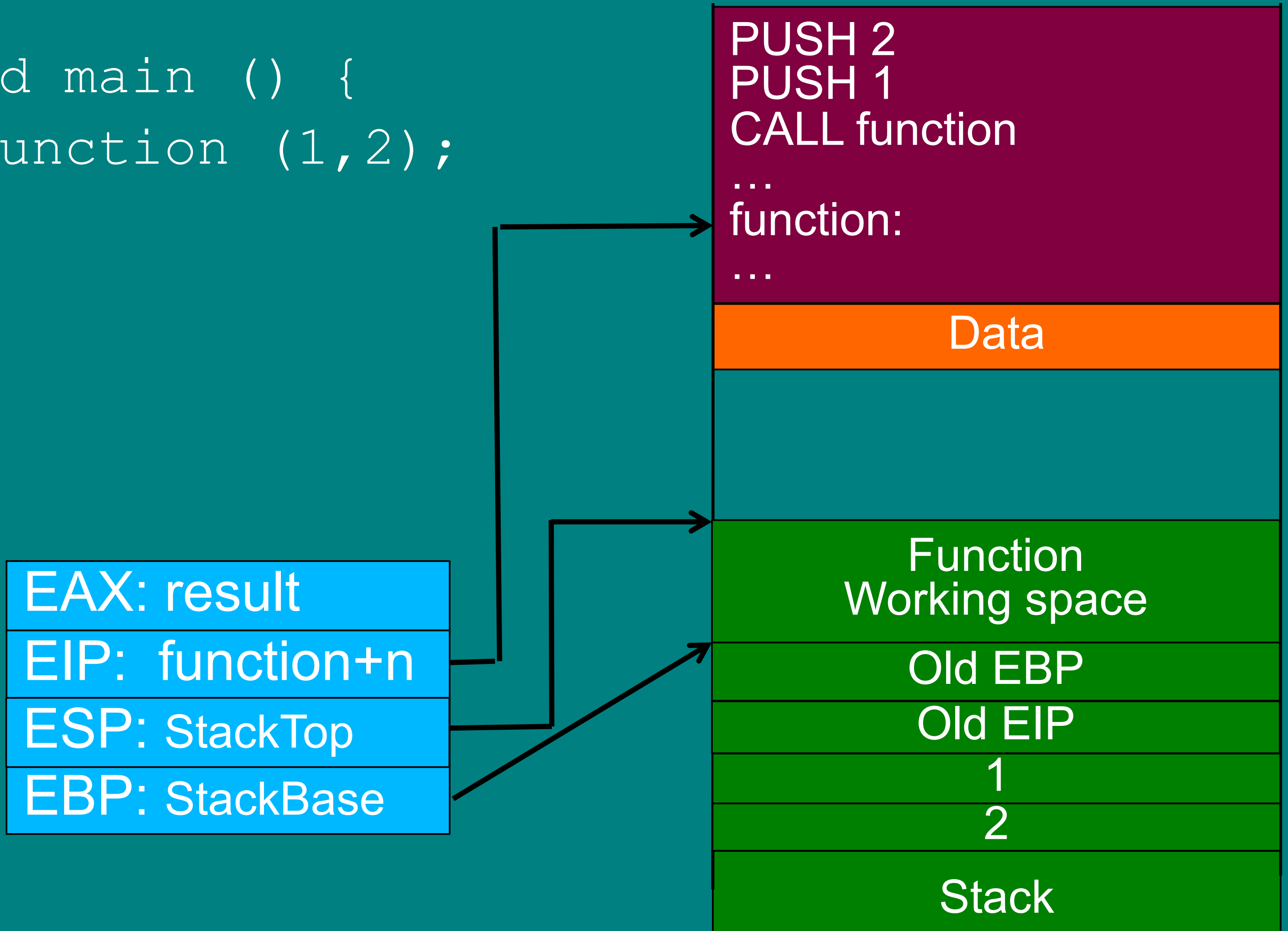
}
```



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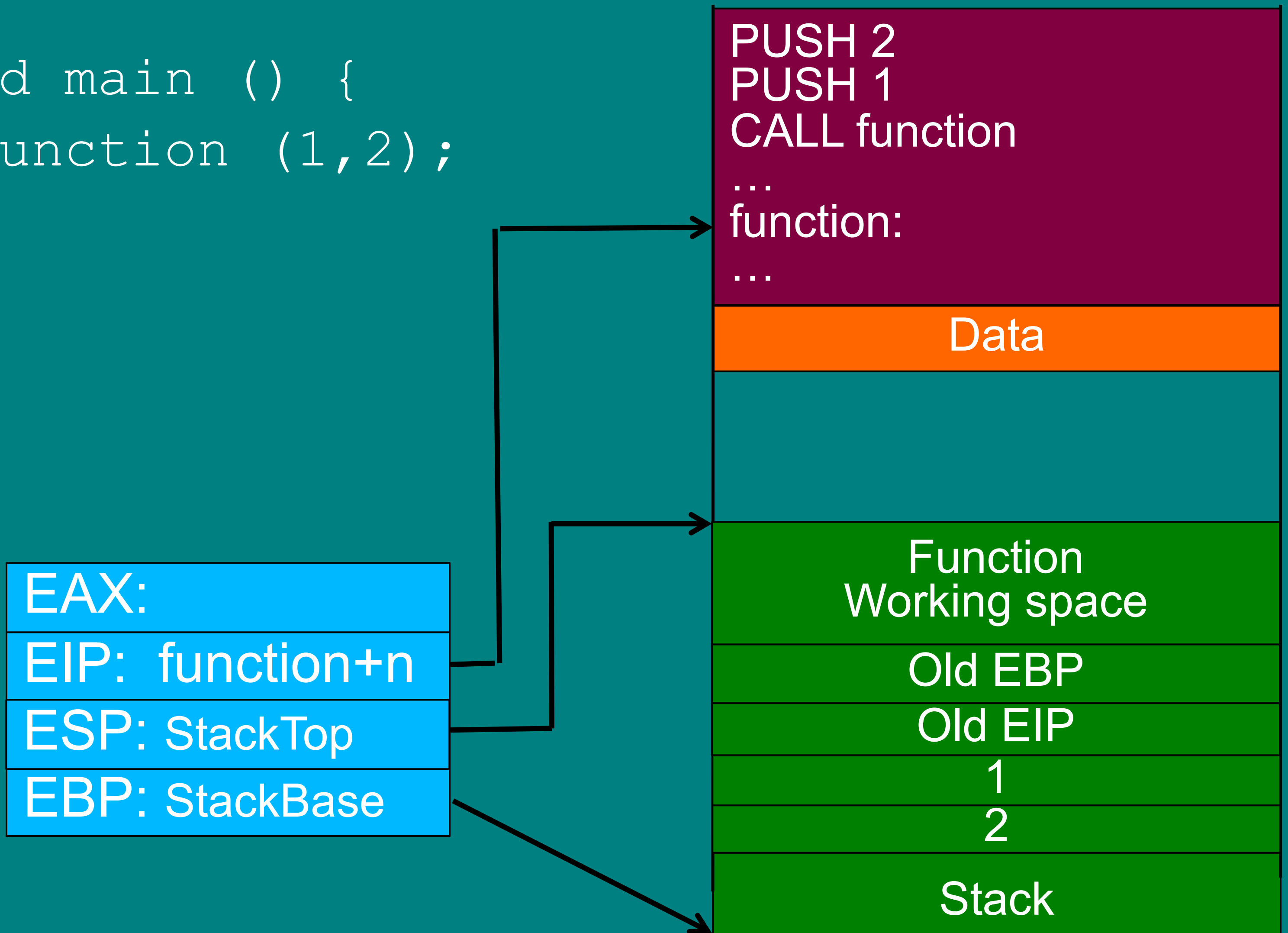

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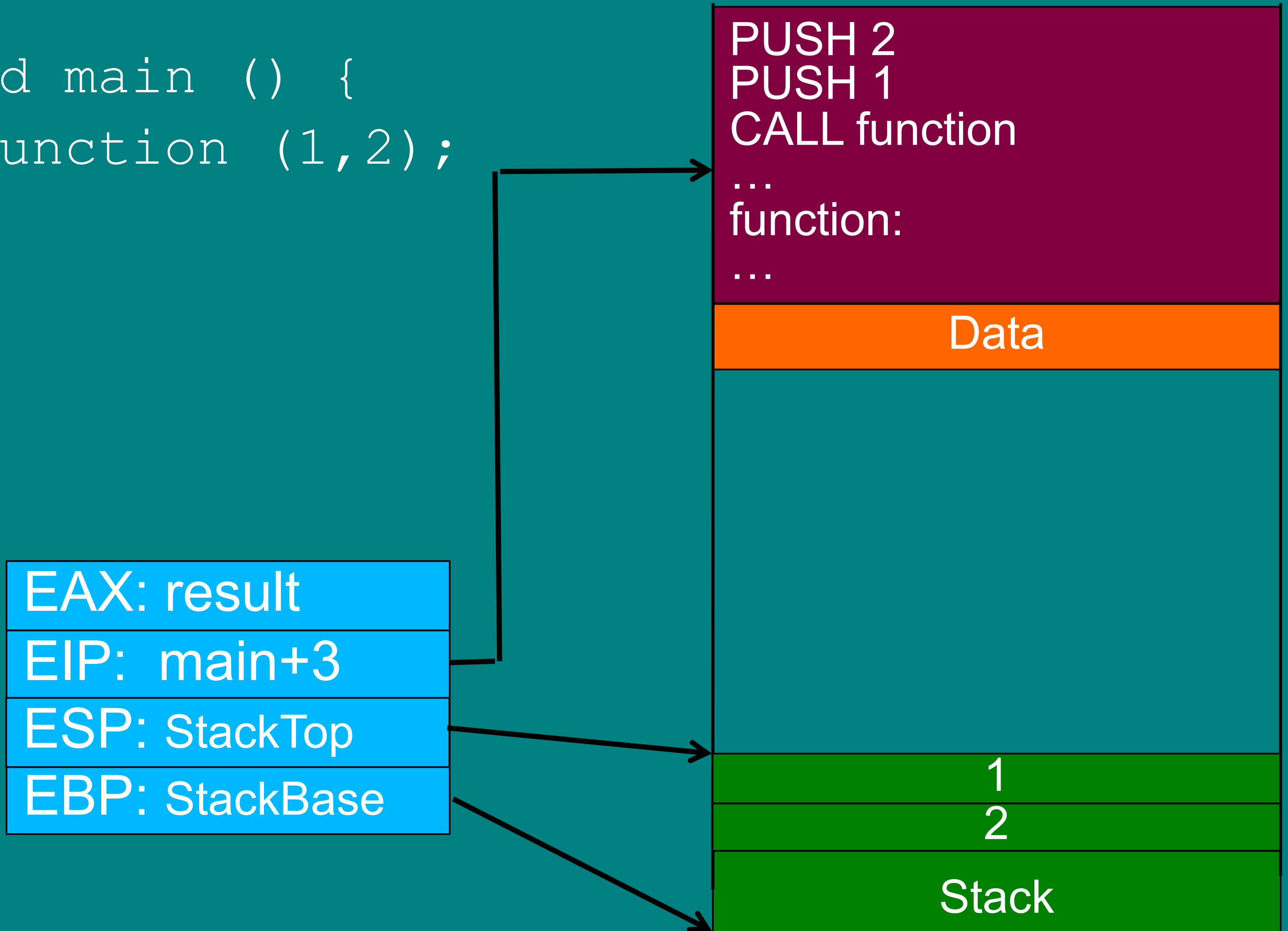

Buffer Overflows

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Buffers

```
…
getname();
…

getname() {
   char buffer[16];
   gets(buffer);
}
```

Buffers

1. Function called

```
…
getname();
…

getname() {
   char buffer[16];
   gets(buffer);
}
```

Buffers

1. Function called
2. EIP & EBP written to stack

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…
getname();
…

getname() {
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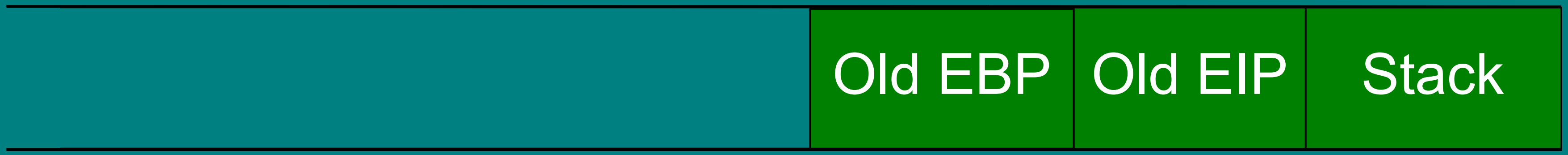
   gets(buffer);
}
```

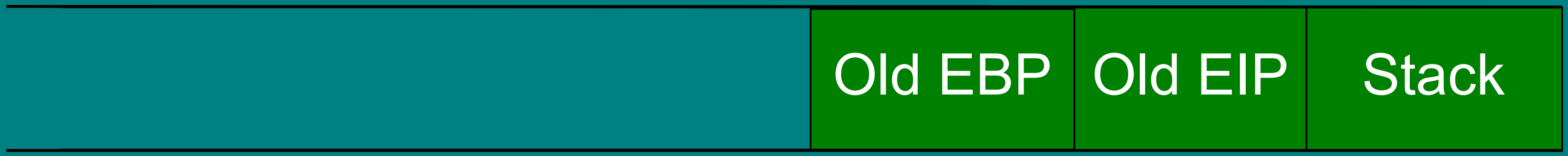


Buffers

1. Function called
2. EIP & EBP written to stack
3. Function runs

```
...
getname();
...

getname() {
   char buffer[16];
   gets(buffer);
}
```



Buffers

1. Function called
2. EIP & EBP written to stack
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4. Buffer allocated

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…

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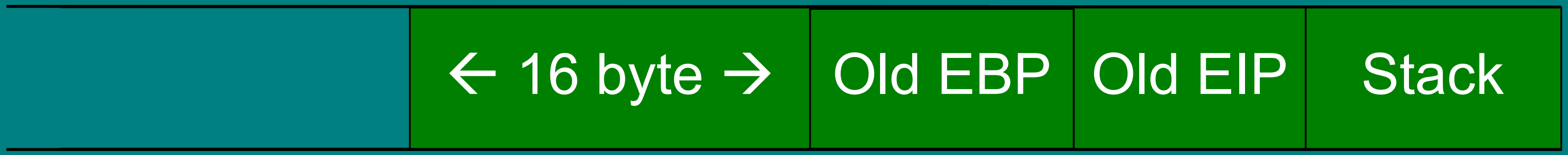

Buffers

1. Function called
2. EIP & EBP written to stack
3. Function runs
4. Buffer allocated
5. User inputs “Hello World”

```
…
getname();
…

getname() {
   char buffer[16];
   gets(buffer);
}
```

	Hello World	Old EBP	Old EIP	Stack

Buffer Overflow

If input is >16 bytes:
Hello World XXXXXXXXXXXXX

```
…
getname();
…

getname() {
   char buffer[16];
   gets(buffer);
}
```

Stack

Buffer Overflow

If input is >16 bytes:
Hello World XXXXXXXXXXXX

1. Runs as before

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…

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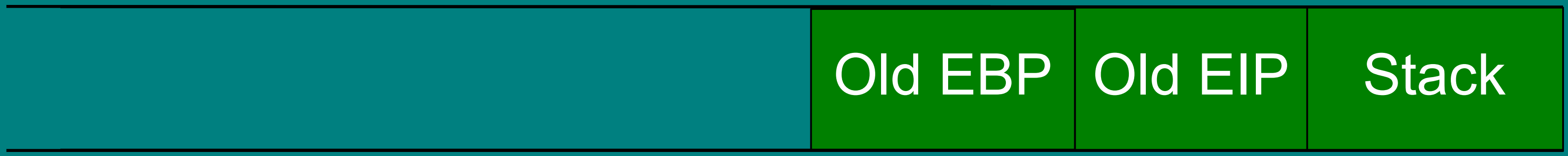
```



Buffer Overflow

If input is >16 bytes:
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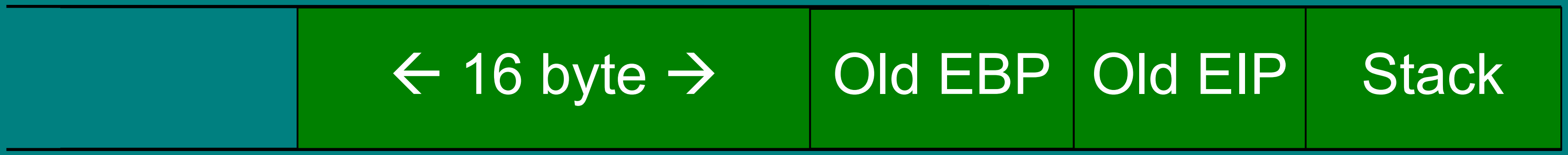


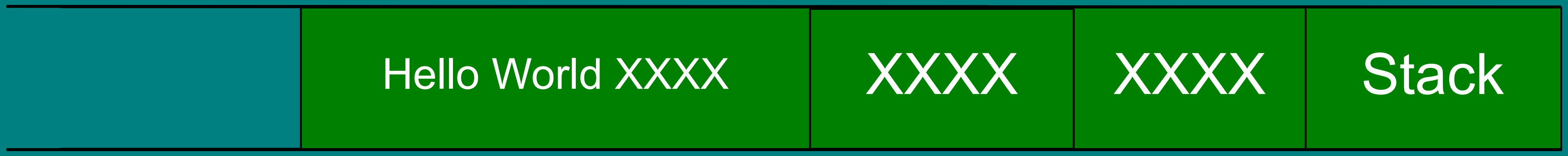
Buffer Overflow

If input is >16 bytes:
Hello World XXXXXXXXXXXX

1. Runs as before
2. But the string flows over the end of the buffer
3. EIP corrupted, segmentation fault

```
…
getname();
…

getname() {
   char buffer[16];
   gets(buffer);
}
```



Once more, with malice

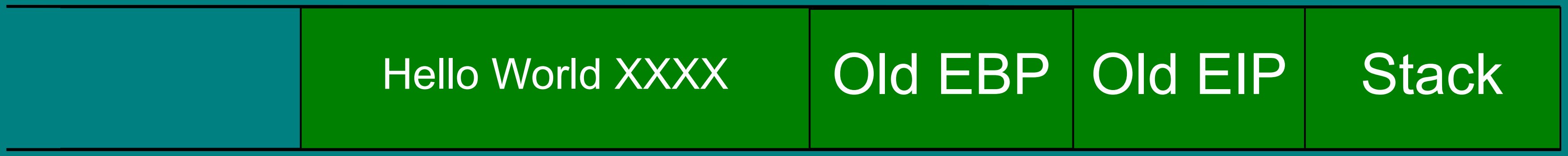
1. Runs as before

	Stack

Once more, with malice

1. Runs as before
2. Attack send a very long message, ending with the address of some code that gives him a shell:

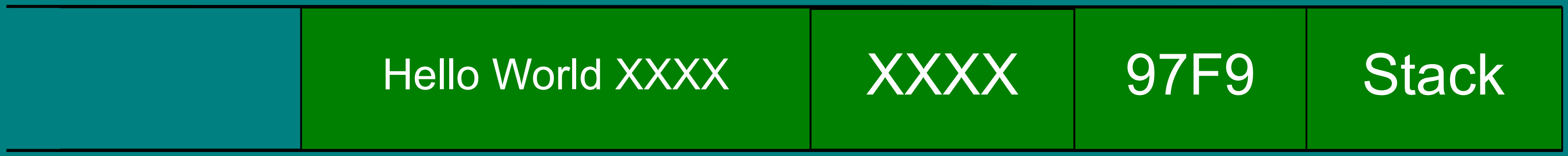
   Hello World XXXX XXXX97F9



Once more, with malice

1. Runs as before
2. Attack send a very long message, ending with the address of some code that gives him a shell:

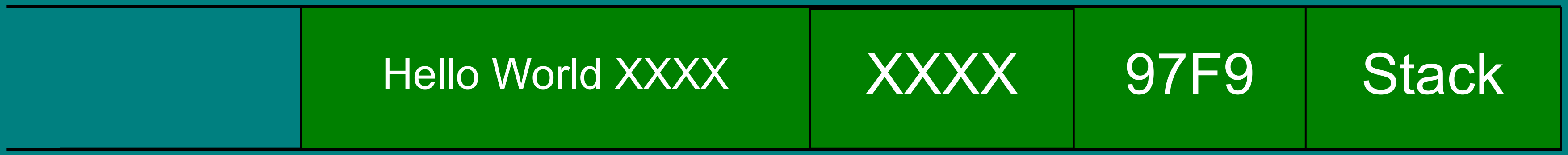
   Hello World XXXX XXXX97F9
3. The attackers value is copied over the old EIP



Once more, with malice

1. Runs as before
2. Attack send a very long message, ending with the address of some code that gives him a shell:

   Hello World XXXX XXXX97F9
3. The attackers value is copied over the old EIP
4. When the function returns the attacks code (here: at 0x97f9) is run

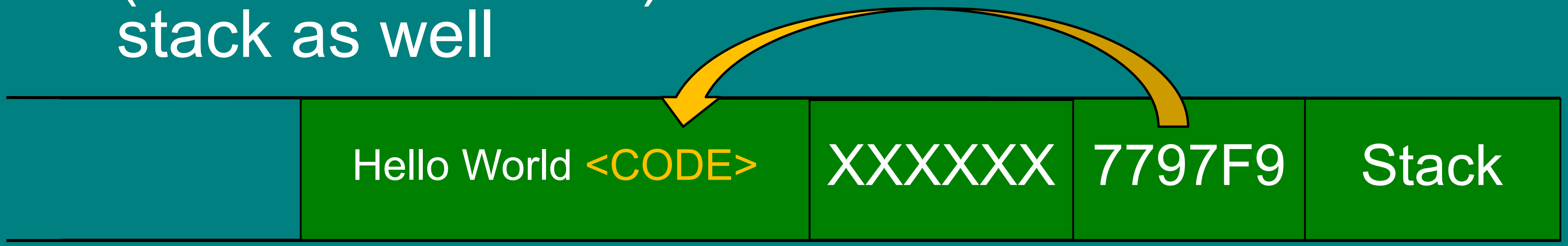


Once more, with malice

1. Runs as before
2. Attack send a very long message, ending with the address of some code that gives him a shell:

   Hello World XXXX XXXX97F9

3. The attackers value is copied over the old EIP
4. When the function returns the attacks code (here: at 0x779ff9) is run: this code can be on the stack as well



Live-Demo

"Anything that can go wrong, will go wrong"

Debugging a buffer overflow with gdb

What To Inject

Shell code (under Linux) is assembly code for

```
exec("/bin/sh", {NULL}, NULL)
```

There are some defenses in modern Linux, hence use that to indirectly call a binary that first calls `setuid(0)` and then spawns a shell (see `msh.c` on Canvas)

```
; PUSH 0x00000000 on the Stack

xor eax, eax
push eax

; PUSH //bin/sh in reverse i.e. hs/nib//

push 0x68732f6e
push 0x69622f2f

; Make EBX point to //bin/sh on the Stack using ESP

mov ebx, esp

; PUSH 0x00000000 using EAX and point EDX to it using ESP

push eax
mov edx, esp

; PUSH Address of //bin/sh on the Stack and make ECX point to it using ESP

push ebx
mov ecx, esp

; EAX = 0, Let's move 11 into AL to avoid nulls in the Shellcode

mov al, 11
int 0x80
```

Live-Demo

"Anything that can go wrong, will go wrong"

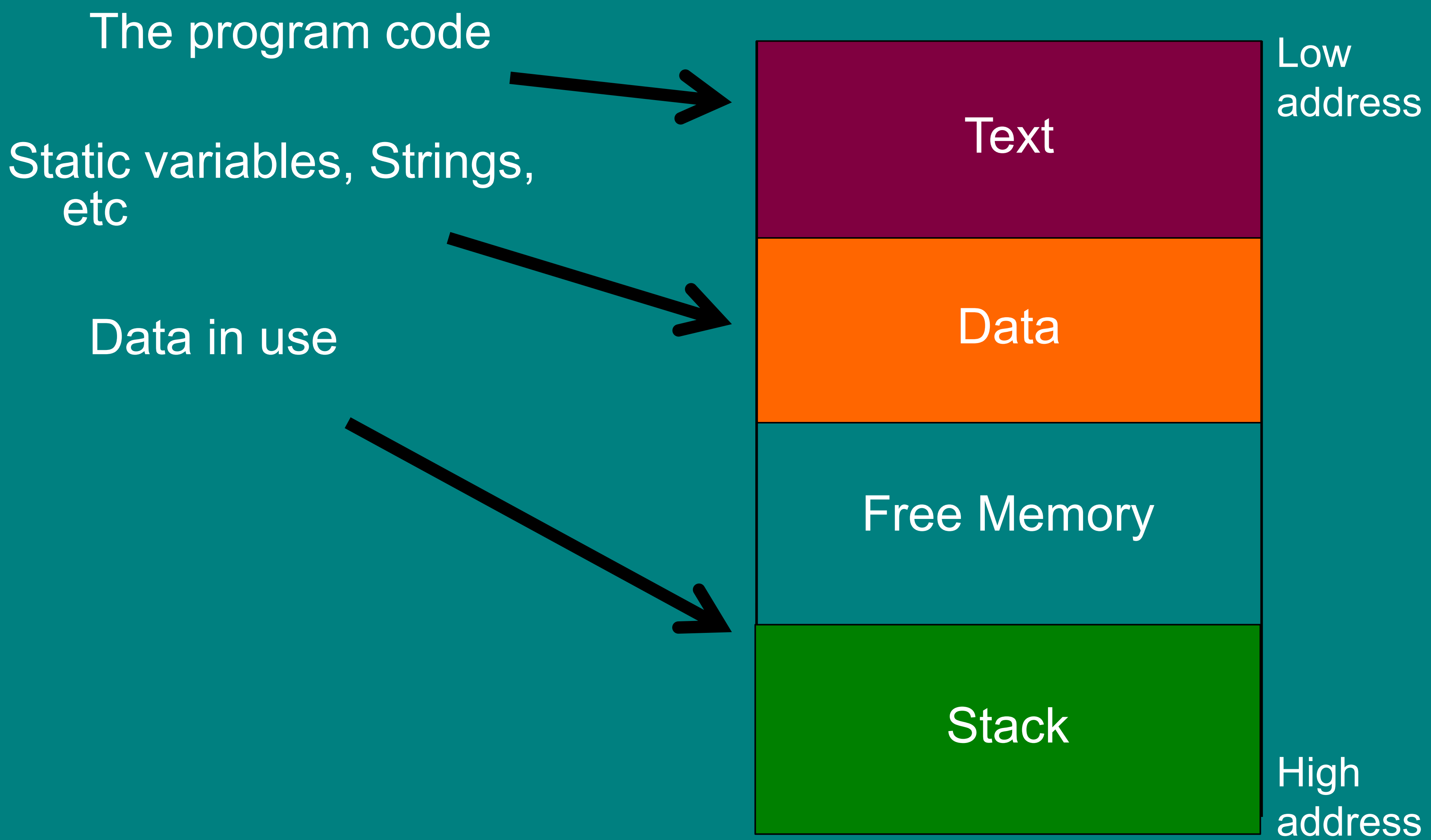
Exploiting a buffer overflow

Live-Demo

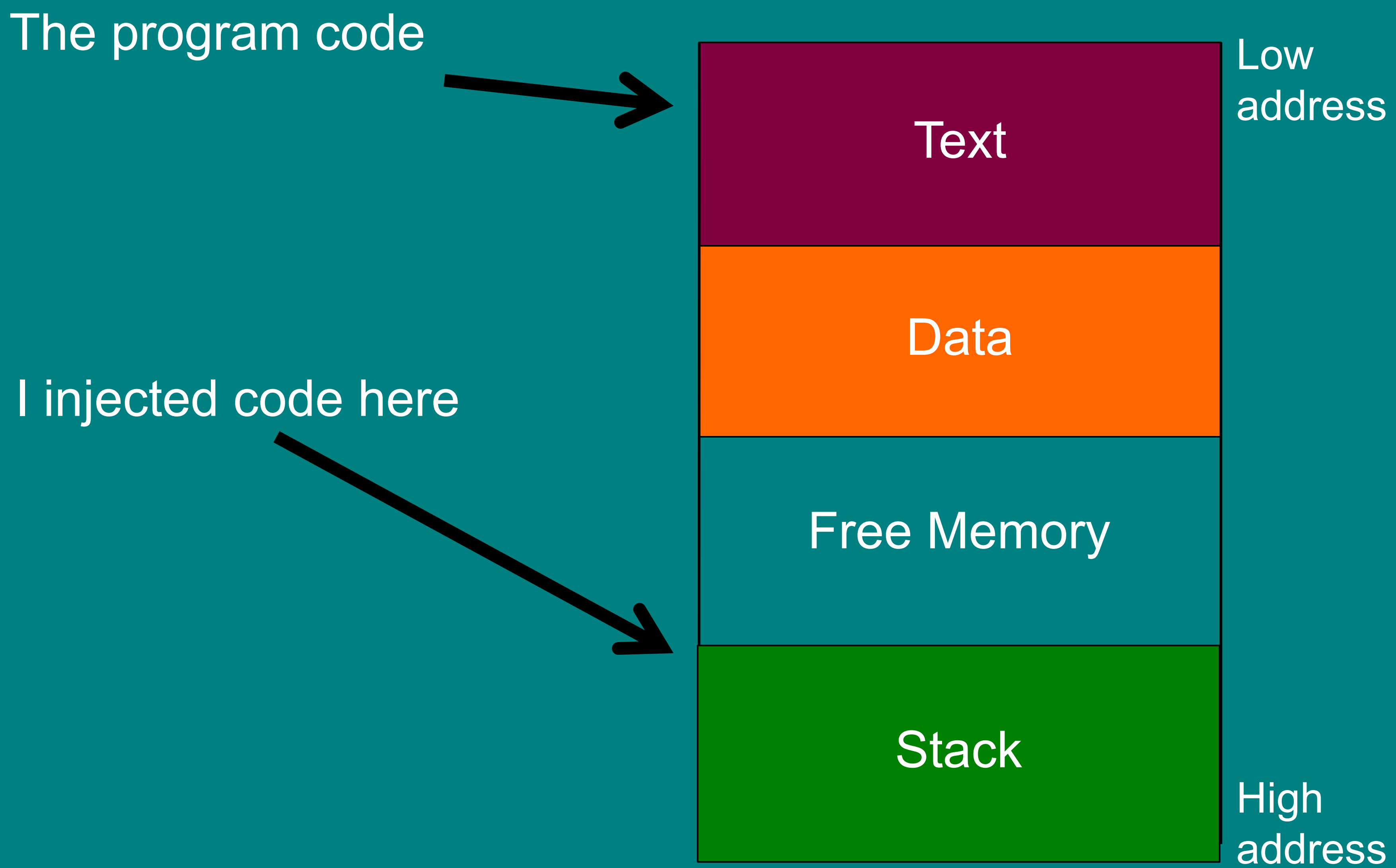
"Anything that can go wrong, will go wrong"

Exploiting a buffer overflow to pop a shell

Defense: The NX-bit

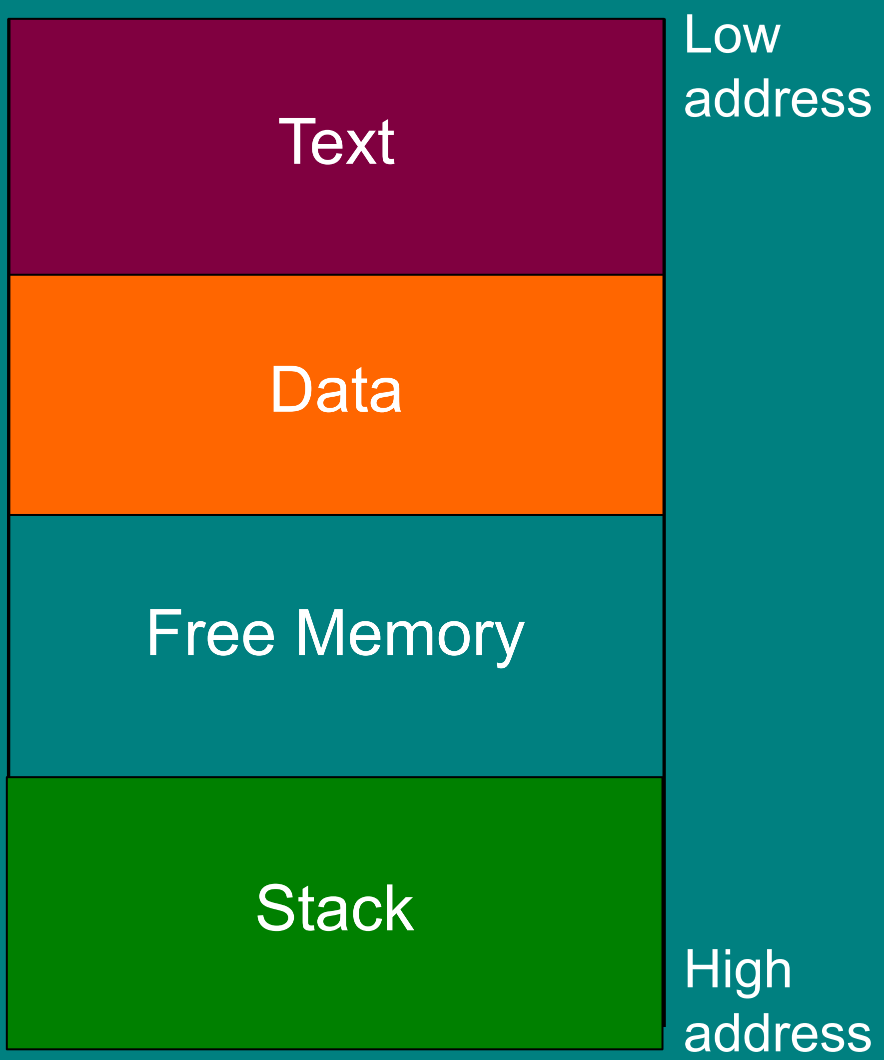


Defense: The NX-bit



Defense: The NX-bit

- Code should be in the text area of the memory. Not on the stack.
- The NX-bit provides a hardware distinction between the text and stack.
- When enabled, the program will crash if the EIP ever points to the stack.



Reuse Code.

The standard attack against the NX-bit is to reuse code from the executable part of memory. E.g.

- Jump to another function in the program.
- Jump to a function from the standard C library (Return to libc)
- String together little pieces of existing code (Return-oriented programming).

Return-to-libc

- Libc is the C standard library.
- It is often packaged with executables to provide a runtime environment.
- It includes lots of useful calls like “system” which runs any command.
- It links to executable memory, therefore bypasses NX-bit protections.

Address space layout randomization.

- ASLR adds a random offset to the stack and code base each time the program runs.
- Jumps in the program are altered to point to the right line.
- The idea is that its now hard for an attacker to guess the address of where they inject code or the address of particular functions.
- On by default in all OS. For Linux, alter it with `sysctl -w kernel.randomize_va_space=X`, where X is 0 (off), 1 (on for the stack and shared libraries), 2 (1, plus also data segment).

Live-Demo

“Anything that can go wrong, will go wrong”

ASLR in action

NOP slide

- In x86 the op code assembly instruction 0x90 does nothing.
- If the stack is 2MB, I could inject 999000 bytes of 0x90 followed by my shell code
- I then guess a return address and hope it is somewhere in the 2MB of NOPs.
- If it is, the program slides down the NOPs to my shell code.

- Often used with other methods of guessing the randomness.

Metasploit

- Metasploit is a framework for testing and executing known buffer overflow attacks.
- If a vulnerability in an application is well known their will be a patch for it, but also a Metasploit module for it.
- If an application is unpatched it can probably be taken over with Metasploit.
- Metasploit also includes a library of shell code which can be injected.
- Without wishing to get into another debate, using it against machines you don’t own is illegal. Do not do this.

Recommend Paper:

- “Smashing the Stack for Fun and Profit”
  Elias Levy (Aleph One)
- A simple introduction to buffer overflows from the mid 90s.
- Standard defenses now stop the attacks in this paper, but it gives an excellent introduction.

Conclusion

Buffer overflows are the result of poor memory management in languages like C: even the “best” programmers **will** make mistakes.

Buffer overflow attacks exploit these to overwrite memory values.

This lets an attack execute arbitrary code.