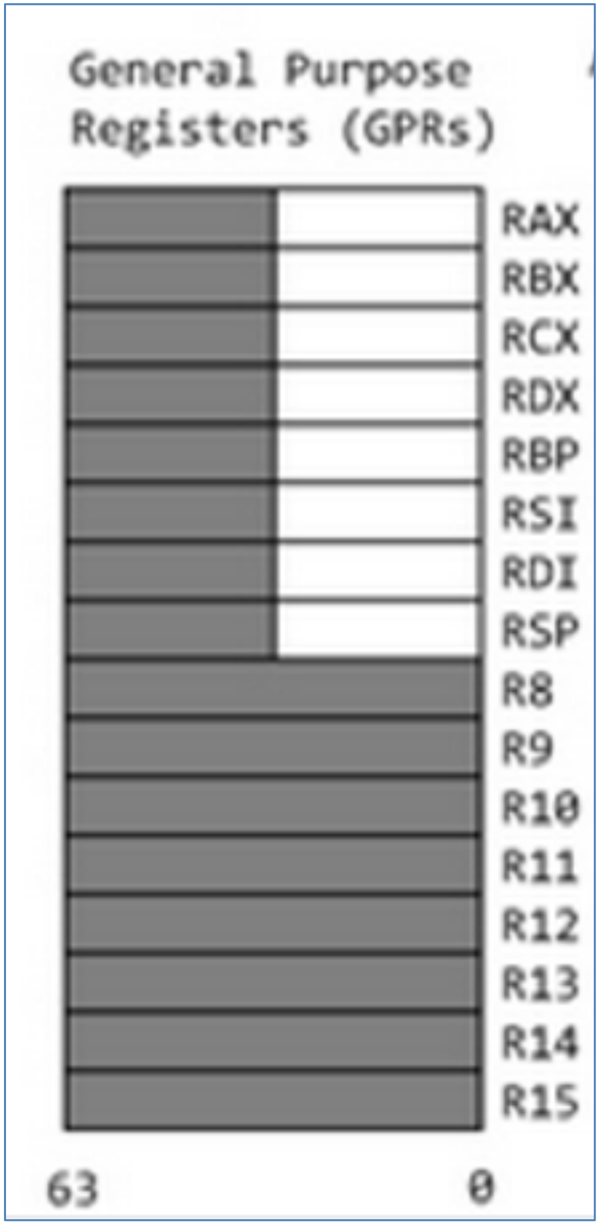
CNIT 127: Exploit Development

Lecture 7: 64-bit Assembler

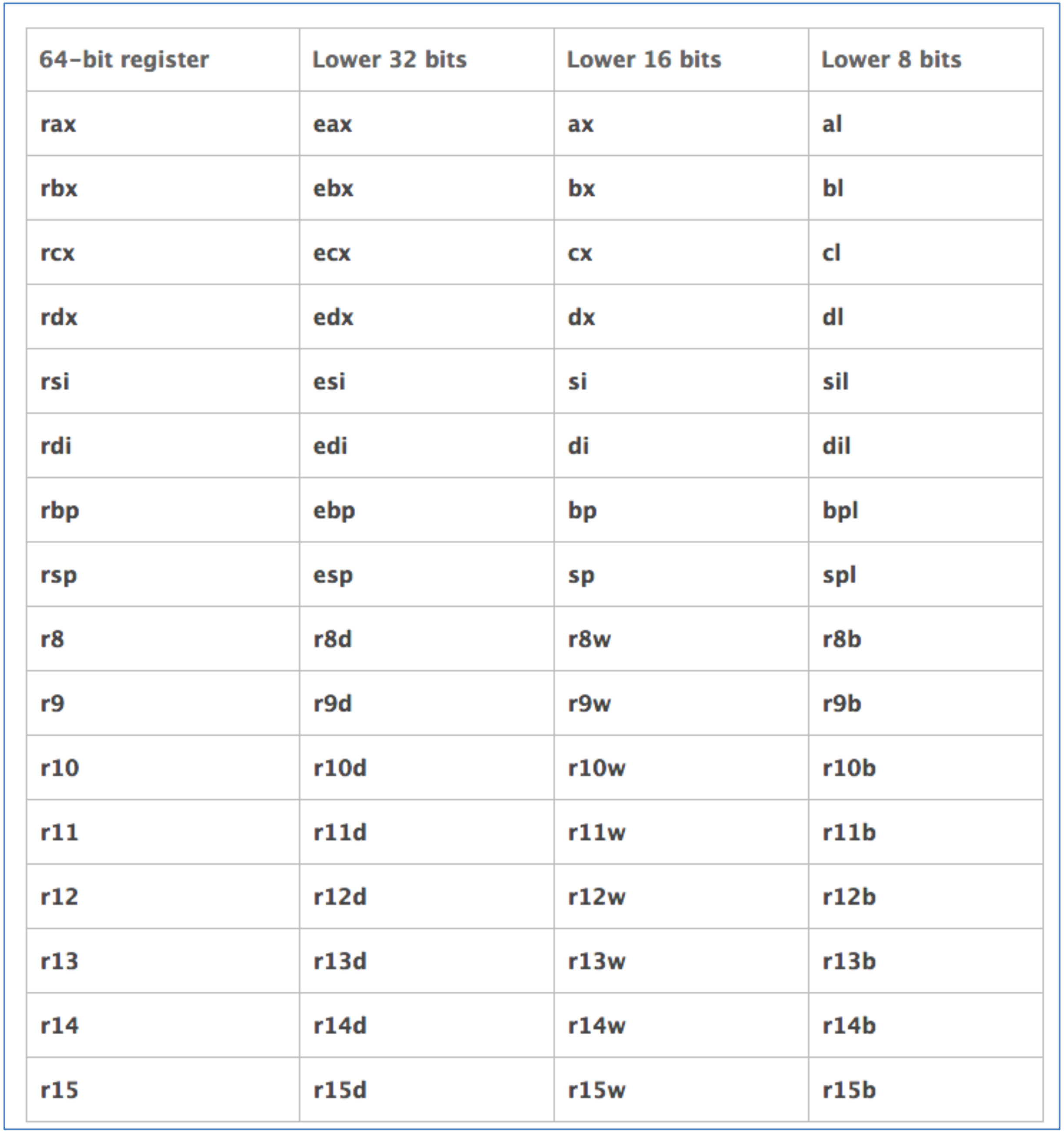
Not in textbook

Rev. 3-21-22

64-bit Registers



- rip = Instruction pointer
- rsp = top of stack

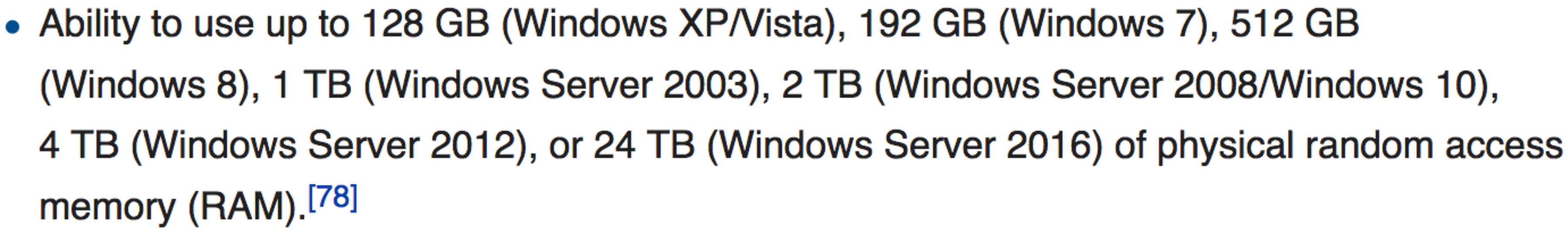


64-bit register	Lower 32 bits	Lower 16 bits	Lower 8 bits
rax	eax	ax	al
rbx	ebx	bx	bl
rcx	ecx	cx	cl
rdx	edx	dx	dl
rsi	esi	si	sil
rdi	edi	di	dil
rbp	ebp	bp	bpl
rsp	esp	sp	spl
r8	r8d	r8w	r8b
r9	r9d	r9w	r9b
r10	r10d	r10w	r10b
r11	r11d	r11w	r11b
r12	r12d	r12w	r12b
r13	r13d	r13w	r13b
r14	r14d	r14w	r14b
r15	r15d	r15w	r15b

Windows Limitations

- Windows doesn't implement full 64-bit addressing
- Windows Server 2016 Datacenter and Win 10 Pro 64-bit Pro uses 48 bits
  - Max. 24 TB RAM
  - Could in principle address 256 TB
- Link L7r

Windows Version Limitations

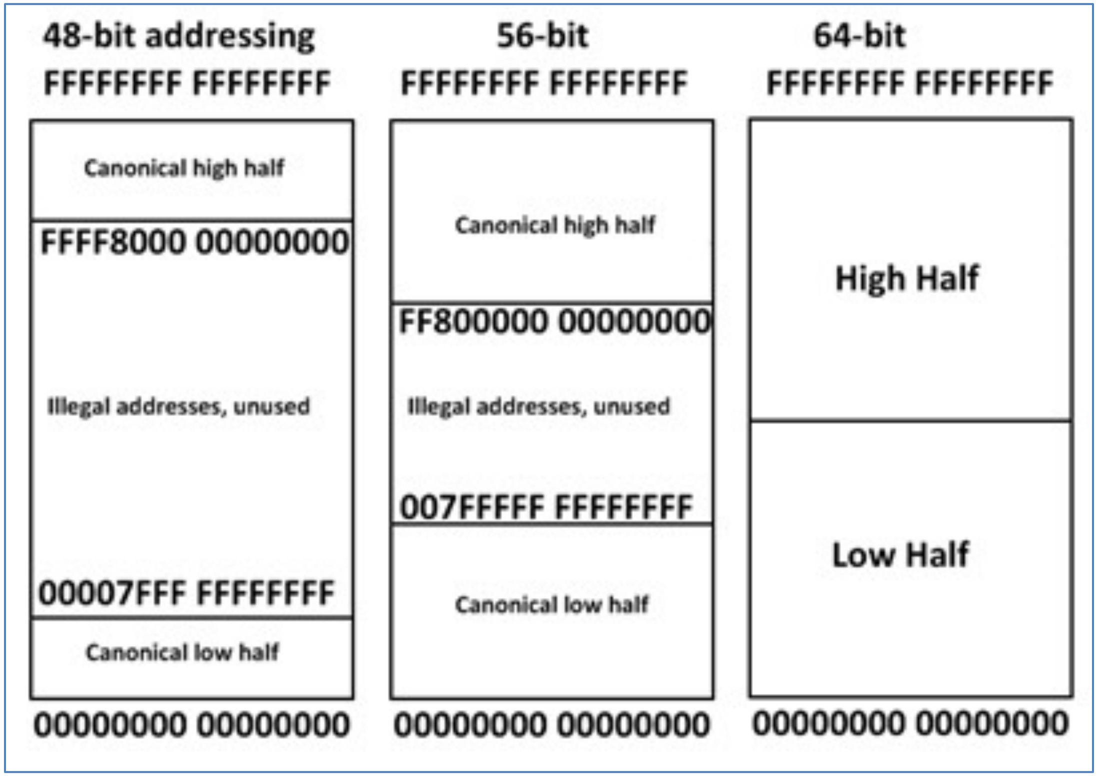


- Ability to use up to 128 GB (Windows XP/Vista), 192 GB (Windows 7), 512 GB (Windows 8), 1 TB (Windows Server 2003), 2 TB (Windows Server 2008/Windows 10), 4 TB (Windows Server 2012), or 24 TB (Windows Server 2016) of physical random access memory (RAM).[78]

- Link L7r

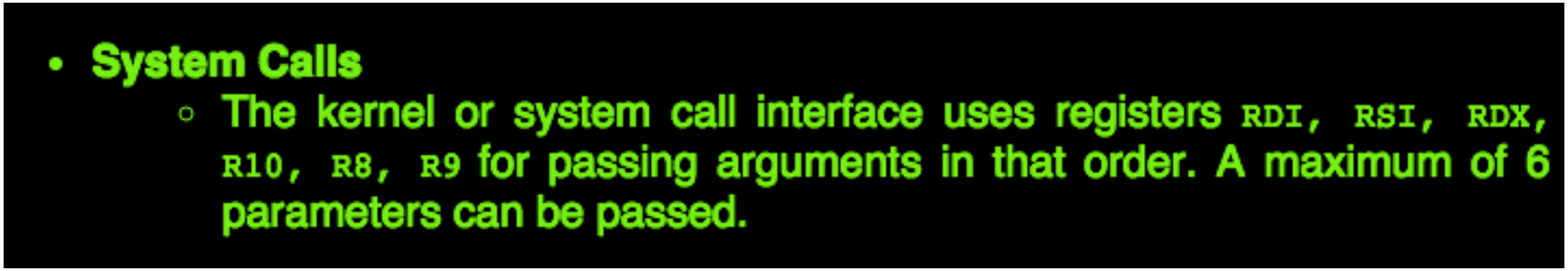
OS Limitations

- OS uses top half
- User programs use lower half

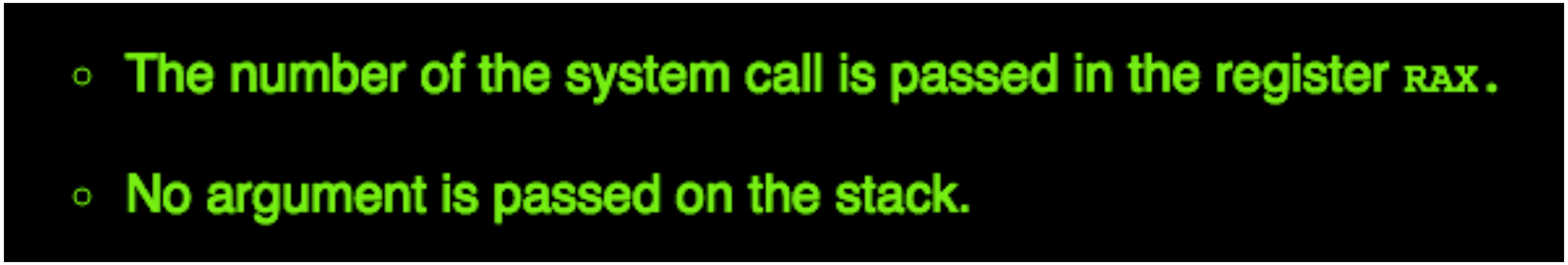


System Calls

- syscall replaces INT 80

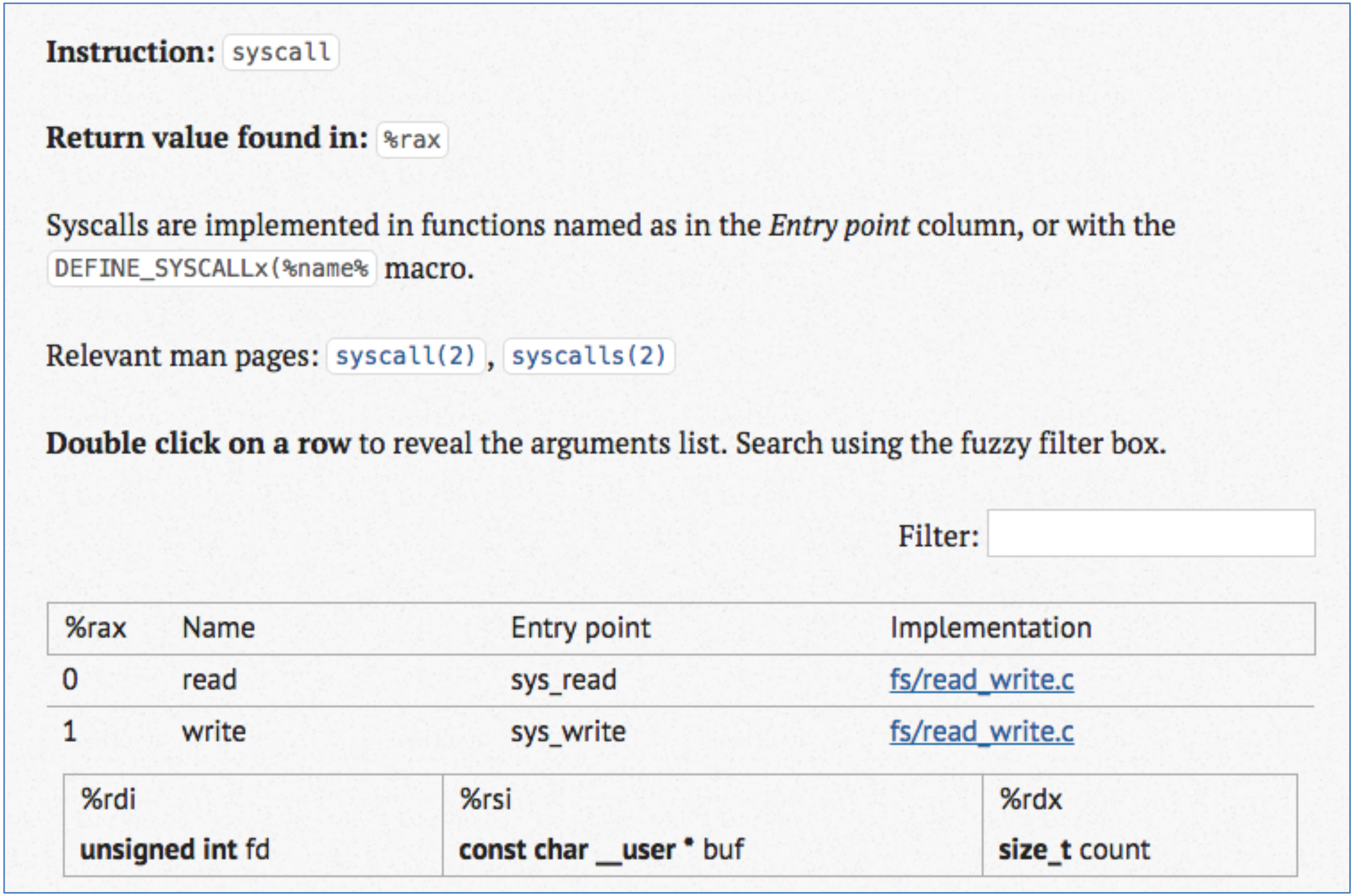


- **System Calls**
  - The kernel or system call interface uses registers `RDI`, `RSI`, `RDX`, `R10`, `R8`, `R9` for passing arguments in that order. A maximum of 6 parameters can be passed.



- The number of the system call is passed in the register `RAX`.
- No argument is passed on the stack.

L7h: Searchable Linux Syscall Table



Instruction: `syscall`

Return value found in: `%rax`

Syscalls are implemented in functions named as in the *Entry point* column, or with the `DEFINE_SYSCALLx(%name%` macro.

Relevant man pages: `syscall(2)`, `syscalls(2)`

Double click on a row to reveal the arguments list. Search using the fuzzy filter box.

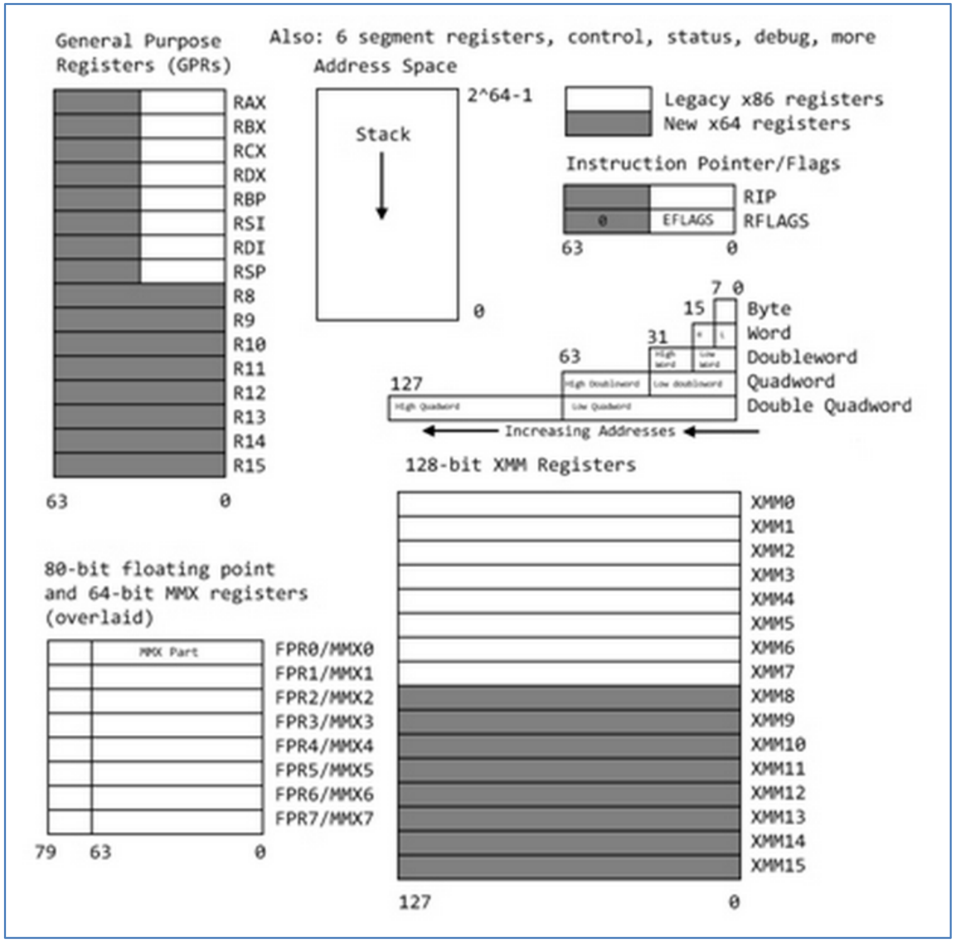
Filter:

%rax	Name	Entry point	Implementation
0	read	sys_read	fs/read_write.c
1	write	sys_write	fs/read_write.c

%rdi	%rsi	%rdx
unsigned int fd	**const char __user *** buf	**size_t** count

L7c: Introduction to x64 Assembly
Intel Developer Zone

- More details about registers



Common Opcodes

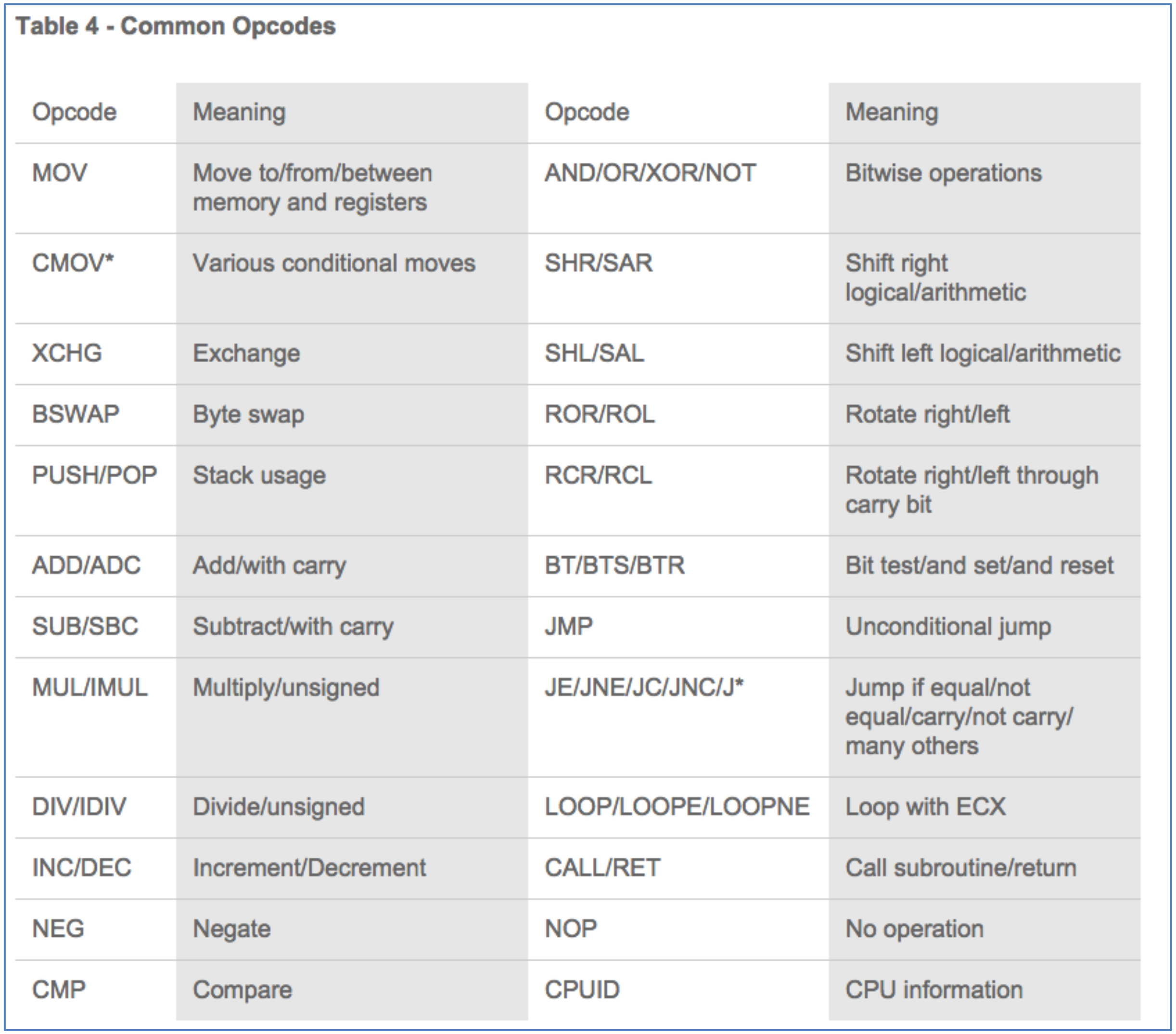
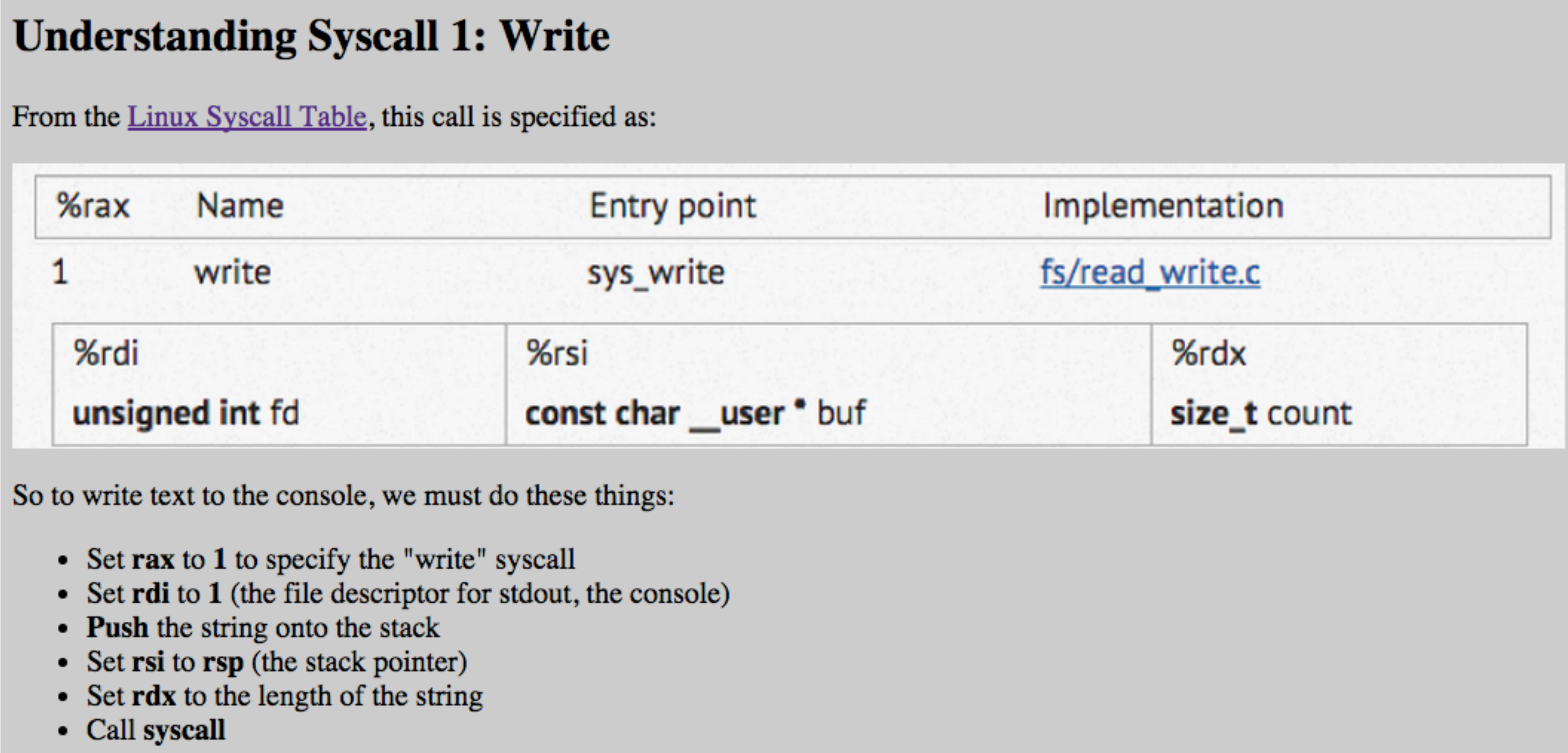


Table 4 - Common Opcodes

Opcode	Meaning	Opcode	Meaning
MOV	Move to/from/between memory and registers	AND/OR/XOR/NOT	Bitwise operations
CMOV*	Various conditional moves	SHR/SAR	Shift right logical/arithmetic
XCHG	Exchange	SHL/SAL	Shift left logical/arithmetic
BSWAP	Byte swap	ROR/ROL	Rotate right/left
PUSH/POP	Stack usage	RCR/RCL	Rotate right/left through carry bit
ADD/ADC	Add/with carry	BT/BTS/BTR	Bit test/and set/and reset
SUB/SBC	Subtract/with carry	JMP	Unconditional jump
MUL/IMUL	Multiply/unsigned	JE/JNE/JC/JNC/J*	Jump if equal/not equal/carry/not carry/ many others
DIV/IDIV	Divide/unsigned	LOOP/LOOPE/LOOPNE	Loop with ECX
INC/DEC	Increment/Decrement	CALL/RET	Call subroutine/return
NEG	Negate	NOP	No operation
CMP	Compare	CPUID	CPU information

Syscall 1: Write



Understanding Syscall 1: Write

From the Linux Syscall Table, this call is specified as:

%rax	Name	Entry point	Implementation
1	write	sys_write	fs/read_write.c

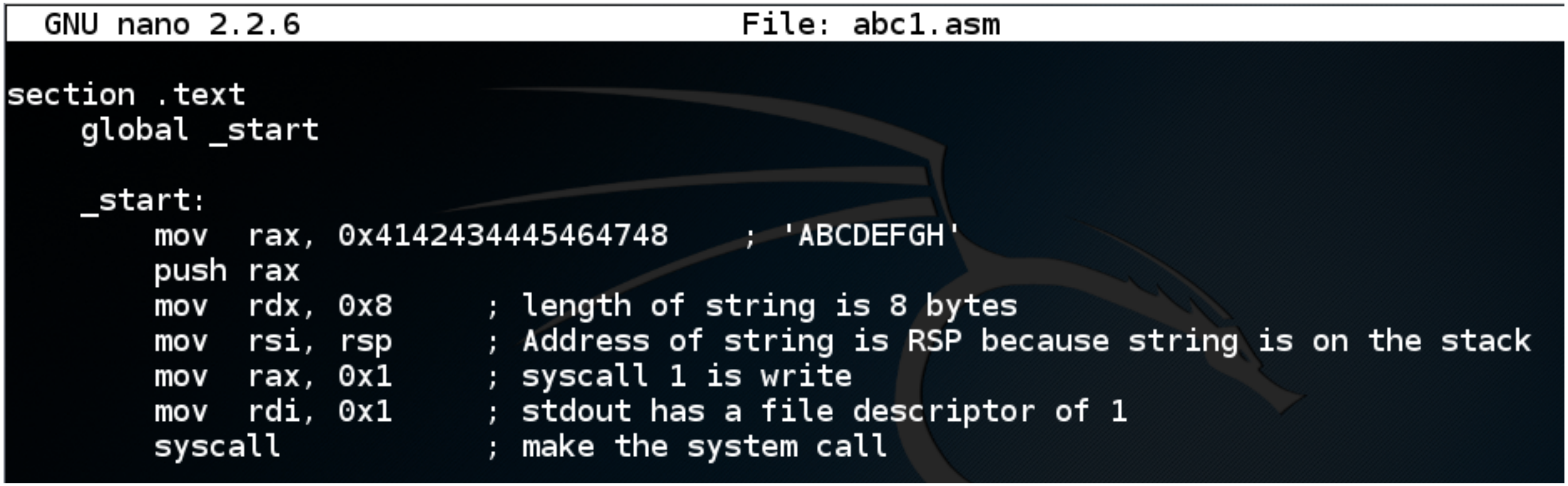
%rdi	%rsi	%rdx
unsigned int fd	**const char __user *** buf	**size_t** count

So to write text to the console, we must do these things:

- Set **rax** to **1** to specify the "write" syscall
- Set **rdi** to **1** (the file descriptor for stdout, the console)
- **Push** the string onto the stack
- Set **rsi** to **rsp** (the stack pointer)
- Set **rdx** to the length of the string
- Call **syscall**

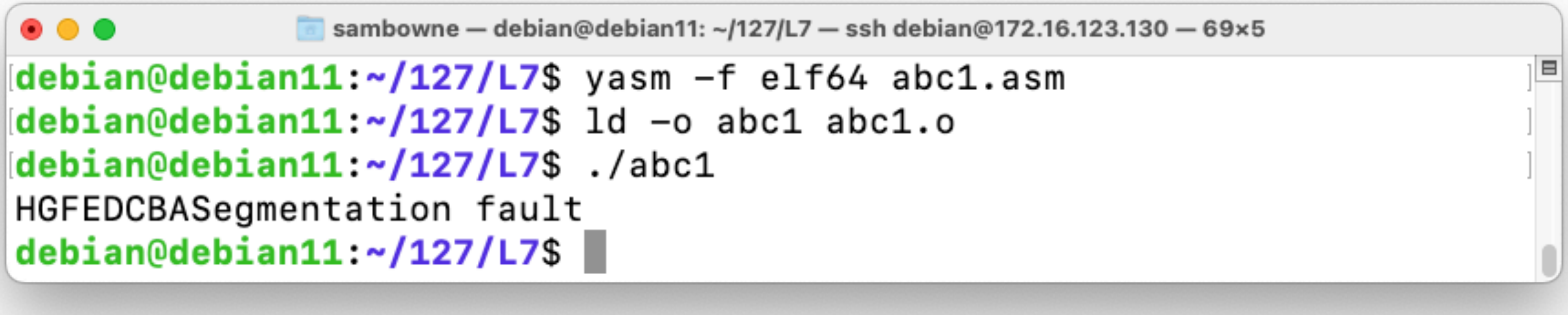
Simplest Program: ABC

Works, then Crashes (no exit)



```
 GNU nano 2.2.6                        File: abc1.asm

section .text
    global _start

    _start:
        mov   rax, 0x4142434445464748     ; 'ABCDEFGH'
        push  rax
        mov   rdx, 0x8        ; length of string is 8 bytes
        mov   rsi, rsp        ; Address of string is RSP because string is on the stack
        mov   rax, 0x1        ; syscall 1 is write
        mov   rdi, 0x1        ; stdout has a file descriptor of 1
        syscall               ; make the system call
```

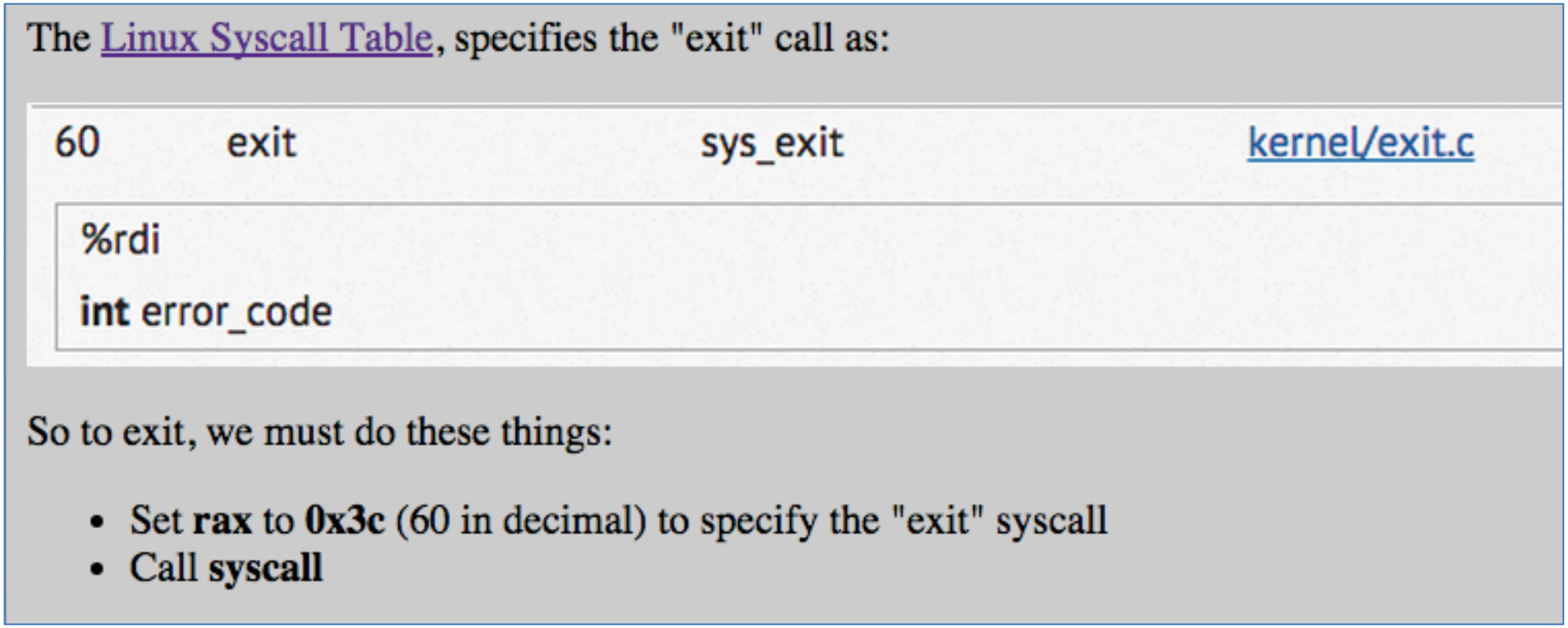
sudo apt install yasm



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 69×5

```
debian@debian11:~/127/L7$ yasm -f elf64 abc1.asm
debian@debian11:~/127/L7$ ld -o abc1 abc1.o
debian@debian11:~/127/L7$ ./abc1
HGFEDCBASegmentation fault
debian@debian11:~/127/L7$ 
```

Exit



The Linux Syscall Table, specifies the "exit" call as:

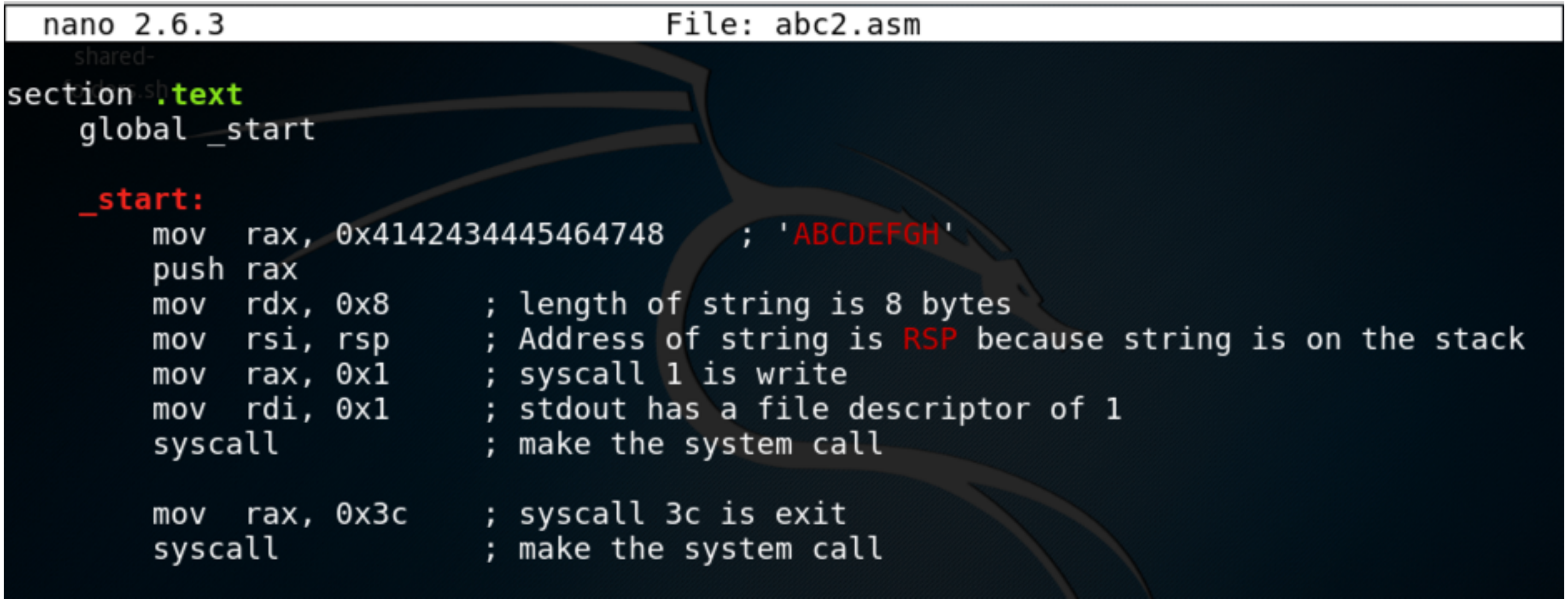
60	exit	sys_exit	kernel/exit.c

%rdi
int error_code

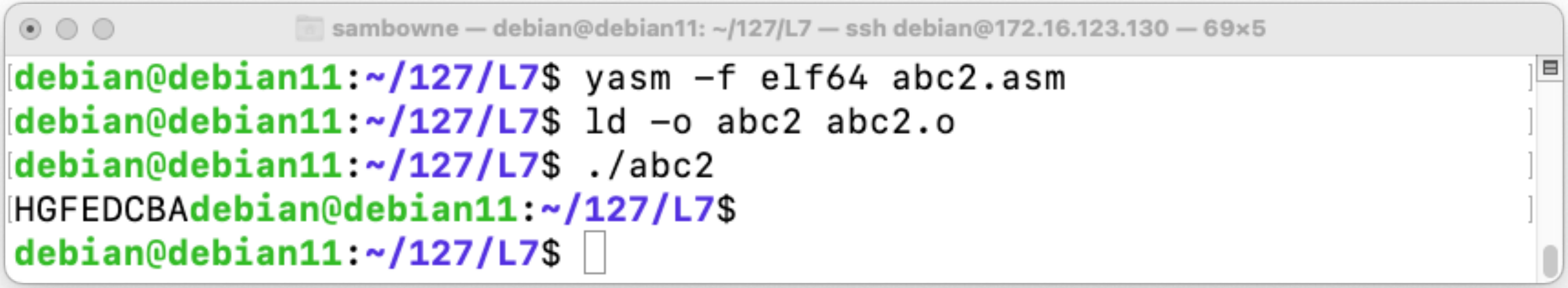
So to exit, we must do these things:

- Set **rax** to **0x3c** (60 in decimal) to specify the "exit" syscall
- Call **syscall**

Works Without Crashing

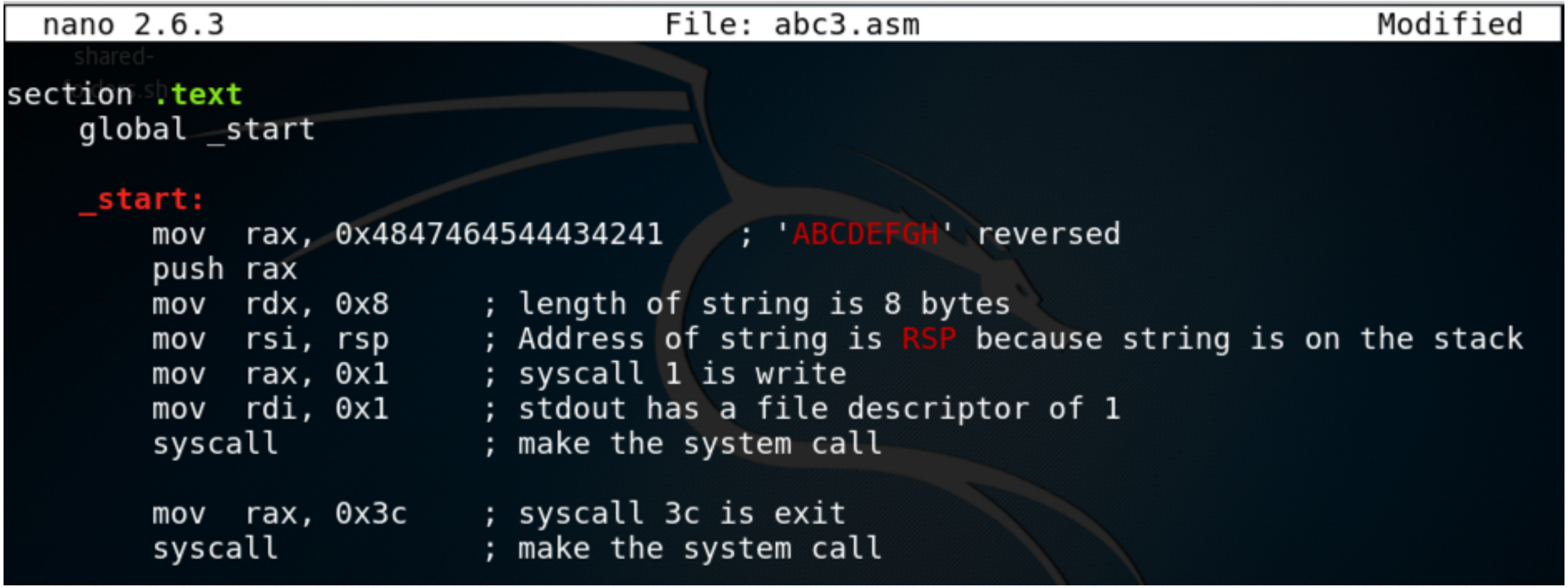


```
section .text
    global _start

    _start:
        mov   rax, 0x4142434445464748     ; 'ABCDEFGH'
        push  rax
        mov   rdx, 0x8       ; length of string is 8 bytes
        mov   rsi, rsp       ; Address of string is RSP because string is on the stack
        mov   rax, 0x1       ; syscall 1 is write
        mov   rdi, 0x1       ; stdout has a file descriptor of 1
        syscall              ; make the system call

        mov   rax, 0x3c      ; syscall 3c is exit
        syscall              ; make the system call
```

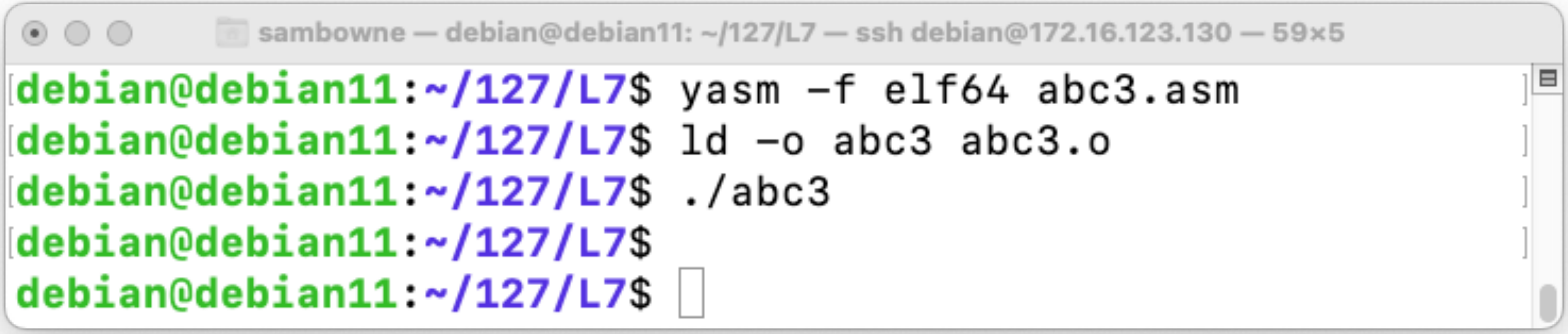

sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 69×5

```
debian@debian11:~/127/L7$ yasm -f elf64 abc2.asm
debian@debian11:~/127/L7$ ld -o abc2 abc2.o
debian@debian11:~/127/L7$ ./abc2
HGFEDCBAdebian@debian11:~/127/L7$
debian@debian11:~/127/L7$
```

Letters in Order



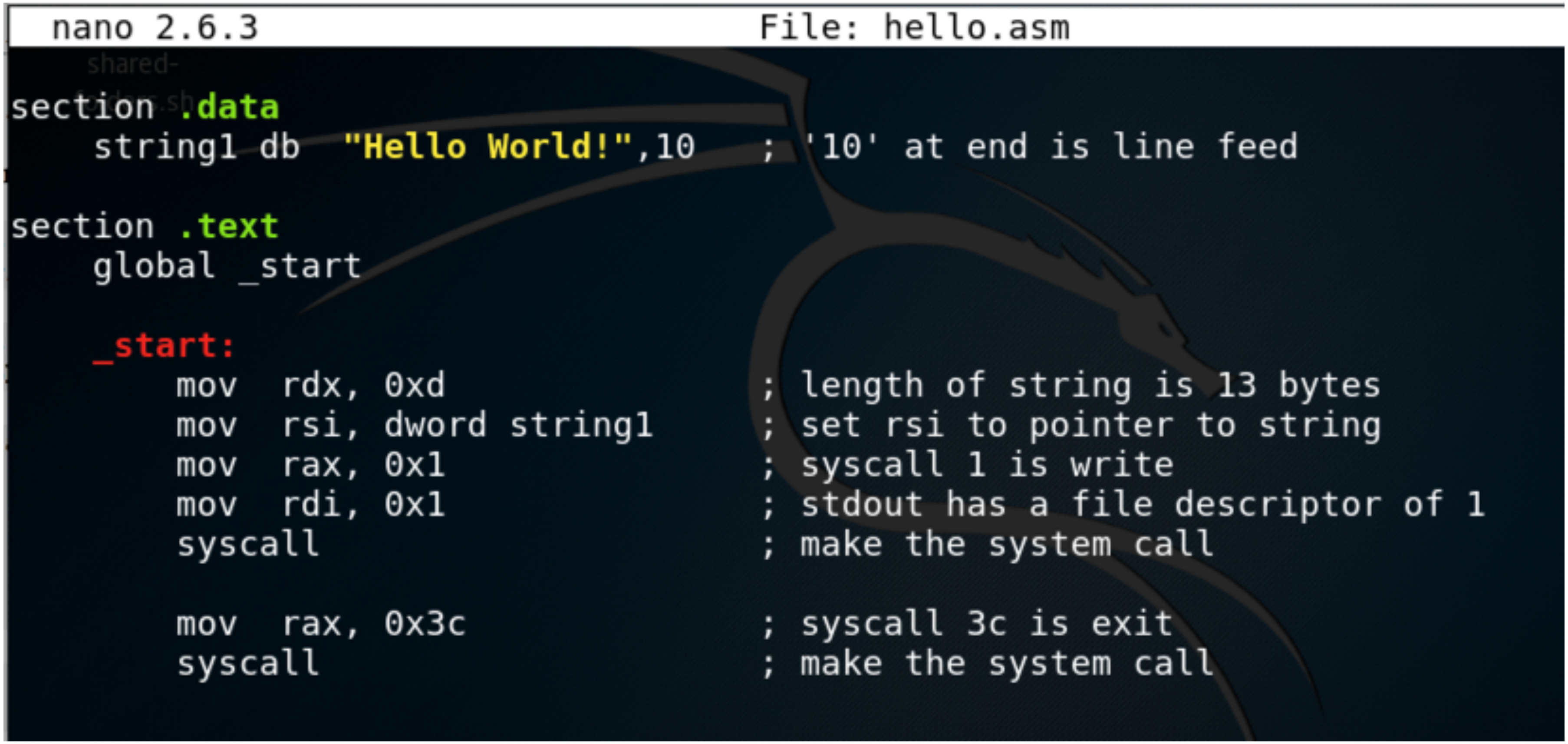
```
 nano 2.6.3                          File: abc3.asm                           Modified

section .text
    global _start

    _start:
        mov   rax, 0x4847464544434241     ; 'ABCDEFGH' reversed
        push rax
        mov   rdx, 0x8      ; length of string is 8 bytes
        mov   rsi, rsp      ; Address of string is RSP because string is on the stack
        mov   rax, 0x1      ; syscall 1 is write
        mov   rdi, 0x1      ; stdout has a file descriptor of 1
        syscall             ; make the system call

        mov   rax, 0x3c     ; syscall 3c is exit
        syscall             ; make the system call
```



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 59×5

```
debian@debian11:~/127/L7$ yasm -f elf64 abc3.asm
debian@debian11:~/127/L7$ ld -o abc3 abc3.o
debian@debian11:~/127/L7$ ./abc3
debian@debian11:~/127/L7$
debian@debian11:~/127/L7$ 
```

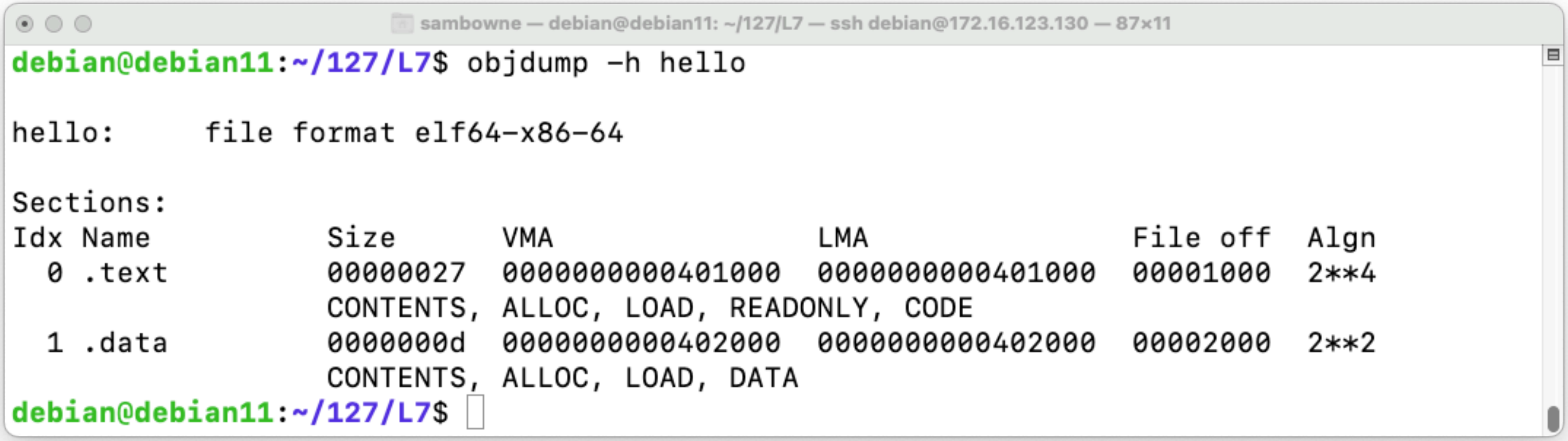
Using a .data section



```
  nano 2.6.3                              File: hello.asm

section .data
    string1 db  "Hello World!",10    ; '10' at end is line feed

section .text
    global _start

    _start:
        mov  rdx, 0xd                ; length of string is 13 bytes
        mov  rsi, dword string1      ; set rsi to pointer to string
        mov  rax, 0x1                ; syscall 1 is write
        mov  rdi, 0x1                ; stdout has a file descriptor of 1
        syscall                      ; make the system call

        mov  rax, 0x3c               ; syscall 3c is exit
        syscall                      ; make the system call
```

- db = "Define Byte"

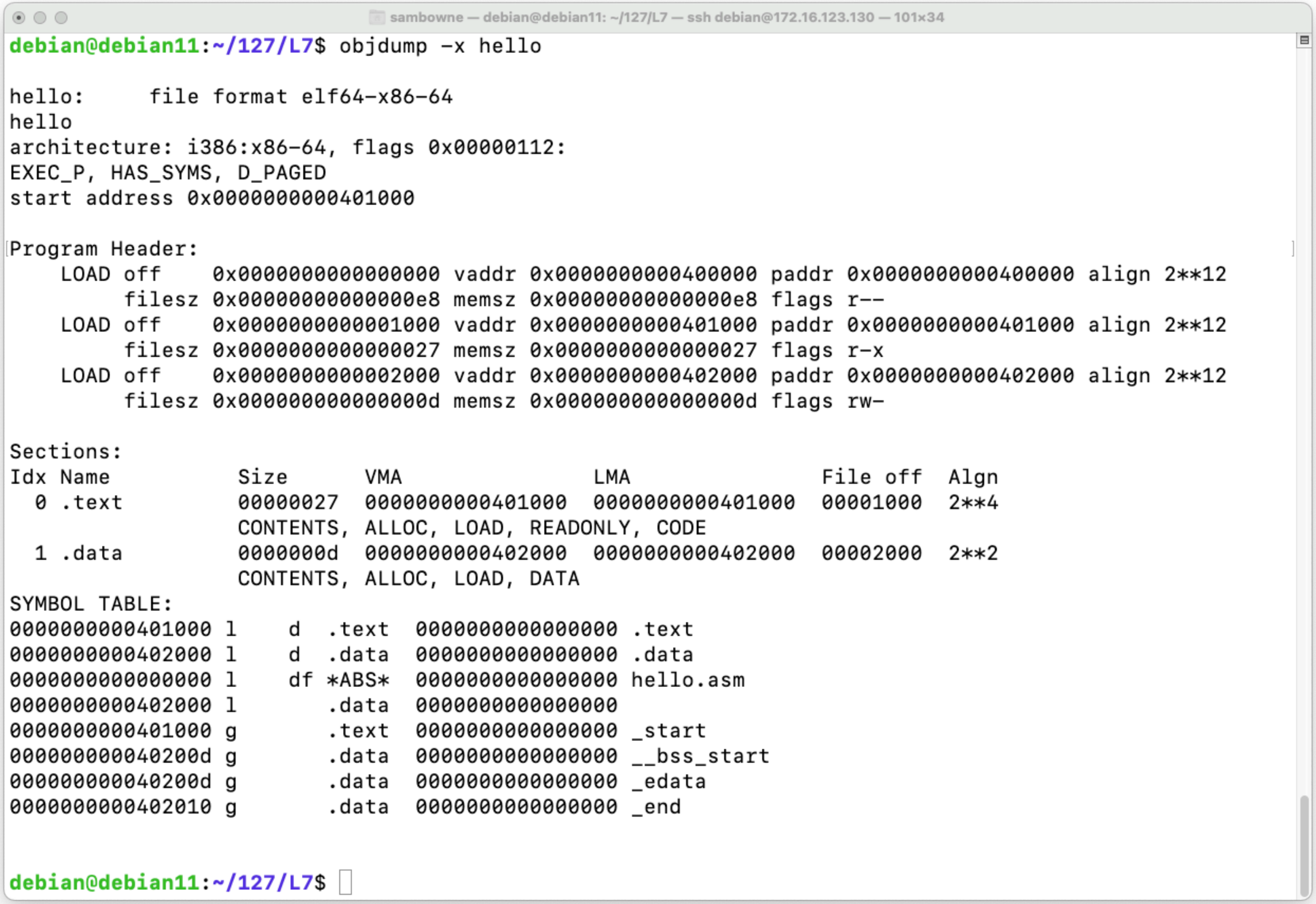
Objdump



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 87×11

```
debian@debian11:~/127/L7$ objdump -h hello

hello:     file format elf64-x86-64

Sections:
Idx Name          Size      VMA               LMA               File off  Algn
  0 .text         00000027  0000000000401000  0000000000401000  00001000  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  1 .data         0000000d  0000000000402000  0000000000402000  00002000  2**2
                  CONTENTS, ALLOC, LOAD, DATA
debian@debian11:~/127/L7$ 
```

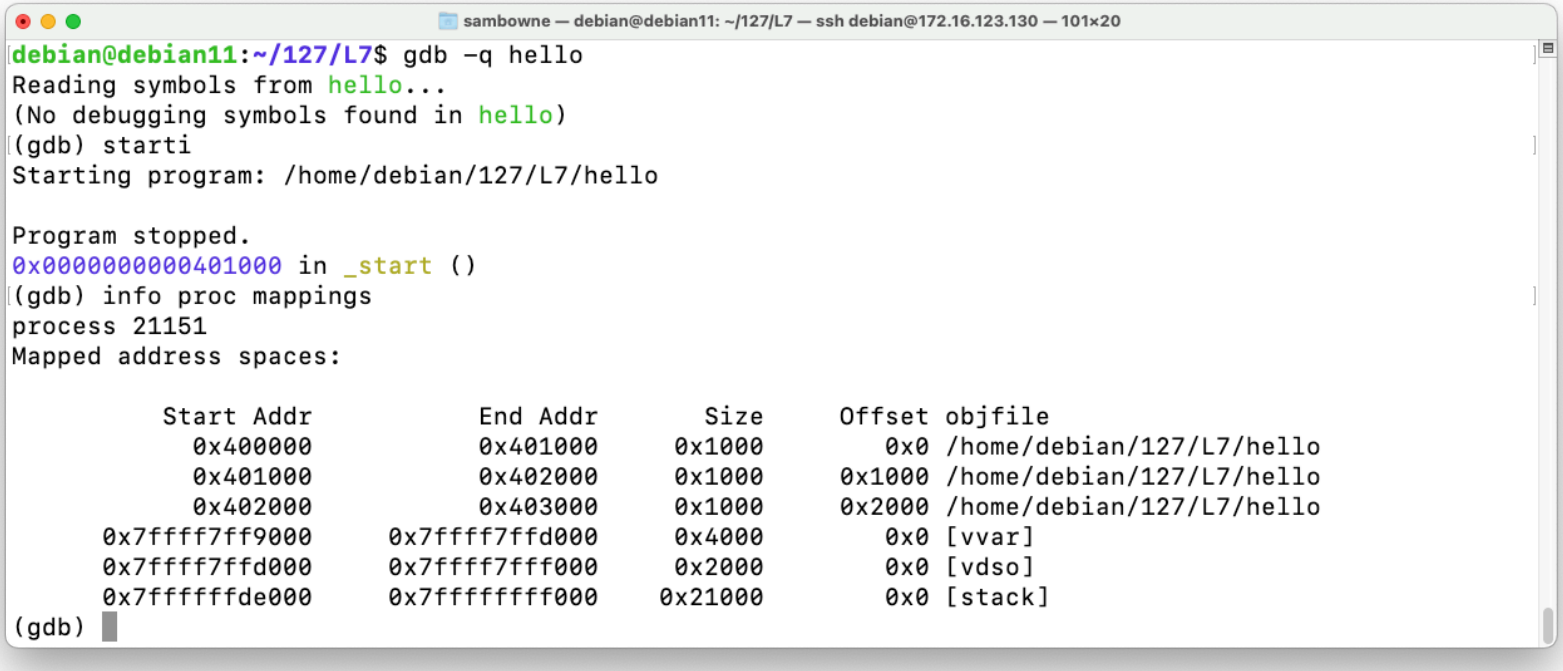
Objdump



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 101×34

```
debian@debian11:~/127/L7$ objdump -x hello

hello:     file format elf64-x86-64
hello
architecture: i386:x86-64, flags 0x00000112:
EXEC_P, HAS_SYMS, D_PAGED
start address 0x0000000000401000

Program Header:
    LOAD off    0x0000000000000000 vaddr 0x0000000000400000 paddr 0x0000000000400000 align 2**12
         filesz 0x00000000000000e8 memsz 0x00000000000000e8 flags r--
    LOAD off    0x0000000000001000 vaddr 0x0000000000401000 paddr 0x0000000000401000 align 2**12
         filesz 0x0000000000000027 memsz 0x0000000000000027 flags r-x
    LOAD off    0x0000000000002000 vaddr 0x0000000000402000 paddr 0x0000000000402000 align 2**12
         filesz 0x000000000000000d memsz 0x000000000000000d flags rw-

Sections:
Idx Name          Size      VMA               LMA               File off  Algn
  0 .text         00000027  0000000000401000  0000000000401000  00001000  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  1 .data         0000000d  0000000000402000  0000000000402000  00002000  2**2
                  CONTENTS, ALLOC, LOAD, DATA
SYMBOL TABLE:
0000000000401000 l    d  .text  0000000000000000 .text
0000000000402000 l    d  .data  0000000000000000 .data
0000000000000000 l    df *ABS*  0000000000000000 hello.asm
0000000000402000 l       .data  0000000000000000
0000000000401000 g       .text  0000000000000000 _start
000000000040200d g       .data  0000000000000000 __bss_start
000000000040200d g       .data  0000000000000000 _edata
0000000000402010 g       .data  0000000000000000 _end


debian@debian11:~/127/L7$
```

Using gdb

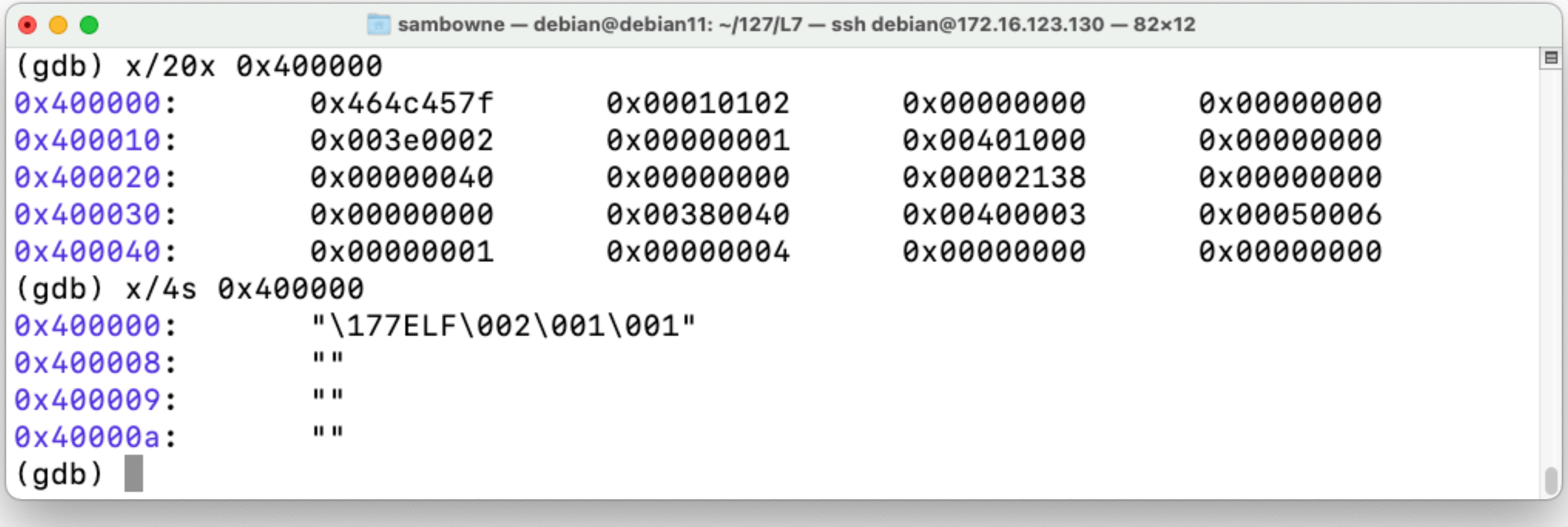


sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 101×20

```
debian@debian11:~/127/L7$ gdb -q hello
Reading symbols from hello...
(No debugging symbols found in hello)
(gdb) starti
Starting program: /home/debian/127/L7/hello

Program stopped.
0x0000000000401000 in _start ()
(gdb) info proc mappings
process 21151
Mapped address spaces:

          Start Addr           End Addr       Size     Offset objfile
            0x400000           0x401000     0x1000        0x0 /home/debian/127/L7/hello
            0x401000           0x402000     0x1000     0x1000 /home/debian/127/L7/hello
            0x402000           0x403000     0x1000     0x2000 /home/debian/127/L7/hello
      0x7ffff7ff9000     0x7ffff7ffd000     0x4000        0x0 [vvar]
      0x7ffff7ffd000     0x7ffff7fff000     0x2000        0x0 [vdso]
      0x7ffffffde000     0x7ffffffff000    0x21000        0x0 [stack]
(gdb) 
```

- There are three "hello.out" sections

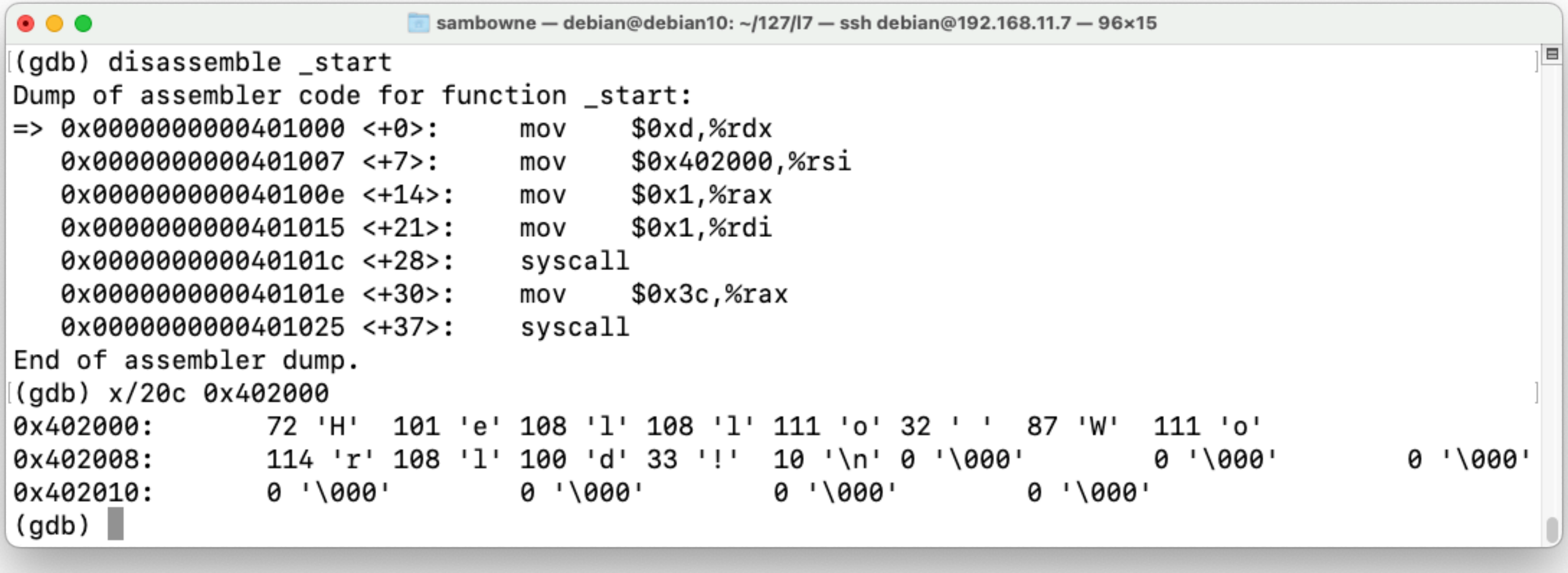
ELF Header



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 82×12

```
(gdb) x/20x 0x400000
0x400000:       0x464c457f      0x00010102      0x00000000      0x00000000
0x400010:       0x003e0002      0x00000001      0x00401000      0x00000000
0x400020:       0x00000040      0x00000000      0x00002138      0x00000000
0x400030:       0x00000000      0x00380040      0x00400003      0x00050006
0x400040:       0x00000001      0x00000004      0x00000000      0x00000000
(gdb) x/4s 0x400000
0x400000:       "\177ELF\002\001\001"
0x400008:       ""
0x400009:       ""
0x40000a:       ""
(gdb) 
```

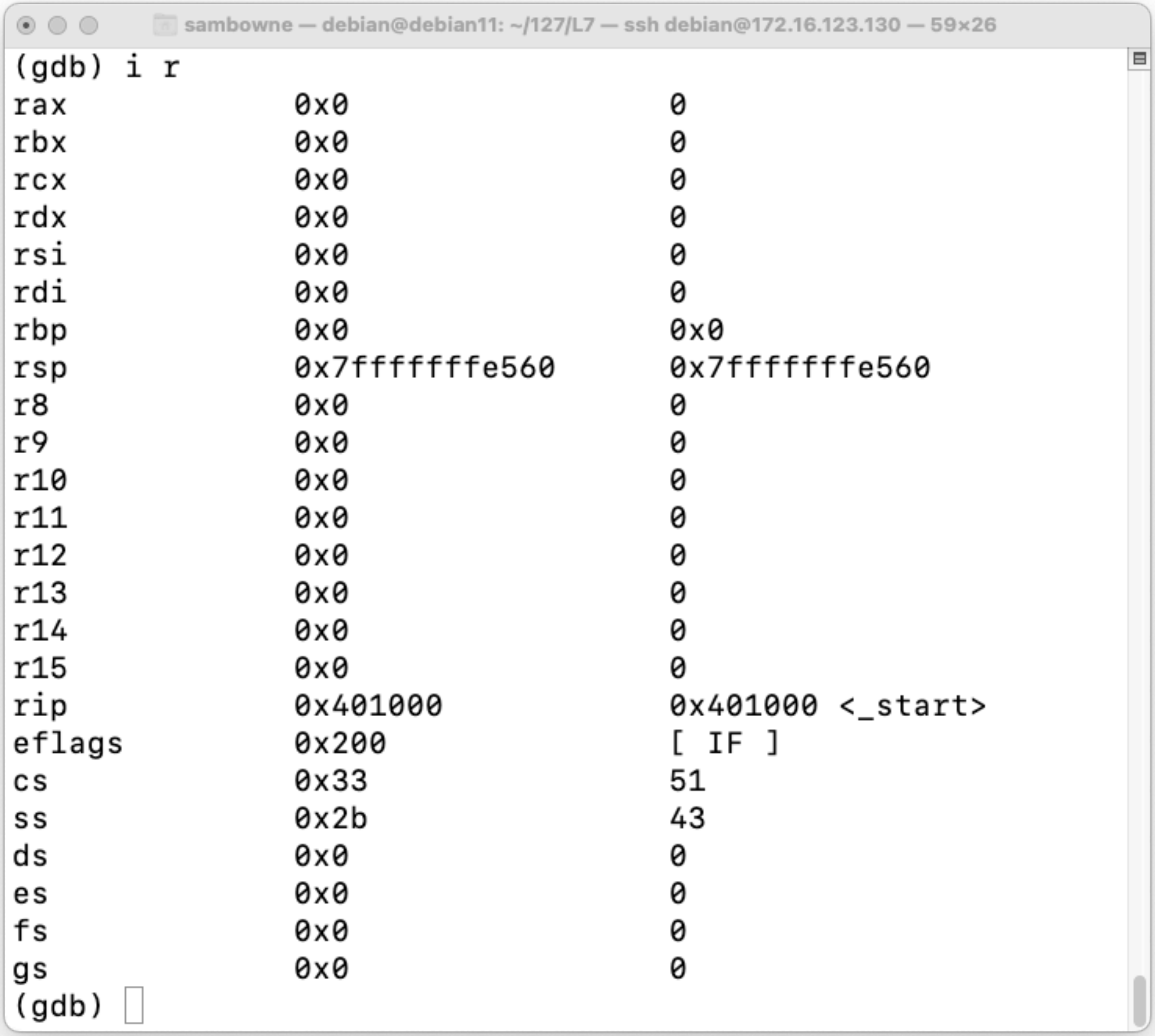
.text and .data Sections



sambowne — debian@debian10: ~/127/l7 — ssh debian@192.168.11.7 — 96×15

```
(gdb) disassemble _start
Dump of assembler code for function _start:
=> 0x0000000000401000 <+0>:     mov    $0xd,%rdx
   0x0000000000401007 <+7>:     mov    $0x402000,%rsi
   0x000000000040100e <+14>:    mov    $0x1,%rax
   0x0000000000401015 <+21>:    mov    $0x1,%rdi
   0x000000000040101c <+28>:    syscall
   0x000000000040101e <+30>:    mov    $0x3c,%rax
   0x0000000000401025 <+37>:    syscall
End of assembler dump.
(gdb) x/20c 0x402000
0x402000:       72 'H'  101 'e' 108 'l' 108 'l' 111 'o' 32 ' '  87 'W'  111 'o'
0x402008:       114 'r' 108 'l' 100 'd' 33 '!'  10 '\n' 0 '\000'        0 '\000'        0 '\000'
0x402010:       0 '\000'        0 '\000'        0 '\000'        0 '\000'
(gdb) 
```

info registers

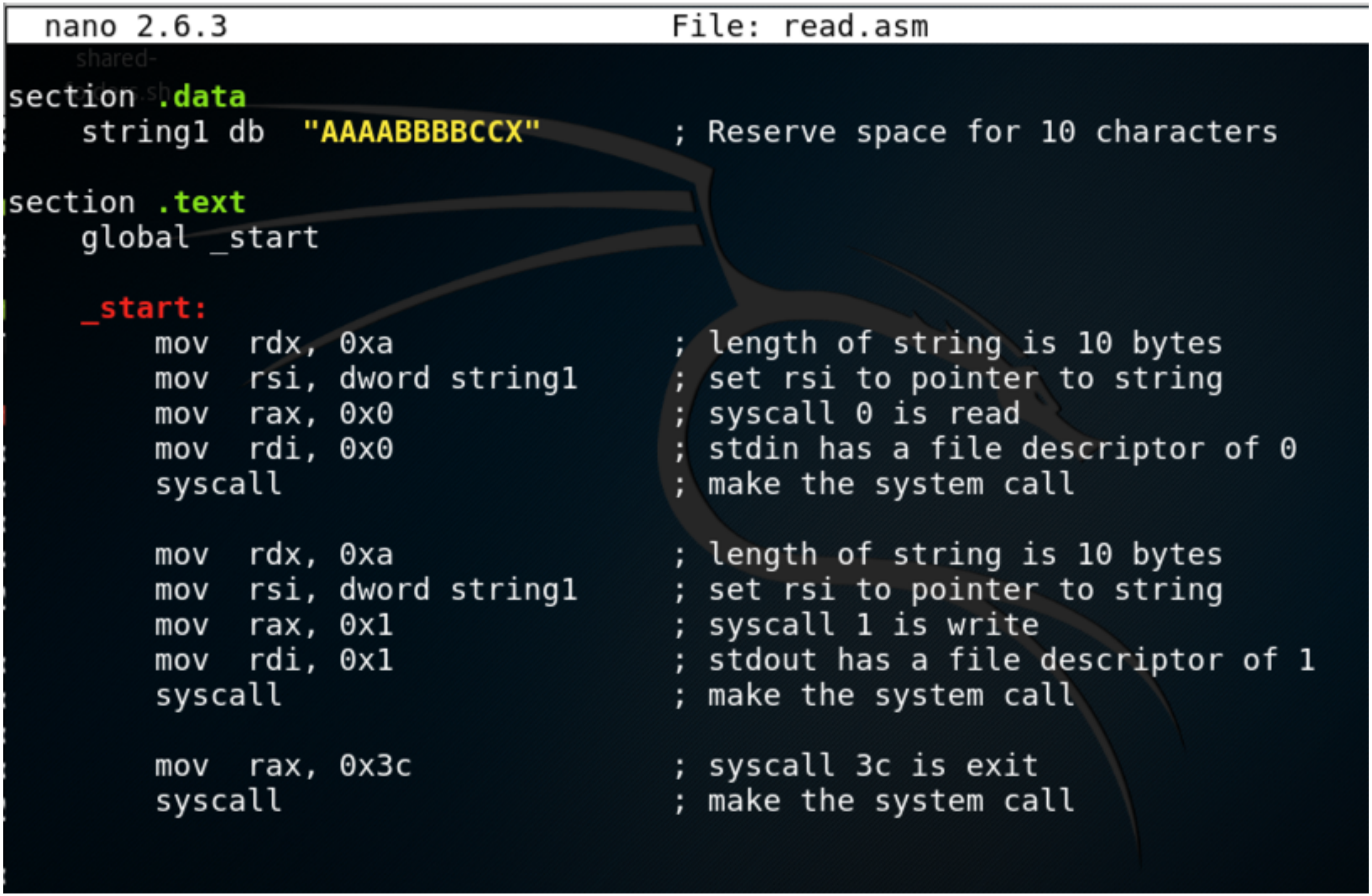


sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 59×26

```
(gdb) i r
rax            0x0                 0
rbx            0x0                 0
rcx            0x0                 0
rdx            0x0                 0
rsi            0x0                 0
rdi            0x0                 0
rbp            0x0                 0x0
rsp            0x7fffffffe560      0x7fffffffe560
r8             0x0                 0
r9             0x0                 0
r10            0x0                 0
r11            0x0                 0
r12            0x0                 0
r13            0x0                 0
r14            0x0                 0
r15            0x0                 0
rip            0x401000            0x401000 <_start>
eflags         0x200               [ IF ]
cs             0x33                51
ss             0x2b                43
ds             0x0                 0
es             0x0                 0
fs             0x0                 0
gs             0x0                 0
(gdb) 
```

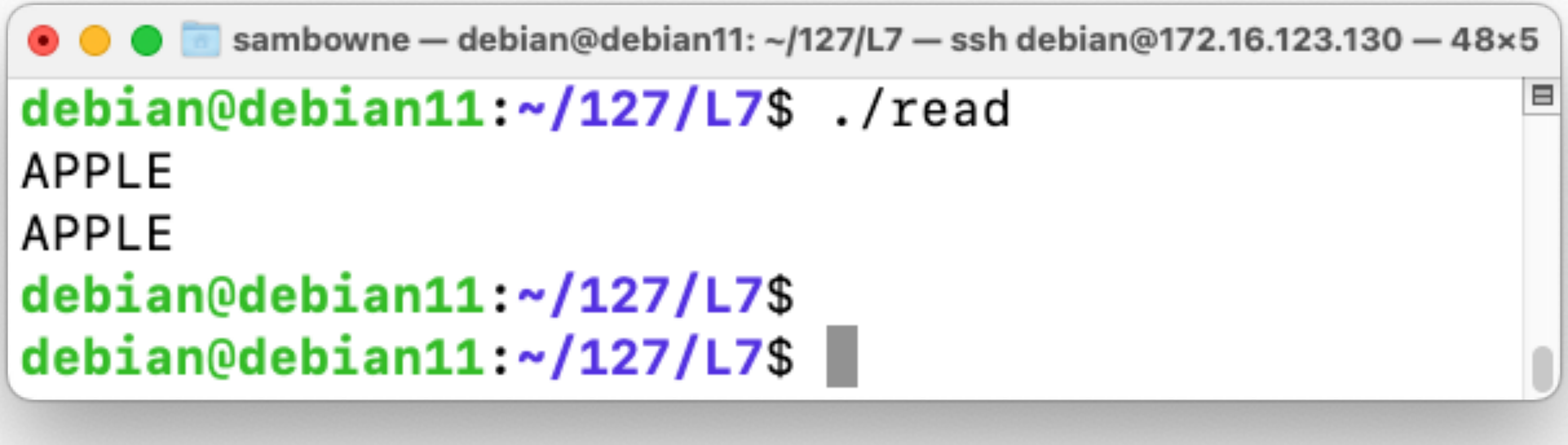
Using read

"echo" with a .data section



```
  nano 2.6.3                             File: read.asm

section .data
    string1 db  "AAAABBBBCCX"           ; Reserve space for 10 characters

section .text
    global _start

    _start:
        mov   rdx, 0xa                   ; length of string is 10 bytes
        mov   rsi, dword string1         ; set rsi to pointer to string
        mov   rax, 0x0                   ; syscall 0 is read
        mov   rdi, 0x0                   ; stdin has a file descriptor of 0
        syscall                          ; make the system call

        mov   rdx, 0xa                   ; length of string is 10 bytes
        mov   rsi, dword string1         ; set rsi to pointer to string
        mov   rax, 0x1                   ; syscall 1 is write
        mov   rdi, 0x1                   ; stdout has a file descriptor of 1
        syscall                          ; make the system call

        mov   rax, 0x3c                  ; syscall 3c is exit
        syscall                          ; make the system call
```

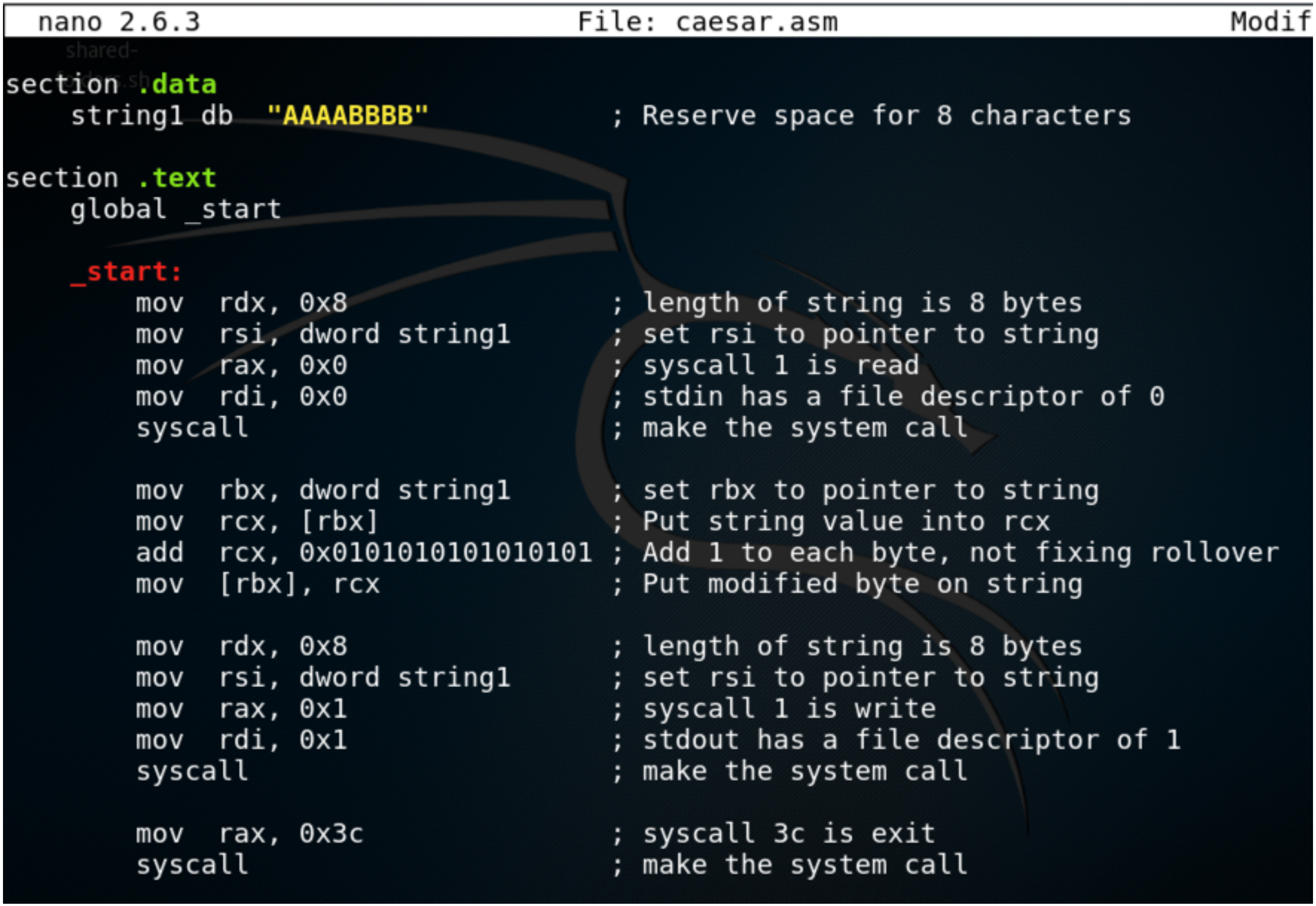
Works with Junk at End



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 48×5

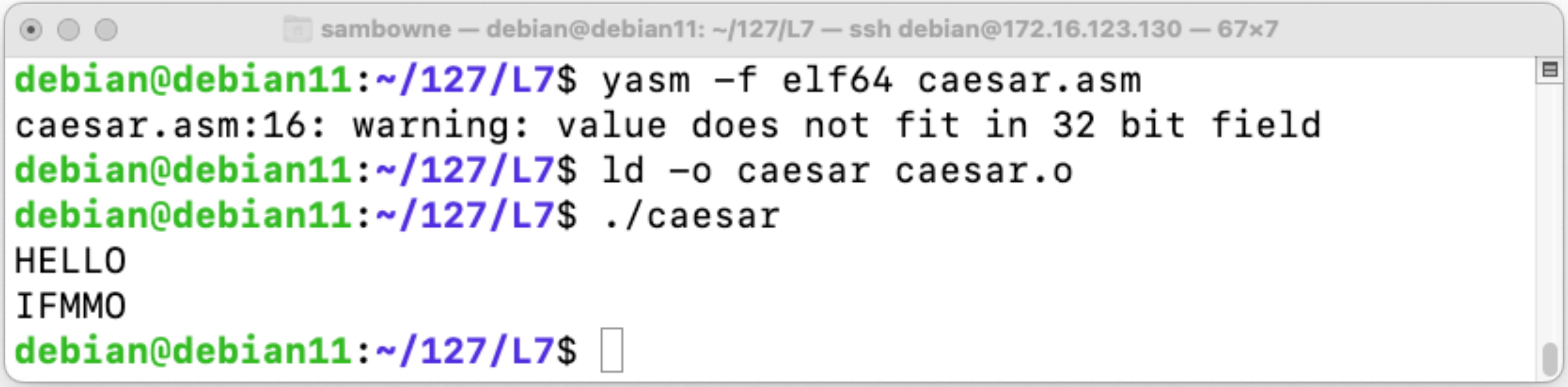
```
debian@debian11:~/127/L7$ ./read
APPLE
APPLE
debian@debian11:~/127/L7$
debian@debian11:~/127/L7$
```

Caesar Cipher



```
  nano 2.6.3                        File: caesar.asm                          Modif

section .data
    string1 db  "AAAABBBB"              ; Reserve space for 8 characters

section .text
    global _start

    _start:
        mov  rdx, 0x8                   ; length of string is 8 bytes
        mov  rsi, dword string1         ; set rsi to pointer to string
        mov  rax, 0x0                   ; syscall 1 is read
        mov  rdi, 0x0                   ; stdin has a file descriptor of 0
        syscall                         ; make the system call

        mov  rbx, dword string1         ; set rbx to pointer to string
        mov  rcx, [rbx]                 ; Put string value into rcx
        add  rcx, 0x0101010101010101 ; Add 1 to each byte, not fixing rollover
        mov  [rbx], rcx                 ; Put modified byte on string

        mov  rdx, 0x8                   ; length of string is 8 bytes
        mov  rsi, dword string1         ; set rsi to pointer to string
        mov  rax, 0x1                   ; syscall 1 is write
        mov  rdi, 0x1                   ; stdout has a file descriptor of 1
        syscall                         ; make the system call

        mov  rax, 0x3c                  ; syscall 3c is exit
        syscall                         ; make the system call
```

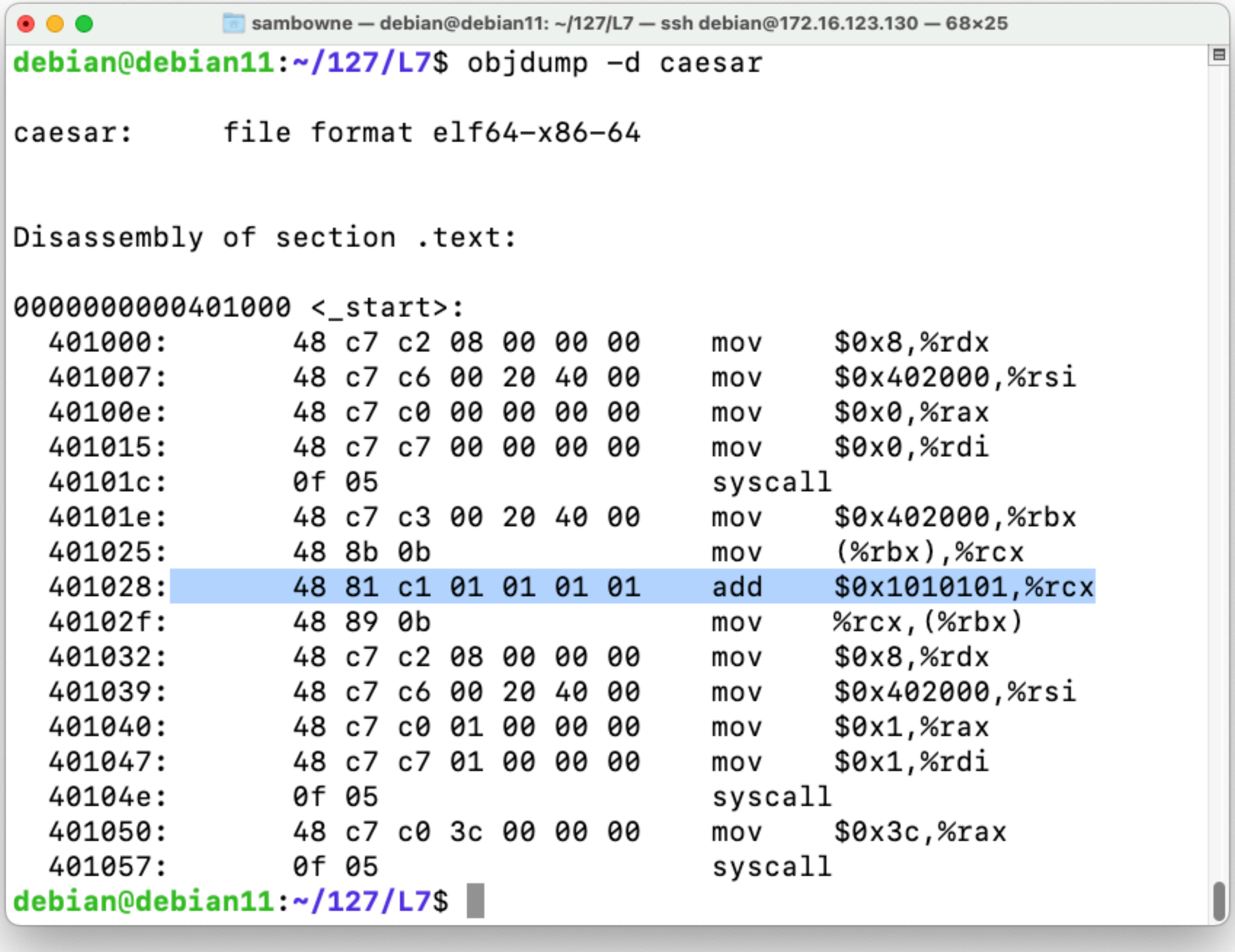
Works for 4 Bytes Only



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 67×7

```
debian@debian11:~/127/L7$ yasm -f elf64 caesar.asm
caesar.asm:16: warning: value does not fit in 32 bit field
debian@debian11:~/127/L7$ ld -o caesar caesar.o
debian@debian11:~/127/L7$ ./caesar
HELLO
IFMMO
debian@debian11:~/127/L7$ 
```

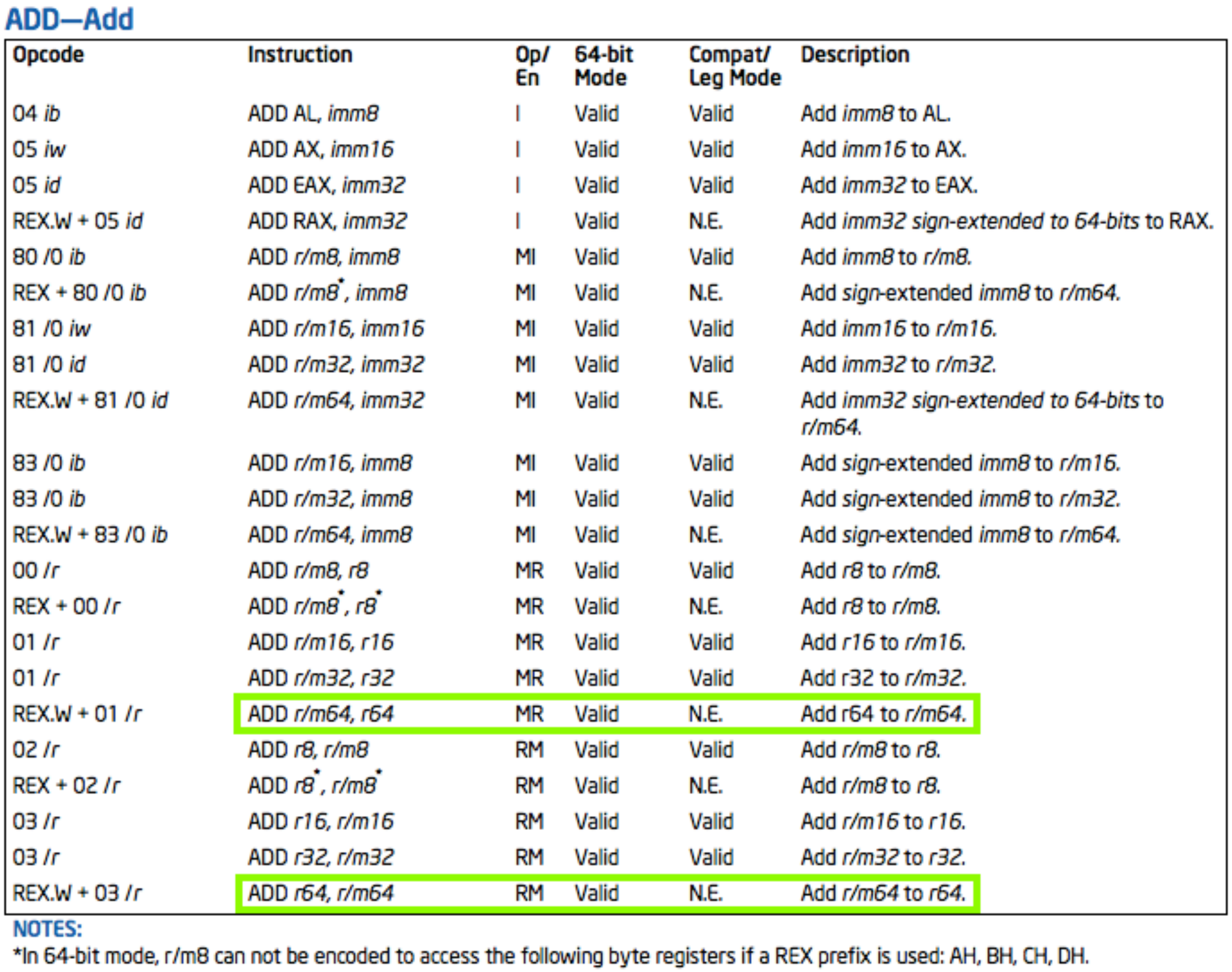
Objdump Shows a 32-bit Value



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 68×25

```
debian@debian11:~/127/L7$ objdump -d caesar

caesar:     file format elf64-x86-64


Disassembly of section .text:

0000000000401000 <_start>:
  401000:	48 c7 c2 08 00 00 00 	mov    $0x8,%rdx
  401007:	48 c7 c6 00 20 40 00 	mov    $0x402000,%rsi
  40100e:	48 c7 c0 00 00 00 00 	mov    $0x0,%rax
  401015:	48 c7 c7 00 00 00 00 	mov    $0x0,%rdi
  40101c:	0f 05                	syscall
  40101e:	48 c7 c3 00 20 40 00 	mov    $0x402000,%rbx
  401025:	48 8b 0b             	mov    (%rbx),%rcx
  401028:	48 81 c1 01 01 01 01 	add    $0x1010101,%rcx
  40102f:	48 89 0b             	mov    %rcx,(%rbx)
  401032:	48 c7 c2 08 00 00 00 	mov    $0x8,%rdx
  401039:	48 c7 c6 00 20 40 00 	mov    $0x402000,%rsi
  401040:	48 c7 c0 01 00 00 00 	mov    $0x1,%rax
  401047:	48 c7 c7 01 00 00 00 	mov    $0x1,%rdi
  40104e:	0f 05                	syscall
  401050:	48 c7 c0 3c 00 00 00 	mov    $0x3c,%rax
  401057:	0f 05                	syscall
debian@debian11:~/127/L7$
```

Intel 64 and IA-32 Architectures Software Developer's Manual



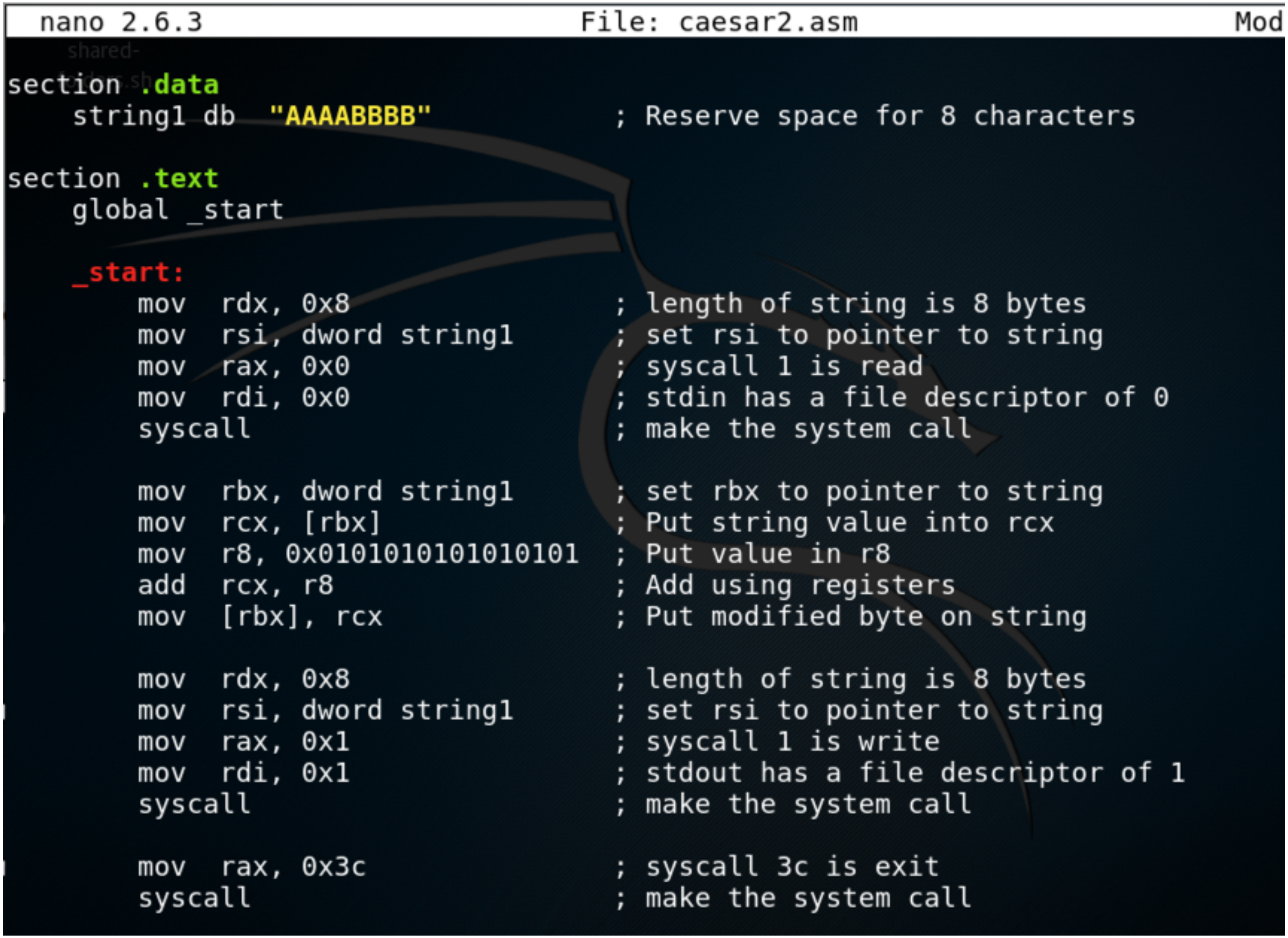
ADD—Add

Opcode	Instruction	Op/ En	64-bit Mode	Compat/ Leg Mode	Description
04 ib	ADD AL, imm8	I	Valid	Valid	Add imm8 to AL.
05 iw	ADD AX, imm16	I	Valid	Valid	Add imm16 to AX.
05 id	ADD EAX, imm32	I	Valid	Valid	Add imm32 to EAX.
REX.W + 05 id	ADD RAX, imm32	I	Valid	N.E.	Add imm32 sign-extended to 64-bits to RAX.
80 /0 ib	ADD r/m8, imm8	MI	Valid	Valid	Add imm8 to r/m8.
REX + 80 /0 ib	ADD r/m8*, imm8	MI	Valid	N.E.	Add sign-extended imm8 to r/m64.
81 /0 iw	ADD r/m16, imm16	MI	Valid	Valid	Add imm16 to r/m16.
81 /0 id	ADD r/m32, imm32	MI	Valid	Valid	Add imm32 to r/m32.
REX.W + 81 /0 id	ADD r/m64, imm32	MI	Valid	N.E.	Add imm32 sign-extended to 64-bits to r/m64.
83 /0 ib	ADD r/m16, imm8	MI	Valid	Valid	Add sign-extended imm8 to r/m16.
83 /0 ib	ADD r/m32, imm8	MI	Valid	Valid	Add sign-extended imm8 to r/m32.
REX.W + 83 /0 ib	ADD r/m64, imm8	MI	Valid	N.E.	Add sign-extended imm8 to r/m64.
00 /r	ADD r/m8, r8	MR	Valid	Valid	Add r8 to r/m8.
REX + 00 /r	ADD r/m8*, r8*	MR	Valid	N.E.	Add r8 to r/m8.
01 /r	ADD r/m16, r16	MR	Valid	Valid	Add r16 to r/m16.
01 /r	ADD r/m32, r32	MR	Valid	Valid	Add r32 to r/m32.
REX.W + 01 /r	ADD r/m64, r64	MR	Valid	N.E.	Add r64 to r/m64.
02 /r	ADD r8, r/m8	RM	Valid	Valid	Add r/m8 to r8.
REX + 02 /r	ADD r8*, r/m8*	RM	Valid	N.E.	Add r/m8 to r8.
03 /r	ADD r16, r/m16	RM	Valid	Valid	Add r/m16 to r16.
03 /r	ADD r32, r/m32	RM	Valid	Valid	Add r/m32 to r32.
REX.W + 03 /r	ADD r64, r/m64	RM	Valid	N.E.	Add r/m64 to r64.

NOTES:

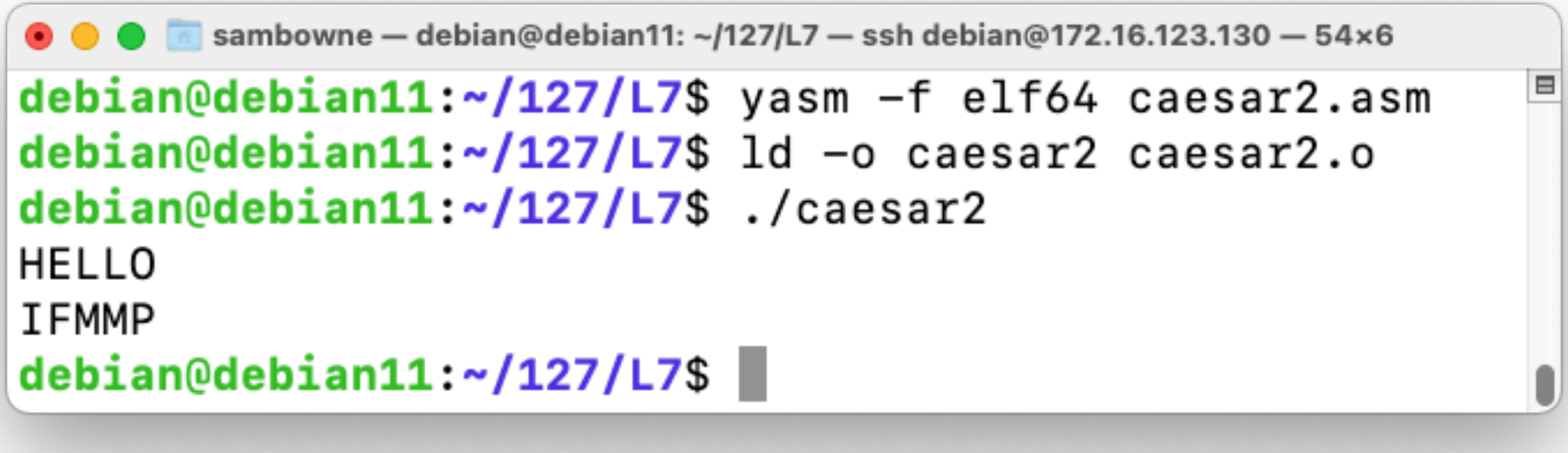
*In 64-bit mode, r/m8 can not be encoded to access the following byte registers if a REX prefix is used: AH, BH, CH, DH.

Must use a Register



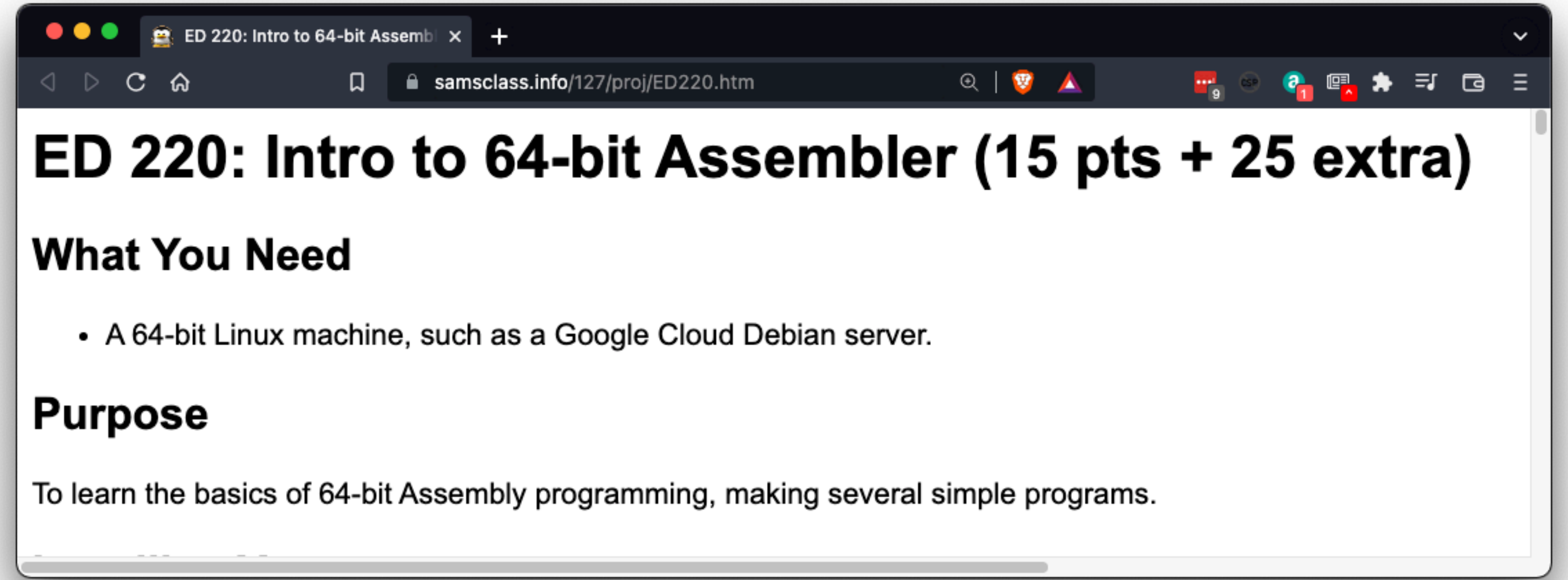
```
  nano 2.6.3                       File: caesar2.asm                       Mod

section .data
    string1 db  "AAAABBBB"             ; Reserve space for 8 characters

section .text
    global _start

    _start:
        mov   rdx, 0x8                 ; length of string is 8 bytes
        mov   rsi, dword string1       ; set rsi to pointer to string
        mov   rax, 0x0                 ; syscall 1 is read
        mov   rdi, 0x0                 ; stdin has a file descriptor of 0
        syscall                        ; make the system call

        mov   rbx, dword string1       ; set rbx to pointer to string
        mov   rcx, [rbx]               ; Put string value into rcx
        mov   r8, 0x0101010101010101   ; Put value in r8
        add   rcx, r8                  ; Add using registers
        mov   [rbx], rcx               ; Put modified byte on string

        mov   rdx, 0x8                 ; length of string is 8 bytes
        mov   rsi, dword string1       ; set rsi to pointer to string
        mov   rax, 0x1                 ; syscall 1 is write
        mov   rdi, 0x1                 ; stdout has a file descriptor of 1
        syscall                        ; make the system call

        mov   rax, 0x3c                ; syscall 3c is exit
        syscall                        ; make the system call
```

Now it Works



sambowne — debian@debian11: ~/127/L7 — ssh debian@172.16.123.130 — 54×6

```
debian@debian11:~/127/L7$ yasm -f elf64 caesar2.asm
debian@debian11:~/127/L7$ ld -o caesar2 caesar2.o
debian@debian11:~/127/L7$ ./caesar2
HELLO
IFMMP
debian@debian11:~/127/L7$ 
```



ED 220: Intro to 64-bit Assembl
samsclass.info/127/proj/ED220.htm

ED 220: Intro to 64-bit Assembler (15 pts + 25 extra)

What You Need

- A 64-bit Linux machine, such as a Google Cloud Debian server.

Purpose

To learn the basics of 64-bit Assembly programming, making several simple programs.

Kahoot!

L7