CS 344 Operating Systems Laboratory Assignment 1

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EXERCISE 1:

Modified Program **ex1.c** which now includes inline assembly that increments the value of x by 1.

```
#include<stdio.h>
int main(int argc, char **argv)
{
	int x=1;
	printf("Hello x = %d\n", x);
	asm("incl %0": "+r"(x));
	/*
	First method to increment the value of x using inline assembly language having one line
	asm("incl %0": "+r"(x));
	    1) incl command adds 1 to the 32-bit contents of the variable specified
	    2) %0 refers to the first variable passed (which in this case is x)
	    3) the '+' sign before r denotes that x acts as both input and output
	*/
	/*
	Second method to increment the value of x using inline assembly language having
	multiple lines (uncomment to use this)
		asm("mov %1, %0 \n\t"
		"add $1, %0"
		:  "=r" (x)
		:  "r" (x));
	*/
	printf("Hello x = %d after increment\n", x);
	if(x == 2) {
		printf("OK\n");
	}
	else {
		printf("ERROR\n");
	}
}
```

EXERCISE 2:

We are trying to explain the instructions to guess what BIOS might be trying to do:

1st instruction: [f000:fff0]   0xffff0: ljmp $0x3630,$0xf000e05b

- Jump to CS = $0xf000 & IP = 0xe05b
- 0x3630 is jump to this CS (earlier in the BIOS)
- 0xf000e05b is the IP which is different from the lab because it is 32 bits rather than 16 bits and that is all the way into the top of the extended memory location but before the memory mapped PCI device location reserved by the BIOS

2nd Instruction: [f000:e05b]   0xfe05b: cmpw $0xffc8,%cs:(%esi)

- Compare content at 0xffc8 & with content at code segment offset with value at esi.
- esi:- 32-bit source index register

3rd Instruction: [f000:e062]   0xfe062:   jne   0xd241d0b2

- Jump to 0xd241d0b2 if the above comparison does not set ZF

4th instruction: [f000:e066]   0xfe066:   xor   %edx,%edx

- ZF was set thus jump of previous instruction doesn't occur
- It set edx to zero, edx is 32-bit general-purpose register.

5th instruction: [f000:e068]   0xfe068:   mov   %edx,%ss

- Move content of stack segment register(ss) to edx

6th instruction: [f000:e06a]   0xfe06a: mov $0x7000,%sp

- Move content at the location pointed 16-bit stack pointer(sp) to $0x7000

```
The target architecture is assumed to be i8086
[f000:fff0]    0xffff0: ljmp   $0x3630,$0xf000e05b
0x0000fff0 in ?? ()
+ symbol-file kernel
warning: A handler for the OS ABI "GNU/Linux" is not built into this configurati
on
of GDB.  Attempting to continue with the default i8086 settings.

(gdb) si
[f000:e05b]    0xfe05b: cmpw   $0xffc8,%cs:(%esi)
0x0000e05b in ?? ()
(gdb) si
[f000:e062]    0xfe062: jne    0xd241d416
0x0000e062 in ?? ()
(gdb) si
[f000:e066]    0xfe066: xor    %edx,%edx
0x0000e066 in ?? ()
(gdb) si
[f000:e068]    0xfe068: mov    %edx,%ss
0x0000e068 in ?? ()
(gdb) si
[f000:e06a]    0xfe06a: mov    $0x7000,%sp
0x0000e06a in ?? ()
```

EXERCISE 3:

Comparison of code at 0x7C00 memory location using first few instructions between original boot loader source code (bootasm.S) and GDB and bootblock.asm :

<u>In Bootasm.S:</u>

```
.code16                          # Assemble for 16-bit mode
.globl start
 start:
        cli                      # BIOS enabled interrupts; disable
        xorw    %ax,%ax          # Set %ax to zero
        movw    %ax,%ds          # -> Data Segment
        movw    %ax,%es          # -> Extra Segment
```

```
        movw   %ax,%ss                  # -> Stack Segment
seta20.1:
        inb    $0x64,%al                # Wait for not busy
        testb  $0x2,%al
        jnz    seta20.1
        movb   $0xd1,%al                # 0xd1 -> port 0x64
        outb   %al,$0x64
```

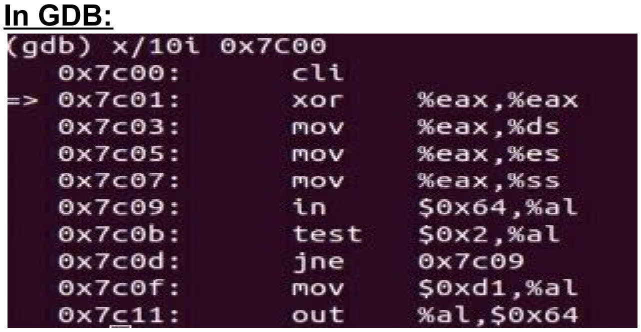
<u>In Bootblock.asm</u>

```
.code16                                 # Assemble for 16-bit mode
.globl start
start:
  cli                                   # BIOS enabled interrupts; disable
        7c00:   fa                       cli
  # Zero data segment registers DS, ES, and SS.
  xorw  %ax,%ax              # Set %ax to zero
        7c01:   31 c0                    xor    %eax,%eax
  movw %ax,%ds               # -> Data Segment
        7c03:   8e d8                    mov    %eax,%ds
  movw %ax,%es               # -> Extra Segment
        7c05:   8e c0                    mov    %eax,%es
  movw %ax,%ss               # -> Stack Segment
        7c07:   8e d0                    mov    %eax,%ss

00007c09 <seta20.1>:
 seta20.1:
  inb   $0x64,%al            # Wait for not busy
        7c09:   e4 64                    in     $0x64,%al
  testb  $0x2,%al
        7c0b:   a8 02                    test   $0x2,%al
  jnz   seta20.1
        7c0d:   75 fa                    jne    7c09 <seta20.1>

  movb $0xd1,%al             # 0xd1 -> port 0x64
        7c0f:   b0 d1                    mov    $0xd1,%al
  outb  %al,$0x64
        7c11:   e6 64                    out    %al,$0x64
```

<u>In GDB:</u>



```
(gdb) x/10i 0x7C00
   0x7c00:      cli
=> 0x7c01:      xor    %eax,%eax
   0x7c03:      mov    %eax,%ds
   0x7c05:      mov    %eax,%es
   0x7c07:      mov    %eax,%ss
   0x7c09:      in     $0x64,%al
   0x7c0b:      test   $0x2,%al
   0x7c0d:      jne    0x7c09
   0x7c0f:      mov    $0xd1,%al
   0x7c11:      out    %al,$0x64
```

Tracing into Bootmain and Readsect:

Statements in readsect in bootmain.c:

1) waitdisk(); // Issue command
   Assembly Instruction:
   7c98: e8 e1 ff ff ff call 7c7e <waitdisk>
2) outb(0x1F2, 1); // count = 1
3) outb(0x1F3, offset);
4) outb(0x1F4, offset >> 8);
   Assembly Instruction:
   7cb0: 89 d8 mov %ebx,%eax
   7cb2: c1 e8 08 shr $0x8,%eax
   7cb5: ba f4 01 00 00 mov $0x1f4,%edx
   7cba: ee out %al,(%dx)
5) outb(0x1F5, offset >> 16);
   Assembly Instruction:
   7cbb: 89 d8 mov %ebx,%eax
   7cbd: c1 e8 10 shr $0x10,%eax
   7cc0: ba f5 01 00 00 mov $0x1f5,%edx
   7cc5: ee out %al,(%dx)
6) outb(0x1F6, (offset >> 24) | 0xE0);
   Assembly Instruction:
   7cc6: 89 d8 mov %ebx,%eax
   7cc8: c1 e8 18 shr $0x18,%eax
   7ccb: 83 c8 e0 or $0xffffffe0,%eax
   7cce: ba f6 01 00 00 mov $0x1f6,%edx
   7cd3: ee out %al,(%dx)
   7cd4: b8 20 00 00 00 mov $0x20,%eax
   7cd9: ba f7 01 00 00 mov $0x1f7,%edx
   7cde: ee out %al,(%dx)
7) outb(0x1F7, 0x20); // cmd 0x20 - read sectors
8) waitdisk(); // Read data.
   Assembly Instruction:
   7cdf: e8 9a ff ff ff call 7c7e <waitdisk>
9) insl(0x1F0, dst, SECTSIZE/4);

<u>Begin and end of loop which reads remaining sectors:</u>

```
for(; pa < epa; pa += SECTSIZE, offset++)
        readsect(pa, offset);
```

<u>What code will run after running out of loop:</u>

```
readseg(pa, ph->filesz, ph->off);
        7d99:   ff 73 04                pushl  0x4(%ebx)
        7d9c:   ff 73 10                pushl  0x10(%ebx)
        7d9f:   57                      push   %edi
        7da0:   e8 53 ff ff ff          call   7cf8 <readseg>
```

Setting up breakpoint at 0x7d99 as it is the first instruction after running out of readseg function and loop consecutively.

```
(gdb) b *0x7c00
Breakpoint 1 at 0x7c00
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
(gdb) b *0x7d99
Breakpoint 2 at 0x7d99
(gdb) c
Continuing.
The target architecture is assumed to be i386
=> 0x7d99:      pushl  0x4(%ebx)

Thread 1 hit Breakpoint 2, 0x00007d99 in ?? ()
(gdb) x/10i 0x7d99
=> 0x7d99:      pushl  0x4(%ebx)
   0x7d9c:      pushl  0x10(%ebx)
   0x7d9f:      push   %edi
   0x7da0:      call   0x7cf8
   0x7da5:      mov    0x14(%ebx),%ecx
   0x7da8:      mov    0x10(%ebx),%eax
   0x7dab:      add    $0xc,%esp
   0x7dae:      cmp    %eax,%ecx
   0x7db0:      jbe    0x7d8f
   0x7db2:      add    %eax,%edi
```

Answer the following questions:

a) The command **ljmp $(SEG_KCODE<<3), $start32** causes the switch from 16 to 32-bit mode in the bootasm.S which occurs at address **0x7C31**.

```
(gdb) b *0x7c29
Breakpoint 1 at 0x7c29
(gdb) c
Continuing.
[   0:7c29] => 0x7c29:  mov    %eax,%cr0

Thread 1 hit Breakpoint 1, 0x00007c29 in ?? ()
(gdb) si
[   0:7c2c] => 0x7c2c:  ljmp   $0xb866,$0x87c31
0x00007c2c in ?? ()
(gdb) si
The target architecture is assumed to be i386
=> 0x7c31:      mov    $0x10,%ax
0x00007c31 in ?? ()
(gdb) x/20i 0x7c29
   0x7c29:      mov    %eax,%cr0
   0x7c2c:      ljmp   $0xb866,$0x87c31
   0x7c33:      adc    %al,(%eax)
   0x7c35:      mov    %eax,%ds
   0x7c37:      mov    %eax,%es
   0x7c39:      mov    %eax,%ss
   0x7c3b:      mov    $0x0,%ax
   0x7c3f:      mov    %eax,%fs
   0x7c41:      mov    %eax,%gs
   0x7c43:      mov    $0x7c00,%esp
   0x7c48:      call   0x7d3b
   0x7c4d:      mov    $0x8a00,%ax
   0x7c51:      mov    %ax,%dx
   0x7c54:      out    %ax,(%dx)
   0x7c56:      mov    $0x8ae0,%ax
   0x7c5a:      out    %ax,(%dx)
   0x7c5c:      jmp    0x7c5c
   0x7c5e:      xchg   %ax,%ax
   0x7c60:      add    %al,(%eax)
   0x7c62:      add    %al,(%eax)
```

b) Last Instruction of boot loader executed:

<u>in bootmain.c it is:</u>

entry = (void(*)(void))(elf->entry);
entry();

<u>in bootblock.asm it is:</u>

7d87: ff 15 18 00 01 00 call *0x10018

The First Instruction of Kernel it just loaded is:

0x10000c : mov %cr4,%eax

Also the first instruction of the kernel should be at **0x10018**.

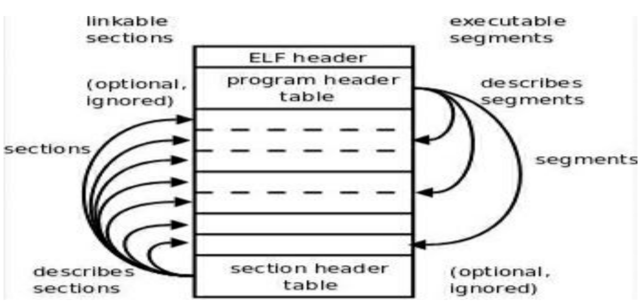
```
(gdb) b *0x7c00
Breakpoint 1 at 0x7c00
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
(gdb) b *0x7d87
Breakpoint 2 at 0x7d87
(gdb) c
Continuing.
The target architecture is assumed to be i386
=> 0x7d87:      call   *0x10018

Thread 1 hit Breakpoint 2, 0x00007d87 in ?? ()
(gdb) si
=> 0x10000c:    mov    %cr4,%eax
0x0010000c in ?? ()
(gdb) x/1x 0x10018
0x10018:        0x0010000c
```

c) The boot loader reads the number the program headers in the ELF header and loads them all. It finds this information in the ELF header.

```
ph = (struct proghdr*)((uchar*)elf + elf->phoff);
eph = ph + elf->phnum;
for(; ph < eph; ph++){
        pa = (uchar*)ph->paddr;
        readseg(pa, ph->filesz, ph->off);
        if(ph->memsz > ph->filesz)
        stosb(pa + ph->filesz, 0, ph->memsz - ph->filesz);
}
```



EXERCISE 4:

$ objdump -h kernel

```
kernel:     file format elf32-i386

Sections:
Idx Name            Size      VMA       LMA       File off  Algn
  0 .text           00006f12  80100000  00100000  00001000  2**4
                    CONTENTS, ALLOC, LOAD, READONLY, CODE
  1 .rodata         00000b6c  80106f20  00106f20  00007f20  2**5
                    CONTENTS, ALLOC, LOAD, READONLY, DATA
  2 .data           00002516  80108000  00108000  00009000  2**12
                    CONTENTS, ALLOC, LOAD, DATA
  3 .bss            0000af88  8010a520  0010a520  0000b516  2**5
                    ALLOC
  4 .debug_line     000025f5  00000000  00000000  0000b516  2**0
                    CONTENTS, READONLY, DEBUGGING
  5 .debug_info     000105a6  00000000  00000000  0000db0b  2**0
                    CONTENTS, READONLY, DEBUGGING
  6 .debug_abbrev   0000397c  00000000  00000000  0001e0b1  2**0
                    CONTENTS, READONLY, DEBUGGING
  7 .debug_aranges 000003a8  00000000  00000000  00021a30  2**3
                    CONTENTS, READONLY, DEBUGGING
  8 .debug_str      00000e6f  00000000  00000000  00021dd8  2**0
                    CONTENTS, READONLY, DEBUGGING
  9 .debug_loc      00005294  00000000  00000000  00022c47  2**0
                    CONTENTS, READONLY, DEBUGGING
 10 .debug_ranges   00000700  00000000  00000000  00027edb  2**0
                    CONTENTS, READONLY, DEBUGGING
 11 .comment        00000029  00000000  00000000  000285db  2**0
                    CONTENTS, READONLY
```

$ objdump -h bootblock.o

```
bootblock.o:     file format elf32-i386

Sections:
Idx Name            Size      VMA       LMA       File off  Algn
  0 .text           000001c0  00007c00  00007c00  00000074  2**2
                    CONTENTS, ALLOC, LOAD, CODE
  1 .eh_frame       000000bc  00007dc0  00007dc0  00000234  2**2
                    CONTENTS, ALLOC, LOAD, READONLY, DATA
  2 .comment        00000029  00000000  00000000  000002f0  2**0
                    CONTENTS, READONLY
  3 .debug_aranges 00000040  00000000  00000000  00000320  2**3
                    CONTENTS, READONLY, DEBUGGING
  4 .debug_info     0000050b  00000000  00000000  00000360  2**0
                    CONTENTS, READONLY, DEBUGGING
  5 .debug_abbrev   000001e3  00000000  00000000  0000086b  2**0
                    CONTENTS, READONLY, DEBUGGING
  6 .debug_line     0000012c  00000000  00000000  00000a4e  2**0
                    CONTENTS, READONLY, DEBUGGING
  7 .debug_str      000001d9  00000000  00000000  00000b7a  2**0
                    CONTENTS, READONLY, DEBUGGING
  8 .debug_loc      0000022a  00000000  00000000  00000d53  2**0
                    CONTENTS, READONLY, DEBUGGING
```

Fields Explanation:

1) Name: Program Sections Name(Program Headers)
2) Size: Size of the loaded section
3) VMA: Link Address, The link address of a section is the memory address from which the section expects to execute.
4) LMA: Load Address, The load address of a section is the memory address at which that section should be loaded into memory.
5) File off: is this section's offset from the beginning of the file
6) Algn: It represents alignment
7) CONTENTS, ALLOC, LOAD, READONLY, DATA are flags. They represent that a particular section is to be LOADED or is READ ONLY.

EXERCISE 5:

When boot loader's link address is 0x7C00 then commands are running properly and transition from 16 to 32 bit was occurring at **0x7C31** address location as seen below:

```
(gdb) b *0x7c00
Breakpoint 1 at 0x7c00
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
(gdb) b *0x7c31
Breakpoint 2 at 0x7c31
(gdb) c
Continuing.
The target architecture is assumed to be i386
=> 0x7c31:      mov    $0x10,%ax

Thread 1 hit Breakpoint 2, 0x00007c31 in ?? ()
```

But when the boot loader's link address is changed to any other address (we took **0x7C24** in this case), after running
make clean
make
and restarting gdb
and continuing by putting breakpoint from address location 0x7C00,
then the boot loader is restarting again and again after running some instructions in the gdb.

```
(gdb) b *0x7c00
Breakpoint 1 at 0x7c00
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
(gdb) b *0x7c55
Breakpoint 2 at 0x7c55
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
(gdb) si
[   0:7c01] => 0x7c01:  xor    %eax,%eax
0x00007c01 in ?? ()
(gdb) si
[   0:7c03] => 0x7c03:  mov    %eax,%ds
0x00007c03 in ?? ()
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
```

As seen in the image above, we tried to run commands after continuing from breakpoint at 0x7C00 address location and we always end up hitting the same breakpoint at 0x7C00.

Also 16 to 32 bit architecture change didn't occured as breakpoint **b *0x7C31** is not hitted which should be responsible for architecture change in this case.

ljmp $(SEG_KCODE<<3), $start32 is the first instruction that breaks.
Before changing the link address of the boot loader, from address 0x7C00, after performing 2-3 **si 10** instructions, architecture changed from 16 to 32 bit.
But after changing the link address to 0x7C24, architecture didn't change which means that the boot loader is not loaded properly at the changed link address.

$ objdump -f kernel

```
kernel:     file format elf32-i386
architecture: i386, flags 0x00000112:
EXEC_P, HAS_SYMS, D_PAGED
start address 0x0010000c
```

EXERCISE 6:

At the point when BIOS enters the boot loader (at first breakpoint):

```
(gdb) b *0x7c00
Breakpoint 1 at 0x7c00
(gdb) c
Continuing.
[   0:7c00] => 0x7c00:  cli

Thread 1 hit Breakpoint 1, 0x00007c00 in ?? ()
(gdb) x/8x 0x00100000
0x100000:       0x00000000      0x00000000      0x00000000      0x00000000
0x100010:       0x00000000      0x00000000      0x00000000      0x00000000
(gdb) x/8i 0x00100000
   0x100000:    add    %al,(%eax)
   0x100002:    add    %al,(%eax)
   0x100004:    add    %al,(%eax)
   0x100006:    add    %al,(%eax)
   0x100008:    add    %al,(%eax)
   0x10000a:    add    %al,(%eax)
   0x10000c:    add    %al,(%eax)
   0x10000e:    add    %al,(%eax)
```

At the point when the boot loader enters the kernel (at second breakpoint):

```
(gdb) b *0x7d87
Breakpoint 2 at 0x7d87
(gdb) c
Continuing.
The target architecture is assumed to be i386
=> 0x7d87:      call   *0x10018

Thread 1 hit Breakpoint 2, 0x00007d87 in ?? ()
(gdb) x/8x 0x00100000
0x100000:       0x1badb002      0x00000000      0xe4524ffe      0x83e0200f
0x100010:       0x220f10c8      0x9000b8e0      0x220f0010      0xc0200fd8
(gdb) x/8i 0x00100000
   0x100000:    add    0x1bad(%eax),%dh
   0x100006:    add    %al,(%eax)
   0x100008:    decb   0x52(%edi)
   0x10000b:    in     $0xf,%al
   0x10000d:    and    %ah,%al
   0x10000f:    or     $0x10,%eax
   0x100012:    mov    %eax,%cr4
   0x100015:    mov    $0x109000,%eax
```

8 words of instruction at 0x00100000 at the point when BIOS enters the boot loader and 8 words of instruction at 0x00100000 at the point when the boot loader enters the kernel are different as when the BIOS enters and loads the boot loader, then it just loads it in memory location between 0x7C00 and 0x7DFF due to which all the 8 words of instructions are zero at 0x00100000. But when the boot loader enters the kernel, it already has performed the 16 to 32 bit transition and setting up of stack and also the bootloader loads kernel at memory locations including 0x00100000 which leads to new instructions at address 0x00100000.

EXERCISE 7:

In order to define our system call in xv6, we changed 5 files mentioned below.

1) **syscall.h:**
   We added a new system call **#define SYS_wolfie 22** at 22nd position as 21 positions we already occupied by the inbuilt system calls in syscall.h.

2) **syscall.c:**
   We added a pointer **[SYS_wolfie] sys_wolfie** to system call at 22nd position in syscall.c file in order to add our custom system call.

   Then a function prototype **extern int sys_wolfie(void);** is added in syscall.c file which will be called by system call number 22.

3) **sysproc.c:**
   System call function is implemented in sysproc.c.

   ```
   int
   sys_wolfie(void){
           // code is given in file sysproc.c
   }
   ```

4) **usys.S:**
   For creating an interface for your user program to access system call we added the following line in usys.S.
   SYSCALL(wolfie)

5) **user.h:**
   We added the following function that the user program will be calling in user.h.
   int wolfie(void *buf, uint size);

Call to the above function from the user program will be simply mapped to system call number 22 which is defined as **SYS_wolfie** preprocessor directive. The system knows what exactly is this system call and how to handle it.

EXERCISE 8:

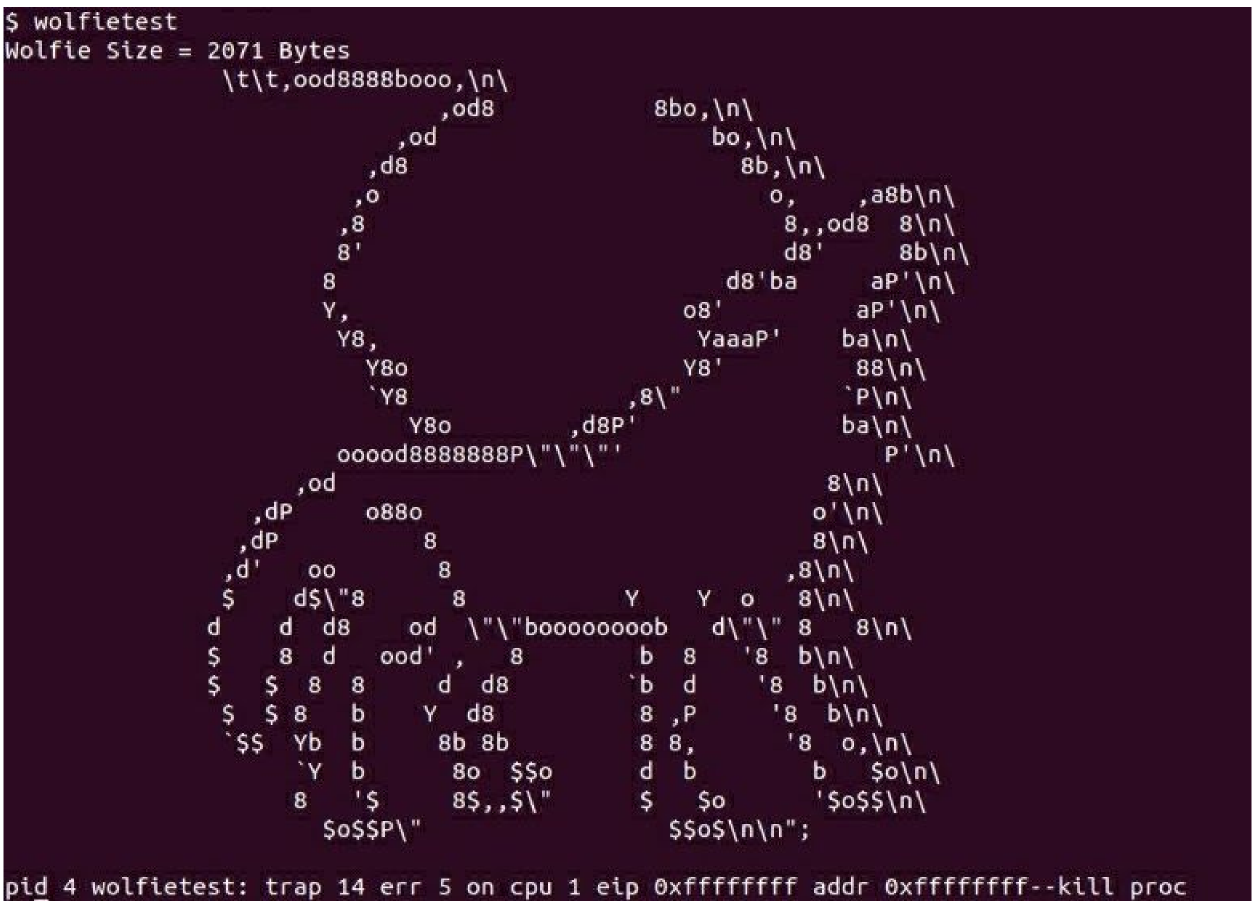
We save a C program named **wolfietest.c** inside the source code directory of xv6 operating system.
Then we edit the MakeFile and added below changes in MakeFile:

1) Under the value UPROGS (present at line 168), we added **_wolfietest** at the end of UPROGS value.
2) Under the value EXTRA (present at line 251), we added **wolfietest.c\.**

Then we run

1) **make clean** (to delete previous object files)
2) **make** (to generate new object files having changes of Makefile)
3) **make qemu** (to start qemu)
4) **ls** (to list all programs/files present in fs.img / second hard disk)
5) **wolfietest** (to run our application program to print wolfie on the screen)

Image generated of wolfie from the qemu emulator/ terminal.



ls command listing all files present inside fs.img

```
cpu1: starting 1
cpu0: starting 0
sb: size 1000 nblocks 941 ninodes 200
init: starting sh
$ ls
.              1 1 512
..             1 1 512
README         2 2 2286
cat            2 3 13640
echo           2 4 12644
forktest       2 5 8084
grep           2 6 15516
init           2 7 13232
kill           2 8 12700
ln             2 9 12600
ls             2 10 14784
mkdir          2 11 12784
rm             2 12 12760
sh             2 13 23248
stressfs       2 14 13428
usertests      2 15 56360
wc             2 16 14180
zombie         2 17 12424
wolfietest     2 18 12740
console        3 19 0
```