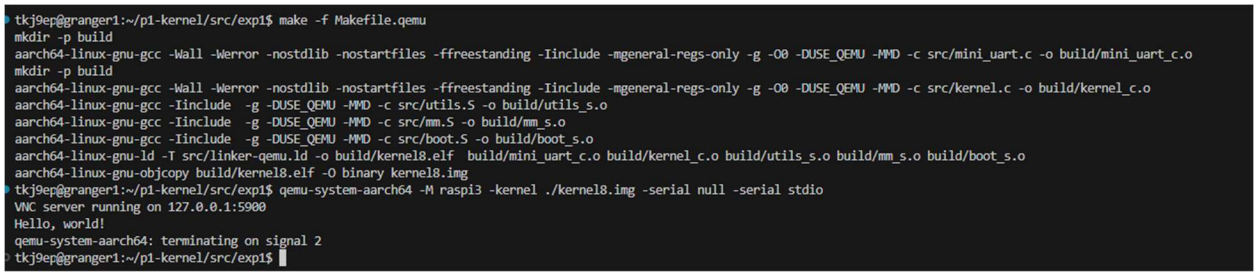
Attach a screenshot of you successfully running the given code

i.e. a screenshot of your emulator/rpi3 terminal printing "hello world".



First, inspect the kernel binary (kernel8.elf) of p1exp1.

You may use command line tools (e.g. objdump or readelf) or GUI tools (e.g. ODA). Btw, we have provided instructions https://fxlin.github.io/p1-kernel/dump/

How many sections are in the elf file? What are these sections?

Include your command line output as text (if you use command line tools) or attach screenshots (if you use GUI tools).

14 sections

1. <blanks>
2. .text.boot
3. .text
4. .rodata
5. .eh_frame
6. .debug_info
7. .debug_abbrev
8. .debug_aranges
9. .debug_line
10. .debug_str
11. .comment
12. .symtab
13. .strtab
14. .shstrtab

tkj9ep@granger1:~/p1-kernel/src/exp1$ readelf -S build/kernel8.elf

There are 14 section headers, starting at offset 0x10f60:

Section Headers:

```
  [Nr] Name              Type            Address          Offset
       Size              EntSize          Flags  Link  Info  Align
  [ 0]                   NULL            0000000000000000  00000000
       0000000000000000  0000000000000000           0     0     0
  [ 1] .text.boot        PROGBITS        0000000000080000  00010000
       0000000000000030  0000000000000000  AX       0     0     4
  [ 2] .text             PROGBITS        0000000000080030  00010030
       0000000000000250  0000000000000000  AX       0     0     4
  [ 3] .rodata           PROGBITS        0000000000080280  00010280
       0000000000000010  0000000000000000   A       0     0     8
  [ 4] .eh_frame         PROGBITS        0000000000080290  00010290
       00000000000000b0  0000000000000000   A       0     0     8
  [ 5] .debug_info       PROGBITS        0000000000000000  00010340
       00000000000001dc  0000000000000000           0     0     1
  [ 6] .debug_abbrev     PROGBITS        0000000000000000  0001051c
       000000000000012b  0000000000000000           0     0     1
  [ 7] .debug_aranges    PROGBITS        0000000000000000  00010650
       00000000000000f0  0000000000000000           0     0     16
  [ 8] .debug_line       PROGBITS        0000000000000000  00010740
       00000000000001cc  0000000000000000           0     0     1
  [ 9] .debug_str        PROGBITS        0000000000000000  0001090c
       0000000000000145  0000000000000001  MS       0     0     1
  [10] .comment          PROGBITS        0000000000000000  00010a51
       000000000000002b  0000000000000001  MS       0     0     1
  [11] .symtab           SYMTAB          0000000000000000  00010a80
```

```
       0000000000000390  0000000000000018          12     26     8
  [12] .strtab           STRTAB           0000000000000000  00010e10
       00000000000000c7  0000000000000000           0      0     1
  [13] .shstrtab         STRTAB           0000000000000000  00010ed7
       0000000000000087  0000000000000000           0      0     1
```

How many symbols are in the elf file?

22 symbols; used nm command

What is the address of symbol kernel_main? What are the first 8 bytes at the symbol? What are the corresponding instructions?

Address: 000000000008022c

First 8 Bytes: a9bf7bfd 910003fd

Instructions:

```
stp     x29, x30, [sp, #-16]!
mov     x29, sp

bl      0x80118 <uart_init>

adrp    x0, 0x80000 <_start>
add     x0, x0, #0x280
bl      0x800bc <uart_send_string>

bl      0x8007c <uart_recv>
and     w0, w0, #0xff
bl      0x80030 <uart_send>
b       0x80244 <kernel_main+24>
```

How many bytes does each aarch64 instruction contain?

Each aarch64 contains 4 bytes

Now examine kernel8.img (use the hexdump command or the VSCode plugin). Search for the first 8 bytes of kernel_main(). Can you find it? At which offset of kernel8.img?

I found the first 8 bytes of kernel_main in memory address 0x22c

How is kernel8.img generated out of kernel8.elf?

The image file is generated by the ELF file by simply taking all the sections of the ELF file and combining them together into an image of which the machine should be able to run. In other words, the kernal8.elf is converted into a binary executable file that can be run by the machine.

Second, some ARM64 exercise:

How many general-purpose registers in aarch64 (i.e. the 64-bit execution state of ARM64)? How many bytes in each register?

There are 31 general purpose registers, x0 – x30 where each register are of size 64-bit or 8 bytes.

Use your own words, explain the following instructions, each in one short sentence.

and: performs the logical AND operation between two values

bl: does a unconditional branch to a target address and stores the return address to the general purpose register x30; the ret instruction can be used to branch back to the target address

mov: moves a constant or a register value to another register

adr: grabs the relative address of a label and loads it into a target register

mrs: takes a value from the system register and loads it into one of the general purpose registers, that is x0 – x30

Back to kernel8.elf. Use your own words, explain instruction by instruction: how the delay() function works.

```
.text:00080260                      unknown delay (unknown)
.text:00080260
.text:00080260  f1000400            subs x0, x0, #0x1
.text:00080264  54ffffe1            b.ne 0x00080260 <delay>
.text:00080268  d65f03c0            ret
```

subs x0, x0, #0x1: decrements value in register x0 by 1; x0 = x0 – 1

b.ne 0x00080260 <delay>: if value in x0 is not equal to value in 0x00080260, then jump to address where delay function begins

ret: (if value in x0 is equal to value in 0x00080260) jump back to original caller of the function; address of original caller stored in register x30

Third, about Rpi3

Watch the video Eben Upton on Rpi3 and answer the questions:

What would be the benefit of supporting 64-bit (AArch64)? In particular, why it is important to support 64-bit by an operating system?

- Broader range of operating systems such as red hat
- Faster by 10 times
- More possible projects especially in IoT

Have you ever used Raspberry in any chance? What was for?

- I have not used a Raspberry before.