Lab 1

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Design

4.1 准备工程

从仓库拉取了源码

4.2 RV64内核引导

4.2.1 Makefile

在这里编写`printk.c`的编译规则

设定`clean`规则以完成清除构建文件

注意到`$(CFLAG)`这些变量已经在最顶层的Makefile中定义，因此直接使用

Makefile *lib/Makefile*

```makefile
SRC = $(wildcard *.c)
OBJ = $(patsubst %.c,%.o,$(SRC))

all: $(OBJ)

%.o: %.c
	$(GCC) $(CFLAG) -c $< -o $@

.PHONY: clean
clean:
	rm -f *.o
```

完成

4.2.2 head.S

根据要求写汇编

注意到这里已经定义了`start_kernel`并且有栈和栈顶的信息，直接使用即可

ARM Assembly *head.S*

```asm
    .extern start_kernel
```

```
    .section .text.entry
    .globl _start
_start:
    la sp, boot_stack_top # set stack pointer to top of boot stack
    jal start_kernel # jump to start_kernel

    .section .bss.stack
    .globl boot_stack
boot_stack:
    .space 4096 # Stack size 4KiB

    .globl boot_stack_top
boot_stack_top:
```

4.2.3 sbi.c

参照示例进行内联汇编撰写，照葫芦画瓢

使用伪指令 `mv` 把寄存器拷贝，然后按照内联汇编格式写，写完返回结构体就完事儿了兄弟们

```c
// sbi.c
struct sbiret sbi_ecall(uint64_t eid, uint64_t fid,
                        uint64_t arg0, uint64_t arg1, uint64_t arg2,
                        uint64_t arg3, uint64_t arg4, uint64_t arg5) {
    struct sbiret ret;
    asm volatile (
        "mv a7, %[eid]\n"
        "mv a6, %[fid]\n"
        "mv a0, %[arg0]\n"
        "mv a1, %[arg1]\n"
        "mv a2, %[arg2]\n"
        "mv a3, %[arg3]\n"
        "mv a4, %[arg4]\n"
        "mv a5, %[arg5]\n"
        "ecall\n"
        "mv %[error], a0\n"
        "mv %[value], a1\n"
        : [error] "=r" (ret.error), [value] "=r" (ret.value)
        : [eid] "r" (eid), [fid] "r" (fid),
          [arg0] "r" (arg0), [arg1] "r" (arg1), [arg2] "r" (arg2),
          [arg3] "r" (arg3), [arg4] "r" (arg4), [arg5] "r" (arg5)
    );
    return ret;
}
```

完成 `sbi_ecall` 后只需要在剩下几个函数里面调用就完事儿了兄弟们

根据表格中每个函数对应的 `eid` 和 `fid` 直接调用

```c
struct sbiret sbi_set_timer(uint64_t stime_value) {
    struct sbiret ret;
    ret = sbi_ecall(0x54494d45, 0x0, stime_value, 0 ,0, 0, 0, 0);
    return ret;
}

struct sbiret sbi_debug_console_write_byte(uint8_t byte) {
    struct sbiret ret;
    ret = sbi_ecall(0x4442434E, 0x2, byte, 0, 0, 0, 0, 0);
    return ret;
}

struct sbiret sbi_system_reset(uint32_t reset_type, uint32_t reset_reason) {
    struct sbiret ret;
    ret = sbi_ecall(0x53525354, 0x0, reset_type, reset_reason, 0, 0, 0, 0);
    return ret;
}
```

4.2.4 defs.h

依旧是照葫芦画瓢，使用指令 `csrr` 进行读取

```c
#define csr_read(csr)                            \
  ({                                             \
    uint64_t __v;                                \
    asm volatile("csrr %0, " #csr : "=r"(__v)); \
    __v;                                         \
  })
```

Run

完成上述后，进行构建

```
rm -f *.o
make[1]: Leaving directory '/home/lqy/ZJU/lab1/src/lib'
make -C init clean
make[1]: Entering directory '/home/lqy/ZJU/lab1/src/init'
make[1]: 'clean' is up to date.
make[1]: Leaving directory '/home/lqy/ZJU/lab1/src/init'
make -C arch/riscv clean
make[1]: Entering directory '/home/lqy/ZJU/lab1/src/arch/riscv'
make -C kernel clean
make[2]: Entering directory '/home/lqy/ZJU/lab1/src/arch/riscv/kernel'
make[2]: 'clean' is up to date.
make[2]: Leaving directory '/home/lqy/ZJU/lab1/src/arch/riscv/kernel'
make[1]: Leaving directory '/home/lqy/ZJU/lab1/src/arch/riscv'

Clean Finished          聚焦资源管理器中的文件夹 (Ctrl + 单击)
make -C lib all
make[1]: Entering directory '/home/lqy/ZJU/lab1/src/lib'
riscv64-linux-gnu-gcc -march=rv64imafd -mabi=lp64 -mcmodel=medany -fno-builtin -ffunction-sections -fdata-sections -nostartfiles -nostdlib -nostdinc -static -lgcc -Wl,--nmagic -Wl
,--gc-sections -g  -I /home/lqy/ZJU/lab1/src/include -I /home/lqy/ZJU/lab1/src/arch/riscv/include -c printk.c -o printk.o
make[1]: Leaving directory '/home/lqy/ZJU/lab1/src/lib'
make -C init all
make[1]: Entering directory '/home/lqy/ZJU/lab1/src/init'
riscv64-linux-gnu-gcc -march=rv64imafd -mabi=lp64 -mcmodel=medany -fno-builtin -ffunction-sections -fdata-sections -nostartfiles -nostdlib -nostdinc -static -lgcc -Wl,--nmagic -Wl
,--gc-sections -g  -I /home/lqy/ZJU/lab1/src/include -I /home/lqy/ZJU/lab1/src/arch/riscv/include -c main.c
riscv64-linux-gnu-gcc -march=rv64imafd -mabi=lp64 -mcmodel=medany -fno-builtin -ffunction-sections -fdata-sections -nostartfiles -nostdlib -nostdinc -static -lgcc -Wl,--nmagic -Wl
,--gc-sections -g  -I /home/lqy/ZJU/lab1/src/include -I /home/lqy/ZJU/lab1/src/arch/riscv/include -c test.c
make[1]: Leaving directory '/home/lqy/ZJU/lab1/src/init'
make -C arch/riscv all
make[1]: Entering directory '/home/lqy/ZJU/lab1/src/arch/riscv'
make -C kernel all
make[2]: Entering directory '/home/lqy/ZJU/lab1/src/arch/riscv/kernel'
riscv64-linux-gnu-gcc  -march=rv64imafd -mabi=lp64 -mcmodel=medany -fno-builtin -ffunction-sections -fdata-sections -nostartfiles -nostdlib -nostdinc -static -lgcc -Wl,--nmagic -W
l,--gc-sections -g  -I /home/lqy/ZJU/lab1/src/include -I /home/lqy/ZJU/lab1/src/arch/riscv/include -c head.S
riscv64-linux-gnu-gcc  -march=rv64imafd -mabi=lp64 -mcmodel=medany -fno-builtin -ffunction-sections -fdata-sections -nostartfiles -nostdlib -nostdinc -static -lgcc -Wl,--nmagic -W
l,--gc-sections -g  -I /home/lqy/ZJU/lab1/src/include -I /home/lqy/ZJU/lab1/src/arch/riscv/include -c sbi.c
make[2]: Leaving directory '/home/lqy/ZJU/lab1/src/arch/riscv/kernel'
riscv64-linux-gnu-ld -T kernel/vmlinux.lds kernel/*.o ../../init/*.o ../../lib/*.o -o ../../vmlinux
riscv64-linux-gnu-objcopy -O binary ../../vmlinux ./boot/Image
riscv64-linux-gnu-objdump -S ../../vmlinux > ../../vmlinux.asm
nm ../../vmlinux >  ../../System.map
make[1]: Leaving directory '/home/lqy/ZJU/lab1/src/arch/riscv'

Build Finished OK
(base) lqy@LAPTOP-SDV26TG8:~/Z/l/src▸
```

构建完成，使用 `make run` 进行运行

```
Platform IPI Device        : aclint-mswi
Platform Timer Device      : aclint-mtimer @ 10000000Hz
Platform Console Device    : uart8250
Platform HSM Device        : ---
Platform PMU Device        : ---
Platform Reboot Device     : sifive_test
Platform Shutdown Device   : sifive_test
Platform Suspend Device    : ---
Platform CPPC Device       : ---
Firmware Base              : 0x80000000
Firmware Size              : 322 KB
Firmware RW Offset         : 0x40000
Firmware RW Size           : 66 KB
Firmware Heap Offset       : 0x48000
Firmware Heap Size         : 34 KB (total), 2 KB (reserved), 9 KB (used), 22 KB (free)
Firmware Scratch Size      : 4096 B (total), 760 B (used), 3336 B (free)
Runtime SBI Version        : 1.0

Domain0 Name               : root
Domain0 Boot HART          : 0
Domain0 HARTs              : 0*
Domain0 Region00           : 0x0000000002000000-0x000000000200ffff M: (I,R,W) S/U: ()
Domain0 Region01           : 0x0000000080040000-0x000000008005ffff M: (R,W) S/U: ()
Domain0 Region02           : 0x0000000080000000-0x000000008003ffff M: (R,X) S/U: ()
Domain0 Region03           : 0x0000000000000000-0xffffffffffffffff M: (R,W,X) S/U: (R,W,X)
Domain0 Next Address       : 0x0000000080200000
Domain0 Next Arg1          : 0x0000000087e00000
Domain0 Next Mode          : S-mode
Domain0 SysReset           : yes
Domain0 SysSuspend         : yes

Boot HART ID               : 0
Boot HART Domain           : root
Boot HART Priv Version     : v1.12
Boot HART Base ISA         : rv64imafdch
Boot HART ISA Extensions   : time,sstc
Boot HART PMP Count        : 16
Boot HART PMP Granularity  : 4
Boot HART PMP Address Bits: 54
Boot HART MHPM Count       : 16
Boot HART MIDELEG          : 0x0000000000001666
Boot HART MEDELEG          : 0x0000000000f0b509
2024 ZJU Operating System
(base) lgy@LAPTOP-SDV26TG8:~/Z/1/src
```

完成!

4.3 RV64时钟中断处理

这一部分写其实压栈了，因为相当于先写4.3.3再写4.3.2再倒着写 🤔

4.3.0 Preparation

首先根据准备工作完成对应修改

4.3.1 head.S

除了根据模板作一些调整之外，还编写了以下四部曲

1. 根据 `_traps` 地址赋值给 `stvec` 用于中断处理

2. 设置开启时钟中断，把 `sie` 的第二位置 `1`
3. 设置第一个时钟中断，这里根据了 `clock.c` 里面的定义设定了下一次时钟中断
4. 开启中断响应

ARM Assembly *head.S*

```
._start:

    # set stvec = _traps
    la t0, _traps
    csrw stvec, t0

    # set sie[STIE] = 1
    csrr t0, sie
    li t1, 0x20
    or t0, t0, t1
    csrw sie, t0

    # set first time interrupt
    li t0, 0x10000000
    csrw stimecmp, t0

    # set sstatus[SIE] = 1
    csrr t0, sstatus
    li t1, 0x2
    or t0, t0, t1
    csrw sstatus, t0
```

4.3.2 entry.S

还是四部曲

1. 首先压栈保存所有寄存器，注意到这里其实我没有保存 `x0` ，因为感觉没啥必要👀
2. 调用 `trap_handler` ，这里后来注意到还需要传参，通过 `a0` 和 `a1` 进行传参
3. 上下文恢复，注意 `sp` 最后恢复，顺序和保存时相反
4. 返回

ARM Assembly *entry.S*

```
    .extern trap_handler
    .section .text.entry
    .align 2
    .globl _traps
_traps:
    # 1. save 32 registers and sepc to stack
    addi sp, sp, -32*8
    sd ra, 0(sp) # x1
    sd sp, 8(sp) # x2
```

```
    sd gp, 16(sp) # x3
    sd tp, 24(sp) # x4
    sd t0, 32(sp) # x5
    sd t1, 40(sp) # x6
    sd t2, 48(sp) # x7
    sd s0, 56(sp) # x8
    sd s1, 64(sp) # x9
    sd a0, 72(sp) # x10
    sd a1, 80(sp) # x11
    sd a2, 88(sp) # x12
    sd a3, 96(sp) # x13
    sd a4, 104(sp) # x14
    sd a5, 112(sp) # x15
    sd a6, 120(sp) # x16
    sd a7, 128(sp) # x17
    sd s2, 136(sp) # x18
    sd s3, 144(sp) # x19
    sd s4, 152(sp) # x20
    sd s5, 160(sp) # x21
    sd s6, 168(sp) # x22
    sd s7, 176(sp) # x23
    sd s8, 184(sp) # x24
    sd s9, 192(sp) # x25
    sd s10, 200(sp) # x26
    sd s11, 208(sp) # x27
    sd t3, 216(sp) # x28
    sd t4, 224(sp) # x29
    sd t5, 232(sp) # x30
    sd t6, 240(sp) # x31
    csrr t0, sepc
    sd t0, 248(sp) # sepc

    # 2. call trap_handler
    csrr a0, scause # arg1: scause
    csrr a1, sepc # arg2: sepc
    call trap_handler

    # 3. restore sepc and 32 registers (x2(sp) should be restore last) from stack
    ld t0, 248(sp) # sepc
    csrw sepc, t0
    ld t6, 240(sp) # x31
    ld t5, 232(sp) # x30
    ld t4, 224(sp) # x29
    ld t3, 216(sp) # x28
    ld s11, 208(sp) # x27
    ld s10, 200(sp) # x26
    ld s9, 192(sp) # x25
    ld s8, 184(sp) # x24
    ld s7, 176(sp) # x23
```

```
    ld s6, 168(sp) # x22
    ld s5, 160(sp) # x21
    ld s4, 152(sp) # x20
    ld s3, 144(sp) # x19
    ld s2, 136(sp) # x18
    ld a7, 128(sp) # x17
    ld a6, 120(sp) # x16
    ld a5, 112(sp) # x15
    ld a4, 104(sp) # x14
    ld a3, 96(sp) # x13
    ld a2, 88(sp) # x12
    ld a1, 80(sp) # x11
    ld a0, 72(sp) # x10
    ld s1, 64(sp) # x9
    ld s0, 56(sp) # x8
    ld t2, 48(sp) # x7
    ld t1, 40(sp) # x6
    ld t0, 32(sp) # x5
    ld tp, 24(sp) # x4
    ld gp, 16(sp) # x3
    ld ra, 0(sp) # x1
    ld sp, 8(sp) # x2
    addi sp, sp, 32*8

    # 4. return from trap
    sret
```

4.3.3 trap.c

查阅了priv-isa-asciidoc第43页可以得到对应的异常代码，然后判断 `scause` 是否符合即可

注意到还要输出，所以调用 `printk` 配合输出

4.3.4 clock.c

主要是内联汇编，根据提示写

顺便调用一下前面已经实现的 `sbi_set_timer`

C clock.c

```c
#include "../../../include/stdint.h"
#include "sbi.h"

// QEMU 中时钟的频率是 10MHz，也就是 1 秒钟相当于 10000000 个时钟周期
uint64_t TIMECLOCK = 10000000;

uint64_t get_cycles() {
```

```c
    // 编写内联汇编，使用 rdtime 获取 time 寄存器中（也就是 mtime 寄存器）的值并返回
    uint64_t time;
    asm volatile ("rdtime %0" : "=r" (time));
    return time;
}

void clock_set_next_event() {
    // 下一次时钟中断的时间点
    uint64_t next = get_cycles() + TIMECLOCK;

    // 使用 sbi_set_timer 来完成对下一次时钟中断的设置
    sbi_set_timer(next);
    return ;
}
```

4.3.5 test.c

根据文档修改

编译成功

运行成功

fish src

```
Boot HART MIDELEG         : 0x0000000000001666
Boot HART MEDELEG         : 0x0000000000f0b509
2024 ZJU Operating System
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
kernel is running!
[S] Supervisor mode timer interrupt!
kernel is running!
[S] Supervisor mode timer interrupt!
kernel is running!
[S] Supervisor mode timer interrupt!
kernel is running!
[S] Supervisor mode timer interrupt!
kernel is running!
[S] Supervisor mode timer interrupt!
kernel is running!
[S] Supervisor mode timer interrupt!
kernel is running!
[S] Supervisor mode timer interrupt!
```

Exercises

1

请总结一下RISC-V的calling convention，并解释Caller / Callee Saved Register有什么区别？

Calling Convention：

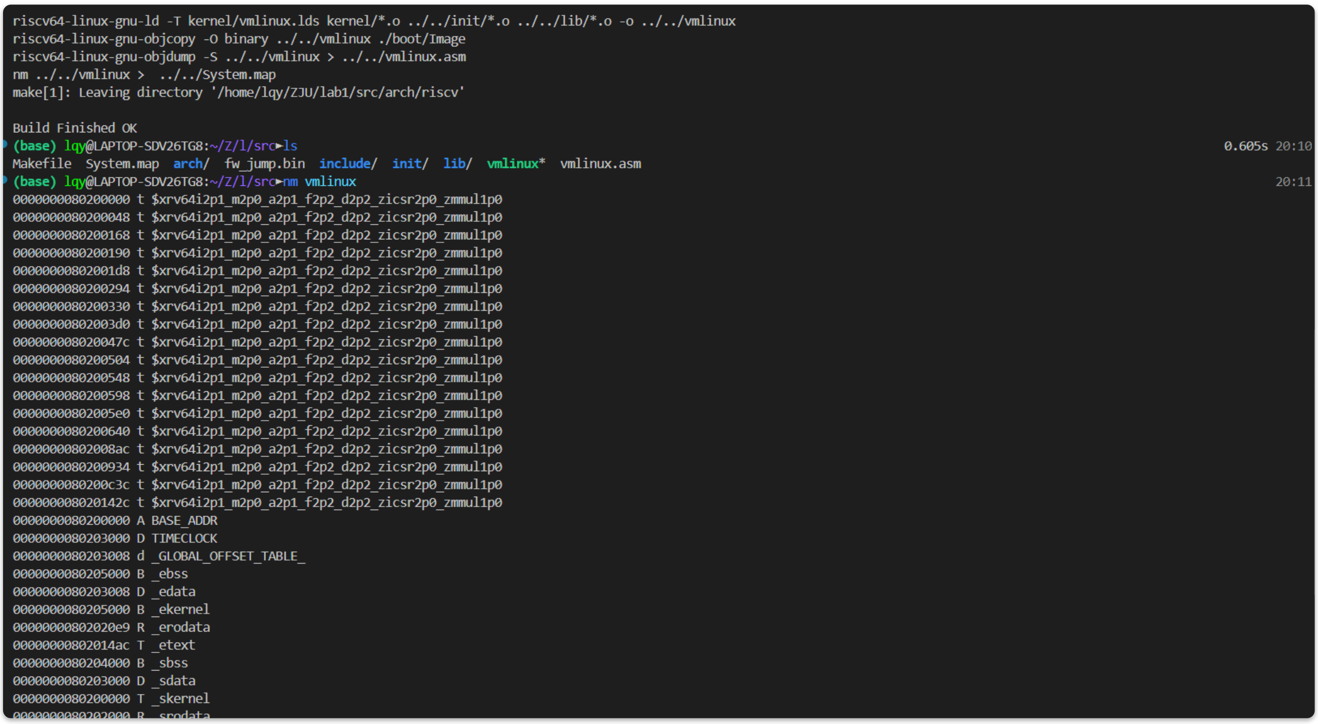
- 函数传参使用寄存器 `a0` 到 `a7` ，如果超过8个则使用栈
- 函数返回值使用寄存器 `a0` 和 `a1` 返回
- 函数调用时通常需要保存当前的上下文并调整栈指针

Caller Saved Register：调用者保存寄存器，在RISC-V中为 `t0` 到 `t6` ，在调用函数之前需要手动保存

Callee Saved Register：被调用者保存寄存器，在RISC-V中为 `s0` 到 `s11` ，在被调用者进入函数时保存在栈上，在函数返回前恢复

2

编译之后，通过System.map查看vmlinux.lds中自定义符号的值并截图.



```
riscv64-linux-gnu-ld -T kernel/vmlinux.lds kernel/*.o ../../init/*.o ../../lib/*.o -o ../../vmlinux
riscv64-linux-gnu-objcopy -O binary ../../vmlinux ./boot/Image
riscv64-linux-gnu-objdump -S ../../vmlinux > ../../vmlinux.asm
nm ../../vmlinux >  ../../System.map
make[1]: Leaving directory '/home/lqy/ZJU/lab1/src/arch/riscv'

Build Finished OK
(base) lqy@LAPTOP-SDV26TG8:~/Z/l/src▸ls                                  0.605s 20:10
Makefile  System.map  arch/  fw_jump.bin  include/  init/  lib/  vmlinux*  vmlinux.asm
(base) lqy@LAPTOP-SDV26TG8:~/Z/l/src▸nm vmlinux                                 20:11
0000000080200000 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200048 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200168 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200190 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
00000000802001d8 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200294 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200330 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
00000000802003d0 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
000000008020047c t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200504 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200548 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200598 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
00000000802005e0 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200640 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
00000000802008ac t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200934 t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200c3c t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
000000008020142c t $xrv64i2p1_m2p0_a2p1_f2p2_d2p2_zicsr2p0_zmmul1p0
0000000080200000 A BASE_ADDR
0000000080203000 D TIMECLOCK
0000000080203008 d _GLOBAL_OFFSET_TABLE_
0000000080205000 B _ebss
0000000080203008 D _edata
0000000080205000 B _ekernel
00000000802020e9 R _erodata
00000000802014ac T _etext
0000000080204000 B _sbss
0000000080203000 D _sdata
0000000080200000 T _skernel
```

3

用 `csr_read` 宏读取 `sstatus` 寄存器的值，对照RISC-V手册解释其含义并截图

在 `arch/riscv/kernel/trap.c` 中加入读取 `sstatus` 的逻辑：

C　trap.c

```c
uint64_t status = csr_read(sstatus);
printk("sstatus = %lx\n", status);
```

重新编译运行后得到

```
kernel is running!
kernel is running!
kernel is running!
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
kernel is running!
QEMU: Terminated
```

即 `sstatus = 0x8000000200006120`，即二进制

```Verilog
64'b10000000_00000000_00000000_00000010_00000000_00000000_01100001_0010000
```

对应置 `1` 位的具体信息为

- `SPIE`(5)： 上一次进入S模式之前的中断使能状态
- `SPP`(8)：S模式中断处理前的特权模式为机器模式
- `FS`(13,14)
- `UXL[1]`(33)
- `SD`(63)

4

用 `csr_write` 宏向 `sscratch` 寄存器写入数据，并验证是否写入成功并截图

还是在 `trap.c` 中写

```C
csr_write(sscratch, 0x666);
uint64_t res = csr_read(sscratch);
printk("sscratch = %lx\n", res);
```

编译后运行结果为

```
kernel is running!
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
sscratch = 666
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
sscratch = 666
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
sscratch = 666
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
sscratch = 666
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
sscratch = 666
kernel is running!
[S] Supervisor mode timer interrupt!
sstatus = 8000000200006120
sscratch = 666
QEMU: Terminated
```

5

详细描述你可以通过什么步骤来得到 `arch/arm64/kernel/sys.i`，给出过程以及截图

首先安装交叉编译链工具 `gcc-aarch64-linux-gnu`

然后使用命令：

```Shell
aarch64-linux-gnu-gcc -E init/main.c -o arch/arm64/kernel/sys.i -Iinclude
```

即可生成

```
(base) lqy@LAPTOP-SDV26TG8:~/Z/l/src▸aarch64-linux-gnu-gcc -E init/main.c -o arch/arm64/kernel/sys.i
init/main.c:1:10: fatal error: printk.h: No such file or directory
    1 | #include "printk.h"
      |          ^~~~~~~~~~
compilation terminated.
(base) lqy@LAPTOP-SDV26TG8:~/Z/l/src[1]▸aarch64-linux-gnu-gcc -E init/main.c -o arch/arm64/kernel/sys.i -Iinclude
(base) lqy@LAPTOP-SDV26TG8:~/Z/l/src▸
```

C   *arch/arm64/kernel/sys.i*

```c
# 0 "init/main.c"
# 0 "<built-in>"
# 0 "<command-line>"
# 1 "/usr/aarch64-linux-gnu/include/stdc-predef.h" 1 3
# 0 "<command-line>" 2
# 1 "init/main.c"
# 1 "include/printk.h" 1



# 1 "include/stddef.h" 1



typedef long int ptrdiff_t;
typedef long unsigned int size_t;
typedef unsigned int wchar_t;




typedef __builtin_va_list va_list;
# 5 "include/printk.h" 2





int printk(const char *, ...);
# 2 "init/main.c" 2

extern void test();

int start_kernel() {
    printk("2024");
    printk(" ZJU Operating System\n");

    test();
    return 0;
}
```

6

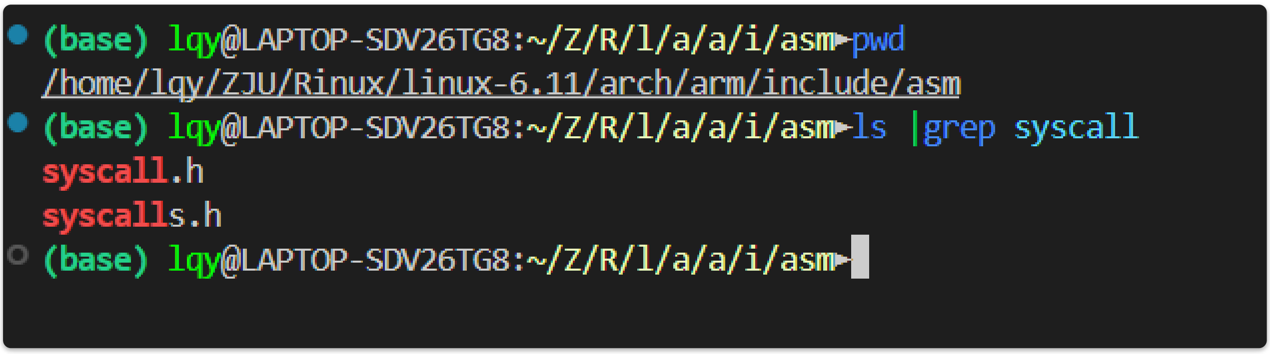
寻找 Linux v6.0 中 ARM32 RV32 RV64 x86_64 架构的系统调用表；请列出源代码文件，展示完整的系统调用表（宏展开后），每一步都需要截图。

> **方便**
>
> 由于本人之前使用了Linux 6.11，因此这里为了方便没有使用Linux v6.0而是直接在6.11基础上进行这一步

各个架构的系统调用表都在Linux源码的根目录下的 `arch/` 中

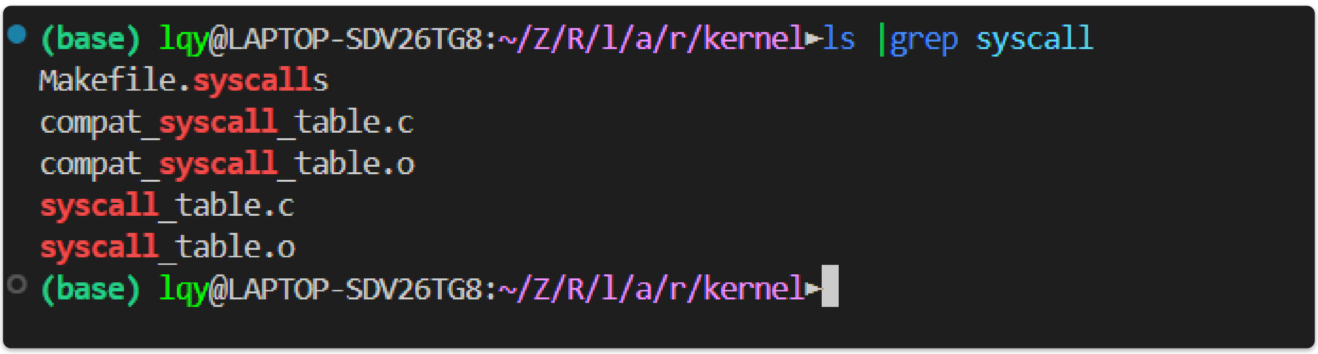
Shell ARM32

```shell
$ cd arch/arm/include/asm
$ ls | grep syscall
syscall.h
syscalls.h
```



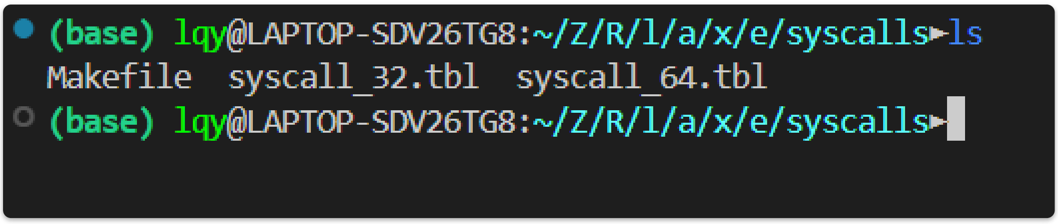
Shell RV

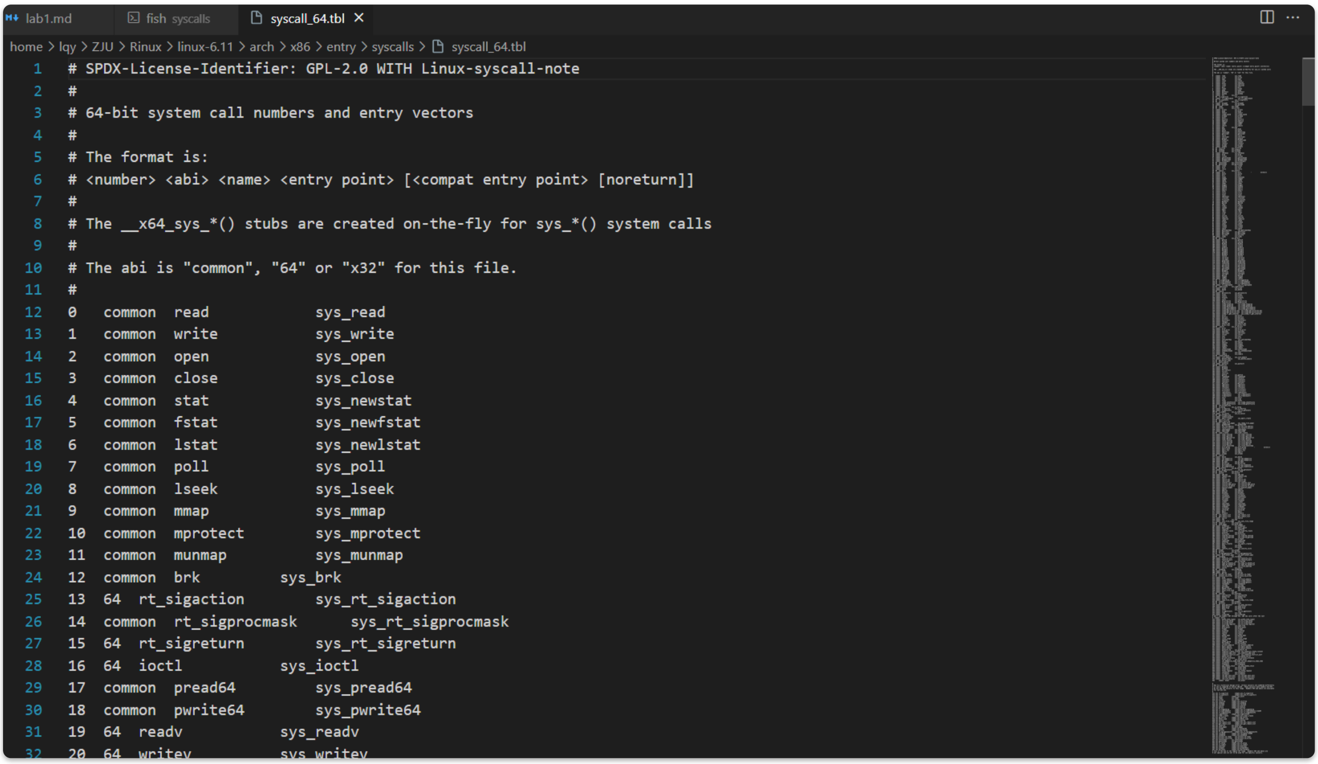
```shell
$ cd arch/riscv/kernel
$ ls | grep syscall
Makefile.syscalls
compat_syscall_table.c
compat_syscall_table.o
syscall_table.c
syscall_table.o
```



Shell x86_64

```
$ cd arch/x86/entry/syscalls
$ ls
Makefile  syscall_32.tbl  syscall_64.tbl
```





7

阐述什么是 ELF 文件？尝试使用 readelf 和 objdump 来查看 ELF 文件，并给出解释和截图。

ELF文件是一种广泛用于Unix和类Unix系统的可执行文件、目标代码、共享库的文件格式，其格式具有灵活性和可扩展性

- `readelf` 可以用于展示ELF文件的信息，有多种可选选项，包括 `-h` , `-a` 等
- `objdump` 可以用于展示目标文件的信息

Shell

```
$ readlef -h vmlinux
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
  Class:                             ELF64
```

```
  Data:                              2's complement, little endian
  Version:                           1 (current)
  OS/ABI:                            UNIX - System V
  ABI Version:                       0
  Type:                              EXEC (Executable file)
  Machine:                           RISC-V
  Version:                           0x1
  Entry point address:               0x80200000
  Start of program headers:          64 (bytes into file)
  Start of section headers:          30864 (bytes into file)
  Flags:                             0x0
  Size of this header:               64 (bytes)
  Size of program headers:           56 (bytes)
  Number of program headers:         4
  Size of section headers:           64 (bytes)
  Number of section headers:         20
  Section header string table index: 19

$ objdump vmlinux -h

vmlinux:     file format elf64-little

Sections:
Idx Name          Size      VMA               LMA               File off  Algn
  0 .text         000014fc  0000000080200000  0000000080200000  00001000  2**12
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  1 .rodata       00000109  0000000080202000  0000000080202000  00003000  2**12
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  2 .eh_frame     000002a8  0000000080202110  0000000080202110  00003110  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  3 .data         00000008  0000000080203000  0000000080203000  00004000  2**12
                  CONTENTS, ALLOC, LOAD, DATA
  4 .got          00000020  0000000080203008  0000000080203008  00004008  2**3
                  CONTENTS, ALLOC, LOAD, DATA
  5 .got.plt      00000010  0000000080203028  0000000080203028  00004028  2**3
                  CONTENTS, ALLOC, LOAD, DATA
  6 .bss          00001000  0000000080204000  0000000080204000  00004038  2**12
                  ALLOC
  7 .debug_info   00000d12  0000000000000000  0000000000000000  00004038  2**0
                  CONTENTS, READONLY, DEBUGGING, OCTETS
```

```
  8 .debug_abbrev 000005a5  0000000000000000  0000000000000000  00004d4a  2**0
                  CONTENTS, READONLY, DEBUGGING, OCTETS
  9 .debug_aranges 00000220  0000000000000000  0000000000000000  000052f0  2**4
                  CONTENTS, READONLY, DEBUGGING, OCTETS
 10 .debug_rnglists 0000010b  0000000000000000  0000000000000000  00005510  2**0
                  CONTENTS, READONLY, DEBUGGING, OCTETS
 11 .debug_line   00001379  0000000000000000  0000000000000000  0000561b  2**0
                  CONTENTS, READONLY, DEBUGGING, OCTETS
 12 .debug_str    0000035a  0000000000000000  0000000000000000  00006994  2**0
                  CONTENTS, READONLY, DEBUGGING, OCTETS
 13 .debug_line_str 00000116  0000000000000000  0000000000000000  00006cee  2**0
                  CONTENTS, READONLY, DEBUGGING, OCTETS
 14 .comment      00000026  0000000000000000  0000000000000000  00006e04  2**0
                  CONTENTS, READONLY
 15 .riscv.attributes 00000046  0000000000000000  0000000000000000  00006e2a  2**0
                  CONTENTS, READONLY

```

运行一个 `ELF` 文件，然后通过 `cat /proc/PID/maps` 来给出其内存布局并截图.

这里随便写一个简单的C程序然后看

C t.c

```c
#include <stdio.h>

int main() {
    int i = 0;
    while (i < 1000000000000000) {
        printf("%d\n", i);
        i++;
    }
    return 0;
}
```

编译并运行

Shell

```shell
gcc t.c -o a.out
./a.out
```

这时开始疯狂跑循环输出

开始另一个终端，查看PID

Shell

```
$ ps -e | grep a.out
  90706 pts/5    00:00:04 a.out

$ cat /proc/90706/maps
5627216a8000-5627216a9000 r--p 00000000 08:20 303404
/home/lqy/ZJU/lab1/a.out
5627216a9000-5627216aa000 r-xp 00001000 08:20 303404
/home/lqy/ZJU/lab1/a.out
5627216aa000-5627216ab000 r--p 00002000 08:20 303404
/home/lqy/ZJU/lab1/a.out
5627216ab000-5627216ac000 r--p 00002000 08:20 303404
/home/lqy/ZJU/lab1/a.out
5627216ac000-5627216ad000 rw-p 00003000 08:20 303404
/home/lqy/ZJU/lab1/a.out
562723442000-562723463000 rw-p 00000000 00:00 0
[heap]
7f5712e0f000-7f5712e12000 rw-p 00000000 00:00 0
7f5712e12000-7f5712e3a000 r--p 00000000 08:20 291046
/usr/lib/x86_64-linux-gnu/libc.so.6
7f5712e3a000-7f5712fc2000 r-xp 00028000 08:20 291046
/usr/lib/x86_64-linux-gnu/libc.so.6
7f5712fc2000-7f5713011000 r--p 001b0000 08:20 291046
/usr/lib/x86_64-linux-gnu/libc.so.6
7f5713011000-7f5713015000 r--p 001fe000 08:20 291046
/usr/lib/x86_64-linux-gnu/libc.so.6
7f5713015000-7f5713017000 rw-p 00202000 08:20 291046
/usr/lib/x86_64-linux-gnu/libc.so.6
7f5713017000-7f5713024000 rw-p 00000000 00:00 0
7f5713032000-7f5713034000 rw-p 00000000 00:00 0
7f5713034000-7f5713035000 r--p 00000000 08:20 291043
/usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7f5713035000-7f5713060000 r-xp 00001000 08:20 291043
/usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7f5713060000-7f571306a000 r--p 0002c000 08:20 291043
/usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7f571306a000-7f571306c000 r--p 00036000 08:20 291043
/usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7f571306c000-7f571306e000 rw-p 00038000 08:20 291043
/usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2
7ffe72256000-7ffe72277000 rw-p 00000000 00:00 0
[stack]
7ffe722cf000-7ffe722d3000 r--p 00000000 00:00 0
[vvar]
```

```
7ffe722d3000-7ffe722d5000 r-xp 00000000 00:00 0 [vdso]

```

8

在我们使用 `make run` 时，OpenSBI 会产生如下输出：

```Shell
OpenSBI v1.5.1
   ____                    _____ ____ _____
  / __ \                  / ____|  _ \_   _|
 | |  | |_ __   ___ _ __ | (___ | |_) || |
 | |  | | '_ \ / _ \ '_ \ \___ \|  _ < | |
 | |__| | |_) |  __/ | | |____) | |_) || |_
  \____/| .__/ \___|_| |_|_____/|____/_____|
        | |
        |_|

......

Boot HART MIDELEG         : 0x0000000000000222
Boot HART MEDELEG         : 0x000000000000b109

......
```

通过查看[RISC-V Privileged Spec](RISC-V Privileged Spec) 中的 medeleg 和 mideleg 部分，解释上面 MIDELEG 和 MEDELEG 值的含义

在手册的35页有详细定义

通常来说，所有的trap都可以在M模式下解决，因为M模式下的陷入解决程序可以重定向到合适的权限等级进行解决陷入；但是为了提升性能表现，引入这两个寄存器

- MIDELEG：用于保存哪些中断需要交给S模式处理
- MEDELEG：用于保存哪些异常需要交给S模式处理

这里的 `MIDELEG == 0x222 == 0b001000100010`，即第1,5,9位置1，则表明

- Supervisor Software Interrupt
- Supervisor Timer Interrupt
- Supervisor External Interrupt

上述三种中断交给S模式处理

这里 `MEDELEG == 0xb109 == 0b101100001001`，即第0,3,8,9,11位置1，则表明

- `Instruction Address Misaligned`
- `Breakpoint`
- `Environment Call from U-mode`
- `Environment Call from S-mode`
- `Environment Call from M-mode`

上述五种异常交给S模式处理

Thinkings

这个lab总体来说难度不大，主要是学习一些船新版本的知识，比如内联汇编之类的，而实验指导非常完善，夸夸助教们👍，因此上手很快，也很容易写完

内容不算多，而且学习新东西的过程比较有趣，所有总体顺利~

不过思考题觉得有点子多，甚至觉得写思考题的时间比写lab还要就，所以偷懒了一些😆