南京航空航天大学《计算机组成原理Ⅱ课程设计》报告

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- 报告阶段：PA3.1
- 完成日期：2021.6.3
- 本次实验，我完成了所有内容。

目录

思考题

一、什么是操作系统?

操作系统是管理计算机硬件与软件资源的计算机程序。操作系统需要处理如管理与配置内存、决定系统资源供需的优先次序、控制输入设备与输出设备、操作网络与管理文件系统等基本事务。操作系统也提供一个让用户与系统交互的操作界面。

二、我们不一样，吗?

我觉得他们没有差距，可以把 `Nanos-lite` 看作一个和 `PA2` 中这些测试用例同等地位的一个 AM 程序，只不过更复杂一些。

三、操作系统的实质

操作系统就是一个较为大型的应用程序，它和直接运行在硬件上的程序无实质差别。

四、程序真的结束了吗?

`_start` 处定义的启动代码主要是一系列过程调用:

1. 调用 `__libc_init_first` 和 `init`，进行初始化;
2. 调用 `atexit()` 对程序正常结束时需要调用的函数进行登记注册，这些函数将由 `exit()` 函数自动调用执行
3. 调用可执行目标中的主函数 `main()`
4. 调用 `_exit()` 过程，结束进程的执行，返回到操作系统内核。

五、触发系统调用

修改 `test.c`

```
#include<stdio.h>
const char str[] = "Hello world!\n";

int main() {
  asm volatile ("movl $4, %eax;"      // system call ID, 4 = SYS_write
                "movl $1, %ebx;"      // file descriptor, 1 = stdout
                "movl $str, %ecx;"    // buffer address
                "movl $13, %edx;"      // length
                "int $0x80");

  return 0;
}
```

```
marui@debian:~$ gcc-o test test.c
-bash: gcc-o: command not found
marui@debian:~$ gcc -o test test.c
marui@debian:~$ ./test
Hello world!
```

六、有什么不同?

和函数调用的过程类似；可以将系统调用的服务程序理解为一个比较特殊的“函数”，因为他们都需要在调用函数前保存现场，之后再将其恢复。

这个“服务程序”和我们的“用户编写的函数”不同之处在于，前者需要在内核和应用程序之间不同切换，使用不同的堆栈；后者不需要进行切换。

七、段错误

编译只是将源程序翻译成汇编语言程序，而不知道程序会访问到哪些地址，所以在编译阶段不能发现潜在的段错误。

段错误通常是程序访问了缺页、地址越界、越权访问、越级访问。

八、对比异常与函数调用

因为他们所处的环境不一样（特权级不同），因此进行异常处理之前要保存更多的信息，还需切换堆栈。

九、诡异的代码

因为在执行`irq_handle`这个函数之前，通过`pusha`形成了`trap frame`（陷阱帧）的数据结构，为了保护现场，需要`pushl %esp`操作。

十、注意区分事件号和系统调用号

事件号是未处理的一个系统调用事件的编号，此时还没有识别；

系统调用号是已经识别了的系统调用的编号。可以去执行的系统调用处理函数。

十一、打印不出来?

因为控制台是行缓冲，也就是说所以在执行到`printf`时并不是直接打印，而是放在缓冲区里面，每次遇到换行符时才会把缓存区内容实际输出到控制台。这个程序触发段错误时缓冲区里面的内容没来得及打印出来，程序就被终止了。

写成`printf("I am here!\n");`即可。

```
marui@debian:~$ gcc test.c
marui@debian:~$ ./a.out
Segmentation fault
```

```
marui@debian:~$ gcc test.c
marui@debian:~$ ./a.out
I am here!
Segmentation fault
```

十二、理解文件管理函数

- `fs_open()`：根据文件名对目标文件进行匹配，如果匹配到则让读写指针为0，并返回文件序号；匹配失败则报错。
- `fs_read()`：先判断文件序号是否大于2，再通过`fd`参数获取读写指针偏移量和大小，用文件大小减去文件读写指针位置作为剩余字节数，比较剩余字节数和要读取文件的长度作为最终要读取的文件大小。最后从`ramdisk`或`dispinfo`中读取数据到`buf`中。
- `fs_write()`：找到最终要读取的文件大小（和`fs_read()`一样），如果文件序号是标准输出的时候就打印到屏幕上面，否则通过`ramdisk`写入文件
- `fs_lseek()`：根据文件序号获取文件的大小和读写指针的位置，再根据`whence`选择新的读写偏移量并返回。
- `fs_close()`：直接返回`0`,因为不需要真的关闭。

十三、不再神秘的秘技

编写游戏代码时产生的bug，没有对数据的有效性等信息进行检验。

十四、必答

`/bin/pal`程序编译后存在`ramdisk`文件中，`make run`后运行`nemu`，并在`nemu`上运行`Nanos-lite`。`Nanos-lite`再加载位于`ramdisk`的`/bin/pal`程序。

`PAL_LoadGame()`调用`nanos.c`里面的`fread()`库函数读取存档信息并进行初始化操作。

`redraw()`调用`NDL_DrawRect`来更新像素矩阵，之后把VGA显存抽象成文件，最后`nemu`把文件通过`I/O`接口显示到屏幕上面。

十五、`git log`和`git branch`截图

```
commit 23c59e7cacfbd4409eeece380bb50e1f7868c2c4 (HEAD -> pa3)
Author: tracer-ics2017 <tracer@njuics.org>
Date:   Thu Jun 3 19:00:36 2021 +0800

    >  run
    161930131
    marui
    Linux debian 4.19.0-14-686 #1 SMP Debian 4.19.171-2 (2021-01-30) i686 GNU/Linux
     19:00:36 up 1 day, 11:17,  1 user,  load average: 0.44, 0.66, 0.68
    265135179e2af811ca43b416aafb198fcbb89f67

commit 1cb1b9ba583de923c2b208cfe19c8ba379bc3d20
Author: tracer-ics2017 <tracer@njuics.org>
Date:   Thu Jun 3 18:59:15 2021 +0800

    >  run
    161930131
    marui
    Linux debian 4.19.0-14-686 #1 SMP Debian 4.19.171-2 (2021-01-30) i686 GNU/Linux
     18:59:14 up 1 day, 11:15,  1 user,  load average: 0.43, 0.71, 0.69
    20d8210ab15b11e58bfee08284adc730f1aa7cb1

commit 31b6d91869e45979f424fe8bfe850c9a28ad704d
Author: tracer-ics2017 <tracer@njuics.org>
Date:   Thu Jun 3 18:56:08 2021 +0800

    >  run
    161930131
    marui
    Linux debian 4.19.0-14-686 #1 SMP Debian 4.19.171-2 (2021-01-30) i686 GNU/Linux
     18:56:08 up 1 day, 11:12,  1 user,  load average: 0.61, 0.79, 0.69
    6c421ea7b81c3e288f0ed417b37713ada73e73ac
:
```

```
marui@debian:~/ics2021/nanos-lite$ git branch
  master
  pa0
  pa1
  pa2
* pa3
```

实验内容

PA3.1.1 实现 loader

根据讲义的描述，修改`nanos-lite/src/loader.c`

```
// 从ramdisk中`offset`偏移处的`len`字节读入到`buf`中
void ramdisk_read(void *buf, off_t offset, size_t len);
// 把`buf`中的`len`字节写入到ramdisk中`offset`偏移处
void ramdisk_write(const void *buf, off_t offset, size_t len);
// 返回ramdisk的大小，单位为字节
size_t get_ramdisk_size();
uintptr_t loader(_Protect *as, const char *filename){
  ramdisk_read(DEFAULT_ENTRY, 0, get_ramdisk_size());
  return (uintptr_t)DEFAULT_ENTRY;
}
```

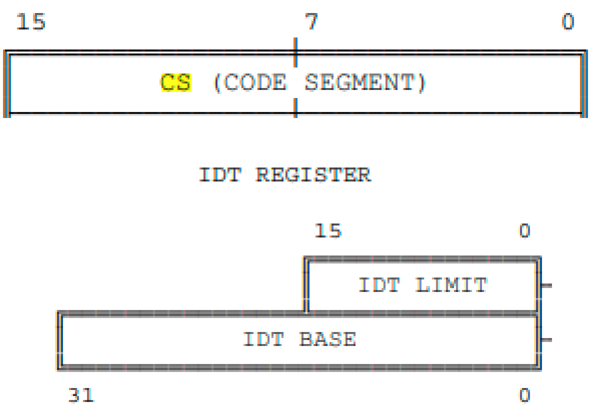
在`nanos-lite/`目录下`make update`，并`make run`

```
(nemu) c
[src/main.c,19,main] 'Hello World!' from Nanos-lite
[src/main.c,20,main] Build time: 16:48:19, Jun  1 2021
[src/ramdisk.c,26,init_ramdisk] ramdisk info: start = 0x1016c0, end = 0x1069fc, size = 21308 bytes
invalid opcode(eip = 0x04001ec0): cd 80 5b 5d c3 66 90 90 ...

There are two cases which will trigger this unexpected exception:
1. The instruction at eip = 0x04001ec0 is not implemented.
2. Something is implemented incorrectly.
Find this eip(0x04001ec0) in the disassembling result to distinguish which case it is.

If it is the first case, see
 _ ____   ___   __    __  __                         _ 
(_)___ \ / _ \ / /   |  \/  |                       | |
 _  __) | (_) / /_   | \  / | __ _ _ __  _   _  __ _| |
| ||__ < > _ < '_ \  | |\/| |/ _` | '_ \| | | |/ _` | |
| |___) | (_) | (_) | | |  | | (_| | | | | |_| | (_| | |
|_|____/ \___/ \___/  |_|  |_|\__,_|_| |_|\__,_|\__,_|_|

for more details.

If it is the second case, remember:
* The machine is always right!
* Every line of untested code is always wrong!
```

PA3.1.2 中断机制前的准备工作

正确添加 `IDTR` 和 `CS` 寄存器，并初始化

查阅 `i386` 手册得到 `CS` 和 `IDTR` 寄存器结构：



实现：

```
typedef struct {
    union {
        union {
            unsigned int _32;
            unsigned short _16;
            unsigned char _8[2];
        } gpr[8];//gpr[i]共用一个空间，gpr[i]与gpr[j]之间使用不同空间
        struct {
            rtlreg_t eax, ecx, edx, ebx, esp, ebp, esi, edi;
        };//这些元素各自使用各自的空间,且每个元素与相应的gpr[i]共用一个地址
    };
    union{
        vaddr_t eip;
        unsigned short ip;
    };
```

```c
    union {
        struct{
        uint32_t CF :1;
        uint32_t ONE :1;
        uint32_t :4;
        uint32_t ZF :1;
        uint32_t SF :1;
        uint32_t :1;
        uint32_t IF :1;
        uint32_t :1;
        uint32_t OF :1;
        uint32_t :20;
    };
        rtlreg_t value;
    } eflags;
    struct{
        uint16_t limit;
        uint32_t base;
    } idtr;
    uint16_t cs;
} CPU_state;
```

修改`nemu/src/monitor/monitor.c`：

```c
static inline void restart() {
  /* Set the initial instruction pointer. */
  cpu.eip = ENTRY_START;
  cpu.eflags_num = 0x2;
  cpu.cs = 8;

#ifdef DIFF_TEST
  init_qemu_reg();
#endif
}
```

PA3.1.3 实现中断机制

实现 LIDT 指令

LGDT/LIDT — Load Global/Interrupt Descriptor Table Register

Opcode	Instruction	Clocks	Description
0F 01 /2	LGDT m16&32	11	Load m into GDTR
0F 01 /3	LIDT m16&32	11	Load m into IDTR

Operation

```
IF instruction = LIDT
THEN
   IF OperandSize = 16
   THEN IDTR.Limit:Base ← m16:24 (* 24 bits of base loaded *)
   ELSE IDTR.Limit:Base ← m16:32
   FI;
ELSE (* instruction = LGDT *)
   IF OperandSize = 16
   THEN GDTR.Limit:Base ← m16:24 (* 24 bits of base loaded *)
   ELSE GDTR.Limit:Base ← m16:32;
   FI;
FI;
```

修改`system.c`:

```
make_EHelper(lidt) {
  cpu.idtr.limit = vaddr_read(id_dest->addr, 2);
  if (decoding.is_operand_size_16)
    cpu.idtr.base = vaddr_read(id_dest->addr + 2, 3);
  else
    cpu.idtr.base = vaddr_read(id_dest->addr + 2, 4);

  print_asm_template1(lidt);
}
```

填表:

```
make_group(gp7,
    EMPTY, EMPTY, EMPTY, EX(lidt),
    EMPTY, EMPTY, EMPTY, EMPTY)
```

加入`all-instr.h`

```
make_EHelper(lidt);
```

在 `nanos-lite/src/main.c` 中定义宏 `HAS_ASYE`

```
#define HAS_ASYE
```

实现 INT 指令

查阅i386手册，得到int指令

```
CD ib     INT imm8     37              Interrupt numbered by byte
CD ib     INT imm8     pm=59           Interrupt--Protected Mode, same privilege
CD ib     INT imm8     pm=99           Interrupt--Protected Mode, more privilege
CD ib     INT imm8     pm=119          Interrupt--from V86 mode to PL 0
CD ib     INT imm8     ts              Interrupt--Protected Mode, via task gate
```

根据讲义描述得到实现步骤：

1. 依次将EFLAGS，CS，EIP寄存器的值压栈
2. 从IDTR中读出IDT的首地址
3. 根据异常号在IDT中进行索引，找到一个门描述符
4. 对门描述符进行P位校验
5. 将门描述符中的offset域组合成目标地址
6. 跳转到目标地址

门描述符结构：

```
 31                23                15        7                 0

+----------------+----------------+---+----------------------------+

|         OFFSET 31..16           | P |         Don't care         |4

+--------------------------------+---+----------------------------+

|          Don't care            |          OFFSET 15..0           |0

+----------------+----------------+----------------+----------------+
```

实现raise_intr()函数

修改nemu/src/cpu/intr.c

```
void raise_intr(uint8_t NO, vaddr_t ret_addr) {
  /* TODO: Trigger an interrupt/exception with ``NO''.
   * That is, use ``NO'' to index the IDT.
   */
  vaddr_t gate_addr = cpu.idtr.base + NO * 8;//乘8是因为IDT由一个8字节的描述符阵列组成
  GateDesc gateDesc;
  *(uint32_t *)&gateDesc = vaddr_read(gate_addr, 4);
  *((uint32_t *)&gateDesc + 1) = vaddr_read(gate_addr + 4, 4) ;
  uint32_t p = *((uint32_t *)&gateDesc + 1) & 0x8000;
  Assert(p != 0, "P is valid");
  rtl_push((rtlreg_t*)&cpu.eflags.value);
  rtl_push((rtlreg_t*)&cpu.cs);
  rtl_push((rtlreg_t*)&ret_addr);

  decoding.is_jmp = 1;
  decoding.jmp_eip = (gateDesc.offset_31_16 << 16) | (gateDesc.offset_15_0 &
0xffff);
}
```

- 使用 INT 的 helper 函数调用 `raise_intr()`

```
void raise_intr(uint8_t NO, vaddr_t ret_addr);
make_EHelper(int) {
  raise_intr(id_dest->val, decoding.seq_eip);

  print_asm("int %s", id_dest->str);

#ifdef DIFF_TEST
  diff_test_skip_nemu();
#endif
}
```

填表:

```
  /* 0xcc */    EX(int3), IDEXW(I, int, 1), EMPTY, EMPTY,
```

加入`all-instr.h`

```
make_EHelper(int);
```

PA3.1.4 重新组织 TrapFrame 结构体

实现 pusha

发现有未实现的指令

```
invalid opcode(eip = 0x00101286): 60 54 e8 1e fd ff ff 83 ...
```

查阅`i386`手册发现是`pusha`指令

```
Opcode  Instruction  Clocks   Description

60      PUSHA        18       Push AX, CX, DX, BX, original SP, BP, SI, and DI
60      PUSHAD       18       Push EAX, ECX, EDX, EBX, original ESP, EBP, ESI, and EDI
```

```
Operation

IF OperandSize = 16 (* PUSHA instruction *)
THEN
   Temp ← (SP);
   Push(AX);
   Push(CX);
   Push(DX);
   Push(BX);
   Push(Temp);
   Push(BP);
   Push(SI);
   Push(DI);
ELSE (* OperandSize = 32, PUSHAD instruction *)
   Temp ← (ESP);
   Push(EAX);
   Push(ECX);
   Push(EDX);
   Push(EBX);
   Push(Temp);
   Push(EBP);
   Push(ESI);
   Push(EDI);
FI;
```

```
make_EHelper(pusha) {
  if (decoding.is_operand_size_16) {
    t0 = reg_w(R_SP);
    //保存当前sp
    rtl_push((rtlreg_t *)&reg_w(R_AX));
    rtl_push((rtlreg_t *)&reg_w(R_CX));
    rtl_push((rtlreg_t *)&reg_w(R_DX));
    rtl_push((rtlreg_t *)&reg_w(R_BX));
    rtl_push(&t0);
    rtl_push((rtlreg_t *)&reg_w(R_BP));
    rtl_push((rtlreg_t *)&reg_w(R_SI));
    rtl_push((rtlreg_t *)&reg_w(R_DI));
  }
  else {
    t0 = reg_w(R_ESP);
    //保存当前esp
    rtl_push(&cpu.eax);
    rtl_push(&cpu.ecx);
    rtl_push(&cpu.edx);
    rtl_push(&cpu.ebx);
    rtl_push(&t0);
    rtl_push(&cpu.ebp);
    rtl_push(&cpu.esi);
    rtl_push(&cpu.edi);
  }

  print_asm("pusha");
}
```

填表：

```
/* 0x60 */     EX(pusha), EMPTY, EMPTY, EMPTY,
```

加入`all-instr.h`

```
make_EHelper(pusha);
```

运行

```
(nemu) c
[src/main.c,19,main] 'Hello World!' from Nanos-lite
[src/main.c,20,main] Build time: 00:38:28, Jun  2 2021
[src/ramdisk.c,26,init_ramdisk] ramdisk info: start = 0x1019e0, end = 0x106d1c, size = 21308 bytes
[src/main.c,27,main] Initializing interrupt/exception handler...
[src/irq.c,5,do_event] system panic: Unhandled event ID = 3
nemu: HIT BAD TRAP at eip = 0x001000f1
```

组织 _RegSet 结构体

修改`nexus-am/am/arch/x86-nemu/include/arch.h`

```
struct _RegSet {
    uintptr_t edi, esi, ebp, esp, ebx, edx, ecx, eax;
    int irq;
    uintptr_t error, eip, cs, eflags;
};
```

这些成员声明的顺序要和构造的`trap frame`保持一致。根据讲义内容，应该先将`EFLAGS`，`CS`，`EIP`压入堆栈，然后`vecsys()`会压入错误码和异常号`#irq`，最后将通用寄存器压入堆栈，这一过程地址从高到低，所以在结构体中最后压入栈的应该在最前面。

运行

```
(nemu) c
[src/main.c,19,main] 'Hello World!' from Nanos-lite
[src/main.c,20,main] Build time: 14:54:50, Jun  2 2021
[src/ramdisk.c,26,init_ramdisk] ramdisk info: start = 0x1019e0, end = 0x106d1c, size = 21308 bytes
[src/main.c,27,main] Initializing interrupt/exception handler...
[src/irq.c,5,do_event] system panic: Unhandled event ID = 8
nemu: HIT BAD TRAP at eip = 0x001000f1
```

PA3.1.5 实现系统调用

1. 修改`nanos-lite/src/irp.c`中的`do_event`.

```c
static _RegSet* do_event(_Event e, _RegSet* r) {
  switch (e.event) {
    case _EVENT_SYSCALL:
      return do_syscall(r);
    default: panic("Unhandled event ID = %d", e.event);
  }

  return NULL;
}
```

2. 根据讲义可知，`_syscall_()` 函数会先把系统调用的参数依次放入 `%eax`，`%ebx`，`%ecx`，`%edx` 四个寄存器中，因此修改 `nexus-am/am/arch/x86-nemu/include/arch.h`，实现 `SYSCALL_ARGx()` 宏.

```c
#define SYSCALL_ARG1(r) (r->eax)
#define SYSCALL_ARG2(r) (r->ebx)
#define SYSCALL_ARG3(r) (r->ecx)
#define SYSCALL_ARG4(r) (r->edx)
```

3. 修改 `nanos-lite/src/syscall.c` 的 `do_syscall()` 函数，实现 `SYS_none` 系统调用，并设置系统调用的返回值

```c
static inline uintptr_t sys_none() {
  return 1;
}

_RegSet* do_syscall(_RegSet *r) {
  uintptr_t a[4];
  a[0] = SYSCALL_ARG1(r);
  a[1] = SYSCALL_ARG2(r);
  a[2] = SYSCALL_ARG3(r);
  a[3] = SYSCALL_ARG4(r);
  switch (a[0]) {
    case SYS_none:
      SYSCALL_ARG1(r) = sys_none();
      Log("Call sys_none");
      break;
    default:
      panic("Unhandled syscall ID = %d", a[0]);
  }

  return NULL;
}
```

4. 实现 `popa` 和 `iret` 指令

- `popa` 指令

```
Opcode    Instruction    Clocks    Description

61        POPA           24        Pop DI, SI, BP, SP, BX, DX, CX, and AX
61        POPAD          24        Pop EDI, ESI, EBP, ESP, EDX, ECX, and EAX
```

```
Operation

IF OperandSize = 16 (* instruction = POPA *)
THEN
   DI ← Pop();
   SI ← Pop();
   BP ← Pop();
   throwaway ← Pop (); (* Skip SP *)
   BX ← Pop();
   DX ← Pop();
   CX ← Pop();
   AX ← Pop();
ELSE (* OperandSize = 32, instruction = POPAD *)
   EDI ← Pop();
   ESI ← Pop();
   EBP ← Pop();
   throwaway ← Pop (); (* Skip ESP *)
   EBX ← Pop();
   EDX ← Pop();
   ECX ← Pop();
   EAX ← Pop();
FI;
```

```
make_EHelper(popa) {
  if (decoding.is_operand_size_16) {
    rtl_pop((rtlreg_t*)&reg_w(R_DI));
    rtl_pop((rtlreg_t*)&reg_w(R_SI));
    rtl_pop((rtlreg_t*)&reg_w(R_BP));
    rtl_pop(&t0);
    rtl_pop((rtlreg_t*)&reg_w(R_BX));
    rtl_pop((rtlreg_t*)&reg_w(R_DX));
    rtl_pop((rtlreg_t*)&reg_w(R_CX));
    rtl_pop((rtlreg_t*)&reg_w(R_AX));
  }
  else {
    rtl_pop(&cpu.edi);
    rtl_pop(&cpu.esi);
    rtl_pop(&cpu.ebp);
    rtl_pop(&t0);
    rtl_pop(&cpu.ebx);
    rtl_pop(&cpu.edx);
    rtl_pop(&cpu.ecx);
    rtl_pop(&cpu.eax);
  }

  print_asm("popa");
}
```

- `iret`指令

```
Opcode  Instruction  Clocks       Description

CF      IRET         22,pm=38     Interrupt return (far return and pop flags)
CF      IRET         pm=82        Interrupt return to lesser privilege
CF      IRET         ts           Interrupt return, different task (NT = 1)
CF      IRETD        22,pm=38     Interrupt return (far return and pop flags)
CF      IRETD        pm=82        Interrupt return to lesser privilege
CF      IRETD        pm=60        Interrupt return to V86 mode
CF      IRETD        ts           Interrupt return, different task (NT = 1)
```

```
IF PE = 0
THEN (* Real-address mode *)
   IF OperandSize = 32 (* Instruction = IRETD *)
   THEN EIP ← Pop();
   ELSE (* Instruction = IRET *)
      IP ← Pop();
   FI;
   CS ← Pop();
   IF OperandSize = 32 (* Instruction = IRETD *)
   THEN EFLAGS ← Pop();
   ELSE (* Instruction = IRET *)
      FLAGS ← Pop();
   FI;
```

```
make_EHelper(iret) {
  rtl_pop(&decoding.jmp_eip);
  rtl_pop(&t0);
  cpu.cs = (uint16_t)t0;
  rtl_pop(&cpu.eflags.value);
  decoding.is_jmp = 1;

  print_asm("iret");
}
```

填表

```
  /* 0x60 */    EX(pusha), EX(popa), EMPTY, EMPTY,
  /* 0xcc */    EX(int3), IDEXW(I, int, 1), EMPTY, EX(iret),
```

加入`all-instr.h`

```
make_EHelper(popa);
make_EHelper(iret);
```

运行（后面才添加的`LOG`，所以这里没有打印）

```
(nemu) c
[src/main.c,19,main] 'Hello World!' from Nanos-lite
[src/main.c,20,main] Build time: 16:17:26, Jun  2 2021
[src/ramdisk.c,26,init_ramdisk] ramdisk info: start = 0x101ac0, end = 0x106dfc, size = 21308 bytes
[src/main.c,27,main] Initializing interrupt/exception handler...
[src/syscall.c,54,do_syscall] system panic: Unhandled syscall ID = 4
nemu: HIT BAD TRAP at eip = 0x001000f1
```

5. 修改 `nanos-lite/src/syscall.c` 的 `do_syscall()` 函数，实现 `SYS_exit` 系统调用，并设置系统调用的返回值

```c
static inline uintptr_t sys_exit(_RegSet *r) {
  Log("Call sys_exit");
  _halt(SYSCALL_ARG2(r));
  return 1;
}

_RegSet* do_syscall(_RegSet *r) {
  uintptr_t a[4];
  a[0] = SYSCALL_ARG1(r);
  a[1] = SYSCALL_ARG2(r);
  a[2] = SYSCALL_ARG3(r);
  a[3] = SYSCALL_ARG4(r);

  switch (a[0]) {
    case SYS_none:
      SYSCALL_ARG1(r) = sys_none(r);
      Log("Call sys_none");
      break;
    case SYS_exit:
      sys_exit(r);
      break;
    default:
      panic("Unhandled syscall ID = %d", a[0]);
  }

  return NULL;
}
```

运行

```
(nemu) c
[src/main.c,19,main] 'Hello World!' from Nanos-lite
[src/main.c,20,main] Build time: 16:17:26, Jun  2 2021
[src/ramdisk.c,26,init_ramdisk] ramdisk info: start = 0x101ca0, end
[src/main.c,27,main] Initializing interrupt/exception handler...
[src/syscall.c,54,do_syscall]
Call sys_none

[src/syscall.c,39,sys_exit]
Call sys_exit

nemu: HIT GOOD TRAP at eip = 0x001000f1
```

PA3.1.6 在 Nanos-lite 上运行 Hello world

实现 `write()` 系统调用的步骤：

- 在 `do_syscall()` 中识别出系统调用号是 `SYS_write`
- 检查 `fd` 的值，如果 `fd` 是 `1` 或 `2`（分别代表 `stdout` 和 `stderr`），则将 `buf` 为首地址的 `len` 字节输出到串口（使用 `_putc()` 即可）

- 设置正确的返回值（查阅`man 2 write`，返回的应该是写入的字节数，也就是`len`）
- 在 `navy-apps/libs/libos/src/nanos.c` 的 `_write()` 中调用系统调用接口函数

发现`fs_write()`函数与所要实现的`write()`函数一致，因此直接使用。

```
static inline uintptr_t sys_write(uintptr_t fd, uintptr_t buf, uintptr_t len) {
  return (uintptr_t)fs_write(fd, (void *)buf, len);
}

_RegSet* do_syscall(_RegSet *r) {
  uintptr_t a[4];
  a[0] = SYSCALL_ARG1(r);
  a[1] = SYSCALL_ARG2(r);
  a[2] = SYSCALL_ARG3(r);
  a[3] = SYSCALL_ARG4(r);

  switch (a[0]) {
    case SYS_none:
      SYSCALL_ARG1(r) = sys_none(r);
      Log("Call sys_none");
      break;
    case SYS_exit:
      sys_exit(r);
      break;
    case SYS_write:
      SYSCALL_ARG1(r) = sys_write(a[1], a[2], a[3]);
      Log("Call sys_write");
      break;
    default:
      panic("Unhandled syscall ID = %d", a[0]);
  }

  return NULL;
}


int _write(int fd, void *buf, size_t count){
  return _syscall_(SYS_write, fd, (uintptr_t)buf, count);
}
```

运行`hello`程序，发现有指令没有填表

```
Hello World!
invalid opcode(eip = 0x04001ad5): a8 08 74 27 8b 53 10 85 ...
```

查阅`i386`手册发现是`test`指令，填表即可

```
  /* 0xa8 */    IDEXW(I2a, test, 1), IDEX(I2a, test), EMPTY, EMPTY,
```

再次运行（后面才添加的`LOG`，所以这里没有打印）

```
Hello World!
Hello World for the 2th time
Hello World for the 3th time
Hello World for the 4th time
Hello World for the 5th time
Hello World for the 6th time
Hello World for the 7th time
Hello World for the 8th time
Hello World for the 9th time
```

PA3.1.7 实现堆区管理

实现 SYS_brk 系统调用

将 `SYS_brk` 系统调用总是返回 `0` 即可

修改 `nanos-lite/src/syscall.c`：

```c
static inline uintptr_t sys_brk(uintptr_t new_brk) {
  return 0;
}

_RegSet* do_syscall(_RegSet *r) {
  uintptr_t a[4];
  a[0] = SYSCALL_ARG1(r);
  a[1] = SYSCALL_ARG2(r);
  a[2] = SYSCALL_ARG3(r);
  a[3] = SYSCALL_ARG4(r);

  switch (a[0]) {
    case SYS_none:
      SYSCALL_ARG1(r) = sys_none(r);
      Log("Call sys_none");
      break;
    case SYS_exit:
      sys_exit(r);
      Log("Call sys_exit");
      break;
    case SYS_write:
      SYSCALL_ARG1(r) = sys_write(a[1], a[2], a[3]);
      Log("Call sys_write");
      break;
    case SYS_brk:
      SYSCALL_ARG1(r) = sys_brk(a[1]);
      Log("Call sys_brk");
      break;
    default:
      panic("Unhandled syscall ID = %d", a[0]);
  }

  return NULL;
}
```

实现 _sbrk()

```
DESCRIPTION
       brk()  and  sbrk() change the location of the program break, which defines the end of the process's
       data segment (i.e., the program break is the first location after the end of the uninitialized data
       segment).   Increasing  the  program  break has the effect of allocating memory to the process; de-
       creasing the break deallocates memory.

       brk() sets the end of the data segment to the value specified by addr, when that value  is  reason-
       able,  the  system  has  enough  memory, and the process does not exceed its maximum data size (see
       setrlimit(2)).

       sbrk() increments the program's data space by increment bytes.  Calling sbrk() with an increment of
       0 can be used to find the current location of the program break.

RETURN VALUE
       On success, brk() returns zero.  On error, -1 is returned, and errno is set to ENOMEM.

       On  success,  sbrk()  returns  the  previous program break.  (If the break was increased, then this
       value is a pointer to the start of the newly allocated memory).  On error, (void *) -1 is returned,
       and errno is set to ENOMEM.
```

```
EXAMPLE
       When run, the program below produces output such as the following:

           $ ./a.out
           First address past:
               program text (etext)       0x8048568
               initialized data (edata)   0x804a01c
               uninitialized data (end)   0x804a024

   Program source

       #include <stdio.h>
       #include <stdlib.h>

       extern char etext, edata, end; /* The symbols must have some type,
                                          or "gcc -Wall" complains */

       int
       main(int argc, char *argv[])
       {
           printf("First address past:\n");
           printf("    program text (etext)      %10p\n", &etext);
           printf("    initialized data (edata)  %10p\n", &edata);
           printf("    uninitialized data (end)  %10p\n", &end);

           exit(EXIT_SUCCESS);
       }
```

1. program break 一开始的位置位于 `_end`
2. 被调用时，根据记录的 program break 位置和参数 `increment`，计算出新 program break
3. 通过 `SYS_brk` 系统调用来让操作系统设置新 program break
4. 更新之前记录的 program break 的位置，并将旧 program break 的位置作为 `_sbrk()` 的返回值返回
5. 若该系统调用失败，`_sbrk()` 会返回 `-1` （其实不会返回 `-1`）

修改`navy-apps/libs/libos/src/nanos.c`实现`_sbrk()`.

```c
extern char _end;
intptr_t program_break = (uintptr_t)&_end;
void *_sbrk(intptr_t increment) {
  intptr_t old_program_break = program_break;
  if(_syscall_(SYS_brk, program_break + increment,0, 0) == 0) {
    program_break += increment;
    return (void *)old_program_break;
  }else{
    return (void *)-1;
  }
}
```

然后切换到 `navy-apps/tests/hello/` 目录下执行 `make` 编译；在 `nanos-lite/Makefile` 下执行 `make update`；最后`make run`

运行，可以看出不是一个字符一个字符的输出了。（参数分别是`SYSCALL_ARG1(r) SYSCALL_ARG2(r) SYSCALL_ARG3(r) SYSCALL_ARG4(r)`）

```
Hello World!

13 1 67121152 13
Hello World for the 2th time

29 1 67134268 29
Hello World for the 3th time

29 1 67134268 29
Hello World for the 4th time

29 1 67134268 29
Hello World for the 5th time

29 1 67134268 29
Hello World for the 6th time

29 1 67134268 29
Hello World for the 7th time

29 1 67134268 29
Hello World for the 8th time

29 1 67134268 29
Hello World for the 9th time

29 1 67134268 29
Hello World for the 10th time

30 1 67134268 30
Hello World for the 11th time
```

```
Hello World!
[src/syscall.c,61,do_syscall]
Call sys_write

1 67121152 13
[src/syscall.c,66,do_syscall]
Call sys_brk

[src/syscall.c,66,do_syscall]
Call sys_brk

[src/syscall.c,66,do_syscall]
Call sys_brk

Hello World for the 2th time
[src/syscall.c,61,do_syscall]
Call sys_write

1 67134268 29
Hello World for the 3th time
[src/syscall.c,61,do_syscall]
Call sys_write
```

PA3.1.8 让 loader使用文件

修改`nanos-lite/src/loader.c`

```
#include"fs.h"
...
uintptr_t loader(_Protect *as, const char *filename) {
  int fd = fs_open(filename, 0, 0);
  size_t f_size = fs_filesz(fd);
  fs_read(fd, DEFAULT_ENTRY, f_size);
  fs_close(fd);

  return (uintptr_t)DEFAULT_ENTRY;
}
```

PA3.1.9 & 3.1.10 实现完整的文件系统 & 实现系统调用

修改`nanos-lite/src/syscall.c`

```
static inline uintptr_t sys_open(uintptr_t pathname, uintptr_t flags, uintptr_t
mode) {
  return (uintptr_t)fs_open((char *)pathname, flags, mode);
}

static inline uintptr_t sys_write(uintptr_t fd, uintptr_t buf, uintptr_t len) {
  return (uintptr_t)fs_write(fd, (void*)buf, len);
}

static inline uintptr_t sys_read(uintptr_t fd, uintptr_t buf, uintptr_t len) {
  return (uintptr_t)fs_read(fd, (void*)buf, len);
}
```

```c
static inline uintptr_t sys_lseek(uintptr_t fd, uintptr_t offset, uintptr_t
whence) {
  return (uintptr_t)fs_lseek(fd, offset, whence);
}

static inline uintptr_t sys_close(uintptr_t fd) {
  return (uintptr_t)fs_close(fd);
}

static inline uintptr_t sys_brk(uintptr_t new_brk) {
  return 0;
}


_RegSet* do_syscall(_RegSet *r) {
  uintptr_t a[4];
  a[0] = SYSCALL_ARG1(r);
  a[1] = SYSCALL_ARG2(r);
  a[2] = SYSCALL_ARG3(r);
  a[3] = SYSCALL_ARG4(r);

  switch (a[0]) {
    case SYS_none:
      SYSCALL_ARG1(r) = sys_none(r);
      Log("Call sys_none\n");
      break;
    case SYS_exit:
      sys_exit(r);
      break;
    case SYS_write:
      SYSCALL_ARG1(r) = sys_write(a[1], a[2], a[3]);
      Log("Call sys_write");
      break;
    case SYS_brk:
      SYSCALL_ARG1(r) = sys_brk(a[1]);
      Log("Call sys_brk");
      break;
    case SYS_open:
      SYSCALL_ARG1(r) = sys_open(a[1], a[2], a[3]);
      Log("Call sys_open");
      break;
    case SYS_read:
      SYSCALL_ARG1(r) = sys_read(a[1], a[2], a[3]);
      Log("Call sys_read");
      break;
    case SYS_lseek:
      SYSCALL_ARG1(r) = sys_lseek(a[1], a[2], a[3]);
      Log("Call sys_lseek");
      break;
    case SYS_close:
      SYSCALL_ARG1(r) = sys_close(a[1]);
      Log("Call sys_close");
      break;
    default:
      panic("Unhandled syscall ID = %d", a[0]);
  }

  return NULL;
```

```
}
```

修改`navy-apps/libs/libos/src/nanos.c`

```c
int _open(const char *path, int flags, mode_t mode) {
  return _syscall_(SYS_open, (uintptr_t)path, flags, mode);
}

int _write(int fd, void *buf, size_t count){
  return _syscall_(SYS_write, fd, (uintptr_t)buf, count);
}

int _read(int fd, void *buf, size_t count) {
  return _syscall_(SYS_read, fd, (uintptr_t)buf, count);
}

int _close(int fd) {
  return _syscall_(SYS_close, fd, 0, 0);
}

off_t _lseek(int fd, off_t offset, int whence) {
  return _syscall_(SYS_lseek, fd, offset, whence);
}
```

修改`nanos-lite\src\main.c`中`loader`函数的参数

```c
uint32_t entry = loader(NULL, "/bin/text");
```

运行

```
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,74,do_syscall] Call sys_lseek
[src/syscall.c,58,do_syscall] Call sys_write
[src/syscall.c,58,do_syscall] Call sys_write
[src/syscall.c,58,do_syscall] Call sys_write
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,74,do_syscall] Call sys_lseek
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,70,do_syscall] Call sys_read
[src/syscall.c,78,do_syscall] Call sys_close
PASS!!!
[src/syscall.c,58,do_syscall] Call sys_write
[src/syscall.c,36,sys_exit] Call sys_exit
nemu: HIT GOOD TRAP at eip = 0x001000f1
```

PA3.1.11 把VGA显存抽象成文件

修改`nanos-lite\src\main.c`中`loader`函数的参数

```
uint32_t entry = loader(NULL, "/bin/bmptest");
```

运行发现有未实现的指令

```
invalid opcode(eip = 0x04000d88): a4 39 d7 75 fb 5e 5f 5d
```

查阅手册得知是`MOVSB`指令

```
Opcode  Instruction      Description
A4      MOVS m8,m8       Move byte [(E)SI] to ES:[(E)DI]
A4      MOVSB            Move byte DS:[(E)SI] to ES:[(E)DI]
```

`MOVS`将`(E)SI`的字节复制到`(E)DI`的字节，并`(E)SI`和`(E)DI`自增`1`。

修改`data-mov.c`：

```
make_EHelper(movsb){
  rtl_lm(&t0,&cpu.esi,1);
  rtl_sm(&cpu.edi,1,&t0);
  cpu.esi+=1;
  cpu.edi+=1;
  print_asm("movsb");

}
```

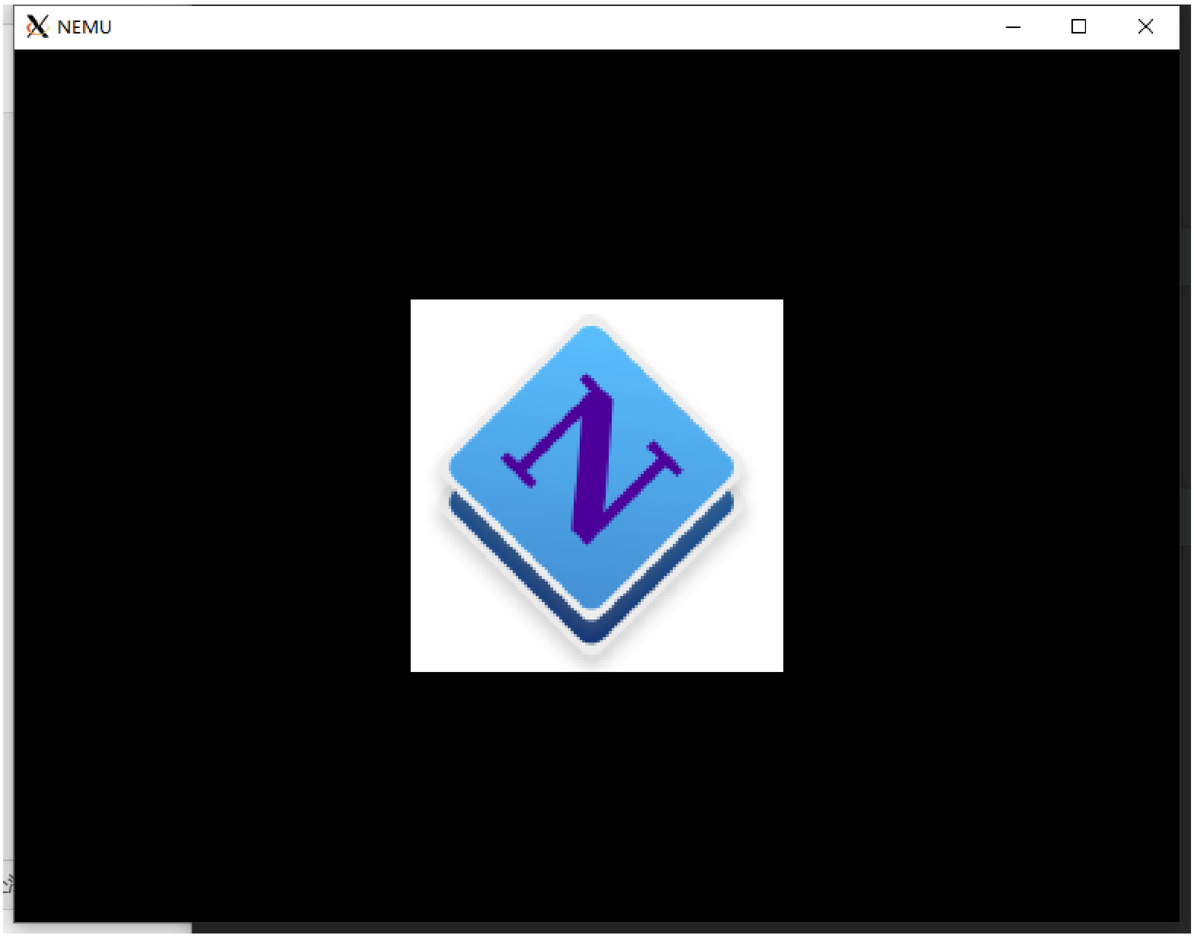
填表

```
  /* 0xa4 */     EX(movsb), EMPTY, EMPTY, EMPTY,
```

加入`all-instr.h`

```
make_EHelper(movsb);
```

运行（关闭`DEBUG`宏，不然很慢）

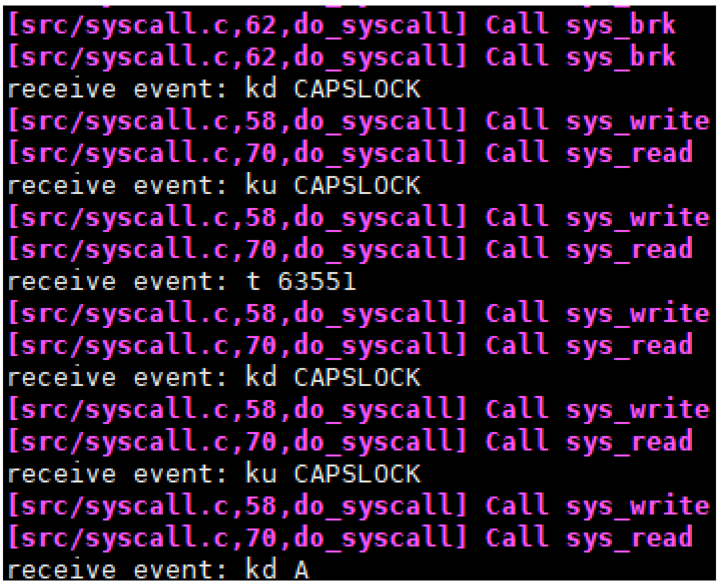


PA3.1.12 把设备输入抽象成文件

修改`nanos-lite\src\main.c`中`loader`函数的参数

```
uint32_t entry = loader(NULL, "/bin/events");
```

运行（很慢）



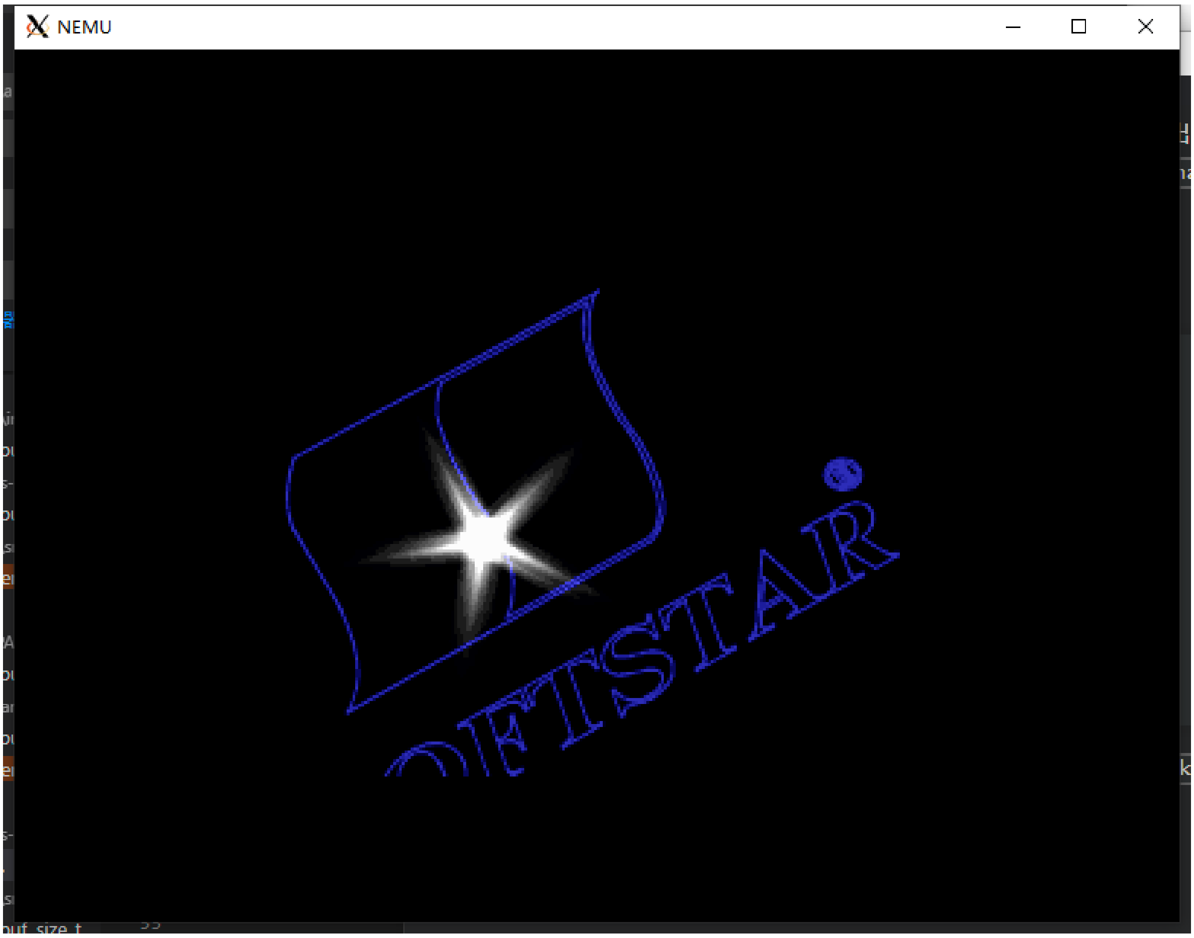
PA3.1.13 把设备输入抽象成文件

将压缩包解压并放到 `navy-apps/fsimg/share/games/pal/` 目录下

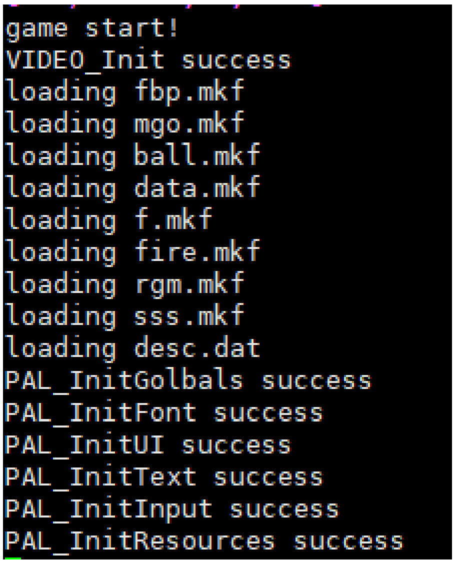
修改`nanos-lite\src\main.c`中`loader`函数的参数

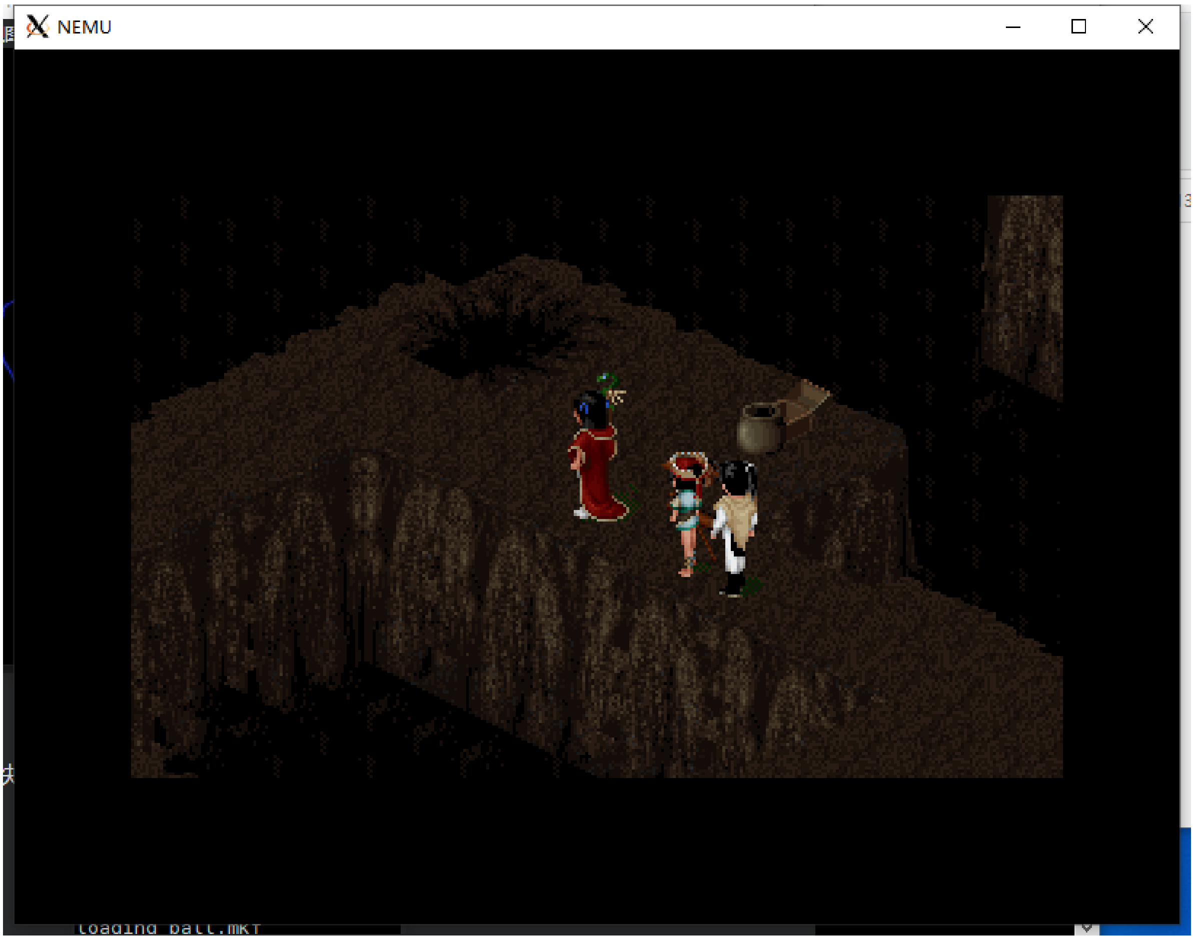
```c
uint32_t entry = loader(NULL, "/bin/pal");
```

运行（因为太慢了，就只到这里就暂停了）



把`Log`注释掉后快了很多





只能到这一步了，后面操控人物很久才会显示动画。

遇到的问题及解决办法

1. 在重新组织 TrapFrame 结构体的时候，无论怎么实现输出的都是 `ID = 3`，最后发现是因为文件传错了，应该传到 `x86` 文件夹而我传到 `native` 文件夹里了
2. 在实现 `_sbrk()` 函数时，总是报错（超出内存范围）

这是原先的代码

```
extern char _end;
void *_sbrk(intptr_t increment) {
  intptr_t program_break = (intptr_t)&_end;
  intptr_t old_program_break = program_break;
  if(_syscall_(SYS_brk, program_break + increment,0, 0) == 0) {
    program_break += increment;
    return (void *)old_program_break;
  }else{
    return (void *)-1;
  }
}
```

调试了半天没发现错误，最后突然发现应该把`program_break`声明为全局变量（或者静态变量）

```
extern char _end;
intptr_t program_break = (intptr_t)&_end;
void *_sbrk(intptr_t increment) {
  intptr_t old_program_break = program_break;
  if(_syscall_(SYS_brk, program_break + increment,0, 0) == 0) {
    program_break += increment;
    return (void *)old_program_break;
  }else{
    return (void *)-1;
  }
}
```

实验心得

做前面的有些任务时没有`make update`，导致花费了很多时间去找一些不存在的`bug`。

感觉这次的实验要做的内容并不是很多，更多的是需要思考和理解的知识。

其他备注

无