Report for lab3, Kexing Zhou, 1900013008

Environment Configuration

```
Hardware Environment:
Memory:         16GB
Processor:      Intel® Core™ i7-8550U CPU @ 1.66GHz × 8
GPU:            NVIDIA GeForce RTX 2070
OS Type:        64 bit
Disk:           924GB

Software Environment:
OS:             Arch Linux
Gcc:            Gcc 11.1.0
Make:           GNU Make 4.3
Gdb:            GNU gdb 11.1
```

Test Compiler Toolchain

```
$ objdump -i   # the 5th line say elf32-i386
$ gcc -m32 -print-libgcc-file-name
/usr/lib/gcc/x86_64-pc-linux-gnu/11.1.0/32/libgcc.a
```

QEMU Emulator

```
$ sudo pacman -S riscv64-linux-gnu-binutils \
    riscv64-linux-gnu-gcc riscv64-linux-gnu-gdb qemu-arch-extra
```

Memory Management

Exercise 1

The setup code in kern/pmap.c, Line 196.

```
// allocating the pages array
envs = boot_alloc(NENV * sizeof(*envs));
memset(envs, 0, NENV * sizeof(*envs));
......
// map envs to UENVS with permission user readonly
boot_map_region(kern_pgdir, UENVS, PTSIZE, PADDR(envs), PTE_P | PTE_U);
```

Exercise 2

env_init

```
void
env_init(void) {
    // Set up envs array
    // make sure the first free env is env 0
    env_free_list = &envs[0];
    for(size_t i = 0; i + 1 < NENV; i++) {
        envs[i].env_link = &envs[i + 1];
    }
    // Per-CPU part of the initialization
    env_init_percpu();
}
```

env_setup_vm

```
static int
env_setup_vm(struct Env *e) {
    int i;
    struct PageInfo *p = NULL;

    // Allocate a page for the page directory
    if (!(p = page_alloc(ALLOC_ZERO)))
        return -E_NO_MEM;

    // use kern_pgdir as a template to initialize env
    memcpy(page2kva(p), kern_pgdir, PGSIZE);
    p->pp_ref++;
    e->env_pgdir = page2kva(p);

    // UVPT maps the env's own page table read-only.
    // Permissions: kernel R, user R
    e->env_pgdir[PDX(UVPT)] = PADDR(e->env_pgdir) | PTE_P | PTE_U;
    return 0;
}
```

region_alloc

```
static void
region_alloc(struct Env *e, void *va, size_t len) {
    uintptr_t start = ROUNDDOWN((uintptr_t)va, PGSIZE);
    uintptr_t end   = ROUNDUP((uintptr_t)va + len, PGSIZE);
    int errno = 0;
    for(uintptr_t i = start; i != end; i += PGSIZE) {
        struct PageInfo * pp = page_alloc(0);
        if(pp == NULL)
            panic("page_alloc failed: %e", -E_NO_MEM);
        if((errno = page_insert(e->env_pgdir, pp, (void*)i, PTE_P | PTE_W |
PTE_U)) < 0)
            panic("page_insert failed: %e", errno);
    }
}
```

load_icode

```

static void
region_copy(struct Env *e, void *dst, void *src, size_t len) {
    uint32_t cr3 = rcr3();
    // load the env's pgdir to copy page
    lcr3(PADDR(e->env_pgdir));
    if(src) memcpy(dst, src, len);
    else memset(dst, 0, len);
    lcr3(cr3);
}

static void
load_icode(struct Env *e, uint8_t *binary) {
    struct Elf * eh = (struct Elf *)(binary);
    assert(eh->e_magic == ELF_MAGIC);

    struct Proghdr * ph_start = (struct Proghdr*)(binary + eh->e_phoff);
    for(size_t i = 0; i < eh->e_phnum; i++) {
        struct Proghdr * ph = ph_start + i;
        if(ph->p_type != ELF_PROG_LOAD) continue;
        void * va = (void*)ph->p_va;
        region_alloc(e, va, ph->p_memsz);
        region_copy(e, va, binary + ph->p_offset, ph->p_filesz);
        if(ph->p_filesz < ph->p_memsz) { // fill rest memory with zero
            region_copy(e, va + ph->p_filesz, 0, ph->p_memsz - ph->p_filesz);
        }
    }
    e->env_tf.tf_eip = eh->e_entry;

    // Now map one page for the program's initial stack
    // at virtual address USTACKTOP - PGSIZE.
    region_alloc(e, (void*)(USTACKTOP - PGSIZE), PGSIZE);
}
```

env_create

```
void
env_create(uint8_t *binary, enum EnvType type)
{
    struct Env * e;
    int errno;
    if((errno = env_alloc(&e, 0)) < 0)
        panic("env_alloc failed: %e", errno);
    e->env_type = type;
    load_icode(e, binary);
}
```

env_run

```

void
env_run(struct Env *e) {
    // change the state of curenv
    if(curenv && curenv->env_status == ENV_RUNNING) {
        curenv->env_status = ENV_RUNNABLE;
    }
    curenv = e;
    curenv->env_status = ENV_RUNNING;
    curenv->env_runs++;

    // Use lcr3() to switch to its address space
    lcr3(PADDR(curenv->env_pgdir));

    // switch to environment
    env_pop_tf(&(curenv->env_tf));
}
```

Exercise 3

nothing to report.

Exercise 4 & Challenge 1

I modified the `PLACEHANDLER` macro to place trap message in `.data` segmeng. The message contains functoin name, trap number, privilege level.

```

// The Privilege Level
#define PL_KERNEL    0
#define PL_DEVDRI1   1
#define PL_DEVDRI2   2
#define PL_USER      3

#define TRAPHANDLER(name, num, dpl)                     \
    .globl name;        /* define global symbol for 'name' */   \
    .type name, @function;  /* symbol type is function */       \
    .align 2;       /* align function definition */     \
    .text; \
    name:           /* function starts here */      \
    pushl $(num);                           \
    jmp _alltraps; \
    .data; .int name; .int num; .int dpl;

#define TRAPHANDLER_NOEC(name, num, dpl)                    \
    .globl name;                            \
    .type name, @function;                      \
    .align 2;                           \
    .text; \
    name:                               \
    pushl $0;                           \
    pushl $(num);                           \
    jmp _alltraps; \
    .data; .int name; .int num; .int dpl;
```

The table entry is at a very begining, followed by the trap handler.

```
.data
.global trapentry_table
trapentry_table:

.text
    TRAPHANDLER_NOEC(  trap_hander_DIVIDE   ,  T_DIVIDE   ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_DEBUG    ,  T_DEBUG    ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_NMI      ,  T_NMI      ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_BRKPT    ,  T_BRKPT    ,  PL_USER    )
    TRAPHANDLER_NOEC(  trap_hander_OFLOW    ,  T_OFLOW    ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_BOUND    ,  T_BOUND    ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_ILLOP    ,  T_ILLOP    ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_DEVICE   ,  T_DEVICE   ,  PL_KERNEL  )
    TRAPHANDLER     (  trap_hander_DBLFLT   ,  T_DBLFLT   ,  PL_KERNEL  )
    TRAPHANDLER     (  trap_hander_TSS      ,  T_TSS      ,  PL_KERNEL  )
    TRAPHANDLER     (  trap_hander_SEGNP    ,  T_SEGNP    ,  PL_KERNEL  )
    TRAPHANDLER     (  trap_hander_STACK    ,  T_STACK    ,  PL_KERNEL  )
    TRAPHANDLER     (  trap_hander_GPFLT    ,  T_GPFLT    ,  PL_KERNEL  )
    TRAPHANDLER     (  trap_hander_PGFLT    ,  T_PGFLT    ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_FPERR    ,  T_FPERR    ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_ALIGN    ,  T_ALIGN    ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_MCHK     ,  T_MCHK     ,  PL_KERNEL  )
    TRAPHANDLER_NOEC(  trap_hander_SIMDERR  ,  T_SIMDERR  ,  PL_KERNEL  )

    TRAPHANDLER_NOEC(  trap_hander_SYSCALL  ,  T_SYSCALL  ,  PL_USER    )

.data
    .int 0; .int 0; .int 0;
```

Three `.int 0` is put at the ending, to tell `trap_init` where the table ends. The `trap_init` function is very simple:

```
void
trap_init(void) {
    extern struct Segdesc gdt[];

    extern uint32_t trapentry_table[];
    for(size_t i = 0; trapentry_table[i]; i += 3) {
        // extract functoin name, trap number, privilege level
        uintptr_t func_addr = trapentry_table[i];
        int trap_no = trapentry_table[i + 1];
        int dpl = trapentry_table[i + 2];
        SETGATE(idt[trap_no], 1, GD_KT, func_addr, dpl);
    }

    // Per-CPU setup
    trap_init_percpu();
}
```

Questoin 1

What is the purpose of having an individual handler function for each exception/interrupt?

Some traps may push an extra `errcode` into stack frame. We implement individual handler to organise the different stack frames into a uniform `Trapframe`, then switch to C code.

if all exceptions/interrupts were delivered to the same handler, what feature that exists in the current implementation could not be provided?

If don't do this, the handler doesn't know whether the code in stack top is an `errcode` or saved registers. He will fail to get the execution context in the trap.

Did you have to do anything to make the user/softint program behave correctly?
When user want to use `int` command to make a software interrupt, his privilege level must be equal to or less than the level of that trap. Among all the traps, only `BRKPT` and `SYSCALL` can be induced by user, so their privilege level is 3, which equals to the user's privilege level.

Exercise 5 & Exercise 6 & Exercise 7

The trap dispatch function:

```
static void
trap_dispatch(struct Trapframe *tf) {
    switch (tf->tf_trapno) {
        case T_DEBUG: monitor(tf); break;
        case T_PGFLT: page_fault_handler(tf); break;
        case T_BRKPT: monitor(tf); break;
        case T_SYSCALL:
            // The system call number will go in %eax,
            // and the arguments (up to five of them) will go in %edx, %ecx, %ebx, %edi, and %esi, respectively.
            // The kernel passes the return value back in %eax.
            tf->tf_regs.reg_eax = syscall(
                tf->tf_regs.reg_eax,
                tf->tf_regs.reg_edx, tf->tf_regs.reg_ecx, tf->tf_regs.reg_ebx,
                tf->tf_regs.reg_edi, tf->tf_regs.reg_esi
            );
            env_run(curenv);
            break;
        default: break;
    }

    // Unexpected trap: The user process or the kernel has a bug.
    print_trapframe(tf);
    if (tf->tf_cs == GD_KT)
        panic("unhandled trap in kernel");
    else {
        env_destroy(curenv);
        return;
    }
}
```

Challenge 2

The the `TF` flag in `eflags` register is set to 1, the processor goes into Trap Mode. In Trap Mode, after each assembly code is executed, the processer will cause a `DEBUG` interrupt.

So I set the flag to 1, to enable step debug. And clear it to 0, to continue the program.

```
int
mon_debug(int argc, char **argv, struct Trapframe * tf) {
    if(argc > 1) {
        if(tf->tf_trapno != T_BRKPT) {
            cprintf("Trap is not a breakpoint, continuing.\n");
        }
        char * cmd = argv[1];
        if(strcmp(cmd, "si") == 0) {
            tf->tf_eflags |= FL_TF; // step one code
            env_run(curenv);
        }
        else if(strcmp(cmd, "c") == 0) {
            tf->tf_eflags &= ~FL_TF; // continuing
            env_run(curenv);
        }
    }
    cprintf("Usage: debug <si|c>\n");
    return 0;
}
```

And the code in `syscall`

```
static void
sys_cputs(const char *s, size_t len) {
    if(user_mem_check(curenv, s, len, PTE_U) < 0) {
        env_destroy(curenv);
    }
    else {
        cprintf("%.*s", len, s);
    }
}

int32_t
syscall(uint32_t syscallno, uint32_t a1, uint32_t a2, uint32_t a3, uint32_t a4,
uint32_t a5)
{
    int32_t ret = 0;
    switch (syscallno) {
        case SYS_cgetc:       ret = sys_cgetc(); break;
        case SYS_cputs:             sys_cputs((const char *)a1, a2); break;
        case SYS_env_destroy: ret = sys_env_destroy(a1); break;
        case SYS_getenvid:    ret = sys_getenvid(); break;
        default:              ret = -E_INVAL; break;
    }
    return ret;
}
```

Questions 2

The break point test case will either generate a break point exception or a general protection fault depending on how you initialized the break point entry in the IDT (i.e., your call to SETGATE from trap_init). Why?

explained in Question 1.

The break point interrupt is a software interrupt -- `int 3`. When user want to use `int` command to make a software interrupt, his privilege level must be equal to or less than the level of that trap.

How do you need to set it up in order to get the breakpoint exception to work as specified above and what incorrect setup would cause it to trigger a general protection fault?

Set the privilege level to 3. Which is user privilege level in JOS.

What do you think is the point of these mechanisms, particularly in light of what the user/softint test program does?

I think this facility prevents user generating some hardware interrupt (such as Timer, BIOS, Security Chips...), to protect the system.

Exercise 8

The code in `libmain`

```
void
libmain(int argc, char **argv) {
    // set thisenv to point at our Env structure in envs[].
    thisenv = envs + ENVX(sys_getenvid());

    // save the name of the program so that panic() can use it
    if (argc > 0)
        binaryname = argv[0];

    // call user main routine
    umain(argc, argv);

    // exit gracefully
    exit();
}
```

Exercise 9

```

void
page_fault_handler(struct Trapframe *tf)
{
    uint32_t fault_va;

    // Read processor's CR2 register to find the faulting address
    fault_va = rcr2();
    // Handle kernel-mode page faults.

    // LAB 3: Your code here.
    if(tf->tf_es == GD_KD && tf->tf_ds == GD_KD) {
        cprintf("kernel page fault va %08x ip %08x\n", fault_va, tf->tf_eip);
        print_trapframe(tf);
        panic("kernel page fault va %08x ip %08x\n", fault_va, tf->tf_eip);
    }

    // We've already handled kernel-mode exceptions, so if we get here,
    // the page fault happened in user mode.

    // Destroy the environment that caused the fault.
    cprintf("[%08x] user fault va %08x ip %08x\n",
        curenv->env_id, fault_va, tf->tf_eip);
    print_trapframe(tf);
    env_destroy(curenv);
}
```

In my implementations, I found the assembly code of function `umain` is mysterious:

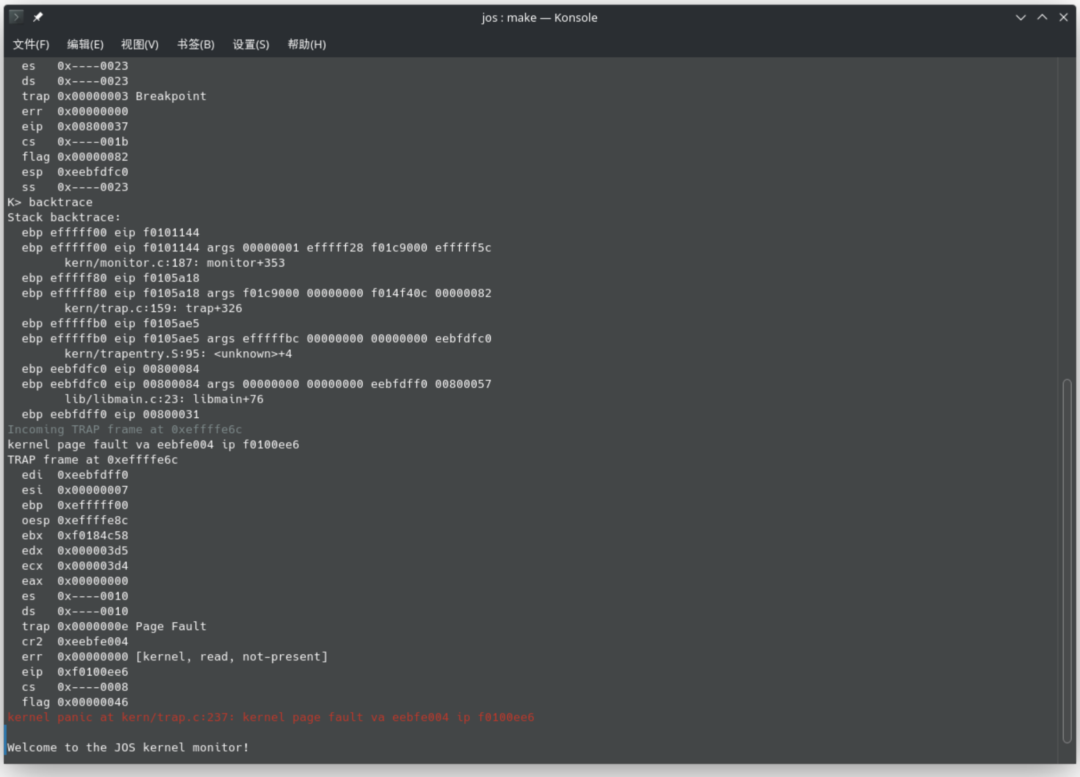
```
00800033 <umain>:
void
umain(int argc, char **argv)
{
    asm volatile("int $3");
  800033:   cc                      int3
}
  800034:   c3                      ret
```

There isn't `push %ebp` and `mov %esp,%ebp`, so the `backtrace` won't work correctly. I made a fix by adding

```

void
umain(int argc, char **argv)
{
    asm volatile("push %ebp");
    asm volatile("mov %esp, %ebp");
    //..... the following code
}
```

It works well:



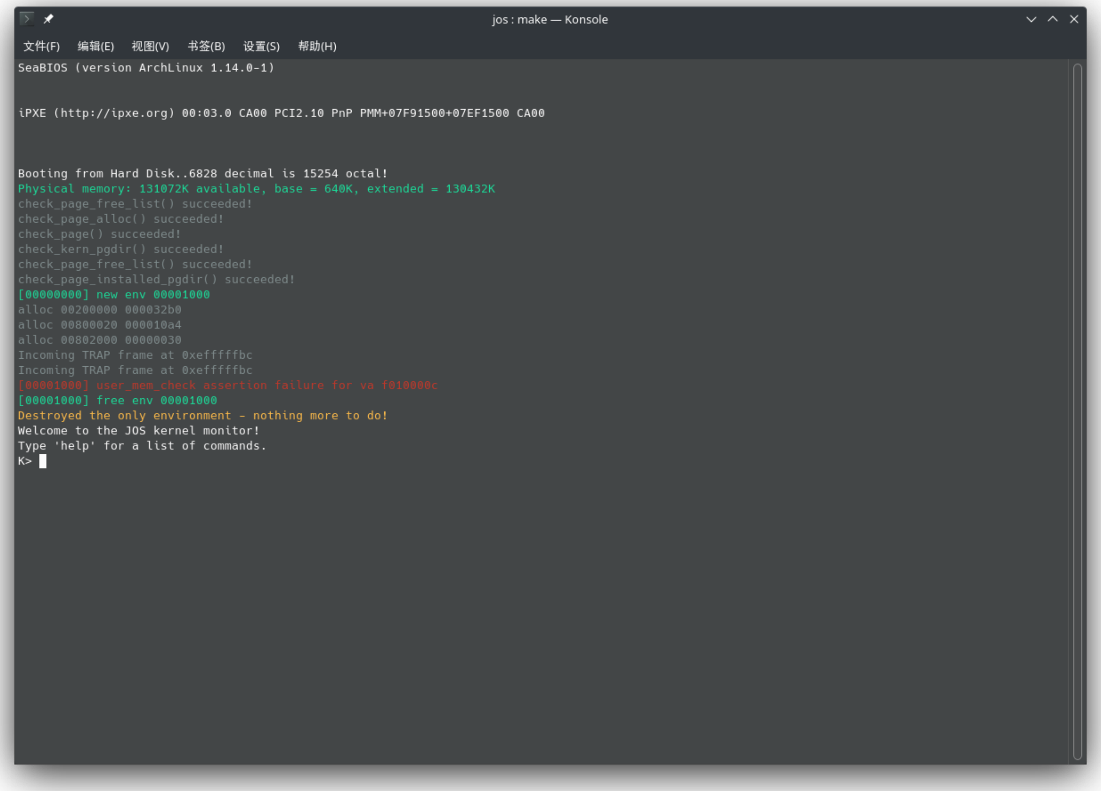
```
  es   0x----0023
  ds   0x----0023
  trap 0x00000003 Breakpoint
  err  0x00000000
  eip  0x00800037
  cs   0x----001b
  flag 0x00000082
  esp  0xeebfdfc0
  ss   0x----0023
K> backtrace
Stack backtrace:
  ebp efffff00 eip f0101144
  ebp efffff00 eip f0101144 args 00000001 efffff28 f01c9000 efffff5c
        kern/monitor.c:187: monitor+353
  ebp efffff80 eip f0105a18
  ebp efffff80 eip f0105a18 args f01c9000 00000000 f014f40c 00000082
        kern/trap.c:159: trap+326
  ebp efffffb0 eip f0105ae5
  ebp efffffb0 eip f0105ae5 args efffffbc 00000000 00000000 eebfdfc0
        kern/trapentry.S:95: <unknown>+4
  ebp eebfdfc0 eip 00800084
  ebp eebfdfc0 eip 00800084 args 00000000 00000000 eebfdff0 00800057
        lib/libmain.c:23: libmain+76
  ebp eebfdff0 eip 00800031
Incoming TRAP frame at 0xeffffe6c
kernel page fault va eebfe004 ip f0100ee6
TRAP frame at 0xeffffe6c
  edi  0xeebfdff0
  esi  0x00000007
  ebp  0xefffff00
  oesp 0xeffffe8c
  ebx  0xf0184c58
  edx  0x000003d5
  ecx  0x000003d4
  eax  0x00000000
  es   0x----0010
  ds   0x----0010
  trap 0x0000000e Page Fault
  cr2  0xeebfe004
  err  0x00000000 [kernel, read, not-present]
  eip  0xf0100ee6
  cs   0x----0008
  flag 0x00000046
kernel panic at kern/trap.c:237: kernel page fault va eebfe004 ip f0100ee6

Welcome to the JOS kernel monitor!
```

There is a `pagefault` in the figure, that is because the `backtrace` will look up to 4 parameters above the stack. But when it traces at `lib/entry.S`, i.e. the user environment init code whose stack is `USTACKTOP`, he will watch 4 parameters above `USTACKTOP`. These page is not mapped, so a `pagefault` is generated.

Exercise 10

It works perfectly:



```
SeaBIOS (version ArchLinux 1.14.0-1)


iPXE (http://ipxe.org) 00:03.0 CA00 PCI2.10 PnP PMM+07F91500+07EF1500 CA00



Booting from Hard Disk..6828 decimal is 15254 octal!
Physical memory: 131072K available, base = 640K, extended = 130432K
check_page_free_list() succeeded!
check_page_alloc() succeeded!
check_page() succeeded!
check_kern_pgdir() succeeded!
check_page_free_list() succeeded!
check_page_installed_pgdir() succeeded!
[00000000] new env 00001000
alloc 00200000 000032b0
alloc 00800020 000010a4
alloc 00802000 00000030
Incoming TRAP frame at 0xefffffbc
Incoming TRAP frame at 0xefffffbc
[00001000] user_mem_check assertion failure for va f010000c
[00001000] free env 00001000
Destroyed the only environment - nothing more to do!
Welcome to the JOS kernel monitor!
Type 'help' for a list of commands.
K> 
```