Report for lab4, Kexing Zhou, 1900013008

Contents

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
```

Preemptive Multitasking

Exercise 1

```
void *
mmio_map_region(physaddr_t pa, size_t size)
{
    size = ROUNDUP(size, PGSIZE);
    boot_map_region(kern_pgdir, base, size, pa, PTE_P | PTE_PCD | PTE_PWT | PTE_W);
    uintptr_t ret = base;
    base += size;
    return (void*)ret;
}
```

Exercise 2

```
for(size_t i = 1; i < npages_basemem; i++) {
    if(i == PGNUM(MPENTRY_PADDR)) continue; // This code ignores MPENTRY
    pages[i].pp_ref = 0;
    pages[i].pp_link = page_free_list;
    page_free_list = &pages[i];
}
```

Question 1

What is the purpose of macro MPBOOTPHYS?

The code which initialize MP is not linked at program position MPENTRY_PADDR, but is loaded there. So the address of each variable need to be translated from the place it is linked to the MPENTRY_PADDR. MPBOOTPHYS just did the translation staticly.

Why is it necessary in kern/mpentry.S but not in boot/boot.S?

The `boot/boot.S` has already placed in 0x7000. It dosen't need the translation.

What could go wrong if it were omitted in kern/mpentry.S?

The address of each variable is wrong, then the MP fails to start up.

Exercise 3

```
for(size_t i = 0; i < NCPU; i++) {
    uintptr_t kstacktop_i = KSTACKTOP - i * (KSTKSIZE + KSTKGAP);
    boot_map_region(kern_pgdir, kstacktop_i - KSTKSIZE, KSTKSIZE, PADDR(percpu_kstacks[i]), PTE_P|PTE_W);
}
```

Exercise 4

```
void
trap_init_percpu(void) {
    int cpuid = cpunum();
    struct Taskstate * ts = &(thiscpu->cpu_ts);

    ts->ts_esp0 = KSTACKTOP - cpuid * (KSTKSIZE + KSTKGAP);
    ts->ts_ss0  = GD_KD;
    ts->ts_iomb = sizeof(struct Taskstate);

    // Initialize the TSS slot of the gdt.
    size_t gdt_idx = (GD_TSS0 >> 3) + cpuid;
    gdt[gdt_idx] = SEG16(STS_T32A, (uint32_t) ts, sizeof(struct Taskstate) - 1, 0);
    gdt[gdt_idx].sd_s = 0;

    ltr(gdt_idx << 3);

    // Load the IDT
    lidt(&idt_pd);
}
```

Exercise 5

The `lock_kernel` is called at:

```
void
i386_init(void) {
// ..............
    pic_init();
    lock_kernel();
    boot_aps();
// ..............
}
```

```
void
mp_main(void) {
// ..............
    xchg(&thiscpu->cpu_status, CPU_STARTED);
    lock_kernel();
    sched_yield();
// ..............
}
```

```
void
trap(struct Trapframe *tf)
{
// ..............
    // Re-acqurie the big kernel lock if we were halted in
    // sched_yield()
    if (xchg(&thiscpu->cpu_status, CPU_STARTED) == CPU_HALTED)
        lock_kernel();
    assert(!(read_eflags() & FL_IF));

    if ((tf->tf_cs & 3) == 3) {
        // Trapped from user mode.
        // Acquire the big kernel lock before doing any
        // serious kernel work.
        // LAB 4: Your code here.
        assert(curenv);
        lock_kernel();
// ..............
    }
}
```

The `unlock_kernel` is called at:

```
void
sched_halt(void) {
// ..............

    // Release the big kernel lock as if we were "leaving" the kernel
    unlock_kernel();

    // Reset stack pointer, enable interrupts and then halt.
    asm volatile (
        "movl $0, %%ebp\n"
        "movl %0, %%esp\n"
        "pushl $0\n" ......
}
```

```
void
env_run(struct Env *e) {
    // LAB 3: Your code here.
    assert(e->env_tf.tf_eflags & FL_IF);
    unlock_kernel();
    env_pop_tf(&(curenv->env_tf));
}
```

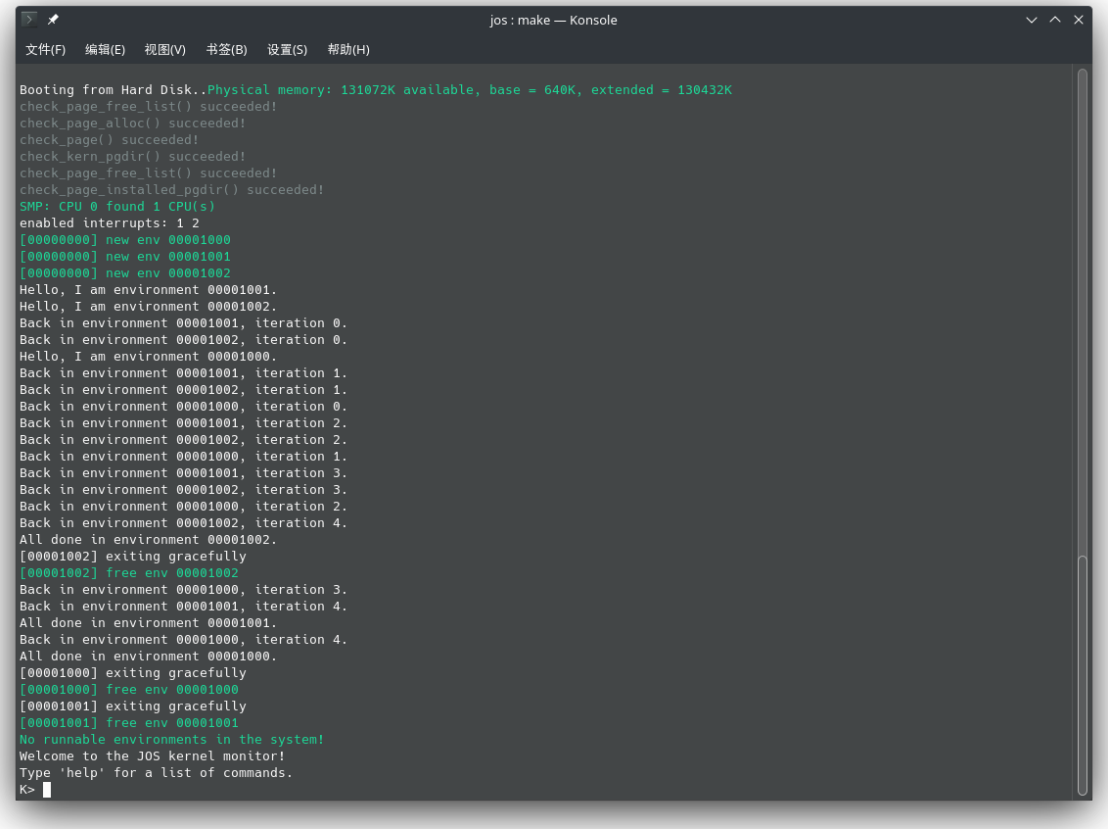
Question 2

It seems that using the big kernel lock guarantees that only one CPU can run the kernel code at a time. Why do we still need separate kernel stacks for each CPU? Describe a scenario in which using a shared kernel stack will go wrong, even with the protection of the big kernel lock.

Two CPU receive exception at the same time. They both need to push execution context into memory, then acquires the big kernel lock. They share the stack so the context crashes. And the kernel fail to get execution context.

Exercise 6

```
void
sched_yield(void) {
    size_t env_id = curenv ? ENVX(curenv->env_id) : 0;
    size_t i = env_id;
    do {
        if(envs[i].env_status == ENV_RUNNABLE) {
            env_run(&envs[i]);
        }
        if(++i == NENV) i = 0;
    } while(i != env_id);
    if(curenv && (curenv->env_status == ENV_RUNNABLE || curenv->env_status == ENV_RUNNING)) {
        env_run(curenv);
    }
    sched_halt();
}
```



Question 3

Why can the pointer e be dereferenced both before and after the addressing switch?

Pointer e is stored in kernel stack, and where it points is in kernel memory. Since all environment share the same kernel memory mapping, the pointer e is dereferenced after addressing switch.

It must ensure the old environment's registers are saved so they can be restored properly later. Why?

The register contains context information such as stack pointer, program counter, and the current used data, which is critical for program running.

Where does this happen?

It happens in `kern/trap.c`, in function `trap`

```
    if ((tf->tf_cs & 3) == 3) {
        //..............
        // Copy trap frame (which is currently on the stack)
        // into 'curenv->env_tf', so that running the environment
        // will restart at the trap point.
        curenv->env_tf = *tf;
        // The trapframe on the stack should be ignored from here on.
        tf = &curenv->env_tf;
    }
```

Challenge 3

First, the FPU should be enabled:

In `entry.S` and `mpentry.S`:

```
# Turn on paging.
movl    %cr0, %eax
# CR0_MP enable x87 co-processor
orl $(CR0_PE|CR0_PG|CR0_WP|CR0_MP), %eax
movl    %eax, %cr0

# CR4_OSFXSR enable FXSAVE and FXRSTOR instructions
# CR4_OSXMMEXCPT enable Unmasked SIMD Floating-Point Exceptions
movl    %cr4, %eax
orl $(CR4_OSFXSR|CR4_OSXMMEXCPT), %eax
movl    %eax, %cr4
```

The command `fxsave` and `fxrstor` need 512byte aligned space to save the registers. So in env.c:

```
typedef uint8_t Fxbuf[512];
Fxbuf * fxbufs = NULL;
```

And `pmap.c`

```
fxbufs = boot_alloc(NENV * sizeof(*fxbufs));
memset(fxbufs, 0, NENV * sizeof(*fxbufs));
```

Then update the code of trap to save and store registers, in `trap.c`

```
    if ((tf->tf_cs & 3) == 3) {
        // Trapped from user mode.

        assert(curenv);
        lock_kernel();

        // save registers
        asm volatile ("fxsave %0"::"m"(fxbufs[curenv->env_id]));

        // ...........
    }
```

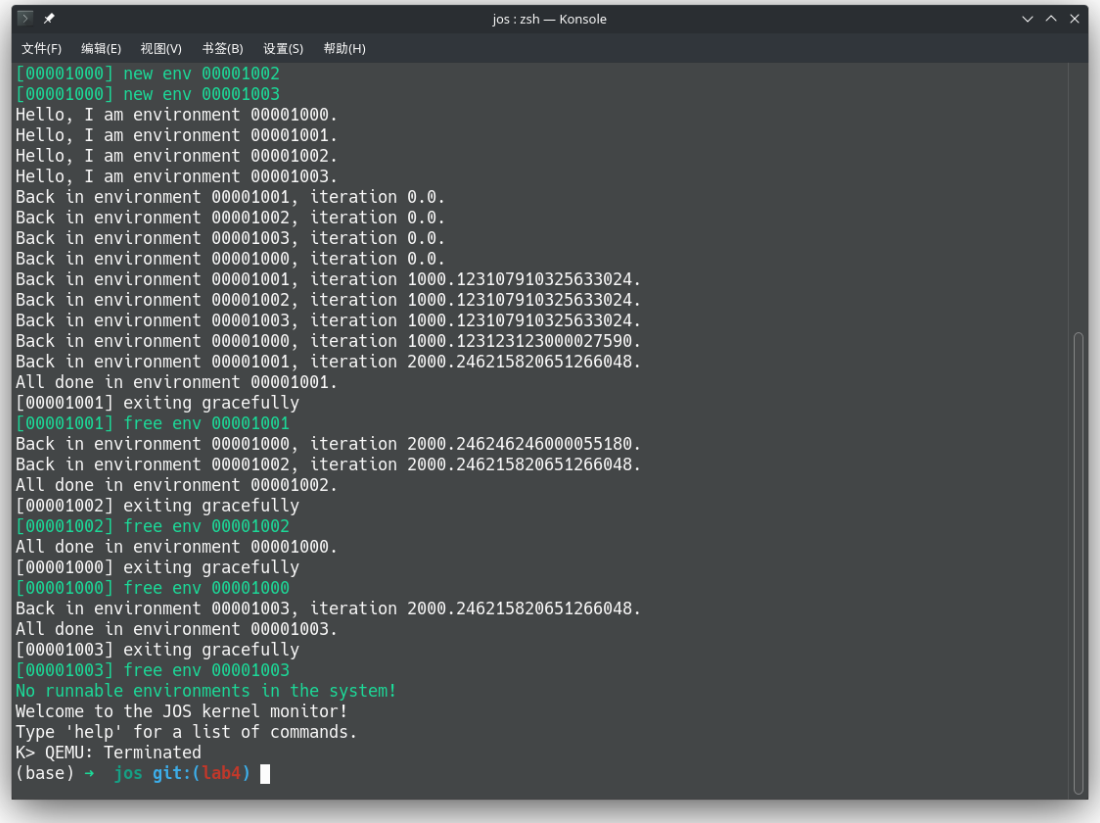
In `env.c`

```
    assert(e->env_tf.tf_eflags & FL_IF);

    asm volatile ("fxrstor %0"::"m"(fxbufs[curenv->env_id]));

    unlock_kernel();
    env_pop_tf(&(curenv->env_tf));
```

I implemented a `yieldf.c` to test the fpu:

```
#include <inc/lib.h>

void
umain(int argc, char **argv) {
    for(int i = 0; i < 3; i++) {
        if(fork() == 0) break;
    }
    cprintf("Hello, I am environment %08x.\n", thisenv->env_id);
    for (int i = 0; i < 3; i++) {
        sys_yield();
        cprintf("Back in environment %08x, iteration %f.\n",
            thisenv->env_id, i * 1000.123123123);
    }
    cprintf("All done in environment %08x.\n", thisenv->env_id);
}
```

It works perfectly.



Exercise 7

```
static envid_t
sys_exofork(void) {
    struct Env * e;
    ckret(env_alloc(&e, curenv->env_id));
    e->env_status = ENV_NOT_RUNNABLE;
    e->env_tf = curenv->env_tf;
    e->env_tf.tf_regs.reg_eax = 0; // child returns 0
    return e->env_id;
}
```

```
10
11  static int
12  sys_env_set_status(envid_t envid, int status) {
13      if(status < 0 || status >= ENV_STATUS_MAX)
14          return -E_INVAL;
15      int errno = 0;
16      struct Env * e;
17      if((errno = envid2env(envid, &e, true)) < 0) {
18          return errno;
19      }
20      e->env_status = status;
21      return 0;
22  }
23
24  static int
25  usr_mem_va_check(void * va) {
26      if((uintptr_t)va >= UTOP) return -E_INVAL;
27      if(PGOFF(va) != 0) return -E_INVAL;
28      return 0;
29  }
30
31  static int
32  usr_mem_perm_check(int perm) {
33      if((perm & PTE_SYSCALL) != perm) return -E_INVAL;
34      if(!(perm & PTE_U)) return -E_INVAL;
35      if(!(perm & PTE_P)) return -E_INVAL;
36      return 0;
37  }
38
39  static int
40  sys_page_alloc(envid_t envid, void *va, int perm) {
41      struct Env * e;
42      ckret(envid2env(envid, &e, true));
43      struct PageInfo * pg = page_alloc(0);
44      if(pg == NULL) return -E_NO_MEM;
45      ckret(usr_mem_perm_check(perm));
46      ckret(page_insert(e->env_pgdir, pg, va, perm));
47      return 0;
48  }
49
50  static int
51  sys_page_map(envid_t srcenvid, void *srcva, envid_t dstenvid, void *dstva, int perm){
52      struct Env * src, * dst;
53      ckret(envid2env(srcenvid, &src, true));
54      ckret(envid2env(dstenvid, &dst, true));
55      ckret(usr_mem_va_check(srcva));
56      ckret(usr_mem_va_check(dstva));
57      ckret(usr_mem_perm_check(perm));
58      pte_t * srcpte = pgdir_walk(src->env_pgdir, srcva, false);
59      if(srcpte == NULL) return -E_INVAL;
60      if((perm & PTE_W) && !(*srcpte & PTE_W)) return -E_INVAL;
61      ckret(page_insert(dst->env_pgdir, pa2page(PTE_ADDR(*srcpte)), dstva, perm));
62      return 0;
63  }
64
65  static int
66  sys_page_unmap(envid_t envid, void *va) {
67      struct Env * e;
68      ckret(envid2env(envid, &e, true));
69      page_remove(e->env_pgdir, va);
70      return 0;
71  }
72
73  int32_t
74  syscall(uint32_t syscallno, uint32_t a1, uint32_t a2, uint32_t a3, uint32_t a4, uint32_t a5) {
75      int32_t ret = 0;
76      switch (syscallno) {
77          case SYS_cgetc:       ret = sys_cgetc(); break;
78          case SYS_cputs:             sys_cputs((const char *)a1, a2); break;
79          case SYS_env_destroy: ret = sys_env_destroy(a1); break;
80          case SYS_getenvid:    ret = sys_getenvid(); break;
81          case SYS_yield:       sched_yield(); break;
82          case SYS_exofork:     ret = sys_exofork(); break;
83          case SYS_env_set_status:ret=sys_env_set_status((envid_t)a1, (int)a2); break;
84          case SYS_page_alloc:  ret = sys_page_alloc((envid_t)a1, (void*)a2, (int)a3); break;
85          case SYS_page_map:    ret = sys_page_map((envid_t)a1, (void*)a2, (envid_t)(a3), (void*)(a4), (int)a5); break;
86          case SYS_page_unmap:  ret = sys_page_unmap((envid_t)a1, (void*)a2); break;
87          case SYS_env_set_pgfault_upcall: ret = sys_env_set_pgfault_upcall((envid_t)a1, (void*)a2); break;
88          case SYS_ipc_try_send:ret = sys_ipc_try_send((envid_t)a1, (uint32_t)a2, (void*)a3, (unsigned int)a4); break;
89          case SYS_ipc_recv:    ret = sys_ipc_recv((void*)a1); break;
90          default:              ret = -E_INVAL; break;
91      }
92      return ret;
93  }
```

Exercise 8

```
1  static int
2  sys_env_set_pgfault_upcall(envid_t envid, void *func) {
3      struct Env * e;
4      ckret(envid2env(envid, &e, true));
5      e->env_pgfault_upcall = func;
6      return 0;
```

```
}
```

Exercise 9

```
    if(curenv->env_pgfault_upcall) {
        void * uxesp = NULL;
        if(UXSTACKTOP - PGSIZE <= tf->tf_esp && tf->tf_esp < UXSTACKTOP) {
            uxesp = (void*)(tf->tf_esp - 4);
        }
        else {
            uxesp = (void*)UXSTACKTOP;
        }
        struct UTrapframe * uxframe = (struct UTrapframe *)(uxesp - sizeof(struct UTrapframe));
        user_mem_assert(curenv, uxframe, sizeof(struct UTrapframe), PTE_P | PTE_U | PTE_W);
        uxframe->utf_fault_va = fault_va;
        uxframe->utf_err      = tf->tf_err;
        uxframe->utf_regs     = tf->tf_regs;
        uxframe->utf_eip      = tf->tf_eip;
        uxframe->utf_eflags   = tf->tf_eflags;
        uxframe->utf_esp      = tf->tf_esp;
        curenv->env_tf.tf_esp = (uintptr_t)(uxframe);
        curenv->env_tf.tf_eip = (uintptr_t)(curenv->env_pgfault_upcall);
        env_run(curenv);
    }
```

If the user environment runs out the exception stack, it will be destoryed.

Exercise 10

```
_pgfault_upcall:
    // Call the C page fault handler.
    pushl %esp          // function argument: pointer to UTF
    movl _pgfault_handler, %eax
    call *%eax
    addl $4, %esp           // pop function argument

    //  trap-time esp                   48
    //  trap-time eflags                44
    //  trap-time eip                   40
    //  utf_regs.reg_eax                36
    //  utf_regs.reg_ecx                32
    //  utf_regs.reg_edx                28
    //  utf_regs.reg_ebx                24
    //  utf_regs.reg_oesp               20
    //  utf_regs.reg_ebp                16
    //  utf_regs.reg_esi                12
    //  utf_regs.reg_edi                 8
    //  utf_err (error code)             4
    //  utf_fault_va            <-- %esp   0

    movl 40(%esp), %eax
    movl 48(%esp), %ebx
    subl $4, %ebx
    movl %ebx, 48(%esp)
    movl %eax, (%ebx)

    // Restore the trap-time registers.  After you do this, you
    // can no longer modify any general-purpose registers.
    // LAB 4: Your code here.

    addl $8, %esp
    popal
    //  trap-time esp                   8
    //  trap-time eflags                4
    //  trap-time eip          <-- %esp   0

    // Restore eflags from the stack.  After you do this, you can
    // no longer use arithmetic operations or anything else that
    // modifies eflags.
    // LAB 4: Your code here.

    addl $4, %esp
    popfl

    // Switch back to the adjusted trap-time stack.
    // LAB 4: Your code here.

    popl %esp

    // Return to re-execute the instruction that faulted.
    // LAB 4: Your code here.

    ret
```

Exercise 11

```c
void
set_pgfault_handler(void (*handler)(struct UTrapframe *utf))
{
    int r;

    if (_pgfault_handler == 0) {
        // First time through!
        // LAB 4: Your code here.
        r = sys_page_alloc(0, (void*)(UXSTACKTOP - PGSIZE), PTE_P | PTE_U | PTE_W);
        if(r < 0) panic("sys_page_alloc fail %e", r);
        r = sys_env_set_pgfault_upcall(0, _pgfault_upcall);
        if(r < 0) panic("set_pgfault_handler fail %e", r);
        // panic("set_pgfault_handler not implemented");
    }

    // Save handler pointer for assembly to call.
    _pgfault_handler = handler;
}
```

Exercise 12

```c
static void
pgfault(struct UTrapframe *utf)
{
    void *addr = (void *) utf->utf_fault_va;
    uint32_t err = utf->utf_err;
    int r;

    assert_panic(err & FEC_PR, "page fault: access non-present page: %p, eip=%08x", addr, utf->utf_eip);
    assert_panic(err & FEC_U,  "page fault: no permission to access: %p, eip=%08x", addr, utf->utf_eip);
    assert_panic(err & FEC_WR, "page fault: not readable: %p, eip=%08x",            addr, utf->utf_eip);

    pte_t pte = get_pte(PDX(addr), PTX(addr));
    assert_panic(is_masked(pte, PTE_P | PTE_U | PTE_COW), "page fault: not writable %p, eip=%08x", addr, utf->utf_eip);

    void * page_addr = ROUNDDOWN(addr, PGSIZE);
    assert(sys_page_alloc(0, UTEMP, PTE_P | PTE_U | PTE_W) == 0);
    memmove(UTEMP, page_addr, PGSIZE);
    assert(sys_page_map(0, UTEMP, 0, page_addr, PTE_P | PTE_U | PTE_W) == 0);
    assert(sys_page_unmap(0, UTEMP) == 0);
}

duppage(envid_t envid, void * pageaddr)
{
    // LAB 4: Your code here.
    ckret(sys_page_map(0, pageaddr, envid, pageaddr, PTE_P | PTE_U | PTE_COW));
    ckret(sys_page_map(0, pageaddr, 0,     pageaddr, PTE_P | PTE_U | PTE_COW));
    return 0;
}

envid_t
fork(void)
{
    // LAB 4: Your code here.
    // panic("fork not implemented");
    set_pgfault_handler(pgfault);

    envid_t envid = sys_exofork();
    if(!envid) {
        thisenv = envs + ENVX(sys_getenvid()); // this is very important
        return envid;
    }

    for(size_t i = 0; i < PDX(UTOP); i++) {
        pde_t pde = get_pde(i);
        if(!is_masked(pde, PTE_P)) continue;
        for(size_t j = 0; j < NPTENTRIES; j++) {
            pte_t pte = get_pte(i, j);
            void * pgaddr = PGADDR(i, j, 0);
            if(pgaddr == (void*)(UXSTACKTOP - PGSIZE)) // ignore UXSTACK
                continue;
            if(!is_masked(pte, PTE_P | PTE_U))            // user not accessable
                continue;
            if(is_masked(pte, PTE_W) || is_masked(pte, PTE_COW)) {  // COW page
                ckret(duppage(envid, pgaddr));
            }
            else{
                ckret(sys_page_map(0, pgaddr, envid, pgaddr, PTE_FLAGS(pte)));
            }
        }
    }

    ckret(sys_page_alloc(envid, (void*)(UXSTACKTOP - PGSIZE), PTE_P | PTE_U | PTE_W));

    extern void _pgfault_upcall(void);
    ckret(sys_env_set_pgfault_upcall(envid, _pgfault_upcall));

    ckret(sys_env_set_status(envid, ENV_RUNNABLE));
    return envid;
}
```

Exercise 13

A new entry is added into the `kern/trapentry.S`. (The initialization in `kern/trap.c` is automatically setup).

```
    TRAPHANDLER_NOEC(  trap_handler_SYSCALL  ,  T_SYSCALL  ,  PL_USER    )
```

Exercise 14

```
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;
    case IRQ_OFFSET + IRQ_TIMER:
        // tell the lapic the interrupt has finished
        // for timers, no matter where the eoi signal is,
        // the next interrupt won't be influenced.
        lapic_eoi();
        sched_yield();
        break;
    default: break;
}
```

Exercise 15

```
static int
sys_ipc_try_send(envid_t envid, uint32_t value, void *srcva, unsigned perm) {
    struct Env * dst;
    ckret(envid2env(envid, &dst, false));
    astret(dst->env_ipc_recving, -E_IPC_NOT_RECV);
    dst->env_ipc_recving = 0;
    dst->env_ipc_from = curenv->env_id;
    if((uintptr_t)srcva < UTOP && (uintptr_t)dst->env_ipc_dstva < UTOP) {
        ckret(usr_mem_va_check(srcva));
        pte_t * pte = pgdir_walk(curenv->env_pgdir, srcva, false);
        astret(pte, -E_INVAL);
        astret(is_masked(*pte, PTE_P), -E_INVAL);
        ckret(usr_mem_perm_check(perm));
        if((perm & PTE_W) && !(*pte & PTE_W)) return -E_INVAL;
        ckret(page_insert(dst->env_pgdir, pa2page(PTE_ADDR(*pte)), dst->env_ipc_dstva, perm));
        dst->env_ipc_perm = perm;
    }
    else {
        dst->env_ipc_perm = 0;
    }
    dst->env_ipc_value = value;
    dst->env_status = ENV_RUNNABLE;
    return 0;
}

static int
sys_ipc_recv(void *dstva) {
    struct Env * e = curenv;
    if((uintptr_t)dstva < UTOP) {
        ckret(usr_mem_va_check(dstva));
    }
    e->env_ipc_dstva = dstva;
    e->env_ipc_value = 0;
    e->env_tf.tf_regs.reg_eax = 0;
    e->env_ipc_recving = 1;
    e->env_status = ENV_NOT_RUNNABLE;
    sched_yield();
    return 0;
}
```

```
int32_t
ipc_recv(envid_t *from_env_store, void *pg, int *perm_store)
{
```

```
    // LAB 4: Your code here.
    // panic("ipc_recv not implemented");
    int r = sys_ipc_recv(pg ? pg : (void*)UTOP);
    if(r < 0) {
        if(from_env_store) *from_env_store = 0;
        if(perm_store) *perm_store = 0;
        // logd("recv error");
        return r;
    }
    else {
        if(from_env_store) *from_env_store = thisenv->env_ipc_from;
        if(perm_store)     *perm_store     = thisenv->env_ipc_perm;
        // logd("recv: %d", thisenv->env_ipc_value);
        return thisenv->env_ipc_value;
    }
}

void
ipc_send(envid_t to_env, uint32_t val, void *pg, int perm)
{
    // LAB 4: Your code here.
    // panic("ipc_send not implemented");
    pg = pg ? pg : (void*) UTOP;
    while(sys_ipc_try_send(to_env, val, pg, perm) < 0) {
        asm volatile("pause");
        sys_yield();
    }
}
```

The end of this lab