Report for lab2, 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

pmap.c, boot_alloc

```
static void *
boot_alloc(uint32_t n)
{
    static char *nextfree;  // virtual address of next byte of free memory
    char *result;

    // Initialize nextfree if this is the first time.
    // 'end' is a magic symbol automatically generated by the linker,
    // which points to the end of the kernel's bss segment:
    // the first virtual address that the linker did *not* assign
    // to any kernel code or global variables.
    if (!nextfree) {
        extern char end[];
        nextfree = ROUNDUP((char *) end, PGSIZE);
    }

    // Allocate a chunk large enough to hold 'n' bytes, then update
    // nextfree.  Make sure nextfree is kept aligned
    // to a multiple of PGSIZE.

    void * ret = nextfree;
    nextfree = ROUNDUP(nextfree + n, PGSIZE);

    return ret;
}
```

pmap.c, mem_init

```
void
mem_init(void)
{
    uint32_t cr0;
    size_t n;

    // Find out how much memory the machine has (npages & npages_basemem).
    i386_detect_memory();
```

```
	// Remove this line when you're ready to test this function.

	//////////////////////////////////////////////////////////////////////
	// create initial page directory.
	kern_pgdir = (pde_t *) boot_alloc(PGSIZE);
	memset(kern_pgdir, 0, PGSIZE);

	//////////////////////////////////////////////////////////////////////
	// Recursively insert PD in itself as a page table, to form
	// a virtual page table at virtual address UVPT.
	// (For now, you don't have understand the greater purpose of the
	// following line.)

	// Permissions: kernel R, user R
	kern_pgdir[PDX(UVPT)] = PADDR(kern_pgdir) | PTE_U | PTE_P;

	//////////////////////////////////////////////////////////////////////
	// Allocate an array of npages 'end's and store it in 'pages'.
	// The kernel uses this array to keep track of physical pages: for
	// each physical page, there is a corresponding struct PageInfo in this
	// array.  'npages' is the number of physical pages in memory.  Use memset
	// to initialize all fields of each struct PageInfo to 0.
	pages = boot_alloc(sizeof(*pages) * npages);
	memset(pages, 0, sizeof(*pages) * npages);

	//////////////////////////////////////////////////////////////////////
	// Now that we've allocated the initial kernel data structures, we set
	// up the list of free physical pages. Once we've done so, all further
	// memory management will go through the page_* functions. In
	// particular, we can now map memory using boot_map_region
	// or page_insert
	page_init();

	check_page_free_list(1);
	check_page_alloc();
	check_page();

	//////////////////////////////////////////////////////////////////////
	// Now we set up virtual memory

	//////////////////////////////////////////////////////////////////////
	// Map 'pages' read-only by the user at linear address UPAGES
	// Permissions:
	//    - the new image at UPAGES -- kernel R, user R
	//      (ie. perm = PTE_U | PTE_P)
	//    - pages itself -- kernel RW, user NONE
	boot_map_region(kern_pgdir, UPAGES, PTSIZE, PADDR(pages), PTE_P | PTE_W);

	//////////////////////////////////////////////////////////////////////
	// Use the physical memory that 'bootstack' refers to as the kernel
	// stack.  The kernel stack grows down from virtual address KSTACKTOP.
	// We consider the entire range from [KSTACKTOP-PTSIZE, KSTACKTOP)
	// to be the kernel stack, but break this into two pieces:
	//     * [KSTACKTOP-KSTKSIZE, KSTACKTOP) -- backed by physical memory
	//     * [KSTACKTOP-PTSIZE, KSTACKTOP-KSTKSIZE) -- not backed; so if
	//       the kernel overflows its stack, it will fault rather than
	//       overwrite memory.  Known as a "guard page".
	//     Permissions: kernel RW, user NONE
```

```
    boot_map_region(kern_pgdir, KSTACKTOP - KSTKSIZE, KSTKSIZE,
PADDR(bootstack), PTE_P | PTE_W);

    //////////////////////////////////////////////////////////////////////
    // Map all of physical memory at KERNBASE.
    // Ie.  the VA range [KERNBASE, 2^32) should map to
    //      the PA range [0, 2^32 - KERNBASE)
    // We might not have 2^32 - KERNBASE bytes of physical memory, but
    // we just set up the mapping anyway.
    // Permissions: kernel RW, user NONE
    boot_map_region(kern_pgdir, KERNBASE, -KERNBASE, 0, PTE_P | PTE_W);


    // Check that the initial page directory has been set up correctly.
    check_kern_pgdir();

    uint32_t cr4 = rcr4();
    cr4 |= CR4_PSE;
    lcr4(cr4);

    // Switch from the minimal entry page directory to the full kern_pgdir
    // page table we just created.  Our instruction pointer should be
    // somewhere between KERNBASE and KERNBASE+4MB right now, which is
    // mapped the same way by both page tables.
    //
    // If the machine reboots at this point, you've probably set up your
    // kern_pgdir wrong.
    lcr3(PADDR(kern_pgdir));

    check_page_free_list(0);

    // entry.S set the really important flags in cr0 (including enabling
    // paging).  Here we configure the rest of the flags that we care about.
    cr0 = rcr0();
    cr0 |= CR0_PE|CR0_PG|CR0_AM|CR0_WP|CR0_NE|CR0_MP;
    cr0 &= ~(CR0_TS|CR0_EM);
    lcr0(cr0);

    // Some more checks, only possible after kern_pgdir is installed.
    check_page_installed_pgdir();
}
```

pmap.c, page_init

```
void
page_init(void)
{
    // The example code here marks all physical pages as free.
    // However this is not truly the case.  What memory is free?
    //  1) Mark physical page 0 as in use.
    //     This way we preserve the real-mode IDT and BIOS structures
    //     in case we ever need them.  (Currently we don't, but...)
    //  2) The rest of base memory, [PGSIZE, npages_basemem * PGSIZE)
    //     is free.
    //  3) Then comes the IO hole [IOIOPHYSMEMPHYSMEM, EXTPHYSMEM), which must
    //     never be allocated.
    //  4) Then extended memory [EXTPHYSMEM, ...).
    //     Some of it is in use, some is free. Where is the kernel
    //     in physical memory?  Which pages are already in use for
    //     page tables and other data structures?
    //
    // Change the code to reflect this.
    // NB: DO NOT actually touch the physical memory corresponding to
    // free pages!

    page_free_list = NULL;

    for(size_t i = PGNUM(PADDR(boot_alloc(0))); i < npages; i++) {
        pages[i].pp_ref = 0;
        pages[i].pp_link = page_free_list;
        page_free_list = &pages[i];
    }
    // at system start, the lower memory is mapped into the initial pagetable
    // so I put these pages into the top of page_free_list
    for(size_t i = 1; i < npages_basemem; i++) {
        pages[i].pp_ref = 0;
        pages[i].pp_link = page_free_list;
        page_free_list = &pages[i];
    }
}
```

pmap.c, page_alloc

```
struct PageInfo *
page_alloc(int alloc_flags)
{
    if(!page_free_list)
        return NULL;
    struct PageInfo * ret = page_free_list;
    page_free_list = ret->pp_link;
    ret->pp_link = NULL;
    if(alloc_flags & ALLOC_ZERO) {
        memset(page2kva(ret), 0, PGSIZE);
    }
    return ret;
}
```

pmap.c, page_free

```
void
page_free(struct PageInfo *pp)
{
    // Fill this function in
    // Hint: You may want to panic if pp->pp_ref is nonzero or
    // pp->pp_link is not NULL.
    if(pp->pp_ref || pp->pp_link)
        panic("page to free is already in free list\n");
    pp->pp_link = page_free_list;
    page_free_list = pp;
}
```

Exercise 2

Nothing to report.

Exercise 3

Use the xp command in the QEMU monitor and the x command in GDB to inspect memory at corresponding physical and virtual addresses and make sure you see the same data.

In QEMU

```
(qemu) xp 0x100000
0000000000100000: 0x1badb002
```

In GDB:

```
(gdb) p/x *0xf0100000
$1 = 0x1badb002
```

Question

Assuming that the following JOS kernel code is correct, what type should variable x have, uintptr_t or physaddr_t?

It should be `uintptr_t`.

Exercise 4

pmap.c, pgdir_walk

```
pte_t *
pgdir_walk(pde_t *pgdir, const void *va, int create) {
    pde_t pde = pgdir[PDX(va)];
    if(pde & PTE_P) {
        pte_t * ptab = KADDR(PTE_ADDR(pde));
        return &ptab[PTX(va)];
    }
    else if(create) {
        struct PageInfo * ptab_info = page_alloc(ALLOC_ZERO);
        if(ptab_info == NULL) return NULL;
        ptab_info->pp_ref++;
        physaddr_t pa = page2pa(ptab_info);
        pgdir[PDX(va)] = pa | PTE_P | PTE_U | PTE_W;
        pte_t * ptab = KADDR(pa);
        return &ptab[PTX(va)];
    }
    else return NULL;
}
```

pmap.c, boot_map_region

```c
static void
boot_map_region(pde_t *pgdir, uintptr_t va, size_t size, physaddr_t pa, int
perm)
{
    perm = (perm & 0x3FF) | PTE_P;
    for(size_t offset = 0; offset < size; offset += PGSIZE) {
        pte_t * ppte = pgdir_walk(pgdir, (void*)va + offset, true);
        if(ppte == NULL) panic("No Avaliable Page");
        *ppte = (pa + offset) | perm;
    }
}
```

pmap.c, page_lookup

```c
struct PageInfo *
page_lookup(pde_t *pgdir, void *va, pte_t **pte_store)
{
    pte_t * pptab = pgdir_walk(pgdir, va, false);
    if(pte_store) {
        *pte_store = pptab;
    }
    if(pptab && (*pptab & PTE_P)) {
        return pa2page(PTE_ADDR(*pptab));
    }
    else {
        return NULL;
    }
}
```

pmap.c, page_remove

```c
void
page_remove(pde_t *pgdir, void *va)
{
    pte_t * ppte;
    struct PageInfo * info = page_lookup(pgdir, va, &ppte);
    if(info == NULL) return;
    *ppte = 0;
    page_decref(info);
    tlb_invalidate(pgdir, va);
}
```

pmap.c, page_insert

```c
int
page_insert(pde_t *pgdir, struct PageInfo *pp, void *va, int perm)
{
    perm = (perm & 0x3FF) | PTE_P;
    pte_t * ppte = pgdir_walk(pgdir, va, true);
    if(ppte == NULL) {
        return -E_NO_MEM;
    }
    physaddr_t pa = page2pa(pp);
    bool same_map = false;
    if(*ppte & PTE_P) {
        if(PTE_ADDR(*ppte) != pa) {
            page_remove(pgdir, va);
        }
        else {
            same_map = true;
        }
    }
    if(!same_map) pp->pp_ref++;
    *ppte = pa | perm;
    return 0;
}
```

Exercise 5

Fill in the missing code in mem_init() after the call to check_page().

```
void
mem_init(void)
{
    uint32_t cr0;
    size_t n;

    // Find out how much memory the machine has (npages & npages_basemem).
    i386_detect_memory();

    // Remove this line when you're ready to test this function.

    //////////////////////////////////////////////////////////////////////
    // create initial page directory.
    kern_pgdir = (pde_t *) boot_alloc(PGSIZE);
    memset(kern_pgdir, 0, PGSIZE);

    //////////////////////////////////////////////////////////////////////
    // Recursively insert PD in itself as a page table, to form
    // a virtual page table at virtual address UVPT.
    // (For now, you don't have understand the greater purpose of the
    // following line.)

    // Permissions: kernel R, user R
    kern_pgdir[PDX(UVPT)] = PADDR(kern_pgdir) | PTE_U | PTE_P;

    //////////////////////////////////////////////////////////////////////
    // Allocate an array of npages 'end's and store it in 'pages'.
    // The kernel uses this array to keep track of physical pages: for
    // each physical page, there is a corresponding struct PageInfo in this
    // array.  'npages' is the number of physical pages in memory.  Use memset
    // to initialize all fields of each struct PageInfo to 0.
    pages = boot_alloc(sizeof(*pages) * npages);
    memset(pages, 0, sizeof(*pages) * npages);

    //////////////////////////////////////////////////////////////////////
    // Now that we've allocated the initial kernel data structures, we set
    // up the list of free physical pages. Once we've done so, all further
    // memory management will go through the page_* functions. In
    // particular, we can now map memory using boot_map_region
    // or page_insert
    page_init();
    check_page_free_list(1);
    check_page_alloc();
    check_page();

    //////////////////////////////////////////////////////////////////////
    // Now we set up virtual memory

    //////////////////////////////////////////////////////////////////////
    // Map 'pages' read-only by the user at linear address UPAGES
    // Permissions:
    //    - the new image at UPAGES -- kernel R, user R
    //      (ie. perm = PTE_U | PTE_P)
    //    - pages itself -- kernel RW, user NONE
    boot_map_region(kern_pgdir, UPAGES, PTSIZE, PADDR(pages), PTE_P | PTE_W);

    //////////////////////////////////////////////////////////////////////
    // Use the physical memory that 'bootstack' refers to as the kernel
    // stack.  The kernel stack grows down from virtual address KSTACKTOP.
    // We consider the entire range from [KSTACKTOP-PTSIZE, KSTACKTOP)
    // to be the kernel stack, but break this into two pieces:
    //     * [KSTACKTOP-KSTKSIZE, KSTACKTOP) -- backed by physical memory
    //     * [KSTACKTOP-PTSIZE, KSTACKTOP-KSTKSIZE) -- not backed; so if
    //       the kernel overflows its stack, it will fault rather than
    //       overwrite memory.  Known as a "guard page".
    //     Permissions: kernel RW, user NONE
    boot_map_region(kern_pgdir, KSTACKTOP - KSTKSIZE, KSTKSIZE,
PADDR(bootstack), PTE_P | PTE_W);

    //////////////////////////////////////////////////////////////////////
    // Map all of physical memory at KERNBASE.
    // Ie.  the VA range [KERNBASE, 2^32) should map to
    //      the PA range [0, 2^32 - KERNBASE)
    // We might not have 2^32 - KERNBASE bytes of physical memory, but
    // we just set up the mapping anyway.
    // Permissions: kernel RW, user NONE
    boot_map_region(kern_pgdir, KERNBASE, -KERNBASE, 0, PTE_P | PTE_W);


    // Check that the initial page directory has been set up correctly.
    check_kern_pgdir();

    uint32_t cr4 = rcr4();
    cr4 |= CR4_PSE;
    lcr4(cr4);

    // Switch from the minimal entry page directory to the full kern_pgdir
    // page table we just created.  Our instruction pointer should be
    // somewhere between KERNBASE and KERNBASE+4MB right now, which is
    // mapped the same way by both page tables.
    //
    // If the machine reboots at this point, you've probably set up your
    // kern_pgdir wrong.
    lcr3(PADDR(kern_pgdir));

    check_page_free_list(0);

    // entry.S set the really important flags in cr0 (including enabling
    // paging).  Here we configure the rest of the flags that we care about.
    cr0 = rcr0();
    cr0 |= CR0_PE|CR0_PG|CR0_AM|CR0_WP|CR0_NE|CR0_MP;
    cr0 &= ~(CR0_TS|CR0_EM);
    lcr0(cr0);

    // Some more checks, only possible after kern_pgdir is installed.
    check_page_installed_pgdir();
}
```

Question

Question 2

What entries (rows) in the page directory have been filled in at this point? What addresses do they map and where do they point? In other words, fill out this table as much as possible:

idx	va	pa	comment
957	ef400000	f011b000	pgdir self loop
956	ef000000	11c000	maps to UPAGES
959	efff8000	10f000	maps to bootstack
960	f0000000	0	maps to physical memory
961	f0400000	400000	maps to physical memory
962	f0800000	800000	maps to physical memory
963	f0c00000	c00000	maps to physical memory
964	f1000000	1000000	maps to physical memory
965	f1400000	1400000	maps to physical memory
966	f1800000	1800000	maps to physical memory
967	f1c00000	1c00000	maps to physical memory
968	f2000000	2000000	maps to physical memory
969	f2400000	2400000	maps to physical memory
970	f2800000	2800000	maps to physical memory
971	f2c00000	2c00000	maps to physical memory
972	f3000000	3000000	maps to physical memory
973	f3400000	3400000	maps to physical memory
974	f3800000	3800000	maps to physical memory
975	f3c00000	3c00000	maps to physical memory
976	f4000000	4000000	maps to physical memory
977	f4400000	4400000	maps to physical memory
978	f4800000	4800000	maps to physical memory
979	f4c00000	4c00000	maps to physical memory
980	f5000000	5000000	maps to physical memory
981	f5400000	5400000	maps to physical memory
982	f5800000	5800000	maps to physical memory
983	f5c00000	5c00000	maps to physical memory
984	f6000000	6000000	maps to physical memory
985	f6400000	6400000	maps to physical memory
986	f6800000	6800000	maps to physical memory

idx	va	pa	comment
987	f6c00000	6c00000	maps to physical memory
988	f7000000	7000000	maps to physical memory
989	f7400000	7400000	maps to physical memory
990	f7800000	7800000	maps to physical memory
991	f7c00000	7c00000	maps to physical memory
992	f8000000	8000000	maps to physical memory
993	f8400000	8400000	maps to physical memory
994	f8800000	8800000	maps to physical memory
995	f8c00000	8c00000	maps to physical memory
996	f9000000	9000000	maps to physical memory
997	f9400000	9400000	maps to physical memory
998	f9800000	9800000	maps to physical memory
999	f9c00000	9c00000	maps to physical memory
1000	fa000000	a000000	maps to physical memory
1001	fa400000	a400000	maps to physical memory
1002	fa800000	a800000	maps to physical memory
1003	fac00000	ac00000	maps to physical memory
1004	fb000000	b000000	maps to physical memory
1005	fb400000	b400000	maps to physical memory
1006	fb800000	b800000	maps to physical memory
1007	fbc00000	bc00000	maps to physical memory
1008	fc000000	c000000	maps to physical memory
1009	fc400000	c400000	maps to physical memory
1010	fc800000	c800000	maps to physical memory
1011	fcc00000	cc00000	maps to physical memory
1012	fd000000	d000000	maps to physical memory
1013	fd400000	d400000	maps to physical memory
1014	fd800000	d800000	maps to physical memory
1015	fdc00000	dc00000	maps to physical memory
1016	fe000000	e000000	maps to physical memory

idx	va	pa	comment
1017	fe400000	e400000	maps to physical memory
1018	fe800000	e800000	maps to physical memory
1019	fec00000	ec00000	maps to physical memory
1020	ff000000	f000000	maps to physical memory
1021	ff400000	f400000	maps to physical memory
1022	ff800000	f800000	maps to physical memory
1023	ffc00000	fc00000	maps to physical memory

Question 3

We have placed the kernel and user environment in the same address space. Why will user programs not be able to read or write the kernel's memory?

What specific mechanisms protect the kernel memory?
We map kernel memory but not set the `PTE_U` flag.

Question 4

What is the maximum amount of physical memory that this operating system can support? Why?

4G, because the memory space is 32bit unsigned integer. The max value of a 32bit unsigned integer is $2^{32} = 4{\rm G}$.

Question 5

How much space overhead is there for managing memory, if we actually had the maximum amount of physical memory? How is this overhead broken down?
The overhead includes 1 pagedir and 2^10 page tables. They cost $(2^{10}+1)\cdot \text{PAGESIZE} = 2^{22}+2^{12} = 4{\rm M}+4{\rm k}$.

Question 6

At what point do we transition to running at an EIP above KERNBASE?

At entry.S, line 64

```
    mov $relocated, %eax
    jmp *%eax
relocated:
```

What makes it possible for us to continue executing at a low EIP between when we enable paging and when we begin running at an EIP above KERNBASE?

At entrypgdir.c, line 21

```
pde_t entry_pgdir[NPDENTRIES] = {
    // Map VA's [0, 4MB) to PA's [0, 4MB)
    [0]
        = ((uintptr_t)entry_pgtable - KERNBASE) + PTE_P,
    // Map VA's [KERNBASE, KERNBASE+4MB) to PA's [0, 4MB)
    [KERNBASE>>PDXSHIFT]
        = ((uintptr_t)entry_pgtable - KERNBASE) + PTE_P + PTE_W
};
```

The `entry_pgdir` maps VA's [0, 4MB) to PA's [0, 4MB), so code fetch won't crash.

Why is this transition necessary?

Because the map from VA's [0, 4MB) to PA's [0, 4MB) is a temporary map. When the virtual memory setups competely, this map won't exists. So the transition is necessary.

Challenge 1

We should turn on `CR4_PSE` to enable big page mode.

```
uint32_t cr4 = rcr4();
cr4 |= CR4_PSE;
lcr4(cr4);
```

My page mapping strategy is, in `boot_map_region`, big page is prefered.

```
static void
boot_map_region(pde_t *pgdir, uintptr_t va, size_t size, physaddr_t pa, int
perm)
{
    perm = perm | PTE_P;
    size_t offset = 0;
    while(offset < size) {
        void * map_va = (void *)va + offset;
        physaddr_t map_pa = pa + offset;
        if(PTX(map_pa) == 0 && size - offset >= PGSIZE * NPTENTRIES) {
            pde_t * ppde = pgdir_walk_bigpg(pgdir, map_va);
            if(ppde != NULL) {
                *ppde = map_pa | perm | PTE_PS;
                offset += PGSIZE * NPTENTRIES;
                continue;
            }
        }
        if(size - offset >= PGSIZE) {
            pte_t * ppte = pgdir_walk(pgdir, map_va, true);
            if(ppte == NULL) panic("No Available Page");
            *ppte = map_pa | perm;
            offset += PGSIZE;
        }
    }
}
```

Then, in `pgdir_walk`, big pages may be split as required.

```
pte_t *
```

```
pgdir_walk(pde_t *pgdir, const void *va, int create) {
    pde_t * pde = &pgdir[PDX(va)];
    if(*pde & PTE_P) {
        if(*pde & PTE_PS) {
            pte_t * ptab = split_large_page(pde);
            if(ptab == NULL) panic("No Available Page");
            return &ptab[PTX(va)];
        }
        else {
            pte_t * ptab = KADDR(PDE_ADDR(*pde));
            return &ptab[PTX(va)];
        }
    }
    else if(create) {
        struct PageInfo * ptab_info = page_alloc(ALLOC_ZERO);
        if(ptab_info == NULL) return NULL;
        ptab_info->pp_ref++;
        physaddr_t pa = page2pa(ptab_info);
        *pde = pa | PTE_P | PTE_U | PTE_W;
        pte_t * ptab = KADDR(pa);
        return &ptab[PTX(va)];
    }
    else return NULL;
}
```

The code for splitting page is:

```
pte_t * split_large_page(pde_t * pde) {
    struct PageInfo * ptab_info = page_alloc(ALLOC_ZERO);
    if(ptab_info == NULL) return NULL;
    uint32_t flags = PDE_FLAGS(*pde) & ~PTE_PS;
    physaddr_t pa = PDE_ADDR(*pde);
    ptab_info->pp_ref++;
    physaddr_t ptab_pa = page2pa(ptab_info);
    pte_t * ptab = KADDR(ptab_pa);
    for(size_t i = 0; i < NPTENTRIES; i++) {
        ptab[i] = (pa + i * PGSIZE) | flags;
    }
    *pde = ptab_pa | PTE_P | PTE_U | PTE_W;
    return ptab;
}
```

The `check_va2pa` function is wrong when in big page mode. So I modified it:

```
static physaddr_t
check_va2pa(pde_t *pgdir, uintptr_t va)
{
    pte_t *p;

    pgdir = &pgdir[PDX(va)];
    if (!(*pgdir & PTE_P))
        return ~0;
    if(*pgdir & PTE_PS) {
        return PDE_ADDR(*pgdir) + PTX(va) * PGSIZE;
    }
    p = (pte_t*) KADDR(PTE_ADDR(*pgdir));
    if (!(p[PTX(va)] & PTE_P))
        return ~0;
    return PTE_ADDR(p[PTX(va)]);
}
```

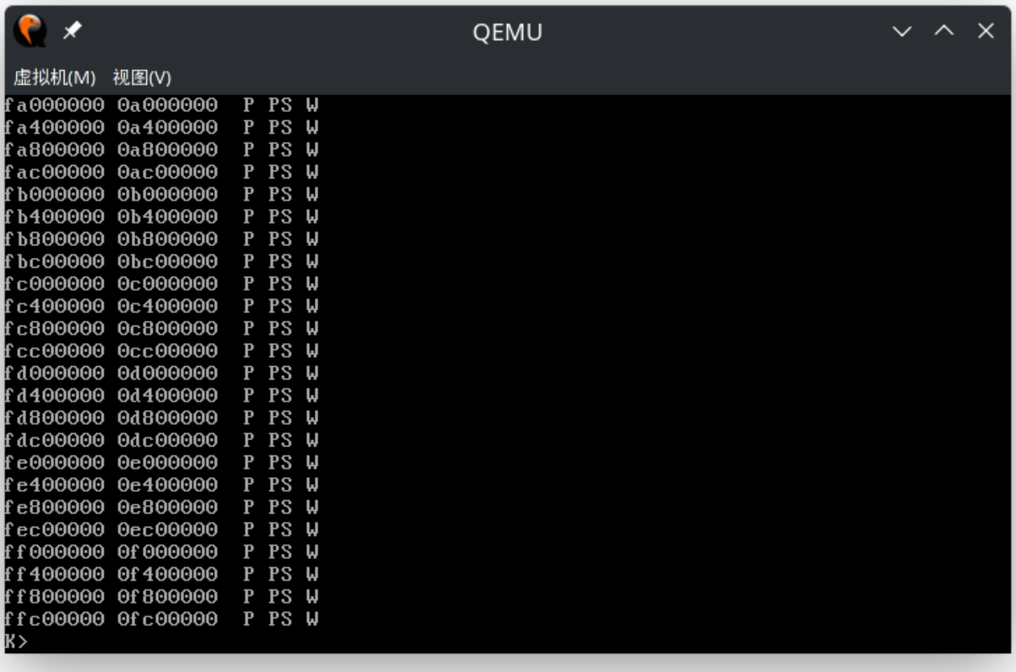
Challenge 2

I implemented the follow commands:

```
mem pde                        # show all pde
mem show 0x0000 0xf000         # show pages from 0x0000 to 0xf000
mem set pde 0x0000 PS 1        # set PS flag of pde at 0x0000
mem dump 0xf0000000 0xf000f000 # dump virtual memory
mem dumpphy 0x0000 0xf000      # dump physical memory
```

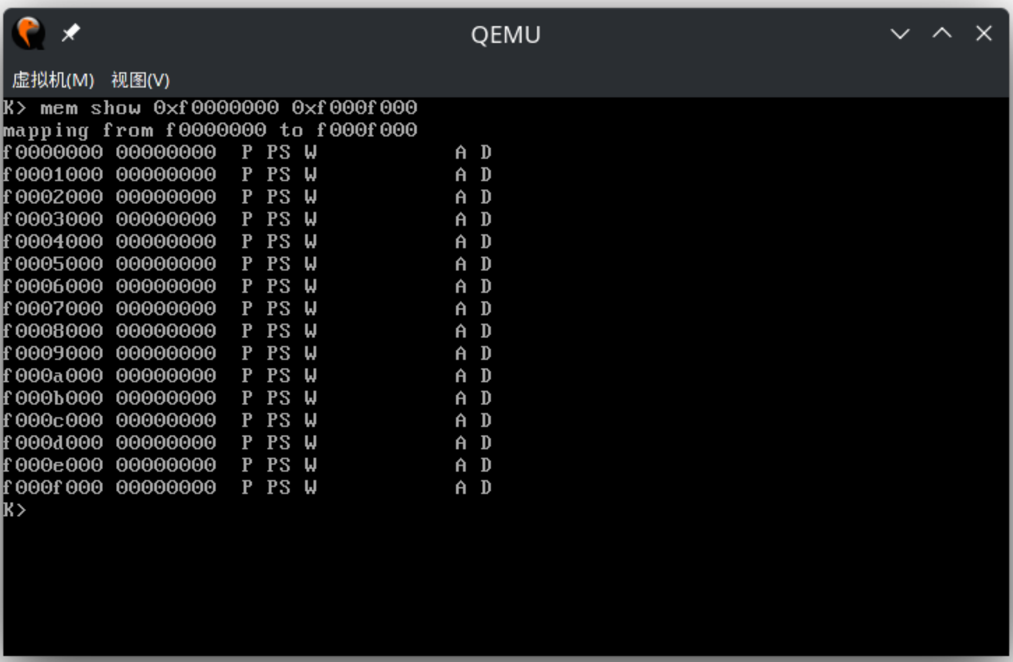
The command result:

```
mem pde
```



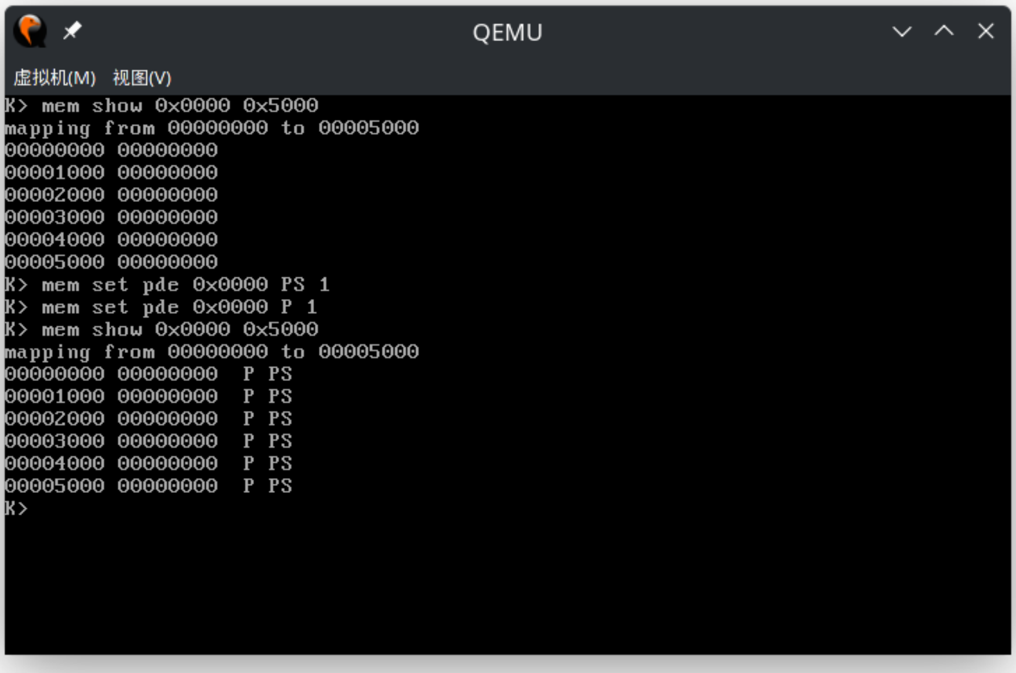
```
fa000000 0a000000  P PS W
fa400000 0a400000  P PS W
fa800000 0a800000  P PS W
fac00000 0ac00000  P PS W
fb000000 0b000000  P PS W
fb400000 0b400000  P PS W
fb800000 0b800000  P PS W
fbc00000 0bc00000  P PS W
fc000000 0c000000  P PS W
fc400000 0c400000  P PS W
fc800000 0c800000  P PS W
fcc00000 0cc00000  P PS W
fd000000 0d000000  P PS W
fd400000 0d400000  P PS W
fd800000 0d800000  P PS W
fdc00000 0dc00000  P PS W
fe000000 0e000000  P PS W
fe400000 0e400000  P PS W
fe800000 0e800000  P PS W
fec00000 0ec00000  P PS W
ff000000 0f000000  P PS W
ff400000 0f400000  P PS W
ff800000 0f800000  P PS W
ffc00000 0fc00000  P PS W
K>
```

```
mem show 0xf0000000 0xf000f000
```



```
K> mem show 0xf0000000 0xf000f000
mapping from f0000000 to f000f000
f0000000 00000000  P PS W           A D
f0001000 00000000  P PS W           A D
f0002000 00000000  P PS W           A D
f0003000 00000000  P PS W           A D
f0004000 00000000  P PS W           A D
f0005000 00000000  P PS W           A D
f0006000 00000000  P PS W           A D
f0007000 00000000  P PS W           A D
f0008000 00000000  P PS W           A D
f0009000 00000000  P PS W           A D
f000a000 00000000  P PS W           A D
f000b000 00000000  P PS W           A D
f000c000 00000000  P PS W           A D
f000d000 00000000  P PS W           A D
f000e000 00000000  P PS W           A D
f000f000 00000000  P PS W           A D
K>
```

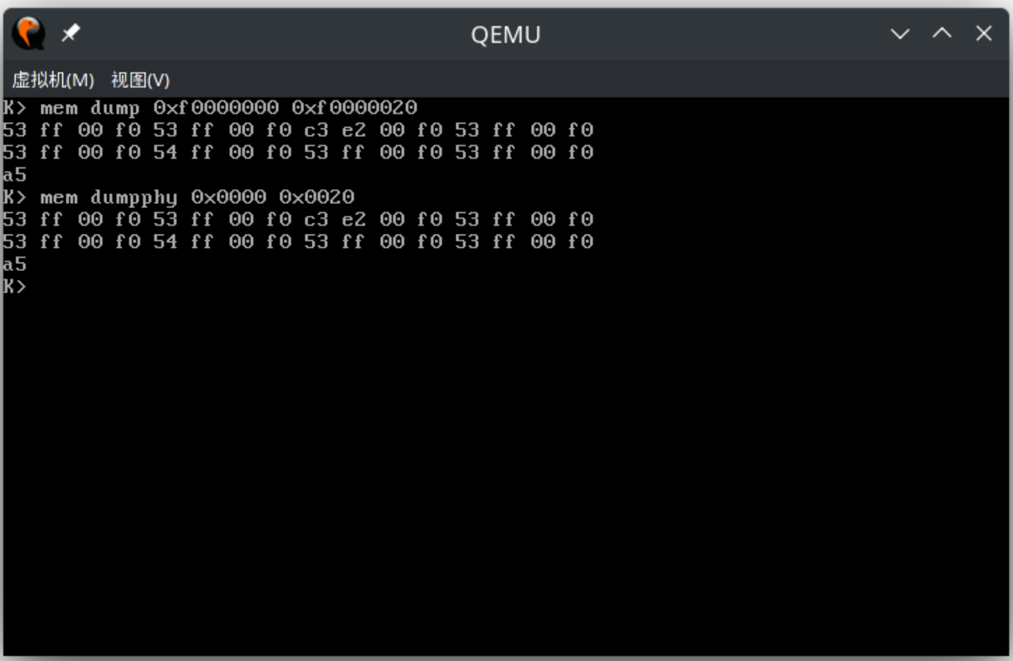
```
mem show 0x0000 0x5000
mem set pde 0x0000 PS 1
mem set pde 0x0000 P 1
mem show 0x0000 0x5000
```



```
K> mem show 0x0000 0x5000
mapping from 00000000 to 00005000
00000000 00000000
00001000 00000000
00002000 00000000
00003000 00000000
00004000 00000000
00005000 00000000
K> mem set pde 0x0000 PS 1
K> mem set pde 0x0000 P 1
K> mem show 0x0000 0x5000
mapping from 00000000 to 00005000
00000000 00000000  P PS
00001000 00000000  P PS
00002000 00000000  P PS
00003000 00000000  P PS
00004000 00000000  P PS
00005000 00000000  P PS
K>
```

- Here, I set PS flag to 1, the pages from 0x0000 to 0x5000 is in the same big page.

```
mem dump 0xf0000000 0xf0000020
mem dumpphy 0x0000 0x0020
```



```
K> mem dump 0xf0000000 0xf0000020
53 ff 00 f0 53 ff 00 f0 c3 e2 00 f0 53 ff 00 f0
53 ff 00 f0 54 ff 00 f0 53 ff 00 f0 53 ff 00 f0
a5
K> mem dumpphy 0x0000 0x0020
53 ff 00 f0 53 ff 00 f0 c3 e2 00 f0 53 ff 00 f0
53 ff 00 f0 54 ff 00 f0 53 ff 00 f0 53 ff 00 f0
a5
K>
```

The code is:

```
// ---------------------------------------------------------------
// Debug functions.
// ---------------------------------------------------------------

static int64_t atoi(char * arg) {
#define _isnum(x) ('0' <= (x) && (x) <= '9') || ('a' <= (x) && (x) <= 'f')
#define _getnum(x) (('0' <= (x) && (x) <= '9') ? ((x) - '0') : ((x) - 'a' +
10))
    int64_t ret = 0, mul = 1, base=10;
    while(!('0' <= *arg && *arg <= '9')) arg++;
    if(*arg == '-') { mul = -1; arg++; }
    if(arg[0] == '0') {
        if(arg[1] == 'x') {
            base = 16;
            arg = arg + 2;
        }
    }
    while(_isnum(*arg)) {
        ret = ret * base + _getnum(*arg);
        arg++;
    }
    return ret * mul;
#undef _getnum
#undef _isnum
}

static void _show_pte(pte_t pde) {
#define _show_pde_inner(flag) \
    if(pde & PTE_##flag) {cprintf(" "); cprintf(#flag);}\
    else {cprintf(" "); for(size_t i = strlen(#flag); i; i--) cprintf(" ");}
    cprintf("%08x ", PTE_ADDR(pde));
    _show_pde_inner(P);
    _show_pde_inner(PS);
    _show_pde_inner(W);
    _show_pde_inner(U);
    _show_pde_inner(PWT);
    _show_pde_inner(PCD);
    _show_pde_inner(A);
    _show_pde_inner(D);
    _show_pde_inner(G);
    _show_pde_inner(AVAIL);
#undef _show_pde_inner
}

static void _show_pde(pde_t pde) {
    _show_pte((pte_t)pde);
}

int
memcmd_pde(int argc, char ** argv, struct Trapframe * tf) {
    for(size_t i = 0; i < NPDENTRIES; i++) {
        uintptr_t va = PGSIZE * NPTENTRIES * i;
        cprintf("%08x ", va);
        _show_pde(kern_pgdir[PDX(va)]);
        cprintf("\n");
    }
    return 0;
}

int
memcmd_show(int argc, char ** argv, struct Trapframe * tf) {
    if(argc != 3) {
        cprintf("usage mem show <start> <end>\n");
        return -1;
    }
    uintptr_t start = ROUNDDOWN(atoi(argv[1]), PGSIZE);
    uintptr_t end = ROUNDUP(atoi(argv[2]) + 1, PGSIZE);
    cprintf("mapping from %08x to %08x\n", start, end - PGSIZE);
    uintptr_t va = start;
    do {
        pde_t * ppde = &kern_pgdir[PDX(va)];
        if(!(*ppde & PTE_P) || (*ppde & PTE_PS)) {
            cprintf("%08x ", va); _show_pde(*ppde); cprintf("\n");
        }
        else {
            pte_t * ppte = pgdir_walk(kern_pgdir, (void*)va, false);
            assert(ppte);
            cprintf("%08x ", va); _show_pte(*ppte); cprintf("\n");
        }
        va += PGSIZE;
    } while(va != end);
    return 0;
}

int
memcmd_set(int argc, char ** argv, struct Trapframe * tf) {
    if(argc != 5) {
        cprintf("usage mem set <pde|pte> <va> <ent> <value>\n");
        return -1;
    }
    bool pde = strcmp(argv[1], "pde") == 0;
    uintptr_t va = atoi(argv[2]);
    const char * ent = argv[3];
    uint64_t value = atoi(argv[4]);
#define _memcmd_set_inner(flag) \
    else if(strcmp(ent, #flag)==0) {\
        if(pde) {\
            pde_t * ppde = &kern_pgdir[PDX(va)]; \
            *ppde = (*ppde & (~PTE_##flag)) | (value * PTE_##flag);\
        } \
        else    {\
            pte_t * ppte = pgdir_walk(kern_pgdir, (void*)va, true); \
            if(ppte == NULL) {cprintf("No Available Pages"); \
                return -1; \
            } \
            *ppte = (*ppte & (~PTE_##flag)) | (value * PTE_##flag); \
        } \
    }
    if(strcmp(ent, "pa")==0) {
        if(pde) {
            pde_t * ppde = &kern_pgdir[PDX(va)];
            *ppde = value | PDE_FLAGS(*ppde);
            tlb_invalidate(kern_pgdir, (void*)va);
        }
        else {
            pte_t * ppte = pgdir_walk(kern_pgdir, (void*)va, true);
            *ppte = value | PTE_FLAGS(*ppte);
            tlb_invalidate(kern_pgdir, (void*)va);
        }
    }
    _memcmd_set_inner(P)
    _memcmd_set_inner(PS)
    _memcmd_set_inner(W)
    _memcmd_set_inner(U)
    _memcmd_set_inner(PWT)
    _memcmd_set_inner(PCD)
    _memcmd_set_inner(A)
    _memcmd_set_inner(D)
    _memcmd_set_inner(G)
    _memcmd_set_inner(AVAIL)
    else {
        cprintf("Unknown entity: %s\n", ent);
        return -1;
    }
    return 0;
}

int
memcmd_dump(int argc, char ** argv, struct Trapframe * tf) {
    if(argc != 3) {
        cprintf("usage mem dump <start> <end>\n");
        return -1;
    }
    uintptr_t start = atoi(argv[1]);
    uintptr_t end = atoi(argv[2]);
    short tick = 0;
    for(uintptr_t i = start; i <= end; i++) {
        cprintf("%02x ", *(unsigned char *)i);
```

```c
        if(((++tick)&0xf)==0) cprintf("\n");
    }
    if(tick)cprintf("\n");
    return 0;
}

int
memcmd_dumpphy(int argc, char ** argv, struct Trapframe * tf) {
    if(argc != 3) {
        cprintf("usage mem dumpphy <start> <end>\n");
        return -1;
    }
    uintptr_t start = atoi(argv[1]);
    uintptr_t end = atoi(argv[2]);
    short tick = 0;
    for(uintptr_t i = start; i <= end; i++) {
        cprintf("%02x ", *(unsigned char*)KADDR(i));
        if(((++tick)&0xf)==0) cprintf("\n");
    }
    if(tick)cprintf("\n");
    return 0;
}

int
mem_memcmd(int argc, char ** argv, struct Trapframe * tf) {
    if(argc == 1) {
        cprintf("Usage: mem <pde|show|set|dump|dumpphy> ...");
        return -1;
    }
    else {
        if(strcmp(argv[1], "pde") == 0) {
            memcmd_pde(argc - 1, argv + 1, tf);
        }
        else if(strcmp(argv[1], "show") == 0) {
            memcmd_show(argc - 1, argv + 1, tf);
        }
        else if(strcmp(argv[1], "set") == 0) {
            memcmd_set(argc - 1, argv + 1, tf);
        }
        else if(strcmp(argv[1], "dump") == 0) {
            memcmd_dump(argc - 1, argv + 1, tf);
        }
        else if(strcmp(argv[1], "dumpphy") == 0) {
            memcmd_dumpphy(argc - 1, argv + 1, tf);
        }
        else {
            cprintf("Unknown command %s\n", argv[1]);
            return -1;
        }
    }
    return 0;
}
```