CS302 OS A4

Zhiyuan Zhong 12110517

Q1

Requirements for CPU hardware:

Hardware Requirements	Notes
Privileged mode	Needed to prevent user-mode processes from executing privileged operations
Base/bounds registers	Need pair of registers per CPU to support address translation and bounds checks
Ability to translate virtual addresses and check if within bounds limits	Circuitry to do translations and check limits
Privileged instruction(s) to update base/bounds	OS must be able to set these values before letting a user program run
Privileged instruction(s) to register exception handlers	OS must be able to tell hardware what code to run if exception occurs
Ability to raise exceptions	When processes try to access privileged instructions or out-of-bounds memory

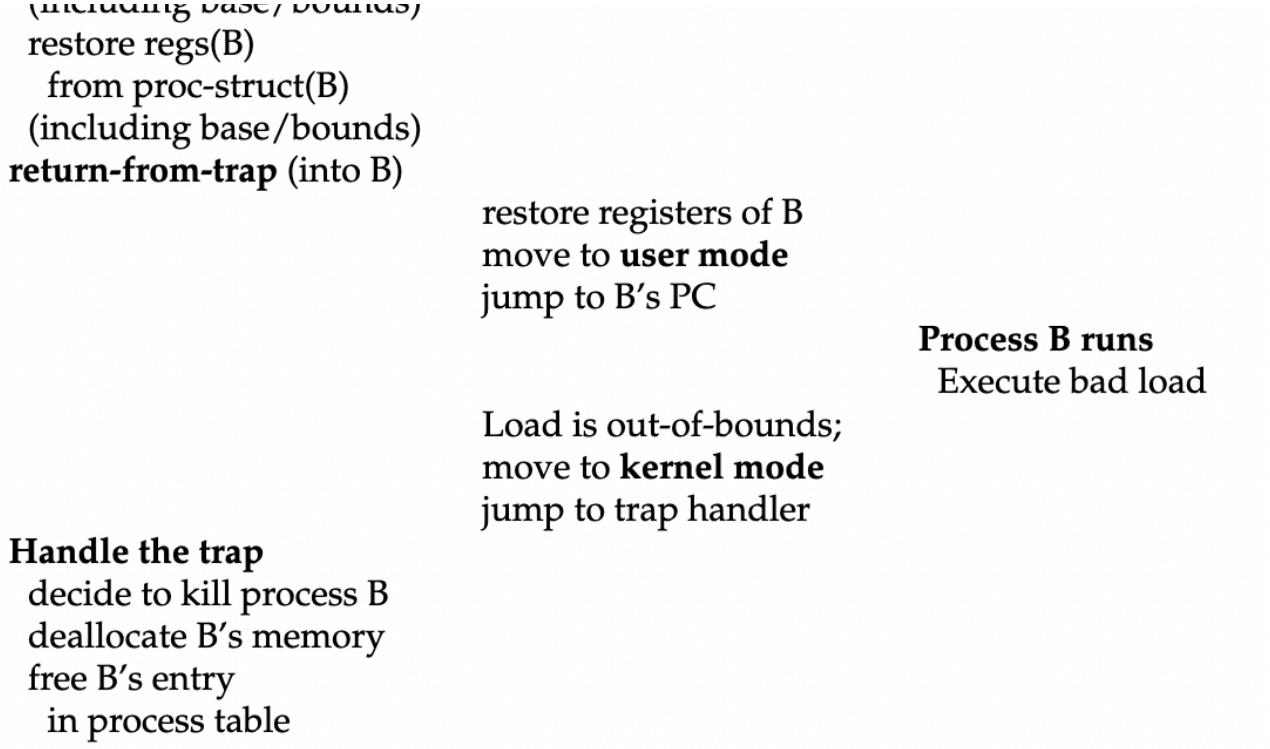
Requirements for OS:

OS Requirements	Notes
Memory management	Need to allocate memory for new processes; Reclaim memory from terminated processes; Generally manage memory via free list
Base/bounds management	Must set base/bounds properly upon context switch
Exception handling	Code to run when exceptions arise; likely action is to terminate offending process

The cooperation needed at boot and runtime:

OS @ boot (kernel mode)	Hardware
initialize trap table	
	remember addresses of...
	system call handler
	timer handler
	illegal mem-access handler
	illegal instruction handler
start interrupt timer	
	start timer; interrupt after X ms
initialize process table	
initialize free list	

OS @ run (kernel mode)	Hardware	Program (user mode)
To start process A:		
allocate entry		
in process table		
alloc memory for process		
set base/bound registers		
return-from-trap (into A)		
	restore registers of A	
	move to **user mode**	
	jump to A's (initial) PC	
		Process A runs
		Fetch instruction
	translate virtual address	
	perform fetch	
		Execute instruction
	if explicit load/store:	
	ensure address is legal	
	translate virtual address	
	perform load/store	
		(A runs...)
	Timer interrupt	
	move to **kernel mode**	
	jump to handler	
Handle timer		
decide: stop A, run B		
call `switch()` routine		
save regs(A)		
to proc-struct(A)		
(including base/bounds)		



Q2

Aspects	Segmentation	Paging
size of chunks	variable-sized	fixed-sized
management of free space	1. compact physical memory by rearranging the existing segments. The OS could stop whichever processes are running, copy their data to one contiguous region of memory, change their segment register values to point to thenew physical locations, and thus have a large free extent of memory with which to work. (But expensive) 2. Simpler: use a free-list management (first-fit, best-fit, worst-fit)	OS keeps a free list of all free pages for this, and just grabs the first few free pages (of the required size) off of this list
context switch overhead	high. OS saves and restores base/bound registers.	low. Updating page tables, which are typically smaller and quicker. But requires one extra memory reading in order to first fetch the translation from the page table (entry)
fragmentation	external fragmentation	internal fragmentation
		Valid bit: to indicate

status bits and protection bits	**Segment bits**: the first few bits protection bits: whether or not a program can read or write a segment, or perhaps execute code that lies within the segment **A grows positive bit**: the hardware also needs to know which way the segment grows (1-segment grows in the positive direction, 0-negative)	whether the particular translation is valid. **Protection bits**: indicating whether the page could be read from, written to, or executed from. **Present bit**: whether this page is in physical memory or on disk (i.e., it has been swapped out) **Dirty bit**: whether the page has been modified since it was brought into memory. **Reference bit** (a.k.a. accessed bit): track whether a page has been accessed, and is useful in determining which pages are popular

Q3

- Page size: 8KB=2^{13}B, the offset has 13 bits.
- PTE size: 4B. To fit a page table into a single page, # of PTE in one page table = $2^{13}/2^2 = 2^{11}$
- The virtual address apace has 46 bits, to map the entire virtual address space, # of pages = $2^{46}/2^{13} = 2^{33}$
- $(2^{11})^3 = 2^{33}$, we need to have 3 levels page table, each page table has 11 bits.

The address translation is as follows: L1, L2, L3 refers to 3 level page tables, the PFN is read by L3 page tables. And the offset is 13 bits.

L1	L2	L3	Offset
45-35	34-24	23-13	12-0

Q4

(a) page size = $2^{12} = 4$KB. 20 bits for page can store 2^{20} pages, each PTE is 4B, so the maximum page table size is $2^{20} \times 4 = 4$MB.

(b) `0xC302C302`(base 16) = `1100 0011 0000 0010 1100 0011 0000 0010`(base 2). The 1-st level page number is `1100001100`(base 2) = 780(base 10), the offset: `0011 0000 0010`(base 2) = 770(base 10).

`0xEC6666AB`(base16) = `1110 1100 0110 0110 0110 0110 1010 1011`(base 2). The 2-nd level page number is `1001100110`(base 2) = 614(base 10), the offset: `011010101011`(base 2) = 1707(base 10).

Q5

- The code: `default_free_pages()` in `default_pmm.c`

```
//---------------------合并空闲块--------------------
list_entry_t* prev = list_prev(&(base->page_link)); // previous block
if (prev != &free_list) { // previous block exists
    struct Page* prev_page = le2page(prev, page_link);
    if (prev_page + prev_page->property == base) { // continuous
        prev_page->property += base->property; // update property
        ClearPageProperty(base); // base is merged into prev_page
        list_del(&(base->page_link));
        base = prev_page;
    }
}

list_entry_t* next = list_next(&(base->page_link)); // next block
if (next != &free_list) { // next block exists
    struct Page* next_page = le2page(next, page_link);
    if (base + base->property == next_page) { // continuous
        base->property += next_page->property; // update base property
        ClearPageProperty(next_page); // next_page is merged into base
        list_del(&(next_page->page_link));
    }
}
//-----------------------------------------------------
```

- The reult:

```
~/oslab/A4_code » make qemu                                    cooper12110517@oslab-vm

OpenSBI v0.6
   ____                    _____ ____ _____
  / __ \                  / ____|  _ \_   _|
 | |  | |_ __   ___ _ __ | (___ | |_) || |
 | |  | | '_ \ / _ \ '_ \ \___ \|  _ < | |
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  \____/| .__/ \___|_| |_|_____/|___/_____|
        | |
        |_|

Platform Name          : QEMU Virt Machine
Platform HART Features : RV64ACDFIMSU
Platform Max HARTs     : 8
Current Hart           : 0
Firmware Base          : 0x80000000
Firmware Size          : 120 KB
Runtime SBI Version    : 0.2

MIDELEG : 0x0000000000000222
MEDELEG : 0x000000000000b109
PMP0    : 0x0000000080000000-0x000000008001ffff (A)
PMP1    : 0x0000000000000000-0xffffffffffffffff (A,R,W,X)
os is loading ...
memory management: default_pmm_manager
physcial memory map:
  memory: 0x0000000007e00000, [0x0000000080200000, 0x0000000087ffffff].
Checking continuous free pages merging...
check_alloc_page() succeeded!
```
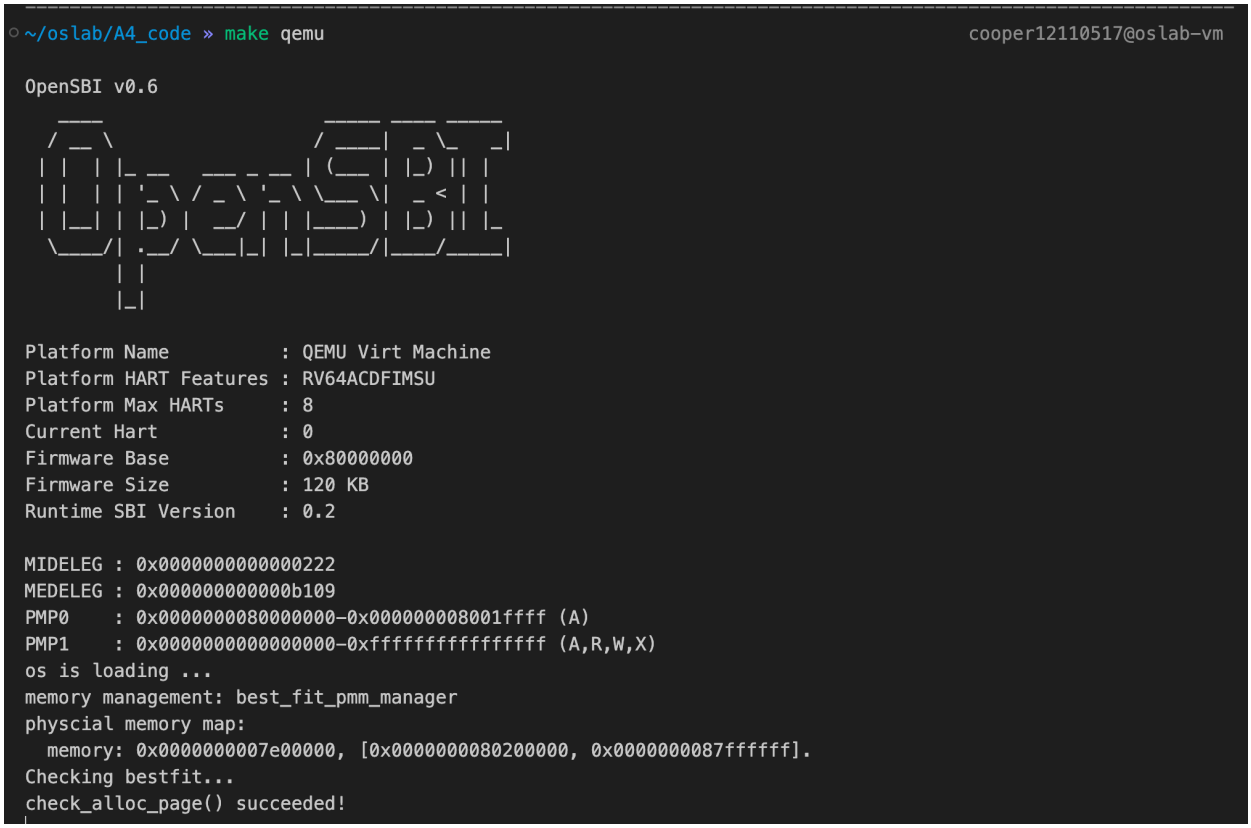

Q6

- The code: The difference is in `best_fit_alloc_pages()`, other functions are the same as `default_pmm.c`.

```
58  static struct Page *
59  best_fit_alloc_pages(size_t n)
60  {
61      assert(n > 0);
62      if (n > nr_free) {
63          return NULL;
64      }
65      struct Page *page = NULL;
66      int closest = __INT32_MAX__; // record the closest property to n
67      list_entry_t *le = &free_list;
68      while ((le = list_next(le)) != &free_list) {
69          struct Page *p = le2page(le, page_link);
70          if (p->property >= n) {
71              if (p->property < closest) { // closer to n
72                  closest = p->property;
73                  page = p;
74              }
75          }
76      }
77      if (page != NULL) {
78          list_entry_t* prev = list_prev(&(page->page_link));
79          list_del(&(page->page_link));
80          if (page->property > n) {
81              struct Page *p = page + n;
82              p->property = page->property - n;
83              SetPageProperty(p);
84              list_add(prev, &(p->page_link));
85          }
86          nr_free -= n;
87          ClearPageProperty(page);
88      }
89      return page;
90  }
```

- The result:


~/oslab/A4_code » make qemu
cooper12110517@oslab-vm
OpenSBI v0.6
Platform Name : QEMU Virt Machine
Platform HART Features : RV64ACDFIMSU
Platform Max HARTs : 8
Current Hart : 0
Firmware Base : 0x80000000
Firmware Size : 120 KB
Runtime SBI Version : 0.2
MIDELEG : 0x0000000000000222
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PMP0 : 0x0000000080000000-0x000000008001ffff (A)
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os is loading ...
memory management: best_fit_pmm_manager
physcial memory map:
memory: 0x0000000007e00000, [0x0000000080200000, 0x0000000087ffffff].
Checking bestfit...
check_alloc_page() succeeded!