CS444/544
Operating Systems II

Lecture 6

JOS Memory Management and Quiz 1 Prep.

4/17/2024

Acknowledgement: Slides drawn heavily from Yeongjin Jiang

Oregon State University

Due Reminder

- Lab 1 past due…
  - 75% due: 4/22 11:59 PM
- Lab 2 posted
  - 100% due: 4/29 11:59 PM
  - 75% due: 5/6 11:59 PM

QUIZ 1 (4/22)

- We will have Quiz 1 on Monday
  - More info later

- No class on Monday (4/22)

Recap: PDE/PTE Permission Examples

- Virtual address 0x01020304
- PDE: PTE_P | PTE_W
- PTE: PTE_P | PTE_U
- valid, inaccessible by ring3, not writable

- PTE_P (PRESENT)
  - 0: invalid entry
  - 1: valid entry
- PTE_W (WRITABLE)
  - 0: read only
  - 1: writable
- PTE_U (USER)
  - 0: kernel (only ring 0 can access)
  - 1: user (accessible by ring 3)

Recap: PDE/PTE Permissions CAVEAT

- A virtual address access is allowed if both **PDE** and **PTE** entries allows the access…

- General practice: put **a more permissive** permission bits in **PDE**, and **be strict** on setting permission bits in **PTE**

- For a conflicting permission setup for Kernel/User, add **an additional virtual address mapping** can enable such a setup

Recap: You can setup the following page permissions…

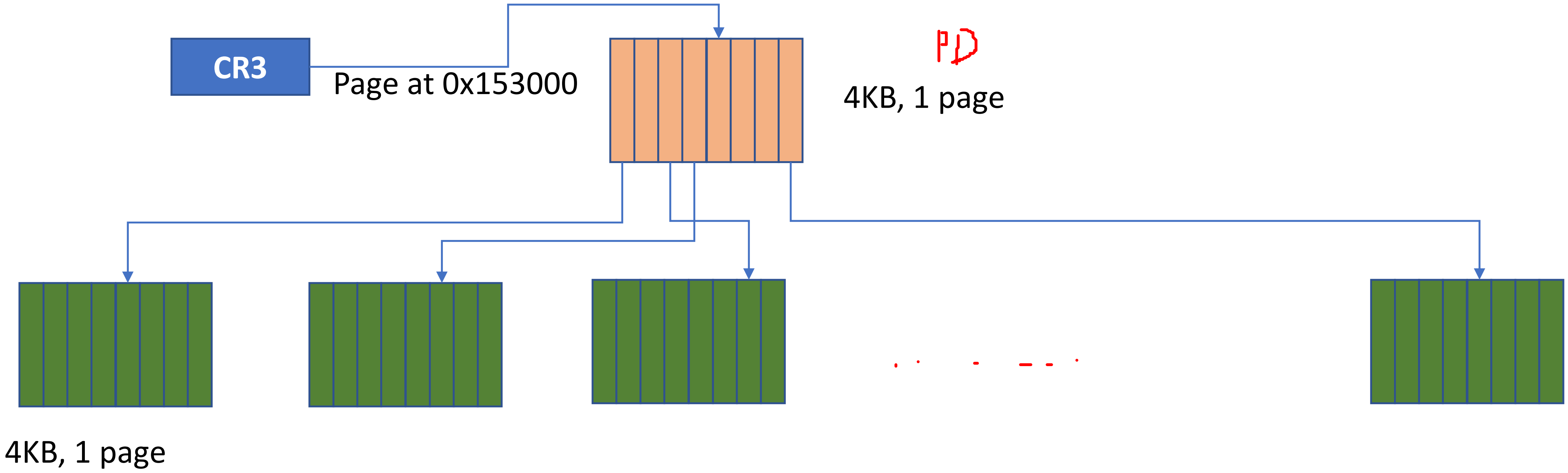
- Kernel: RW, User: R
  - VA 0x00001000 -> PA 0x50000, PTE_P | PTE_U (User R)
  - VA 0xf0050000 -> PA 0x50000, PTE_P | PTE_W (Kernel RW)
- Kernel: R, User: RW
  - VA 0x00002000 -> PA 0x60000, PTE_P | PTE_U | PTE_W (User RW)
  - VA 0xf0060000 -> PA 0x60000, PTE_P (Kernel R)
- Kernel: --, User: RW
  - VA 0x00003000 -> PA 0x70000, PTE_P | PTE_U | PTE_ W
  - VA 0xf0070000 -> PA 0x70000, 0 for flag…

Today's Topic

- Managing Physical/Virtual Memory in JOS
- Prep for Quiz 1

Creating a Virtual Memory Space

- A page directory manages the entire virtual memory space
  - For a process
- CR3 points to the Page directory, and each PDE entry points to a PT...



Assigning VA -> PA mapping

- Suppose a process would like to use a virtual address
  - 0x400000 (RW from user)

- Allocation procedure
  - Check page directory entry (PDE)
    - If not set with PTE_P, **allocate a physical page** for a new page table

Page at 0x153000

PDE 0: EMPTY
PDE 1: EMPTY
PDE 2: EMPTY
PDE ….: EMPTY
PDE ….: EMPTY
PDE ….: EMPTY
PDE 1022: EMPTY
PDE 1023: EMPTY

0~4MB

4~8MB

Assigning VA -> PA mapping

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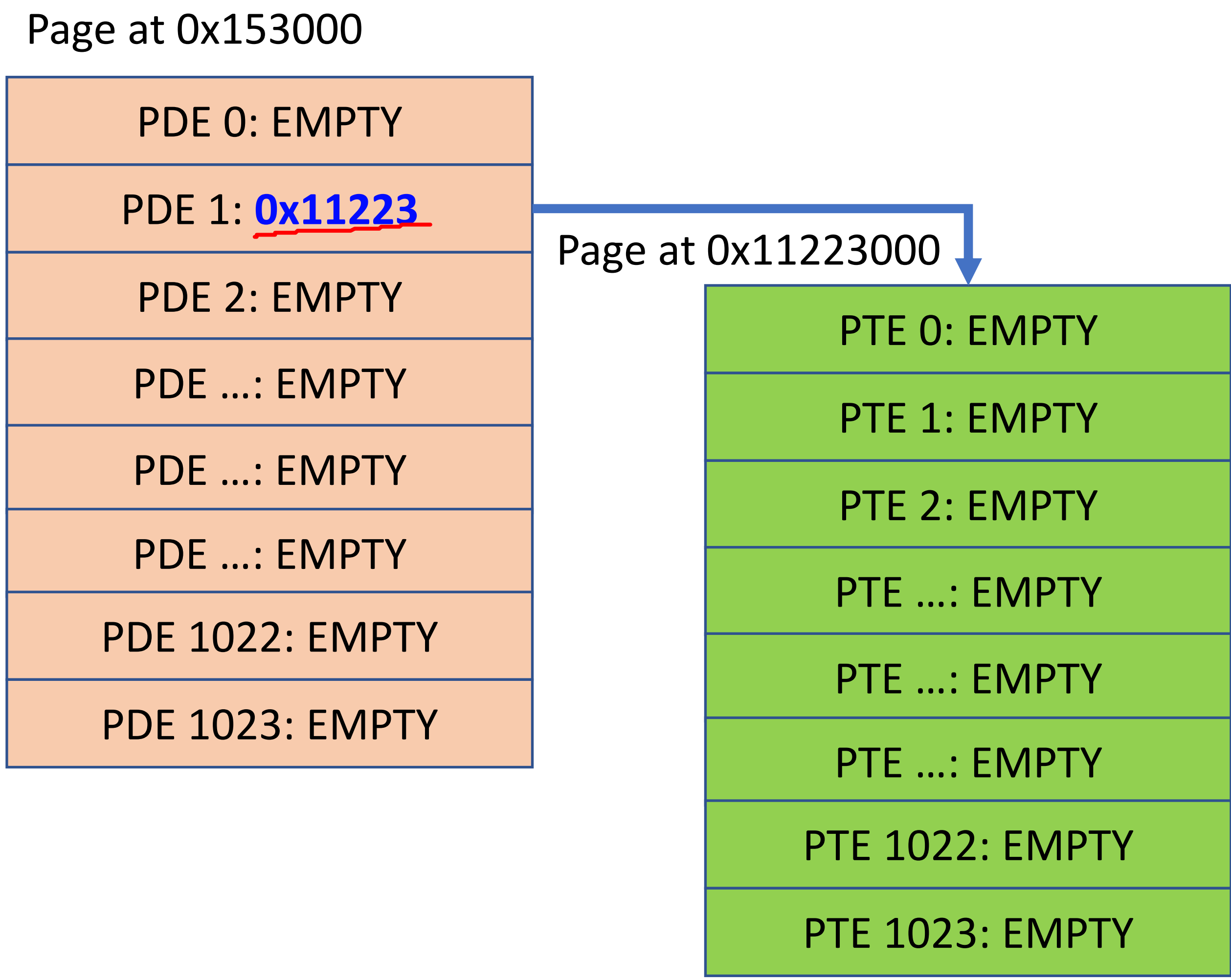

Assigning VA -> PA mapping

- Suppose a process would like to use a virtual address
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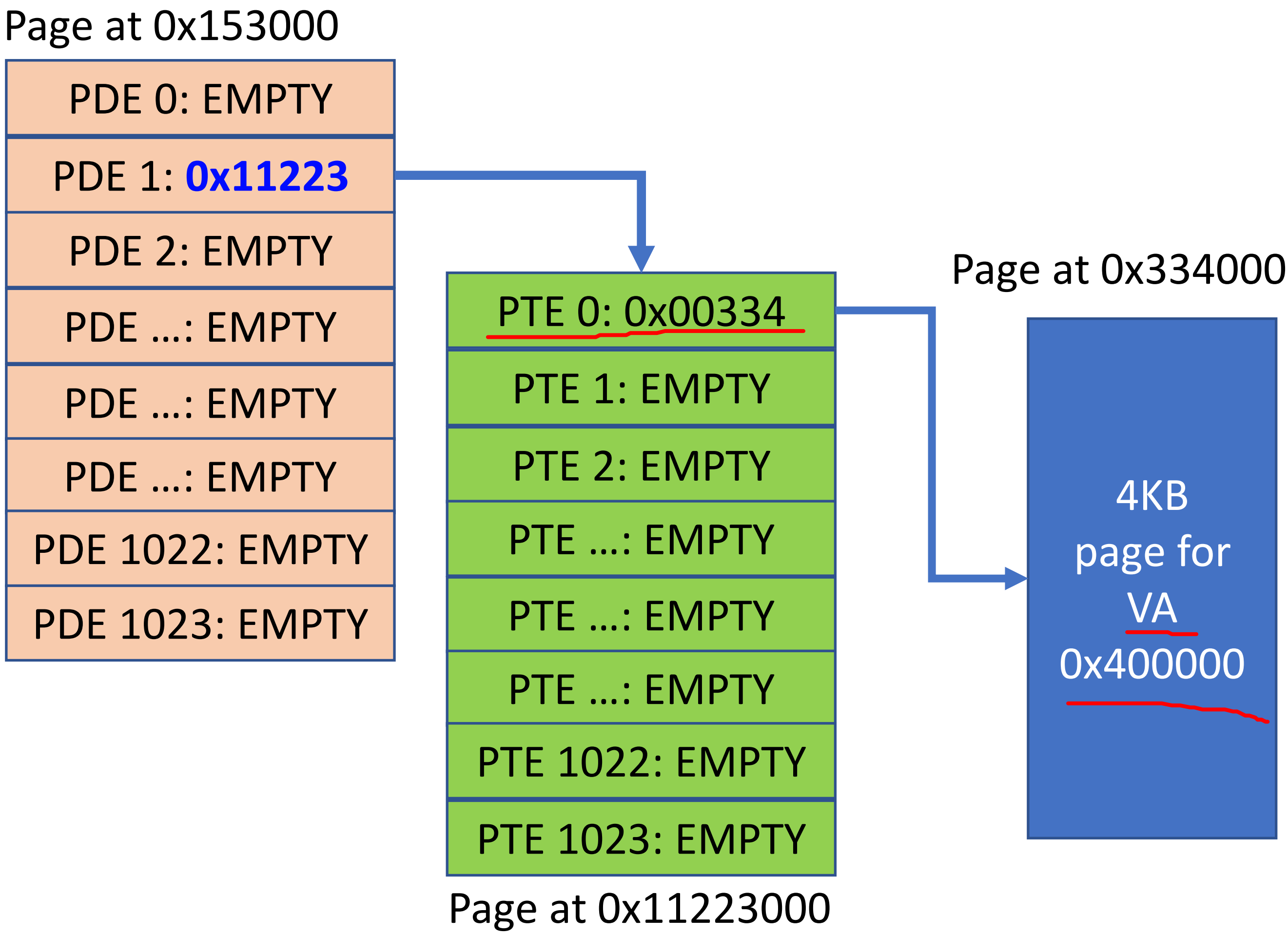

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- We need to keep track of '**free**' physical pages...

Struct PageInfo *pages in JOS

- A **one-to-one** mapping from a struct **PageInfo** to a physical page
  - An 8 byte struct per each physical memory page
  - If we support 128MB memory, then we will create
    - Total number of physical pages: 128 * 1048576 / 4096 = 32768
  - Total size of pages = **32768 * 8** = 262,144 = 256KB for `pages`
- A linked-list for managing free physical pages
  - Starting from `page_free_list->pp_link`…
- `pp_ref`
  - Count references
  - Non-zero – in-use
  - Zero – free

```
struct PageInfo {
    // Next page on the free list.
    struct PageInfo *pp_link;

    // pp_ref is the count of pointers (usually in page table entries)
    // to this page, for pages allocated using page_alloc.
    // Pages allocated at boot time using pmap.c's
    // boot_alloc do not have valid reference count fields.

    uint16_t pp_ref;
};
```

How JOS manages Physical Memory?

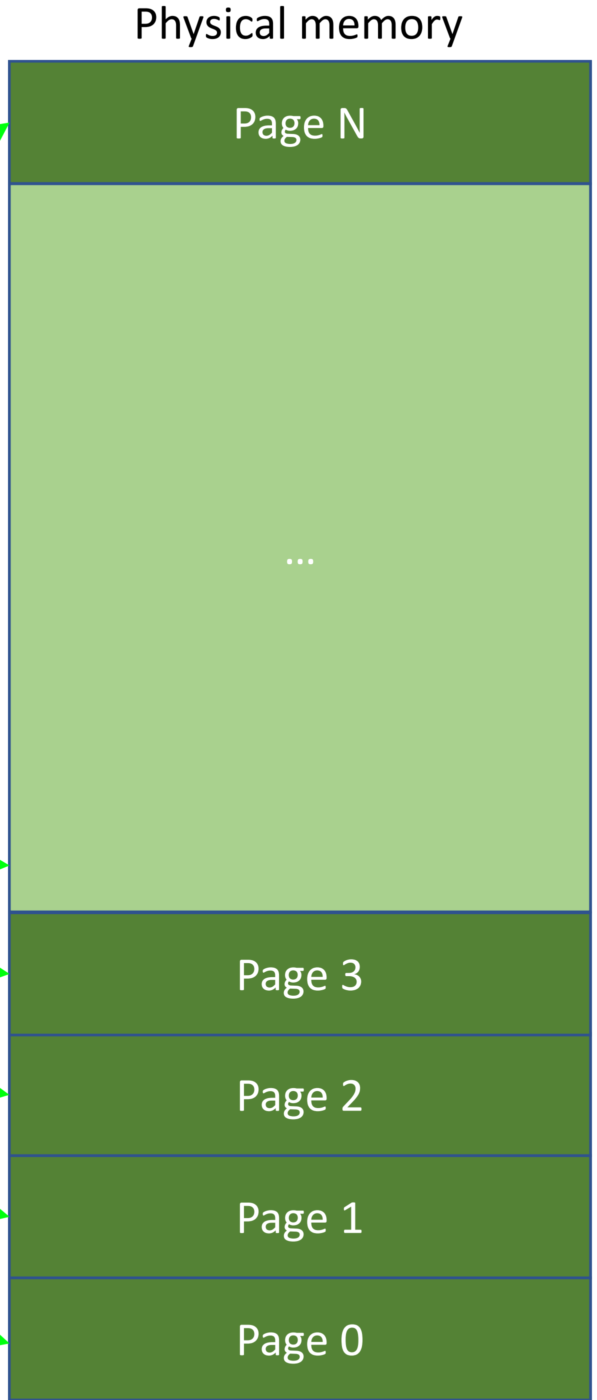
- Struct PageInfo
  - A metadata type that counts number of ‘references’ of the page
  - NOT IN USE : pp_ref == 0
- Struct PageInfo * page_free_list
  - A linked list that contains free physical pages
- We will create Struct PageInfo per each Physical Page and then
  - Create a linked list of free pages…

Example

Struct PageInfo * pages (array)

idx	pp_ref	pp_link
N	0	
…	0	
…	0	
3	0	
2	0	
1	0	
0	0	

page_free_list



Example

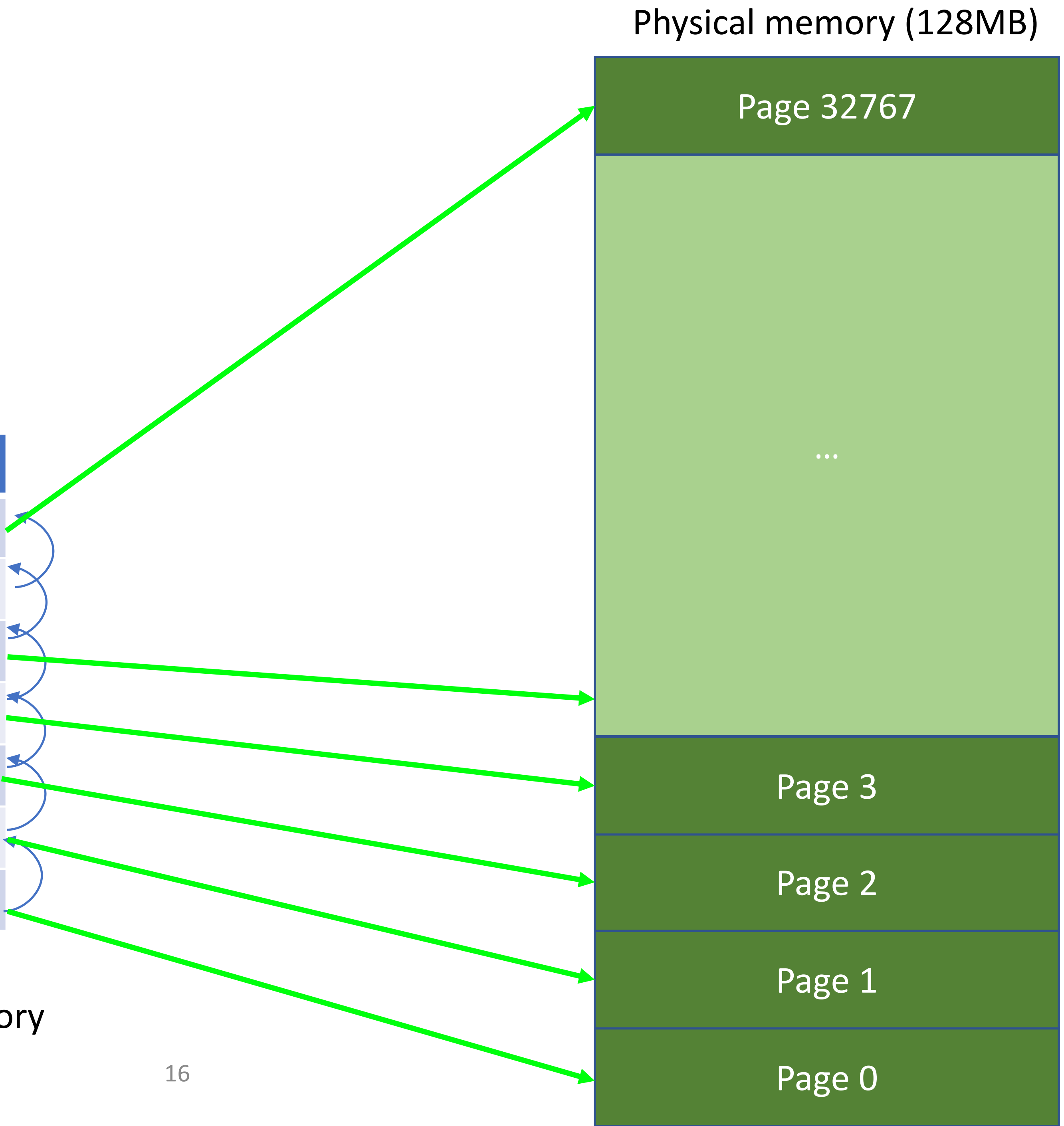
npages

128 * 1048576 / 4096 = 32768 Pages

8 byte per each entry = 32K * 8 = 256KB

Struct PageInfo * pages (array)

idx	pp_ref	pp_link
32K	0	
…	0	
…	0	
3	0	
2	0	
1	0	
0	0	



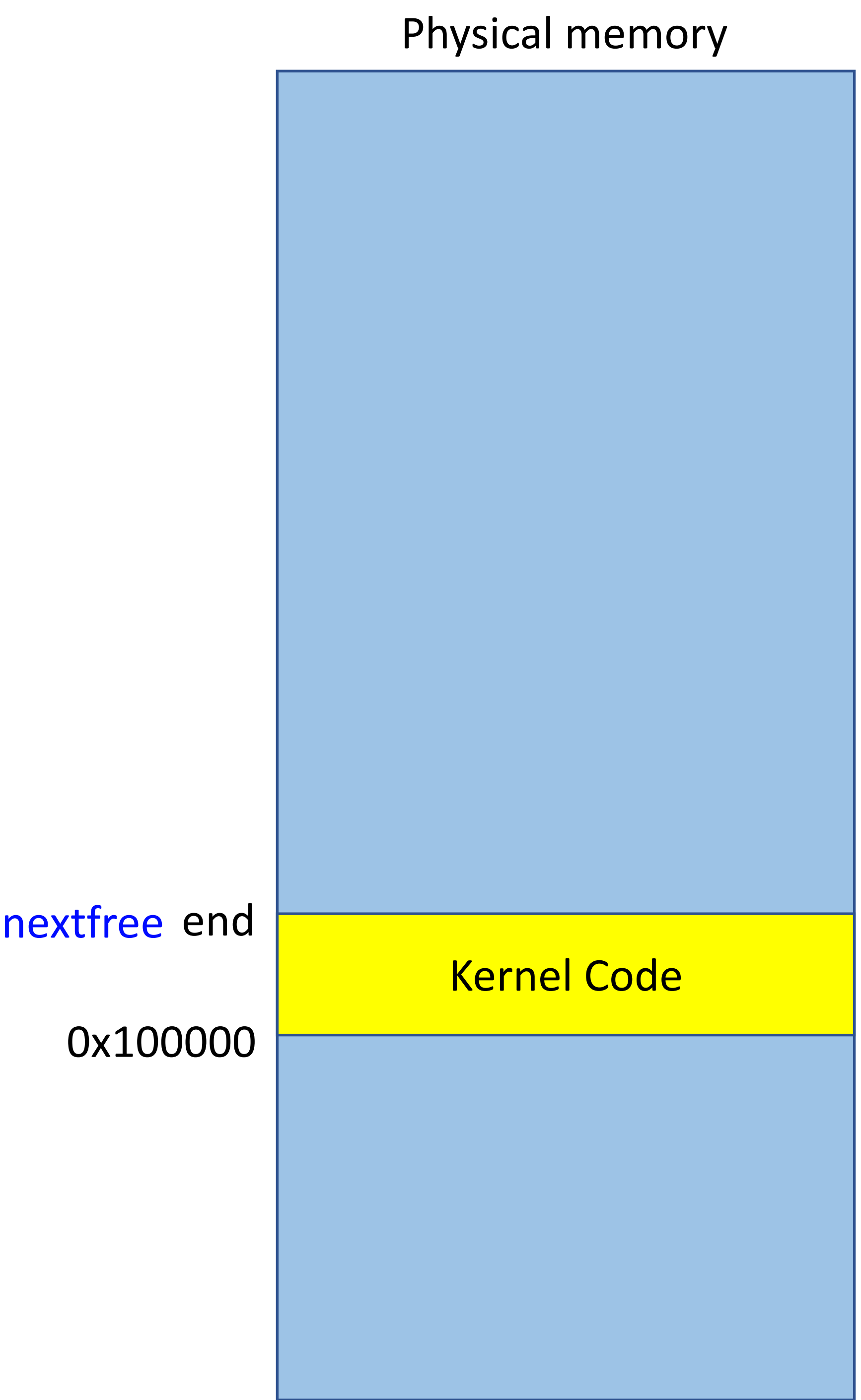
We can put this array into our physical memory

Free Physical Memory (init)

In kern/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);
    }
```



nextfree will point to the end of the kernel code/data

Free Physical Memory (init)

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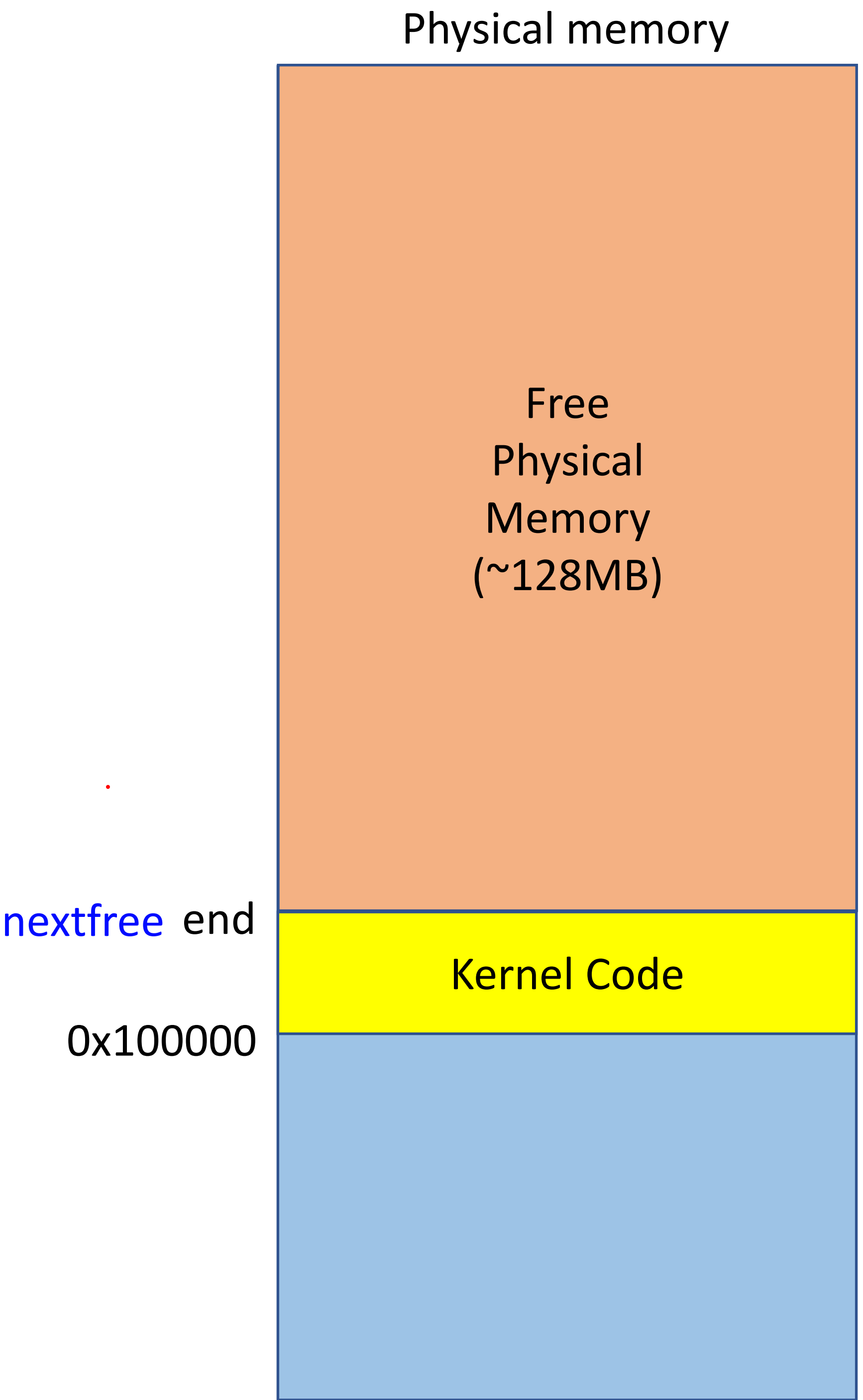

Allocating struct PageInfo

```
// These variables are set in mem_init()
pde_t *kern_pgdir;        // Kernel's initial page directory
struct PageInfo *pages;      // Physical page state array
static struct PageInfo *page_free_list; // Free list of physical pages
```

```
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    uint16_t pp_ref;
};
```

```
pages =
boot_alloc(npages * sizeof(struct PageInfo));
```

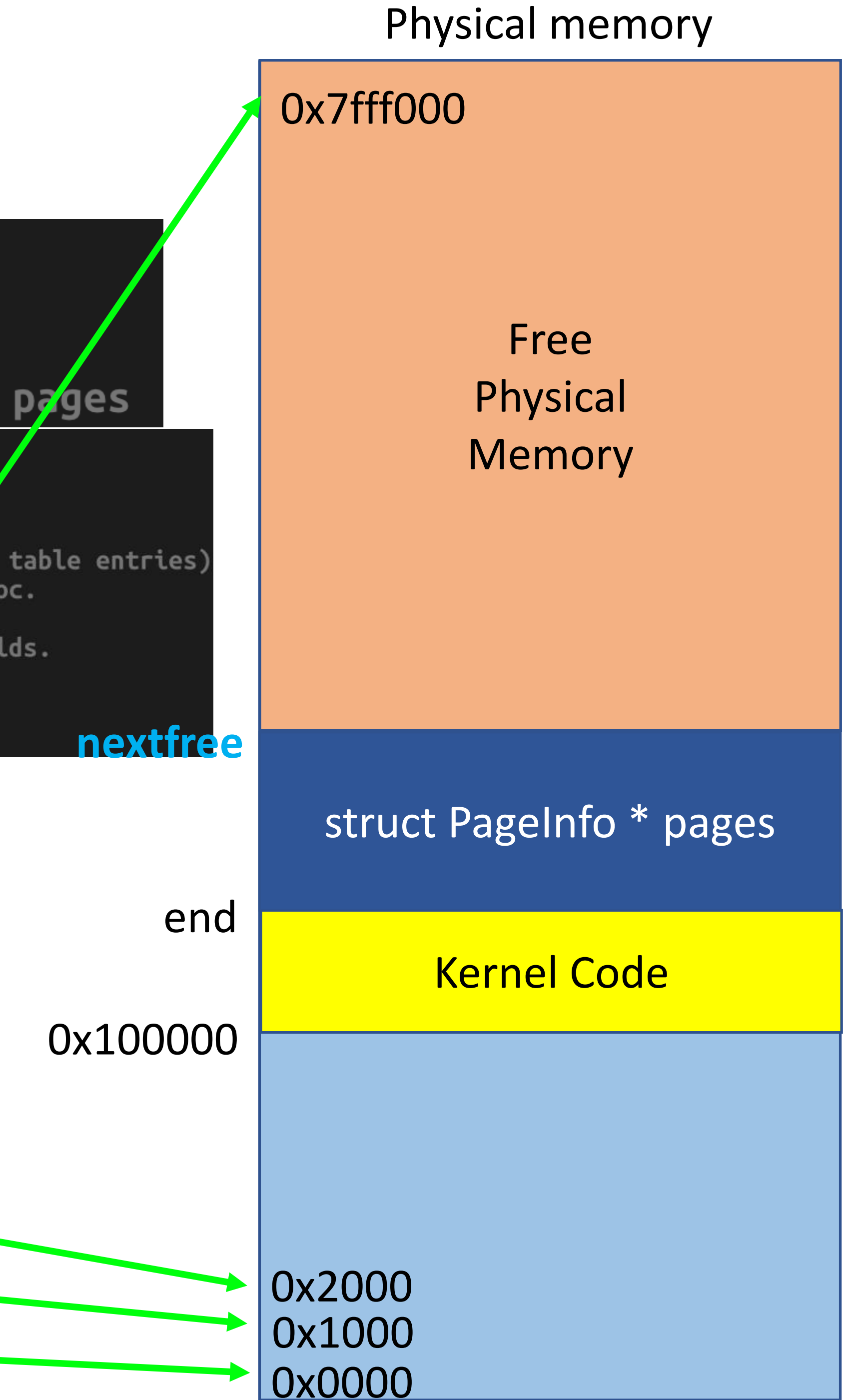
idx	pp_ref	pp_link
N	0	
…	0	
…	0	
3	0	
2	0	
1	0	
0	0	

Physical page N

Physical page 2

Physical page 1

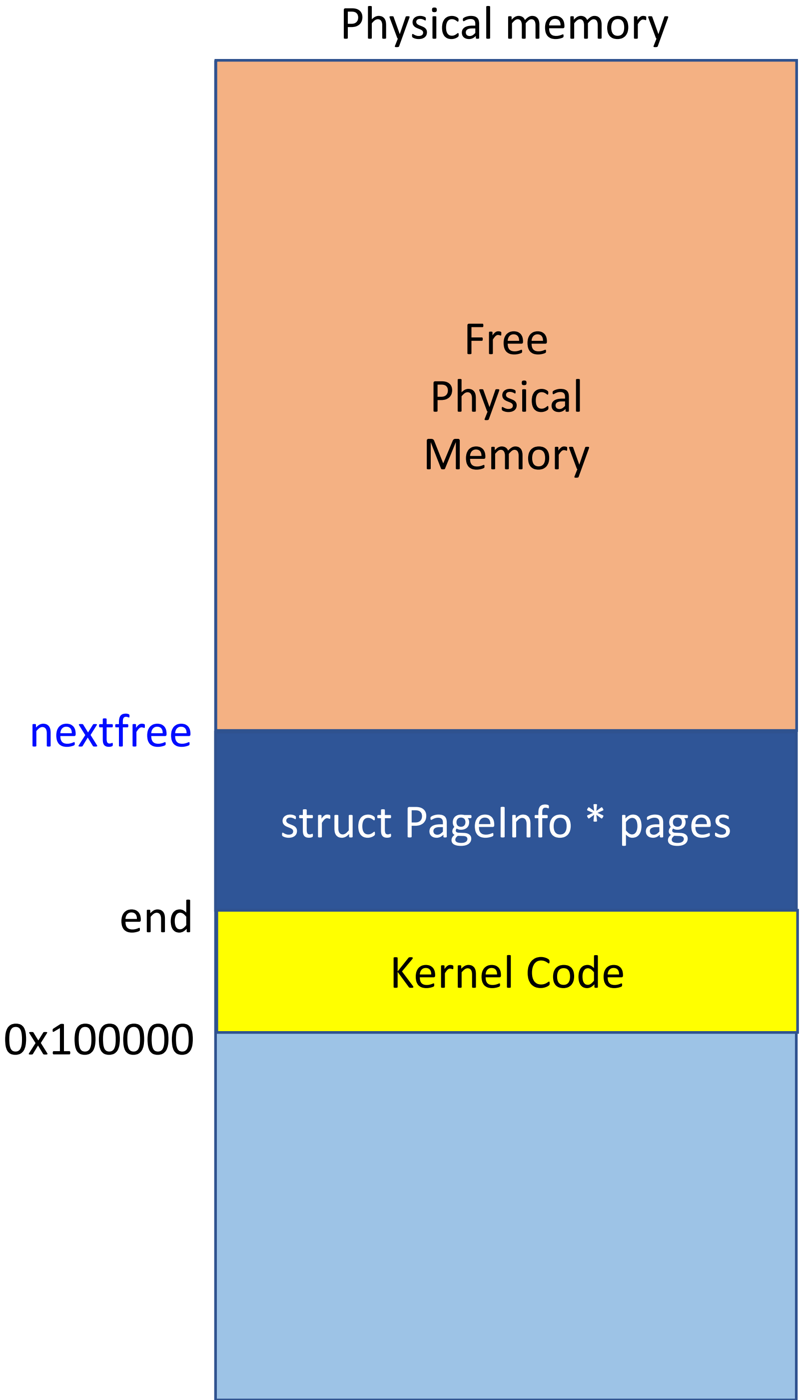
Physical page 0



Where are the free pages?

- in page_init()

```
// 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 [IOPHYSMEM, 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!
```



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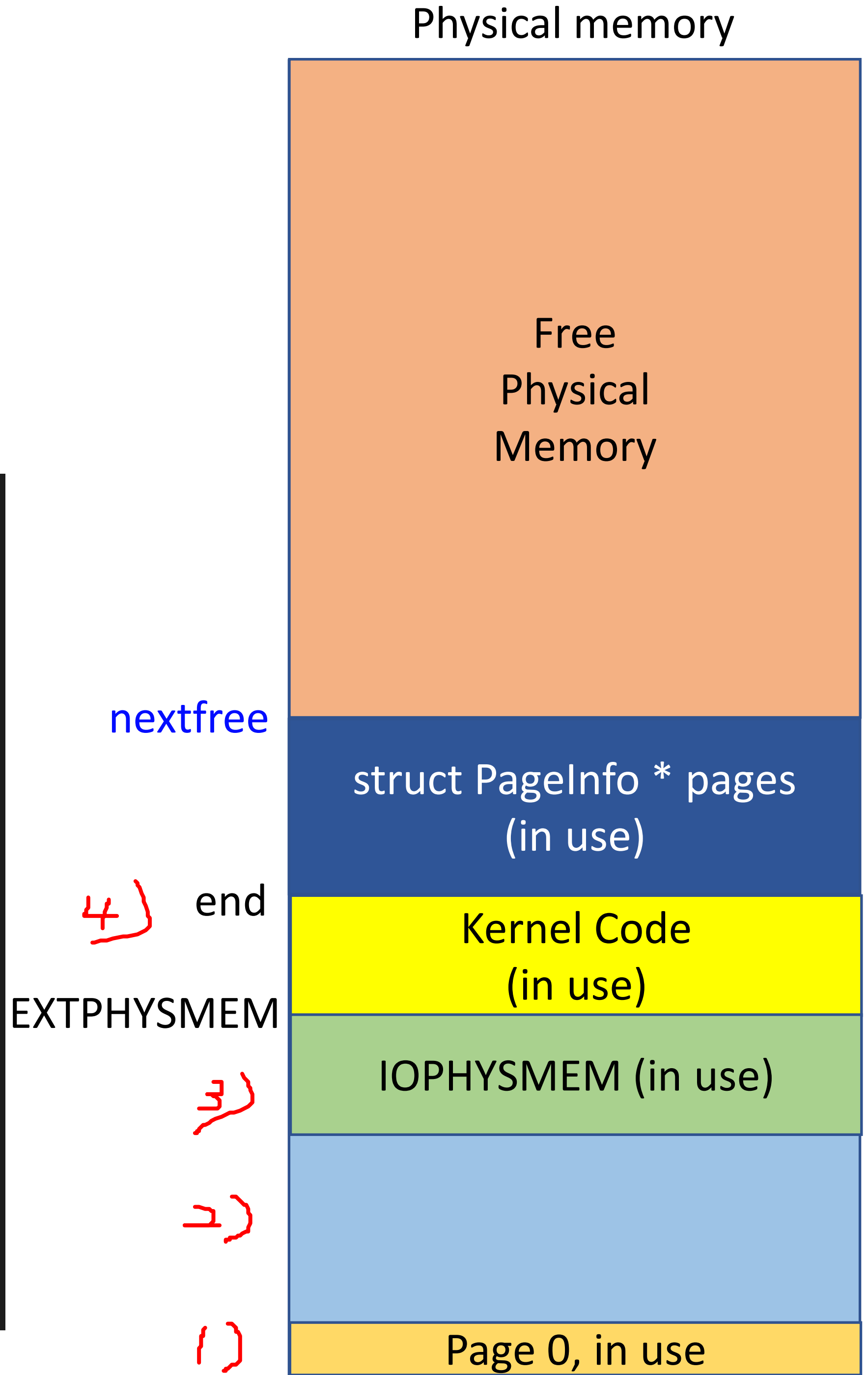
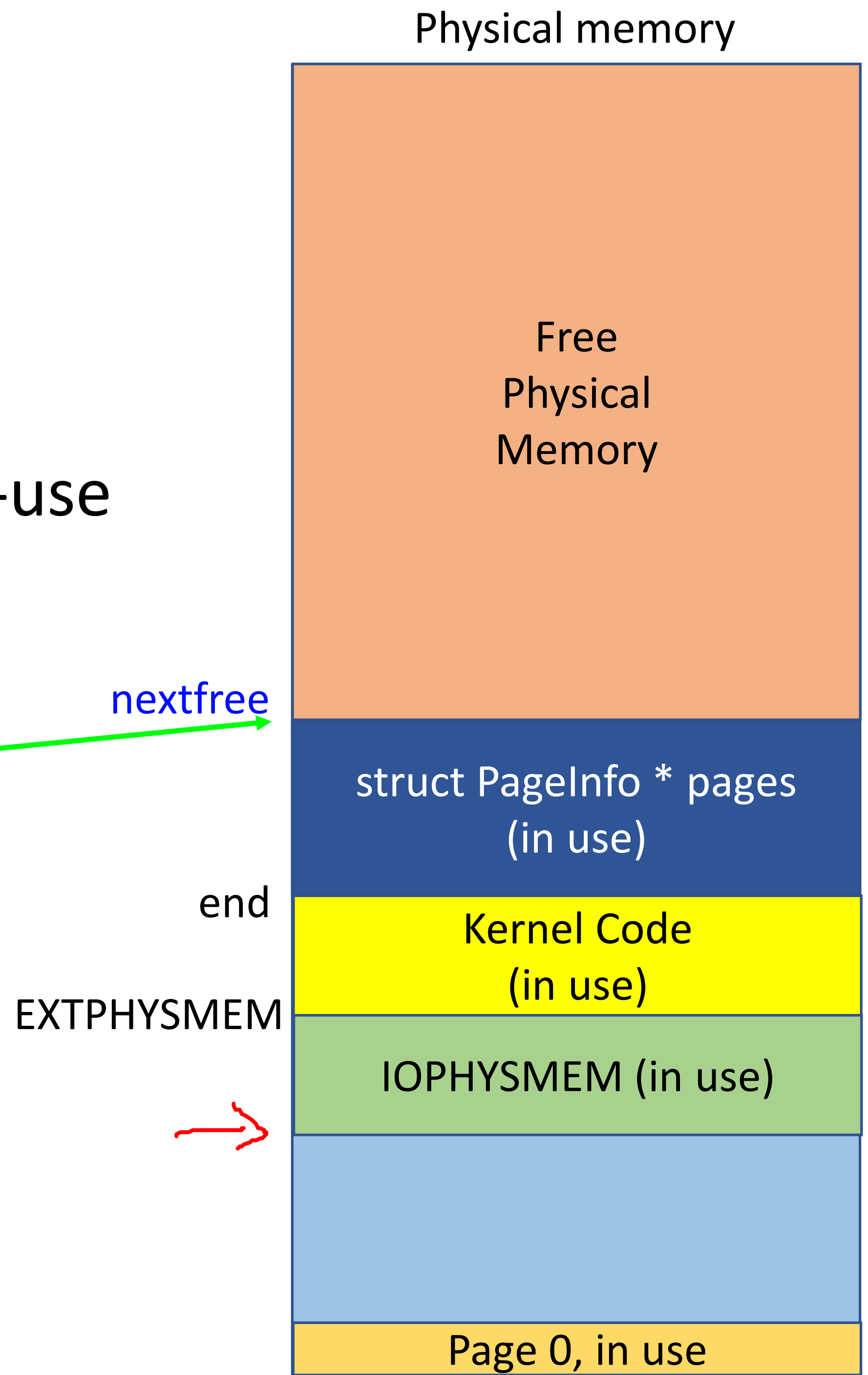


Where are the free pages?

- Page 0 is in-use pages[0].pp_ref = 1
- Pages in [IOPHYSMEM ~ EXTPHYSMEM] are in-use
- Pages for the kernel code are in-use
- Pages for struct PageInfo *pages are in-use
- How can you point this?
  - pages + npages ?
  - boot_alloc(0)?

boot_alloc(0) is better…



Reference Counting

- A typical mechanism for tracking free memory blocks

- Mechanism
  - Count up the value (pp_ref++) if the page is referenced by others (in use!)
  - Count down the value (pp_ref--) if not used for one of usages anymore
  - Free if pp_ref == 0

- In C++, `shared_ptr<T>`
  - When a pointer is assigned to a variable, count up!
  - When the variable no longer uses the variable, count down!
  - Free the memory when the count become 0

Ref. Counting with struct PageInfo

- For in-use memory
  - Set `pp_ref = 1`
- For not-in-use memory
  - Invariant: `pp_ref == 0`
  - Must be linked with pages_free_list
- When assigning the page to a virtual address
  - `pp_ref++`
- When releasing the page from a virtual address
  - `pp_ref--`

Caveat

- Some pages are mapped but does not have to be marked as in-use
- Make sure you do not count up pages for dirmap
  - `0xf0000000 ~ 0xffffffff`
- Read the comment at the top of `boot_map_region` thoroughly

```
// This function is only intended to set up the ``static'' mappings
// above UTOP. As such, it should *not* change the pp_ref field on the
// mapped pages.
//
// Hint: the TA solution uses pgdir_walk
static void
boot_map_region(pde_t *pgdir, uintptr_t va, size_t size, physaddr_t pa, int perm)
```

Linked-list for Free Pages

- Start with NULL at the head
  - `page_free_list = NULL;`
- After set `pp_ref` of all pages, do something like the following..

This will build a linked list...

```
for (int i=0; i < npages; ++i) {
    if (pages[i].pp_ref == 0) {
        pages[i].pp_link = page_free_list;
        page_free_list = &pages[i];
    }
}
```

page2pa(struct PageInfo *pp)

- Changes a pointer to **struct PageInfo** to a physical address
- idx = (pp – pages)
  - Gets the index of pp in pages
  - E.g., &pages[idx] == pp
- idx here is a physical page number

```
struct PageInfo {
    // Next page on the free list.
    struct PageInfo *pp_link;

    // pp_ref is the count of pointers (usually in page table entries)
    // to this page, for pages allocated using page_alloc.
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    uint16_t pp_ref;
};
```

pp →

idx	pp_ref	pp_link
4	0	
3	0	
2	0	
1	0	
0	0	

pages →

```
static inline physaddr_t
page2pa(struct PageInfo *pp)
{
    return (pp - pages) << PGSHIFT;
}
```

pp – pages = 4

0x4000 ← physical page address!

pa2page(physaddr_t pa)

- PGNUM(pa) idx
  - Returns page number
- &pages[PGNUM(pa)] idx
  - Returns struct PageInfo * of that pa..

```
static inline struct PageInfo*
pa2page(physaddr_t pa)
{
    if (PGNUM(pa) >= npages)
        panic("pa2page called with invalid pa");
    return &pages[PGNUM(pa)];
}
```

idx	pp_ref	pp_link
4	0	
3	0	
2	0	
1	0	
0	0	

Quiz 1 (4/22)

- Released via CANVAS
  - Quiz 1 available at 8:00 am
  - Deadline: 4/22 11:59pm
  - Duration: 90 min, but you can finish it around 30 min
- You will have 2 attempts to take quiz (but you CANNOT see the quiz results for those attempts)
- Open material; you may refer to
  - Contents at our Canvas course website
  - Slides
  - Lab document and tutorials
  - Your code for Lab 1 / Lab 2
  - Textbook (not required)

Communicating with others during Quiz is **not allowed**

Quiz 1 (4/22)

- Question type: T/F, multiple choices, less than 15 questions
  - 1 pts per each question
- All three weeks content will be covered in the Quiz 1
  - BIOS/Booting/CPU, Real mode segmentation (Lecture 2)
  - Protected mode segmentation and Paging (Lecture 3)
  - Virtual address translation (Lecture 4)
  - Virtual memory layout (Lecture 5)
  - JOS Memory management (Lecture 6)
  - JOS Lab 1 (Lab Tutorial 1 & 2)
  - First part of JOS Lab 2 (Lab Tutorial 3)

Prep for Quiz 1

- Which one of the following is not a job that JOS Bootloader does?
  - A. Enable protected mode
  - B. Enable paging
  - C. Load kernel image from disk
  - D. Enable A20

Prep for Quiz 1

- Which one of the following is not a job that JOS Bootloader does?
  - A. Enable protected mode
  - B. Enable paging (is done in kenrel, in kern/entry.S)
  - C. Load kernel image from disk
  - D. Enable A20

Prep for Quiz 1

- In the x86 real mode, which address the following segment:offset pair points to?
- 0x8000:0x3131
  - A. 0xb131
  - B. 0x3131
  - C. 0x83131
  - D. 0x103131
  - E. 0x11131

Prep for Quiz 1

- In the x86 real mode, which address the following segment:offset pair points to?
- 0x8000:0x3131
  - A. 0xb131
  - B. 0x3131
  - C. 0x83131 (0x8000 * 16 + 0x3131 = 0x80000 + 0x3131 = 0x83131)
  - D. 0x103131
  - E. 0x11131

Prep for Quiz 1

- Which of the following x86 register stores the current privilege level?
  - A. ds
  - B. eip
  - C. ebp
  - D. esp
  - E. cs

Prep for Quiz 1

- Which of the following x86 register stores the end of the current stack frame (and moves if the CPU runs push/pop) ?
  - A. ds
  - B. eip
  - C. ebp
  - D. esp
  - E. cs

Prep for Quiz 1

- Which of the following x86 register stores the start of the current stack frame (also points to the address that stores previous frame's stack base pointer) ?
  - A. ds
  - B. eip
  - C. ebp
  - D. esp
  - E. cs

Prep for Quiz 1

- What kind of benefit can we enjoy by enabling virtual memory?
- Choose all ~~(no partial credits)~~
  - A. Performs faster execution than when using physical memory
  - B. Suffers less memory fragmentation than when using physical memory
  - C. Provides a better isolation / protection than when using physical memory
  - D. Provides memory transparency
  - E. Enables virtual reality