

SW3004 Operating Systems, Fall 2024

# Project 4. Page Replacement

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# Project plan

- Total 6 projects

- ~~0) Booting xv6 operating system~~

- ~~1) System call~~

- ~~2) CPU scheduling~~

- ~~3) Virtual memory~~

- 4) Page replacement**

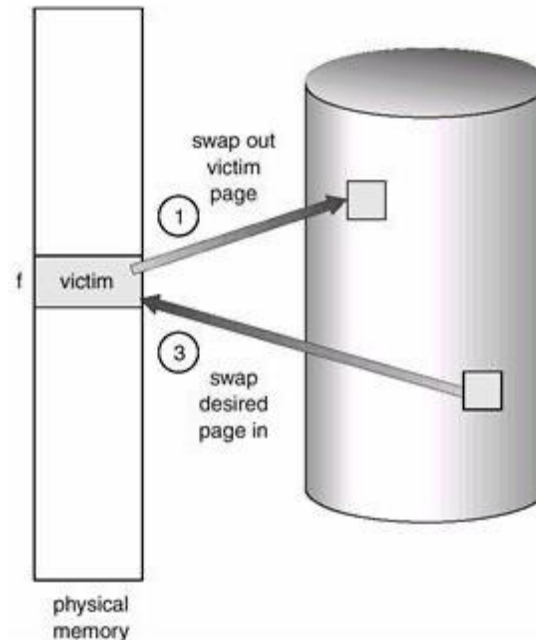
- 5) File systems (optional)

# Project Objective

- Implement page-level swapping
  - Swap-in: move the victim page from backing store to main memory
  - Swap-out: move the victim page from main memory to backing store
- Manage swappable pages with LRU list
  - Page replacement policy: clock algorithm
- Codes you need to create or modify in xv6
  - Swap-in, swap-out operation
  - LRU list management
  - Some extras

# What is Swapping?

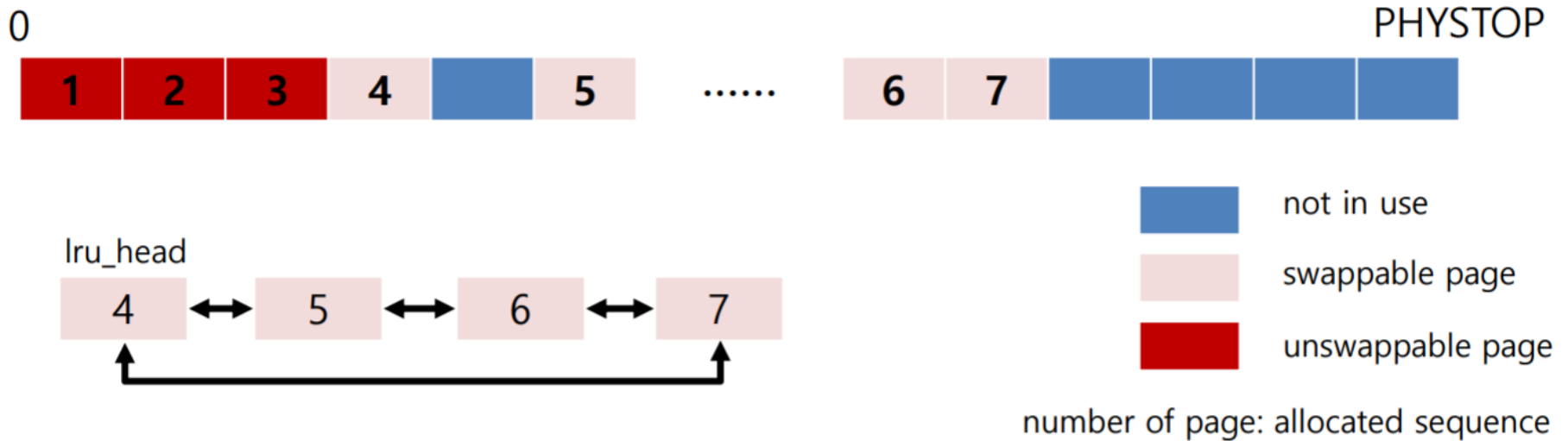
- Support processes when not enough physical memory
  - Can be swapped temporarily out of memory to a backing store
    - Swap pages out of memory to a backing store (swap-out)
    - Swap pages into memory from the backing store (swap-in)



⇒ But, not implemented in xv6!

# Swappable Pages in xv6 (I)

- Only user pages are swappable
  - Some of physical pages should not be swapped out
    - E.g., page table pages
  - So, manage swappable pages with LRU list (circular doubly linked list)
    - When init/alloc/dealloc/copy user virtual memories



# Swappable Pages in xv6 (2)

- Page replacement algorithm: clock algorithm
  - Use A (Accessed) bit in each PTE (PTE\_A : 0x20)
  - From `lru_head`, select a victim page following `next` pointer
    - If `PTE_A==1`, clear it and send the page to the tail of LRU list
    - If `PTE_A==0`, evict the page (victim page)
  - QEMU automatically sets `PTE_A` bit when accessed
- If free page is not obtained through the **`kalloc()`** function, swap-out the victim page

```
char*
kalloc(void)
{
    struct run *r;

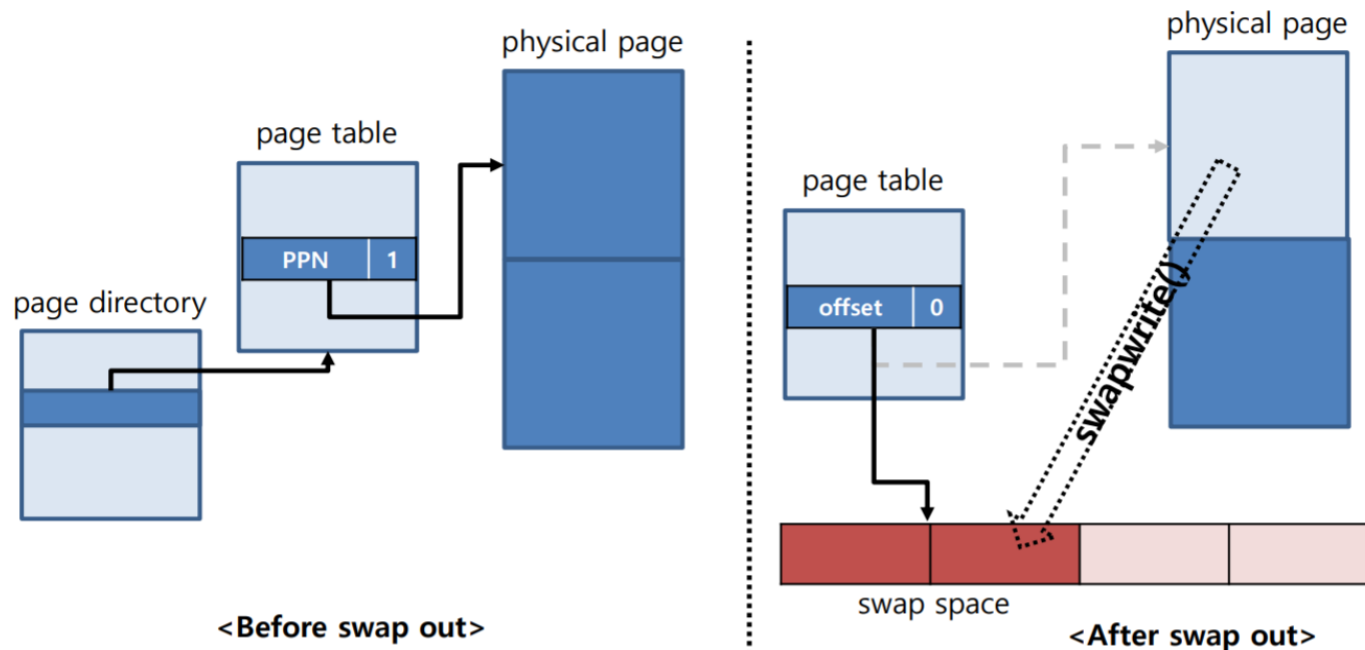
    if(kmem.use_lock)
        acquire(&kmem.lock);
    r = kmem.freelist;
    if(r)
        kmem.freelist = r->next;
    if(kmem.use_lock)
        release(&kmem.lock);
    return (char*)r;
}
```



When freelist is empty: if(!r)  
Do page reclaim

# Swap-out Operation in xv6

1. Use **swapwrite()** function, write the victim page in swap space
  - **swapwrite()** will be provided in skeleton code
2. Victim page's PTE will be set as swap space offset
3. PTE\_P will be cleared



# Swap-in Operation in xv6

- When accessing a page that has been swapped out
  1. Get new physical page
  2. Using **swapread()** function, read from swap space to physical page
    - **swapread()** will be provided in skeleton code
  3. Change PTE value with physical address & set `PTE_P`
    - Tip: do not need to call **mappages()**, because page table had already been allocated

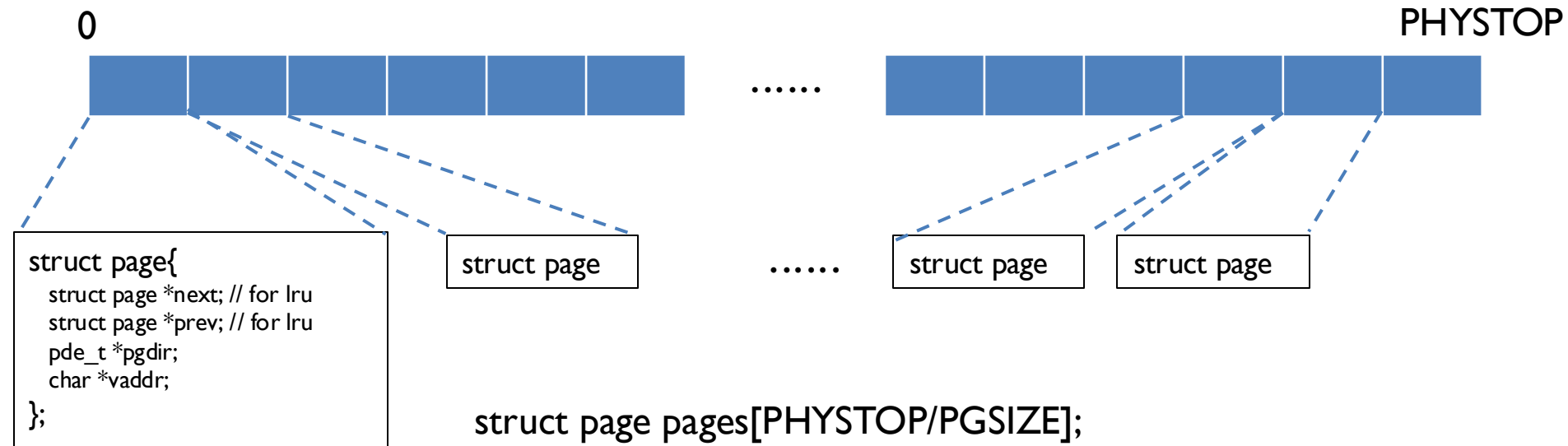


# Several Considerations and Assumptions

- Use 1 physical page for bitmap to track swap space
  - Bit in bitmap is set when page swapped out to swap space
  - Bit in bitmap is cleared when page swapped in
- When user virtual memory is copied
  - Present pages should be copied
  - Swapped-out pages should also be copied
- When user virtual memory is deallocated
  - Present pages should be freed, set PTE bits to 0 and remove them from LRU list
  - Swapped-out pages should be cleared in bitmap and set PTE bits to 0

# Several Considerations and Assumptions

- When swap-out should be occurred and there is no page in LRU list, OOM(Out of memory) error should occur
  - Inside the kalloc function, just `cprintf` error message
  - `kalloc` should return 0 when OOM occurs
- Lock should be considered with shared resource for synchronization
- All pages are managed in a **struct page**
  - Already implemented in skeleton code (`mmu.h`)



# Skeleton Code

- Skeleton code will provide three functions
  - Functions to read/write from/to swap space are provided
    - void **swapread**(char\* **ptr**, int **blkno**)
    - void **swapwrite**(char\* **ptr**, int **blkno**)
  - Function for measuring swap space accesses
    - void **swapstat**(int\* **nr\_sectors\_read**, int\* **nr\_sectors\_write**)
- Kernel bootblock has been expanded to use as swap space

Makefile

```
xv6.img: bootblock kernel  
    dd if=/dev/zero of=xv6.img count=100000
```

param.h

```
#define SWAPBASE 500  
#define SWAPMAX (100000 - SWAPBASE)
```

# How to Test? (I)

- `main()` of `main.c`

```
main(void)
{
    kinit1(end, P2V(4*1024*1024)); // phys p
    kvmalloc(); // kernel page table
    mpinit(); // detect other process
    lapicinit(); // interrupt controller
    seginit(); // segment descriptors
    picinit(); // disable pic
    ioapicinit(); // another interrupt co
    consoleinit(); // console hardware
    uartinit(); // serial port
    pinit(); // process table
    tvinit(); // trap vectors
    binit(); // buffer cache
    fileinit(); // file table
    ideinit(); // disk
    startothers(); // start other process
    kinit2(P2V(4*1024*1024), P2V(PHYSTOP));
    userinit(); // first user process
    mpmain(); // finish this process
}
```

```
void
kinit1(void *vstart, void *vend)
{
    initlock(&kmem.lock, "kmem");
    kmem.use_lock = 0;
    freerange(vstart, vend);
}

void
kinit2(void *vstart, void *vend)
{
    freerange(vstart, vend);
    kmem.use_lock = 1;
}

void
freerange(void *vstart, void *vend)
{
    char *p;
    p = (char*)PGROUNDUP((uint)vstart);
    for(; p + PGSIZE <= (char*)vend; p += PGSIZE)
        kfree(p);
}
```

- When `xv6` is started, the `kinit1` and `kinit2` functions are called
  - The call to `kinit1` sets up for lockless allocation in the first 4 megabytes
  - And the call to `kinit2` enables locking and arranges for more memory to be allocatable

# How to Test? (2)

There are too many free pages in the beginning, you need to reduce the `PHYSTOP` to reduce free pages

1. Choose one of the followings to consume memory
  1. Create many processes (**`fork()`**)
  2. User command **`ls`**
  3. **`sbrk()`** system call
2. Choose one of the followings to monitor swap
  1. **`swapstat()`**
  2. Monitor LRU list length & swap in/out operations

Using above methods, test your own code

# Submission

- Begin with skeleton code (not with the prev. project)
  - `$ cp ~swe3004/pa4_skl_t_xv6.tar.gz ~/`
  - `$ tar -xzf ~/pa4_skl_t_xv6.tar.gz`
- Use the ***submit*** & ***check-submission*** binary file in Ui Server
  - `$ ~swe3004/bin/submit pa4 xv6-public`
  - You can submit several times, and the submission history can be checked through check-submission
    - Only the last submission will be graded

# Submission

- PLEASE DO NOT COPY
  - We will run inspection program on all the submissions
  - Any unannounced penalty can be given to **both students**
    - 0 points / negative points / F grade ...
- Due date: 11/27(Wed.), 23:59:59 PM
  - -25% per day for delayed submission

# Questions

- If you have questions, please ask on i-campus
  - Please use the discussion board
  - We don't reply i-campus messages
- You can also visit Corporate Collaboration Center #85533
  - Please e-mail TA before visiting
- Reading xv6 commentary will help you a lot
  - <http://csl.skku.edu/uploads/SSE3044S20/book-rev11.pdf>