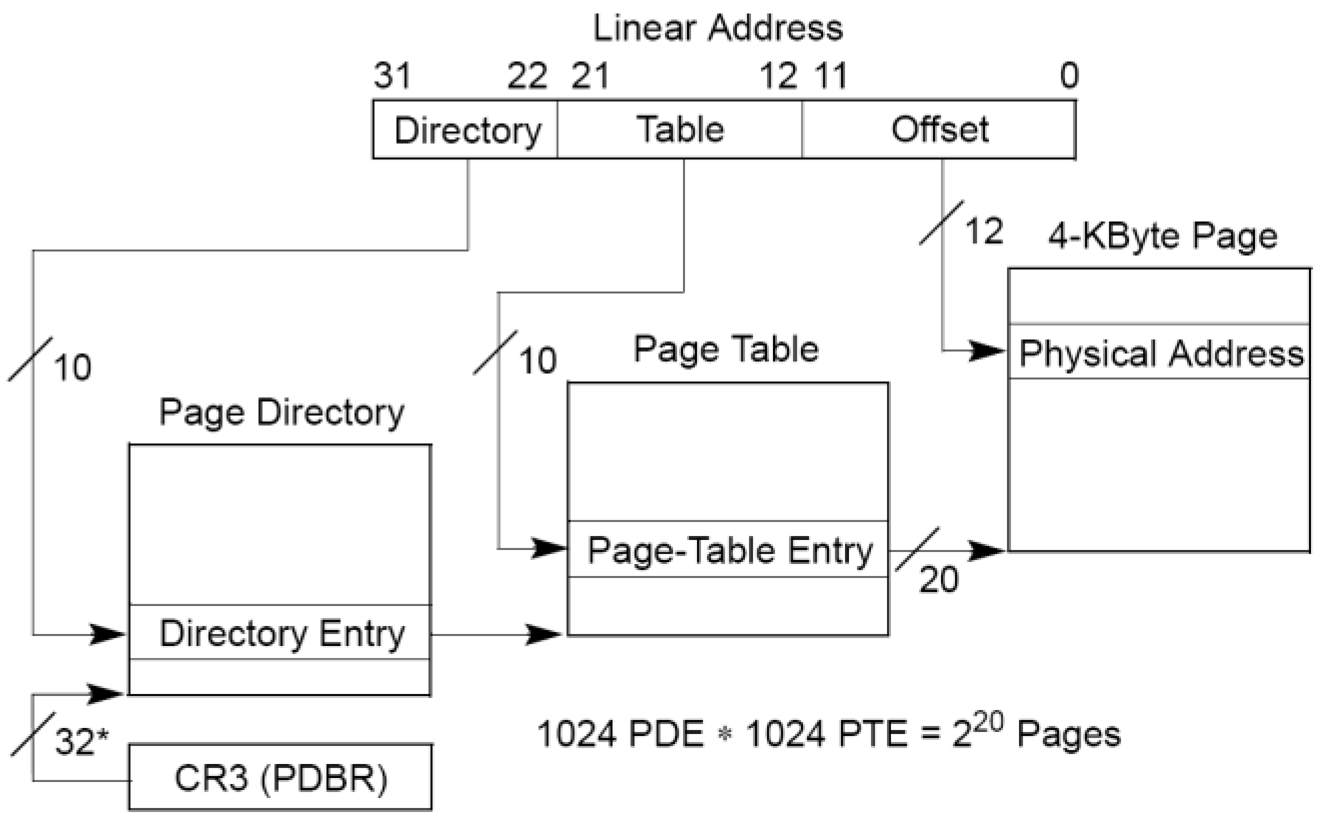
LAB3: VIRTUAL MEMORY

Operating Systems 2015 Spring by Euiseong Seo

Background: Paging (1)

- Paging in the x86 architecture



*32 bits aligned onto a 4-KByte boundary.

Background: Paging (2)

- Current Pintos VM implementation
  - Use paging
  - Page size: 4KB
  - Each process has its own page tables
    - The page directory is allocated when the process is created (pagedir_create() @ userprog/pagedir.c)
    - (struct thread *) t->pagedir points to the page directory (load() @ userprog/process.c)
    - The (secondary) page tables are dynamically created if necessary (lookup_page() @ userprog/pagedir.c)
    - For kernel region, processes have the same mapping (PHYS_BASE ~ 0xffffffff)

Background: Paging (3)

- Current Pintos VM implementation (cont'd)
  - No demand paging
    - When a process is created, all the contents of code and data segments are read into the physical memory (load_segment() @ userprog/process.c)
  - Fixed stack size
    - Only one stack page is allocated to each process (setup_stack() @ userprog/process.c)

Project 3 Overview

- Requirements
  - Lazy loading (or demand paging)
  - Swapping in/out pages from/to swap disk
  - Dynamic stack growth
  - Memory mapped files

Lazy Loading (1)

- Why?
  - An executable file holds code and data images
  - A process will not need all the pages immediately
- How to?
  - Use the executable file as the backing store
    - Only when a page is needed at run time, load the corresponding code/data page into the physical memory
    - Loaded pages will have valid PTEs
  - Handling page faults
    - Accesses to not-yet-loaded pages will cause page faults
    - Find the corresponding location in the executable file
    - Read in the page from the executable file
    - Setup the corresponding PTE

Lazy Loading (2)

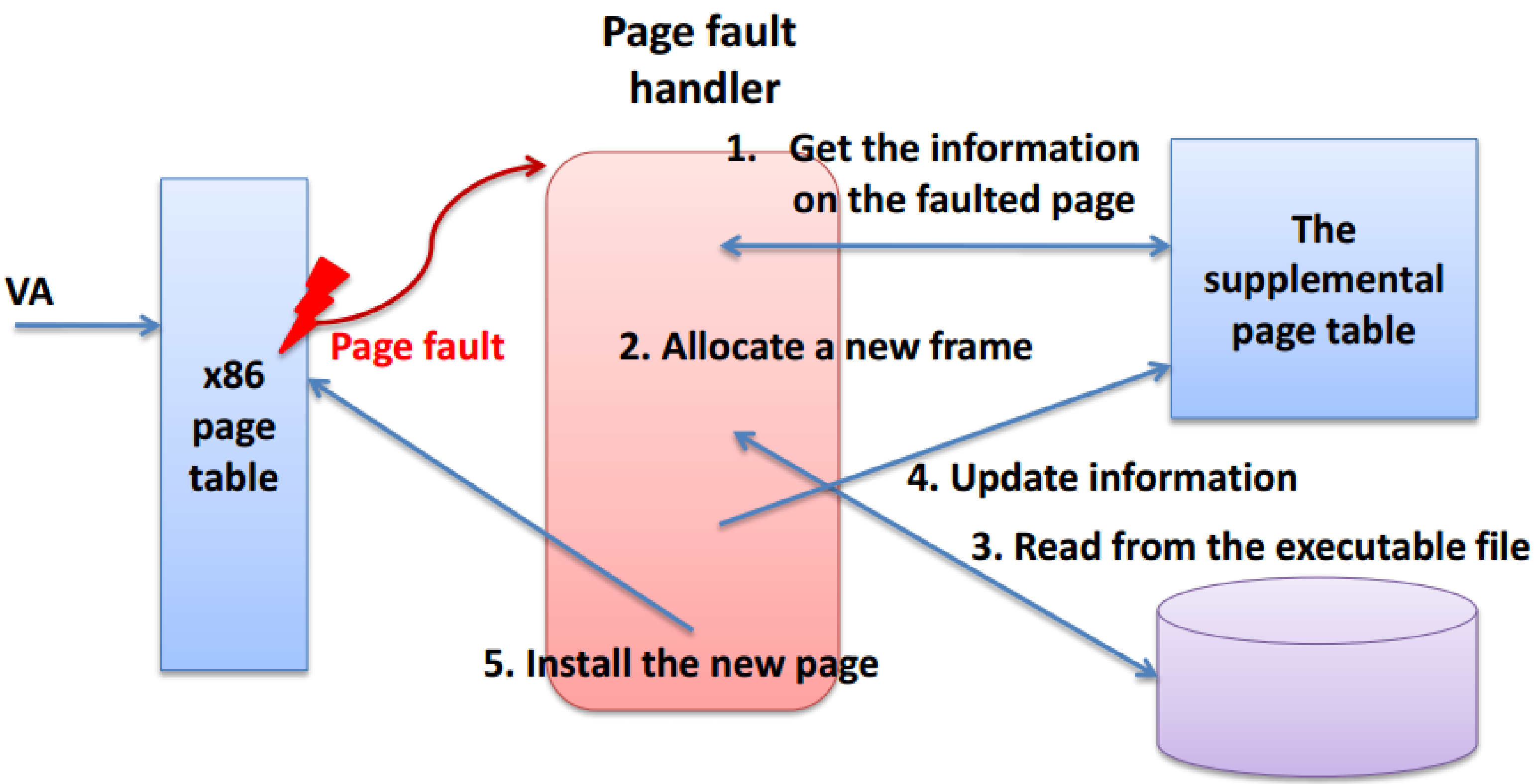
- Loading code/data from the executable file
  - In load_segment() @ userprog/process.c
  - Each page is filled with data using "page_zero_bytes" and "page_read_bytes"
    - page_zero_bytes + page_read_bytes = PGSIZE
  - All zeroed page (page_zero_bytes == PGSIZE)
    - Allocate a new page and initialize it with zeroes
  - Full code/data page (page_read_bytes == PGSIZE)
    - Allocate a new page and read its contents from the executable file
  - Partial page (0 < page_read_bytes < PGSIZE)
    - Read page_read_bytes from the executable file and fill the rest of the page with zeroes

Lazy Loading (3)

- The supplemental page table
  - The page table with additional data about each page
  - Main purposes
    - On a page fault, find out what data should be there for the faulted virtual page
    - On a process termination, decide what resources to free
  - Possible organizations
    - Per-segment
    - Per-page
  - Implementation
    - You can use any data structure for the supplemental page table
    - <hash.h> will be useful (lib/kernel/hash.[ch])

Lazy Loading (4)

- Flows



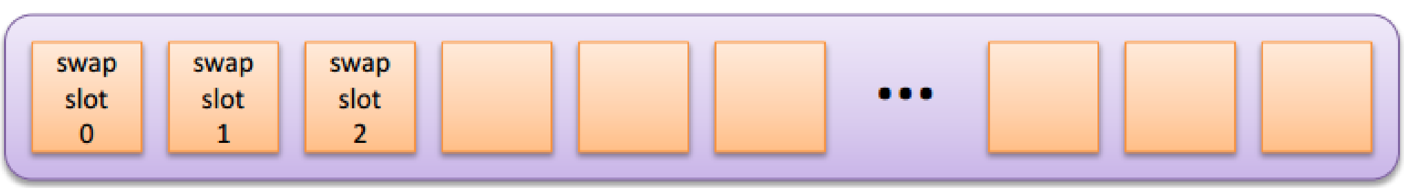
Swapping (1)

- Why?
  - You may run out of the physical memory
  - Your program's memory footprint can be larger than the physical memory size
- How to?
  - Find a victim page in the physical memory
  - Swap out the victim page to the swap disk
  - Extend your supplemental page table to indicate the victim page has been swapped out
  - When the page is accessed later, swap in the page from the swap disk to the physical memory

Swapping (2)

- Swap disk
  - Use the following command to create an 4 MB swap disk in the vm/build directory

    $ pintos-mkdisk swap.dsk 4
  - Alternatively, you can tell Pintos to use a temporary 4-MB swap disk for a single run with --swap-size=4
    - Used during "make check"
  - A swap disk consists of swap slots
    - A swap slot is a continuous, page-size region of disk space on the swap disk



Swapping (3)

- Accessing swap disk
  - Use the disk interface in devices/block.h
    - A size of a disk sector is 512 bytes
    - You can read or write one sector at a time

```
struct block *block_get_role (enum block_type);
block_sector_t block_size (struct block *);
void block_read (struct block *, block_sector_t, void *);
void block_write (struct block *, block_sector_t,
                const void *);
```

Swapping (4)

- Managing swap slots
  - Pick an unused swap slot for evicting a page from its from to the swap disk
  - Free a swap slot when its page is read back or the process is terminated
  - Allocate lazily, i.e., only when they are actually required by eviction
- The swap table
  - The swap table tracks in-use and free swap slots
  - <bitmap.h> will be useful (lib/kernel/bitmap.[ch])

Swapping (5)

- Page replacement policy
- You should implement a global page replacement algorithm that approximates LRU
  - Do not use FIFO or RANDOM
  - The “second chance” or “clock” algorithm is OK
  - Bonus if you implement your own page replacement policy better than the “second chance” algorithm
  - Get/Clear Accessed and Dirty bits in the PTE
    - pagedir_is_dirty(), pagedir_set_dirty()
    - pagedir_is_accessed(), pagedir_set_accessed()
  - Other processes should be able to run while you are performing I/O due to page faults
    - Some synchronization effort will be required

Swapping (6)

- The frame table
  - Allows efficient implementation of eviction policy
  - One entry for each frame that contains a user page
    - Each entry contains a pointer to the page, if any, that currently occupies it, and other data of your choice
  - Use the frame table while you choose a victim page to evict when no frames are free
  - Code pages can be shared among those processes created from the same executable file (optional)

Swapping (7)

- User pool vs. kernel pool
  - The physical memory is divided into the user pool and the kernel pool
    - Running out of pages in the user pool just causes user programs to page
    - Running out of pages in the kernel pool means a disaster
    - The size of the user pool can be limited (–ul option)
  - The frames used for user pages should be obtained from the “user pool”
    - By calling palloc_get_page (PAL_USER)

Swapping (8)

- Frame allocation
  - On top of the current page allocator (threads/palloc.c)
    - palloc_get_page(), palloc_free_page()
  - If there are free frames in the user pool, allocate one by calling palloc_get_page()
  - If none is free
    - Choose a victim page using your page replacement policy
    - Remove references to the frame from any page table that refers to it
    - If the frame is modified, write the page to the file system or to the swap disk
    - Return the frame

Stack Growth (1)

- Growing the stack segment
  - Allocate additional pages as necessary
  - Devise a heuristic that attempts to distinguish stack accesses from other accesses
    - Bug if a program writes to the stack below the stack pointer
    - However, in x86, it is possible to fault 4 ~ 32 bytes below the stack pointer
  - You may impose some absolute limit on stack size
  - The first stack page need not be allocated lazily
    - The page is initialized with the command line arguments
  - All stack pages should be candidates for eviction
    - An evicted stack page should be written to swap

Stack Growth (2)

- How to obtain the user stack pointer?
  - You need the current value of the user program's stack pointer on page fault
    - Compare it with the faulted address
  - When the page fault occurred in the user mode
    - Use (struct intr_frame *) f->esp
  - When the page fault occurred in the kernel mode
    - struct intr_frame is not saved by the processor
    - (struct intr_frame *) f->esp yields an undefined value
    - Save esp into struct thread on the initial transition from user to kernel mode

Memory Mapped Files (1)

- Example
  - Writes the contents of a file to the console

```
#include <stdio.h>
#include <syscall.h>
int main (int argc, char *argv[])
{
    void *data = (void *) 0x10000000;

    int fd = open (argv[1]);
    mapid_t map = mmap (fd, data);
    write (1, data, filesize(fd));
    munmap (map);
    return 0;
}
```

Memory Mapped Files (2)

- System calls to implement

```
mapid_t mmap (int fd, void *addr);
void munmap (mapid_t mapping);
```

  - mmap() fails if
    - fd is 0 or 1
    - The file has a length of zero bytes
    - addr is 0
    - addr is not page-aligned
    - The range of pages mapped overlaps any exisitng set of mapped pages
  - All mappings are implicitly unmapped when a process exits

Memory Mapped Files (3)

- Managing mapped files
  - Lazily load pages in mmap regions
    - For the final mapped page, set the bytes beyond the end of the file to zero
  - Use the mmap'd file itself as backing store for mapping
    - All pages written to by the process are written back to the file
  - Closing or removing a file does not unmap any of its mappings
    - Once created, a mapping is valid until munmap() is called or the process exits

Summary (1)

- Pages
  - Code page (clean)
  - Data page (clean/dirty)
  - Stack page (dirty)
  - mmaped page (clean/dirty)

Summary (2)

- When you attach a new frame,
  - It may be just initialized to zero
  - It may be read from a file
  - It may be read from a swap slot
- When you evict a frame,
  - It may be just dropped
  - It may be swapped out to a swap slot
  - It may be written to a file

Tips (1)

- Suggested order of implementation
  - Lazy loading
    - Modify load_segment() and page_fault()
    - Construct the supplemental page table
    - You should be able to run all user programs of Project 2
  - Frame allocation/deallocation layer
    - Add a new interface that can allocate or free a frame
    - Construct the frame table as you allocate a new frame
    - Assume there is enough physical memory
      - No eviction is necessary
    - You should be able to run all user programs of Project 2

Tips (2)

- Suggested order of implementation (cont'd)
  - Page replacement policy
    - Develop your own page replacement policy
    - Need to interact with the supplemental page table and the frame table
    - First, try to evict read-only pages and make sure it has no problem
    - And then, implement the swap table and test your code to access the swap disk
    - Finally, implement the full-fledged page replacement policy
  - Stack growth
    - Extend your page fault handler
  - Memory mapped files

Tips (3)

- No files in the vm directory
  - You should add your files in the directory
  - The Pintos documentation says…

```
vm/frame.c             |  162 +++++++++
vm/frame.h             |   23 +
vm/page.c              |  297 ++++++++++++++++
vm/page.h              |   50 ++
vm/swap.c              |   85 ++++
vm/swap.h              |   11
```

Tips (4)

- Adding your own source files (src/Makefile.build)

jminlee@jminlee-desktop: ~/OS_project/pintos/src

```
lib/kernel_SRC += lib/kernel/console.c  # printf(), putchar().

# User process code.
userprog_SRC  = userprog/process.c  # Process loading.
userprog_SRC += userprog/pagedir.c  # Page directories.
userprog_SRC += userprog/exception.c    # User exception handler.
userprog_SRC += userprog/syscall.c  # System call handler.
userprog_SRC += userprog/gdt.c      # GDT initialization.
userprog_SRC += userprog/tss.c      # TSS management.

# No virtual memory code yet.
#vm_SRC = vm/file.c         # Some file.
vm_SRC += vm/page.c
vm_SRC += vm/frame.c
vm_SRC += vm/swap.c

# Filesystem code.
filesys_SRC  = filesys/filesys.c    # Filesystem core.
filesys_SRC += filesys/free-map.c   # Free sector bitmap.
filesys_SRC += filesys/file.c       # Files.
filesys_SRC += filesys/directory.c  # Directories.
filesys_SRC += filesys/inode.c      # File headers.
filesys_SRC += filesys/fsutil.c     # Utilities.
-- 끼워넣기 --                                      68,20          59%
```

Submission

- Due
  - June 9, 11:59PM
  - Fill out the design document and save it with PDF format (GDHong_2012345678.pdf)
    - NO .doc or .hwp
  - Tar and gzip your Pintos source codes

    ```
    $ tar cvzf GDHong_2012345678.tar.gz src
    ```

    - **You must tar *src* folder (NOT PINTOS)**
  - This is your final project. Good luck! ☺

Q & A