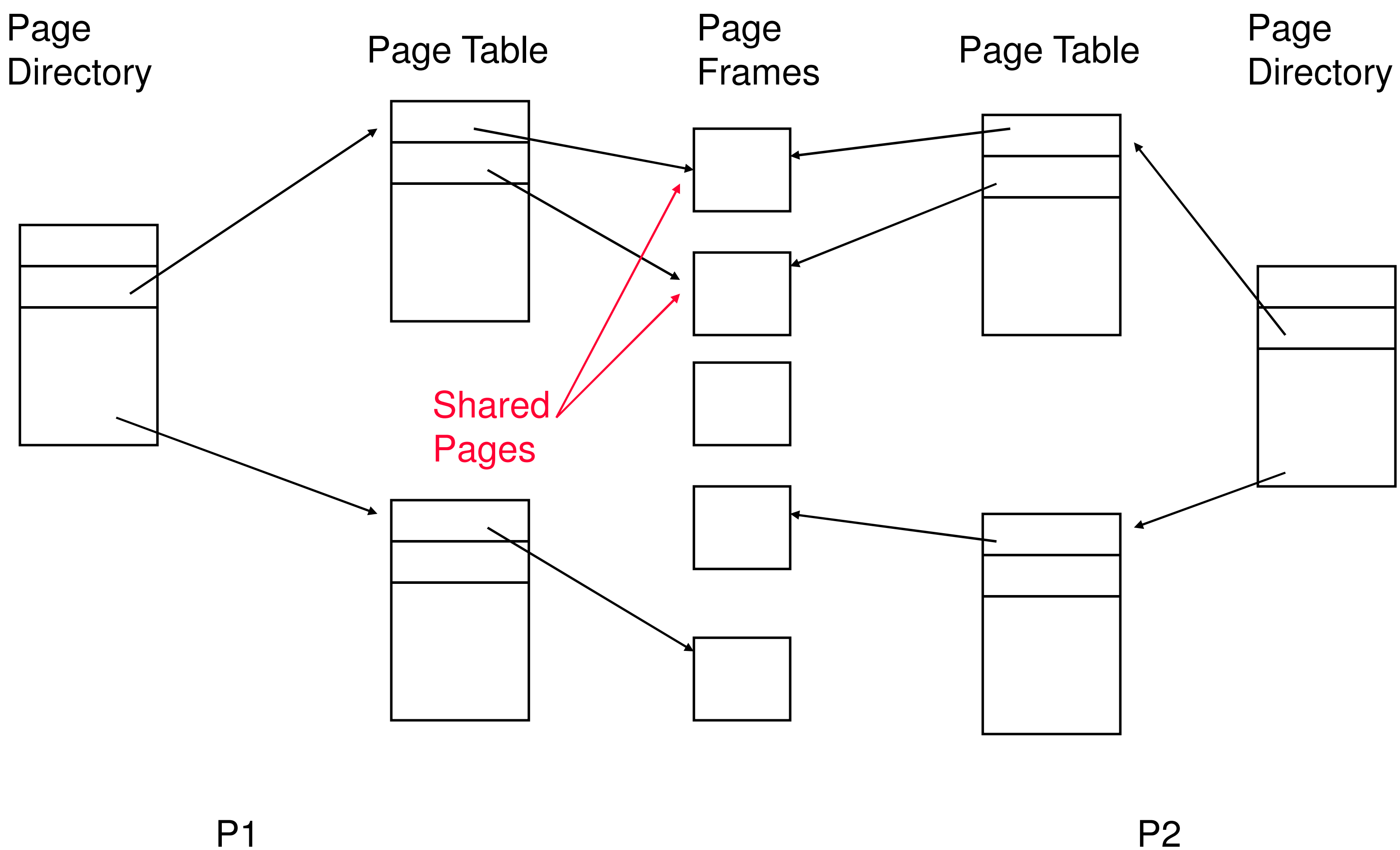
Announcements

- Reading
  - 8.6-8.8, 9.1-9.4
- Midterm #1
  - Thursday
- Project #3
  - Is Due March 22th

Sharing Memory

- Pages can be shared
  - several processes may share the same code or data
  - several pages can be associated with the same page frame
  - given read-only data, sharing is always safe
- when writes occur, decide if processes share data
  - operating systems often implement "copy on write" - pages are shared until a process carries out a write
    - when a shared page is written, a new page frame is allocated
    - writing process owns the modified page
    - all other sharing processes own the original page
  - page could be shared
    - processes use semaphores or other means to coordinate access

Page Sharing



Inverted Page Tables

- Solution to the page table size problem
- One entry per page frame of physical memory

  <process-id, page-number>

  – each entry lists process associated with the page and the page number
  – when a memory reference:
    - **<process-id,page-number,offset>**occurs, the inverted page table is searched (usually with the help of a hashing mechanism)
    - if a match is found in entry ***i*** in the inverted page table, the physical address **<i,offset>** is generated
  – The inverted page table does not store information about pages that are not in memory
    - page tables are used to maintain this information
    - page table need only be consulted when a page is brought in from disk

What Happens when a virtual address has no physical address?

- called a *page fault*
  - a trap into the operating system from the hardware
- caused by: the first use of a page
  - called *demand paging*
  - the operating system allocates a physical page and the process continues
  - read code from disk or init data page to zero
- caused by: a reference to an address that is not valid
  - program is terminated with a "segmentation violation"
- caused by: a page that is currently on disk
  - read page from disk and load it into a physical page, and continue the program
- causde by: a copy on write page

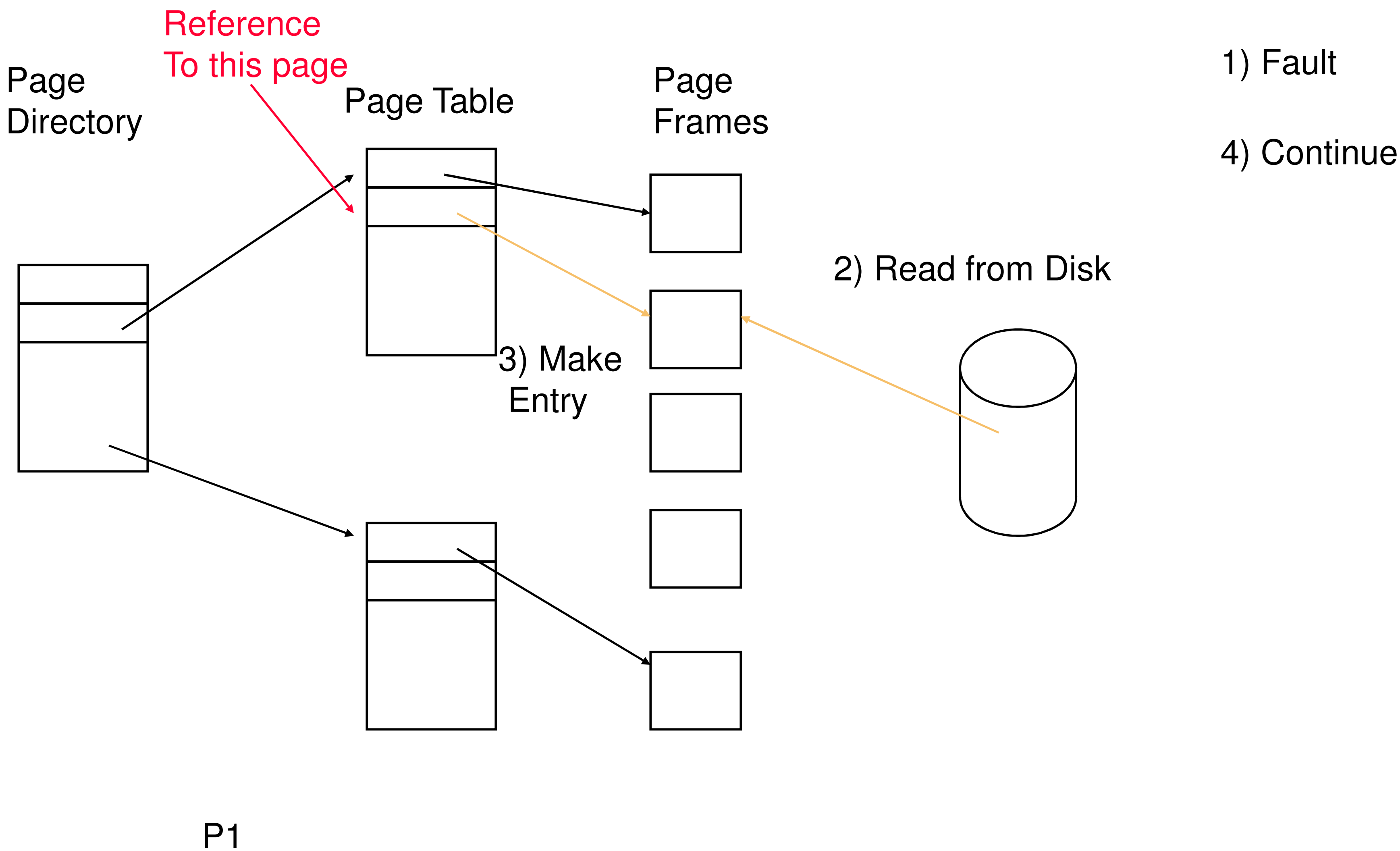
OS Protection attributes (Win32)

- NOACCESS: attempts to read, write or execute will cause an access violation
- READONLY: attempts to write or execute memory in this region cause an access violation
- READWRITE: attempts to execute memory in this region cause an access violation
- EXECUTE: Attempts to read or write memory in this region cause an access violation
- EXECUTE_READ: Attempts to write to memory in this region cause an access violation
- EXECUTE_READ_WRITE: Do anything to this page
- WRITE_COPY: Attempts to write will cause the system to give a process its own copy of the page. Attempts to execute cause access violation
- EXECUTE_WRITE_COPY: Attempts to write will cause the system to give a process its own copy of a page. Can't cause an access violation

Handling a page fault

1) Check if the reference is valid
   - if not, terminate the process
2) Find a page frame to allocate for the new process
   - for now we assume there is a free page frame.
3) Schedule a read operation to load the page from disk
   - we can run other processes while waiting for this to complete
4) Modify the page table entry to the page
5) Restart the faulting instruction
   - hardware normally will abort the instruction so we just return from the trap to the correct location.

Page Fault – Page is Paged out



Page State (hardware view)

- Page frame number (location in memory or on disk)
- *Valid Bit*
  - indicates if a page is present in memory or stored on disk
- A *modify* or *dirty* bit
  - set by hardware on write to a page
  - indicates whether the contents of a page have been modified since the page was last loaded into main memory
  - if a page has not been modified, the page does not have to be written to disk before the page frame can be reused
- *Reference bit*
  - set by the hardware on read/write
  - cleared by OS
  - can be used to approximate LRU page replacement
- Protection attributes
  - read, write, execute

What happens when we fault and there are no more physical pages?

- Need to remove a page from main memory
  - if it is “dirty” we must store it to disk first.
    - dirty pages have been modified since they were last stored on disk.
- How to we pick a page?
  - Need to choose an appropriate algorithm
    - should it be global?
    - should it be local (one owned by the faulting process)