Announcements

- Reading 8.7, 9.1-9.4
- Suggested problems
  - 8.10, 8.12, 8.17
- Midterm #1 was returned

Midterm Results

	1	*2*	*3*	*4*	*5*	*6*	*Total*
Avg	12	6	12	9	9	4	51.4
Min	5	0	0	0	0	0	15
Max	15	12	20	22	15	15	88
S.D.							17.3

- Charles will go over the questions in section on Wed.
- Notes:
  - will see synchronization again
    - maybe next midterm, for sure on the final
    - understand: Critical Section, Deadlock, Starvation
  - don't think your project grade will improve your overall grade
  - in addition to reading material, do the problems!
- Appeal Process
  - 24 hour cooling off period
  - reserve right to regrade your entire midterm

Inverted Page Tables

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

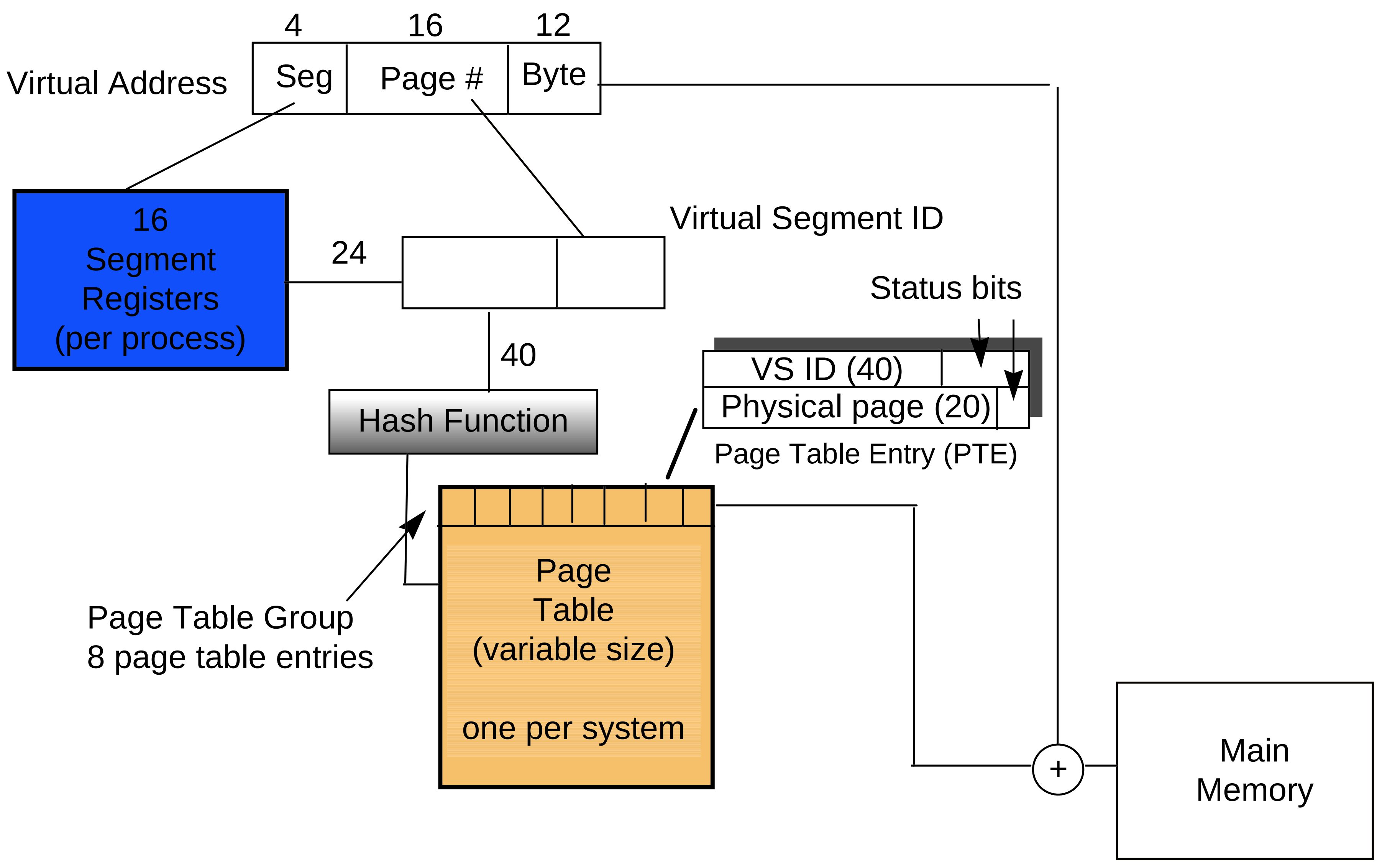
  <process-id, page-number>

  – 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

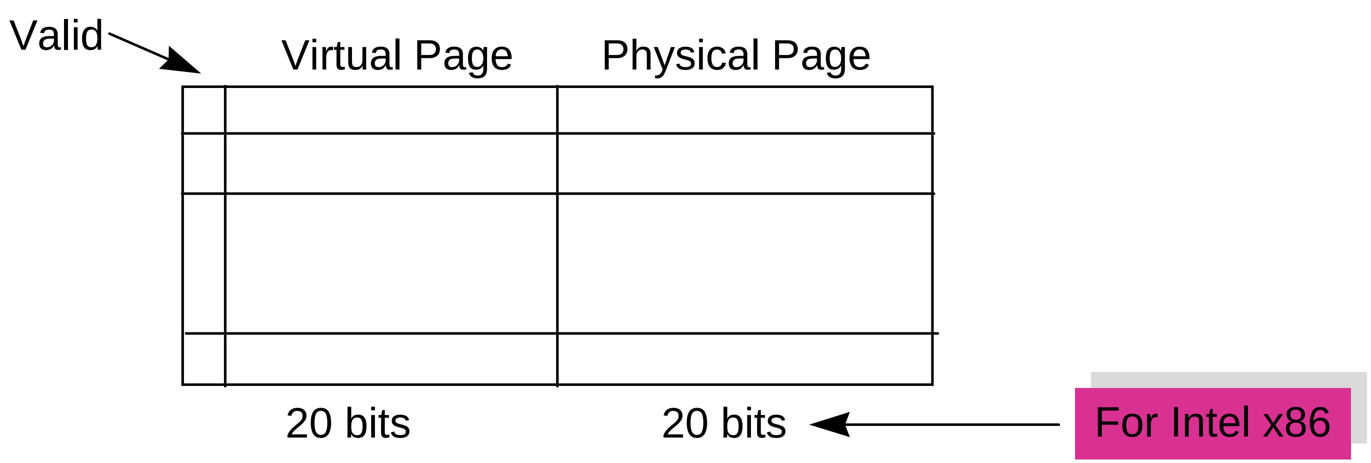
  – The inverted page table does not store information about pages that are not in memory
    - page tables are used to maintain this information
    - page table need only be consulted when a page is brought in from disk

Inverted Page Table Example (PPC)



Faster Mapping from Virtual to Physical Addresses

- need hardware to map between physical and virtual addresses
  - can require multiple memory references
  - this can be slow
- answer: build a cache of these mappings
    - called a translation look-aside buffer (TLB)
    - associative table of virtual to physical mappings
    - typically 16- 64 entries



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

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

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

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