Announcements

- Midterm is next Tuesday
  - Covers up through deadlock
- Project #3 is available on the web
- Reading:
  - Today: Chapter 9.4-9.6

Managing Memory

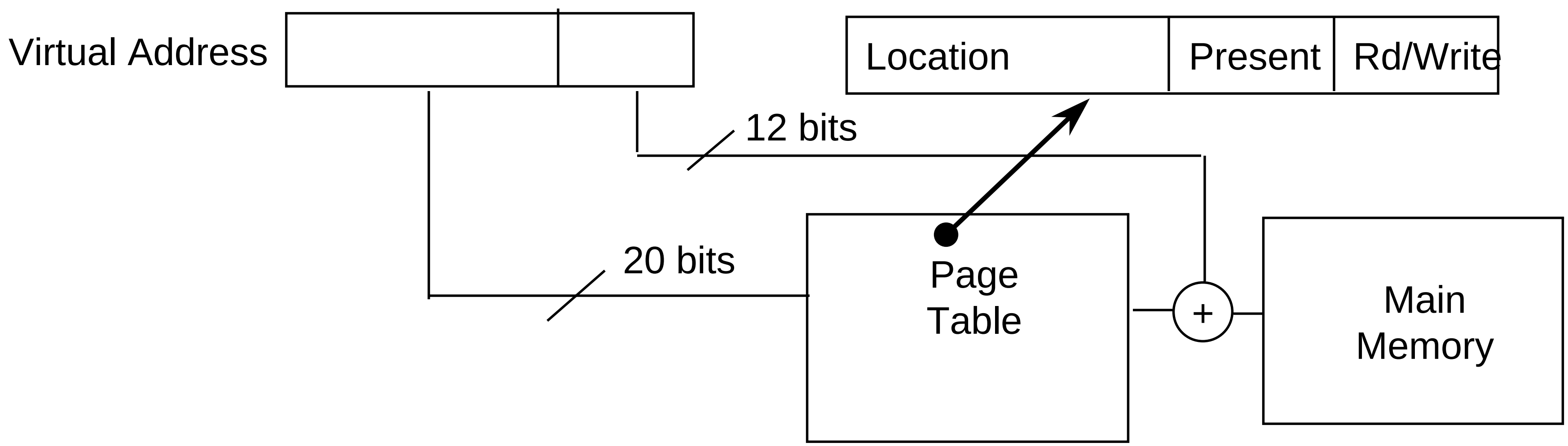
- Main memory is big, but what if we run out
  - use virtual memory
  - keep part of memory on disk
    - bigger than main memory
    - slower than main memory
- Want to have several program in memory at once
  - keeps processor busy while one process waits for I/O
  - need to protect processes from each other
  - have several tasks running at once
    - compiler, editor, debugger
    - word processing, spreadsheet, drawing program
- Use *virtual addresses*
  - look like normal addresses
  - hardware translates them to *physical addresses*

Advantages of Virtual Addressing

- Can assign non-contiguous regions of physical memory to programs
- A program can only gain access to its mapped pages
- Can have more virtual pages than the size of physical memory
  - pages that are not in memory can be stored on disk
- Every program can start at (virtual) address 0

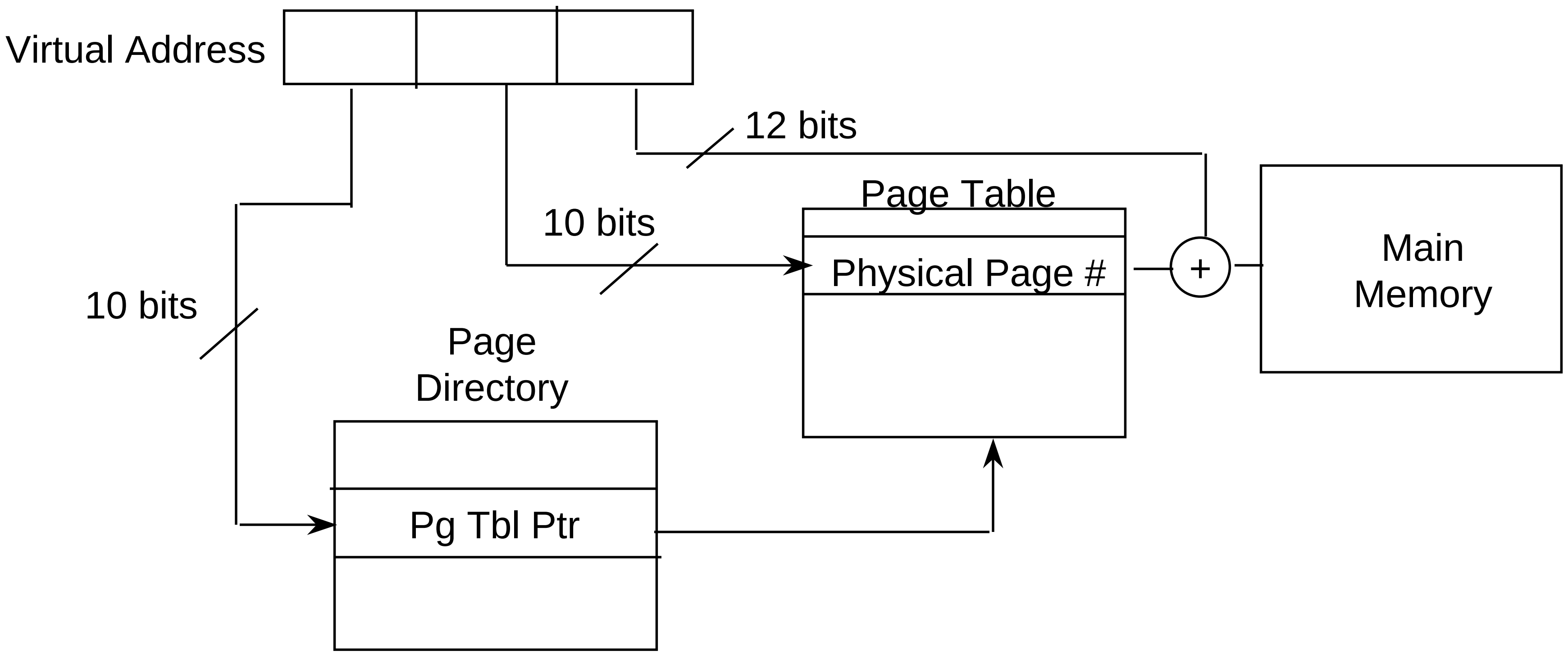
Paging

- Divide physical memory into fixed sized chunks called *pages*
  - typical pages are 512 bytes to 64k bytes
  - When a process is to be executed, load the pages that *are actually used* into memory
- Have a table to map virtual pages to physical pages
- Consider a 32 bit addresses
  - 4096 byte pages (12 bits for the page)
  - 20 bits for the page number



Problems with Page Tables

- One page table can get very big
  - 2^{20} entries (for most programs, most items are empty)
- solution1: use a hierarchy of page tables



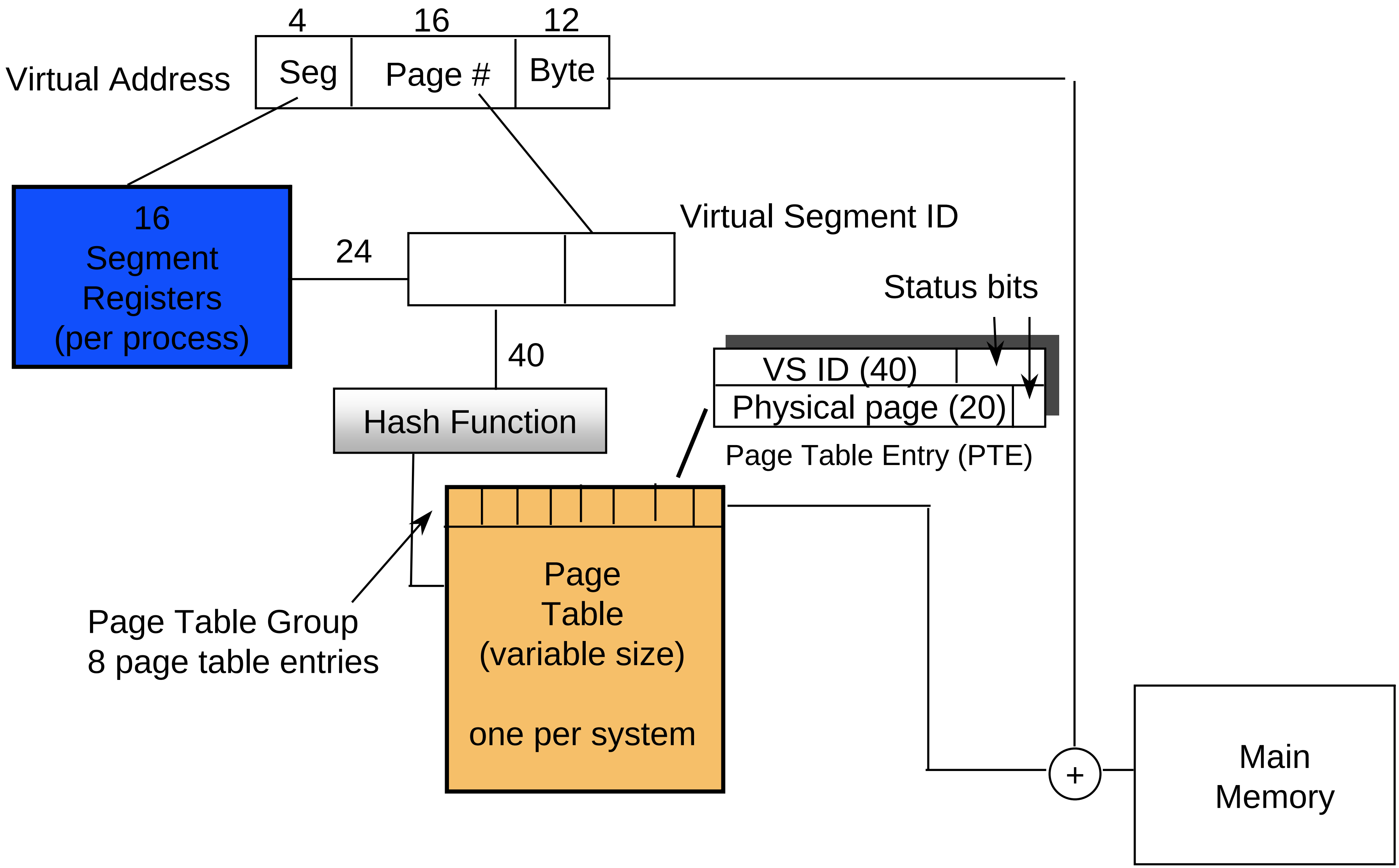
Inverted Page Tables

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

  <process-id, page-number>

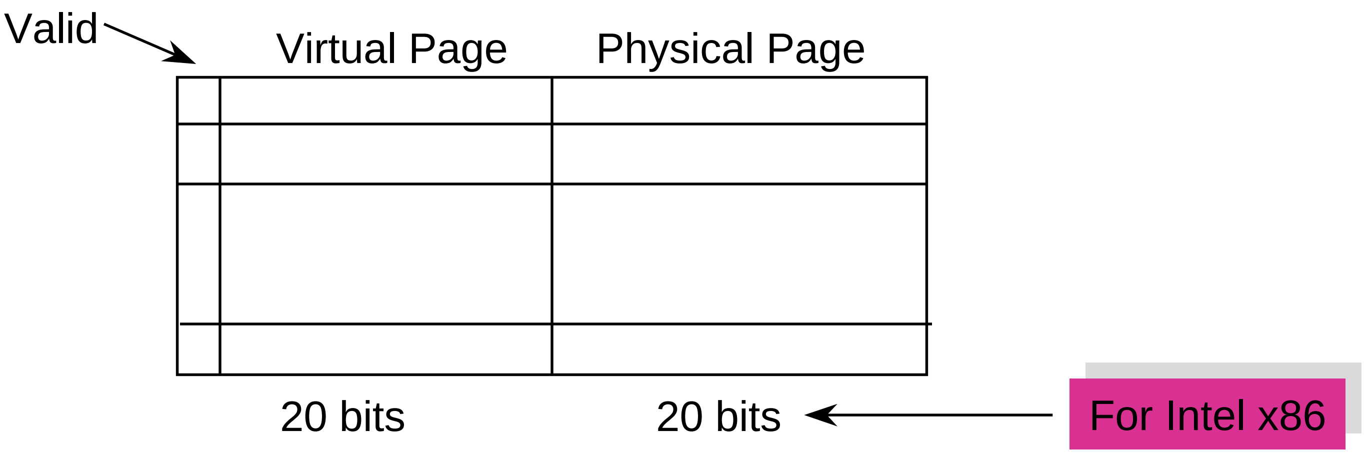
  - each entry lists process associated with the page and the page number
  - when a memory reference:
    - **<process-id,page-number,offset>**occurs, the inverted page table is searched (usually with the help of a hashing mechanism)
    - if a match is found in entry ***i*** in the inverted page table, 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



Super Pages

- TLB Entries
  - Tend to be limited in number
  - Can only refer to one page
- Idea
  - Create bigger pages
  - 4MB instead of 4KB
  - One TLB entry covers more memory

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