CSC 4103 - Operating Systems
Spring 2008

Lecture - XIV
Virtual Memory - II

Tevfik Koşar

Louisiana State University
March 27th, 2008

Background

- **Virtual memory** – separation of user logical memory from physical memory.
  - Only part of the program needs to be in memory for execution.
  - Logical address space can therefore be much larger than physical address space.
  - Allows address spaces to be shared by several processes.
  - Allows for more efficient process creation.

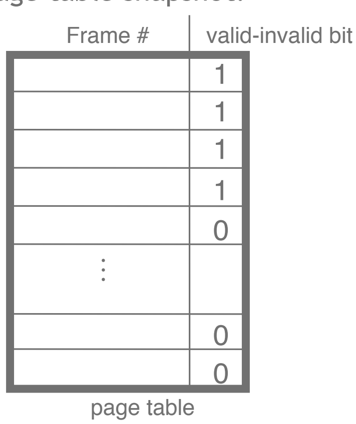
- Virtual memory can be implemented via:
  - Demand paging
  - Demand segmentation

Demand Paging

- Bring a page into memory only when it is needed
  - Less I/O needed
  - Less memory needed
  - Faster response
  - More users
- Page is needed $\Rightarrow$ reference to it
  - invalid reference $\Rightarrow$ abort
  - not-in-memory $\Rightarrow$ bring to memory

Valid-Invalid Bit

- With each page table entry a valid–invalid bit is associated
  (1 $\Rightarrow$ in-memory and legal, 0 $\Rightarrow$ not-in-memory or invalid)
- Initially valid–invalid bit is set to 0 on all entries
- Example of a page table snapshot:



- During address translation, if valid–invalid bit in page table entry is 0 $\Rightarrow$ page fault

Page Fault

- If there is ever a reference to a page, first reference will trap to
  OS ⇒ page fault
- OS looks at another table to decide:
  - Invalid reference ⇒ abort.
  - Just not in memory.
- Get empty frame.
- Swap page into frame.
- Reset tables, validation bit = 1.
- Restart instruction: Least Recently Used
  - block move
  - auto increment/decrement location

Page Replacement

- Prevent over-allocation of memory by modifying page-fault service routine to include page replacement
- Use **modify (dirty) bit** to reduce overhead of page transfers – only modified pages are written to disk
- Page replacement completes separation between logical memory and physical memory – large virtual memory can be provided on a smaller physical memory

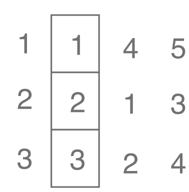
Page Replacement Algorithms

- Want lowest page-fault rate
- Evaluate algorithm by running it on a particular string of memory references (reference string) and computing the number of page faults on that string
- In all our examples, the reference string is

  1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5

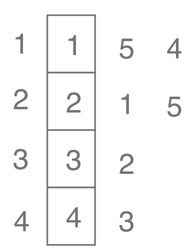
First-In-First-Out (FIFO) Algorithm

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
- 3 frames (3 pages can be in memory at a time per process)



9 page faults

- 4 frames

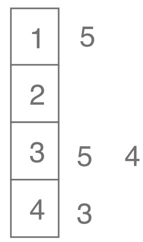


10 page faults

- FIFO Replacement – Belady's Anomaly
  - more frames $\Rightarrow$ more page faults

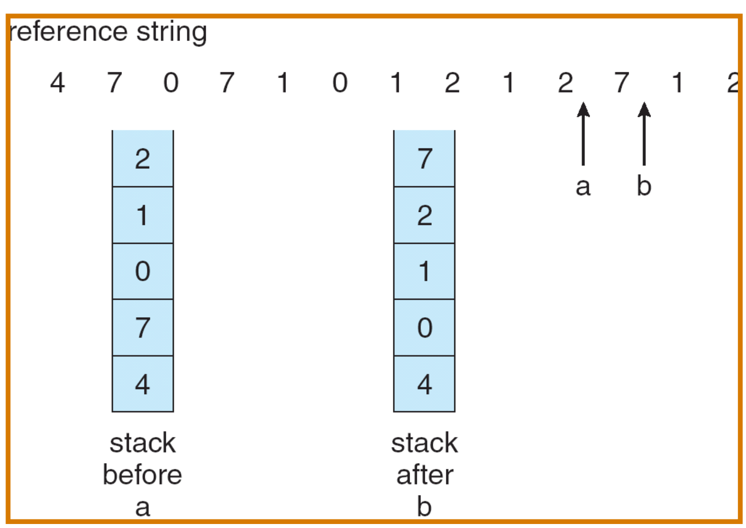
Least Recently Used (LRU) Algorithm

- Reference string: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5



- Needs hardware assistance
- Counter implementation
  - Every page entry has a counter; every time page is referenced through this entry, copy the clock into the counter
  - When a page needs to be changed, look at the counters to determine which are to change

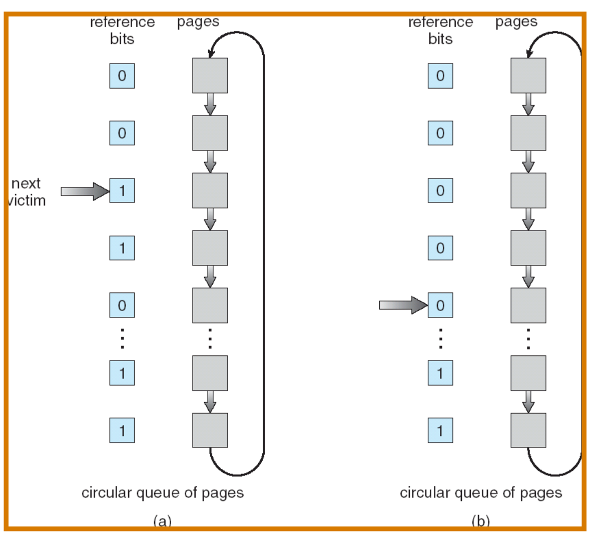
Use Of A Stack to Record The Most Recent Page References



LRU Approximation Algorithms

- Reference bits
  - 1 byte for each page: eg. 00110011
  - With each page associate a bit, initially = 0
  - When page is referenced bit set to 1
  - Shift right at each time interval
  - Replace the one with smaller value
- Second chance
  - Need single reference bit
  - Clock replacement
  - If page to be replaced (in clock order) has reference bit = 1 then:
    - set reference bit 0
    - leave page in memory
    - replace next page (in clock order), subject to same rules

Second-Chance (clock) Page-Replacement Algorithm



Counting Algorithms

- Keep a counter of the number of references that have been made to each page
- **LFU Algorithm**: replaces page with smallest count
- **MFU Algorithm**: based on the argument that the page with the smallest count was probably just brought in and has yet to be used

Optimal Algorithm

- Replace page that will not be used for longest period of time
- 4 frames example

1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5

1	4
2	
3	
4	5

6 page faults

- How do you know this?
- Used for measuring how well your algorithm performs

Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne

- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings

- “Modern Operating Systems” book and supplementary material by A. Tanenbaum

- R. Doursat and M. Yuksel from UNR