More on Virtual Memory

CS 256/456

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Recap of the Last Class

- **Virtual memory** – separation of user logical memory from physical memory.
  - Transparent page sharing:
    - Copy-on-write: allows for more efficient process creation.
  - Only part of the program address space needs to be in physical memory for execution:
    - Demand paging.
    - Memory-mapped I/O.
- Page replacement algorithm: the algorithm that picks the victim page.
  - FIFO, Optimal, LRU.

Implementations of Page Replacement Algorithms

- FIFO implementation.
- LRU implementations:
  - Time-of-use implementation
  - Stack implementation
- What needs to be done at each memory reference?
- What needs to be done at page loading or page replacement?

LRU Approximation Algorithms

- LRU approximation with a little help from the hardware.
- Reference bit
  - With each page associate a bit, initially = 0
  - When page is referenced, the bit is set to 1 by the hardware.
  - Replace a page whose reference bit is 0 (if one exists). We do not know the order, however.
- Second chance
  - Combining the reference bit with FIFO replacement
  - If page to be replaced (in FIFO order) has reference bit = 1. then:
    - set reference bit 0.
    - leave page in memory.
    - replace next page (in FIFO order), subject to same rules.
  - Also called CLOCK algorithm

LRU Approximation Algorithms

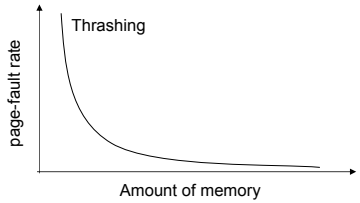
- Enhancing the reference bit algorithm:
  - it would be nice if there is more information about the reference history than a single bit.
  - with some more help from software, e.g., a memory reference counter (in page table entry and TLB)
- Maintain more reference bits in software:
  - at every N-th clock interrupt, the OS moves each hardware page reference bit (in page table entry and TLB) into a multi-bit page reference history word (in software-maintained memory).

Counting-based Page Replacement

- Least frequently used page-replacement algorithm
  - the page with smallest access count (within a period of time) is replaced
- Implementation?

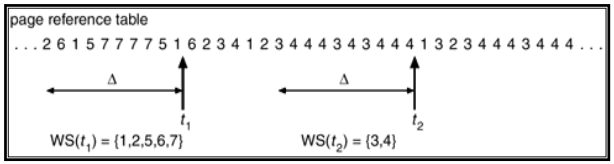
How much memory does a process need?

- Our discussion so far is "Given the amount of memory, what order should we evict pages?"
- Now we look at "How much memory does a process need?"
- If a process does not have "enough" pages, the page-fault rate is very high.
  - **Thrashing** ≡ a process is mostly busy with swapping pages.



Working-Set Model

- WSS_i (working set of Process P_i) = total number of pages referenced in the most recent Δ (working-set window).



- data access locality:
  - working set does not change or changes very slowly over time.
  - so enough memory for the working set should be good.
- How to choose Δ?

Working-Set-Based Memory Allocation

- Two components
- How much memory does a process need?
  - try to allocate enough frames for each process's working set.
  - if ΣWSS_i > m, then suspend one of the processes.
  - How to determine the working set size over a recent period Δ?
- Given the amount of memory, what order should we evict pages?
  - LRU and augment (WSClock)

Pitfall of Working-Set-Based Memory Allocation

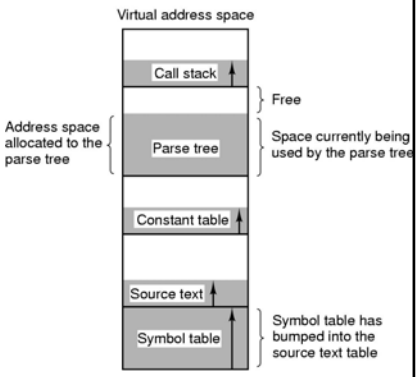
- Pitfall:
  - The working set size is not a good indicator of how much memory a process "actually" needs.
- Example:
  - Consider a process that accesses a large amount of data over time but rarely reuses any of them (e.g., sequential scan).
  - It would exhibit a large working set but different memory sizes would not significantly affect its page fault rate.

Other Memory Management Issues

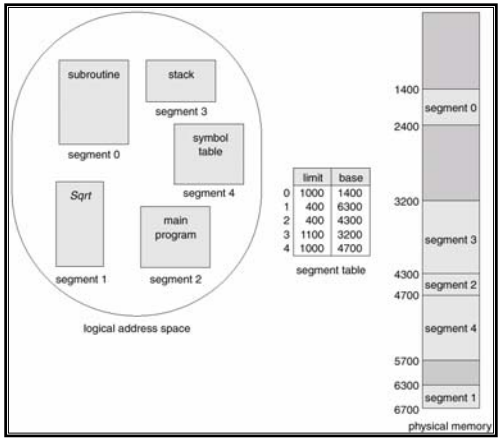
- When to swap out pages?
- Prepaging
  - swap in pages that are expected to be accessed in the future

Segmentation

- One-dimensional address space with growing pieces
- At compile time, one table may bump into another
- Segmentation:
  - generate segmented logical address at compile time
  - segmented logical address is translated into physical address at execution time

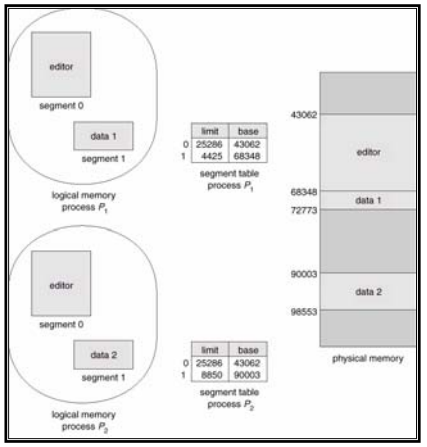


Example of Segmentation



Sharing of Segments

- Convenient sharing of libraries



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