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.
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 help from software.

- Maintain more reference bits in software:
  - at every N-th clock interrupt, the OS moves each hardware page reference bit into a page reference history word (with more than one bit).

Counting-based Page Replacement

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

- Implementation?

Per-process Memory Allocation and Thrashing

- Our discussion of memory replacement is at global level, with no concern of how much memory each process gets

- If a process does not have "enough" pages, the page-fault rate is very high. This leads to low CPU utilization.

- Thrashing ≡ a process is mostly busy with swapping

Page-Fault Frequency Scheme

- Establish "acceptable" page-fault rate range.
  - If actual rate too low, process loses frame.
  - If actual rate too high, process gains frame.
Working-Set Model

- data access locality.
- \( WSS_i \) (working set of Process \( P_i \)) = total number of pages referenced in the most recent \( \Delta \) (working-set window).

\[
\text{WS}(t_1) = \{1,2,5,6,7\} \\
\text{WS}(t_2) = \{3,4\}
\]

Policy:
- try to allocate enough frames for each process’s working set.
- if \( \sum WSS_i > m \), then suspend one of the processes.

Transparent Sharing of Memory Pages

- You are asked to implement a memory management system that transparently discover and share pages of the same content over multiple processes.
  - pay some overhead is fine, but not too excessive.
  - discover: compare hash coding of pages.
  - share: copy-on-write.

How often do pages have the same content?

Other Memory Management Issues

- When to swap out pages?
  - Prepaging
    - swap in pages that are expected to be accessed in the future
  - Page size selection
    - fragmentation
    - page table size
    - TLB reach

TLB Reach

- \( \text{TLB Reach} \) – the amount of memory accessible from the TLB.
  - \( \text{TLB Reach} = (\text{TLB Size}) \times (\text{Page Size}) \)

Advantage of a large TLB reach?

- Increasing the TLB reach:
  - \( \text{Increase the Page Size} \). This may lead to an increase in fragmentation as not all applications require a large page size.
  - \( \text{Provide Multiple Page Sizes} \). This allows applications that require larger page sizes the opportunity to use them without an increase in fragmentation.
User Program Optimization

- **Assume:**
  - page size is 4KB
  - the program is allocated 1023 physical frames.

- **Program structure**
  - `int A[][] = new int[1024][1024];`
  - Program 1
    - `for (j = 0; j < A.length; j++)`
    - `for (i = 0; i < A.length; i++)`
    - `A[i,j] = 0;`
    - 1024 x 1024 page faults
  - Program 2
    - `for (i = 0; i < A.length; i++)`
    - `for (j = 0; j < A.length; j++)`
    - `A[i,j] = 0;`
    - 1024 page faults

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