Virtual Memory
Page Replacement Algorithms

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Page Replacement Algorithms

When a page fault occurs, the memory manager must decide which page should be evicted. A page replacement algorithm is used to make that decision.

Optimal Page Replacement Algorithm

remove the page which will be referenced last.

- impossible to implement.

- used only for comparison.

Not Recently Used (NRU)

- two status bits are used;
  - R = referenced (read or written recently)
  - M = modified (written to)
  when a process starts, both bits R and M are set to 0 for all pages.

- periodically, (on each clock interval (20msec)), the R bit is cleared.

- when a page fault occurs, the pages are divided into 4 classes.
  - class 0: R=0, M=0
  - class 1: R=0, M=1
  - class 2: R=1, M=0
  - class 3: R=1, M=1

- the NRU algorithm is to select a page at random from the lowest numbered, nonempty class.

First_in, First_out (FIFO)

- a list is maintained, with the oldest page at the front of the list. The page at the front of the list is selected to be evicted.

- Problem: important, frequently-used pages may be evicted.

Second Chance (Clock) Page Replacement

Maintain a circular list. The pages are inspected in order. However, if the R bit is 1, the page is spared for the time being, and the R bit is set to 0; that is, the page is given a "second chance". If the R bit is 0, then the page is selected for eviction.

Least Recently Used: (LRU):

- replace the page that has gone unused for the largest period of time.

- *Software Implementation*: Maintain a list or stack of pages that are updated on every memory access. Generally, too expensive (remember the mapping must be fast).

- *Hardware Implementations*:

  1. Equip hardware with a 64 bit counter that is incrementing after each instruction. The counter value is stored in the page table entry of the page that was just referenced. When a page fault occurs, find the page with the smallest counter. PROBLEM: page table may be large.

  2. Maintain a matrix of nxn bits for a machine with n page frames. When page frame K is referenced:
     (i) Set row K to all 1s.
     (ii) Set column K to all 0s.
     The row whose binary value is smallest is the LRU page.

Not-Frequently-Used Algorithm (NFU)

- Simulate LRU in software. At each clock interrupt, the R bit is added to the counter associated with each page. When a page fault occurs, the page with the lowest counter is replaced.

- Problem: NFU never forgets, so a page referenced frequently long ago may have the highest counter.

Modified NFU = NFU with AGING

- At each clock interrupt:
    a. the counters are shifted right one bit, and
    b. the R bits are added to the leftmost bit.

- In this way, we can give higher priority to recent R values.

Belady's Anomaly

shows that increasing the number of page frames does not necessarily mean that the number of page faults will stay the same or decrease.