IT308: Operating Systems

Virtual memory: Page replacement policies cont.

- When the OS must allocate a frame but none are available, the page replacement policy chooses a page to evict from a frame
- Optimal page replacement (OPT) policy:
 - Evict the page that will be used farthest in the future
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- Problem: OPT is unrealizable can't really implement it (why?)

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 - (And, this data is usually stored in memory as well ...)

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			Resulting
Access	Hit/Miss?	Evict	Cache State
0	Miss		0
1	Miss		0, 1
2	Miss		0, 1, 2
0	Hit		0, 1, 2
1	Hit		0, 1, 2
3	Miss	2	0, 1, 3
0	Hit		0, 1, 3
3	Hit		0, 1, 3
1	Hit		0, 1, 3
2	Miss	3	0, 1, 2
1	Hit		0, 1, 2

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Hit		0, 1, 2
	Miss Miss Miss Hit Hit Miss Hit Hit Miss Hit Hit Hit Hit	Miss Miss Miss Hit Hit Miss 2 Hit Hit Hit Hit Hit Hit Hit Hit Hit Miss 3

- What will LRU do?
 - LRU will make same decisions as OPT here, but won't always be true!



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 - When referencing 3, evict 2 since it is referenced farthest in future

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- Extend page-table entries to hold the counter value when the memory was last accessed
 - The MMU must update this value on every page access

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- Memory accesses incur additional accesses to update a page's counter-value
 - Can cache values in TLB entries to reduce writes to main memory

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- As unappealing as counter approach, but in different ways

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- ... but the per-memory-access cost is significantly higher!
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- In practice, LRU is too slow / difficult to implement for virtual memory systems

Approximating the LRU Policy

- Systems can implement a policy that approximates LRU
- MMUs usually maintain several bits in page table entries:
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- MMUs usually maintain several bits in page table entries:
 - An "accessed" bit recording if the page was read or written
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- Replacement policies can examine the "accessed" bit on regular interval, to see if a page was accessed recently

Approximating the LRU Policy (2)

- Example: Not Frequently Used Policy
 - Maintain a counter for each page in memory
- Periodically scan through all pages on a timer interrupt:
 - If a page's "accessed" bit is set to 1, increment the page's counter and clear the page's "accessed" bit

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- When a page must be evicted, choose the page with the lowest count

Approximating the LRU Policy (3)

- Problem with Not Frequently Used policy is that it never forgets a page's history
- e.g. if a page is accessed heavily in the early parts of a program's execution, then never again – it will be unlikely to be paged out

Approximating the LRU Policy (4)

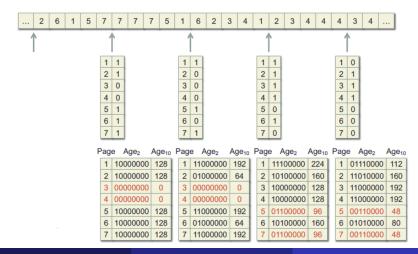
- A much better policy is called the Aging policy
- As before, the OS maintains a b-bit value for each page
- On a periodic timer, OS traverses all pages in memory:
 - Shift the page's value to the right by one bit, store the page's "accessed" bit as the new topmost bit, then clear "accessed" bit

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 - Shift the page's value to the right by one bit, store the page's "accessed" bit as the new topmost bit, then clear "accessed" bit
- Pages with more recent accesses will have a larger value than pages with less recent accesses
- Evict the page(s) with the lowest value

The Aging Policy

- Each interrupt, page table is scanned and age values are updated
- Smallest age approximates least recently used pages
- Example:



The Aging Policy (2)

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 - LRU would know which page was accessed furthest in past, but aging policy treats them the same
- Similarly, if two pages have a value of 0:
 - LRU would know which one was accessed most recently, but aging views both as having not been accessed recently

The Aging Policy (3)

- The main difference between aging policy and LRU is that aging has a much lower resolution on its "recency" info
- Nonetheless, aging policy generally performs well with a relatively small number of bits, e.g. 8 or 16 bits per page

Other Policies Using the Accessed Bit

- Many other replacement policies that use "accessed" bit
- Example: make FIFO policy more intelligent
 - Original policy: always evict the page at the front of the FIFO
 - Tweak this policy to also use a page's "accessed" bit

Other Policies Using the Accessed Bit

- When a page must be evicted:
 - Consider the page at the front of the FIFO
 - If the page's "accessed" bit is 1, clear the "accessed" bit and then move the page back to the end of the FIFO
 - Otherwise, evict the page at the front of the FIFO
- Called the Second-Chance replacement policy
 - If a page has been accessed during its time in the FIFO, it is given a second chance

Second-Chance Replacement Policy

- What happens if all pages have their "accessed" bits set?
 - Pager will scan through all pages in the FIFO ...
 - Every page's "accessed" bit will be cleared during this pass . . .
 - On second pass, pager will simply evict the first page in the FIFO
- Second-chance policy degenerates to FIFO replacement if all pages have been accessed since the last timer tick

Question

Suppose you had a virtual memory system with a physical memory that consists of only 4 page frames. Suppose also that "accessed" bits are supported and are cleared after every 6 memory accesses.

Consider the following sequence of page accesses:

• 3, 0, 1, 2, 3, 0, 1, 4

Which page is evicted when page 4 needs to be brought into memory, for the following policies?

- LRU
- Second-chance