Page Replacement

- A virtual memory system is a combination of hardware and software techniques. The memory management software system handles all the software operations for the efficient utilization of memory space.
- It must decide (1) which page in main memory ought to be removed to make room for a new page, (2) when a new page is to be transferred from auxiliary memory to main memory, and (3) where the page is to be placed in main memory.
- The hardware mapping mechanism and the memory management software together constitute the architecture of a virtual memory.
- When a program starts execution, one or more pages are transferred into main memory and the page table is set to indicate their position.
- The program is executed from main memory until it attempts to reference a page that is still in auxiliary memory.
- This condition is called page fault. When page fault occurs, the execution of the present program is suspended until the required page is brought into main memory. Since loading a page from auxiliary memory to main memory is basically an I/O operation.
- In the meantime, control is transferred to the next program in memory that is waiting to be processed in the CPU. Later, when the memory block has been assigned and the transfer completed, the original program can resume its operation.

- When a page fault occurs in a virtual memory system, it signifies that the page referenced by the CPU is not in main memory.
- A new page is then transferred from auxiliary memory to main memory. If main memory is full, it would be necessary to remove a page from a memory block to make room for the new page. The policy for choosing pages to remove is determined from the replacement algorithm that is used.
- The goal of a replacement policy is to try to remove the page least likely to be referenced in the immediate future. Three of the most common replacement algorithms used are the first-in, first-out (FIFO), the least recently used (LRU) and Optimal (OPT).
- The FIFO algorithm selects for replacement the page that has been in memory the longest time. Each time a page is loaded into memory, its identification number is pushed into a FIFO stack. FIFO will be full whenever memory has no more empty blocks.
- When a new page must be loaded**,** the page least recently brought in is removed. The page to be removed is easily determined because its identification number is at the top of the FIFO stack. The FIFO replacement policy has the advantage of being easy to implement.
- It has the disadvantage that under certain circumstances pages are removed and loaded from memory too frequently.
- The LRU policy is more difficult to implement but has been more attractive on the assumption that the least recently used page is a better candidate for removal than the least recently loaded page as in FIFO.

- The LRU algorithm can be implemented by associating a counter with every page that is in main memory. When a page is referenced, its associated counter is set to zero.
- At fixed intervals of time, the counters associated with all pages presently in memory are incremented by 1. The least recently used page is the page with the highest count.
- The counters are often called aging registers, as their count indicates their age, that is, how long ago their associated pages have been referenced.

Advantages and Disadvantages of various Page Replacement algorithms

1. First In First Out (FIFO): Principle: Replace the oldest page.

- Advantages –
  1. It is simple and easy to understand & implement.
- Disadvantages –
  1. The process effectiveness is low.
  2. When we increase the number of frames while using FIFO, we are giving more memory to processes. So, page fault should decrease, but here the page faults are increasing. This problem is called as Belady's Anomaly.
  3. Every frame needs to be taken account off.

2. Least Recently Used (LRU): Principle: Replace the page that has not been used for the longest time.

- Advantages –
    1. It is open for full analysis.
    2. In this, we replace the page which is least recently used, thus free from Belady's Anomaly.
    3. Easy to choose page which has faulted and hasn't been used for a long time.
- Disadvantages –
    1. It requires additional Data Structure to be implemented.
    2. Hardware assistance is high.

3. Optimal Page Replacement (OPR): Principle: Replace the page that will not be used for the longest time.

- Advantages –
    1. Complexity is less and easy to implement.
    2. Assistance needed is low i.e Data Structure used are easy and light.
- Disadvantages –
    1. OPR is perfect, but not possible in practice as the operating system cannot know future requests.
    2. Error handling is tough.

While FIFO and LRU have their share of advantages and disadvantages, OPR is used as a benchmark to measure the performance of other algorithms. So according to the situation appropriate algorithm is used.

FIFO (Principle: Replace the oldest page)

4	2	0	1	2	6	1	4	0	1	0	2	3	5	7
4	4	4	4	4	6	6	6	6	6	6	6	6	5	5
	2	2	2	2	2	2	4	4	4	4	4	4	4	7
		0	0	0	0	0	0	0	0	0	2	2	2	2
			1	1	1	1	1	1	1	1	1	3	3	3
				H		H		H	H	H				

LRU (Principle: Replace the page that has not been used for the longest time)

4	2	0	1	2	6	1	4	0	1	0	2	3	5	7
4	4	4	4	4	6	6	6	6	6	6	2	2	2	2
	2	2	2	2	2	2	2	0	0	0	0	0	0	7
		0	0	0	0	0	4	4	4	4	4	3	3	3
			1	1	1	1	1	1	1	1	1	1	5	5
				H		H			H	H				

OPR (Principle: Replace the page that will not be used for the longest time)

4	2	0	1	2	6	1	4	0	1	0	2	3	5	7
4	4	4	4	4	4	4	4	4	4	4	2	2	2	2
	2	2	2	2	6	6	6	6	6	6	6	6	6	7
		0	0	0	0	0	0	0	0	0	0	3	3	3
			1	1	1	1	1	1	1	1	1	1	5	5
				H		H	H	H	H	H				