Operating System

Unit – 5
(Part-C)
Memory Management

Mayank Mishra
School of Electronics Engineering
KIIT-Deemed to be University

Page Replacement Algorithms

- Page replacement algorithms are techniques used in operating systems to manage memory efficiently when the virtual memory is full.

- When a new page needs to be loaded into physical memory, and there is no free space, these algorithms determine which existing page to replace.

- If no page frame is free, the virtual memory manager performs a page replacement operation to replace one of the pages existing in memory with the page whose reference caused the page fault.

Common Page Replacement Techniques:

- First In First Out (FIFO)
- Optimal Page replacement
- Least Recently Used (LRU)
- Most Recently Used (MRU)

First In First Out (FIFO)

- This is the simplest page replacement algorithm. In this algorithm, the operating system keeps track of all pages in the memory in a queue, the oldest page is in the front of the queue.

- When a page needs to be replaced page in the front of the queue is selected for removal.

Question 1: Consider page reference string **7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 1, 2, 0** with 3-page frames. Find the number of page faults using FIFO Page Replacement Algorithm. Also calculate the Hit ratio and Miss ratio.

Question 1: Consider page reference string **7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 1, 2, 0** with 3-page frames. Find the number of page faults using FIFO Page Replacement Algorithm. Also calculate the Hit ratio and Miss ratio.

Solution:

Page reference string **7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 1, 2, 0**

Frame 3			1	1	1	1	0	0	0	3	3	3	3	2	2
Frame 2		0	0	0	0	3	3	3	2	2	2	2	1	1	1
Frame 1	7	7	7	2	2	2	2	4	4	4	0	0	0	0	0
Page Fault	Yes	Yes	Yes	Yes	No (HIT)	Yes	Yes	Yes	Yes	Yes	Yes	No (HIT)	Yes	Yes	No (HIT)

Solution (Contd.):

Frame 3			1	1	1	1	0	0	0	3	3	3	3	2	2
Frame 2		0	0	0	0	3	3	3	2	2	2	2	1	1	1
Frame 1	7	7	7	2	2	2	2	4	4	4	0	0	0	0	0
Page Fault	Yes	Yes	Yes	Yes	No (HIT)	Yes	Yes	Yes	Yes	Yes	Yes	No (HIT)	Yes	Yes	No (HIT)

Number of Page Hit = 3 Number of Page Miss/Page Fault = 12

Solution (Contd.):

Frame 3			1	1	1	1	0	0	0	3	3	3	3	2	2
Frame 2		0	0	0	0	3	3	3	2	2	2	2	1	1	1
Frame 1	7	7	7	2	2	2	2	4	4	4	0	0	0	0	0
Page Fault	Yes	Yes	Yes	Yes	No (HIT)	Yes	Yes	Yes	Yes	Yes	Yes	No (HIT)	Yes	Yes	No (HIT)

Number of Page Hit = 3

Number of Page Miss/Page Fault = 12

Hit Ratio = (Number of Page Hits / Total Number of References)
= (3/15) x 100

Miss Ratio = (Number of Page Hits / Total Number of References)
= (12/15) x 100

Question 2: Consider page reference string 1, 3, 0, 3, 5, 6, 3 with 3-page frames. Find the number of page faults using FIFO Page Replacement Algorithm.

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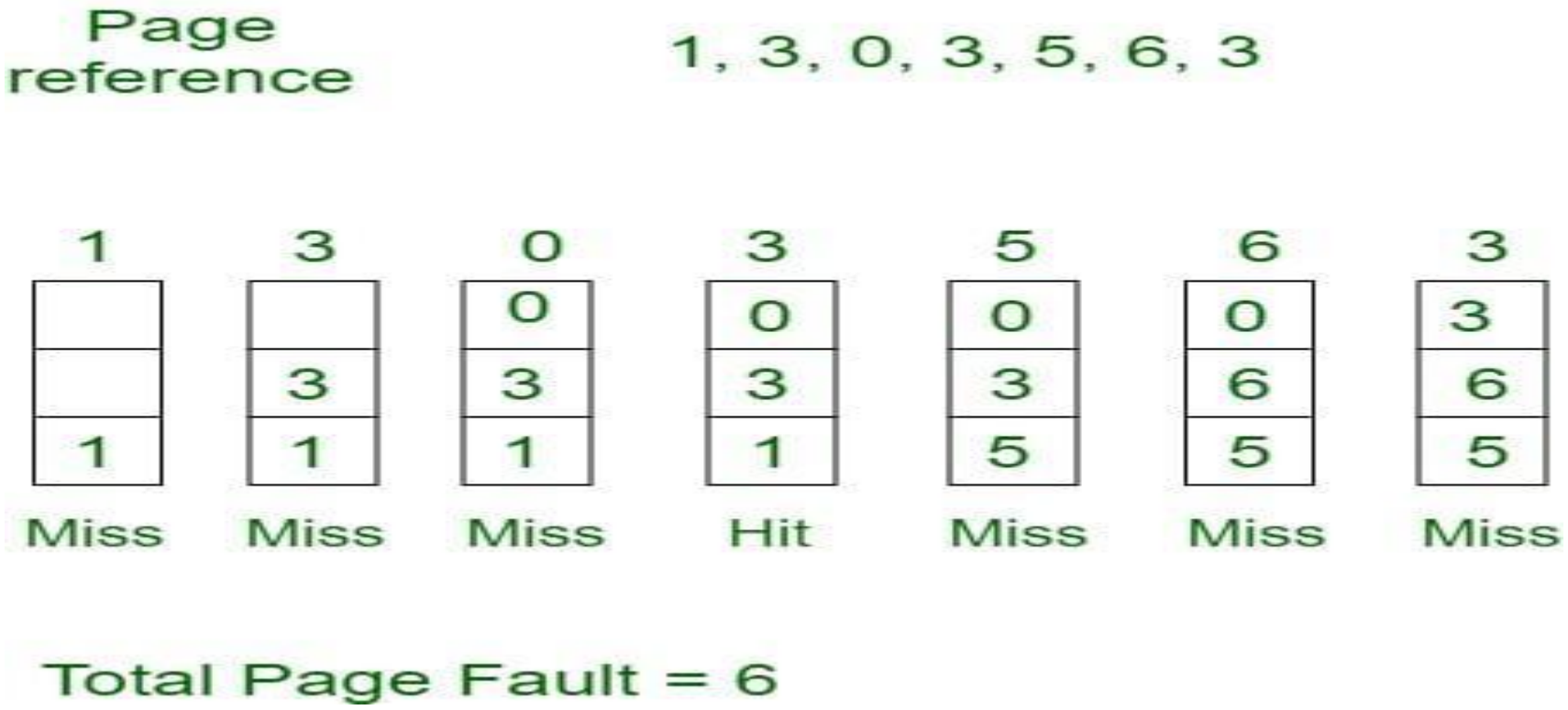

Question 3: Consider page reference string 1, 2, 3, 4, 2, 1, 5, 6, 2, 1, 2, 3, 7 with 3-page frames. Find the number of page faults using FIFO Page Replacement Algorithm.

Question 3: Consider page reference string 1, 2, 3, 4, 2, 1, 5, 6, 2, 1, 2, 3, 7 with 3-page frames. Find the number of page faults using FIFO Page Replacement Algorithm.

Solution:

Frame 1	1	1	1	4	4	4	4	6	6	6	6	6	7
Frame 2	-	2	2	2	2	2	5	5	5	5	5	3	3
Frame 3	-	-	3	3	3	1	1	1	2	2	2	2	2
Page Fault	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes

Belady's Anomaly in FIFO

- Belady's Anomaly is a phenomenon in operating systems where increasing the number of page frames in memory leads to an increase in the number of page faults for certain page replacement algorithms.

- In FIFO page replacement it is supposed that the number of page faults should be less when we increase the number of frames. But sometimes, when the number of page faults increases even after increasing the number of frames, "**Belady's Anomaly**" occurs.

Assuming a system that has no pages loaded in the memory and uses the FIFO Page replacement algorithm. Consider the following reference string:

```
1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
```

Case-1: If the system has 3 frames, the given reference string the using FIFO page replacement algorithm yields a total of 9 page faults. The diagram below illustrates the pattern of the page faults occurring in the example.

1	1	1	2	3	4	1	1	1	2	5	5
	2	2	3	4	1	2	2	2	5	3	3
		3	4	1	2	5	5	5	3	4	4
PF	PF	PF	PF	PF	PF	PF	X	X	PF	PF	X

Case-2: If the system has 4 frames, the given reference string using the FIFO page replacement algorithm yields a total of 10 page faults. The diagram below illustrates the pattern of the page faults occurring in the example.

1	1	1	1	1	1	2	3	4	5	1	2
	2	2	2	2	2	3	4	5	1	2	3
		3	3	3	3	4	5	1	2	3	4
			4	4	4	5	1	2	3	4	5
PF	PF	PF	PF	X	X	PF	PF	PF	PF	PF	PF

It can be seen from the above example that on increasing the number of frames while using the FIFO page replacement algorithm, the number of **page faults increased** from 9 to 10.

Note –

It is not necessary that every string reference pattern cause ***Belady's anomaly*** *in FIFO but there is certain kind of string references that worsen the FIFO performance on increasing the number of frames.*

Optimal Page Replacement Algorithm

- In this algorithm, pages are replaced which would not be used for the longest duration of time in the future.

- The idea is simple, for every reference we do following:
  - If referred page is already present, increment hit count.
  - If not present, find if a page that is never referenced in future. If such a page exists, replace this page with new page. If no such page exists, find a page that is referenced farthest in future. Replace this page with new page

Question 4: Consider the page references 7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 2, 3 with 4-page frame. Find number of page fault using Optimal Page Replacement Algorithm.

Question 4: Consider the page references 7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 2, 3 with 4-page frame. Find number of page fault using Optimal Page Replacement Algorithm.

Solution:

7	0	1	2	0	3	0	4	2	3	0	3	2	3
			2	2	2	2	2	2	2	2	2		
		1	1	1	1	1	4	4	4	4	4	4	4
	0	0	0	0	0	0	0	0	0	0	0	0	0
7	7	7	7	7	3	3	3	3	3	3	3	3	3
Miss	Miss	Miss	Miss	Hit	Miss	Hit	Miss	Hit	Hit	Hit	Hit	Hit	Hit

Question 5:

Input: Number of frames = 3, Reference String = {7, 0, 1, 2, 0, 3, 0, 4, 2, 3}.
Find number of page fault using Optimal Page Replacement Algorithm.

Question 4:

Input: Number of frames = 3, Reference String = {7, 0, 1, 2, 0, 3, 0, 4, 2, 3}.
Find number of page fault using Optimal Page Replacement Algorithm.

Solution:

7	0	1	2	0	3	0	4	2	3
		1	1	1	3	3	3	3	3
	0	0	0	0	0	0	4	4	4
7	7	7	2	2	2	2	2	2	2
M	M	M	M	H	M	H	M	H	H

Least Recently Used (LRU) Algorithm

- The Least Recently Used (LRU) page replacement algorithm is a method used in operating systems to manage pages in memory.

- It works by keeping track of the order in which pages are accessed. When a page is needed and the memory is full, the least recently used page (the page that hasn't been used for the longest time) is replaced.

- LRU tends to have fewer page faults than FIFO in most cases because it replaces the page that hasn't been used for the longest time, which is likely to be less useful in the future. But, **LRU** takes more time compared with **FIFO.**

Question 6:

Consider the page reference string **7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 2, 3** with **4-page** frames. Find number of page faults using LRU Page Replacement Algorithm.

Question 6:

Consider the page reference string **7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 2, 3** with **4-page** frames. Find number of page faults using LRU Page Replacement Algorithm.

Solution:

Page reference 7,0,1,2,0,3,0,4,2,3,0,3,2,3 No. of Page frame - 4

7	0	1	2	0	3	0	4	2	3	0	3	2	3
7	7	7	7	7	3	3	3	3	3	3	3	3	3
	0	0	0	0	0	0	0	0	0	0	0	0	0
		1	1	1	1	1	4	4	4	4	4	4	4
			2	2	2	2	2	2	2	2	2	2	2
Miss	Miss	Miss	Miss	Hit	Miss	Hit	Miss	Hit	Hit	Hit	Hit	Hit	Hit

Total Page Fault = 6

Here LRU has same number of page fault as optimal but it may differ according to question.

Most Recently Used (MRU)Algorithm

- In this algorithm, page will be replaced which has been used recently.
- Belady’s anomaly can occur in this algorithm.

Question 7:

Consider the page reference string **7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 2, 3** with **4-page** frames. Find number of page faults using MRU Page Replacement Algorithm.

Question 7:

Consider the page reference string **7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 2, 3** with **4-page** frames. Find number of page faults using MRU Page Replacement Algorithm.

Solution:

Page reference 7,0,1,2,0,3,0,4,2,3,0,3,2,3 No. of Page frame - 4

7	0	1	2	0	3	0	4	2	3	0	3	2	3
			2	2	2	2	2	2	3	0	3	2	3
		1	1	1	1	1	1	1	1	1	1	1	1
	0	0	0	0	3	0	4	4	4	4	4	4	4
7	7	7	7	7	7	7	7	7	7	7	7	7	7
Miss	Miss	Miss	Miss	Hit	Miss	Miss	Miss	Hit	Miss	Miss	Miss	Miss	Miss

Total Page Fault = 12

References

1. Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, “Operating System Concepts,” Eleventh Edition (Willey).

2. Andrew S. Tanenbaum, “Modern Operating Systems”, Fourth Edition (Pearson Publications), 2014.

3. https://www.geeksforgeeks.org/

4. https://www.javatpoint.com/

5. https://www.tutorialspoint.com/

6. https://www.nesoacademy.org/

7. https://www.tpointtech.com/