CS & IT ENGINEERING

Operating System

Virtual Memory

Lecture - 03

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Recap of Previous Lecture

- **Topic** Effective Memory Access Time
- **Topic** Page Replacement Algorithm
- **Topic** FIFO, Optimal Algorithms

Topics to be Covered

Topic Page Replacement Algorithm

Topic LRU, MRU Algorithms

Topic LIFO, Frequency Based Algorithms

Topic : Least Recently Used (LRU)

Replace the page which has not been used since longest period of time.

Assume:

- Number of frames = 3 (All empty initially)
- Page reference sequence: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5

1	1	1	4	4	4	5			3	3	3
	2	2	2	1	1	1			1	4	4
		3	3	3	2	2			2	2	5
✓	✓	✓	✓	✓	✓	✓	Hit	Hit	✓	✓	✓

No. of p.f. = 10

Topic : Least Recently Used (LRU)

Advantages:

1. Efficient.
2. Doesn't suffer from Belady's Anomaly

Disadvantages:

1. Complex Implementation
2. Expensive
3. Requires hardware support

Topic : Question

- Number of frames = 4
- Pure demand paging used
- Page reference sequence: 5, 7, 0, 1, 7, 6, 7, 2, 1, 6, 7, 6, 1
- Number of page faults for FIFO, optimal and LRU policies? 7, 6, 6

FIFO:-

no. of p. faults = 7

5	5	5	5	6	6	6
	7	7	7	7	2	2
		0	0	0	0	7
			1	1	1	1

✓ ✓ ✓ ✓ φ ✓ φ ✓ φ φ ✓

optimal :-

5	7	0	1	7	6	7	2	1	6	7	6	1
5	5	5	5		6		6					
	7	7	7		7		7					
		0	0		0		2					
			1		1		1					
✓	✓	✓	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗

no. of P.F. = 6

LRU :-

5	7	0	1	7	6	7	2	1	6	7	6	1
5	5	5	5		6		6					
	7	7	7		7		7					
		0	0		0		2					
			1		1		1					
✓	✓	✓	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗

P.f. = 6

Topic : Question

Consider the following page references:

2, 3, 4, 5, 6, 4, 5, 2, 7, 8, 9, 8, 9, 8, 9, 1, 6, 5, 6, 5, 3

Using optimal policy and 4 frames. Memory access time is 2ms without page fault and 40ms with page fault. The effective memory access time for servicing the above page requests is ____ ms?

2	2	2	2	2	7	7	9	9	9
	3	3	3	6	6	6	6	6	6
		4	4	4	4	8	8	1	1
			5	5	5	5	5	5	3

no. of p.f. = 10

Page fault rate $= \frac{10}{21}$

$$EMAT = \frac{11}{21} * 2 + \frac{10}{21} * 40 = 20.095$$
$$= 20.1 \text{ ms}$$

Topic : Last In First Out (LIFO)

replace the page which comes last in mm.

Assume:

- Number of frames = 3 (All empty initially)
- Page reference sequence: 1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5

1	1	1	1	1	1	1	1
	2	2	2	2	2	2	2
		3	4	5	3	4	5
✓	✓	✓	✓	✓	✓	✓	✓

no. of page faults = 8

Topic : Most Recently Used (MRU)

replace the page which has been refered most recently.

Assume:

- Number of frames = 3 (All empty initially)
- Page reference sequence: ~~1, 2, 3, 4,~~ 1, 2, 5, 1, 2, 3, 4, 5

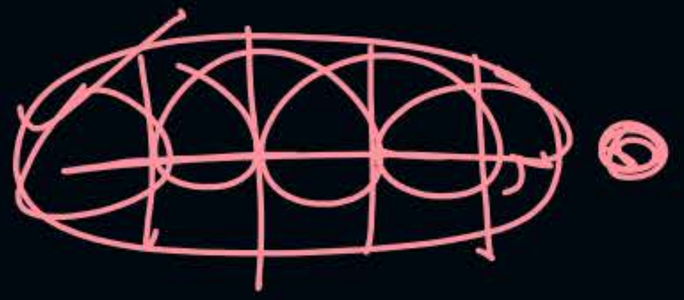
1	1	1	1	1	2	3
	2	2	2	5	5	5
		3	4	4	4	4

✓ ✓ ✓ ✓ p p ✓ ✓ ✓

no. of p.f. = 7

Topic : Counting Algorithms

- Counting algorithms look at the number of occurrences of a particular page and use this as the criterion for replacement.



- Such counting algorithms includes:
  - LFU (Least Frequently Used)
  - MFU (Most Frequently Used)

Topic : Least Frequently Used (LFU)

replace the page which has been refered min. no. of times → Tie breaker ⇒ FIFO

Assume:

- Number of frames = 3 (All empty initially)
- Page reference sequence: ~~1~~ ~~2~~ ~~0~~ ~~3~~ 0 ~~4~~ ~~2~~ ~~3~~ 0 3 2

1	1	1	3	3	2	2
	2	2	2	4	4	3
		0	0	0	0	0

✓ ✓ ✓ ✓ φ ✓ ✓ ✓ φ φ φ

no. of p. faults = 7

Page	Frequency
1	1
2	~~1~~ ~~2~~ 3
0	~~1~~ ~~2~~ 3
3	~~1~~ ~~2~~ 3
4	1

Topic : Most Frequently Used (MFU)

replace the page which has been refered max. no. of times

↳ tie breaker = FIFO

Assume:

- Number of frames = 3 (All empty initially)
- Page reference sequence: ~~1~~ ~~2~~ ~~0~~ ~~3~~ ~~0~~ ~~4~~ ~~2~~ ~~3~~ 0 3 2

1	1	1	3	3	3	2
	2	2	2	2	0	0
		0	0	4	4	4

✓ ✓ ✓ ✓ ✗ ✓ ✗ ✗ ✓ ✗ ✓

no. of p.f. = 7

Page	frequency
1	1
2	~~1~~ ~~2~~ 3
0	~~1~~ ~~2~~ 3
3	~~1~~ ~~2~~ 3
4	1

Topic : Question

Ans = 1

[GATE-2016]

#Q. Consider a computer system with ten physical page frames. The system is provided with an access sequence $a_1, a_2, \ldots, a_{20}, a_1, a_2, \ldots, a_{20}$ where each ai is a page number. The difference in the number of page faults between the last-in-first-out page replacement policy and the optimal page replacement policy is ______

faults — 9 hits — faults

LIFO:- a_1 a_2 … a_{10} a_{11} a_{12} …… a_{19} a_{20} a_1 a_2 a_3 a_4 a_5 a_9 - a_{10} … a_{20}

a_1 | a_1, a_2 | …… | a_1, a_2, ⋮, a_{10} | a_1, a_2, ⋮, a_9, a_{11} | a_1, ⋮, a_{12} | …… | a_1, ⋮, a_9, a_{20} | a_1, ⋮, a_9, a_{10} … a_{20}

p.f. = 31

optimal:-

20 faults | hits ⇒ 9 | hit

$a_1 \; a_2 \cdots a_{10} \; a_{11} \; a_{12} \cdots a_{20} \; a_1 \; a_2 \cdots a_9 \; a_{10} \; a_{11} \cdots a_{20}$

a_1	a_1	a_1	a_1
a_2	a_2		$\vdots$
$\vdots$	$\vdots$		
a_9	a_9		a_9
a_{10}	a_{11}	a_{12}	a_{20}

a_{20}

P.f. = 30

Difference = 31 - 30 = 1

Topic : Question

H.W.

[GATE-2014]

#Q. A main memory can hold 3 page frames and initially all of them are vacant. Consider the following stream of page requests :
2, 3, 2, 4, 6, 2, 5, 6, 1, 4, 6
If the stream uses FIFO replacement policy, the hit ratio h will be ?

A. 11/3

B. 1/11

C. 3/11

D. 2/11

Topic : Question

H. ω.

#Q. A virtual memory system has only 2-page frames which are empty initially. Using demand paging the following sequence of page reference is passed through this system.

9, 8, 7, 8, 7, 9, 7, 9, 8, 9

Minimum possible number of page faults ?

Topic : Question

[GATE-2007]

#Q. The address sequence generated by tracing a particular program executing in a pure demand paging system with 100 bytes per page is
0100, 0200, 0430, 0499, 0510, 0530, 0560, 0120, 0220, 0240, 0260, 0320, 0410.
Suppose that the memory can store only one page and if X is the address which causes a page fault then the bytes from addresses x to x + 99 are loaded on to the memory.
How many page faults will occur?

A 0

B 4

C 7

D 8

Page in mm

~~0100 – 0199~~

~~0200 – 0299~~

~~0430 – 0529~~

~~0530 – 0629~~

~~0120 – 0219~~

~~0220 – 0319~~

0320 – 0419

Topic : Making Page Reference Sequence

Logical add. or virtual add. $\Rightarrow$ Page no.

option 1 :-

L.A. (V.A.) given in Binary / hexadecimal (convert)

$\Downarrow$

$\xleftarrow{\quad L.A. \quad}$

p	d

example :- L.A. = 10 bits

Page size = 16 bytes = 2^4 B

L.A. = 1011101110 $\Rightarrow$ $P = (101110)_2$

$\xleftarrow{\quad 10 \quad}$

p	d
6	4

p: 101110 | 1110

6

$P = (46)_{10}$

option 2 :-

L.A. (V.A.) given in decimal

$$p = \left\lfloor \frac{L.A.}{\text{Page size}} \right\rfloor$$

$$d = L.A. \ \% \ \text{Page size}$$

ex:-

Page size = 4B

$0/4 = \overset{p}{0}$

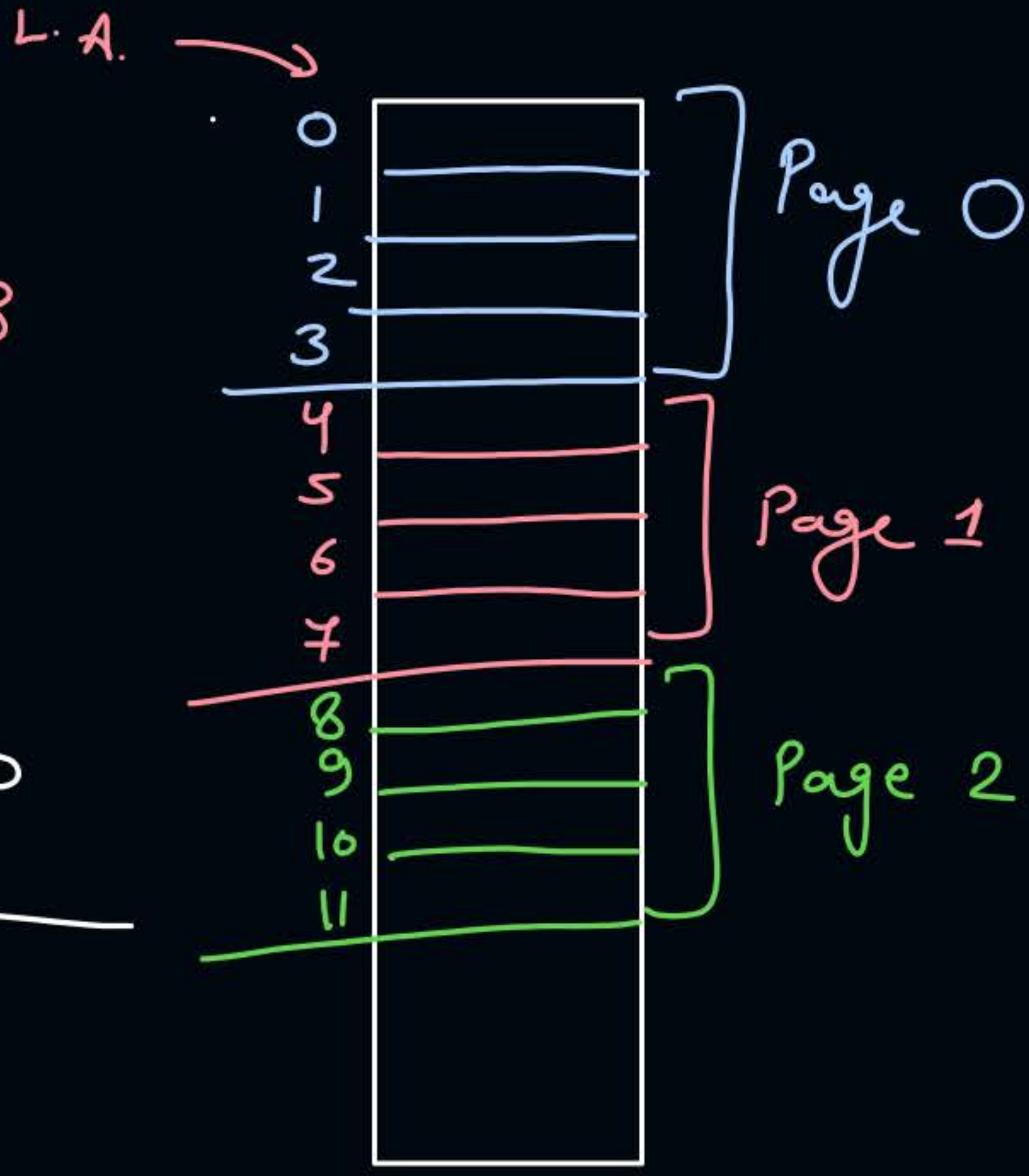
$0 \% 4 = d = 0$

Add = 1

$\lfloor 1/4 \rfloor = \overset{p}{0}$

$1 \% 4 = \overset{d}{1}$

10 $\lfloor 10/4 \rfloor \Rightarrow 2$ | $10 \% 4 = 2$



4) 10 (2
 − 8
 2

Ques)

H.W.

Page size = 2048 bytes

L.A.	p	d
5184		
2590		
2003		
1004		
9822		
15623		

2 mins Summary

Topic Page Replacement Algorithm

Topic LRU, MRU Algorithms

Topic LIFO, Frequency Based Algorithms

Happy Learning

THANK - YOU