CS & IT ENGINEERING

Operating System

Memory Management

Lecture -5

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Recap of Previous Lecture

Topic Virtual Memory

Topic Effective Memory Access Time

Topics to be Covered

Topic Virtual Memory

Topic Page Replacement Policies

Topic : Question

[GATE-2020]

#Q. Consider a paging system that uses 1-level page table residing in main memory and a TLB for address translation. Each main memory access takes 100 ns and TLB lookup takes 20 ns. Each page transfer to/from the disk takes 5000 ns. Assume that the TLB hit ratio is 95%, page fault rate is 10%. Assume that for 20% of the total page faults, a dirty page has to be written back to disk before the required page is read from disk. TLB update time is negligible. The average memory access time in ns (round off to 1 decimal places) is___155___.

Topic : Question

4.4 ns

#Q. A processor uses 1–level page table for virtual to physical address translation. Page table is stored in the main memory. Further, the processor has a translation look-aside buffer (TLB), with a hit rate of 96%. The TLB caches recently used virtual page numbers and the corresponding physical page numbers. The processor also has a physically addressed cache with a hit rate of 90%. Main memory access time is 10 ns, cache access time is 2 ns, and TLB access time is also 1 ns.

Assuming that no page faults occur, the average time taken to access a virtual address is approximately?

Topic : Page Replacement Policies

1. First In First Out (FIFO)
2. Optimal Policy
3. Least Recently Used (LRU)
4. Last in First Out (LIFO)
5. Most Recently Used (MRU)
6. Least Frequently Used (LFU)
7. Most Frequently Used (MFU)

Topic : Optimal Policy

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

no. of p. faults = 7

Topic : Optimal Policy

Advantages:

1. Easy to Implement
2. Simple data structures are used
3. Highly efficient as it gives minimum number of page faults
4. Doesn't suffer from Belady's Anomaly

Disadvantages:

1. Requires future knowledge of the program $\Rightarrow$ hence practically not implemented
2. Time-consuming

Topic : Least Recently Used (LRU)

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

no. of faults = 10

Topic : Least Recently Used (LRU)

Advantages:

1. Efficient → Practically less no. of page faults
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?

FIFO:-

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

No. of page faults = 7

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?

optimal :-

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

Page faults = 6

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?

LRU:-

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

No. of page faults = 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

Page faults = 10

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

Page hit rate $= \frac{11}{21}$

$$E.M.A.T. = \frac{11}{21} * 2ms + \frac{10}{21} * 40$$

$$= \frac{22 + 400}{21}$$

$$= \frac{422}{21} ms$$

$$= 20.095 ms$$

Topic : Last In First Out (LIFO)

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 page which has been used 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

no. of page faults = 7

Ques) no. of frames = 3 (all empty)

(LIFO, MRU) ⇒ no. of page faults

1 3 1 4 1 6 2 1 9 6 2 5

LIFO :-

1	1	1	1	1	1	1	1	1
	3	3	3	3	3	3	3	3
		4	6	2	9	6	2	5

no. of faults = 9

MRU :-

1	1	1	6	2	1	9	6	2	5
	3	3	3	3	3	3	3	3	3
		4	4	4	4	4	4	4	4

no. of faults = 10

Ques) Assume mm has 4 frames (all empty initially)

MRU policy

10 unique pages $P_1, P_2, \ldots, P_{10}$

are refered 3 times in sequence $\Rightarrow \underbrace{P_1, P_2, \ldots P_{10}}_{\text{10 faults}}, \underbrace{P_1 \ldots}_{\text{3 hits}} \underbrace{\ldots P_{10}}_{\text{6 faults}}, \underbrace{P_1 \ldots}_{\text{2 hits}} \underbrace{\ldots}_{\text{6 faults}} \underbrace{P_{10}}_{\text{2 hits}}$.

No. of page faults ? = 22 Ans.

Soln

P1	P1		P1	P1	P1		P1	P1	P1	P1		P1
P2	P2		P2	P2	P2		P2	P3	P4			P8
P3	P3		P3	P4	P5	.....	P9	P9	P9			P9
P4	P5	.....	P10	P10	P10		P10	P10	P10	......		P10

Ques) Assume mm has 4 frames (all empty initially)

optimal policy

10 unique pages $P_1, P_2, \ldots, P_{10}$

are refered 3 times in sequence $\Rightarrow \underbrace{P_1, P_2, \ldots P_{10}}_{\text{10 faults}}, \underbrace{P_1 \ldots}_{\text{3 hits}} \underbrace{\ldots P_{10}}_{\text{6 faults}}, \underbrace{P_1 \ldots}_{2} \underbrace{\ldots P_{10}}_{6}$

hit.

hits faults

2 hits

No. of page faults? $\Rightarrow$ 22

P1 ..... P1	P1	P1	P1		P1
	P2	P2	P2		P2
	P3	P3	P3		
	P4	P5	P10		
				P4	P9
				P10	P10

Ques) Assume mm has 4 frames (all empty initially)

LIFO policy

10 unique pages $P_1, P_2, \dots, P_{10}$

are refered 3 times in sequence $\Rightarrow \underbrace{P_1, P_2, \dots P_{10}}_{10 \text{ faults}}, \underbrace{P_1 \dots}_{3 \text{ hits}} \underbrace{\dots P_{10}}_{7 \text{ faults}}, \underbrace{P_1 \dots}_{3 \text{ hits}} \underbrace{\dots P_{10}}_{7 \text{ faults}}$

No. of page faults ? = 24

$10 + 7 + 7 = 24$ faults

P1

P2

P3

P10

Topic : Counting Algorithms

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

Tie breaker ⇒ FIFO

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

Topic : Least Frequently Used (LFU)

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

no. of faults = 7

Topic : Most Frequently Used (MFU)

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 page faults = 7

Topic : Question

#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 ? ⇒ use optimal policy

↳ Ans = 5

9 9 7 7 8

8 8 9 9

Topic : Question

[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

2	2	2	6	6	6	1	1	1
	3	3	3	2	2	2	4	2
		4	4	4	5	5	5	6

P.f. rate $= \frac{9}{11}$

hit rate $= \frac{2}{11}$

Topic : Question

H. ω.

[GATE-2016]

#Q. Consider a computer system with ten physical page frames. The system is provided with an access sequence $a_1, a_2, ..., a_{20}, a_1, a_2, ..., a_{20}$ where each ai 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 ________

#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

~~0100 – 0199~~
~~0200 – 0299~~
~~0430 – 0529~~
~~0530 – 0629~~
~~0120 – 0219~~
~~0220 – 0319~~
0320 – 0419

Topic : Making Page Reference Sequence

if L.A. or virtual add. given

$\Downarrow$

obtain page no.

if L.A. given

1. binary $\Rightarrow$ | p | d |

2. Hexadecimal

3. Decimal $\Rightarrow$ $p = \left(\frac{L.A.}{\text{Page size}}\right)$

#Q. A demand paged virtual memory system uses 16 bit virtual address, page size of 256 bytes, and has 1Kbyte of main memory. LRU page replacement is implemented using the list, whose current status (page number is decimal) is

17	1	63

↑
LRU Page

For each hexadecimal address in the address sequence given below,

00FF, 010D, 10FF, 11B0

indicate

1. the new status of the list $\Rightarrow$

0	1	16	17

⇑
LRU page

2. page faults, if any, and $\Rightarrow 3$
3. page replacements, if any.

no. of frames $= \frac{1KB}{256B} = 4$

L.A. 16

p	d
8	8

$00FF \Rightarrow \boxed{00 \mid FF}$

$p = 00000000 = (0)_{10}$

$010D \Rightarrow \boxed{01 \mid 0D}$

$(00000001)_2 = (1)_{10}$

$10FF \Rightarrow \boxed{10 \mid FF}$

$(00010000)_2 = (16)_{10}$

$(11B0) \Rightarrow \boxed{11 \mid B0}$

$(00010001)_2 = (17)_{10}$

Page reference $\Rightarrow$ 0 ✓, 1 ✗, 16 ✓, 17 ✓

	0	1	16	17
17	17		16	16
1	1		1	1
63	63		63	17
	0		0	0

replacements

H.W.

#Q. Assume that a main memory with only 4 pages, each of 16 bytes, is initially empty. The CPU generates the following sequence of virtual addresses and uses the Least Recently Used (LRU) page replacement policy.

0, 4, 8, 20, 24, 36, 44, 12, 68, 72, 80, 84, 28, 32, 88, 92

How many page faults does this sequence cause? What are the page numbers of the pages present in the main memory at the end of the sequence?

A. 6 and 1,2,3,4

B. 7 and 1,2,4,5

C. 8 and 1,2,4,5

D. 9 and 1,2,3,5

min. size page $\Rightarrow$ one instⁿ size (max instⁿ size)

Topic : Frame Allocation

- How many frames do we allocate per process?

Topic : Frame Allocation

How many frames do we allocate per process?

- If it is a single-user, single-tasking system, it's simple – all the frames belong to the user's process

2 Questions

- What is the minimum number of frames that a process needs?
- Is page replacement global or local?

replace pages of same process only

replace
page of any process

Topic : Minimum Number of Frames

Every process must have enough pages to complete an instruction.

Topic : Frame Allocation

1. Equal Allocation
2. Proportional Allocation

ex:- no. of frames = 6

2 Processes P1 and P2

P1 ⇒ 6 pages
P2 ⇒ 3 pages

Total 9 pages

equal allocation

P1 ⇒ 3 frames
P2 ⇒ 3 frames

Proportional

$P1 = \frac{6}{9} * 6$
$= 4$ frames

$P2 = \frac{3}{9} * 6$
$= 2$ frames

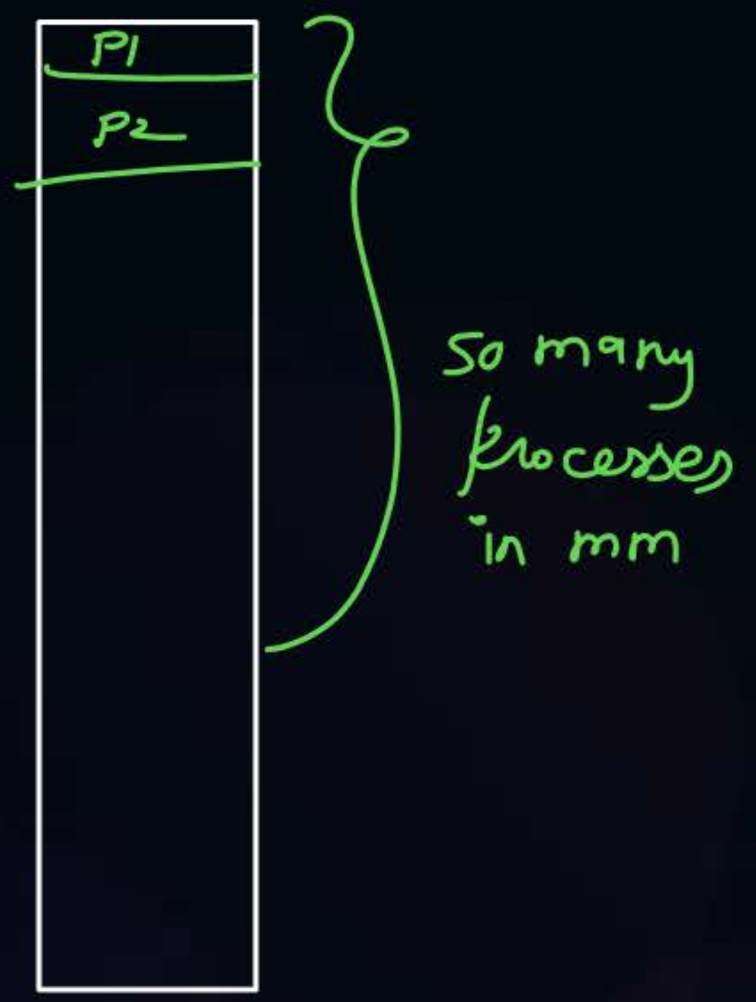
Topic : Local Allocation

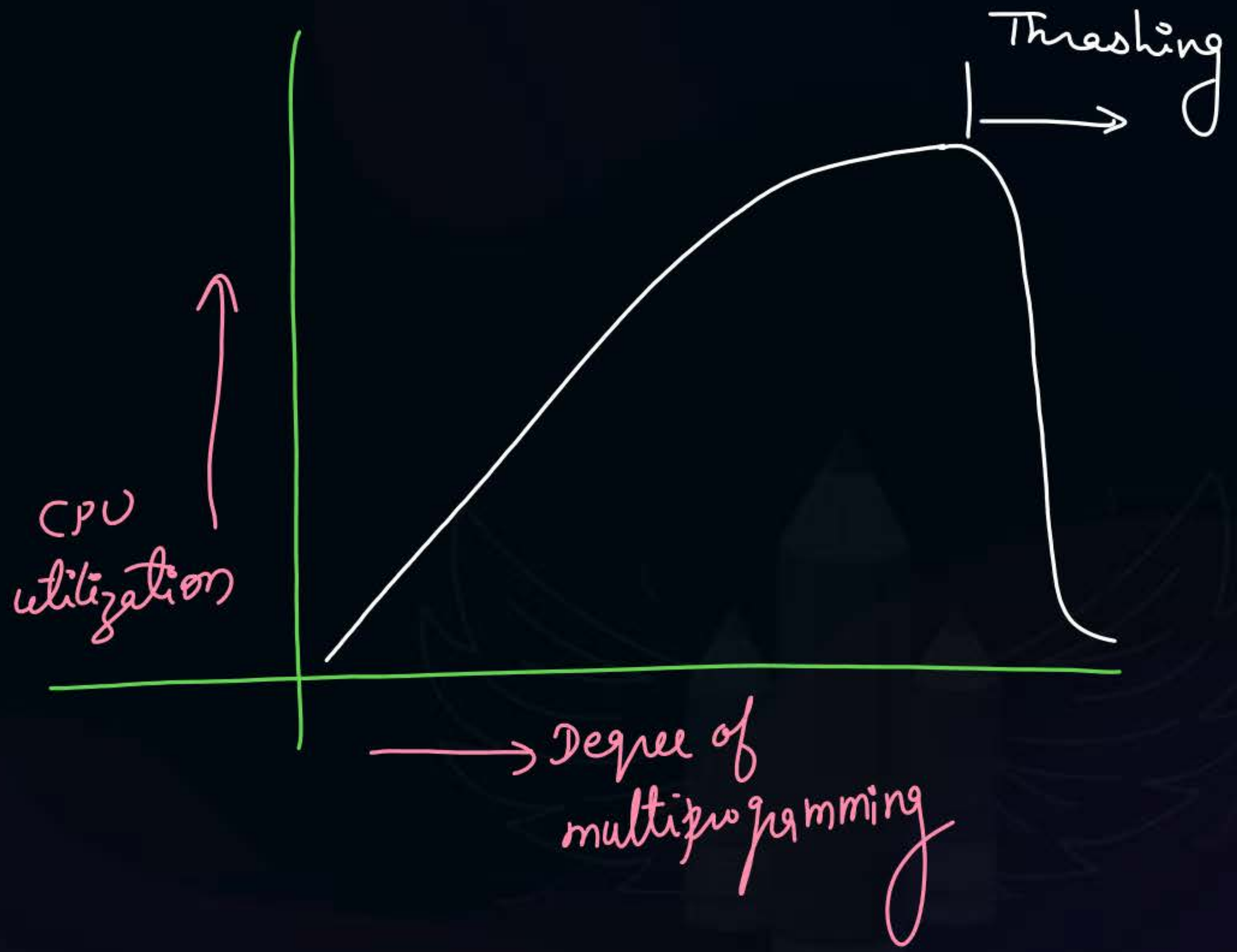
1. Local replacement requires that the page being replaced be in a frame belonging to the same process
2. The number of frames belonging to the process will not change
3. This allows processes to control their own page fault rate

Topic : Global Allocation

1. The process can replace a page from a set that includes all the frames allocated to user processes
2. High-priority processes can increase their allocation at the expense of lower-priority processes
3. Global allocation makes for more efficient use of frames and their better throughput

Topic : Thrashing





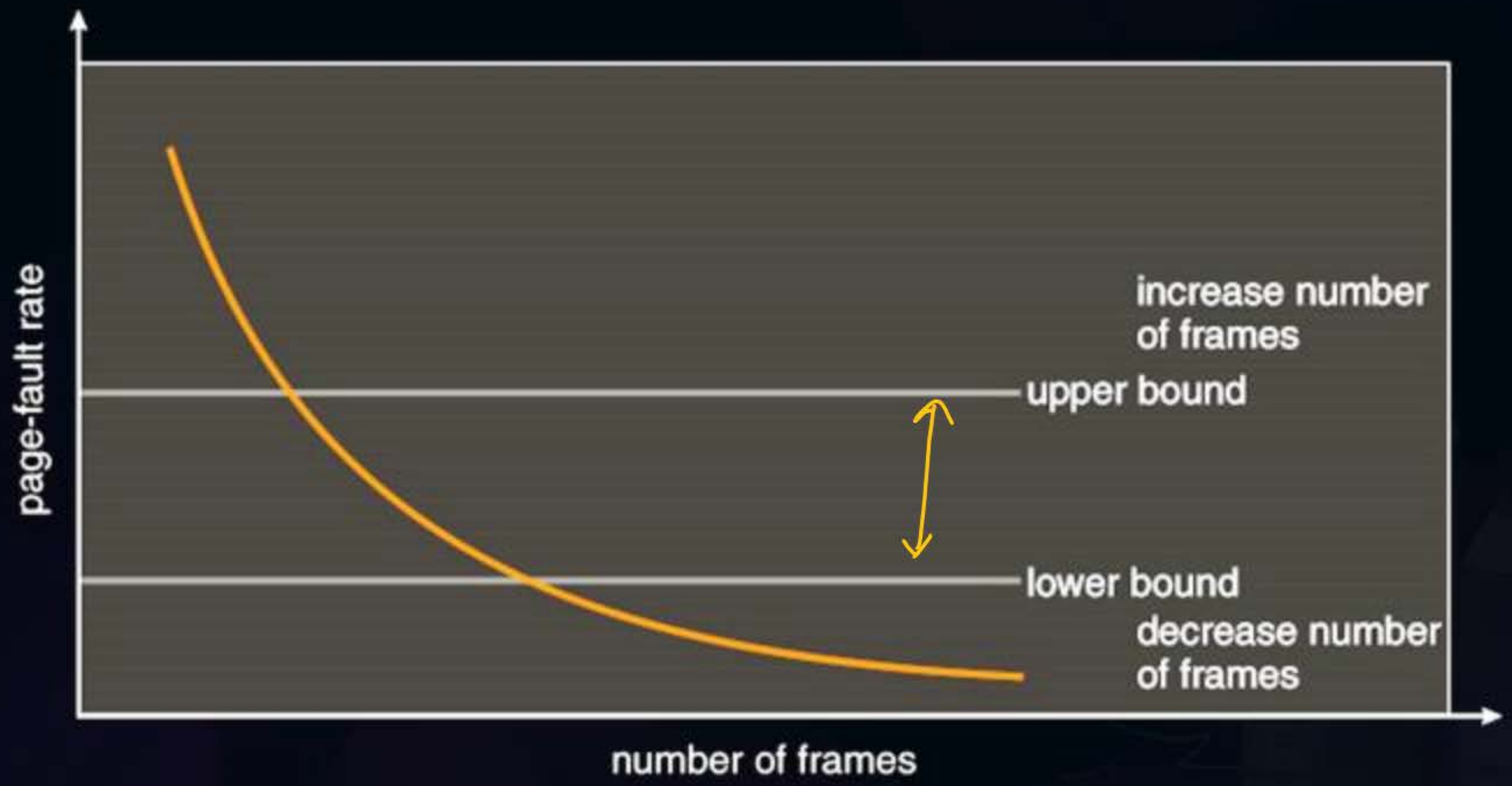
Topic : Locality Model

1. Working Set Model
2. Page Fault Frequency

Topic : Working Set

find working set ⇒ frames allocated to the process equal to set

Topic : Page Fault Frequency



2 mins Summary

Topic Virtual Memory

Topic Page Replacement Policies

Happy Learning

THANK - YOU