CS & IT ENGINEERING

Operating System

Virtual Memory

Lecture - 05

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Recap of Previous Lecture

Topic Frame Allocation

Topic Thrashing

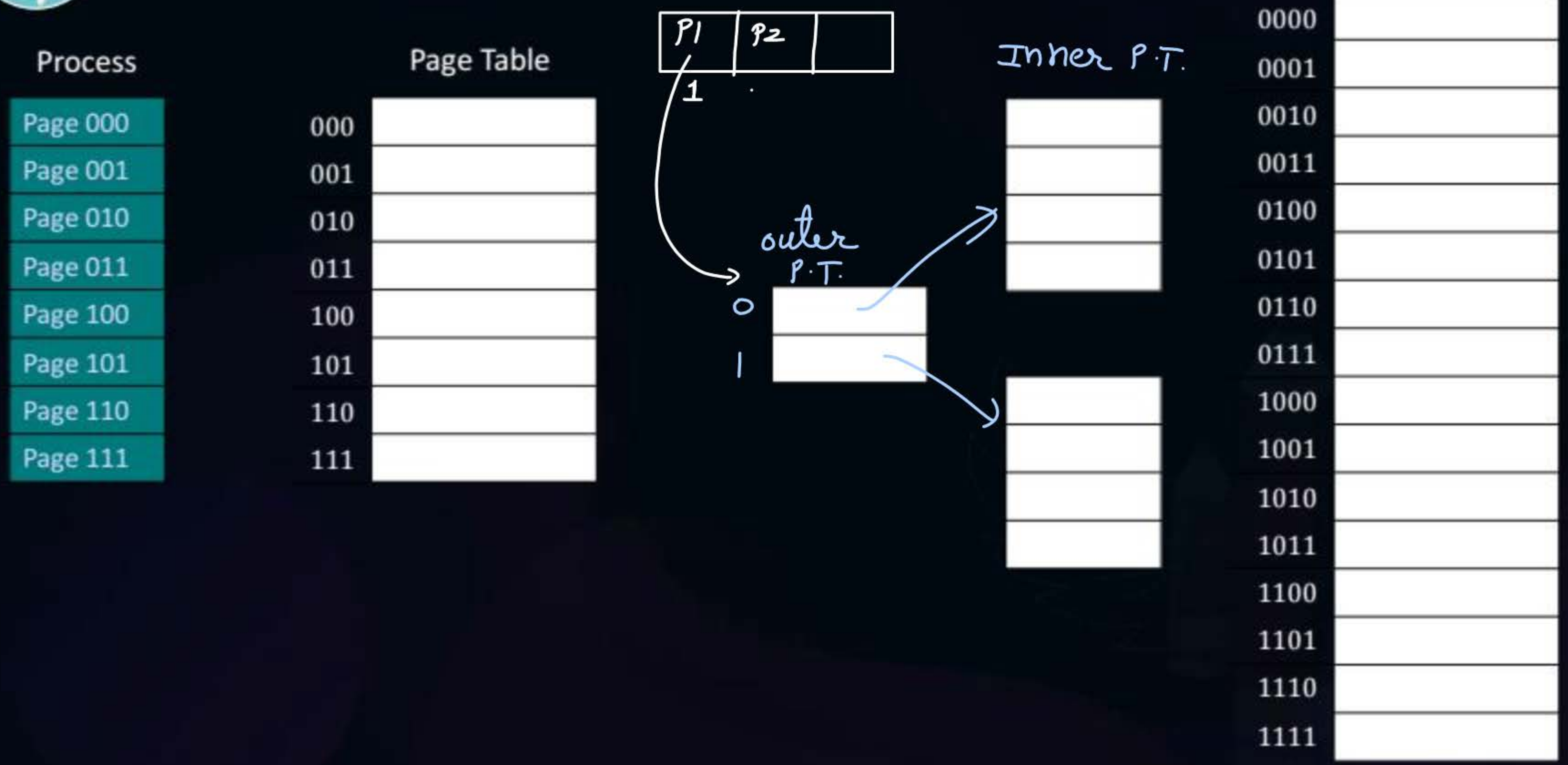
Topic Multilevel Paging

Topics to be Covered

Topic Multilevel Paging

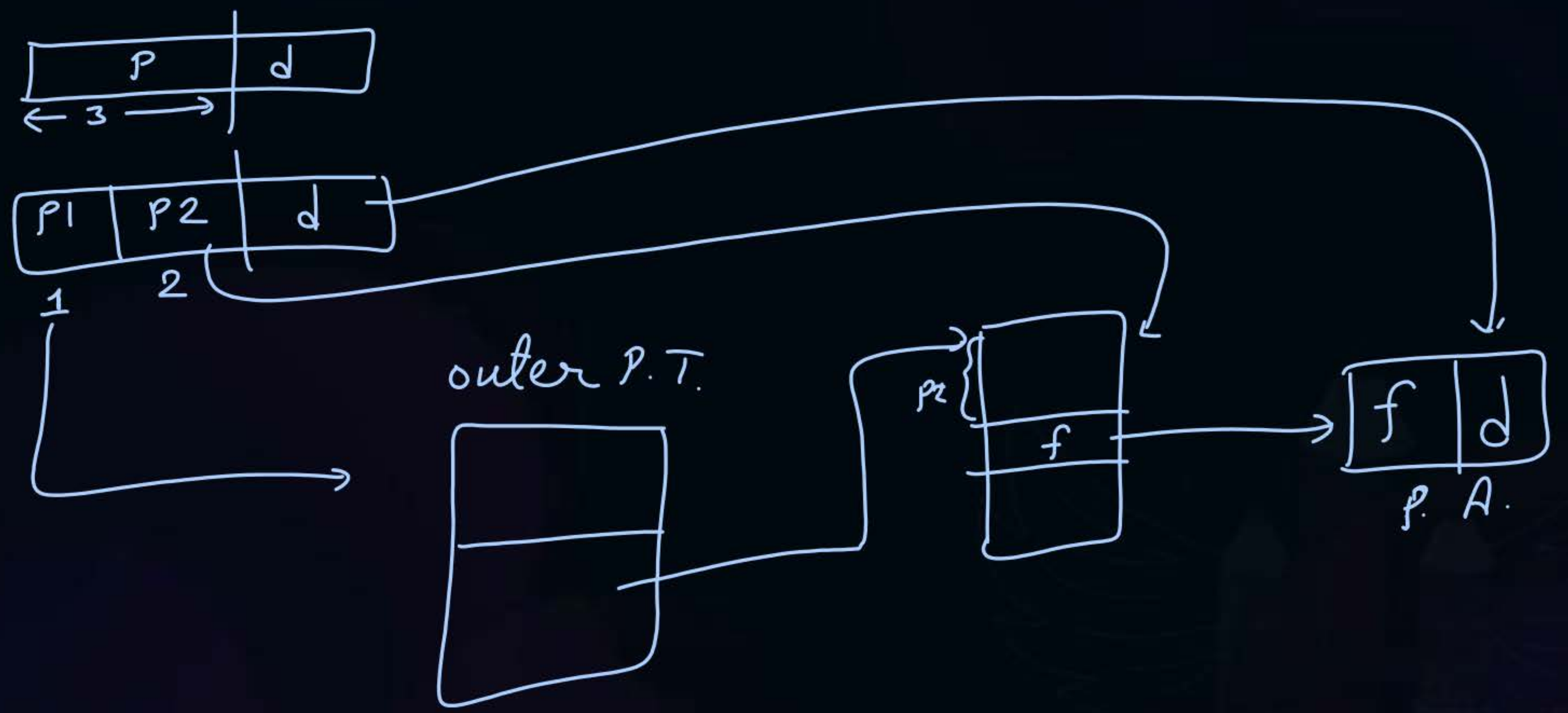
Topic Access Time in Multilevel Paging

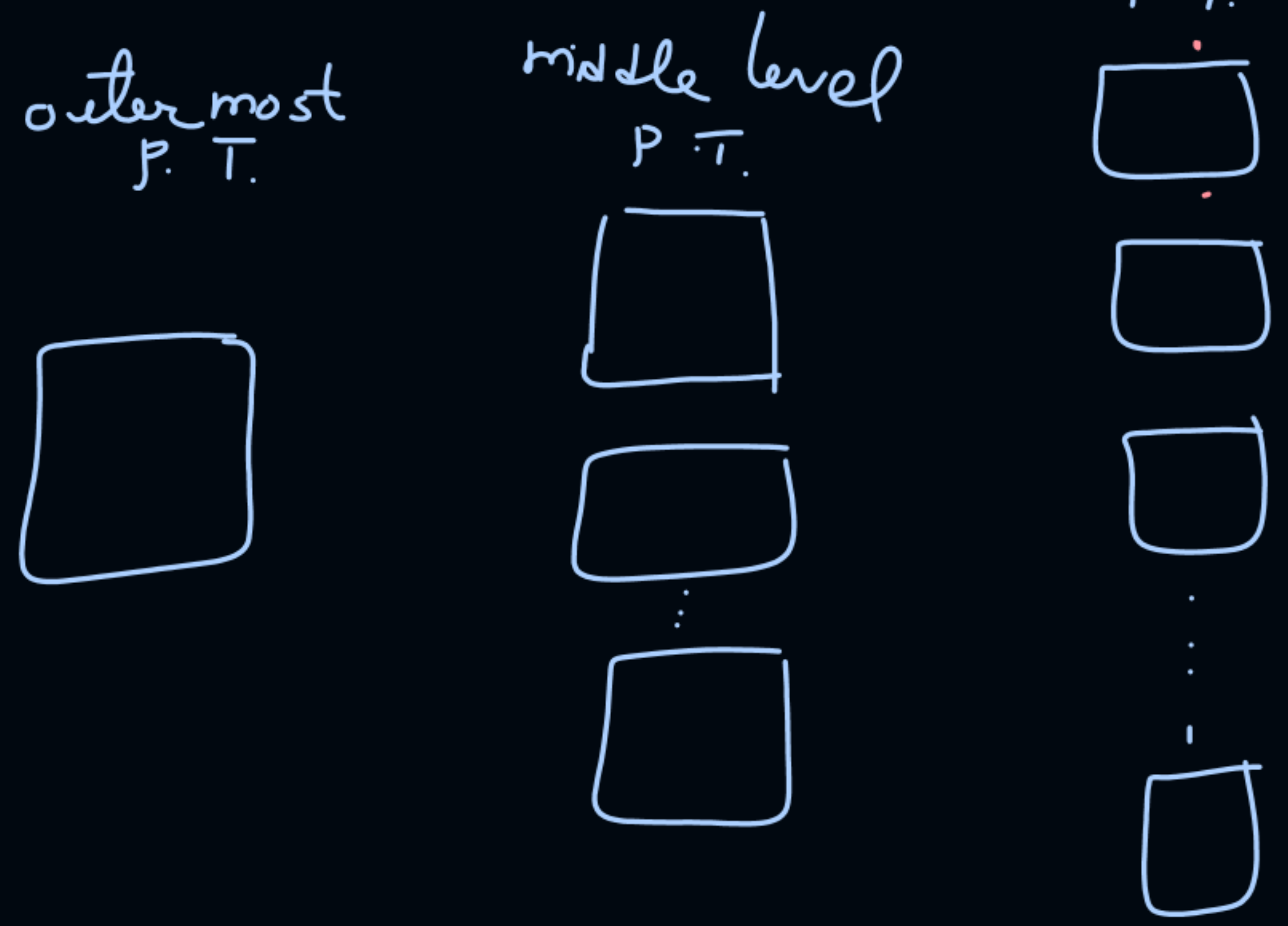
Topic : Page Table in Memory



Topic : Multilevel Paging

PTBR stores add. of outer P.T.





outermost P.T. must be stored in single page.

If any level P.T. cannot fit into a single page, then level must be increased.

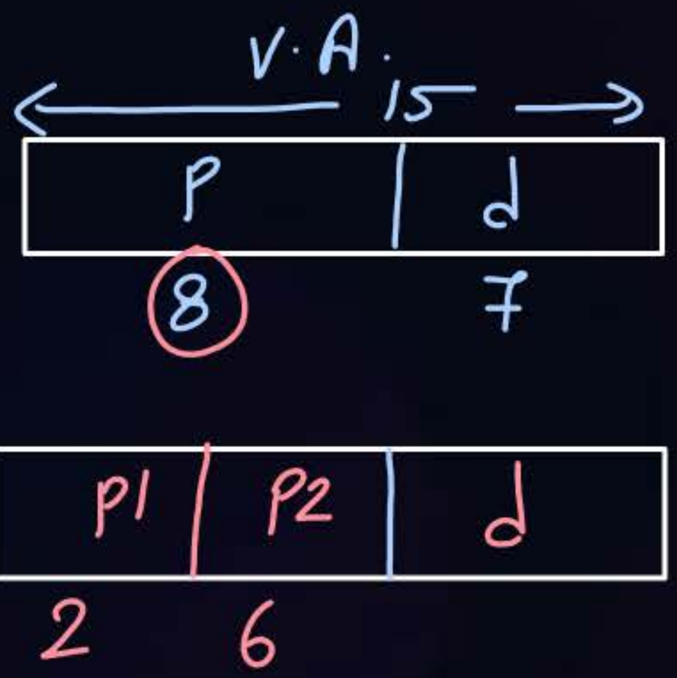
Topic : Question

VA = 15 bits

Page size = 128 bytes $= 2^7 B \Rightarrow d = 7$ bits

Page table entry size = 2 bytes

Number of levels in multilevel page __2__?



$$\text{no. of P.T. entries stored in single page} = \frac{\text{Page size}}{\text{P.T.E. size}}$$

$$= \frac{128B}{2B} = 64 = 2^6$$

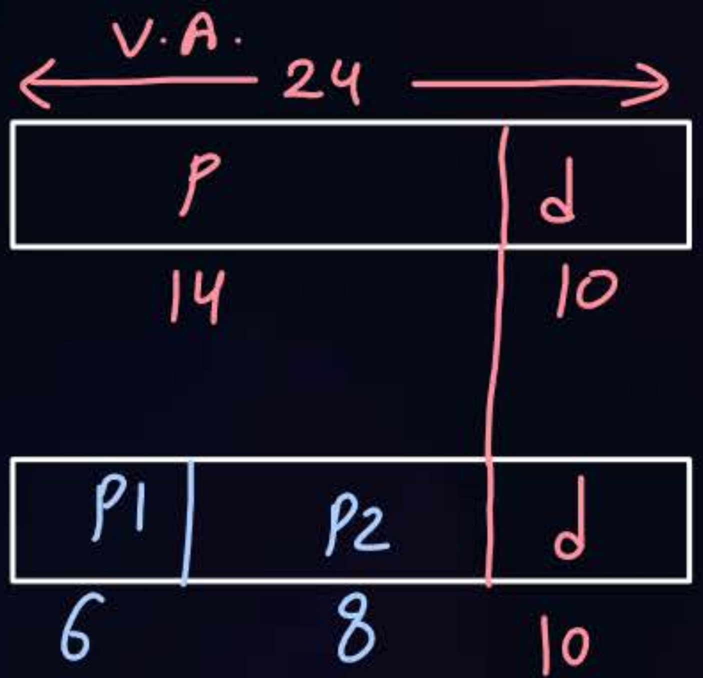
Topic : Question

VA = 24 bits

Page size = 1Kbytes $= 2^{10} B \Rightarrow d = 10$ bits

Page table entry size = 4 bytes

Number of levels in multilevel page ___2___?



no. of P.T. entries stored in page $= \dfrac{2^{10} B}{2^{2} B} = 2^{8}$

Topic : Question

VA = 29 bits

Page size = 2Kbytes $= 2^{11} B \Rightarrow d = 11$ bits

Page table entry size = 4 bytes

Number of levels in multilevel page 2 ?

$\longleftarrow 29 \longrightarrow$

p1	p2	d
9	9	11

no. of P.T. entries per page $= \dfrac{2^{11} B}{4B} = 2^9$

Topic : Question

VA = 40 bits

Page size = 4Kbytes $= 2^{12}\,B \Rightarrow d = 12$ bits

Page table entry size = 8 bytes

Number of levels in multilevel page <u>4</u> ?

$\longleftarrow 40 \longrightarrow$

P1	P2	P3	P4	d
1	9	9	9	12

no. of P.T.E. Per page $= \dfrac{2^{12}}{2^3} = 2^9$

Topic : Question

Ans = 3

$2^{13}B \Rightarrow d = 13$

#Q. Consider a virtual memory system with physical memory of 8GB, a page size of 8KB and 46-bit virtual address. Assume every page table exactly fits into a single page. If page table entry size is 4B then how many levels of page tables would be required.

$\longleftarrow 46 \longrightarrow$

p1	p2	p3	d
11	11	11	13

no. of P.T. entries per page $= \dfrac{2^{13}B}{2^{2}B} = 2^{11}$

Topic : Question

GATE- 2023

#Q. Consider a computer system with 57-bit virtual addressing using multi-level tree-structured page tables with L levels for virtual to physical address translation. The page size is 4KB (1KB=1024B) and a page table entry at any of the levels occupies 8 bytes.

$\rightarrow 2^{12} B \Rightarrow d = 12$

The value of L is ___5___?

$\longleftarrow 57 \longrightarrow$

p1	p2	p3	p4	p5	d
9	9	9	9	9	12

No. of PTE per page $= \frac{4KB}{8B} = \frac{2^{12}}{2^3} = 2^9$

Topic : Question

VA = 26 bits

Page table entry size = 4 bytes

2-level paging

Outer page table fits into a page exactly

Page size = <u>1</u> Kbytes?

$\longleftarrow 26 \longrightarrow$

p1	p2	d
$x-2$	$x-2$	x

$(x-2)+(x-2)+x = 26$

$3x-4 = 26 \Rightarrow \boxed{x = 10}$

Assume page size $= 2^x$ B $\Rightarrow d = x$ bits

no. of P.T.E. per page $= \dfrac{2^x \cancel{B}}{2^2 \cancel{B}}$

$= 2^{x-2}$

Page size $= 2^{10}$ B $= 1$ KB

Topic : Question

VA = 35 bits

Page table entry size = 8 bytes

3-level paging

Outer page table fits into a page exactly

Page size = 2 Kbytes?

Page $= 2^x$ B

no. of P.T.E. per page

$$= \frac{2^x B}{2^3 B} = 2^{x-3}$$

35

p1	p2	p3	d
$x-3$	$x-3$	$x-3$	x

$3(x-3) + x = 35$

$4x - 9 = 35$

$x = 11$

Page size $= 2^{11}$ B $= 2$ KB

Topic : Question

GATE - 2013

#Q. A computer uses 46–bit virtual address, 32–bit physical address, and a three–level paged page table organization. The page table base register stores the base address of the first–level table (T1), which occupies exactly one page. Each entry of T1 stores the base address of a page of the second–level table (T2). Each entry of T2 stores the base address of a page of the third–level table (T3). Each entry of T3 stores a page table entry (PTE). The PTE is 32 bits in size. What is the size of a page in KB in this computer?

$\Downarrow$ 4B

$\longleftarrow$ L.A. 46 $\longrightarrow$

P1	P2	P3	d
$x-2$	$x-2$	$x-2$	x

$3(x-2)+x = 46$ bits

$3x-6+x = 46$

$x = 13$

Page size $= 2^{13}$ B

$= 8$ KB

Page size = 4 Bytes

p1	p2	d
1	2	⟷

no. of pages in outer most p.T. = 1

no. of —"— Inner —"— $= 2^{p1} = 2^{1} = 2$

3 pages needed to store p.T. across all levels

p1


p.T. size across all levels = 3 * 4B

= 12 Bytes

Topic : Question

Size of page tables across all levels?

P1	P2	D
1	8	10

Page $= 2^{10}$ B
$= 1$ KB

no. of pages in outermost P.T. $= 1$

—11— Inner P.T. $= 2^{P1} = 2^1 = 2$

Total no. of pages $= 3$

P.T. size across all level $= 3 * 1$ KB
$= 3$ KB

Topic : Question

Size of page tables across all levels?

P1	P2	D
2	9	12

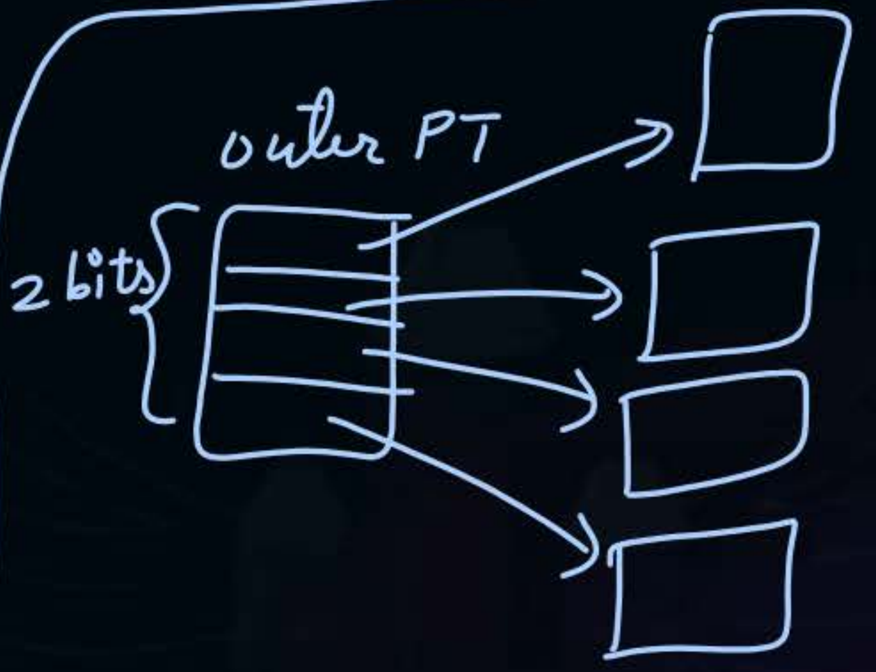
Page size $= 2^{12}$ Bytes

$= 4$ KB

No. of pages to store outer P.T. $= 1$

—— 11 —— Inner P.T. $= 2^2 = 4$

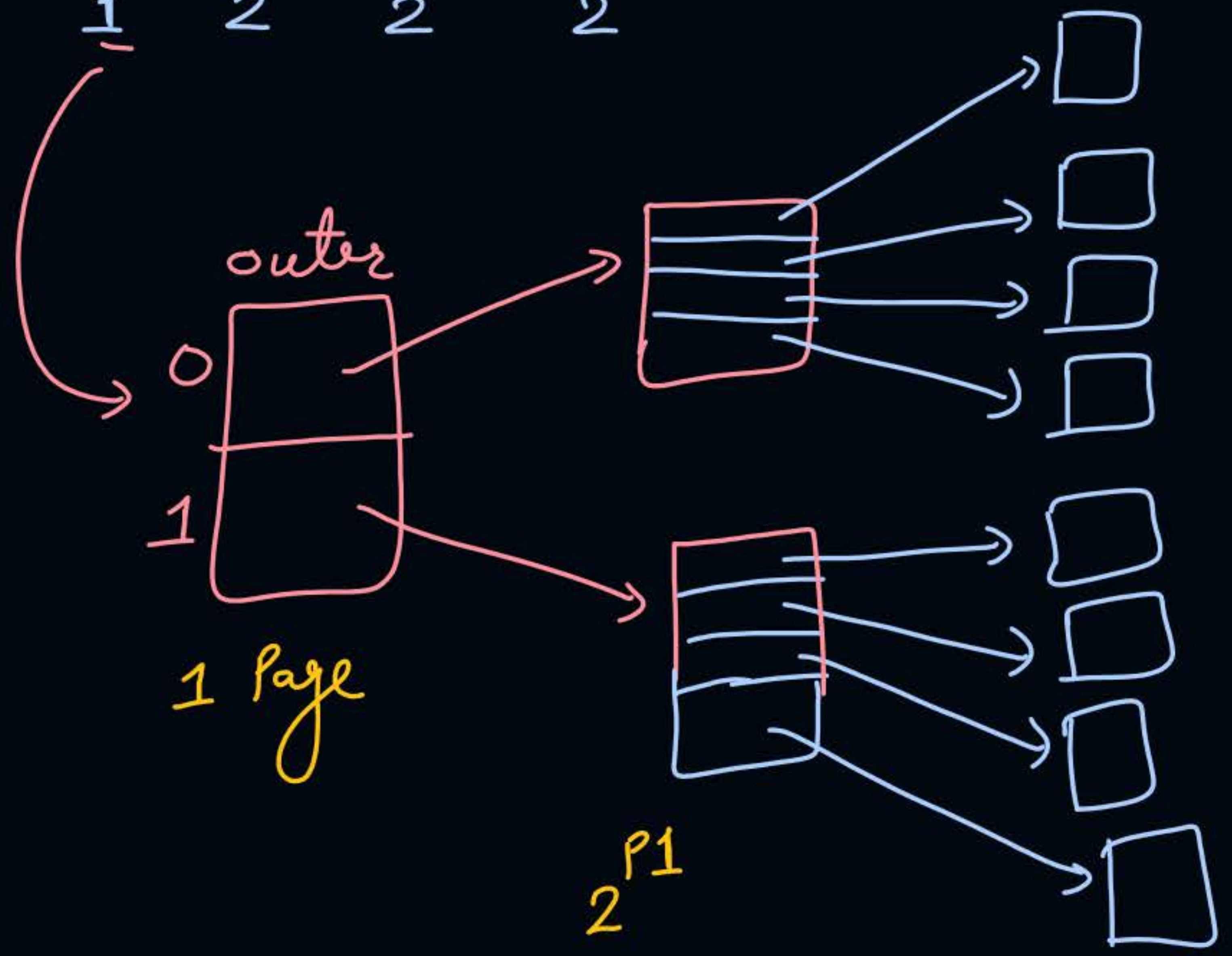
Total $= 5$



P.T. size across all level $= 5 * 4KB = 20kB$

ex:-

p1	p2	p3	d
1	2	2	2



$$\text{Total pages} = 1 + 2 + 8$$
$$= 11$$

$$2^{p1} * 2^{p2} = 2^1 * 2^2 = 2^3 = 8$$

Topic : Question

Size of page tables across all levels?

P1	P2	P3	D
1	8	8	10

1 Page size = 2^{10} B = 1 KB

no. of pages in outer most P.T. = 1

— " — middle level PT = $2^{P1} = 2^{1} = 2$

— " — Inner most PT = $2^{P1} * 2^{P2} = 2^{1} * 2^{8} = 2^{9} = 512$

Total = 515 pages

space = 515 * 1 KB = 515 KB

#Q.

p1	p2	p3	d
2	10	10	11

Page size $= 2^{11}$ B $= 2$ kB

no. of pages to store outermost PT $= 1$

—— 11 —— middle —11— $= 2^2 = 4$

—— 11 —— Innermost —11— $= 2^2 * 2^{10} = 2^{12} = 4096$

Total no. of pages $= 4101$

Total P.T. size across all levels $= 4101 * 2$ kB

$= 8202$ KB

Topic : Question

H.W.

#Q. Size of page Consider a three-level page table to translate a 39-bit virtual address to a physical address as shown below:

39-bits Virtual Address

Level-1 Offset	Level-2 Offset	Level-3 Offset	Page Offset
9 bits	9 bits	9 bits	12 bits

The page size is 4 KB = (1KB = 2^{10} bytes) and page table entry size at every level is 8 bytes. A process P is currently using 2 GB (1 GB = 2^{30} bytes) virtual memory which OS mapped to 2 GB of physical memory. The minimum amount of memory required for the page table of P across all levels is _______ KB across all levels?

Topic : Question

H.ω.

#Q. Consider a 32-bit system with 4 KB page size and page table entries of size 4 bytes each. Assume 1 KB = 2^{10} bytes. The OS uses a 2-level page table for memory management, with the page table containing an outer page directory and an inner page table. The OS allocates a page for the outer page directory upon process creation. The OS uses demand paging when allocating memory for the inner page table, i.e. a page of the inner page table is allocated only if it contains at least one valid page table entry.

An active process in this system accesses 2000 unique pages during its execution, and none of the pages are swapped out to disk. After it completes the page accesses, let X denote the minimum and Y denote the maximum number of pages across the two levels of the page table of the process.

The value of X + Y is ________?

2 mins Summary

Topic Multilevel Paging

Topic Access Time in Multilevel Paging

Happy Learning

THANK - YOU