CS & IT ENGINEERING

Operating Systems

Memory Management

Lecture No. 8

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TOPICS TO BE COVERED

- Multi-Level Paging
- Segmentation
- Problem Solving

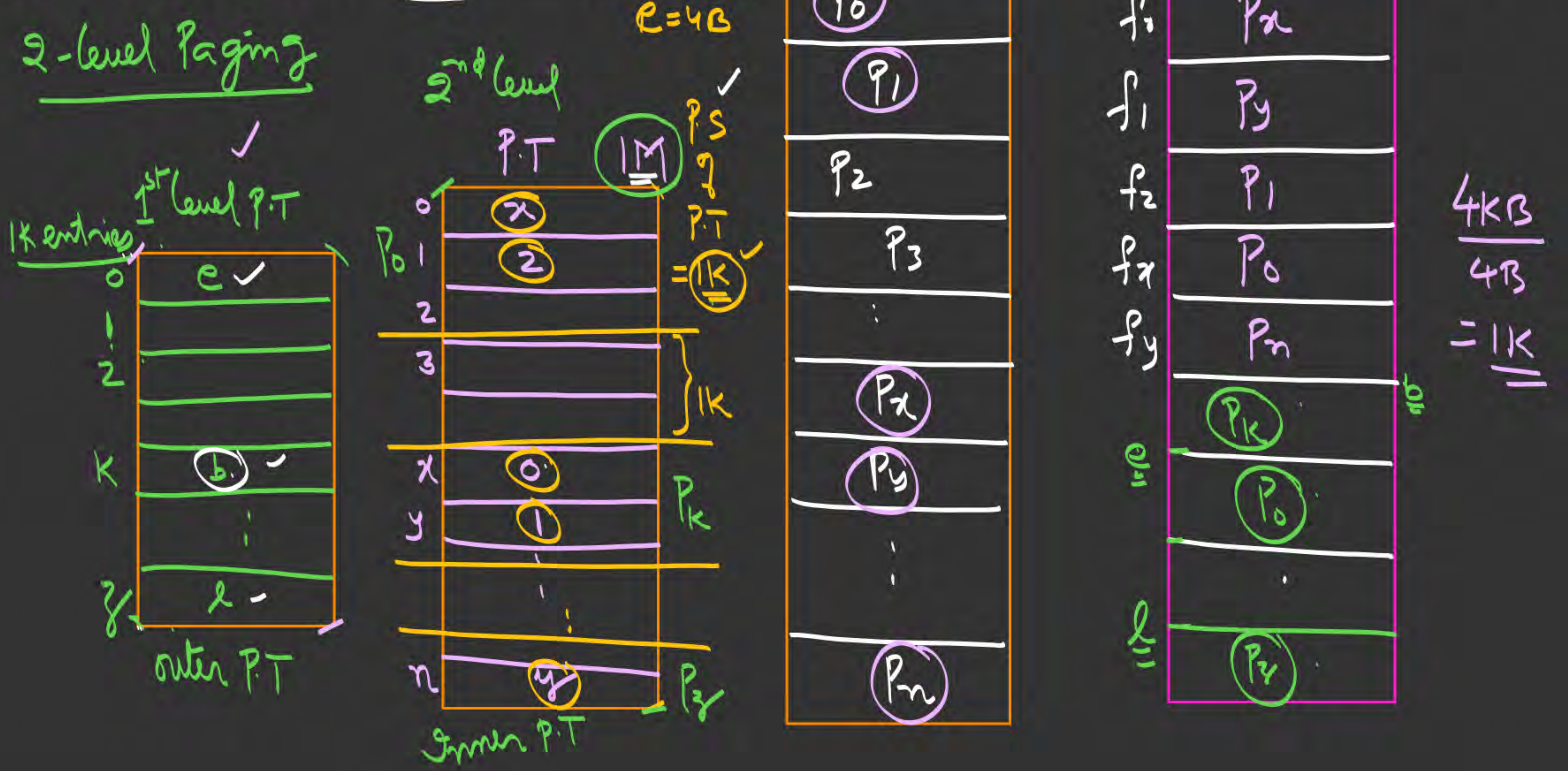
$1K + 3K = 4K$

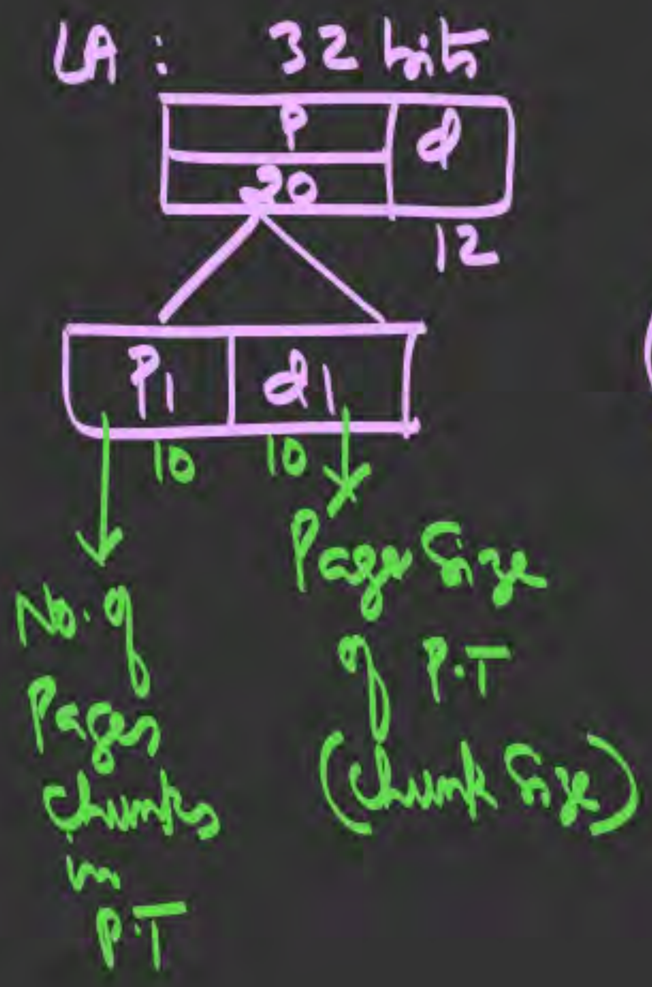
Multi-Level Paging / Hierarchical Paging / Tree-level

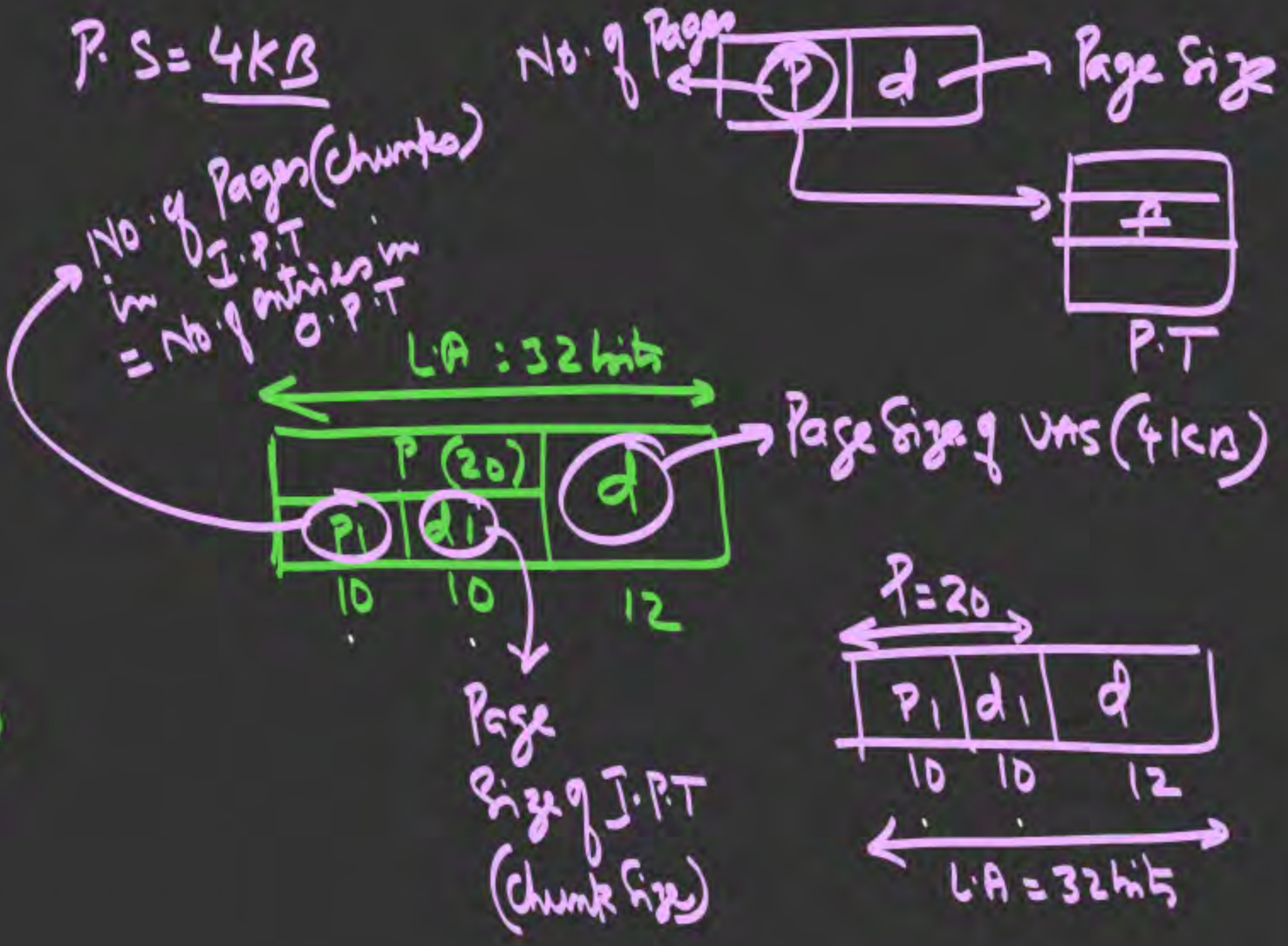
L.A = 32 bits ; P.S = 4KB ; N = 1M

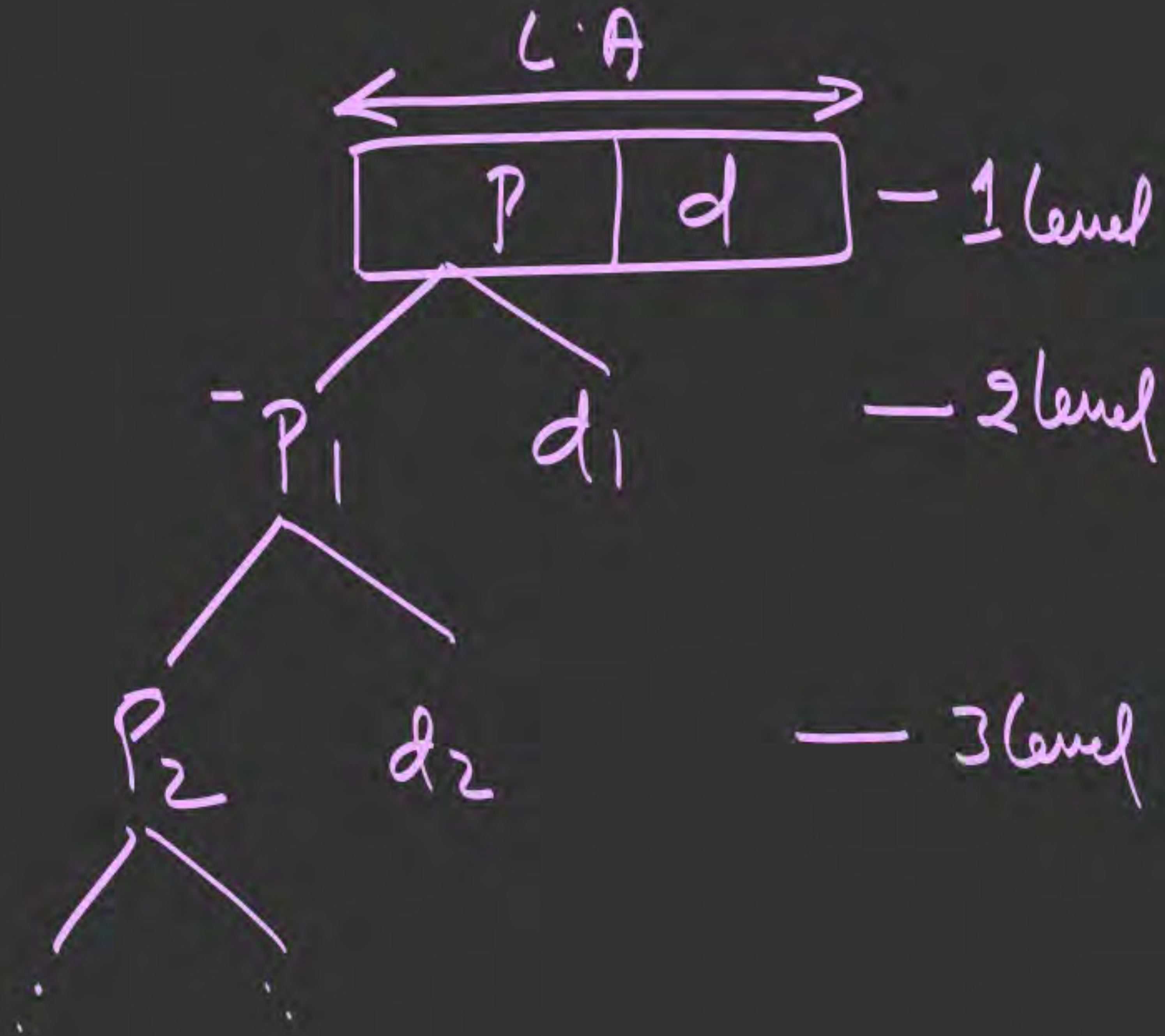
1M Pages VAS = 4GB

P.A.S




LA : 32 bits
P
d
20
12
P1
d1
10
10
No. g Pages chunks in P.T
Page Size g P.T (chunk Size)


P. S = 4KB
No. g Pages
p
d
Page Size
f
P.T
No. g Pages (chunks) in I.P.T = No. g entries in O.P.T
L.A : 32 bits
P (20)
d
P1
d1
10
10
12
Page Size g VAS (4KB)
Page Size g I.P.T (chunk Size)
P=20
P1
d1
d
10
10
12
L.A = 32 bits

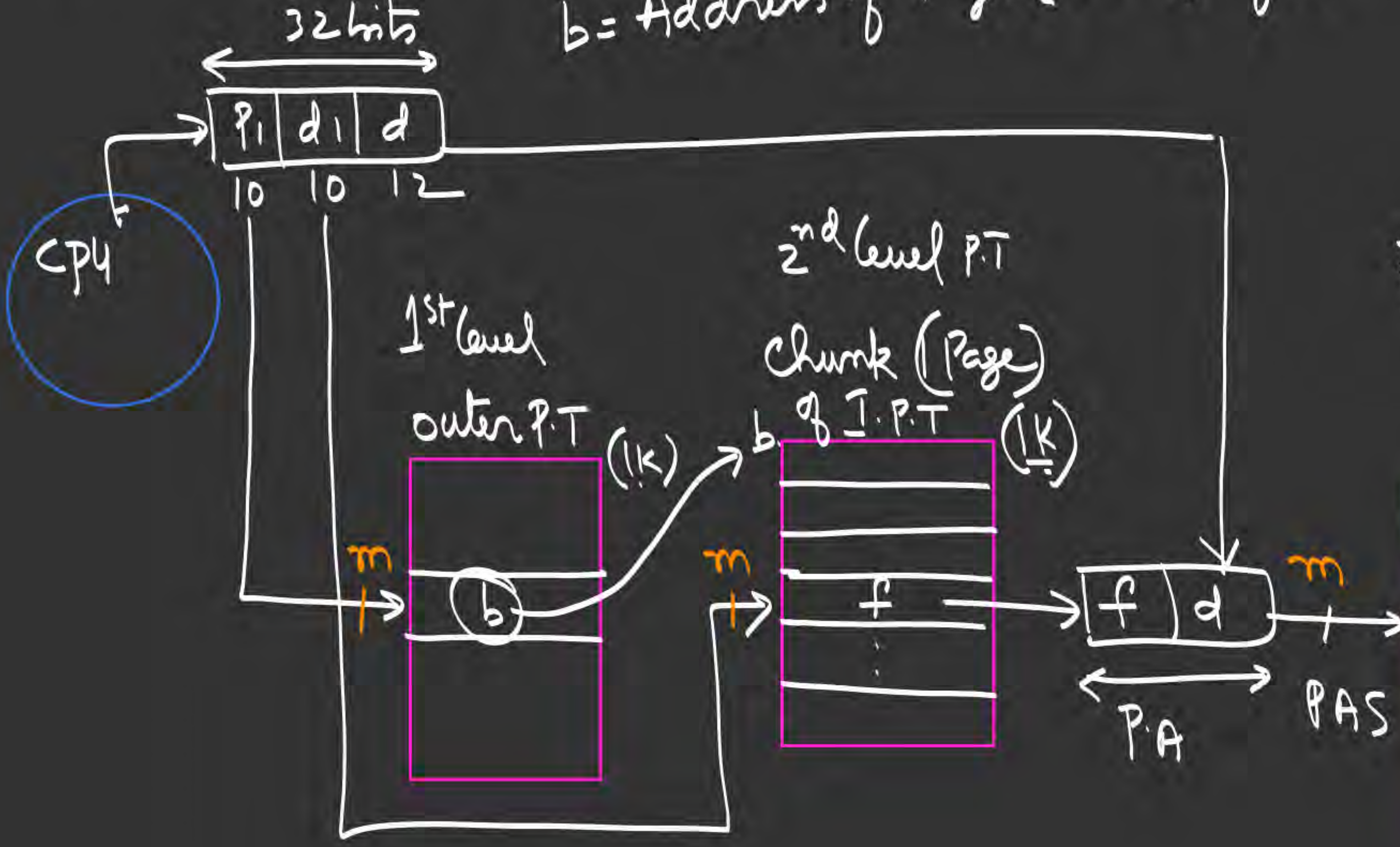

L.A
P
d
1 level
P1
d1
2 level
P2
d2
3 level

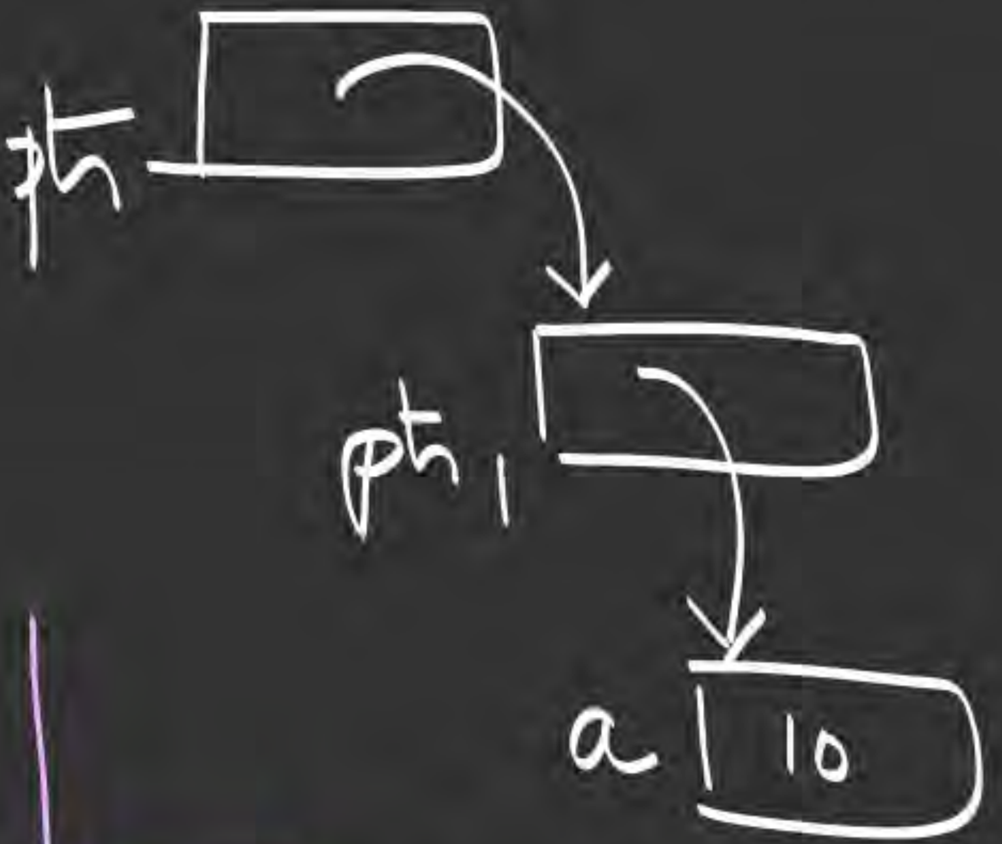
L.A : 32 bits ; P.S = 4KB ;

b = Address of Page (Chunk) of I.P.T

Perf.

int **ptr;

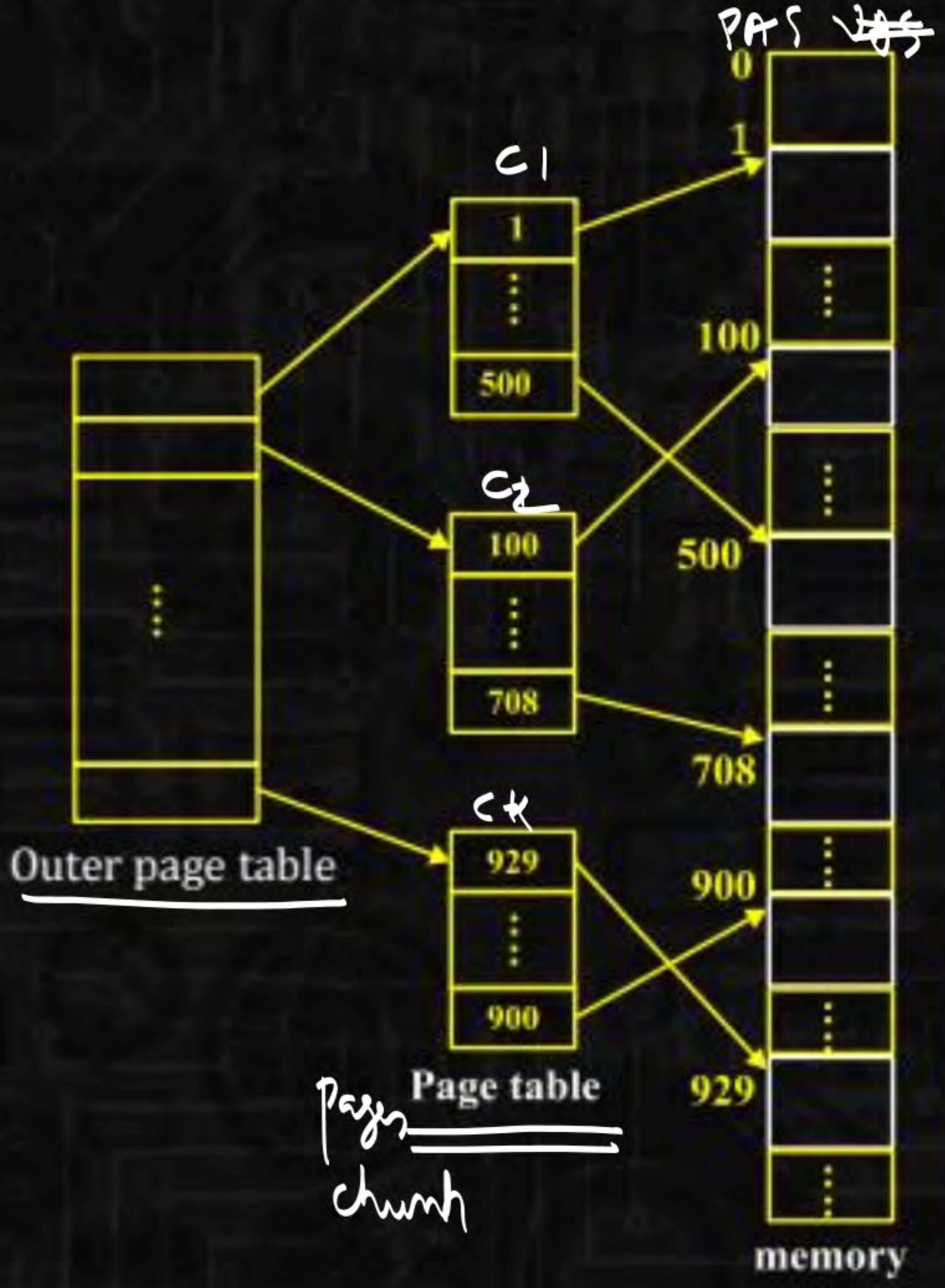


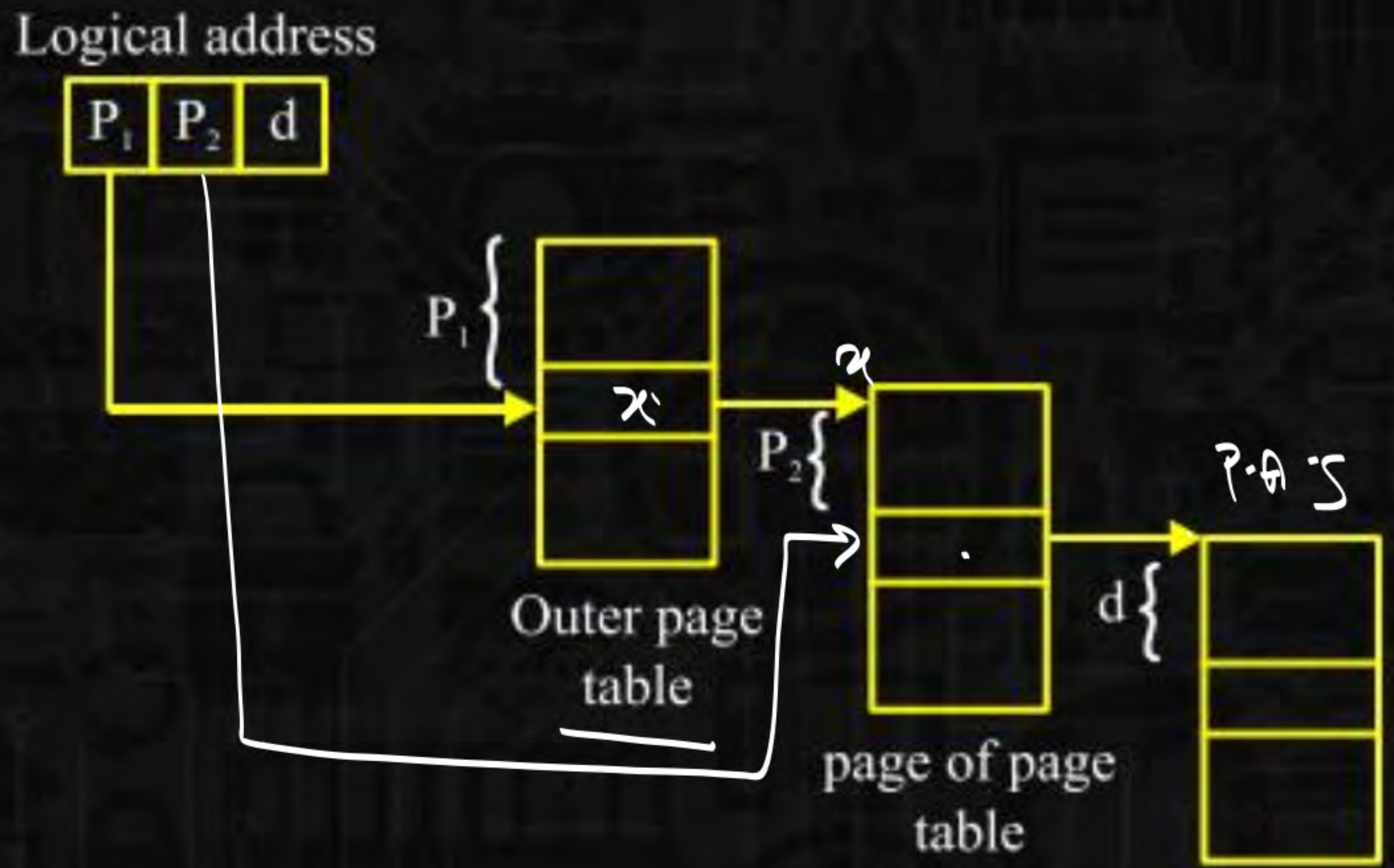


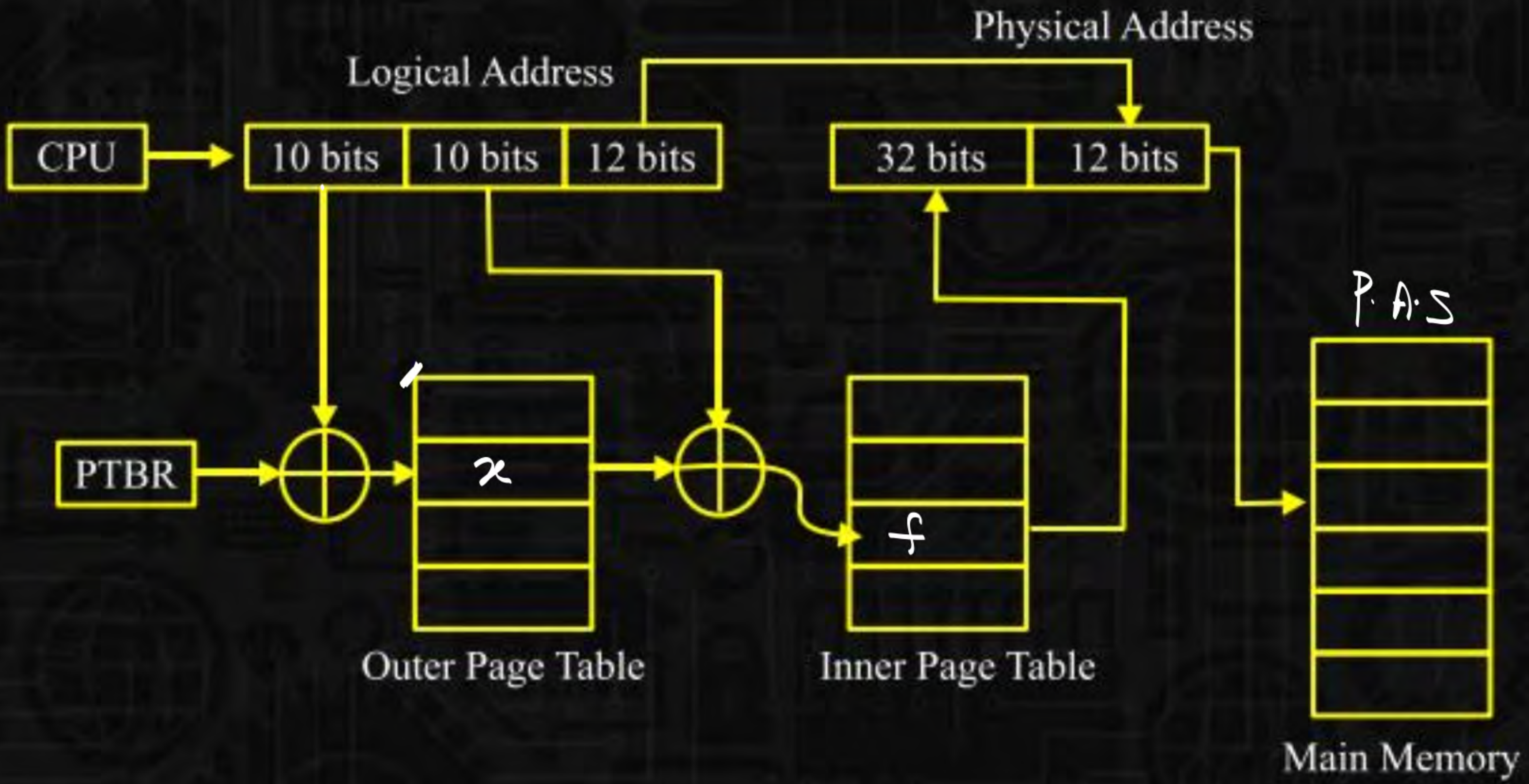
→ MMAT = 'm'

→ $EMAT_{2LP} = 3m$

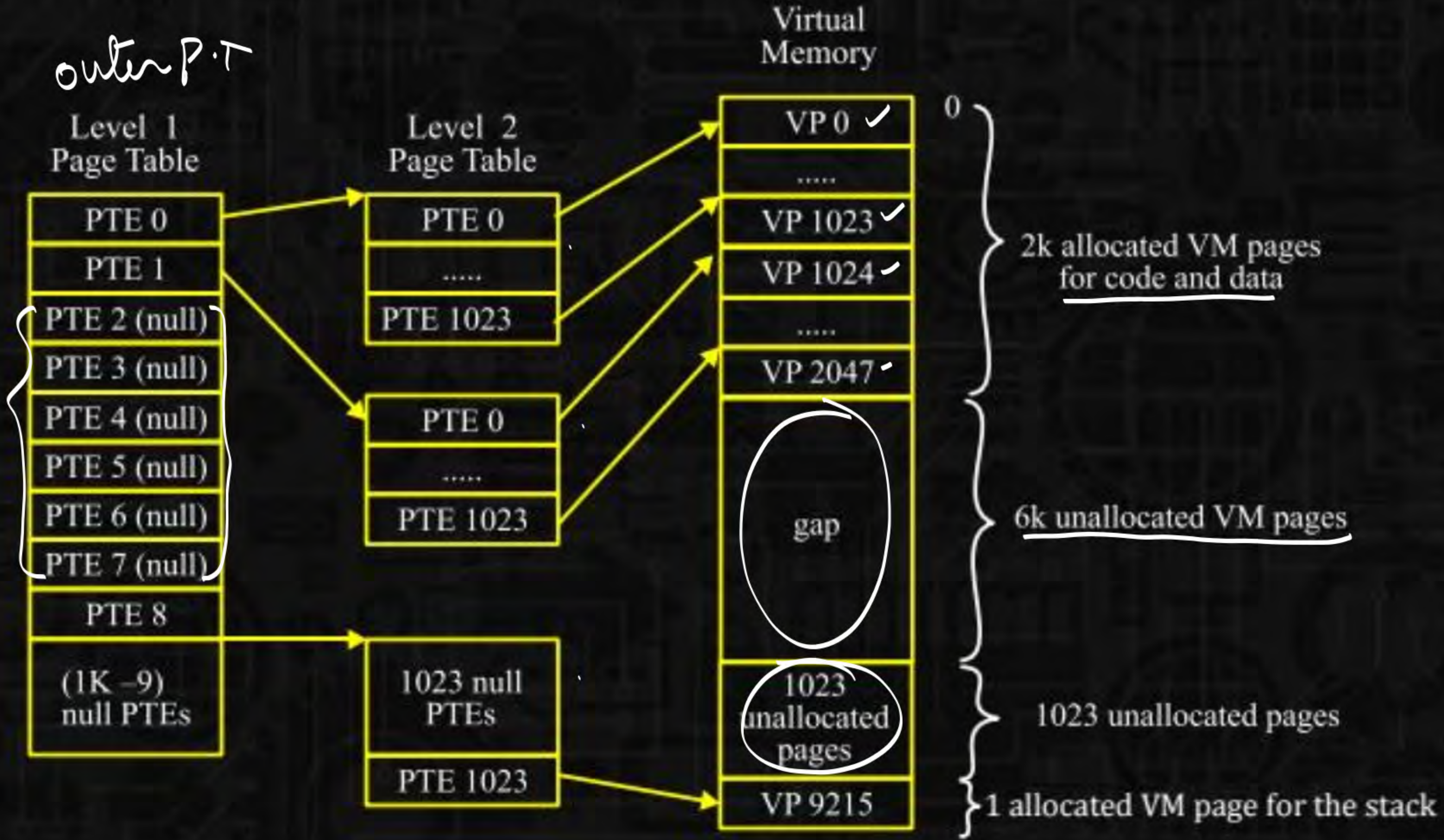
→ $EMAT_{nLP} = (n+1) \cdot m$


PAS ~~VAS~~
0
1
C1
1
500
100
500
C2
100
708
708
Ck
929
900
900
929
Outer page table
Page table
Pages
chunk
memory


Logical address
P_1
P_2
d
P_1
x
x
P_2
P.A.S
d
Outer page table
page of page table


Physical Address
Logical Address
CPU
10 bits
10 bits
12 bits
32 bits
12 bits
P.A.S
1
PTBR
x
f
Outer Page Table
Inner Page Table
Main Memory

Multi-Level Page Table



outer P.T

Level 1 Page Table

- PTE 0
- PTE 1
- PTE 2 (null)
- PTE 3 (null)
- PTE 4 (null)
- PTE 5 (null)
- PTE 6 (null)
- PTE 7 (null)
- PTE 8
- (1K –9) null PTEs

Level 2 Page Table

- PTE 0
- .....
- PTE 1023

- PTE 0
- .....
- PTE 1023

- 1023 null PTEs
- PTE 1023

Virtual Memory

- VP 0 ✓
- .....
- VP 1023 ✓
- VP 1024 ✓
- .....
- VP 2047 ✓
- gap
- 1023 unallocated pages
- VP 9215

0

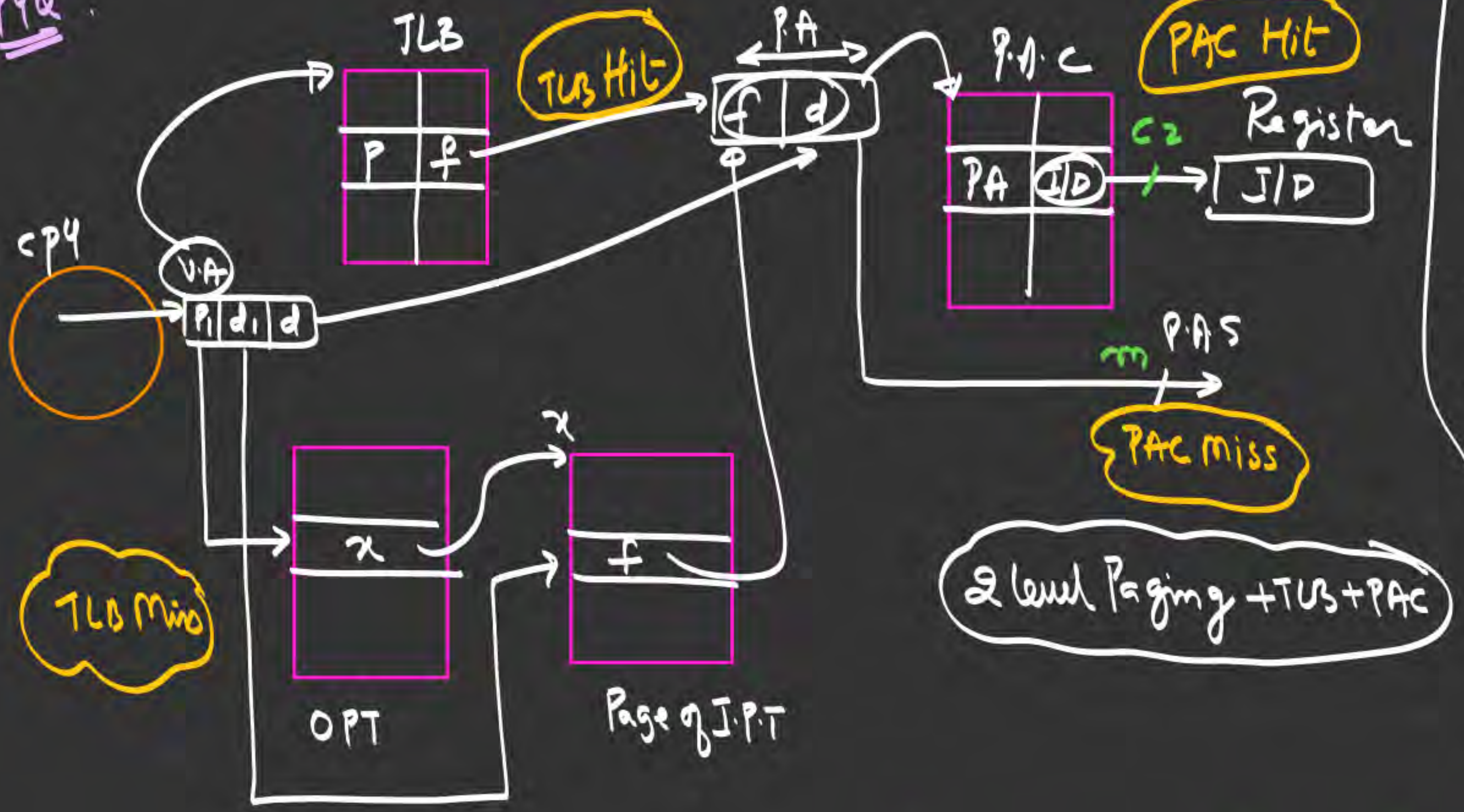
2k allocated VM pages for code and data

6k unallocated VM pages

1023 unallocated pages

1 allocated VM page for the stack

PYQ



→ MMAT = m

→ TLB AT = c_1

→ TLB Hit ratio = x_1

→ PAC AT = c_2

→ PAC Hit ratio = x_2

$$EMAT_{2LP} = x_1\left[c_1 + x_2c_2 + (1-x_2)(c_2+m)\right]$$
$$+ (1-x_1)\left[c_1 + \underline{m + m} + x_2c_2 + (1-x_2)(c_2+m)\right]$$

Q. In the context of operating systems, which of the following statements is/are correct with respect to paging?

MSQ

A. ✗ Page size has no impact on internal fragmentation.

B. ✓ Paging helps solve the issue of external fragmentation.

C. ✓ Paging incurs memory overheads

Space (PT's)

D. ✗ Multi-level paging is necessary to support pages of different sizes

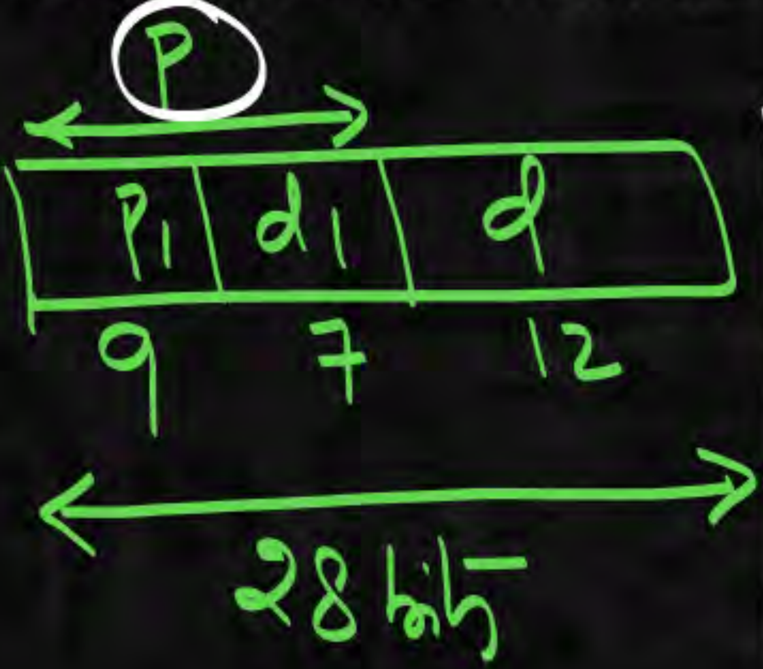
(B & C) ✓

Q. Consider a System using 2 Level Paging Architecture. The Top level 9 bits of the Virtual Address are used to index into the outer Page Table. The next 7 bits of the Address are used to index into next level Page Table. If the size of Virtual Address is 28 bits. Then

(i) How large are the Pages and How many are there in Virtual Address Space?

(ii) If P.T.E at both levels is 32 bits in size then what is the Space Overhead needed to translate Virtual Address to Physical Address of an Instruction or Data Unit?

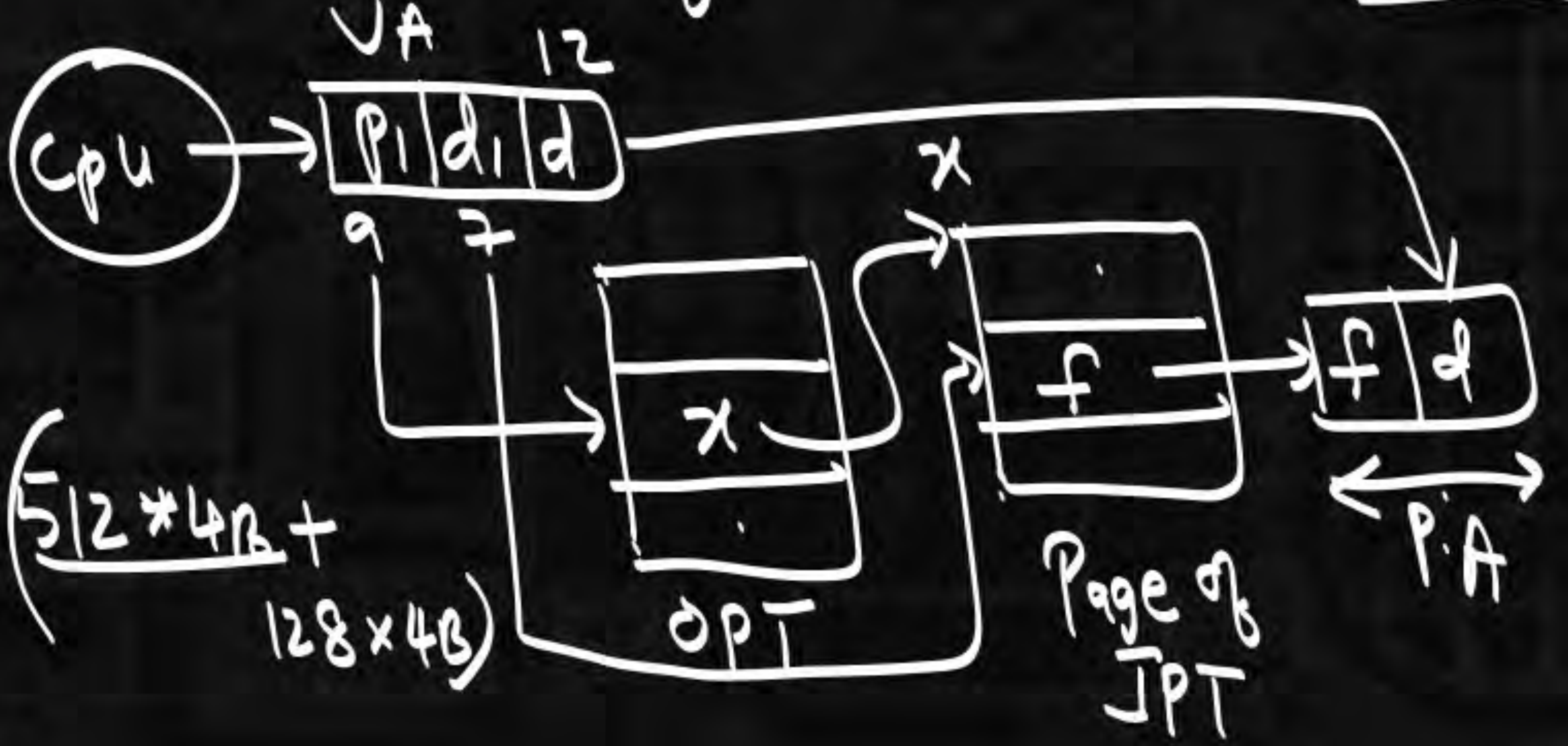
4B



$(2KB + 512B)$

$(2.5KB)$

$d \sim$ P.S of VAS $= 2^{12} = 4KB$



$(512 * 4B + 128 \times 4B)$

P ~ No. of Pages in VAS

$N = 2^{16} = 64K$

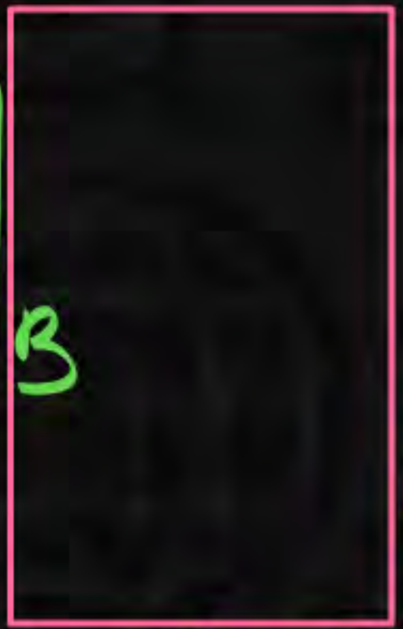
Q. Consider a Computer System using 3 Level Paging Architecture with a uniform Page Size at all levels of Paging. The size of Virtual Address is 46 bits. Page Table Entries at all levels of Paging is 32 bits. What must be the Page Size in Bytes such that the Outer Page Table exactly fits in one frame of Memory. Assume Page Size is power of 2 in Bytes. Show the Virtual Address format indicating the number of bits required to access all the three levels of Page Tables and the Page offset of Virtual Address Space.

*

(3 LP)

OPT

$\left[2^{46-3x+2+2+2}\right]B$



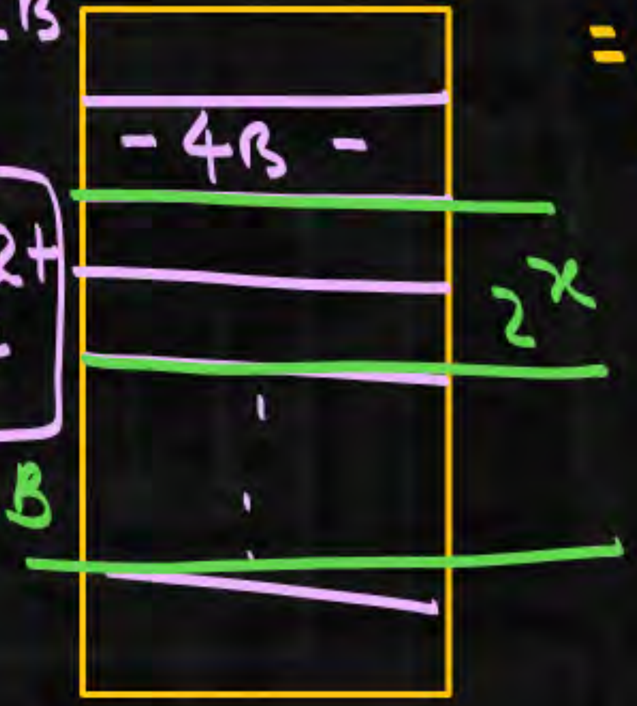
$\left[2^{46-3x+2+2+2}\right] = 2^{x}$

$x = 13$

(2-LP)

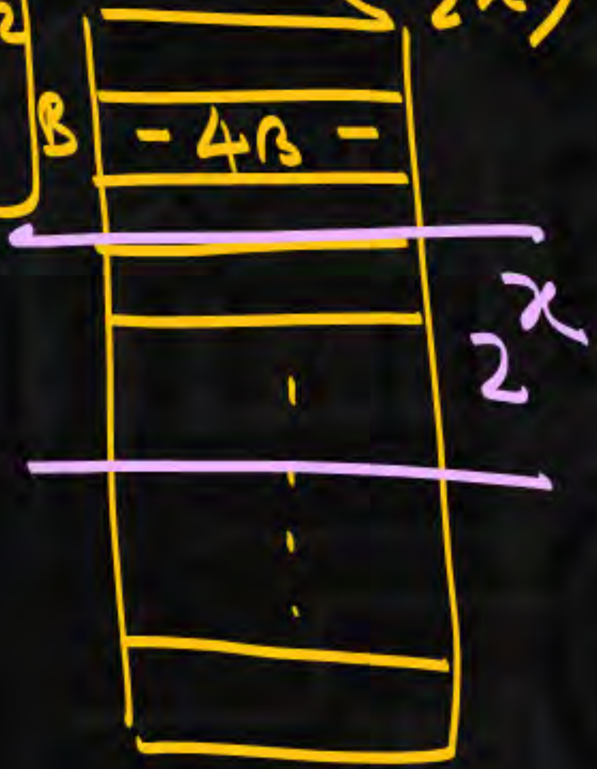
$\left[\frac{2^{46-x+2}}{2^{x}}\right] 2^{2} B$ P.T

$\left[2^{46-2x+2+2}\right] B$

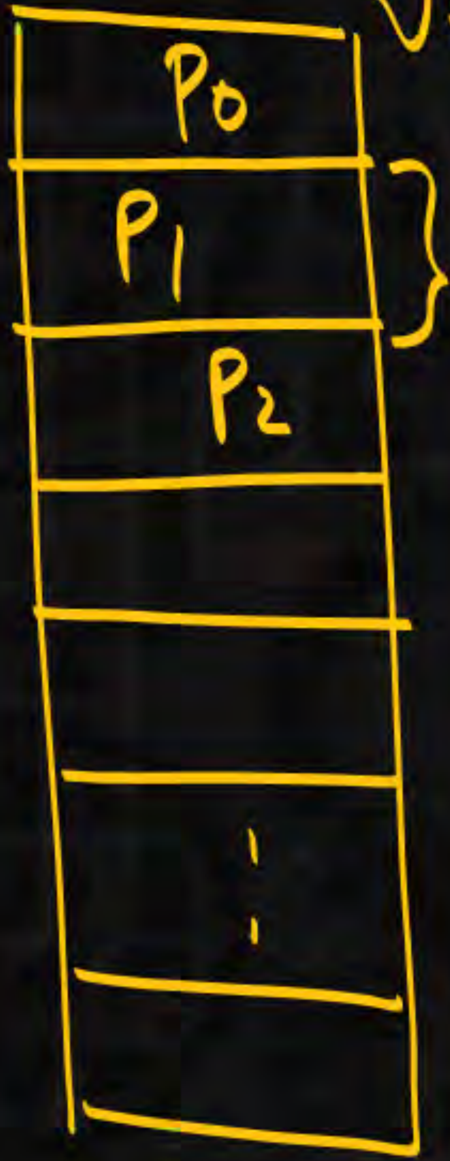


$\left[2^{46-x}\right] 2^{2} B$ P.T $\left(\frac{2^{46}}{2^{x}}\right)$

$= \left[2^{46-x+2}\right] B$



VAS $= 2^{46}$



Let

P.S $= 2^{x} B$

P.S $= 2^{13}$

$= 8KB$ ✓

Let $VAS = 2^S$ Bytes $V.A = S$ bits

$P.S = 2^x$ Bytes

$PTE = 2^c$ Bytes

No. of level's of Paging = 'l'

$$\boxed{\text{Size of outer P.T} = 2^{S - l\cdot x + l\cdot c} \text{ Bytes}}$$

$$= \left(\frac{2^S}{2^x}\right)\cdot 2^c = \left[2^{S-x+c}\right]$$

$VA = 46$ bits

$PTE = 4$ Bytes

$P.S = \underline{2^x}$ By

$l = \underline{\underline{3}}$ $\longrightarrow$ $\underline{\underline{2^{13} = 8KB}}$

$$\boxed{OPT = 2^x}$$

$LA = 46$ bits

P_1	P_2	P_3	d
$\bigcirc\!\!\!\!y$	y	y	x

$(2^y)4B$

$3y + x = 46$ — ①

$x = y + 2$ — ②

$x = 13$

$OPT = (2^y)\,4B$

$$\boxed{= 2^{y+2} \text{ By} = 2^x \text{ By}}$$

$3y + y + 2 = 46$

$4y = 44$

$\therefore y = 11$

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. Page size is 4KB and Page Table Entry is of 8 Bytes at all levels.

G2023

The value of L is ________.

VA = 57 bits

No. of levels = 'L'

P.S = 4KB ✓

PTE = 8B

No. of entries that Can be stored in one Page = $\frac{4KB}{8B}$

$= \frac{2^{12}}{2^3} = 2^9 = 512$

$OPT = \left[2^{57 - L\cdot 12 + L\cdot 3}\right]$ By ✓

$= \left[2^{57-12L+3L}\right] = 2^{12}$ B

$57 - 9L = 12$

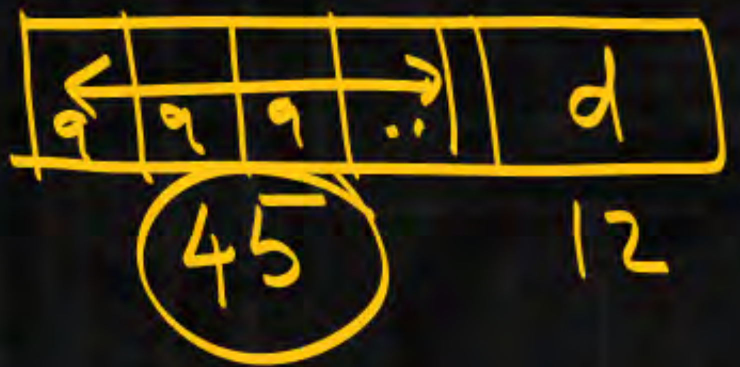
$\boxed{L = 5}$ ✓

OPT = 1 Page/Frame

$\boxed{OPT = 4KB}$

2^{12}

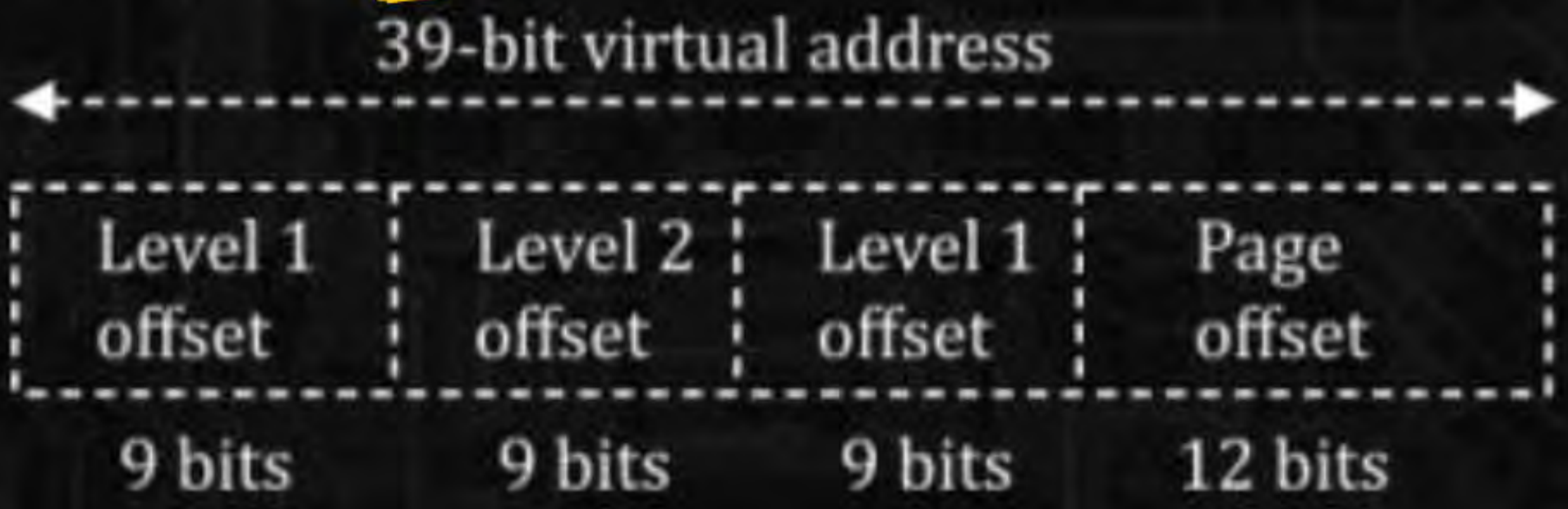
VA: 57 bits ✓



$9 \cdot L = 45$

$L = \frac{45}{9} = 5$

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



39-bit virtual address

Level 1 offset	Level 2 offset	Level 1 offset	Page offset
9 bits	9 bits	9 bits	12 bits

$2^{GB} = 31$ bit

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

(OPT + 2nd level PT + 3rd level P.T)

4 = 100

00100 0100

V·A·S = 64 KB

Text = S_1 B

Data = S_2 B

Stack = S_3 B

P.S = ? 2^x

VAS = $\left(2^{16-x}\right)$

Text =

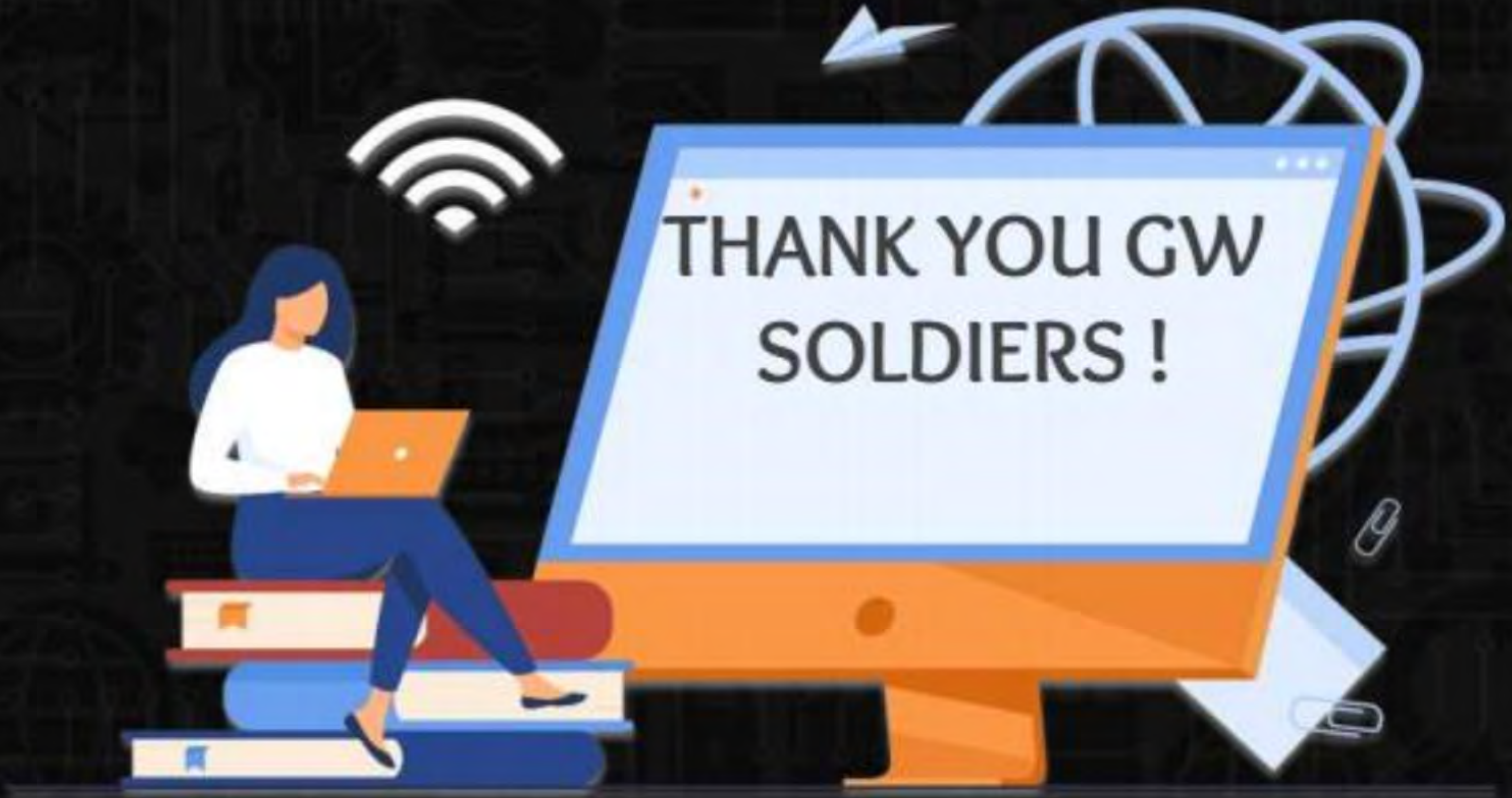
Data =

Stack =

Ans: 512 B

< Internal Frag. >

Hint



THANK YOU GW SOLDIERS !