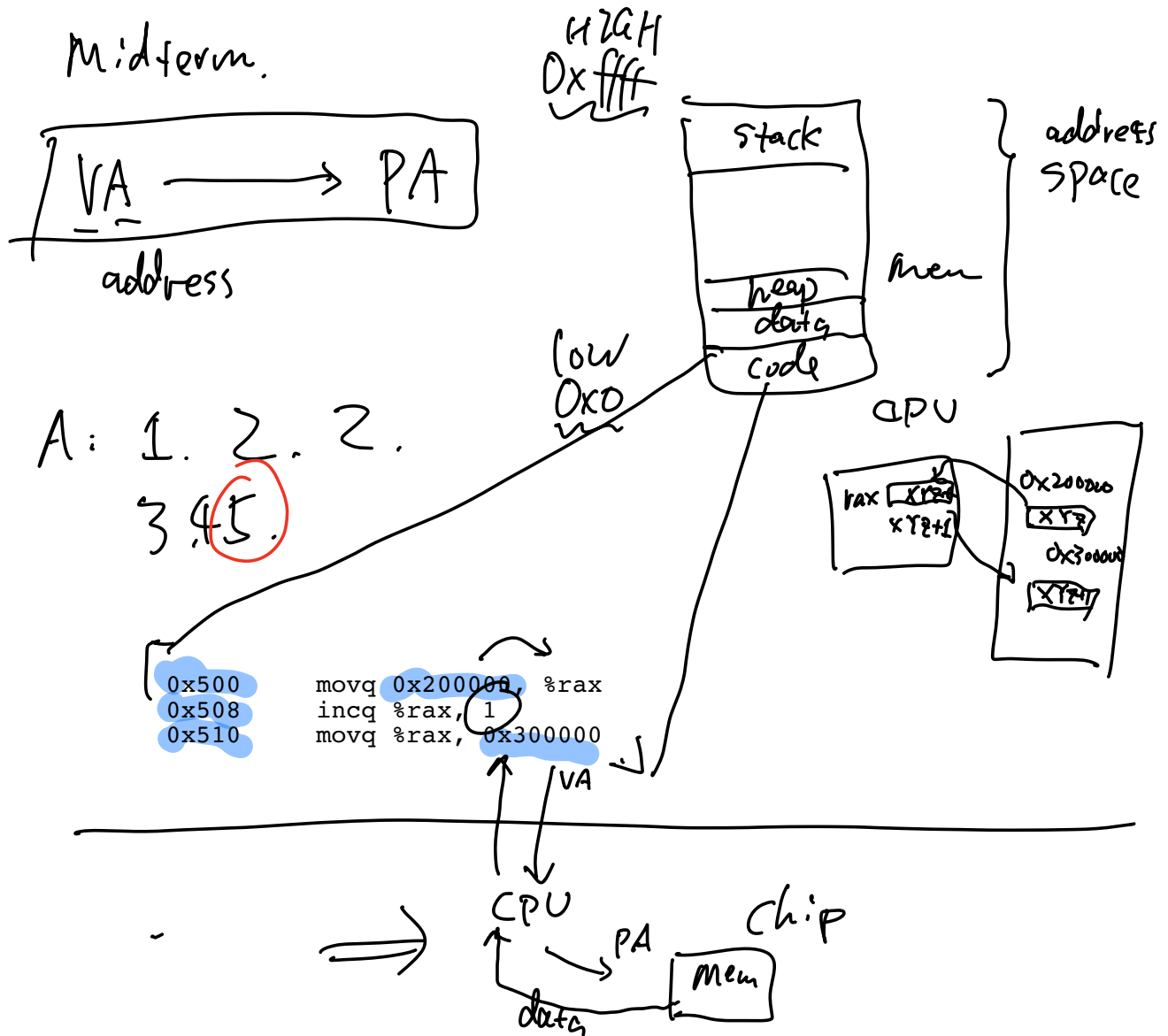


1. Intro to Virtual memory ←
 2. bit manipulation
 3. Paging
 - intro
 - page table
 - multilevel page table
 - alternatives & tradeoffs
-



benefits

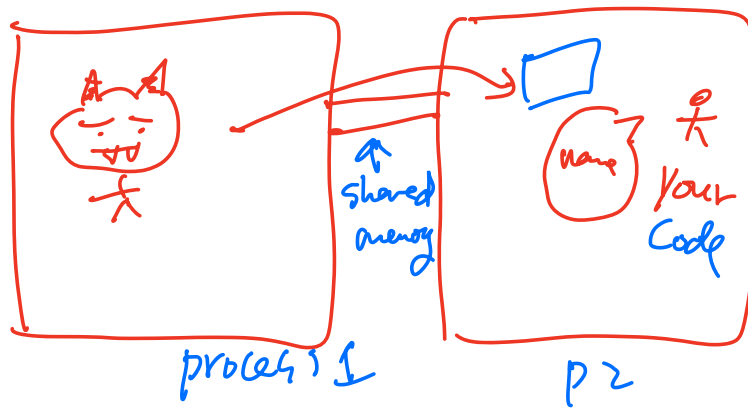
(a) program mobility

x86-64

256TB

(b) protection.

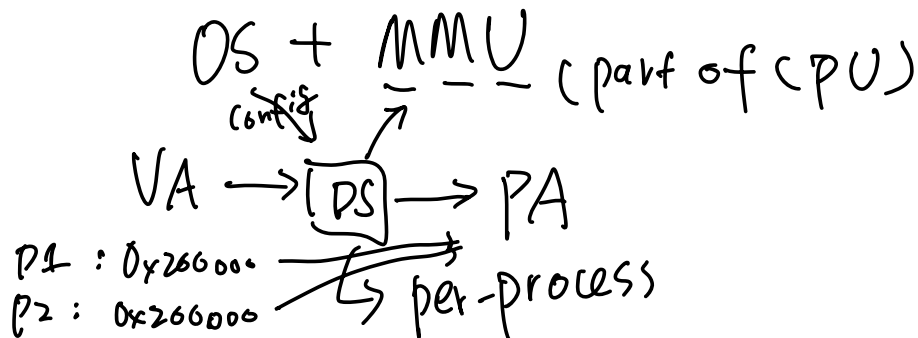
" if you cannot name it,
you cannot use it."



Q: redirection & file name.
monitor
function scope. }
file descriptor }

LCI effective use
(d) sharing.

- How to imple VM.



• Crash Course: bit manipulation.

• 0, 1: bit

• 0x 123456789abcdef

↳ hex number: base 16.

$\frac{0x10}{11}$
16

• 0000 = 0x0

1111 = 0xf

byte-addressing

$2^{40} \times (1B) = \underline{\underline{256TB}}$

• 32-bit vs. 64-bit CPUs.

↳ address: 32bit

↳ x86-64: 48bit (CPU imp.), 64bit (theoretical)

↳ $2^{40} \times (1B) = \underline{\underline{256TB}}$

• 2^{10} kilo → 1KB ≈ 1000

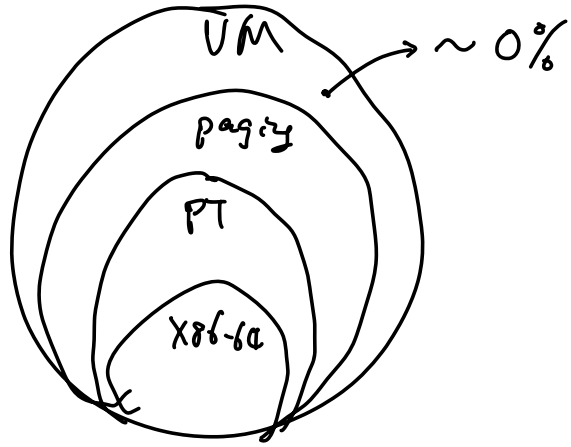
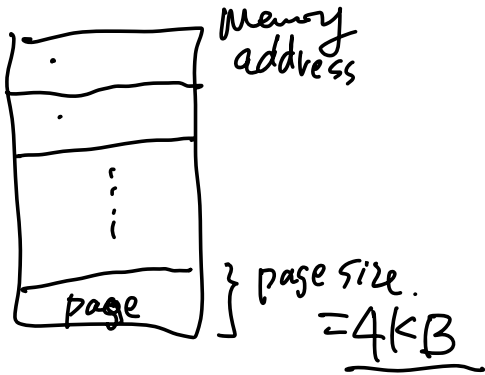
2^{20} Mega. 1MB million

2^{30} giga 1GB ← 1 billion

2^{40} tera 1TB ← 1 trillion

2^{50} peta 1PB ← quadrillion

• Paging.



Q = how many pages are there in

$$\frac{\text{total mem}}{\text{page size}} = \frac{1 \text{ GB}}{4 \text{ KB}}$$

a 32-bit CPU?

$$\Rightarrow 4 \text{ GB} = 2^2 \cdot 2^{30} \text{ B}$$

$$= \frac{2^{32} \text{ B}}{2^2 \cdot 2^{10} \text{ B}}$$

2^{20} 1990
1 million today

Q = 48-bit?

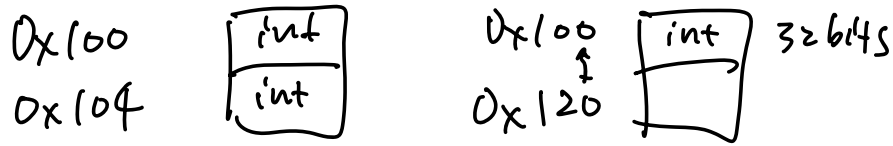
$$\frac{2^{48} \text{ B}}{2^{12} \text{ B}} = 2^{36}$$

"Byte-addressable"

address 0x0



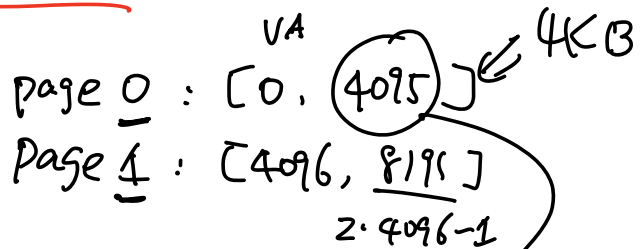
C99: int (4B) intarr[2]



$32 = 0x20$

48
48+9=57 bits

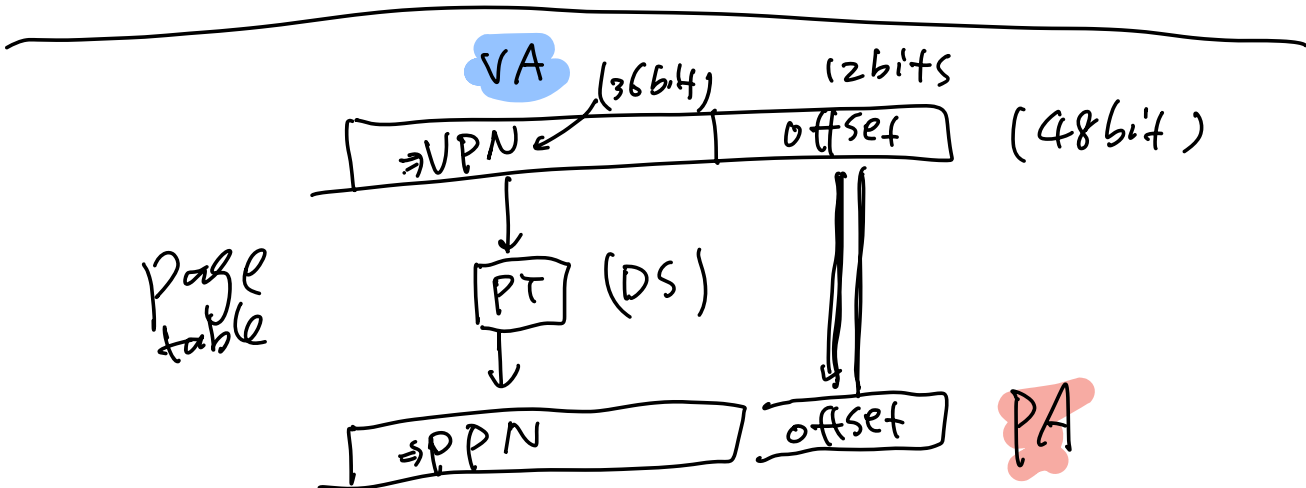
VA, PA
↓ paging



Q: address?

VPN : Virtual Page number 4096-1

PPN : Physical ... High = $2^{12} - 1 = 0xfff$ Low = 0x0
↓
1111

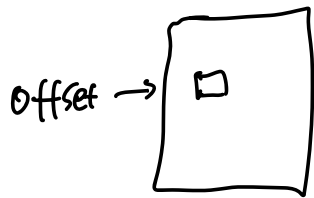
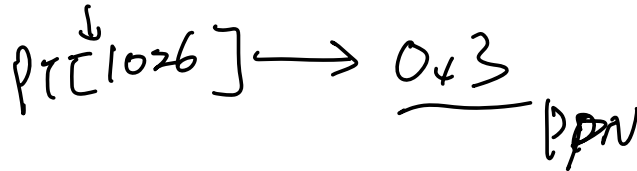
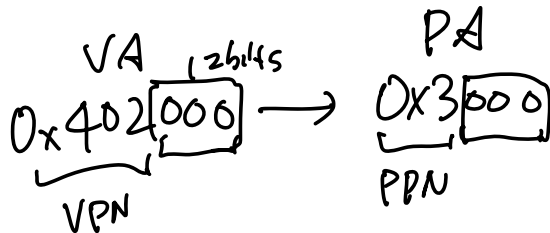


Q: offset vs. page size? ←

$$2^{\text{offset}} = \text{Page size} \\ (12 \text{ bits}) \quad (4 \text{ KB})$$

int PT [VPN] ;

↳ PPN (int)

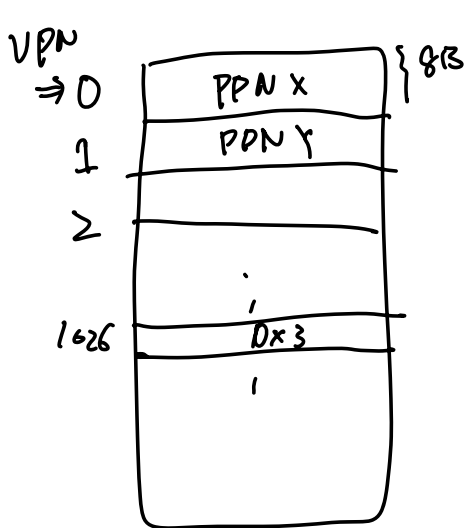


4KB

↳ 2¹² Bytes

↳ 2¹² number/addresses

↳ 12 bits as offset



PT:
 (int) VPN → (int) PPN

Q:
 hash table / map [☆]
 array
 linked list
 tree

48-bit VA

↳ 36-bit VPN

$$\begin{aligned}
 &\hookrightarrow 2^{36} \times 8B \\
 &= 2^{36} \cdot 2^3 B \\
 &= \underline{\underline{2^{30}}} \cdot \underline{\underline{2^9}} B \\
 &= 512 GB
 \end{aligned}$$

Neural net?

