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CS:3620 Operating Systems

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Paging

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Recap: Base and Bound Registers

- An easy solution: Base and bound registers

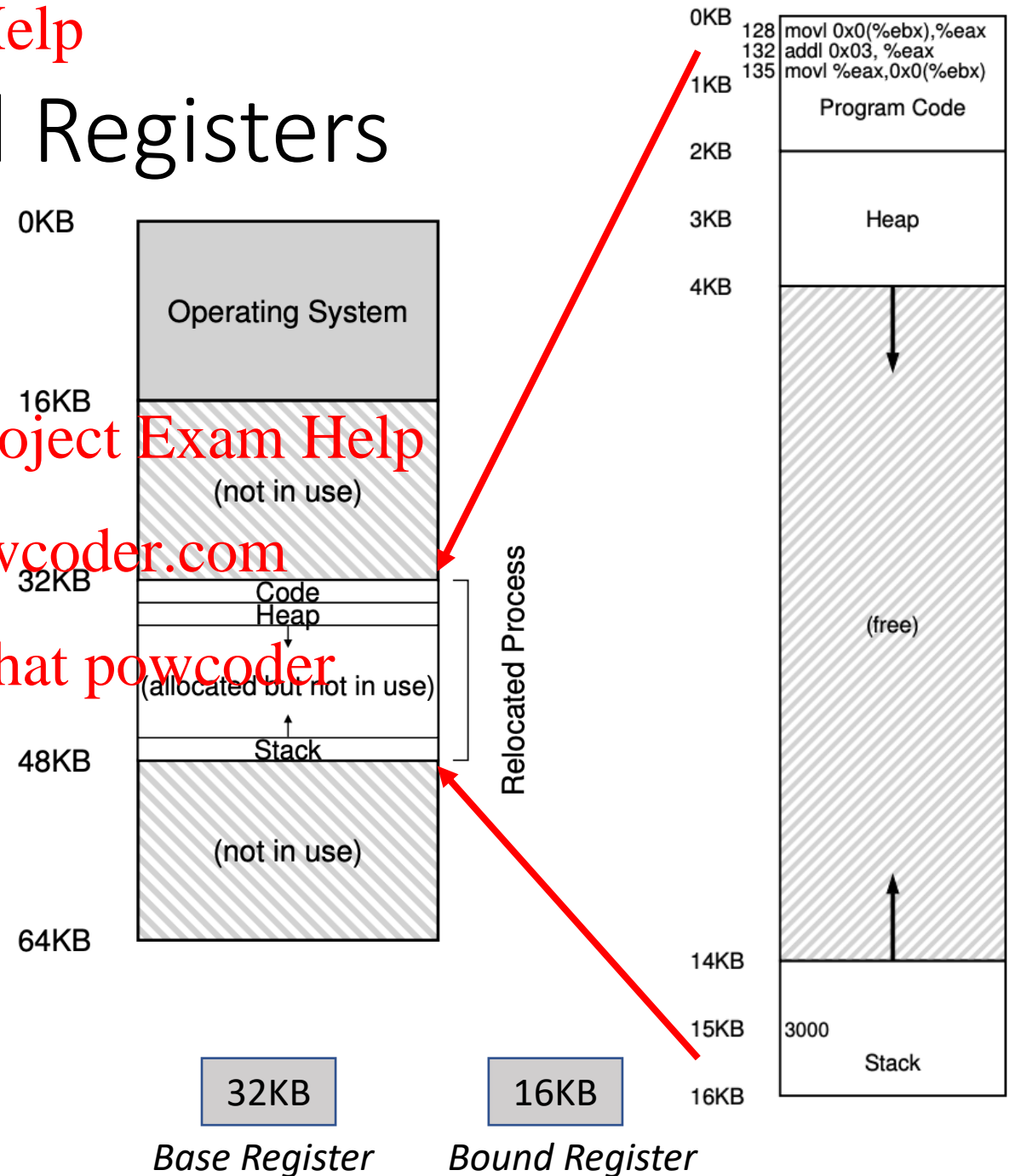
- Places entire memory image in one chunk

physical address = virtual address + base

- Need the following translation from VA to

PA

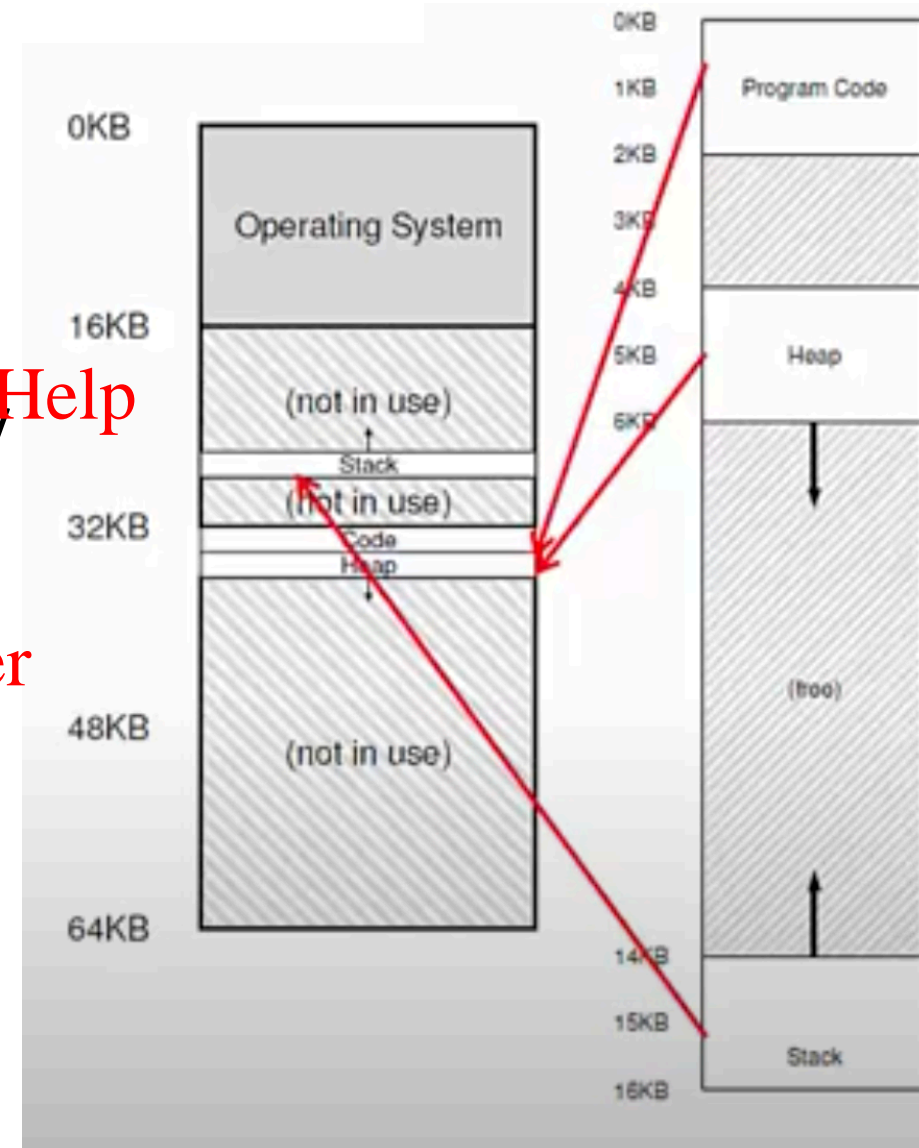
- 128 to 32896 (32KB + 128)
- 1KB to 33 KB
- 20KB? Error!



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Recap: Segmentation

- Generalized base and bounds
- Each segment of memory image placed separately
- Multiple (base, bound) values stored in MMU
- Good for sparse address spaces
- But variable sized allocation leads to external fragmentation
 - Small holes in memory left between segments

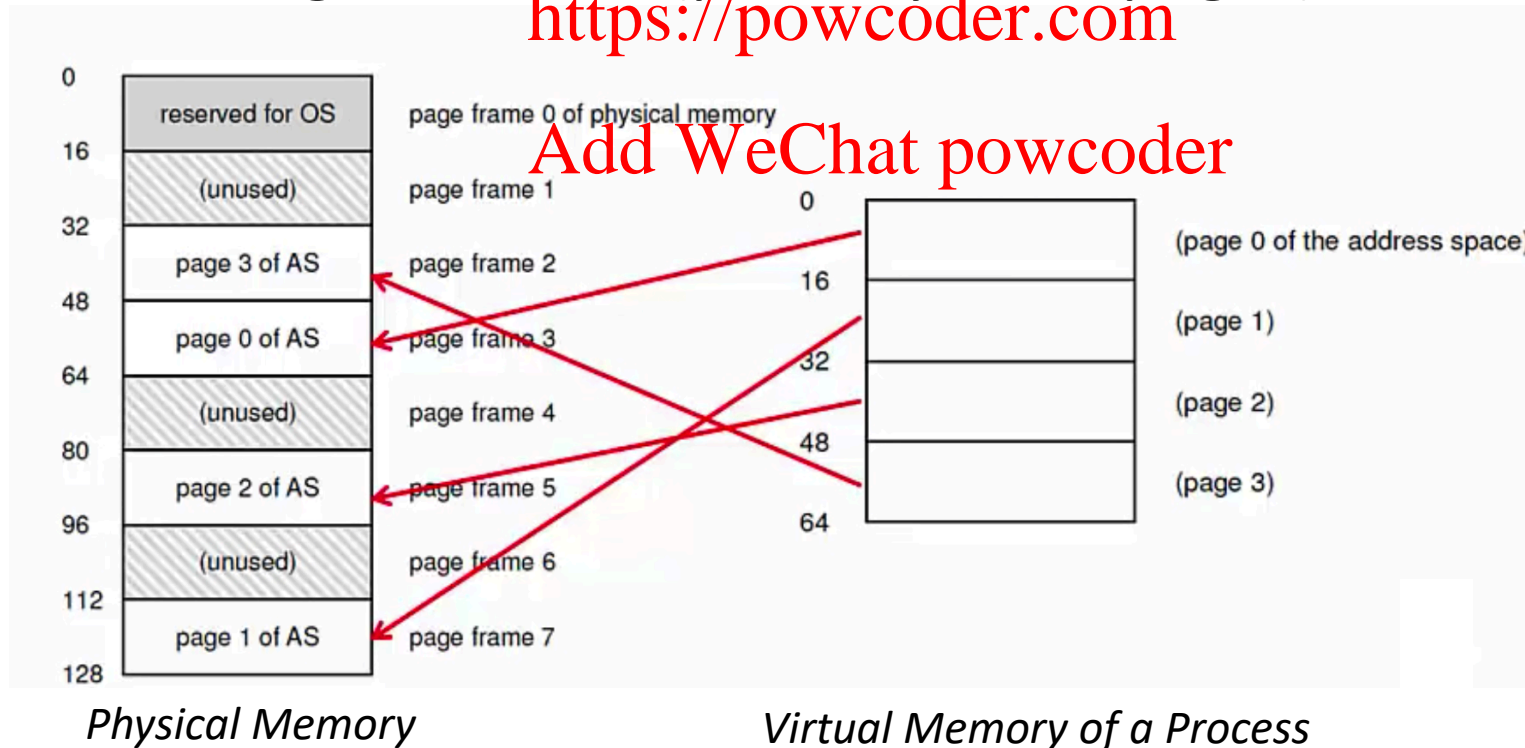


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- Allocate memory in fixed size chunks (“pages”)
- Avoids external fragmentation (no small “holes”)
- Has internal fragmentation (partially filled pages)

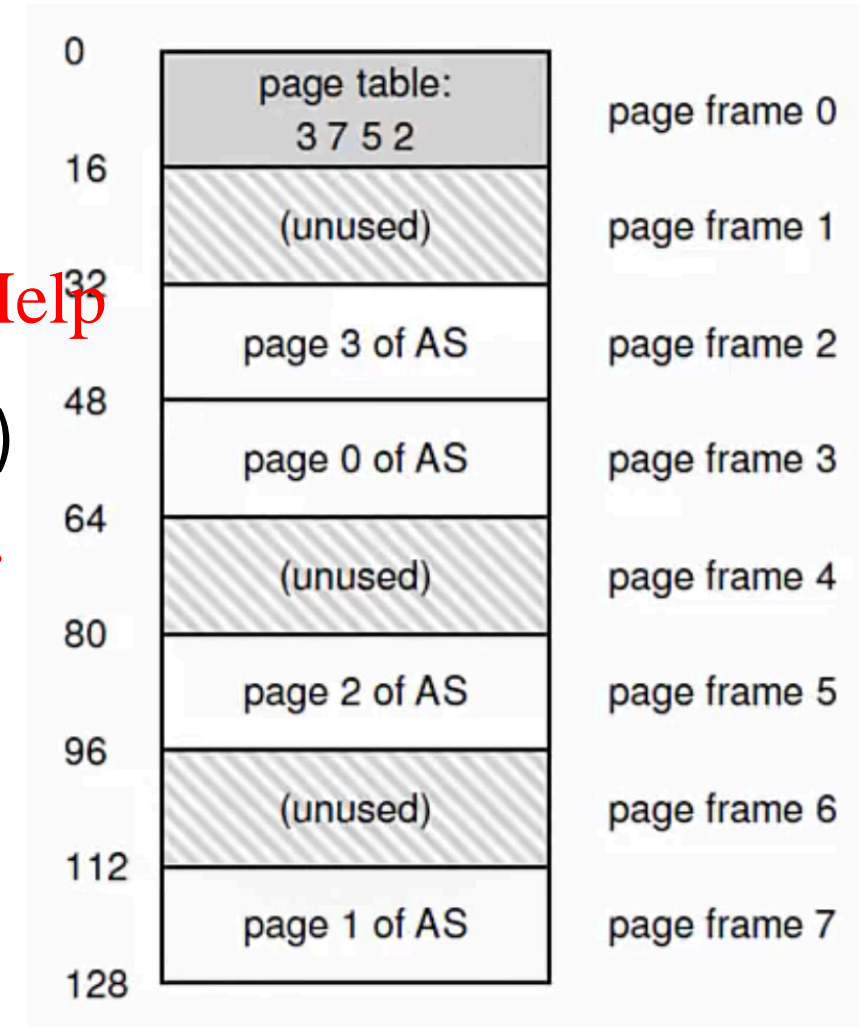
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Page table

- Per process data structure to help VA-PA translation
- Array stores mappings from virtual page number (VPN) to physical frame number (PFN)
 - E.g., VP 0 -> PF 3, VP 1 -> PF 7
- Part of OS memory (in PCB)
- MMU has access to page table and uses it for address translation
- OS updates page table upon context switch



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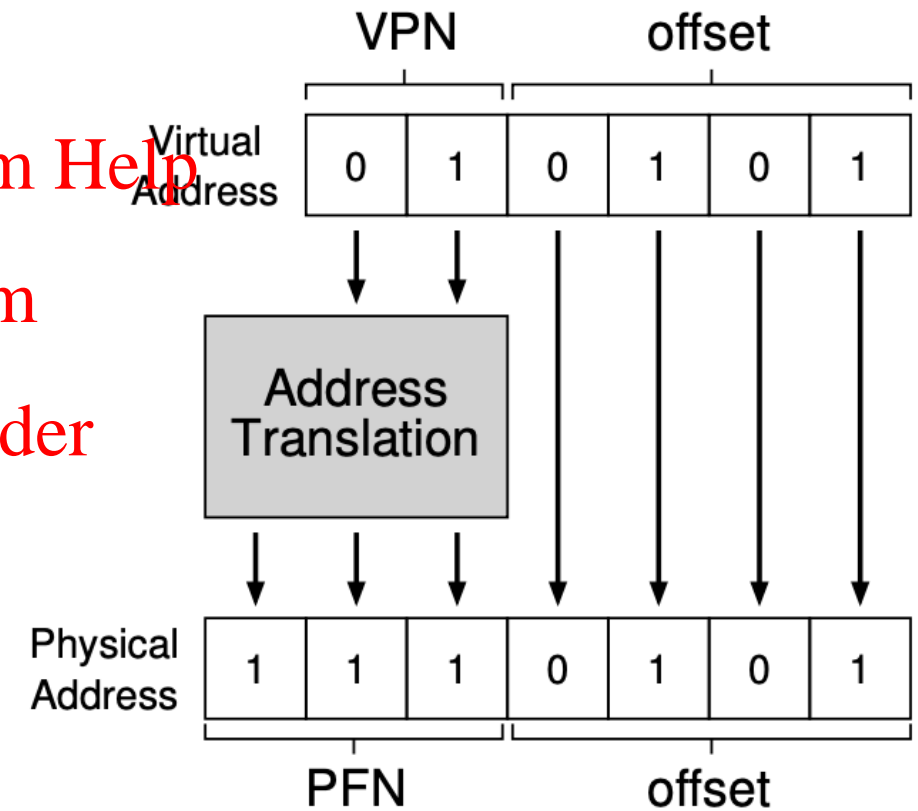
Page table entry (PTE)

- Simplest page table: linear page table
- Page table is an array of page table entries, one per virtual page
- VPN (virtual page no.) is index into this array
- Each PTE contains PFN (physical frame number) and few other bits
 - Valid bit: is this page used by process?
 - Protection bits: read/write permissions
 - Present bit: is this page in memory? (more later)
 - Dirty bit: has this page been modified?
 - Accessed bit: has this page been recently accessed?

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Address translation in hardware

- Most significant bits of VA give the VPN
- Page table maps VPN to PFN
- PA is obtained from PFN and offset within a page
- MMU stores (physical) address of start of page table, not all entries.
- “Walks” the page table to get relevant PTE



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What happens on memory access?

- CPU requests code or data at a virtual address
- MMU must translate VA to PA
 - First, access memory to read page table entry
 - Translate VA to PA
 - Then, access memory to fetch code/data
- Paging adds overhead to memory access
- Solution? A cache for VA-PA mappings

Translation Lookaside Buffer (TLB)

- A cache of recent VA-PA mappings
- To translate VA to PA, MMU first looks up TLB
- If TLB hit, PA can be directly used
- If TLB miss, then MMU performs additional memory accesses to “walk” page table
- TLB misses are expensive (multiple memory accesses)
 - Locality of reference helps to have high hit rate
- TLB entries may become invalid on context switch and change of page tables

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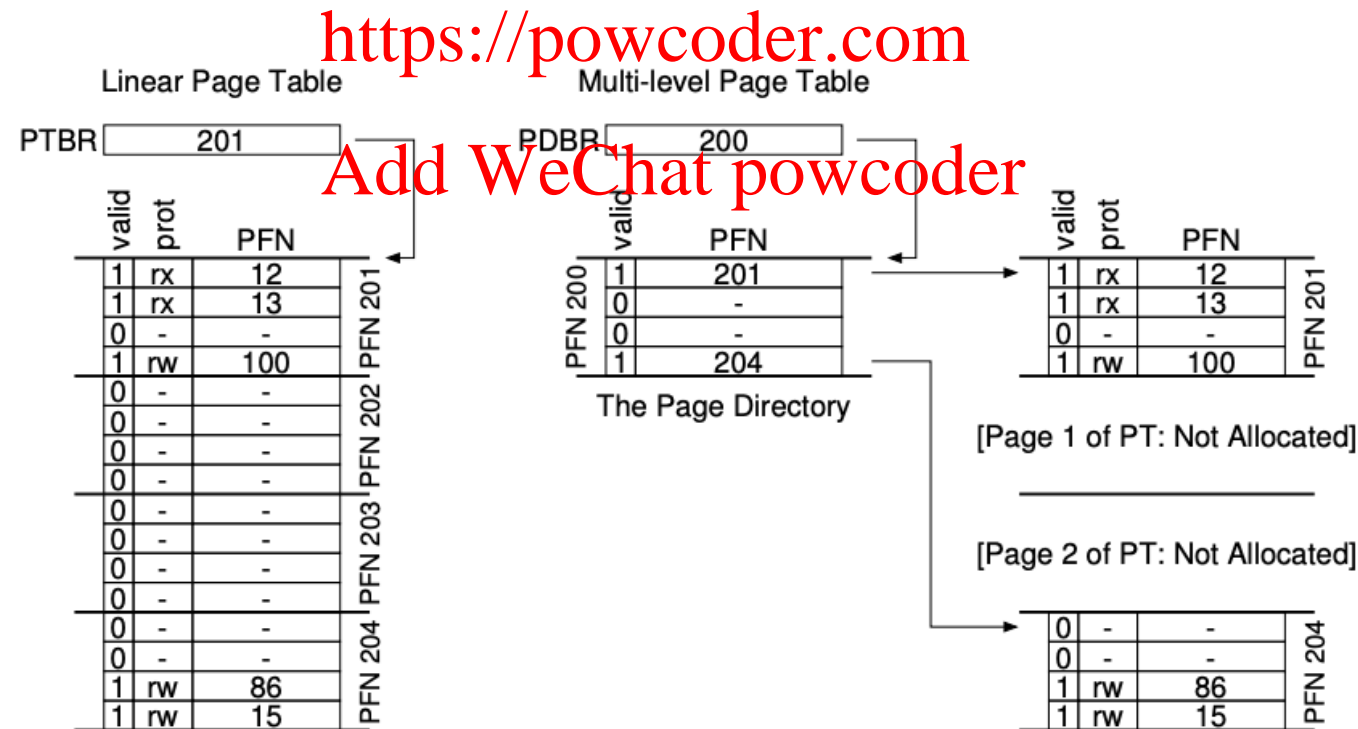
How are page tables stored in memory?

- What is typical size of page table?
 - 32 bit VA, 4 KB pages, so $2^{32} / 2^{12} = 2^{20}$ entries
 - If each PTE is 4 bytes, then page table is 4MB
 - One such page table per process!
- How to reduce the size of page tables?
 - Larger pages, so fewer entries
- How does OS allocate memory for such large tables?
 - Page table is itself split into smaller chunks! (Why?)

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Multilevel page tables

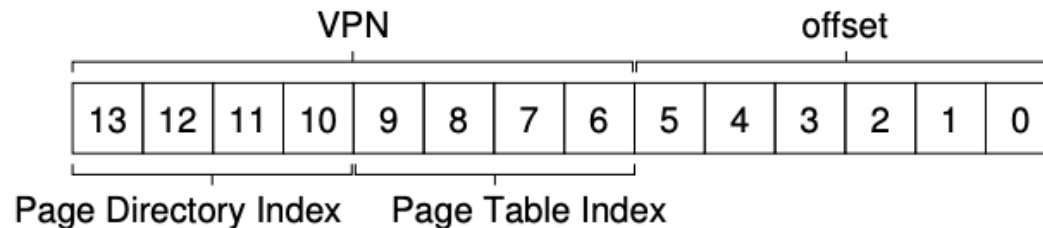
- A page table is spread over many pages
- An “outer” page table or page directory tracks the PFNs of the page table pages



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Multilevel page tables

- Depending on how large the page table is, we may need more than 2 levels also
 - 64-bit architectures may need 7 levels
- What about address translation?
 - First few bits of VA to identify outer page table entry
 - Next few bits to index into next level of PTEs



- In case of TLB miss, multiple accesses to memory required to access all the levels of page tables

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Disclaimer

- *These lecture slides are based on a slide set by Youjip Won (Hanyang University) and Mythili Vutukuru (IIT Bombay)*

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