Virtual Memory

15-213 / 18-213: Introduction to Computer Systems
10th Recitation, March 24th, 2014

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Section C

Today

- **Management and Stuff**
- Shell Lab
- Malloc Lab
- Git primer
- Virtual Memory
- TLB

Management and Stuff

- Shell Lab due Thursday, March 27th 2014, 11:59 PM
- Malloc Lab out Thursday, March 27th 2014, 11:59 PM

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Shell Lab

- **FAQs**
  - **Adding sigsuspend breaks my code (was working fine with a while loop)?**
    - Read the documentation for sigsuspend again, especially the example.
    - http://www.gnu.org/software/libc/manual/html_node/Sigsuspend.html

Shell Lab

- **FAQs**
  - **trace_xx passes intermittently?**
    - You still have race conditions in your code.
    - Reproduce the failed scenario and compare with reference shell.
    - Understand the trace file.

Shell Lab

- **FAQs**
  - **time out error?**
    - Driver says that it timed out while waiting for shell prompt.
    - Most likely the fg job was not reaped.

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Malloc Lab

- Out March 27th
- Due April 15th
- *Start early*
- Ask questions

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Git primer

- **Afraid of losing files but too confused/lazy to learn Git and set up an account?**
- **Make a local repository**
  - No account required
  - >cd tshlab-handout
    >git init
    >git add (files)
    >git commit

Git primer

- **git init**
  - Creates a git repository.
  - Directory named .git will be created.
- **git status**
  - Shows the status of repository.
- **git add file_name**
  - Stages file for commit.
  - git add .
    - Stages all the files in current directory for commit.

Git primer

- **git commit**
  - Commits the files to respository.
  - git commit –m “commit_Msg”
- **git push**
  - Pushes the local repository to remote location.
- **git clone**
  - Copies a remote repository
    - git clone git://github.com/path/file_name.git
- **git pull**
  - Merges remote repository with local.

Git primer

- **Remote repositories**
  - Github, Bitbucket
  - **Beware**, do not make your repository public.
  - Public repositories are indexed by google.
- **Help**
  - http://www.contrib.andrew.cmu.edu/~cakrivou/98174/
  - http://stackoverflow.com/questions/315911/git-for-beginners-the-definitive-practical-guide#323764

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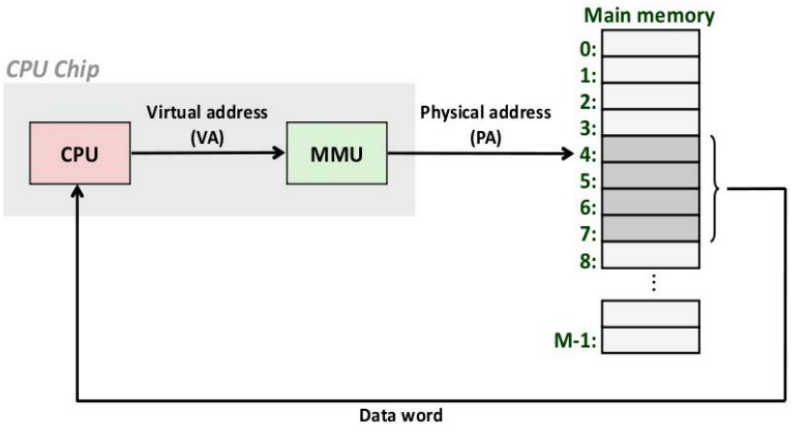
Virtual Memory Abstraction

- **Virtual memory is layer of indirection between processor and physical memory providing:**
  - Caching
    - Memory treated as cache for much larger disk
  - Memory management
    - Uniform address space eases allocation, linking, and loading
  - Memory protection
    - Prevent processes from interfering with each other by setting permission bits

Virtual Memory Implementation

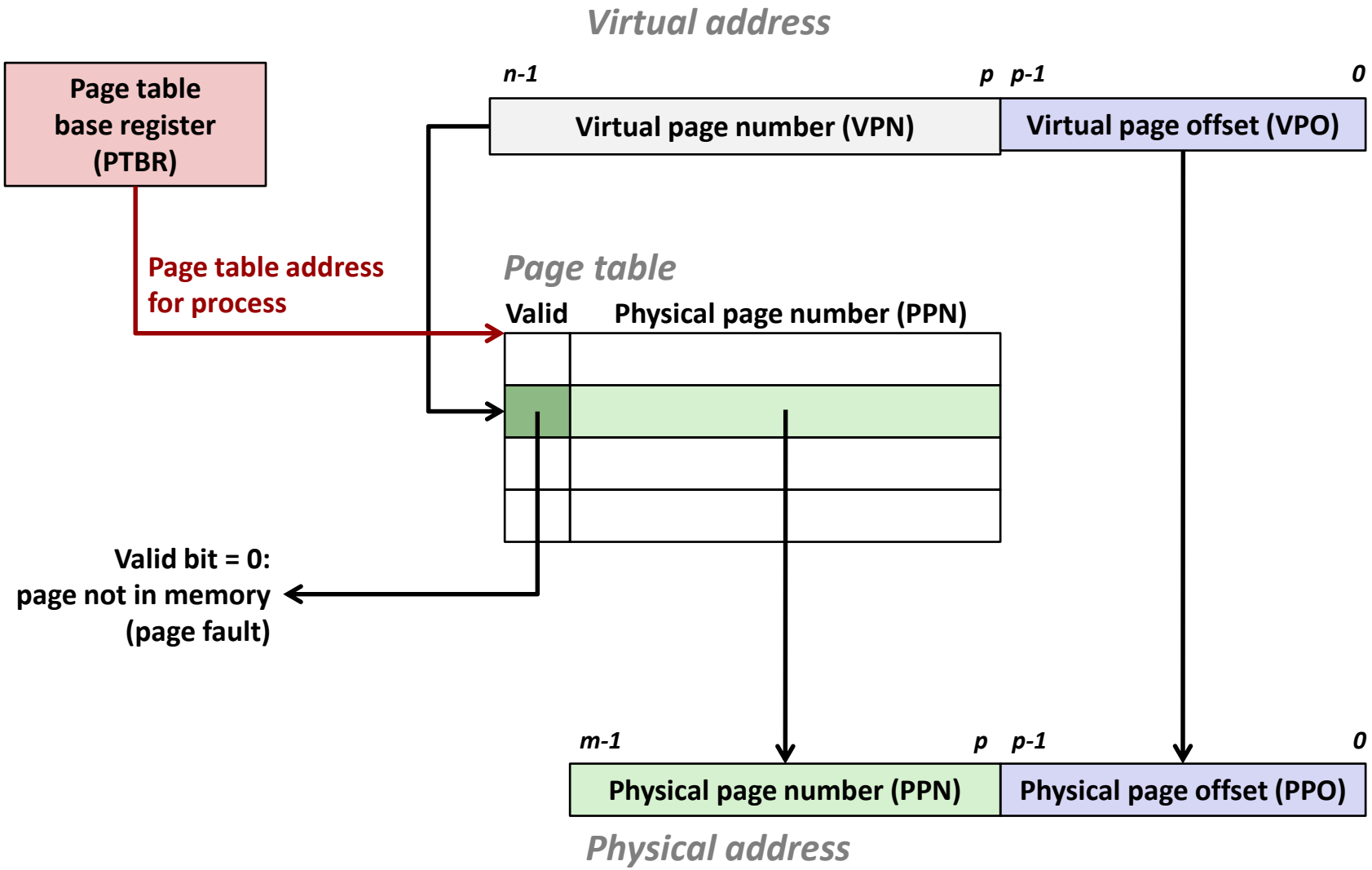
- **Virtual memory implemented by combination of hardware and software**
  - Operating system creates page tables
    - Page table is array of Page Table Entries (PTEs) that map virtual pages to physical pages
  - Hardware Memory Management Unit (MMU) performs address translation



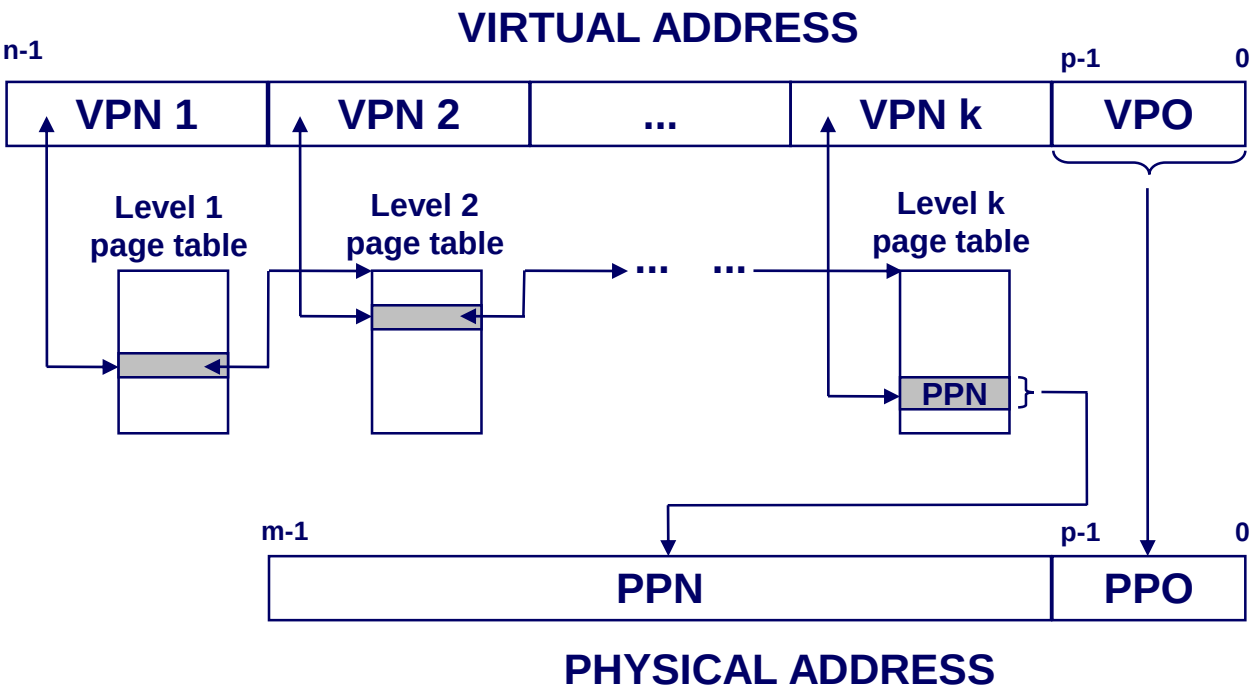
Address Translation and Lookup

- **On memory access (e.g., mov 0xdeadbeef, %eax)**
  - CPU sends virtual address to MMU
  - MMU uses virtual address to index into in-memory page tables
  - Cache/memory returns PTE to MMU
  - MMU constructs physical address and sends to mem/cache
  - Cache/memory returns requested data word to CPU

Recall: Address Translation With a Page Table



Translating with a k-level Page Table



x86 Example Setup

- **Page size 4KB (2^12 Bytes)**
- **Addresses: 32 bits (12 bit VPO, 20 bit VPN)**
- **Consider a one-level page table with:**
  - Base address: 0x01000000
  - 4-byte PTEs
    - 4KB aligned (i.e., lowest 12 bits are zero)
    - Lowest 3 bits used as permissions
      - Bit 0: Present?
      - Bit 1: Writeable?
      - Bit 2: UserAccessible?
- **How big overall?**
  - 2^20 entries

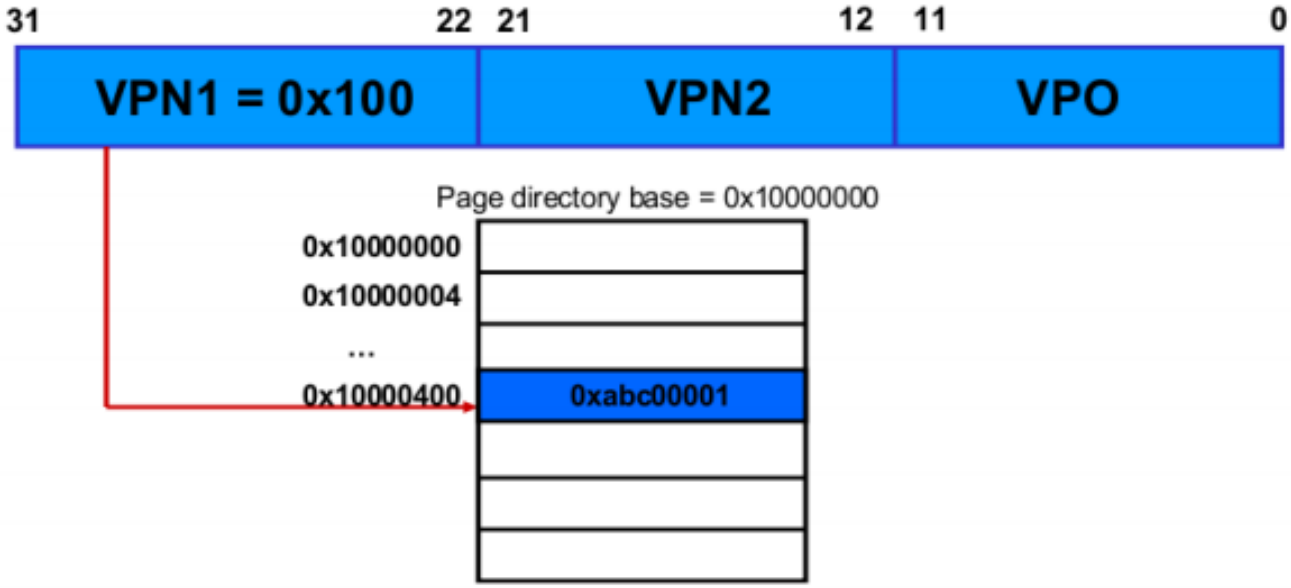
Example

- Given the setup from the previous slide, what are the VPN (index), PPO, and VPO of address: 0xdeadbeef?

Example

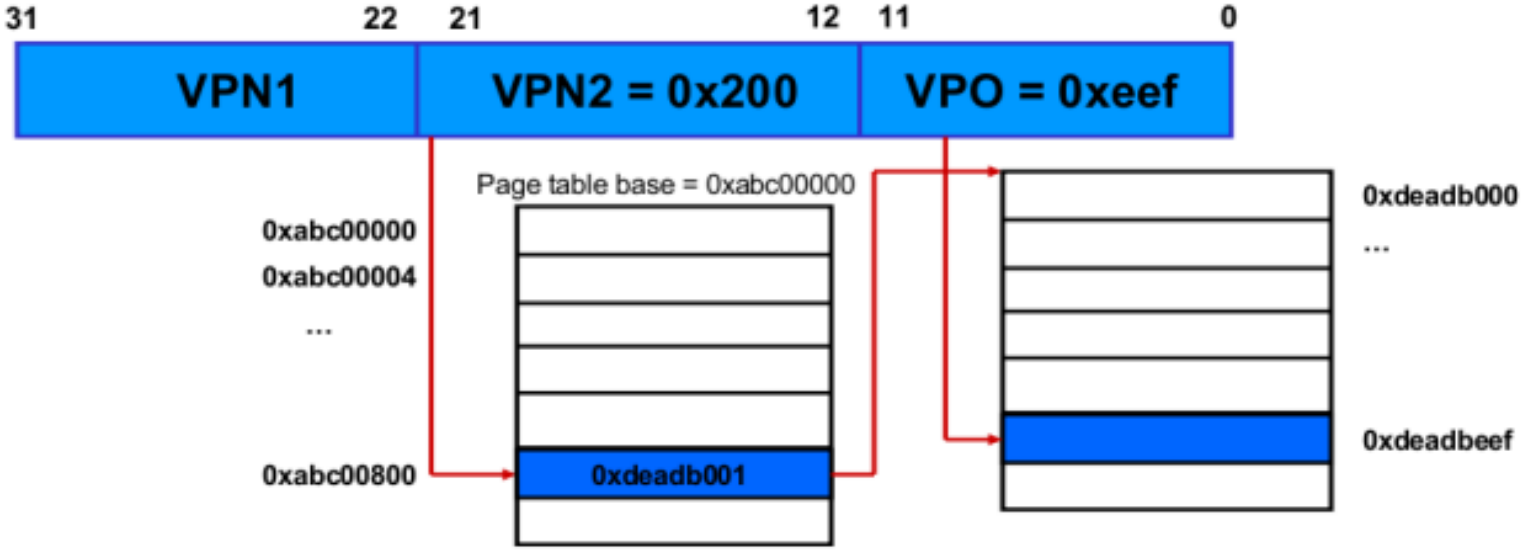
- **Answers:**
  - VPN (index) = 0xdeadb (1101 1110 1010 1101 1011)
  - VPO = PPO = 0xeef
- **Consider a page table entry in our example PT:**
  - Location of PTE = base + (size * index)
    - 0x0137ab6c = base + 4 * index
  - PTE: 0x98765007
  - Physical address: 0x98765eef

Example: 2 level page table



Use the first VPN to index into the page directory. This gives the address of the start of the page table.

2-level page table – cont'd



Use the second VPN to index into the page table. This gives the address of the start of the page frame. Add the offset to obtain the location in physical memory.

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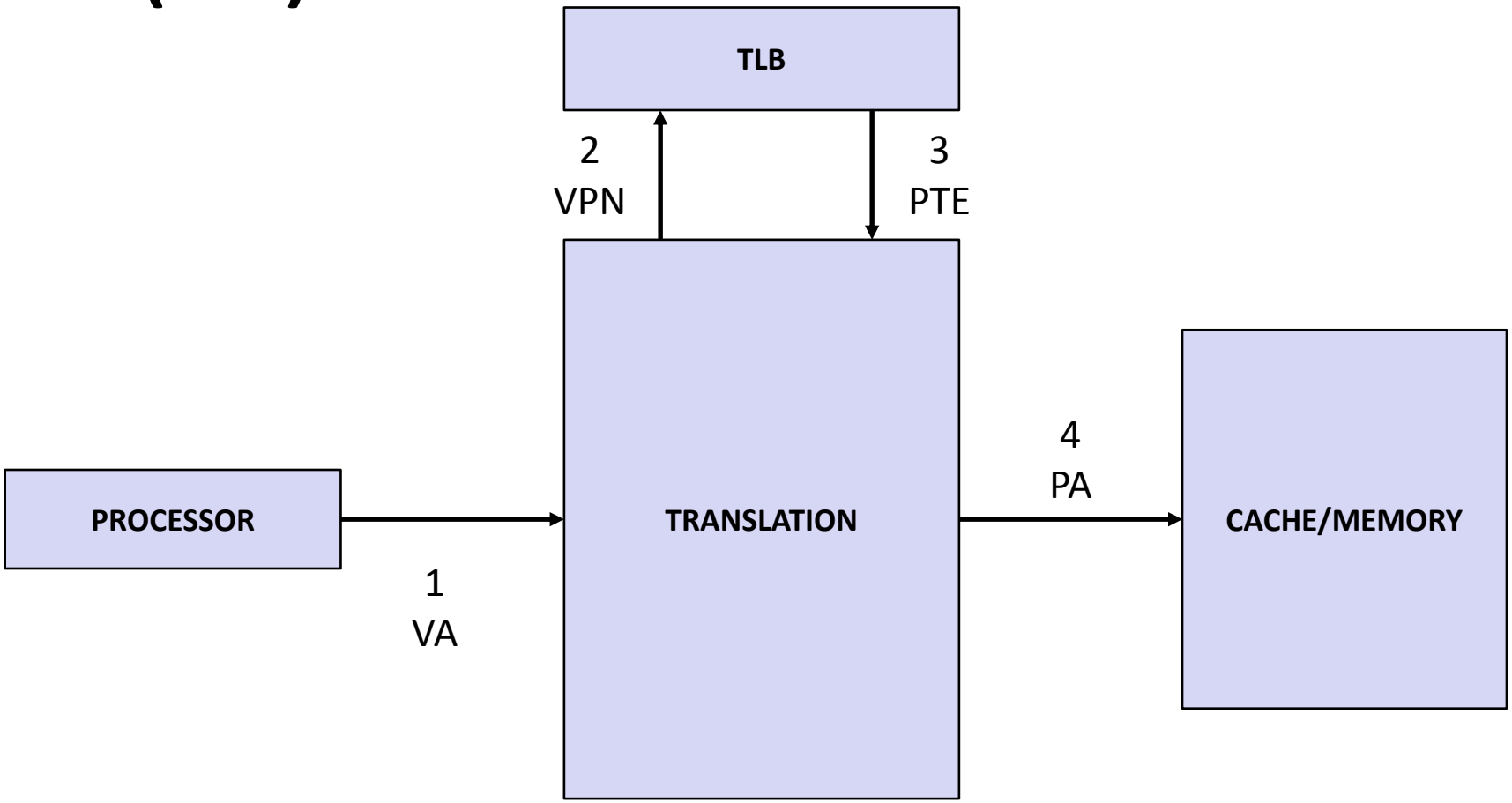
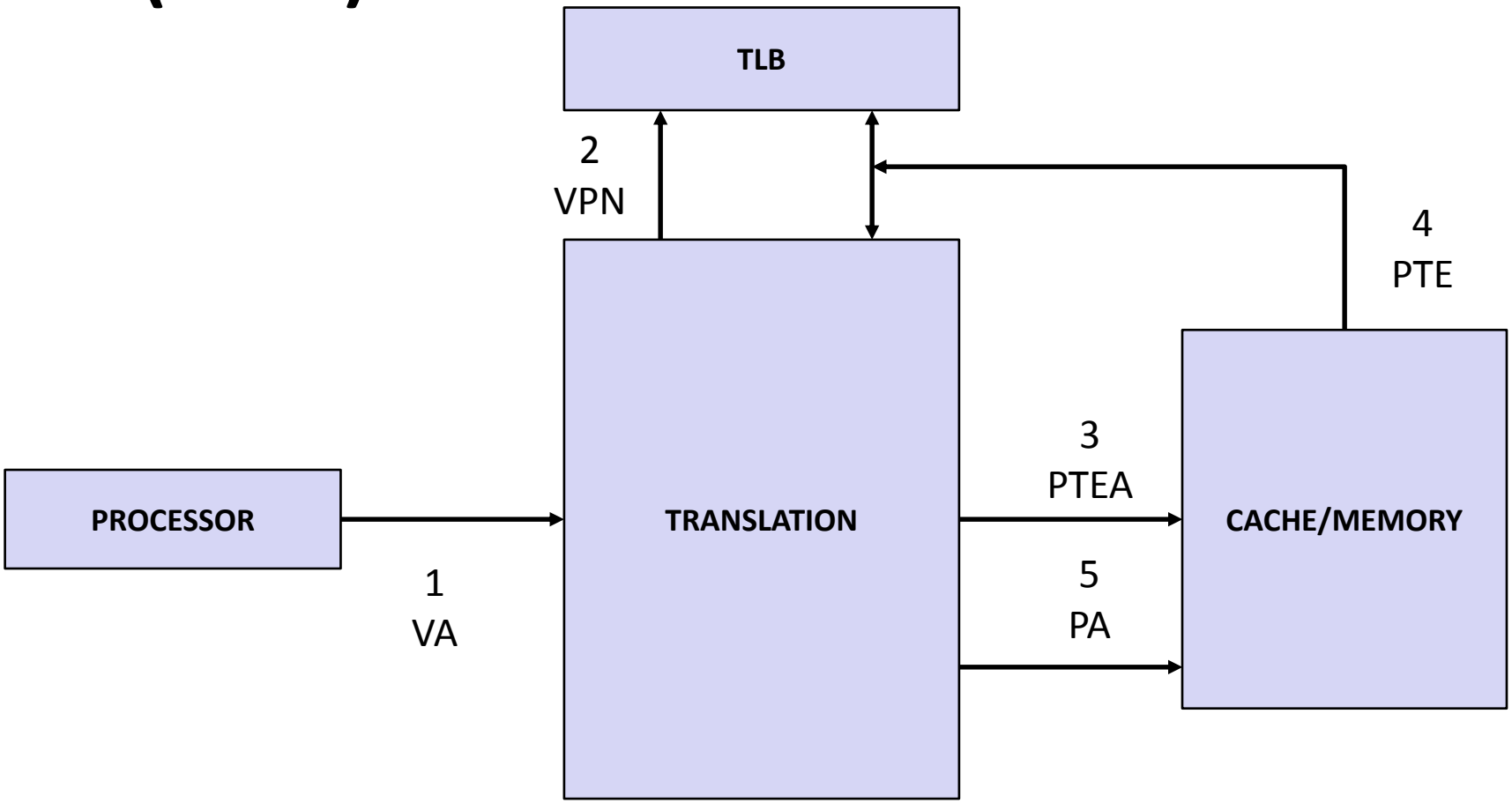
TLB

- **TLB (Translation Lookaside Buffer) is cache for page table entries.**
  - Each PTE lookup leads to a memory access.
  - TLB caches the Page Table entries.

TLB (HIT)



TLB (MISS)


TLB
2
VPN
4
PTE
PROCESSOR
TRANSLATION
3
PTEA
CACHE/MEMORY
1
VA
5
PA

Questions?