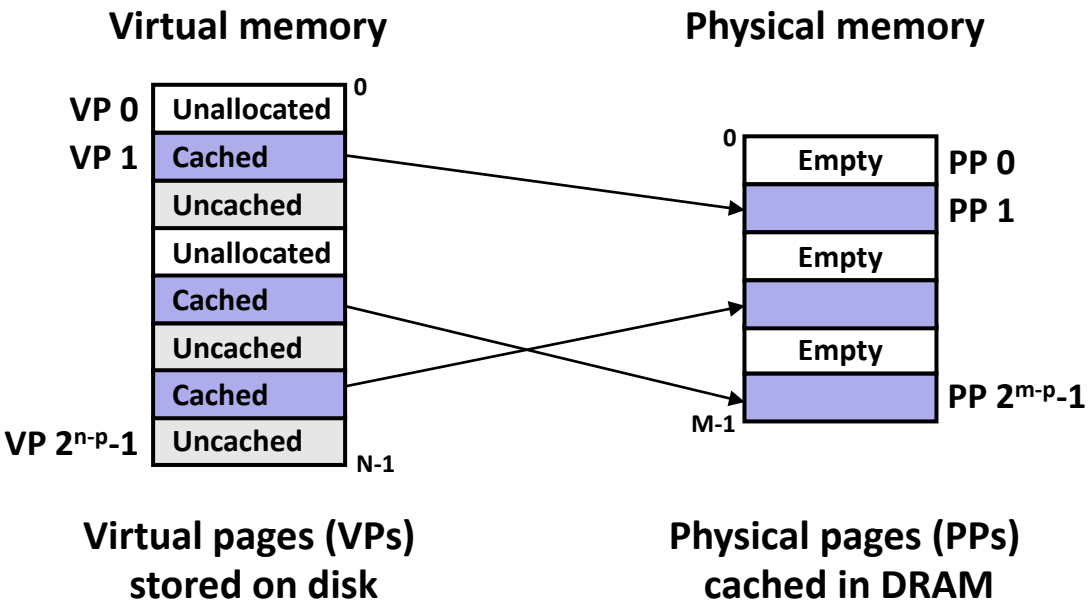
Virtual Memory:
… as a tool for caching

VM as a Tool for Caching

- **Conceptually, *virtual memory* is an array of N contiguous bytes stored on disk**
- **The contents of the array on disk are cached in *physical memory* (*DRAM cache*)**
  - These cache *blocks* are called *pages* (size is P = 2^p bytes, e.g., 4KB)



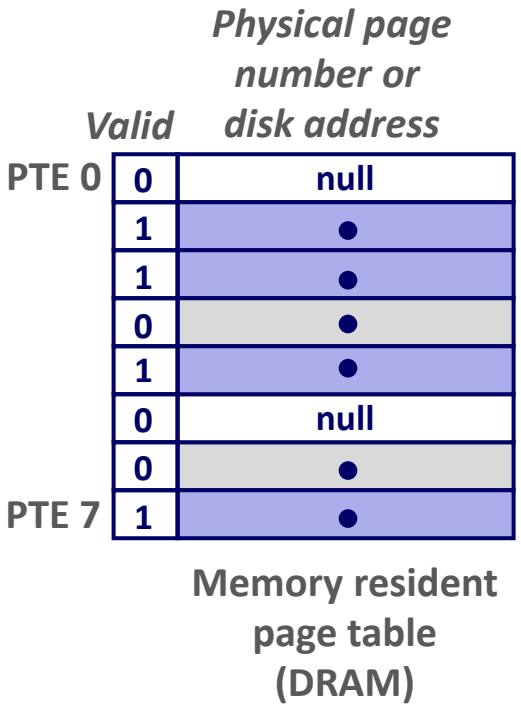
DRAM Cache Organization

- **DRAM cache organization driven by the enormous miss penalty**
  - DRAM is about ***10x*** slower than SRAM
  - Disk is about ***10,000x*** slower than DRAM

- **Consequences**
  - Large page (block) size: typically 4 KB, sometimes 4 MB
  - Fully associative (1 set!)
    - Any VP can be placed in any PP
    - Requires a “large” mapping function – different from cache memories
  - Highly sophisticated, expensive replacement algorithms
    - Too complicated and open-ended to be implemented in hardware
    - CSC 443
  - Write-back rather than write-through

Enabling Data Structure: Page Table

- **A *page table* is an array of page table entries (PTEs) that maps virtual pages to physical pages.**
  - Per-process kernel data structure in DRAM



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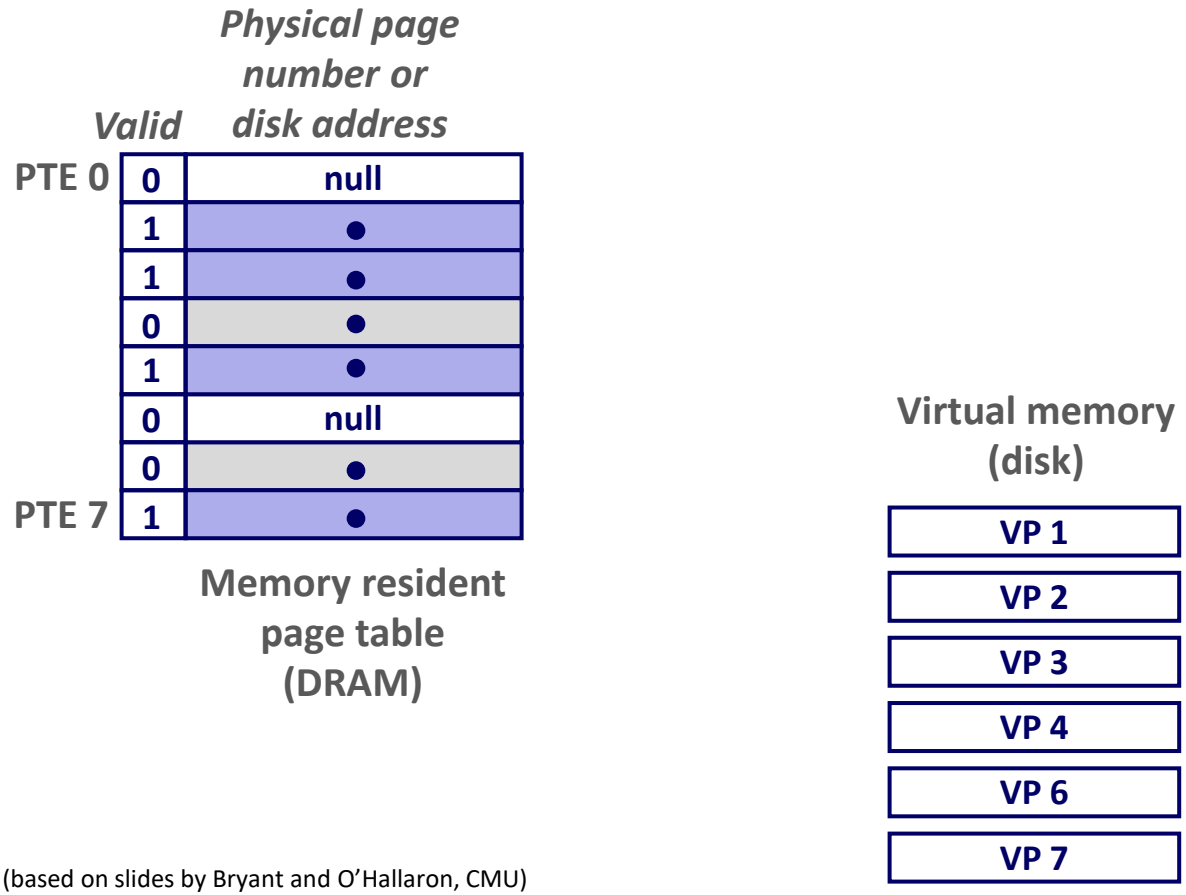

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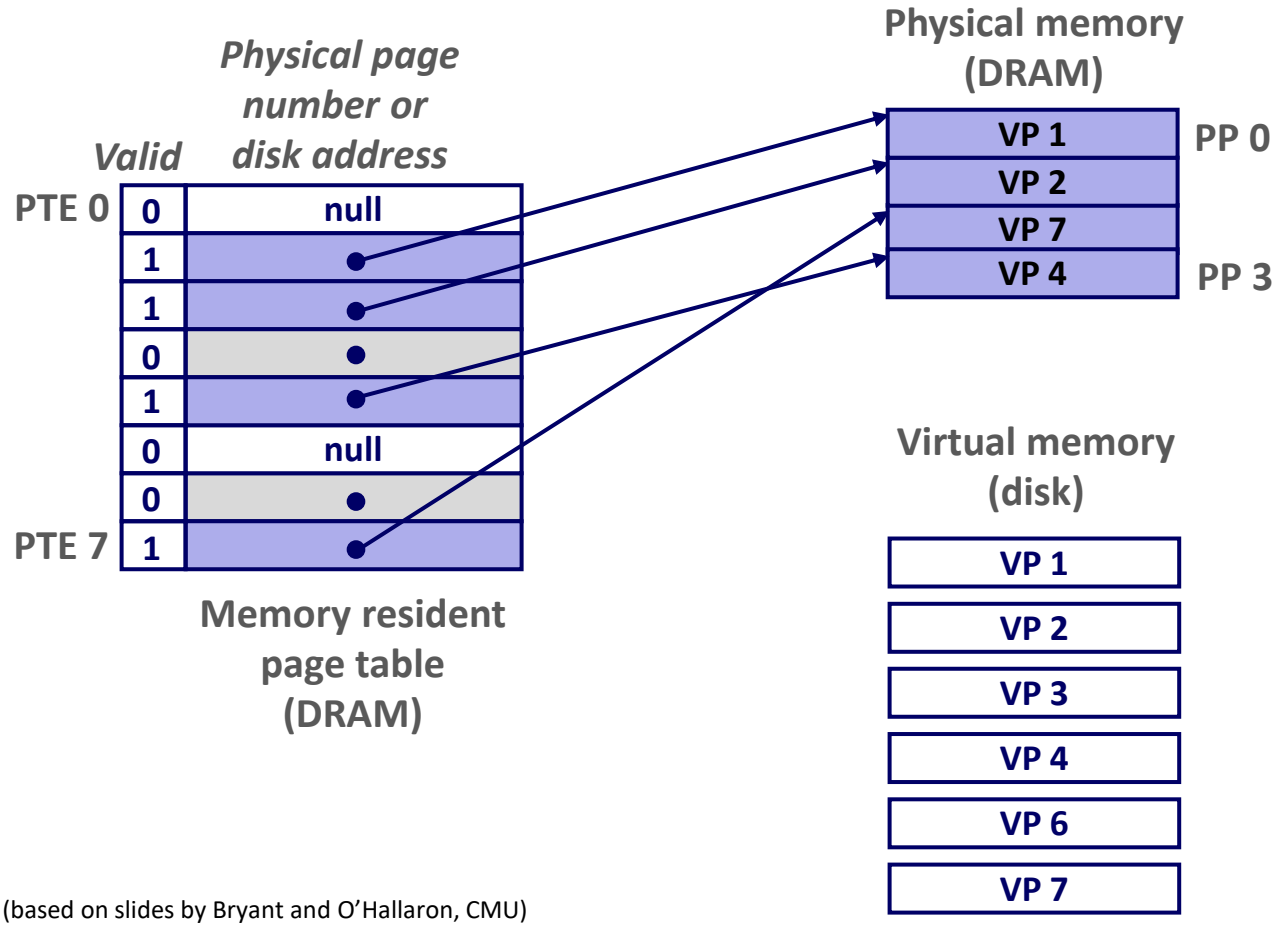

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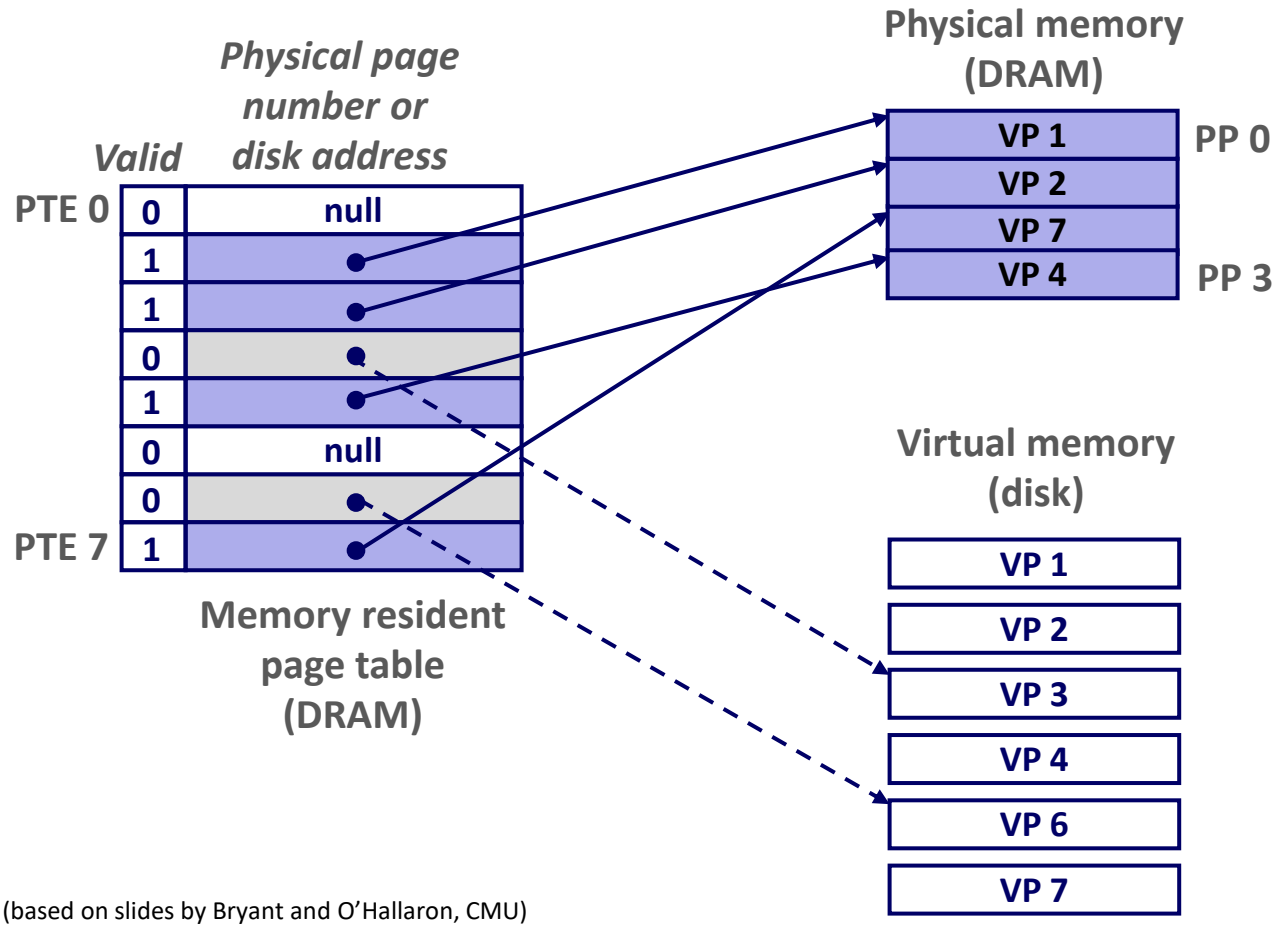

Page Hit

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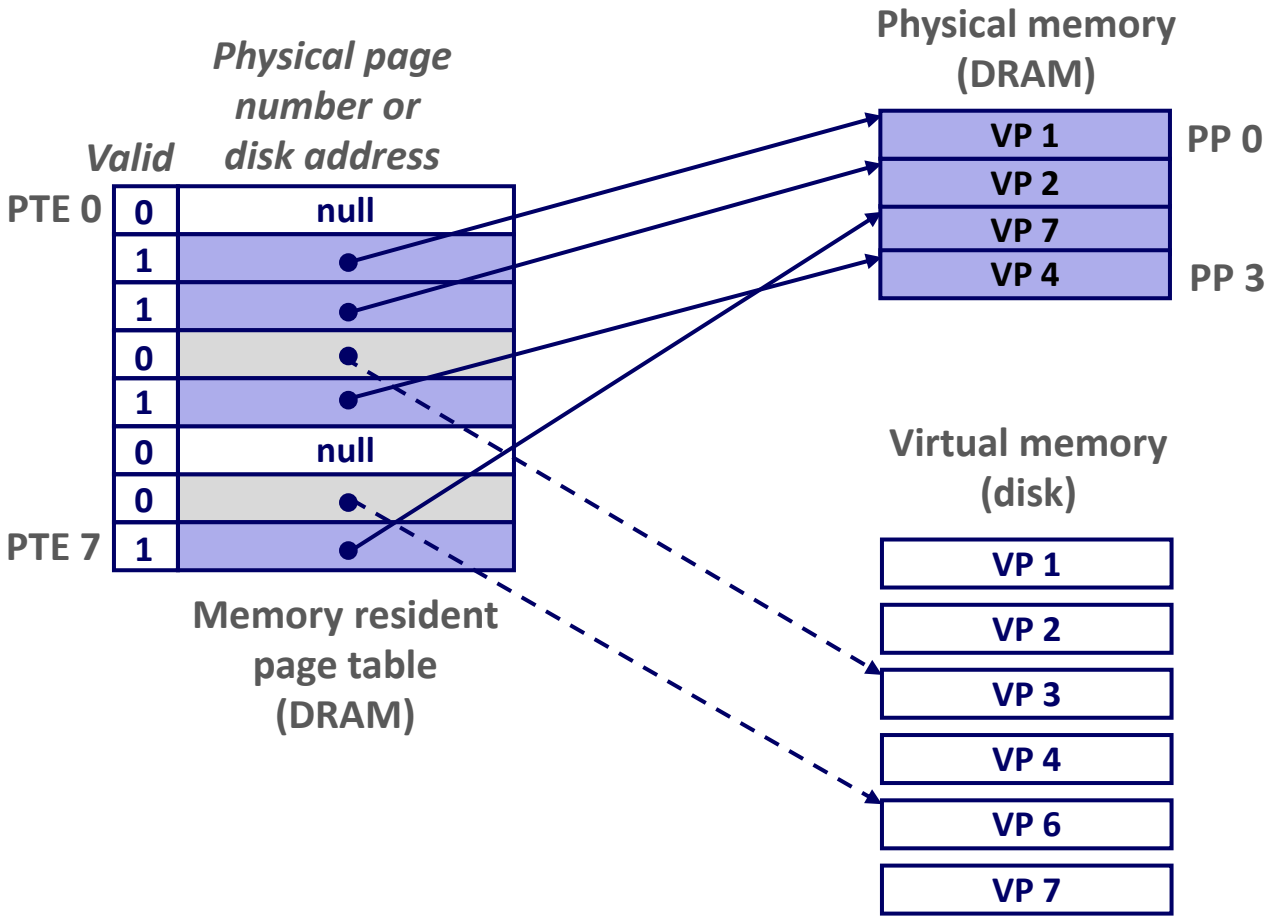

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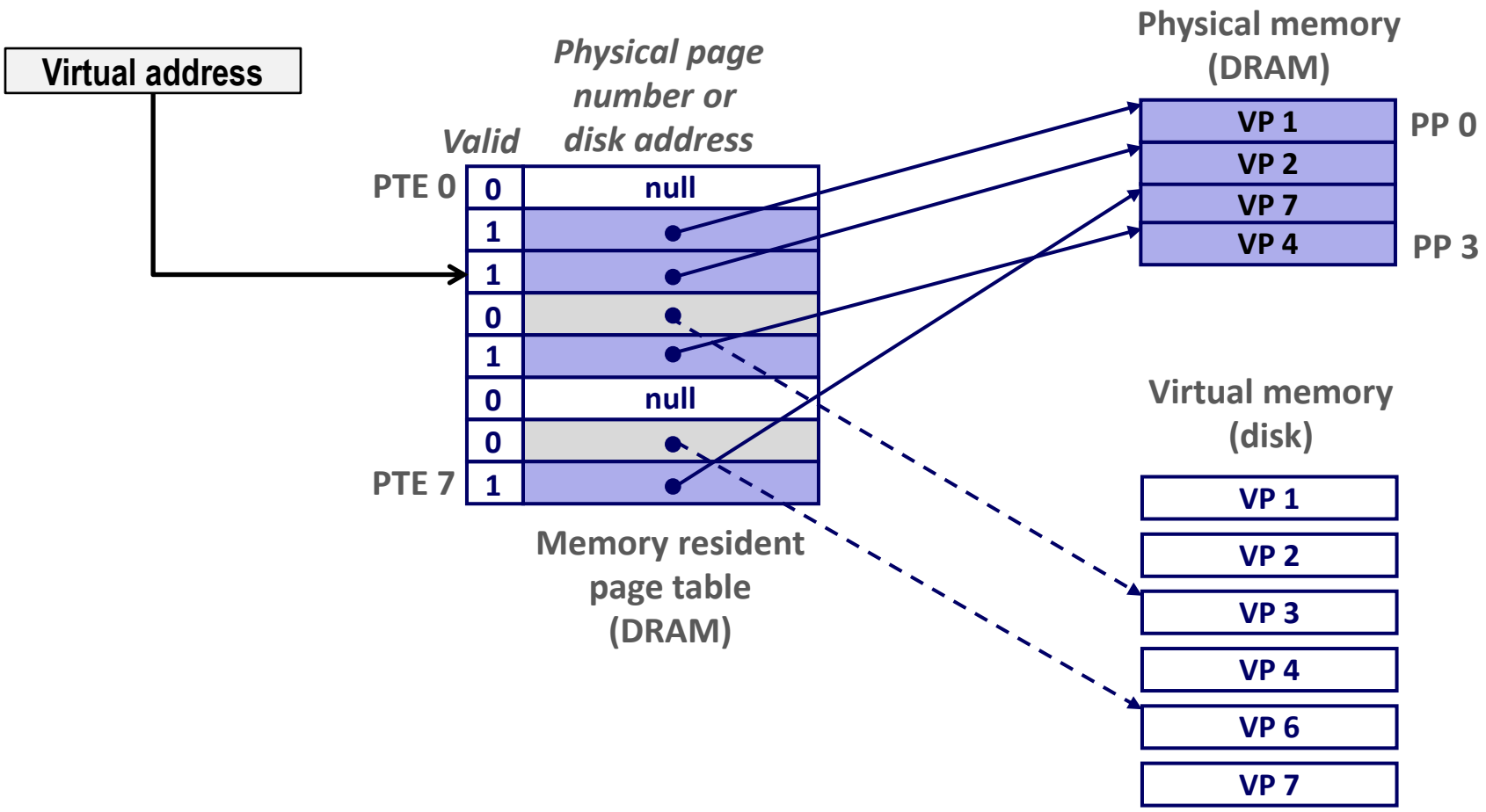
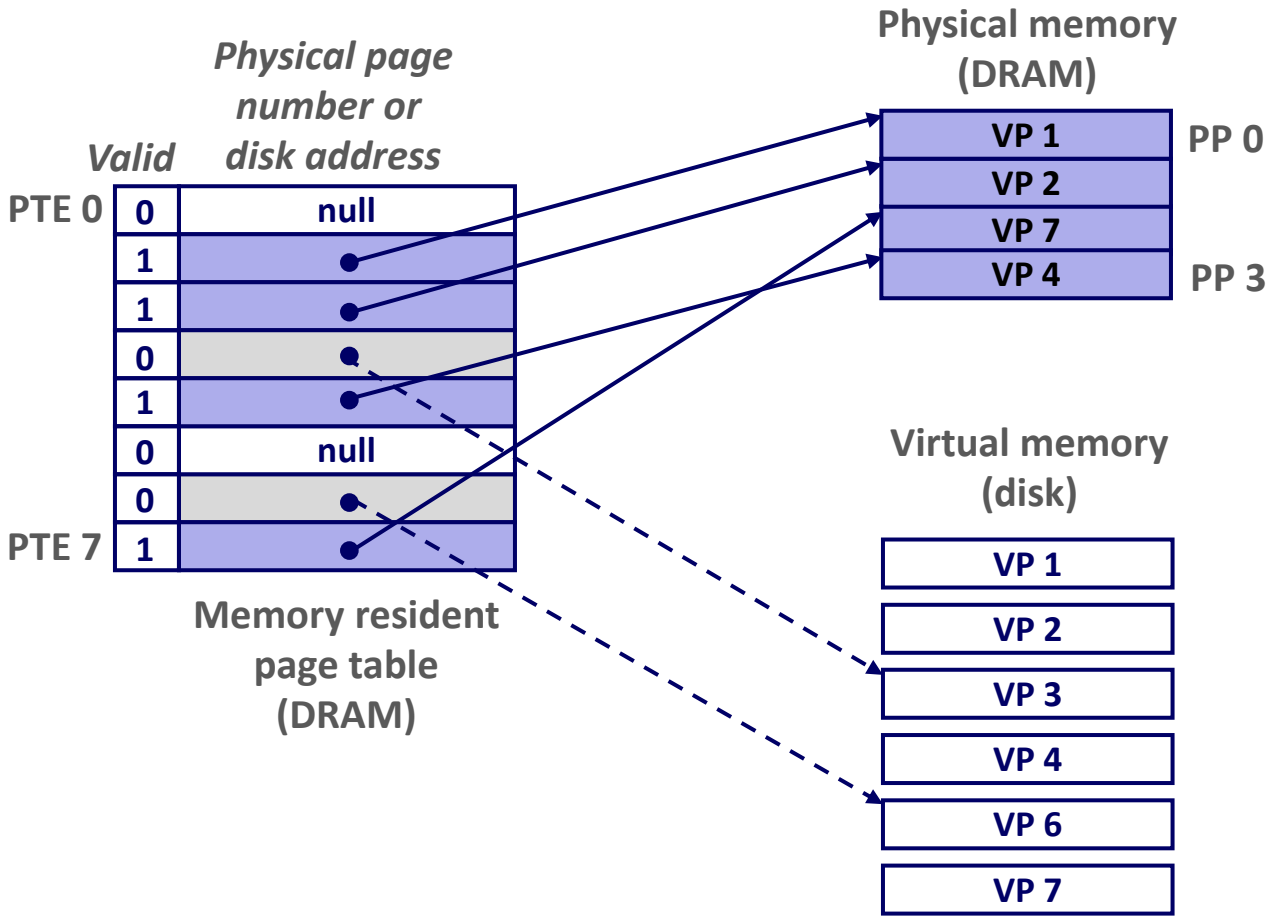


Page Fault

- ***Page fault:*** **reference to VM word that is not in physical memory (DRAM cache miss)**



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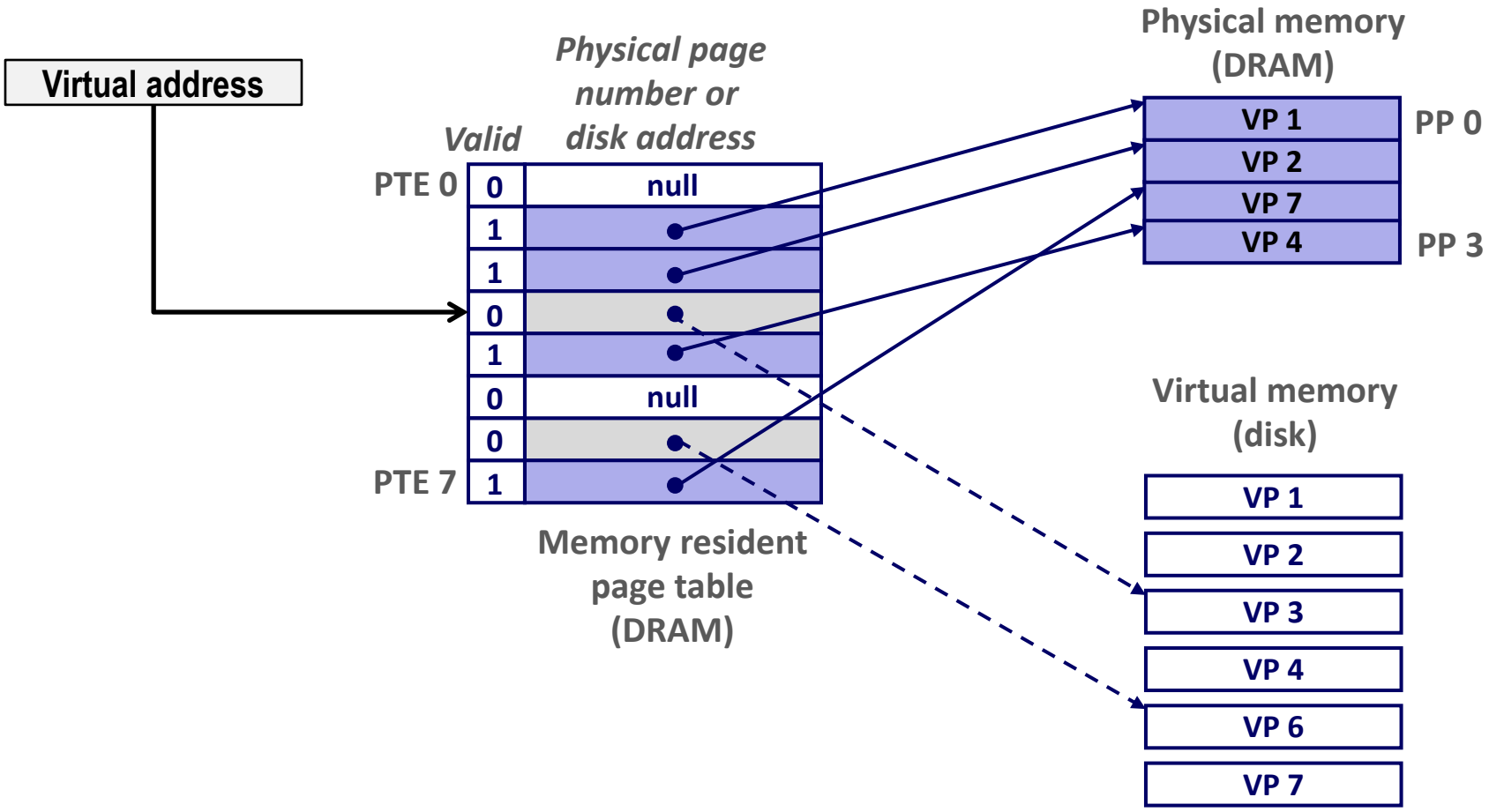

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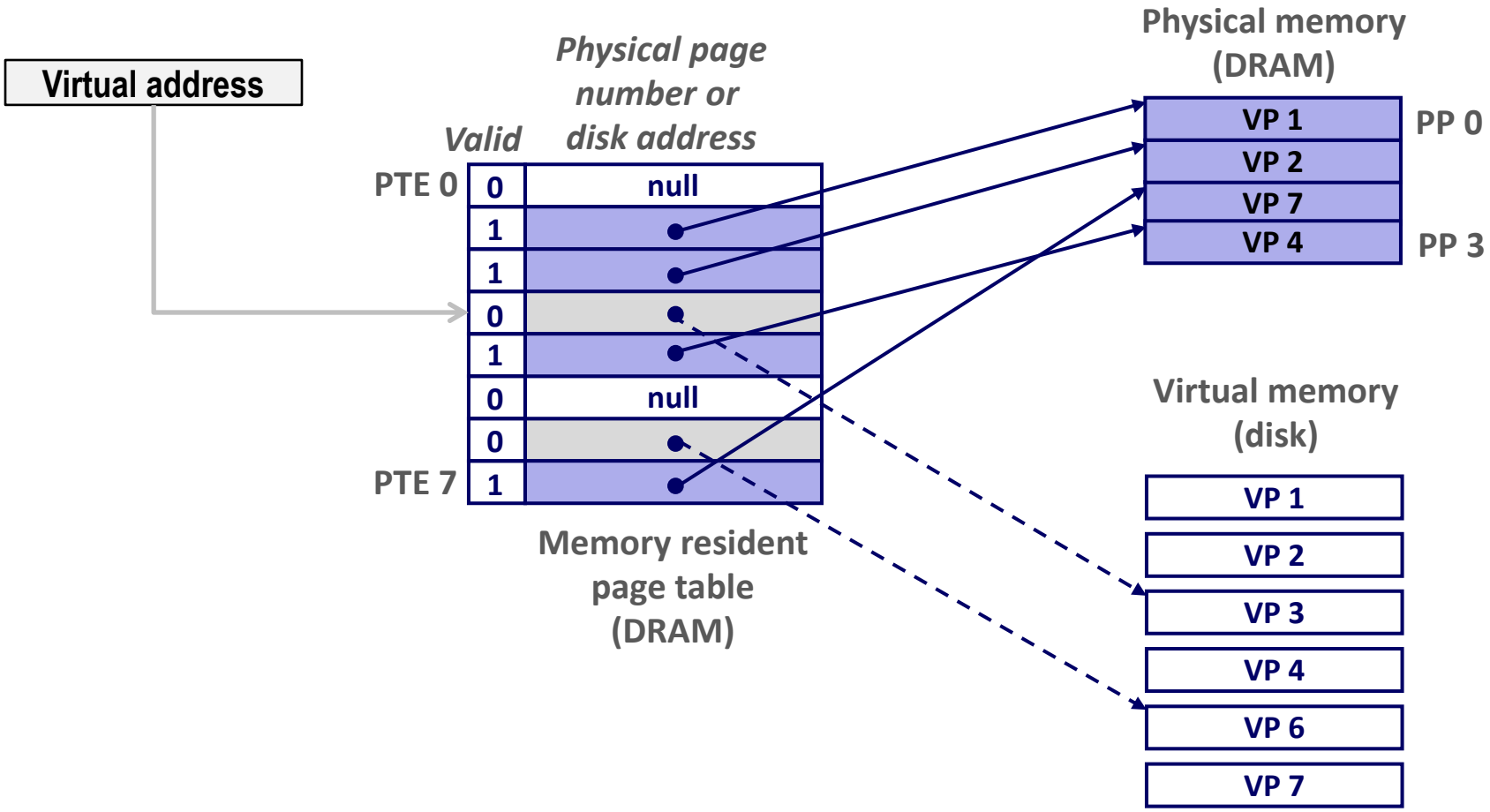
- Page miss causes page fault (an exception)



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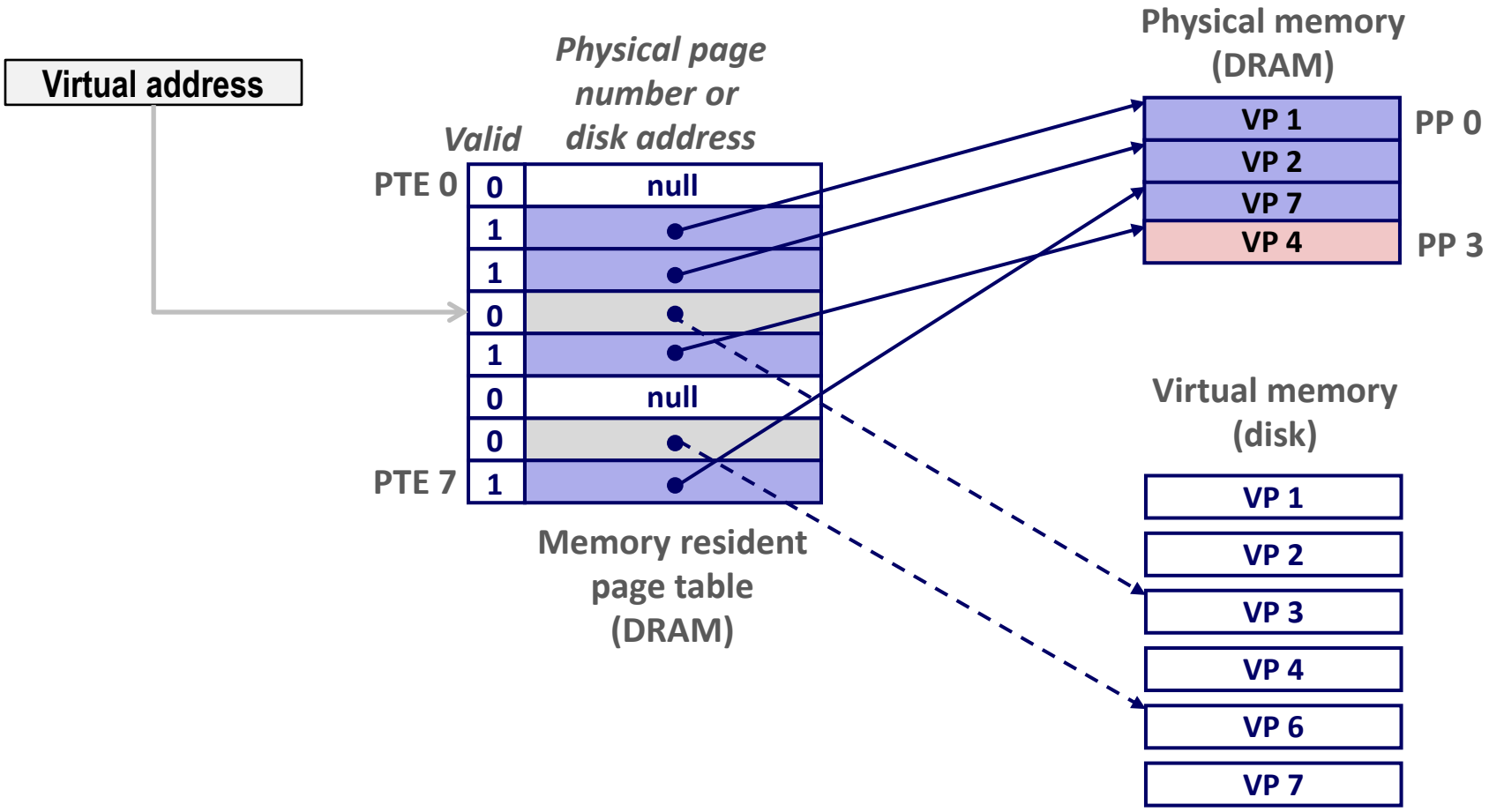

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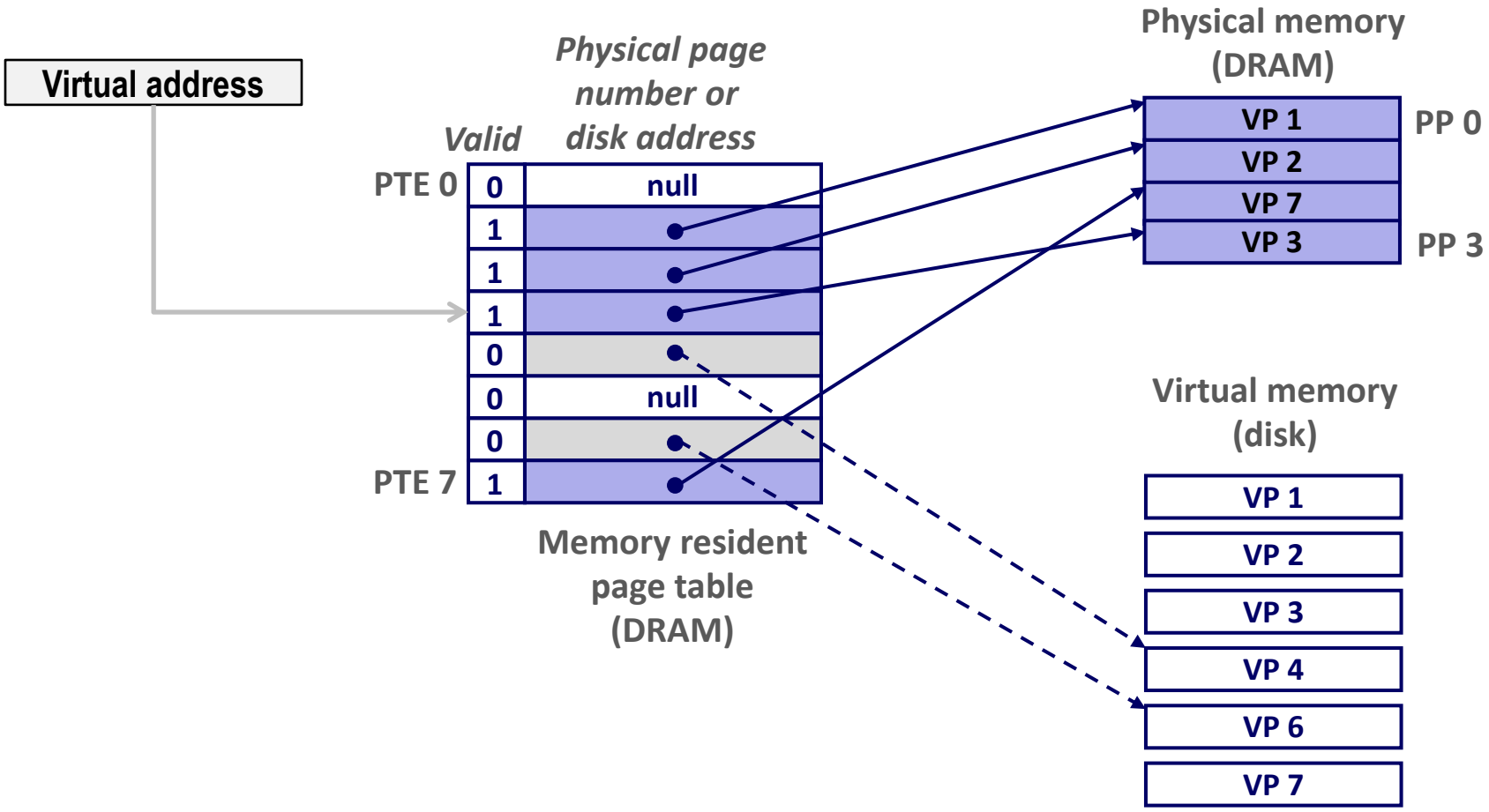

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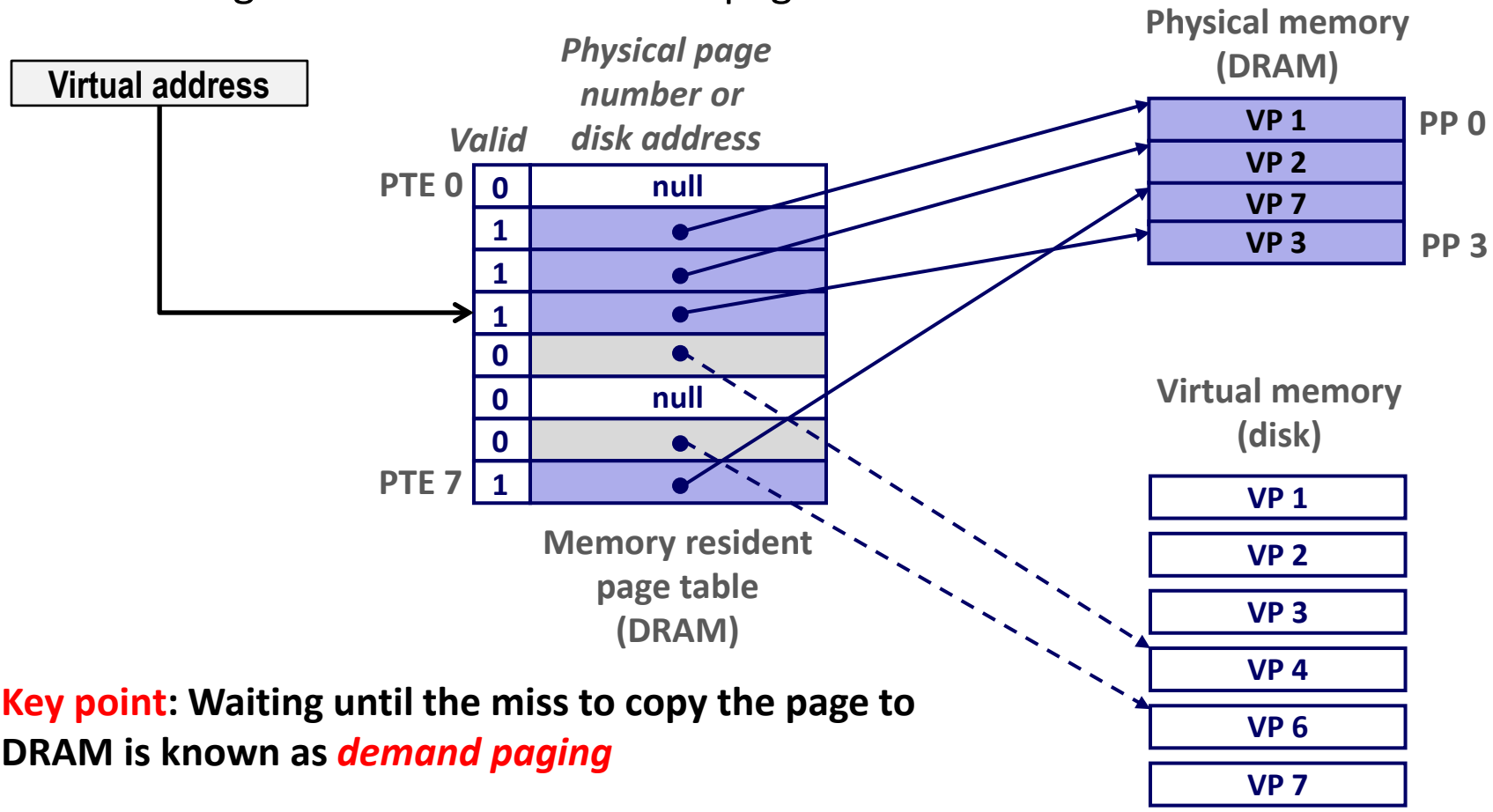
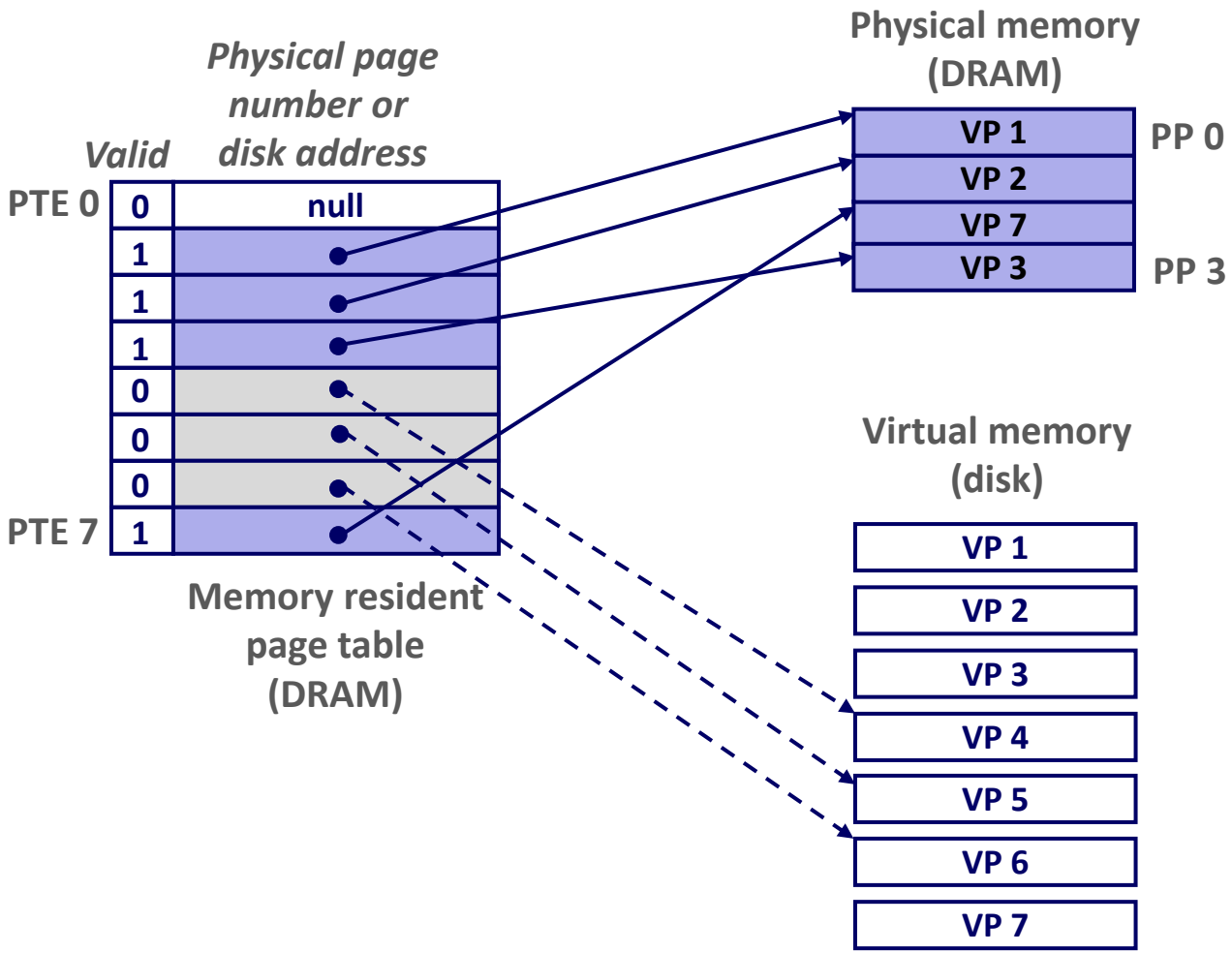
- Offending instruction is restarted: page hit!



Key point: Waiting until the miss to copy the page to DRAM is known as *demand paging*

Allocating Pages

- **Allocating a new page (VP 5) of virtual memory.**



Locality to the Rescue Again!

- **Virtual memory seems terribly inefficient, but it works because of locality.**
- **At any point in time, programs tend to access a set of active virtual pages called the *working set***
  - Programs with better temporal locality will have smaller working sets
- **If (working set size < main memory size)**
  - Good performance for one process after compulsory misses
- **If (SUM(working set sizes) > main memory size)**
  - *Thrashing:* Performance meltdown where pages are swapped (copied) in and out continuously