

# Chapter 9: Virtual Memory

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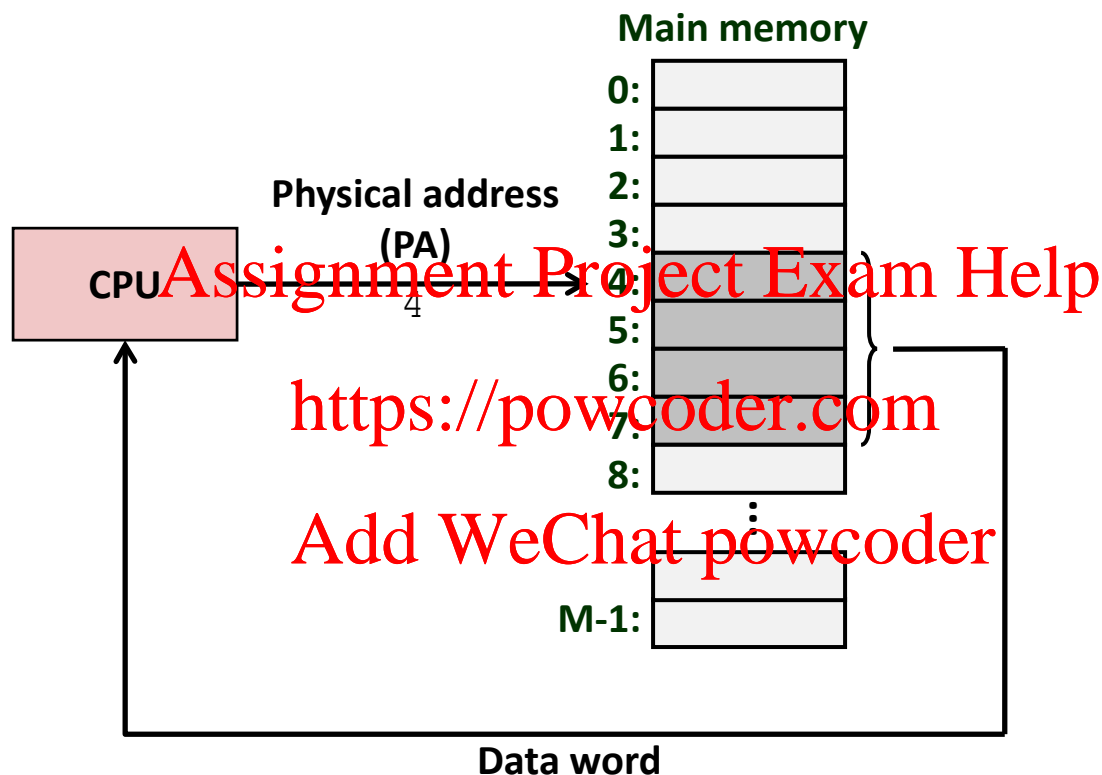
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# Today

- Address spaces
  - VM as a tool for caching
  - VM as a tool for memory management
  - VM as a tool for memory protection
  - Address translation
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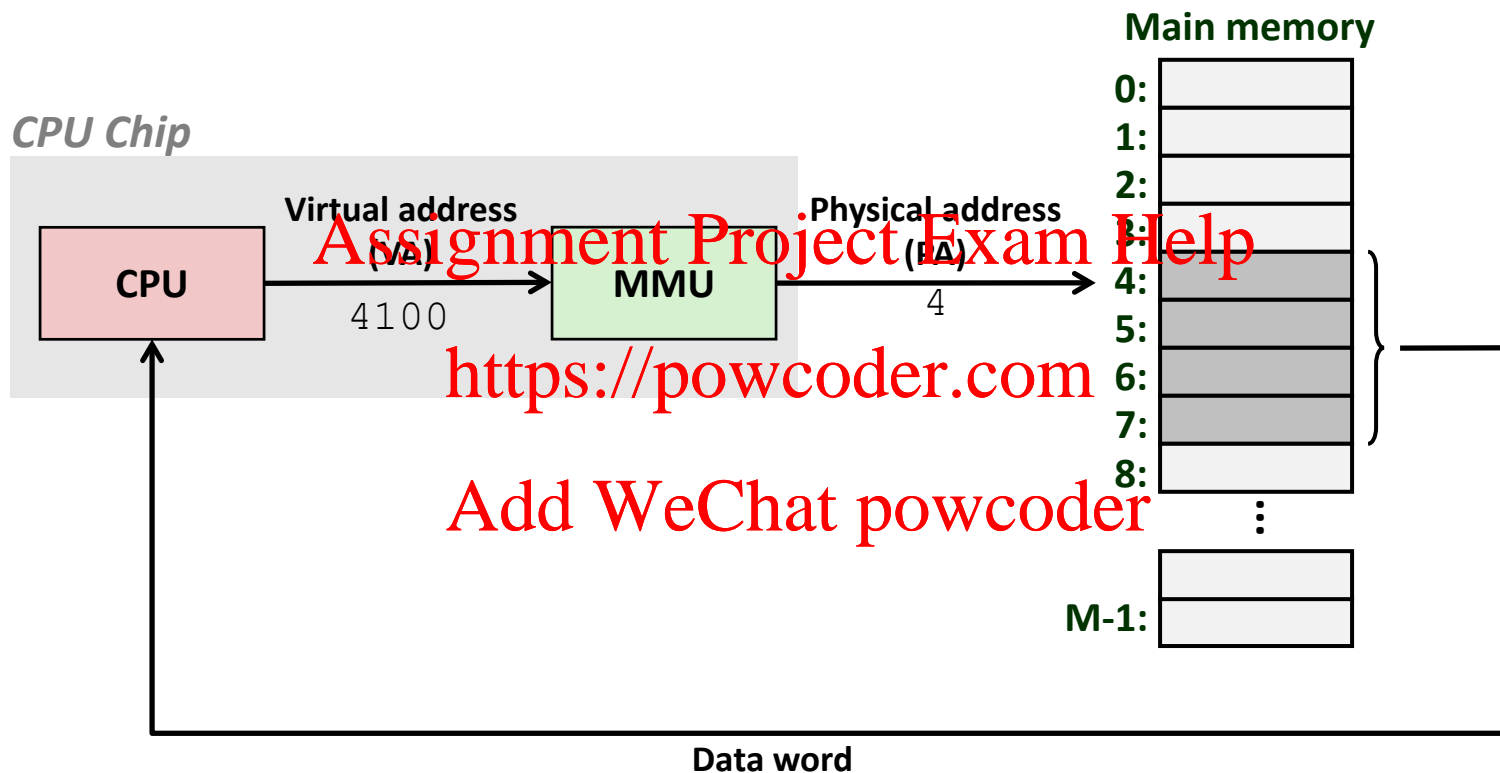
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# A System Using Physical Addressing



- Used in “simple” systems like embedded microcontrollers in devices like cars, elevators, and digital picture frames

# A System Using Virtual Addressing



- Used in all modern servers, desktops, and laptops
- One of the great ideas in computer science

# Address Spaces

- **Linear address space:** Ordered set of contiguous non-negative integer addresses:

$\{0, 1, 2, 3 \dots \}$

- **Virtual address space:** Set of  $N = 2^n$  virtual addresses  
 $\{0, 1, 2, 3, \dots, N-1\}$

- **Physical address space:** Set of  $M = 2^m$  physical addresses  
 $\{0, 1, 2, 3, \dots, M-1\}$

- Clean distinction between data (bytes) and their attributes (addresses)
- Each object can now have multiple addresses
- Every byte in main memory:  
one physical address, one (or more) virtual addresses

# Why Virtual Memory (VM)?

## ■ Uses main memory efficiently

- Use DRAM as a cache for the parts of a virtual address space

## ■ Simplifies memory management

- Each process gets the same uniform linear address space

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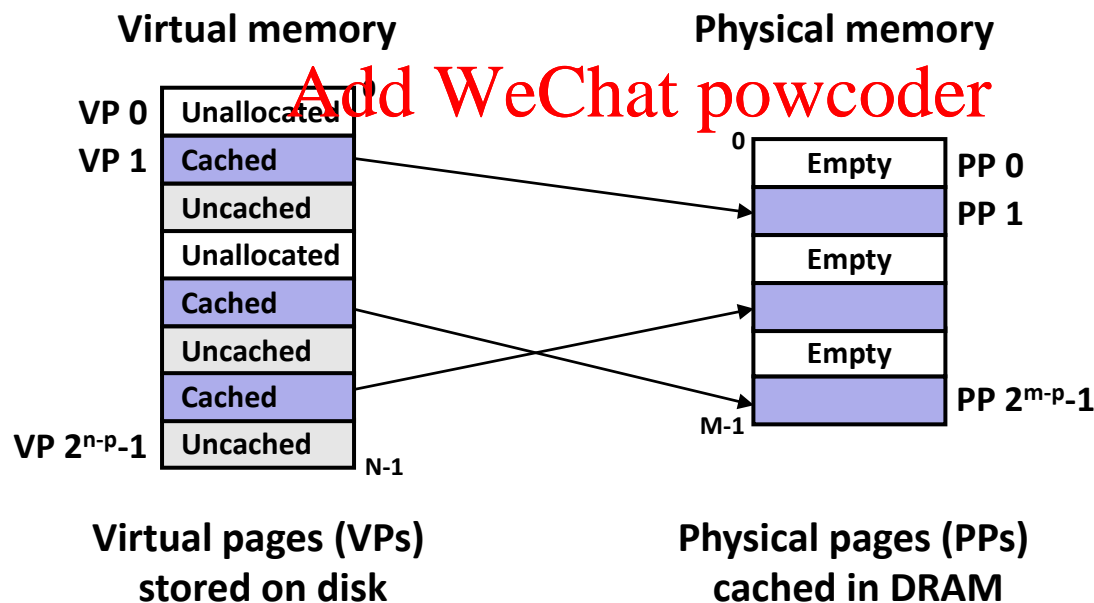
## ■ Isolates address spaces

- One process can't interfere with another's memory
- User program cannot access privileged kernel information

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# VM as a Tool for Caching

- **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)



# 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

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## ■ Consequences

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- Large page (block) size: typically 4-8 KB, sometimes 4 MB
- Fully associative **Add WeChat powcoder**
  - Any VP can be placed in any PP
  - Requires a “large” mapping function – different from CPU caches
- Highly sophisticated, expensive replacement algorithms
  - Too complicated and open-ended to be implemented in hardware
- Write-back rather than write-through