Lecture 7: Memory Management

CSE 120: Principles of Operating Systems

UC San Diego: Summer Session I, 2009
Frank Uyeda

Announcements

- PeerWise questions due tomorrow.
- Project 2 is due on Friday.
  - Milestone on Tuesday night.
- Homework 3 is due next Monday.

Goals for Today

- Motivation for Memory Management
- Understand Paging
  - How to translate from virtual to physical address
  - Determine size, structure of page tables

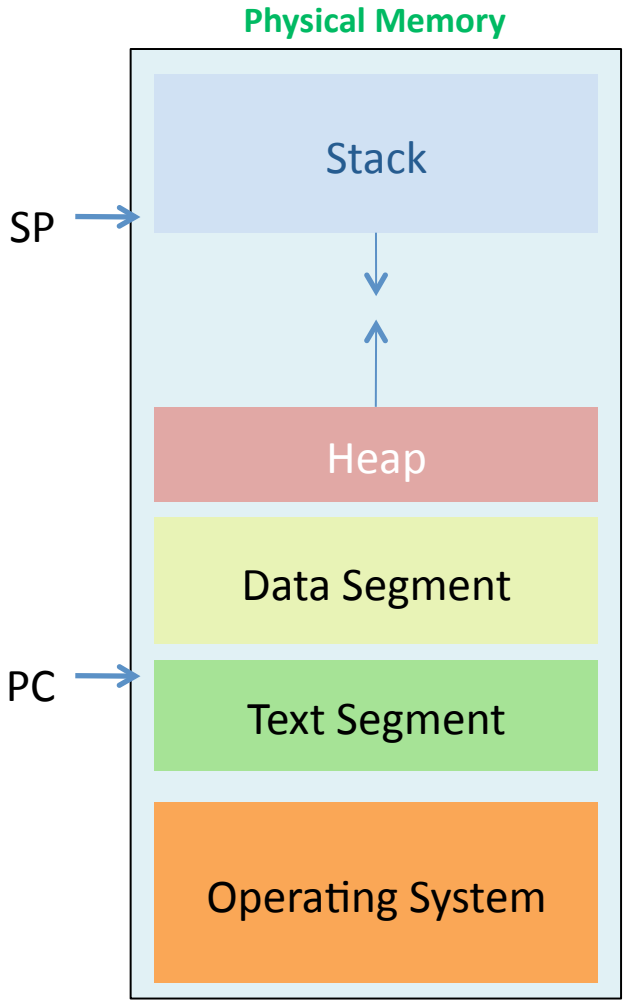
Memory Management

- Goals of memory management
  - Provide a convenient abstraction for programming
  - Allocate scarce memory resources among competing processes
  - Maximize performance with minimal overhead
- Mechanisms
  - Physical and virtual addressing
  - Techniques: Partitioning, paging, segmentation
  - Page table management, TLBs, VM tricks
- Policies
  - Page replacement algorithms

In the beginning…..

- Batch programmed systems
  - Programs use physical addresses directly
  - OS loads job, runs it, unloads it
  - Similar to what nachos does right now

    (you'll change this in Project 2)



Let there be Multiprogramming

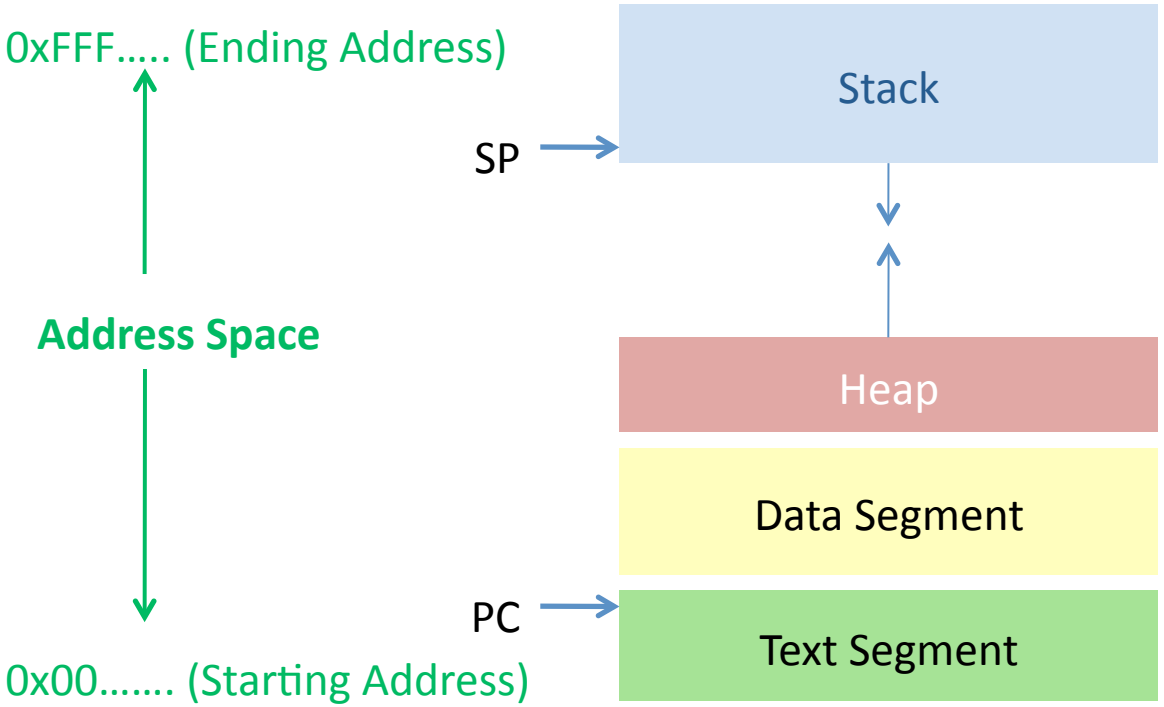
- Multiprogramming changes all of this
  - Want multiple processes in memory at once
    - Overlap I/O and CPU of multiple jobs
  - Can do it a number of ways
    - Fixed and variable partitioning, paging, segmentation
  - Requirements
    - Need protection – restrict which addresses jobs can use
    - Fast translation – lookups need to be fast
    - Fast changes – updating memory hardware on context switch

Virtual Memory

- The basic abstraction provided by the OS memory management is virtual memory
  - A process's address space in memory is not necessarily the same as the physical memory (RAM) address in which it resides
  - When a process requests a memory address, the OS will translate the address from a virtual address to a physical address.

Virtual Addresses

- Processes access memory using a virtual address
  - The virtual address is not the same as the physical RAM address in which it resides
  - The OS (hardware MMU) translates the virtual address into the physical RAM address
  - Who determines the mapping for the translation?



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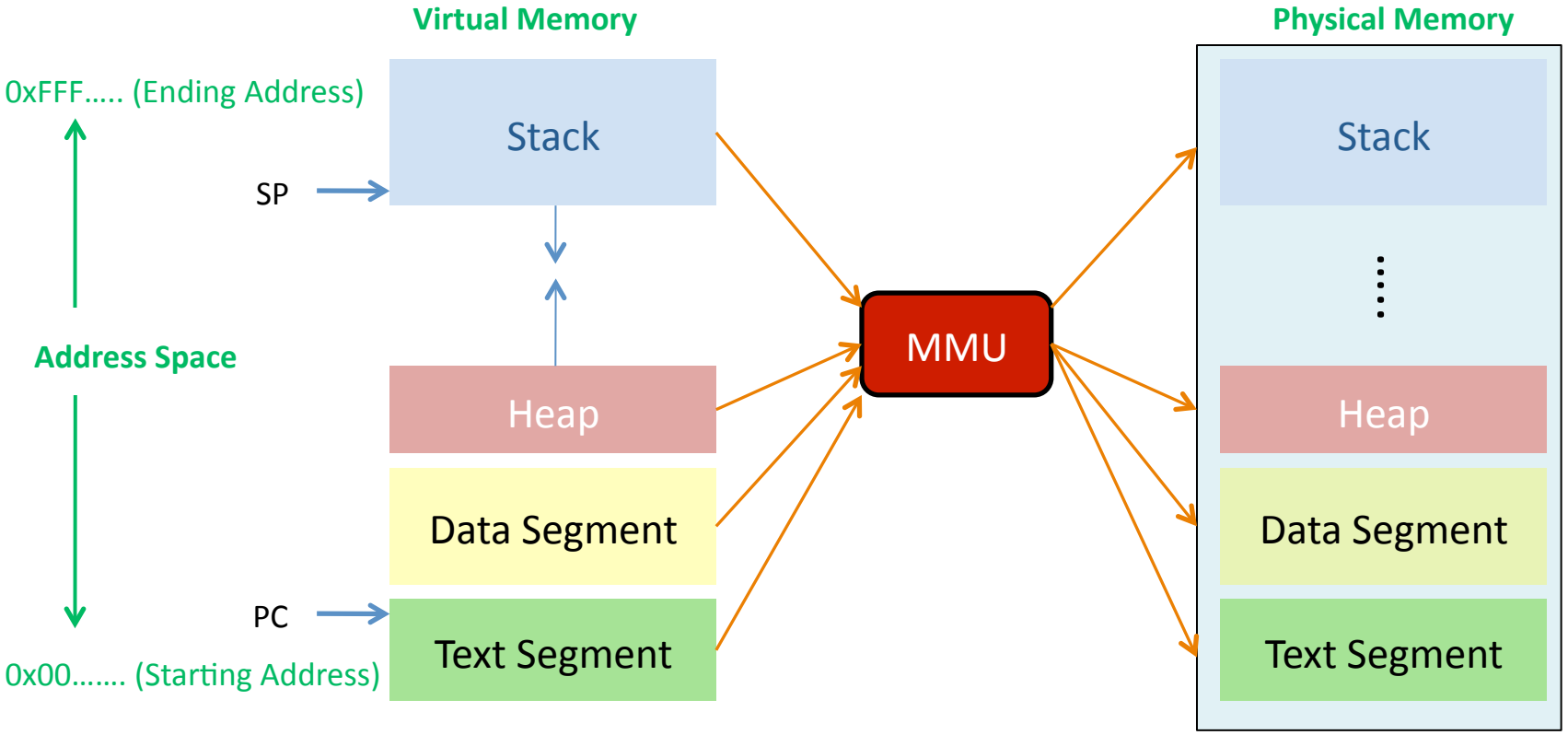

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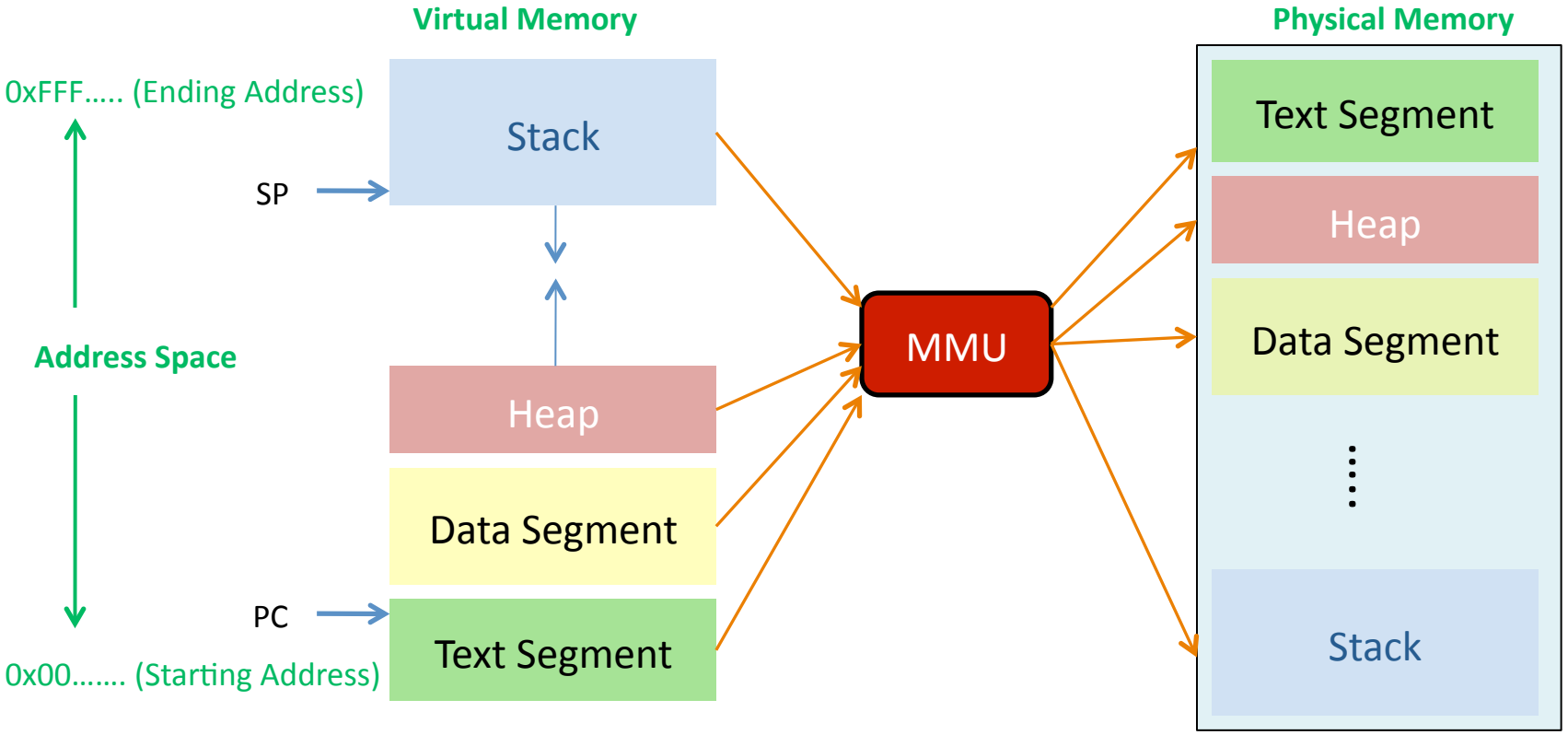


Virtual Memory

- Virtual memory enables programs to execute without requiring their entire address space reside in physical memory
  - Saves space
    - Many programs do not need all of their code and data at once (or ever), so there is no need to allocate memory for it
  - Allows flexibility for application and OS
    - Indirection allows moving programs around in memory; OS can adjust amount of memory allocated based upon its run-time behavior
    - Allows processes to address more *or* less memory than physically installed in the machine
  - Isolation and protection
    - One process cannot access memory addresses in others
    - Exception: shared memory, which we've already covered

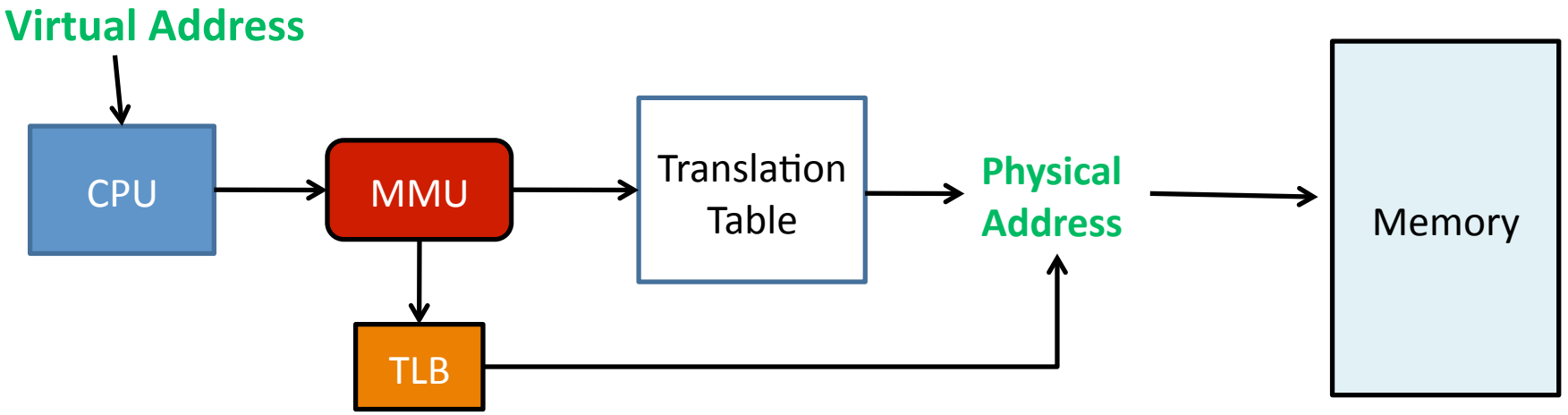
Memory Management Requirements

- Protection
  - Restrict which physical addresses processes can use, so they can't stomp on each other
- Fast translation
  - Accessing memory must be fast, regardless of the protection scheme
- Fast context switching
  - Overhead of updating memory hardware on a context switch must be low

- Requires hardware support for efficient implementation

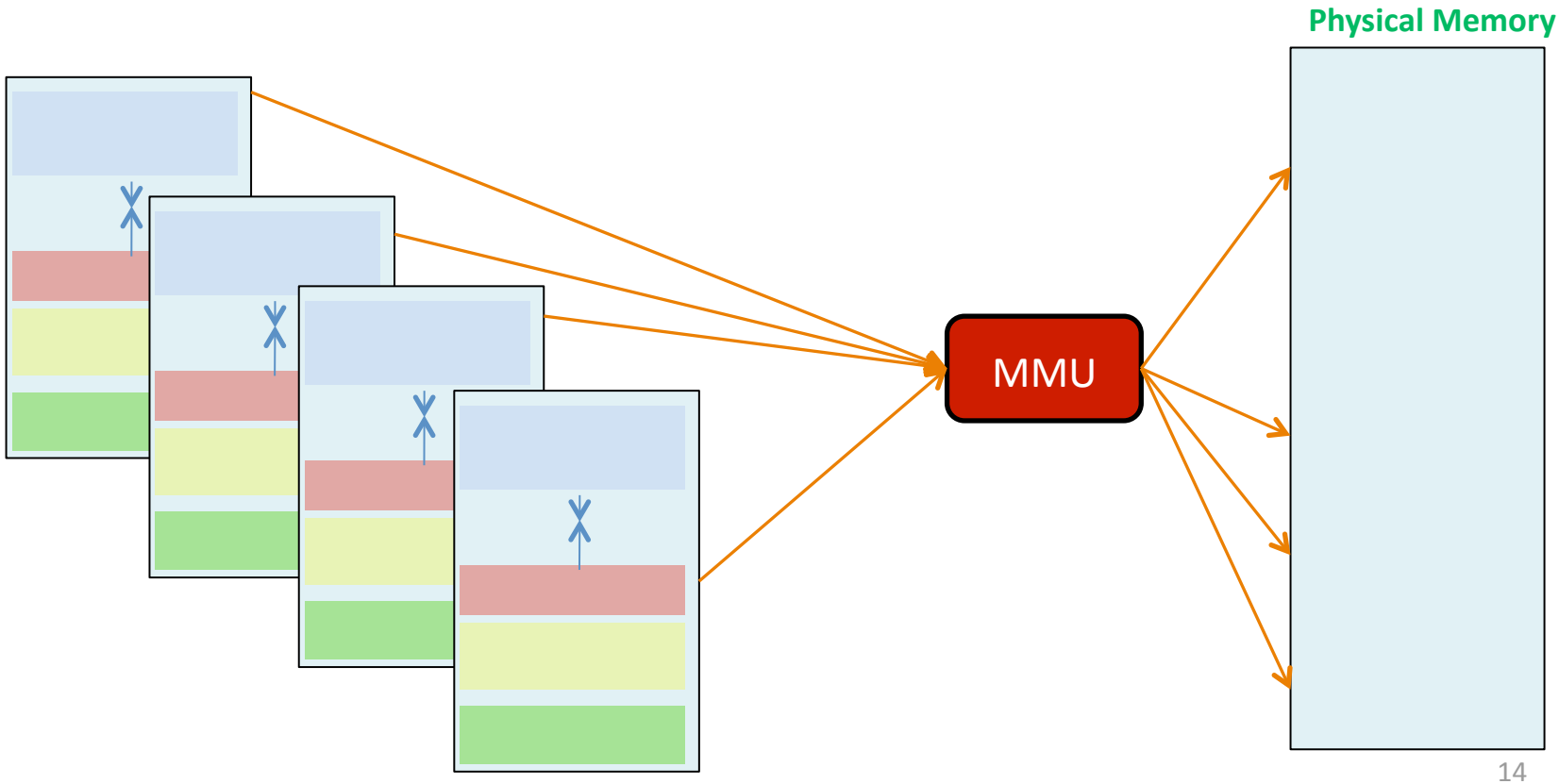
MMU and TLB

- Memory Management Unit (MMU)
  - Hardware unit that translates a virtual address to a physical address
  - Each memory reference is passed through the MMU
  - Translate a virtual address to a physical address
- Translation Lookaside Buffer (TLB)
  - Essentially a cache for the MMU's virtual-to-physical translations table
  - Not needed for correctness but source of *significant* performance gain



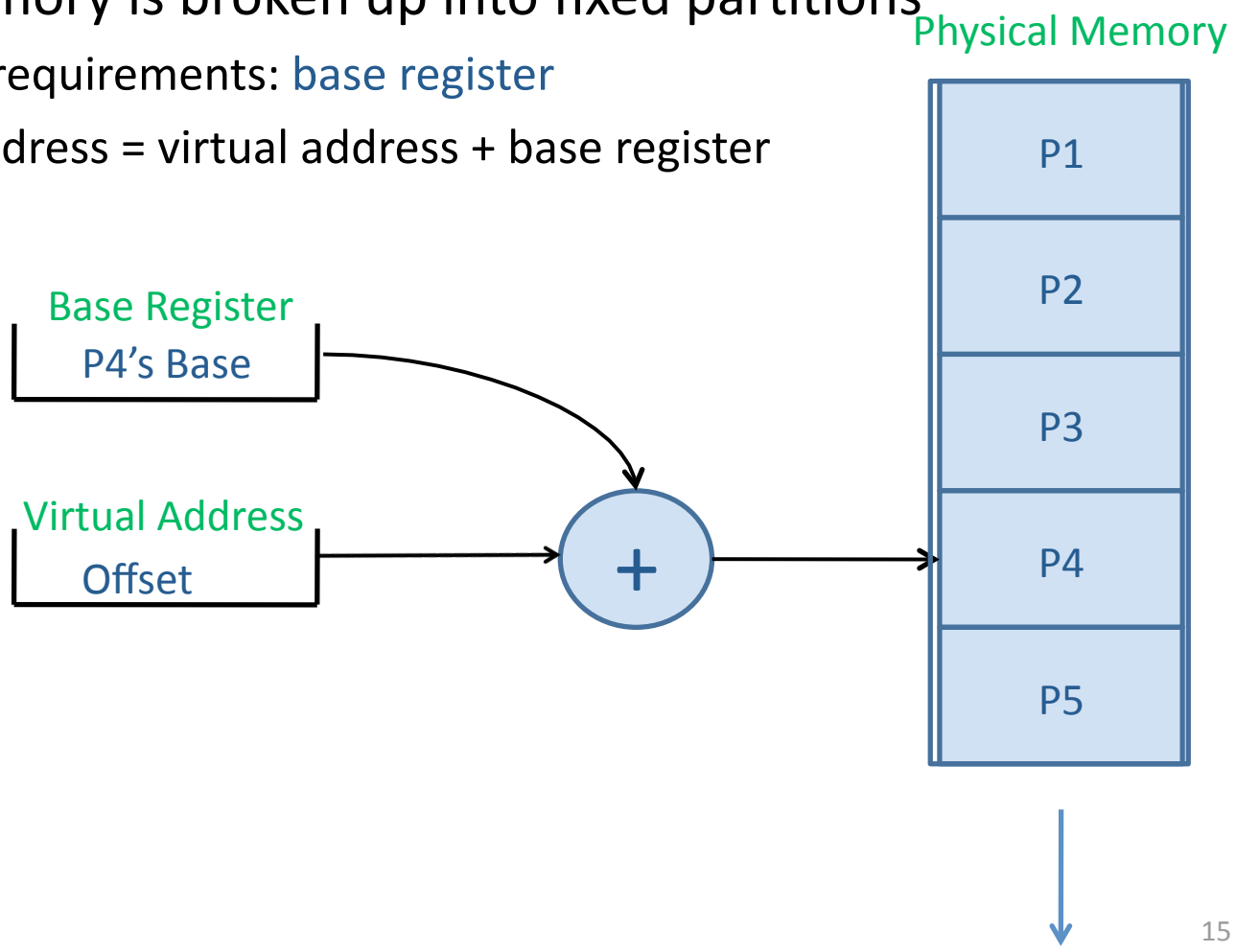
Memory Allocation

- How should we allocate memory to processes?



Fixed Partitions

- Physical memory is broken up into fixed partitions
  - Hardware requirements: base register
  - Physical address = virtual address + base register



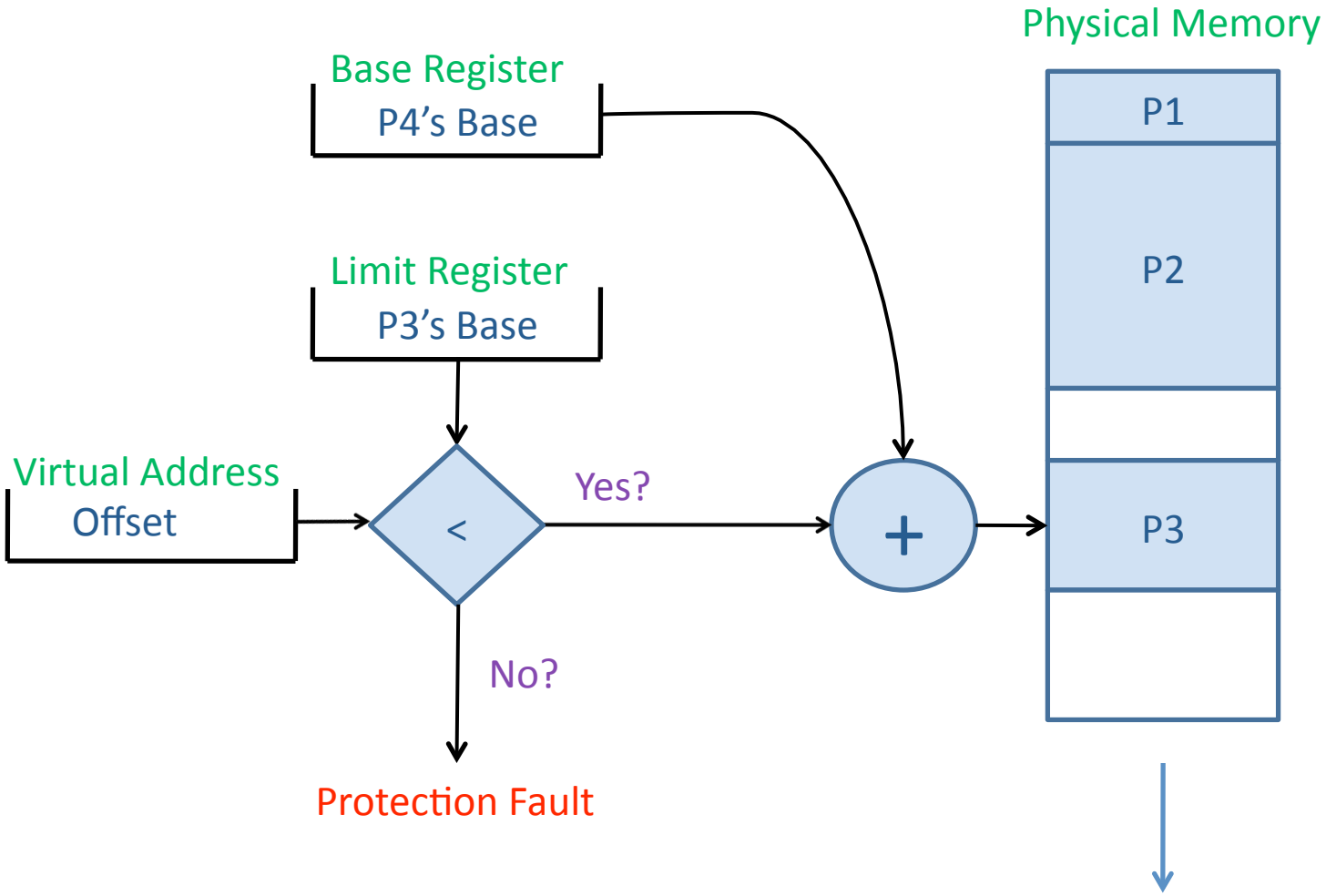
Fixed Partitions

- Physical memory is broken up into fixed partitions
  - Hardware requirements: base register
  - Physical address = virtual address + base register
  - Base register loaded by OS when it switches to a process
  - Size of each partition is the same and fixed
  - How do we provide protection?
- Advantages
  - Easy to implement, fast context switch
- Problems
  - Internal fragmentation: memory in a partition not used by a process is not available to other processes
  - Partition size: one size does not fit all (very large processes?)

Variable Partitions

- Natural extension – physical memory is broken up into variable sized partitions
  - Hardware requirements: base register and limit register
  - Physical address = virtual address + base register
  - Why do we need the limit register? Protection
    - If (physical address > base + limit) then protection fault

Variable Partitions

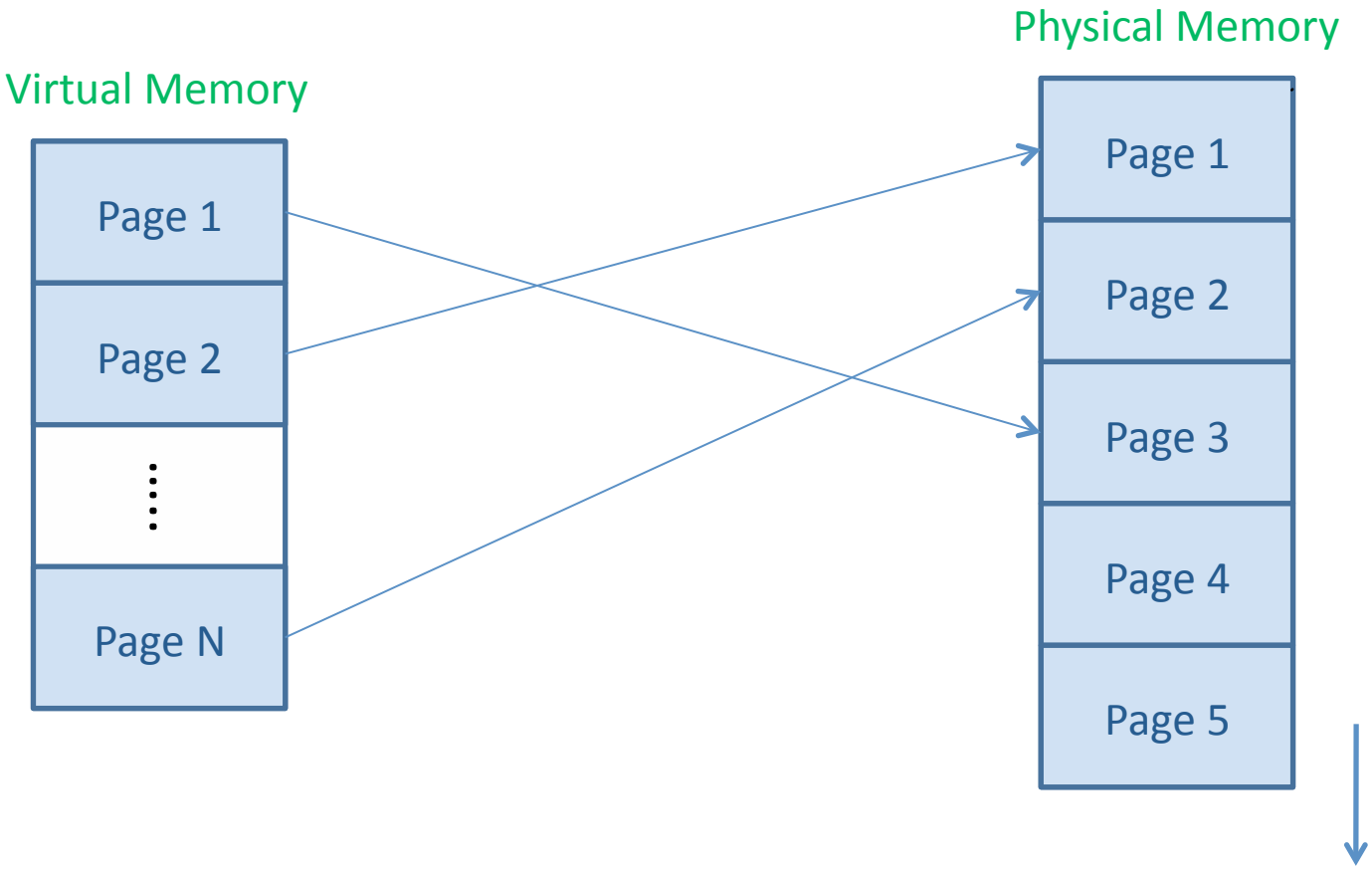


Variable Partitions

- Natural extension – physical memory is broken up into variable sized partitions
  - Hardware requirements: base register and limit register
  - Physical address = virtual address + base register
  - Why do we need the limit register? Protections
    - If (physical address > base + limit) then exception fault
- Advantages
  - No internal fragmentation: allocate just enough for process
- Problems
  - External fragmentation: job loading and unloading produces empty holes scattered throughout memory

Paging

- Paging solves the external fragmentation problem by using fixed sized units in both physical and virtual memory

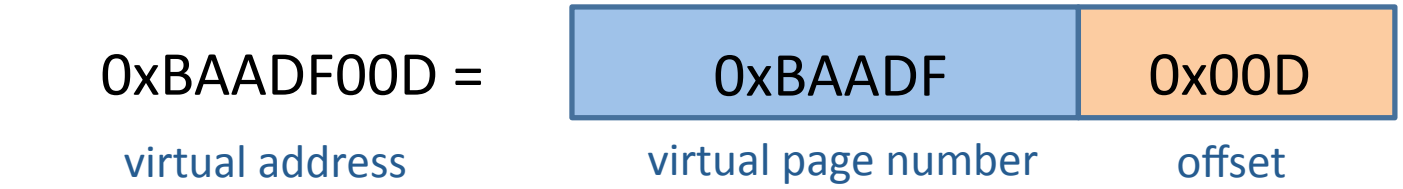


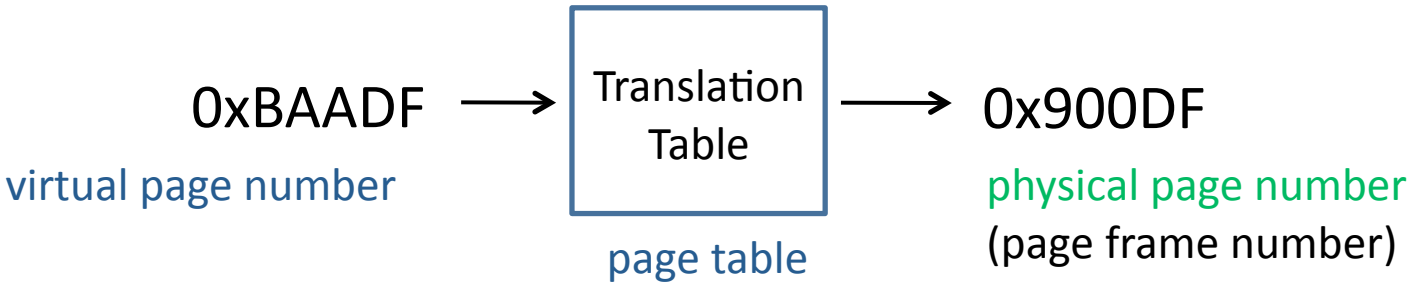
User/Process Perspective

- Users (and processes) view memory as one contiguous address space from 0 to N
  - Virtual address space
- In reality, pages are scattered throughout physical storage
- The mapping is invisible to the program
- Protection is provided because a program cannot reference memory outside of its virtual address space
  - The address "0x1000" maps to different physical addresses in different processes

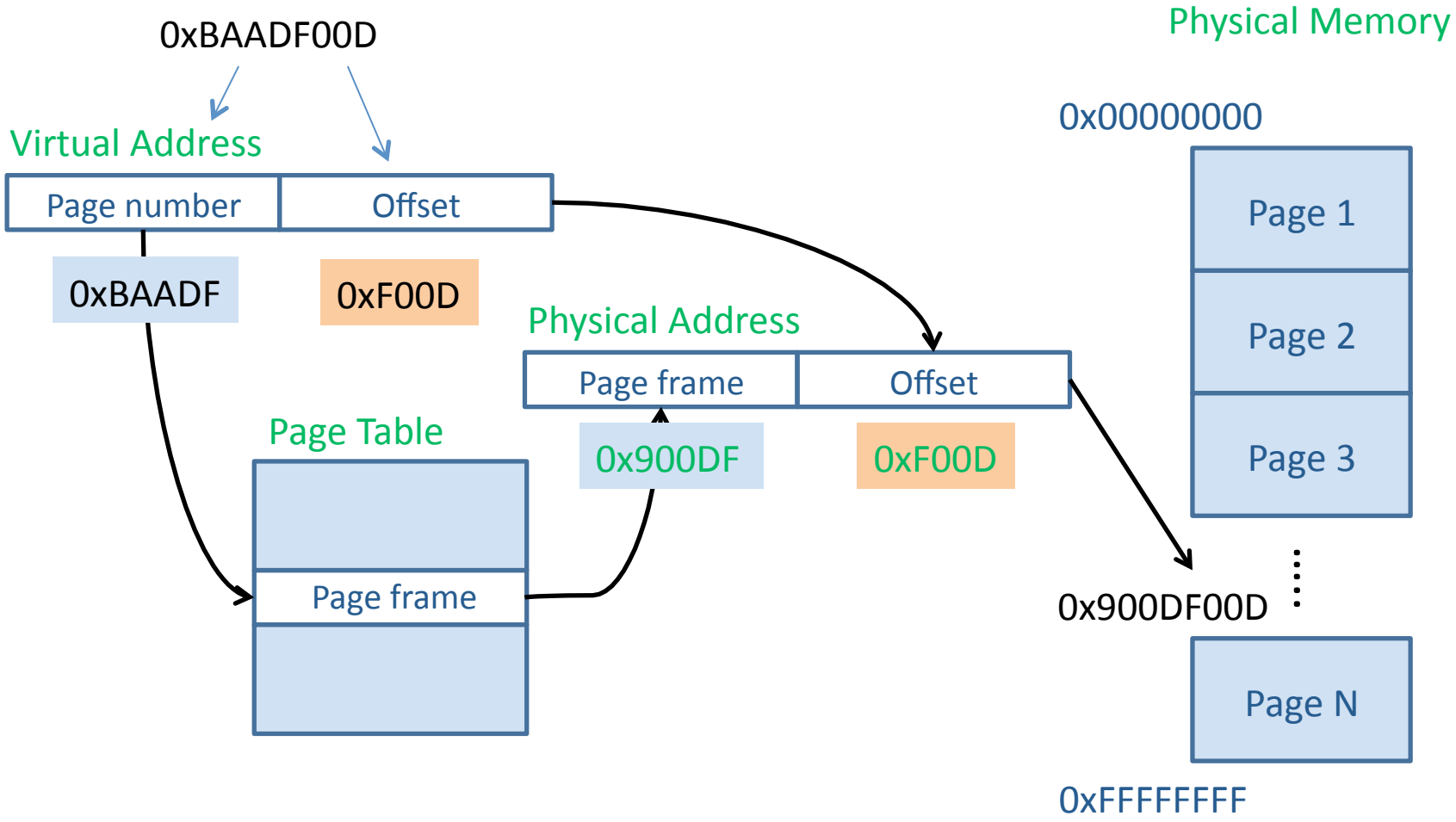
Paging

- Translating addresses
  - Virtual address has two parts: virtual page number and offset
  - Virtual page number (VPN) is an index into a page table
  - Page table determines page frame number (PFN)
  - Physical address is PFN::offset





Page Lookups



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  - Physical address is PFN::offset
- Page tables
  - Map virtual page number (VPN) to page frame number (PFN)
    - VPN is the index into the table that determines PFN
  - One page table entry (PTE) per page in virtual address space
    - Or, one PTE per VPN

Paging Example

- Memory address is 32 bits
- Pages are 4K
  - VPN is____bits (___VPNs), offset is___bits
- Virtual address is 0x7468
  - Virtual page is ___, offset is _____
- Page table entry ___ contains 0x2
  - Page frame base is 0x2 << _____= _____
  - _____th virtual page is address _____ (3rd physical page)
- Physical address = _____ + _____ = _____

Paging Example

- Memory address is 32 bits
- Pages are 4K
  - VPN is 20 bits (1M VPNs), offset is 12 bits
- Virtual address is 0x7468
  - Virtual page is 0x7, offset is 0x468
- Page table entry 0x7 contains 0x2
  - Page frame base is 0x2 << 12 bits = 0x2000
  - 7th virtual page is address 0x2000 (3^{rd} physical page)
- Physical address = 0x2000 + 0x468 = 0x2468

Next Time

- Read Chapter 8.3-8.8
- Peerwise questions due tomorrow at midnight.
- Check Web site for course announcements
  - http://www.cs.ucsd.edu/classes/su09/cse120