



Operating System Concepts

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Chapter 8. Memory- Management Strategies

Objectives

- ▶ To provide a detailed description of various ways of organizing memory hardware
- ▶ To discuss various memory-management techniques, including paging and segmentation



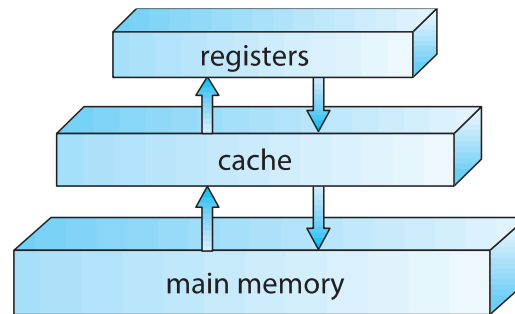
Background

- ▶ Program must be brought (from disk) into memory and placed within a process for it to be run
- ▶ Main memory and registers are the storages which CPU can access directly
- ▶ Register access is in one CPU clock (or less)
- ▶ Main memory access can take cycles, causing a **stall**
- ▶ **Cache** sits between main memory and CPU registers

Storage-Device Hierarchy

Primary Storage

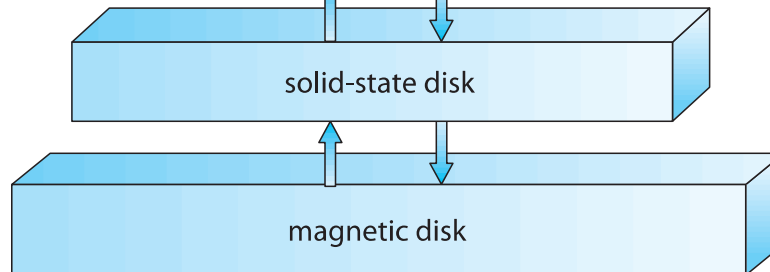
- volatile storage



- Access time: a cycle
- Access time: several cycles
- Access time: many cycles

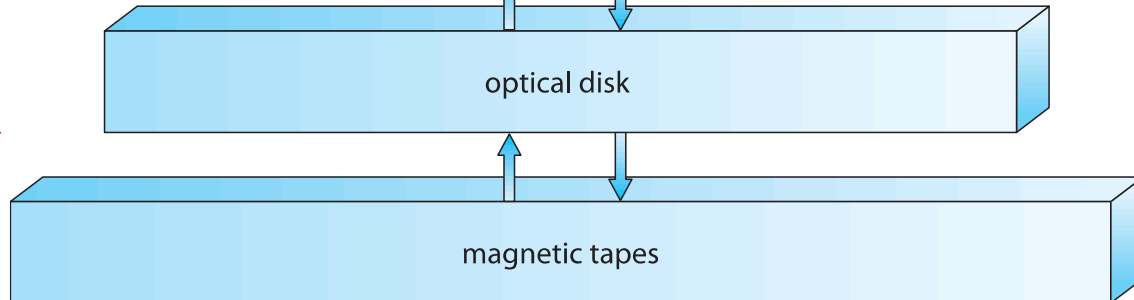
Secondary Storage

- nonvolatile storage



Tertiary Storage

- removable media



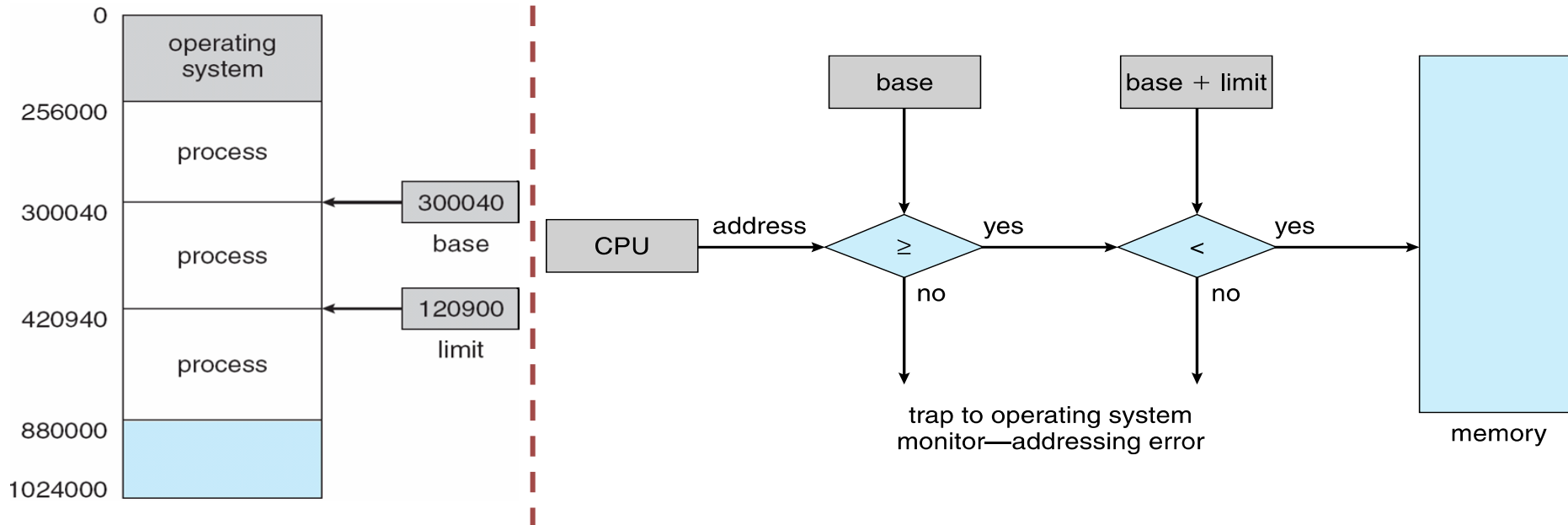
Memory Management

- ▶ Motivation
 - Keep several processes in memory to improve a system's performance
- ▶ Selection of different memory management methods
 - Application-dependent
 - Hardware-dependent
- ▶ Memory – A large array of words or bytes, each with its own address
 - Memory is always too small
- ▶ What should be done
 - Know which areas are free or used
 - Decide which processes to get memory
 - Perform allocation and de-allocation



Base and Limit Registers

- ▶ A pair of **base** and **limit registers** define the logical address space
- ▶ CPU must check every memory access generated in user mode is between base and limit for that user



Binding of Instructions and Data to Memory

- ▶ Address binding of instructions and data to memory addresses can happen at three different stages
 - **Compile time:** If memory location is known a priori, absolute code can be generated → must recompile code if starting location changes
 - **Load time:** Must generate relocatable code if memory location is not known at compile time
 - **Execution time:** Binding delayed until run time if the process can be moved during its execution from one memory segment to another



Logical and Physical Address Space

- ▶ **Logical address** – generated by the CPU; also referred to as **virtual address**
- ▶ **Physical address** – address seen by the memory unit
- ▶ Logical and physical addresses are the same in compile-time and load-time address-binding schemes; logical and physical addresses differ in execution-time address-binding scheme
- ▶ **Logical address space** is the set of all logical addresses generated by a program
- ▶ **Physical address space** is the set of all physical addresses generated by a program



Dynamic Linking

- ▶ Static linking – system libraries and program code combined by the loader into the binary program image
- ▶ Dynamic linking –linking postponed until execution time
- ▶ Small piece of code, **stub**, used to locate the appropriate memory-resident library routine
- ▶ Stub replaces itself with the address of the routine, and executes the routine
- ▶ Dynamic linking is particularly useful for shared libraries

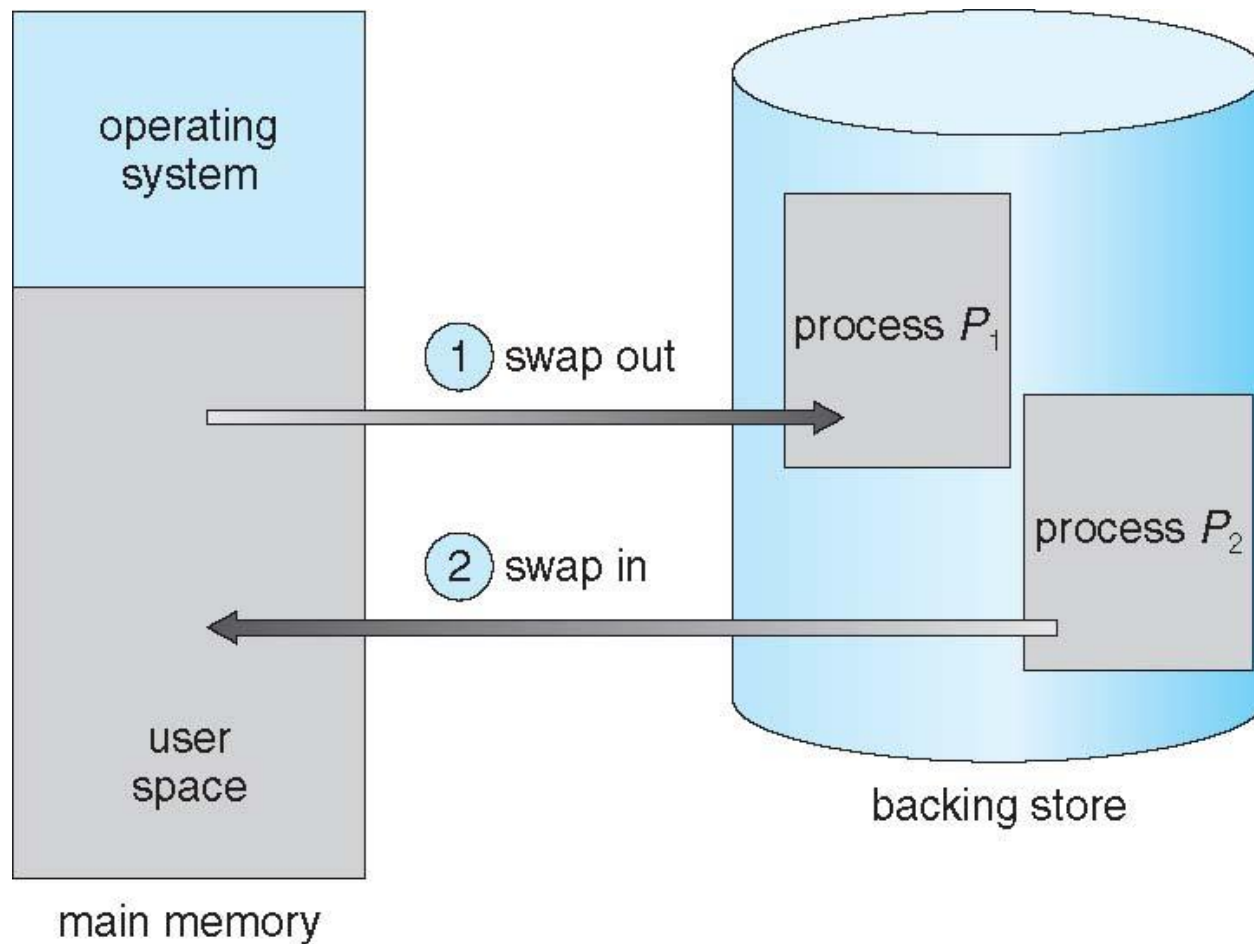


Swapping

- ▶ A process can be swapped temporarily out of memory to a backing store, and then brought back into memory for continued execution
- ▶ Does the swapped out process need to swap back in to the same physical addresses?
- ▶ Modified versions of swapping are found on many systems (i.e., UNIX, Linux, and Windows)
 - Swapping normally disabled
 - Started if more than threshold amount of memory allocated
 - Disabled again once memory demand reduced below threshold



Schematic View of Swapping



Swapping on Mobile Systems

- ▶ Not typically supported
 - Flash memory
 - Small amount of space
 - Limited number of write cycles
 - Poor throughput between flash memory and CPU on mobile platform
- ▶ Instead use other methods to free memory if it is low
 - iOS asks apps to voluntarily relinquish allocated memory
 - Read-only data thrown out and reloaded from flash if needed
 - Failure to free can result in termination
 - Android terminates apps if low free memory, but first writes application state to flash for fast restart



Contiguous Allocation (1 / 2)

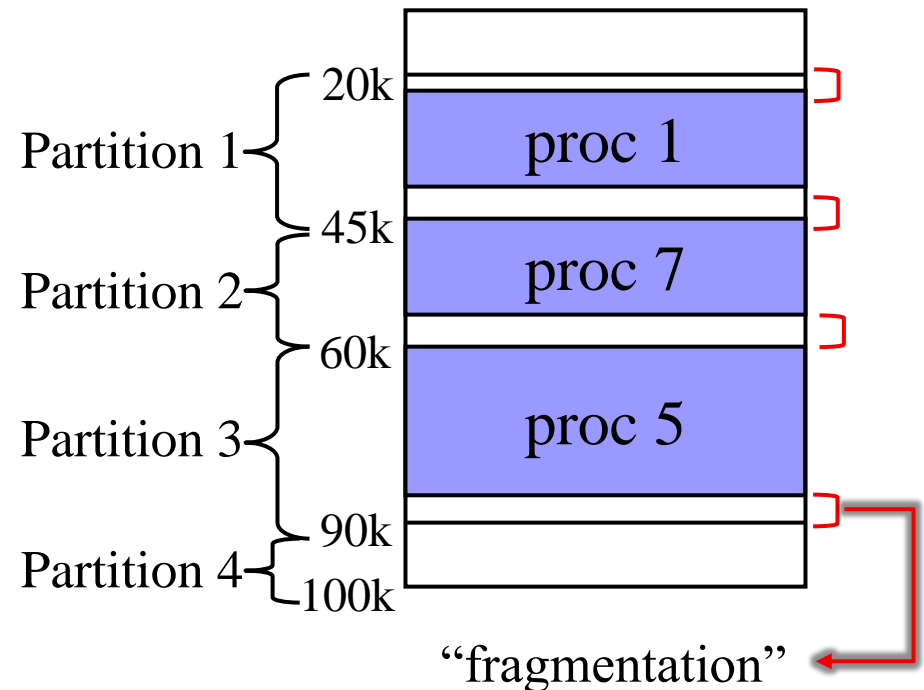
► Fixed Partitions

- Memory is divided into fixed partitions, e.g., OS/360
- A process is allocated on an entire partition

Partitions

number size location status

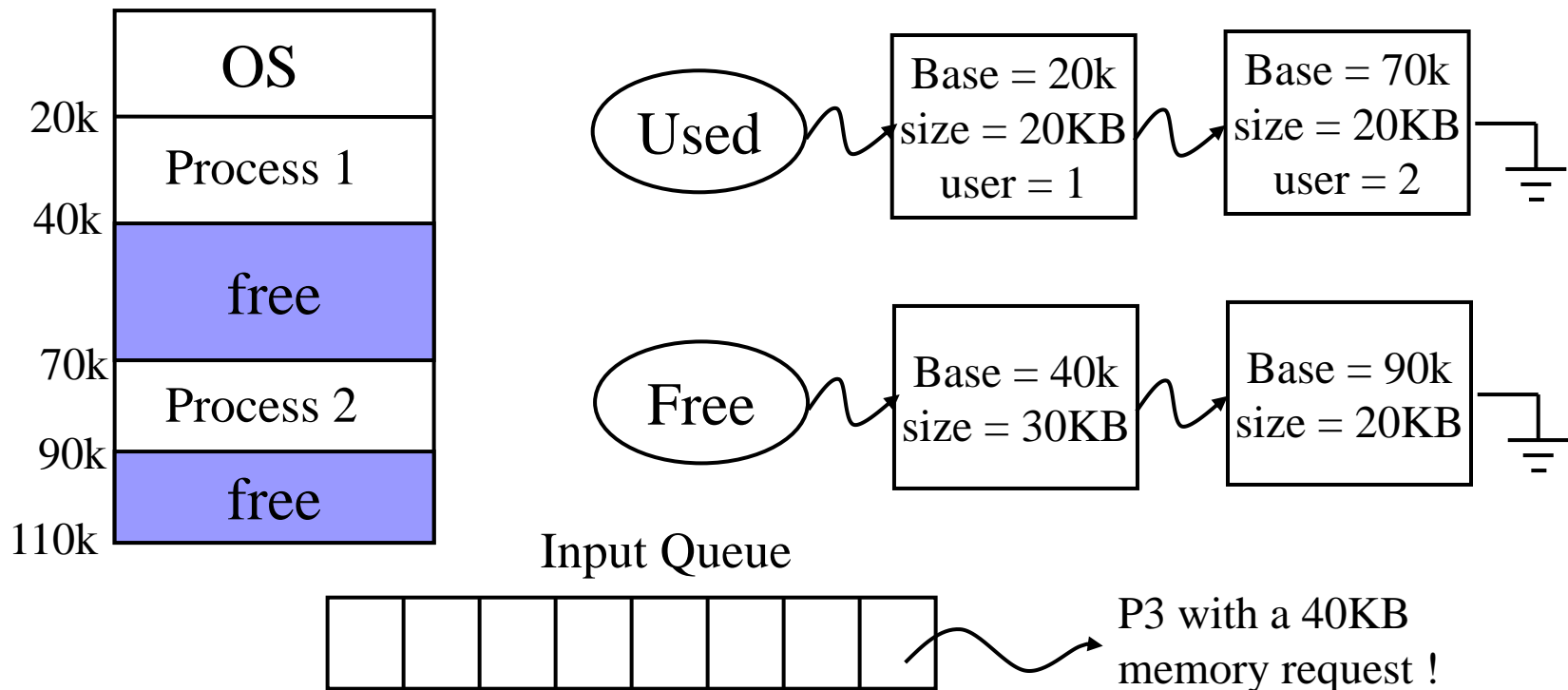
number	size	location	status
1	25KB	20k	Used
2	15KB	45k	Used
3	30KB	60k	Used
4	10KB	90k	Free



Contiguous Allocation (2/2)

► Dynamic Partitions

- Partitions are dynamically created
- OS tables record free and used partitions



Dynamic Allocation

- ▶ **First-fit**: Allocate the *first* hole that is big enough
- ▶ **Best-fit**: Allocate the *smallest* hole that is big enough; must search entire list, unless ordered by size
 - Produces the smallest leftover hole
- ▶ **Worst-fit**: Allocate the *largest* hole; must also search entire list
 - Produces the largest leftover hole

➔ First-fit and best-fit are better than worst-fit in terms of speed and storage utilization

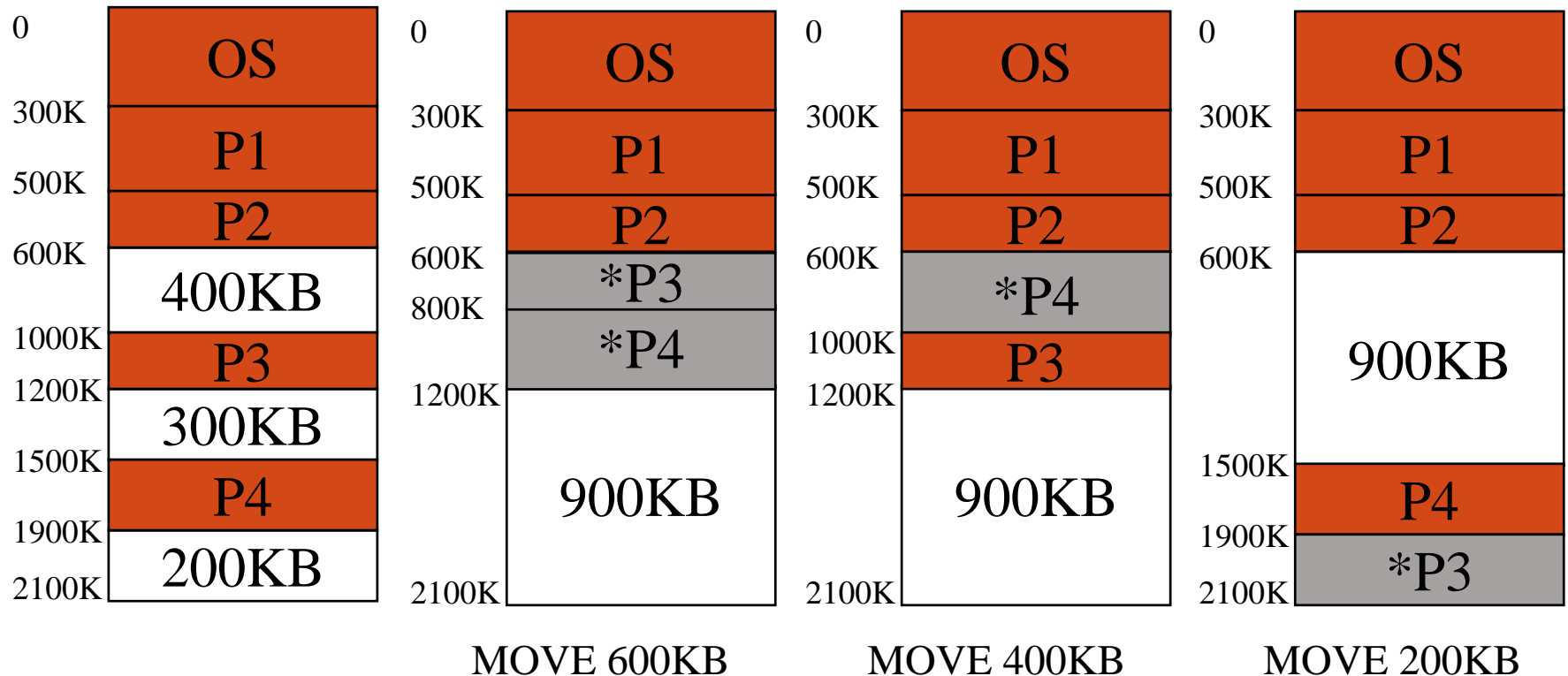


Fragmentation

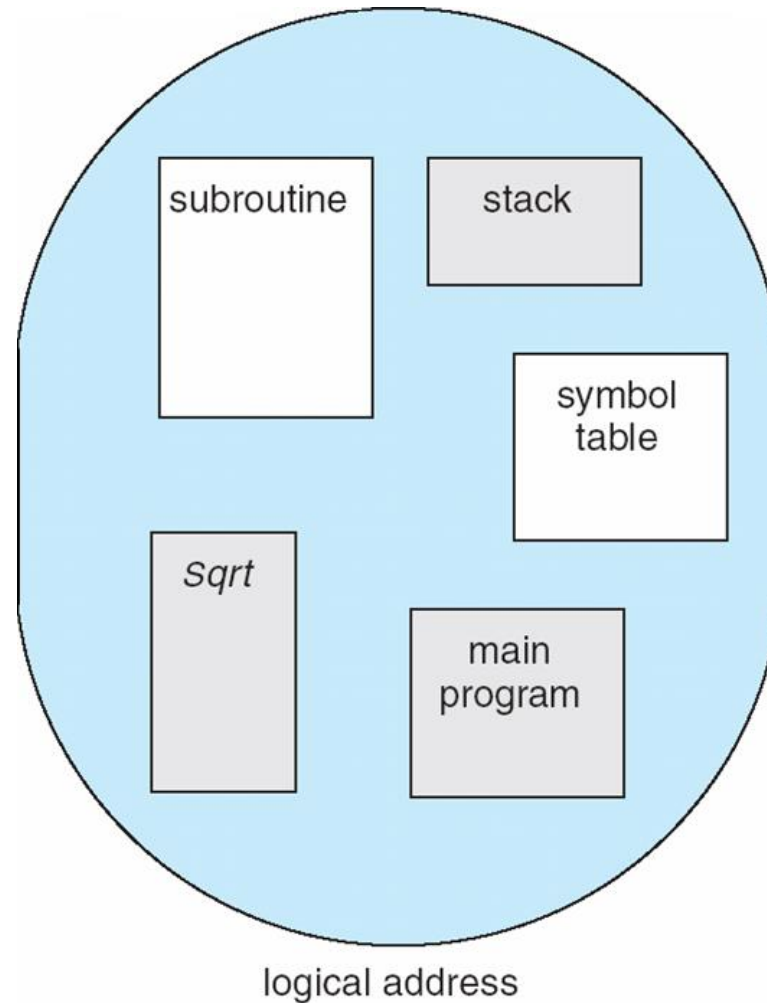
- ▶ **External Fragmentation** – total memory space exists to satisfy a request, but it is not contiguous
- ▶ **Internal Fragmentation** – allocated memory may be slightly larger than requested memory; this size difference is memory internal to a partition, but not being used
- ▶ First fit analysis reveals that given N blocks allocated, $0.5 N$ blocks lost to fragmentation
 - $1/3$ may be unusable -> **50-percent rule**



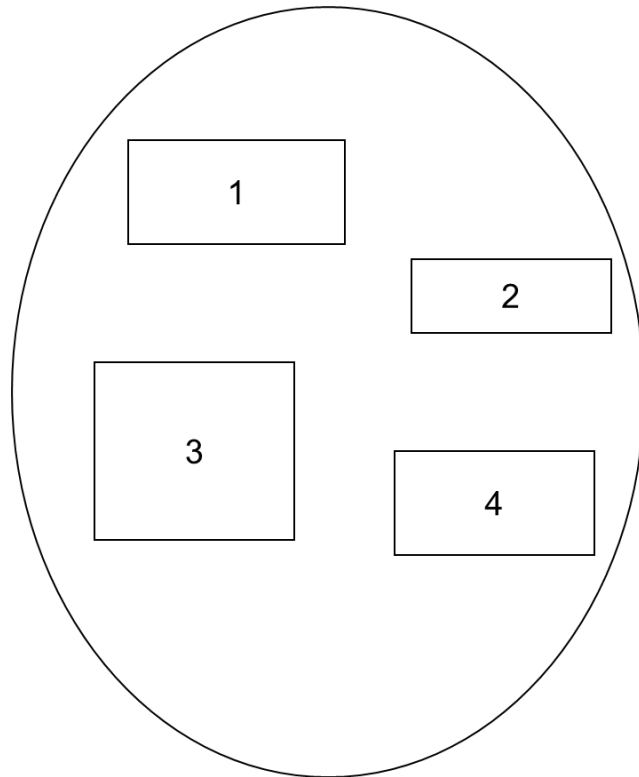
Fragmentation — Compaction



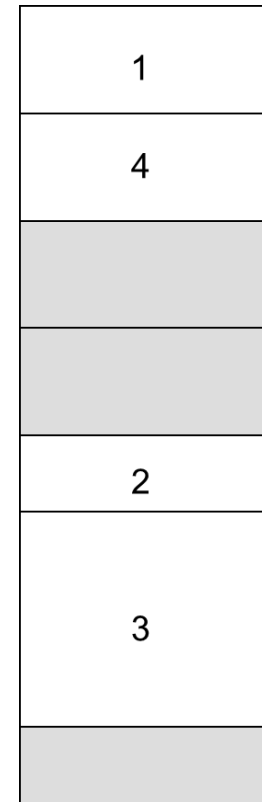
User's View of a Program



Logical View of Segmentation



user space



physical memory space

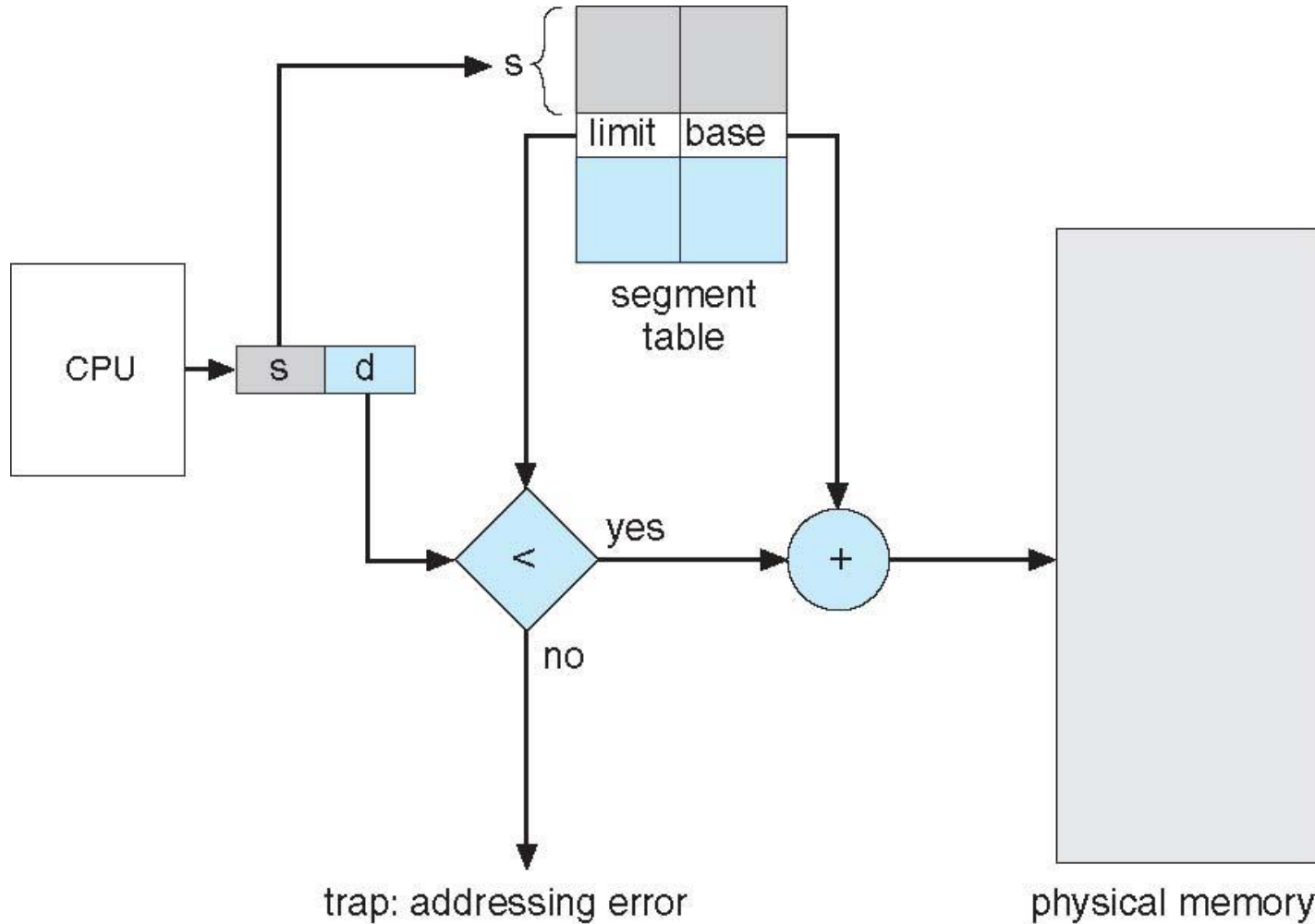


Segmentation

- ▶ Segmentation is a memory management scheme that supports the user view of memory
 - A logical address space is a collection of segments with variable lengths
- ▶ Logical address consists of a tuple:
 $\langle \text{segment-number, offset} \rangle$
- ▶ **Segment table** – maps two-dimensional physical addresses; each table entry has:
 - **base** – contains the starting physical address where the segments reside in memory
 - **limit** – specifies the length of the segment



Segmentation Architecture



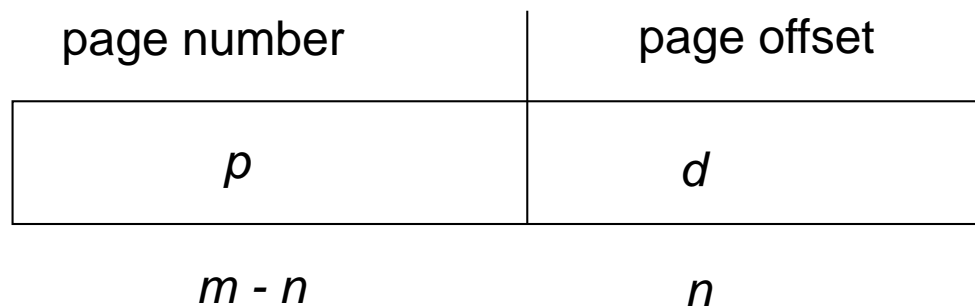
Paging

- ▶ Objective
 - Users see a logically contiguous address space although its physical addresses are throughout physical memory
- ▶ Units of Memory and Backing Store
 - Physical memory is divided into fixed-sized blocks called **frames**
 - The logical memory space of each process is divided into blocks of the same size called **pages**
 - The backing store is also divided into blocks of the same size if used



Address Translation Scheme

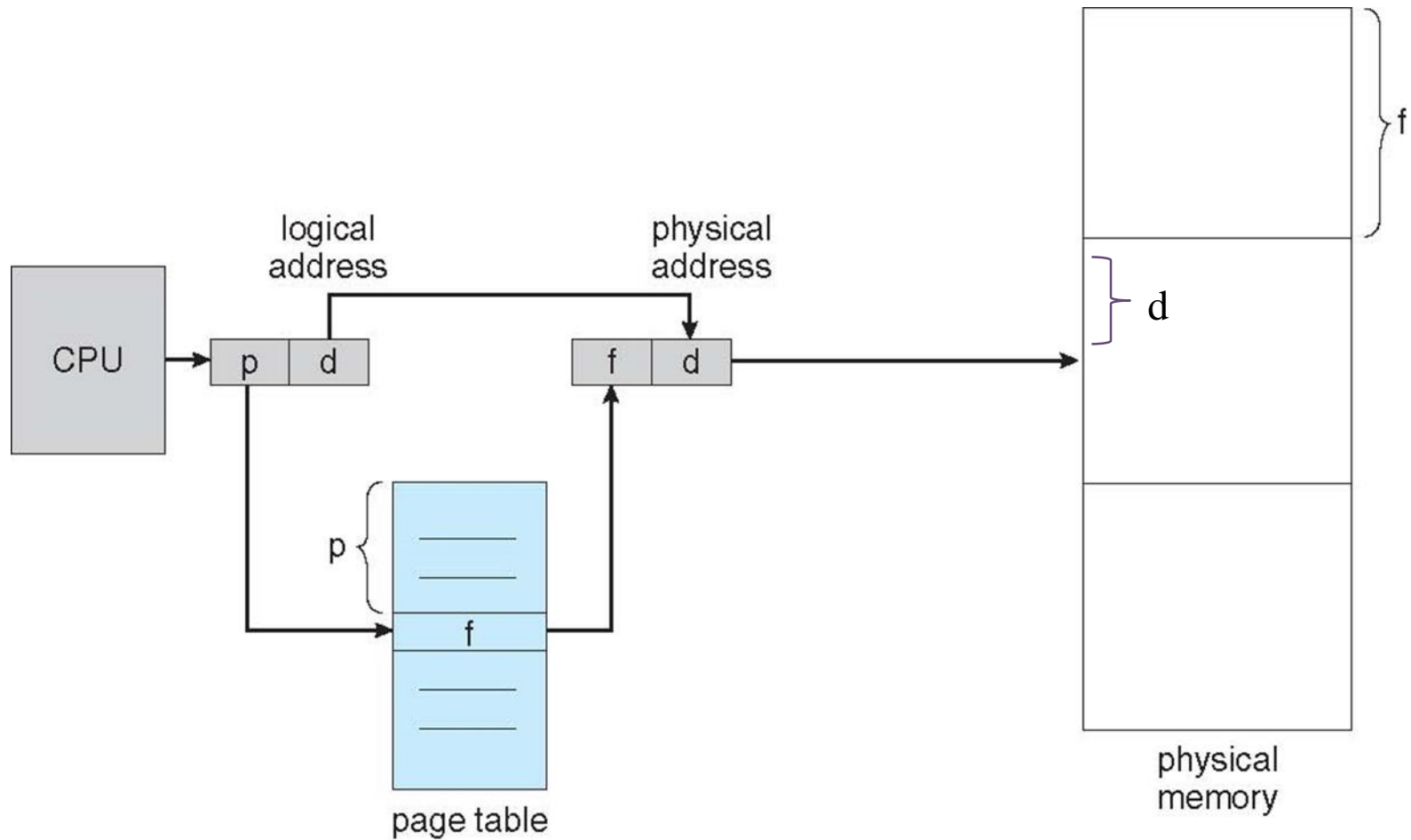
- ▶ Address generated by CPU is divided into:
 - **Page number (p)** – used as an index into a page table which contains base address of each page in physical memory
 - **Page offset (d)** – combined with base address to define the physical memory address that is sent to the memory unit



- For given logical address space 2^m and page size 2^n



Paging Hardware



Paging Model of Logical and Physical Memory

Page 0
Page 1
Page 2
Page 3

Logical
Memory

0	1
1	4
2	3
3	7

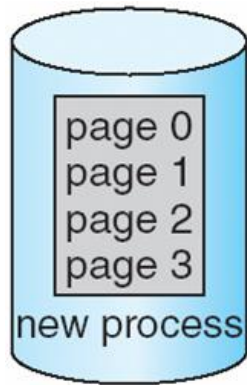
Page
Table

0	
1	Page 0
2	
3	Page 2
4	Page 1
5	
6	
7	Page 3

Physical
Memory



Free Frames

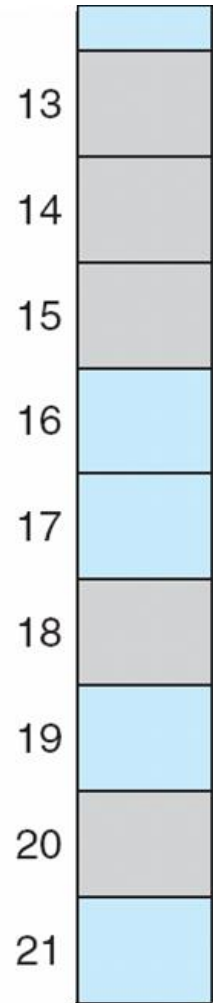


0	14
1	13
2	18
3	20

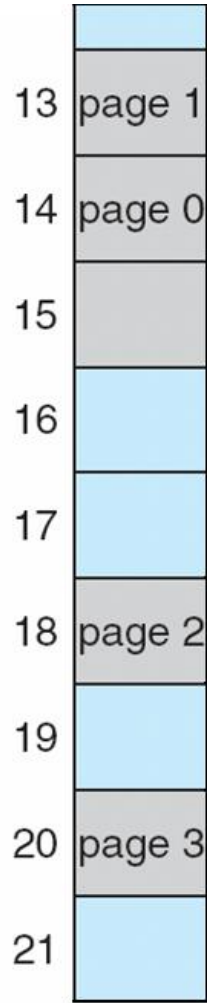
new-process page table

free-frame list

- 14
- 13
- 18
- 20
- 15



free-frame list
15

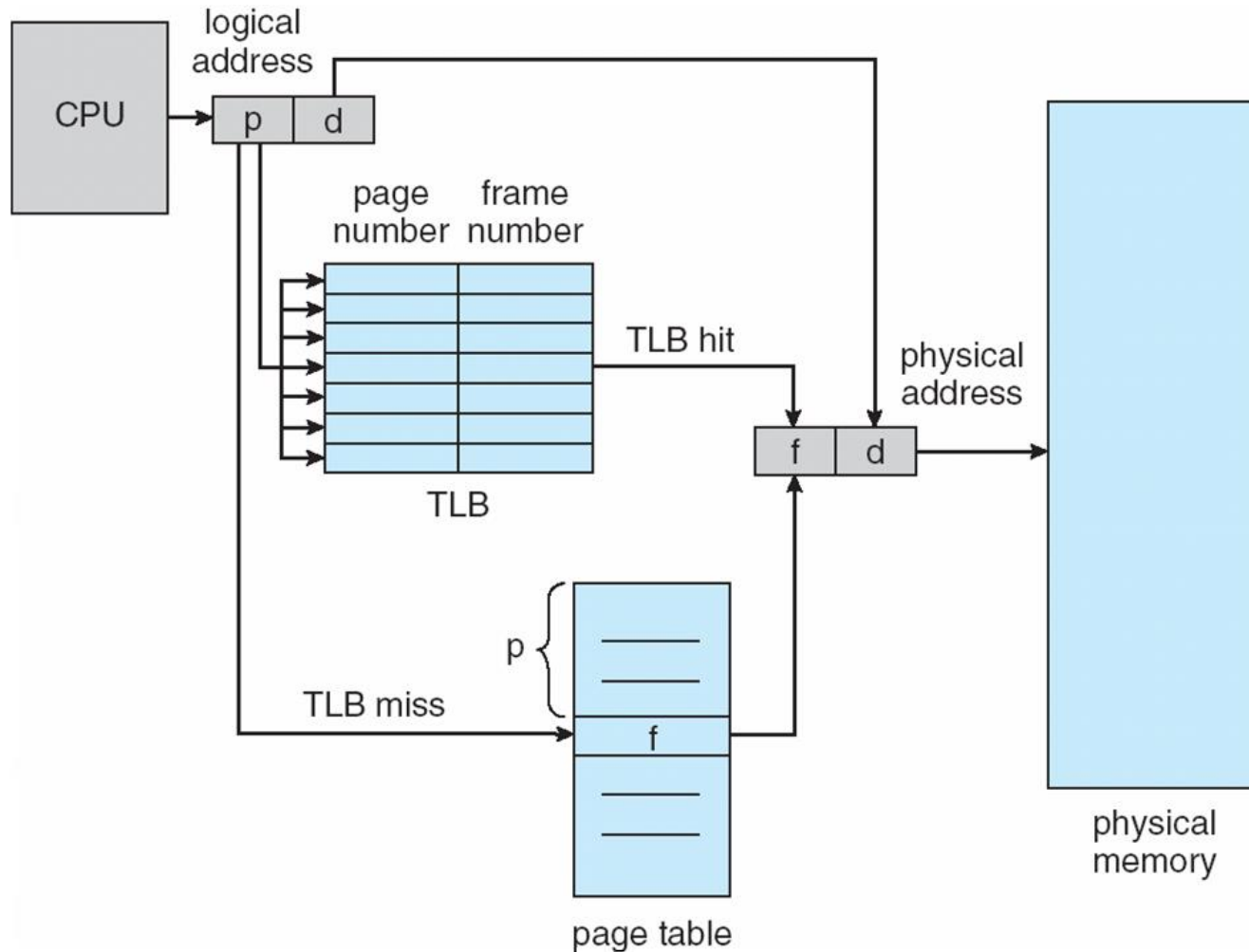


Implementation of Page Table

- ▶ Page table is kept in main memory
- ▶ **Page-table base register (PTBR)** points to the page table
- ▶ **Page-table length register (PTLR)** indicates size of the page table
- ▶ The two memory access problem can be solved by the use of a special fast-lookup hardware cache called **translation look-aside buffers (TLBs)**
- ▶ Some TLBs store **address-space identifiers (ASIDs)** in each TLB entry – uniquely identifies each process to provide address-space protection for that process
 - Otherwise need to flush at every context switch



Paging Hardware With TLB



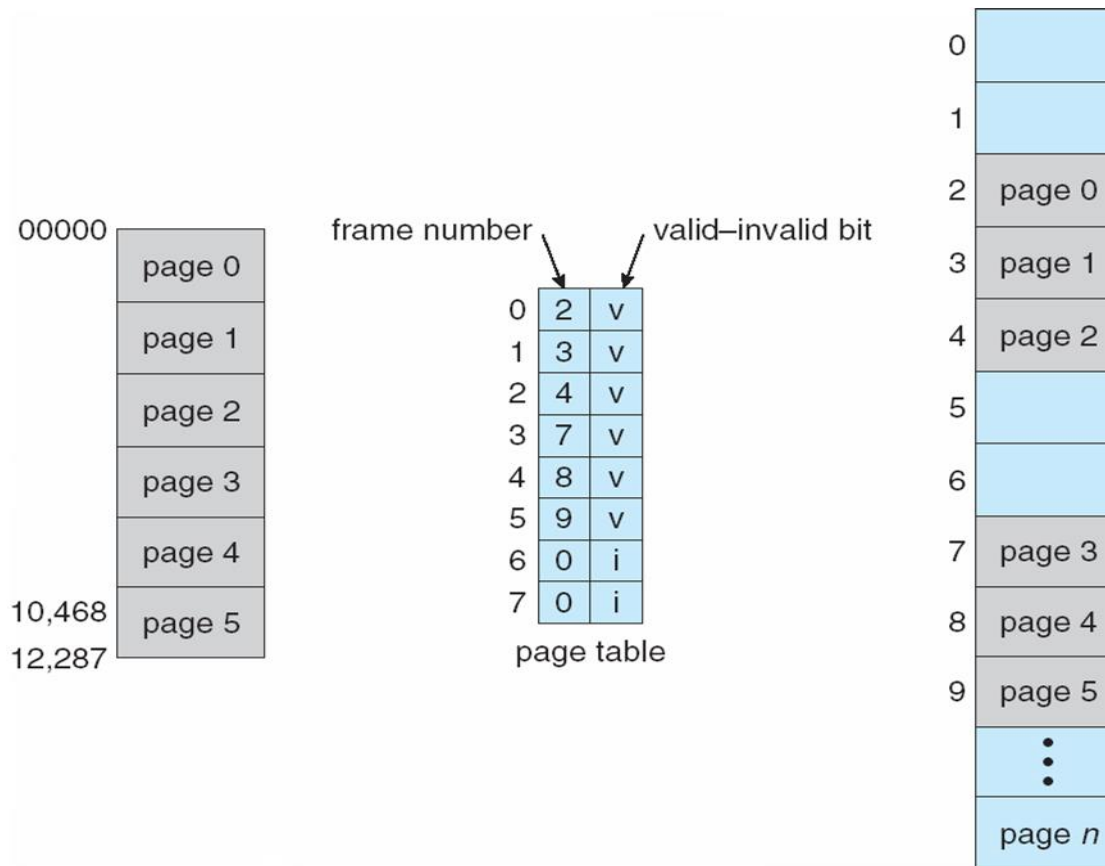
Effective Access Time With TLB

- ▶ TLB Hit ratio = p
- ▶ Consider $p = 80\%$, 100ns for memory access
 - Effective Access Time (EAT)
 $= 0.80 \times 100 + 0.20 \times 200 = 120\text{ns}$
- ▶ Consider more realistic hit ratio $p = 99\%$, 100ns for memory access
 - $\text{EAT} = 0.99 \times 100 + 0.01 \times 200 = 101\text{ns}$



Memory Protection

▶ Valid (v) or Invalid (i) Bit in A Page Table

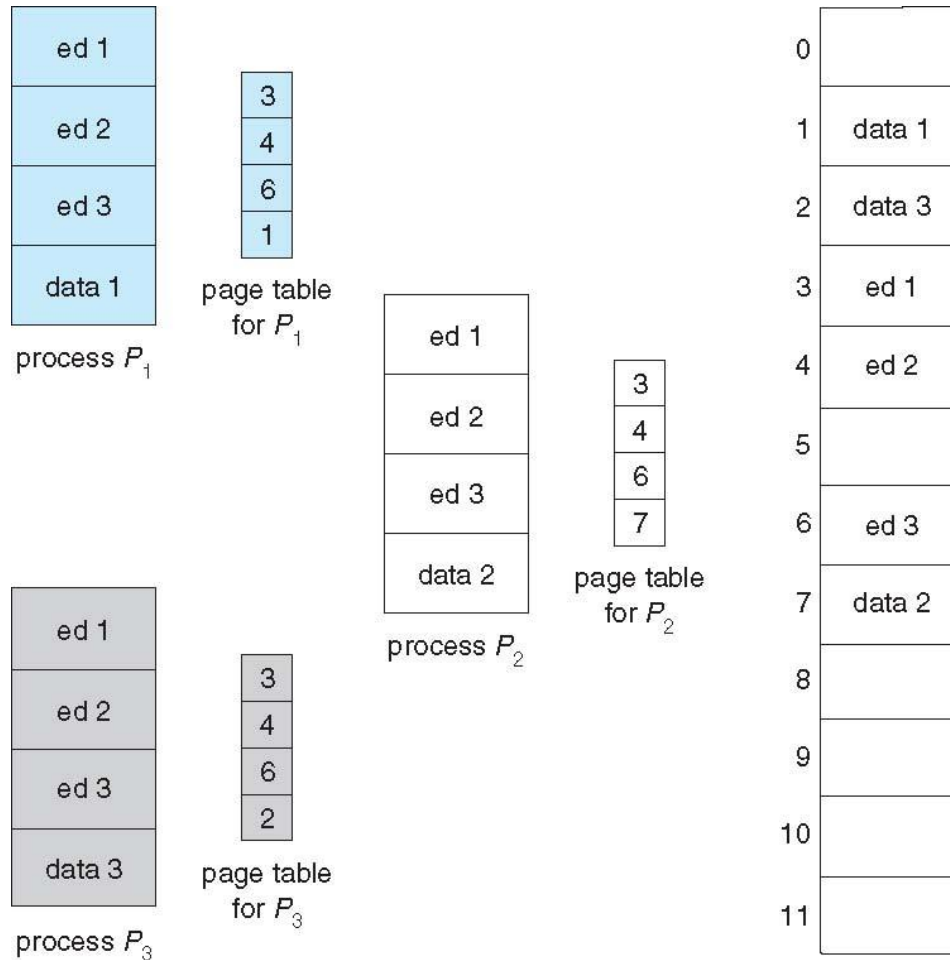


Shared Pages

- ▶ Shared code
 - One copy of read-only (reentrant) code shared among processes (i.e., text editors, compilers, window systems)
 - Similar to multiple threads sharing the same process space
 - Also useful for inter-process communication if sharing of read-write pages is allowed
- ▶ Private code and data
 - Each process keeps a separate copy of the code and data
 - The pages for the private code and data can appear anywhere in the logical address space



An Example of Shared Pages



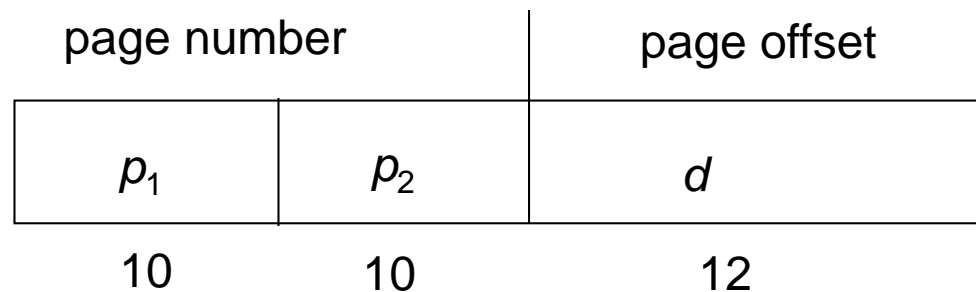
Structure of the Page Table

- ▶ Memory structures for paging can get huge using straight-forward methods
 - Consider a 32-bit logical address space as on modern computers, and the page size is 4 KB (2^{12})
 - Page table would have 1 million entries ($2^{32} / 2^{12}$)
 - If each entry is 4 bytes → 4 MB of physical memory space for a page table
- ▶ Advanced structure of the page table
 - Hierarchical Paging
 - Hashed Page Tables
 - Inverted Page Tables



Two-Level Page-Table Scheme

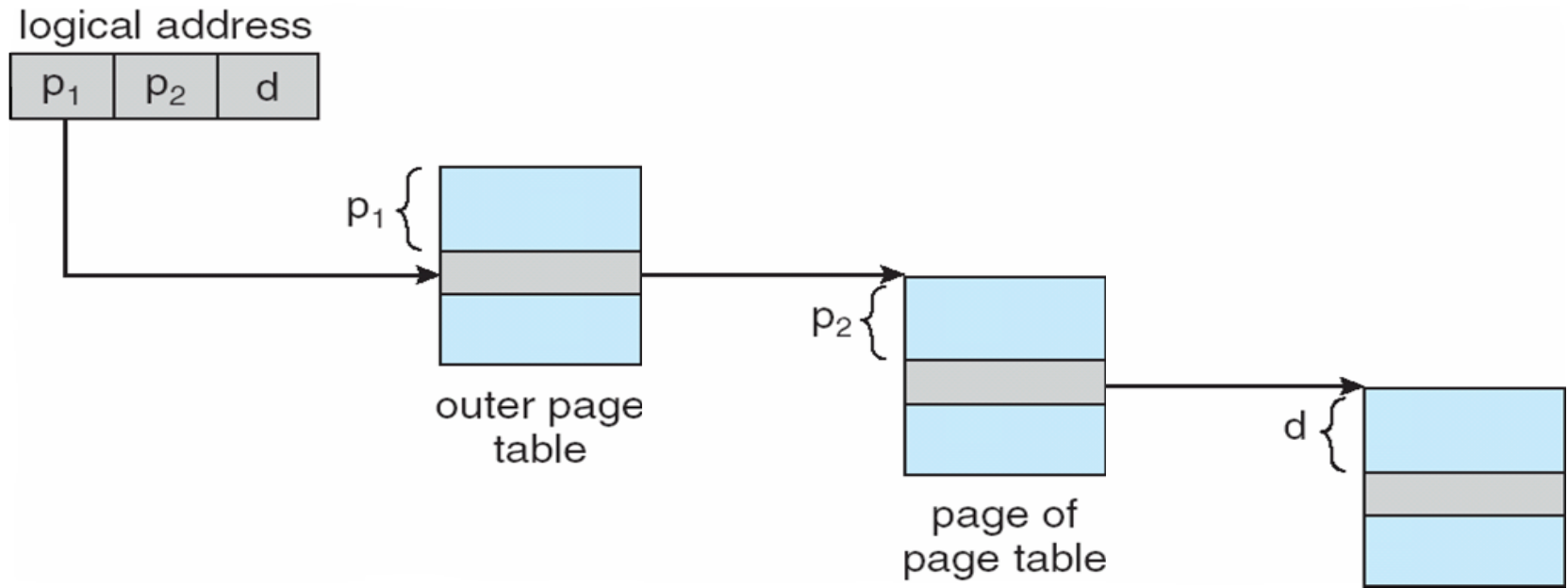
- ▶ A logical address on 32-bit machine with 4K page size is divided into:
 - a page number consisting of 20 bits
 - a page offset consisting of 12 bits
- ▶ Thus, a logical address is as follows:



- ▶ Where p_1 is an index into the outer page table, and p_2 is the index into the inner page table



Address Translation Scheme of Two-Level Paging



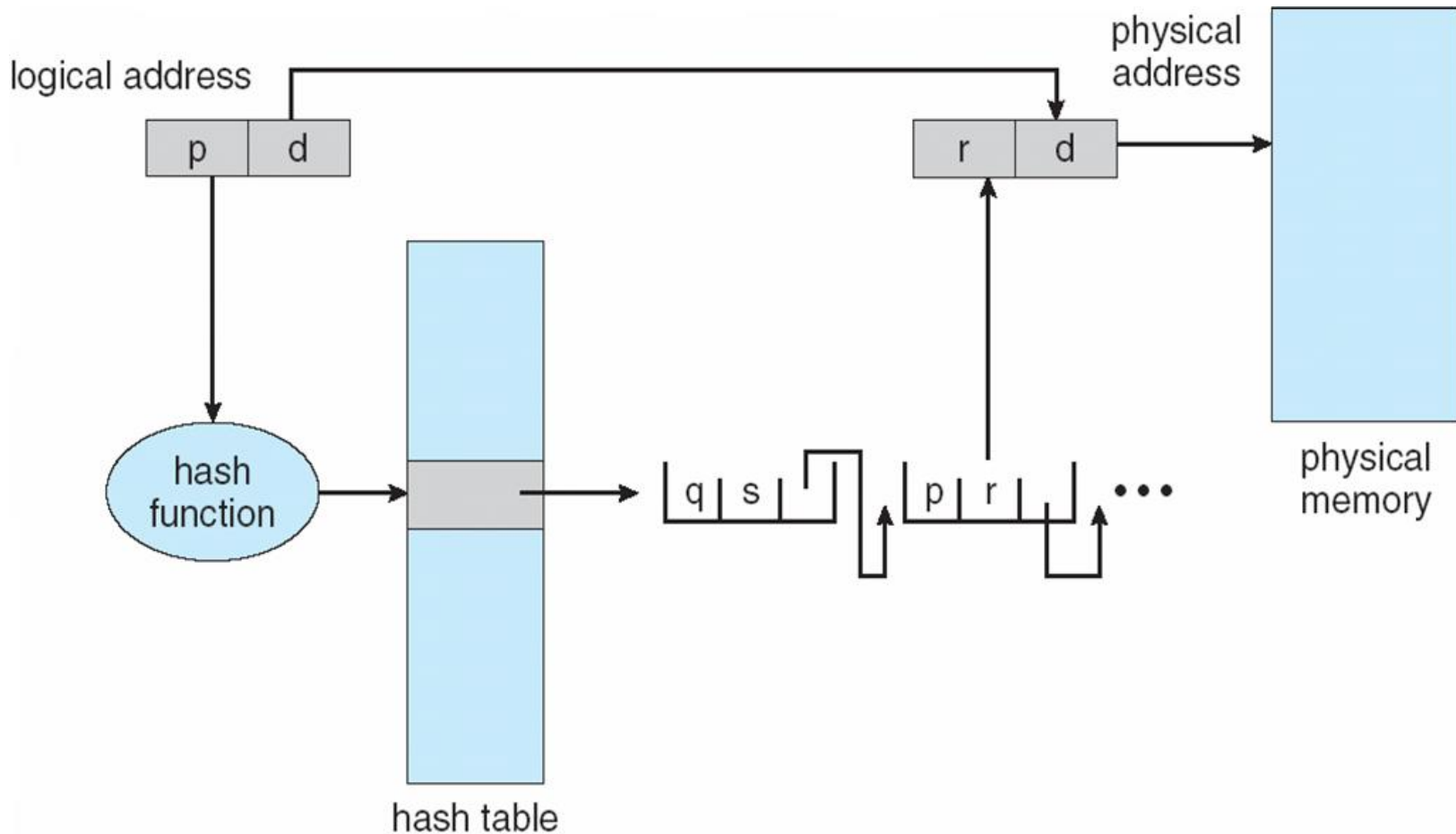
- ▶ The size of each table is 4KB if each entry has 4 Bytes
- ▶ The total size of the inner page tables is still 4MB, but each inner page table is created when it is used

Hashed Page Tables (1 / 2)

- ▶ Objective:
 - To handle large address spaces
- ▶ Virtual address \rightarrow hash function \rightarrow a linked list of elements: (virtual page number, frame number, a pointer)
- ▶ Clustered Page Tables
 - Each entry contains the mappings for several physical-page frames, e.g., 16



Hashed Page Tables (2/2)

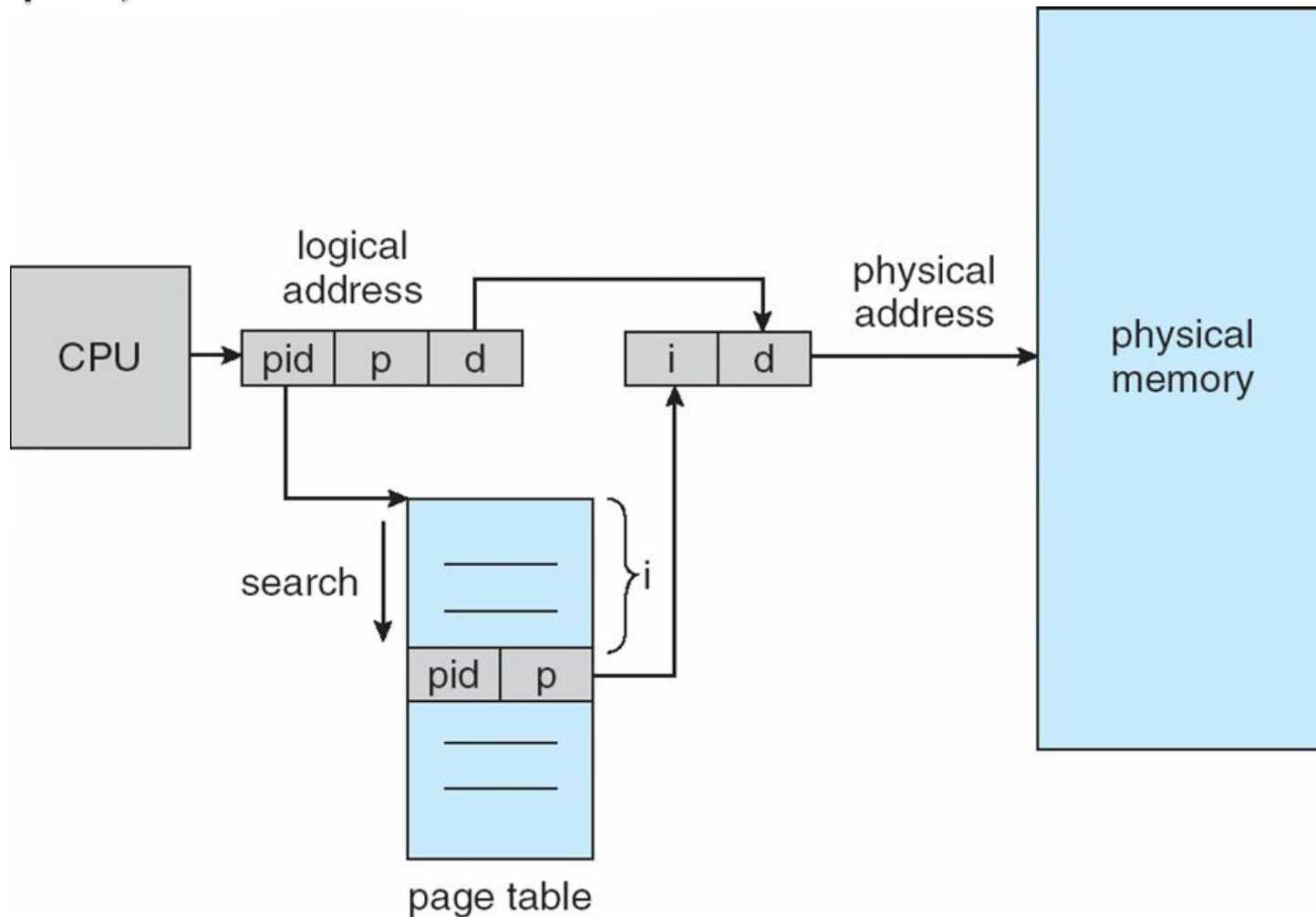


Inverted Page Table Architecture (1 / 2)

- ▶ Only on page table for all processes
- ▶ Each entry corresponds to a physical frame.
 - Virtual Address: <Process ID, Page Number, Offset>
- Long search time to find out the match
- Difficult to implement with shared memory

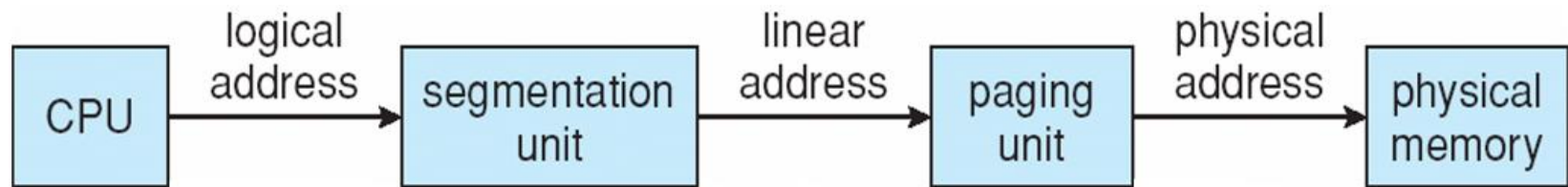


Inverted Page Table Architecture (2/2)



Example: The Intel IA-32 Architecture

- ▶ Supports both segmentation and paging
 - Each segment can be 4 GB
 - Up to 16 K segments per process



- ▶ Two-level paging

