Memory Management

Reading:

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chapter 9

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chapter 7

Outline

- Background
- Issues in Memory Management
- Logical Vs Physical address, MMU
- Dynamic Loading
- Memory Partitioning
  - Placement Algorithms
  - Dynamic Partitioning
- Buddy System
- Paging
- Memory Segmentation
- Example – Intel Pentium

Background

- *Main memory* $\rightarrow$ fast, relatively high cost, volatile
- *Secondary memory* $\rightarrow$ large capacity, slower, cheaper than main memory and is usually non volatile
- The CPU fetches instructions/data of a program from memory; therefore, the *program/data* must reside in the *main* (RAM and ROM) *memory*
- Multiprogramming systems $\rightarrow$ main memory must be subdivided to accommodate several processes
- This subdivision is carried out dynamically by OS and known as **memory management**

Issues in Memory Management

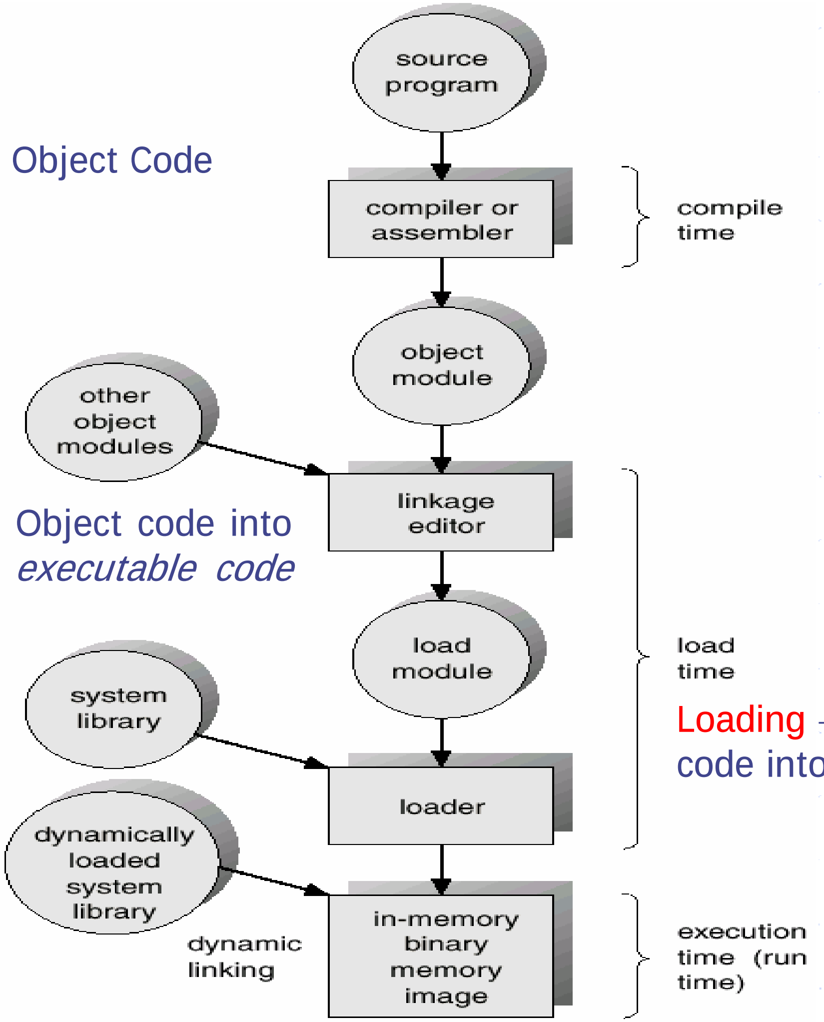
- **Relocation:** Swapping of active process in and out of main memory to maximize CPU utilization
  - *Process may not be placed back in same main memory region*!
  - Ability to relocate the process to different area of memory
- **Protection:** Protection against *unwanted interference* by another process

  Must be ensured by processor (hardware) rather than OS
- **Sharing:** Flexibility to allow several process to access the same portions of the main memory
- **Efficiency:** Memory must be fairly allocated for high processor utilization, Systematic flow of information between main and secondary memory

Binding of Instructions and Data to Memory

Compiler → Generates Object Code

Linker → Combines the Object code into a single self sufficient *executable code*



Loading → Copies executable code into memory

Execution → dynamic memory allocation

Binding of Instructions and Data to Memory

Address binding of instructions and data to *memory addresses* can happen at three different stages

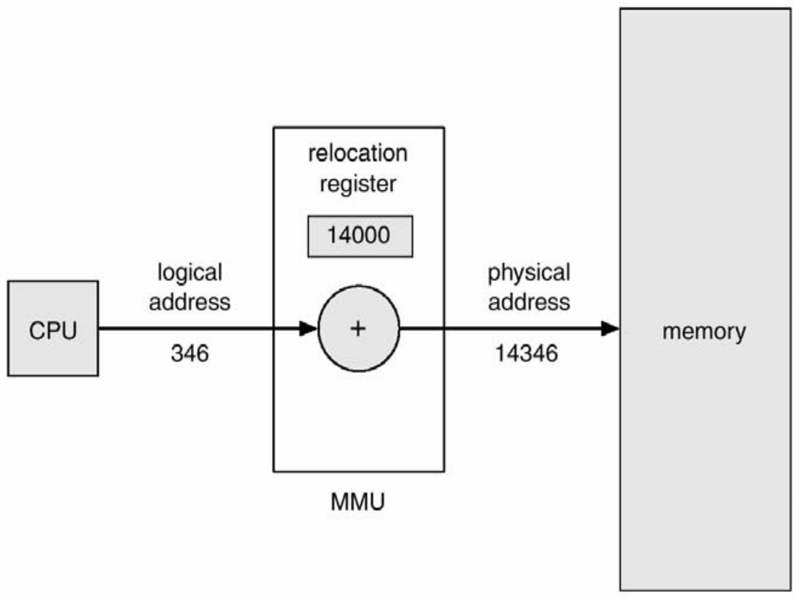
- **Compile time**: If memory location known a priori, **absolute code** can be generated; must recompile code if starting location changes
- **Load time**: Must generate *relocatable* code if memory location is not known at compile time
- **Execution time**: Binding delayed until run time if the process can be moved during its execution from one memory segment to another $\rightarrow$ most general purpose OS

Logical Vs Physical Address Space

- Each logical address is bound to 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 ;
  - Same in *compile-time* and *load-time* address-binding schemes
  - Differ in execution-time address-binding scheme
  - Logical address ↔ Virtual address

Memory-Management Unit (MMU)

- The **runtime mapping** from virtual → physical address



- Relocation register is added to every address → generated by user process

- The user program → *logical* addresses, it never sees the *real* physical addresses

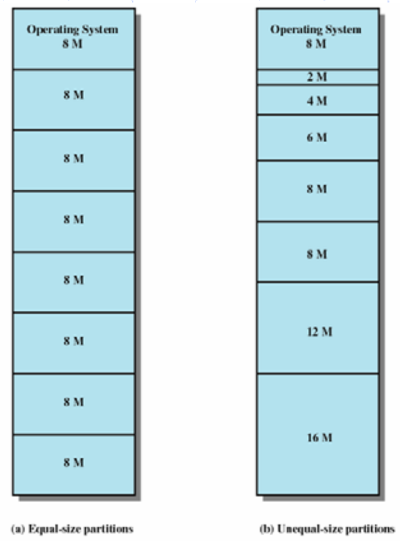
Dynamic Loading

- Routine is not loaded until it is called
- *Better memory-space utilization* $\rightarrow$ unused routine is never loaded
- Useful to handle infrequently occurring cases, *e.g*. error handling routines
- No special support from the OS required implemented through *user* program design

Memory Partitioning

Two schemes – used in several variations of now-obsolete OS

- **Fixed Partitioning:** OS occupies fixed portion of main memory, rest available for multiple processes. Two alternatives;
  - *Equal size fixed partitions* $\rightarrow$ any process $\leq$ partition size can be loaded
  - *Unequal size partitions* $\rightarrow$ several unequal size partitions, process of matching sizes



- **Problems with equal size fixed partitions:**
  - If program is bigger than a partition size, use of overlays
  - Main memory utilization is extremely inefficient; **Internal Fragmentation** – waste of space internal to partition due to the fact that block of data loaded is smaller than partition

Unequal-Size Partitions

Assign each processes the smallest partition to which it will fit

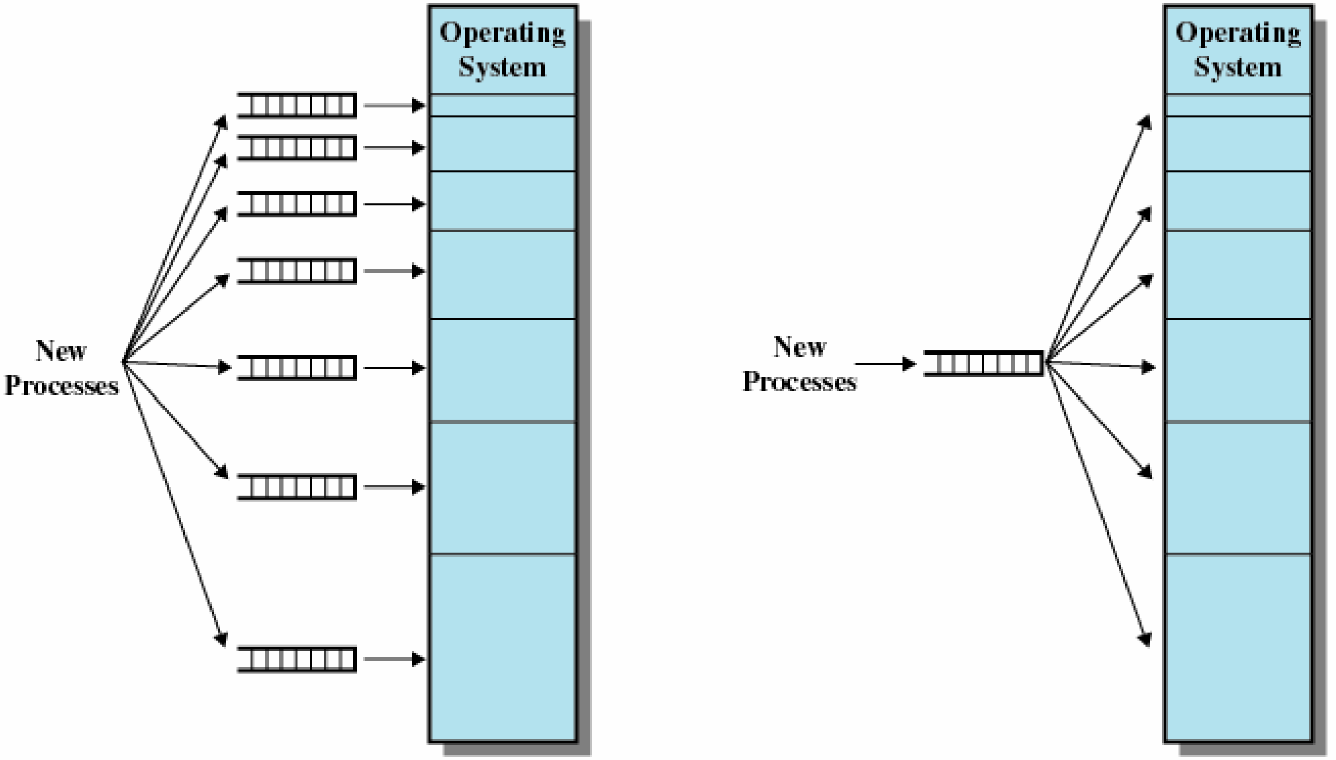
- **Advantages:**
  - Process are always assigned in such a way as to minimize wasted memory within a partition → internal fragmentation
  - Relatively simple and require minimal OS software and overhead
- **Disadvantages:**
  - Limitations on the active number of processes, number of partitions specified at system generation time
  - Small jobs cannot utilize partition space efficiently; In most cases it is an inefficient technique

Placement Algorithm with Partitions

- Equal-size partitions
  - Because all partitions are of equal size, it does not matter which partition is used

- Unequal-size partitions
  - Can assign each process to the smallest partition within which it will fit
  - Queue for each partition size
  - Processes are assigned in such a way as to minimize wasted memory within a partition

Placement Algorithm with Partitions



(a) One process queue per partition

(b) Single queue

Dynamic Partitioning

Developed to address the drawbacks of fixed partitioning

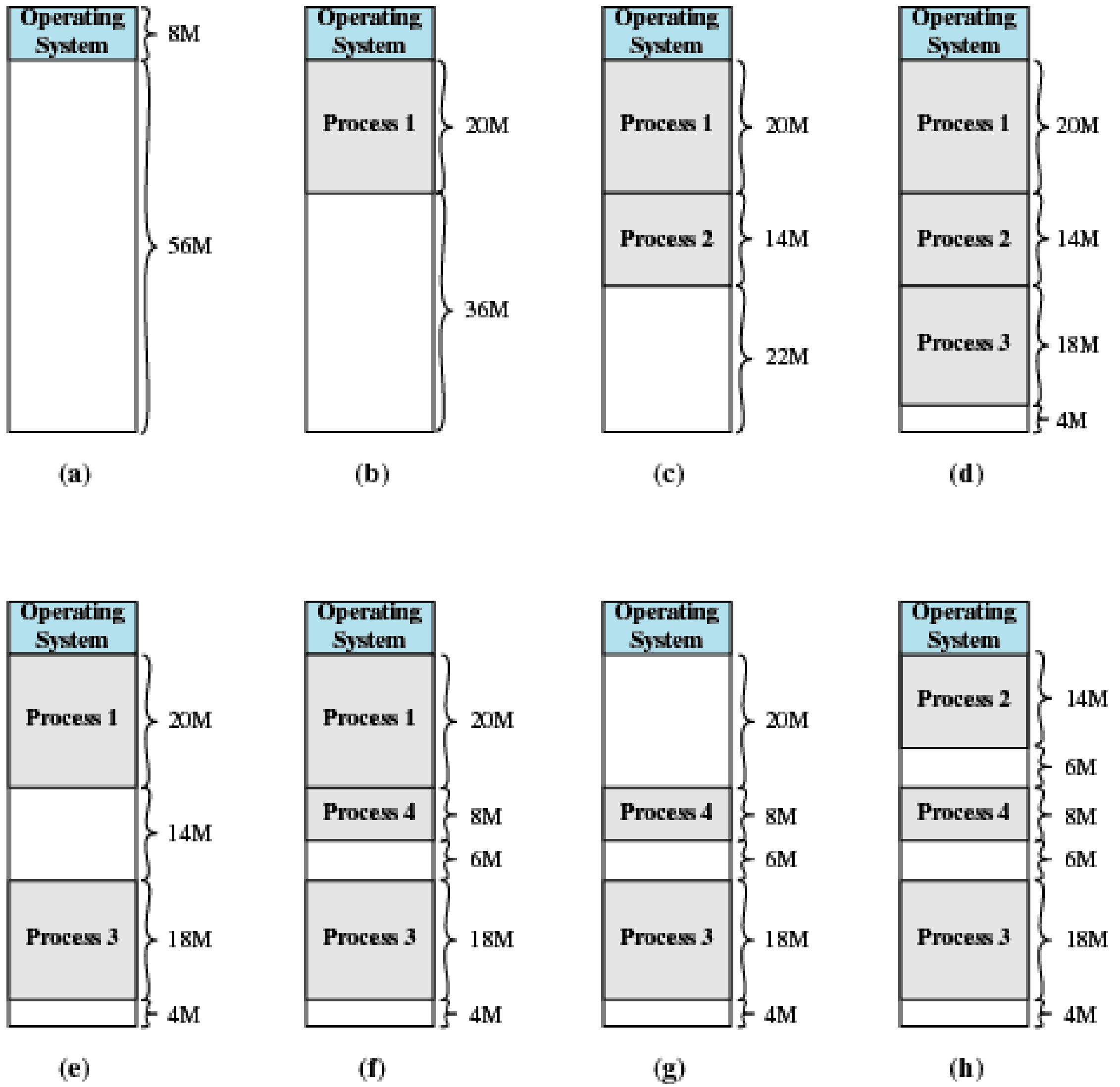
- Partitions of variable length and number; Process in bought into main memory, it is allocated *exactly as much memory as it requires*

- **Leaves Holes**
  - First at the end → eventually lot of small holes
  - Memory becomes more fragmented with time, *memory utilization* ↓

- **External Fragmentation**
  - Memory that is external to all partitions becomes increasingly fragmented

- **Compaction**
  - Used to overcome *external fragmentation*
  - OS shifts processes so that free memory is together in one block
  - Compaction requires use of *dynamic relocation capability*
  - Time consuming procedure and <u>wasteful</u> of processor time

Dynamic Partitioning



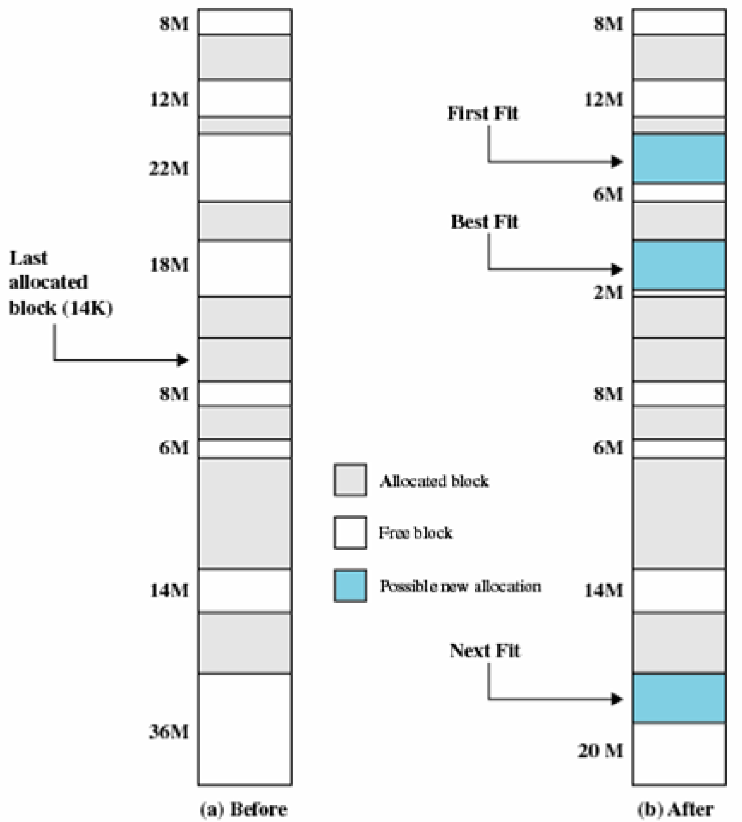
Placement Algorithms

Compaction is time consuming $\rightarrow$ OS must be clever in plugging holes while assigning processes to memory

- *Three placement algorithms* $\rightarrow$ Selecting among free blocks of main memory
- **Best-Fit:** Closest in size to the request
- **First-Fit:** Scans the main memory *from the beginning* and first available block that is *large enough*
- **Next-Fit:** Scans the memory *from the location of last placement* and chooses next available block that is large enough

Placement Algorithms - Example

Allocation of 16 MB block using three placement algorithms



Placement Algorithms

- Which of the above approaches is the best?
  Process Size/Sequence, General Comments
  - First-Fit → Simplest, usually the best and fastest
  - Next-Fit → Slightly worst results with next fit
    Compaction may be more frequently required
  - Best-Fit→ Usually the worst performer; main memory is quickly littered by blocks too small to satisfy memory allocation requests

    Compaction - more frequently than other algorithms

Buddy System

- Drawbacks
  - **Fixed partitioning**: Limits number of active process, inefficient if poor match between partition and process sizes
  - **Dynamic Partitioning**: Complex to maintain, includes the overhead of compaction
- Compromise may be the Buddy System - Entire space available is treated as a single block of 2^U
- If a request of size s such that $2^{U-1} < s \leq 2^U$, entire block is allocated
  - Otherwise block is split into two equal buddies
  - Process continues until smallest block greater than or equal to s is generated

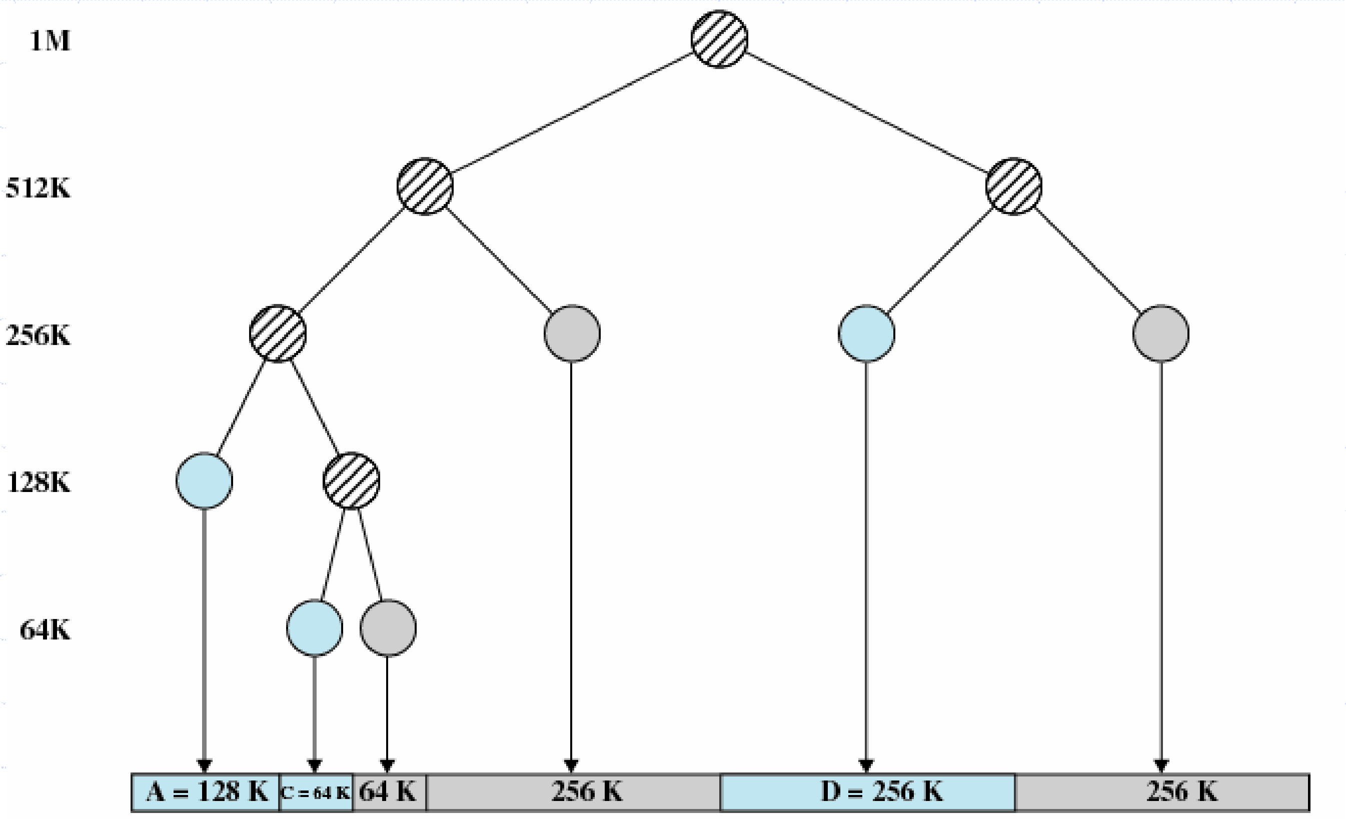
Buddy System - Example

Initial block size 1 MB; First request *A* is for 100 KB

1 Mbyte block	1 M					
Request 100 K	A = 128 K	128 K		256 K	512 K	
Request 240 K	A = 128 K	128 K		B = 256 K	512 K	
Request 64 K	A = 128 K	C = 64 K	64 K	B = 256 K	512 K	
Request 256 K	A = 128 K	C = 64 K	64 K	B = 256 K	D = 256 K	256 K
Release B	A = 128 K	C = 64 K	64 K	256 K	D = 256 K	256 K
Release A	128 K	C = 64 K	64 K	256 K	D = 256 K	256 K
Request 75 K	E = 128 K	C = 64 K	64 K	256 K	D = 256 K	256 K
Release C	E = 128 K	128 K		256 K	D = 256 K	256 K
Release E	512 K				D = 256 K	256 K
Release D	1 M					

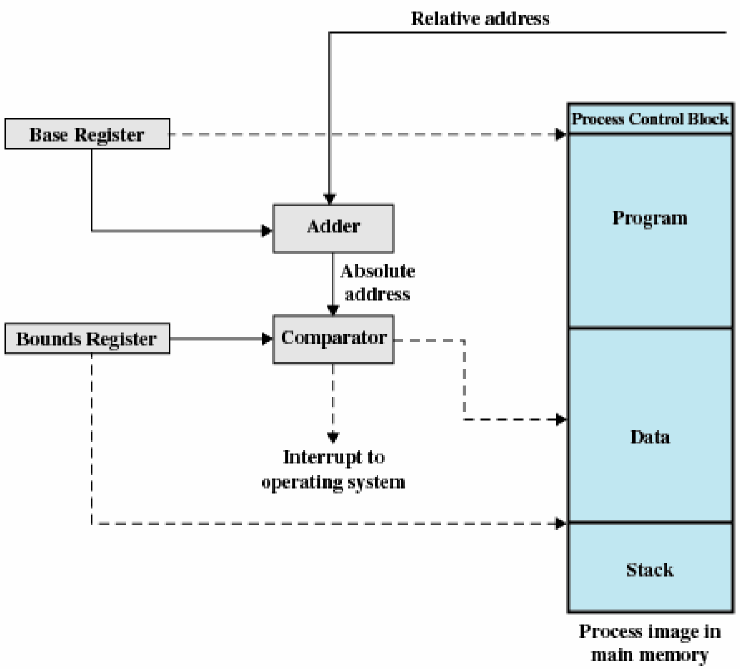
Buddy System - Example

Binary tree representation immediately after *Release B* request.



Relocation

- A process may occupy different partitions which means *different absolute memory locations* during execution (from swapping)



- Compaction will also cause a program to occupy a different partition which means *different absolute memory locations*

Paging

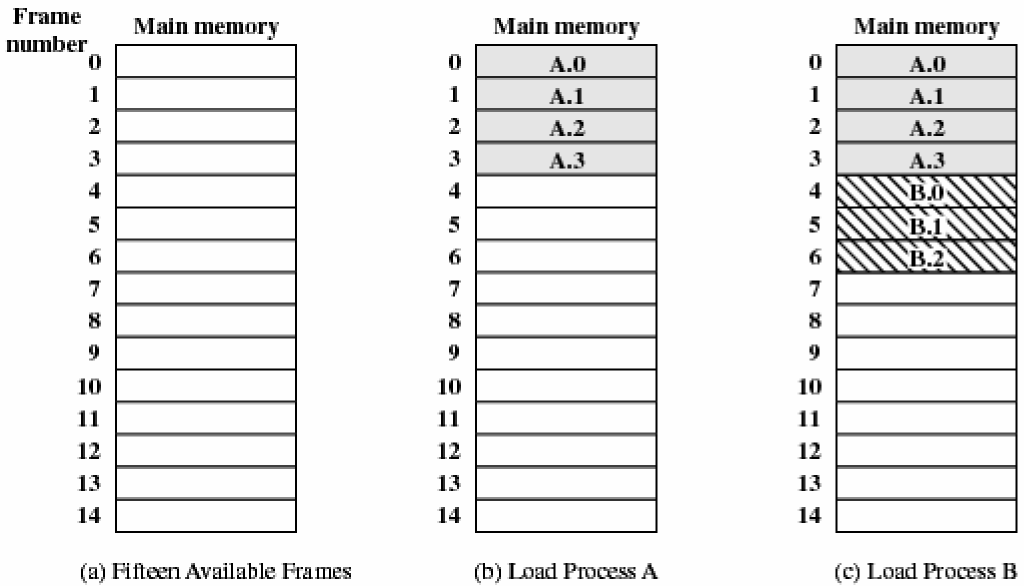
- Partitioning main memory → *small equal fixed-size* chunks
  - Each process is divided into the same size chunks → pages
  - *Chunks of memory* → frames or page frames

- Advantages
  - No external fragmentation
  - Internal fragmentation → only a fraction of last page of a process

- OS maintains a page table for each process
  - Contains frame location for each page in the process
  - Memory address → a page number, a offset within the page
  - Processor hardware → logical-to-physical address translation

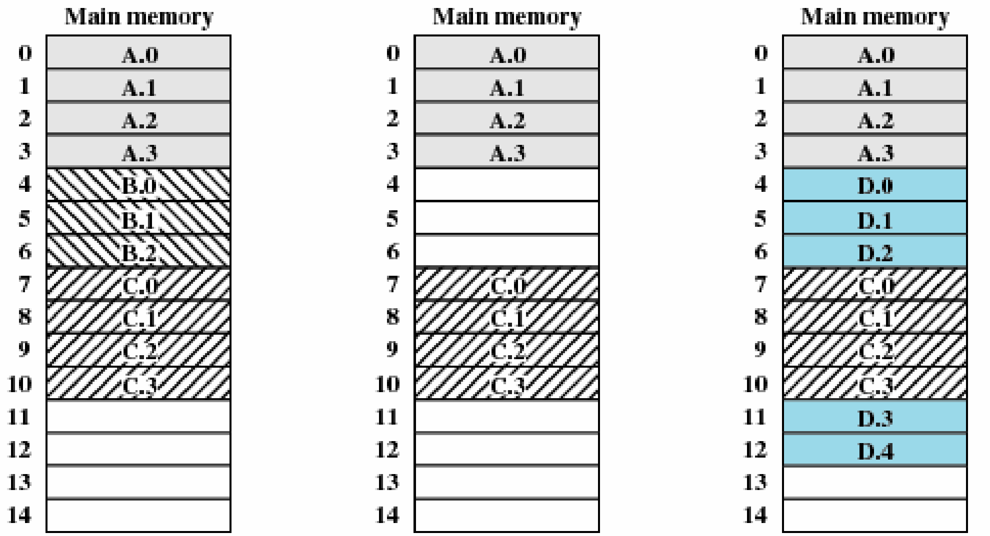
Paging - Example

Assignment of process pages to free frames



Paging - Example

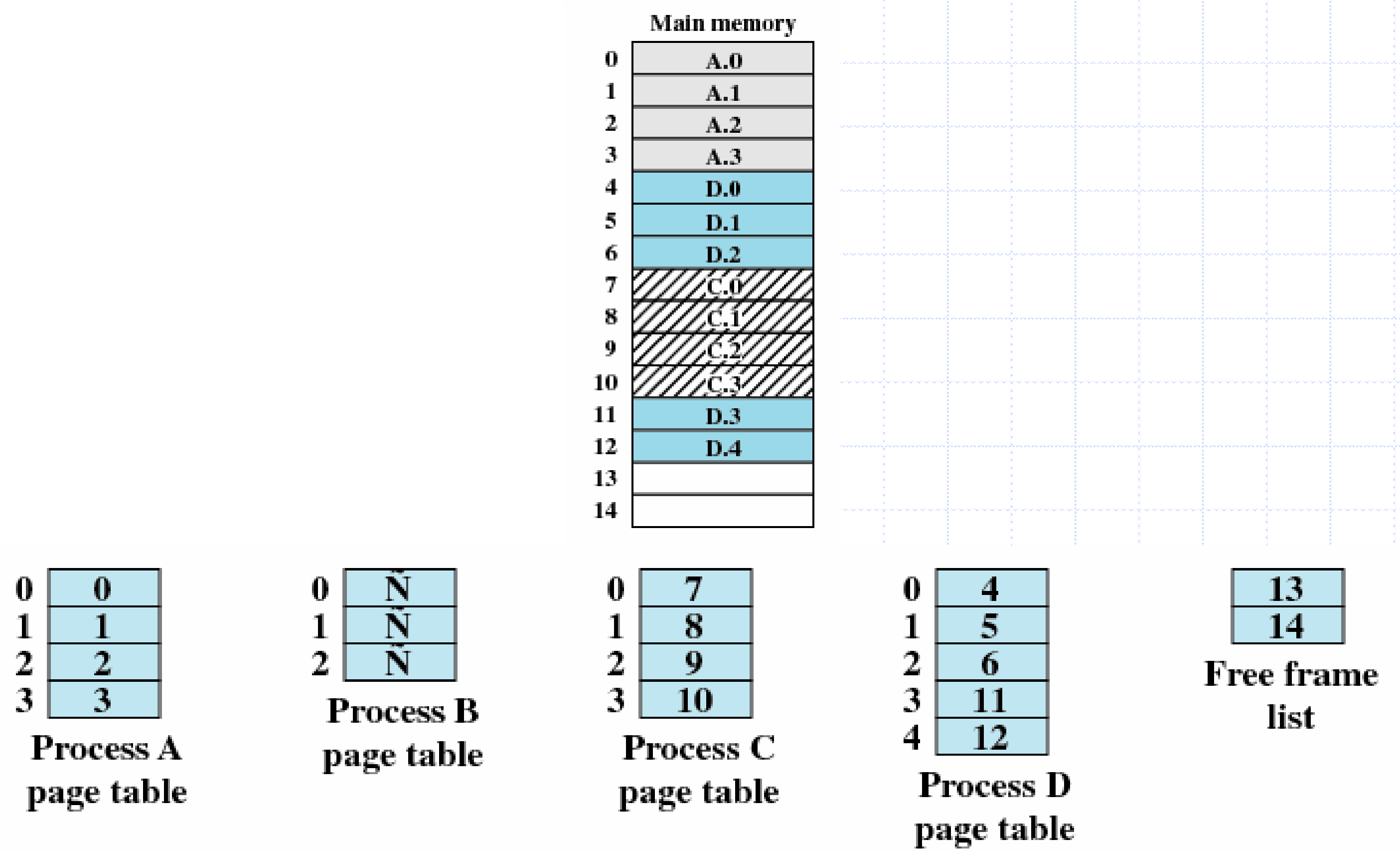
Assignment of process pages to free frames.



(d) Load Process C (e) Swap out B (f) Load Process D

Paging - Example

Data structures for page tables at time epoch (*f*)

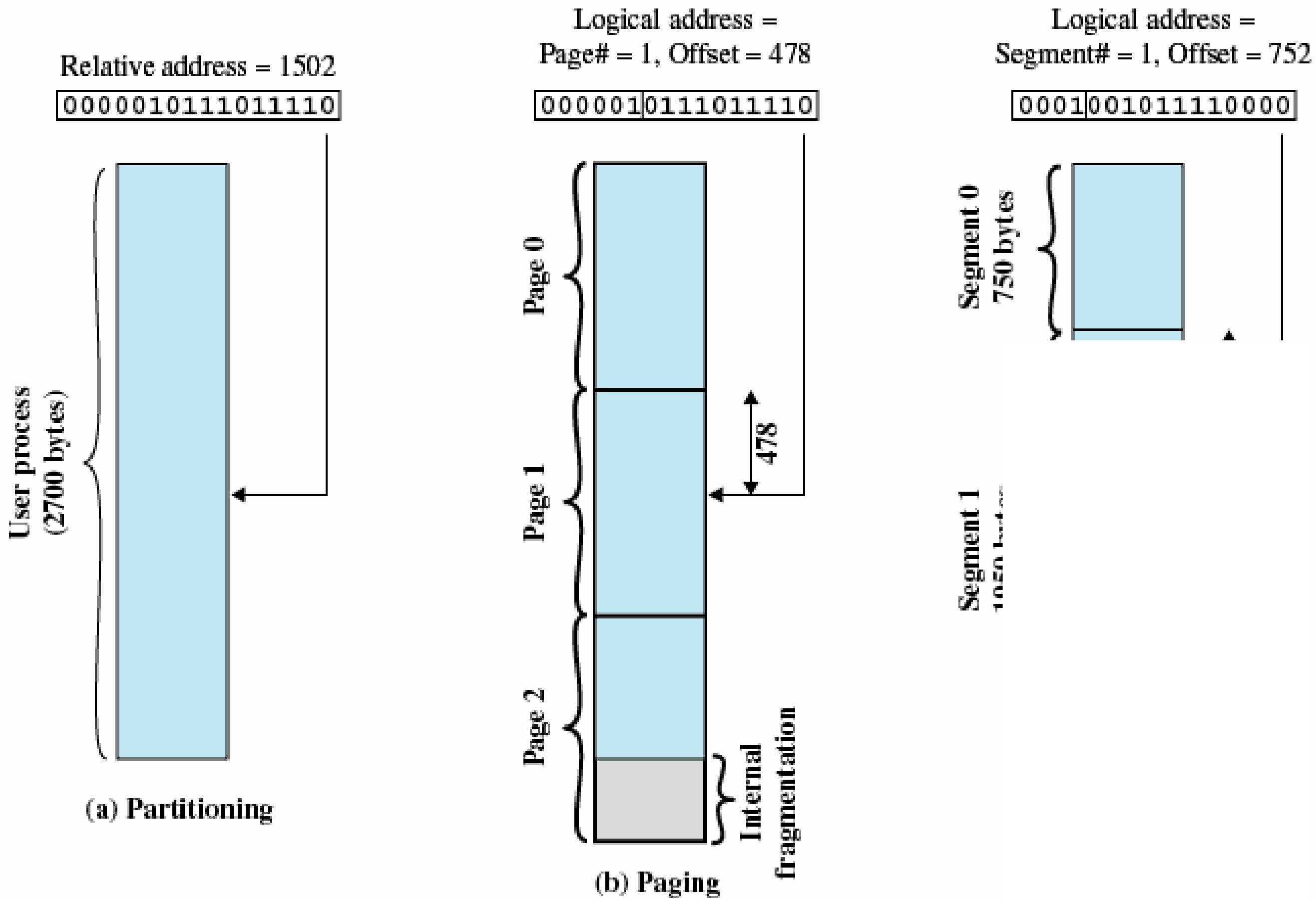


Paging - Example

- Convenience in Paging scheme
  - Frame size → power of 2
  - Relative address (*wrt* origin of program) and the logical address (page # and offset) are same
  - Example - 16 bit address, page size → 1K or 1024 bytes
    - Maximum 64 (2^6) pages of 1K bytes each

- Advantages
  - Logical addressing → transparent to programmer, assembler, linker
  - Relatively easy to implement a function to perform dynamic address translation at run time

Paging - Example

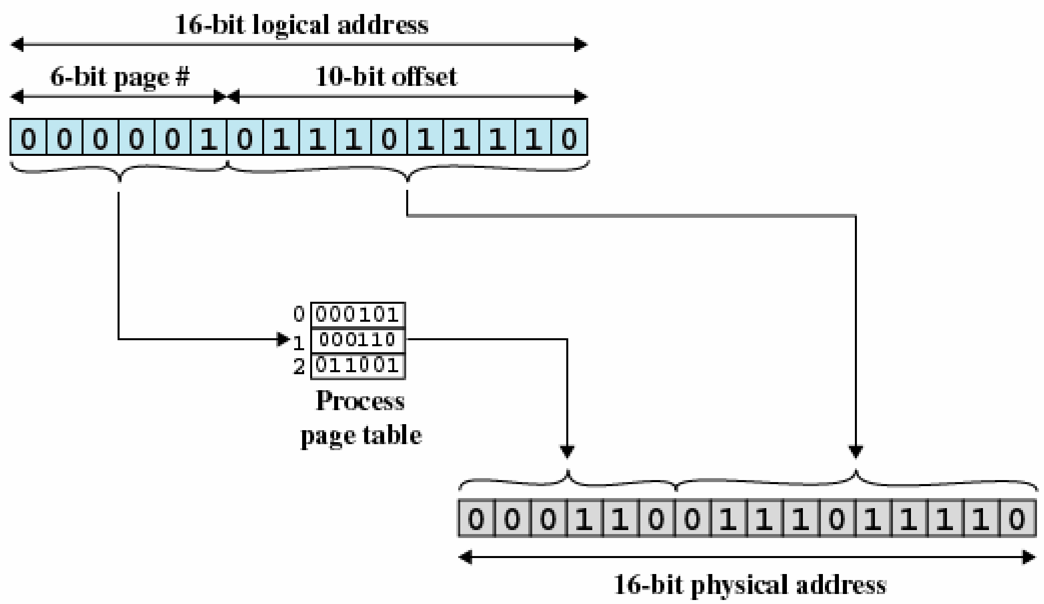


(a) Partitioning

(b) Paging (page size = 1K)

Paging - Example

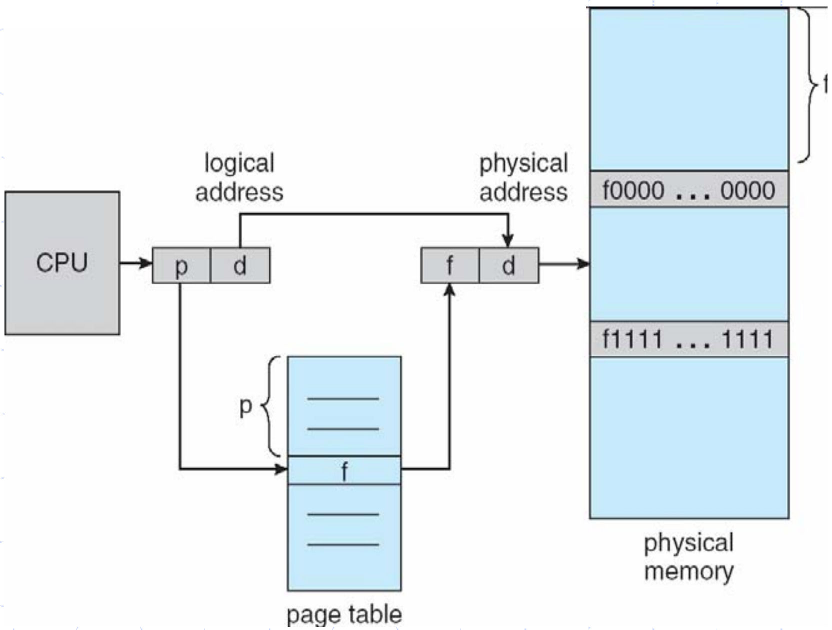
Logical-to-physical address translation in Paging



(a) Paging

Paging - Example

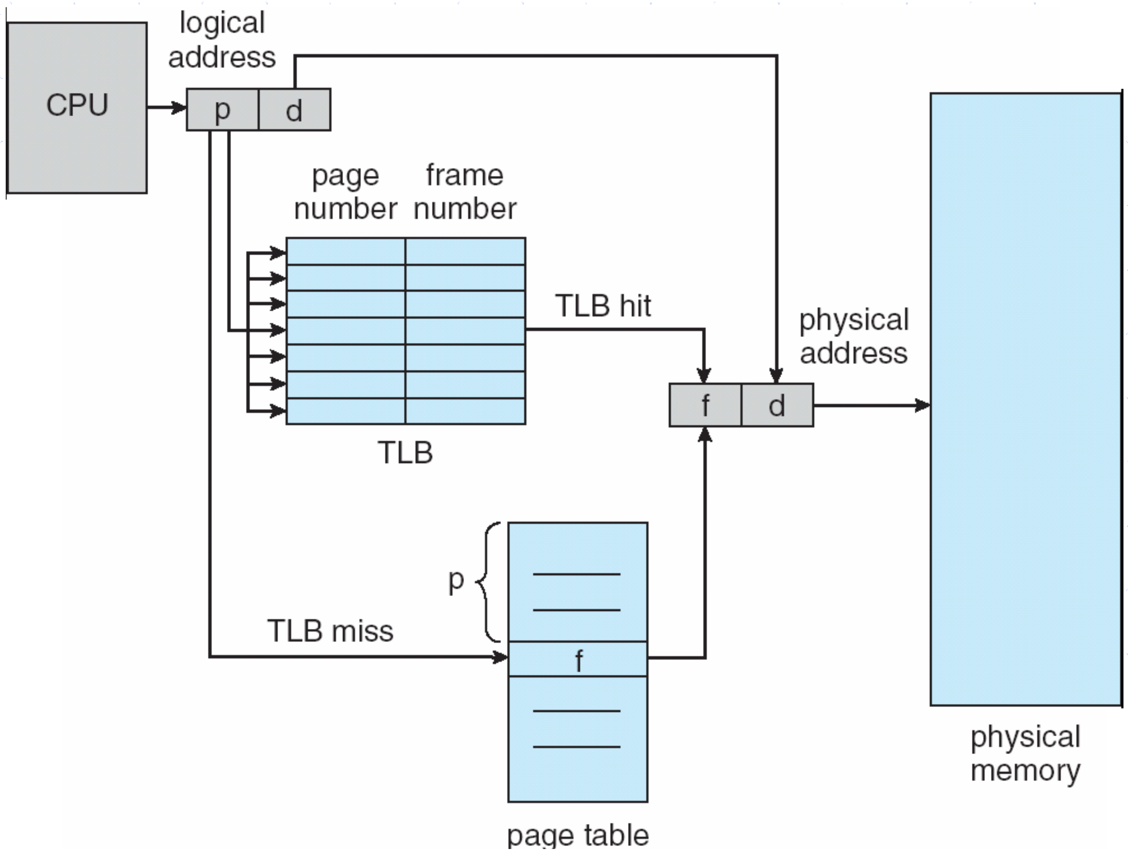
Logical-to-physical address translation in Paging



Implementation of Page Table

- Different methods of storing page tables, OS dependent
- Pointer to page table $\rightarrow$ PCB
- Hardware implementation of page tables
  - Page table $\rightarrow$ Set of dedicated high speed registers, Simplest
  - Suitable for small page table sizes, Usually very large requirements
- Page table is kept in main memory
  - *Page-table base register* (PTBR) points to the page table
  - Two memory access, page table and other for data/instruction
  - Memory access slowed by a factor of two
- Solution to the two memory access problem
  - Usage of a special fast-lookup hardware cache called *associative memory* or *translation look-aside buffers* (TLBs)
  - TLB contains Page # $\rightarrow$ Frame #, Small # of TLB entries (64-1024)

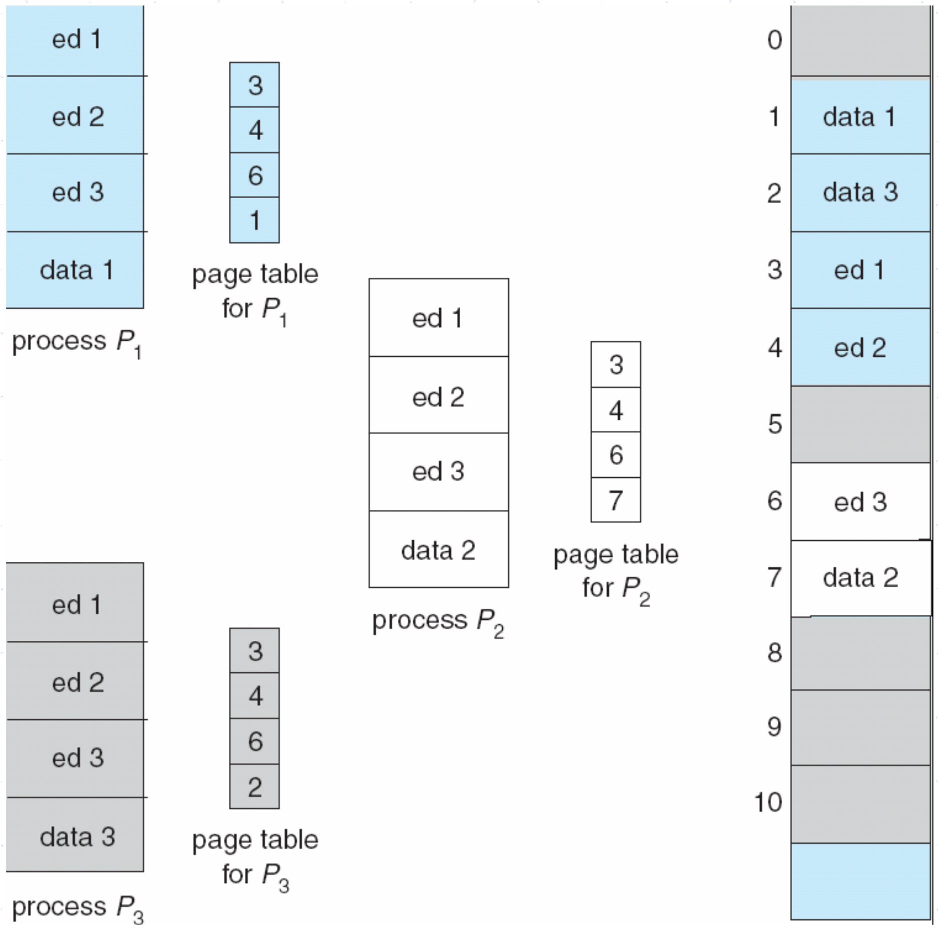
Paging Hardware With TLB



Shared Pages

- **Shared code**
  - One copy of read-only (reentrant) code shared among processes, *e.g*. text editors, compilers
  - Shared code must appear in same location in the logical address space of all processes
- **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

Shared Pages Example



Sharing of code in paging environment

Segmentation

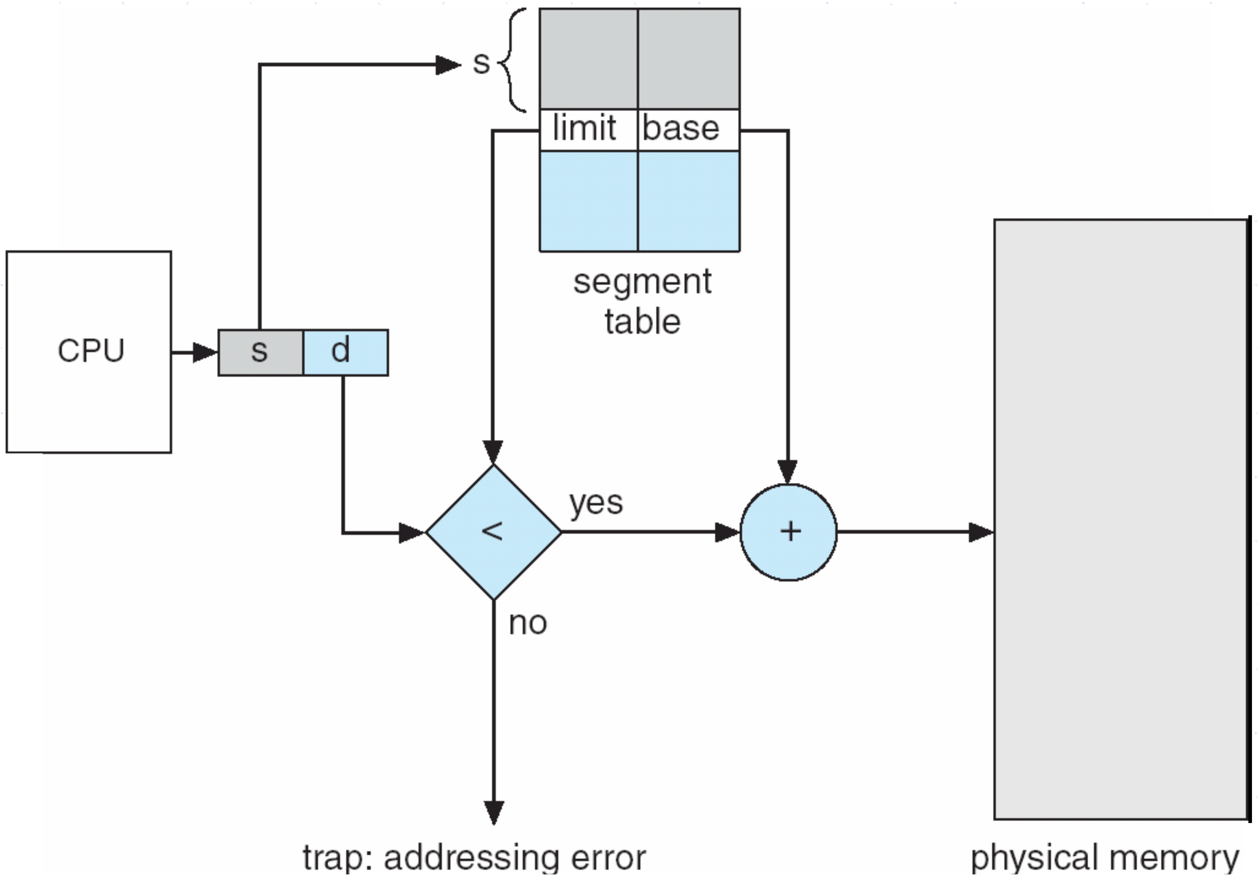
- Memory-management scheme that supports user view of memory
- Program → Collection of segments (name and length)
- Complier automatically constructs segments reflecting input program
- Example – A C complier might create separate segments for the following

  main program,
  procedure,
  function,
  object,
  local variables, global variables,
  common block,
  stack,
  symbol table, arrays

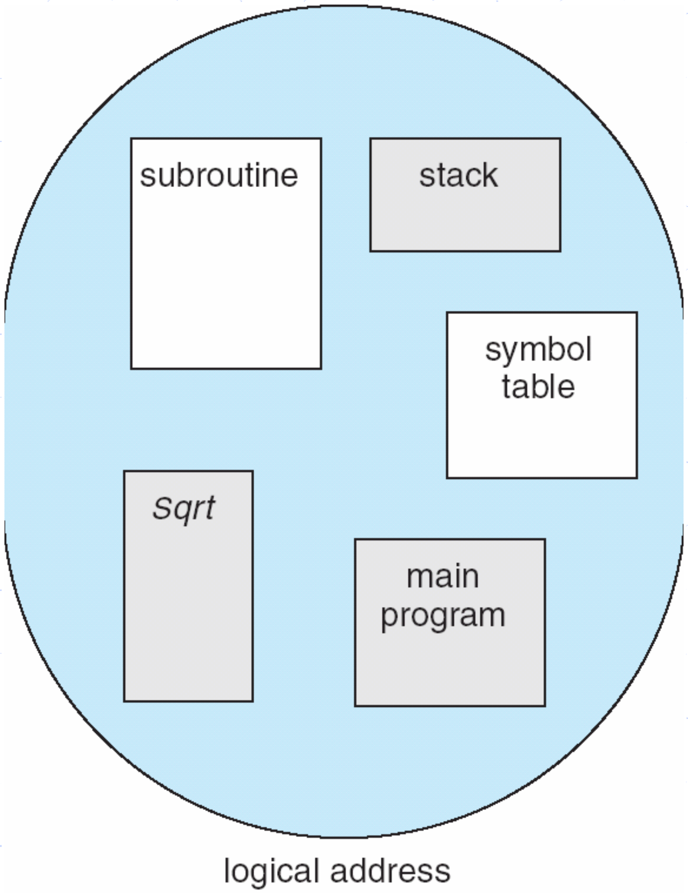
Segmentation

- The program/process and its associated data is divided into a number of segments
- All segments of all programs do not have to be of the same length
- There is a maximum segment length
- *Addressing* consist of two parts - a segment number and an offset
- Since segments are not equal, segmentation is similar to dynamic partitioning

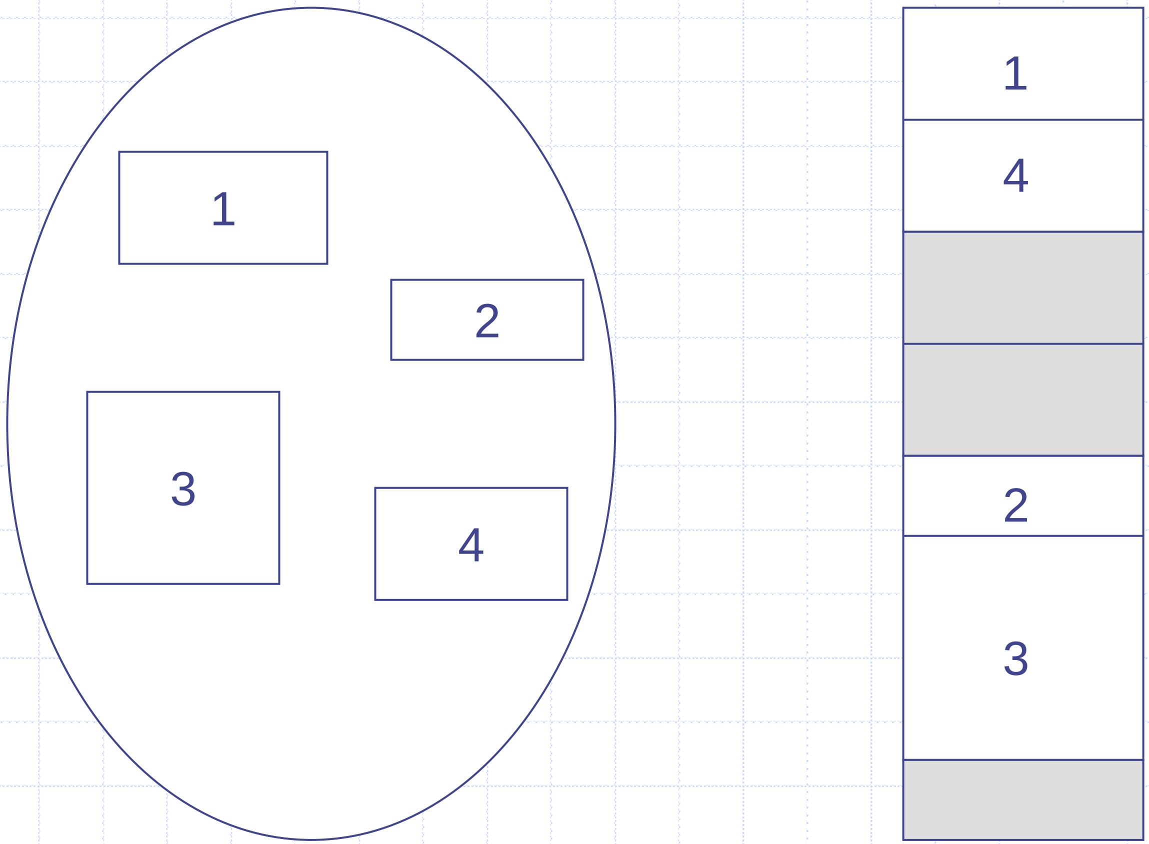
Address Translation Architecture



User's View of a Program



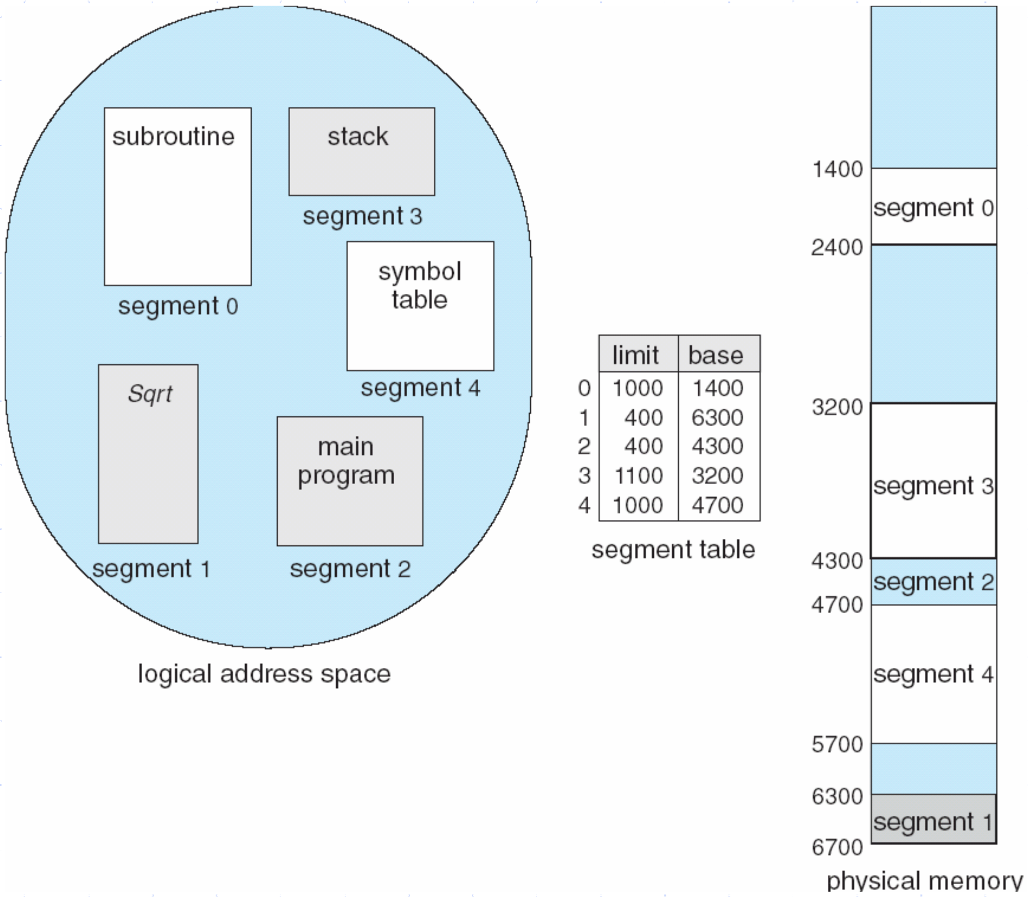
Logical View of Segmentation



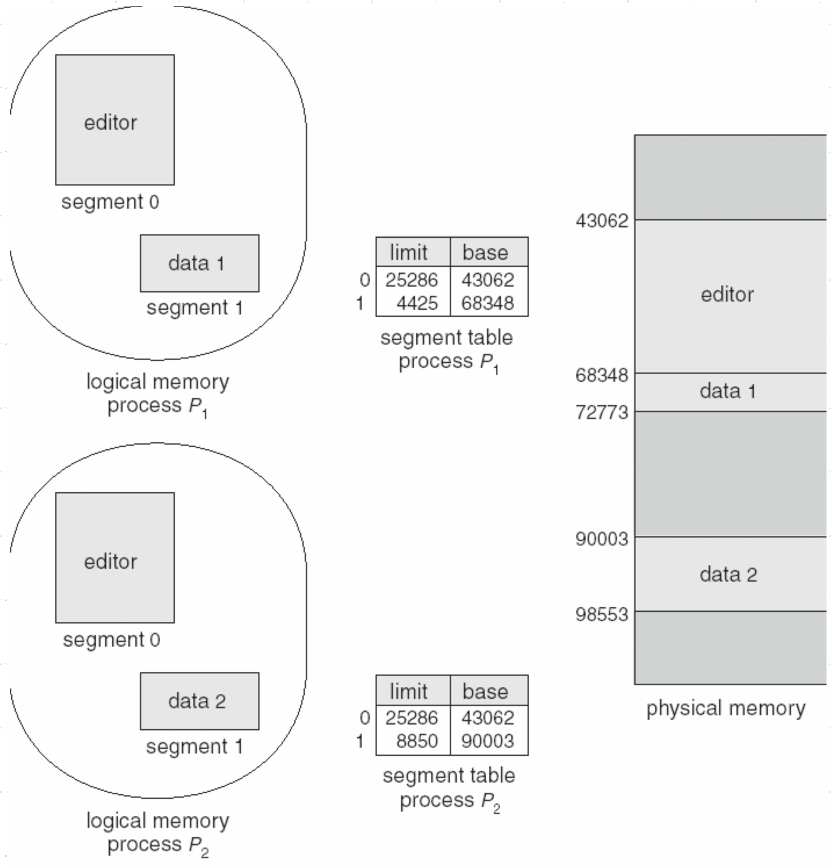
user space

physical memory space

Example of Segmentation



Sharing of Segments

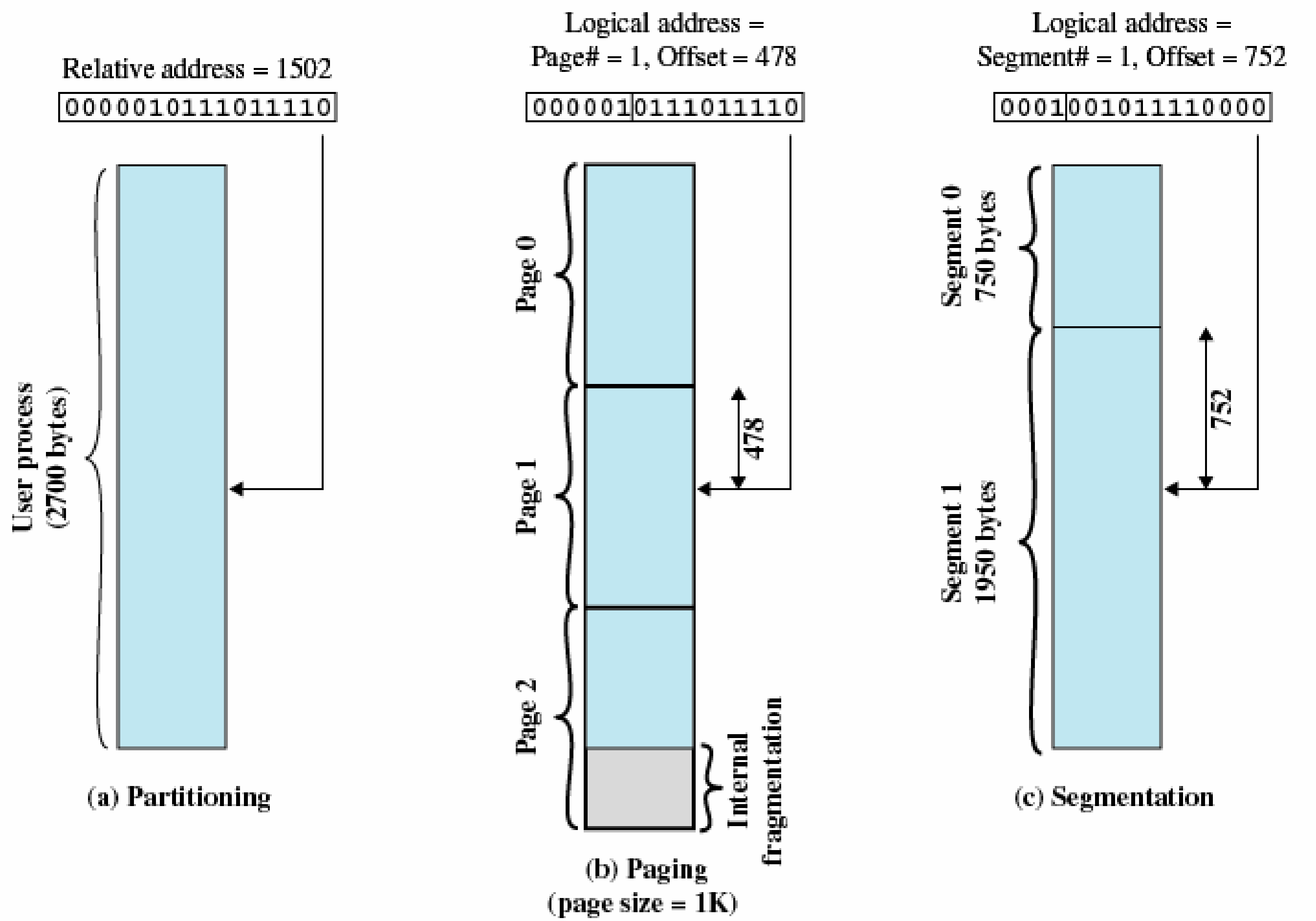


Segmentation

- Compared to dynamic partition, segmentation program may occupy *more than one partition* and these partitions need not be contiguous
- Segmentation *eliminates* the need for *internal fragmentation* but like dynamic partitioning it suffers from external fragmentation
- Process is broken in small pieces, the *external fragmentation is less with segmentation* than dynamic partition
- Paging is invisible to the programmer, segmentation is usually *visible*

Segmentation

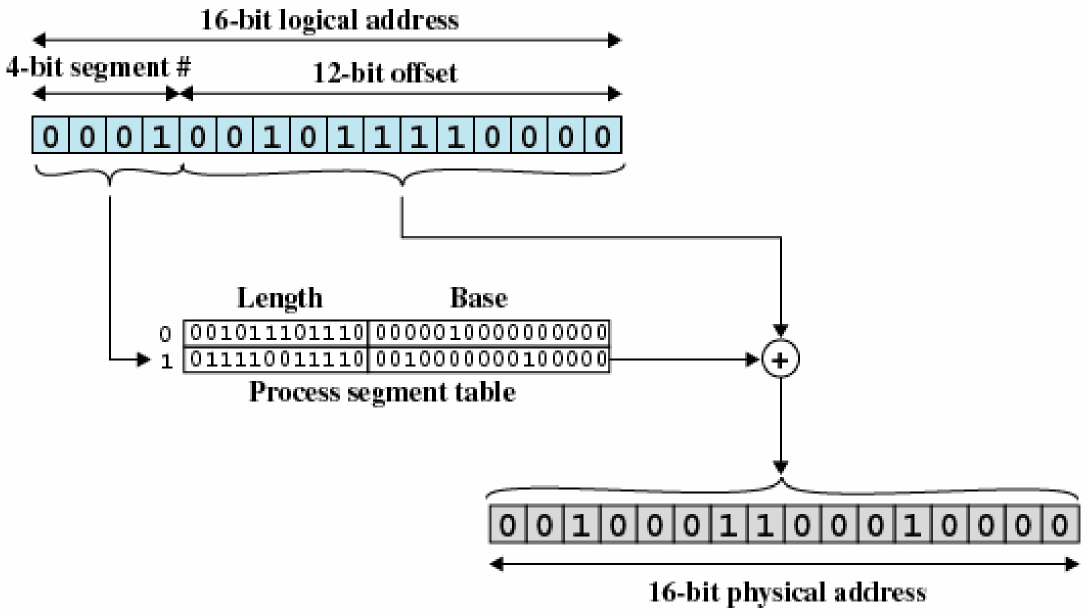
EXAMPLE: Logical Addresses.



Segmentation

EXAMPLE:

Logical-to-physical address translation in Segmentation



(b) Segmentation

Hierarchical Page Tables

- Most systems support a large logical address space
  - $2^{32} – 2^{64}$, page table itself becomes excessively large
- Break up the logical address space into multiple page tables

- A simple technique is a two-level page table

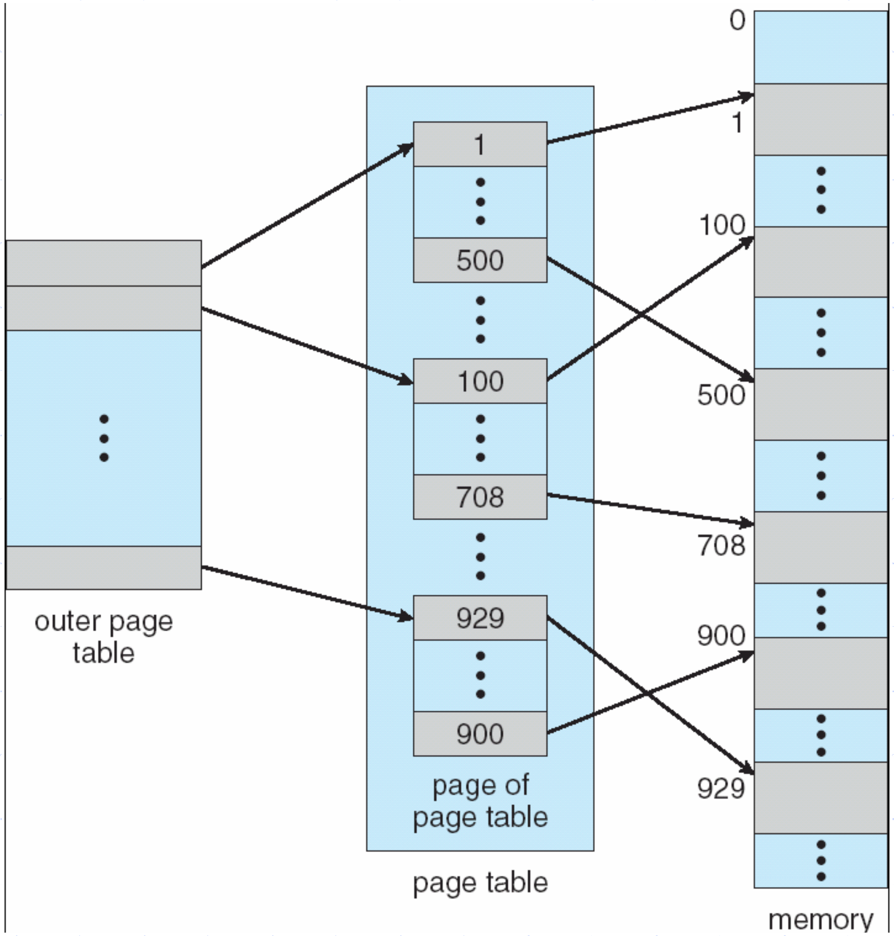
Two-Level Paging Example

- A logical address (32-bit machine with 4K page size) is divided into:
  - a page number consisting of 20 bits
  - a page offset consisting of 12 bits
- Since the page table is paged, page number is further divided into:
  - a 10-bit page number
  - a 10-bit page offset
- Thus, a logical address is as follows:

page number		page offset
p_i	p_2	d
10	10	12

where p_i is an index into the outer page table, and p_2 is the displacement within the page of the outer page table

Two-Level Page-Table Scheme



Address-Translation Scheme

- Address-translation scheme for a two-level 32-bit paging architecture