Unit 3

Memory Management

9/18/2017

Main Memory Management

- For the computation of a program, requirement is that it should be resident in main memory to run.

- Motivation : The main motivation for management of main memory comes from the fact we need to provide support for several programs which are memory resident in main memory as in a multiprogramming environment.

Main Memory Management

Issues that prompt main memory management :-

- Allocation : processes must be allocated space in the main memory.

- Swapping, Fragmentation and Compaction : If a program terminates or is moved out, it creates a hole in the main memory. The main memory is fragmented and needs to be compacted for organized allocation.

Main Memory Management

- Garbage Collection : The area released by a process is usually not accounted for immediately by the processor – its garbage!!. Compaction or garbage collection is responsibility of the OS.

- Protection : checking for illegal access of data from another process's memory area.

Main Memory Management

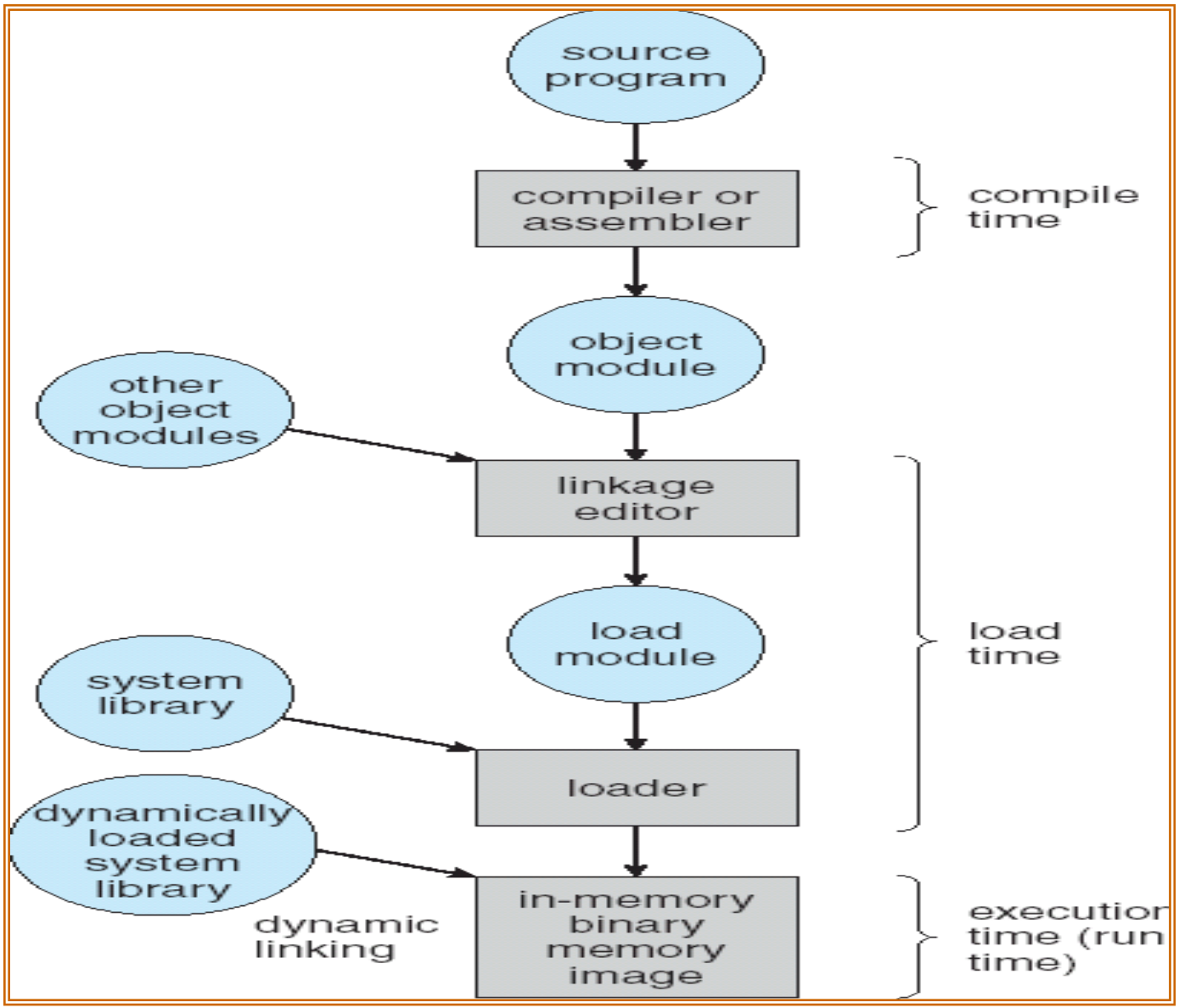
- Virtual Memory : VM support requires an address translation mechanism to map a logical address to the physical address to access the desired data or instruction.

- IO Support : Most block oriented devices are recognized as specialized files. Their buffers need to be managed within main memory alongside other processes.

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. Need hardware support for address maps (e.g., *base* and *limit registers*).

Multistep Processing of a User Program



Logical vs. Physical Address Space

- The concept of a logical *address space* that is bound to a separate *physical address space* is central to proper memory management
  - **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 (virtual) and physical addresses differ in execution-time address-binding scheme

Memory-Management Unit (MMU)

- Hardware device that maps virtual to physical address
- In MMU scheme, the value in the relocation register is added to every address generated by a user process at the time it is sent to memory
- The user program deals with *logical* addresses; it never sees the *real* physical addresses

Compiler Generated Bindings

- The advantage of relocation can be seen in the light of binding of addresses to variables in a program.

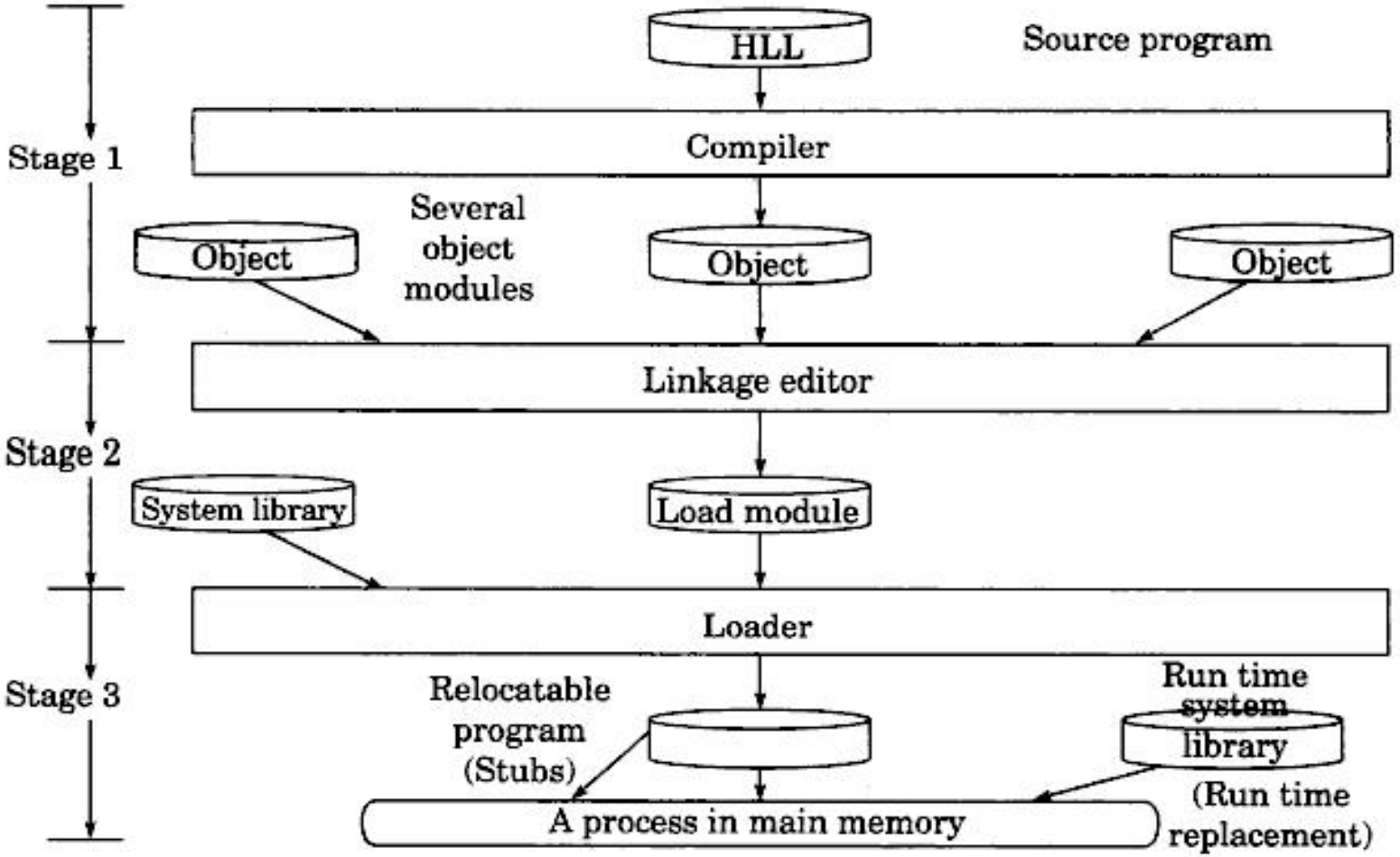
- For a variable x in a program P, a fixed address allocation for x will mean that P can be run only when x is allocated the same memory again

Compiler Generated Bindings

- The fixed address allocated by the compiler for the variable x is known as binding.
- If x is bound to fixed location then we can execute a Program P , only when x would be put in its allocated memory location.
- Otherwise all the address reference to x would be incorrect.
- If, however, variable can be assigned location relative to assumed origin, then relocating the program's origin anywhere in the main memory, we will still be able to generate proper relative reference address for x, & execute the program.
- Compilers generate re-locatable code.

Linking and loading concepts

- Following the creation of a high level language (HLL) source program, there are three stages of processing before we can get a process as shown in figure below.



LINKING AND LOADING CONCEPTS

- Stage1: In the first stage the HLL source program is compiled and an object code is produced. Technically, depending upon the program, this object code may by itself be sufficient to generate a relocatable process. However, many programs are compiled in parts, so this object code may have to link up with other object modules. At this stage the compiler may also insert stub at points where run time library modules may be linked.

- Stage2: All object modules which have sufficient linking information (generated by the compiler) for static linking are taken up for linking. The linking editor generates a relocatable code. At this stage, however, we still do not replace the stubs placed by compilers for a run time library link up.

LINKING AND LOADING CONCEPTS

- Stage 3 : The final step is to arrange to make substitution for the stubs with run time library code which is a relocatable code.

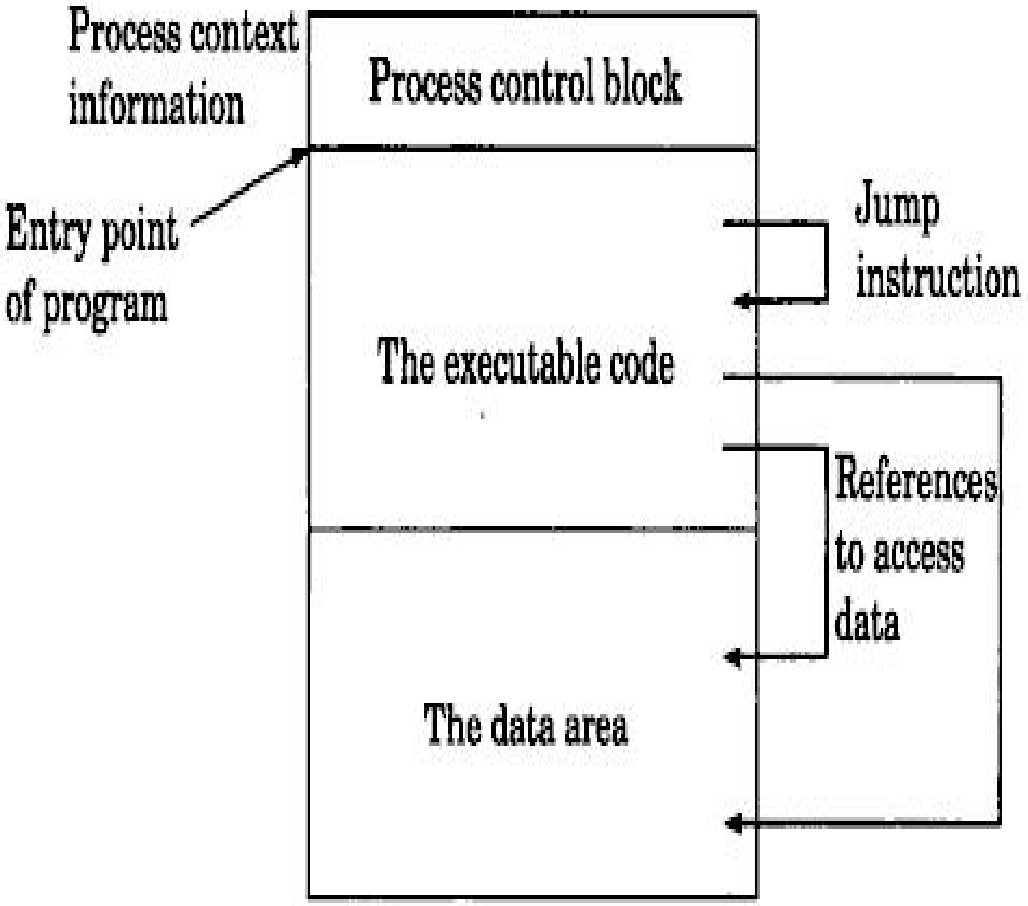
- When all the three stages are completed we have an executable. When this executable is resident in the main memory it is a runnable process.

Memory Relocation Concept

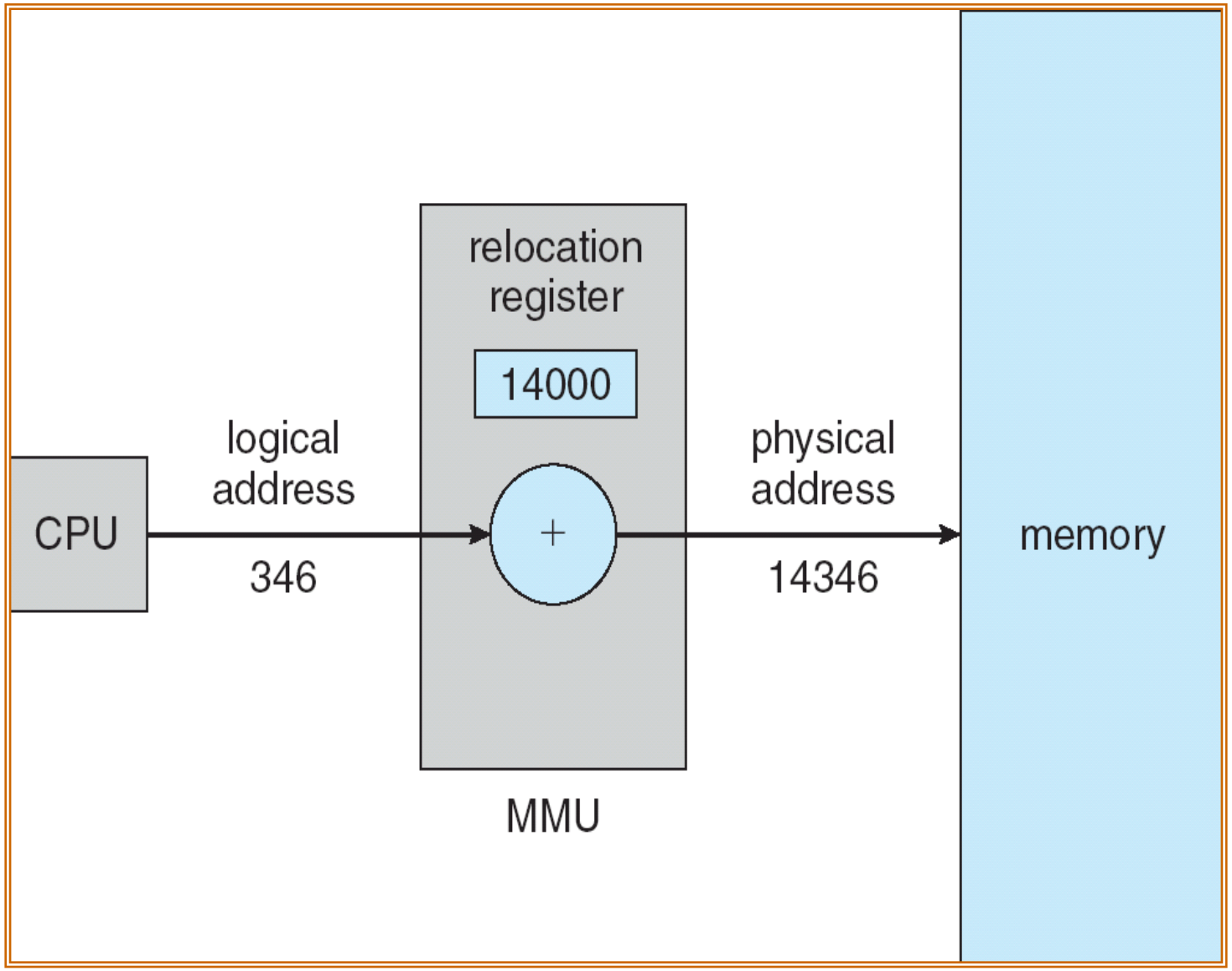
Why do we need relocatable Processes ?

- Consider a linear map (1-D view) of main memory.
- Program Counter is set to the absolute address of the first instruction of the program.
- Data can also fetched if we know its absolute address.
- In case that part of memory is currently in use then this program can not be run.
- Note if we have program instructions then we should be able to execute the program from starting at any location.

Memory Relocation Concept



Dynamic relocation using a relocation register



Memory Relocation Concept

- With this flexibility, we can allocate any area in the memory to load this process.

- Note that this is most useful when processes move in and out of main memory – recall that a hole created by a process at the time of moving out of the main memory will not be available when it is brought into main memory again.

Dynamic Loading

- Routine is not loaded until it is called
- Better memory-space utilization; unused routine is never loaded
- Useful when large amounts of code are needed to handle infrequently occurring cases
- No special support from the operating system is required implemented through program design

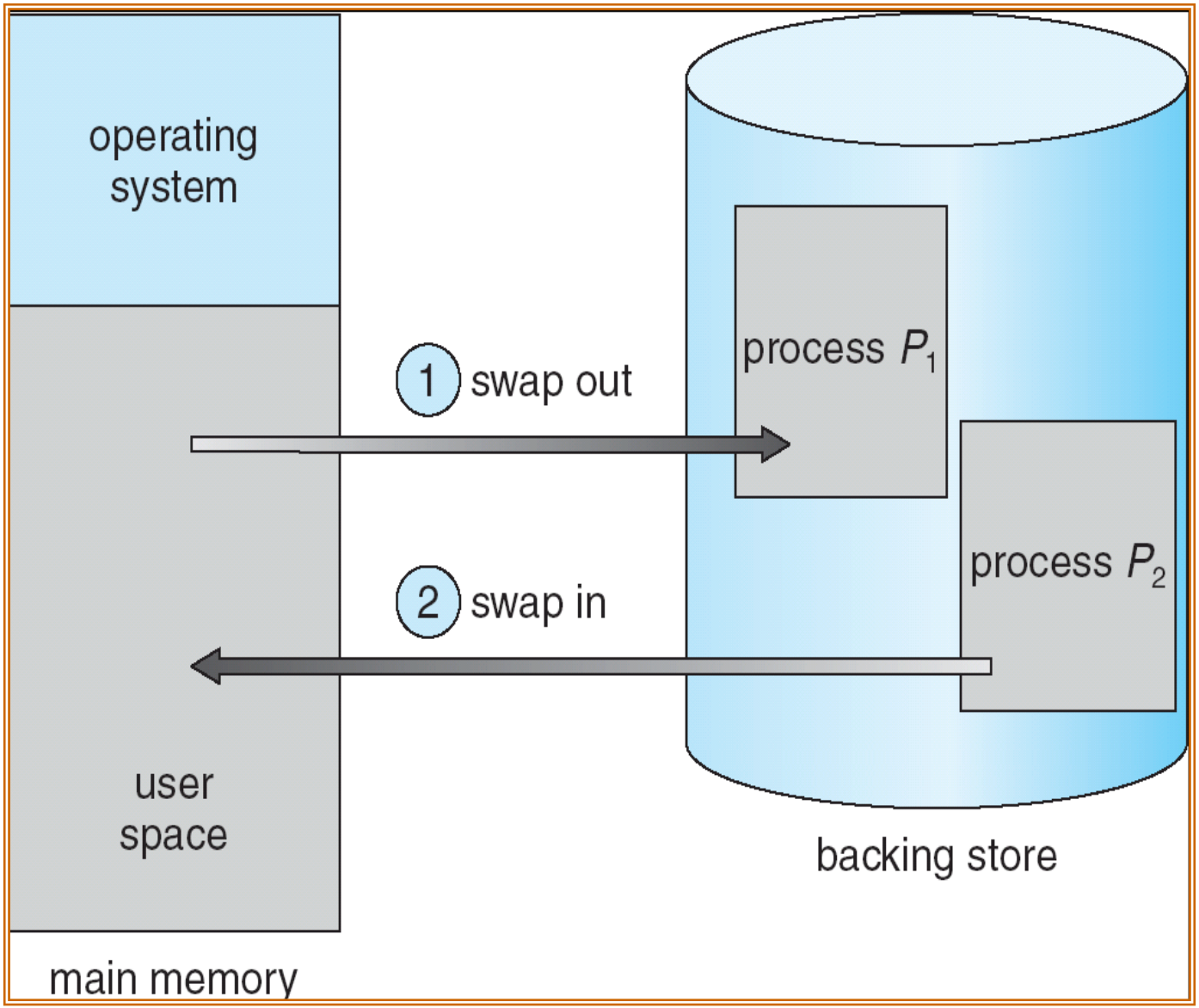
Dynamic Linking

- 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
- Operating system needed to check if routine is in processes' memory address
- Dynamic linking is particularly useful for libraries

SWAPPING

- A process can be swapped temporarily out of memory to a backing store, and then brought back into memory for continued execution
- **Backing store** – fast disk large enough to accommodate copies of all memory images for all users; must provide direct access to these memory images
- **Roll out, roll in** – swapping variant used for priority-based scheduling algorithms; lower-priority process is swapped out so higher-priority process can be loaded and executed
- Major part of swap time is transfer time; total transfer time is directly proportional to the amount of memory swapped
- Modified versions of swapping are found on many systems (i.e., UNIX, Linux, and Windows)

Schematic View of Swapping

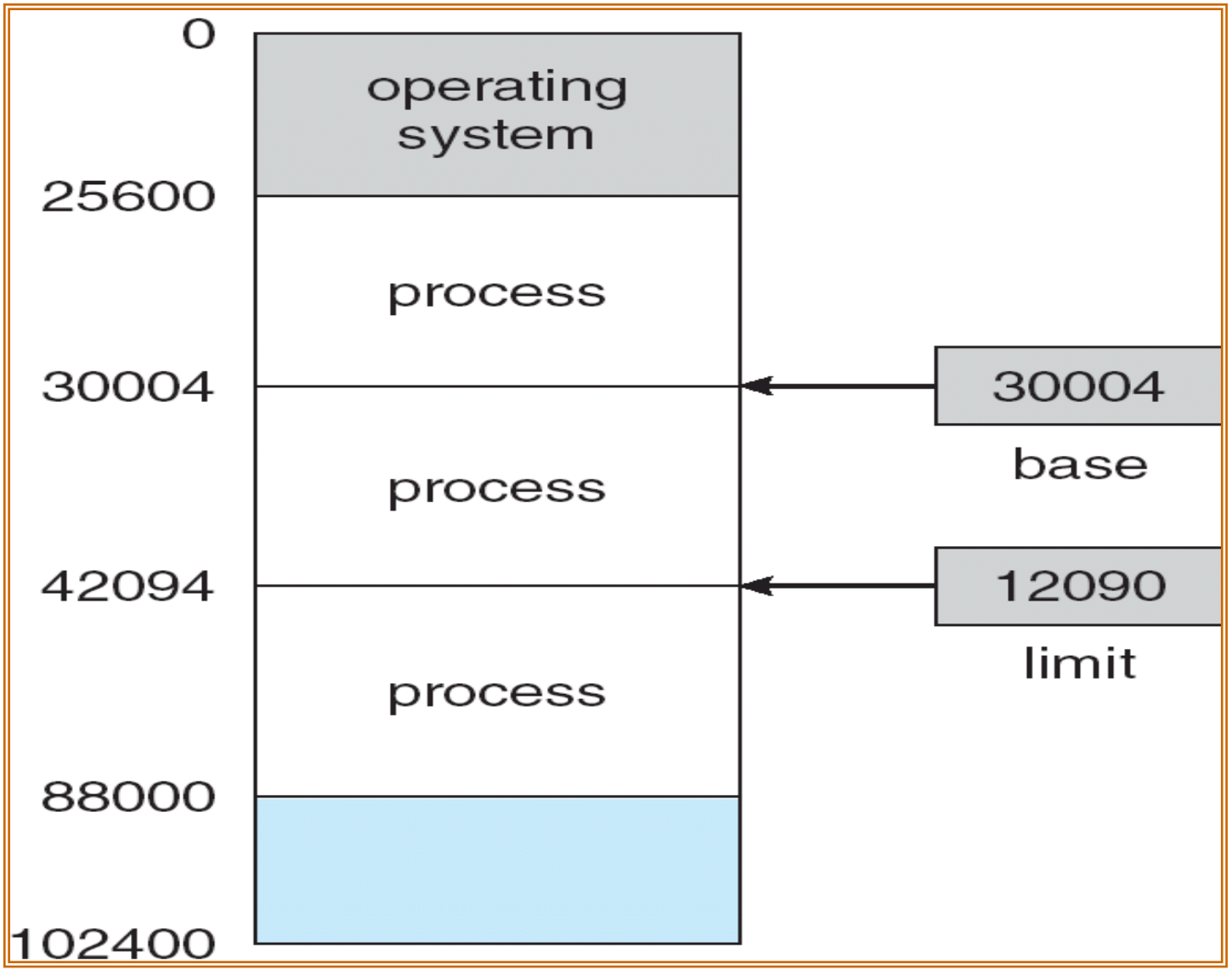


Contiguous Allocation

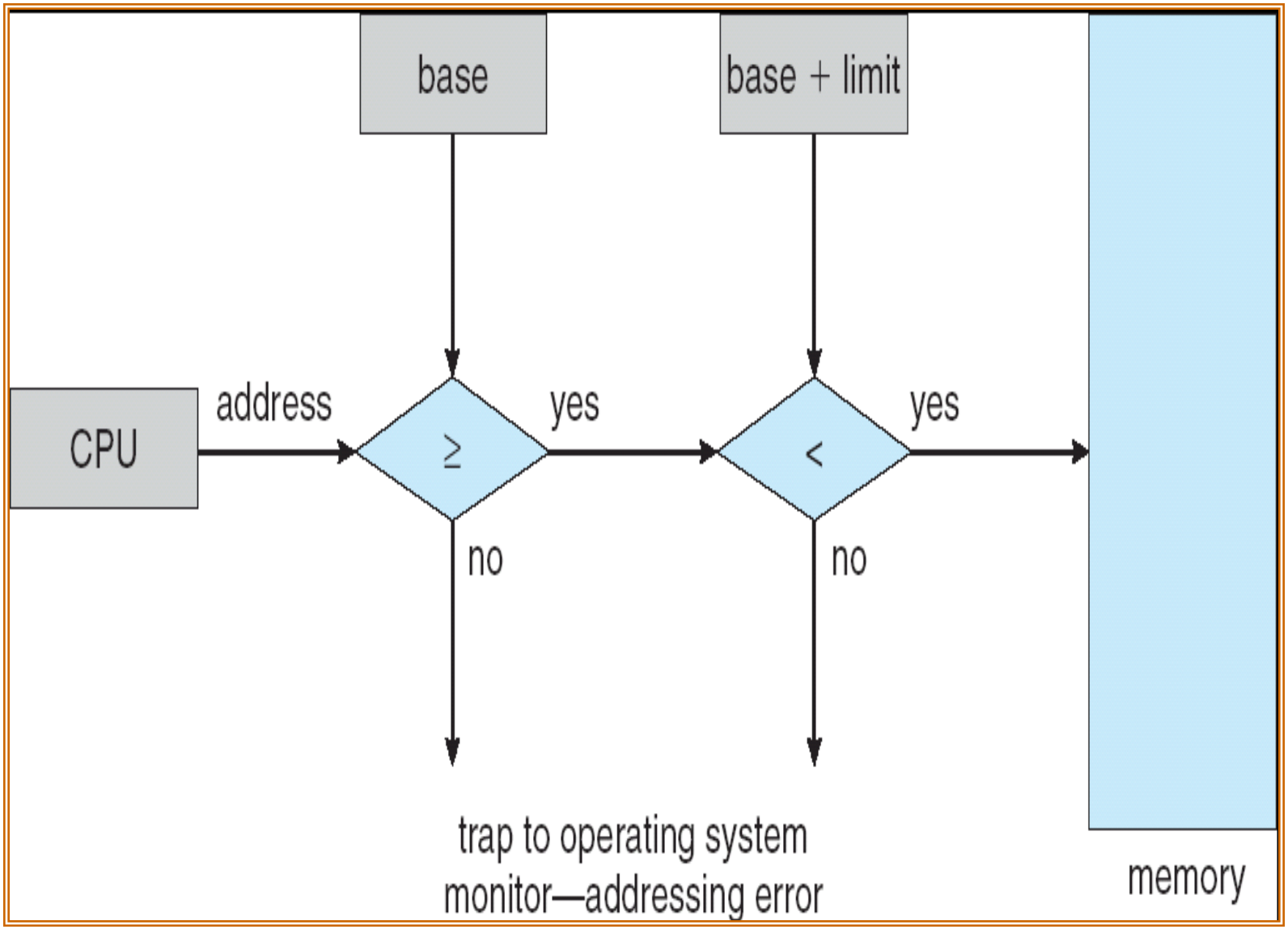
- Main memory usually into two partitions:
  - Resident operating system, usually held in low memory with interrupt vector
  - User processes then held in high memory

- Single-partition allocation
  - Relocation-register scheme used to protect user processes from each other, and from changing operating-system code and data
  - Relocation register contains value of smallest physical address; limit register contains range of logical addresses – each logical address must be less than the limit register

A BASE AND A LIMIT REGISTER DEFINE A LOGICAL ADDRESS SPACE

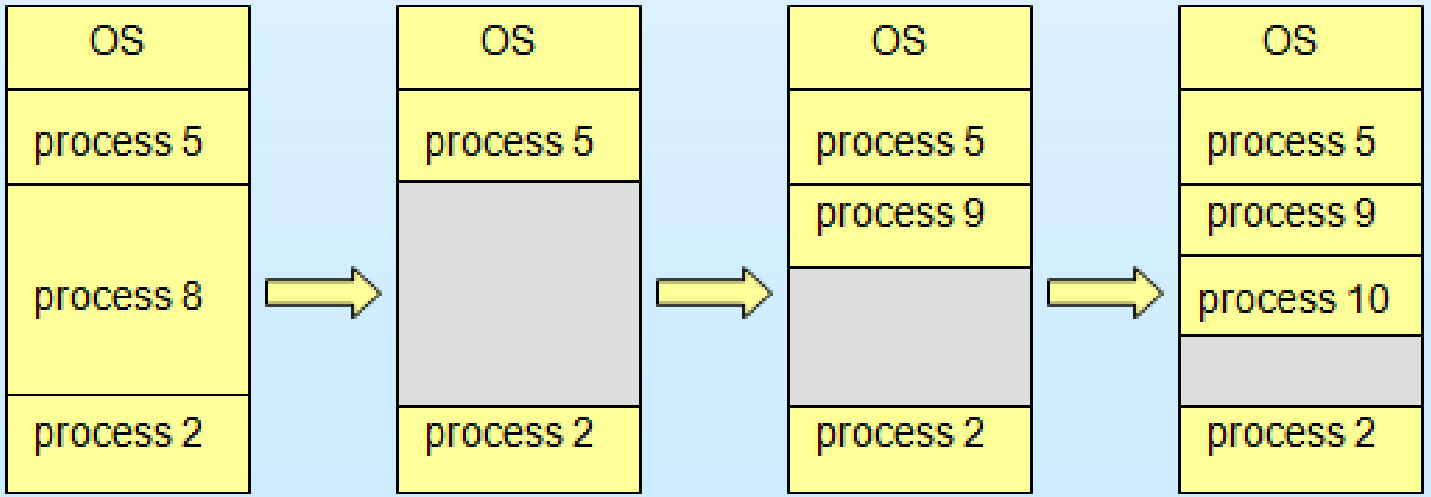


HW ADDRESS PROTECTION WITH BASE AND LIMIT REGISTERS



Contiguous Allocation

- Multiple-partition allocation
  - *Hole* – block of available memory; holes of various size are scattered throughout memory
  - When a process arrives, it is allocated memory from a hole large enough to accommodate it
  - Operating system maintains information about:
    a) allocated partitions b) free partitions



Dynamic Storage-Allocation Problem

- How to satisfy a request of size *n* from a list of free holes
- **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 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
- Reduce external fragmentation by **compaction**
  - Shuffle memory contents to place all free memory together in one large block
  - Compaction is possible *only* if relocation is dynamic, and is done at execution time
  - I/O problem
    - Latch job in memory while it is involved in I/O
    - Do I/O only into OS buffers

The First Fit Policy of Memory Allocation

- We are following *FCFS (process management) and First Fit (memory allocation) policies.*
- First Fit main memory allocation policy is *very easy to implement and is fast in execution.*
- First Fit policy may leave *many small holes.*

Memory Allocation Policies

- Best Fit Policy *scans all available holes and chooses the* one with a *size closest to the requirement.*
- It requires a *scan of the whole memory and is slow.*
- Next Fit has a *search pointer continues from where the* previous search ended.
- Worst Fit method allocates the *largest hole.*
- First Fit and Next Fit are *fastest and are hence preferred* methods.
- Worst Fit is the *poorest of all the four methods.*
- To compare these policies, we shall examine the effect of using various policies on a given set of data next.

The Given Data For Policy Comparison

- The given Data:
  - Memory available 20 units
  - OS resides in 6 units
  - User processes share 14 units.
- The user process data:

	P1	P2	P3	P4	P5	P6
Time of arrival	0	0	0	0	10	15
Processing time required	8	5	20	12	10	5
Memory required	3 units	7 units	2 units	4 units	2 units	2 units

FCFS Policy

- Statement: "*Jobs are processed in the order they arrive*".

FCFS Memory Allocation

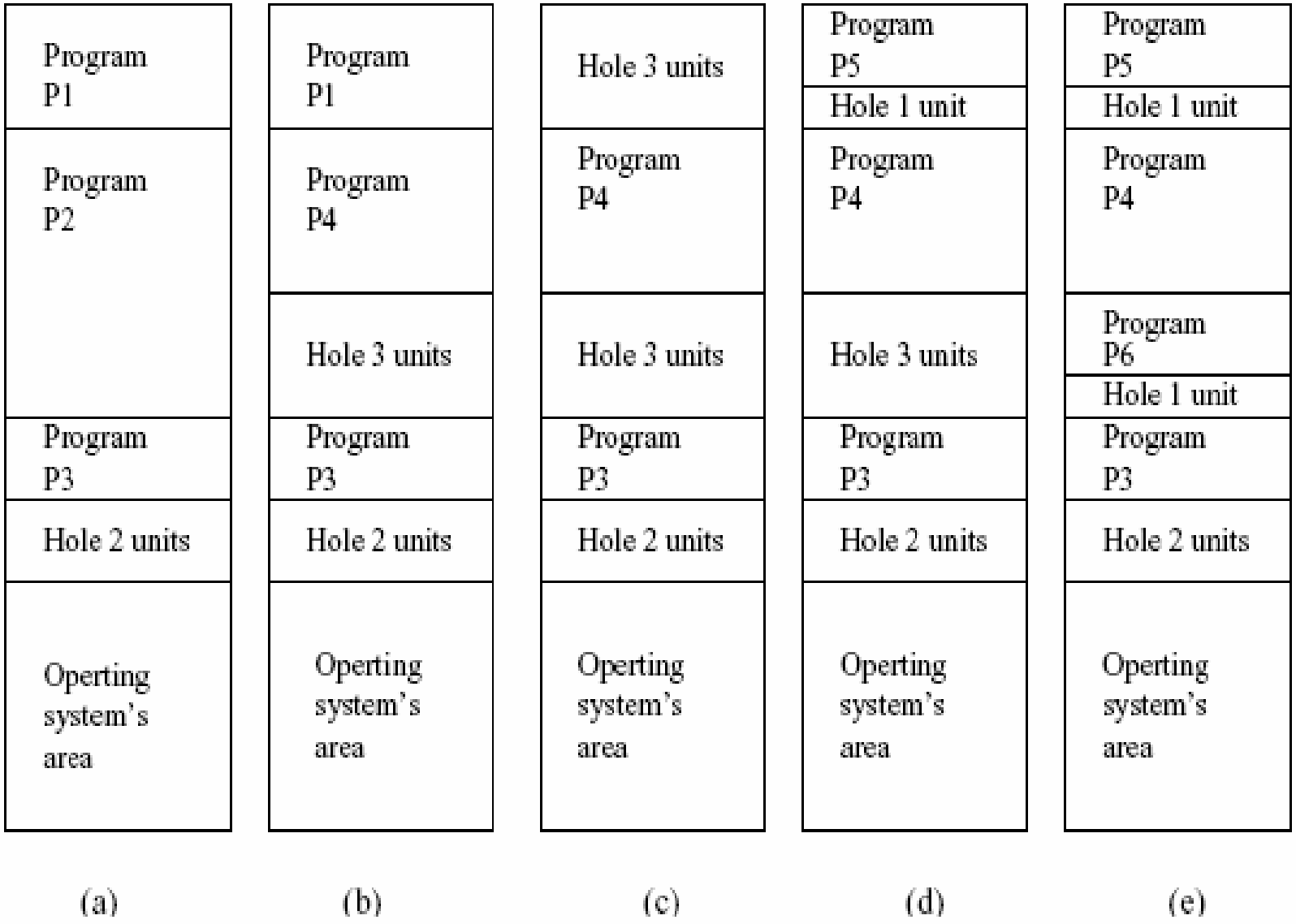
Time units	Programs in Main memory	Programs on disk	Holes with sizes	Figure 4.3	Comments
0	P1, P2, P3	P4	H1=2	(a)	P4 requires more space than H1
5	P1, P4, P3		H1=2; H2=3	(b)	P2 is Finished P4 is loaded Hole H2 is created
8	P4, P3		H1=2; H2=3; H3=3	(c)	New hole created
10	P4, P3	P5			P5 arrives
10+	P5, P4, P3		H1=2; H2=3 H3=1	(d)	P5 is allocated P1's space
15	P5, P4, P3	P6	H1=2; H2=3; H3=1		P6 has arrived
15+	P5, P4, P6, P3		H1=2; H2=1; H3=1	(e)	P6 is allocated

The First Fit Policy

- Statement: "Jobs are processed always from one end and find the first block of free space which is large enough to accommodate the incoming process".
- Given Data:

	P1	P2	P3	P4	P5	P6
Time of arrival	0	0	0	0	10	15
Processing time required	8	5	20	12	10	5
Memory required	3 units	7 units	2 units	4 units	2 units	2 units

The First Fit Policy of Memory Allocation

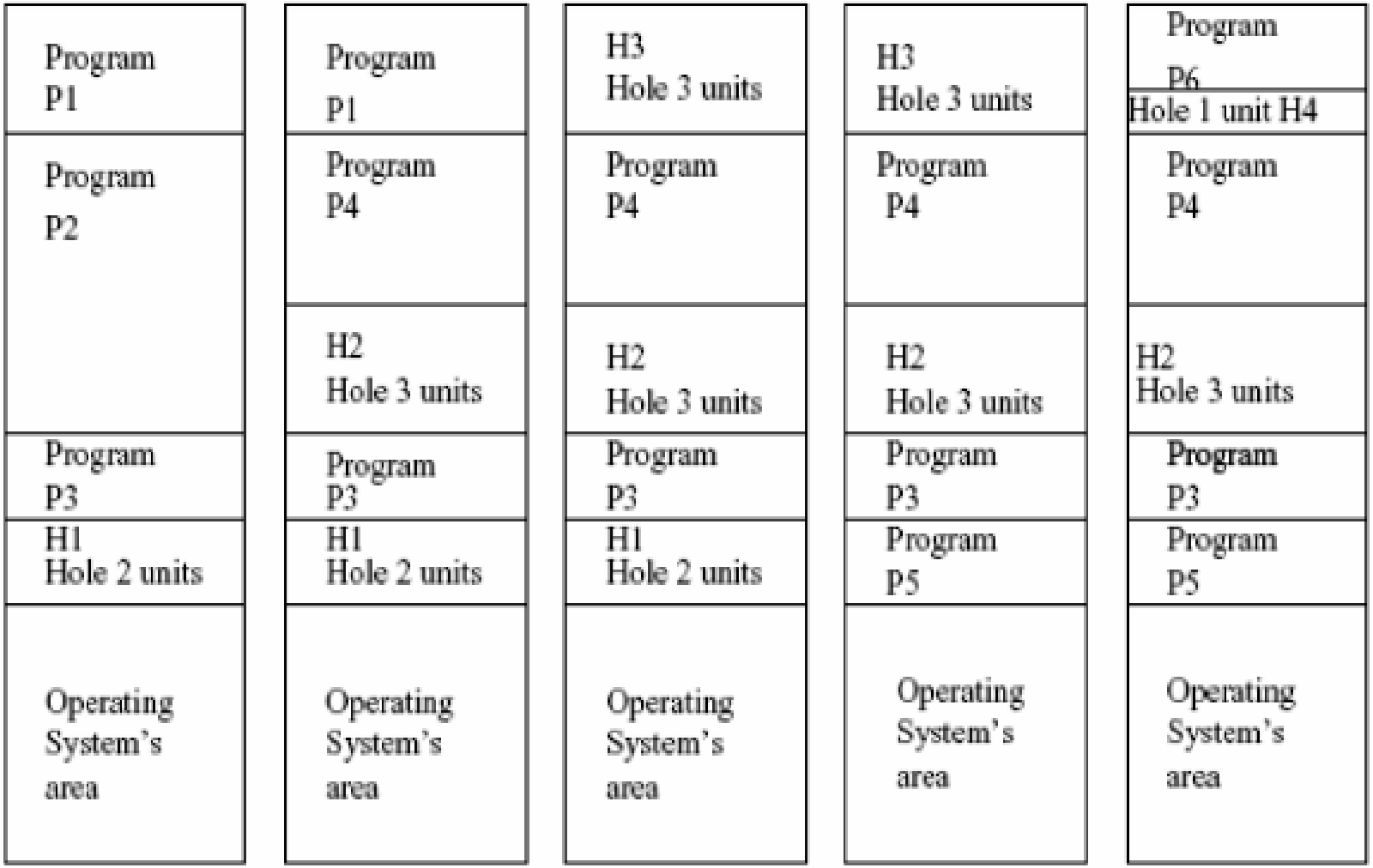


The Best Fit Policy

- Statement: "Jobs are selected after scanning the main memory for all the available holes and having information about all the holes in the memory, the job which is closest to the size of the requirement of the process will be processed ".
- Given Data:

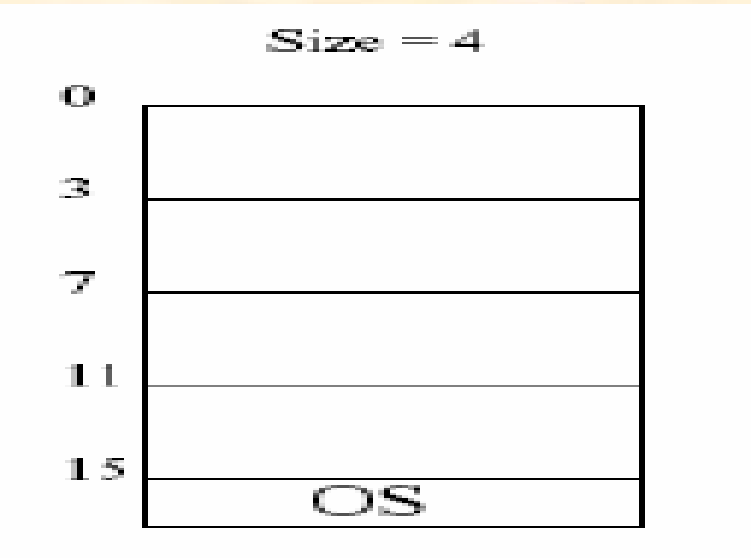
	P1	P2	P3	P4	P5	P6
Time of arrival	0	0	0	0	10	15
Processing time required	8	5	20	12	10	5
Memory required	3 units	7 units	2 units	4 units	2 units	2 units

The Best Fit Policy of Memory Allocation



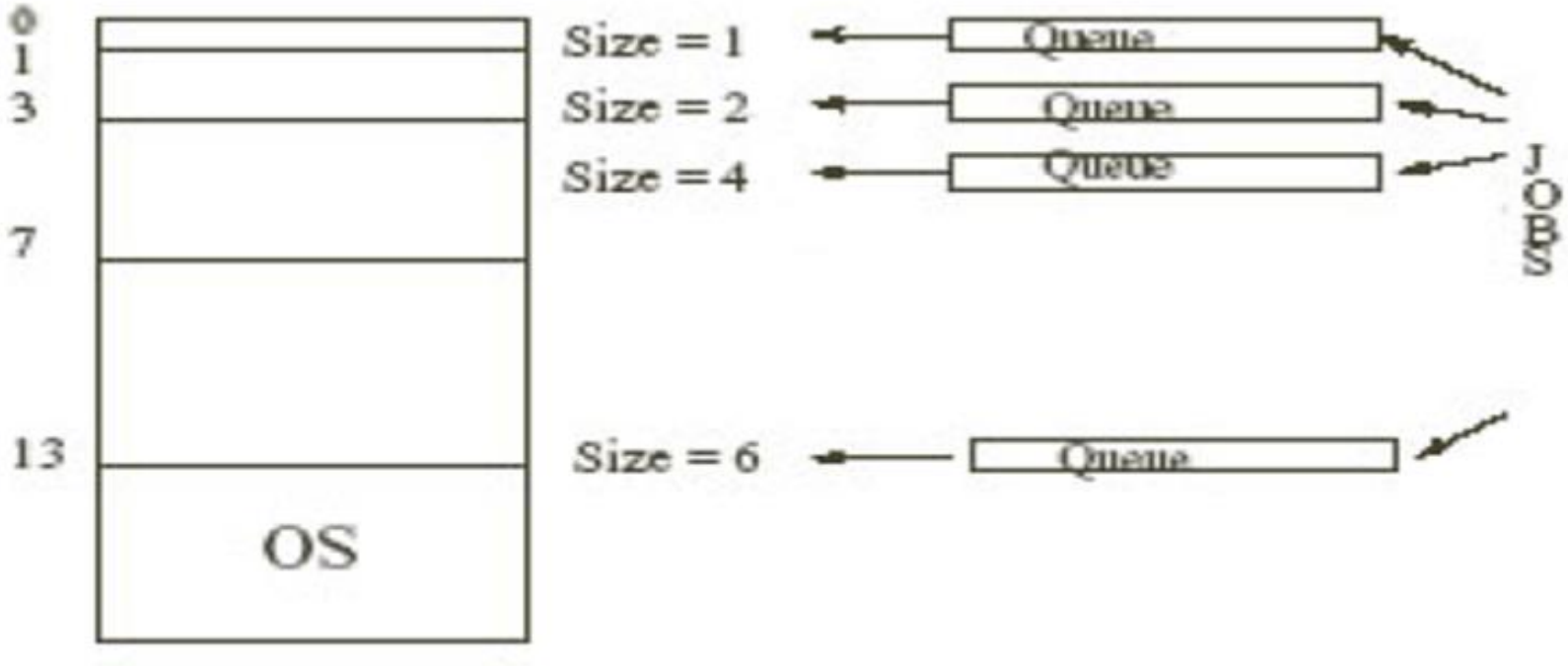
Fixed and Variable Partition

- *Fixed Partition : Memory is divided into chunks. For* example, 4K/8K/16K Bytes. All of these are same size.
- *Allocation : If a certain chunk can hold the program/data, then* the allocation. If a chunk can not hold program/data then multiple chunks are allocated to accommodate the program/data.



Fixed and Variable Partition

- *Variable Partition: Memory is divided into chunks of* various sizes. For Example there could be chunks of 8K, some may be 16 K or even more.
- *Allocation: The program/Data are allocated to the chunks* that can accommodate the incoming program/Data.



Buddy System

- The *buddy system of partitioning relies on the fact that space* allocations can be conveniently handled in sizes of power of 2.

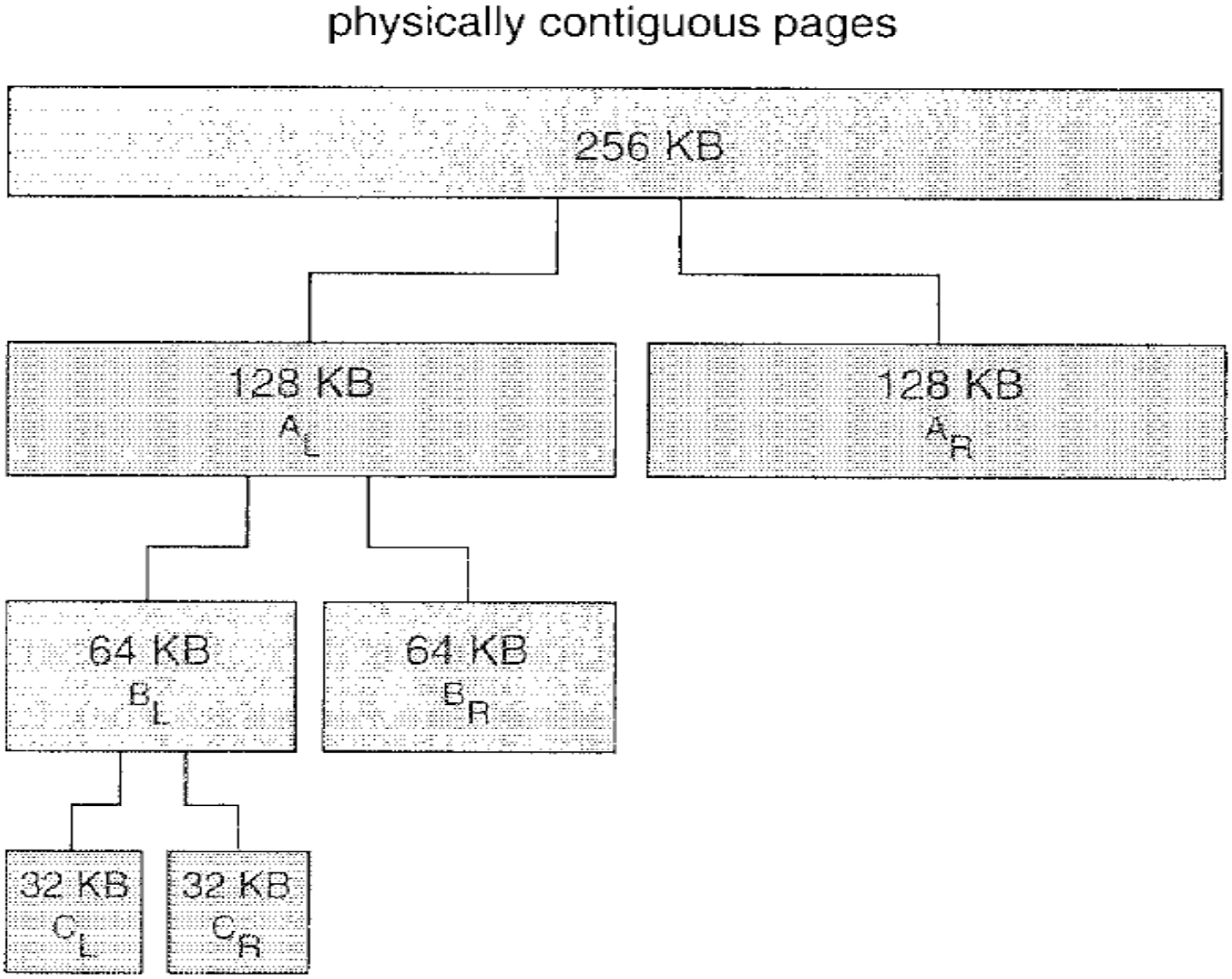
- There are two ways in which the buddy system allocates space.

  - Suppose we have a hole which is the closest power of two. In that case, that hole is used for allocation.

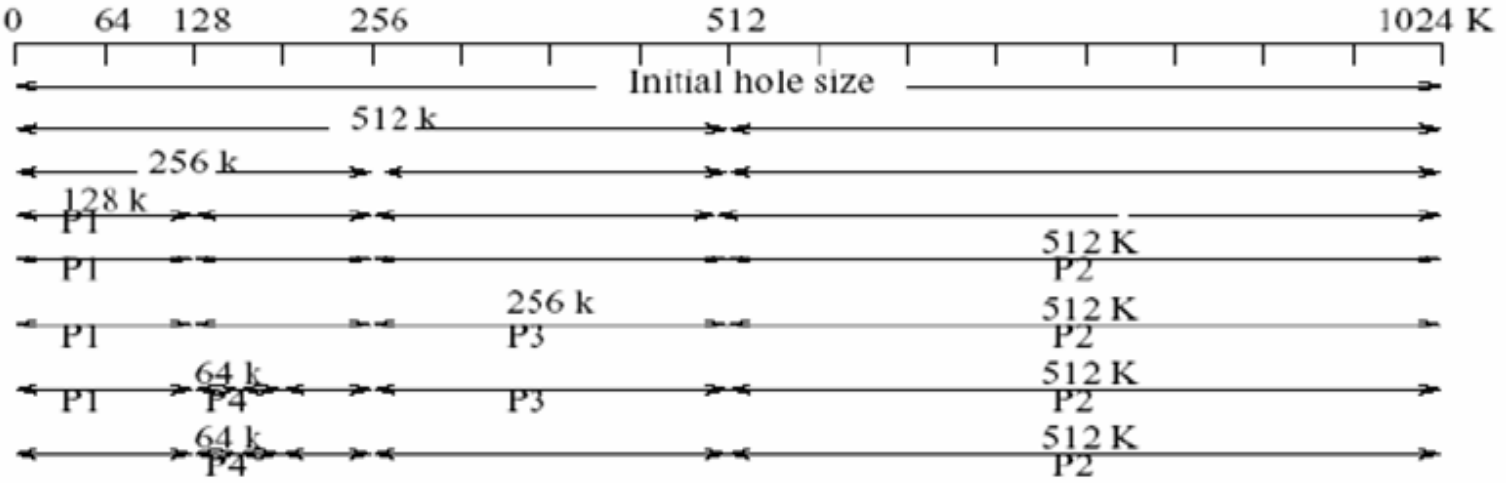
  - In case we do not have that situation then we look for the next power of *2 hole size, split it in two equal halves and* allocate one of these.

- Because we always split the holes in two equal sizes, the two are "*buddies*". *Hence, the name buddy system*.

Buddy System



BUDDY SYSTEM



We assume that initially we have a space of *1024 K. We also* assume that processes arrive and are allocated following a time sequence as shown in figure.

In the figure we assume the requirements as *(P1:80K);(P2:312K);(P3:164 K); (P4:38 K). These processes arrive in the order of* their index and *P1 and P3 finish at the same time*

Buddy System

- With *1024 K or (1M) storage space we split it into buddies of 512 K, splitting one of them to two 256 K buddies and so on till* we get the right size. Also, we assume scan of memory from the beginning. We always use the first hole which accommodates the process.

- Otherwise, we split the next sized hole into buddies. Note that the buddy system begins search for a hole as if we had a *number of holes of variable sizes. In fact, it turns into a dynamic* partitioning scheme if we do not find the best-fit hole initially.

- The buddy system has the advantage that it minimizes the *internal fragmentation*.

- But not popular because it is very slow.

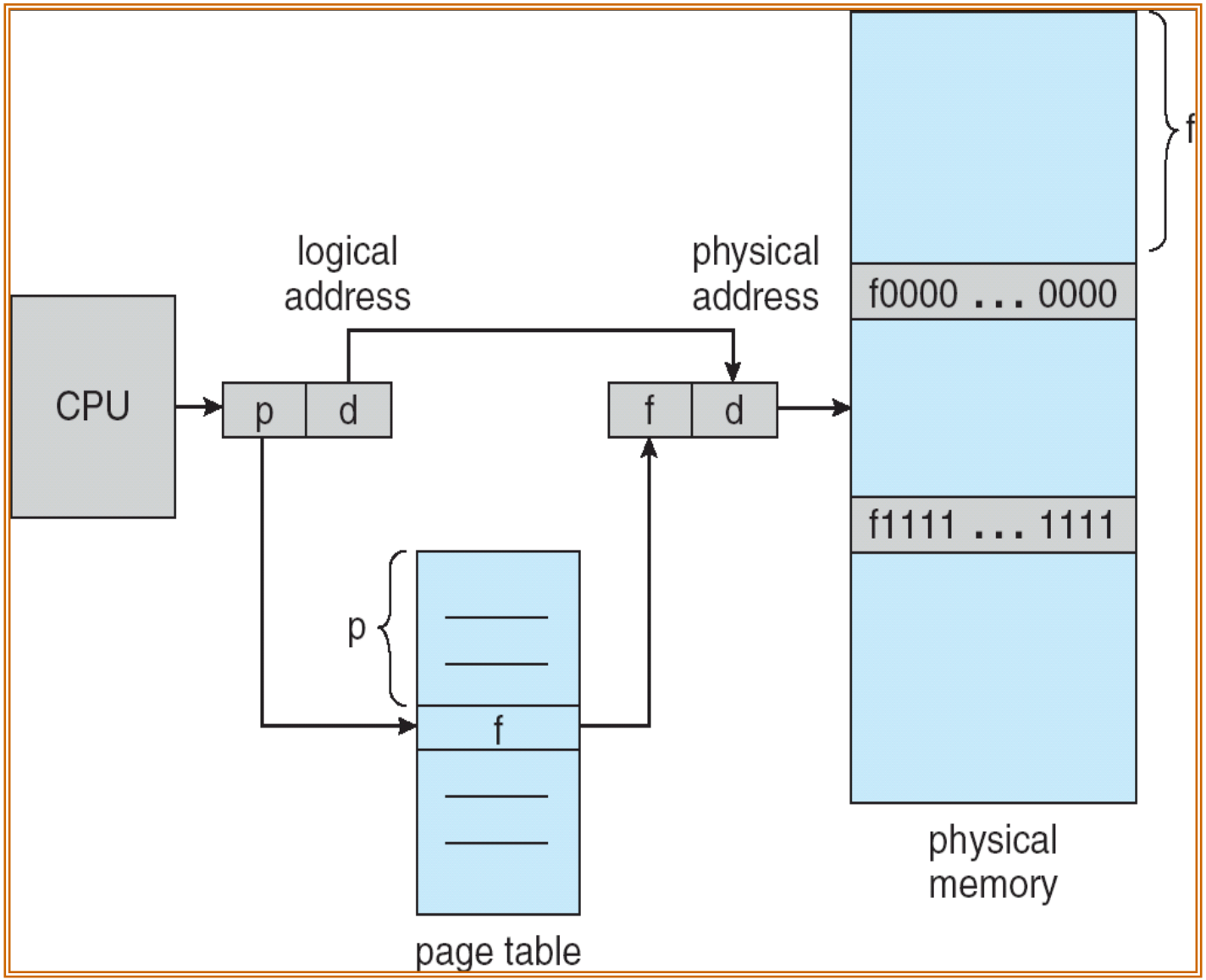
Paging

- Logical address space of a process can be noncontiguous; process is allocated physical memory whenever the latter is available
- Divide physical memory into fixed-sized blocks called **frames** (size is power of 2, between 512 bytes and 8192 bytes)
- Divide logical memory into blocks of same size called **pages**.
- Keep track of all free frames
- To run a program of size *n* pages, need to find *n* free frames and load program
- Set up a page table to translate logical to physical addresses
- Internal fragmentation

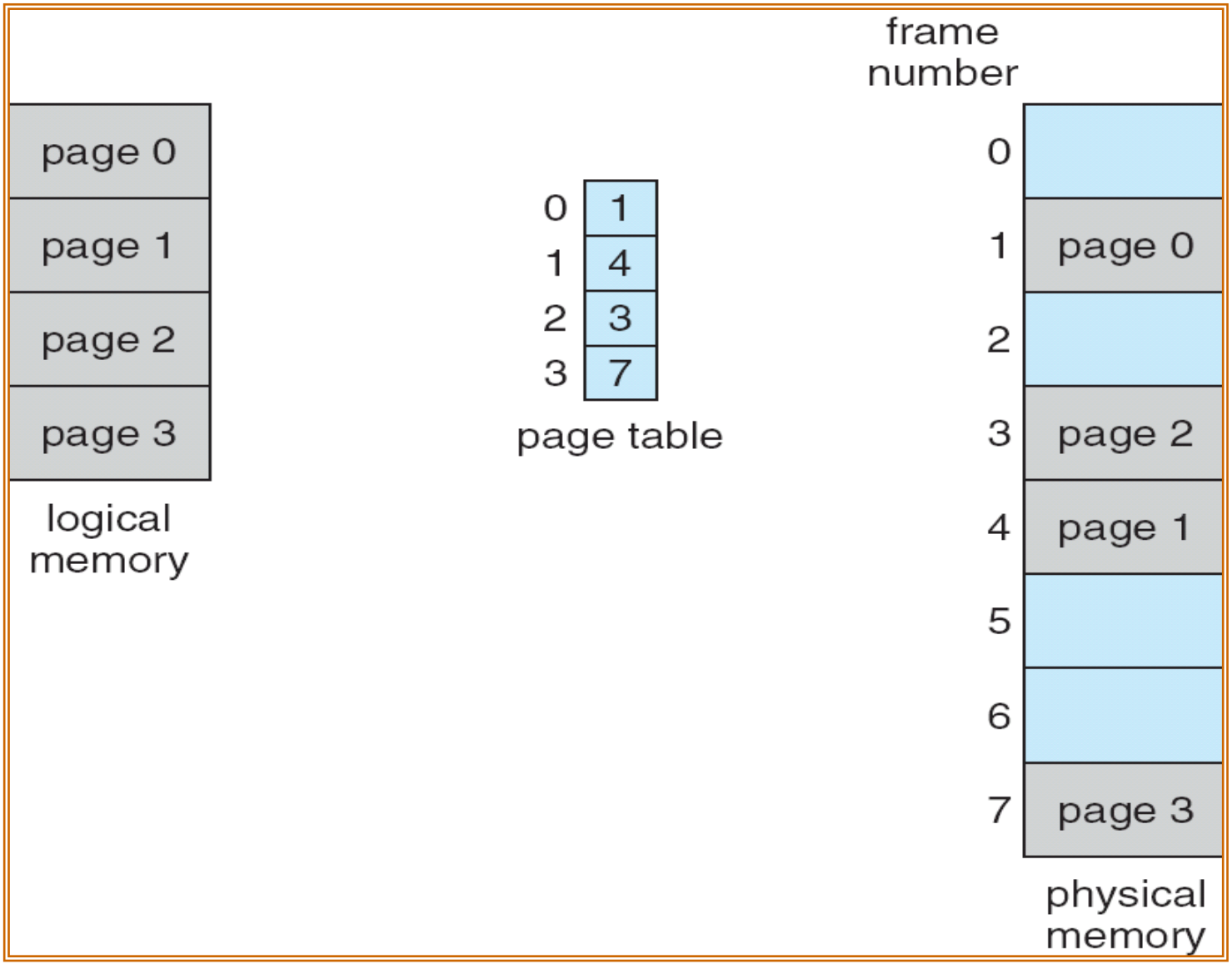
Address Translation Scheme

- 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

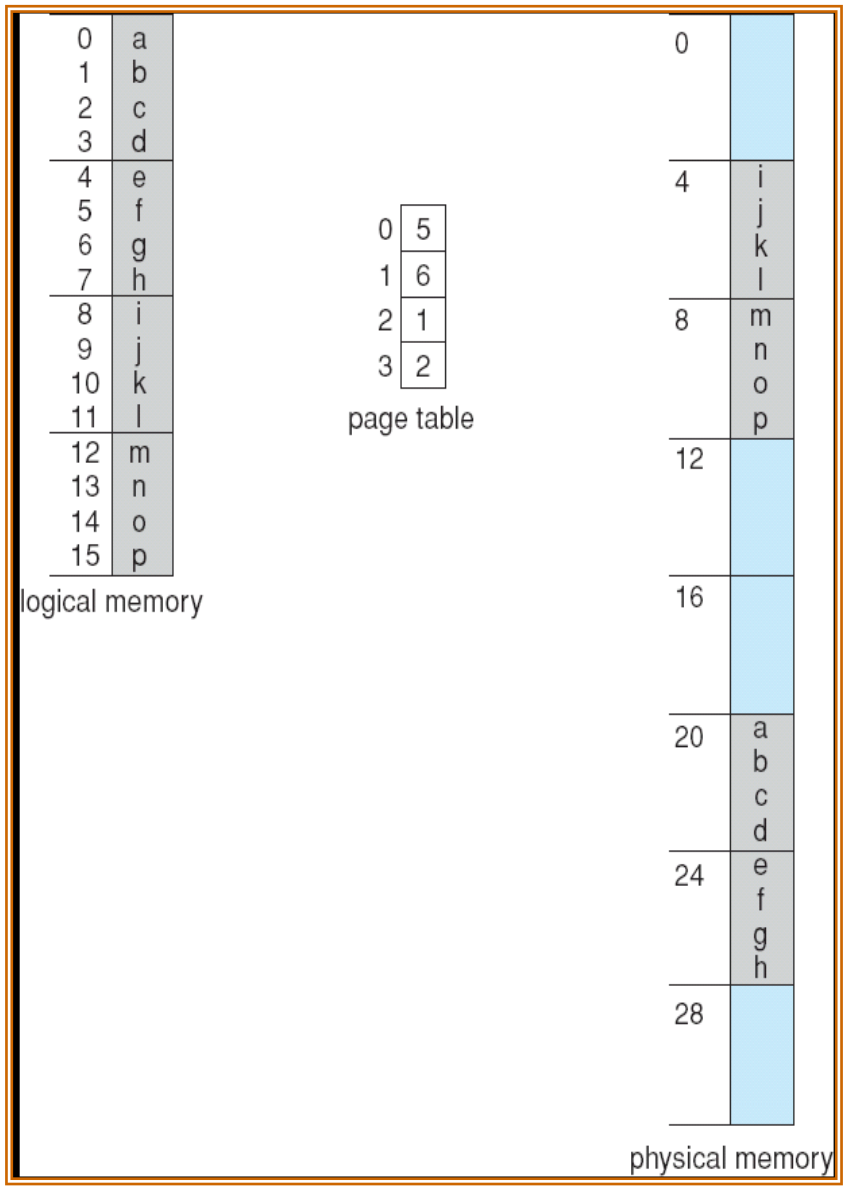
Address Translation Architecture



Paging Example



Paging Example



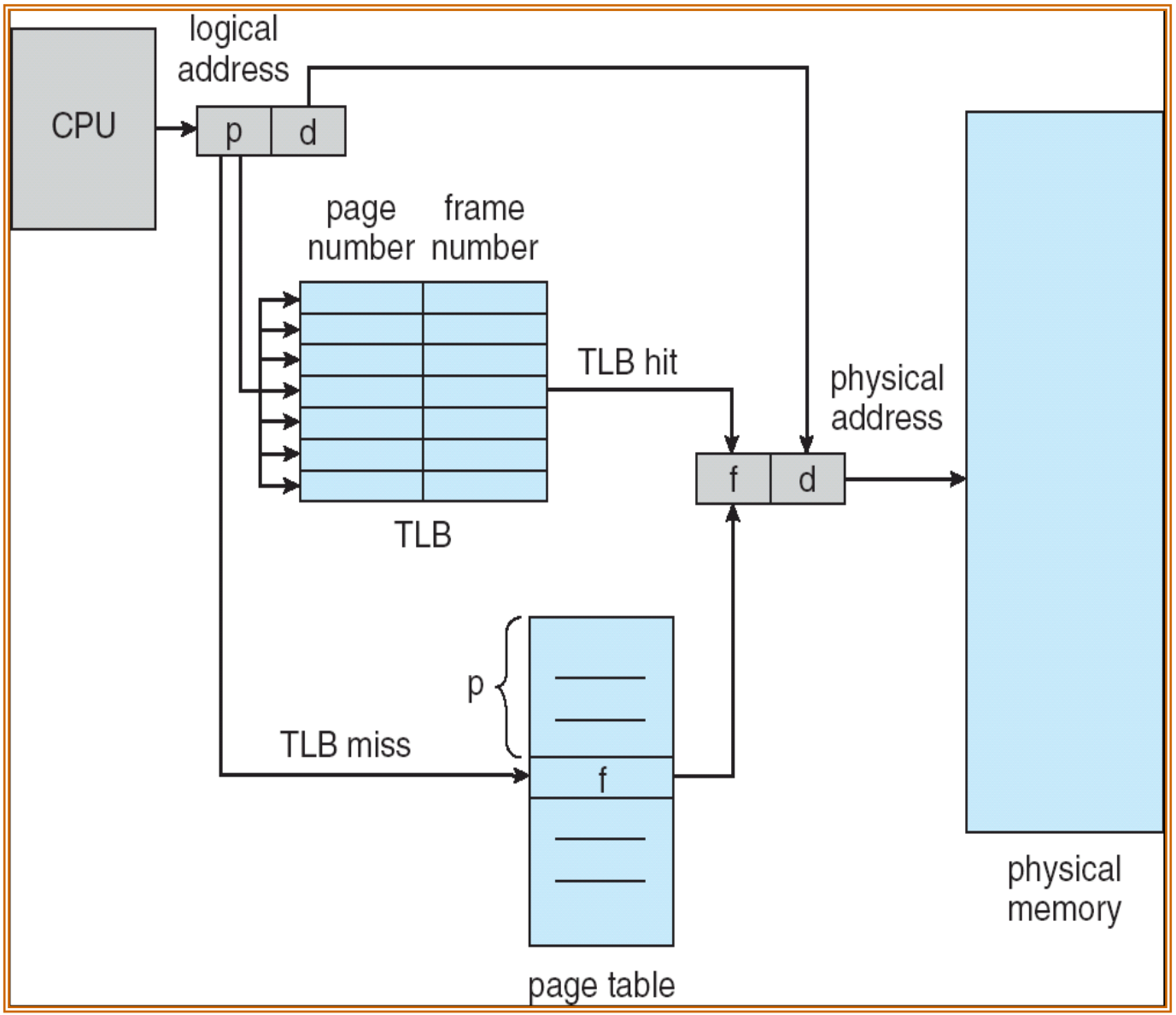
Free Frames


free-frame list
14
13
18
20
15
page 0
page 1
page 2
page 3
new process
13
14
15
16
17
18
19
20
21
(a)
free-frame list
15
page 0
page 1
page 2
page 3
new process
0 14
1 13
2 18
3 20
new-process page table
13 page 1
14 page 0
15
16
17
18 page 2
19
20 page 3
21
(b)

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* (PRLR) indicates size of the page table
- In this scheme every data/instruction access requires two memory accesses. One for the page table and one for the data/instruction.
- The two memory access problem can be solved by the use of a special fast-lookup hardware cache called **associative memory** or **translation look-aside buffers (TLBs)**

Paging Hardware With TLB

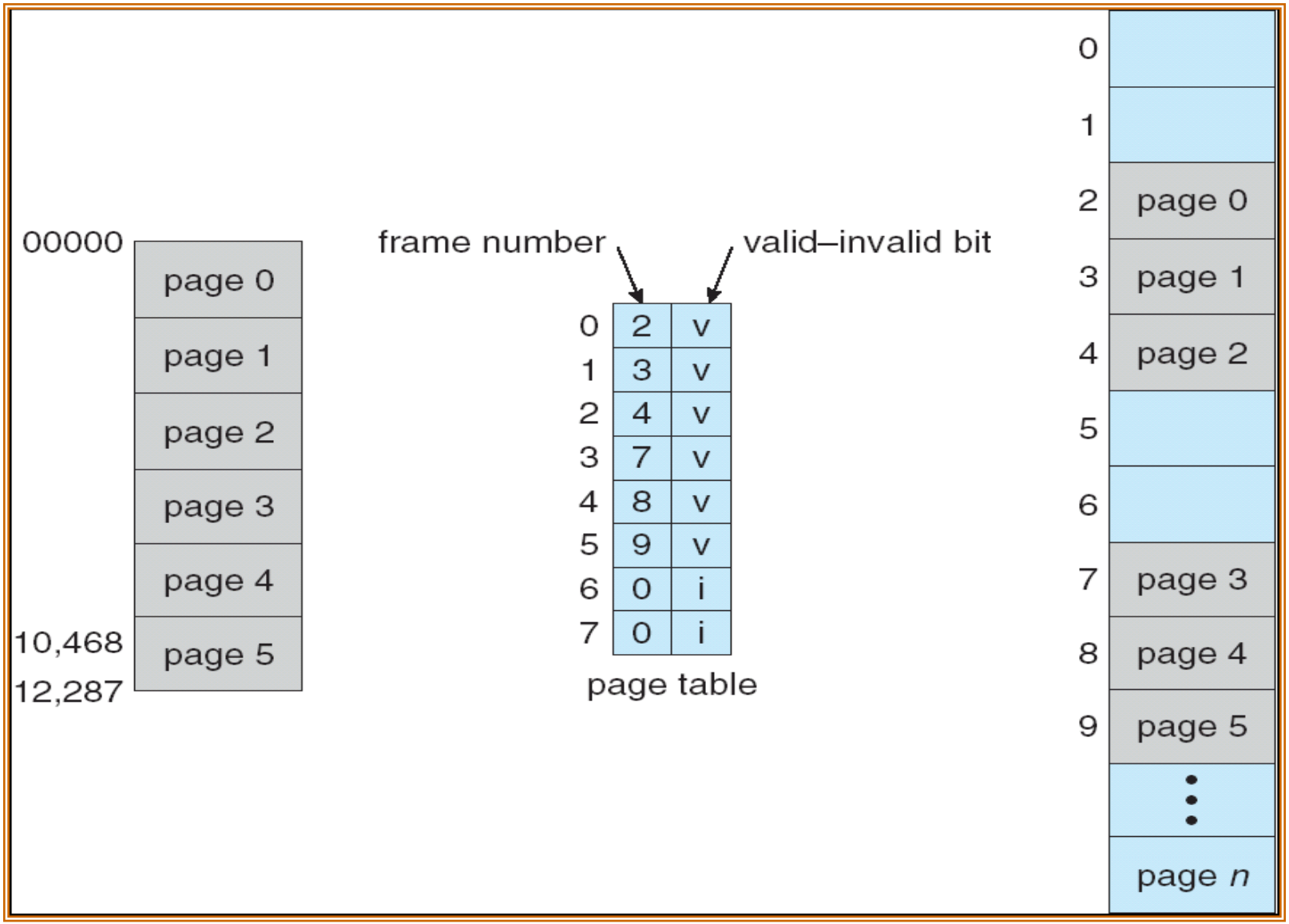


Memory Protection

- Memory protection implemented by associating protection bit with each frame

- **Valid-invalid** bit attached to each entry in the page table:
  - "valid" indicates that the associated page is in the process' logical address space, and is thus a legal page
  - "invalid" indicates that the page is not in the process' logical address space

Valid (v) or Invalid (i) Bit In A Page Table

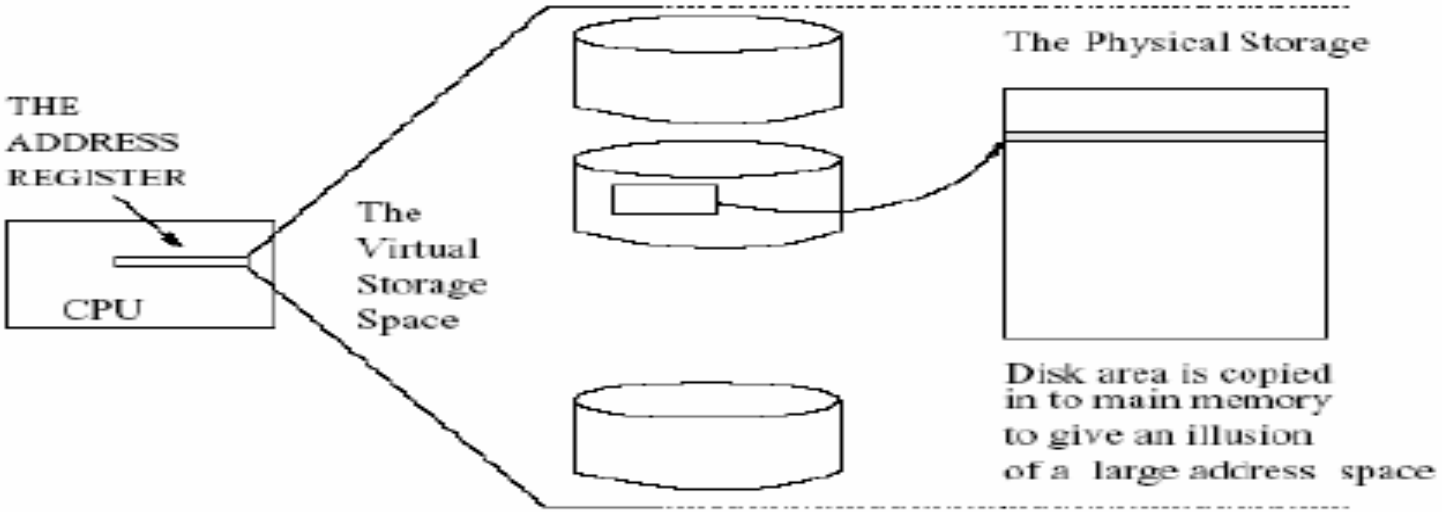


Concept of Virtual Storage

- The *directly addressable main memory is limited and is quite* small in comparison to the *logical addressable space.*
- The actual size of main memory is referred as the *physical memory. The logical addressable space is referred to as virtual memory.*
- The concept of virtual storage is to give an impression of a large addressable storage space without necessarily having a *large primary memory.*
- The basic idea is to offer a *seamless extension of primary* memory into the space within the secondary memory. The address register *generate addresses for a space much larger* than the primary memory.
- The notion of virtual memory is a bit of an illusion. The OS *supports and makes this illusion possible.*

VIRTUAL STORAGE

- The OS creates this illusion by *copying chunks of disk memory* into the *main memory as shown in figure. In other words, the* processor is fooled into believing that it is *accessing a large addressable space. Hence, the name virtual storage space. The* disk area may map to the virtual space requirements and even beyond.



VIRTUAL MEMORY : PAGING

- Once we have addressable segments in the *secondary memory-we need to bring it within the main memory for* physical access for process. Often mechanism of *paging* helps.

- Paging is like *reading a book. At any time we do not need* all pages-except the ones we are reading. The analogy suggest that pages we are reading are in the main memory and the rest can be in the secondary memory.

Virtual Memory : Paging

- The primary idea is to always keep focus on that area of memory from which instructions are executed. Once that area is identified – it is loaded into the primary memory into the fixed size pages.

- To enable such a loading, page sizes have to be defined and observed for both primary as well as secondary memory.

- Paging support *locality of reference for efficient access*

- For instance we have location of reference during execution of *while or for loop or a call to a procedure.*

Mapping the Pages

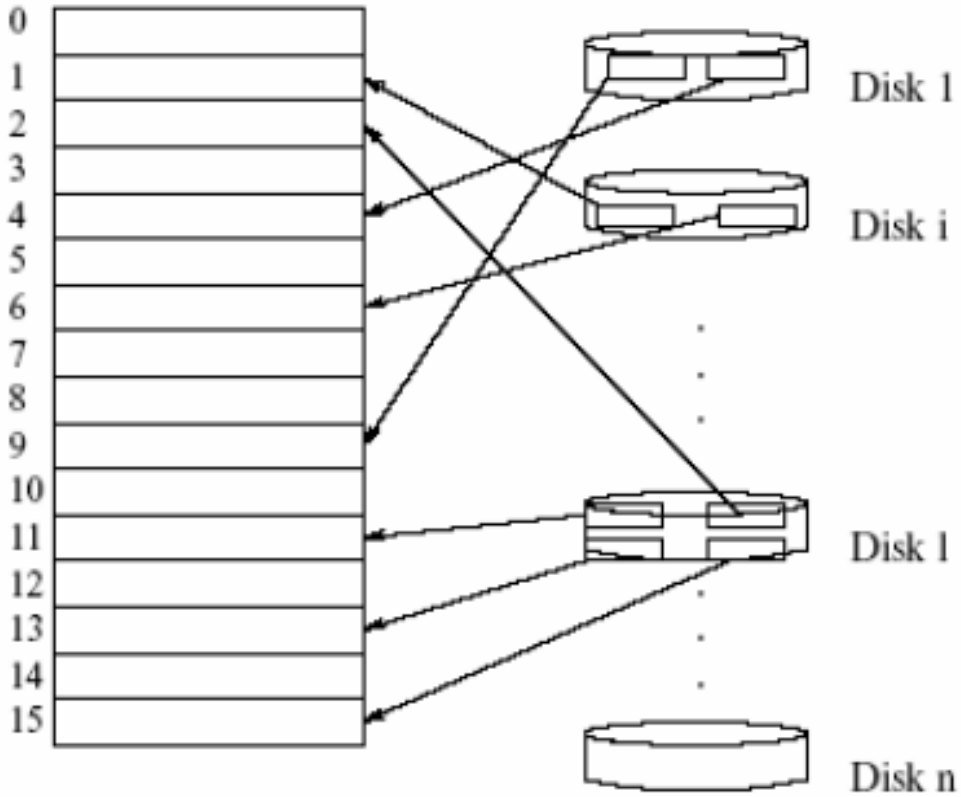
- Paging stipulates that main memory is partitioned into *frames of sufficiently small sizes*.
- Also, we require that the virtual space is divided into *pages* of the same size as the frames.
- This equality facilitates movement of a *page from anywhere* in the virtual space (on disks) to a *frame anywhere in the* physical memory.
- The capability to map *"any page" to "any frame" gives a lot* of flexibility of operation.

Mapping the Pages

- Division of main memory into frames is *like fixed partitioning*. So keeping the frame size small helps to keep the internal fragmentation small.

- Paging supports *multi-programming*. *In general there can be* many processes in main memory, each with a different number of pages. To that extent, paging is like *dynamic variable partitioning*.

Paging : Implementation



Process 1 may be in Disk 1 occupying 20 pages. Pages 2 and 3 at virtual address 20 and 21 are mapped to main memory location 9 and 4.

Process 6 may be in Disk i Occupying 30 pages. Pages 17 and 18 at virtual address 39 and 40 are mapped to main memory location 1 and 6.

Process 29 may be in Disk l occupying 4 pages, 77 to 80 are mapped to main memory.

The OS maintains a list of free pages in main memory for allocating a new free page.

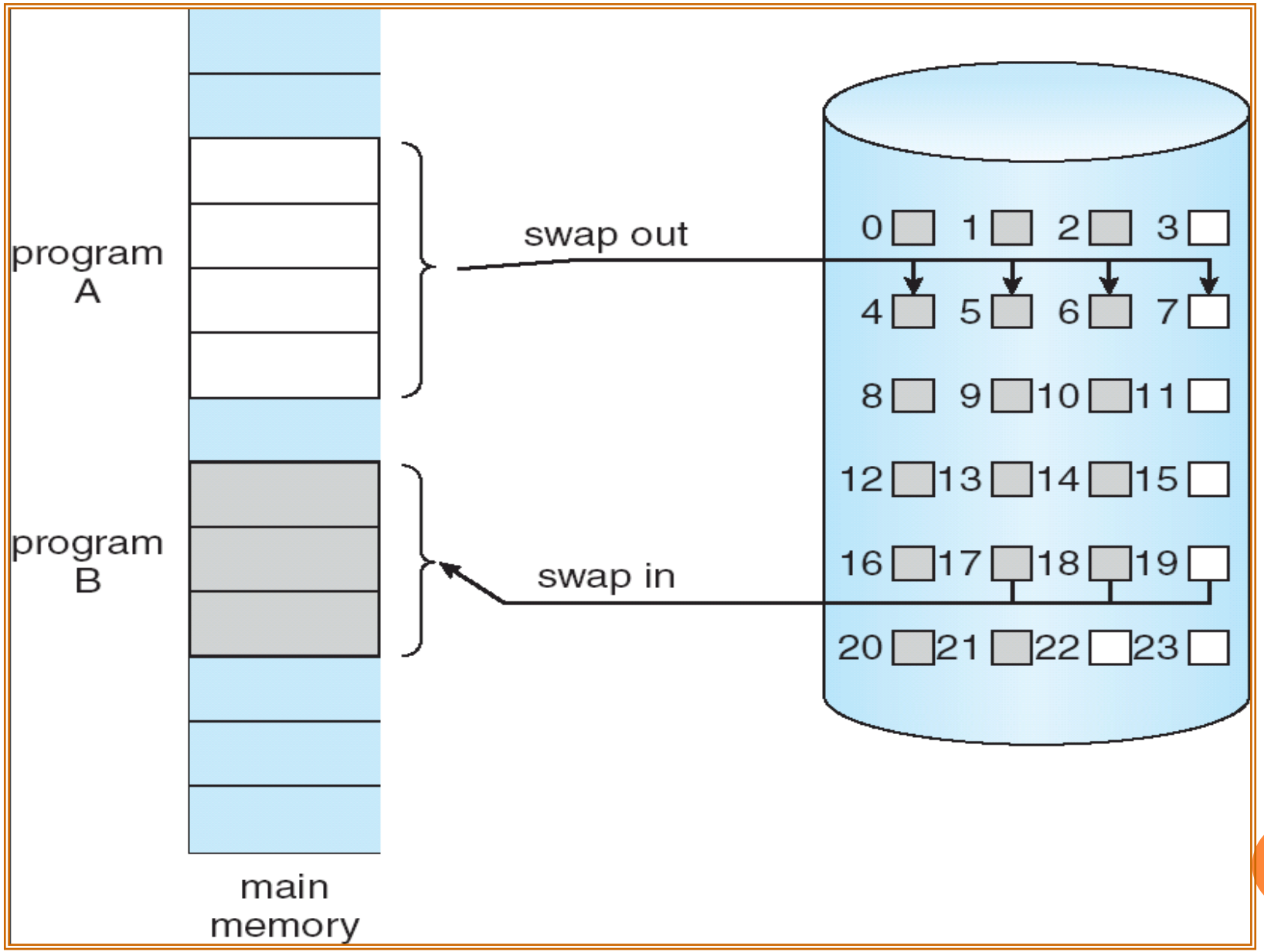
	PAGE TABLES FOR PROCESSES P1, .. P6, .. P29 ...									
LOGICAL	20	21		39	40		77	78	79	80
PHYSICAL	9	4		1	6		11	2	13	15
	← P1 →			← P6 →			← P29 →			

Demand Paging

- Bring a page into memory only when it is needed
  - Less I/O needed
  - Less memory needed
  - Faster response
  - More users

- Page is needed ⇒ reference to it
  - invalid reference ⇒ abort
  - not-in-memory ⇒ bring to memory

Transfer of a Paged Memory to Contiguous Disk Space



Paging: Replacement

- When a page is no longer needed it can be replaced.
- Consider an example shown in figure process P29 has all its pages present in main memory.
- Process P6 does not have all its pages in main memory. If a page is present we record 1 against its entry. The OS also records if a page has been referenced to read or to write. In both these cases a reference is recorded.

Page tables for processes P1, .. P6, .. P29 ...

	P1		P6				P29							
Logical	20	21	. .	39	40	.	.	77	78	79	80	.		
Physical	9	4	·	1	6		·	11	2	13	15			
Present	0	1	1	0	0	0	1	1	0	1	1	1	1	1	1
Referenced	1	1		0	1			1	0	1	0			
Modified	1	0		0	0			0	0	1	0			
Protection	rw–	rw–						r—		r—				

Paging: Replacement

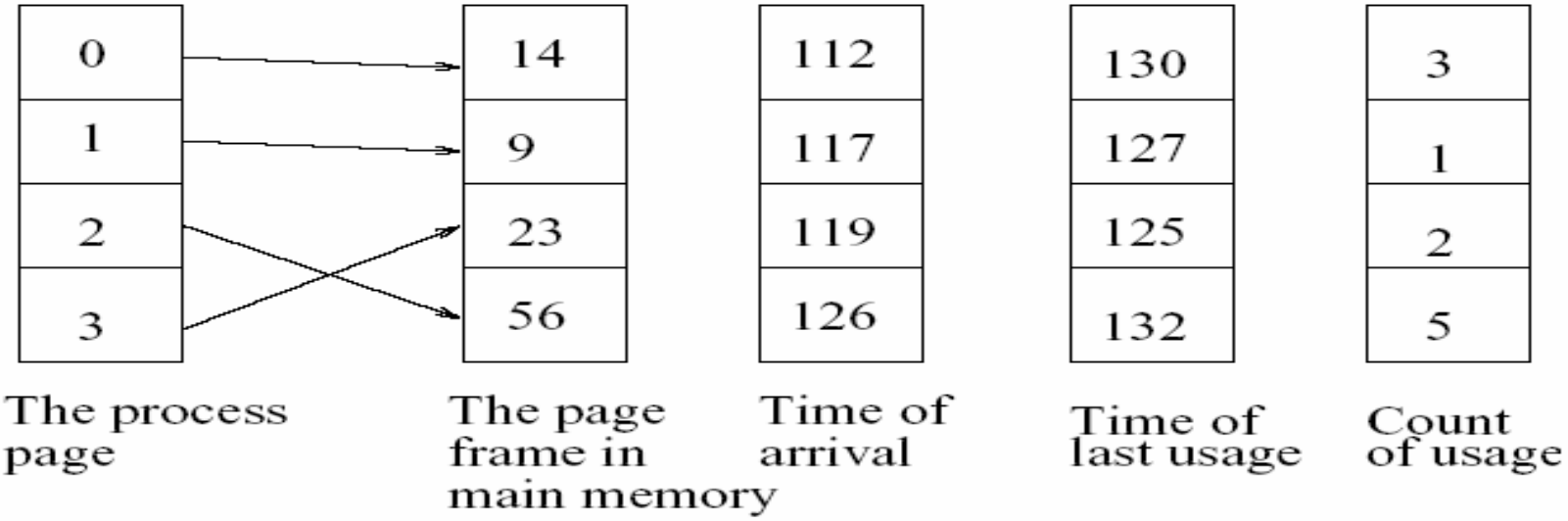
- If a page frame is written into, then *a modified bit is set. In our* example, frames 4, 9, 40, 77, 79 have been referenced and page frames 9 and 13 have been modified.

- Sometimes OS may also have some information about protection using *rwe information. If a reference is made to a* certain virtual address and its corresponding page is not present in main memory, then we say a *page fault has* occurred.

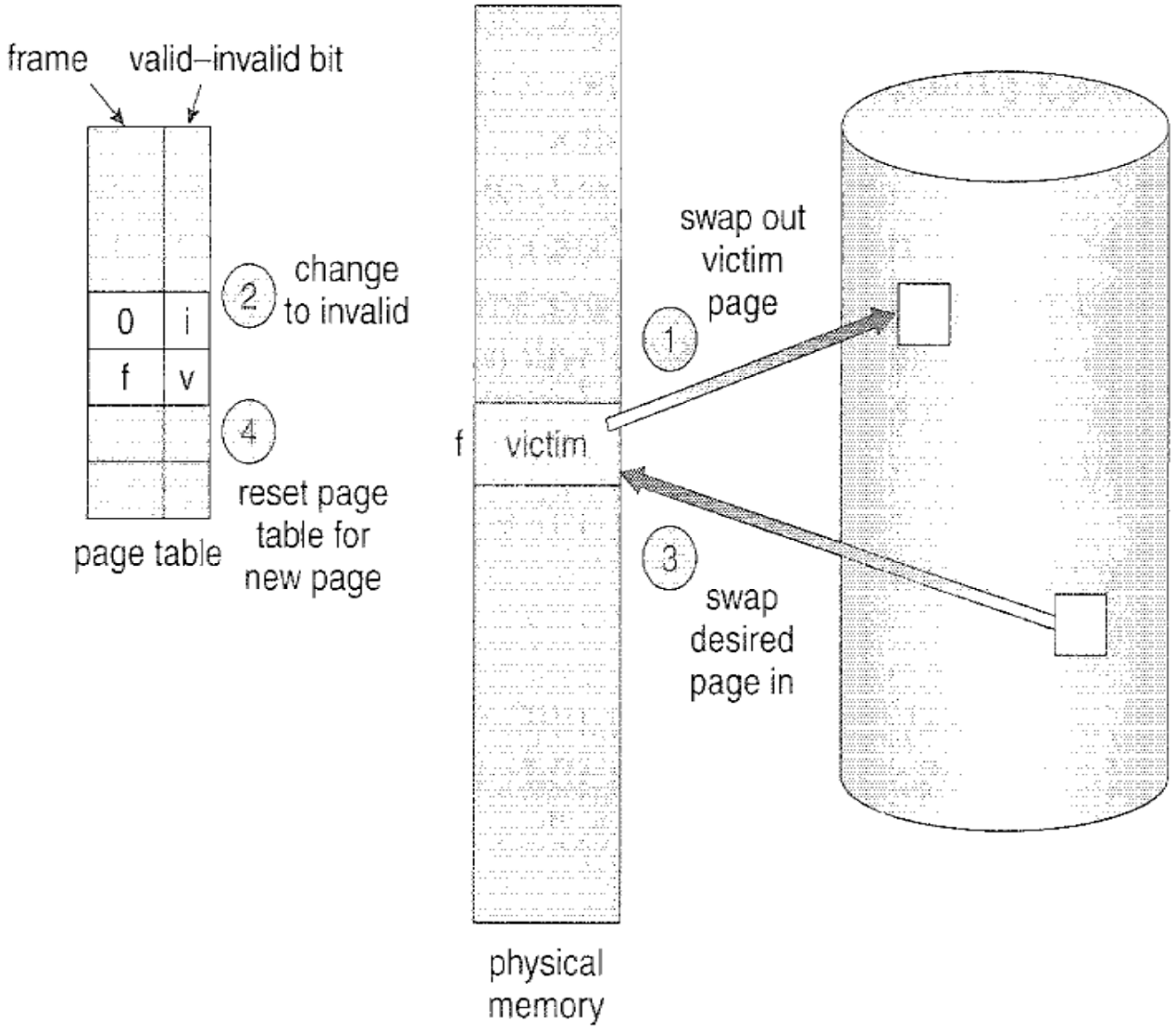
- Typically, a page fault is followed by moving in a page. However, this may require that we move a page out to create a space for it. Usually this is done by using an appropriate *page replacement policy to ensure that the throughput of a system* does not suffer. We shall next see how a page replacement policy can affect performance of a system.

Page Replacement Policies

- Towards understanding page replacement policies we shall consider a simple example of a process *P which gets an* allocation of four pages to execute.
- Further, we assume that the OS collects some information (depicted in figure) about the use of these pages as this process progresses in execution.



Page replacement



Page Replacement Policies

- Let us examine the information depicted in figure in some detail to determine how this may help in evolving a page replacement policy.

- Note that we have the following information available about *P*.

  - *The time of arrival of each page: We assume that the process* began at some time with value of time unit 100. During its course of progression we now have pages that have been loaded at times 112, 117 119, and 120.

  - *The time of last usage: This indicates when was a certain* page last used. This entirely depends upon which part of the process *P is being executed at any time.*

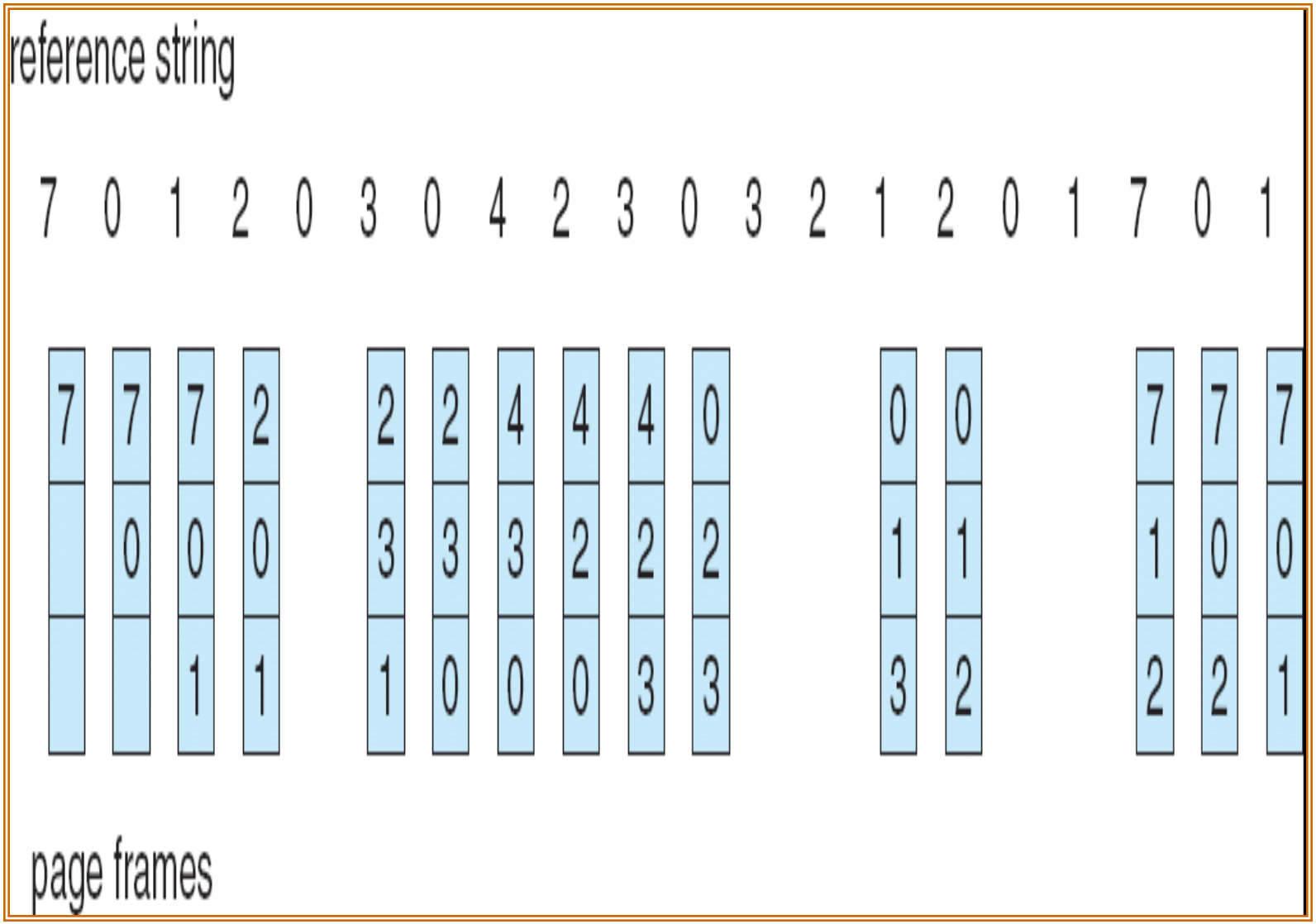
  - *The frequency of use: We have also maintained the* frequency of use over some fixed interval of time *T in the* immediate past. This clearly depends upon the nature of control flow in process *P*.

Page Replacement Policies

- Based on the previous pieces of information if we now assume that at time unit 135 the process *P experiences a* page-fault, what should be done. Based on the choice of the policy and the data collected for *P, we shall be able to* decide which page to swap out to bring in a new page.

- *FIFO policy: This policy simply removes pages in the* order they arrived in the main memory. Using this policy we simply remove a page based on the time of its arrival in the memory. Clearly, use of this policy would suggest that we swap page located at 14 as it arrived in the memory earliest.

FIFO Page Replacement

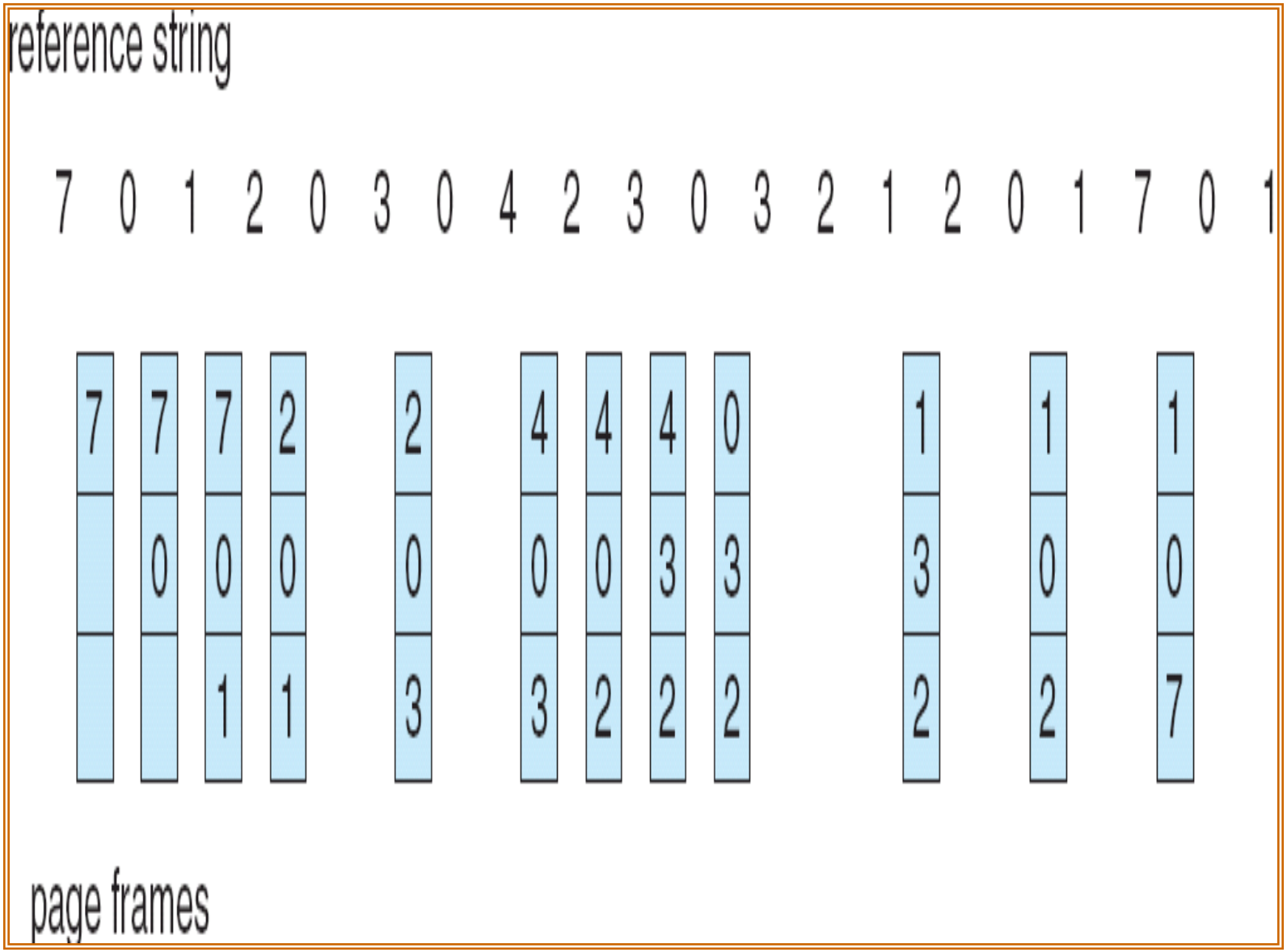


Page Replacement Policies

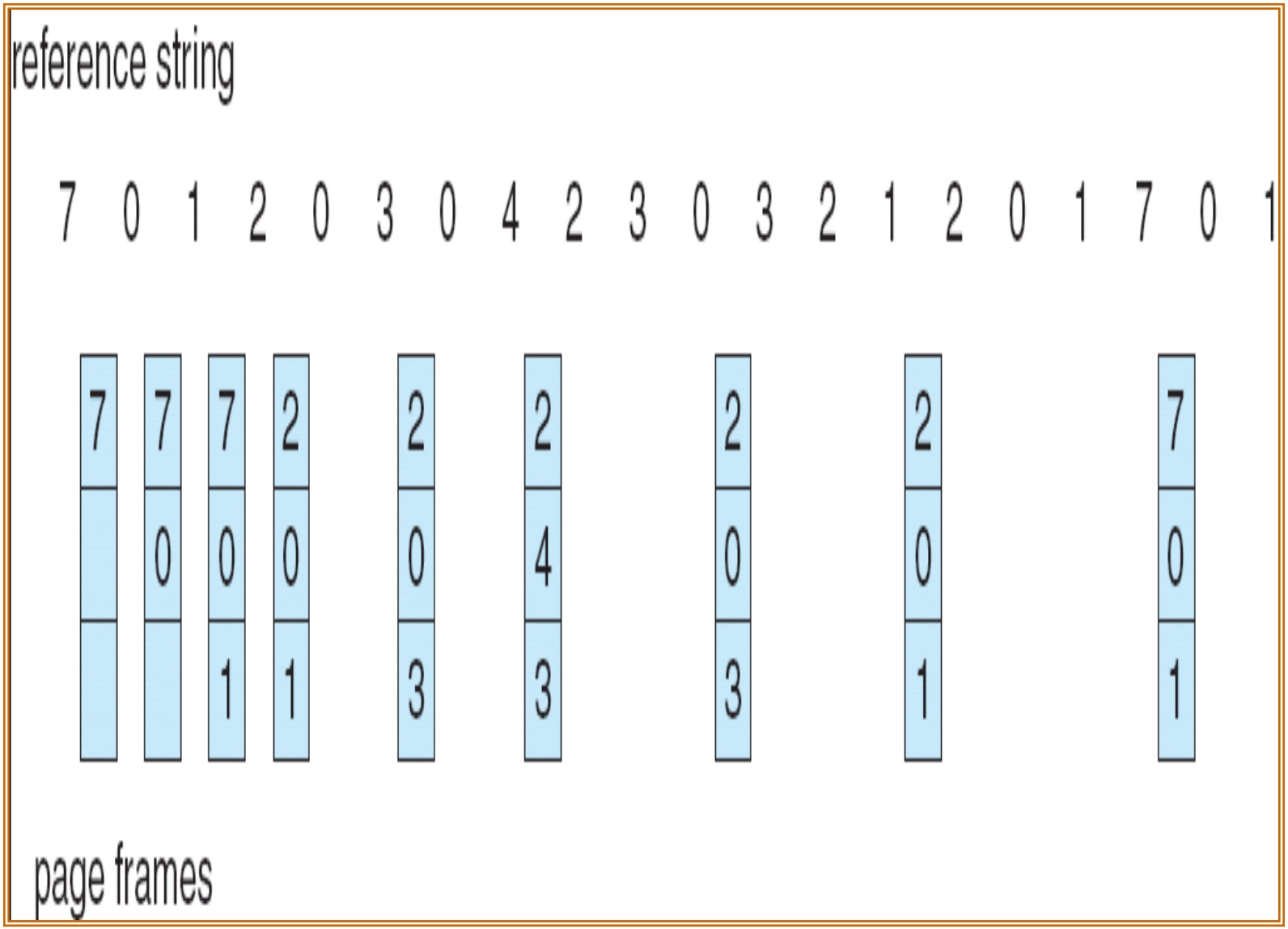
- *LRU policy: LRU expands to least recently used. This policy* suggests that we remove a page whose last usage is farthest from current time. Note that the current time is 135 and the least recently used page is the page located at 23. It was used last at time unit 125 and every other page is more recently used. So page 23 is the least recently used page and so it should be swapped if LRU replacement policy is employed.

- *NFU policy: NFU expands to not frequently used. This policy* suggests to use the criterion of the count of usage of page over the interval *T. Note that process P has not made use of page* located at 9. Other pages have a count of usage like 2, 3 or even 5 times. So the basic argument is that these pages may still be needed as compared to the page at 9. So page 9 should be swapped.

LRU Page Replacement



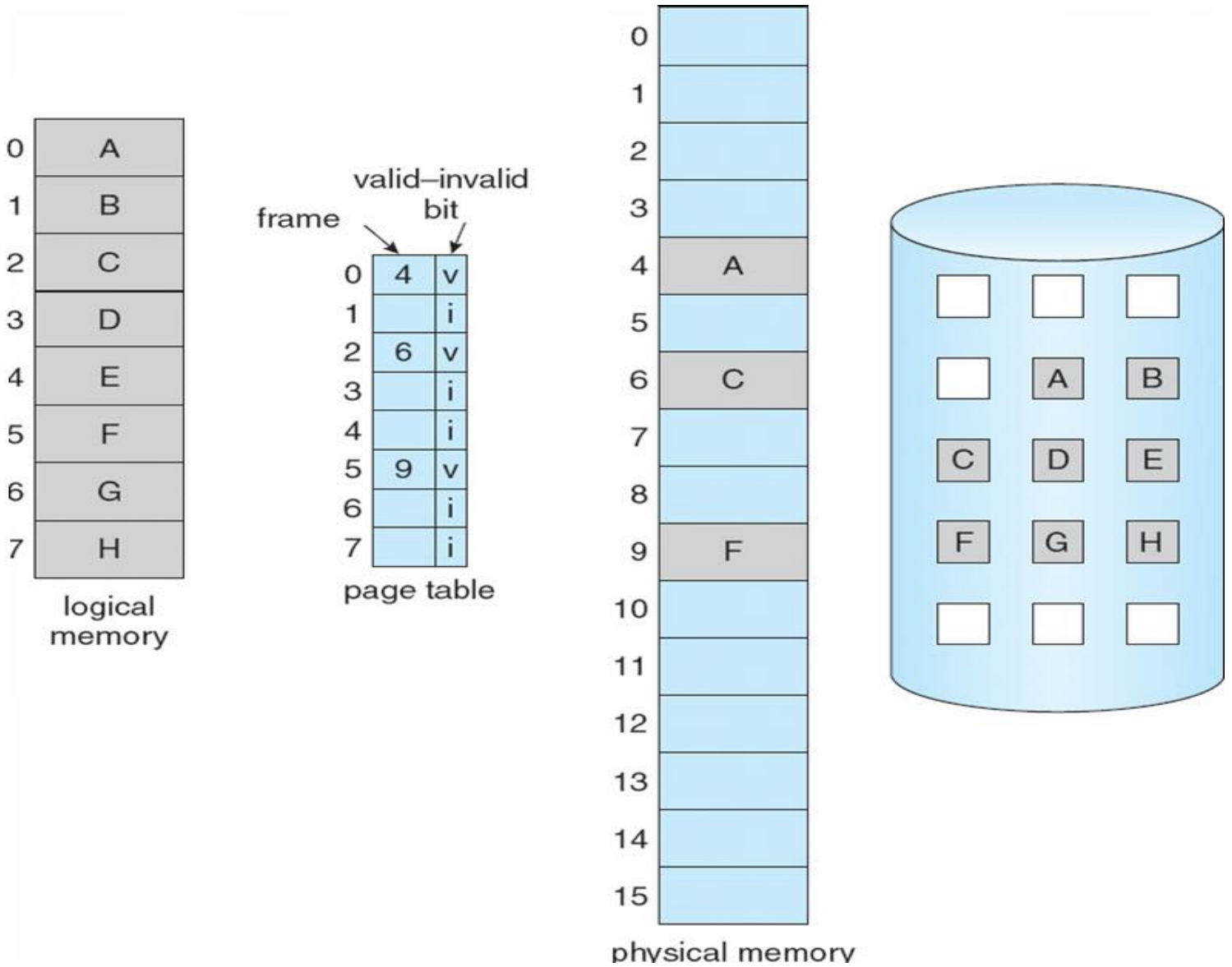
Optimal (NFU) Page Replacement



Page Hit and Page Miss

- When we find that a page frame reference is in the main memory then we have a *page hit and when page fault occurs we say we* have a *page miss*.

Page Table When Some Pages Are Not in Main Memory



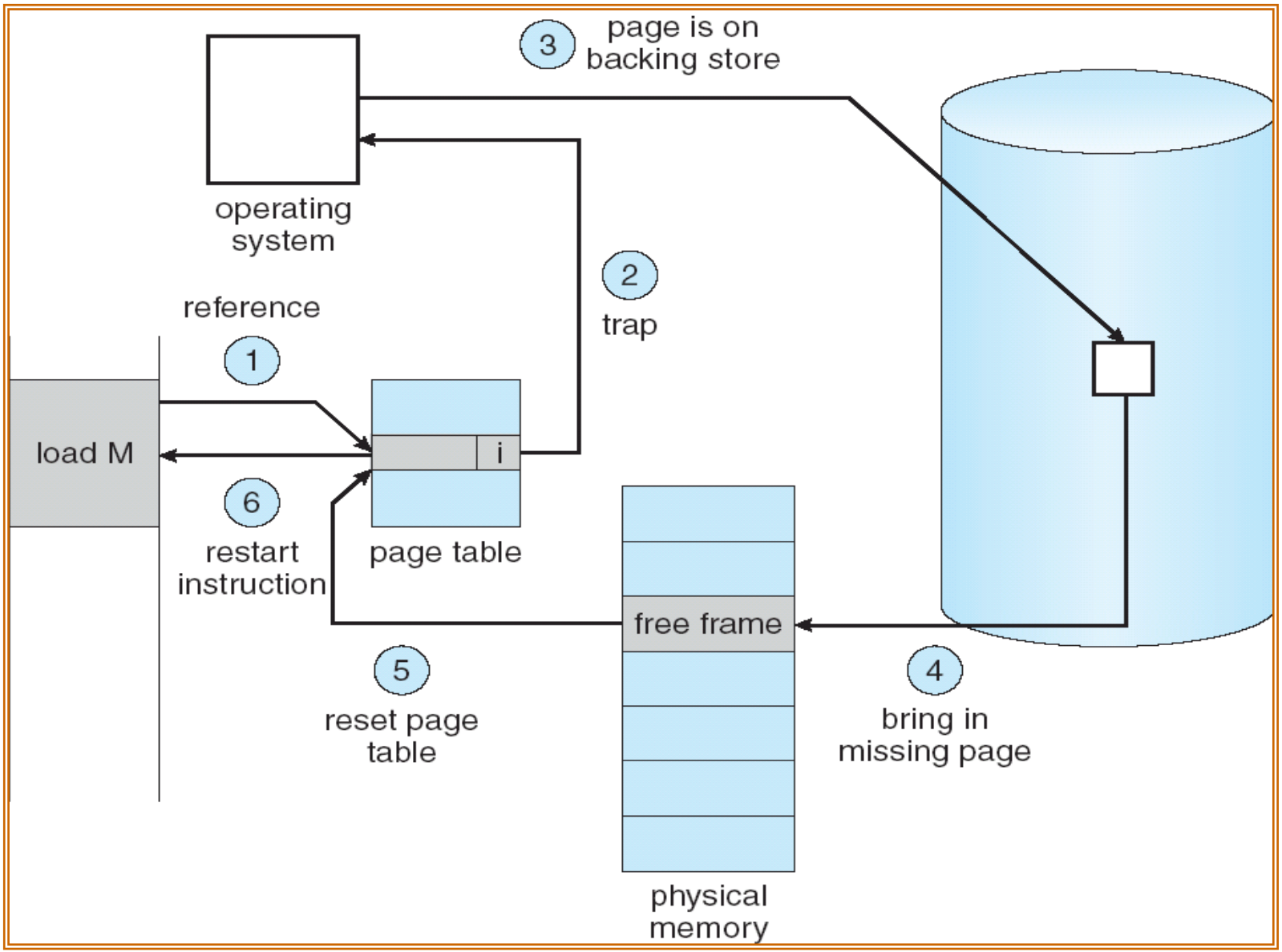
Page Fault

- If there is a reference to a page, first reference to that page will trap to operating system:

  page fault

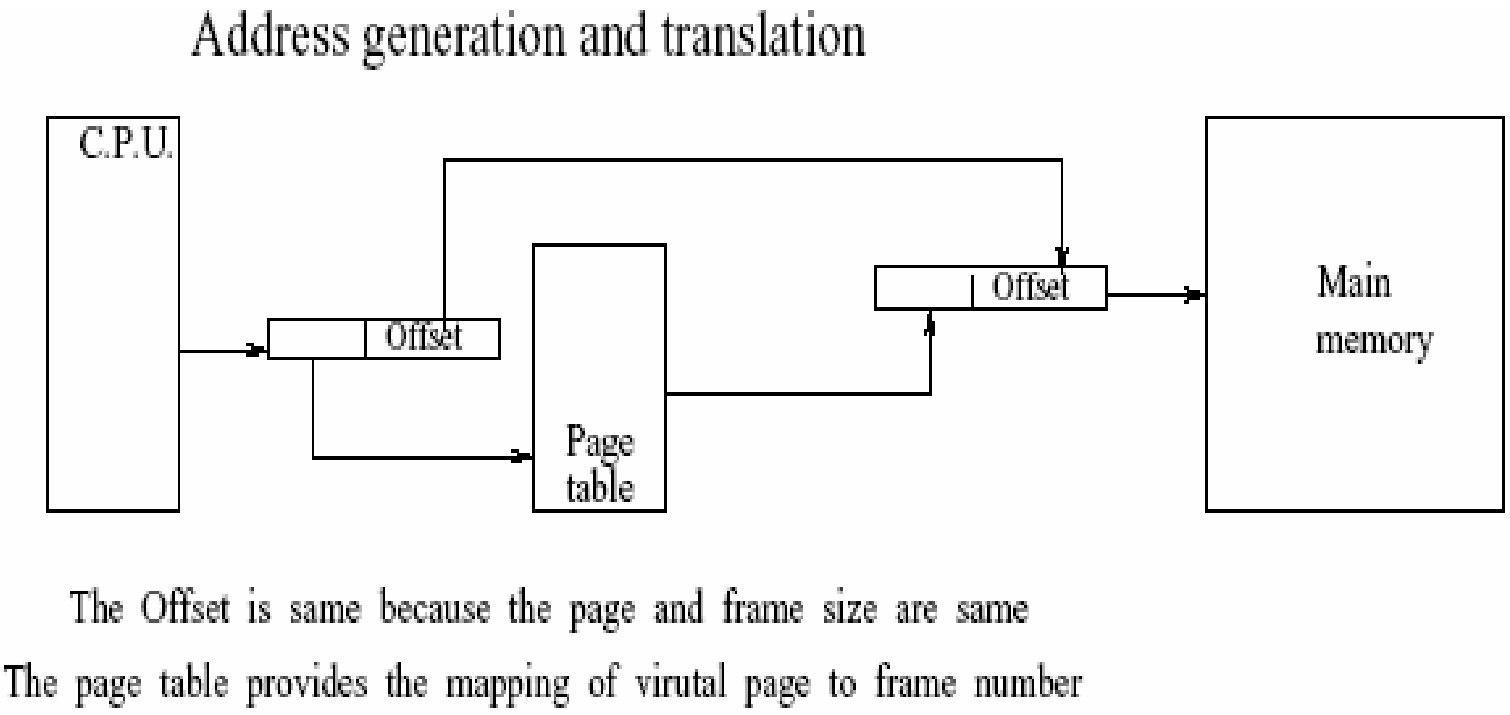
1. Operating system looks at another table to decide:
   - Invalid reference ⇒ abort
   - Just not in memory
2. Get empty frame
3. Swap page into frame
4. Reset tables
5. Set validation bit = **v**
6. Restart the instruction that caused the page fault

Steps in handling page fault



Paging: HW Support

- Recall the point we need HW within CPU to support paging. The CPU generates a logical address which must get translated to a physical address. In Figure we indicate the basic address generation and translation.



Paging: HW Support

- The *sequence of steps in generation of address is as* follows:

  - The *process generates a logical address. This* address is *interpreted in two parts.*

  - The *first part of the logical address identifies the virtual page.*

  - The *second part of the logical address gives the offset within the page.*

PAGING: HW SUPPORT

- The *first part is used as an input to the page table to* find out the following:

  - Is the page in the main memory;
  - What is the page frame number for this virtual page;

- The *page frame number is the first part of the* physical memory address.

- The *offset is the second part of the correct physical* memory location.

Paging: HW Support

- A *page fault is generated if the page is not in the* physical memory – *trap*.

- The *trap suspends the regular sequence of operations and brings the required page from disc to* main memory.

SEGMENTATION

- Segmentation also *supports virtual memory concept.*

- One view of segmentation could be that each part like its *code segment, its stack requirements (of data,* nested procedure calls), its different *object modules etc.* has a contiguous space. This view is *uni- dimensional.*

Segmentation

- Memory-management scheme that supports user view of memory
- A program is a collection of segments. A segment is a logical unit such as:

-main program,

-procedure,

-function,

-method,

-object,

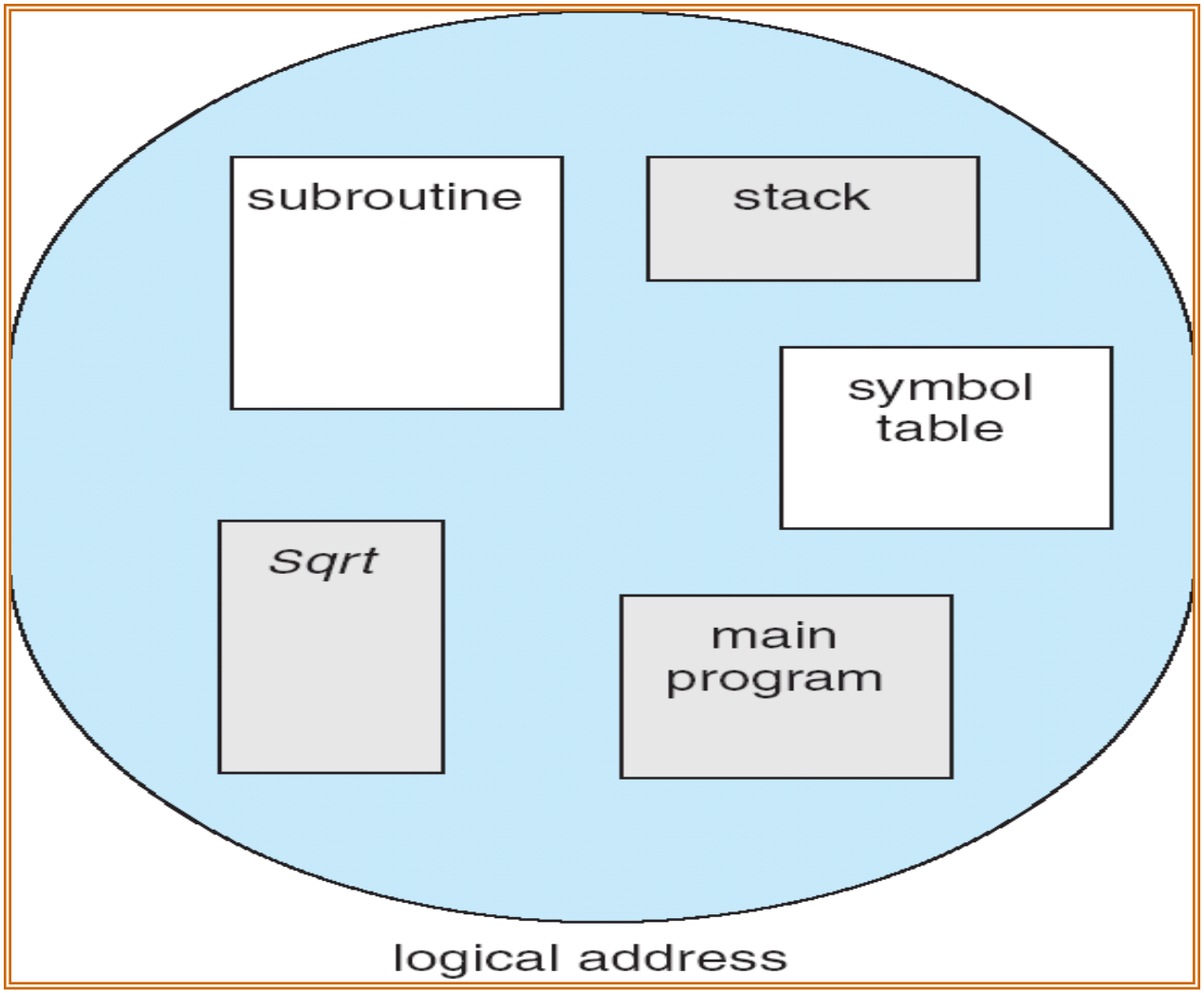
-local variables, global variables,

-common block,

-stack,

-symbol table, arrays

User View of program

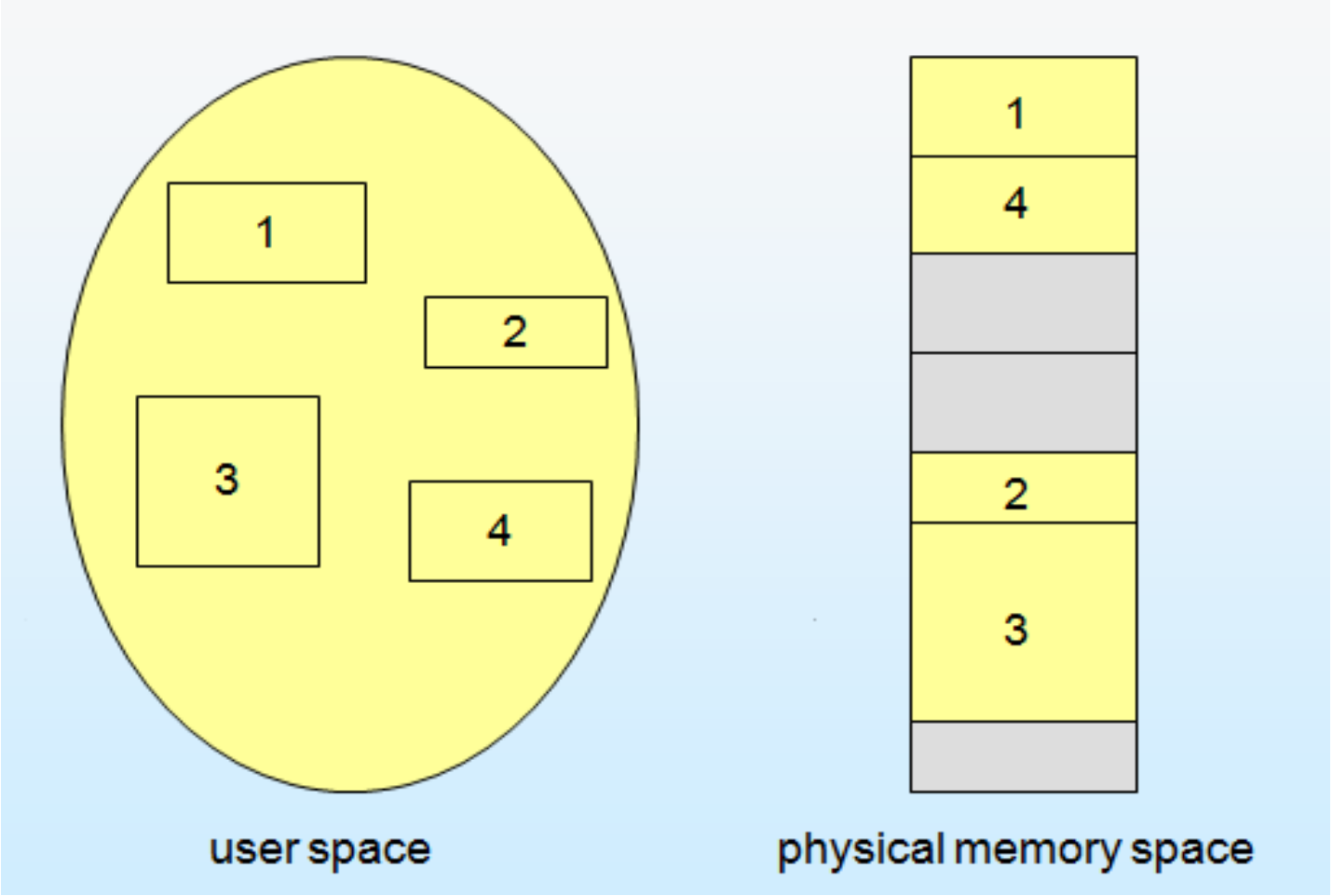


SEGMENTATION

- Each segment has *requirements that vary over time – stacks grow or shrink, memory requirements of* object and data segments may change during the process's lifetime.

  We, therefore, have a *two dimensional view of a* process's memory requirement - each process segment *can acquire a variable amount of space over time.*

Logical View of segmentation



Segmentation architecture

- Logical address consists of a two tuple:

  <segment-number, offset>,

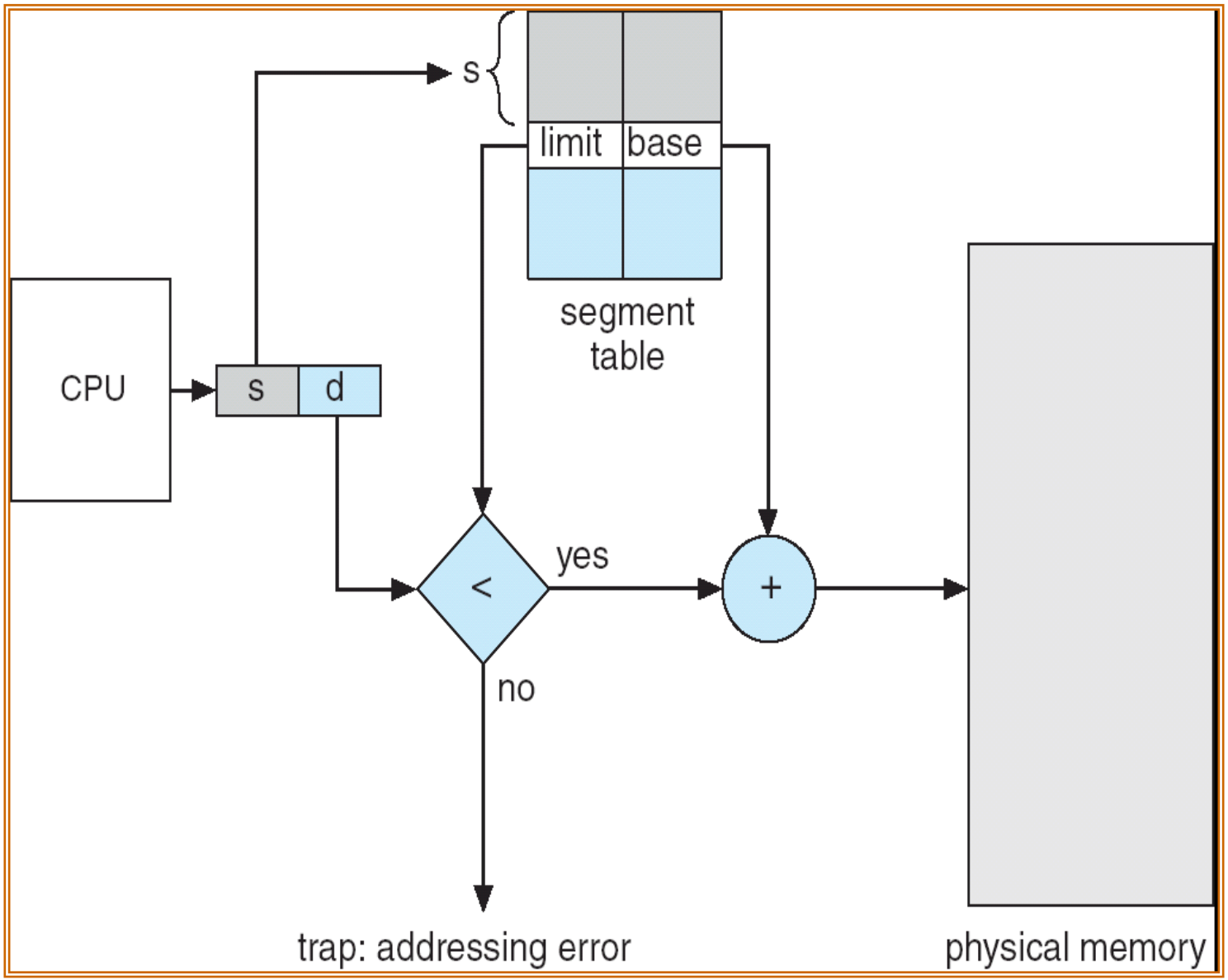
- **Segment table** – maps two-dimensional physical addresses; each table entry has:
  - base – contains the starting physical address where the segments reside in memory
  - *limit* – specifies the length of the segment
- *Segment-table base register (STBR)* points to the segment table's location in memory
- *Segment-table length register (STLR)* indicates number of segments used by a program;

  segment number *s* is legal if *s* < STLR

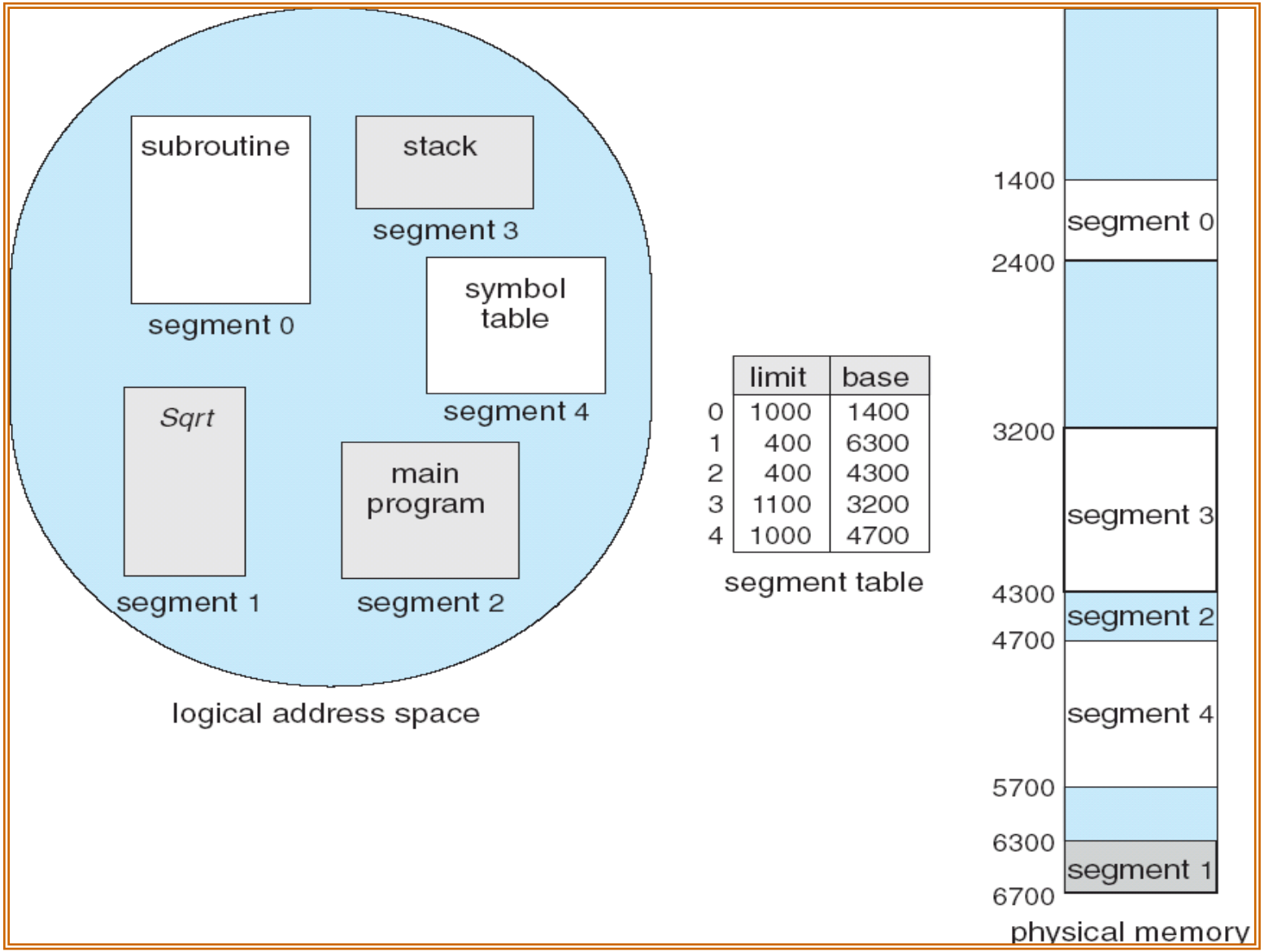
Segmentation architecture

- Protection. With each entry in segment table associate:
  - validation bit = 0 ⇒ illegal segment
  - read/write/execute privileges
- Protection bits associated with segments; code sharing occurs at segment level
- Since segments vary in length, memory allocation is a dynamic storage-allocation problem

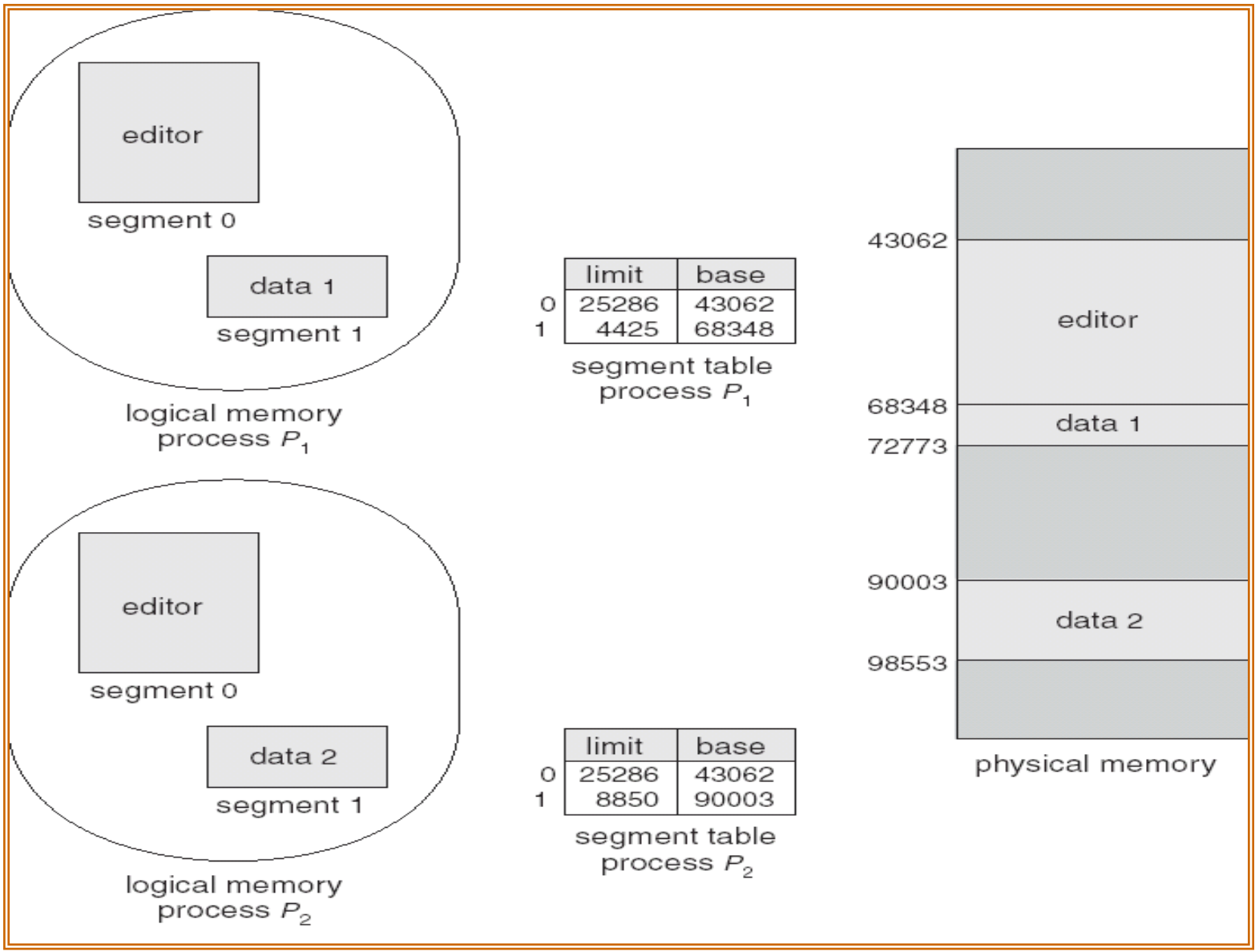
Address translation architecture



Segmentation example



Sharing of segments



Segmentation

Segmentation : paging with variable page size

Advantages:

- memory protection added to segment table like paging
- sharing of memory similar to paging (but per area rather than per page)

Drawbacks:

- allocation algorithms as for memory partitions
- external fragmentation, back to compaction problem…

Solution: combine segmentation and paging

SEGMENTATION

- Segmentation is similar to paging, except that we have a segment table look ups to identify address values.

- *Comparing segmentation and paging :*

  - Paging offers the *simplest mechanism to effect* virtual addressing.

  - Paging *suffers from internal fragmentation,* segmentation *from external fragmentation.*

SEGMENTATION

- Segmentation affords *separate compilation of each* segment with a view to link up later.
- A user may develop a code segment and *share it* amongst many applications.
- In paging, a process address space is linear and hence, *unidimensional*. For segmentation each procedure and data segment has its own *virtual space mapping*. *Therefore this offers a greater degree of protection*.

SEGMENTATION

- In case a program's address space *fluctuates* considerably, paging may result in *frequent page faults. Segmentation offers no such problems.*

- Paging partitions a program and data space *uniformly* and hence *simpler to manage; difficult to distinguish* data and program space. In segmentation, space required is *partitioned according to logical division of* program segments.

Segmentation and Paging

- In practice, there are segments for the code(s), data and stack.
- Each segment carries the *rwe information as well*.
- Usually, stack and data have *read and write permissions* only; code has *read and execute permissions only*.

Segmentation & Paging

- A clever scheme with advantages of both would be segmentation with paging. In such a scheme each segment would have a descriptor with its pages identified. Such a scheme is shown in figure.