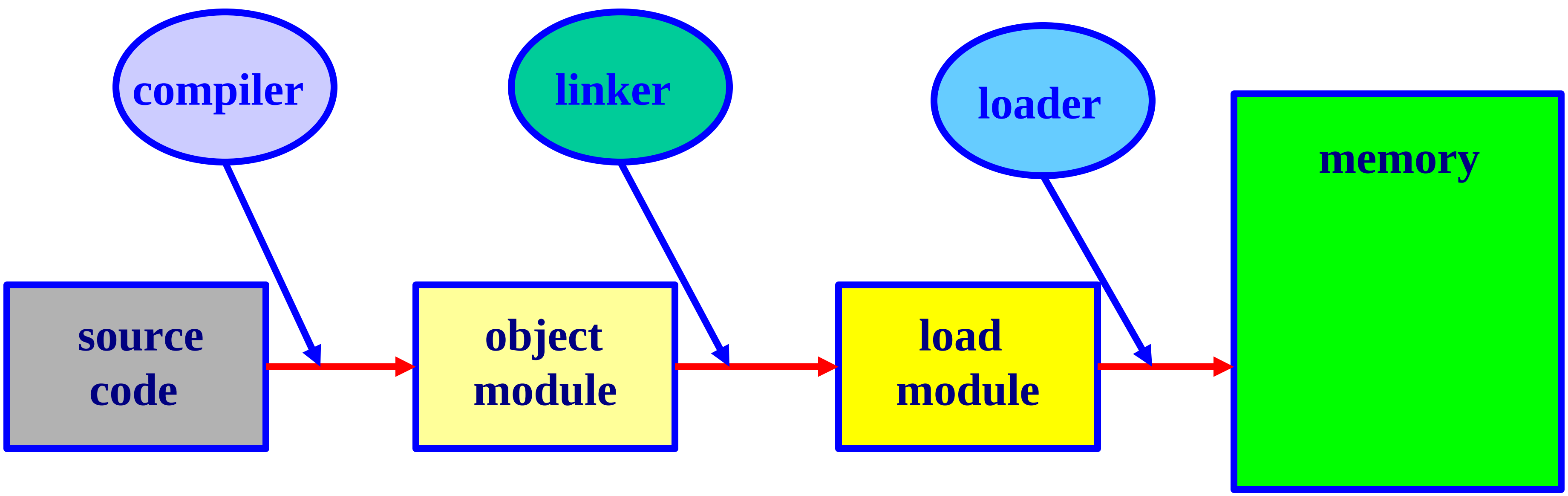
Part III
Storage Management
Chapter 8: Memory Management

Address Generation

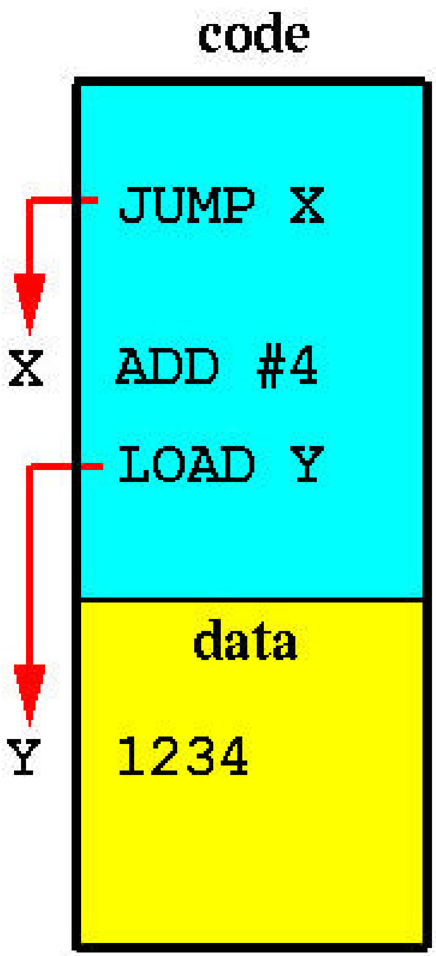
- Address generation has three stages:
  - **Compile**: compiler
  - **Link**: linker or linkage editor
  - **Load**: loader

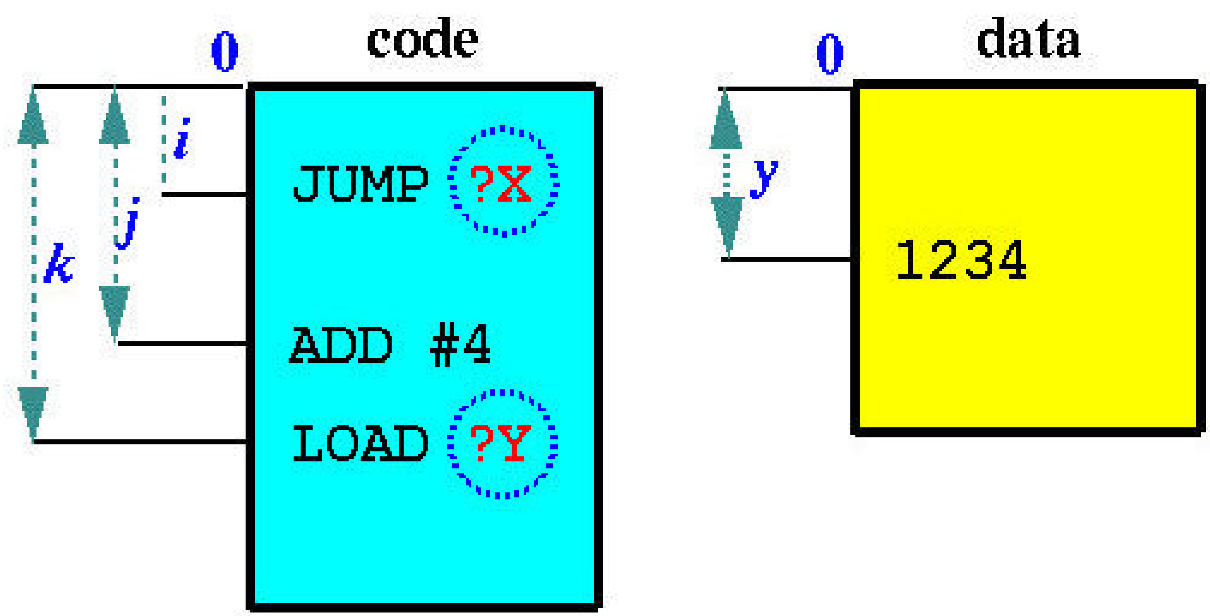


Three Address Binding Schemes

- **Compile Time: If the complier knows the location a program will reside, the compiler generates absolute code. Example: compile-go systems and MS-DOS `.COM`-format programs.**
- **Load Time: A compiler may not know the absolute address. So, the compiler generates *relocatable* code. Address binding is delayed until load time.**
- **Execution Time: If the process may be moved in memory during its execution, then address binding must be delayed until run time. This is the commonly used scheme.**

Address Generation: Compile Time

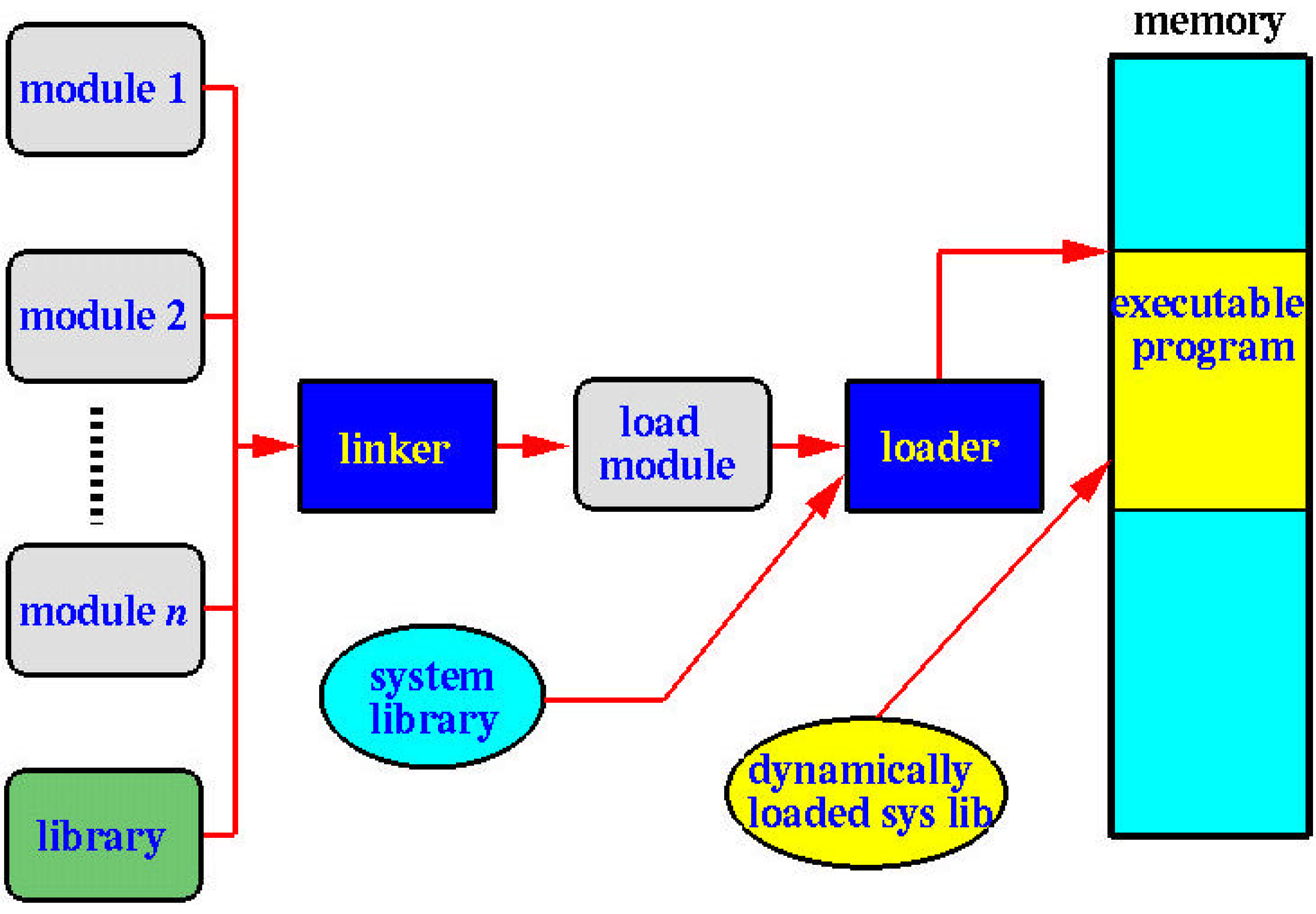




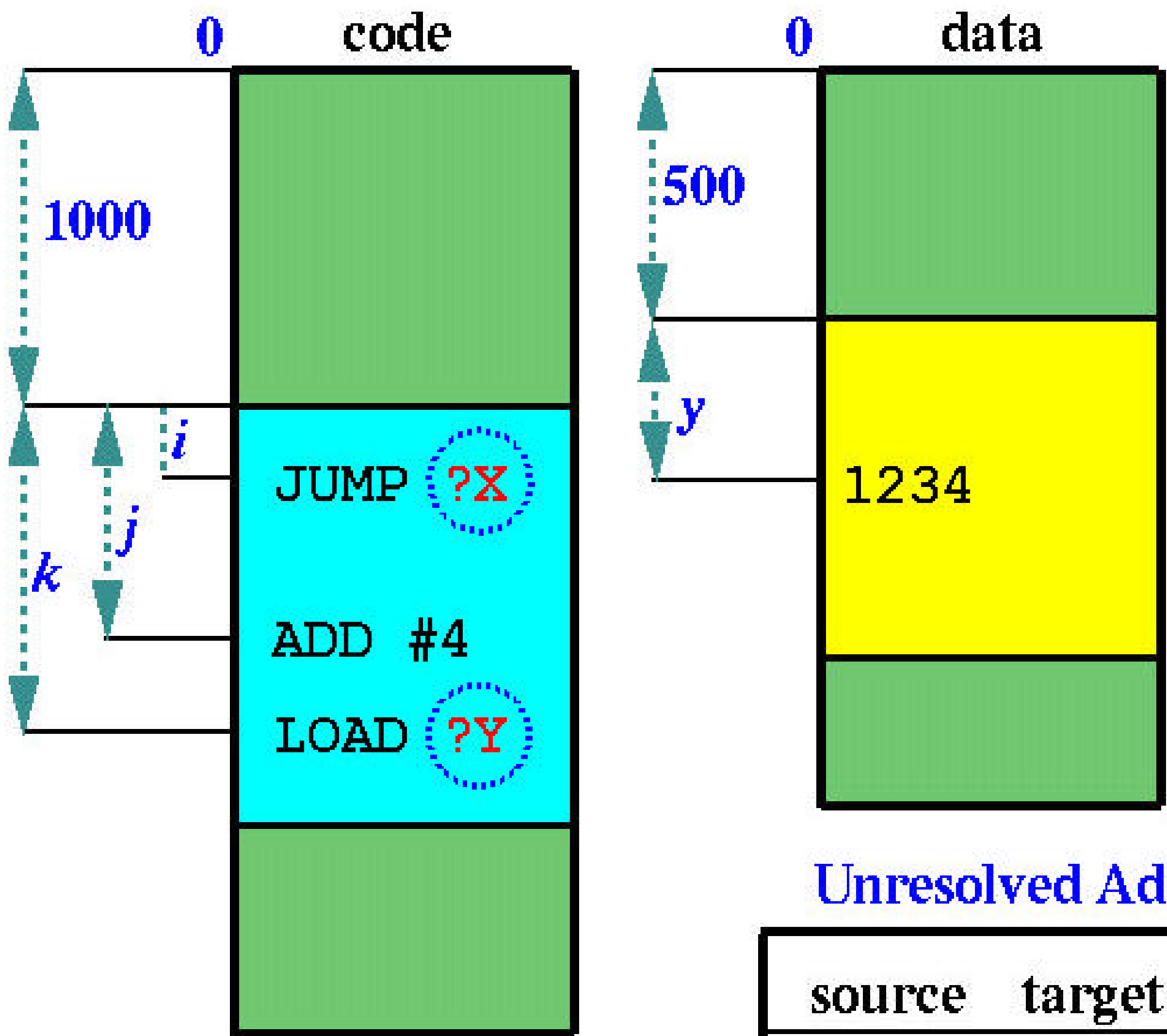
Unresolved Address Table

source	target	in which seg?
i	*j*	code
k	*y*	data

Linking and Loading

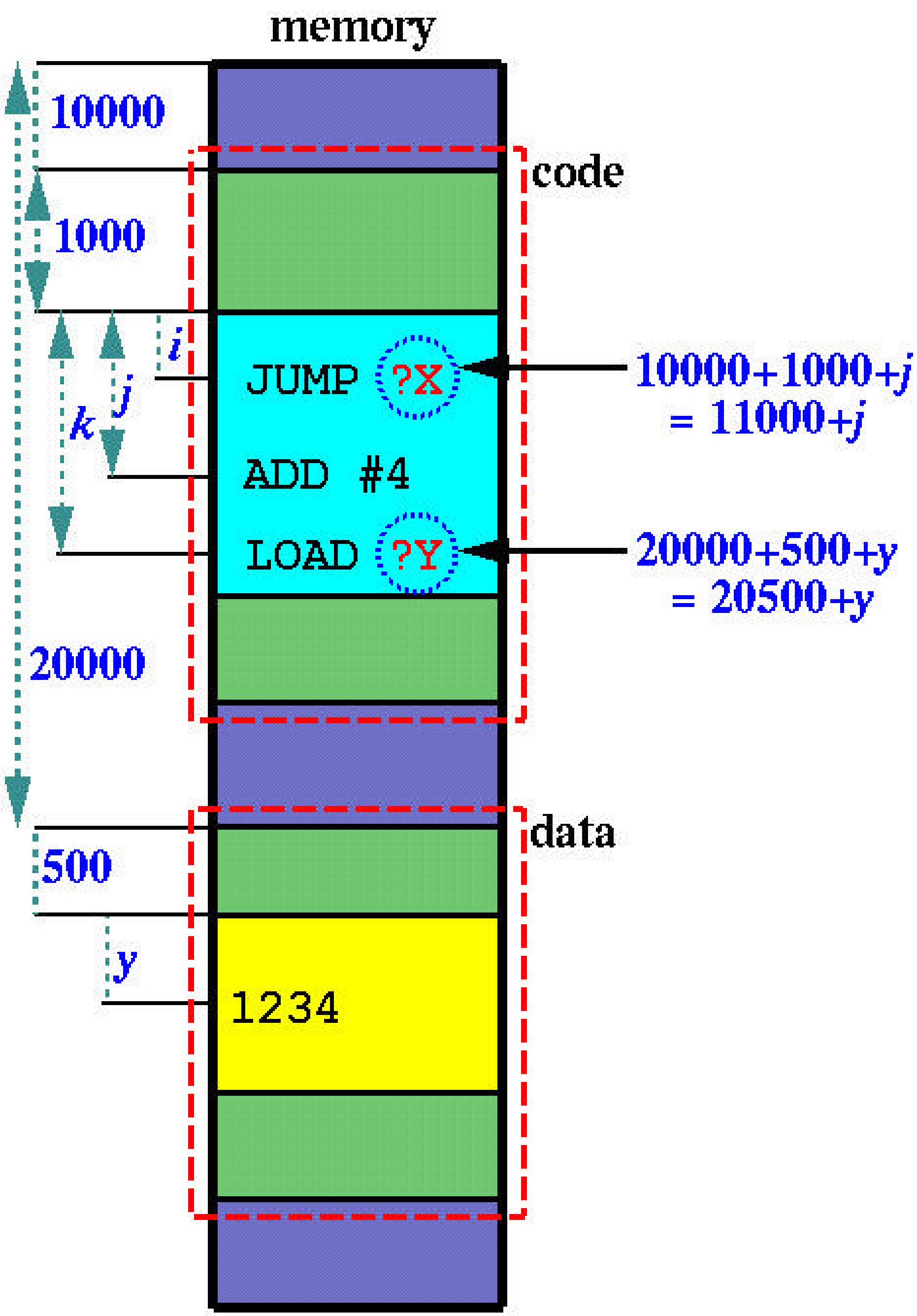


Address Generation: Static Linking



Unresolved Address Table

source	target	which seg?
i+1000	j+1000	code
k+1000	y+500	data



Loaded into Memory

- Code and data are loaded into memory at addresses 10000 and 20000, respectively.
- Every unresolved address must be adjusted.

Logical, Virtual, Physical Address

- **Logical Address: the address generated by the CPU.**
- **Physical Address: the address seen and used by the memory unit.**
- **Virtual Address: Run-time binding may generate different logical address and physical address. In this case, logical address is also referred to as virtual address. (Logical = Virtual in this course)**

Dynamic Loading

- **Some routines in a program (*e.g.*, error handling) may not be used frequently.**
- **With *dynamic loading*, a routine is not loaded until it is called.**
- **To use dynamic loading, all routines must be in a relocatable format.**
- **The main program is loaded and executes.**
- **When a routine *A* calls *B*, *A* checks to see if *B* is loaded. If *B* is not loaded, the relocatable linking loader is called to load *B* and updates the address table. Then, control is passed to *B*.**

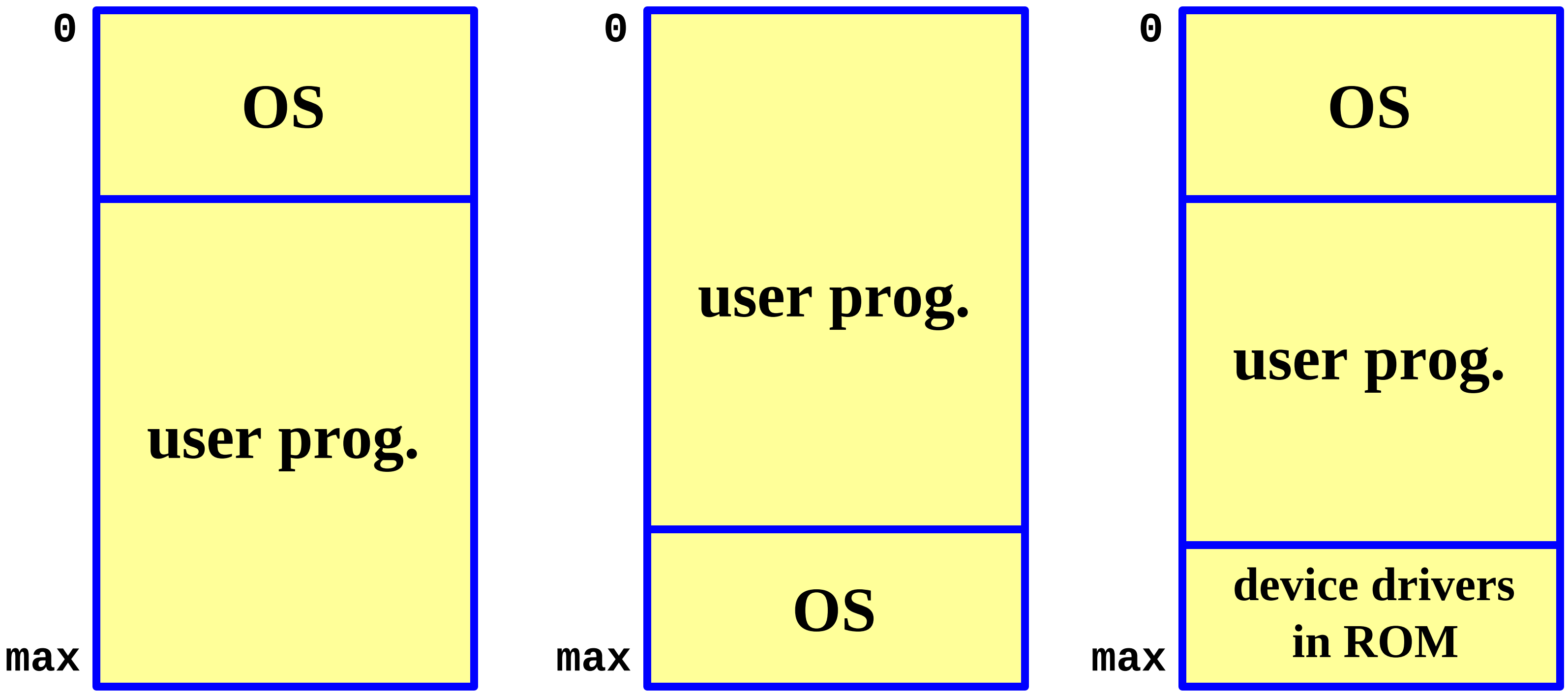
Dynamic Linking

- **Dynamic loading postpones the loading of routines until run-time.** ***Dynamic linking*** **postpones both linking and loading until run-time.**
- **A** ***stub*** **is added to each reference of library routine. A stub is a small piece of code that indicates how to locate and load the routine if it is not loaded.**
- **When a routine is called, its stub is executed. The routine is loaded, the address of that routine replaces the stub, and executes the routine.**
- **Dynamic linking usually applies to language and system libraries. A Windows DLL is a dynamic linking library.**

Major Memory Management Schemes

- Monoprogramming Systems: MS-DOS
- Multiprogramming Systems:
  - Fixed Partitions
  - Variable Partitions
  - Paging

Monoprogramming Systems

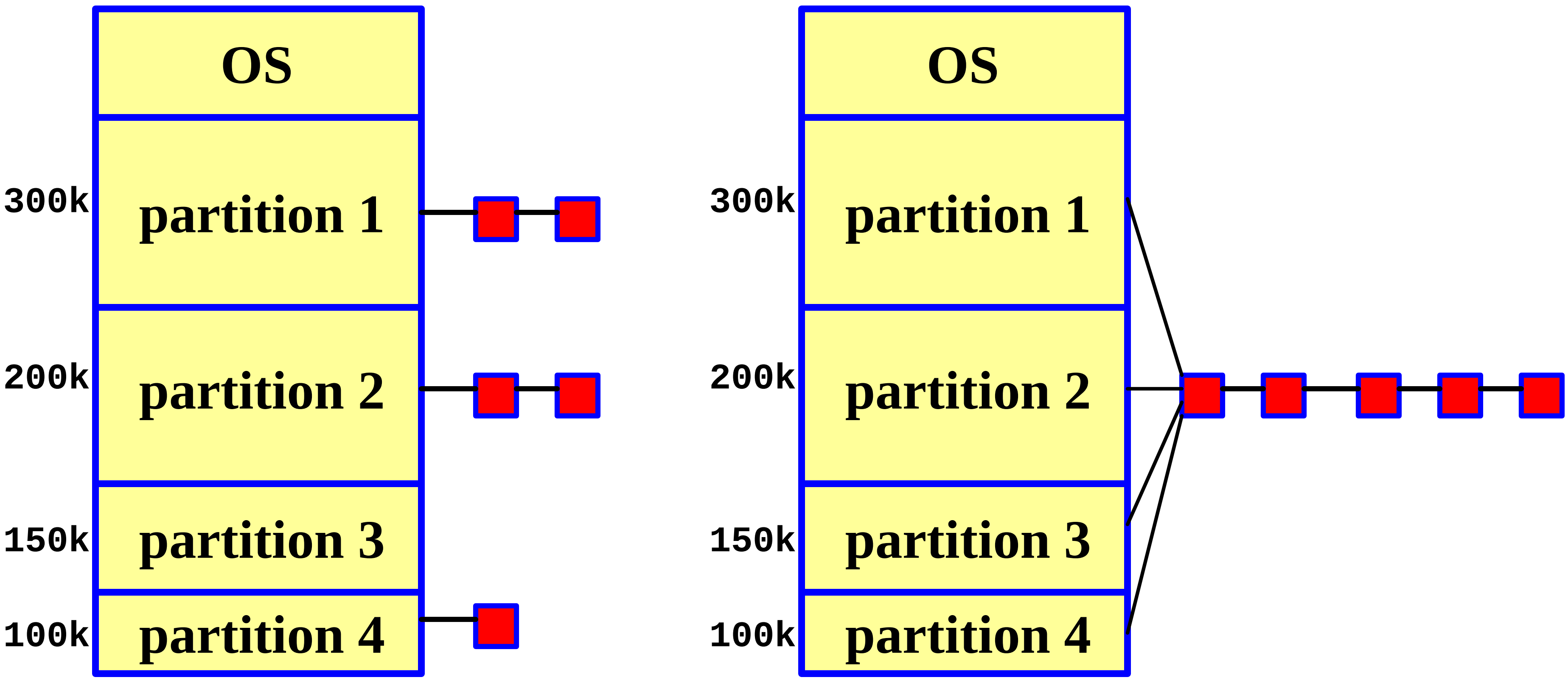


Why Multiprogramming?

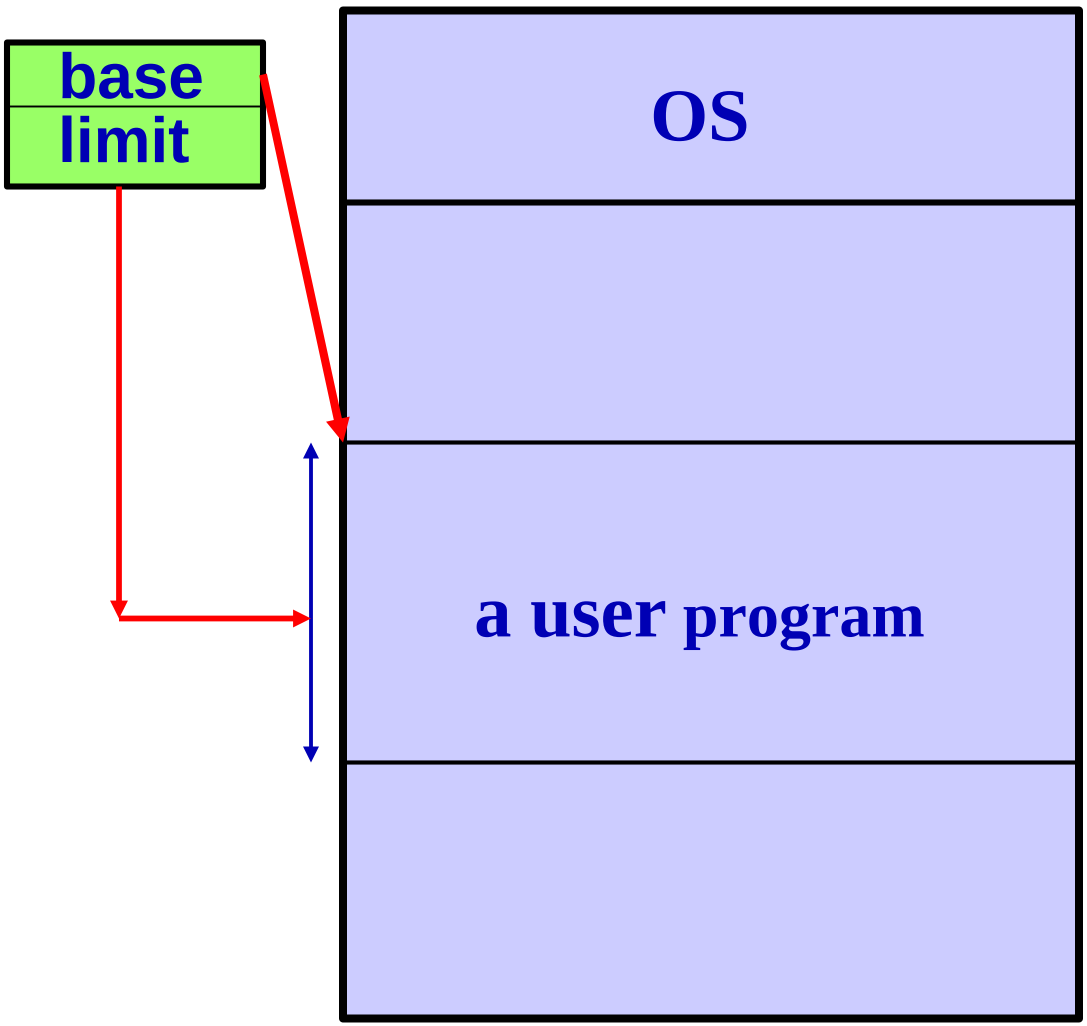
- Suppose a process spends a fraction of p of its time in I/O wait state.
- Then, the probability of n processes being *all* in wait state at the same time is p^n.
- The CPU utilization is $1 - p^n$.
- Thus, the more processes in the system, the higher the CPU utilization.
- Well, since CPU power is limited, throughput decreases when n is sufficiently large.

Multiprogramming with Fixed Partitions

- Memory is divided into ***n*** (possibly unequal) partitions.
- Partitioning can be done at the startup time and altered later on.
- Each partition may have a job queue. Or, all partitions share the same job queue.

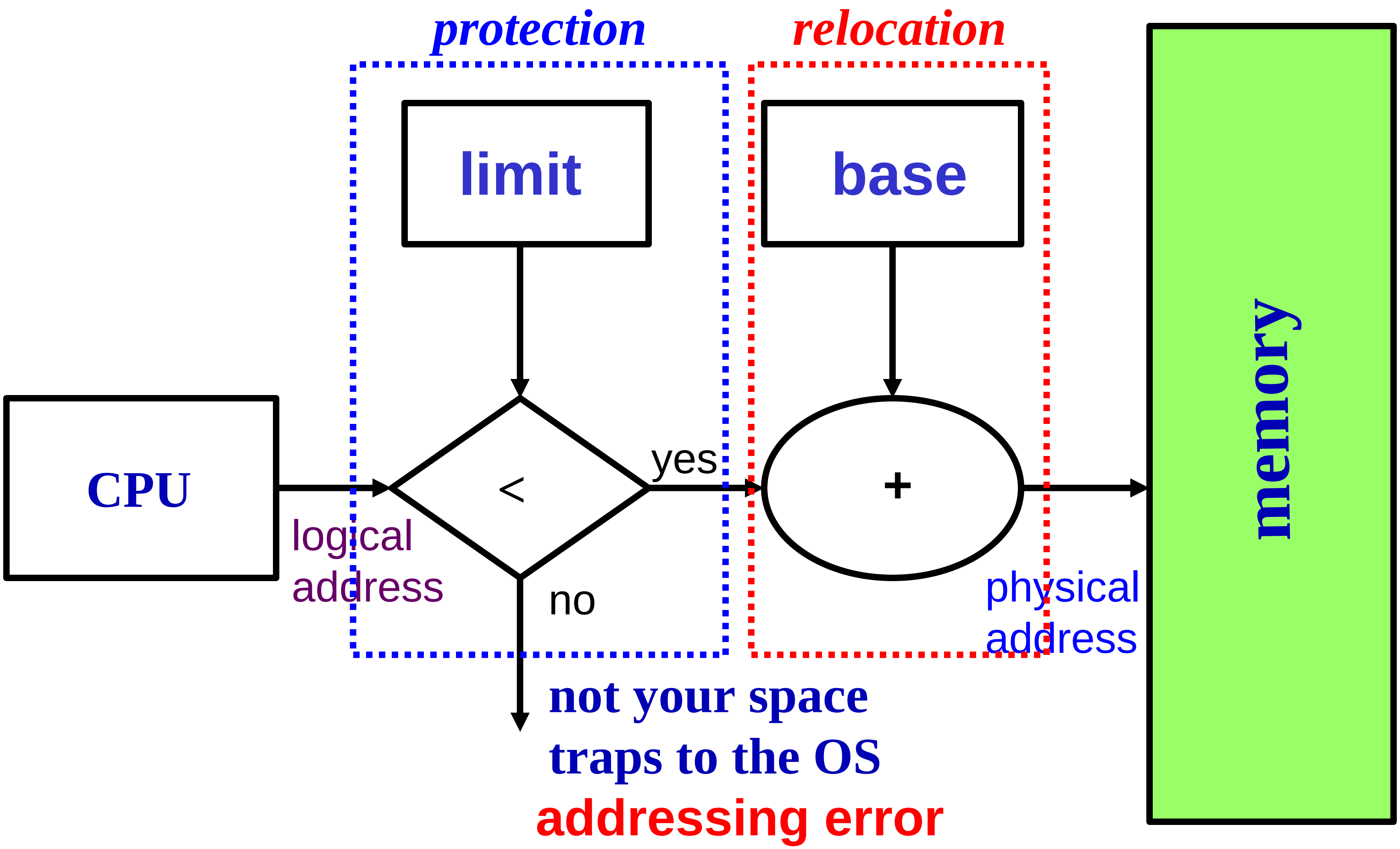


Relocation and Protection

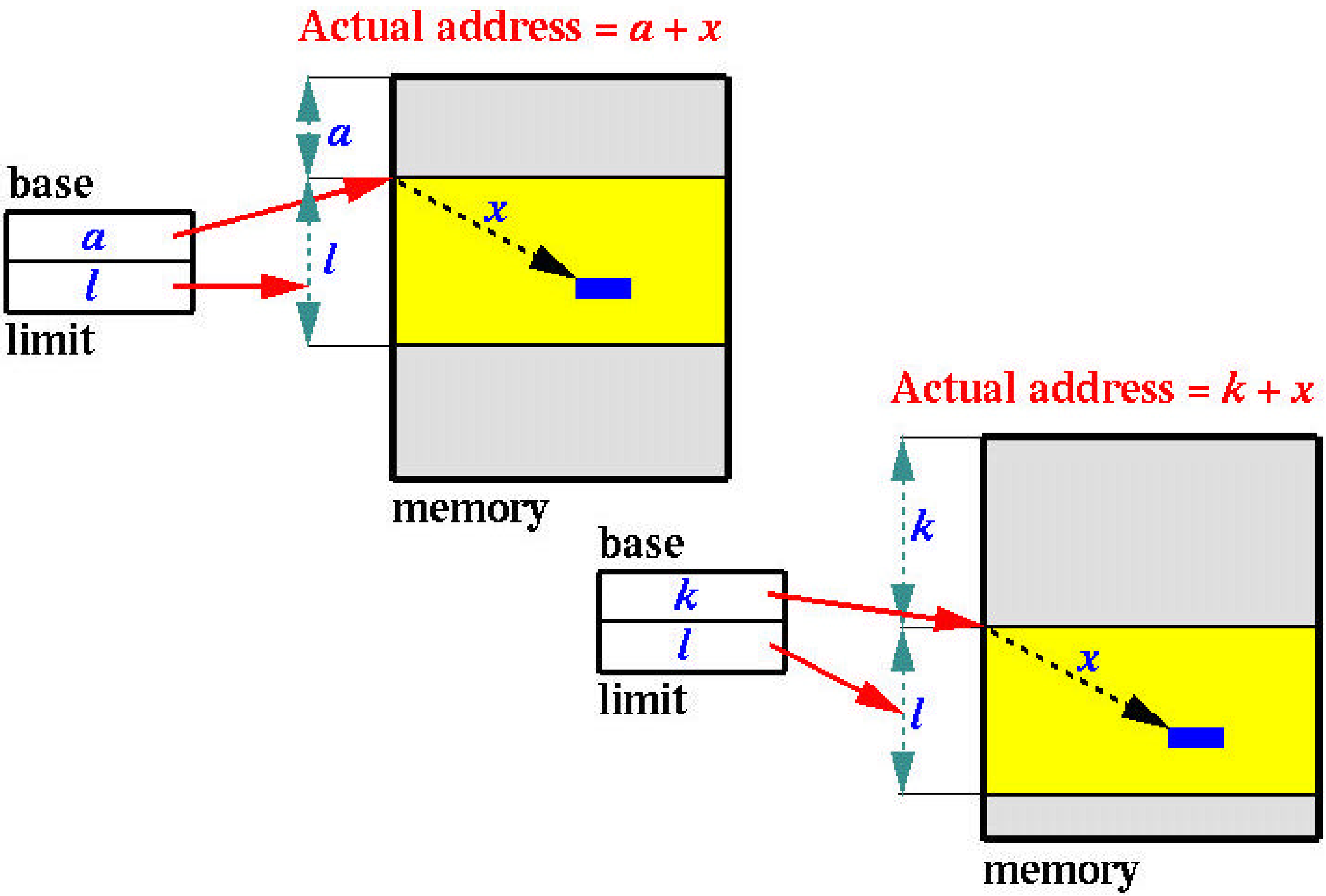


- Because executables may run in any partition, relocation and protection are needed.
- Recall the **base**/**limit** register pair for memory protection.
- It could also be used for relocation.
- Linker generates ***relocatable*** code starting with **0**. The **base** register contains the **starting address**.

Relocation and Protection

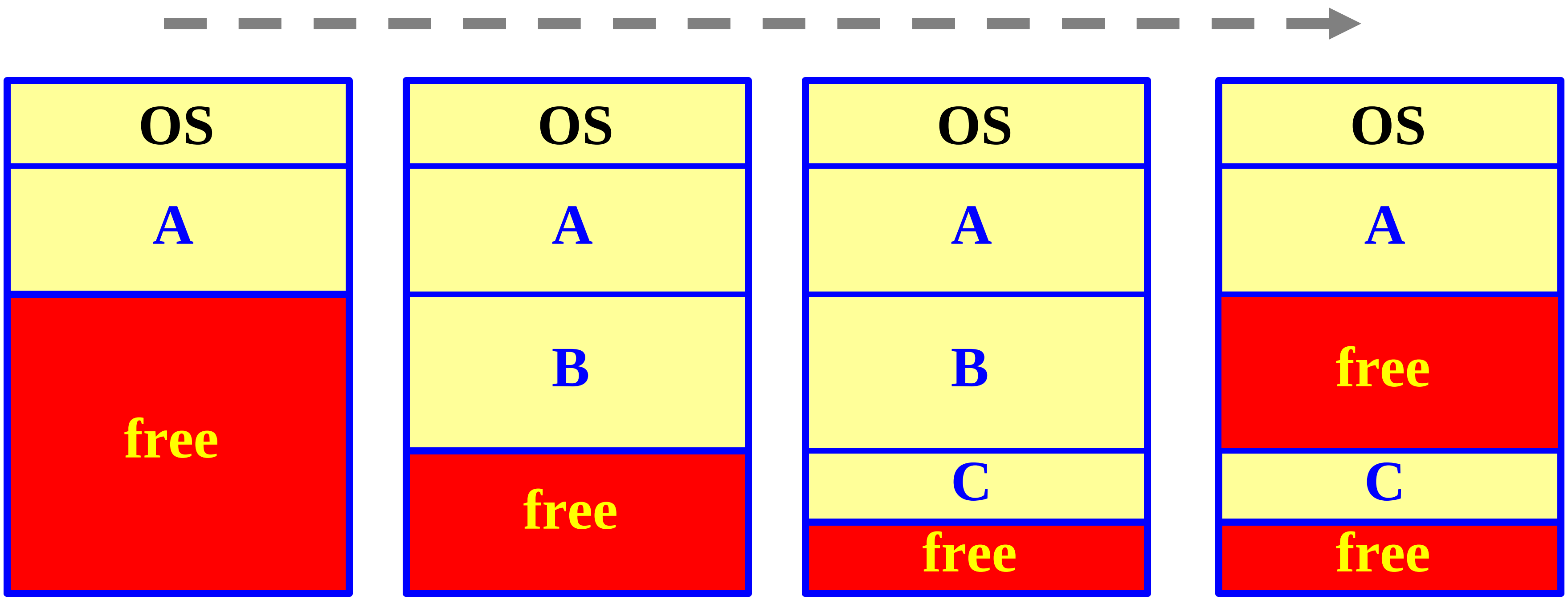


Relocation: How does it work?



Multiprogramming with Variable Partitions

- The OS maintains a memory pool. When a job comes in, the OS allocates whatever a job needs.
- Thus, partition sizes are not fixed, The number of partitions also varies.

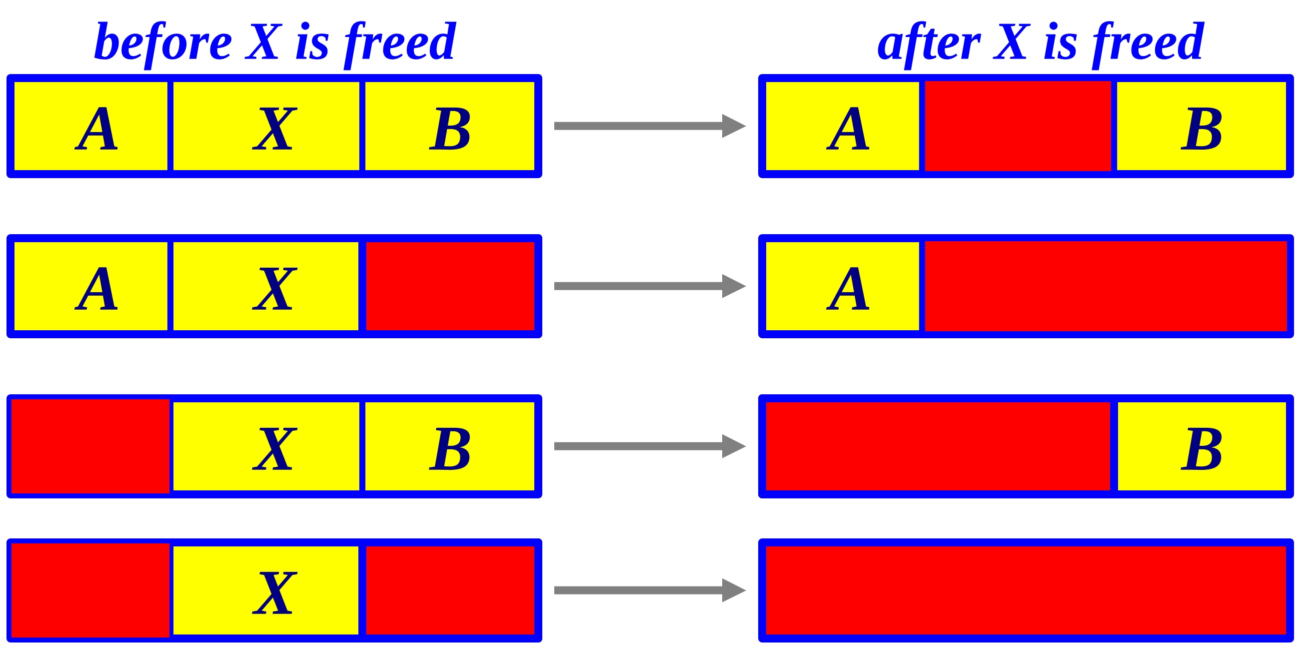


Memory Allocation: 1/2

- **When a memory request comes, we must search all free spaces (*i.e.*, holes) to find a *suitable* one.**
- **There are some commonly seen methods:**
  - **First Fit: Search starts at the *beginning* of the set of holes and allocate the first large enough hole.**
  - **Next Fit: Search starts from *where the previous first-fit search ended*.**
  - **Best-Fit: Allocate the *smallest* hole that is larger than the request one.**
  - **Worst-Fit: Allocate the *largest* hole that is larger than the request one.**

Memory Allocation: 2/2

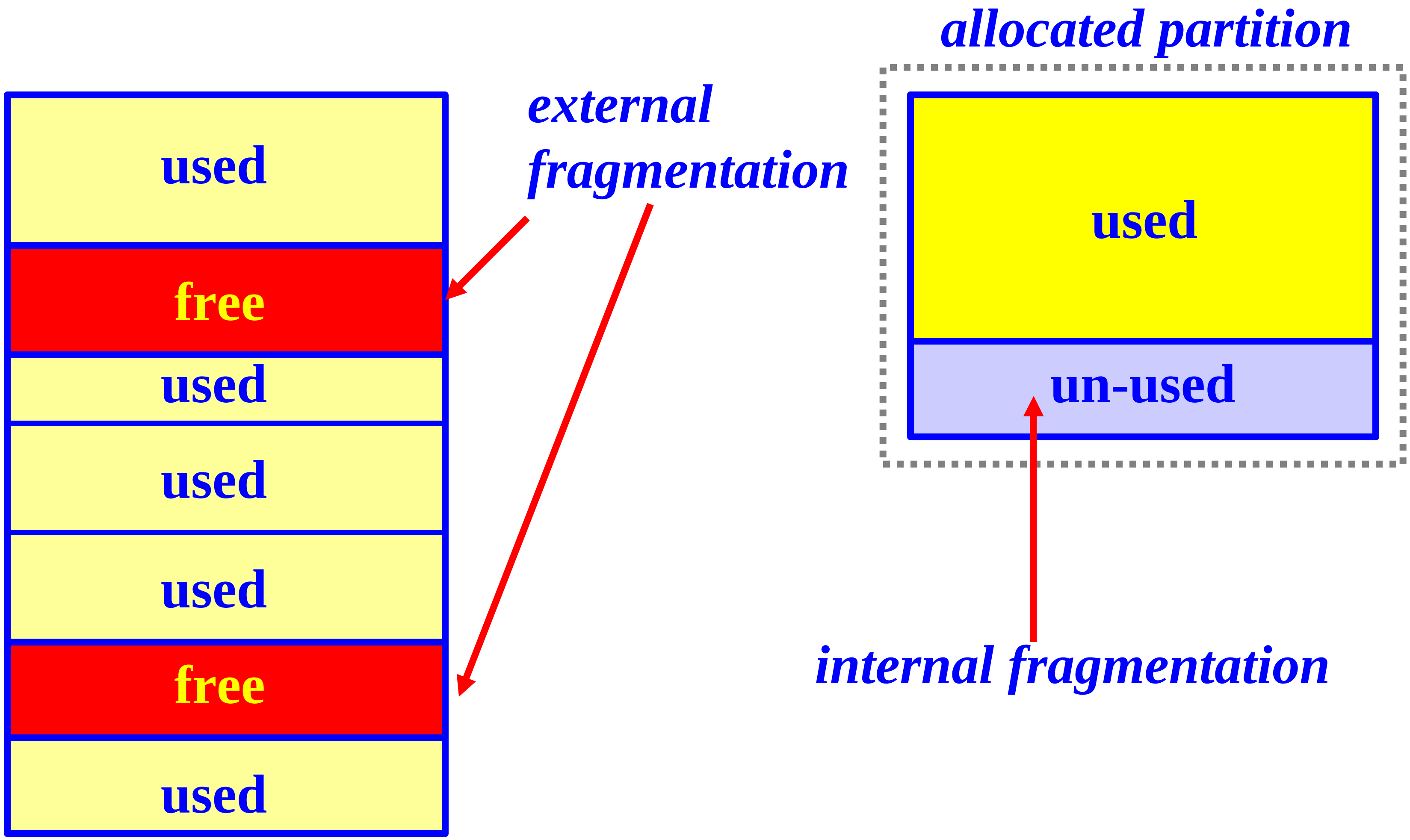
- **If the hole is larger than the requested size, it is cut into two. The one of the requested size is given to the process, the remaining one becomes a *new* hole.**
- **When a process returns a memory block, it becomes a hole and must be combined with its neighbors.**



Fragmentation

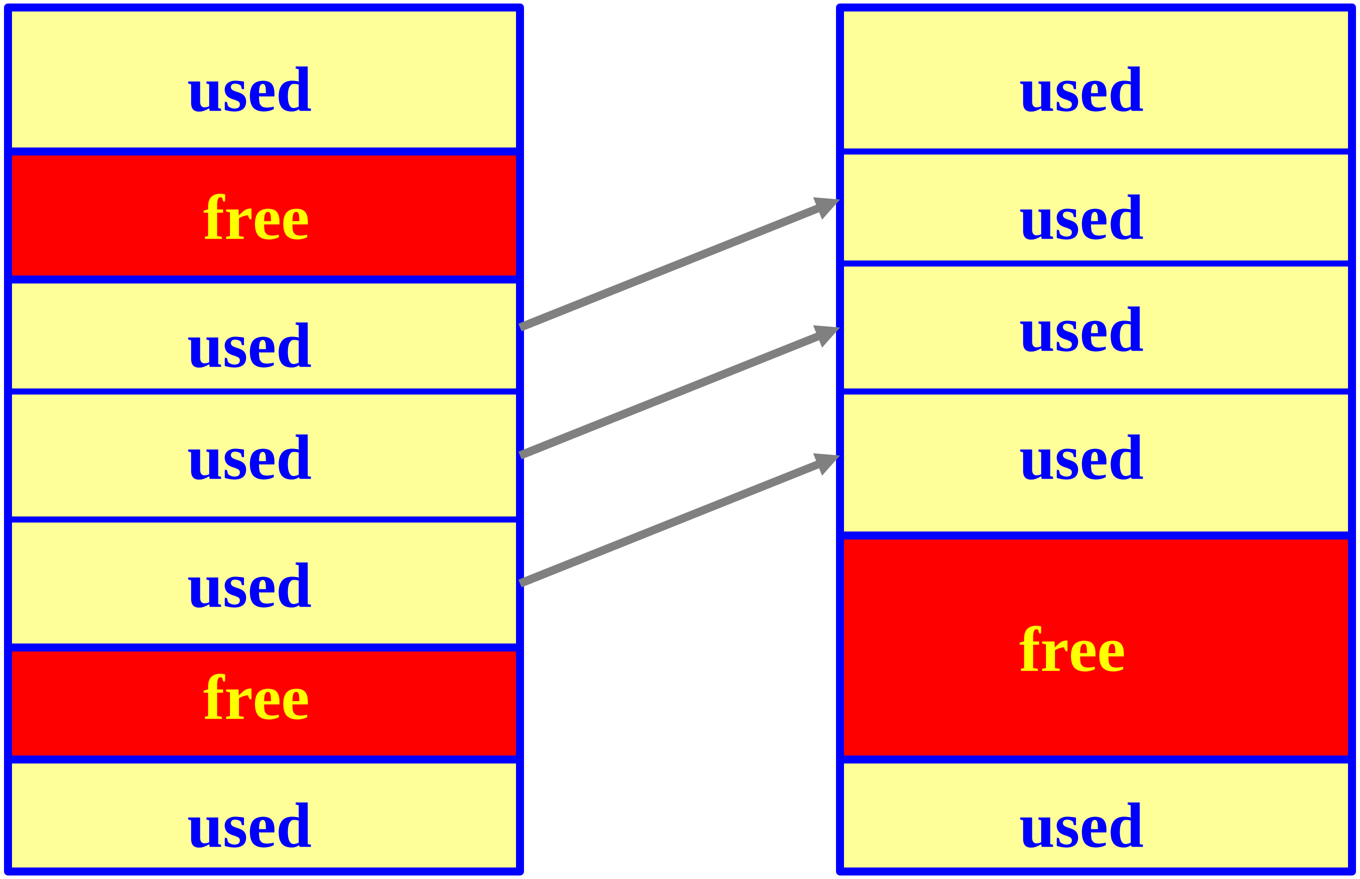
- **Processes are loaded and removed from memory, eventually the memory will be cut into small holes that are not large enough to run any incoming process.**
- **Free memory holes between allocated ones are called *external fragmentation*.**
- **It is unwise to allocate exactly the requested amount of memory to a process, because of address boundary alignment requirements or the minimum requirement for memory management.**
- **Thus, memory that is allocated to a partition, but is not used, are called *internal fragmentation*.**

External/Internal Fragmentation



Compaction for External Fragmentation

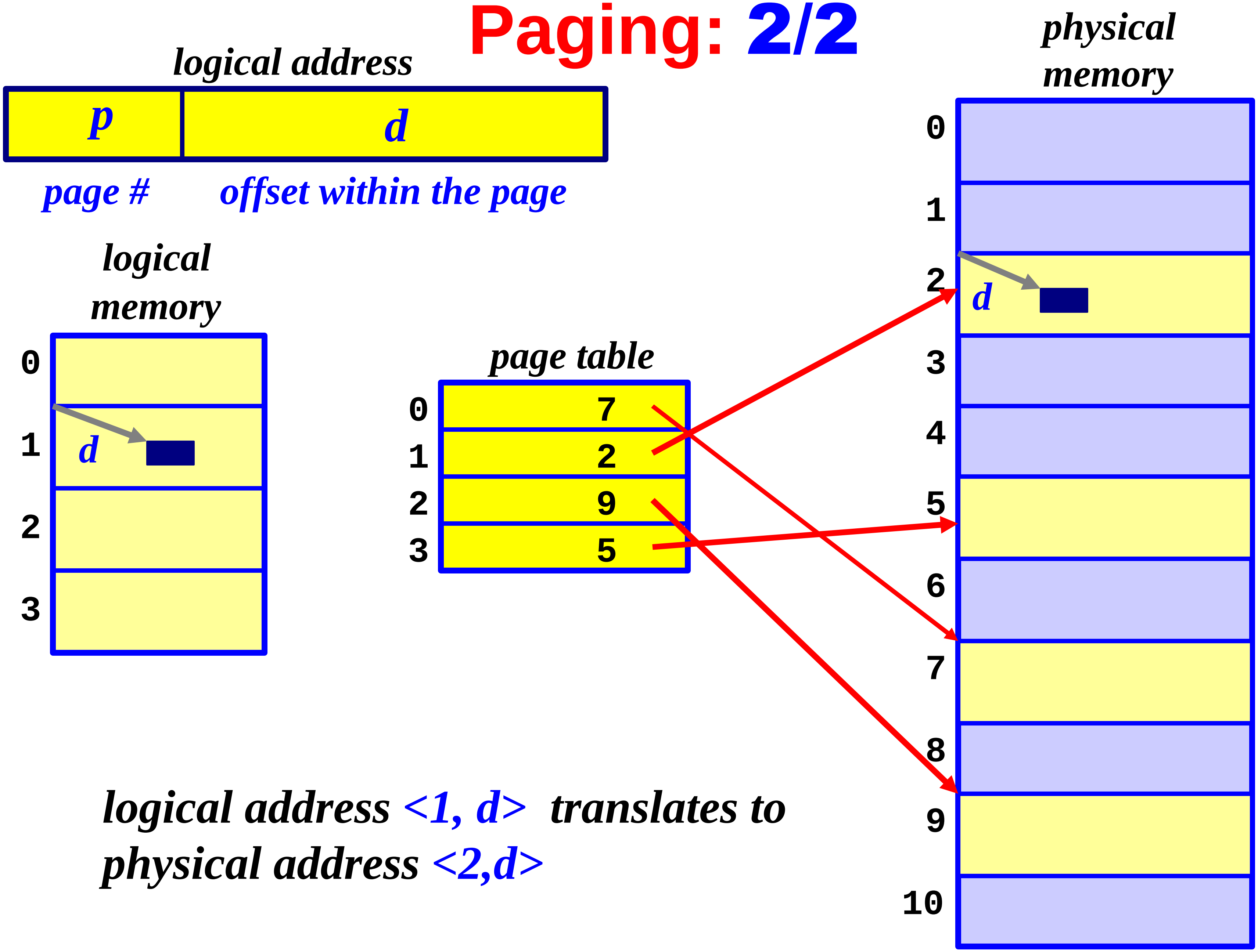
- If processes are relocatable, we may move used memory blocks together to make a larger free memory block.



Paging: 1/2

- **The physical memory is divided into fixed-sized *page frames*, or *frames*.**
- **The virtual address space is also divided into blocks of the same size, called *pages*.**
- **When a process runs, its pages are loaded into page frames.**
- **A page table stores the *page numbers* and their corresponding *page frame numbers*.**
- **The virtual address is divided into two fields: *page number* and *offset* (with that page).**

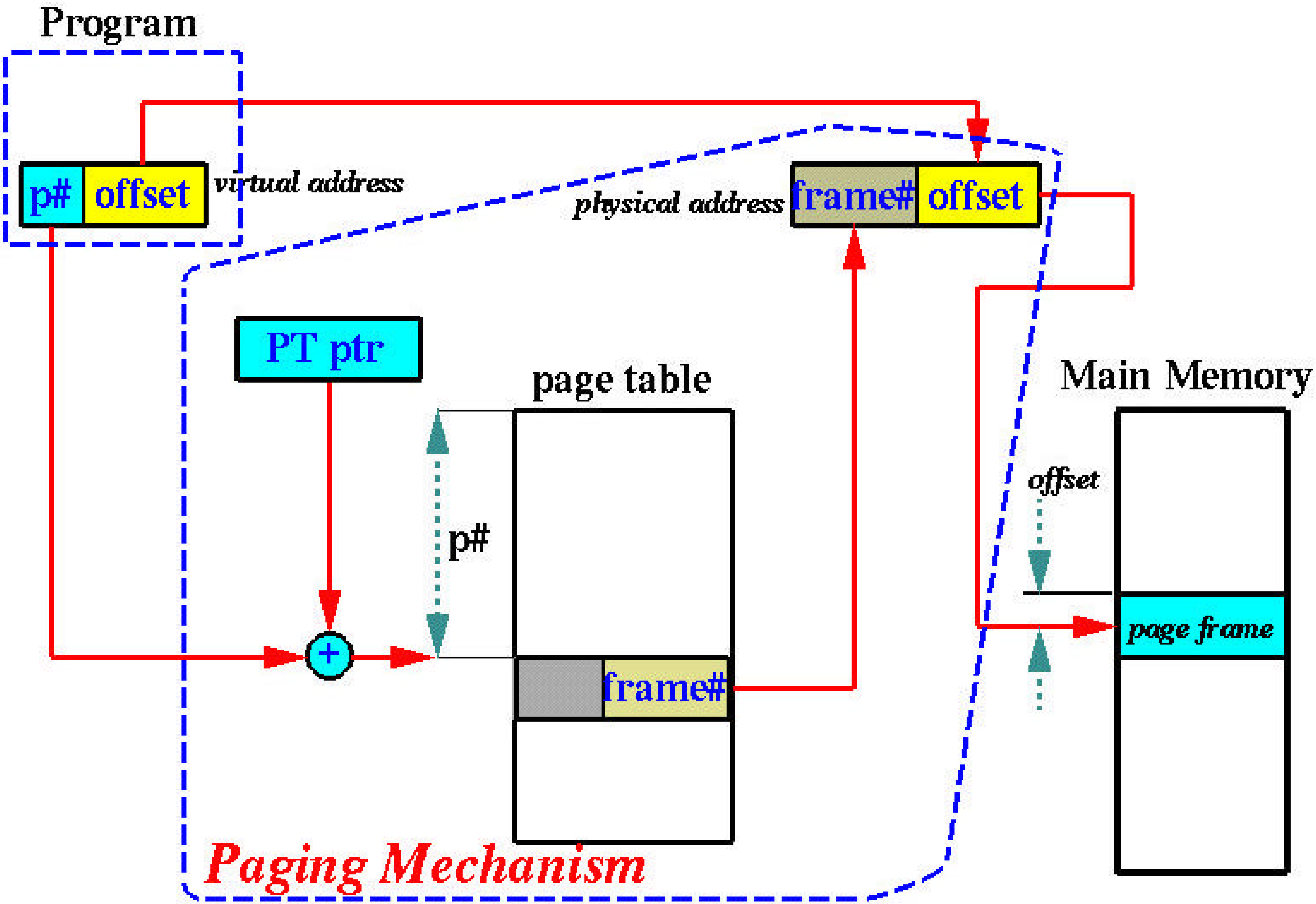
Paging: 2/2



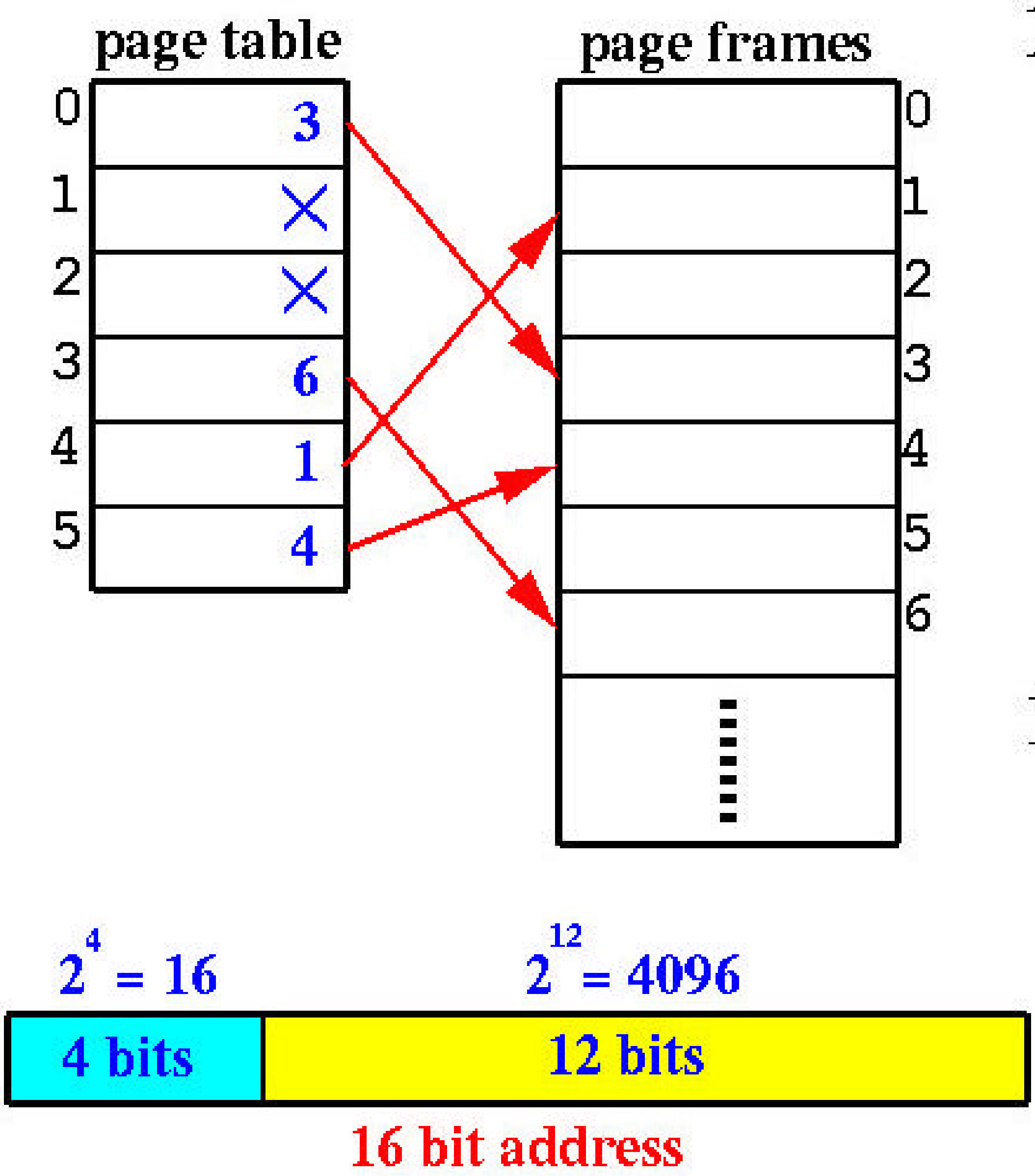
***logical address** *

logical address ***<1, d>*** *translates to*
physical address ***<2,d>***

Address Translation



Address Translation: Example



15000 (virtual address):

15000/4096:
quotient = 3 (page #)
remainder = 2712 (offset)

From page table,
page #3 is in frame #6

Real address
= (frame#)*4096+offset
= 6*4096 + 2712 = 27288

10000 (virtual address):

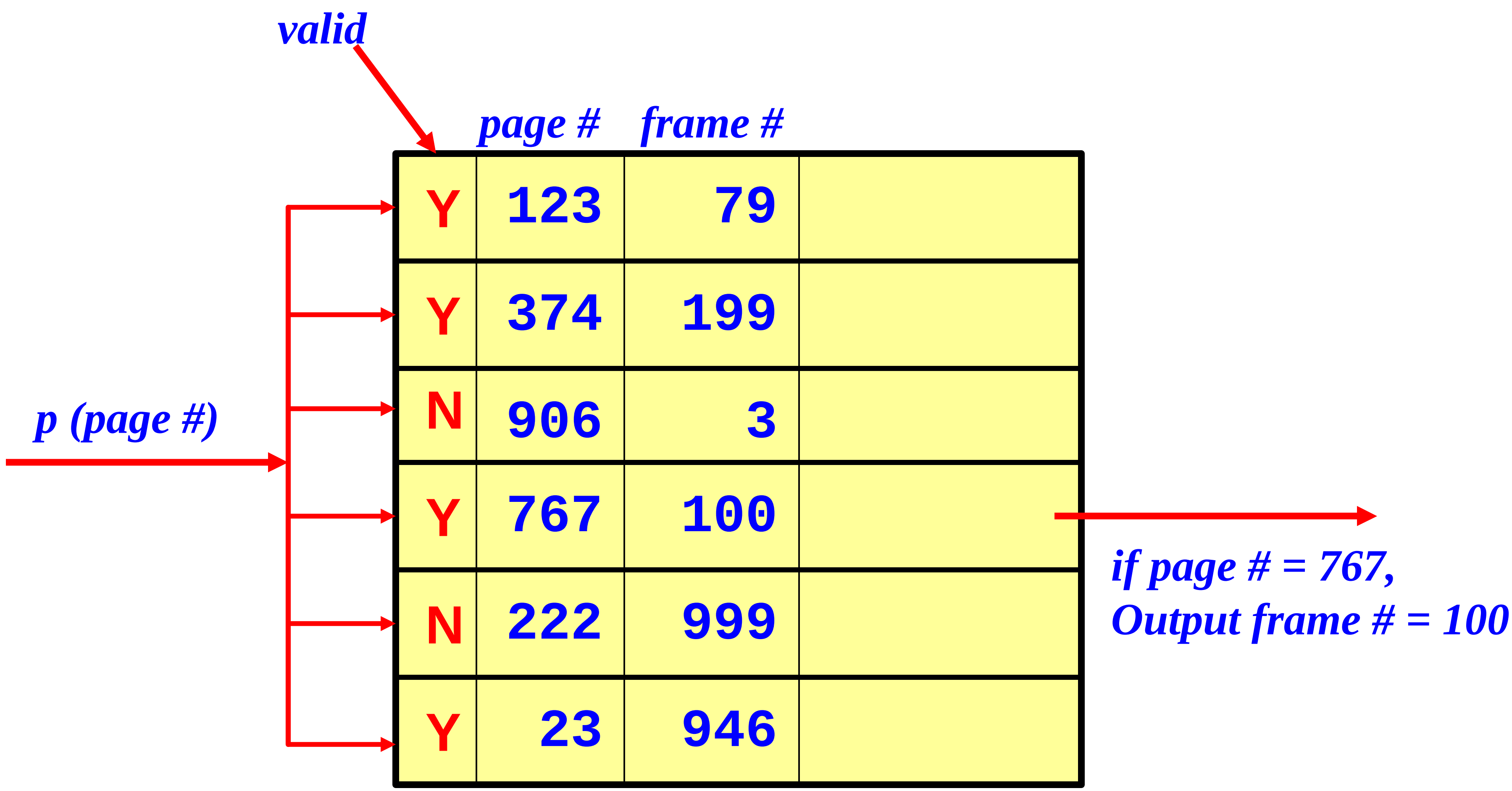
10000/4096:
quotient = 2 (page #)
remainder = 1808 (offset)

From page table:
page 2 not in memory
a *page fault* occurs

Hardware Support

- **Page table may be stored in special registers if the number of pages is small.**
- **Page table may be stored in physical memory, and a special register, page-table base register, points to the page table.**
- **Use translation look-aside buffer (TLB). TLB stores recently used pairs (page #, frame #). It compares the input page # against the stored ones. If a match is found, the corresponding frame # is the output. Thus, no physical memory access is required.**
- **The comparison is carried out in *parallel* and is *fast*.**
- **TLB normally has 64 to 1,024 entries.**

Translation Look-Aside Buffer



If the TLB reports no hit, then we go for a page table look up!

Fragmentation in a Paging System

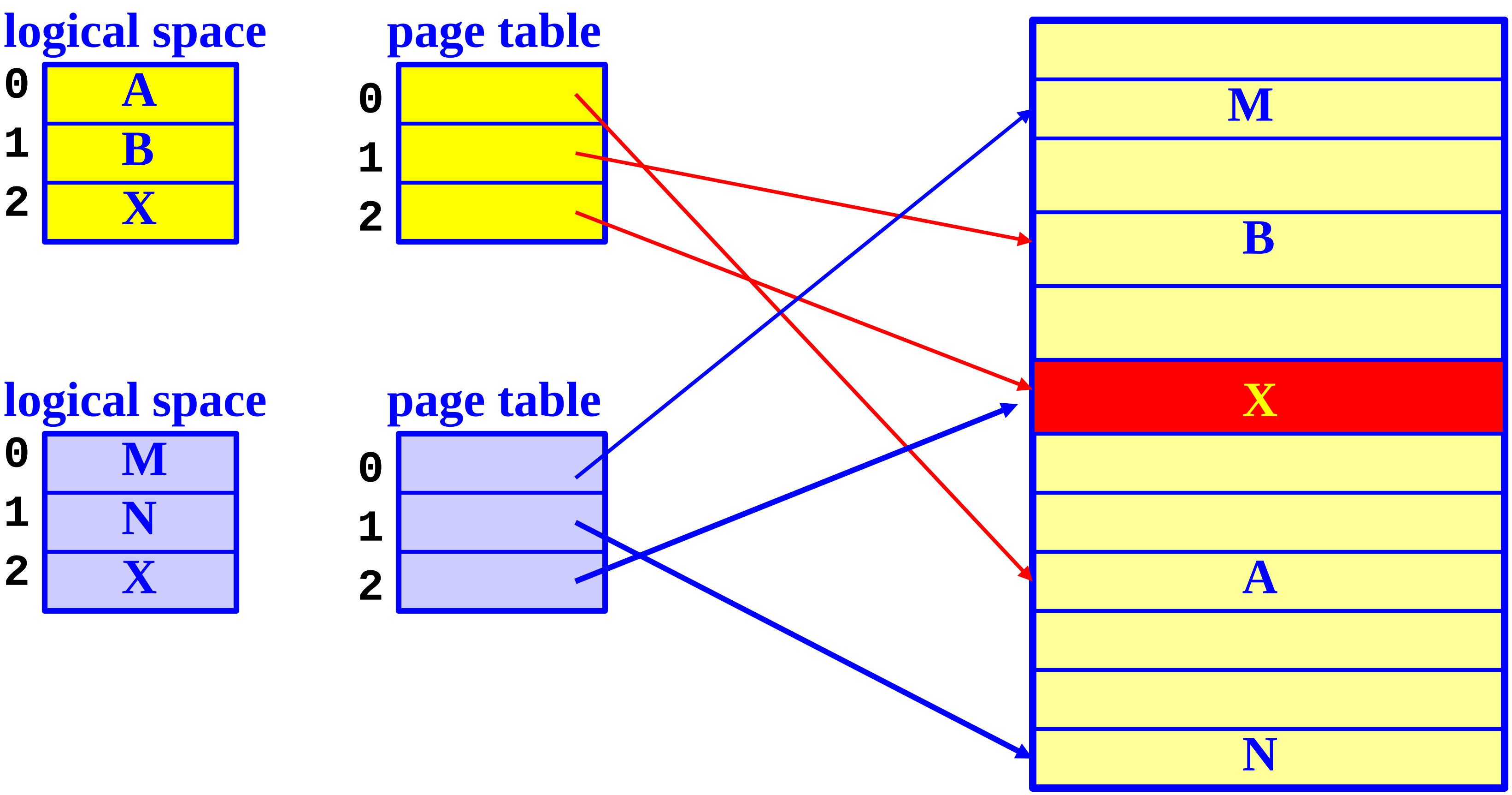
- **Does a paging system have fragmentation?**
- **Paging systems do not have external fragmentation, because un-used page frames can be used by the next process.**
- **Paging systems do have internal fragmentation.**
- **Because the address space is divided into equal size pages, all but the last one will be filled completely. Thus, the last page contains internal fragmentation and may be 50% full.**

Protection in a Paging System

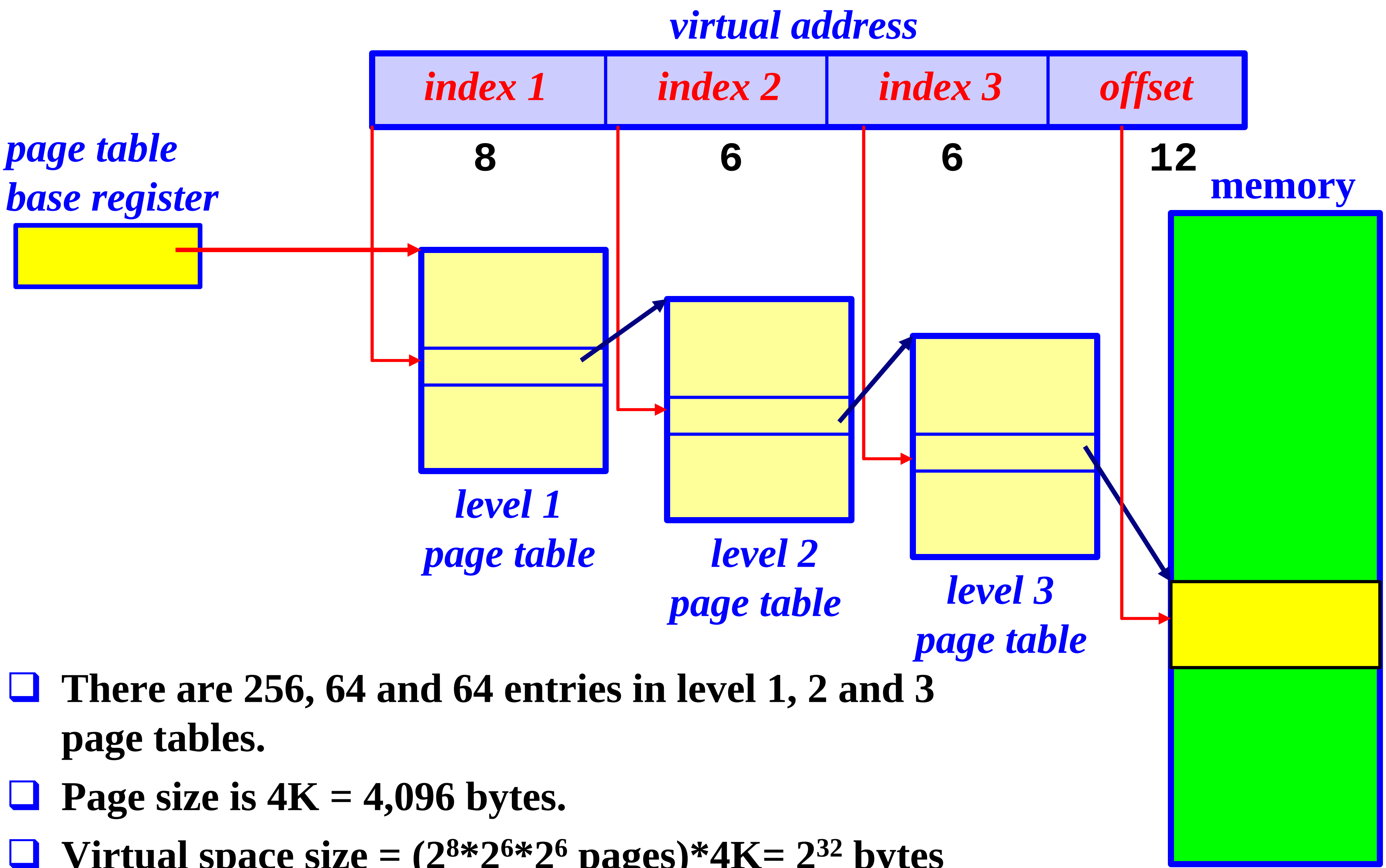
- **Is it required to protect among users in a paging system? No, because different processes use different page tables.**
- **However, we can use a page table length register that stores the length of a process's page table. In this way, a process cannot access the memory beyond its region. Compare this with the base/limit register pair.**
- **We can also add read-only, read-write, or execute bits in page table to enforce r-w-e permission.**
- **We can also add a valid/invalid bit to each page entry to indicate if the page is in memory.**

Shared Pages

- Pages may be shared by multiple processes.
- If the code is a ***re-entrant*** (or ***pure***) one, a program does not modify itself, routines can also be shared!



Multi-Level Page Table



- There are 256, 64 and 64 entries in level 1, 2 and 3 page tables.
- Page size is 4K = 4,096 bytes.
- Virtual space size = ($2^8*2^6*2^6$ pages)*4K= 2^{32} bytes

Inverted Page Table: 1/2

- **In a paging system, each process has its own page table, which usually has many entries.**
- **To save space, we can build a page table which has one entry for each page frame. Thus, the size of this *inverted page table* is equal to the number of page frames.**
- **Each entry in an inverted page table has two items:**
  - **Process ID: the owner of this frame**
  - **Page Number: the page number in this frame**
- **Each virtual address has three sections:**

<process-id, page #, offset>

Inverted Page Table: 2/2