memory management

summary

- goals and requirements
- techniques that do not involve virtual memory

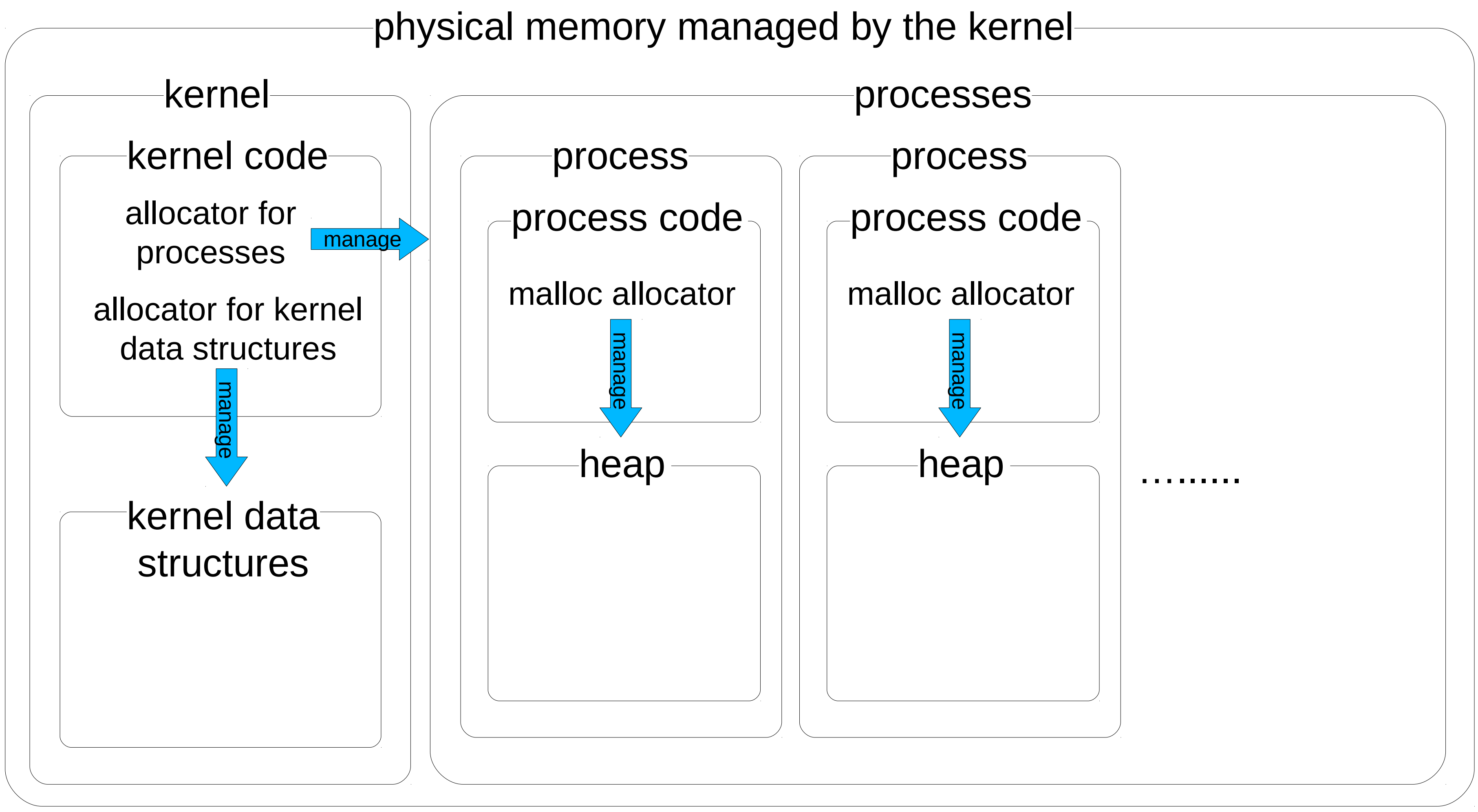
memory management

- tracking used and free memory
- primitives
  - **allocation** of a certain amount of memory
  - **de-allocation** of what allocated,
    - it permits reuse of de-allocated memory
- reason for **allocation request**
  - data structures (e.g. array, objects, ecc.)
    - kernel data structures (allocator implemented in the kernel)
    - process data structures (allocator implemented by language runtime libraries, e.g. C/C++ malloc)
  - processes (within an O.S.)

summary and applicability

- many techniques and concepts in memory management equally apply to memory allocation for processes and for data
  - fixed partitioning, dynamic compaction, fragmentation, placement algorithms, buddy system
  - the book talks about a "process" but it may be any kind of allocation request
- hardware supported techniques apply only to processes
  - virtual memory, paging, segmentation

kinds of memory and allocators



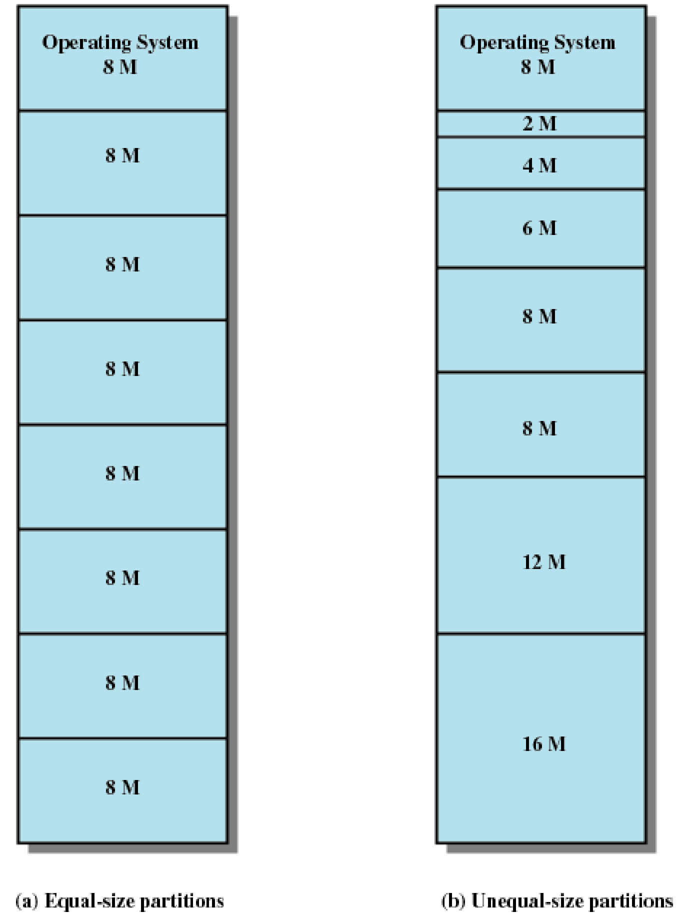
allocators inventory

- in the processes
  - heap managed by malloc
    - allocate data structures for the process
- in the kernel
  - “sort of heap” managed by a “sort of malloc” in the kernel
    - allocate data structures for the kernel
    - remember that the kernel cannot use libraries!
    - in linux this is provided by a buddy-system plus a “slab allocator”
  - allocation of images of the processes
    - for old OSes adopt the same approaches for data structures
    - in modern OSes relies on paging and virtual memory

memory management techniques that do not involves virtual memory

Fixed Partitioning

- memory is partitioned in a fixed way
- equal size
- unequal size



Fixed Partitioning

- inefficient memory use
  - any program, no matter how small, occupies an entire partition.
- the fact that same space within a partition is wasted is called **internal fragmentation**.

Fixed Partitioning

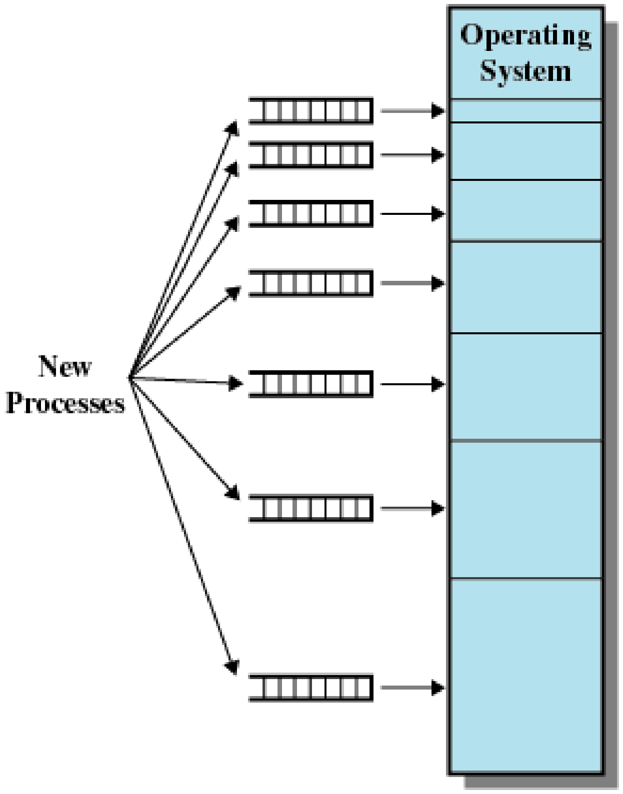
- Equal-size partitions
  - Any process or data whose size is less than or equal to the partition size can be loaded into an available partition
  - If all partitions are full, the operating system can swap a process out of a partition
  - A process/data may not fit in a partition.
    - For processes, the programmer must design the program with overlays
  - still used in hard disk partitioning
    - LVM overcome such limitation (linux)

Placement Algorithm with Partitions

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

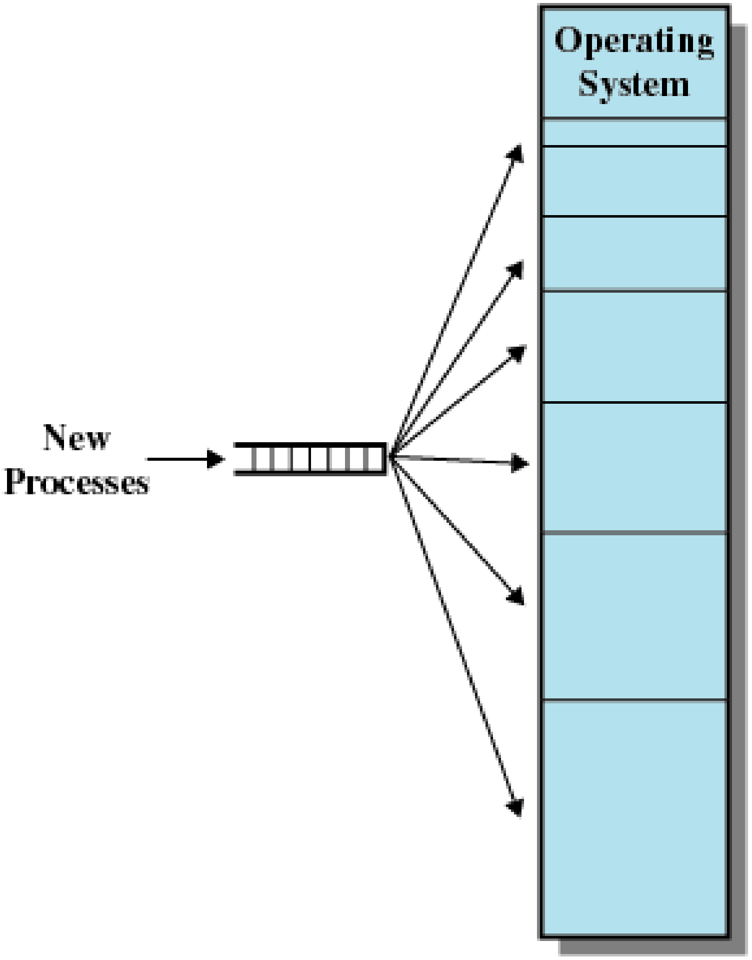
Placement Algorithm with Partitions

- Unequal-size partitions
  - minimize internal fragmentation
    - assign each process/data to the smallest partition it will fit into
    - one queue for each partition: a process might wait until it “best fit” partition is free, even if there are other partitions availableminimize wait time



Placement Algorithm with Partitions

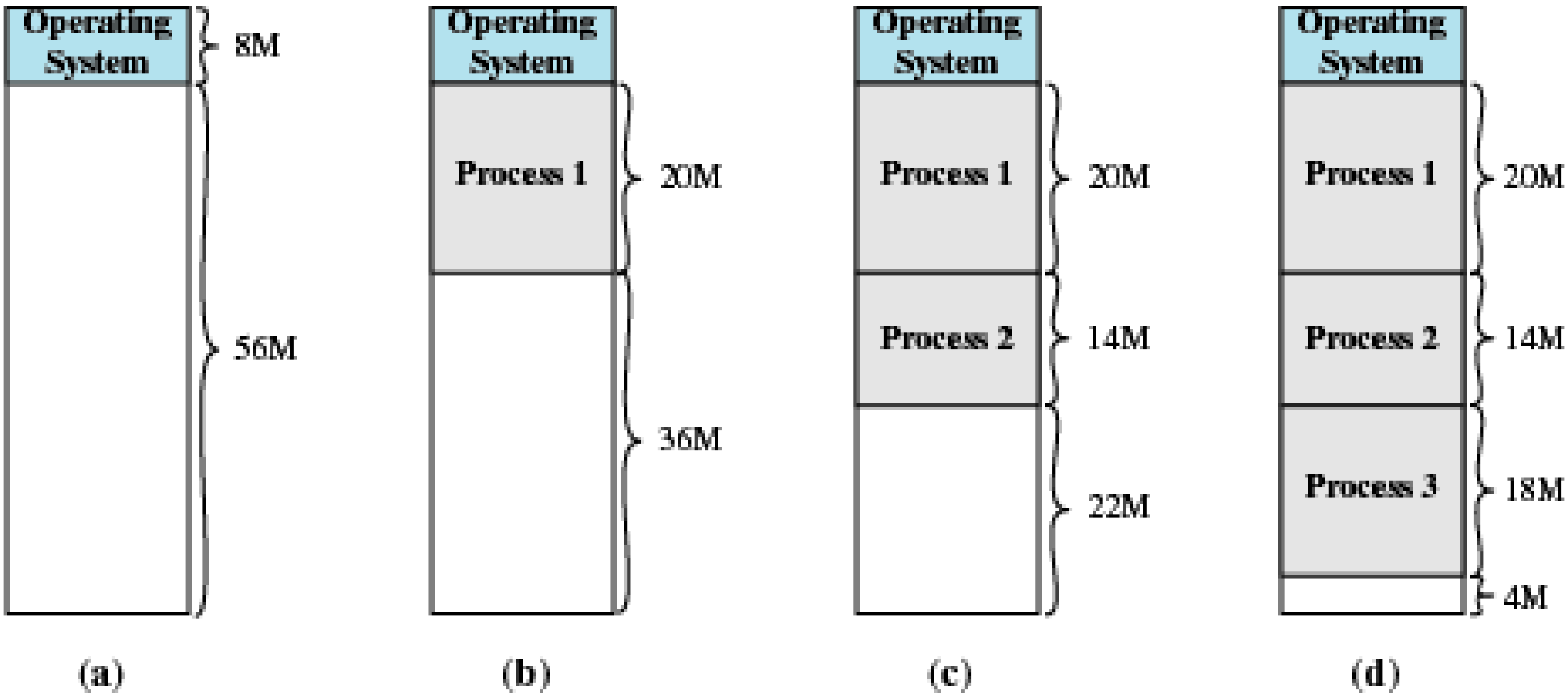
- Unequal-size partitions
  - minimize wait time and, *secondarily*, internal fragmentation
    - one single queue
    - request is assigned to the best partition available when served



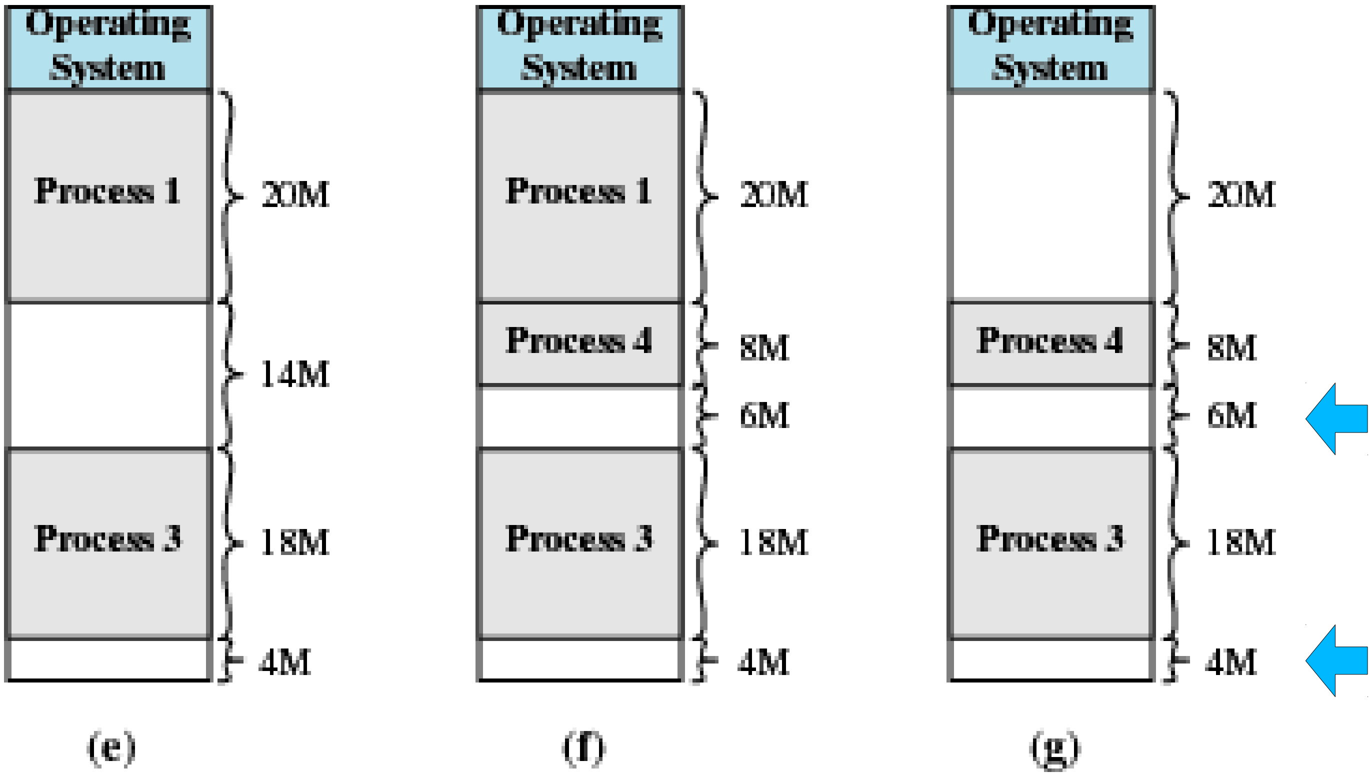
dynamic partitioning

- partitions are of variable length and number
- process/data is allocated exactly as much memory as required
- eventually, small holes in the memory remain. This is called **external fragmentation**

external fragmentation



external fragmentation



compaction

- it is a solution for external fragmentation
- compaction shifts allocated blocks so they are contiguous and all free memory is in one block
  - in the general case compaction is unfeasible
  - e.g. for C/C++ memory allocators: need for re-directing all pointers
    - but location of pointers is unknown!
    - tracking and redirecting pointers is inefficient
    - C/C++ are designed to be very very efficient
- so compaction is never used, all dynamic allocation systems stand with external fragmentation

Dynamic Partitioning Placement Algorithm

- allocators must decide which free block to allocate to an allocation request
- Best-fit algorithm
  - Chooses the block that is closest in size to the request
  - Worst performer overall
    - since smallest block is found for the request, the smallest amount of fragmentation is left
  - Memory compaction must be done more often

Dynamic Partitioning Placement Algorithm

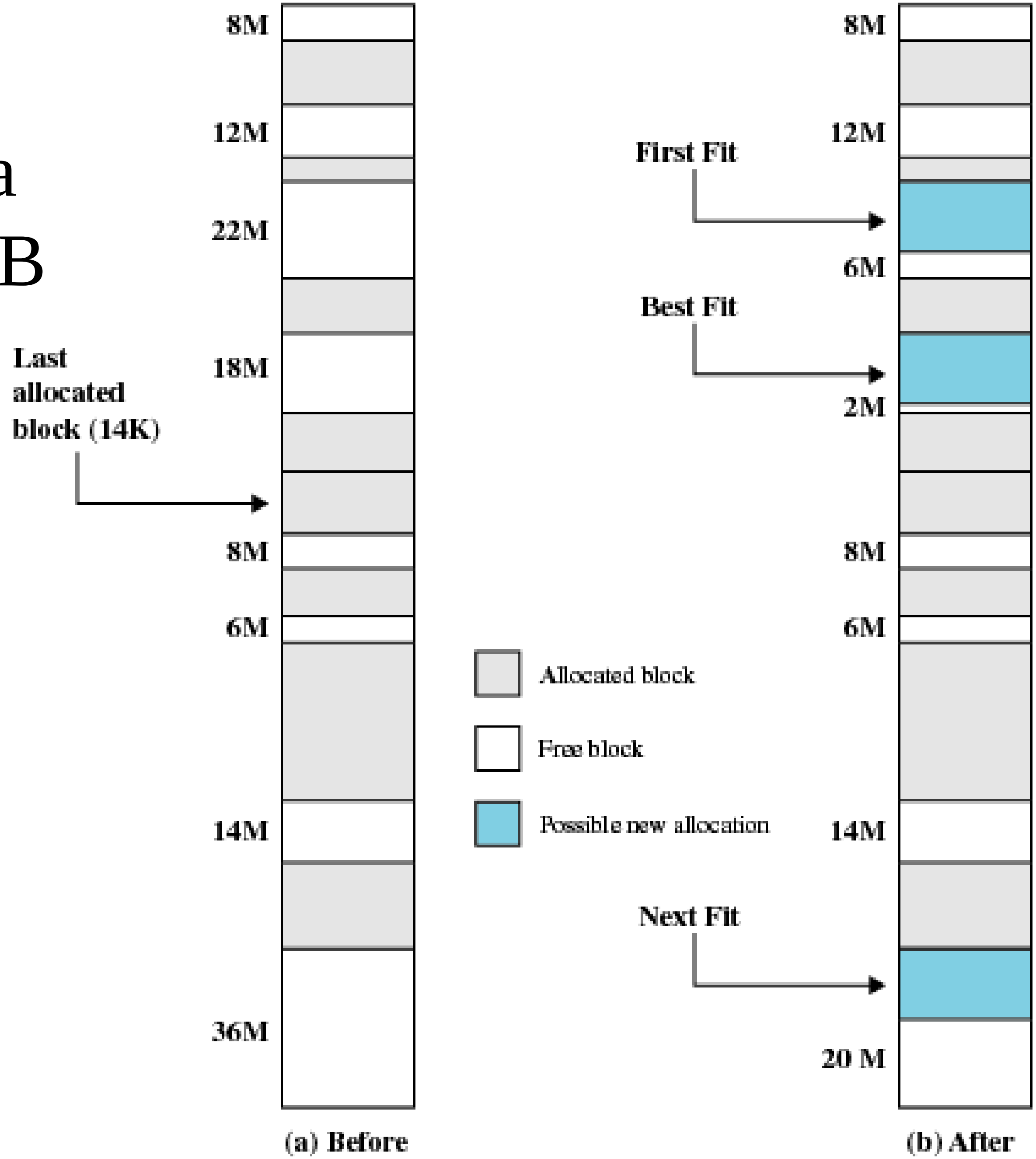
- First-fit algorithm
  - Scans memory form the beginning and chooses the first available block that is large enough
  - Fastest
  - May have many requestes loaded in the front end of memory that must be searched over when trying to find a free block

Dynamic Partitioning Placement Algorithm

- Next-fit
  - Scans memory from the location of the last placement
  - More often allocate a block of memory at the end of memory where the largest block is found
  - The largest block of memory is broken up into smaller blocks
  - Compaction is required to obtain a large block at the end of memory

examples

- allocation of a block of 16MB



Buddy System

- simple but powerful allocator
- widely used in O.S. to allocate large chunks of fixed size
  - e.g. 4KB pages in many architectures (x86_32)
- it can be used as a base for a more fine-grained allocator
  - which is called slab allocator in Linux and Solaris and is used for kernel data structures

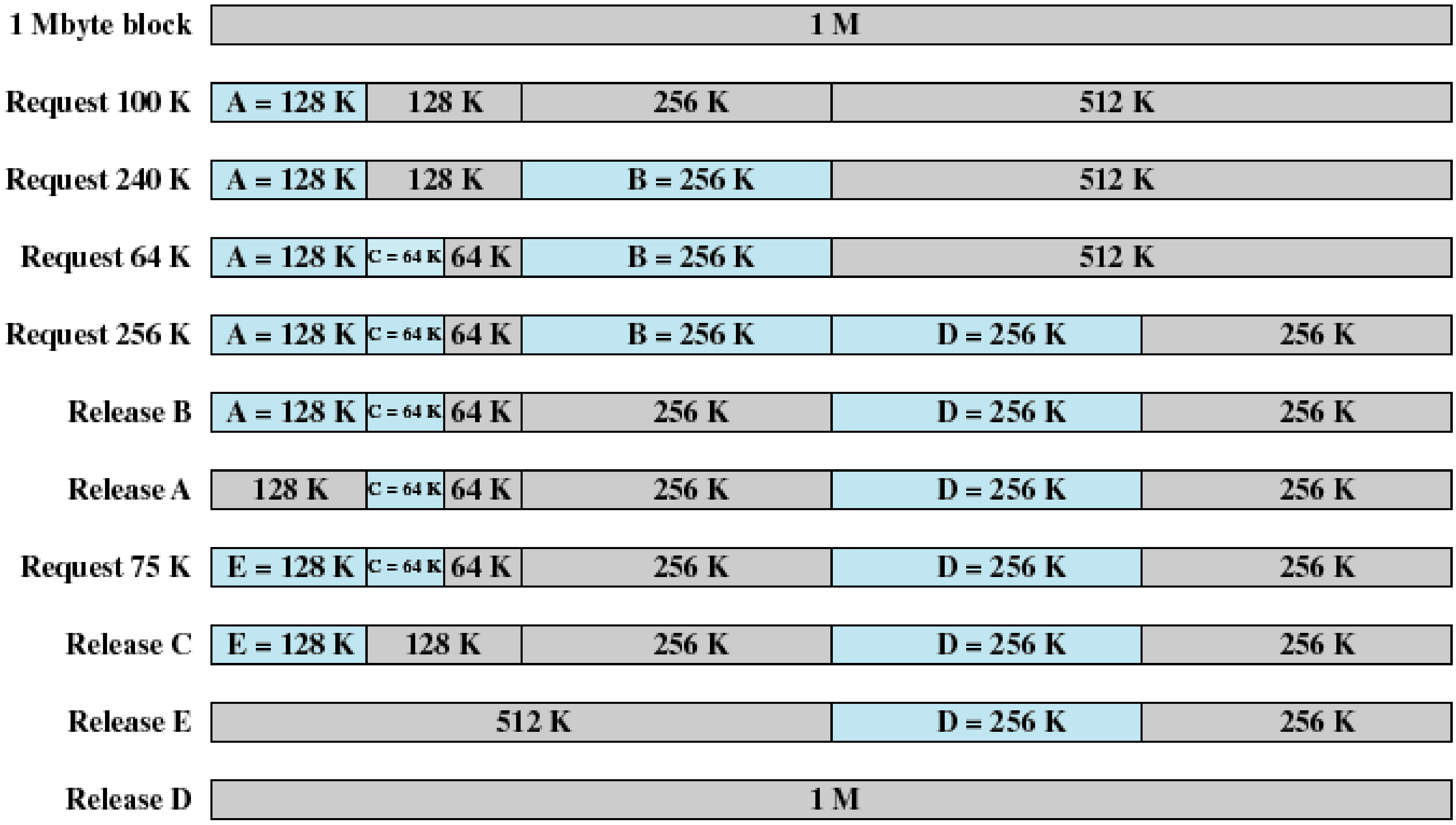
Buddy System

- entire space available is treated as a single block of 2^U
- a request of *s* bytes returns a block of ceil($\log_2 s$) bytes
  - if a request of size *s* such that $2^{i-1} < s <= 2^i$, a block of length 2^i is allocated
  - a 2^i block can be split into two equal **buddies** of 2^{i-1} *bytes*
  - for each request a “big” block is found and split until the smallest block greater than or equal to *s* is generated

Buddy System

- it maintains a lists L_i ($i=1..U$) of unallocated blocks (*holes*) of size 2^i
  - splitting: remove a hole from L_{i+1} split it, and put the two buddies it into L_i
  - coalescing: remove two unallocated buddies from L_i and put it into L_{i+1}

buddy system: example



Buddy System

procedure **get_hole**

- input: *i* (precondition: $i \leq U$)
- output: a block *c* of size 2^i (postcondition: L_i does not contain *c*)

if (L_i is empty)

< b= get_hole(i+1);

< split b into two buddies b_1 and b_2>

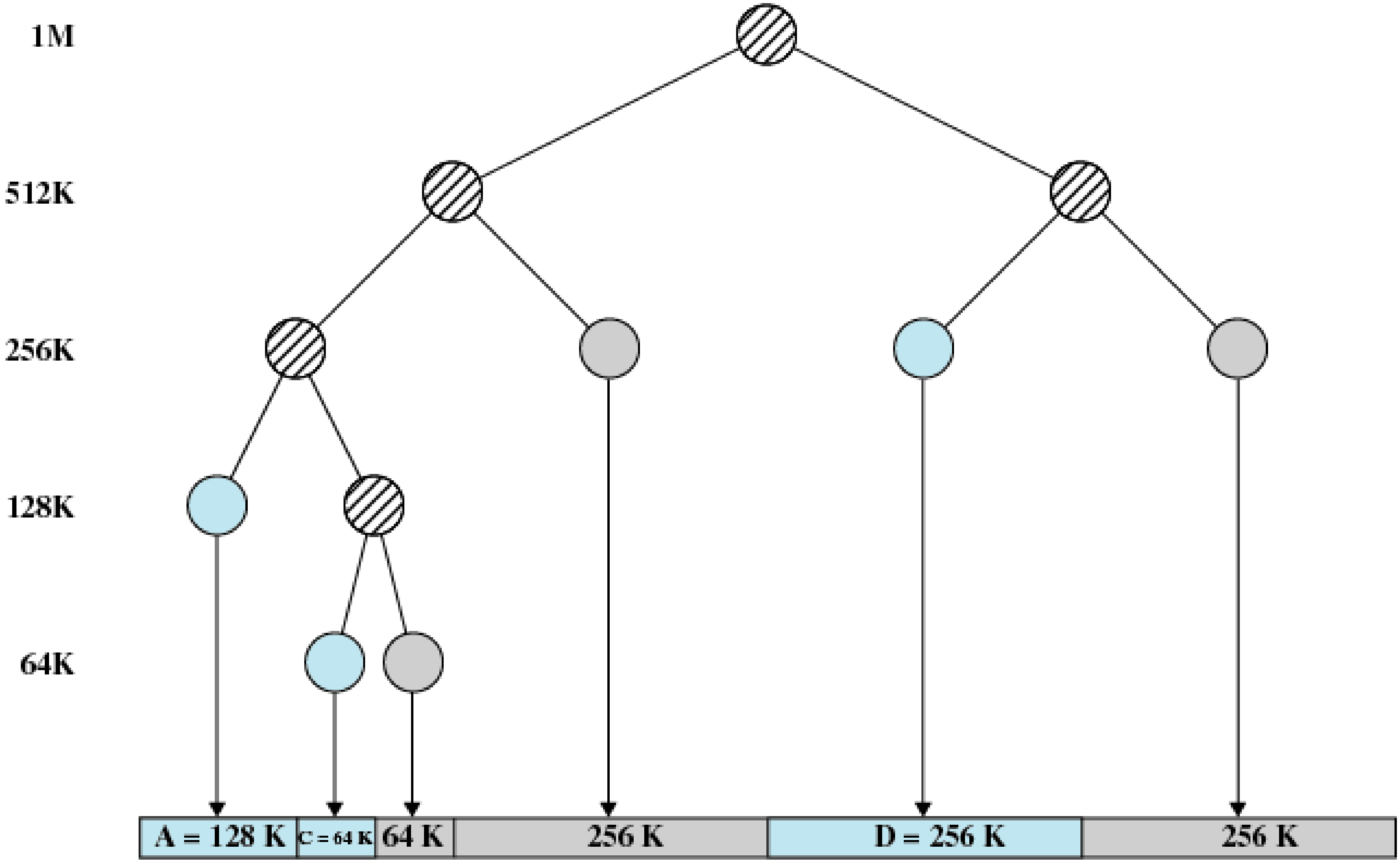
< put b_1 and b_2 into L_i>

c= < first hole in L_i>

<remove c form L_i>

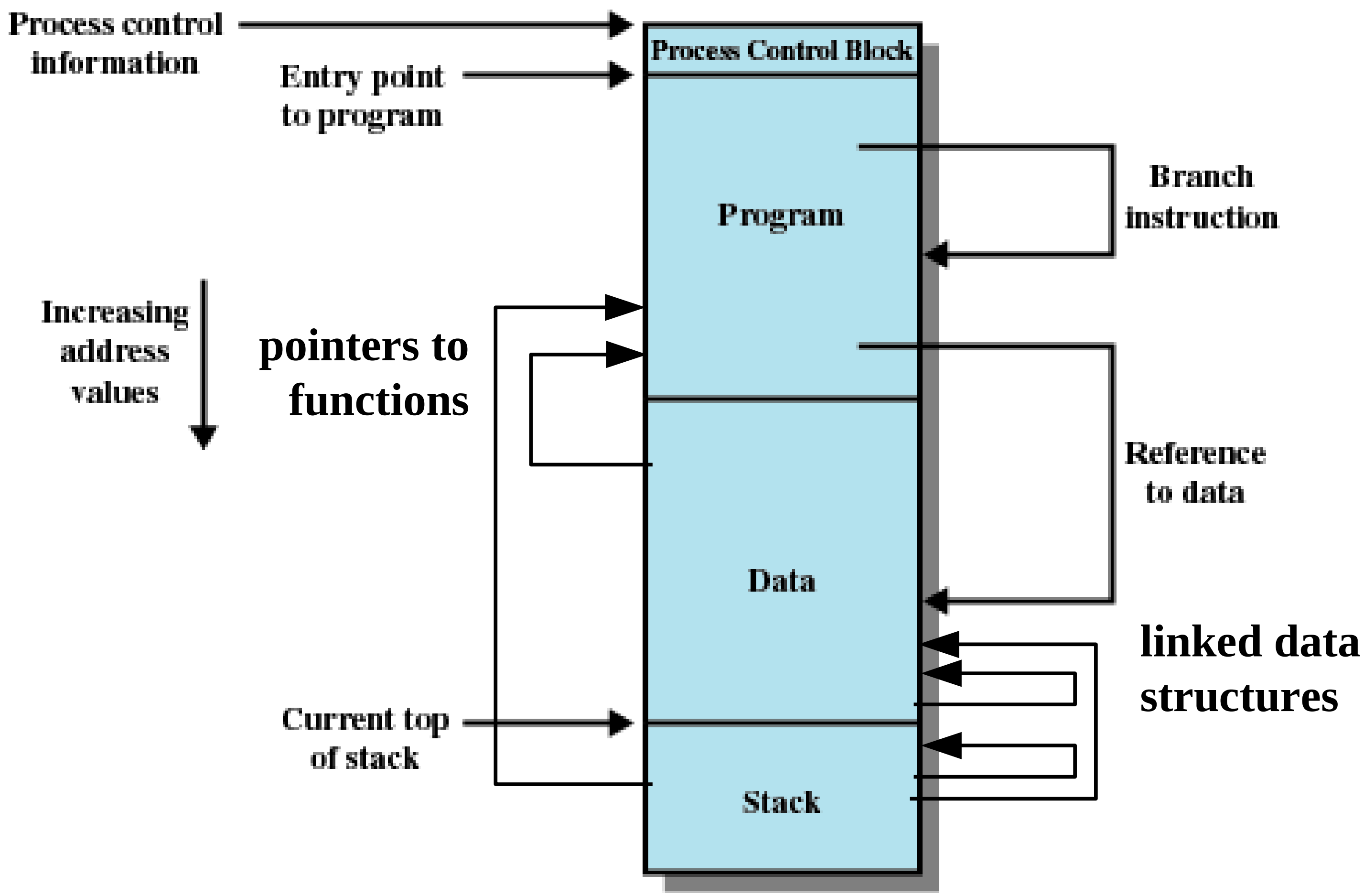
return c

buddy system: tree representation



memory requirements for processes

pointers in processes



relocation for processes

(without hw support)

- when a program is loaded into memory the absolute memory locations are determined
  - different execution may lead to different locations
  - memory references in the code must be translated to actual physical memory address
    - before run or on-the-fly
- on-the-fly relocation during execution
  - swap out and swap in
  - compaction of allocated partitions
- this kind of relocation is part of the linking phase

protection

- processes should not be able to reference memory locations in another process without permission
- references must be checked at run time
  - impossible to check memory references at compile time (may directly depend on the input)
  - exercise: given a generic input and program prove that reference check is not computable! (reduce stopping problem to it)
- memory protection requirement must be satisfied by the processor (hardware) rather than the operating system (software)
  - Operating system cannot anticipate all of the memory references a process will perform

sharing

- allow several processes to access the same portion of memory
- better to allow each process access to the same copy of the program rather than have their own separate copy

logical organization

- programs are written in modules
  - sw engineering reasons: divide the responsibility for development, maintenance, testing, ecc
- modules can be written and compiled independently
- different degrees of protection given to modules (read-only, execute-only)
- share modules among processes

physical organization

- memory available for a program plus its data may be insufficient
  - overlaying allows various modules to be assigned the same region of memory
- programmer does not know how much memory will be available

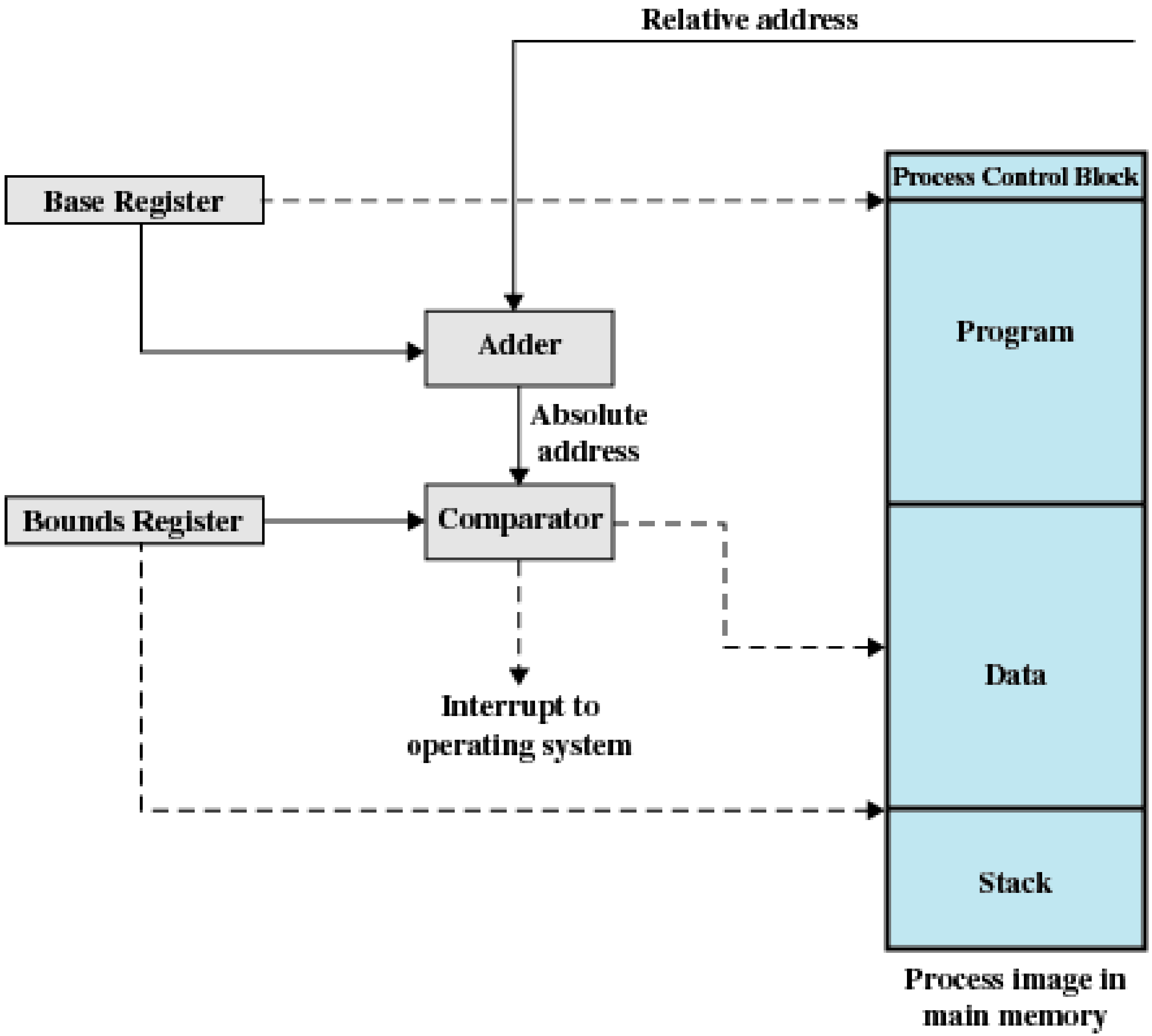
addresses in the program

- Physical
  - The absolute address or actual location in main memory
- Logical
  - Reference to a location in a “logical” memory independent of the current assignment of data to memory
  - Translation must be made to the physical address by the hardware (MMU)
- Relative (logical or physical)
  - Address expressed as a location relative to some known point

hardware support for relocation

- Base register
  - Starting address for the process
- Bounds register
  - Ending location of the process
- These values are set when the process is loaded or when the process is swapped in

hardware support for relocation



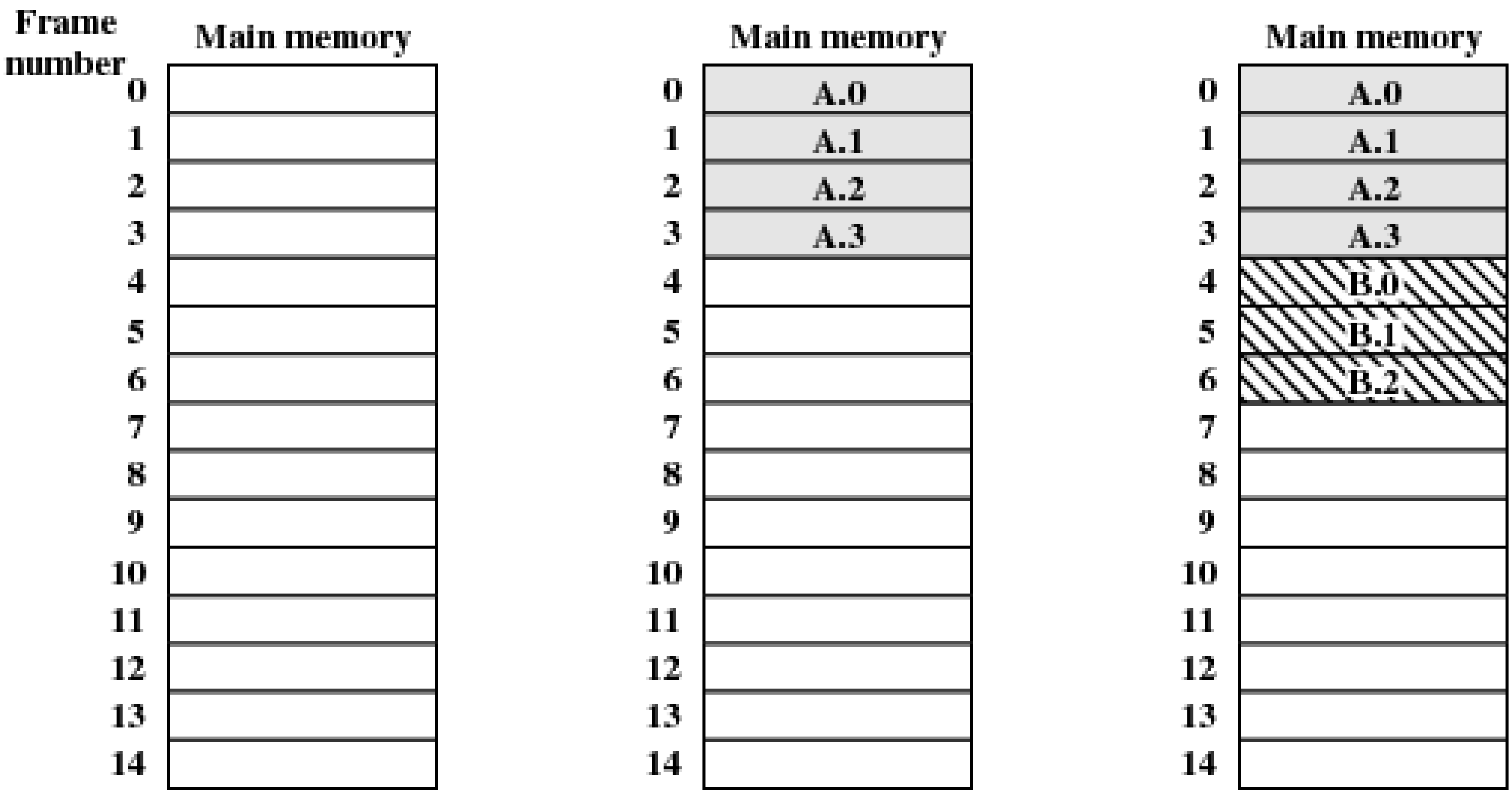
hardware support for relocation

- The value of the base register is added to a relative address to produce an absolute address
- The resulting address is compared with the value in the bounds register
- If the address is not within bounds, an interrupt is generated to the operating system
- If the address is ok it is used to access memory
- relocation is performed by setting appropriate value in the registers

Paging

- Partition memory into small equal fixed-size chunks and divide each process into the same size chunks
- The chunks of a process are called **pages** and chunks of memory are called **frames**
- Operating system maintains a **page table** for each process
  - Contains the **frame location for each page** in the process
  - **Memory address consist of a page number and offset within the page**

Assignment of Process Pages to Free Frames

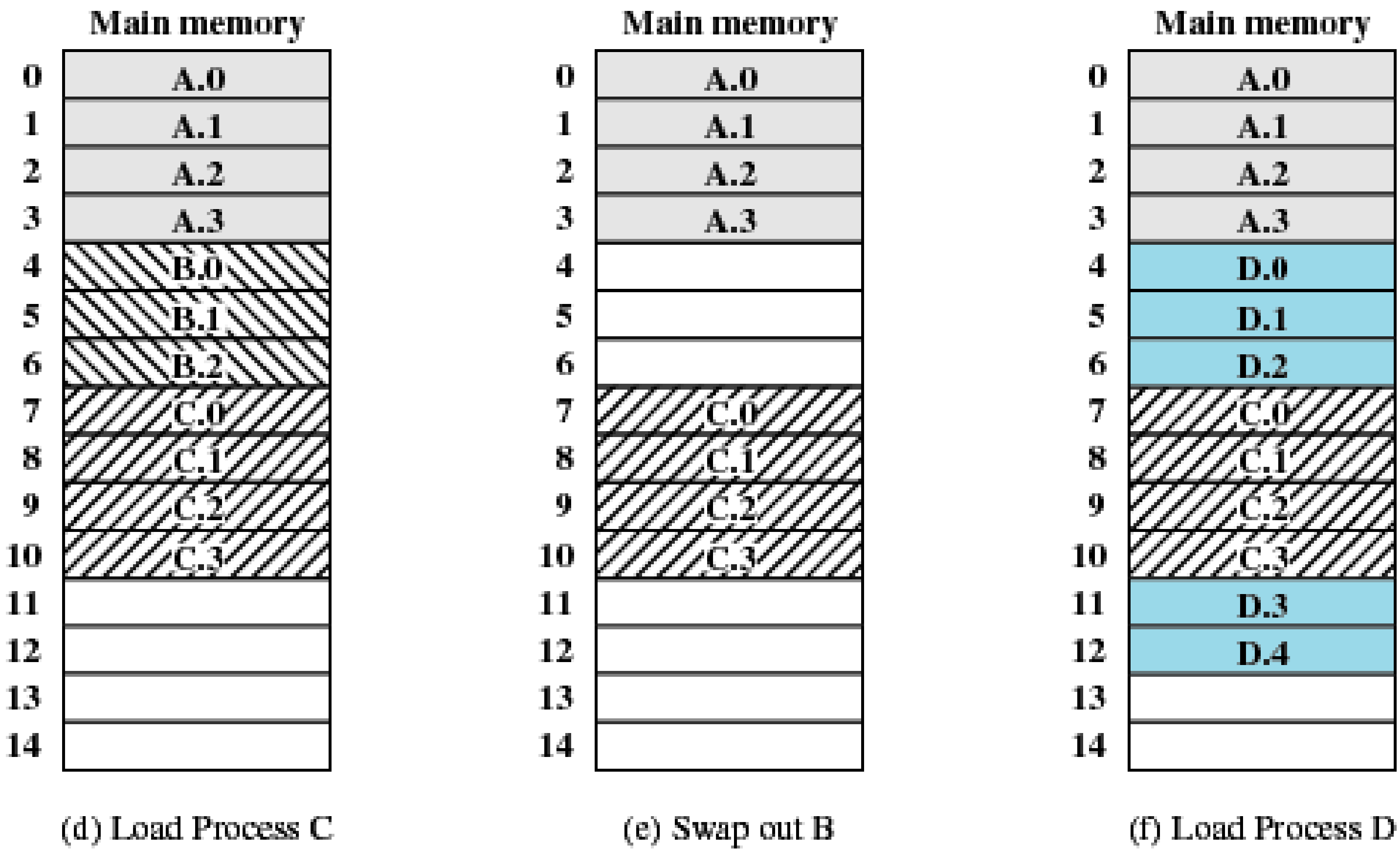


(a) Fifteen Available Frames

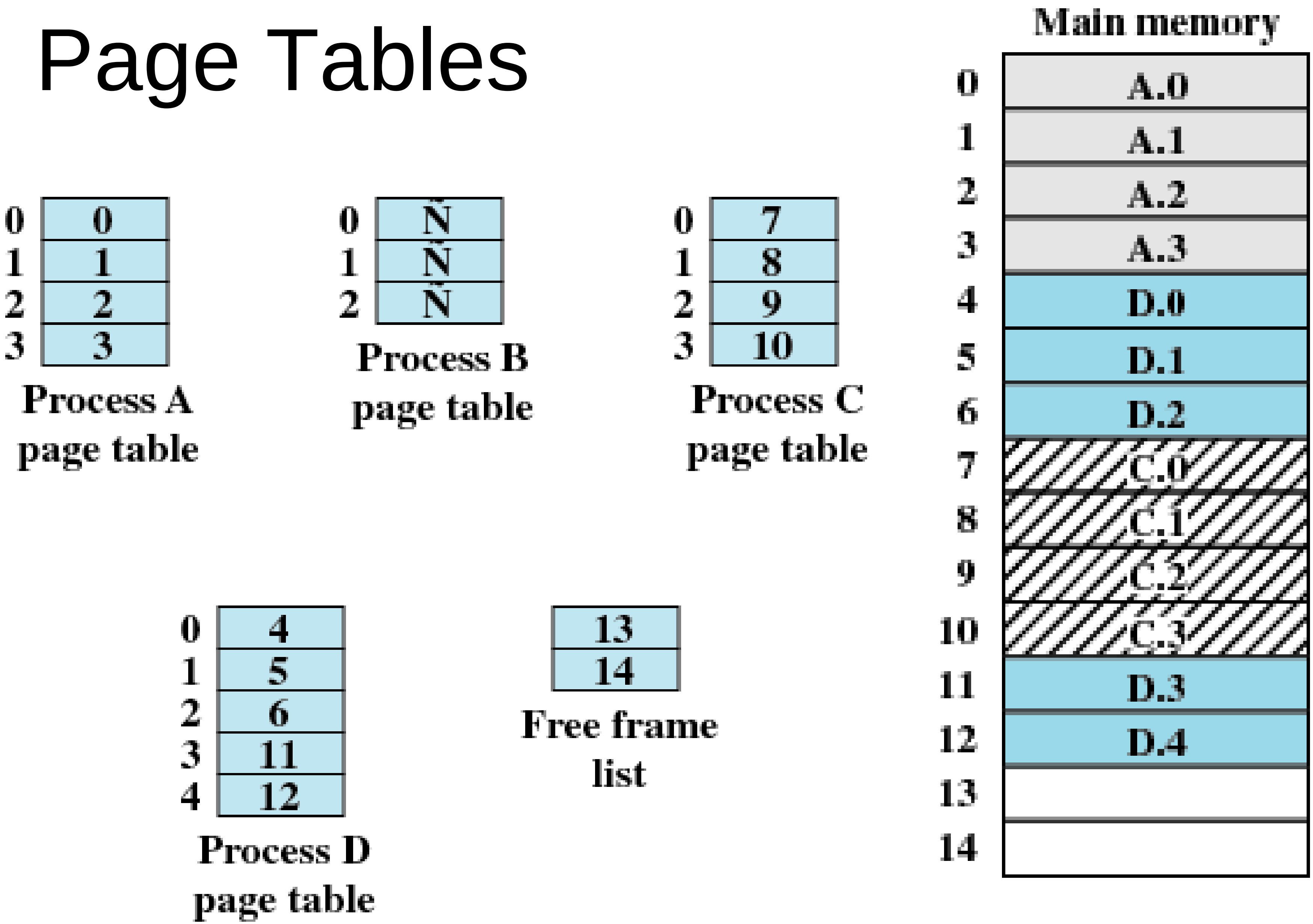
(b) Load Process A

(c) Load Process B

Assignment of Process Pages to Free Frames



Page Tables

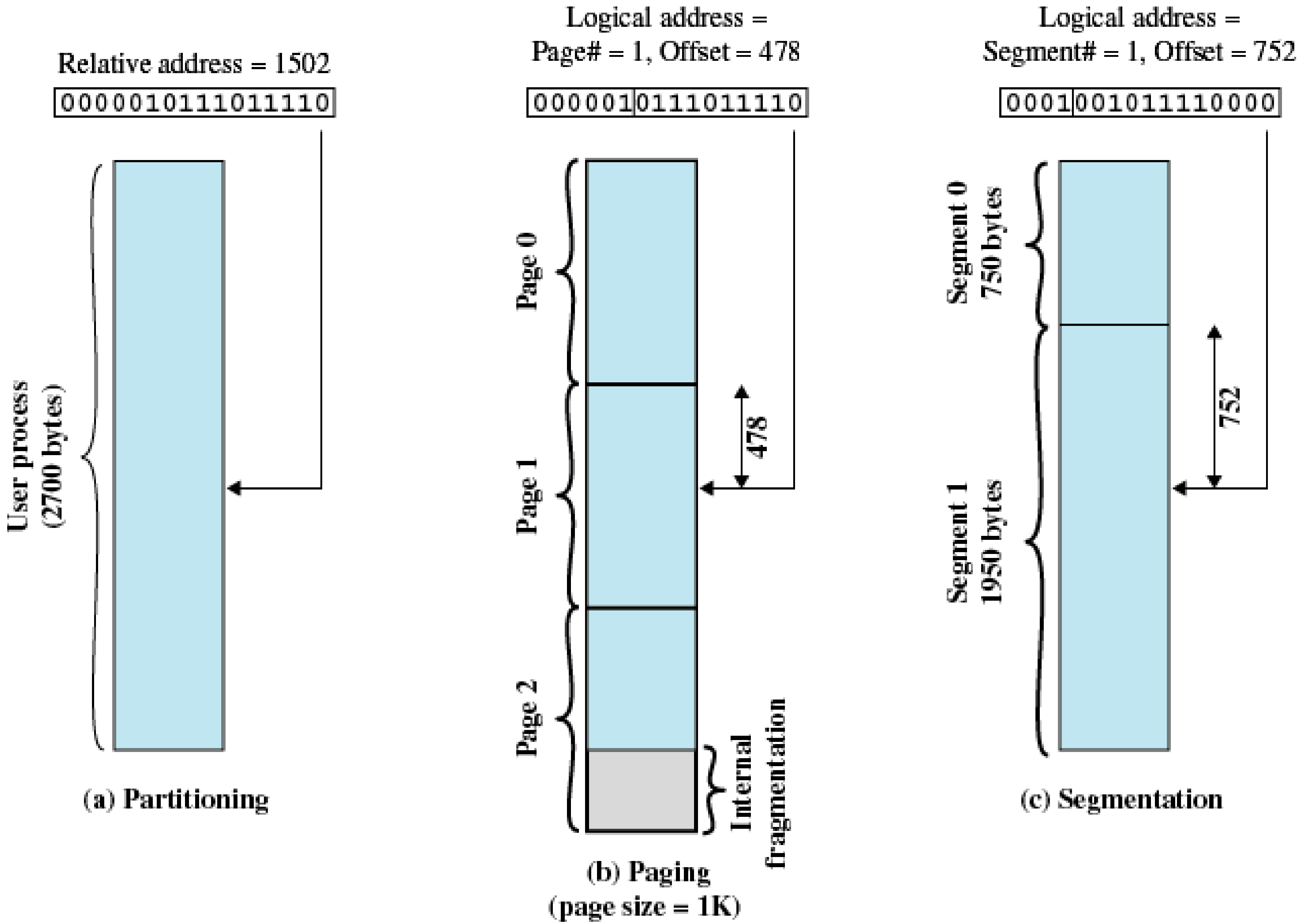


(f) Load Process D

Segmentation

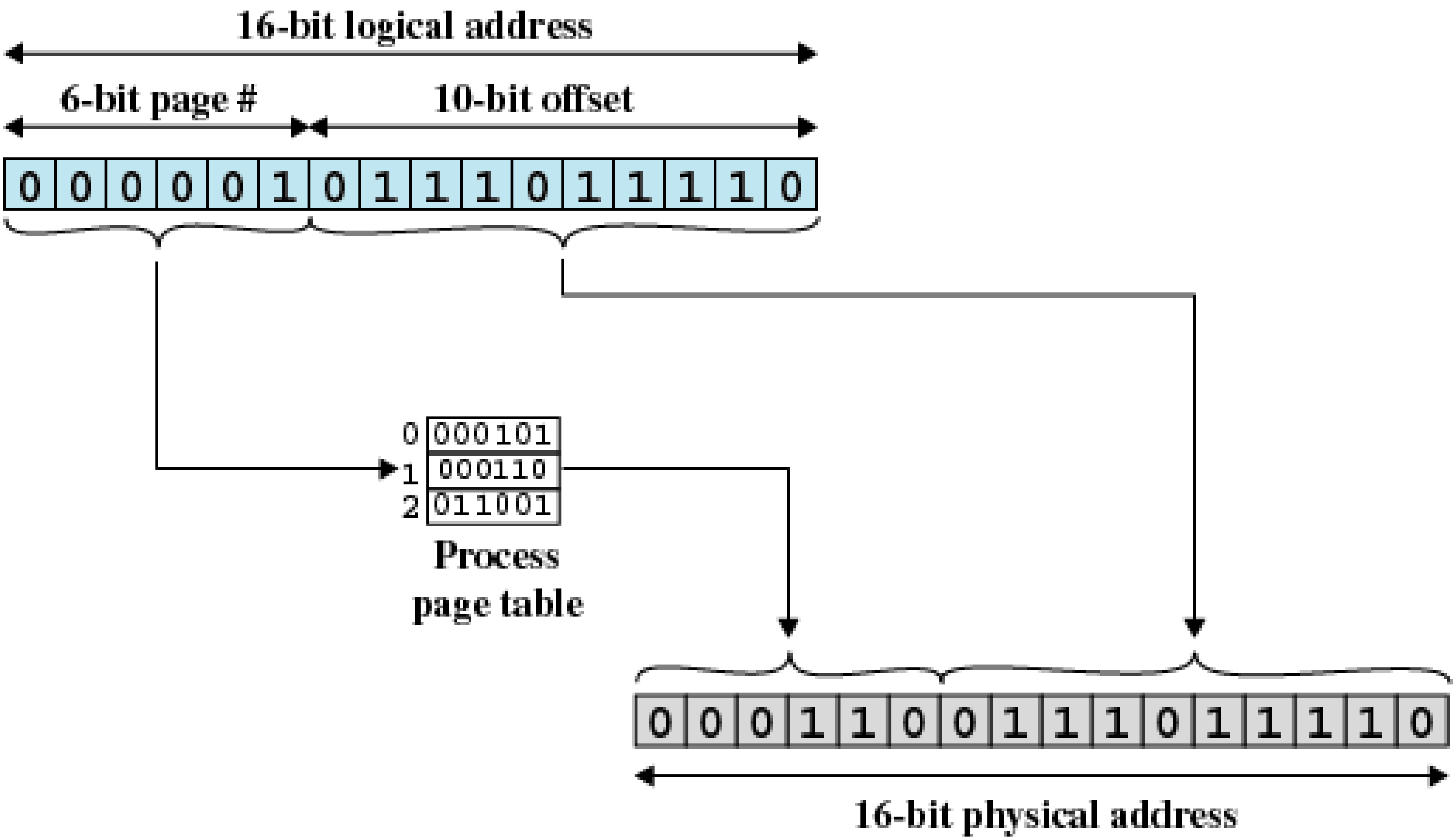
- All segments of all programs do **not** have to be of the **same length**
- There is a maximum segment length
- Addressing consist of two parts - a **segment number and an offset**
- Since segments are not equal, segmentation is similar to dynamic partitioning

paging vs. segmentation



logical to physical translation

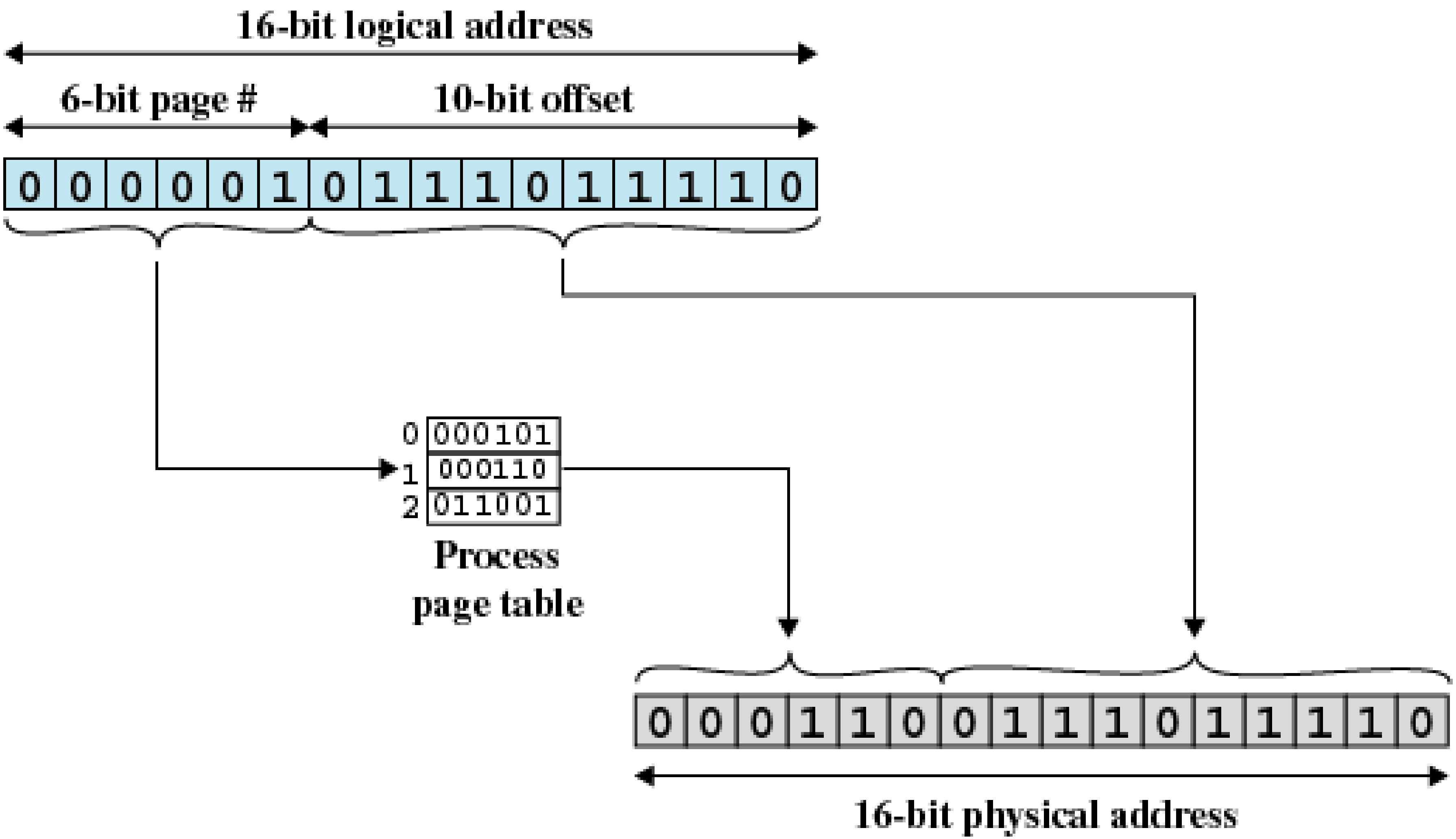
paging



(a) Paging

logical to physical translation

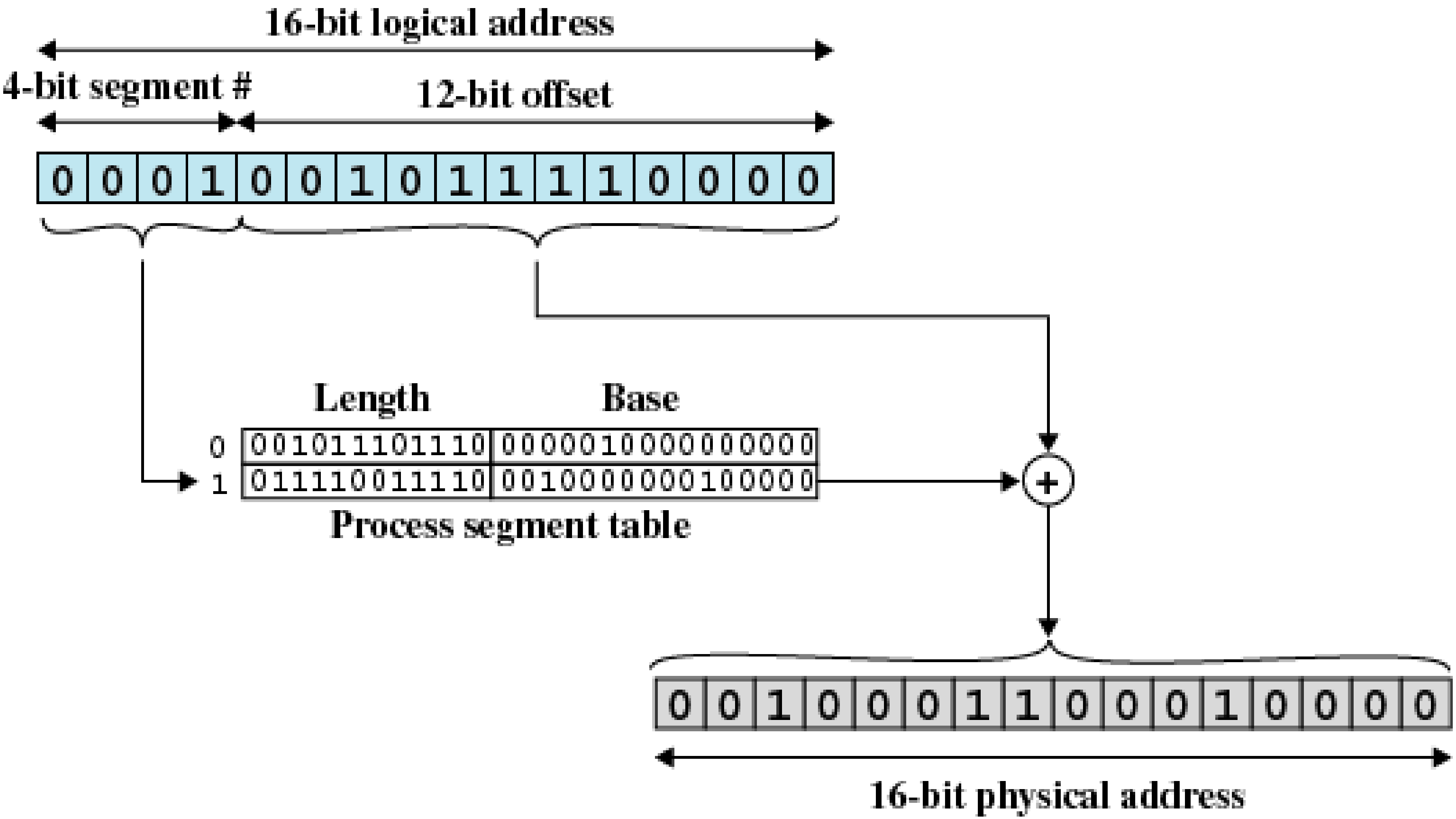
paging



(a) Paging

logical to physical translation

segmentation



(b) Segmentation