Memory Management

COMP3231 Operating Systems

2004 S2

PROCESS

- One or more threads of execution
- Resources required for execution
  - Memory (RAM)
    - program code ("text")
    - data (initialised, uninitialised, stack)
    - buffers etc held by kernel on behalf of process
  - others
    - CPU time
    - files, disk space
    - ...

Memory Management

- ➜ Subdividing memory to accommodate multiple concurrent processes
  (*multiprogramming, multitasking*)
- ➜ Goals:
  - Maximise memory utilisation
  - Maximise processor utilisation
  - Ensure minimum response time
  - Ensure timely execution of "important" processes
- ➜ Conflicting goals $\Rightarrow$ tradeoffs

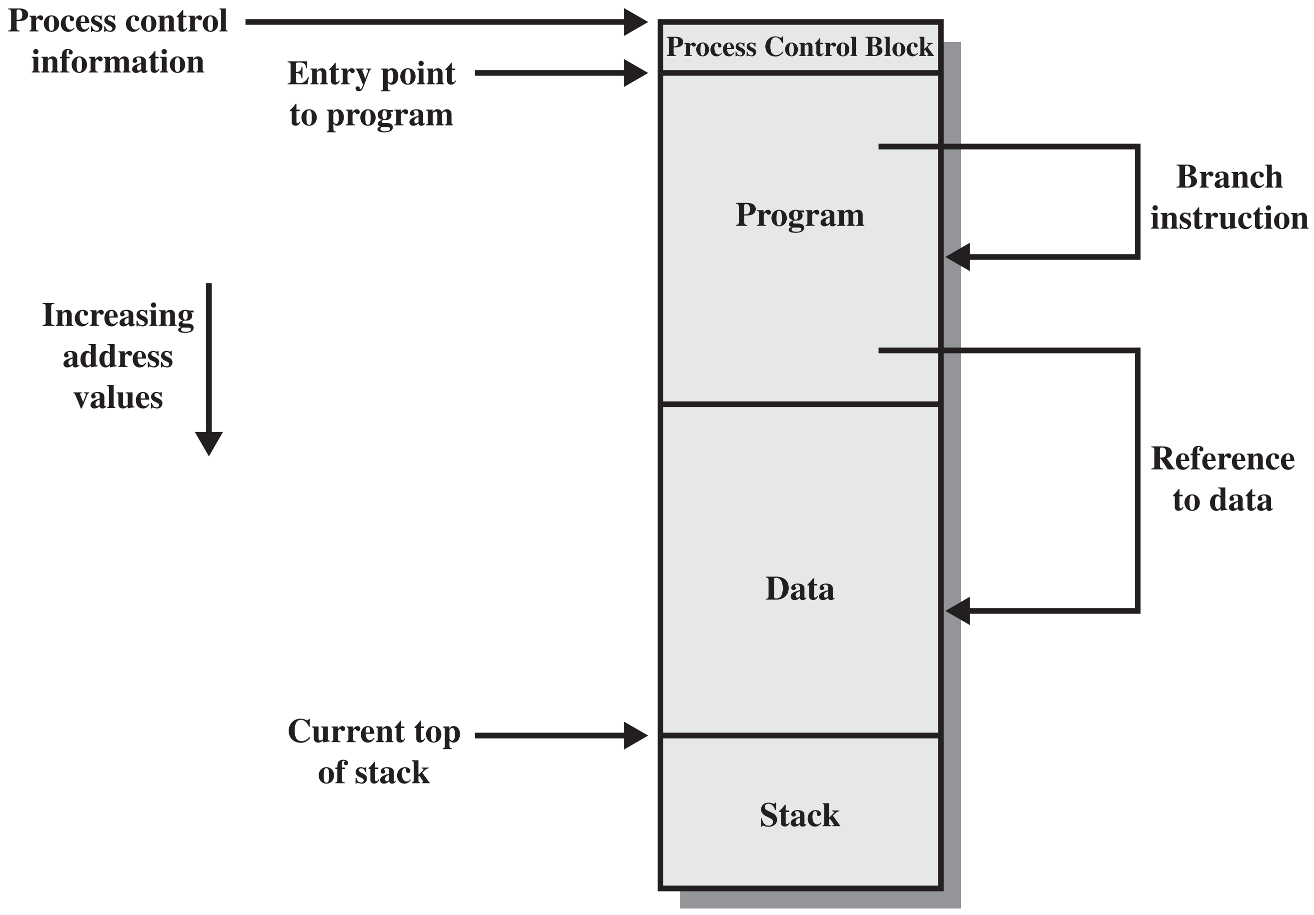
Memory Management Requirements

1. Address binding/relocation::

➜ Actual program location in memory unknown at the time the program is written

- Programs use various forms of symbolic references to data and instructions
- These must be bound to actual physical memory addresses
- Can happen:
  - at compile/link time,
  - at load time,
  - at run (execution) time.

Example logical address-space layout::



Compile/load-time binding::

➜ Can generate absolute addresses at compile/link time

- Must recompile/relink code if starting address changes

Load-time binding::

- ➜ Compiler/linker generates relocatable addresses
- ➜ Loader replaces by absolute addresses once starting address is known
  - Must relink if starting address changes

Run-time binding::

- ➜ Compiler/linker/loader produce logical addresses
- ➜ Hardware translates addresses during execution
  - Allows dynamic relocation (moving) of program

Dynamic linking::

- ➜ Libraries not linked (copied) into executable file
- ➜ Libraries are linked to program at load time
- ➜ Library entry points are accessed via jump table initialised by dynamic linke
- ➜ Supports sharing of library code between programs

Dynamic loading::

- ➜ Library code is not loaded until actually invoked
- ➜ Entrypoint table initially points to dynamic loader
- ➜ After loading library, loader resets entrypoint addresses.

2. Protection::

➜ Processes should not be able to reference memory locations in another process without permission

- Impossible to check absolute addresses in programs since the program could be relocated
- Checks must be done at run-time
  - Requires hardware

3. Sharing::

- ➜ Allow several processes to access the same portion of memory
  - Shared code $\Rightarrow$ better memory utilisation
  - Communication via shared data
- ➜ Selective sharing requires hardware support

4. Logical Organisation:

- ➜ Software engineering:
  - Programs are written in modules
  - Modules can be written and compiled independently
  - Different degrees of protection given to modules (read-only, execute-only)
  - Share modules
- ➜ Needs OS support

5. Physical Organisation:

- ➜ 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 space will be available
  - Memory size of system?
  - How many active processes?
- ➜ OS should abstract physical organisation

Simple MM Approach: Fixed Partitioning

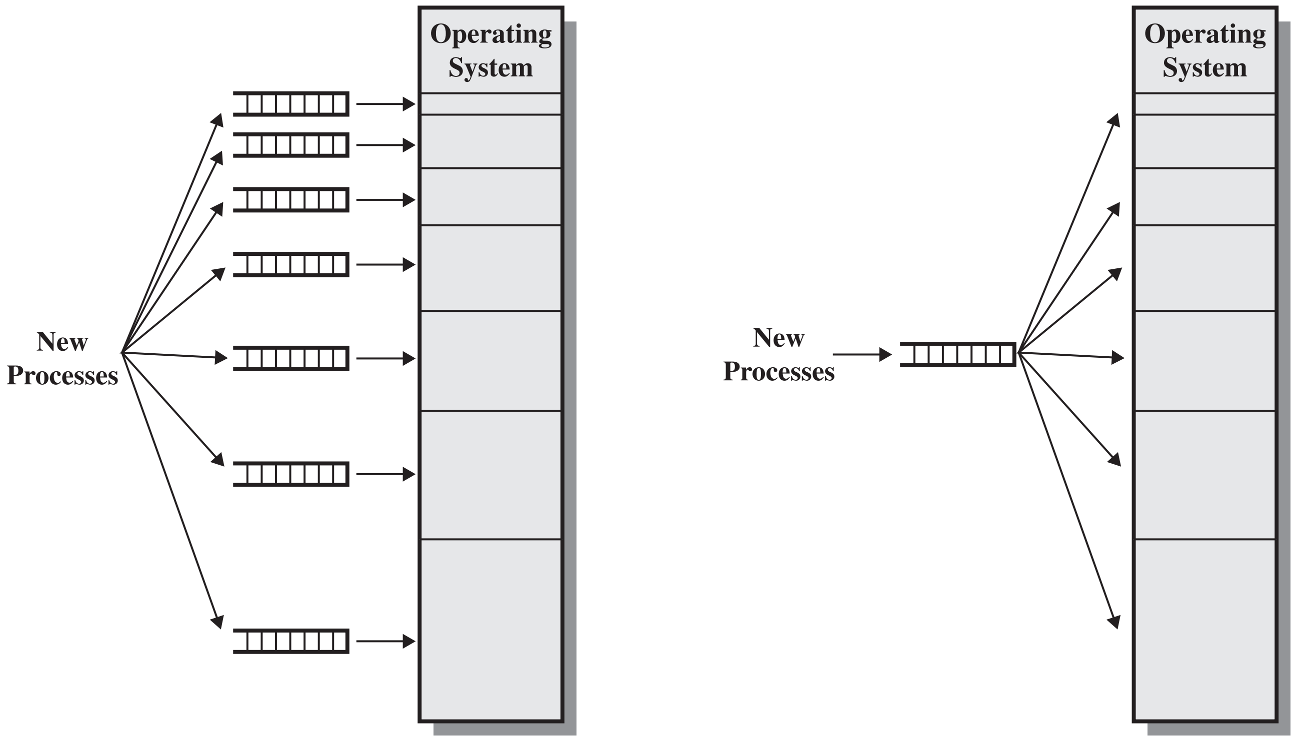
Equal-size partitions::

- ➜ Any process $\leq$ partition size can be loaded into any partition
- ➜ If all partitions are full, swap out some process
- ➜ A program may not fit in a partition.
  - The programmer must design the program with overlays
- ➜ Any unused space within a partition is wasted:
  - Called internal fragmentation

Unequal-size partitions::

- ➜ Assign process to the smallest partition within which it will fit
- ➜ Reduces internal fragmentation
- ➜ May have contention for some partitions while others are unused
  - reduces memory and CPU utilisation
  - can allocate bigger partition (increases internal fragmentation)

Memory allocation for fixed partitioning::



(a) One process queue per partition

(b) Single queue

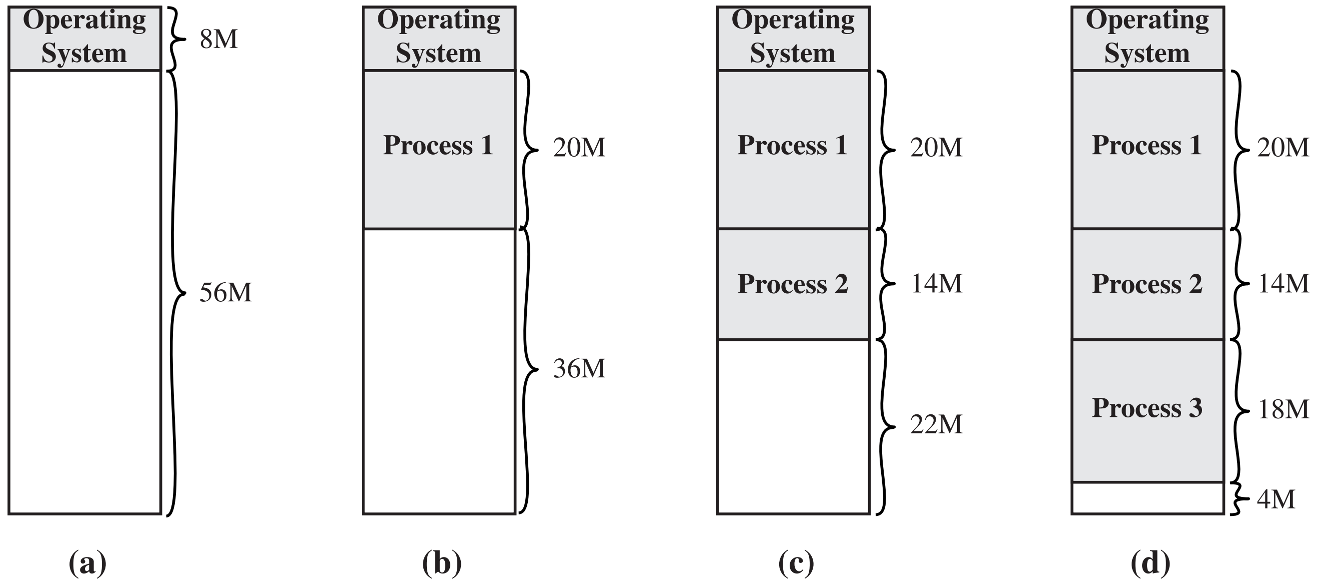
Fixed partitioning summary:

- ➜ Simple
- ➜ Low CPU overhead
- ➜ Poor memory utilisation
- ➜ limits number of processes
- ➜ no support for
  - sharing
  - logical organisation
  - abstracting physical organisation

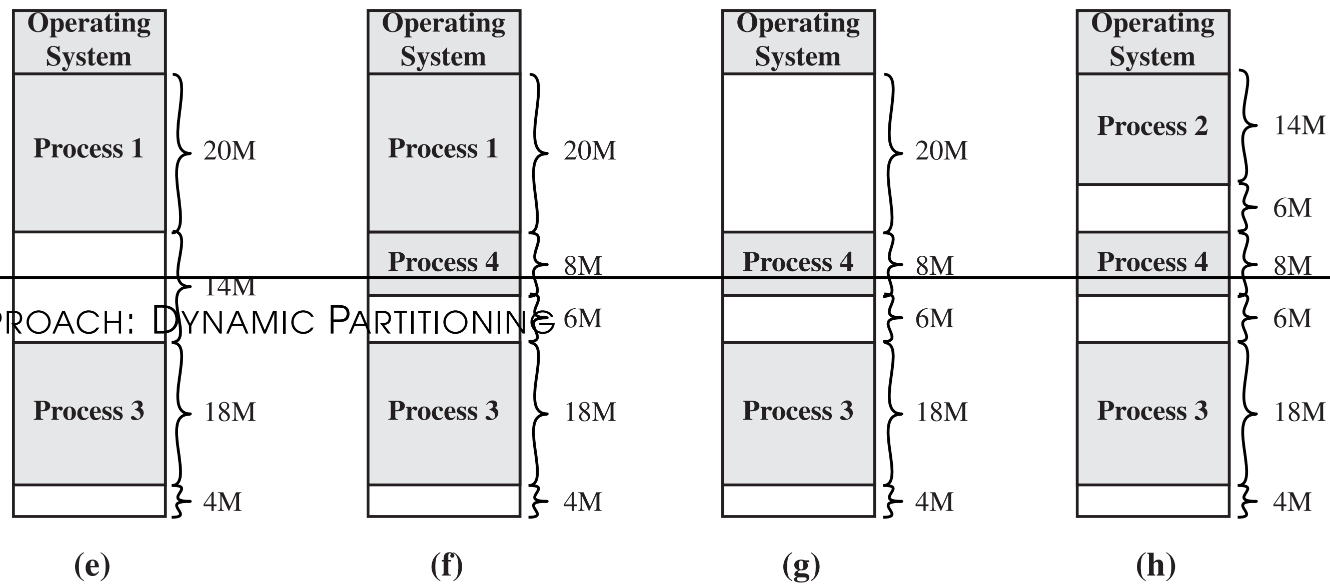
Simple MM Approach: Dynamic Partitioning

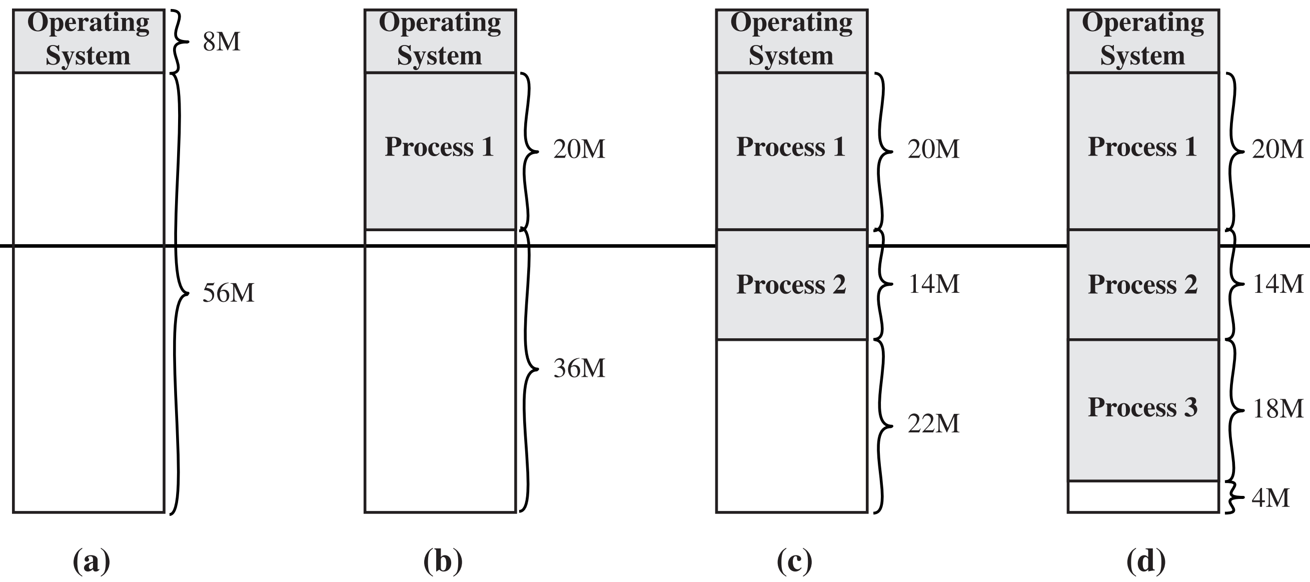
- ➜ Partitions are of variable length and number
- ➜ Process is allocated exactly as much memory as required
- ➜ Eventually get unusable holes in the memory.
  - Called external fragmentation
- ➜ Must use compaction to free up memory
  - shift processes so they are contiguous and all free memory is in one block

External fragmentation::

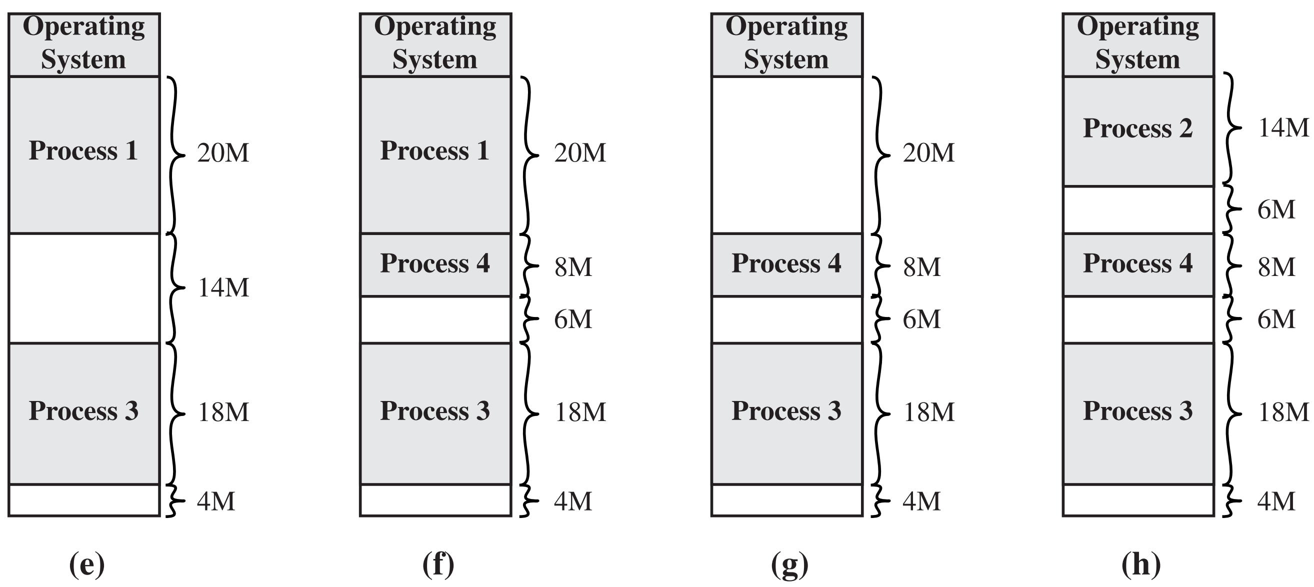


Now swap out process 2 to make space for process 4:





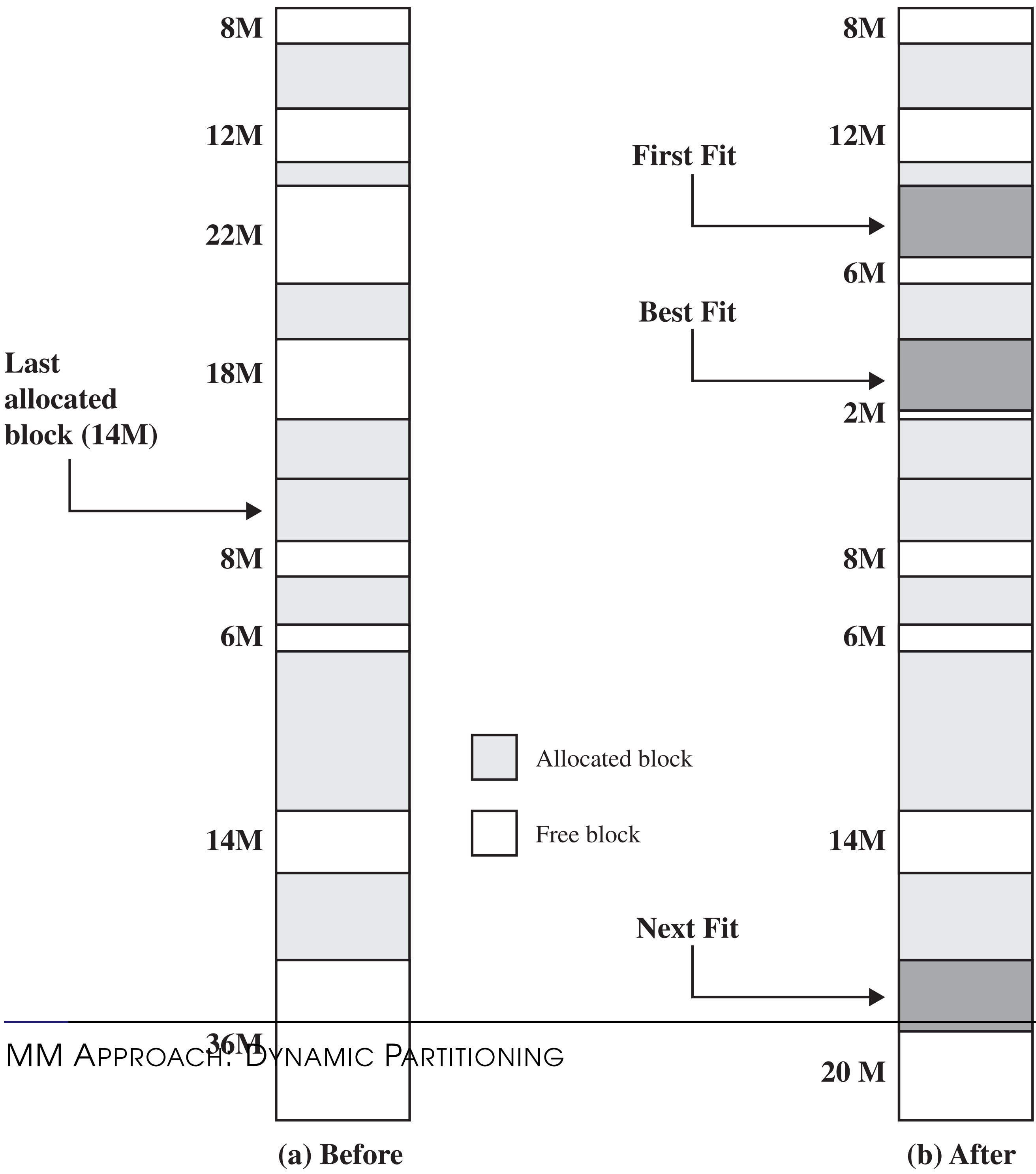
External fragmentation...:



Dynamic Partitioning Placement Algorithms: OS must pick free block to allocate to a process

- ➜ Best-fit algorithm:
  - Chooses the block that is closest in size to the request
  - Maintain block list in size order
  - Leaves small fragments, unlikely to be useful
  - Tends to be slow
- ➜ First-fit algorithm:
  - Use first block big enough
  - Maintain block list in address order
  - May have to search frequently past same allocated blocks
- ➜ Next-fit algorithm:
  - Continue search from where last allocation was made

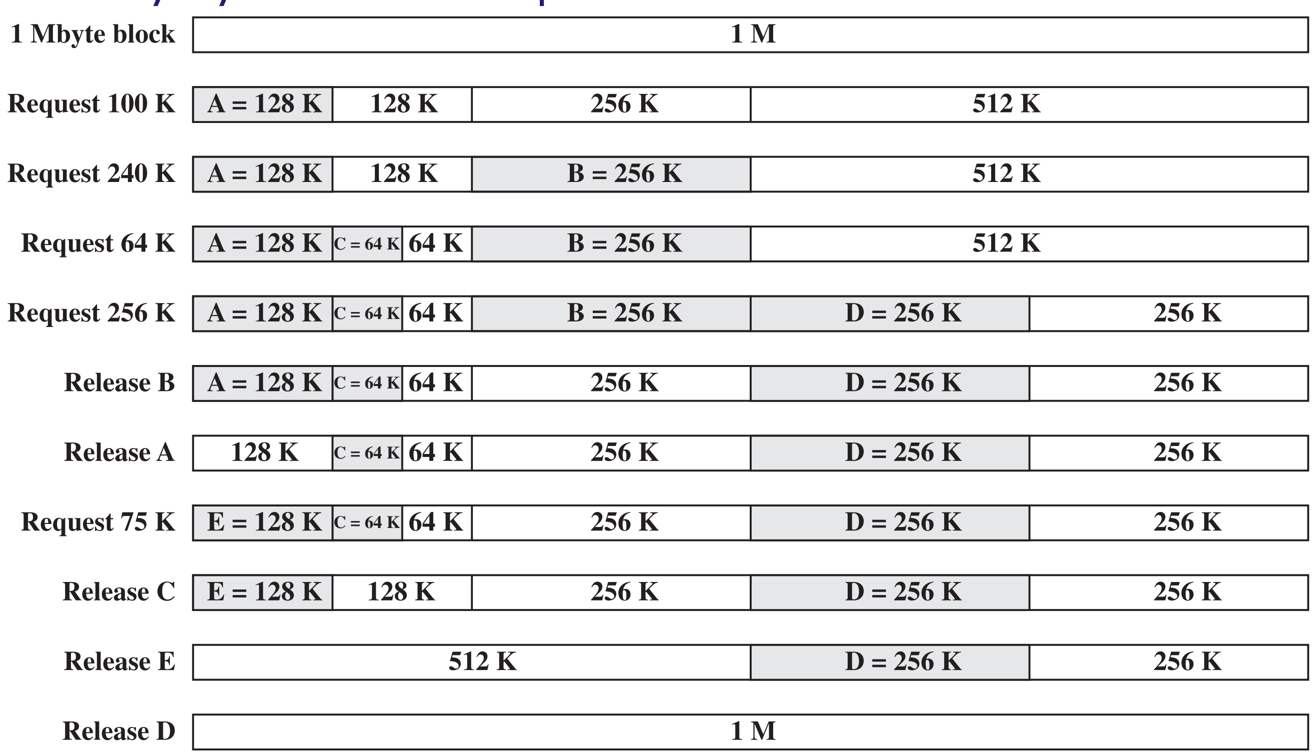
Example:: Allocate 16M


8M
12M
22M
18M
Last
allocated
block (14M)
8M
6M
14M
36M
(a) Before
Allocated block
Free block
8M
12M
First Fit
6M
Best Fit
2M
8M
6M
14M
Next Fit
20 M
(b) After

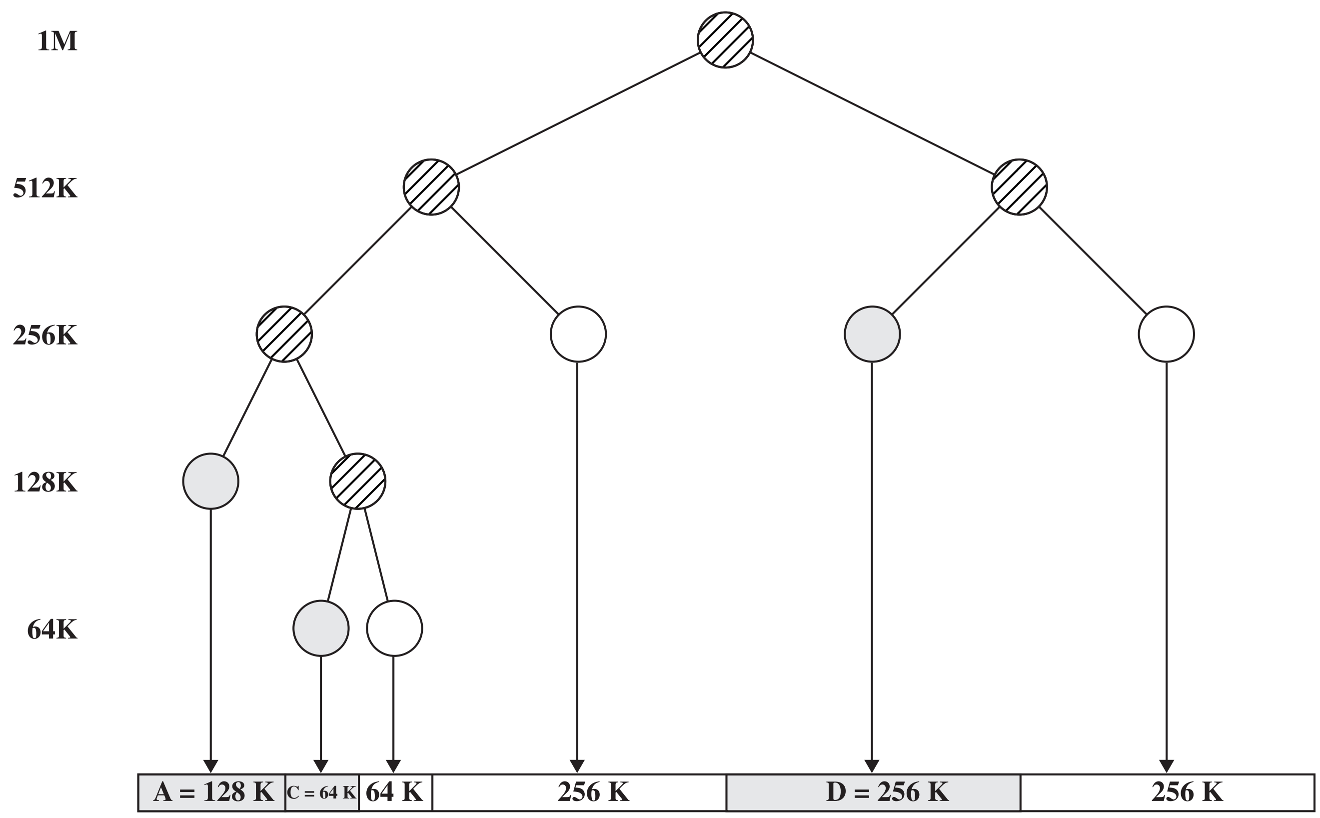
Dynamic partitioning: buddy system:

- ➜ 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 suitable size block of size 2^b is generated, so that $2^{b-1} < s \leq 2^b$
- ➜ Useful also for dynamic heap management (`malloc()`)

Buddy system example::



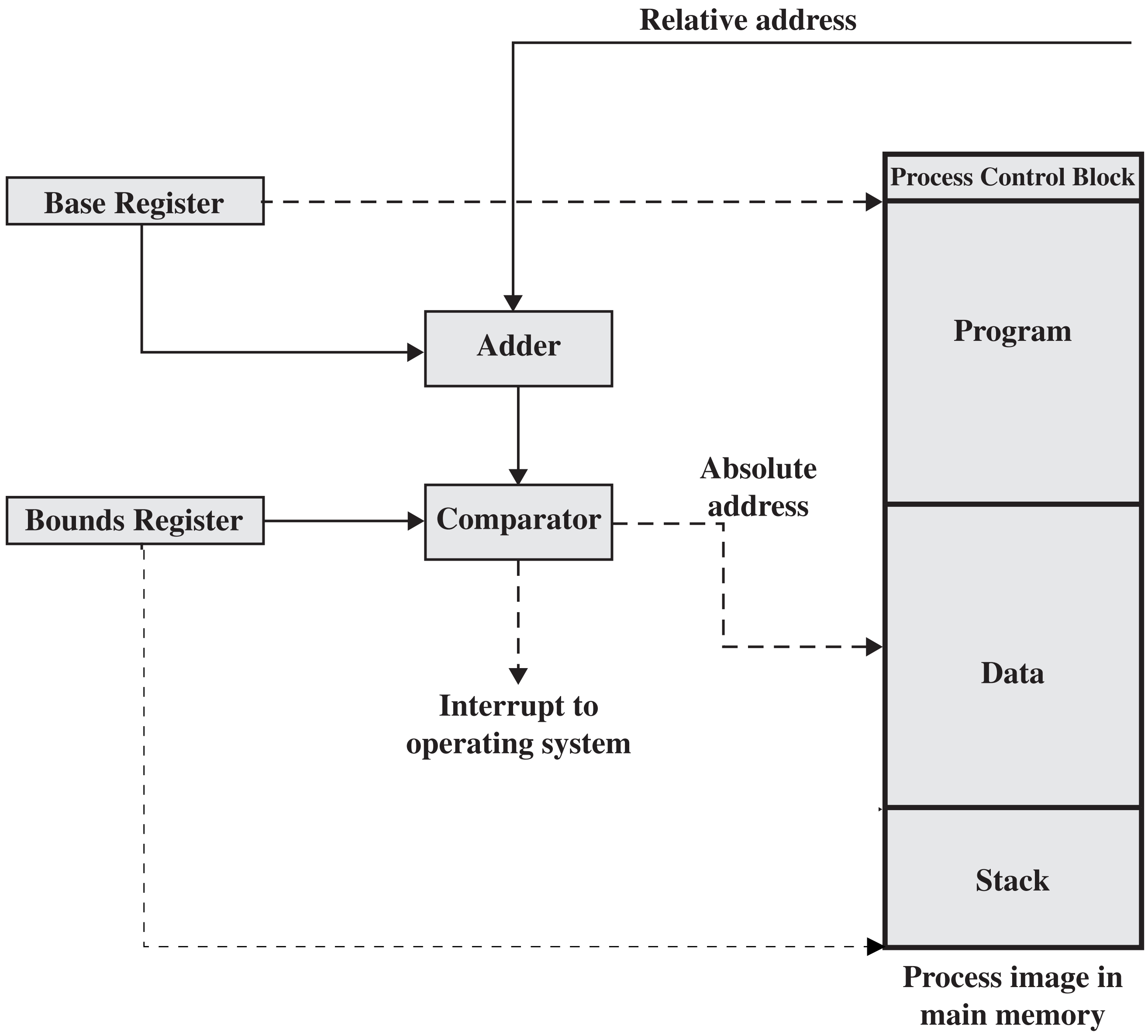
Buddy system representation::



Relocation::

- ➜ Program uses logical (or virtual) addresses
- ➜ Actual (absolute or physical) addresses are determined at load time
- ➜ Addresses change at run time due to
  - swapping
  - compaction
- ➜ Requires address translation at run time (by hardware)
- ➜ This approach to memory management is called virtual memory

Minimal hardware support for relocation:


Relative address
Base Register
Process Control Block
Program
Adder
Absolute
address
Bounds Register
Comparator
Data
Interrupt to
operating system
Stack
Process image in
main memory

Registers used during execution::

➜ Base register

- starting address for the process
- added to logical address to obtain absolute address

➜ Limit (bounds) register

- ending location of the process
- compared to absolute address to detect address-range violation

➜ Set at load or relocation time

➜ Part of process context

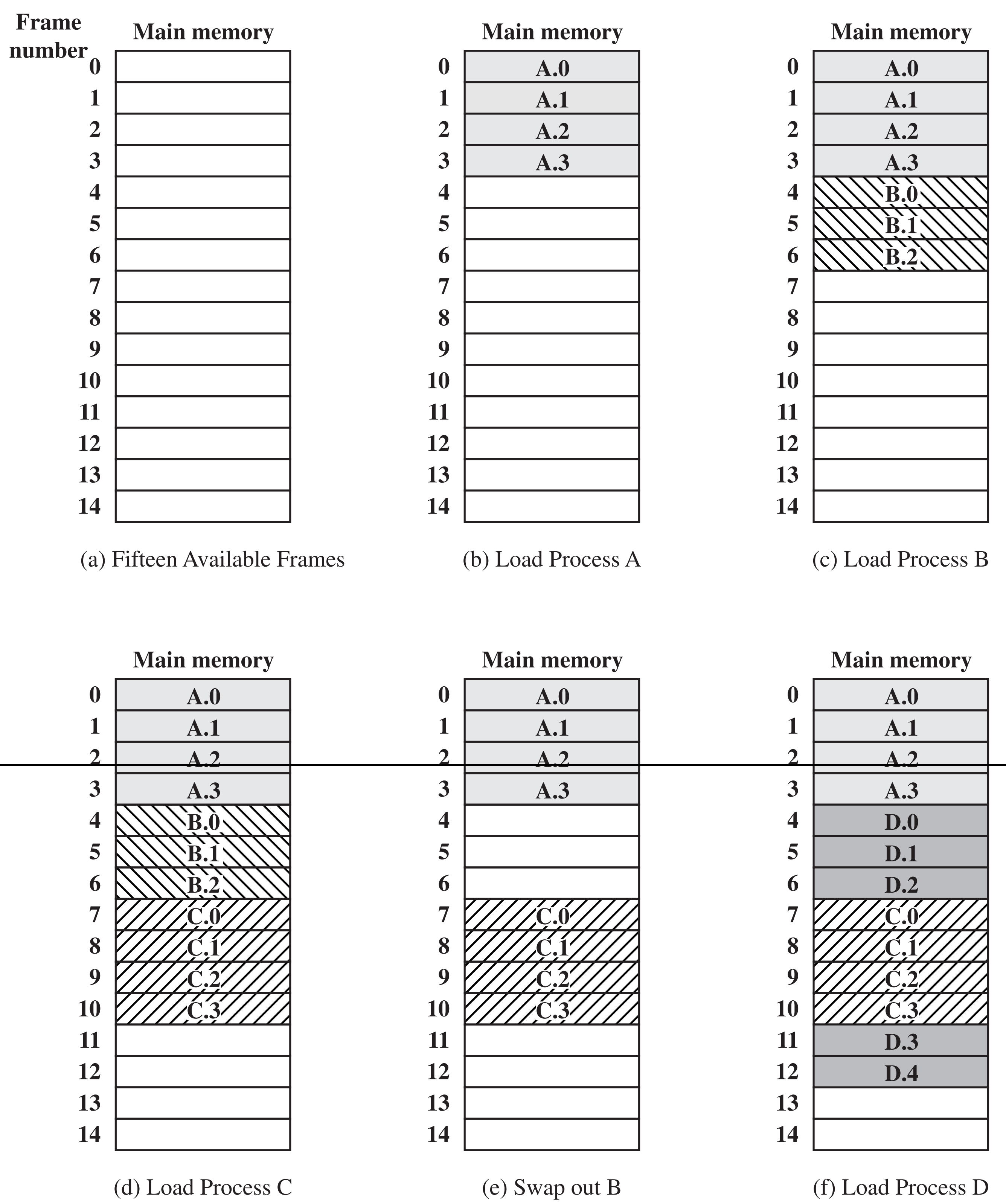
➜ Implies contiguous allocation of physical memory

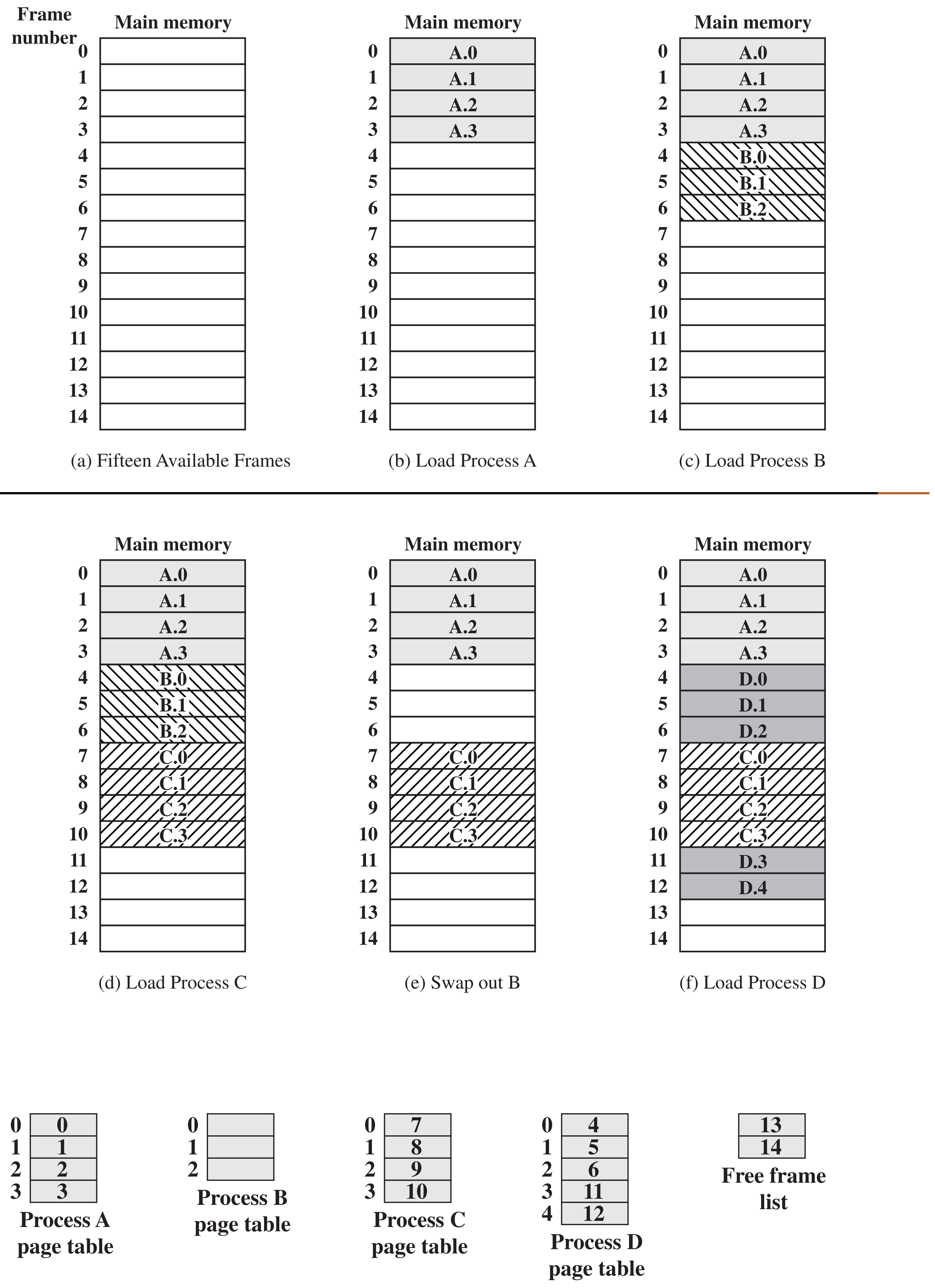
➜ Cannot support partial sharing of address spaces

Paging

- Partition physical memory into small equal-size chunks
  - called frames
- divide each process' (virtual) address space into the same size chunks
  - called pages
  - virtual memory address consist of page number and offset within the page
- OS maintains a page table for each process
  - contains the frame location for each page in the process
- Process' physical memory does **not** have to be contiguous

Page assignment::




Frame number
Main memory
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
(a) Fifteen Available Frames
A.0 A.1 A.2 A.3
(b) Load Process A
A.0 A.1 A.2 A.3 B.0 B.1 B.2
(c) Load Process B
A.0 A.1 A.2 A.3 B.0 B.1 B.2 C.0 C.1 C.2 C.3
(d) Load Process C
A.0 A.1 A.2 A.3 C.0 C.1 C.2 C.3
(e) Swap out B
A.0 A.1 A.2 A.3 D.0 D.1 D.2 C.0 C.1 C.2 C.3 D.3 D.4
(f) Load Process D
Process A page table
Process B page table
Process C page table
Process D page table
Free frame list
13
14

Paging::

- No external fragmentation
- Small internal fragmentation
- Allows sharing by mapping several pages to the same frame
- Abstracts physical organisation
- Moderate support for logical organisation

SEGMENTATION

- ➜ Instead of equal-size pages use arbitrary-sized segments
- ➜ Address consist of two parts: segment number and offset
- ➜ Properties:
  - Supports sharing by mapping several segments to same PM
  - Supports logical organisation
  - Abstracts physical organisation
- ➜ Since segments are not equal get similar issues as with dynamic partitioning
  - no internal fragmentation
  - significant external fragmentation