MODERN OPERATING SYSTEMS

Third Edition

ANDREW S. TANENBAUM

Chapter 3
Memory Management

No Memory Abstraction

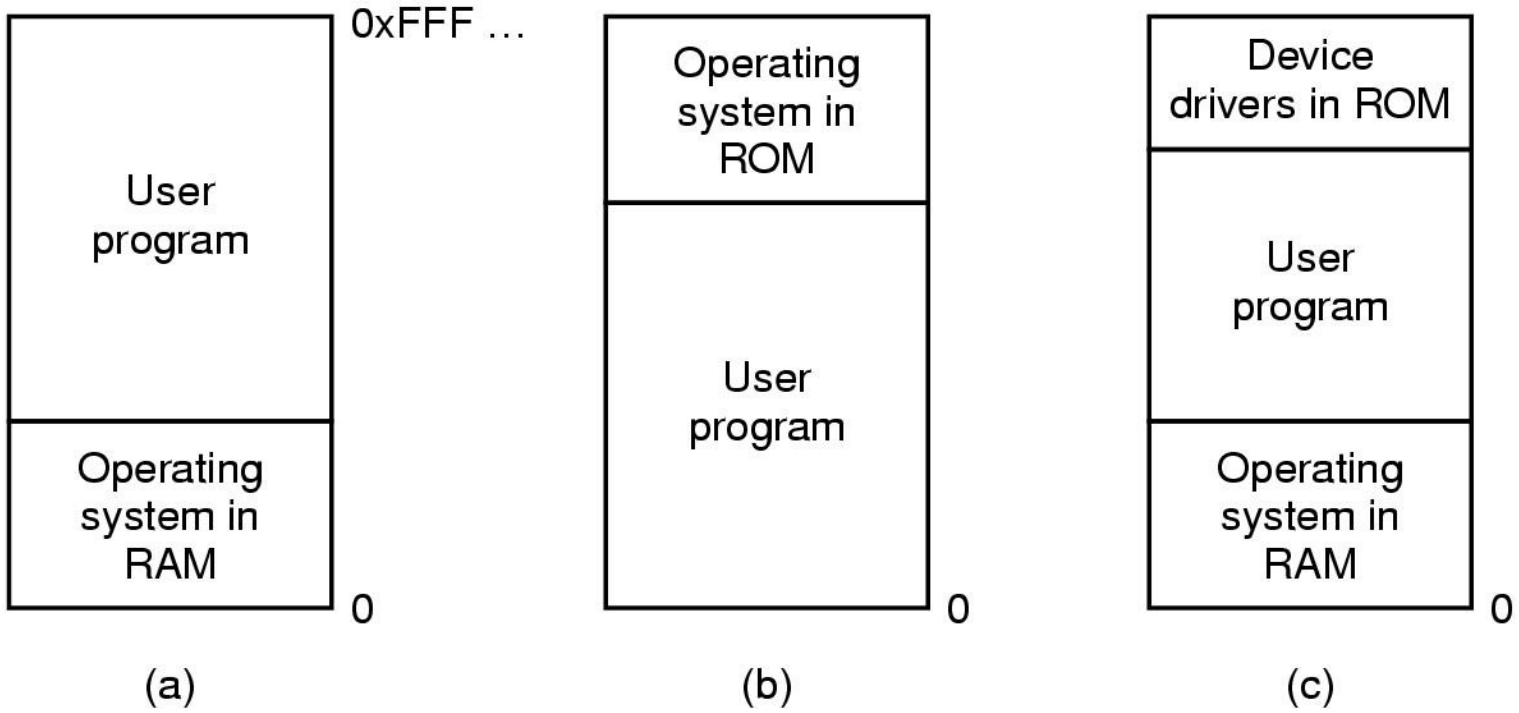


Figure 3-1. Three simple ways of organizing memory with an operating system and one user process.

Base and Limit Registers

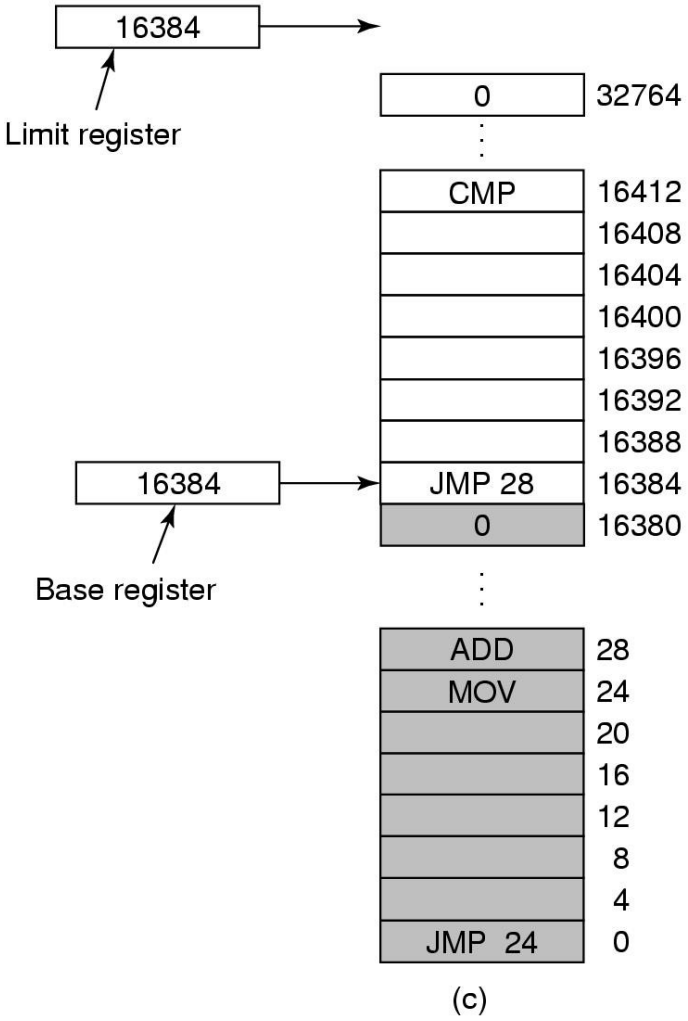


Figure 3-3. Base and limit registers can be used to give each process a separate address space.

Swapping (1)

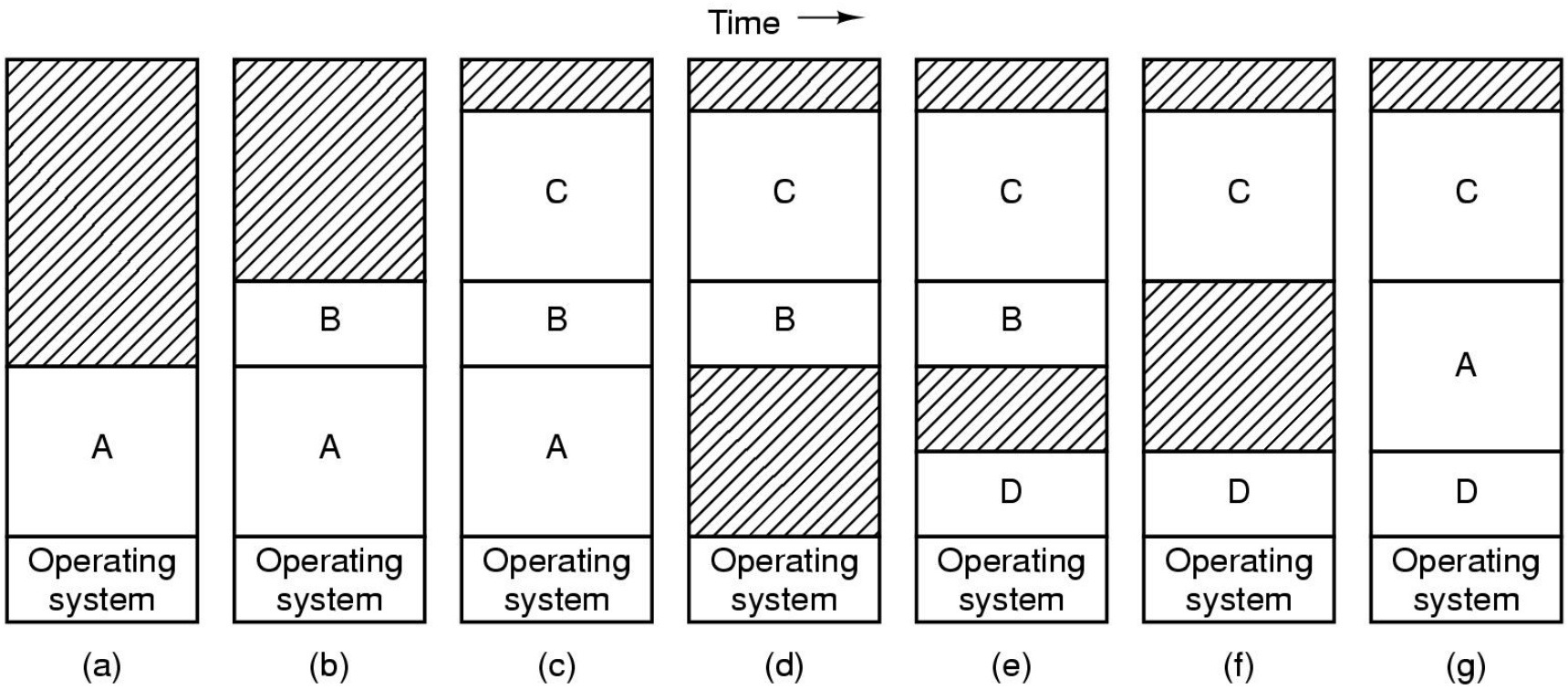


Figure 3-4. Memory allocation changes as processes come into memory and leave it. The shaded regions are unused memory.

Swapping (2)

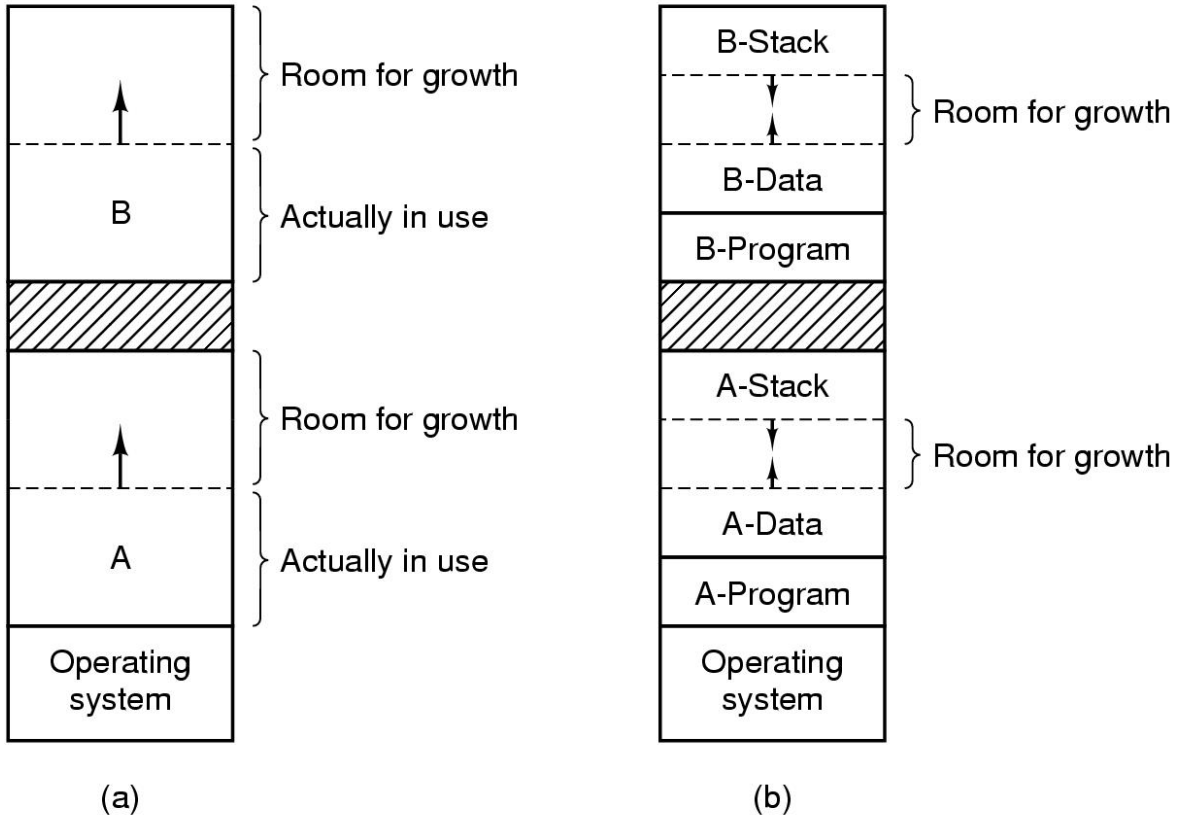


Figure 3-5. (a) Allocating space for growing data segment. (b) Allocating space for growing stack, growing data segment.

Memory Management with Bitmaps

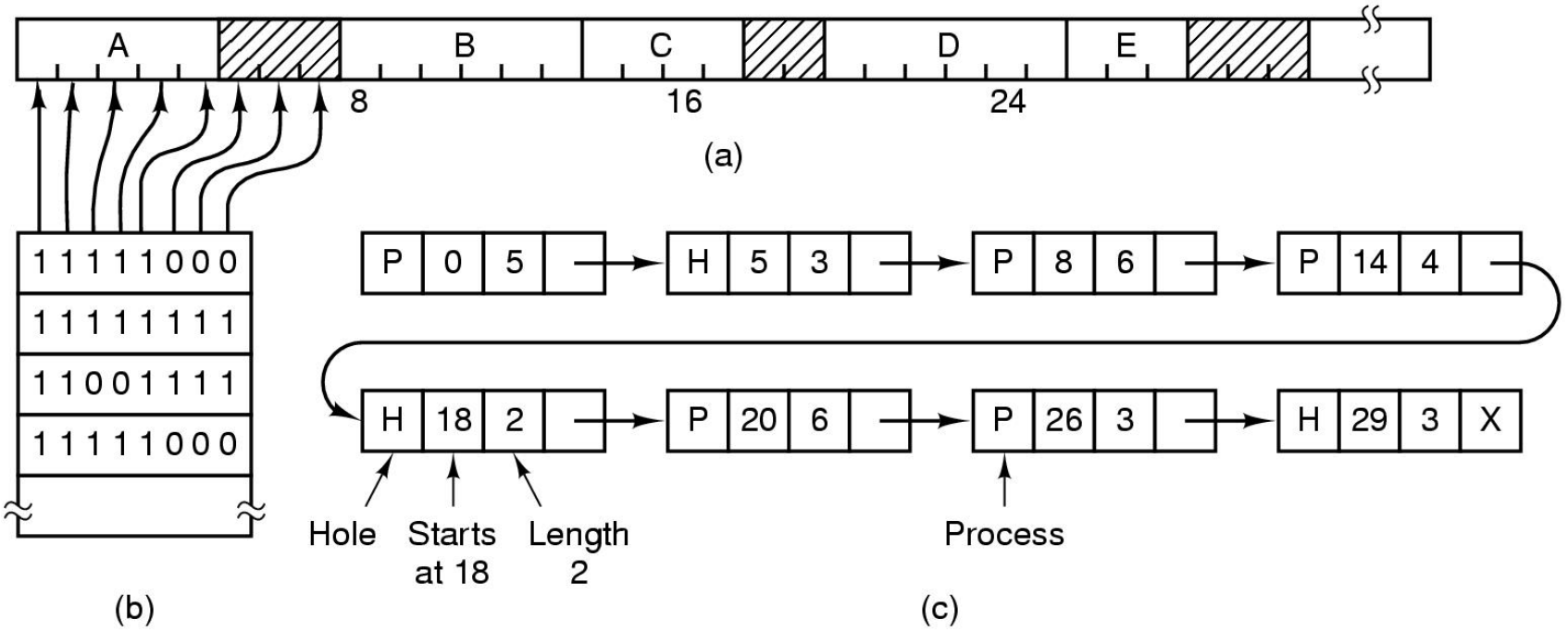


Figure 3-6. (a) A part of memory with five processes and three holes. The tick marks show the memory allocation units. The shaded regions (0 in the bitmap) are free. (b) The corresponding bitmap. (c) The same information as a list.

Memory Management with Holes

- First Fit
- Next Fit
- Best Fit

Virtual Memory – Paging (1)

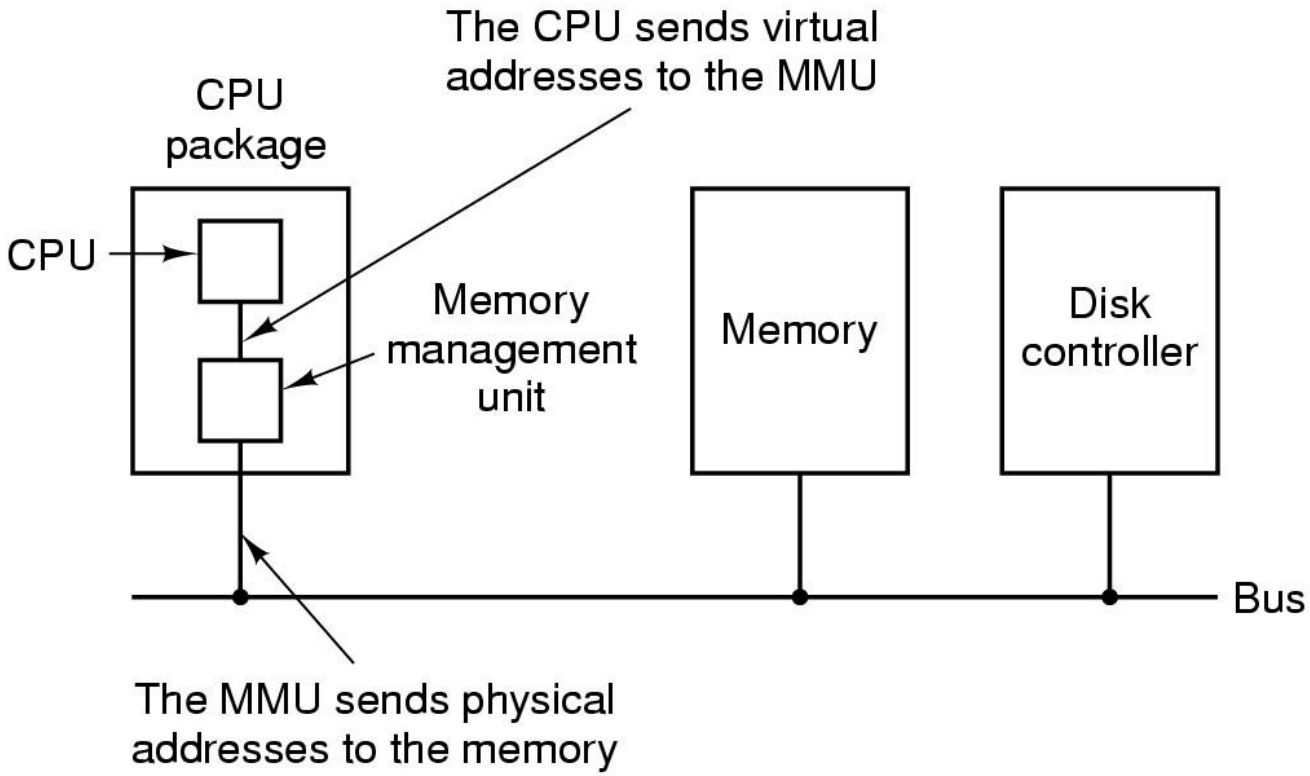


Figure 3-8. The position and function of the MMU – shown as being a part of the CPU chip (it commonly is nowadays). Logically it could be a separate chip, was in years gone by.

Paging (2)

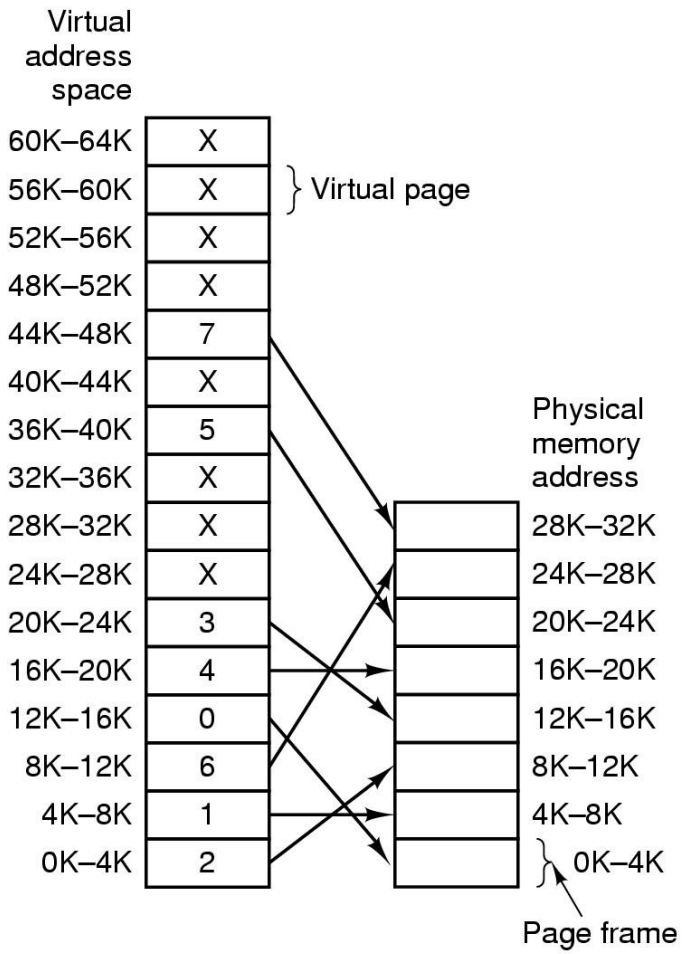


Figure 3-9. Relation between virtual addresses and physical memory addresses given by page table.

Structure of Page Table Entry

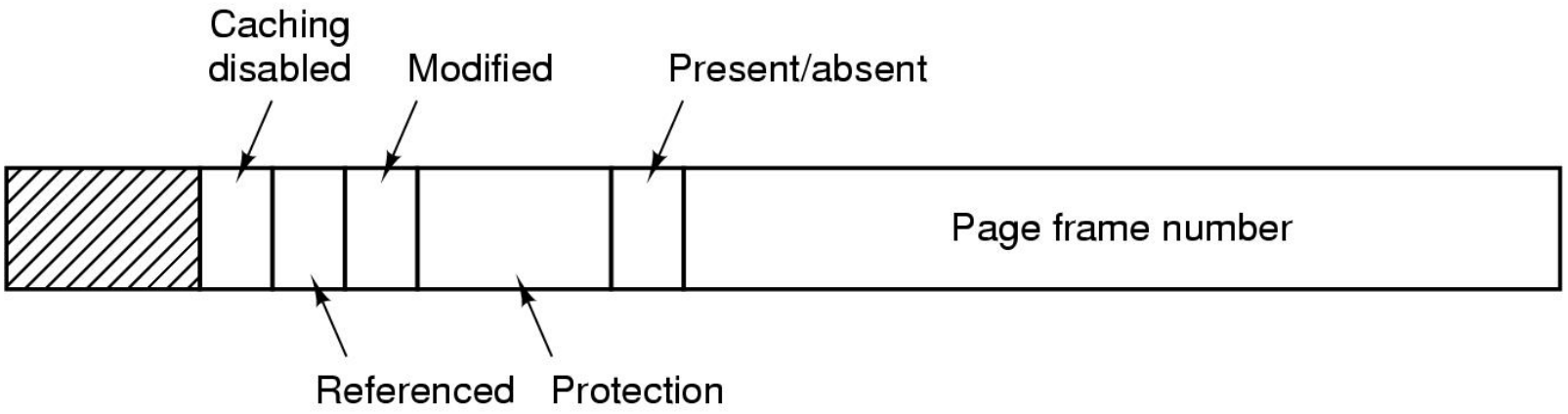


Figure 3-11. A typical page table entry.

Speeding Up Paging

Paging implementation issues:

- The mapping from virtual address to physical address must be fast.
- If the virtual address space is large, the page table will be large.

Multilevel Page Tables

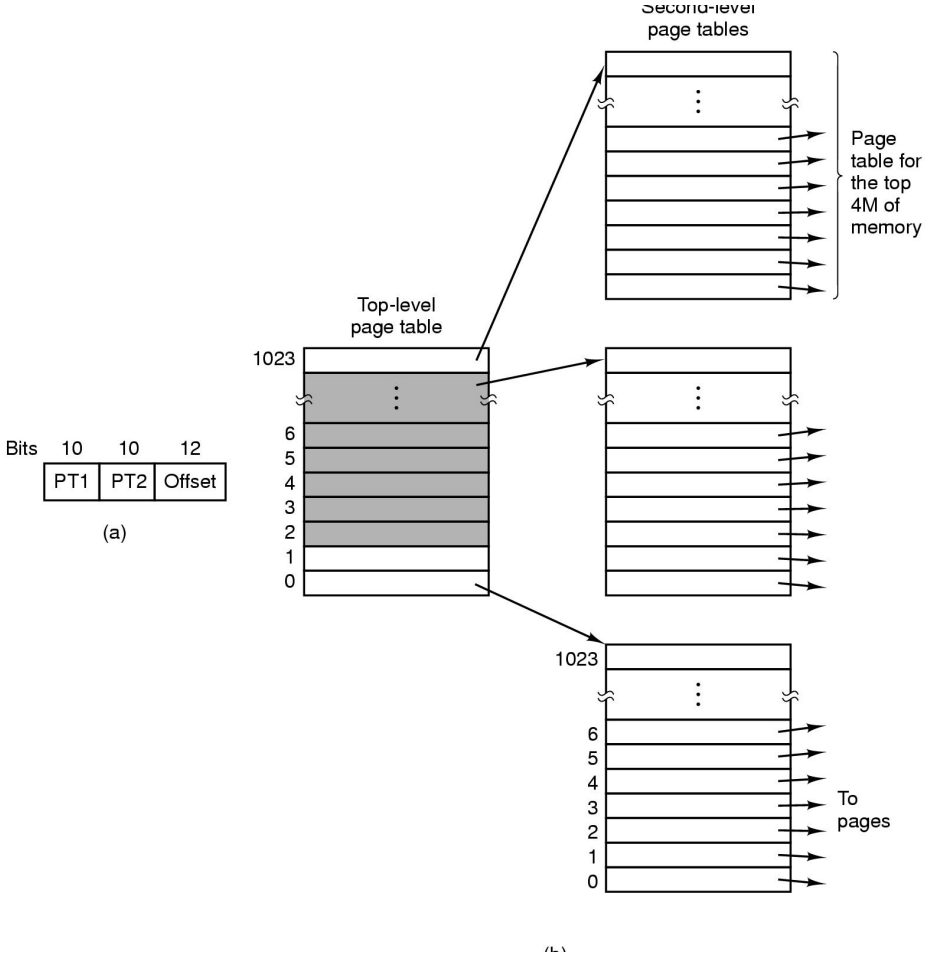


Figure 3-13. (a) A 32-bit address with two page table fields. (b) Two-level page tables.

Page Replacement Algorithms

- Optimal page replacement algorithm
- Not recently used page replacement
- First-In, First-Out page replacement
- Second chance page replacement
- Clock page replacement
- Least recently used page replacement
- Working set page replacement
- WSClock page replacement

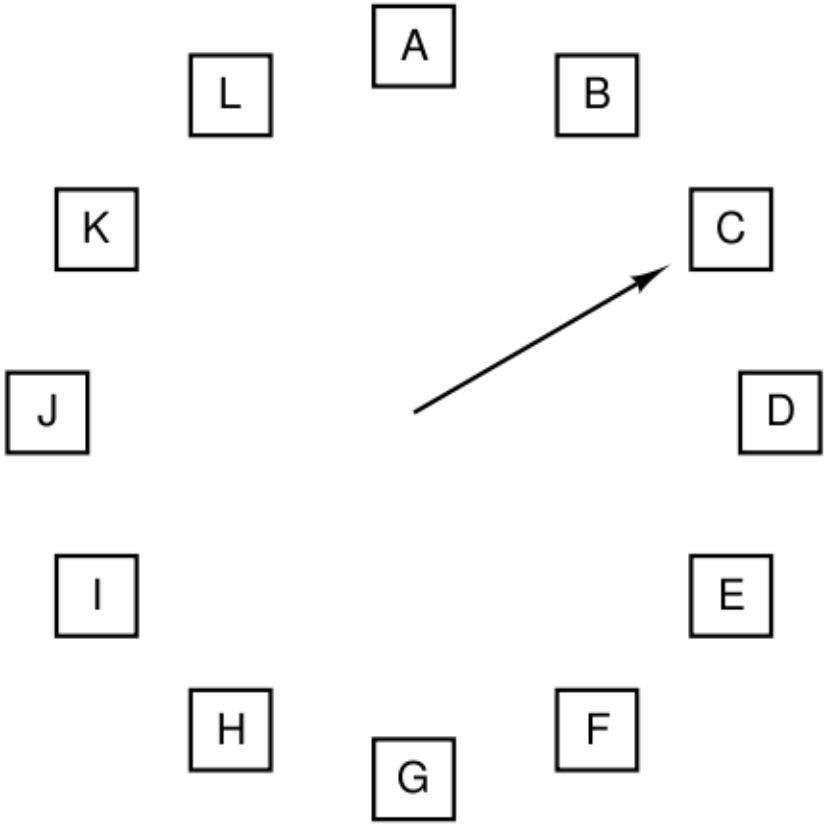
Optimal Page Replacement

Sequence of Pages: 1 2 3 4 1 2 5 1 2 3 4 5

FIFO Page Replacement Algorithm

Sequence of Pages: 1 2 3 4 1 2 5 1 2 3 4 5

Clock Page Replacement Algorithm



When a page fault occurs, the page the hand is pointing to is inspected. The action taken depends on the R bit:

R = 0: Evict the page

R = 1: Clear R and advance hand

LRU Page Replacement Algorithm

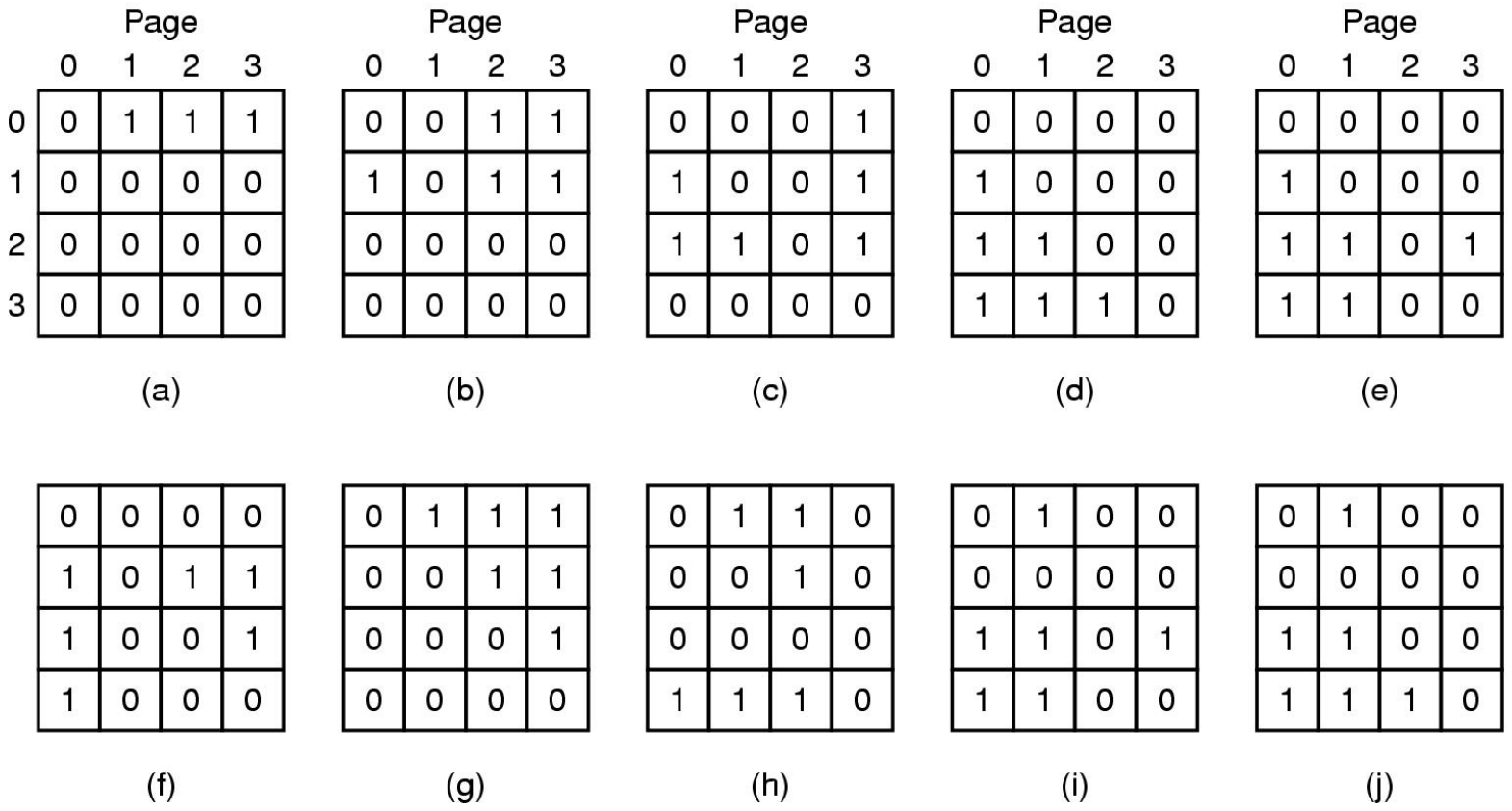


Figure 3-17. LRU using a matrix when pages are referenced in the order 0, 1, 2, 3, 2, 1, 0, 3, 2, 3.

Summary of Page Replacement Algorithms

Algorithm	Comment
Optimal	Not implementable, but useful as a benchmark
NRU (Not Recently Used)	Very crude approximation of LRU
FIFO (First-In, First-Out)	Might throw out important pages
Second chance	Big improvement over FIFO
Clock	Realistic
LRU (Least Recently Used)	Excellent, but difficult to implement exactly
NFU (Not Frequently Used)	Fairly crude approximation to LRU
Aging	Efficient algorithm that approximates LRU well
Working set	Somewhat expensive to implement
WSClock	Good efficient algorithm

Figure 3-22. Page replacement algorithms discussed in the text.

Local vs Global Allocation Policies

If we have multiple processes running on the system (A, B, C, D, ...), when A has a page fault, should we remove one of A's pages in memory (local), or should we look at all of the pages in memory (global).

Separate Instruction and Data Spaces

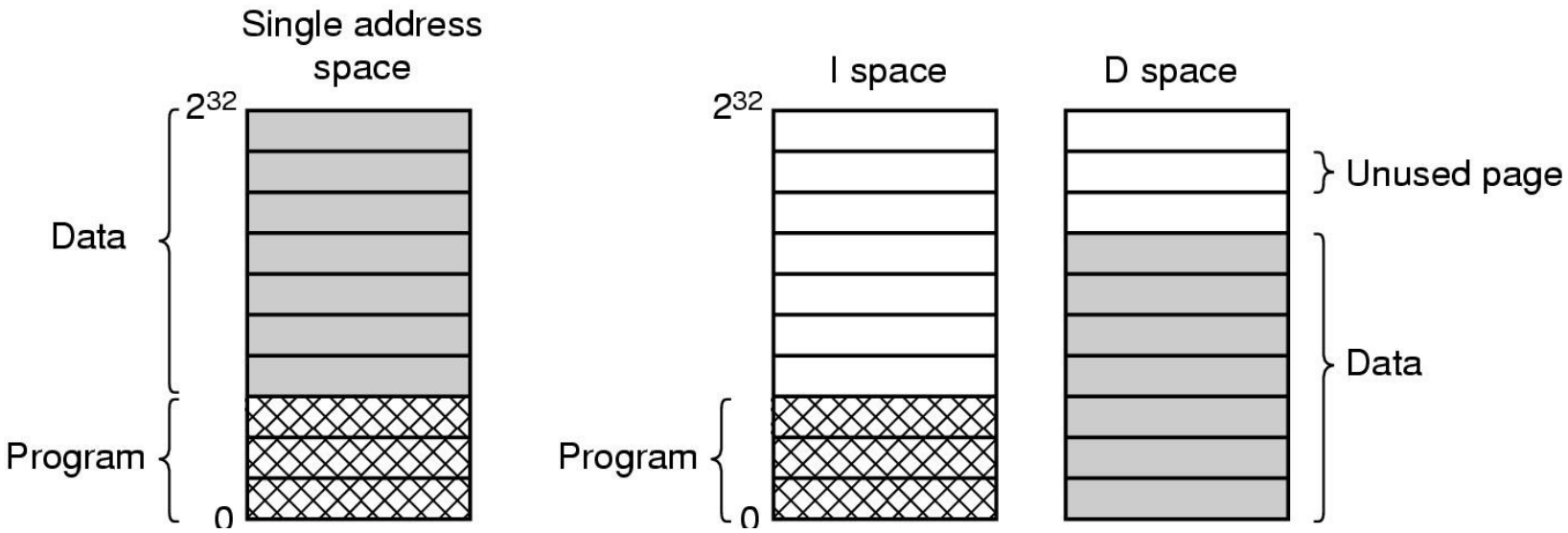


Figure 3-25. (a) One address space.
(b) Separate I and D spaces.

Shared Pages

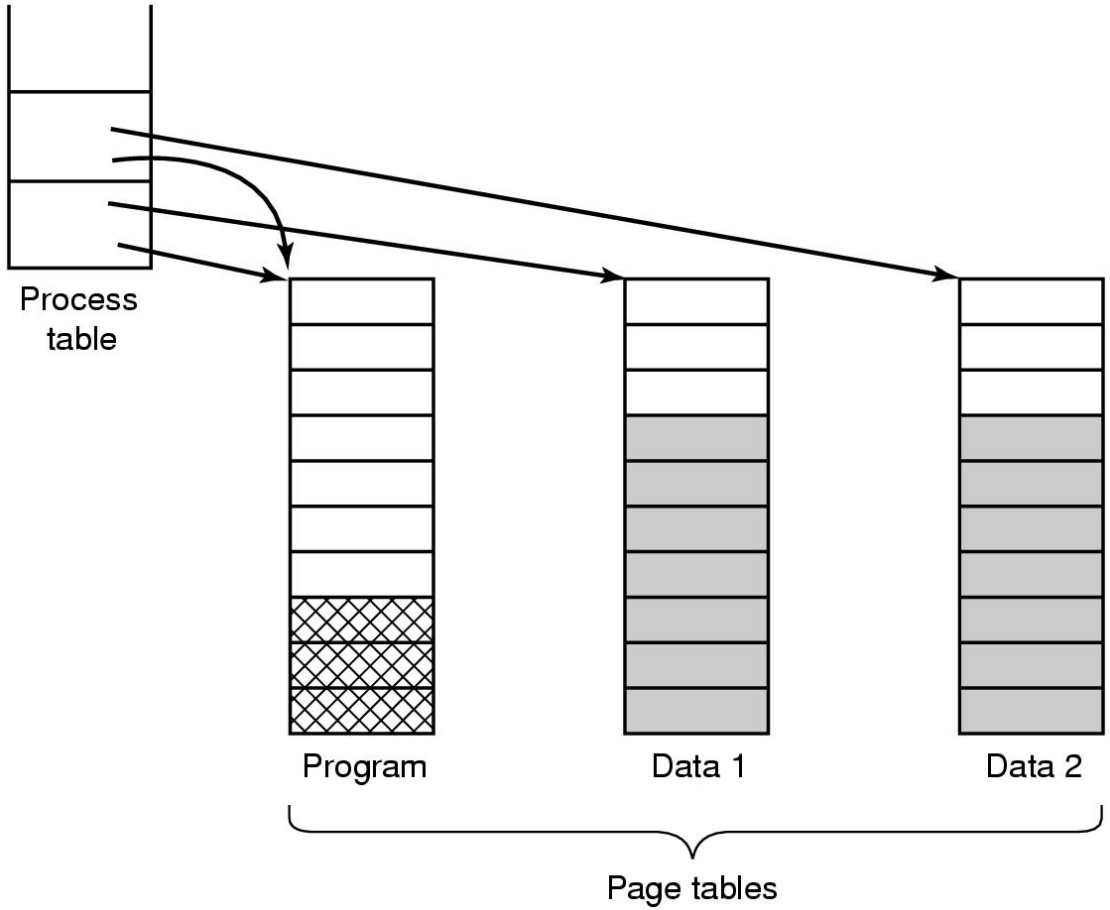


Figure 3-26. Two processes sharing the same program sharing its page table.

Shared Libraries

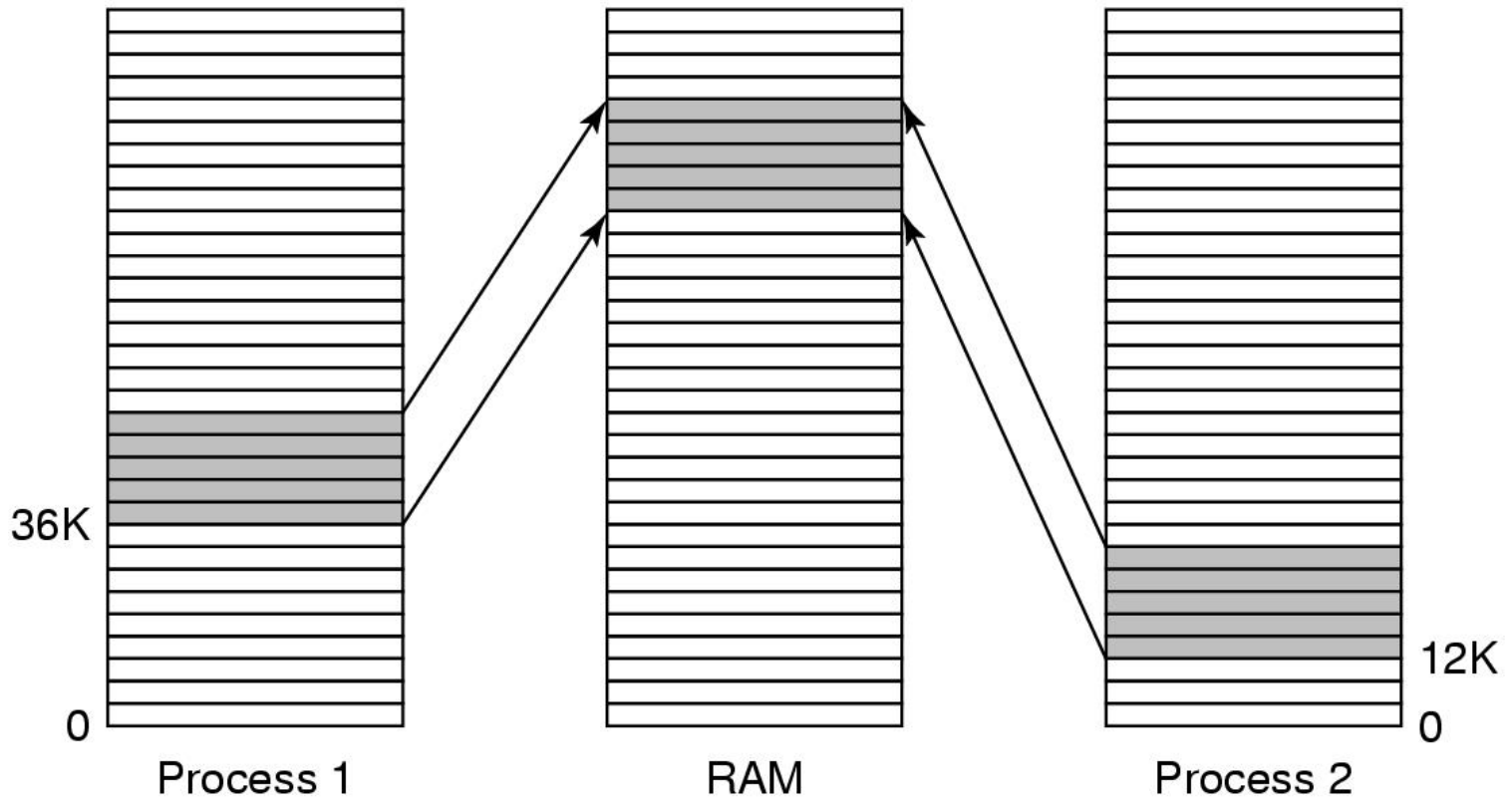


Figure 3-27. A shared library being used by two processes.

Page Fault Handling (1)

- The hardware traps to the kernel, saving the program counter on the stack.
- An assembly code routine is started to save the general registers and other volatile information.
- The operating system discovers that a page fault has occurred, and tries to discover which virtual page is needed.
- Once the virtual address that caused the fault is known, the system checks to see if this address is valid and the protection consistent with the access

Page Fault Handling (2)

- If the page frame selected is dirty, the page is scheduled for transfer to the disk, and a context switch takes place.
- When page frame is clean, operating system looks up the disk address where the needed page is, schedules a disk operation to bring it in.
- When disk interrupt indicates page has arrived, page tables updated to reflect position, frame marked as being in normal state.

Page Fault Handling (3)

- Faulting instruction backed up to state it had when it began and program counter reset to point to that instruction.
- Faulting process scheduled, operating system returns to the (assembly language) routine that called it.
- This routine reloads registers and other state information and returns to user space to continue execution, as if no fault had occurred.

Segmentation (1)

A compiler has many tables that are built up as compilation proceeds, possibly including:

- The source text being saved for the printed listing (on batch systems).
- The symbol table – the names and attributes of variables.
- The table containing integer, floating-point constants used.
- The parse tree, the syntactic analysis of the program.
- The stack used for procedure calls within the compiler.

Segmentation (2)

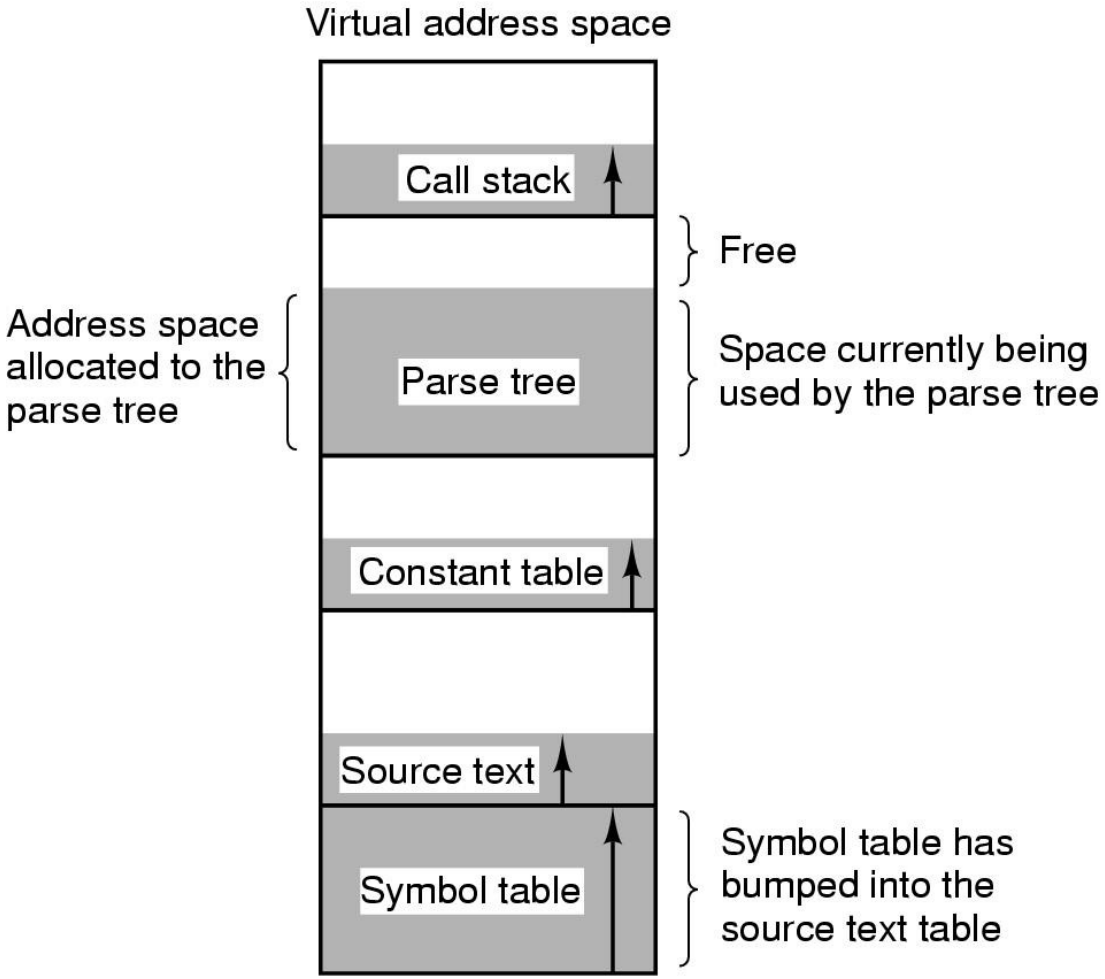


Figure 3-31. In a one-dimensional address space with growing tables, one table may bump into another.

Segmentation (3)

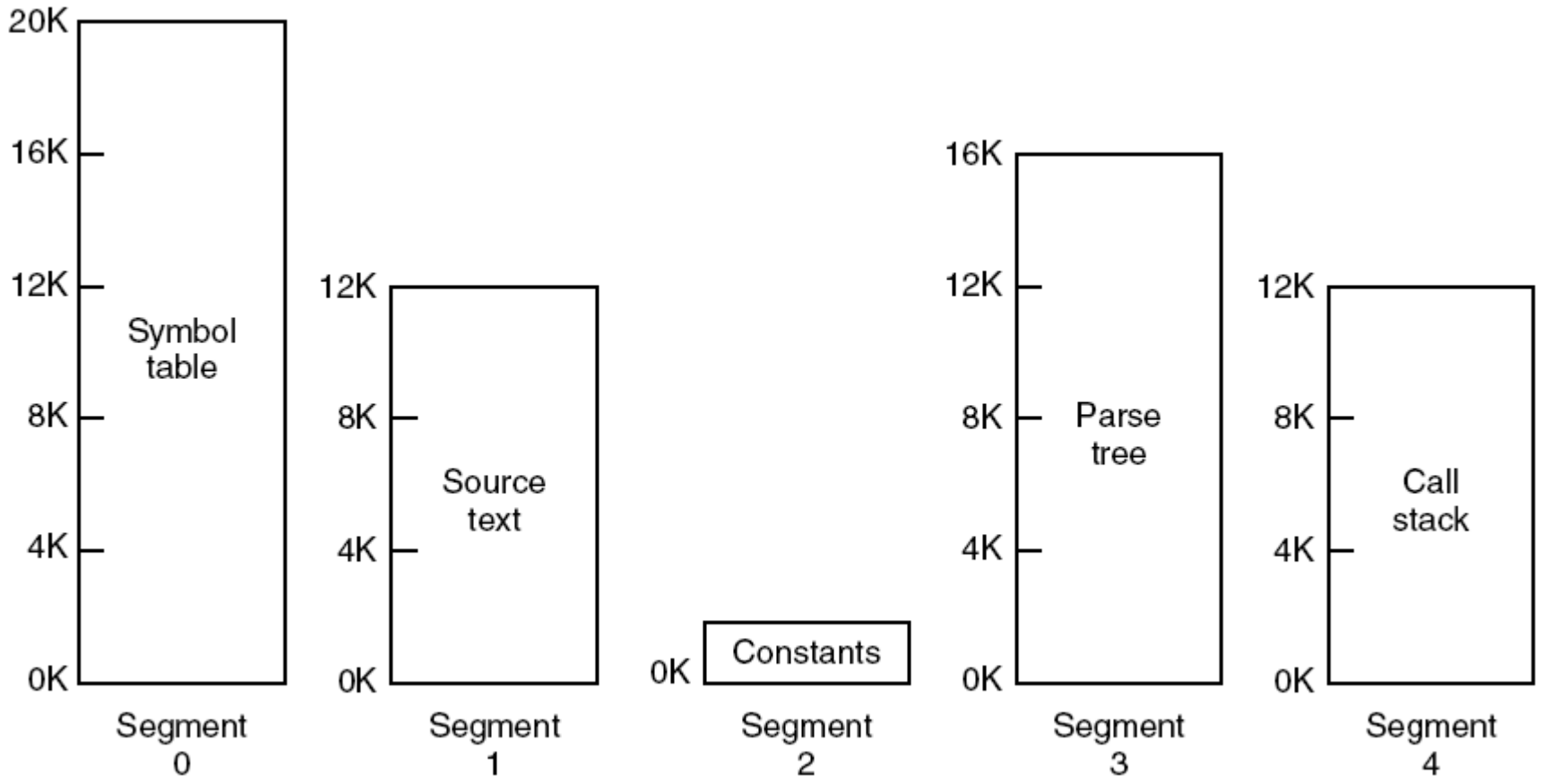


Figure 3-32. A segmented memory allows each table to grow or shrink independently of the other tables.