William Stallings
Computer Organization and Architecture
7th Edition

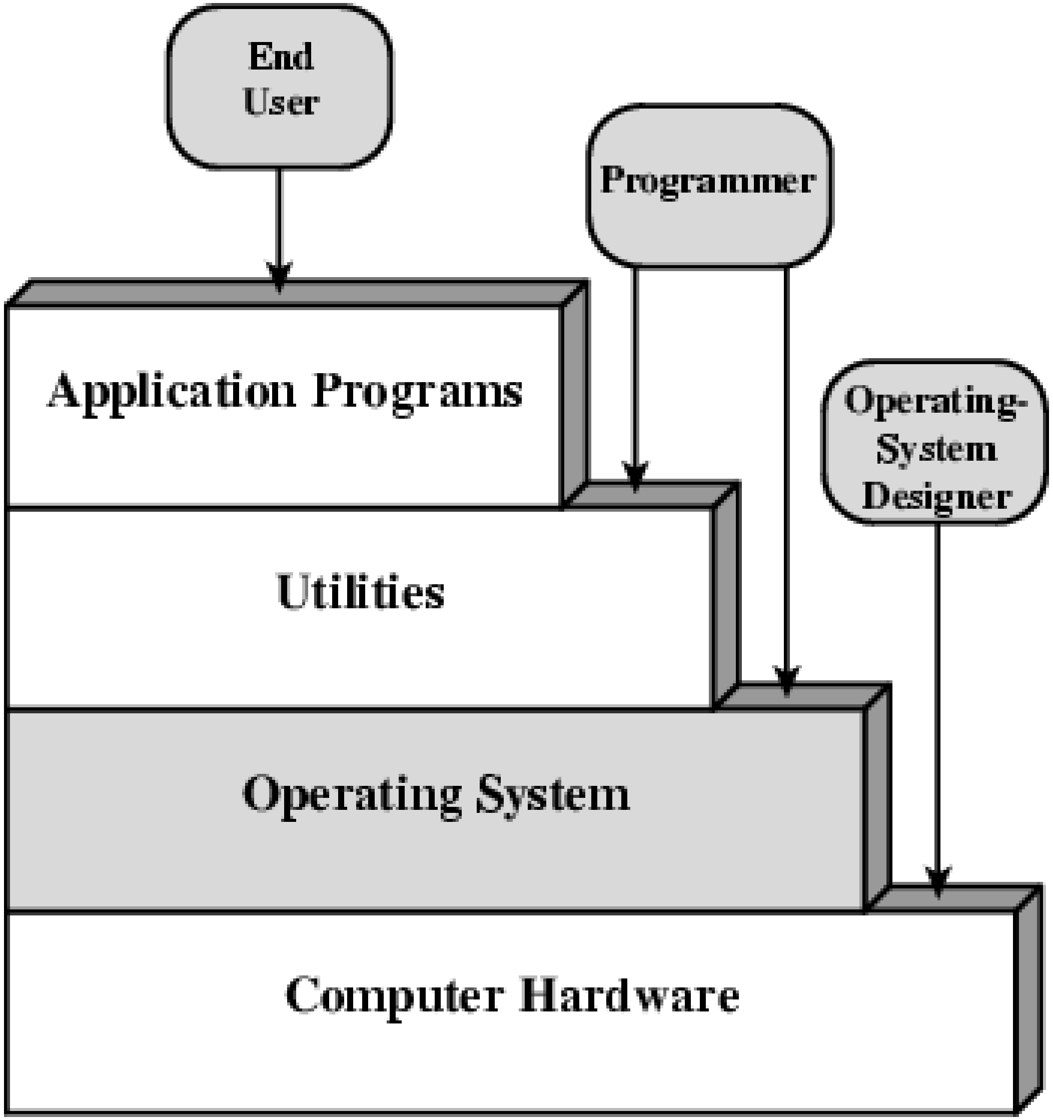
Chapter 8

Operating System Support

Objectives and Functions

- Convenience
  - Making the computer easier to use
- Efficiency
  - Allowing better use of computer resources

Layers and Views of a Computer System

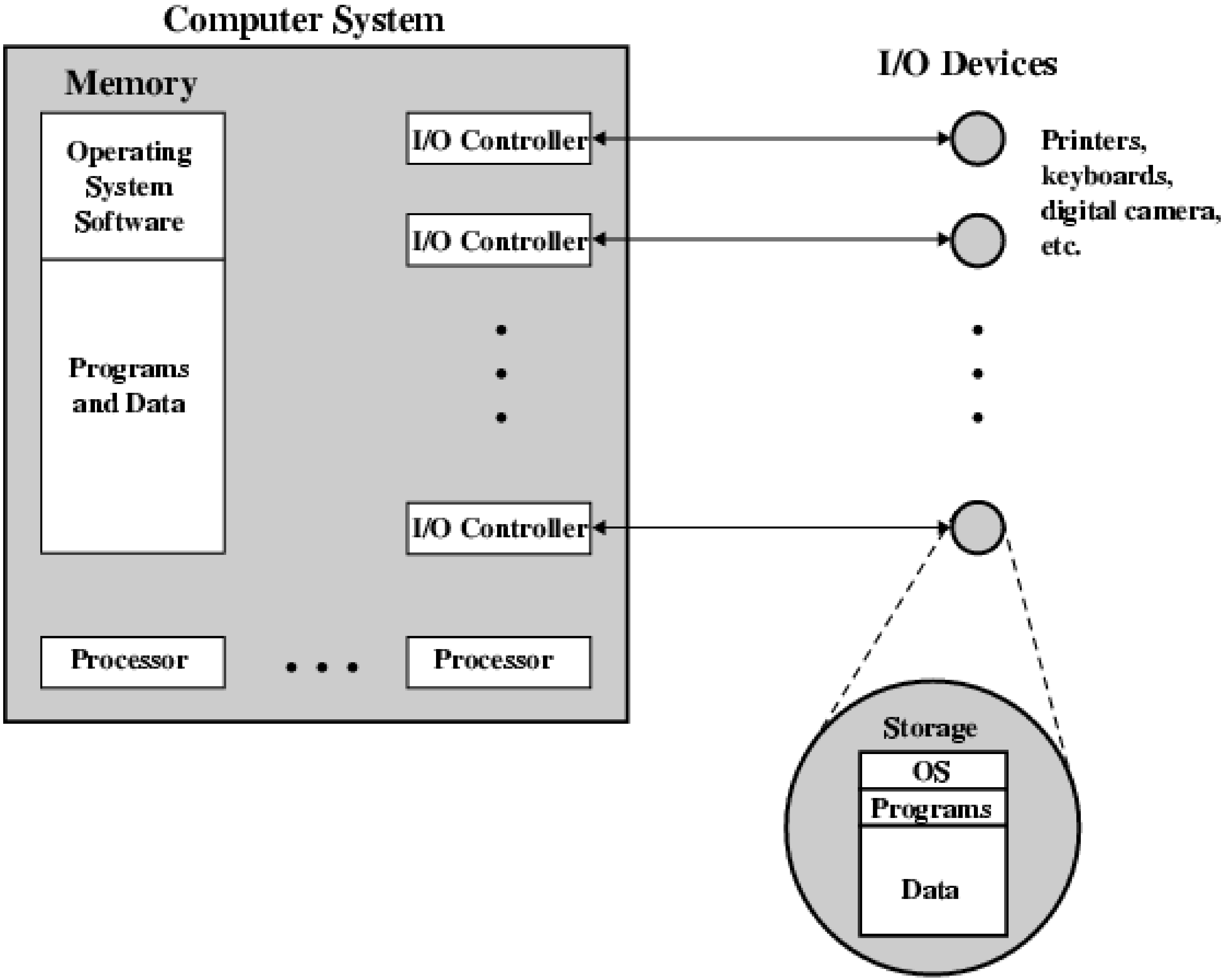


Operating System Services

- Program creation (editors, debuggers, compilers)
- Program execution (loaders, device & file initialization, resource assignment)
- Access to I/O devices (interfacing signalling and device specific control instructions)
- Controlled access to files (format specific actions & protection)
- System access (secure access & optimized shared resource organization)
- Error detection and response
- Accounting (usage statistics, log files)

- The operating system is, in fact, nothing more than a computer program.
- The operating system directs the processor in the use of other system resources and in the timing of its execution of other programs. But in order the processor to do this, it must cease executing the operating system and execute other programs.
- The processor itself is a resource and the oprating system must determine its shared usage by the user programs, while consuming a significant portion of it, directly by itself.

O/S as a Resource Manager



Types of Operating System

- Interactive
- Batch
- Single program (Uni-programming)
- Multi-programming (Multi-tasking)
- Single user
- Multi-user
- Single-processor
- Multi-processor

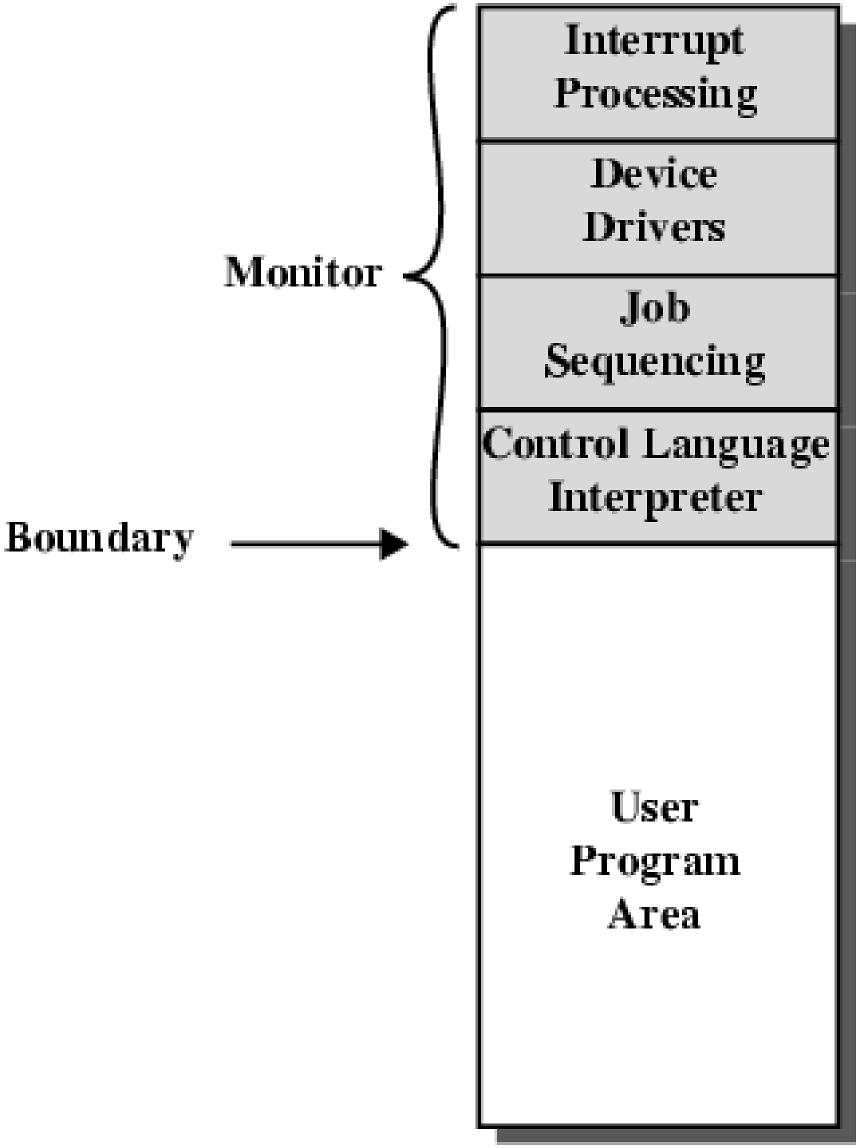
Early Systems

- Late 1940s to mid 1950s
- No Operating System
- Programs interact directly with hardware
- Two main problems:
  - Scheduling (sign-up sheet to reserve CPU time)
  - Setup time (loading compiler, source program, saving the object program, loading and linking the modules, mounting or dismounting tapes cards etc.)

Simple Batch Systems

- Resident Monitor program
- Users submit jobs to operator
- Operator batches jobs
- Monitor controls sequence of events to process batch
- When one job is finished, control returns to Monitor which reads next job
- Monitor handles scheduling

Memory Layout for Resident Monitor



Job Control Language

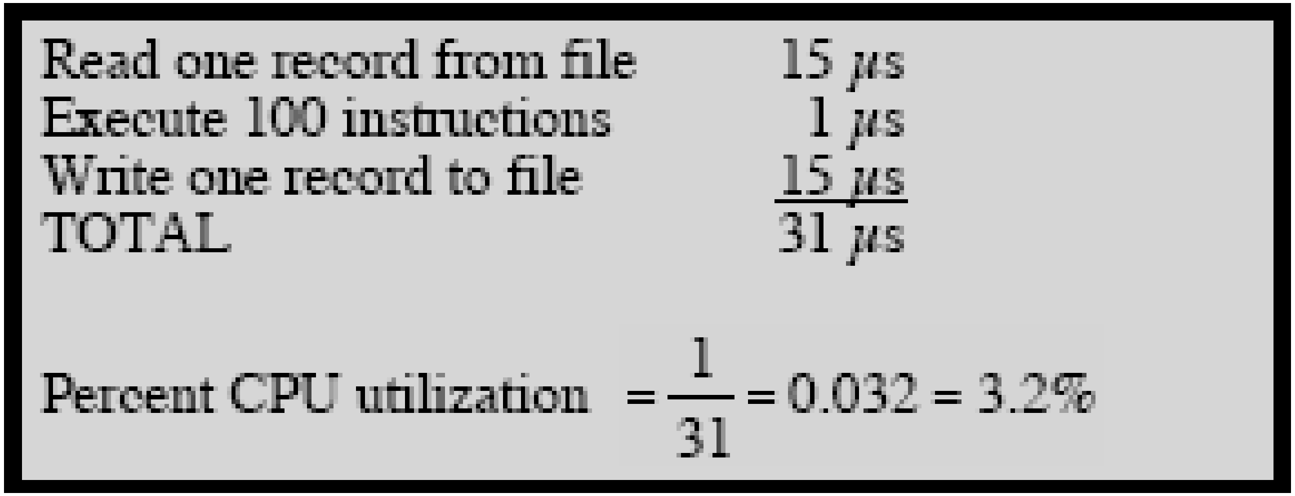
- Instructions to Monitor
- Usually denoted by $
- e.g.
  - $JOB
  - $FTN
  - ...   Some Fortran instructions
  - $LOAD
  - $RUN
  - ...   Some data
  - $END

Desirable Hardware Features

- Memory protection
  - To protect the Monitor
- Timer
  - To prevent a job monopolizing the system
- Privileged instructions
  - Only executed by Monitor
  - e.g. I/O
- Interrupts
  - Allows for relinquishing and regaining control. Not available in early models.

Multi-programmed Batch Systems

- I/O devices very slow
- When one program is waiting for I/O, another can use the CPU

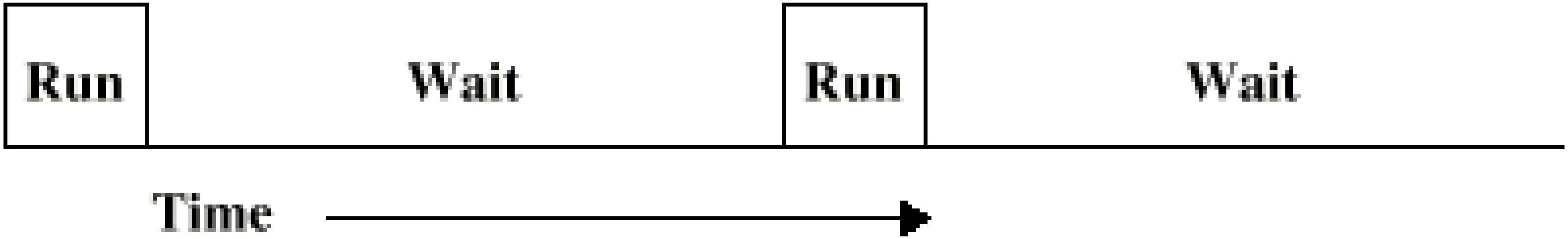


Read one record from file	15 μs
Execute 100 instructions	1 μs
Write one record to file	15 μs
TOTAL	31 μs

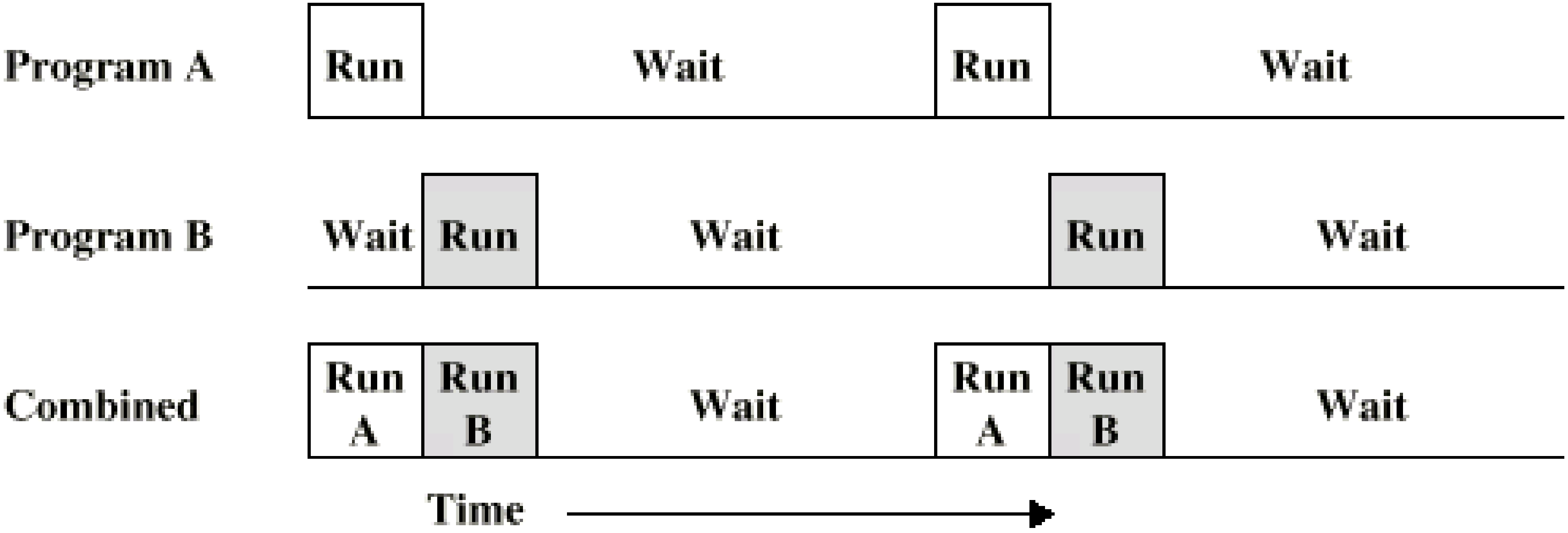
Percent CPU utilization $= \frac{1}{31} = 0.032 = 3.2\%$

Figure 8.4 System Utilization Example

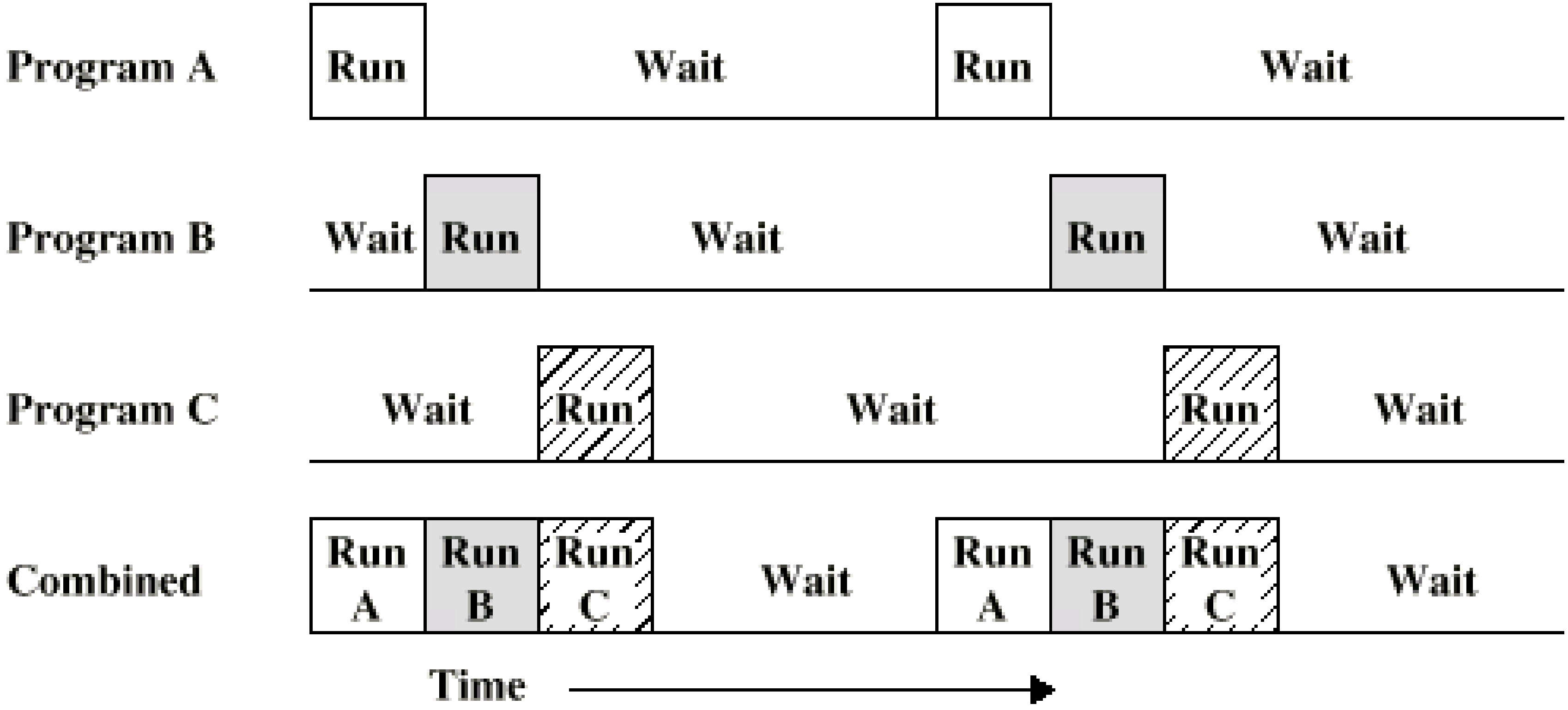
Single Program

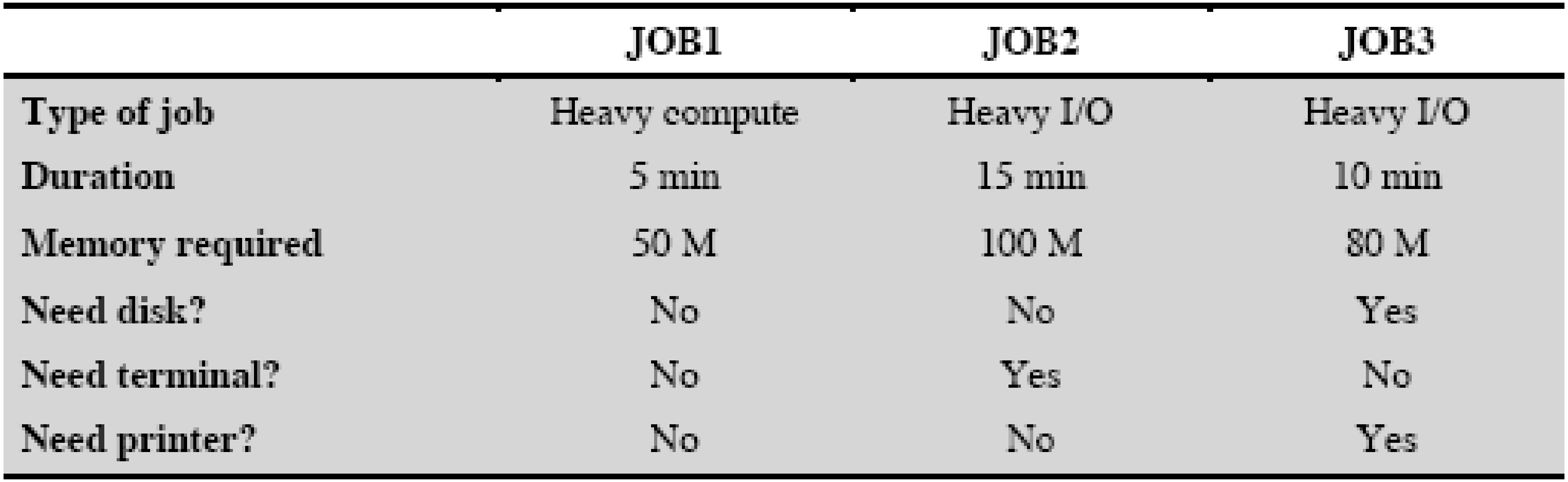


Multi-Programming with Two Programs



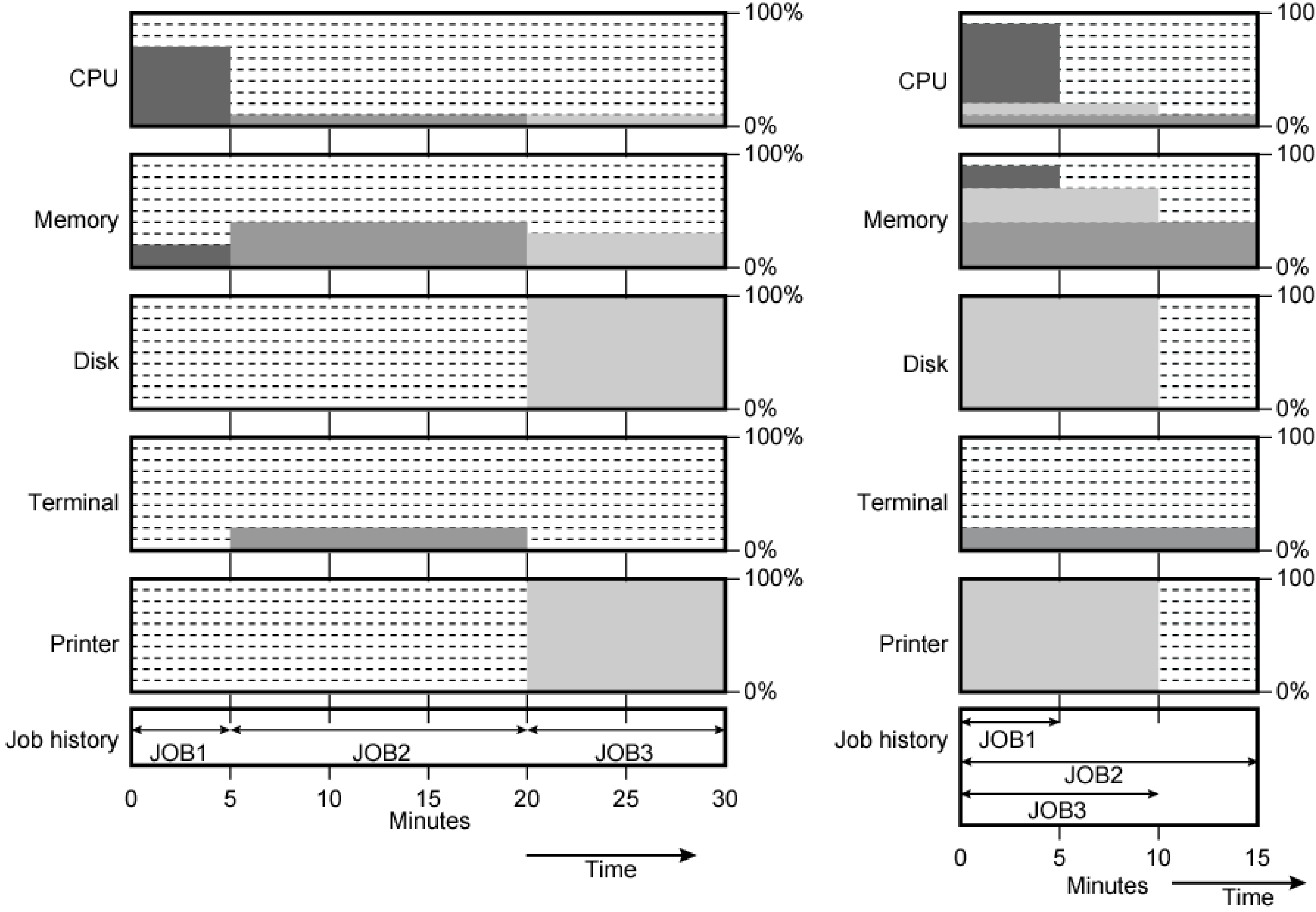
Multi-Programming with Three Programs





	JOB1	JOB2	JOB3
Type of job	Heavy compute	Heavy I/O	Heavy I/O
Duration	5 min	15 min	10 min
Memory required	50 M	100 M	80 M
Need disk?	No	No	Yes
Need terminal?	No	Yes	No
Need printer?	No	No	Yes

Utilization



(a) Uniprogramming

(b) Multiprogramming

	Uniprogramming	Multiprogramming
Processor use	20%	40%
Memory use	33%	67%
Disk use	33%	67%
Printer use	33%	67%
Elapsed time	30 min	15 min
Throughput rate	6 jobs/hr	12 jobs/hr
Mean response time	18 min	10 min

Time Sharing Systems

- Allow users to interact directly with the computer
  - i.e. Interactive
- Multi-programming allows a number of users to interact with the computer

Scheduling

- Key to multi-programming
- Long term (decision to add to the pool for execution)
- Medium term (decision to add to the processes that are partially or fully in memory)
- Short term (decision for execution)
- I/O (decision as to which process’s pending I/O request will be handled)

Long Term Scheduling

- Determines which programs are submitted for processing
- i.e. controls the degree of multi-programming
- Once submitted, a job becomes a process for the short term scheduler (memory allocated).
- (or it becomes a swapped out job for the medium term scheduler)
- For interactive programs in time sharing systems, a process request is generated when a user attempts to connect to the system. Op. System accepts all authorized comers till it saturates.

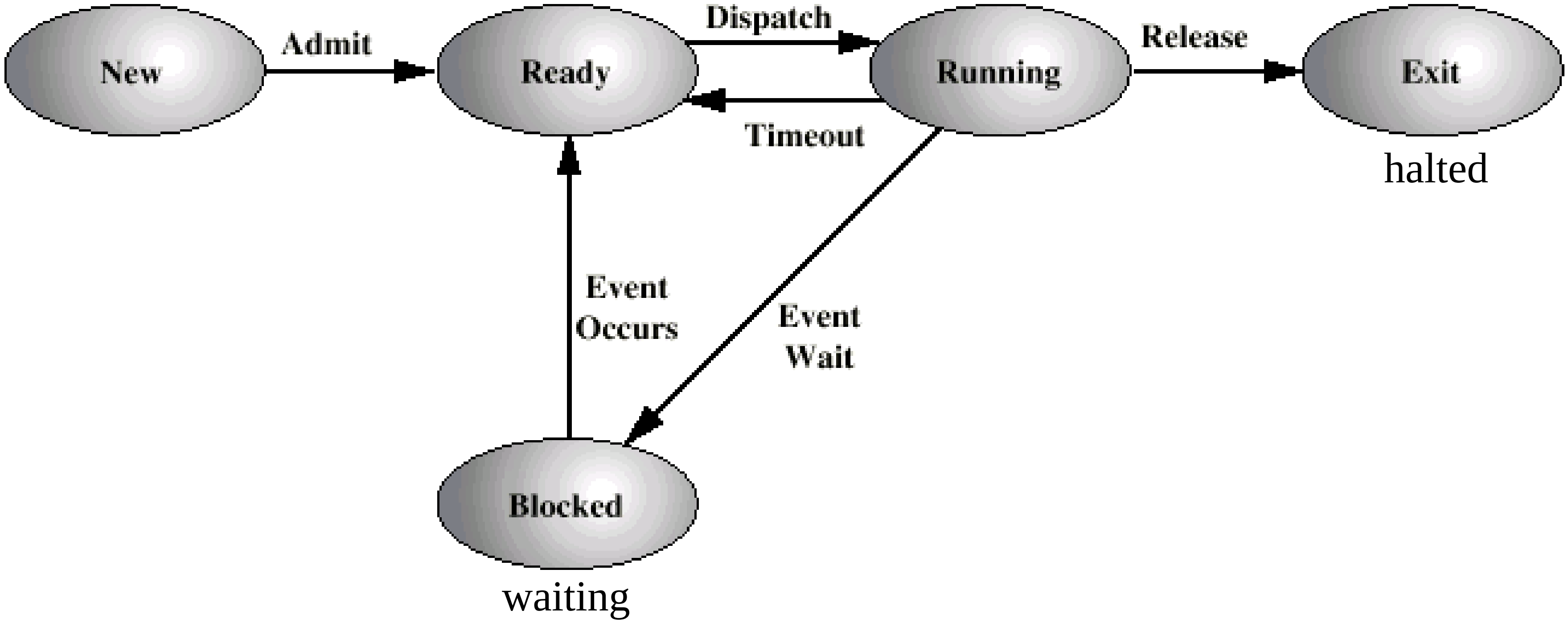
Medium Term Scheduling

- Part of the swapping function
- Usually based on the need to manage multi-programming
- If no virtual memory, memory management is also an issue

Short Term Scheduler

- Also known as Dispatcher
- Fine grained decisions of which job to execute next
- i.e. which job actually gets to use the processor in the next time slot

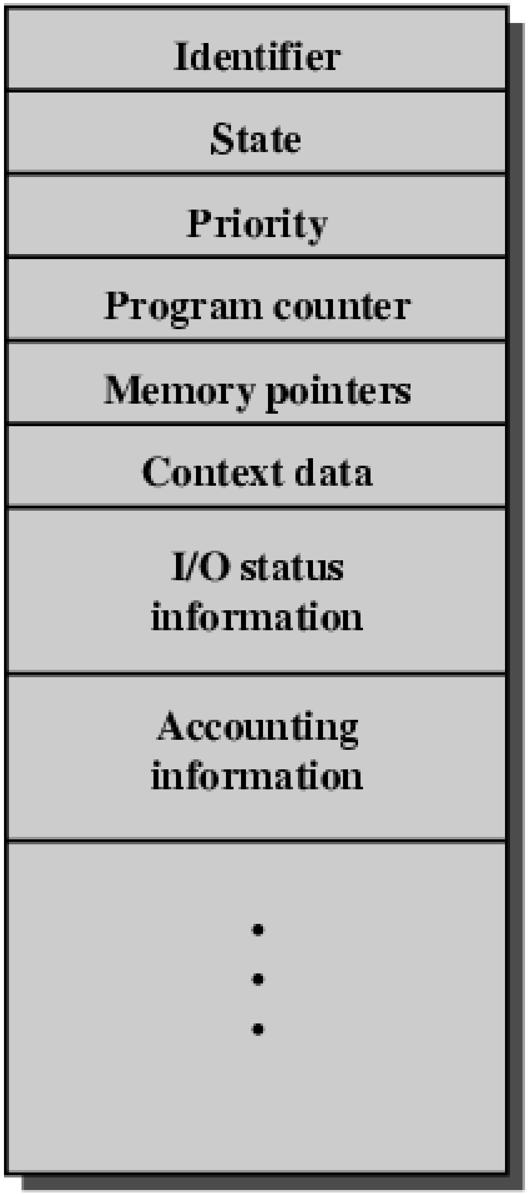
Five State Process Model



Process Control Block

- Identifier
- State
- Priority
- Program counter (address of the next inst.)
- Memory pointers (starting & ending locations)
- Context data (critical contents to be saved)
- I/O status (outstanding I/O requests, devices & files assigned etc.)
- Accounting information

PCB Diagram



Identifier

State

Priority

Program counter

Memory pointers

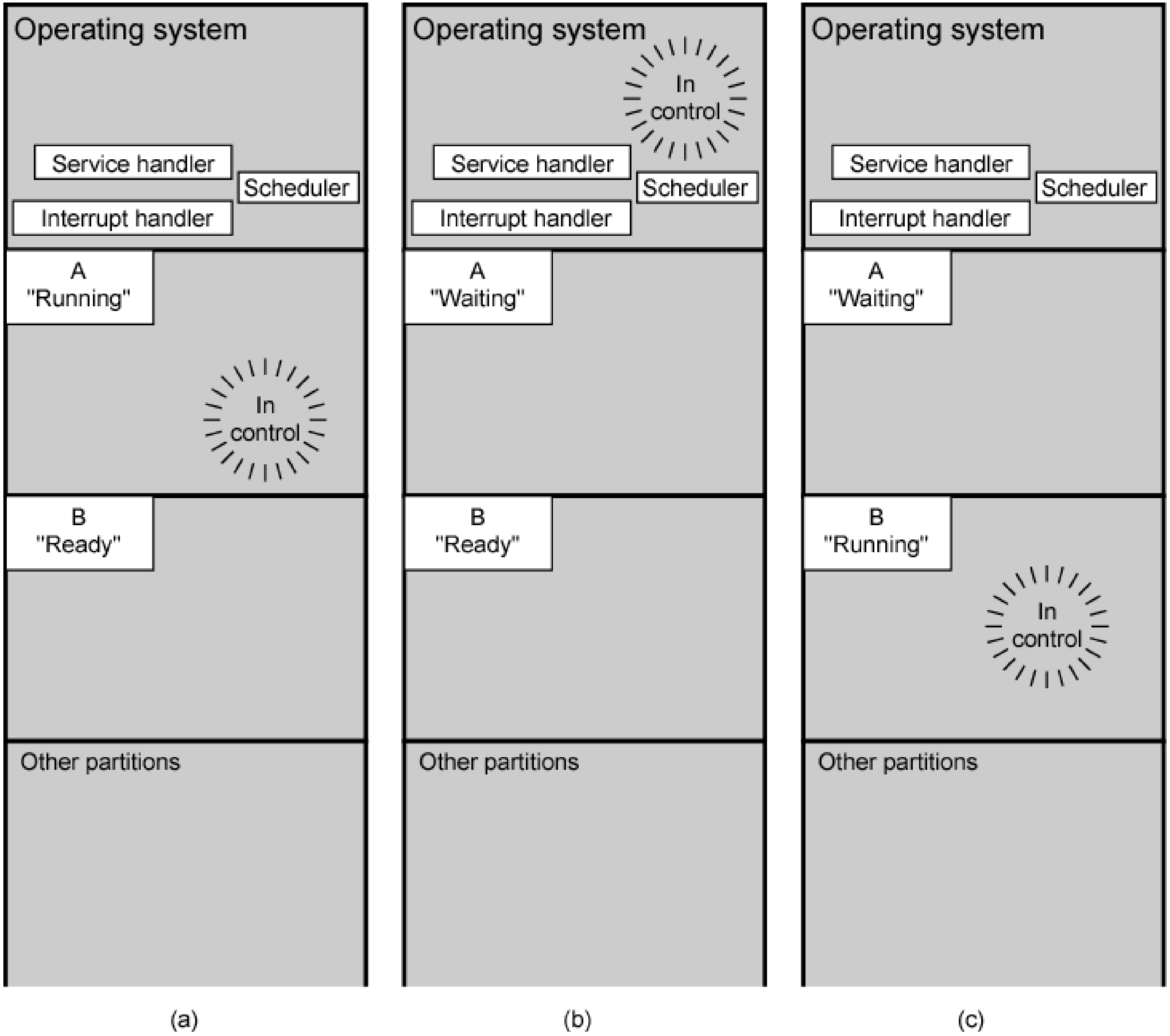
Context data

I/O status information

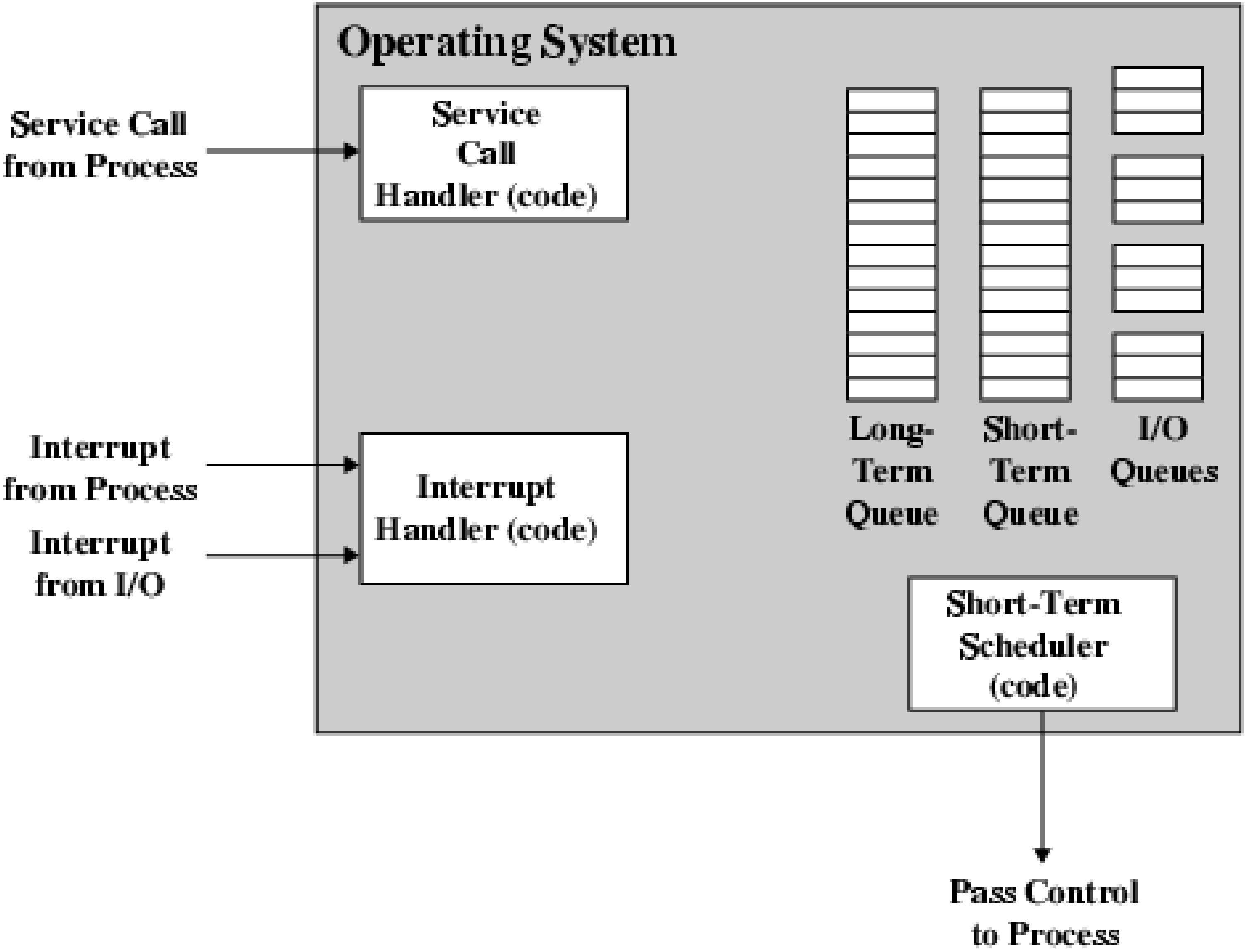
Accounting information

•
•
•

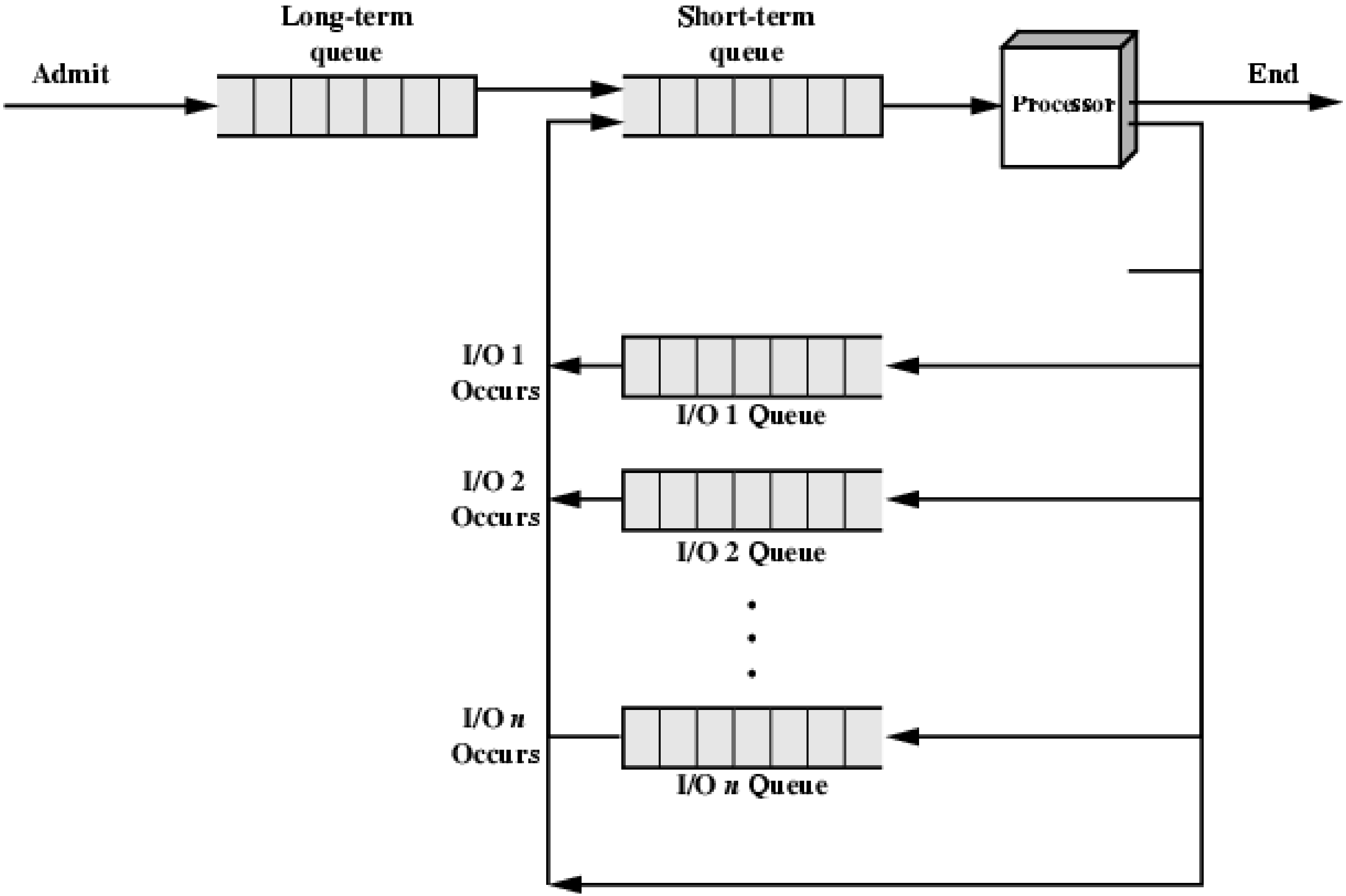
Scheduling Example



Key Elements of O/S



Process Scheduling



Memory Management

- Uni-program
  - Memory split into two
  - One for Operating System (monitor)
  - One for currently executing program
- Multi-program
  - “User” part is sub-divided by the operating system dynamically and shared among active processes (called memory management)
  - Effective memory management is vital for multiprogramming systems.

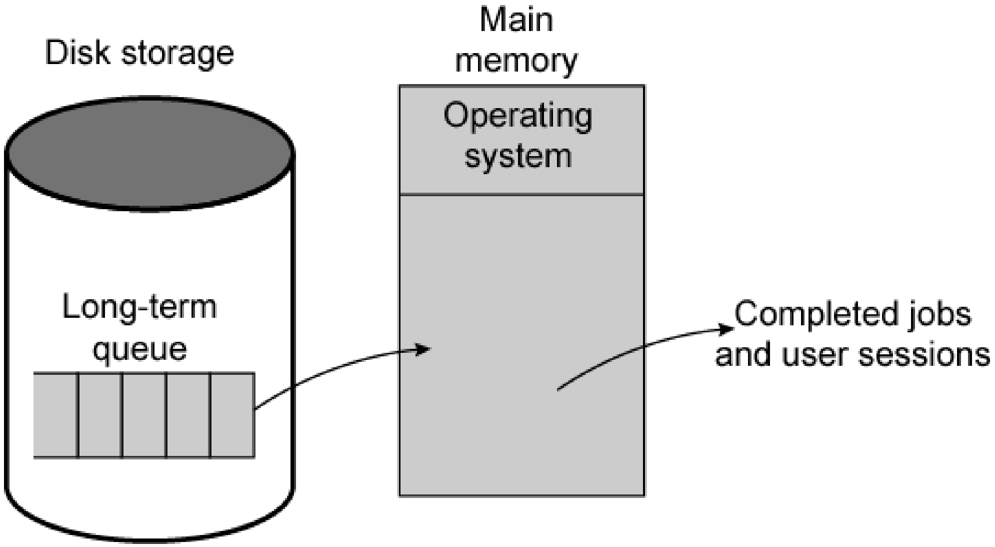
Swapping

- Problem: I/O is so slow compared with CPU that even in multi-programming system, CPU can be idle most of the time
- Solutions:
  - Increase main memory
    - Expensive
    - Leads to larger programs
  - Swapping

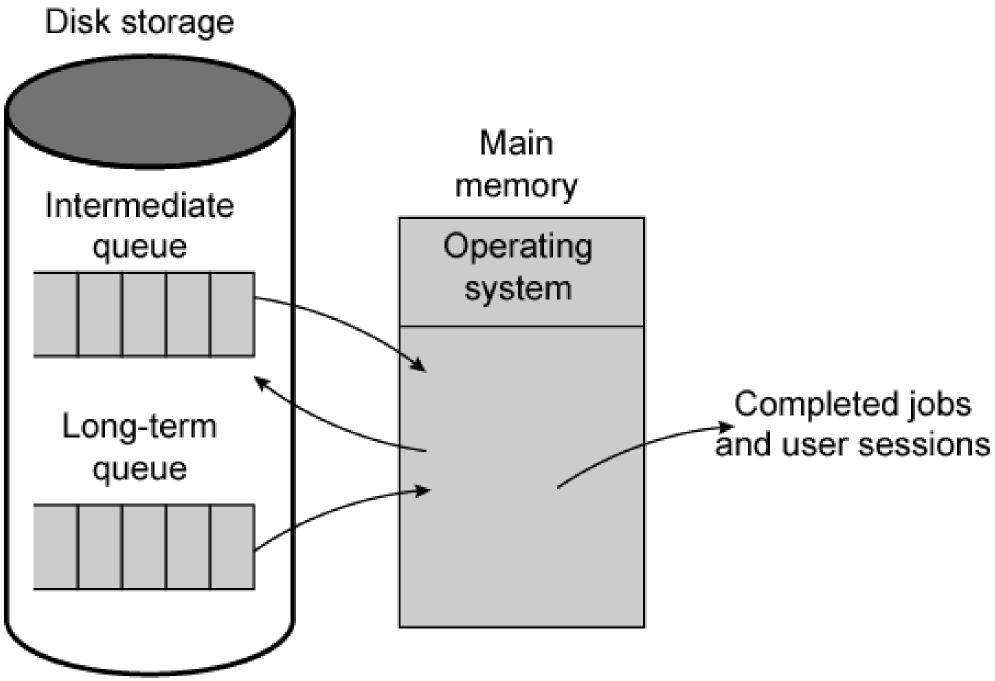
What is Swapping?

- Long term queue of processes stored on disk
- Processes “swapped” in as space becomes available
- As a process completes it is moved out of main memory
- If none of the processes in memory are ready (i.e. all I/O blocked)
    - Swap out a blocked process to **intermediate queue** in disk
    - Swap in a process from the intermediate queue, or a new process from the long-term queue.
    - But swapping is an I/O process...

Use of Swapping



(a) Simple job scheduling



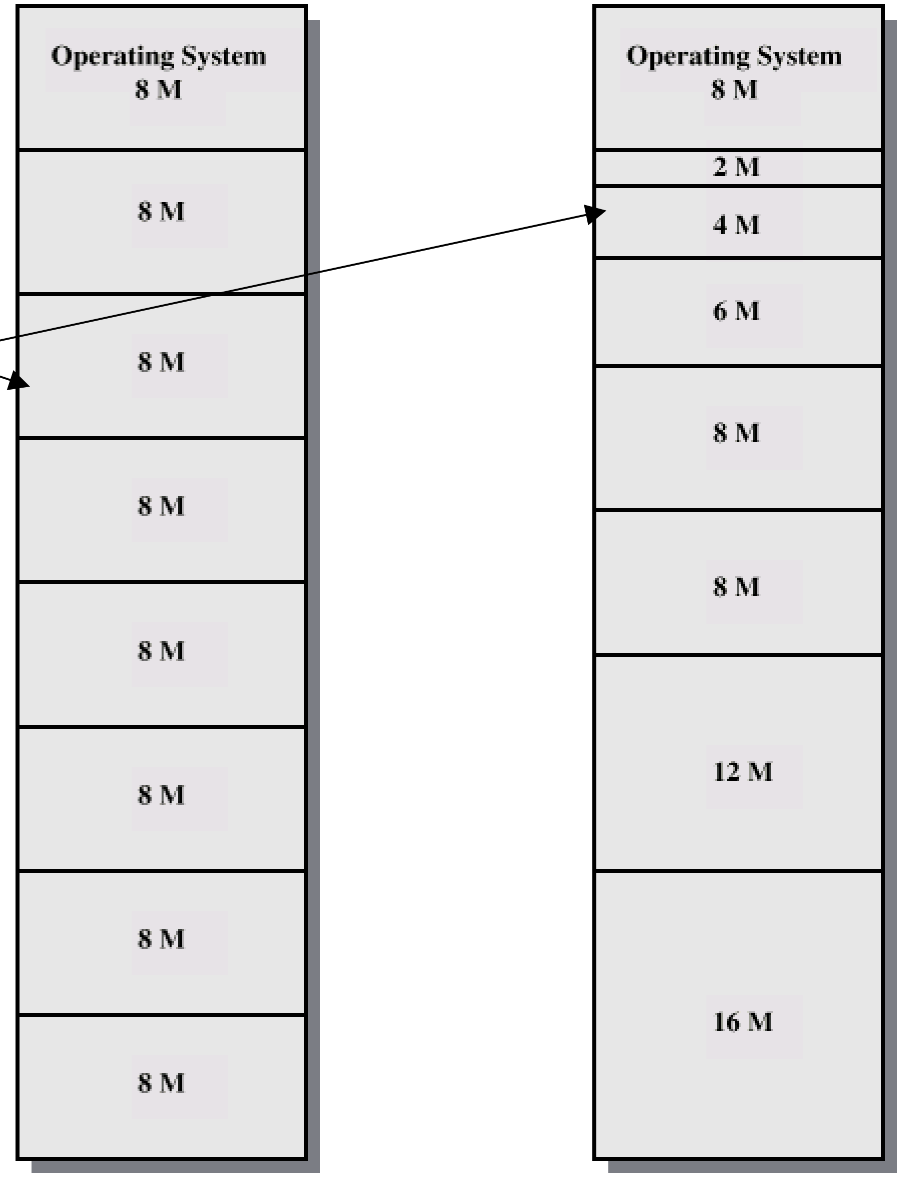
(b) Swapping

Partitioning

- Splitting memory into sections to allocate to processes (including Operating System)
- Fixed-sized partitions
    - May not be equal size
    - Process is fitted into smallest hole that will take it (best fit)
    - Some wasted memory
    - Leads to variable sized partitions

Fixed Partitioning

A 3MB process will fit into a 8MB or 4M partition (wasted memory)



(a) Equal-size partitions

(b) Unequal-size partitions

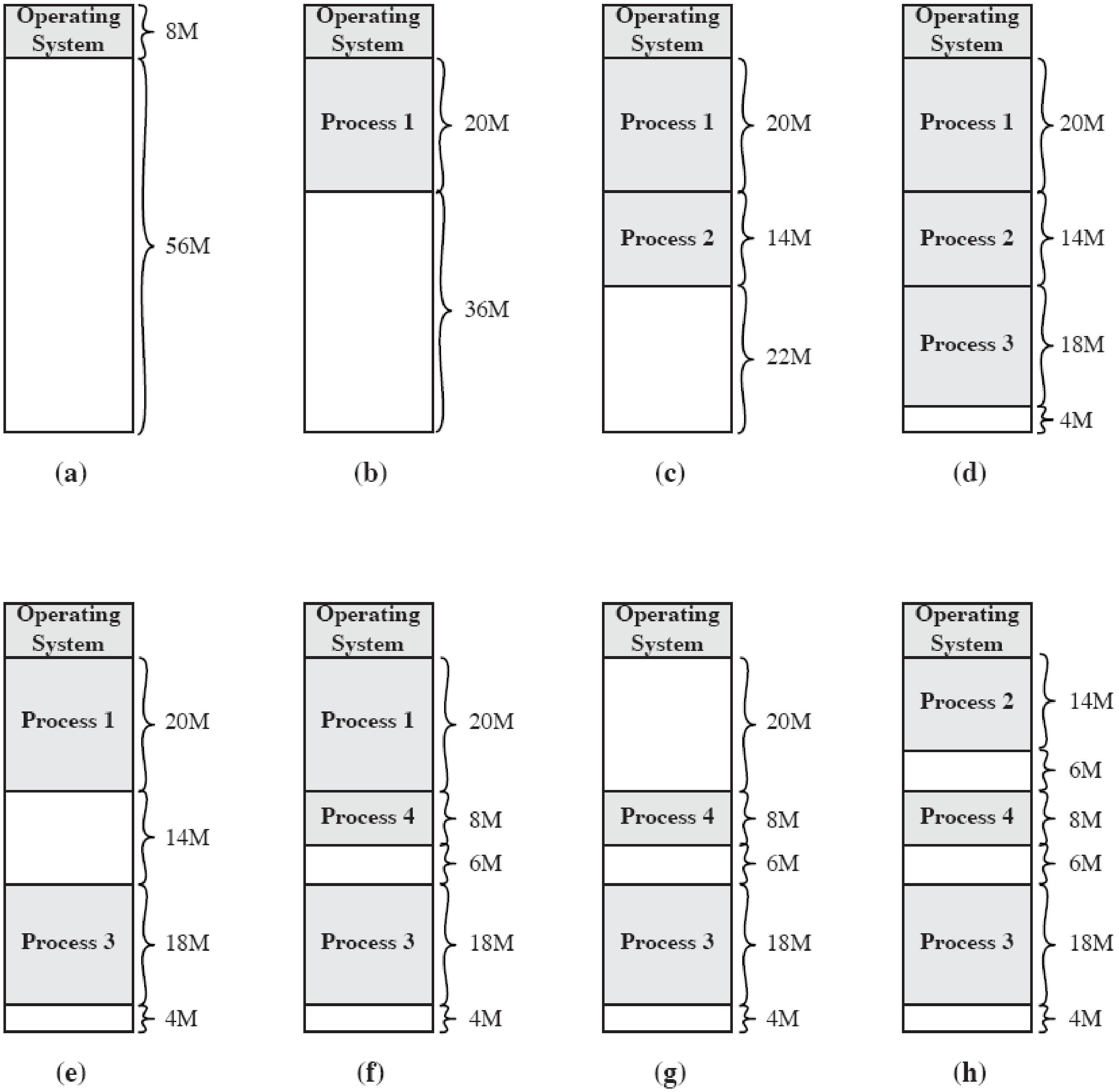
Variable Sized Partitions (1)

- Allocate exactly the required memory to a process
- This leads to a hole at the end of memory, too small to use
    - Only one small hole - less waste
- When all processes are blocked, swap out a process and bring in another
- New process may be smaller than swapped out process
- Another hole

Variable Sized Partitions (2)

- Eventually have lots of holes (fragmentation)
- Solutions:
  - Coalesce - Join adjacent holes into one large hole
  - Compaction - From time to time go through memory and move all hole into one free block (c.f. disk de-fragmentation) This is a time consuming process.

Effect of Dynamic Partitioning



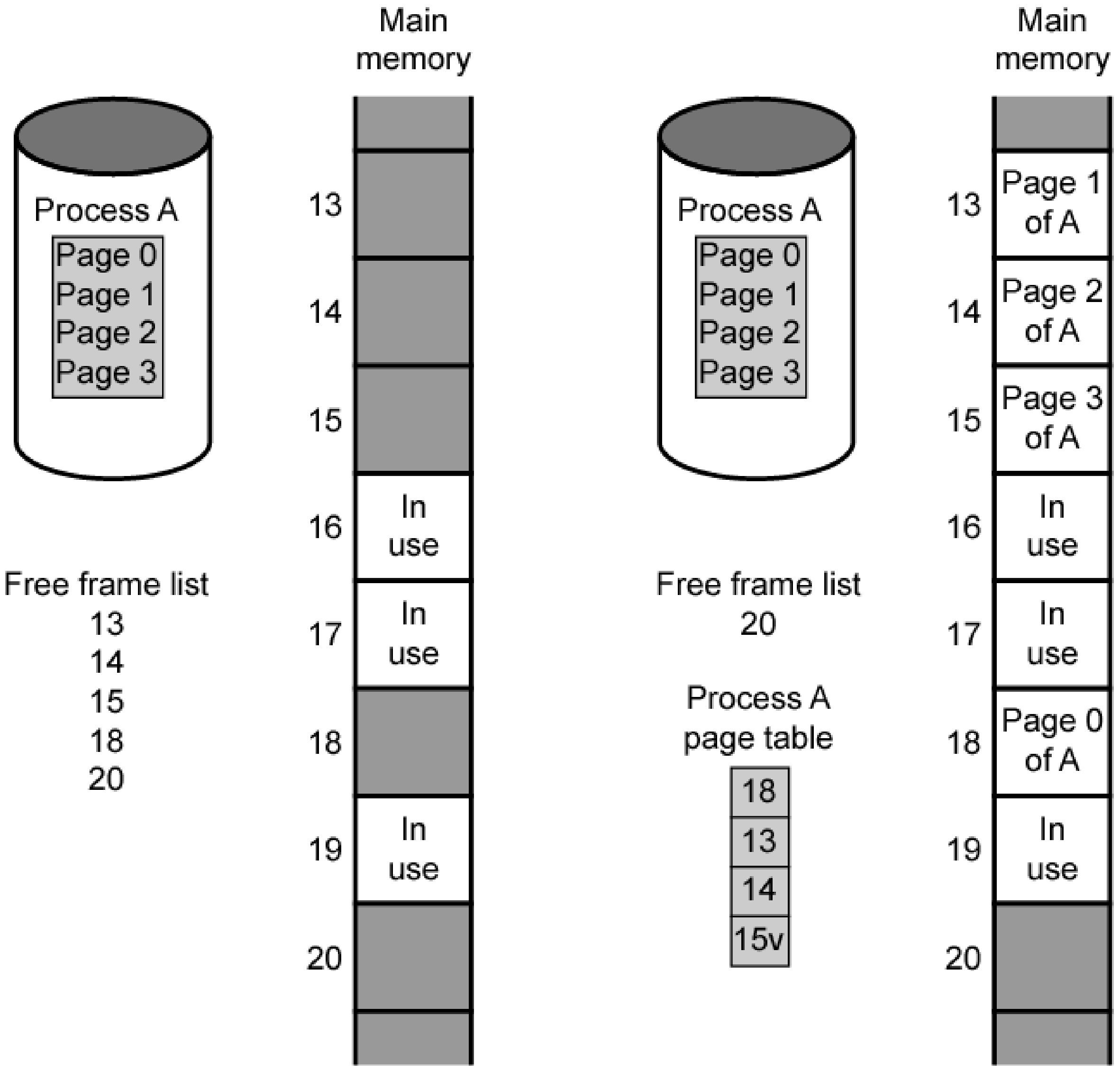
Relocation

- No guarantee that process will load into the same place in memory
- Instructions contain addresses
  - Locations of data
  - Addresses for instructions (branching)
- Logical address - relative to beginning of program
- Physical address - actual location in memory (this time)
- Automatic conversion using (adding) base address (starting location of the process)

Paging

- Split memory into equal sized, small chunks -page frames
- Split programs (processes) into equal sized small chunks - pages
- Allocate the required number page frames to a process
- Operating System maintains list of free frames
- A process does not require contiguous page frames
- Use page table to keep track

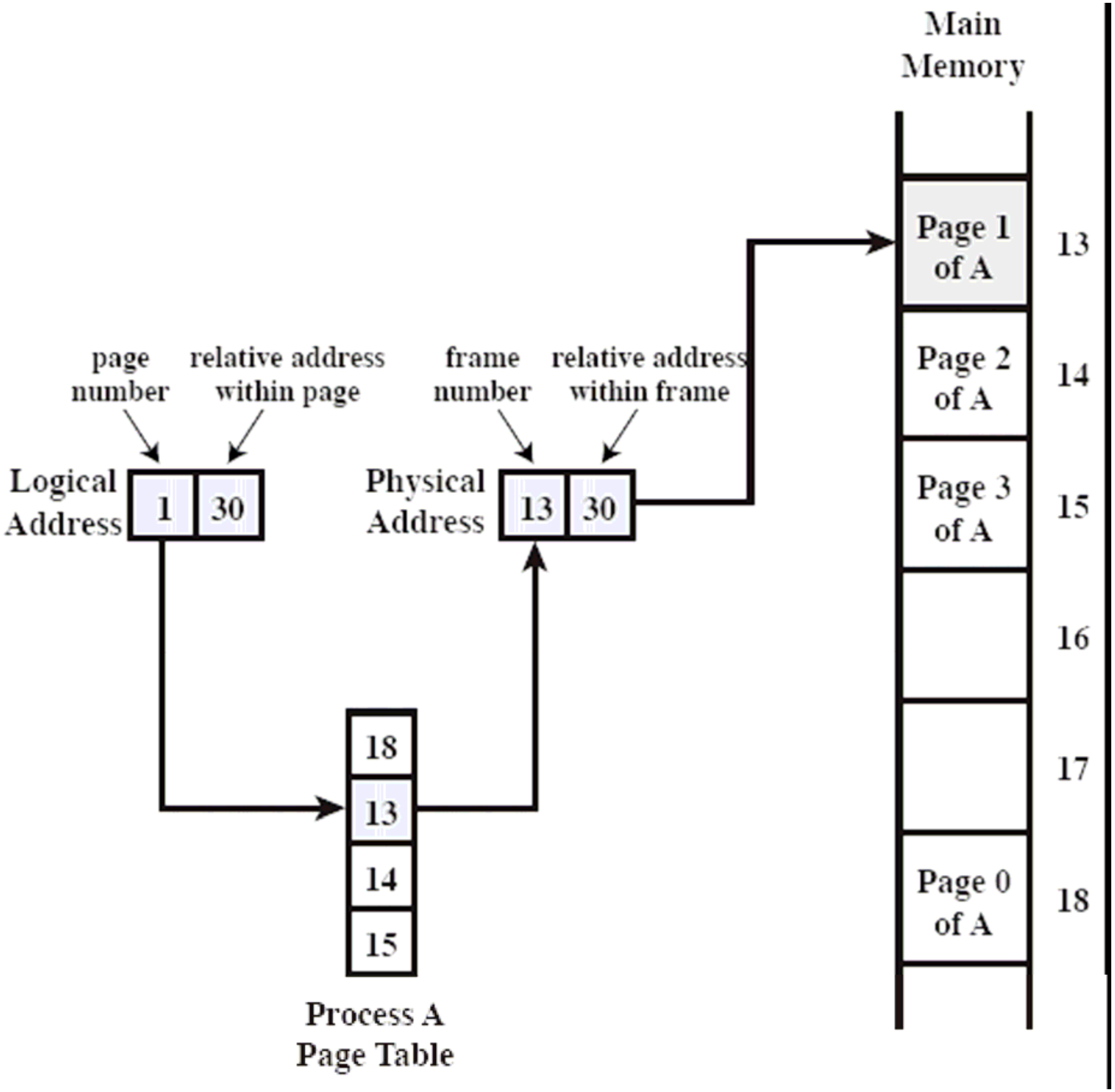
Allocation of Free Frames



(a) Before

(b) After

Logical and Physical Addresses - Paging



Virtual Memory

- Demand paging
  - Do not require all pages of a process in memory
  - Bring in pages as required
  - If the program branches to an instruction on a page not in main memory, a “page fault” is triggered
- Page fault
  - Required page is not in memory
  - Operating System must swap in required page
  - May need to swap out a page to make space
  - Select page to throw out based on recent history (guess which pages are least likely to be used in the near future)

Thrashing

- Too many processes in too little memory
- Operating System spends all its time swapping
- Little or no real work is done
- Disk light is on all the time

- Solutions
  - Good page replacement algorithms
  - Reduce number of processes running
  - Fit more memory

Bonus

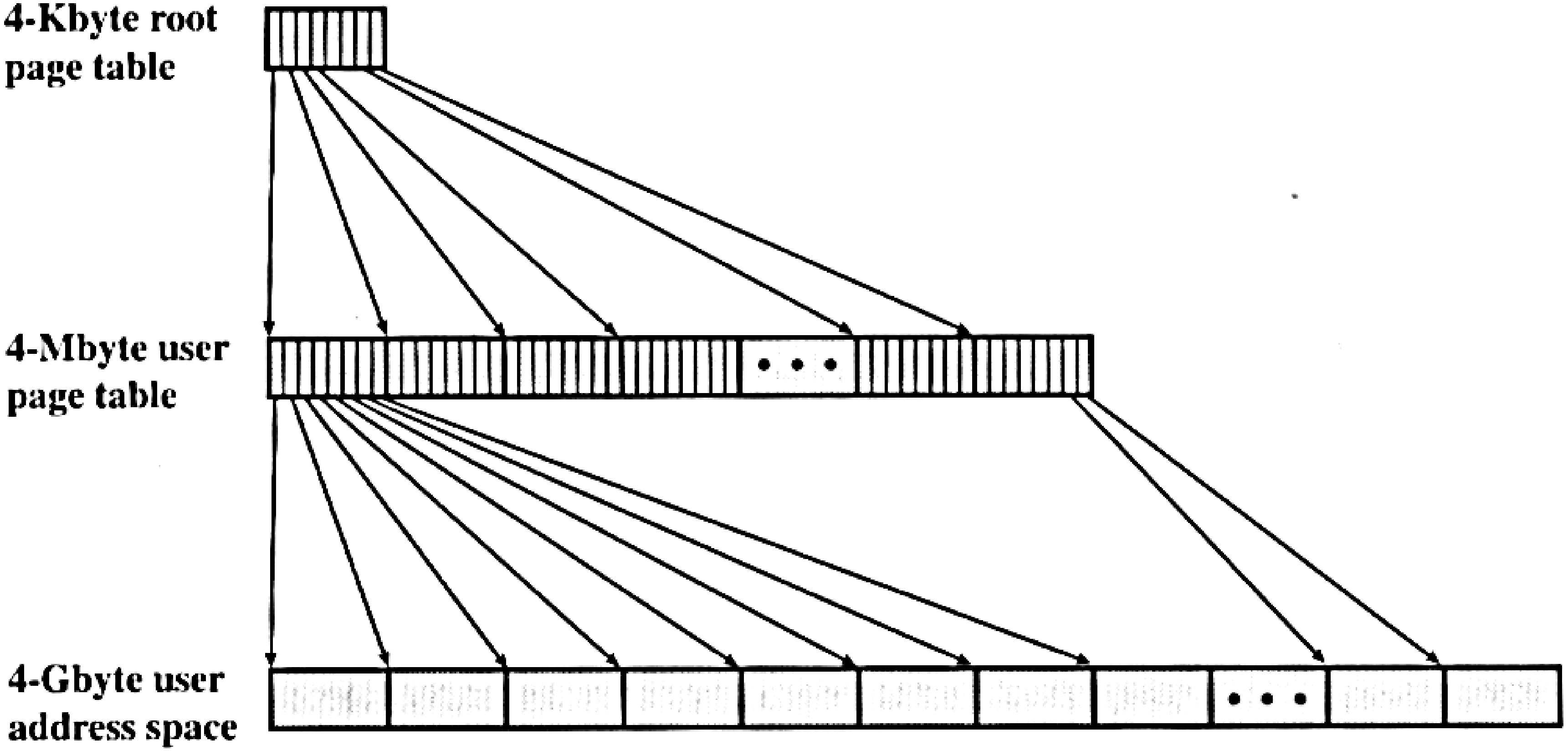
- We do not need all of a process in memory for it to run (also time is saved since unused pages are not swapped in and out of memory)
- We can swap in pages as required
- So - **we can now run processes that are bigger than total memory available!**
- Main memory is called real memory
- User/programmer sees much bigger memory - **virtual memory**, the size associated by disk storage.

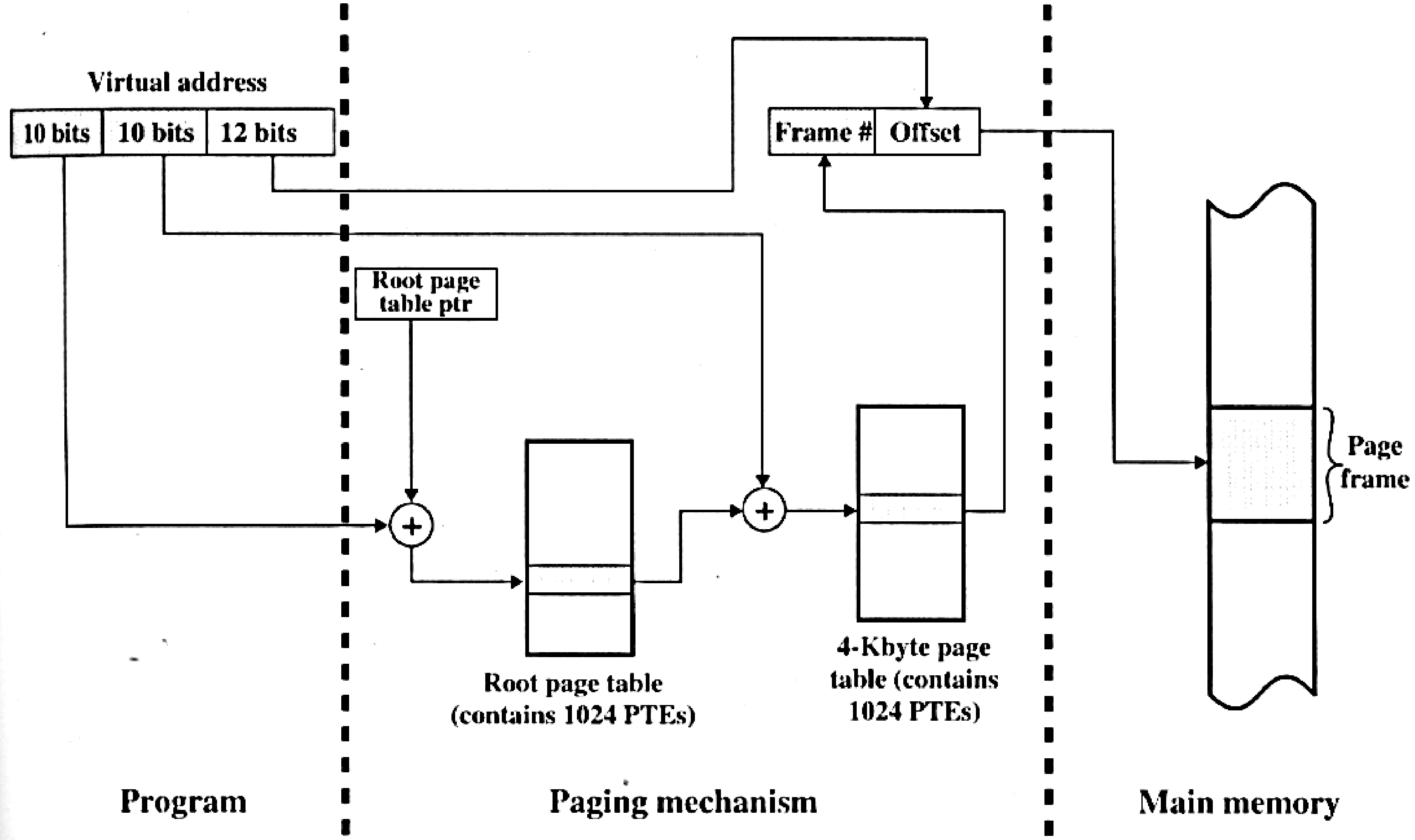
- In VAX architecture each process can have up to 2^{31} = 2GBytes of virtual memory.
- Using 2^{9} = 512 Byte pages, as many as 2^{22} page table entries are required per process. That is unacceptably high for main memory
- To overcome this problem, page tables are kept in virtual memory.
- This means that page tables are subject to paging as well

- Some processors (ex: Pentium) make use of a 2-level scheme.

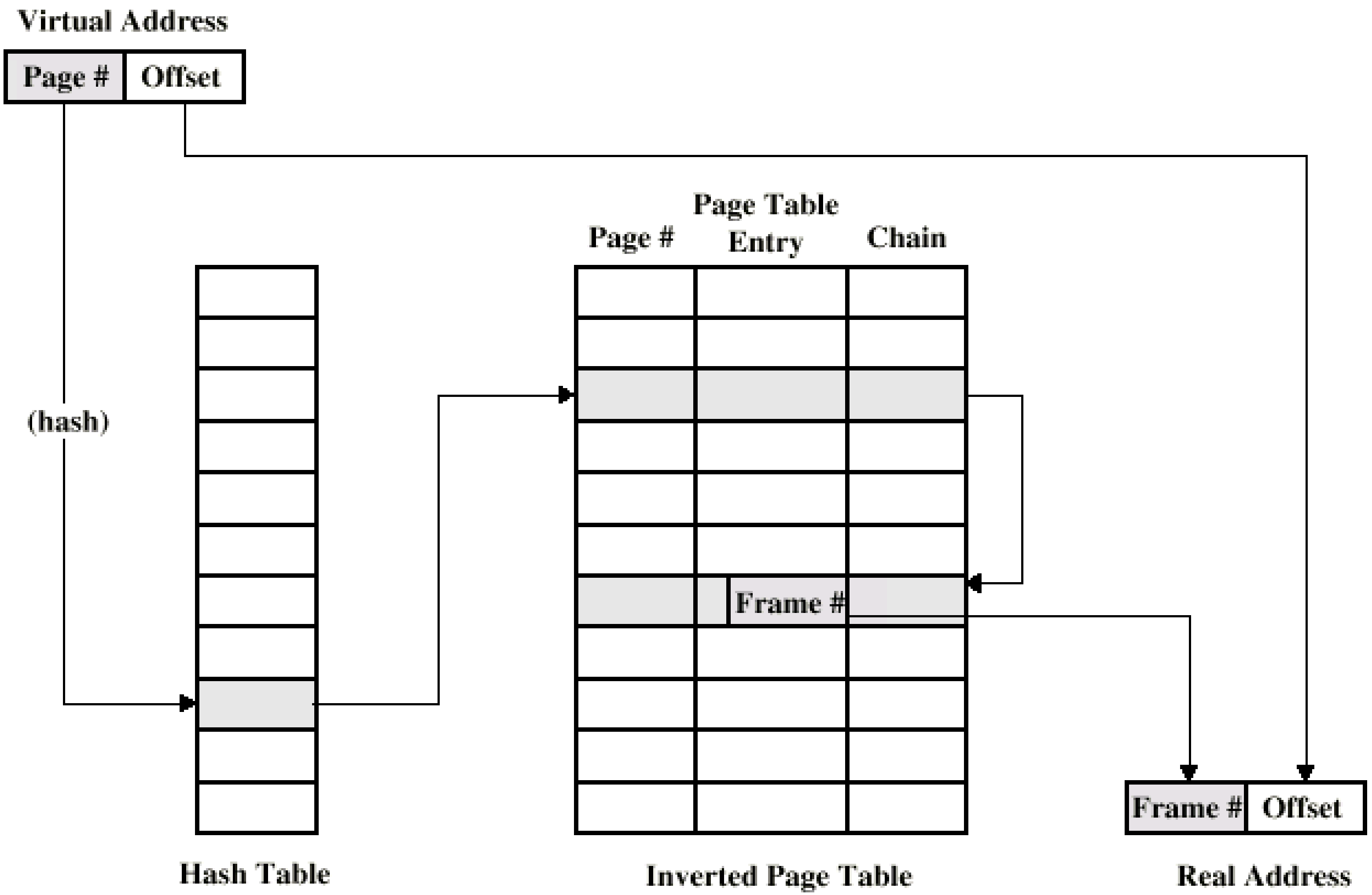
- There is a page directory, in which each entry points to a page table, where the corresponding frame # (in real memory) can be fetced.

- For 32-bit address, assuming byte level addressing and 2^{12} = 4-kbyte pages, the 4-Gbyte (2^{32}) virtual address space is composed of 2^{20} pages. If each page is mapped by a 4-byte page table entry (PTE), we can create a user page table composed of 2^{20} PTEs requiring 2^{22} = 4 Mbytes.


4-Kbyte root page table
4-Mbyte user page table
4-Gbyte user address space


Virtual address
10 bits
10 bits
12 bits
Frame #
Offset
Root page table ptr
+
+
Root page table (contains 1024 PTEs)
4-Kbyte page table (contains 1024 PTEs)
Page frame
Program
Paging mechanism
Main memory

Inverted Page Table Structure

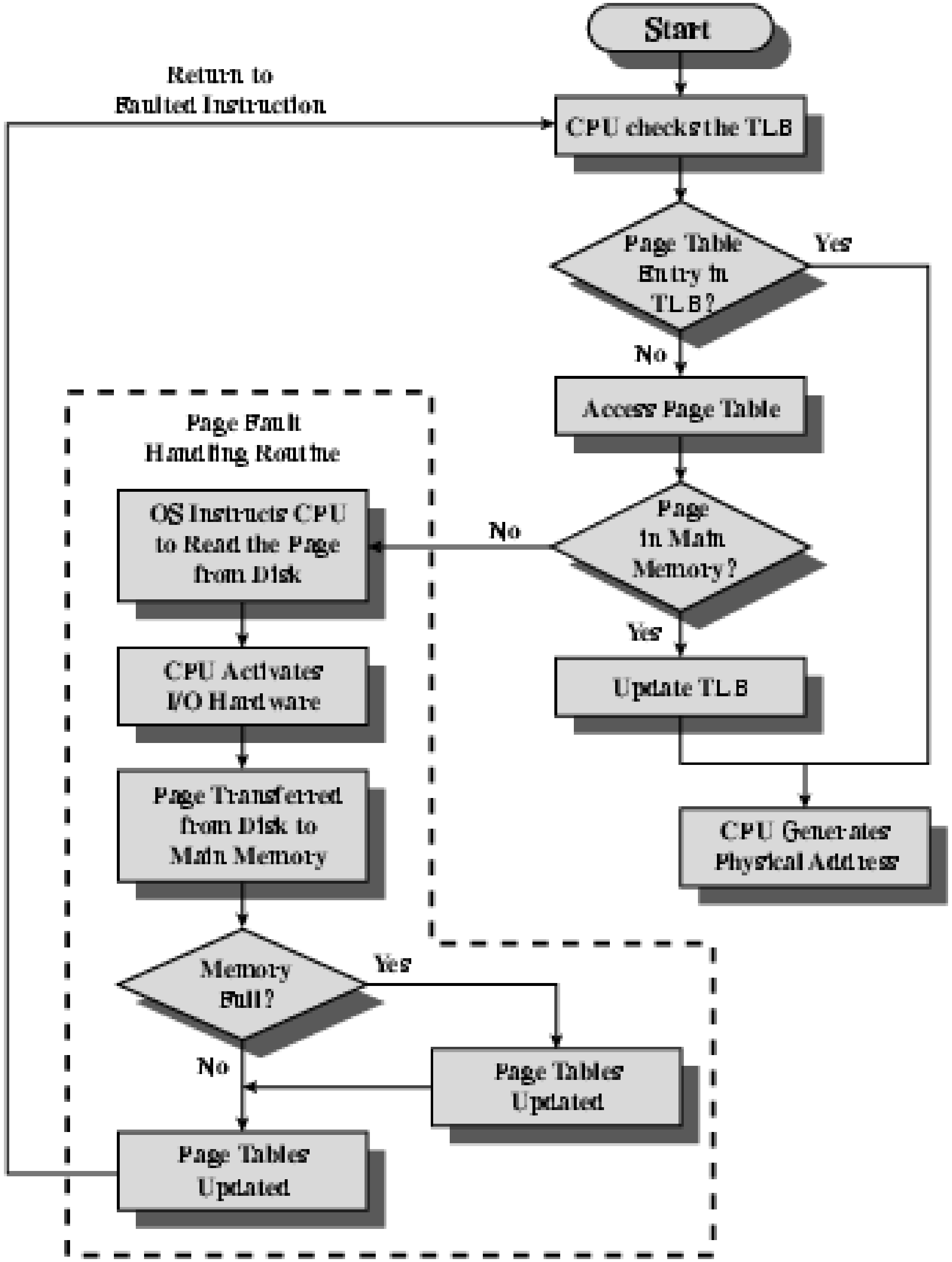


Translation Lookaside Buffer

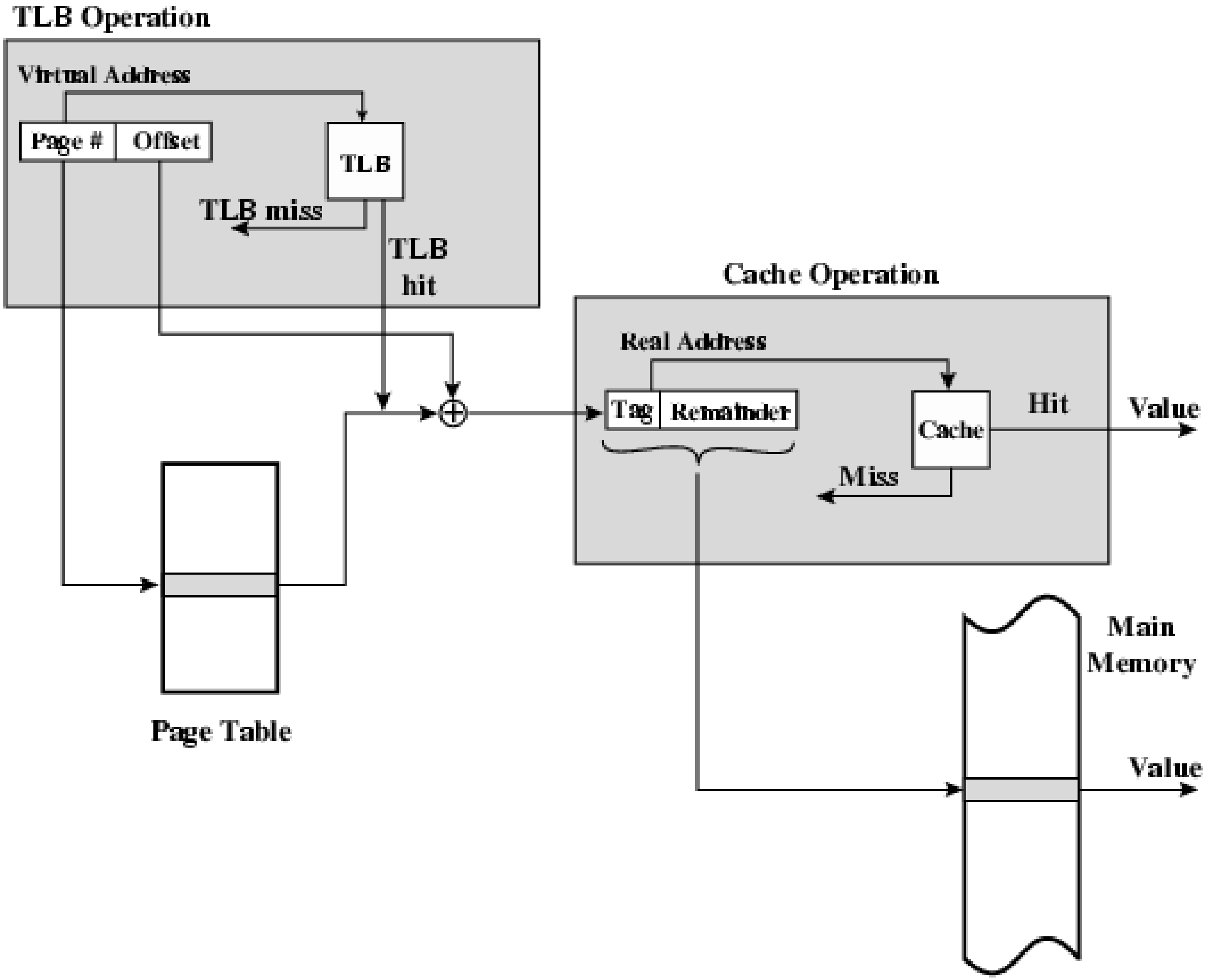
- Every virtual memory reference causes two physical memory access
  - Fetch page table entry
  - Fetch data

  Which doubles the memory access time
- Use special cache for page table entries
  - Translation Lookaside Buffer (TLB)
  - Functions in the same way as a memory cache

TLB Operation


Start
CPU checks the TLB
Return to Faulted Instruction
Page Table Entry in TLB?
Yes
No
Access Page Table
Page in Main Memory?
No
Yes
Update TLB
CPU Generates Physical Address
Page Fault Handling Routine
OS Instructs CPU to Read the Page from Disk
CPU Activates I/O Hardware
Page Transferred from Disk to Main Memory
Memory Full?
Yes
No
Page Tables Updated
Page Tables Updated

TLB and Cache Operation



Segmentation

- Paging is not (usually) visible to the programmer
- Segmentation is visible to the programmer
- Usually different segments allocated to program and data
- May be a number of program and data segments
- Each segment may be assigned access and usage rights

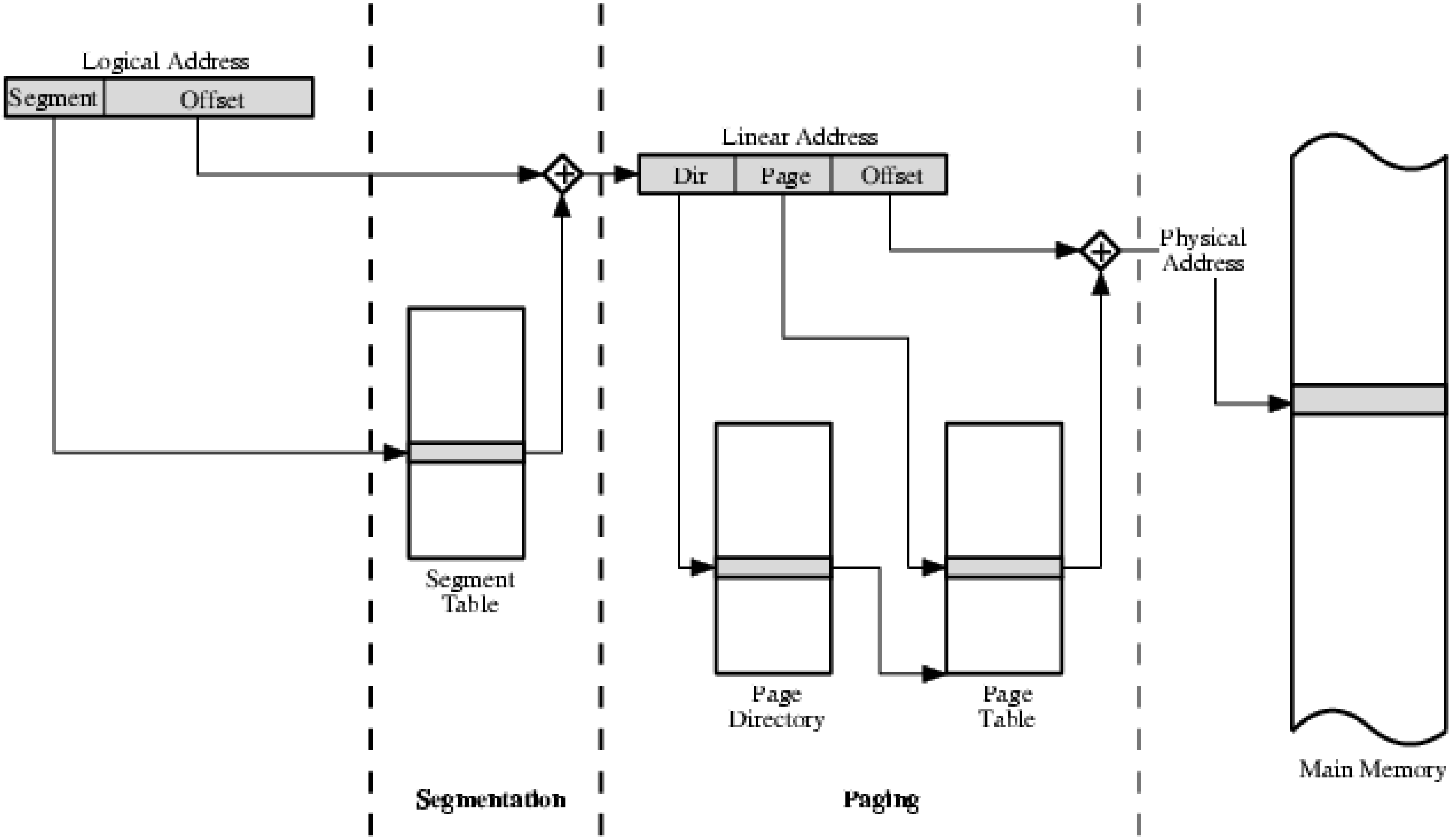
Advantages of Segmentation

- Simplifies handling of growing data structures
- Allows programs to be altered and recompiled independently, without re-linking and re-loading
- Lends itself to sharing among processes
- Lends itself to protection
- The operating system expands or shrinks the segment as needed
- Some systems combine segmentation with paging

Pentium II

- Hardware for segmentation and paging
- Unsegmented unpaged
  - virtual address = physical address
  - Low complexity
  - High performance
- Unsegmented paged
  - Memory viewed as paged linear address space
  - Protection and management via paging
  - Berkeley UNIX
- Segmented unpaged
  - Collection of logical address spaces
  - Protection to single byte level
  - Translation table needed is on chip when segment is in memory (predictable access time)
- Segmented paged
  - Segmentation used to define logical memory partitions subject to access control
  - Paging manages allocation of memory within partitions
  - Unix System V

Pentium II Address Translation Mechanism



Pentium II Segmentation

- Each virtual address is 16-bit segment and 32-bit offset
- 2 bits of segment are protection mechanism
- 14 bits specify segment
- Unsegmented virtual memory 2^{32} = 4Gbytes
- Segmented 2^{46}=64 terabytes
  - Can be larger – depends on which process is active
  - Half (8K segments of 4Gbytes) is global
  - Half is local and distinct for each process

Pentium II Protection

- Protection bits give 4 levels of privilege
  - 0 most protected, 3 least
  - Use of levels software dependent
  - Usually level 3 for applications, level 1 for O/S and level 0 for kernel (level 2 not used)
  - Level 2 may be used for apps that have internal security e.g. database
  - Some instructions only work in level 0

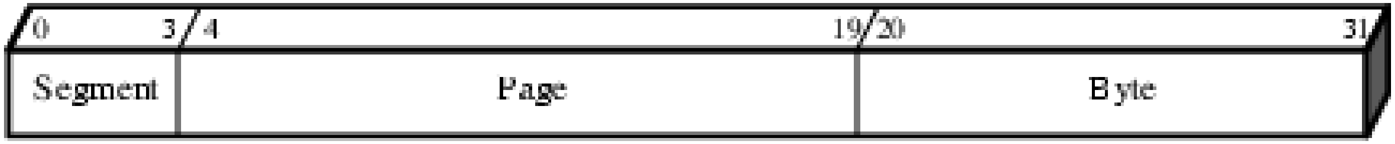
Pentium II Paging

- Segmentation may be disabled
  - In which case linear address space is used
- Two level page table lookup
  - First, page directory
    - 1024 entries max
    - Splits 4G linear memory into 1024 page groups of 4Mbyte
    - Each page table has 1024 entries corresponding to 4Kbyte pages
    - Can use one page directory for all processes, one per process or mixture
    - Page directory for current process always in memory
  - Use TLB holding 32 page table entries
  - Two page sizes available 4k or 4M

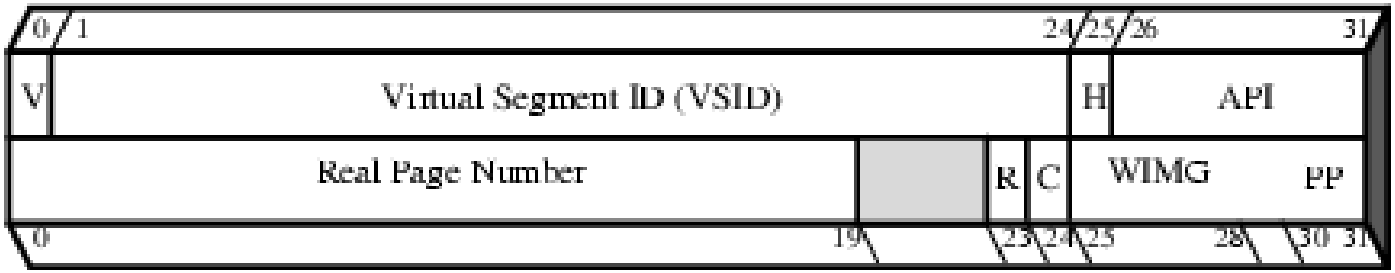
PowerPC Memory Management Hardware

- 32 bit – paging with simple segmentation
  - 64 bit paging with more powerful segmentation
- Or, both do block address translation
  - Map 4 large blocks of instructions & 4 of memory to bypass paging
  - e.g. OS tables or graphics frame buffers
- 32 bit effective address
  - 12 bit byte selector
    - =4kbyte pages
  - 16 bit page id
    - 64k pages per segment
  - 4 bits indicate one of 16 segment registers
    - Segment registers under OS control

PowerPC 32-bit Memory Management Formats



(a) Effective address

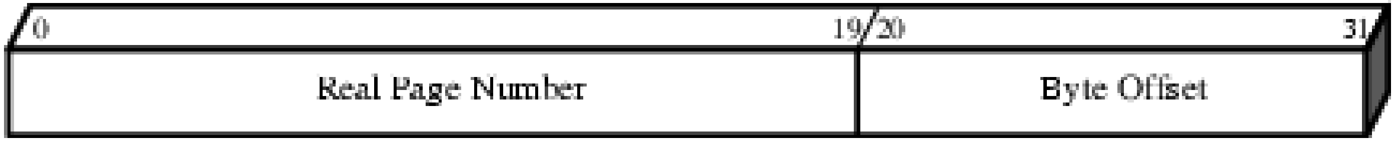


V = Entry valid bit
H = Hash function identifier
API = Abbreviated page index

R = Referenced bit
C = Changed bit
WIMG = Cache and storage access control bits
PP = Page protection bits

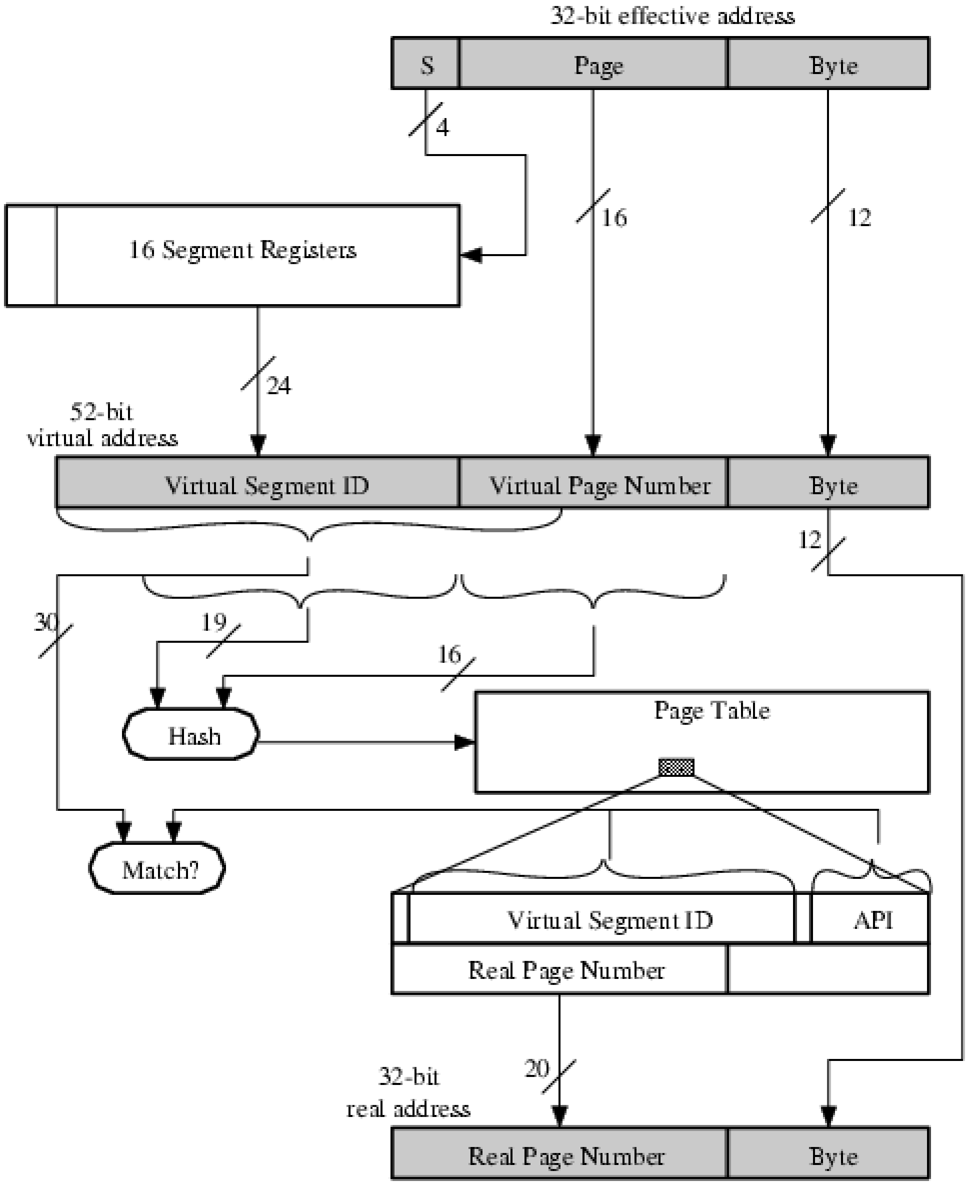
▨ = reserved

(b) Page Table Entry



(c) Real address

PowerPC 32-bit Address Translation



Required Reading

- Stallings chapter 8
- Stallings, W. [2004] *Operating Systems*, Pearson
- Loads of Web sites on Operating Systems