William Stallings
Computer Organization and Architecture
7th Edition

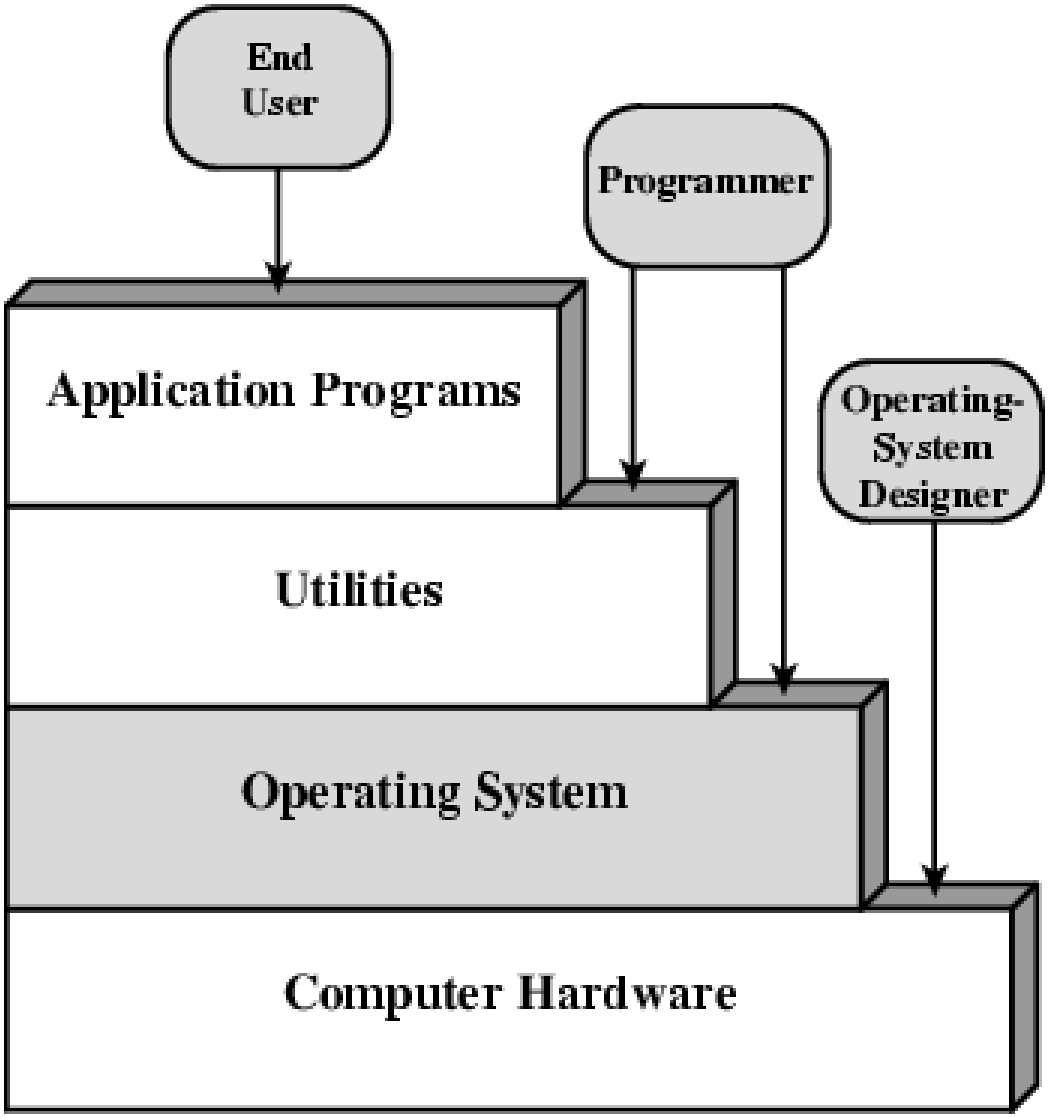
Chapter 8

Operating System Support

Objectives and Functions

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

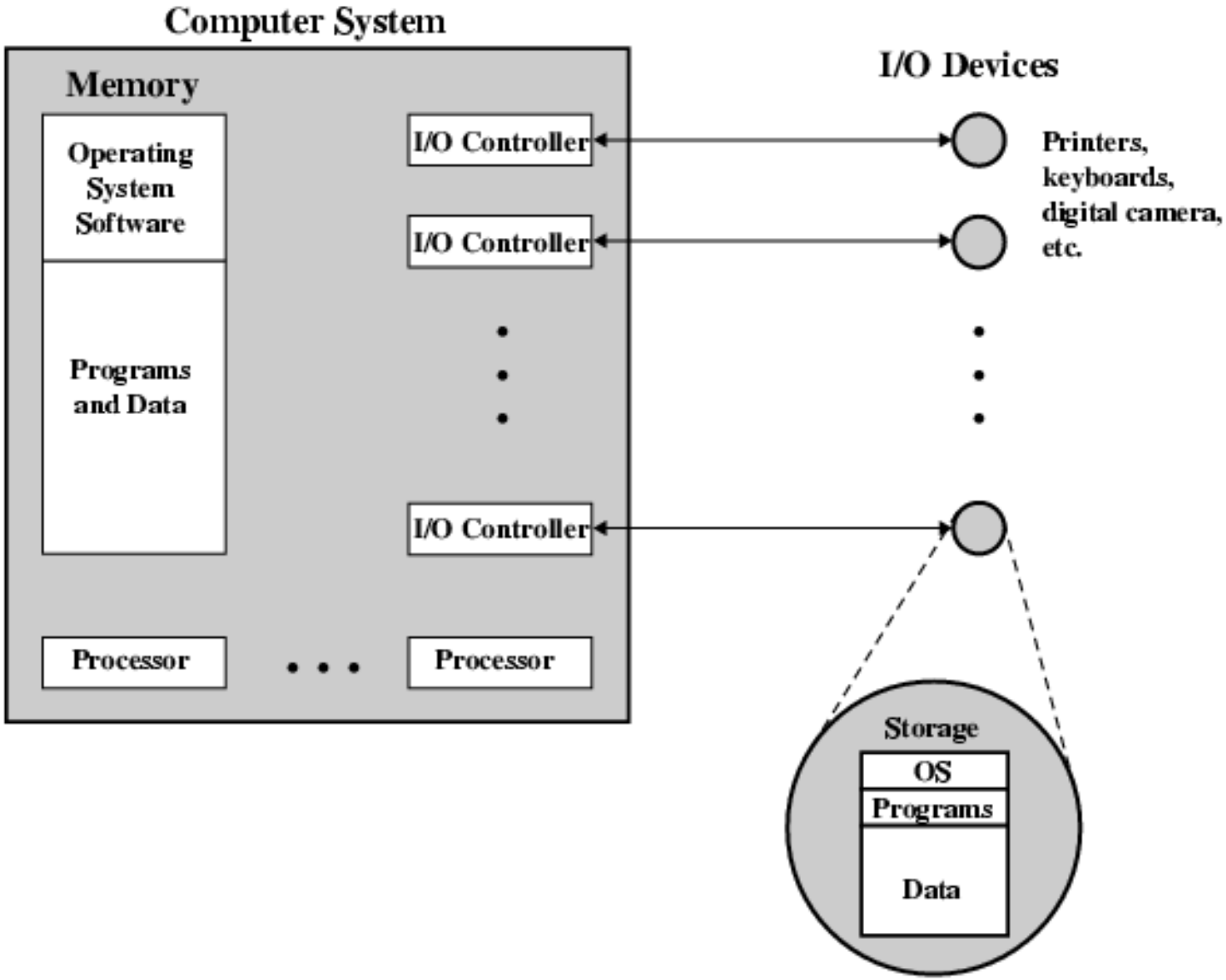
Layers and Views of a Computer System



Operating System Services

- Program creation
- Program execution
- Access to I/O devices
- Controlled access to files
- System access
- Error detection and response
- Accounting

O/S as a Resource Manager



Types of Operating System

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

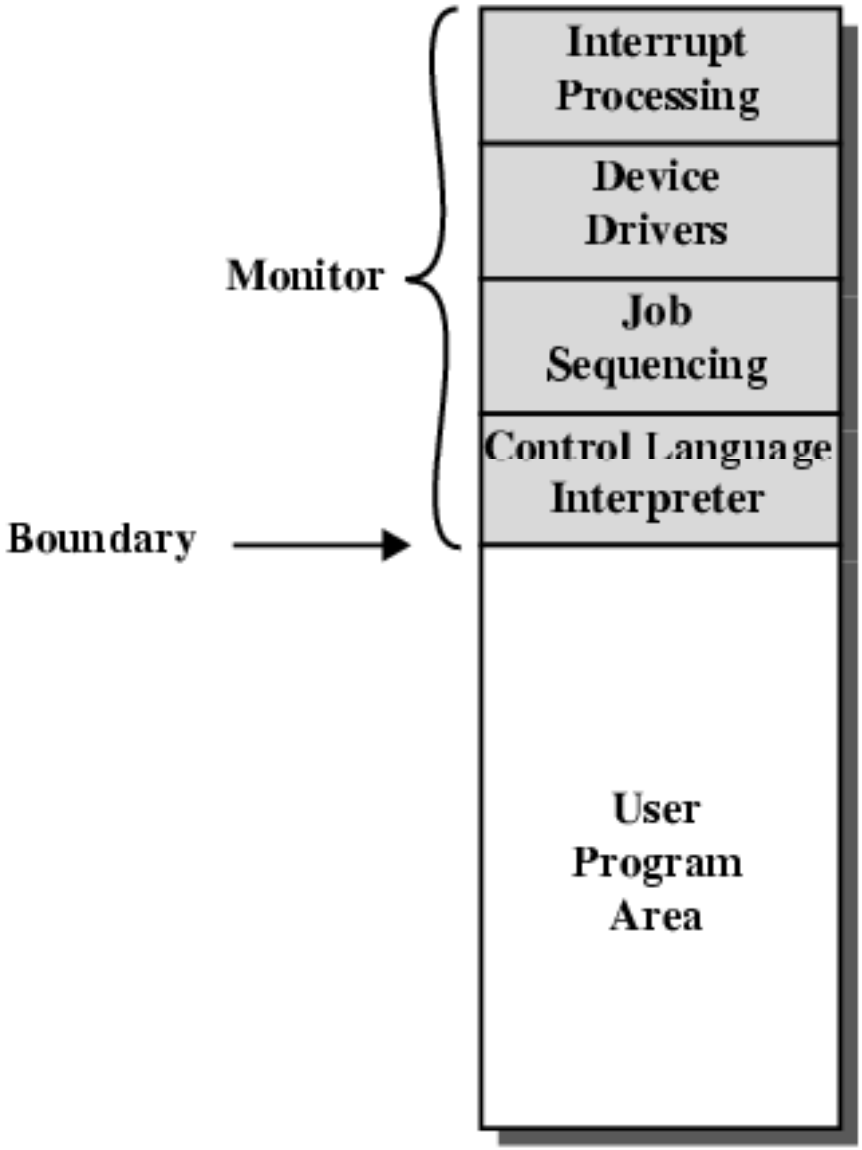
Early Systems

- Late 1940s to mid 1950s
- No Operating System
- Programs interact directly with hardware
- Two main problems:
  - Scheduling
  - Setup time

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

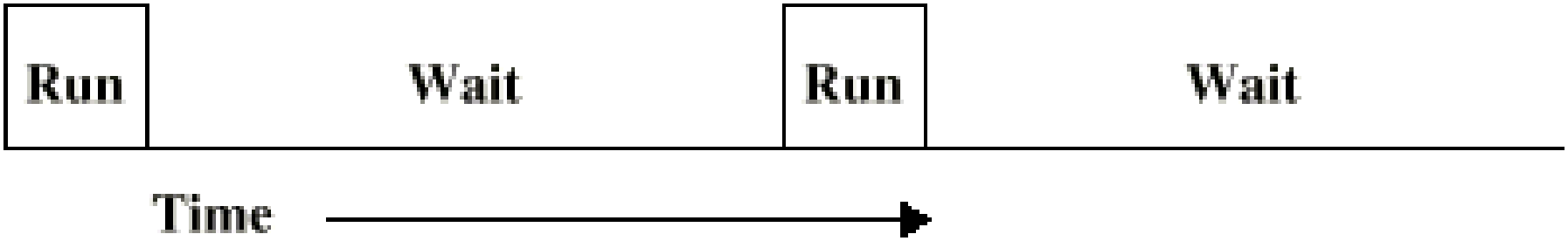
Desirable Hardware Features

- **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

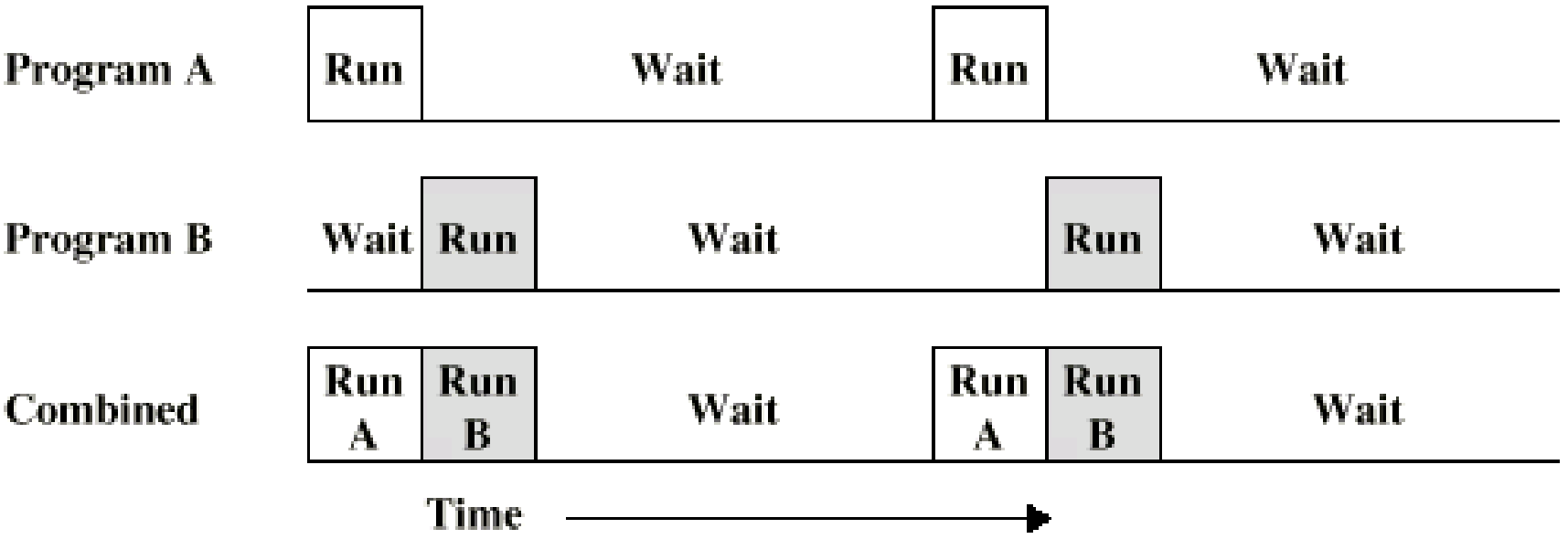
Multi-programmed Batch Systems

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

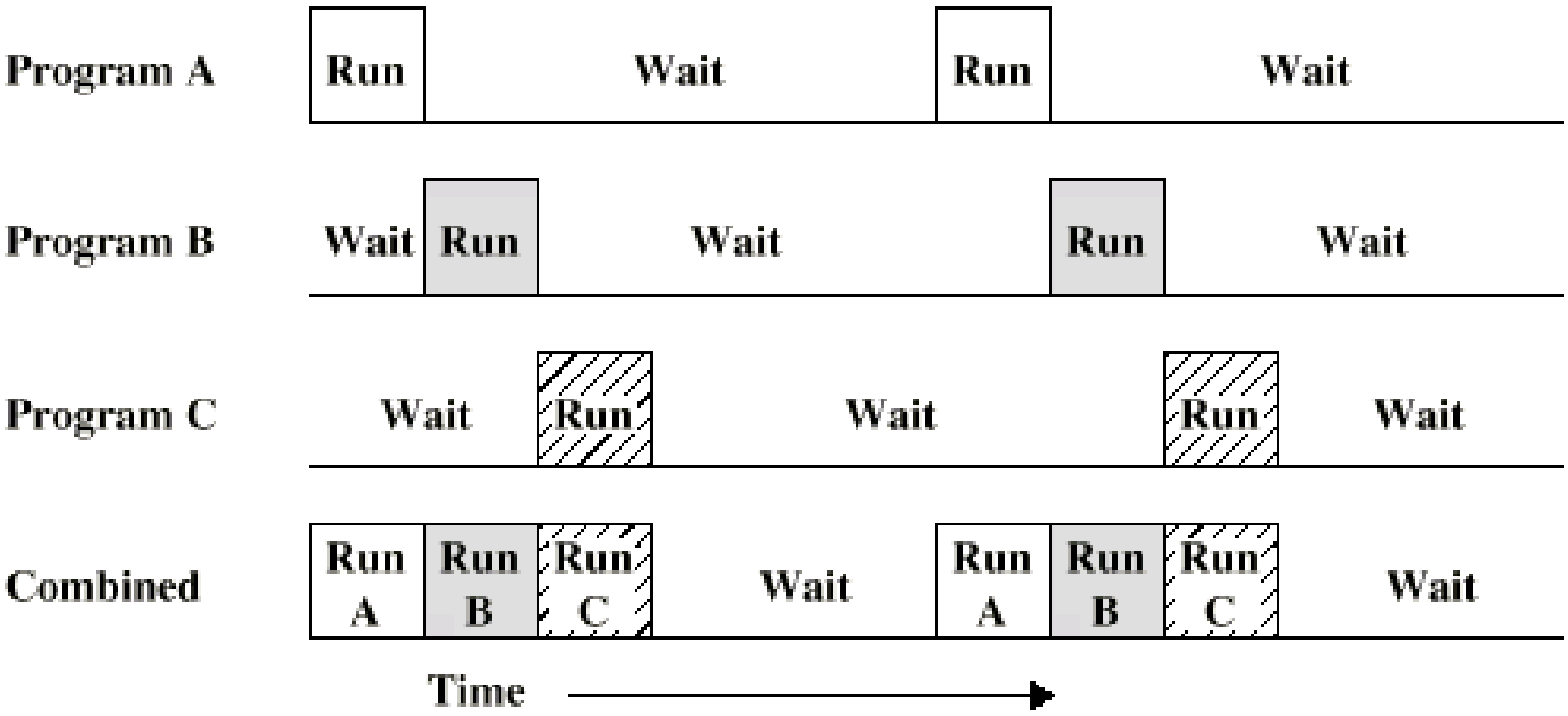
Single Program



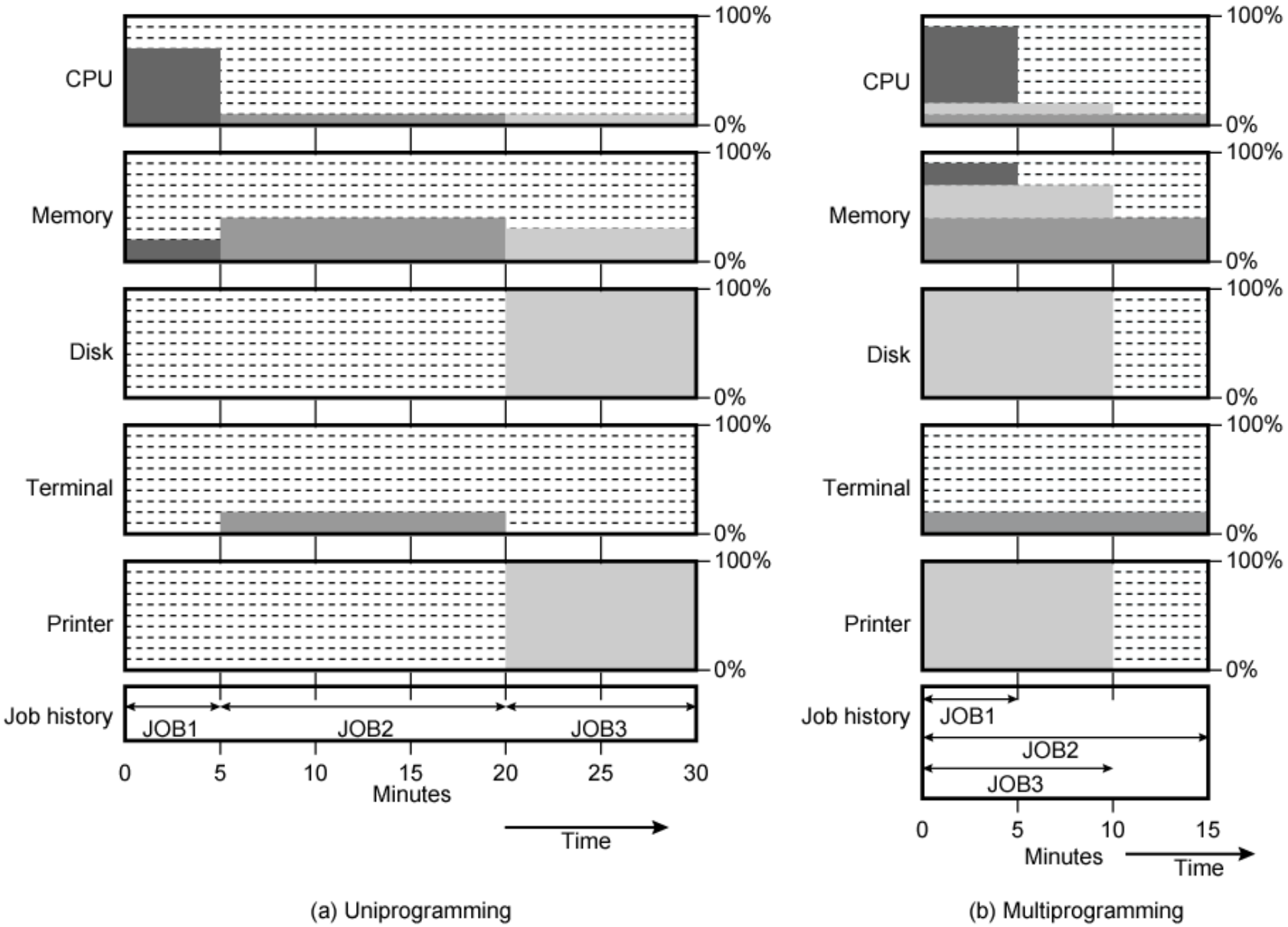
Multi-Programming with Two Programs



Multi-Programming with Three Programs



Utilization



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
- Medium term
- Short term
- I/O

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
- (or it becomes a swapped out job for the medium term scheduler)

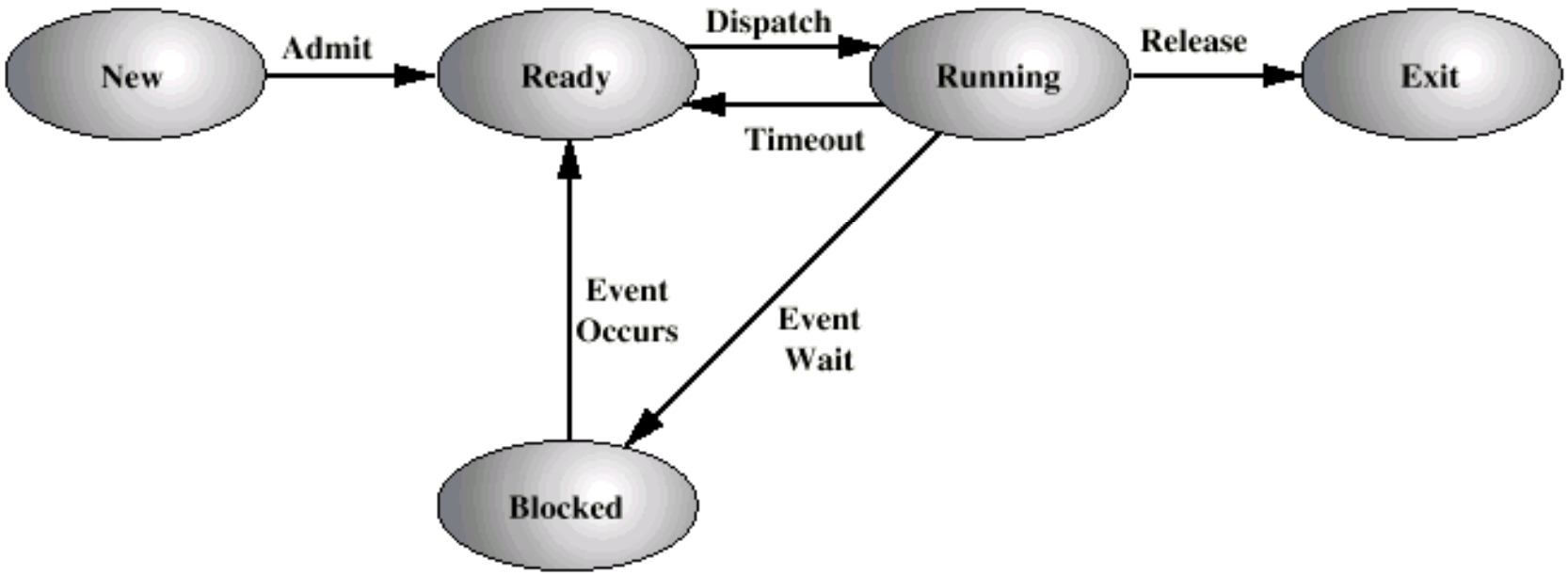
Medium Term Scheduling

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

Short Term Scheduler

- 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

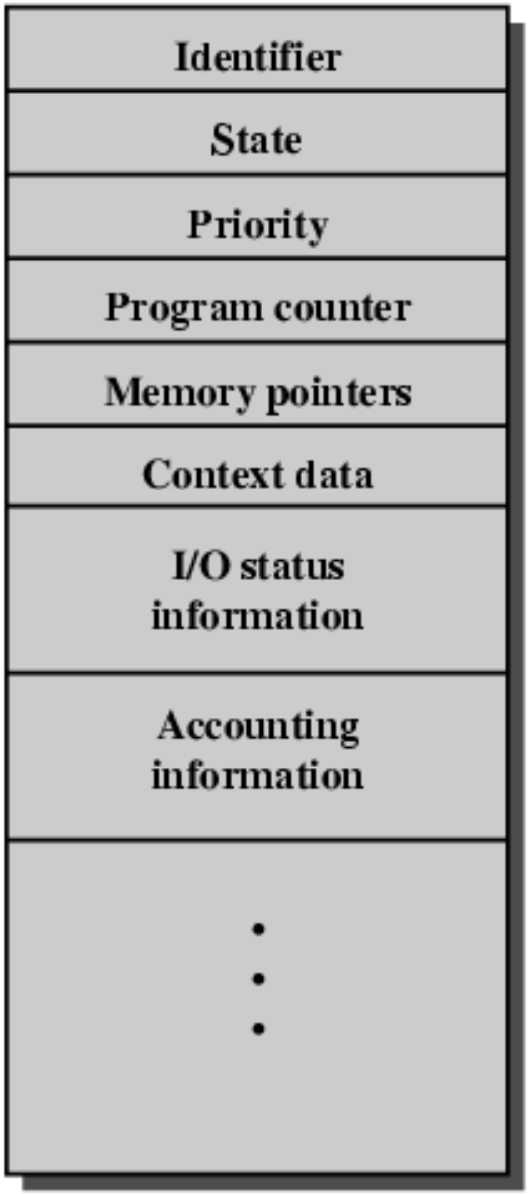
Five State Process Model



Process Control Block

- Identifier
- State
- Priority
- Program counter
- Memory pointers
- Context data
- I/O status
- Accounting information

PCB Diagram


Identifier
State
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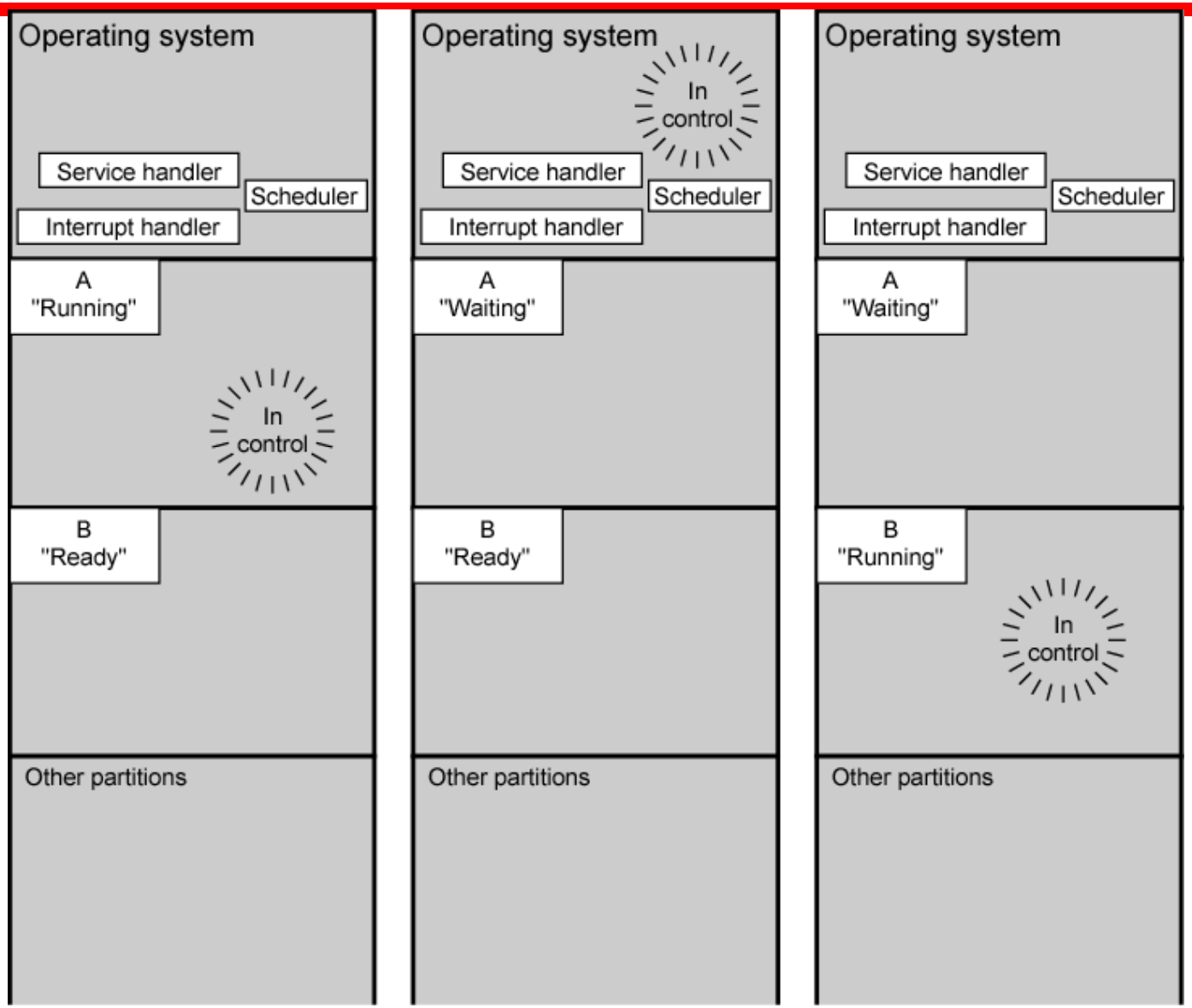
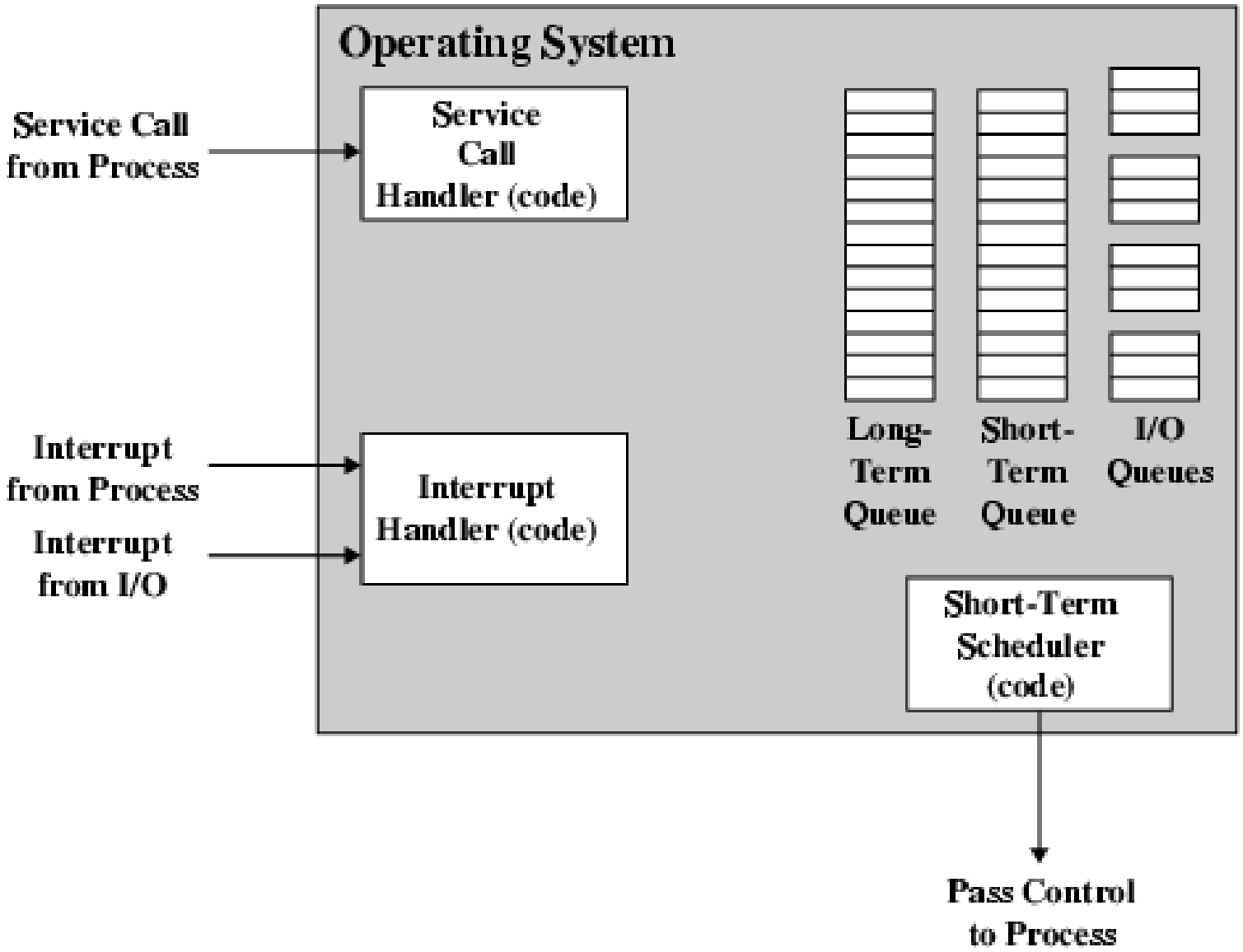
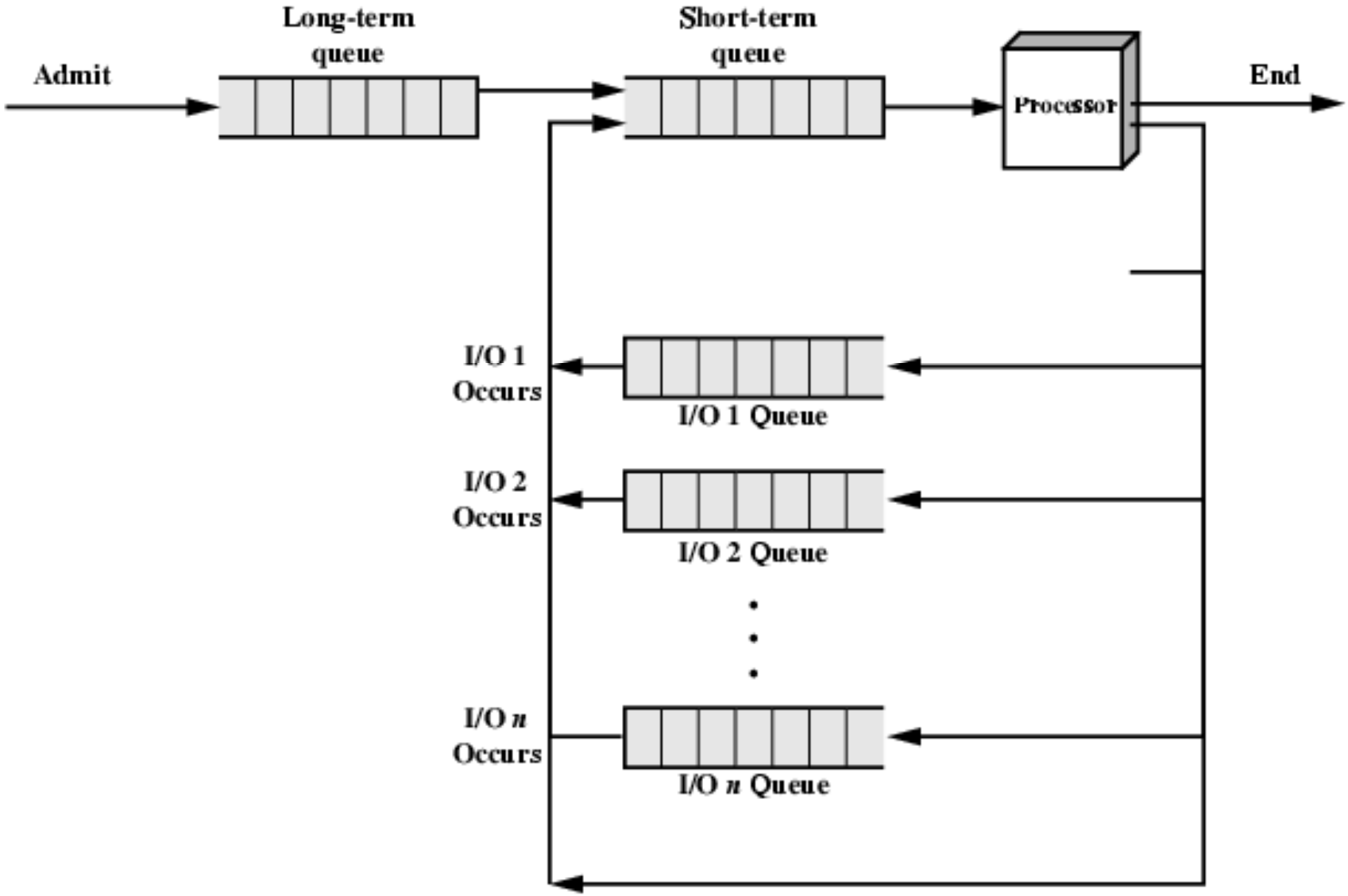
Scheduling Example



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 and shared among active processes**

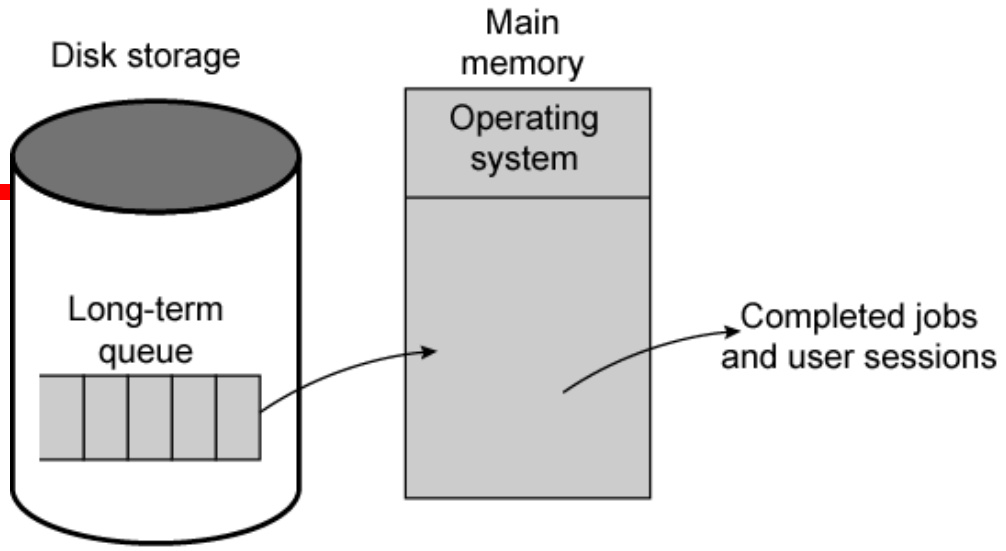
Swapping

- **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**

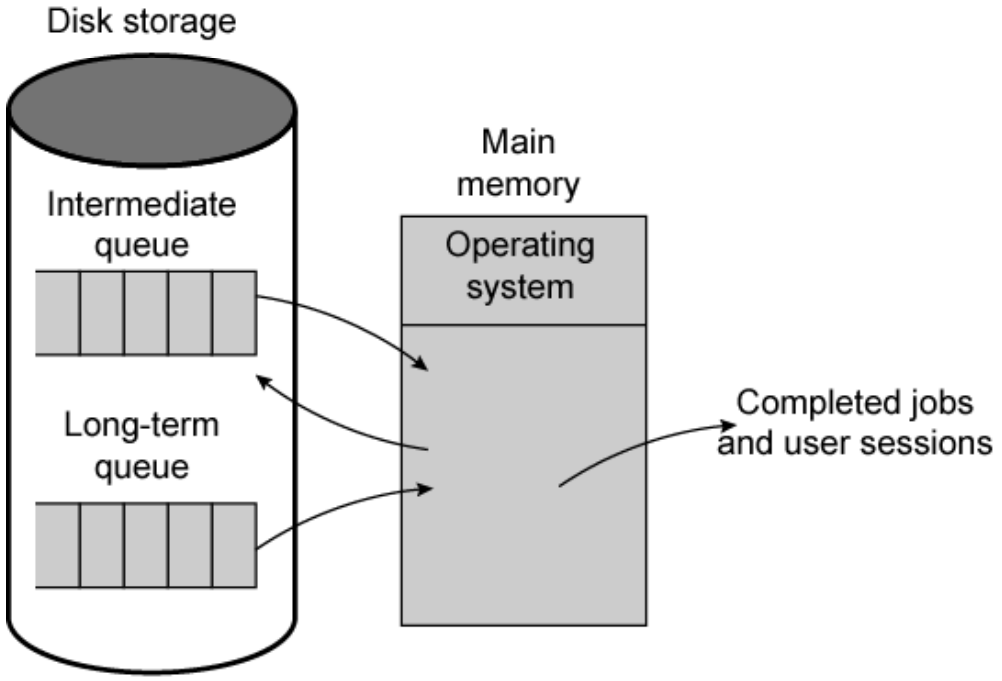
What is Swapping?

- 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
  - Swap in a ready process or a new process
  - But swapping is an I/O process...

Use of Swapping



(a) Simple job scheduling

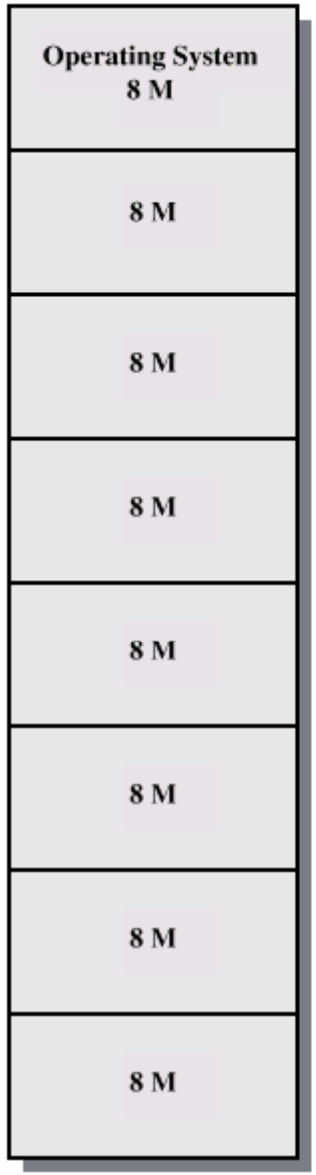


(b) Swapping

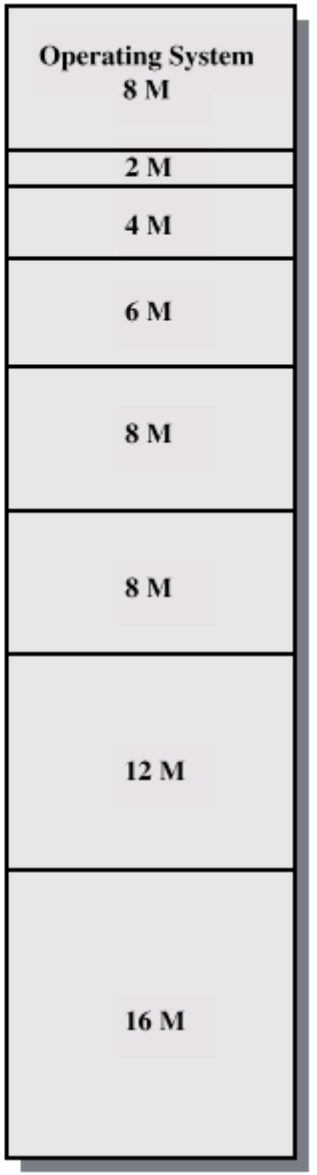
Partitioning

- 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) Equal-size partitions



(b) Unequal-size partitions

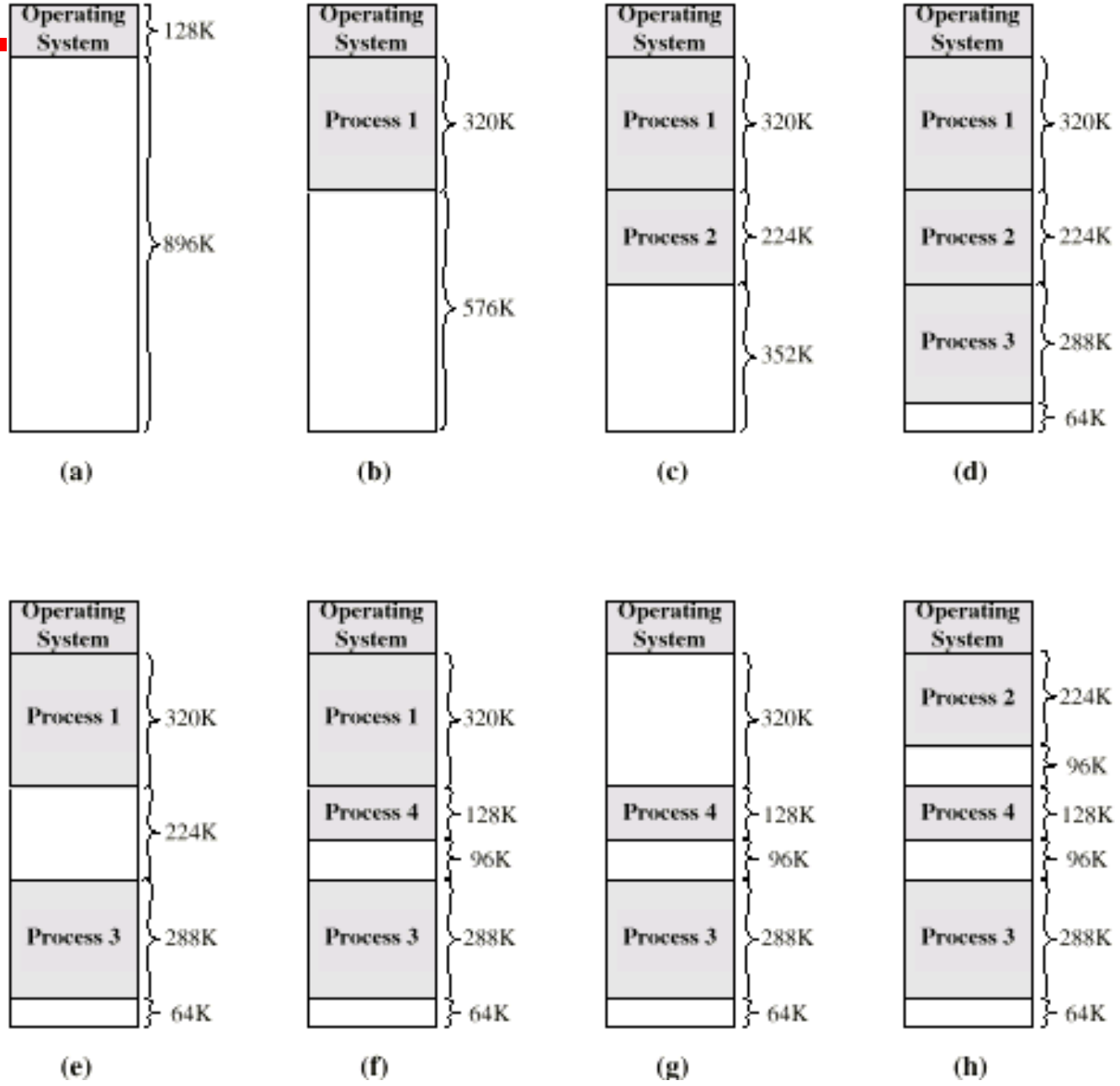
Variable Sized Partitions (1)

- 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)

Effect of Dynamic Partitioning



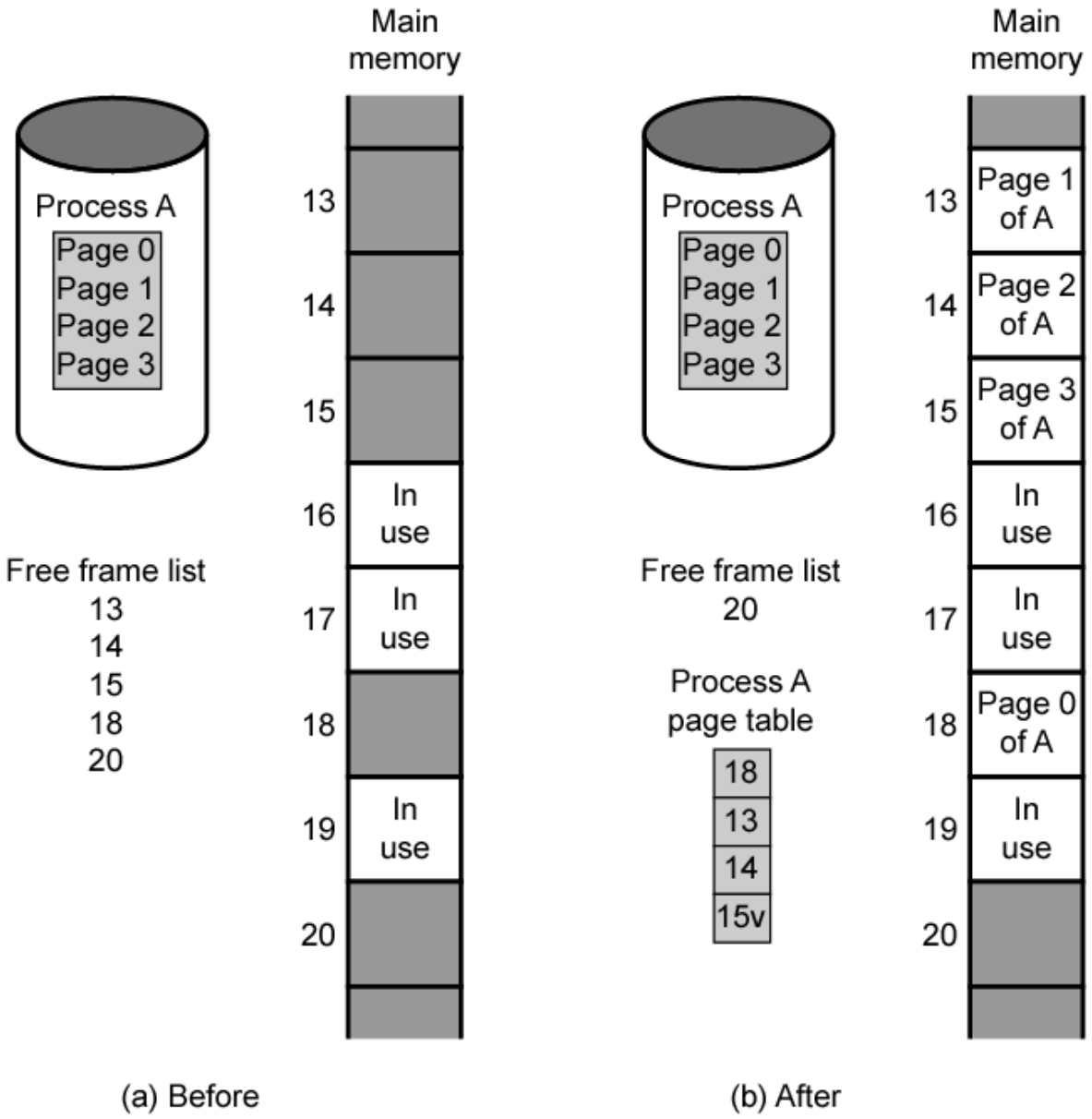
Relocation

- 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 base address

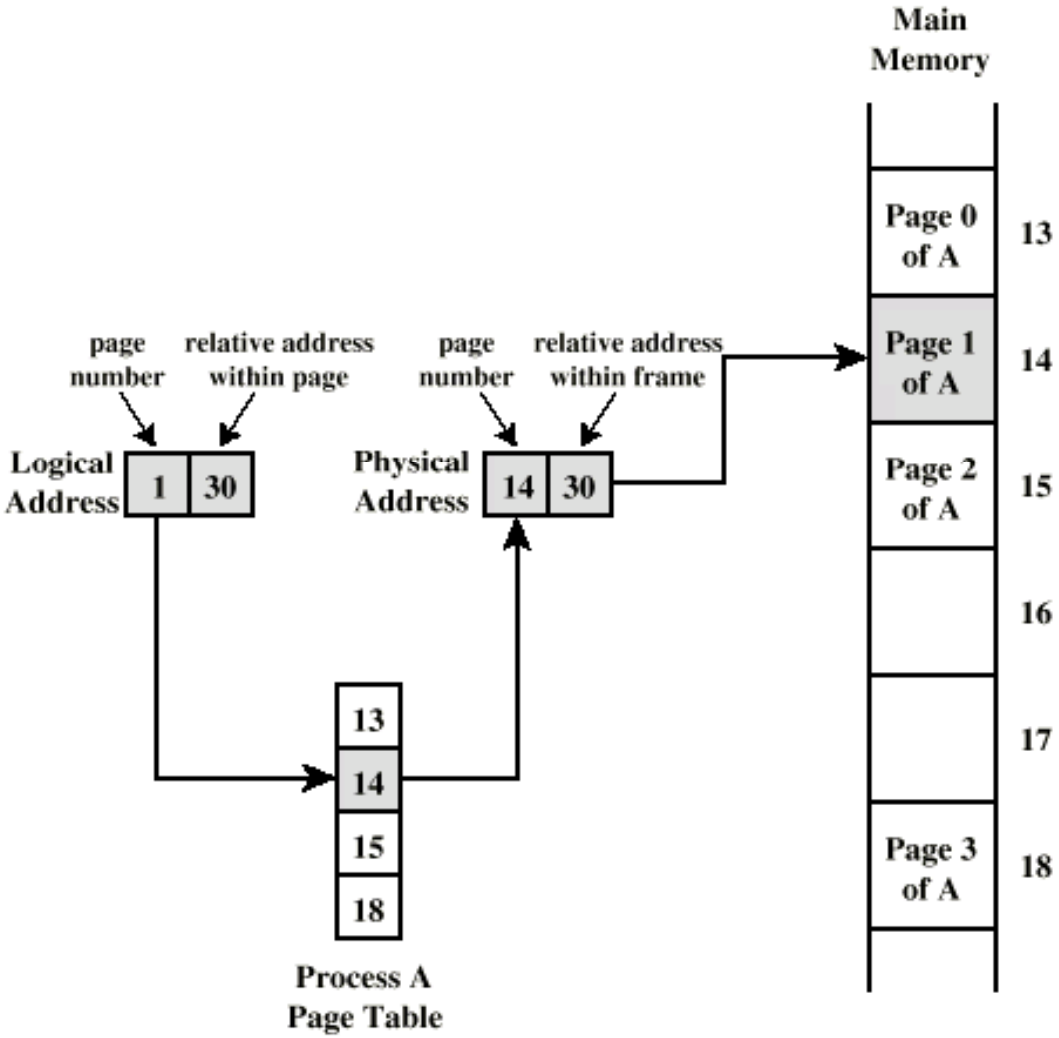
Paging

- 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



Logical and Physical Addresses - Paging



Virtual Memory

- **Demand paging**
  - —Do not require all pages of a process in memory
  - —Bring in pages as required
- **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

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

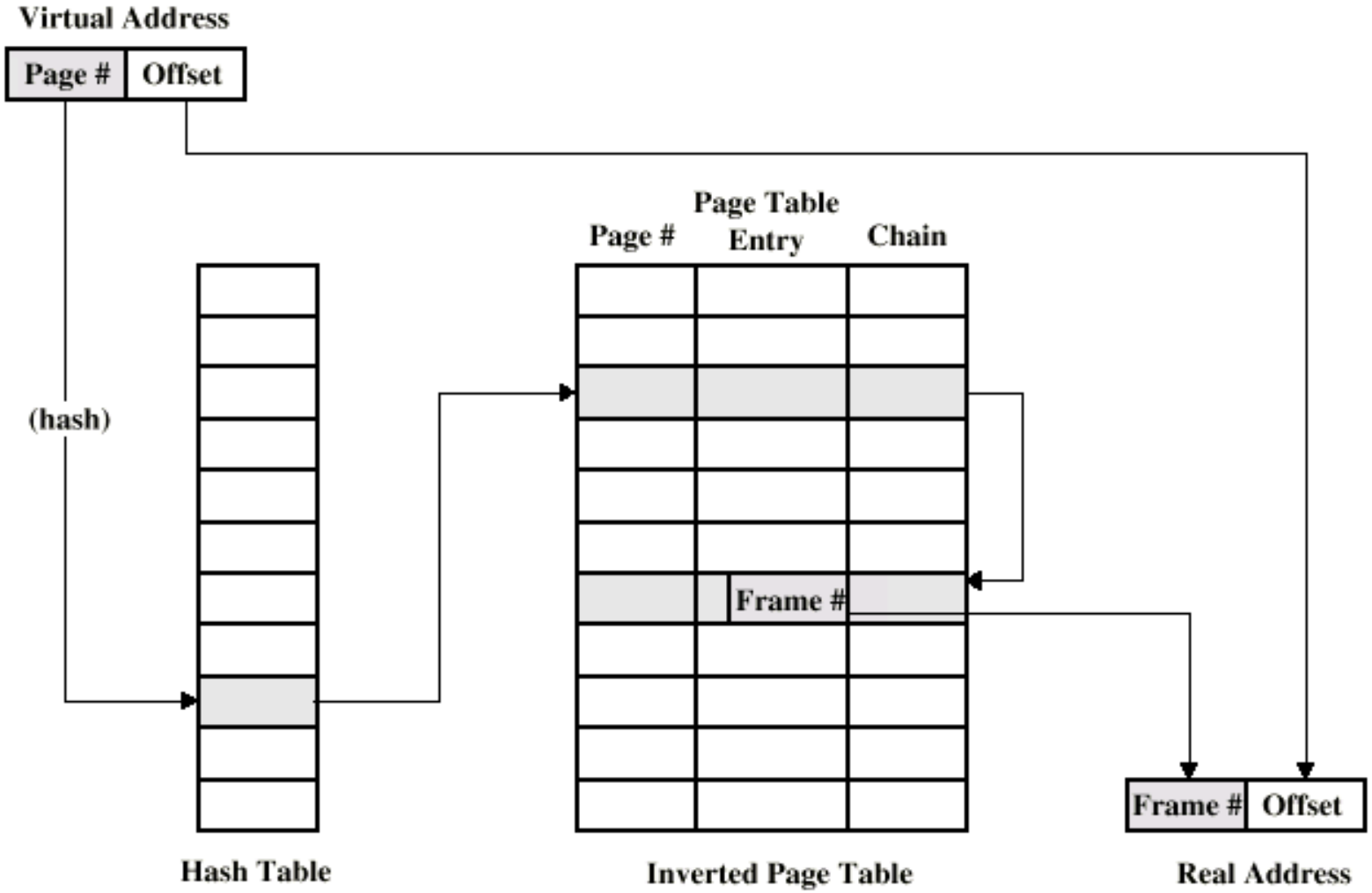
- Solutions
  - Good page replacement algorithms
  - Reduce number of processes running
  - Fit more memory

Bonus

- We do not need all of a process in memory for it to run
- 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

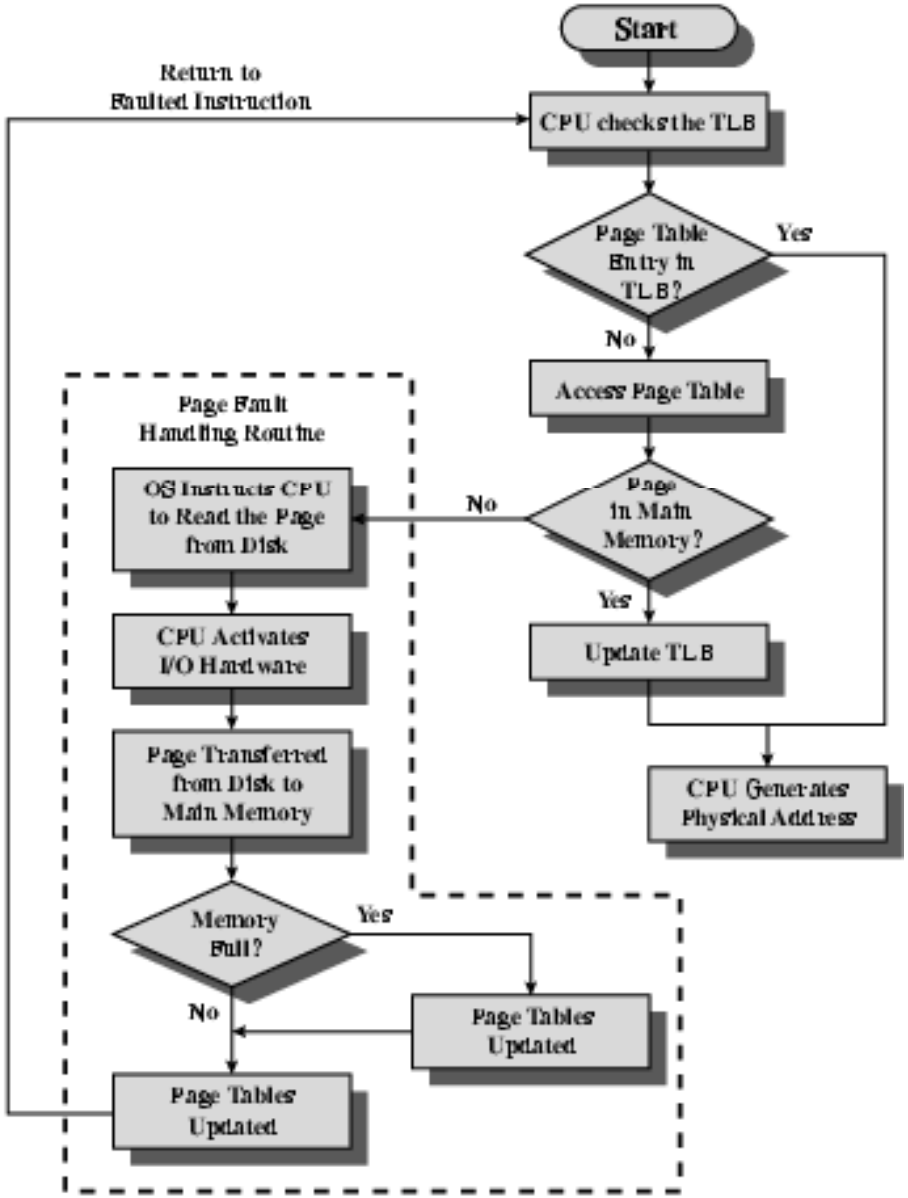
Inverted Page Table Structure



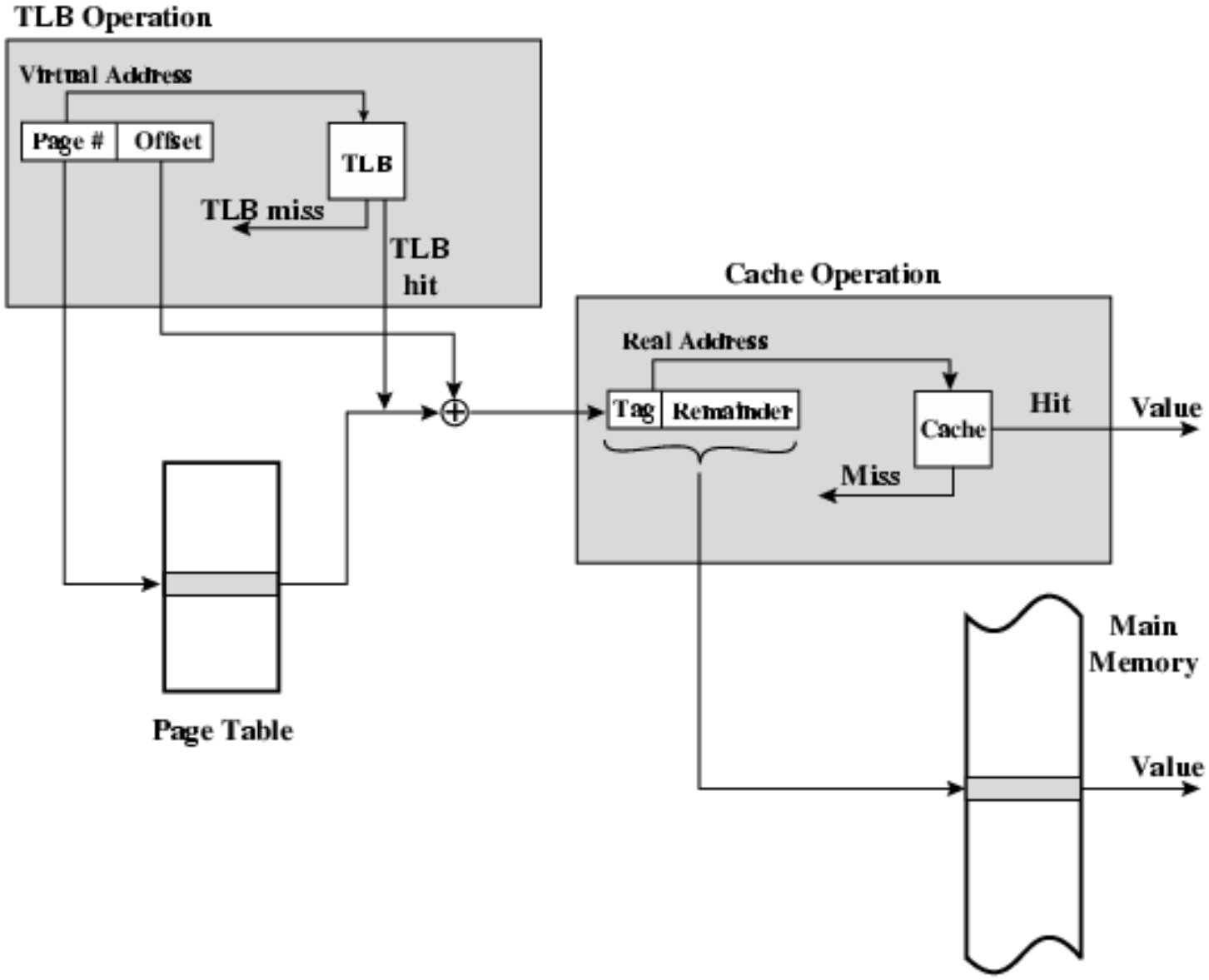
Translation Lookaside Buffer

- Every virtual memory reference causes two physical memory access
  - —Fetch page table entry
  - —Fetch data
- Use special cache for page table
  - —TLB

TLB Operation



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

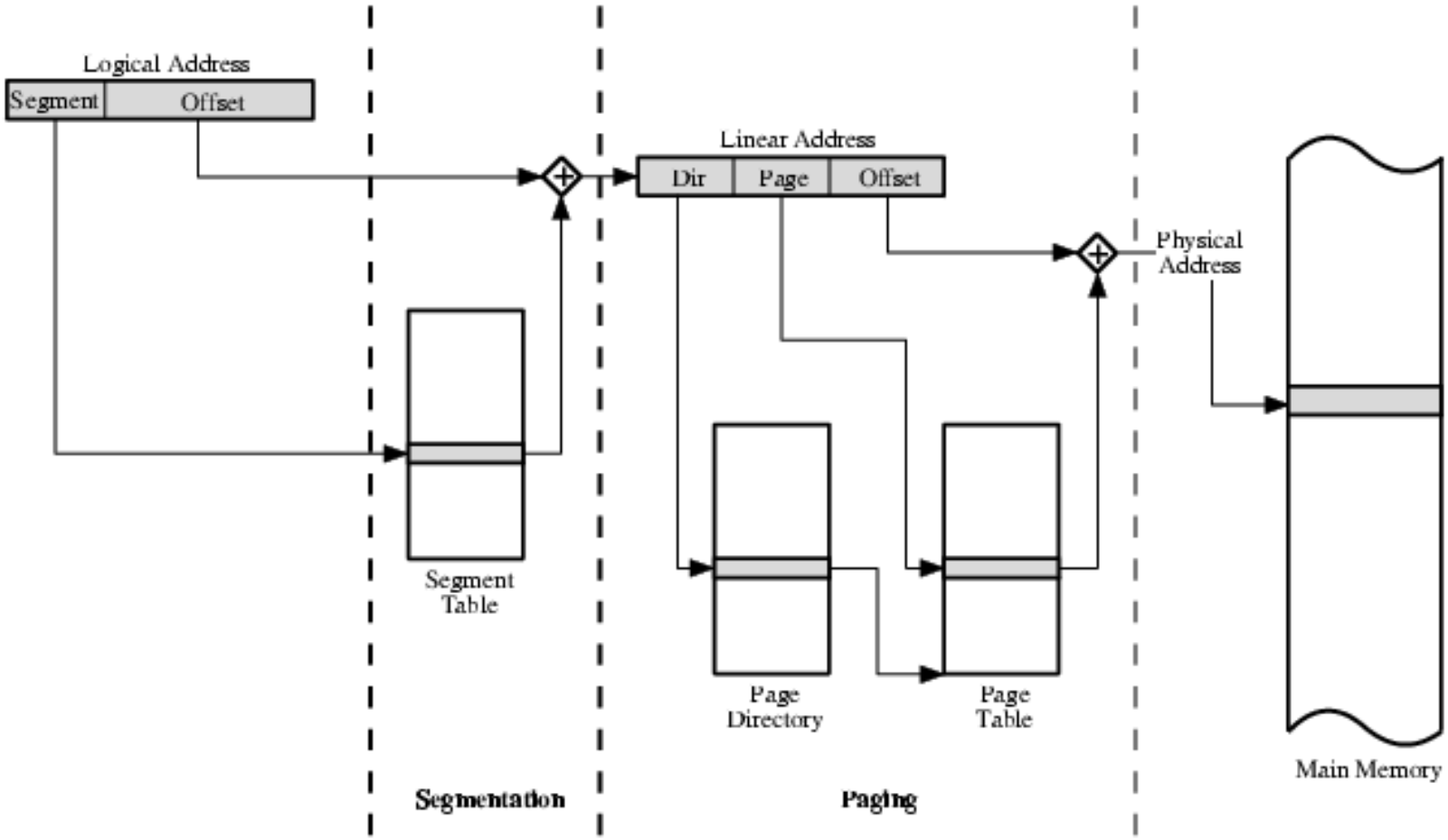
Advantages of Segmentation

- 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
- 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 local address spaces
  - Protection to single byte level
  - Translation table needed is on chip when segment is in memory
- 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

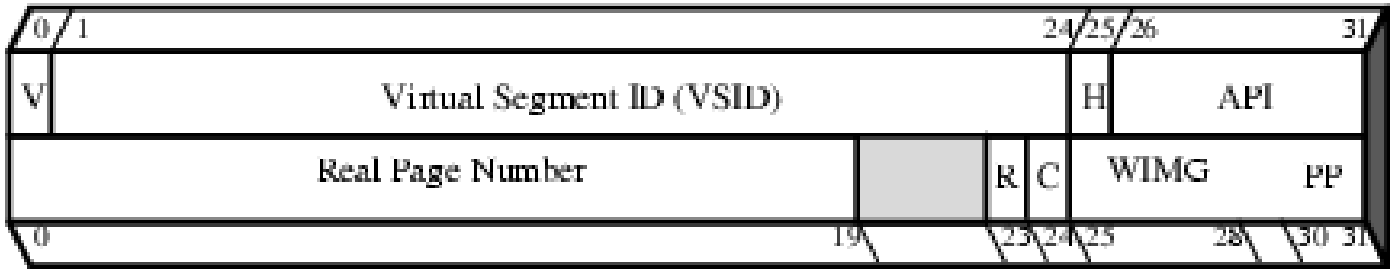
- Segmentation may be disabled
  - —In which case linear address space is used
- Two level page table lookup
  - —First, page directory
    - – 1024 entries max
    - – Splits 4G linear memory into 1024 page groups of 4Mbyte
    - – Each page table has 1024 entries corresponding to 4Kbyte pages
    - – 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

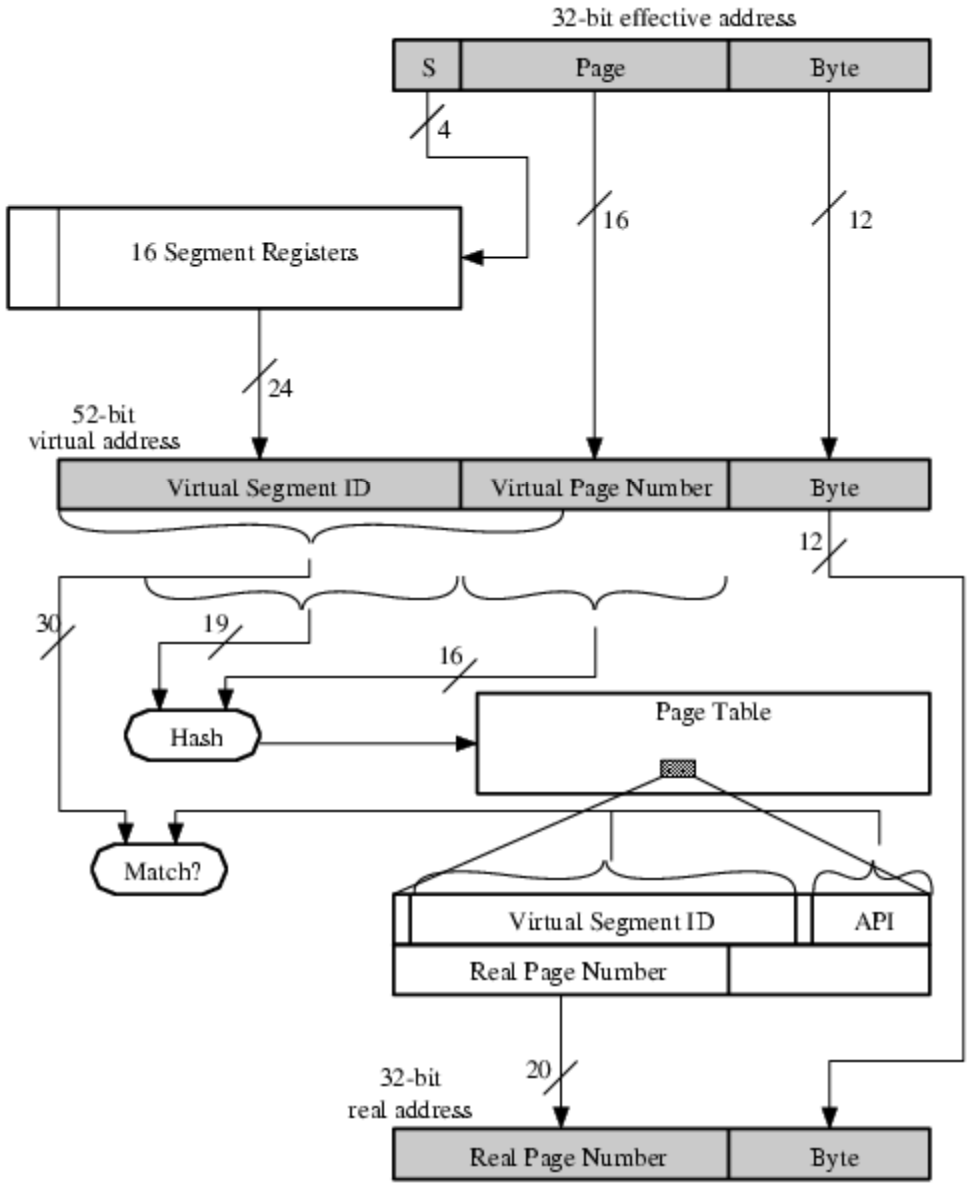


V = Entry valid bit
H = Hash function identifier
API = Abbreviated page index
R = Referenced bit
C = Changed bit
WIMG = Cache and storage access control bits
PP = Page protection bits
= reserved

(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**