SRM
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18CSC205J Operating Systems

UNIT I

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- Operating System Objectives and functions
- Gaining the role of Operating systems
- The evolution of operating system, Major achievement
- Understanding the evolution of Operating systems from early batch processing systems to modern complex systems
- OS Design considerations for Multiprocessor and Multicore
- Understanding the key design issues of Multiprocessor Operating systems and Multicore Operating systems
- PROCESS CONCEPT– Processes, PCB
- Understanding the Process concept and Maintenance of PCB by OS
- Threads – Overview and its Benefits
- Understanding the importance of threads
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- Understanding the system calls – fork(),wait(),exit()
- Inter Process communication : Shared Memory, Message Passing ,Pipe()
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- PROCESS SYNCHRONIZATION: Background, Critical section Problem
- Understanding the race conditions and the need for the Process synchronization

What is operating system?

Definition:

- **The operating system acts as an Interface between the user and computer hardware**

- Without an operating system, a computer would be useless

"OS is designed in such a way, that it is convenient to use in an efficient manner"

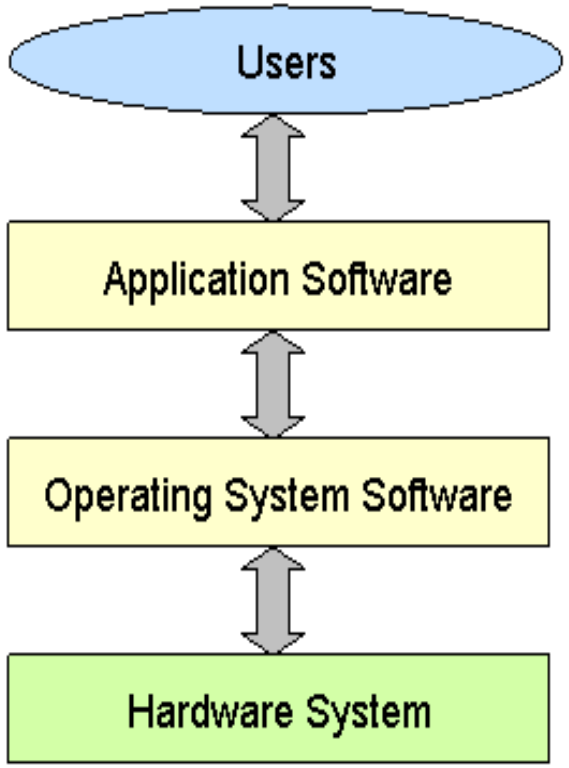


Figure 1 Components of Computer system

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Hardware

- CPU Central processing unit
- Memory
- I/O devices

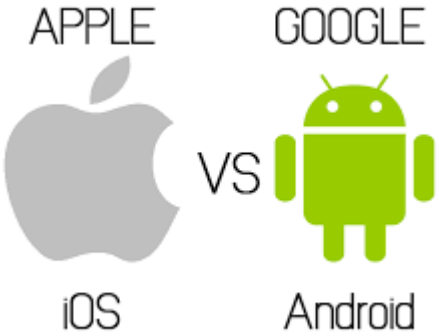
•**Computer Hardware** is the physical parts or **components** of a **computer**

Software

- Application Programs
- Word Processors
- Microsoft Office

- **Computer software** or simply **software** is any set of instructions that directs a **computer** to perform specific operations.

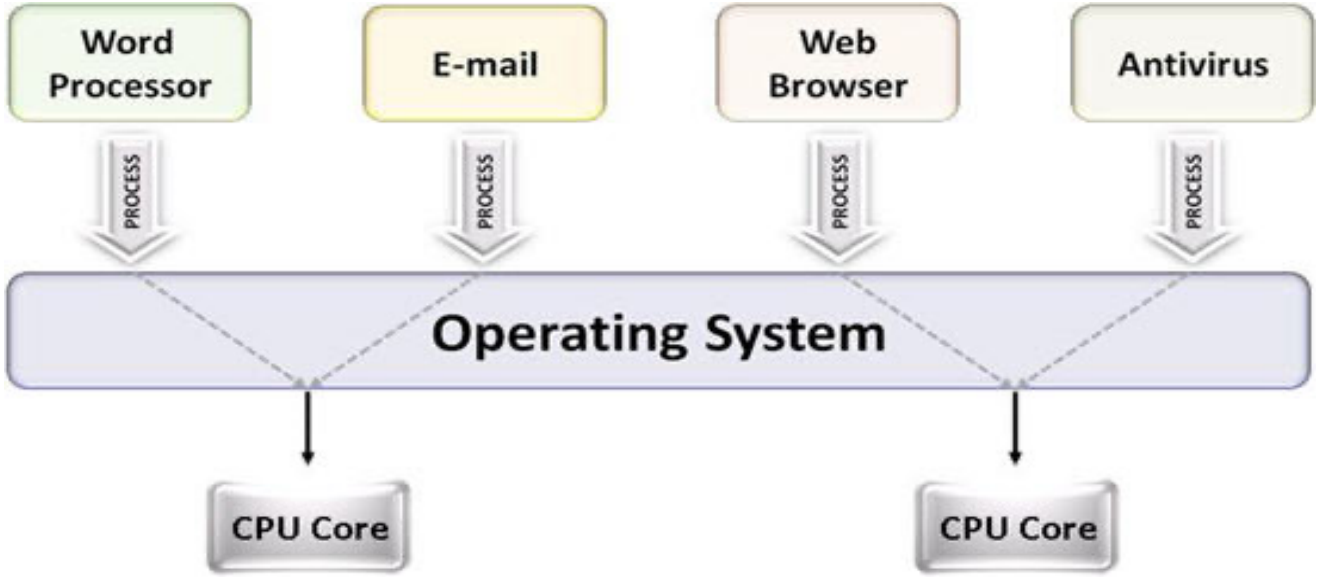
Some Examples of Operating System



Mobile OS

Tasks performed by Operating System

1. It manages computer hardware
2. It controls and coordinates the computer H/W
3. It specifies, how various resources like hardware and software can be used in an efficient manner.



Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

Two view points of Operating System

User's view

1. Users want → **ease of use** and **good performance & highly convenience**
   - Don't care about **resource utilization**
2. Users can share the terminals, connected to mainframe or minicomputer.
   - Resources are shared, hence maximum resource utilization is possible.
3. Individual Users with dedicate systems such as **workstations** use shared resources from **servers or Printers.**
4. In case of hand held devices, the operating system is designed for individual usability. Example: OS on iPhone, or any Android phone.

Two view points of Operating System

System view

1. The computer system, need to consider CPU time, memory, I/O Devices.

Hence,

OS is a **resource allocator**

- Manages all resources
- Conflicting requests between resources are managed for efficient use

◦ OS is a **control program**

- Controls execution of programs to prevent errors and improper use of the computer

Objectives of Operating system

- Convenience
- Efficiency
- Ability to evolve
- It specifies how resources are convenient to use in an efficient manner.

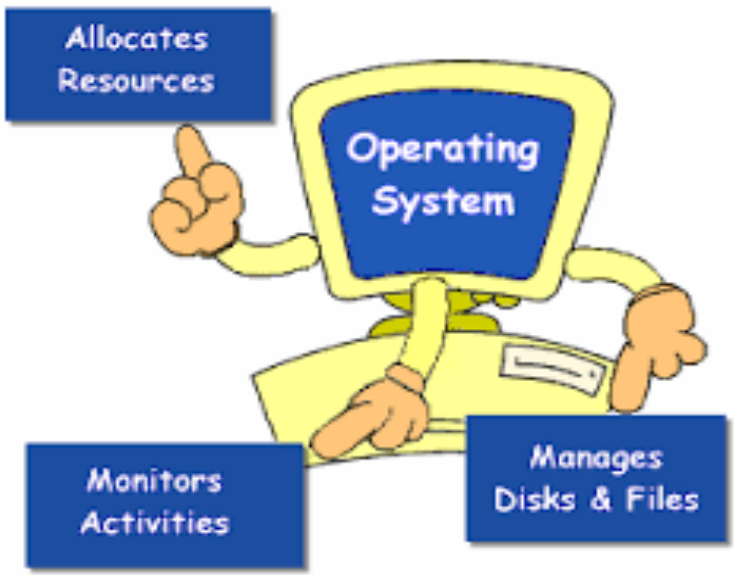
Note:

- The Operating system is like a government. It does not perform any useful function by itself.

Functions of Operating system

OS as a service routine

1. Program development.
   Ex: Editors & Debuggers
1. Program Execution
2. Access I/O devices and controlling access to I/O devices
3. Error detection & response
4. Performance maintenance

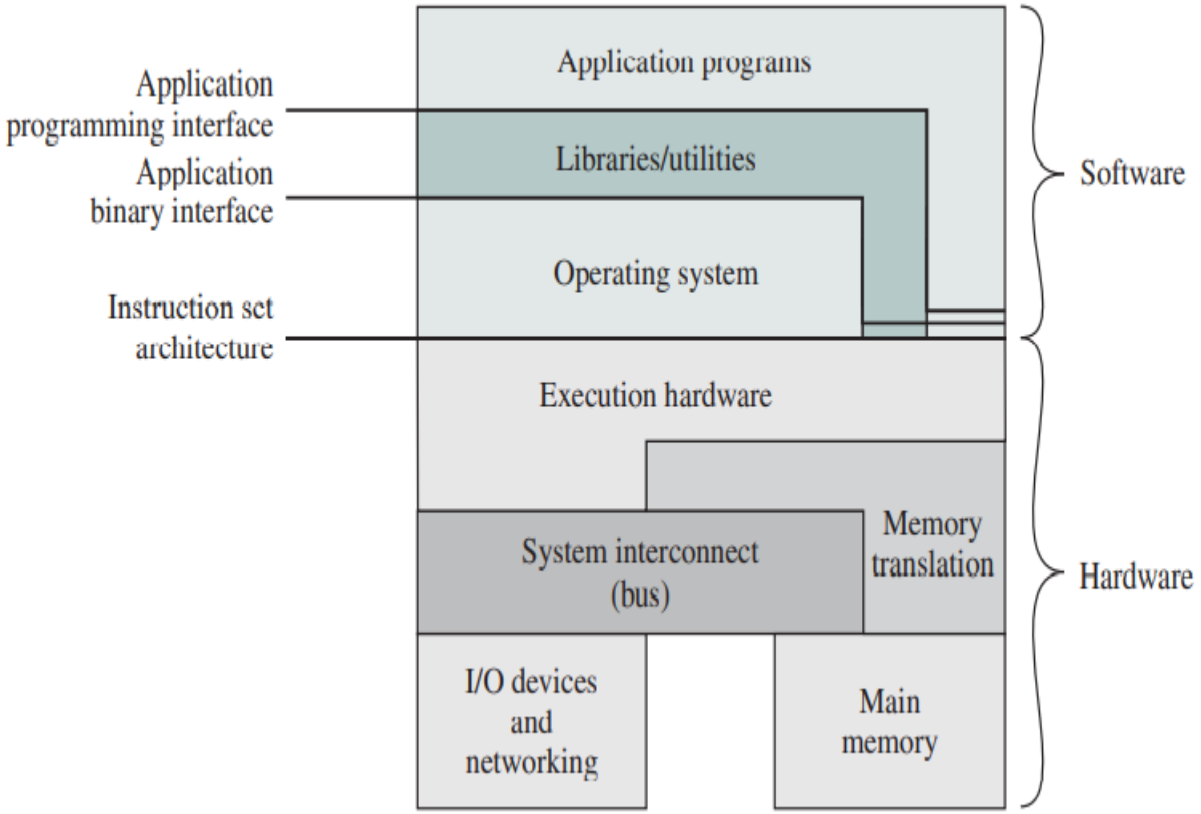


Role of Operating System

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

The OS as a User/Computer Interface

- OS provides services in following areas
  - Program development
  - Program execution
  - Access to I/O devices
  - Controlled Access to files
  - System access
  - Error detection and response
  - Accounting
  - Instruction set Architecture(ISA)
  - Application Binary Interface (ABI)
  - Application Programming Interface(API)

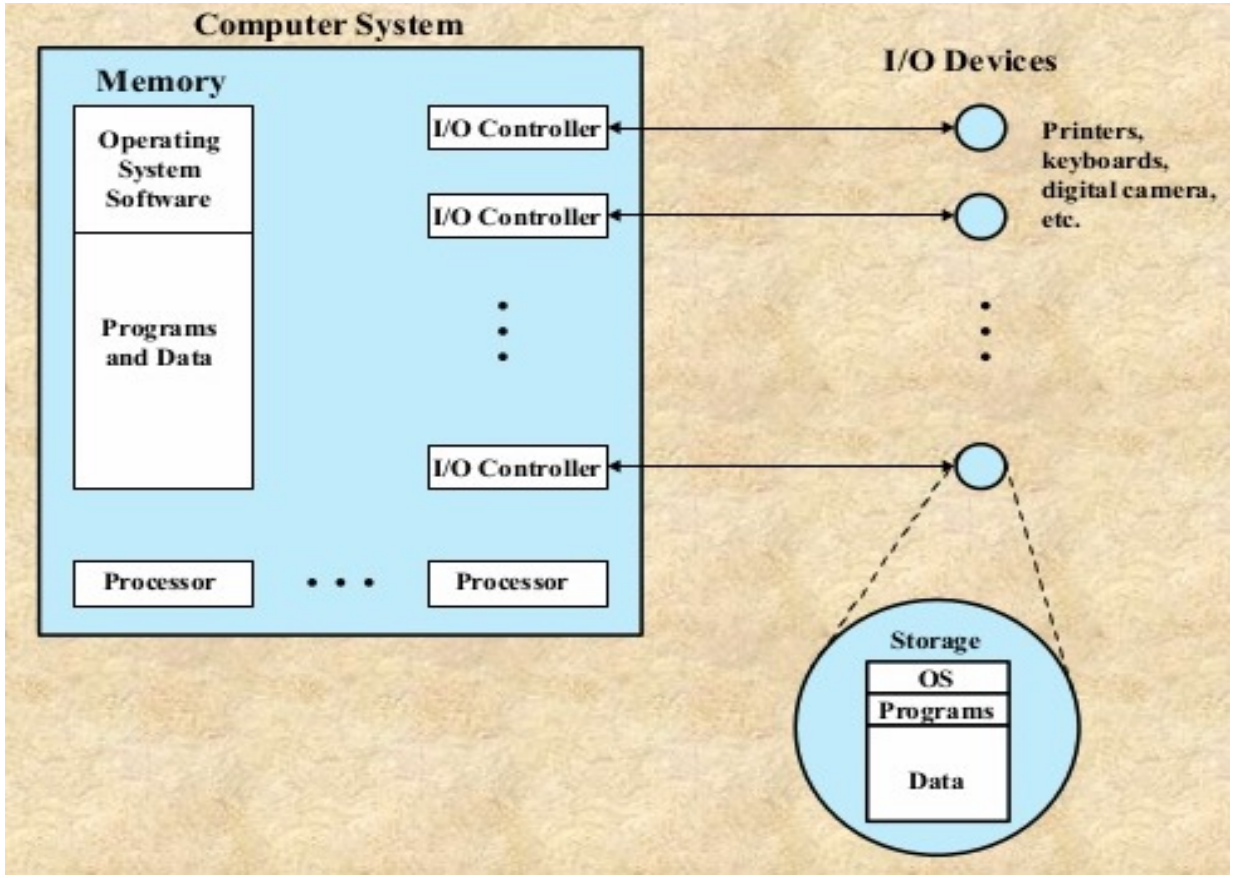


Computer Hardware & Software Structure

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

The Operating System as a Resource Manager

- OS is responsible for managing resources for movement, storage, processing and control.
- By managing OS is controller of these resources
- OS has control mechanism which is unusual in two aspects
- OS functions in same way as ordinary computer software, i.e it's a program or s/w suit of programs executed by processor
- The OS frequently relinquish the control and depends on the processor to regain the control



OS as Resource Manager

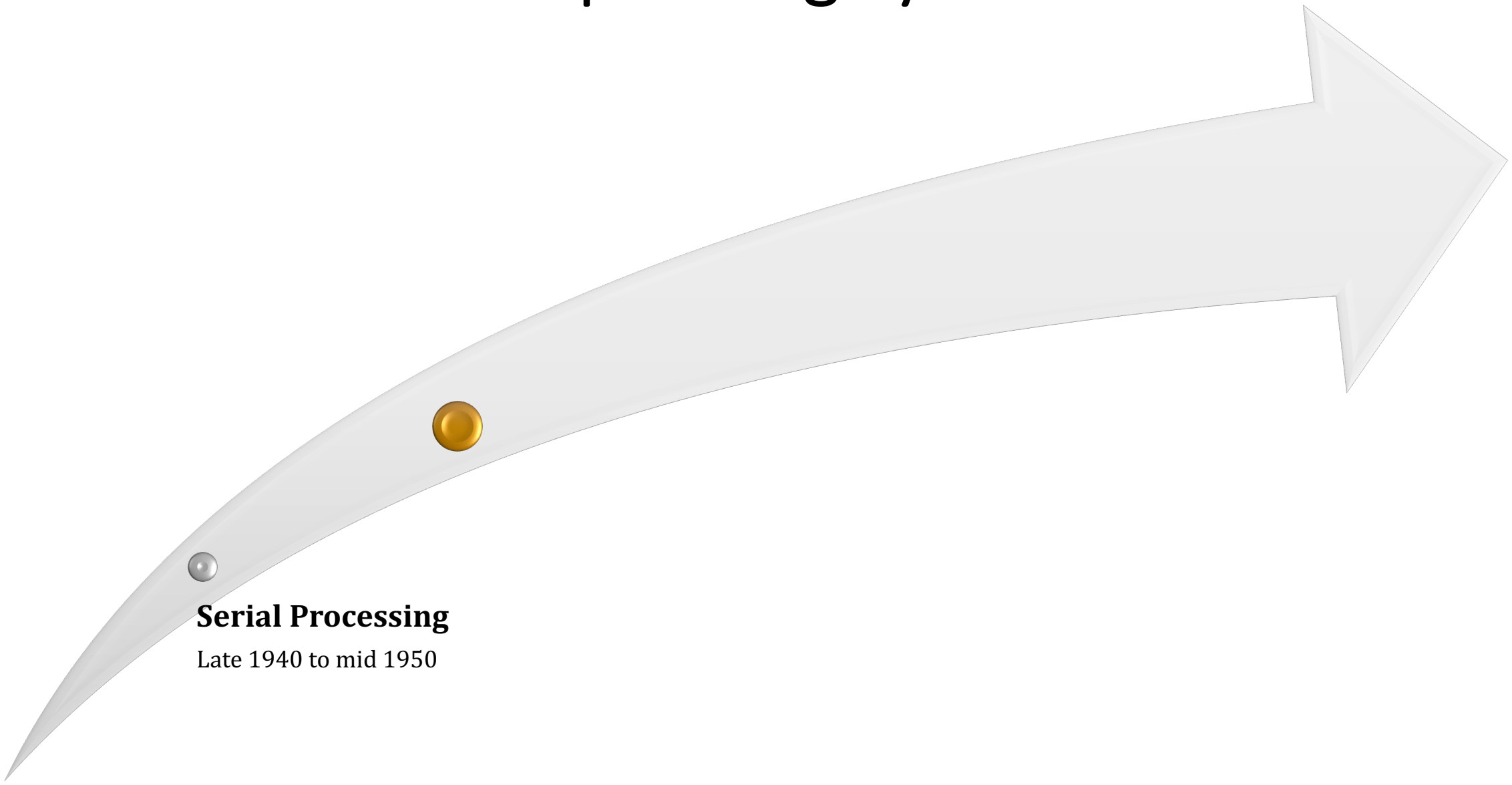
Figure shows main resources managed by OS

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

- **So, how OS differs form other computer programs ??**
  - It directs the processor in use of other system resources'
  - It makes processor to coordinate and work with other resources
  - If processor wants to do any other program it cease the execution of OS program and do
  - Then OS relinquish the control and prepare processor to do next useful task
- The (Ref Figure) part of OS remains in main memory known as **Kernal/nucleus ,** which contains most frequently used programs.
- The user program and data are also available in mainmemory
- The memory management Hardware (in the processor) and OS jointly controls the memory allocations
- The os decides when and I/O devices and files can be used by the user programs and controls the access accordingly.

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

The Evolution of Operating System



Serial Processing

Late 1940 to mid 1950

Serial Processing (Late 1940 and Mid 1950)

- No Operating System
- Programmers interacted Straight away with hardware
- Lights, toggles, input devices and printers
- Inputs are given through input devices (card readers), errors are intimated through lights and normal completion is done through printers
- These systems had two problems
  - **Scheduling**
    - Used hard copy sign-off sheets for reserving computing time (multiples of 30 minutes)
    - User block 2 slots and use only 45 min
    - User block 2 slots and unable complete within it

    Under/Over utilization
  - **Setup time**
    - Single program (Job) need to load compiler and source program in to the memory
    - Later save the compiled program and then loading and linking
    - All these steps cards are to be mounted and unmounted in sequence
    - Failing in any of these steps needs repetition of entire steps
- Later there were many System software developed to make this process efficient however these process are done one after another

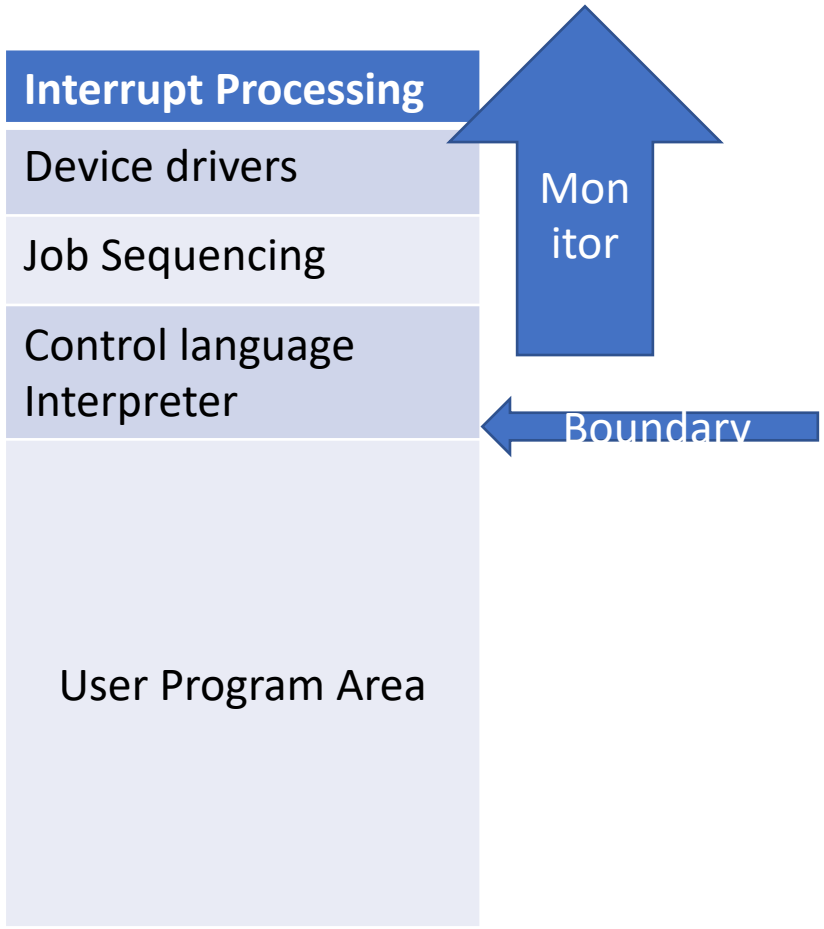
Simple Batch Systems

- Executes jobs in batched controlled by Monitors
- User submits jobs to the operator, who make them it to batches loads the tape in to input.
- jobs branch back to monitor, which loads another batch of jobs
- Batch system can be seen in two views

Monitor Point of View	Processor Point of View
• Controls sequence of events • Partially Resides on main memory for execution – **Called Resident Monitor** • Rest is loaded as subroutine in user program • It reads the jobs at once (from card/tape)and loaded in to user program area , control passed to user job • Once completed user program transfer the control to monitor, • Monitor starts to read next batch • Results are sent to Output devices	• At a point in time Current batch programs executed in main memory • On completion (sent control to monitor) brings next batch get loaded in another portion in user area • Once loaded, job gains control and execute the instructions • This continues util end of program or error • Process gains control means- processor executes the current program instructions.

- Monitor performs scheduling of batches & improves job setup time
- The programs instruction are given to the monitor using special language called Job Control Language(JCL)
- Eg: Program is written in FORTRAN, the program & data is fed in a separate card, in addition to this job is described using JCL

Simple Batch System..



Modes in Batch Processing

- **User Mode** : Executes user program
- **Kernel mode/Monitor Mode : E**xecutes Privileged Instruction

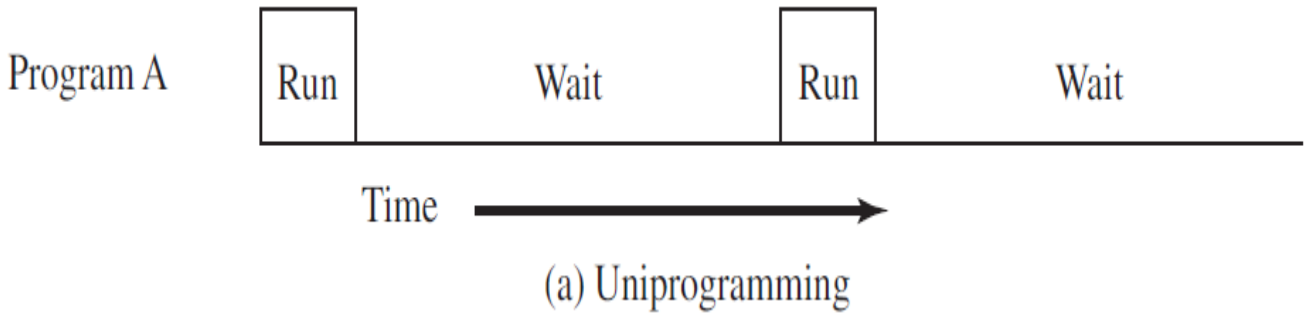
Simple Batch System..

- The hardware features by monitors (Apart from fetching inst, seize and relinquish control)
- Memory Protection :
  - When user program in under execution the it must not attempt to access the other users memory area, if so the processor Hardware detects is as error and transfers the control to the monitor. Monitor aborts the job with an error message and takes up a next job
- Timer :
  - To avoid job monopolising the processor, it sets timer at the beginning of job, if timer expires user job is stopped and control transferred to the monitor
- Privileged Instructions:
  - Few special/ Privileged instructions are executed under monitor mode, if such instructions are happened to attempted by user, then control is transferred to monitor. All I/O instructions are Privileged instructions, which prevents the user programs from reading the Job control instructions
- Interrupts
  - This facilitates the OS in relinquish control and regaining control from user programs

- **Limitations**
  - Thought it is advantageous than serial processing, it often requires same process done by the programmer in batches.

Multiprogrammed Batch Systems

- In batch processing system, memory holds resident monitor (OS) and one user program
- Batch processing hold Processor on idle state when I/O operations are being done.
- If the memory is sufficiently large to hold more than one user program then, while one program is getting I/O , processor can be switched to another program, this is called as **Multiprogramming/ Multitasking.**

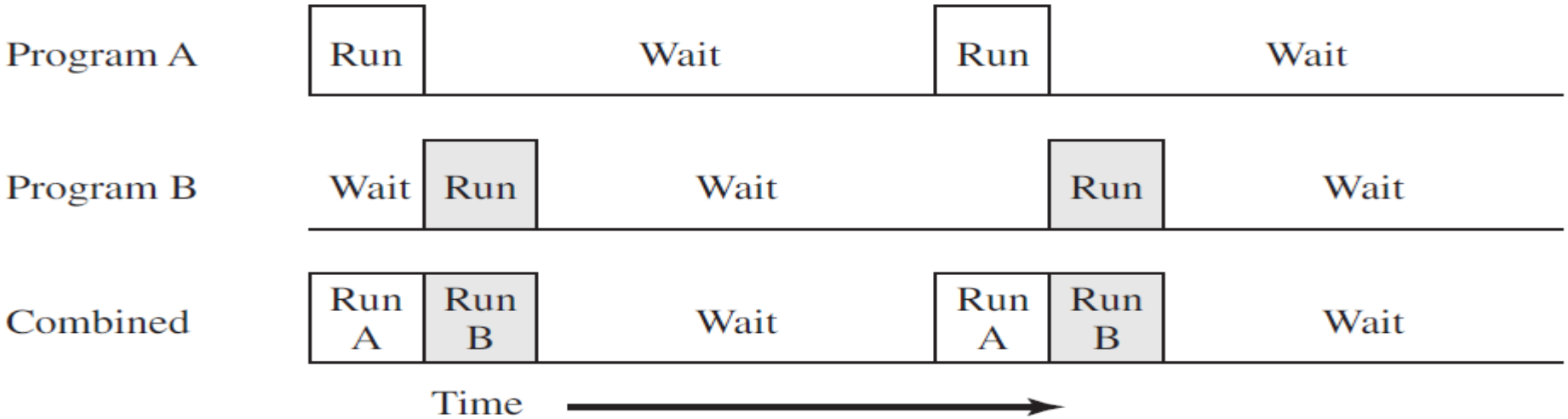


Read one record from file	15 μs
Execute 100 instructions	1 μs
Write one record to file	15 μs
TOTAL	31 μs

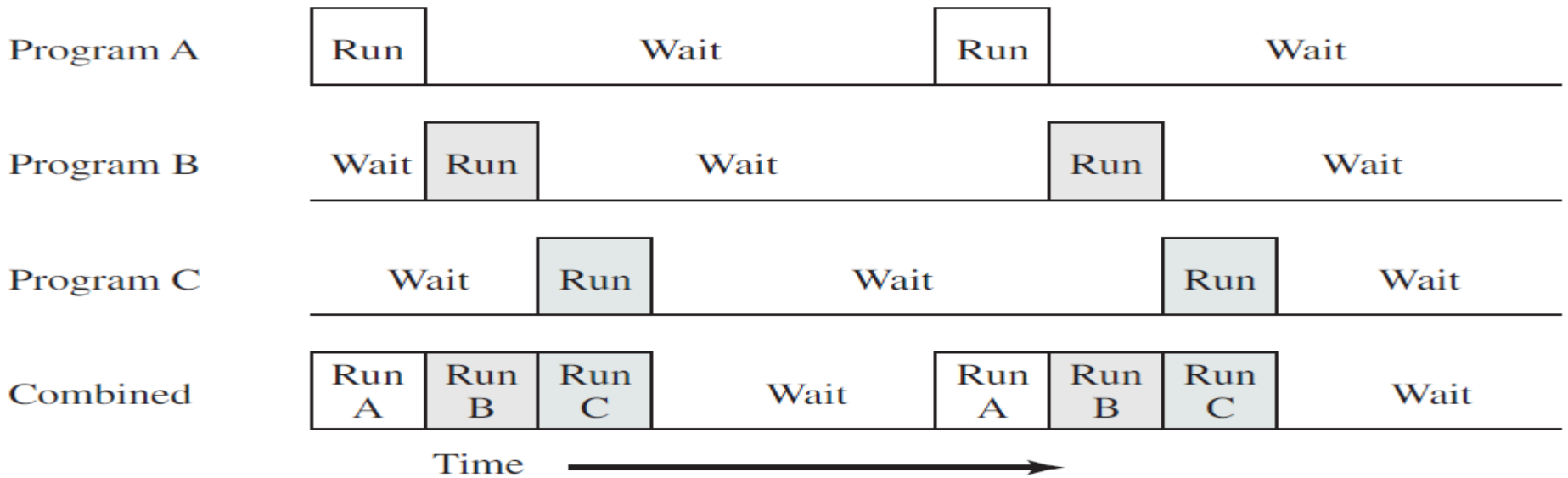
Percent CPU Utilization $= \frac{1}{31} = 0.032 = 3.2\%$

Figure 2.4 System Utilization Example

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI



(b) Multiprogramming with two programs



(c) Multiprogramming with three programs

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

Time-Sharing Systems

- In 1960 programs need dedicated computers, which wasn't possible as it was too costly in those days
- Application with more user interactions, needs dedicated computers
- Multiprogramming designed to handle multiple interactive jobs referred as time slicing
- Used to share processor among multiple user, an makes each user to feel that they have dedicated system but interleaved among all of them.
- Hence if n user using the system, then each user see 1/n of effective computer capacity.

Table 2.3 Batch Multiprogramming versus Time Sharing

	Batch Multiprogramming	Time Sharing
Principal objective	Maximize processor use	Minimize response time
Source of directives to operating system	Job control language commands provided with the job	Commands entered at the terminal

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

CTSS First Time sharing OS→

Resident Monitor: 0-5000 words
User program : 5000- 32000 words timeslice : 0.2 sec

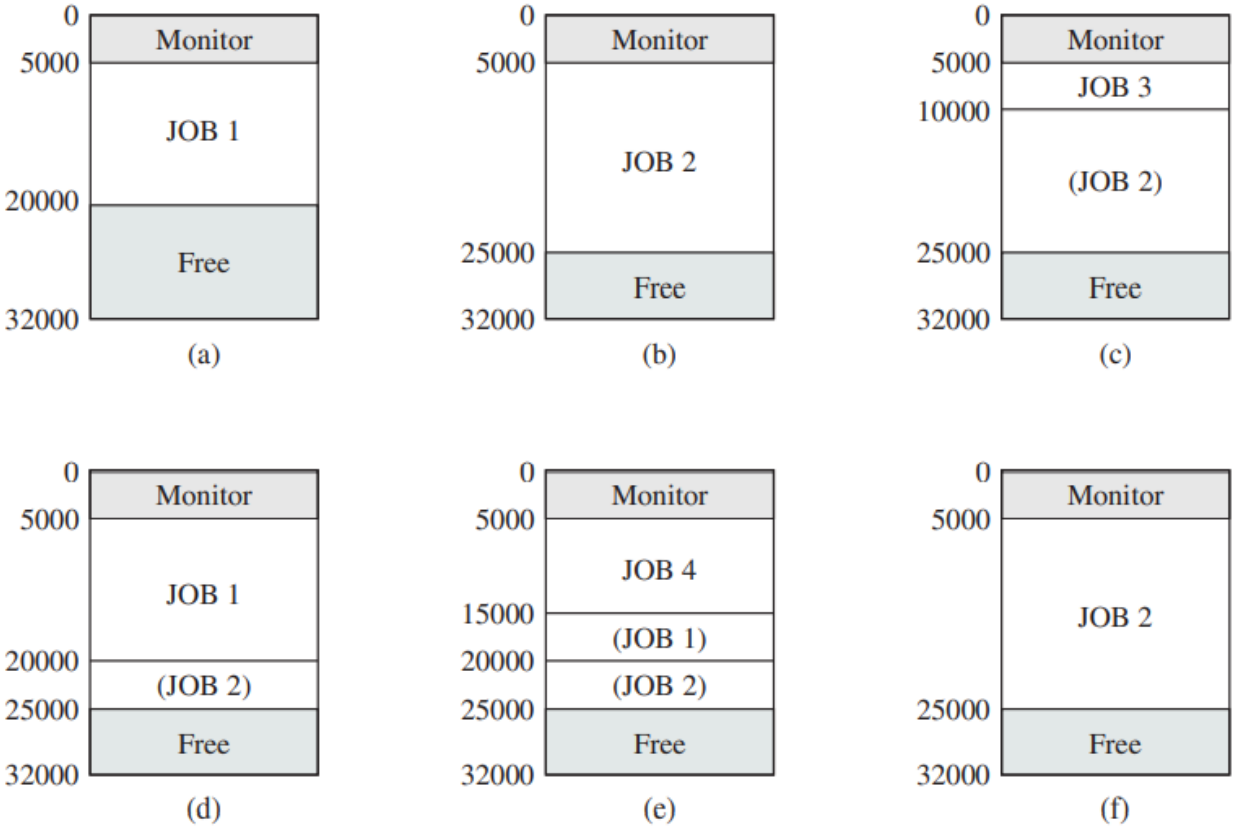


Figure 2.7 CTSS Operation

Example :
J1->Job 1: 15000
J2->Job 2: 20000
J3->Job3 : 5000
J4->Job 4: 10000

(a) Job 1 is loaded in the memory,
(b) Job2 is loaded since job2 and 1 can not accommodate together job 1 is flushed out
(c) Job 3 is loaded in memory since job 2 & 3 can accommodate in memory job 2 remains there
(d) Now processor takes job1, only portion of job2 is accommodated in memory
(e) Now the timeslice of j1 is over processor takes J4 so portion of J1 and J2 remains in memory, Now to activate J1 or J2 only partial data is to be loaded.
(f) JOB2 is loaded for completion.

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

Compatible Time-Sharing Systems

CTSS

- One of the first time-sharing operating systems
- Developed at MIT by a group known as Project MAC
- Ran on a computer with 32,000 36-bit words of main memory, with the resident monitor consuming 5000 of that
- To simplify both the monitor and memory management a program was always loaded to start at the location of the 5000th word

Time Slicing

- System clock generates interrupts at a rate of approximately one every 0.2 seconds
- At each interrupt OS regained control and could assign processor to another user
- At regular time intervals the current user would be preempted and another user loaded in
- Old user programs and data were written out to disk
- Old user program code and data were restored in main memory when that program was next given a turn

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

MAJOR ACHIEVEMENTS

Operating Systems are among the most complex pieces of software ever developed.
Four major theoretical advances in the development of operating systems:

1) Process
2) Memory management
3) Information protection and security
4) Scheduling and resource management

MAJOR ACHIEVEMENTS-The Process

- Central to the design of operating systems is the concept of process.
- Three major lines of computer system development created problems in timing and synchronization that contributed to the development of concept of the process:
  - Multiprogramming batch operation -
  - Time sharing
  - Real time transaction systems

- Four main course of error
  - 1)Improper Synchronization
  - 2) Failed mutual exclusion
  - 3) Nondeterministic program operation
  - 4) Deadlocks

Process consisting of three components:

1) An executable program
2) The associated data needed by the program
3) The execution context of the program

The Process…

- The execution context, or process state is the internal data by which the OS is able to supervise and control the process.
- This internal information is separated from the process, because the OS has information not permitted to the process
- Fig.1 indicates a way in which processes may be managed. Two processes, a and B, exist in portions of main memory.
- The process list contains one entry for each process, which includes a pointer to the location of the block of memory that contains the process.
- The entry may also include part or all of the execution context of the process.

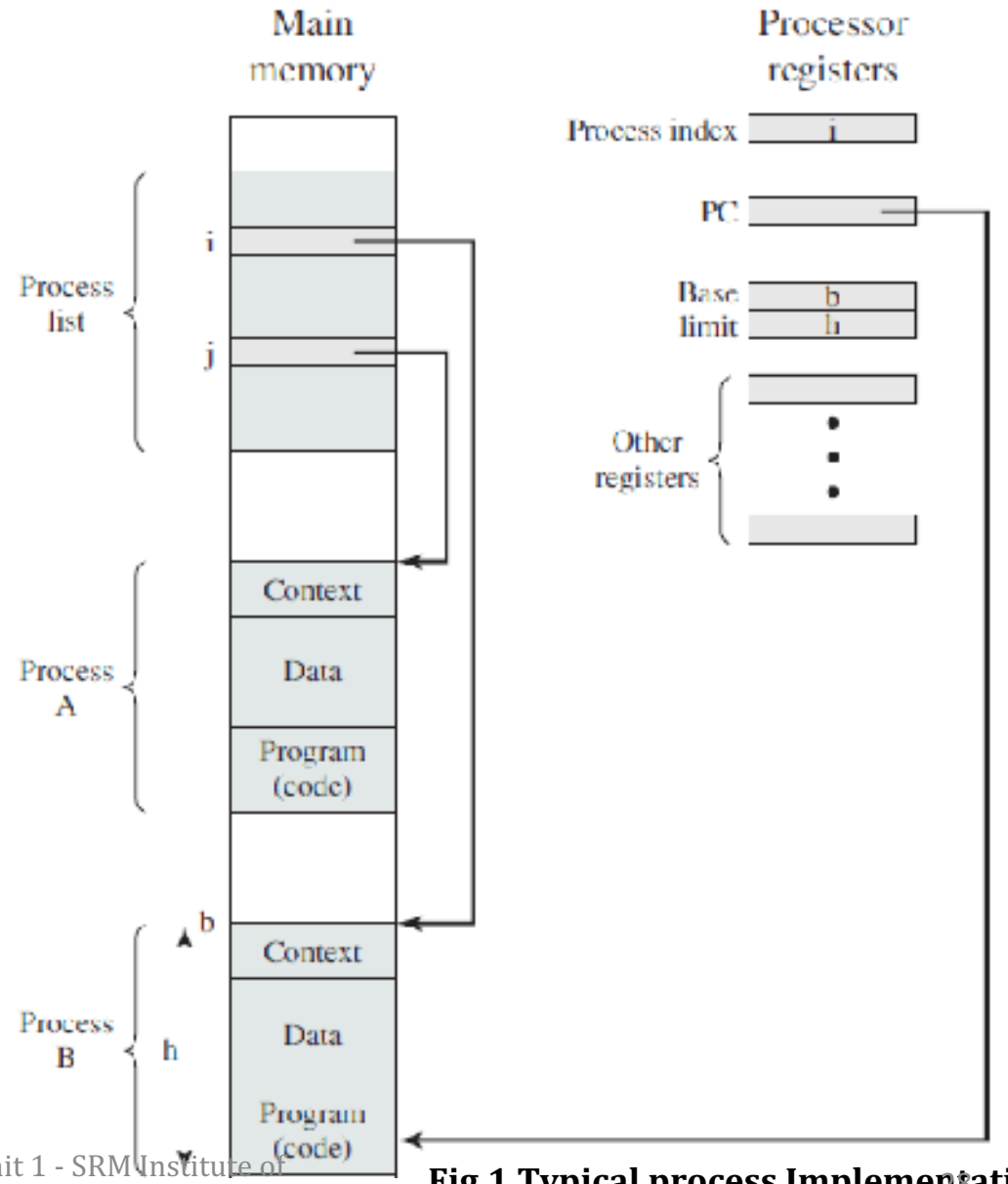


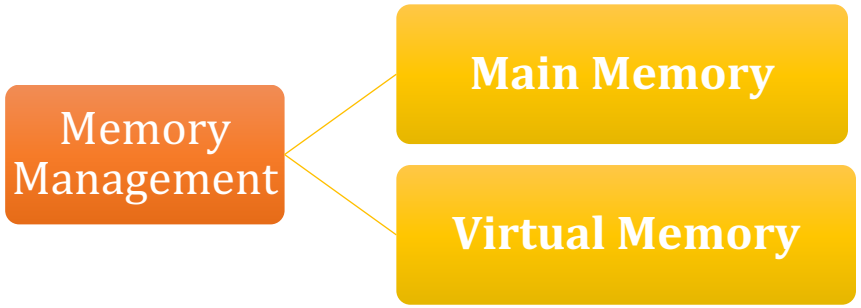
Fig.1 Typical process Implementation

Courtesy :William Stallings, Operating Systems-Internals and Design Principles, 7th ed., Prentice Hall, 2012

The Process…

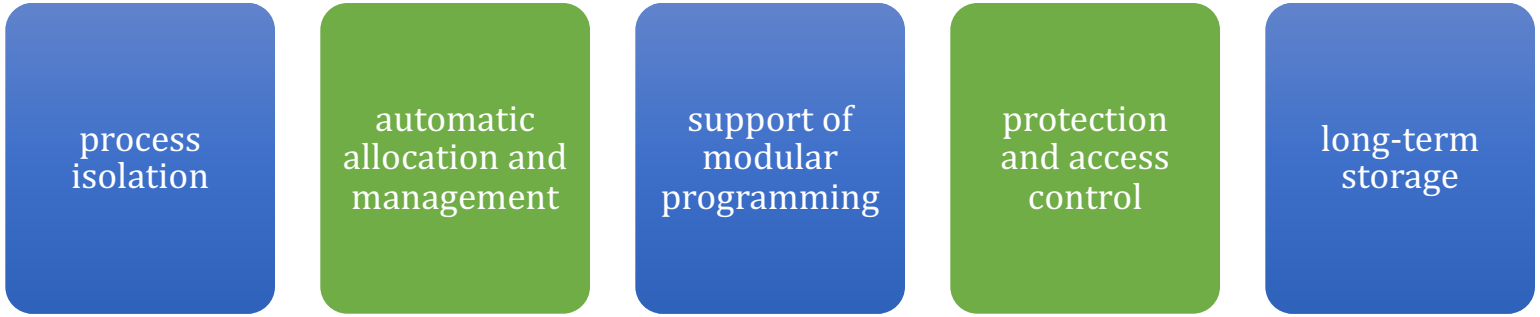
- The remainder of the execution context is stored elsewhere, perhaps with the process itself or frequently in a separate region of memory.
- The process index register contains the index into the process list of the process currently controlling the processor.
- The program counter points to the next instruction in that process to be executed.
- The base and limit registers define the region in memory occupied by the process.

MAJOR ACHIEVEMENTS - Memory Management



Main Memory

- The needs of users can be met by a computing environment that supports modular programming and the flexible use of data.
- System managers need efficient and orderly control of storage allocation.
- The OS, to satisfy these requirements, has five principal storage management responsibilities:



- Typically, operating system meet these requirements with virtual memory and file system facilities.

Virtual Memory

- Virtual memory is a facility that allows programs to address memory from a logical point of view, without regard to the amount of main memory physically available.

- Paging systems were introduced, which allow Processes to be comprised of a number of fixed size blocks, called pages.

- A program references a word by means of a virtual address consisting of a page number and an offset within the page.
- The paging system provides for a dynamic mapping between the virtual address used in the program and a real address, or physical address, in main memory. Fig 2. represents virtual memory addressing.

Memory Management...

Paging Concepts

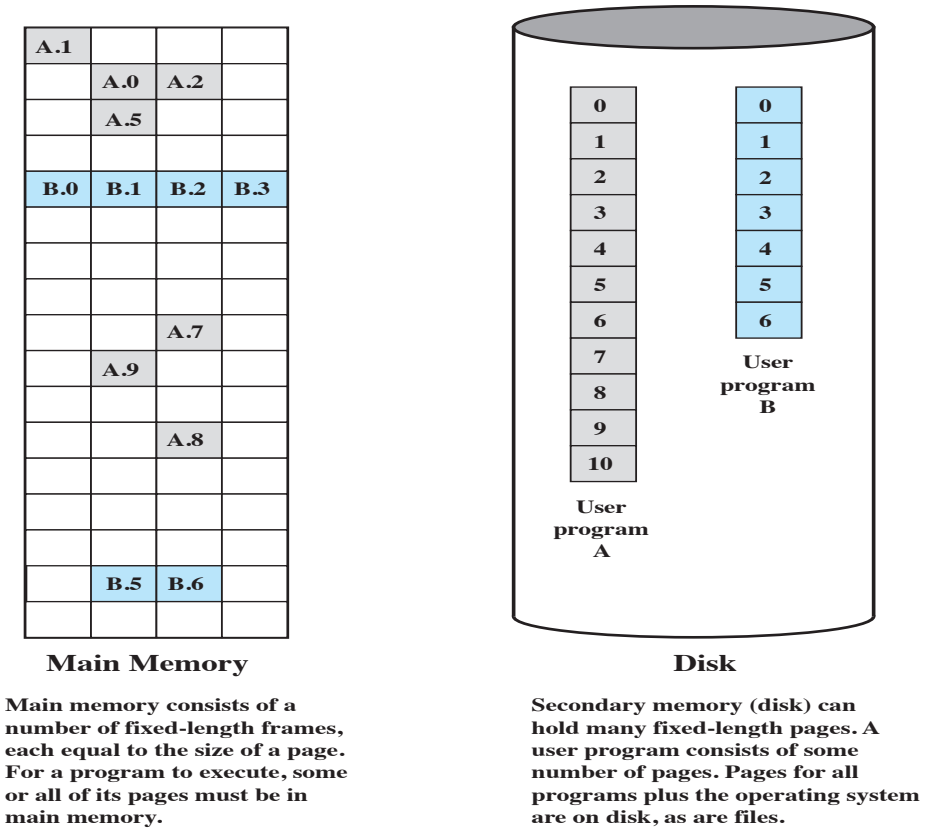
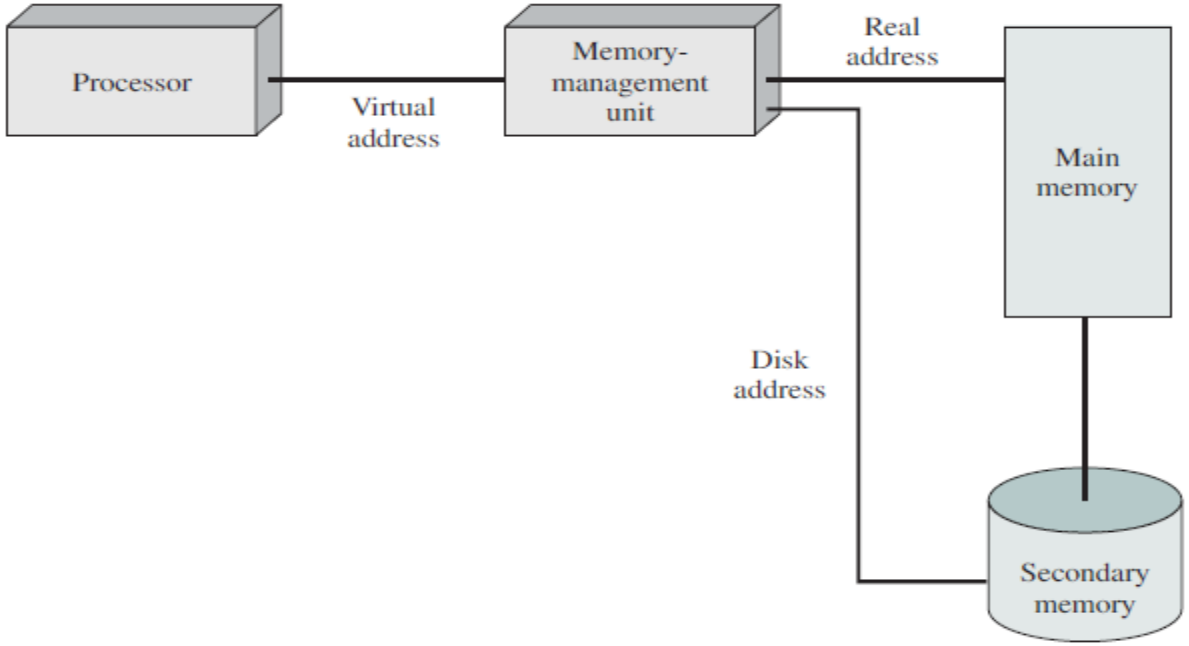


Figure 2.9 Virtual Memory Concepts

Virtual memory addressing



MAJOR ACHIEVEMENTS - **Information Protection and Security**

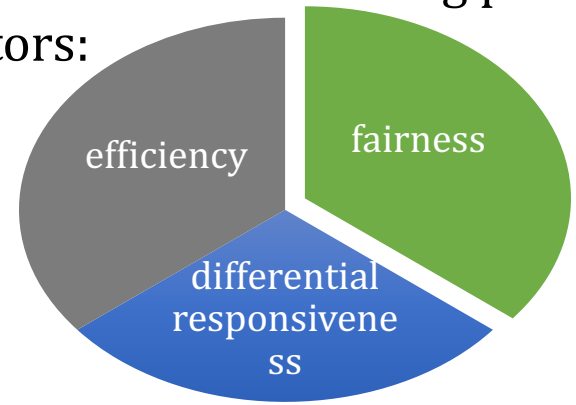
- The growth in the use of time-sharing systems and, more recently, computer networks has brought with it a growth in concern for the protection of information.

- Much of the work in security and protection as it relates to operating systems can be roughly grouped into four categories:
  - Availability
  - Confidentiality
  - Data Integrity
  - Authenticity

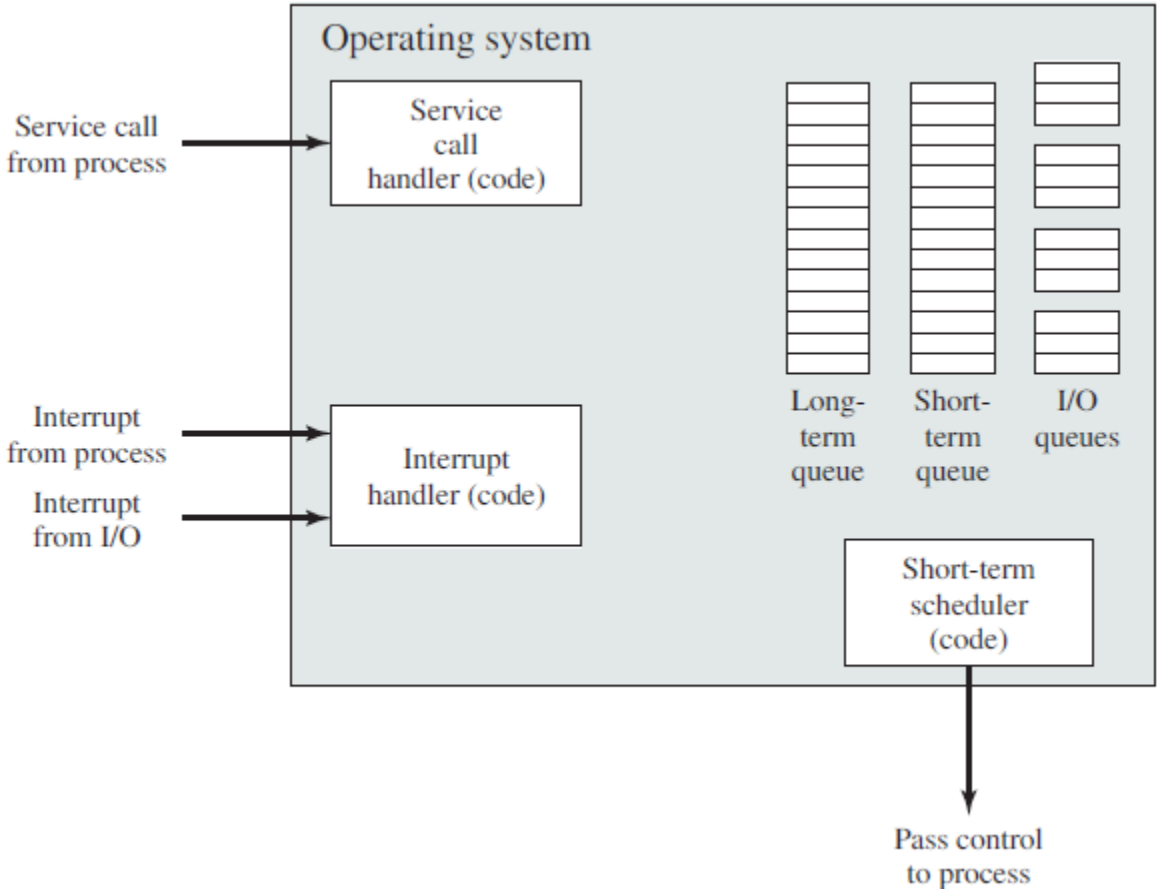
MAJOR ACHIEVEMENTS- Scheduling and Resource Management

- A key responsibility of the OS is to manage the various resources available to it (main memory space, I/O devices, processors) and to schedule their use by the various active processes.

- Any resource allocation and scheduling policy must consider three factors:



- Figure suggests the major elements of the OS involved in the scheduling of processes and the allocation of resources in a multiprogramming environment.



Key elements of an operating system for multiprogramming

Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

Understanding the evolution of Operating systems from early batch processing systems to modern complex systems

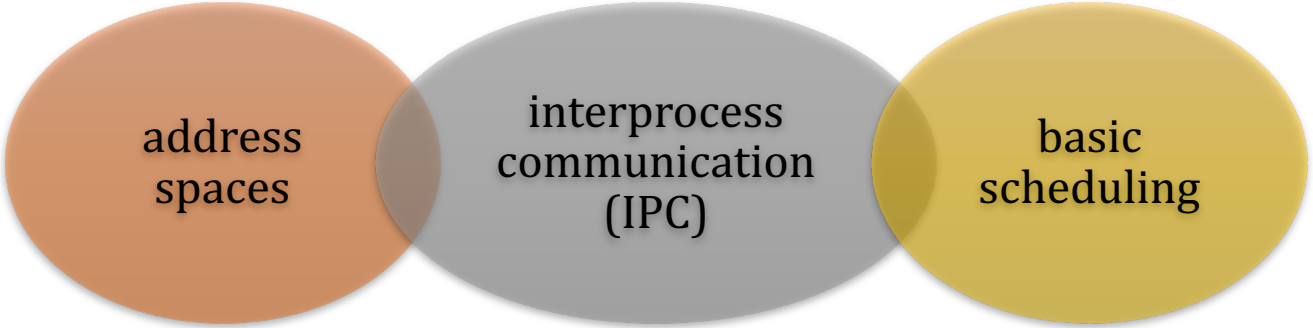
Different approaches and design elements have been tried:

- microkernel architecture
- multithreading
- symmetric multiprocessing
- distributed operating systems
- object-oriented design

Understanding the evolution of Operating systems from early batch processing systems to modern complex systems

microkernel architecture

- Assigns only a few essential functions to the kernel:



- The approach:

Understanding the evolution of Operating systems from early batch processing systems to modern complex systems

multithreading

- Technique in which a process, executing an application, is divided into threads that can run concurrently

Thread

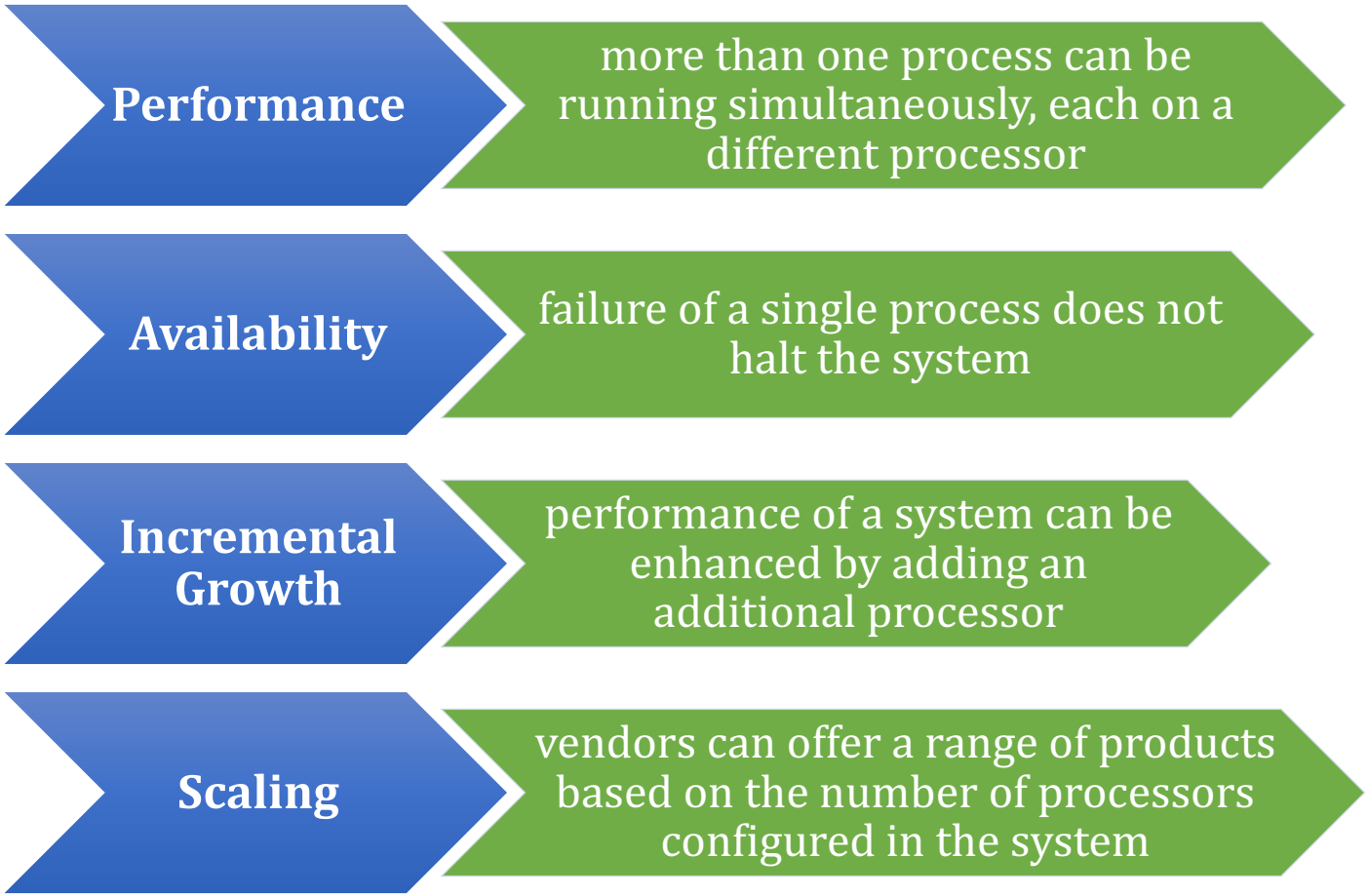
Understanding the evolution of Operating systems from early batch processing systems to modern complex systems

symmetric multiprocessing

- Term that refers to a computer hardware architecture and also to the OS behavior that exploits that architecture
- Several processes can run in parallel
- Multiple processors are transparent to the user
  - these processors share same main memory and I/O facilities
  - all processors can perform the same functions
- The OS takes care of scheduling of threads or processes on individual processors and of synchronization among processors

Understanding the evolution of Operating systems from early batch processing systems to modern complex systems

symmetric multiprocessing - Advantages



Understanding the evolution of Operating systems from early batch processing systems to modern complex systems

Multiprogramming Vs Multiprocessing

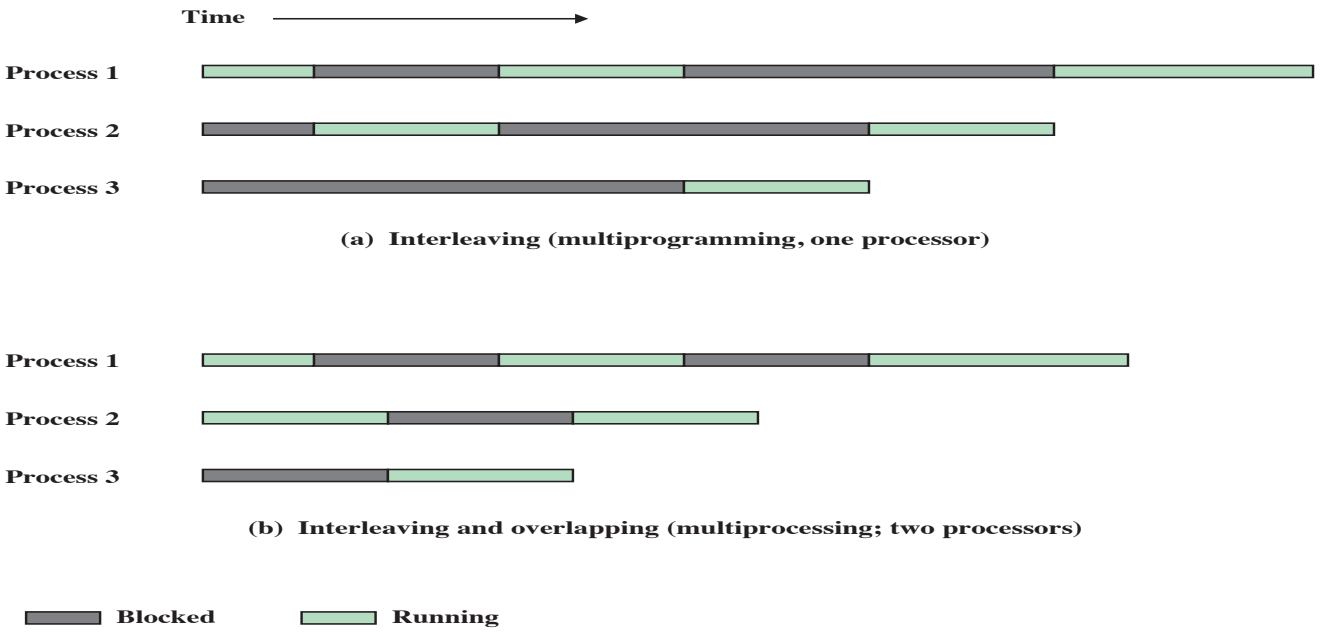


Figure 2.12 Multiprogramming and Multiprocessing

Understanding the evolution of Operating systems from early batch processing systems to modern complex systems

Distributed operating systems Vs Object-Oriented Design

Distributed operating systems	**Object-Oriented Design**

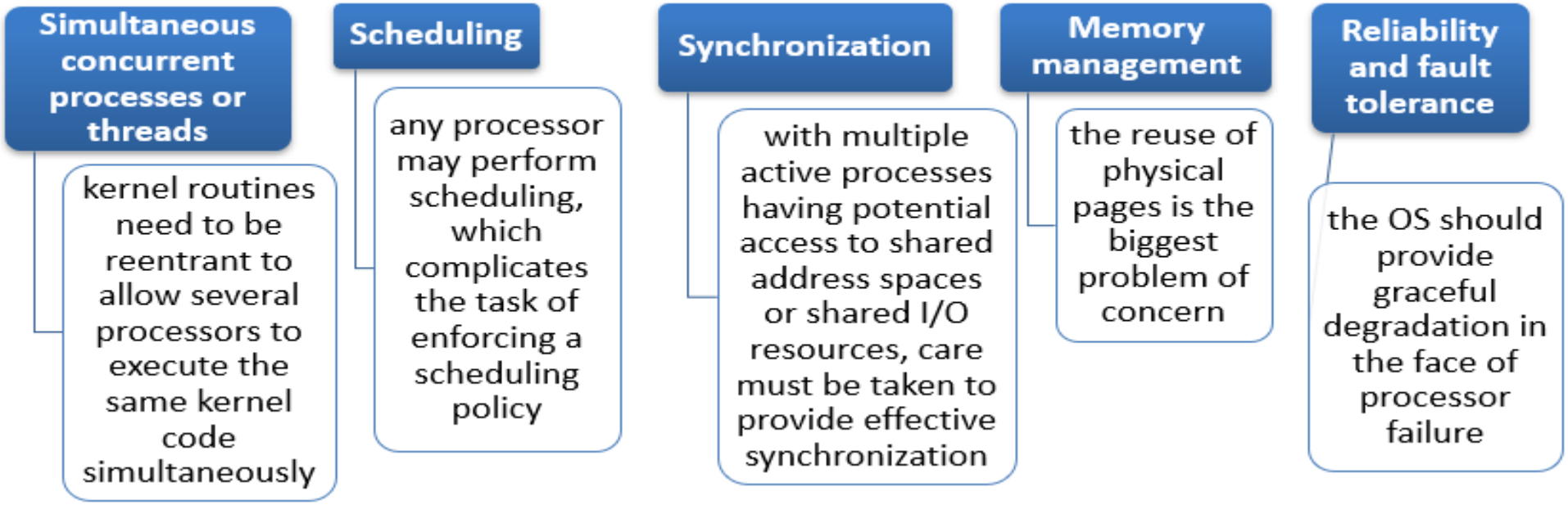
• Provides the illusion of
  • a single main memory space
  • single secondary memory space
  • unified access facilities
• State of the art for distributed operating systems lags that of uniprocessor and SMP operating systems
	• Used for adding modular extensions to a small kernel
	• Enables programmers to customize an operating system without disrupting system integrity
	• Eases the development of distributed tools and full-blown distributed operating systems

OS Design considerations for Multiprocessor and Multicore

Symmetric Multiprocessor OS Considerations

- A multiprocessor OS must provide all the functionality of a multiprogramming system plus additional features to accommodate multiple processors

Key design issues:

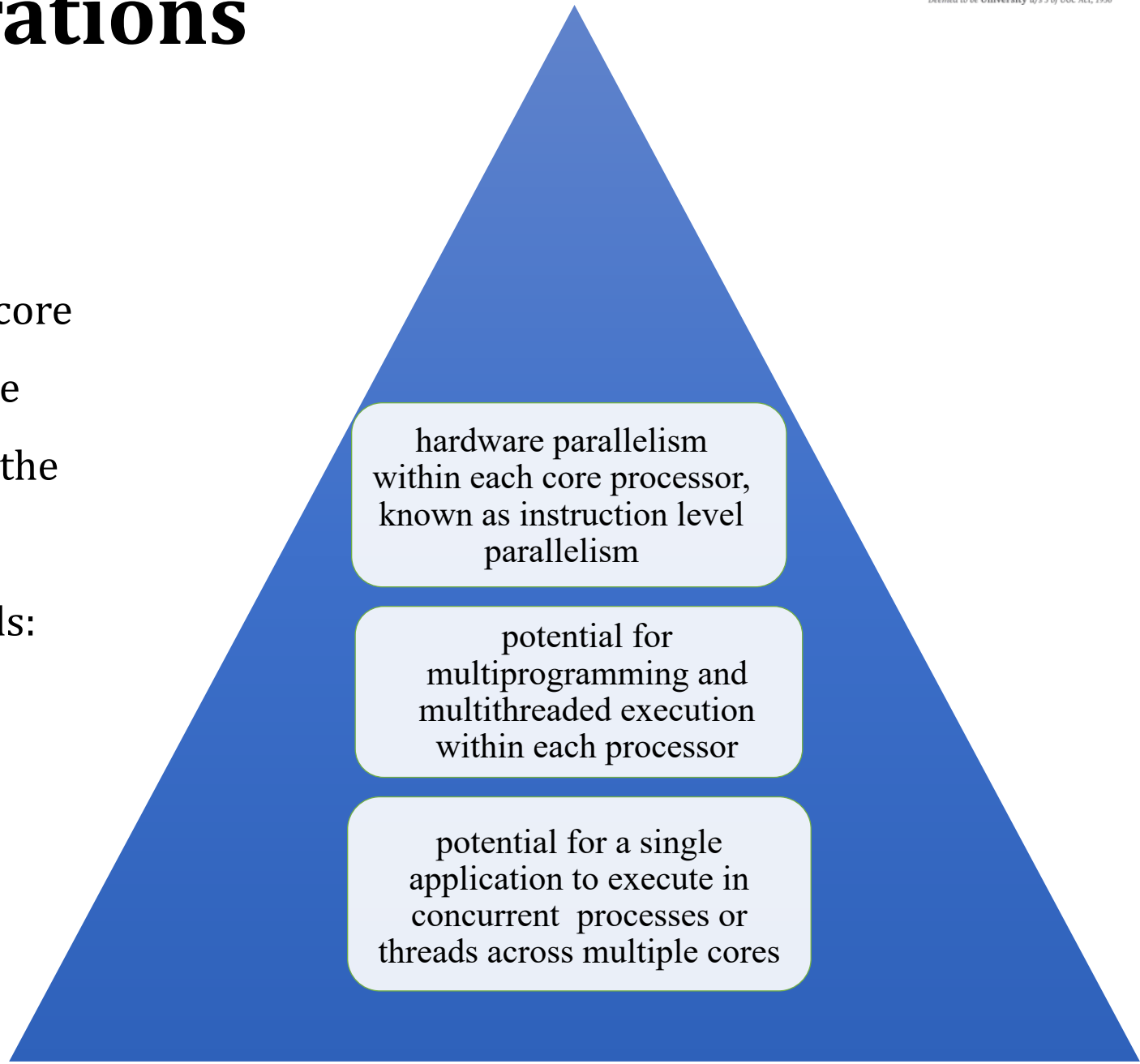


Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

Multicore OS Considerations

Key design Issues:

- The design challenge for a many-core multicore system is to efficiently harness the multicore processing power and intelligently manage the substantial on-chip resources efficiently
- Potential for parallelism exists at three levels:



Courtesy : Operating systems : Internals and design principles, 7th ed William Stallings, PHI

Process

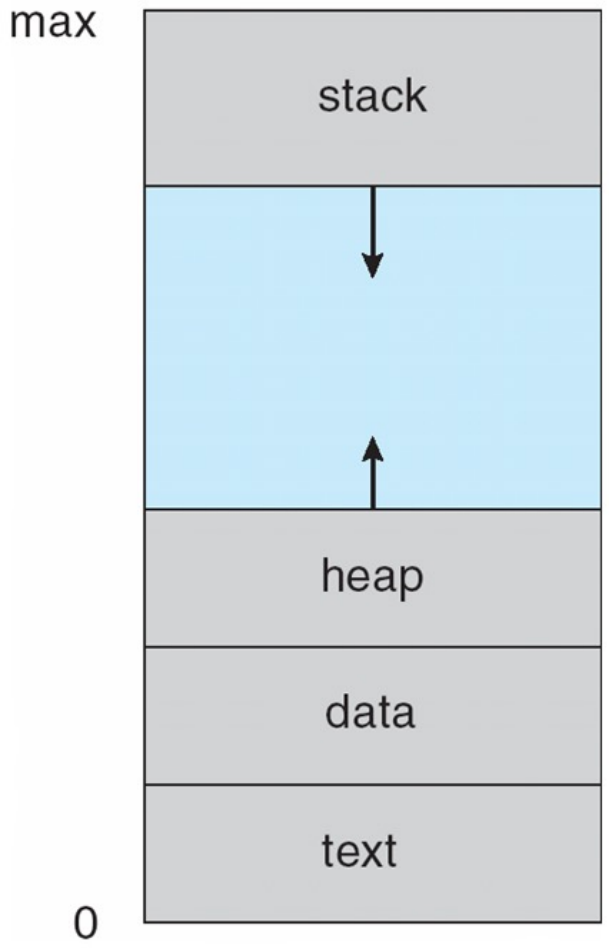
- Process Concept and States
- PCB
- Process Scheduling
- Operations on Processes
- Interprocess Communication
- Examples of IPC Systems

Process Concept

- An operating system executes a variety of programs:
  - Batch system – **jobs**
  - Time-shared systems – **user programs** or **tasks**
- Textbook uses the terms ***job*** and ***process*** almost interchangeably
- **Process** – a program in execution; process execution must progress in sequential fashion
- Multiple parts
  - The program code, also called **text section**
  - Current activity including **program counter**, processor registers
  - **Stack** containing temporary data
    - Function parameters, return addresses, local variables
  - **Data section** containing global variables
  - **Heap** containing memory dynamically allocated during run time
- Program is ***passive*** entity stored on disk (**executable file**), process is ***active***
  - Program becomes process when executable file loaded into memory
- Execution of program started via GUI mouse clicks, command line entry of its name, etc
- One program can be several processes
  - Consider multiple users executing the same program

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

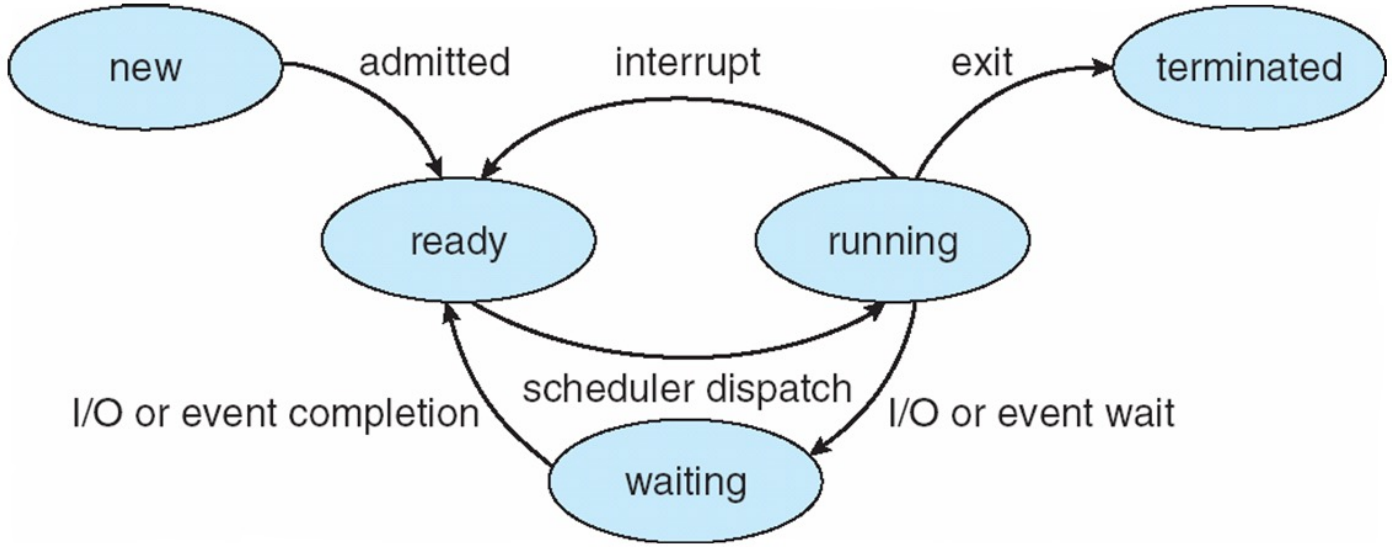
Process in Memory



Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Process State

- As a process executes, it changes **state**
  - **new**: The process is being created
  - **running**: Instructions are being executed
  - **waiting**: The process is waiting for some event to occur
  - **ready**: The process is waiting to be assigned to a processor
  - **terminated**: The process has finished execution



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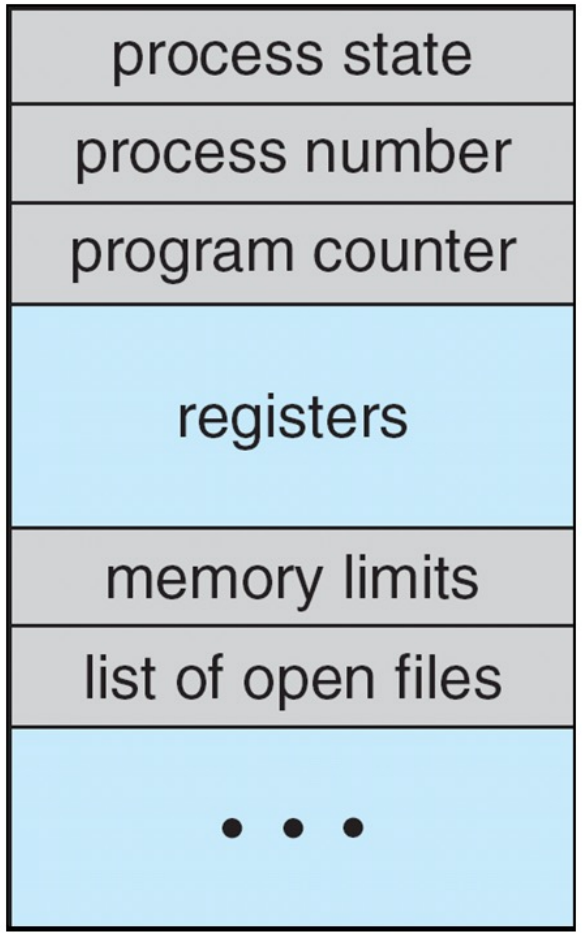
Process Control Block (PCB)

Information associated with each process

(also called **task control block**)

- Process state – running, waiting, etc
- Program counter – location of instruction to next execute
- CPU registers – contents of all process-centric registers
- CPU scheduling information- priorities, scheduling queue pointers
- Memory-management information – memory allocated to the process
- Accounting information – CPU used, clock time elapsed since start, time limits
- I/O status information – I/O devices allocated to process, list of open files



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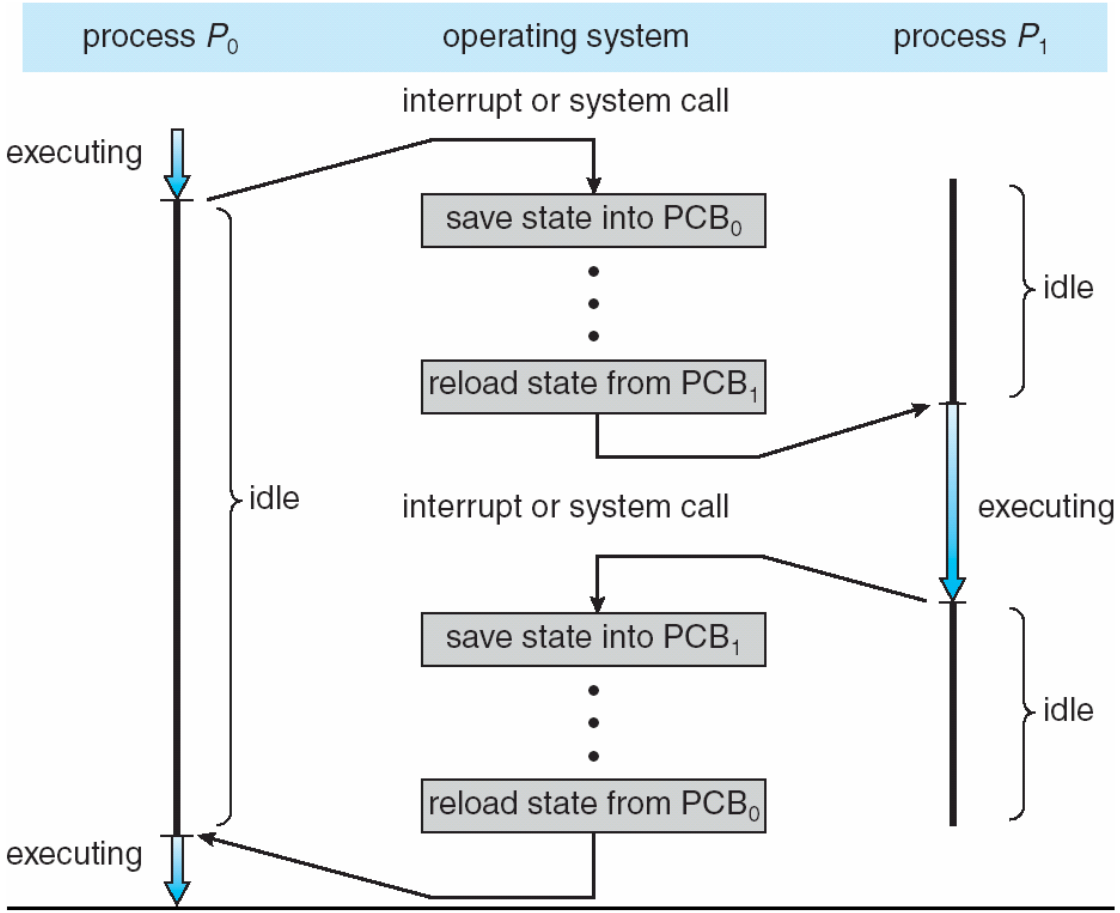
CPU Switch From Process to Process



Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

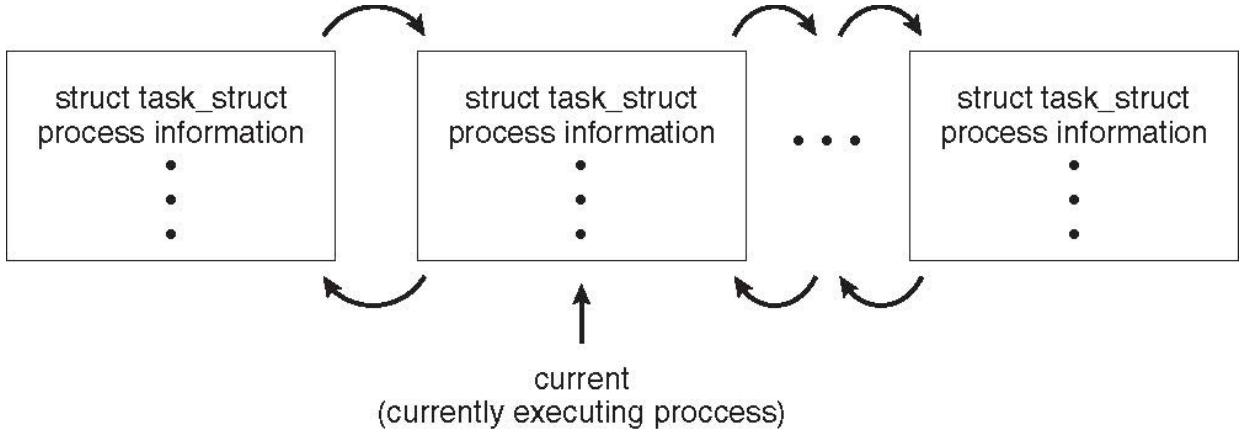
Threads

- So far, process has a single thread of execution
- Consider having multiple program counters per process
  - Multiple locations can execute at once
    - Multiple threads of control -> **threads**
- Must then have storage for thread details, multiple program counters in PCB

Process Representation in Linux

Represented by the C structure `task_struct`

```
pid t_pid; /* process identifier */
long state; /* state of the process */
unsigned int time_slice /* scheduling information */
struct task_struct *parent; /* this process's parent */
struct list_head children; /* this process's children */
struct files_struct *files; /* list of open files */
struct mm_struct *mm; /* address space of this process */
```



Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Process Scheduling

- The aim is **to assign processes to be executed by the processor** or processors over time, in a way that **meets system objectives**,
  - **Such as response time, throughput, and processor efficiency.**

- In many systems, this scheduling activity is **broken down into three separate functions**:
  - **long-, medium-, and short term scheduling**

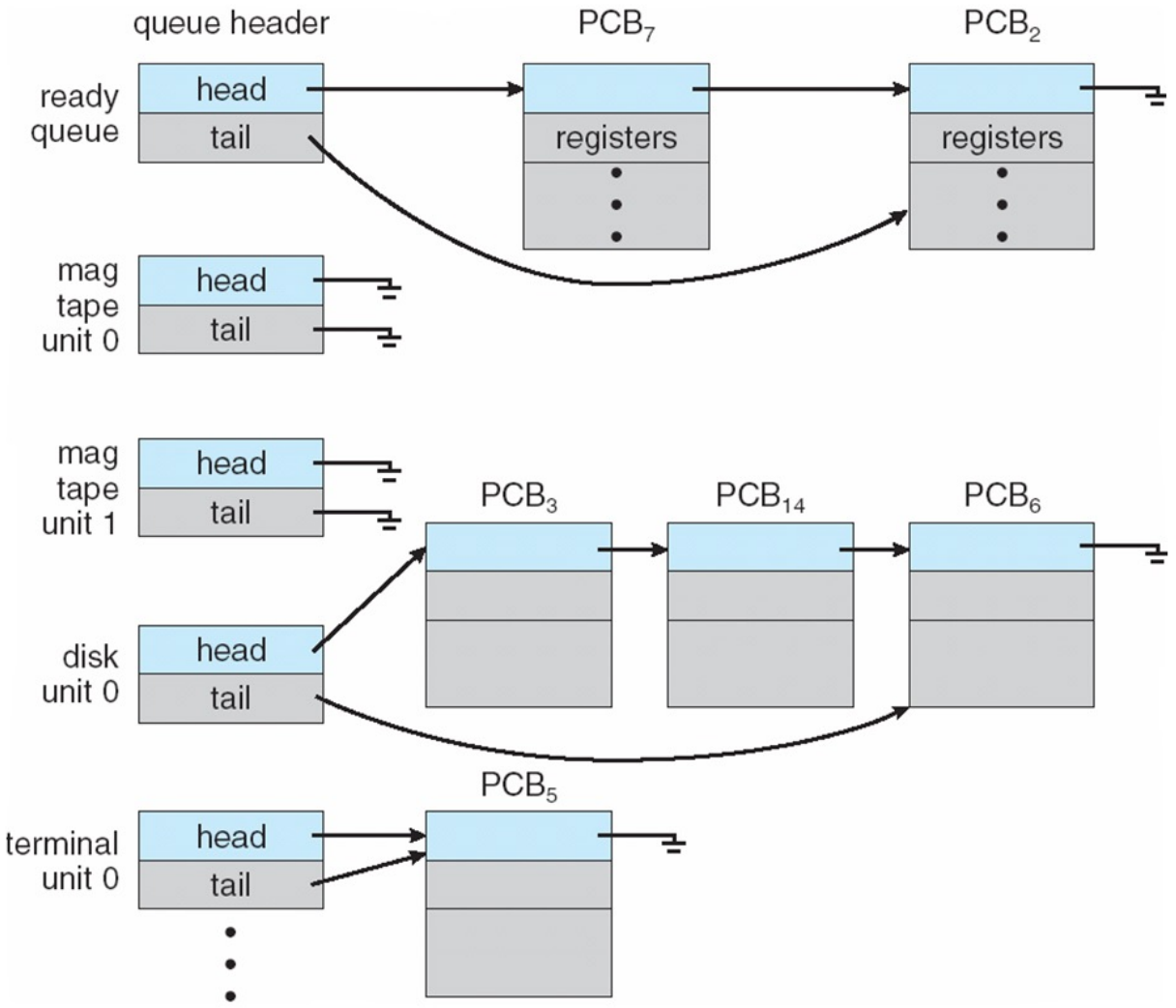
- The names suggest the **relative time scales with which these functions are performed**.

Process Scheduling

- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
  - **Job queue** – set of all processes in the system
  - **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
  - **Device queues** – set of processes waiting for an I/O device
  - Processes migrate among the various queues

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

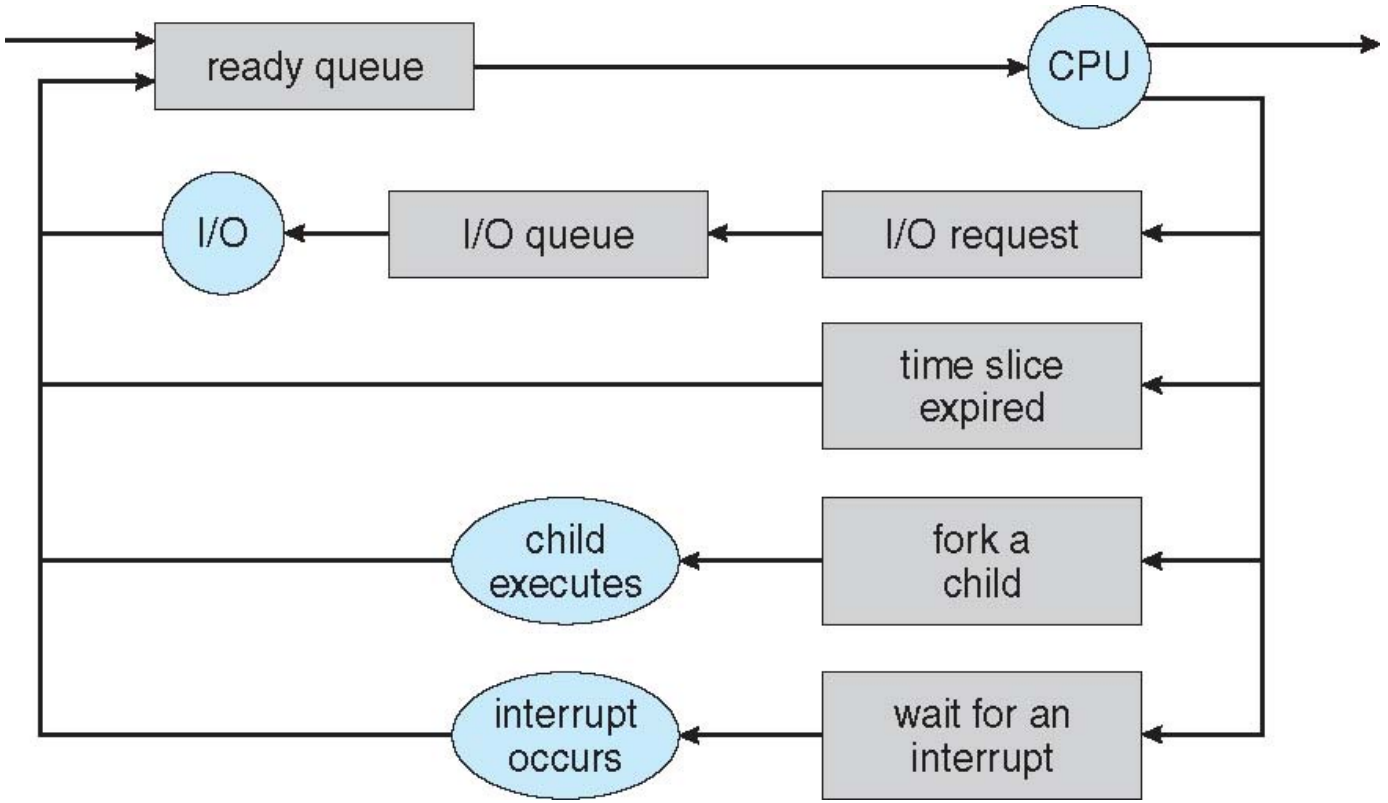
Ready Queue And Various I/O Device Queues



Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Representation of Process Scheduling

- **Queueing diagram** represents queues, resources, flows



Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Scheduler

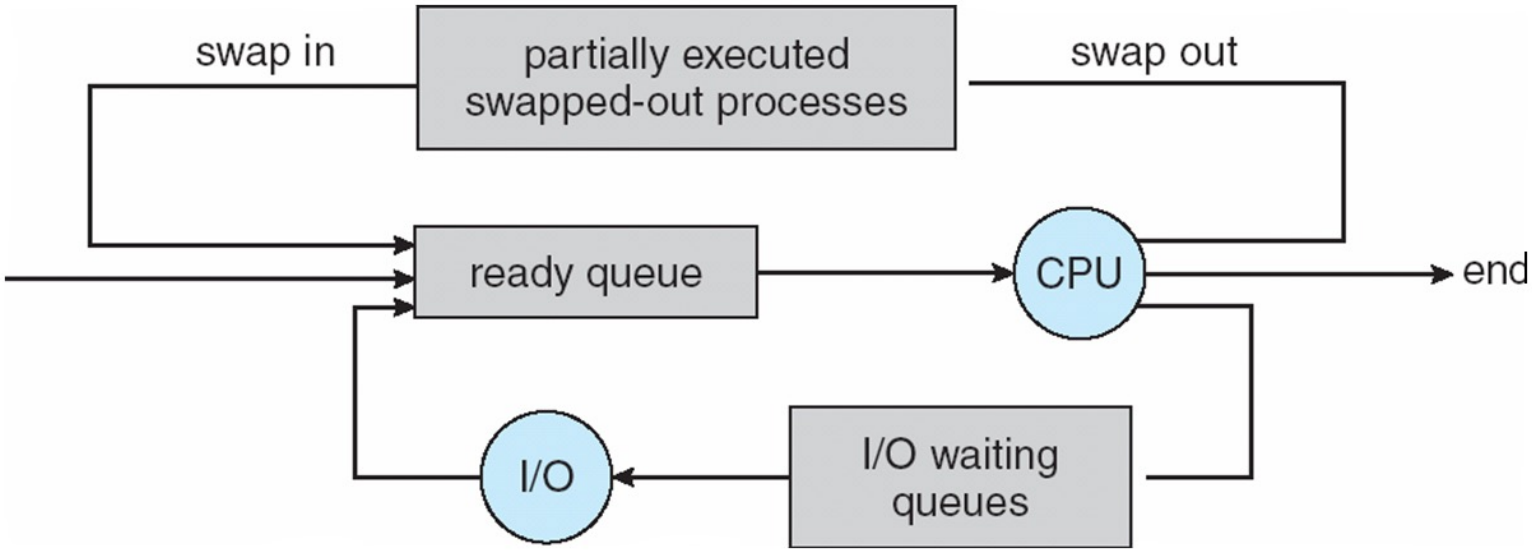
- A **process migrates among the various scheduling queues** throughout its lifetime.
- The operating system must select, for scheduling purposes, processes from these queues in some fashion.
- The **selection process is carried out** by the appropriate **scheduler.**

Schedulers

- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - Sometimes the only scheduler in a system
  - Short-term scheduler is invoked frequently (milliseconds) ⇒ (must be fast)
- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
  - Long-term scheduler is invoked infrequently (seconds, minutes) ⇒ (may be slow)
  - The long-term scheduler controls the **degree of multiprogramming**
- Processes can be described as either:
  - **I/O-bound process** – spends more time doing I/O than computations, many short CPU bursts
  - **CPU-bound process** – spends more time doing computations; few very long CPU bursts
- Long-term scheduler strives for good ***process mix***

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

- **Medium-term scheduler** can be added if degree of multiple programming needs to decrease
  - Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**
  - **A part of the *swapping function*.**



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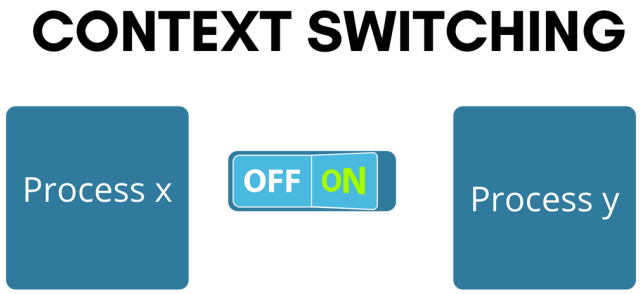
Context Switch

- When CPU switches to another process, the system must **save the state** of the old process and load the **saved state** for the new process via a **context switch**
- **Context** of a process represented in the PCB
- Context-switch time is overhead; the system does no useful work while switching
  - The more complex the OS and the PCB ➔ the longer the context switch
- Time dependent on hardware support
  - Some hardware provides multiple sets of registers per CPU ➔ multiple contexts loaded at once



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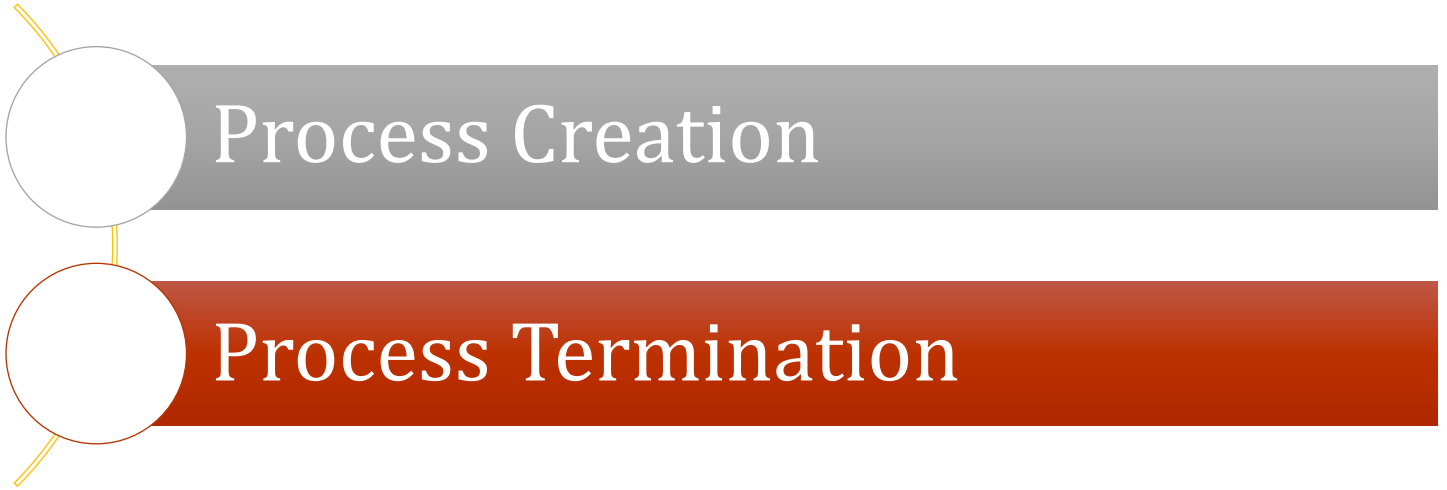
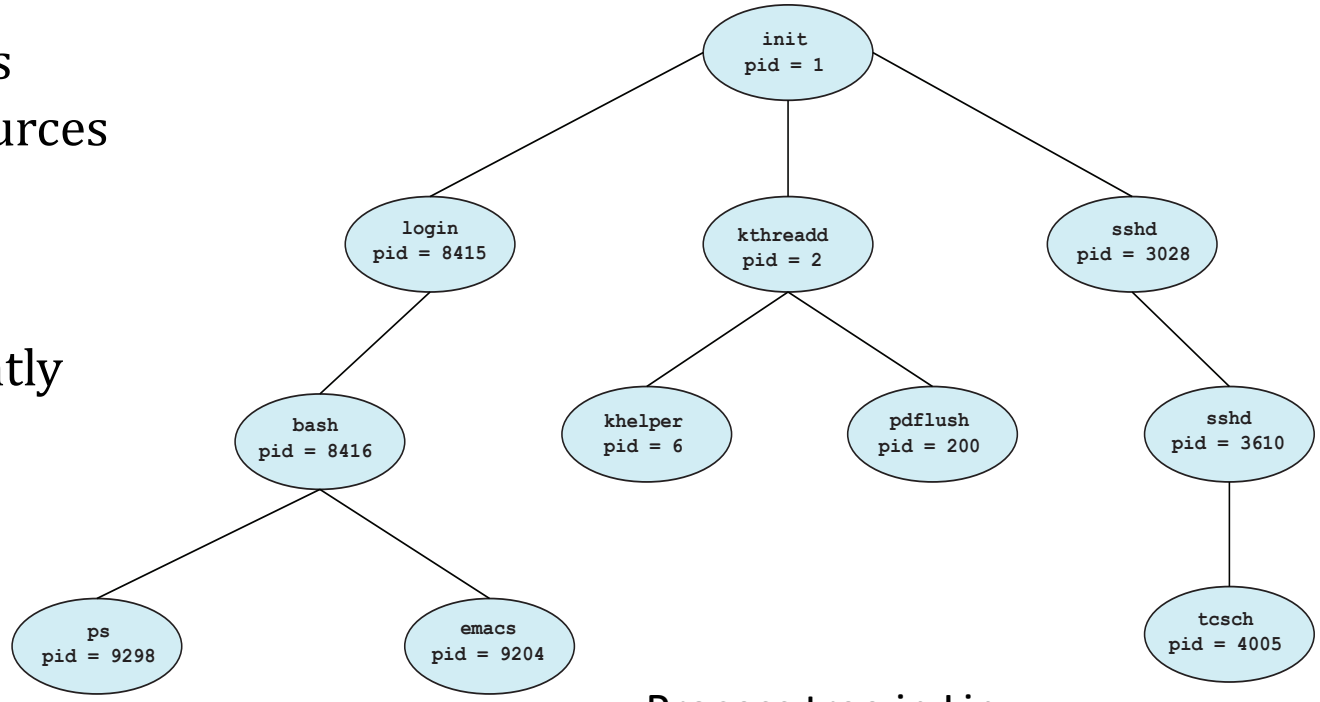
Operations on Processes

- System must provide mechanisms for:



Process Creation

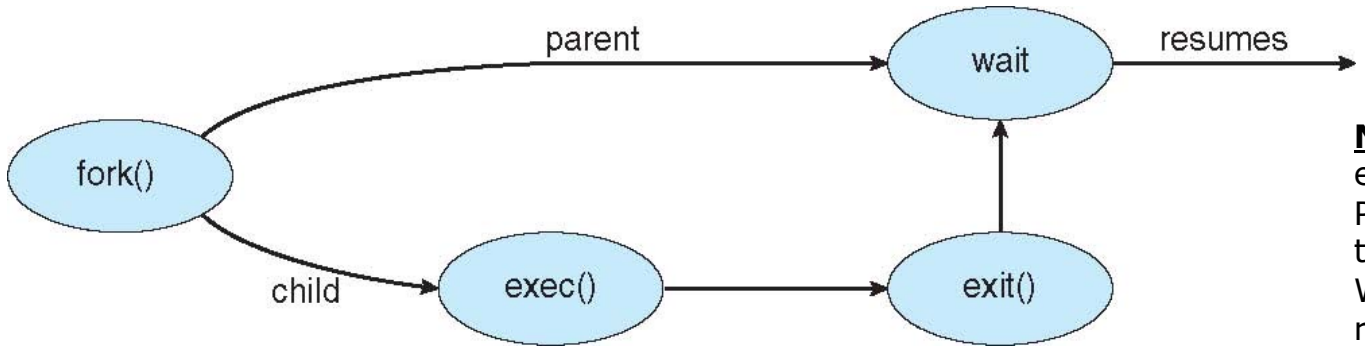
- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- Generally, process identified and managed via a **process identifier** (**pid**)
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution options
  - Parent and children execute concurrently
  - Parent waits until children terminate



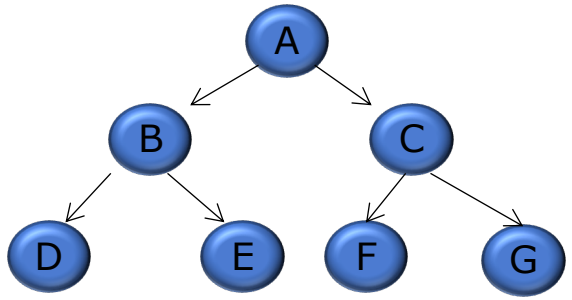
Process tree in Linux

Process Creation

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - **fork()** system call creates new process
  - **exec()** system call used after a **fork()** to replace the process' memory space with a new program



Note:
execlp() – version of exec()
Parent waits for the child process to complete
When child completes exit(), resumes from wait().



A forks B and C
B forks D and E
C forks F and G

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Process Creation

- **Steps involved in process creation :**
- **(i).** When a new process is created, operating system assigns a unique Process Identifier (PID) to it and inserts a new entry in primary process table.
- **(ii).** Then the required the required memory space for all the elements of process such as program, data and stack is allocated including space for its Process Control Block (PCB).
- **(iii).** Next, the various values in PCB are initialized such as,
  - Process identification part is filled with PID assigned to it in step (1) and also its parent's PID.
  - The processor register values are mostly filled with zeroes, except for the stack pointer and program counter. Stack pointer is filled with the address of stack allocated to it in step (ii) and program counter is filled with the address of its program entry point.
  - The process state information would be set to 'New'.
  - Priority would be lowest by default, but user can specify any priority during creation.
- In the beginning, process is not allocated to any I/O devices or files. The user has to request them or if this is a child process it may inherit some resources from its parent.
- **(iv).** Then the operating system will link this process to scheduling queue and the process state would be changed from 'New' to 'Ready'. Now process is competing for the CPU.
- **(v).** Additionally, operating system will create some other data structures such as log files or accounting files to keep track of processes activity.

Process Creation

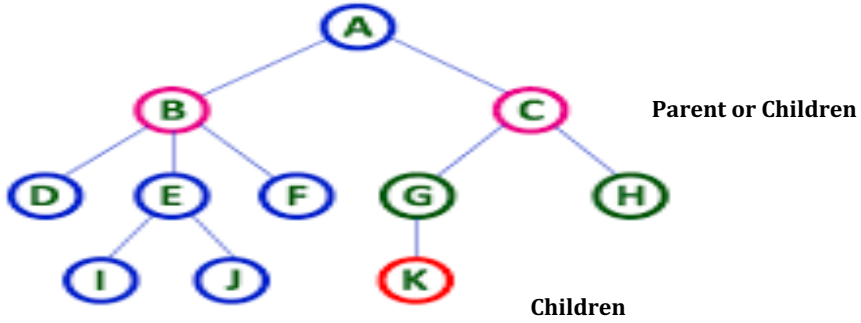
[createprocess()]

- Process that create new process (via)

  createprocess system call

Creating process → Parent Process

The created process → child



Note:
Each process is identified by Process Identifier **(PID)**

Process Creation

- Resource Sharing(CPU time, Memory files, I/O devices)
  - Parent and children share all resources
  - Children share subset of parent resources
  - Parent & child share no resources
- Execution
  - Parent & children execute concurrently
    - **(Asynchronous Process creation)**
  - Parent waits until children terminate
    - **(Synchronous Process creation)**
- Address Space
  - Child process, copy the address space of the parent
  - Child process occupy the separate address space
- Note:
  - When one process creates a new process, the identity of the newly created process is passed to the parent.

Example

- Both Parent & Child continue creation of the new process with fork().

- Return code of fork() ➔ 0 (Child Process)
- Return code of fork() ➔ Non Zero (Parent Process)

Creating a Separate Process using fork()

Example 1

```
#include <sys/types.h>
#include <studio.h>
#include <unistd.h>
int main()
{
processID  pid;
    /* create a process */
    pid = fork();
    if (pid < 0)                /* error occurred */
        fprintf(stderr, “ERROR");
    else if (pid == 0)          /* child process */
        execlp("/bin/ls", "ls", NULL);
    else                        /* parent process */
                /* parent waits for the child to complete */
                wait (NULL);
                printf ("Child Complete");
    }
```

Example 2

```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

int main()
{
pid_t pid;

    /* fork a child process */
    pid = fork();

    if (pid < 0) { /* error occurred */
       fprintf(stderr, "Fork Failed");
       return 1;
    }
    else if (pid == 0) { /* child process */
       execlp("/bin/ls","ls",NULL);
    }
    else { /* parent process */
       /* parent will wait for the child to complete */
       wait(NULL);
       printf("Child Complete");
    }

    return 0;
}
```

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Process Termination

- Processes are terminated by themselves when they finish'1 executing their last statement, then operating system USES exit( ) system call to delete its context.
- Then all the resources held by that process like physical and virtual memory, 10 buffers, open files etc., are taken back by the operating system. A process P can be terminated either by operation system or by the parent process of P.
- A parent may terminate a process due to one of the following reasons,
- **(i).** When task given to the child is not required now.
- **(ii).** When child has taken more resources than its limit.
- **(iii).** The parent of the process is exiting, as a result all its children are deleted. This is called as cascaded termination.

Process Termination

Exit()

- Process terminates by itself (ie) when the process finish executing the final statement.
  - System call: exit()
  - Returns status data from child to parent (via **wait()**)
  - Process' resources are deallocated by operating system

Abort()

- The parent process terminating the child process
  - System call: Terminate Process()
- Parent may terminate the execution of children processes using the **abort()** system call. Some reasons for doing so:
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - The parent is exiting and the operating systems does not allow a child to continue if its parent terminates
- Reasons for termination
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - If parent is exiting, some OS doesn't allow child to process
  - Cascading termination (2 mark Question)
    - If the process terminates (either normally or abnormally), then all its children must be terminated.

Kill()

- By system admin for administration purpose

Process Termination

- Some operating systems do not allow child to exists if its parent has terminated. If a process terminates, then all its children must also be terminated.
  - **cascading termination.** All children, grandchildren, etc. are terminated.
  - The termination is initiated by the operating system.
- The parent process may wait for termination of a child process by using the **wait()**system call**.** The call returns status information and the pid of the terminated process

  pid = wait(&status);
- If no parent waiting (did not invoke **wait()**) process is a **zombie**
- If parent terminated without invoking **wait** , process is an **orphan**

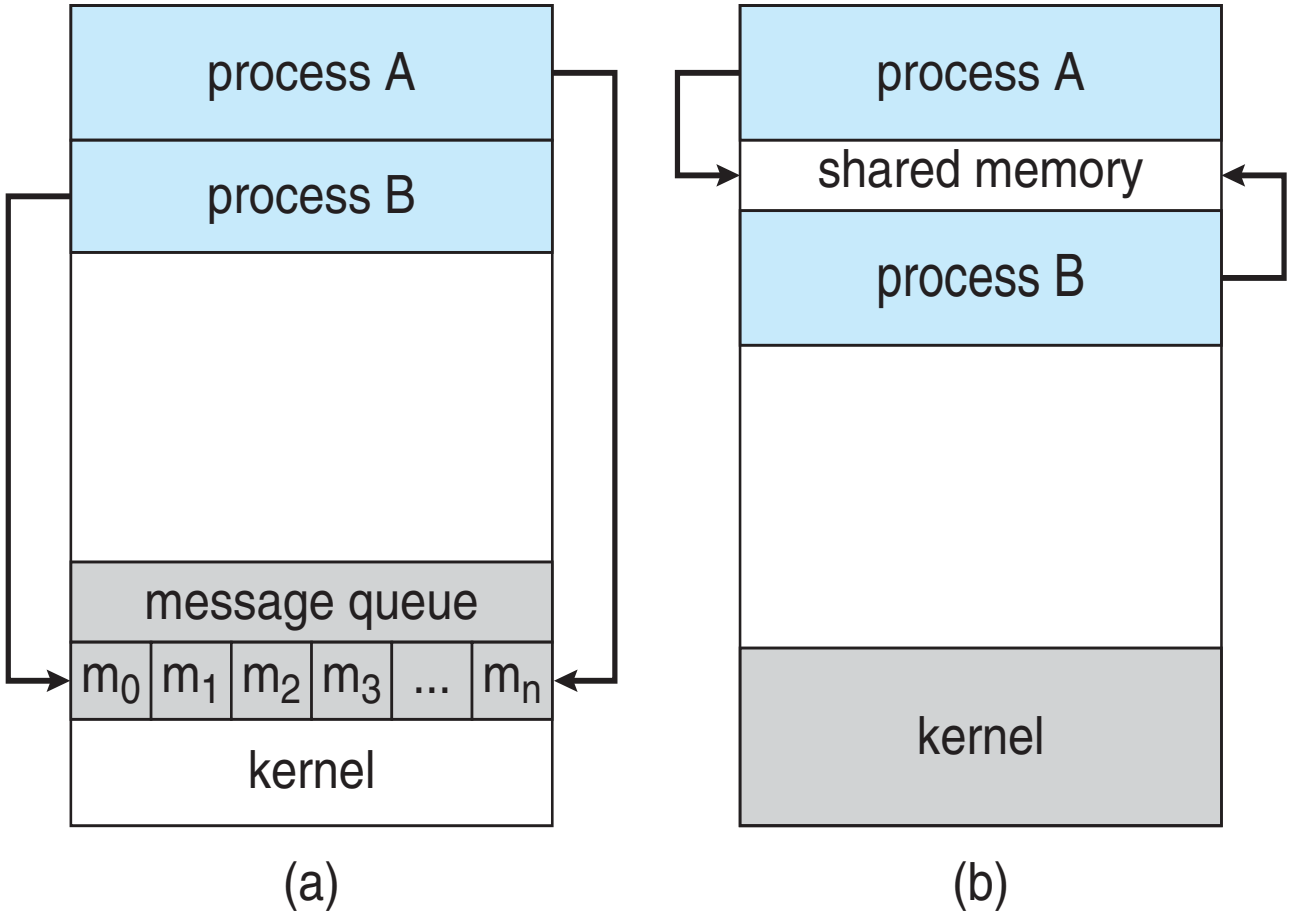
Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Interprocess Communication

- Processes within a system may be ***independent*** or ***cooperating***
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - –Information sharing
  - –Computation speedup
  - –Modularity
  - –Convenience
- Cooperating processes need **interprocess communication** (**IPC**)
- Two models of IPC
  - **–Shared memory**
  - **–Message passing**

Communications Models (Modes of IPC)

(a) Message passing. (b) shared memory.



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Cooperating Processes

- ***Independent*** process cannot affect or be affected by the execution of another process
- ***Cooperating*** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - –Information sharing
  - –Computation speed-up
  - –Modularity
  - –Convenience

IPC Example - Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
  - **–unbounded-buffer** places no practical limit on the size of the buffer
  - **–bounded-buffer** assumes that there is a fixed buffer size

Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
   . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

- Solution is correct, but can only use BUFFER_SIZE-1 elements

Bounded-Buffer –Producer

```
item next_produced;
while (true) {
        /* produce an item in next produced */
        while (((in + 1) % BUFFER_SIZE) == out)
                ; /* do nothing */
        buffer[in] = next_produced;
        in = (in + 1) % BUFFER_SIZE;
}
```

Bounded-Buffer – Consumer

```
item next_consumed;
while (true) {
        while (in == out)
                ; /* do nothing */
        next_consumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;

        /* consume the item in next consumed */
}
```


Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate
- The communication is under the control of the users processes not the operating system.
- Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.
- Synchronization is discussed in great details in Chapter 5.

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Interprocess Communication – Message Passing

- Mechanism for processes to communicate and to synchronize their actions
- Message system – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - **send**(*message*)
  - **receive**(*message*)
- The *message* size is either fixed or variable

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Message Passing (Cont.)

- If processes *P* and *Q* wish to communicate, they need to:
  - Establish a ***communication link*** between them
  - Exchange messages via send/receive
- Implementation issues:
  - How are links established?
  - Can a link be associated with more than two processes?
  - How many links can there be between every pair of communicating processes?
  - What is the capacity of a link?
  - Is the size of a message that the link can accommodate fixed or variable?
  - Is a link unidirectional or bi-directional?

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Message Passing (Cont.)

- Implementation of communication link
  - Physical:
    - Shared memory
    - Hardware bus
    - Network
  - Logical:
    - Direct or indirect
    - Synchronous or asynchronous
    - Automatic or explicit buffering

Naming: Direct Communication

- Processes must name each other explicitly:
  - **send** (*P, message*) – send a message to process P
  - **receive**(*Q, message*) – receive a message from process Q
- Properties of communication link
  - Links are established automatically
  - A link is associated with exactly one pair of communicating processes
  - Between each pair there exists exactly one link
  - The link may be unidirectional, but is usually bi-directional

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Naming: Indirect Communication

- Messages are directed and received from mailboxes (also referred to as ports)
  - –Each mailbox has a unique id
  - –Processes can communicate only if they share a mailbox
- Properties of communication link
  - –Link established only if processes share a common mailbox
  - –A link may be associated with many processes
  - –Each pair of processes may share several communication links
  - –Link may be unidirectional or bi-directional
- Operations
  - –create a new mailbox (port)
  - –send and receive messages through mailbox
  - –destroy a mailbox
- Primitives are defined as:

  send(*A, message*) – send a message to mailbox A

  receive(*A, message*) – receive a message from mailbox A

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Naming: Indirect Communication

- Mailbox sharing
  - P_1, P_2, and P_3 share mailbox A
  - P_1, sends; P_2 and P_3 receive
  - Who gets the message?
- Solutions
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a receive operation
  - Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.

Synchronization

- Message passing may be either blocking or non-blocking
- **Blocking** is considered **synchronous**
  - **Blocking send** -- the sender is blocked until the message is received
  - **Blocking receive** -- the receiver is blocked until a message is available
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking send** -- the sender sends the message and continue
  - **Non-blocking receive** -- the receiver receives:
    - A valid message, or
    - Null message
- Different combinations possible
  - If both send and receive are blocking, we have a **rendezvous**

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Synchronization (Contd)

Producer-consumer becomes trivial

```
message next_produced;
while (true) {
    /* produce an item in next produced */
send(next_produced);
}
```

```
message next_consumed;
while (true) {
   receive(next_consumed);

   /* consume the item in next consumed */
}
```

Buffering

- Queue of messages attached to the link.

Implemented in one of three ways

1. Zero capacity – no messages are queued on a link.
   Sender must wait for receiver (rendezvous)
2. Bounded capacity – finite length of *n* messages
   Sender must wait if link full
3. Unbounded capacity – infinite length
   Sender never waits

Pipes

- **Act as a channel** allowing **two processes to communicate**
- **One of the first IPC mechanisms in early UNIX systems**
- Typically provide **one of the simpler ways for processes to communicate with one another**,
  - **Communication medium** between **two or more related or interrelated processes**.
  - Either **within one process** or a communication between **the child and the parent processes**.
  - Communication can also be **multi-level** such as communication between
    - **The parent,**
    - **The child and**
    - **The grand-child, etc.**
  - Communication is achieved by **one process writing into the pipe and other reading from the pipe.**

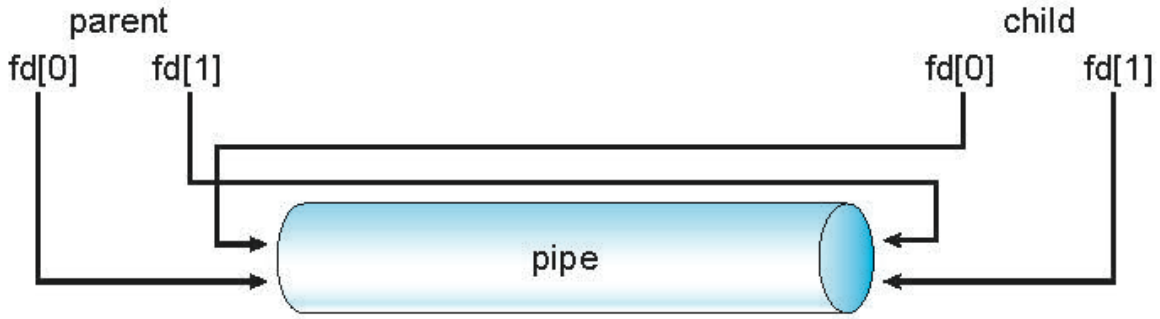
Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Pipes

- In implementing a pipe, four issues must be considered:
  - Is communication unidirectional or bidirectional?
  - In the case of two-way communication, is it half or full-duplex?
  - Must there exist a relationship (i.e., ***parent-child***) between the communicating processes?
  - Can the pipes be used over a network?
- Ordinary pipes – cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.
- Named pipes – can be accessed without a parent-child relationship.

Ordinary Pipes

- Ordinary Pipes allow communication in standard producer-consumer style
- Producer writes to one end (the **write-end** of the pipe)
- Consumer reads from the other end (the **read-end** of the pipe)
- Ordinary pipes are therefore unidirectional
- Require parent-child relationship between communicating processes



- Windows calls these **anonymous pipes**
- See Unix and Windows code samples in textbook

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Ordinary Pipes

```
#include<unistd.h>

int pipe(int pipedes[2]);
```

```
int pipe(int fds[2]);

Parameters :
fd[0] will be the fd(file descriptor) for the
read end of pipe.
fd[1] will be the fd for the write end of pipe.
Returns : 0 on Success.
-1 on error.
```

- This system call would create a pipe for one-way communication
- It creates two descriptors,
  - **First one is connected to read from the pipe and**
  - **Other one is connected to write into the pipe**
- Descriptor **pipedes[0] is for reading** and **pipedes[1] is for writing**.
- Whatever is written into pipedes[1] can be read from pipedes[0].

This call would **return zero on success** and **-1 in case of failure.**

Cannot be accessed from outside the process that creates it.

A parent process **creates a pipe and uses it to communicate with a child process** it creates via fork().

The **child process inherits open files from its parent**.

A **pipe is a special type of file**, the **child inherits the pipe from its parent process**.

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Named Pipes

- Named Pipes are more powerful than ordinary pipes
- Communication is bidirectional
- No parent-child relationship is necessary between the communicating processes
- Several processes can use the named pipe for communication
- Provided on both UNIX and Windows systems

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Need for IPC

- Processes can execute concurrently
  - May be interrupted at any time, partially completing execution
- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Illustration of the problem:
  Suppose that we wanted to provide a solution to the consumer-producer problem that fills ***all*** the buffers. We can do so by having an integer **`counter`** that keeps track of the number of full buffers. Initially, **`counter`** is set to 0. It is incremented by the producer after it produces a new buffer and is decremented by the consumer after it consumes a buffer.

Process Synchronization

•Process Synchronization means sharing system resources by processes in a such a way that, Concurrent access to shared data is handled thereby minimizing the chance of inconsistent data.

•Maintaining data consistency demands mechanisms to ensure synchronized execution of cooperating processes.

•Process Synchronization was introduced to handle problems that arose while multiple process executions

- **Background**
- Processes can execute concurrently
  - May be interrupted at any time, partially completing execution
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- Illustration of the problem:
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Need for Process Synchronization & Race Condition

- **Race condition**: The situation where several processes access – and manipulate shared data concurrently.
- The final value of the shared data depends upon which process finishes last.

- To prevent race conditions, concurrent processes must be **synchronized**.

Process Synchronization - Example

Producer

```
while (true) {
        /* produce an item in next produced
*/


        while (counter == BUFFER_SIZE) ;
                /* do nothing */
        buffer[in] = next_produced;
        in = (in + 1) % BUFFER_SIZE;
        counter++;
}
```

Consumer

```
while (true) {
        while (counter == 0)
                ; /* do nothing */
        next_consumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;
        counter--;
        /* consume the item in next consumed */
}
```

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Race Condition

- **`counter++`** could be implemented as

```
register1 = counter
register1 = register1 + 1
counter = register1
```

- **`counter--`** could be implemented as

```
register2 = counter
register2 = register2 - 1
counter = register2
```

- Consider this execution interleaving with "count = 5" initially:

S0: producer execute `register1 = counter` {register1 = 5}
S1: producer execute `register1 = register1 + 1` {register1 = 6}
S2: consumer execute `register2 = counter` {register2 = 5}
S3: consumer execute `register2 = register2 – 1` {register2 = 4}
S4: producer execute `counter = register1` {counter = 6 }
S5: consumer execute `counter = register2` {counter = 4}

Courtesy : Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Critical Section Problem

- Consider system of ***n*** processes $\{p_0, p_1, \ldots p_{n-1}\}$
- Each process has **critical section** segment of code
  - Process may be changing common variables, updating table, writing file, etc
  - When one process in critical section, no other may be in its critical section
- ***Critical section problem*** is to design protocol to solve this
- Each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**

Critical Section

- General structure c

```
do {
    entry section
        critical section
    exit section
        remainder section
} while (true);
```

Algorithm for Process P_i

```
do {
        while (turn == j);

                critical section

        turn = j;

                remainder section

 } while (true);
```

Solution to Critical-Section Problem

1. **Mutual Exclusion** - If process P_i is executing in its critical section, then no other processes can be executing in their critical sections
2. **Progress** - If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the processes that will enter the critical section next cannot be postponed indefinitely
3. **Bounded Waiting** - A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted
   - Assume that each process executes at a nonzero speed
   - No assumption concerning **relative speed** of the ***n*** processes