ACT

College of Computer Studies

COURSE NOTES iN

PLATEC:

Platform Technologies

Course Description:

This course covers the major parts of operating systems, computer architecture, and organization as the components of Platform Technologies. In the area of the operating systems, topics included are the common scheduling algorithm and resource management. This course prepares the students to become IT professionals where their major role is to analyze the organization's IT requirements based on the demand of an organization so that they can fully operate their services.

Learning Outcomes:

- Describe, discuss, and compare different operating systems, and the role they play in a computer system.
- Describe the structure of a computer system and explain its principles of operation.
- Analyze the integration of new platforms into existing environments.

Tools or Application to Use:

- Student Achievement Monitoring System (SAMS)
- Schoology (web application)
- Messenger
- Other Applications

Mode of Assessment:

- Online Quiz
- Activities
- Recitation during synchronous class
- Presentation

References:

- Operating System Concepts, Silberschatz 10th Edition

1 COMPUTER SYSTEM ARCHITECTURE

A computer system can be organized in a number of different ways, which we can categorize roughly according to the number of general-purpose processors used.

Single-Processor Systems

The **core** is the component that executes instructions and registers for storing data locally. The one main CPU with its core is capable of executing a general-purpose instruction set, including instructions from processes. They may come in the form of device-specific processors, such as disk, keyboard, and graphics controllers.

All of these special-purpose processors run a limited instruction set and do not run processes. Sometimes, they are managed by the operating system, in that the operating system sends them information about their next task and monitors their status. For example, a disk-controller microprocessor receives a sequence of requests from the main CPU core and implements its own disk queue and scheduling algorithm. This arrangement relieves the main CPU of the overhead of disk scheduling. PCs contain a microprocessor in the keyboard to convert the keystrokes into codes to be sent to the CPU. In other systems or circumstances, special-purpose processors are low-level components built into the hardware. The operating system cannot communicate with these processors; they do their jobs autonomously. The use of special-purpose microprocessors is common and does not turn a single-processor system into a multiprocessor. If there is only one general-purpose CPU with a single processing core, then the system is a single-processor system. According to this definition, however, very few contemporary computer systems are single-processor systems.

Multiprocessor Systems

On modern computers, from mobile devices to servers, **multiprocessor systems** now dominate the landscape of computing. Traditionally, such systems have two (or more) processors, each with a single-core CPU. The processors share the computer bus and sometimes the clock, memory, and peripheral devices. The primary advantage of multiprocessor systems is increased throughput. That is, by increasing the number of processors, we expect to get more work done in less time. The speed-up ratio with N processors is not N, however; it is less than N. When multiple processors cooperate on a task, a certain amount of overhead is incurred in keeping all the parts working correctly. This overhead, plus contention for shared resources, lowers the expected gain from additional processors.

The most common multiprocessor systems use **symmetric multiprocessing (SMP)**, in which each peer CPU processor performs all tasks, including operating-system functions and user processes. Figure 1.8 illustrates a typical SMP architecture with two processors, each with its own CPU. Notice that each CPU processor has its own set of registers, as well as a private — or local — cache. However, all processors share physical memory over the system bus.

The benefit of this model is that many processes can run simultaneously — N processes can run if there are N CPUs — without causing performance to deteriorate significantly. However, since the CPUs are separate, one may be sitting idle while another is overloaded, resulting in inefficiencies. These inefficiencies can be avoided if the processors share certain data structures. A multiprocessor system of this form will allow processes and resources — such as memory — to be shared dynamically among the various processors and can lower the workload variance among the processors.

The definition of multiprocessor has evolved over time and now includes **multicore** systems, in which multiple computing cores reside on a single chip. Multicore systems can be more efficient than multiple chips with single cores because on-chip communication is faster than between-chip communication.

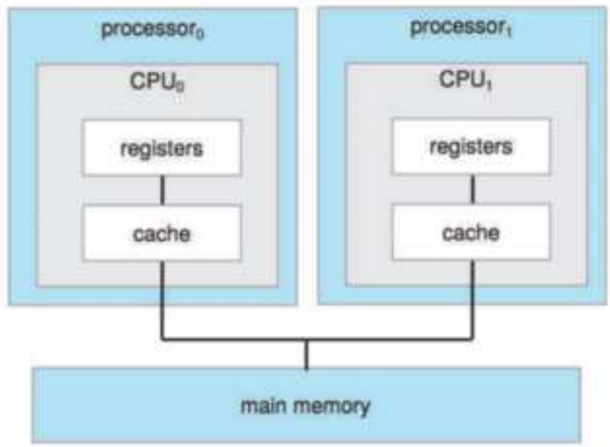


Figure 1.8 Symmetric multiprocessing architecture.

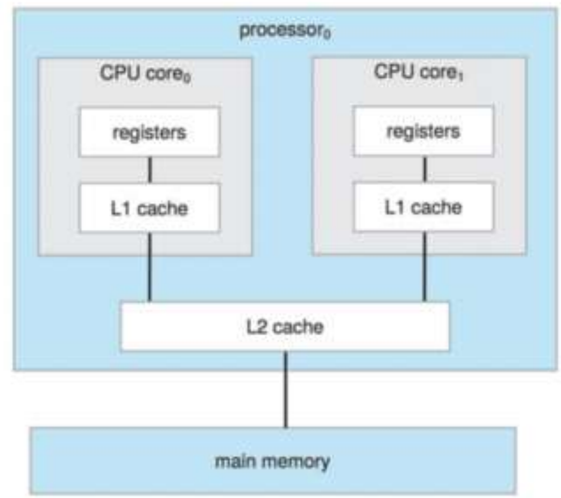


Figure 1.9 A dual-core design with two cores on the same chip.

In addition, one chip with multiple cores uses significantly less power than multiple single-core chips, an important issue for mobile devices as well as laptops.

In Figure 1.9, we show a dual-core design with two cores on the same processor chip. In this design, each core has its own register set, as well as its own local cache, often known as a level 1, or L1, cache. Notice, too, that a level 2 (L2) cache is local to the chip but is shared by the two processing cores. Most architectures adopt this approach, combining local and shared caches, where local, lower-level caches are generally smaller and faster than higher-level shared caches. Aside from architectural considerations, such as cache, memory, and bus contention, a multicore processor with N cores appears to the operating system as N standard CPUs. This characteristic put pressure on operating-system designers — and application programmers — to make efficient use of these processing cores.

Virtually all modern operating systems — including Windows, macOS, and Linux, as well as Android and iOS mobile systems — support multicore SMP systems.

Adding additional CPUs to a multiprocessor system will increase computing power; however, as suggested earlier, the concept does not scale very well, and once we add too many CPUs, contention for the system bus becomes a bottleneck and performance begin to degrade. An alternative approach is instead to provide each CPU (or group of CPUs) with its own local memory that is accessed via a small, fast local bus. The CPUs are connected by a **shared system interconnect**, so that all CPUs share one physical address space. This approach — known as **non-uniform memory access**, or NUMA— is illustrated in Figure 1.10. The advantage is that, when a CPU accesses its local memory, not only is it fast, but there is also no contention over the system interconnect. Thus, NUMA systems can scale more effectively as more processors are added.

A potential drawback with a NUMA system is increased latency when a CPU must access remote memory across the system interconnect, creating a possible performance penalty. In other words, for example, CPU0 cannot access the local memory of CPU3 as quickly as it can access its own local memory, slowing down performance. Operating systems can minimize this NUMA penalty through careful CPU scheduling and memory management. Because NUMA systems can scale to accommodate a large number of processors, they are becoming increasingly popular on servers as well as high-performance computing systems.

Finally, **blade servers** are systems in which multiple processor boards, I/O boards, and networking boards are placed in the same chassis. The difference between these and traditional multiprocessor systems is that each blade processor board boots independently and runs its own operating system. Some blade-server boards are multiprocessor as well, which blurs the lines between types of computers. In essence, these servers consist of multiple independent multiprocessor systems.

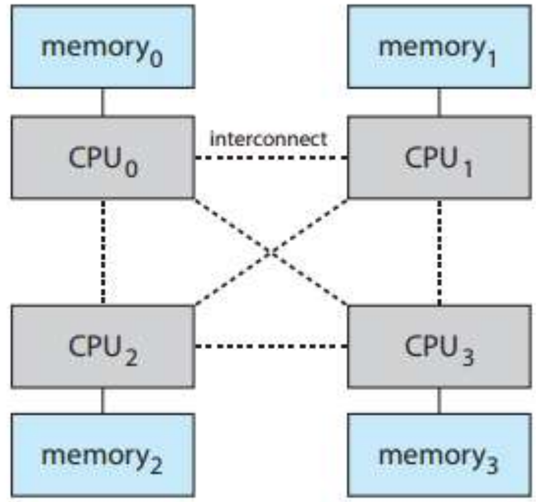


Figure 1.10 NUMA multiprocessing architecture.

Clustered Systems

Another type of multiprocessor system is a **clustered system**, which gathers together multiple CPUs. Clustered systems differ from the multiprocessor systems in that they are composed of two or more individual systems — or nodes — joined together; each node is typically a multicore system. Such systems are considered **loosely coupled**. We should note that the definition of clustered is not concrete; many commercial and open-source packages wrestle to define what a clustered system is and why one form is better than another. The generally accepted definition is that clustered computers share storage and are closely linked via a local-area network LAN or a faster interconnect, such as InfiniBand.

Clustering is usually used to provide **high-availability service**—that is, service that will continue even if one or more systems in the cluster fail. Generally, we obtain high availability by adding a level of redundancy in the system. A layer of cluster software runs on the cluster nodes. Each node can monitor one or more of the others (over the network). If the monitored machine fails, the monitoring machine can take ownership of its storage and restart the applications that were running on the failed machine. The users and clients of the applications see only a brief interruption of service.

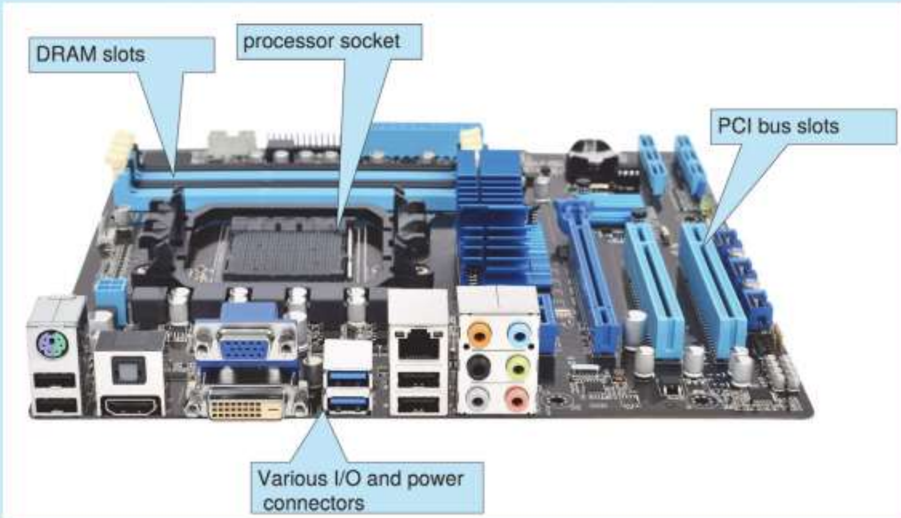
High availability provides increased reliability, which is crucial in many applications. The ability to continue providing service proportional to the level of surviving hardware is called **graceful degradation**. Some systems go beyond graceful degradation and are called **fault tolerant**, because they can suffer a failure of any single component and still continue operation. Fault tolerance requires a mechanism to allow the failure to be detected, diagnosed, and, if possible, corrected.

Clustering can be structured asymmetrically or symmetrically. In **asymmetric clustering**, one machine is in **hot-standby mode** while the other is running the applications. The hot-standby host machine does nothing but monitor the active server. If that server fails, the hot-standby host becomes the active server. In **symmetric clustering**, two or more hosts are running applications and are monitoring each other. This structure is obviously more efficient, as it uses all of the available hardware. However, it does require that more than one application be available to run.

Since a cluster consists of several computer systems connected via a network, clusters can also be used to provide **high-performance computing** environments. Such systems can supply significantly greater computational power than single-processor or even SMP systems because they can run an application concurrently on all computers in the cluster. The application must have been written specifically to take advantage of the cluster, however. This involves a technique known as **parallelization**, which divides a program into separate components that run in parallel on individual cores in a computer or computers in a cluster. Typically, these applications are designed so that once each computing node in the cluster has solved its portion of the problem, the results from all the nodes are combined into a final solution.

PC MOTHERBOARD

Consider the desktop PC motherboard with a processor socket shown below:



This board is a fully functioning computer, once its slots are populated. It consists of a processor socket containing a CPU, DRAM sockets, PCIe bus slots, and I/O connectors of various types. Even the lowest-cost general-purpose CPU contains multiple cores. Some motherboards contain multiple processor sockets. More advanced computers allow more than one system board, creating NUMA systems.

Other forms of clusters include parallel clusters and clustering over a wide-area network (WAN). Parallel clusters allow multiple hosts to access the same data on shared storage. Because most operating systems lack support for simultaneous data access by multiple hosts, parallel clusters usually require the use of special versions of software and special releases of applications. For example, Oracle Real Application Cluster is a version of Oracle's database that has been designed to run on a parallel cluster. Each machine runs Oracle, and a layer of software tracks access to the shared disk. Each machine has full access to all data in the database. To provide this shared access, the system must also supply access control and locking to ensure that no conflicting operations occur. This function, commonly known as a distributed lock manager (DLM), is included in some cluster technology.

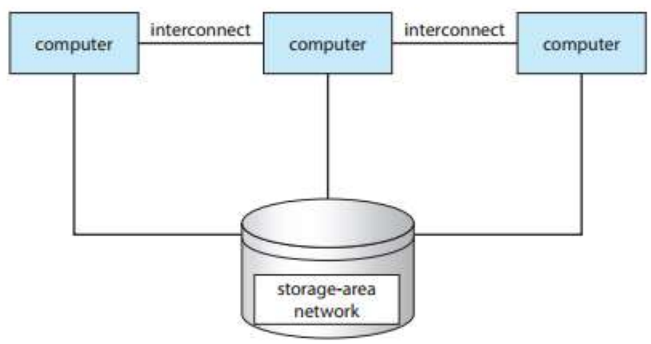


Figure 1.11 General structure of a clustered system.

Cluster technology is changing rapidly. Some cluster products support thousands of systems in a cluster, as well as clustered nodes that are separated by miles. Many of these improvements are made possible by storage-area networks (SANs), which allow many systems to attach to a pool of storage. If the applications and their data are stored on the SAN, then the cluster software can assign the application to run on any host that is attached to the SAN. If the host fails, then any other host can take over. In a database cluster, dozens of hosts can share the same database, greatly increasing performance and reliability. Figure 1.11 depicts the general structure of a clustered system.

DEFINITIONS OF COMPUTER SYSTEM COMPONENTS

- **CPU**—The hardware that executes instructions.
- **Processor**—A physical chip that contains one or more CPUs.
- **Core**—The basic computation unit of the CPU.
- **Multicore**—Including multiple computing cores on the same CPU.
- **Multiprocessor**—Including multiple processors.

Although virtually all systems are now multicore, we use the general term ***CPU*** when referring to a single computational unit of a computer system and ***core*** as well as ***multicore*** when specifically referring to one or more cores on a CPU.

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You have reached the end of the lesson. Be sure to answer the corresponding **activity of this lesson** on the activities folder of our class materials in the file server.

2 OPERATING-SYSTEM OPERATIONS

OVERVIEW

An operating system provides the environment within which programs are executed. Internally, operating systems vary greatly, since they are organized along many different lines. There are, however, many commonalities.

For a computer to start running — for instance, when it is powered up or rebooted — it needs to have an initial program to run. As noted earlier, this initial program, or bootstrap program, tends to be simple. Typically, it is stored within the computer hardware in firmware. It initializes all aspects of the system, from CPU registers to device controllers to memory contents. The bootstrap program must know how to load the operating system and how to start executing that system. To accomplish this goal, the bootstrap program must locate the operating-system kernel and load it into memory.

Once the kernel is loaded and executing, it can start providing services to the system and its users. Some services are provided outside of the kernel by system programs that are loaded into memory at boot time to become **system daemons**, which run the entire time the kernel is running. On Linux, the first system program is “systemd,” and it starts many other daemons. Once this phase is complete, the system is fully booted, and the system waits for some event to occur.

If there are no processes to execute, no I/O devices to service, and no users to whom to respond, an operating system will sit quietly, waiting for something to happen. Events are almost always signaled by the occurrence of an interrupt.

MULTIPROGRAMMING AND MULTITASKING

One of the most important aspects of operating systems is the ability to run multiple programs, as a single program cannot, in general, keep either the CPU or the I/O devices busy at all times. Furthermore, users typically want to run more than one program at a time as well. Multiprogramming increases CPU utilization, as well as keeping users satisfied, by organizing programs so that the CPU always has one to execute. In a multiprogrammed system, a program in execution has termed a process.

The idea is as follows: The operating system keeps several processes in memory simultaneously (Figure 1.12). The operating system picks and begins to execute one of these processes. Eventually, the process may have to wait for some tasks, such as an I/O operation, to complete. In a non-multiprogrammed system, the CPU would sit idle. In a multiprogrammed system, the operating system simply switches to and executes another process. When that process needs to wait, the CPU switches to another process, and so on. Eventually, the first process finishes waiting and gets the CPU back. As long as at least one process needs to execute, the CPU is never idle.

This idea is common in other life situations. A lawyer does not work for only one client at a time, for example. While one case is waiting to go to trial or have papers typed, the lawyer can work on another case. If she has enough clients, the lawyer will never be idle for lack of work. (Idle lawyers tend to become politicians, so there is a certain social value in keeping lawyers busy.)

Multitasking is a logical extension of multiprogramming. In multitasking systems, the CPU executes multiple processes by switching among them, but the switches occur frequently, providing the user with a fast response time. Consider that when a process executes, it typically executes for only a short time before it either finishes or needs to perform I/O. I/O may be interactive; that is, output goes to a display for the user, and input comes from a user keyboard, mouse, or touch screen. Since interactive I/O typically runs at “people speeds,” it may take a long time to complete. Input, for example, maybe bounded by the user’s typing speed; seven characters per second is fast for people but incredibly slow for computers. Rather than let the CPU sit idle as this interactive input takes place, the operating system will rapidly switch the CPU to another process.

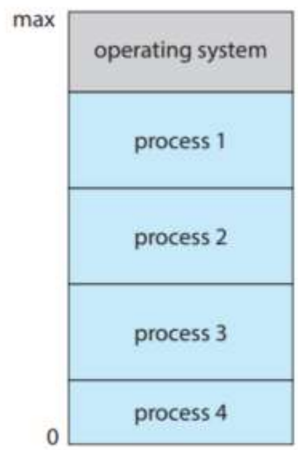

Figure 1.12 Memory layout for a multiprogramming system.

In a multitasking system, the operating system must ensure reasonable response time. A common method for doing so is **virtual memory**, a technique that allows the execution of a process that is not completely in memory. The main advantage of this scheme is that it enables users to run programs that are larger than actual **physical memory**. Further, it abstracts main memory into a large, uniform array of storage, separating **logical memory** as viewed by the user from physical memory. This arrangement frees programmers from concern over memory-storage limitations.

DUAL-MODE AND MULTIMODE OPERATION

Since the operating system and its users share the hardware and software resources of the computer system, a properly designed operating system must ensure that an incorrect (or malicious) program cannot cause other programs — or the operating system itself — to execute incorrectly. In order to ensure the proper execution of the system, we must be able to distinguish between the execution of operating-system code and user-defined code. The approach taken by most computer systems is to provide hardware support that allows differentiation among various modes of execution.

At the very least, we need two separate modes of operation: **user mode** and **kernel mode** (also called **supervisor mode, system mode, or privileged mode**). A bit, called the **mode bit**, is added to the hardware of the computer to indicate the current mode: kernel (0) or user (1). With the mode bit, we can distinguish between a task that is executed on behalf of the operating system and one that is executed on behalf of the user. When the computer system is executing on behalf of a user application, the system is in user mode. However, when a user application requests a service from the operating system (via a system call), the system must transition from user to kernel mode to fulfill the request. This is shown in Figure 1.13. As we shall see, this architectural enhancement is useful for many other aspects of system operation as well.

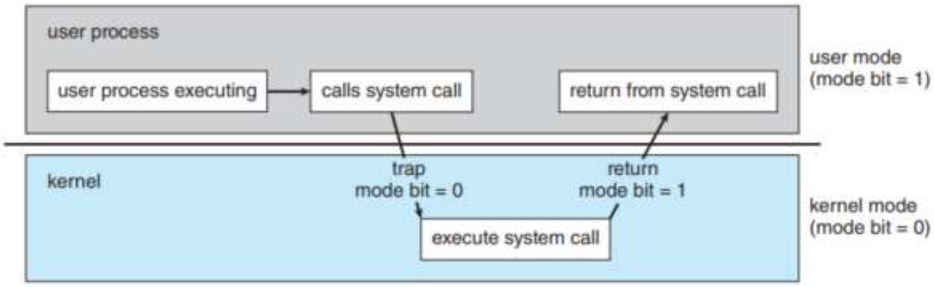

Figure 1.13 Transition from user to kernel mode.

At system boot time, the hardware starts in kernel mode. The operating system is then loaded and starts user applications in user mode. Whenever a trap or interrupt occurs, the hardware switches from user mode to kernel mode (That is, changes the state of the mode bit to 0). Thus, whenever the operating system gains control of the computer, it is in kernel mode. The system always switches to user mode (by setting the mode bit to 1) before passing control to a user program.

The dual-mode of operation provides us with the means for protecting the operating system from errant users — and errant users from one another. We accomplish this protection by designating some of the machine instructions that may cause harm as **privileged instructions**. The hardware allows privileged instructions to be executed only in kernel mode. If an attempt is made to execute a privileged instruction in user mode, the hardware does not execute the instruction but rather treats it as illegal and traps it in the operating system.

The instruction to switch to kernel mode is an example of a privileged instruction. Some other examples include I/O control, timer management, and interrupt management. Many additional privileged instructions are discussed throughout the text.

The concept of modes can be extended beyond two modes. For example, Intel processors have four separate **protection rings**, where ring 0 is kernel mode and ring 3 is user mode. (Although rings 1 and 2 could be used for various operating-system services, in practice they are rarely used.) ARMv8 systems have seven modes. CPUs that support virtualization frequently have a separate mode to indicate when the **virtual machine manager (VMM)** is in control of the system. In this mode, the VMM has more privileges than user processes but fewer than the kernel. It needs that level of privilege so it can create and manage virtual machines, changing the CPU state to do so.

We can now better understand the life cycle of instruction execution in a computer system. Initial control resides in the operating system, where instructions are executed in kernel mode. When control is given to a user application, the mode is set to user mode. Eventually, control is switched back to the operating system via an interrupt, a trap, or a system call. Most contemporary operating systems — such as Microsoft Windows, Unix, and Linux —take advantage of this dual-mode feature and provide greater protection for the operating system.

System calls provide the means for a user program to ask the operating system to perform tasks reserved for the operating system on the user program's behalf. A system call is invoked in a variety of ways, depending on the functionality provided by the underlying processor. In all forms, it is the method used by a process to request action by the operating system. A system call usually takes the form of a trap to a specific location in the interrupt vector. This trap can be executed by a generic trap instruction, although some systems have a specific syscall instruction to invoke a system call.

When a system call is executed, it is typically treated by the hardware as a software interrupt. Control passes through the interrupt vector to a service routine in the operating system, and the mode bit is set to kernel mode. The system-call service routine is a part of the operating system. The kernel examines the interrupting instruction to determine what system call has occurred; a parameter indicates what type of service the user program is requesting.

Additional information needed for the request may be passed in registers, on the stack, or in memory (with pointers to the memory locations passed in registers). The kernel verifies that the parameters are correct and legal, executes the request, and returns control to the instruction following the system call.

Once hardware protection is in place, it detects errors that violate modes. These errors are normally handled by the operating system. If a user program fails in some way — such as by making an attempt either to execute an illegal instruction or to access memory that is not in the user's address space — then the hardware traps to the operating system. The trap transfers control through the interrupt vector to the operating system, just as an interrupt does. When a program error occurs, the operating system must terminate the program abnormally. This situation is handled by the same code as a user-requested abnormal termination. An appropriate error message is given, and the memory of the program may be dumped. The memory dump is usually written to a file so that the user or programmer can examine it and perhaps correct it and restart the program.

TIMER

We must ensure that the operating system maintains control over the CPU. We cannot allow a user program to get stuck in an infinite loop or to fail to call system services and never return control to the operating system. To accomplish this goal, we can use a **timer**. A timer can be set to interrupt the computer after a specified period. The period may be fixed (for example, 1/60 second) or variable (for example, from 1 millisecond to 1 second). A **variable timer** is generally implemented by a fixed-rate clock and a counter. The operating system sets the counter. Every time the clock ticks, the counter is decremented. When the counter reaches 0, an interrupt occurs. For instance, a 10-bit counter with a 1-millisecond clock allows interrupts at intervals from 1 millisecond to 1,024 milliseconds, in steps of 1 millisecond.

Before turning over control to the user, the operating system ensures that the timer is set to interrupt. If the timer interrupts, control transfers automatically to the operating system, which may treat the interrupt as a fatal error or may give the program more time. Clearly, instructions that modify the content of the timer are privileged.

LINUX TIMERS

On Linux systems, the kernel configuration parameter HZ specifies the frequency of timer interrupts. An HZ value of 250 means that the timer generates 250 interrupts per second, or one interrupt every 4 milliseconds. The value of HZ depends upon how the kernel is configured, as well the machine type and architecture on which it is running. A related kernel variable is `jiffies`, which represent the number of timer interrupts that have occurred since the system was booted. A programming project in Chapter 2 further explores timing in the Linux kernel.

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3 RESOURCE MANAGEMENT

An operating system is a **resource manager**. The system's CPU, memory space, file-storage space, and I/O devices are among the resources that the operating system must manage.

PROCESS MANAGEMENT

- A process is a **program in execution**. It is a unit of work within the system. Program is a ***passive entity;*** the process is an ***active entity***.
- Process needs resources to accomplish its task
    - CPU, memory, I/O, files
    - Initialization data
- Process termination requires reclaim of any reusable resources
- Single-threaded process has one **program counter** specifying location of next instruction to execute
- Process executes instructions sequentially, one at a time, until completion
- Multi-threaded process has one program counter per thread
- Typically system has many processes, some users, some operating systems running concurrently on one or more CPUs
- Concurrency by multiplexing the CPUs among the processes/threads

Process Management Activities

The operating system is responsible for the following activities in connection with process management:

- Creating and deleting both user and system processes
- Suspending and resuming processes
- Providing mechanisms for process synchronization
- Providing mechanisms for process communication
- Providing mechanisms for deadlock handling

A process is the unit of work in a system. A system consists of a collection of processes, some of which are operating-system processes (those that execute system code) and the rest of which are user processes (those that execute user code). All these processes can potentially execute concurrently — by multiplexing on a single CPU core — or in parallel across multiple CPU cores.

MEMORY MANAGEMENT

- To execute a program all (or part) of the instructions must be in memory
- All (or part) of the data that is needed by the program must be in memory
- Memory management determines what is in memory and when
  - Optimizing CPU utilization and computer response to users
- Memory management activities
  - Keeping track of which parts of memory are currently being used and by whom
  - Deciding which processes (or parts thereof) and data to move into and out of memory
  - Allocating and deallocating memory space as needed

Background

- Program must be brought (from disk) into memory and placed within a process for it to be run
- Main memory and registers are only storage CPU can access directly
- Memory unit only sees a stream of:
  - addresses + read requests, or
  - address + data and write requests
- Register access is done in one CPU clock (or less)
- Main memory can take many cycles, causing a **stall**
- **Cache** sits between main memory and CPU registers
- Protection of memory required to ensure correct operation

Main memory is a large array of bytes, ranging in size from hundreds of thousands to billions. Each byte has its own address. Main memory is a repository of quickly accessible data shared by the CPU and I/O devices. The CPU reads instructions from main memory during the instruction-fetch cycle and both reads and writes data from main memory during the data-fetch cycle (on a von Neumann architecture).

FILE-SYSTEM MANAGEMENT

File management is one of the most visible components of an operating system. Computers can store information on several different types of physical media. Secondary storage is the most common, but tertiary storage is also possible.

A file is a collection of related information defined by its creator. Commonly, files represent programs (both source and object forms) and data. Data files may be numeric, alphabetic, alphanumeric, or binary.

- OS provides uniform, logical view of information storage
  - Abstracts physical properties to logical storage unit - **file**
  - Each medium is controlled by device (i.e., disk drive, tape drive)
    - Varying properties include access speed, capacity, data-transfer rate, access method (sequential or random)

- File-System management
  - Files usually organized into directories
  - Access control on most systems to determine who can access what
  - OS activities include
    - Creating and deleting files and directories
    - Primitives to manipulate files and directories
    - Mapping files onto secondary storage
    - Backup files onto stable (non-volatile) storage media

File Concept

- Contiguous logical address space
- Types:
  - Data
    - Numeric
    - Character
    - Binary
  - Program
- Contents defined by file's creator
  - Many types
    - **text file,**
    - **source file,**
    - **executable file**

File Attributes

- **Name** – only information kept in human-readable form
- **Identifier** – unique tag (number) identifies file within file system
- **Type** – needed for systems that support different types
- **Location** – pointer to file location on device
- **Size** – current file size
- **Protection** – controls who can do reading, writing, executing

- **Time, date, and user identification** – data for protection, security, and usage monitoring
- Information about files are kept in the directory structure, which is maintained on the disk
- Many variations, including extended file attributes such as file checksum
- Information kept in the directory structure

File Operations

- **Create**
- **Write –** at **write pointer** location
- **Read –** at **read pointer** location
- **Reposition within file -** **seek**
- **Delete**
- **Truncate**
- **Open (F_i)** – search the directory structure on disk for entry F_i, and move the content of entry to memory
- **Close (F_i)** – move the content of entry F_i in memory to directory structure on disk

File Types – Name, Extension

file type	usual extension	function
executable	exe, com, bin or none	ready-to-run machine-language program
object	obj, o	compiled, machine language, not linked
source code	c, cc, java, pas, asm, a	source code in various languages
batch	bat, sh	commands to the command interpreter
text	txt, doc	textual data, documents
word processor	wp, tex, rtf, doc	various word-processor formats
library	lib, a, so, dll	libraries of routines for programmers
print or view	ps, pdf, jpg	ASCII or binary file in a format for printing or viewing
archive	arc, zip, tar	related files grouped into one file, sometimes compressed, for archiving or storage
multimedia	mpeg, mov, rm, mp3, avi	binary file containing audio or A/V information

File Structure

- None - sequence of words, bytes
- Simple record structure
  - Lines
  - Fixed length
  - Variable length
- Complex Structures
  - Formatted document
  - Relocatable load file
- Can simulate last two with first method by inserting appropriate control characters
- Who decides:
  - Operating system
  - Program

MASS-STORAGE MANAGEMENT

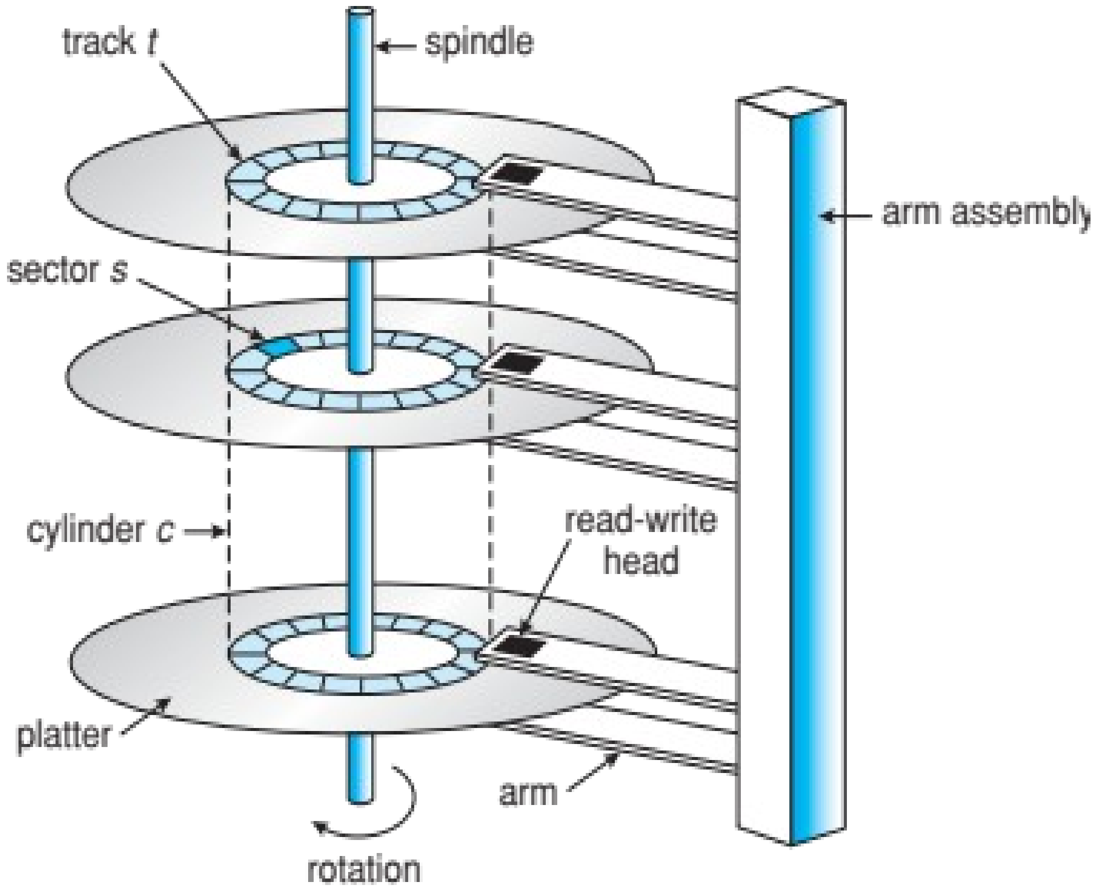
- Usually disks used to store data that does not fit in main memory or data that must be kept for a "long" period of time
- Proper management is of central importance
- Entire speed of computer operation hinges on disk subsystem and its algorithms
- OS activities
  - Mounting and unmounting
  - Free-space management
  - Storage allocation
  - Disk scheduling
  - Partitioning
  - Protection

Overview of Mass Storage Structure

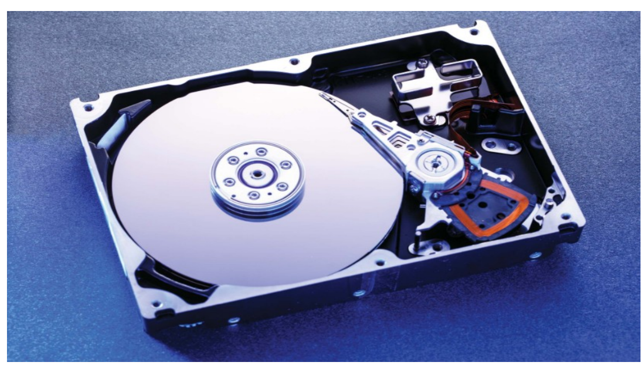
- Bulk of secondary storage for modern computers is **hard disk drives** (**HDDs**) and **nonvolatile memory** (**NVM**) devices
- **HDDs** spin platters of magnetically-coated material under moving read-write heads
  - Drives rotate at 60 to 250 times per second
  - **Transfer rate** is rate at which data flow between drive and computer
  - **Positioning time** (**random-access time**) is time to move disk arm to desired cylinder (**seek time**) and time for desired sector to rotate under the disk head (**rotational latency**)

- ○ **Head crash** results from disk head making contact with the disk surface -- That's bad
- Disks can be removable

Moving-head Disk Mechanism



Hard Disk Drives



- Platters range from .85" to 14" (historically)
  - Commonly 3.5", 2.5", and 1.8"
- Range from 30GB to 3TB per drive
- Performance
  - Transfer Rate – theoretical – 6 Gb/sec
  - Effective Transfer Rate – real – 1Gb/sec
  - Seek time from 3ms to 12ms – 9ms common for desktop drives
  - Average seek time measured or calculated based on 1/3 of tracks
  - Latency based on spindle speed
  - 1 / (RPM / 60) = 60 / RPM
  - Average latency = ½ latency

Nonvolatile Memory Devices

- If disk-drive like, then called **solid-state disks** (**SSDs**)
- Other forms include **USB drives** (thumb drive, flash drive), DRAM disk replacements, surface-mounted on motherboards, and main storage in devices like smartphones

- Can be more reliable than HDDs
- More expensive per MB
- Maybe have shorter life span – need careful management
- Less capacity
- But much faster
- Busses can be too slow -> connect directly to PCI for example
- No moving parts, so no seek time or rotational latency
- Have characteristics that present challenges
- Read and written in "page" increments (think sector) but can't overwrite in place
- Must first be erased, and erases happen in larger "block" increments
- Can only be erased a limited number of times before worn out – ~ 100,000
- Life span measured in **drive writes per day** (**DWPD**)
- A 1TB NAND drive with rating of 5DWPD is expected to have 5TB per day written within warrantee period without failing

Volatile Memory

- DRAM frequently used as mass-storage device
  - Not technically secondary storage because volatile, but can have file systems, be used like very fast secondary storage
- **RAM drives** (with many names, including RAM disks) present as raw block devices, commonly file system formatted
- Computers have buffering, caching via RAM, so why RAM drives?
  - Caches / buffers allocated / managed by programmer, operating system, hardware
  - RAM drives under user control
  - Found in all major operating systems
    - Linux /dev/ram, macOS diskutil to create them, Linux /tmp of file system type tmpfs
- Used as high speed temporary storage
  - Programs could share bulk date, quickly, by reading/writing to RAM drive

CACHE MANAGEMENT

- Important principle, performed at many levels in a computer (in hardware, operating system, software)
- Information in use copied from slower to faster storage temporarily
- Faster storage (cache) checked first to determine if information is there
  - If it is, information used directly from the cache (fast)
  - If not, data copied to cache and used there
- Cache smaller than storage being cached
  - Cache management important design problem
  - Cache size and replacement policy

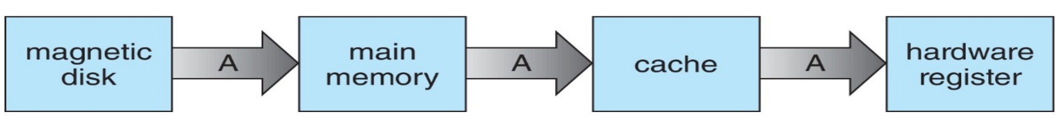
Characteristics of Various Types of Storage

Level	1	2	3	4	5
Name	registers	cache	main memory	solid-state disk	magnetic disk
Typical size	< 1 KB	< 16MB	< 64GB	< 1 TB	< 10 TB
Implementation technology	custom memory with multiple ports CMOS	on-chip or off-chip CMOS SRAM	CMOS SRAM	flash memory	magnetic disk
Access time (ns)	0.25-0.5	0.5-25	80-250	25,000-50,000	5,000,000
Bandwidth (MB/sec)	20,000-100,000	5,000-10,000	1,000-5,000	500	20-150
Managed by	compiler	hardware	operating system	operating system	operating system
Backed by	cache	main memory	disk	disk	disk or tape

Movement between levels of storage hierarchy can be explicit or implicit

Migration of data "A" from Disk to Register

- Multitasking environments must be careful to use most recent value, no matter where it is stored in the storage hierarchy



- Multiprocessor environment must provide **cache coherency** in hardware such that all CPUs have the most recent value in their cache
- Distributed environment situation even more complex
- Several copies of a datum can exist

I/O SYSTEM MANAGEMENT

- One purpose of OS is to hide peculiarities of hardware devices from the user
- I/O subsystem responsible for
    - Memory management of I/O including buffering (storing data temporarily while it is being transferred), caching (storing parts of data in faster storage for performance), spooling (the overlapping of output of one job with input of other jobs)
    - General device-driver interface
    - Drivers for specific hardware devices

NOTE:

Read Chapter 1 from the reference book, Operating System Concepts 10^{th} edition, to learn more about this lesson.

Hi I'm Flashee!

You have reached the end of the lesson. Be sure to answer the corresponding **activity of this lesson** on the activities folder of our class materials in the file server.

4 PROCESS CONCEPT

PROCESSES

Early computers allowed only one program to be executed at a time. This program had complete control of the system and had access to all the system's resources. In contrast, contemporary computer systems allow multiple programs to be loaded into memory and executed concurrently. This evolution required firmer control and more compartmentalization of the various programs; and these needs resulted in the notion of a process, which is a program in execution. A process is the unit of work in a modern computing system.

The more complex the operating system is, the more it is expected to do on behalf of its users. Although its main concern is the execution of user programs, it also needs to take care of various system tasks that are best done in user space, rather than within the kernel. A system therefore consists of a collection of processes, some executing user code, others executing operating system code. Potentially, all these processes can execute concurrently, with the CPU (or CPUs) multiplexed among them. In this chapter, you will read about what processes are, how they are represented in an operating system, and how they work.

PROCESS CONCEPT

A question that arises in discussing operating systems involves what to call all the CPU activities. Early computers were batch systems that executed jobs, followed by the emergence of time-shared systems that ran user programs, or tasks. Even on a single-user system, a user may be able to run several programs at one time: a word processor, a web browser, and an e-mail package. And even if a computer can execute only one program at a time, such as on an embedded device that does not support multitasking, the operating system may need to support its own internal programmed activities, such as memory management.

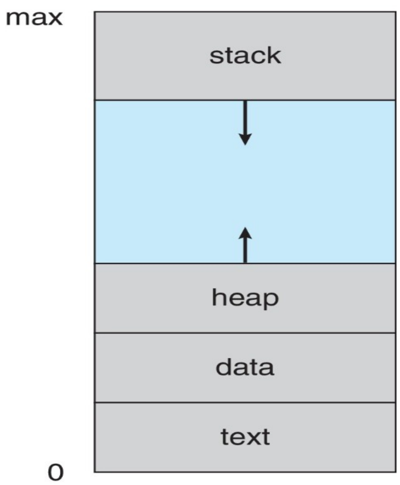
In many respects, all these activities are similar, so we call all of them processes. Although we personally prefer the more contemporary term process, the term job has historical significance, as much of operating system theory and terminology was developed during a time when the major activity of operating systems was job processing. Therefore, in some appropriate instances we use job when describing the role of the operating system. As an example, it would be misleading to avoid the use of commonly accepted terms that include the word job (such as job scheduling) simply because process has superseded job.

The Process

A process is a program in execution. The status of the current activity of a process is represented by the value of the program counter and the contents of the processor 's registers. The memory layout of a process is typically divided into multiple sections. These sections include:

- Text section — the executable code
- Data section — global variables

- Heap section — memory that is dynamically allocated during program run time
- Stack section — temporary data storage when invoking functions (such as function parameters, return addresses, and local variables)



Notice that the sizes of the text and data sections are fixed, as their sizes do not change during program run time. However, the stack and heap sections can shrink and grow dynamically during program execution. Each time a function is called, an activation record containing function parameters, local variables, and the return address is pushed onto the stack; when control is returned from the function, the activation record is popped from the stack. Similarly, the heap will grow as memory is dynamically allocated, and will shrink when memory is returned to the system. Although the stack and heap sections grow toward one another, the operating system must ensure they do not overlap one another.

We emphasize that a program by itself is not a process. A program is a passive entity, such as a file containing a list of instructions stored on disk (often called an executable fil). In contrast, a process is an active entity, with a program counter specifying the next instruction to execute and a set of associated resources. A program becomes a process when an executable file is loaded into memory. Two common techniques for loading executable files are double-clicking an icon representing the executable file and entering the name of the executable file on the command line (as in prog.exe or a.out).

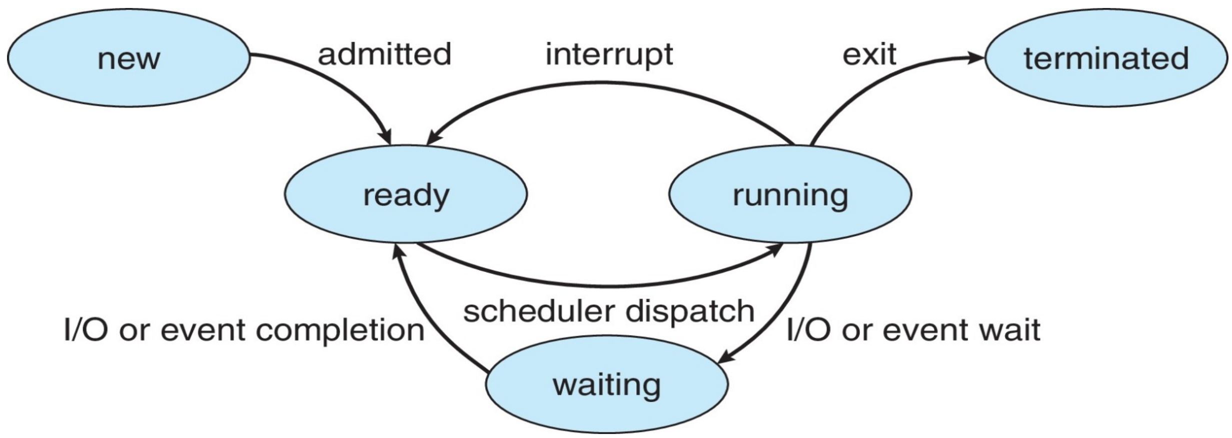
Although two processes may be associated with the same program, they are nevertheless considered two separate execution sequences. For instance, several users may be running different copies of the mail program, or the same user may invoke many copies of the web browser program. Each of these is a separate process; and although the text sections are equivalent, the data, heap, and stack sections vary. It is also common to have a process that spawns many processes as it runs.

Process State

As a process executes, it changes state. The state of a process is defined in part by the current activity of that process. A process may be in one of the following states:

- New. The process is being created.
- Running. Instructions are being executed.

- Waiting. The process is waiting for some event to occur (such as an I/O completion or reception of a signal).
- Ready. The process is waiting to be assigned to a processor.
- Terminated. The process has finished execution.



Process Control Block (PCB)

Each process is represented in the operating system by a process control block (PCB) — also called a task control block. It contains many pieces of information associated with a specific process, including these:

- Process state. The state may be new, ready, running, waiting, halted, and so on.
- Program counter. The counter indicates the address of the next instruction to be executed for this process.
- CPU registers. The registers vary in number and type, depending on the computer architecture. They include accumulators, index registers, stack pointers, and general-purpose registers, plus any condition-code information. Along with the program counter, this state information must be saved when an interrupt occurs, to allow the process to be continued correctly afterward when it is rescheduled to run.
- CPU-scheduling information. This information includes a process priority, pointers to scheduling queues, and any other scheduling parameters.
- Memory-management information. This information may include such items as the value of the base and limit registers and the page tables, or the segment tables, depending on the memory system used by the operating system.
- Accounting information. This information includes the amount of CPU and real time used, time limits, account numbers, job or process numbers, and so on.
- I/O status information. This information includes the list of I/O devices allocated to the process, a list of open files, and so on.

Threads

The process model discussed so far has implied that a process is a program that performs a single thread of execution. For example, when a process is running a word-processor program, a single thread of instructions is being executed. This single thread of control allows the process to perform only one task at a time. Thus, the user cannot simultaneously type in characters and run the spell checker. Most modern operating systems have extended the process concept to allow a process to have multiple threads of execution and thus to perform more than one task at a time. This feature is especially beneficial on multi-core systems, where multiple threads can run in parallel. A multi-threaded word processor could, for example, assign one thread to manage user input while another thread runs the spell checker.

5 PROCESS SCHEDULING

The objective of multiprogramming is to have some process running at all times so as to maximize CPU utilization. The objective of time sharing is to switch a CPU core among processes so frequently that users can interact with each program while it is running. To meet these objectives, the **process scheduler** selects an available process (possibly from a set of several available processes) for program execution on a core. Each CPU core can run one process at a time. For a system with a single CPU core, there will never be more than one process running at a time, whereas a multicore system can run multiple processes at one time. If there are more processes than cores, excess processes will have to wait until a core is free and can be rescheduled. The number of processes currently in memory is known as the **degree of multiprogramming**.

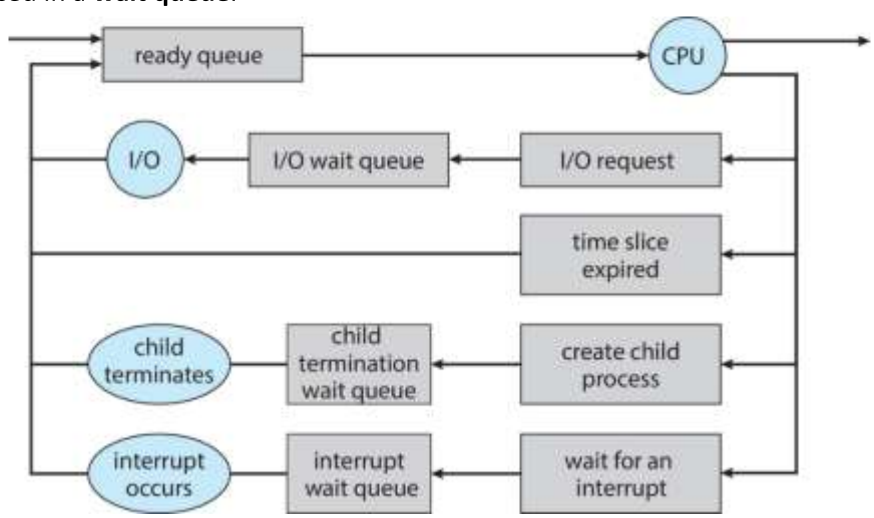
Balancing the objectives of multiprogramming and time sharing also requires taking the general behavior of a process into account. In general, most processes can be described as either I/O bound or CPU bound. An **I/O-bound process** is one that spends more of its time doing I/O than it spends doing computations. A **CPU-bound process**, in contrast, generates I/O requests infrequently, using more of its time doing computations.

SCHEDULING QUEUES

As processes enter the system, they are put into a **ready queue**, where they are ready and waiting to execute on a CPU's core This queue is generally stored as a linked list; a ready-queue header contains pointers to the first PCB in the list, and each PCB includes a pointer field that points to the next PCB in the ready queue.

The system also includes other queues. When a process is allocated a CPU core, it executes for a while and eventually terminates, is interrupted, or waits for the occurrence of a particular event, such as the completion of an I/O request. Suppose the process makes an I/O request to a device such as a disk. Since devices run significantly slower than processors, the process will have to wait for the I/O to become available. Processes that are waiting for a certain event to occur — such as completion of I/O — are placed in a **wait queue**.

A common representation of process scheduling is a **queueing diagram**, such as that in Figure 3.5. Two types of queues are present: the ready queue and a set of wait queues. The circles represent the resources that serve the queues, and the arrows indicate the flow of processes in the system.



A new process is initially put in the ready queue. It waits there until it is selected for execution, or **dispatched**. Once the process is allocated a CPU core and is executing, one of several events could occur:

• The process could issue an I/O request and then be placed in an I/O wait queue.
• The process could create a new child process and then be placed in a wait queue while it awaits the child's termination.
• The process could be removed forcibly from the core, as a result of an interrupt or having its time slice expire, and be put back in the ready queue.

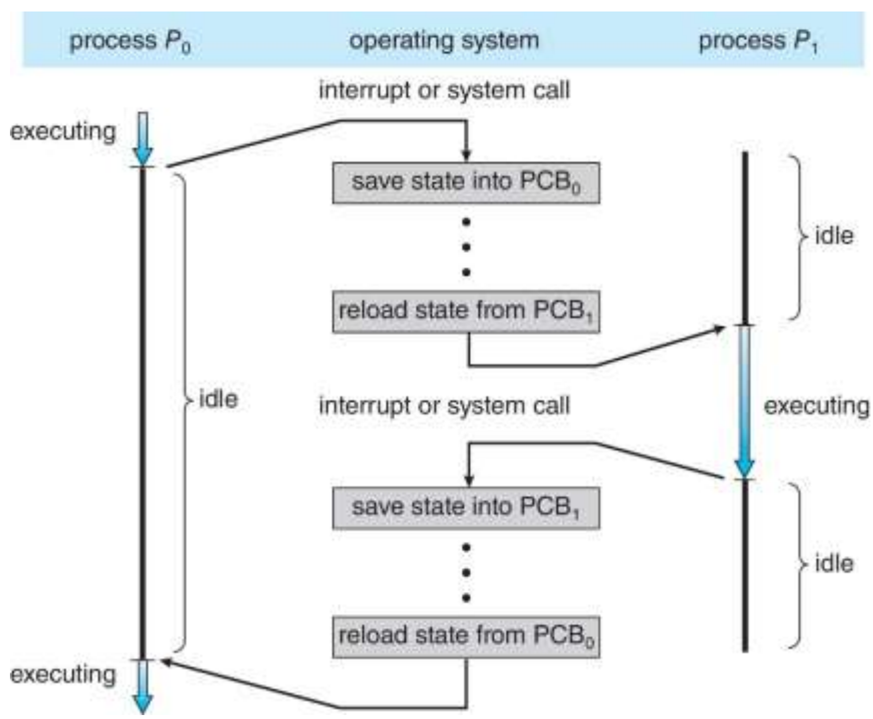
CPU SCHEDULING

A process migrates among the ready queue and various wait queues through-out its lifetime. The role of the **CPU scheduler** is to select from among the processes that are in the ready queue and allocate a CPU core to one of them. The CPU scheduler must select a new process for the CPU frequently. An I/O-bound process may execute for only a few milliseconds before waiting for an I/O request. Although a CPU-bound process will require a CPU core for longer durations, the scheduler is unlikely to grant the core to a process for an extended period. Instead, it is likely designed to forcibly remove the CPU from a process and schedule another process to run. Therefore, the CPU scheduler executes at least once every 100 milliseconds, although typically much more frequently.
Some operating systems have an intermediate form of scheduling, known as **swapping**, whose key idea is that sometimes it can be advantageous to remove a process from memory (and from active contention for the CPU) and thus reduce the degree of multiprogramming. Later, the process can be reintroduced into memory, and its execution can be continued where it left off. This scheme is known as **swapping** because a process can be "swapped out" from memory to disk, where its current status is saved, and later "swapped in" from disk back to memory, where its status is restored.

CONTEXT SWITCH

When an interrupt occurs, the system needs to save the current **context** of the process running on the CPU core so that it can restore that context when its processing is done, essentially suspending the process and then resuming it. The context is represented in the PCB of the process. It includes the value of the CPU registers, the process state, and memory-management information. Generically, we perform a **state save** of the current state of the CPU core, be it in kernel or user mode, and then a **state restore** to resume operations.

Switching the CPU core to another process requires performing a state save of the current process and a state restore of a different process. This task is known as a **context switch**. When a context switch occurs, the kernel saves the context of the old process in its PCB and loads the saved context of the new process scheduled to run. Context-switch time is pure overhead, because the system does no useful work while switching. Switching speed varies from machine to machine, depending on the memory speed, the number of registers that must be copied, and the existence of special instructions (such as a single instruction to load or store all registers). A typical speed is a several microseconds.



Context-switch times are highly dependent on hardware support. For instance, some processors provide multiple sets of registers. A context switch here simply requires changing the pointer to the current register set. Of course, if there are more active processes than there are register sets, the system resorts to copying register data to and from memory, as before. Also, the more complex the operating system, the greater the amount of work that must be done during a context switch.

Multitasking in Mobile Systems

- Some mobile systems (e.g., early version of iOS) allow only one process to run, others suspended
- Due to screen real estate, user interface limits iOS provides for a
    - Single **foreground** process- controlled via user interface
    - Multiple **background** processes– in memory, running, but not on the display, and with limits
    - Limits include single, short task, receiving notification of events, specific long-running tasks like audio playback
- Android runs foreground and background, with fewer limits
    - Background process uses a **service** to perform tasks
    - Service can keep running even if background process is suspended
    - Service has no user interface, small memory use

Operations on Processes

- System must provide mechanisms for:
    - Process creation
    - Process termination

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 Termination

- Process executes last statement and then asks the operating system to delete it using the **exit()** system call.
    - Returns status data from child to parent (via **wait()**)
    - Process' resources are deallocated by operating system
- 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

Android Process Importance Hierarchy

- Mobile operating systems often have to terminate processes to reclaim system resources such as memory. From **most** to **least** important:
  - Foreground process
  - Visible process
  - Service process
  - Background process
  - Empty process
- Android will begin terminating processes that are least important.

Multiprocess Architecture – Chrome Browser

- Many web browsers ran as single process (some still do)
  - If one web site causes trouble, entire browser can hang or crash
- Google Chrome Browser is multiprocess with 3 different types of processes:
  - **Browser** process manages user interface, disk and network I/O
  - **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
    - Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
  - **Plug-in** process for each type of plug-in

Hi I'm Flashee!

You have reached the end of the lesson. Be sure to answer the corresponding **activity of this lesson** on the activities folder of our class materials in the file server.

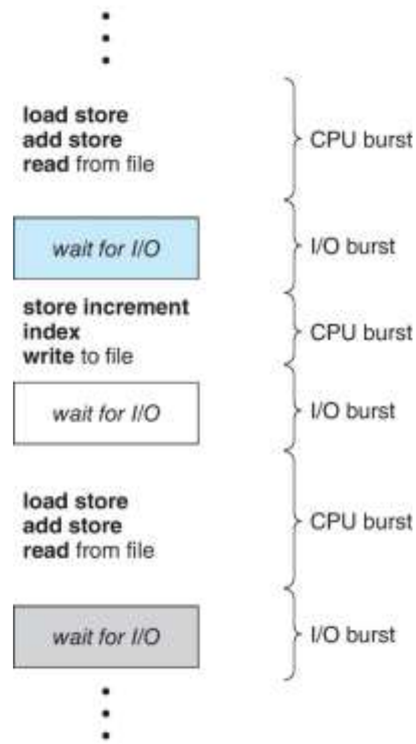
6 NON-PREEMPTIVE SCHEDULING

CPU SCHEDULING

CPU scheduling is the basis of multiprogrammed operating systems. By switching the CPU among processes, the operating system can make the computer more productive.

In a system with a single CPU core, only one process can run at a time. Others must wait until the CPU's core is free and can be rescheduled. The objective of multiprogramming is to have some process running at all times, to maximize CPU utilization. The idea is relatively simple. A process is executed until it must wait, typically for the completion of some I/O request. In a simple computer system, the CPU then just sits idle. All this waiting time is wasted; no useful work is accomplished. With multiprogramming, we try to use this time productively. Several processes are kept in memory at one time. When one process has to wait, the operating system takes the CPU away from that process and gives the CPU to another process. This pattern continues. Every time one process has to wait, another process can take over use of the CPU. On a multicore system, this concept of keeping the CPU busy is extended to all processing cores on the system.

Scheduling of this kind is a fundamental operating-system function. Almost all computer resources are scheduled before use. The CPU is, of course, one of the primary computer resources. Thus, its scheduling is central to operating-system design.



CPU – I/O Burst Cycle

The success of CPU scheduling depends on an observed property of processes: process execution consists of a cycle of CPU execution and I/O wait. Processes alternate between these two states. Process execution begins with a CPU burst. That is followed by an I/O burst, which is followed by another CPU burst, then another I/O burst, and so on.

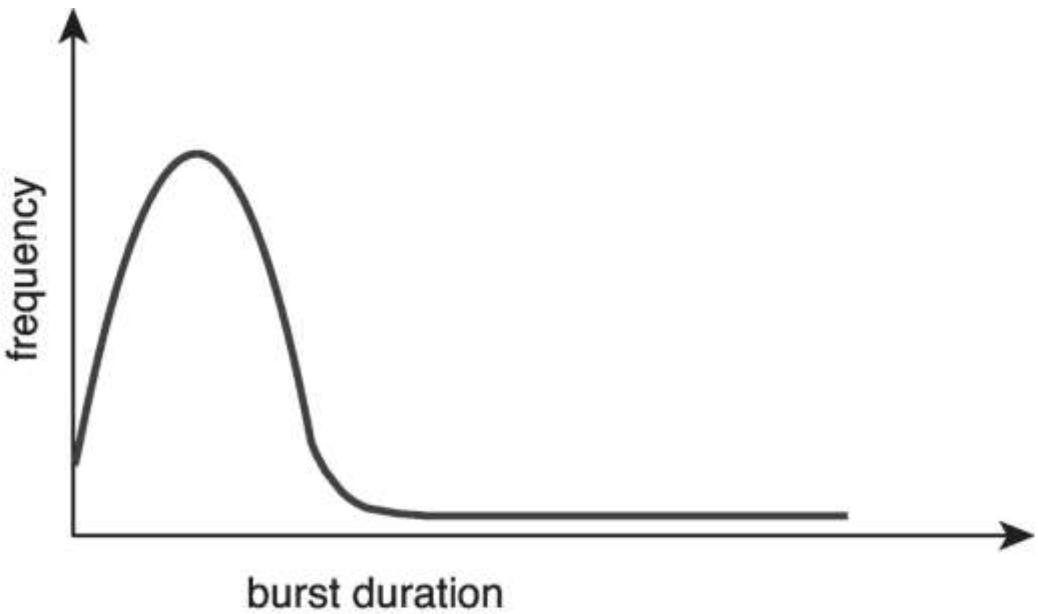
The durations of CPU bursts have been measured extensively. Although they vary greatly from process to process and from computer to computer, they tend to have a frequency curve.

The curve is generally characterized as exponential or hyperexponential, with a large number of short CPU bursts and a small number of long CPU bursts. An I/O-bound program typically has many short CPU bursts. A CPU-bound program might have a few long CPU bursts. This distribution can be important when implementing a CPU-scheduling algorithm.

CPU SCHEDULER

Whenever the CPU becomes idle, the operating system must select one of the processes in the ready queue to be executed. The selection process is carried out by the CPU scheduler, which selects a process from the processes in memory that are ready to execute and allocates the CPU to that process.

Note that the ready queue is not necessarily a first-in, first-out (FIFO) queue. As we shall see when we consider the various scheduling algorithms, a ready queue can be implemented as a FIFO queue, a priority queue, a tree, or simply an unordered linked list. Conceptually, however, all the processes in the ready queue are lined up waiting for a chance to run on the CPU. The records in the queues are generally process control blocks (PCBs) of the processes.



PREEMPTIVE AND NON-PREEMPTIVE SCHEDULING

CPU-scheduling decisions may take place under the following four circumstances:

1. When a process switches from the running state to the waiting state (for example, as the result of an I/O request or an invocation of wait() for the termination of a child process)
2. When a process switches from the running state to the ready state (for example, when an interrupt occurs)
3. When a process switches from the waiting state to the ready state (for example, at completion of I/O)
4. When a process terminates

For situations 1 and 4, there is no choice in terms of scheduling. A new process (if one exists in the ready queue) must be selected for execution. There is a choice, however, for situations 2 and 3.

When scheduling takes place only under circumstances 1 and 4, we say that the scheduling scheme is non-preemptive or cooperative. Otherwise, it is preemptive. Under non-preemptive scheduling, once the CPU has been allocated to a process, the process keeps the CPU until it releases it either by terminating or by switching to the waiting state. Virtually all modern operating systems including Windows, macOS, Linux, and UNIX use preemptive scheduling algorithms.

Unfortunately, preemptive scheduling can result in race conditions when data are shared among several processes. Consider the case of two processes that share data. While one process is updating the data, it is preempted so that the second process can run. The second process then tries to read the data, which are in an inconsistent state.

Preemption also affects the design of the operating-system kernel. During the processing of a system call, the kernel may be busy with an activity on behalf of a process. Such activities may involve changing important kernel data (for instance, I/O queues). What happens if the process is preempted in the middle of these changes and the kernel (or the device driver) needs to read or modify the same structure? **Chaos ensues**.

A non-preemptive kernel will wait for a system call to complete or for a process to block while waiting for I/O to complete to take place before doing a context switch. This scheme ensures that the kernel structure is simple, since the kernel will not preempt a process while the kernel data structures are in an inconsistent state. Unfortunately, this kernel-execution model is a poor one for supporting real-time computing, where tasks must complete execution within a given time frame.

A preemptive kernel requires mechanisms such as mutex locks to prevent race conditions when accessing shared kernel data structures. Most modern operating systems are now fully preemptive when running in kernel mode.

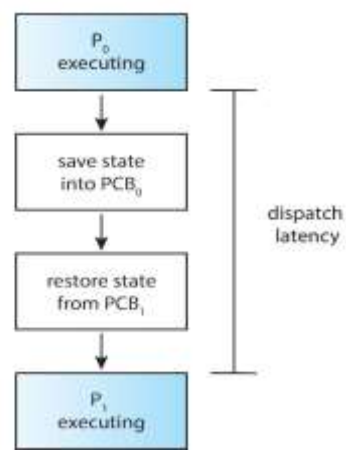
Because interrupts can, by definition, occur at any time, and because they cannot always be ignored by the kernel, the sections of code affected by interrupts must be guarded from simultaneous use. The operating system needs to accept interrupts at almost all times. Otherwise, input might be lost or output overwritten. So that these sections of code are not accessed concurrently by several processes, they disable interrupts at entry and reenable interrupts at exit. It is important to note that sections of code that disable interrupts do not occur very often and typically contain few instructions.

DISPATCHER

Another component involved in the CPU-scheduling function is the dispatcher. The dispatcher is the module that gives control of the CPU's core to the process selected by the CPU scheduler. This function involves the following:

- Switching context from one process to another
- Switching to user mode
- Jumping to the proper location in the user program to resume that program

The dispatcher should be as fast as possible, since it is invoked during every context switch. The time it takes for the dispatcher to stop one process and start another running is known as the dispatch latency.



SCHEDULING CRITERIA

Different CPU-scheduling algorithms have different properties, and the choice of a particular algorithm may favor one class of processes over another. In choosing which algorithm to use in a particular situation, we must consider the properties of the various algorithms.

Many criteria have been suggested for comparing CPU-scheduling algorithms. Which characteristics are used for comparison can make a substantial difference in which algorithm is judged to be best? The criteria include the following:

- **CPU utilization** – keep the CPU as busy as possible
- **Throughput** – # of processes that complete their execution per time unit
- **Turnaround time** – amount of time to execute a particular process
- **Waiting time** – amount of time a process has been waiting in the ready queue
- **Response time** – amount of time it takes from when a request was submitted until the first response is produced.

It is desirable to maximize CPU utilization and throughput and to minimize turnaround time, waiting time, and response time. In most cases, we optimize the average measure. However, under some circumstances, we prefer to optimize the minimum or maximum values rather than the average. For example, to guarantee that all users get good service, we may want to minimize the maximum response time.

Investigators have suggested that, for interactive systems (such as a PC desktop or laptop system), it is more important to minimize the variance in the response time than to minimize the average response time. A system with reasonable and predictable response time may be considered more desirable than a system that is faster on the average but is highly variable. However, little work has been done on CPU-scheduling algorithms that minimize variance.

As we discuss various CPU-scheduling algorithms in the following section, we illustrate their operation. An accurate illustration should involve many processes, each a sequence of several hundred CPU bursts and I/O bursts. For simplicity, though, we consider only one CPU burst (in milliseconds) per process in our examples. Our measure of comparison is the average waiting time.

SCHEDULING ALGORITHMS

CPU scheduling deals with the problem of deciding which of the processes in the ready queue is to be allocated the CPU's core. There are many different CPU scheduling algorithms. In this section, we describe several of them. Although most modern CPU architectures have multiple processing cores, we describe these scheduling algorithms in the context of only one processing core available. That is, a single CPU that has a single processing core, thus the system is capable of only running one process at a time.

FIRST-COME, FIRST-SERVED SCHEDULING

By far the simplest CPU-scheduling algorithm is the first-come first-serve (FCFS) scheduling algorithm. With this scheme, the process that requests the CPU first is allocated the CPU first. The implementation of the FCFS policy is easily managed with a FIFO queue. When a process enters the ready queue, its PCB is linked onto the tail of the queue. When the CPU is free, it is allocated to the process at the head of the queue. The running process is then removed from the queue. The code for FCFS scheduling is simple to write and understand.

On the negative side, the average waiting time under the FCFS policy is often quite long. Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

Process	Burst Time
P_1	24
P_2	3
P_3	3

- Suppose that the processes *arrive in the order*: $\boldsymbol{P_1, P_2, P_3}$
  The **Gantt Chart** for the schedule is:

- Waiting time for $P_1 = 0$; $P_2 = 24$; $P_3 = 27$
  Average waiting time: $(0 + 24 + 27)/3 = 17$

Suppose that the processes arrive in the order:

P_2 , P_3 , P_1

- The Gantt chart for the schedule is:

- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
- Average waiting time: (6 + 0 + 3)/3 = 3
- Much better than previous case
- Convoy effect - short process behind long process
    - Consider one CPU-bound and many I/O-bound processes

In addition, consider the performance of FCFS scheduling in a dynamic situation. Assume we have one CPU-bound process and many I/O-bound processes. As the processes flow around the system, the following scenario may result. The CPU-bound process will get and hold the CPU. During this time, all the other processes will finish their I/O and will move into the ready queue, waiting for the CPU. While the processes wait in the ready queue, the I/O devices are idle. Eventually, the CPU-bound process finishes its CPU burst and moves to an I/O device. All the I/O-bound processes, which have short CPU bursts, execute quickly and move back to the I/O queues. At this point, the CPU sits idle. The CPU-bound process will then move back to the ready queue and be allocated the CPU. Again, all the I/O processes end up waiting in the ready queue until the CPU-bound process is done.

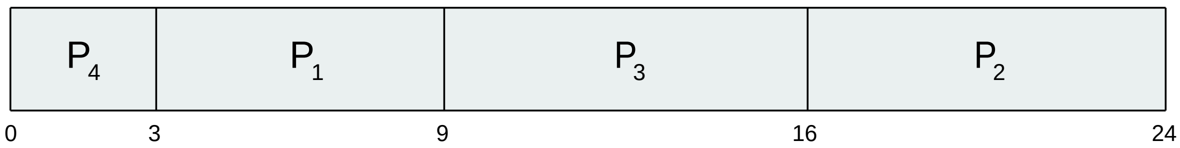
Note also that the FCFS scheduling algorithm is non-preemptive. Once the CPU has been allocated to a process, that process keeps the CPU until it releases the CPU, either by terminating or by requesting I/O. The FCFS algorithm is thus particularly troublesome for interactive systems, where it is important that each process get a share of the CPU at regular intervals. It would be disastrous to allow one process to keep the CPU for an extended period.

SHORTEST-JOB-FIRST SCHEDULING (SJF)

A different approach to CPU scheduling is the shortest-job-firs (SJF) scheduling algorithm. This algorithm associates with each process the length of the process's next CPU burst. When the CPU is available, it is assigned to the process that has the smallest next CPU burst. If the next CPU bursts of two processes are the same, FCFS scheduling is used to break the tie. Note that a more appropriate term for this scheduling method would be the shortest-next-CPU-burst algorithm, because scheduling depends on the length of the next CPU burst of a process, rather than its total length. We use the term SJF because most people and textbooks use this term to refer to this type of scheduling.

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart



- Average waiting time = (3 + 16 + 9 + 0) / 4 = 7 ms

PRIORITY SCHEDULING

The SJF algorithm is a special case of the general priority-scheduling algorithm. A priority is associated with each process, and the CPU is allocated to the process with the highest priority. Equal-priority processes are scheduled in FCFS order. An SJF algorithm is simply a priority algorithm where the priority (p) is the inverse of the (predicted) next CPU burst. The larger the CPU burst, the lower the priority, and vice versa.

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest integer ≡ highest priority)
  - Preemptive
  - **Non-preemptive**
  - SJF is priority scheduling where priority is the inverse of predicted next CPU burst time
- Problem ≡ **Starvation** – low priority processes may never execute
- Solution ≡ **Aging** – as time progresses increase the priority of the process

Process	Burst Time	Priority
P_1	10	3
P_2	1	1
P_3	2	4
P_4	1	5
P_5	5	2

- Priority scheduling Gantt Chart

- Average waiting time = 8.2 ms

Hi I'm Flashee!

You have reached the end of the lesson. Be sure to answer the corresponding **activity of this lesson** on the activities folder of our class materials in the file server.