# UNIT-2

# PROCESS MANAGEMENT

## PROCESS CONCEPT

The process concept includes the following:

1. Process
2. Process state
3. Process Control Block
4. Threads

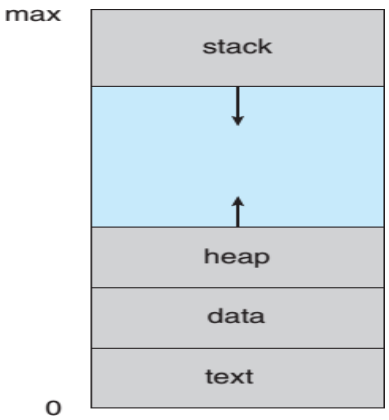
### Process

A process can be thought of as a program in execution (or) A process is the unit of work in a modern time-sharing system.

A process will need certain resources such as CPU time, memory, files and I/O devices to accomplish its task.

These resources are allocated to the process either when it is created or while it is executing.

The below figure shows the structure of process in memory:




The process contains several sections: Text, Data, Heap and Stack.

- **Text section** contains the program code. It also includes the current activity, as represented by the value of the **program counter** and the contents of the processor's registers.
- **Process stack** contains temporary data such as function parameters, return addresses and local variables.
- **Data section** contains global variables.
- **Heap** is memory that is dynamically allocated during process run time.

Difference between Program and Process:

- A program is a ***passive*** entity, such as a file containing a list of instructions stored on disk often called an **executable file**.
- 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 considered as 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 considered as a separate process.

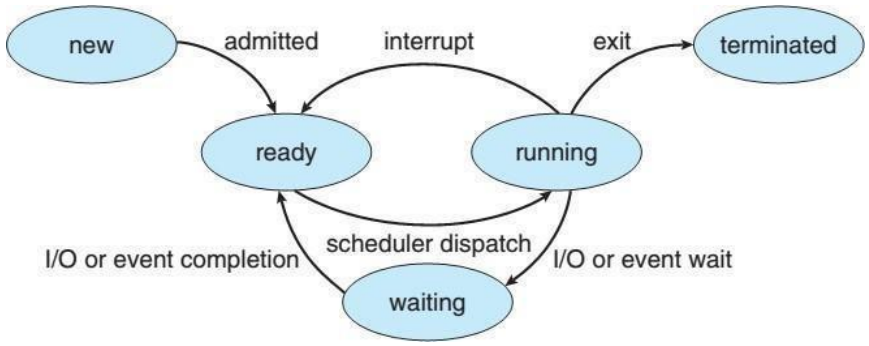
## Process State

As a process executes, it changes **state**. The process state defines the current activity of that process.

A process may be in one of the following states:

- **New**: The process is being created.
- **Ready**: The process is waiting to be assigned to a processor.
- **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.
- **Terminated**: The process has finished execution.

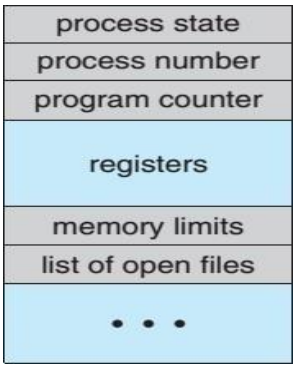
**Note:** Only one process can be *running* on any processor at any instant of time.




## Process Control Block

Each process is represented in the operating system by a **Process Control Block (PCB)**. It is also called a **Task Control Block**.

PCB serves as the repository for any information that may vary from process to process.




The PCB contains information related to process such as:

- **Process state**: The state may be new, ready, running, waiting and terminated.
- **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 etc. Along with the program counter, this state information must be saved when an interrupt occurs, to allow the process to be continued correctly afterward.

- **CPU-scheduling information**: This information includes a process priority, pointers to scheduling queues and any other scheduling parameters.
- **Memory-management information**: This information includes the base and limit registers values, 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**

In a single processor system a process is a program that performs a single **thread** of execution.

- **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.
- The user cannot simultaneously type in characters and run the spell checker within the same process.

A multicore system or multi-processor system allows a process to run multiple threads of execution in parallel.

On a system that supports threads, the PCB is expanded to include information for each thread.

**Process Scheduling**

The objective of multiprogramming is to have some process running at all times, to maximize CPU utilization.

The objective of time sharing is to switch the CPU 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 for program execution on the CPU.

Process scheduling involves three things:

1. Scheduling Queues
2. Schedulers
3. Context Switch

**Scheduling Queues**

There are several queues implemented in the operating system such as Job Queue, Ready Queue, Device Queue.

- **Job Queue:** It consists of all processes in the system. As processes enter the system, they are put into a **job queue**.
- **Ready Queue:** The processes that are residing in main memory and they are ready and waiting to execute are kept on a list called the **Ready Queue**. Ready queue is generally stored as a linked list. A ready-queue header contains pointers to the first and final PCBs in the list. Each PCB includes a pointer field that points to the next PCB in the ready queue.

- **Device Queue:** Each device has its own device queue. It contains the list of processes waiting for a particular I/O device.

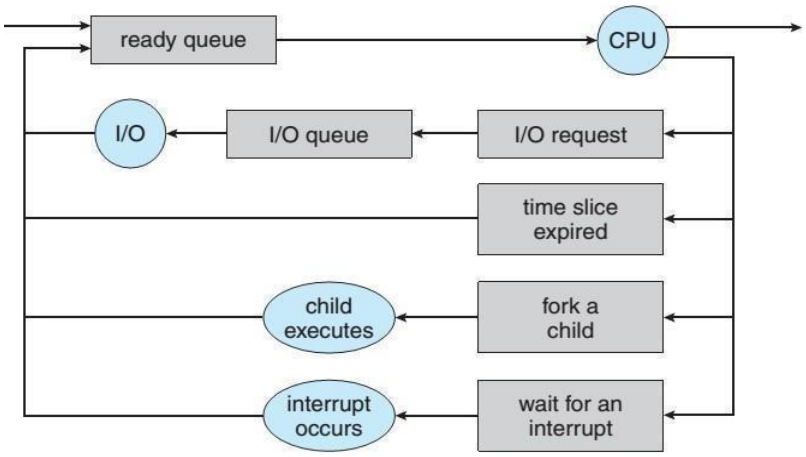



**Figure 3.6** Queueing-diagram representation of process scheduling.

Consider the above Queuing Diagram:

- Two types of queues are present: the **Ready Queue** and a set of **Device Queues**. CPU and I/O are the resources that serve the queues.
- 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 the CPU 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 queue.
- The process could create a new child process and wait for the child's termination.
- The process could be removed forcibly from the CPU, as a result of an interrupt and be put back in the ready queue.

**Schedulers**

A process migrates among the various scheduling queues throughout its lifetime. For scheduling purposes, the operating system must select processes from these queues. The selection process is carried out by the **Scheduler.**

There are three types of Schedulers are used:

1. Long Term Scheduler
2. Short Term Scheduler
3. Medium Term Scheduler

**Long Term Scheduler (New to ready state)**

- Initially processes are spooled to a mass-storage device (i.e Hard disk), where they are kept for later execution.
- Long-term scheduler or job scheduler selects processes from this pool and loads them into main memory for execution. (i.e. from Hard disk to Main memory).
- The long-term scheduler executes much less frequently, there may be minutes of time between creation of one new process to another process.
- The long-term scheduler controls the **degree of multiprogramming** (the number of processes in memory).

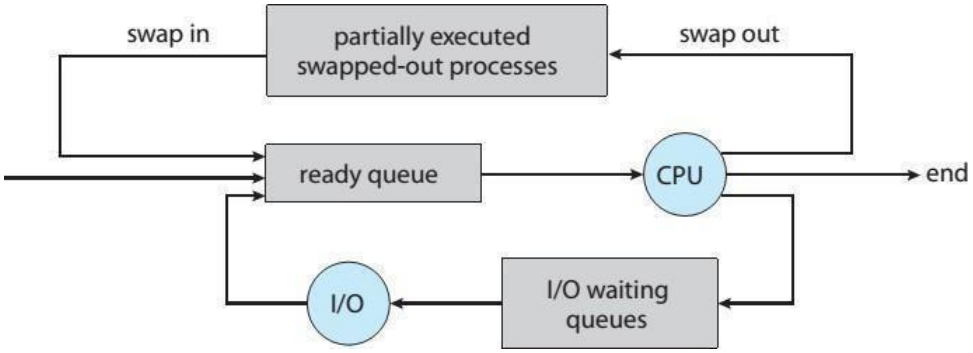
**Short Term Scheduler (Ready to Running)**

- Short-term scheduler or CPU scheduler selects from among the processes that are ready to execute and allocates the CPU to one of them. (i.e. a process that resides in main memory will be taken by CPU for execution).
- The short-term scheduler must select a new process for the CPU frequently.
- The short term scheduler must be very fast because of the short time between executions of processes.

**Medium Term Scheduler**

Medium Term Scheduler does two tasks:

1. **Swapping:** Medium-term scheduler removes a process from main memory and stores it into the secondary storage. After some time, the process can be reintroduced into main memory and its execution can be continued where it left off. This procedure is called Swapping.
2. Medium Term Scheduler moves a process from CPU to I/O waiting queue and I/O queue to the ready queue.




The processes can be described as two types:

1. I/O bound process is one that spends more of its time doing I/O than it spends doing computations.
2. The CPU Bound process uses more of its time doing computations and generates I/O requests infrequently.

The long-term scheduler selects a good ***process mix*** of I/O-bound and CPU-bound processes.

- If all processes are I/O bound, the ready queue will almost always be empty and the CPU will remain idle for a long time because I/O device processing takes a lot of time.
- If all processes are CPU bound, the I/O waiting queue will almost always be empty. I/O devices will be idle and the CPU is busy for most of the time.
- Thus if the system maintains the combination of CPU bound and I/O bound processes then the system performance will be increased.

**Note:** Time-sharing systems such as UNIX and Microsoft Windows systems often have no long-term scheduler but simply put every new process in memory for the short-term scheduler.

**Context Switching**

- Switching the CPU from one process 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**.
- 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.

- 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. Context switch time may be in a few milliseconds.

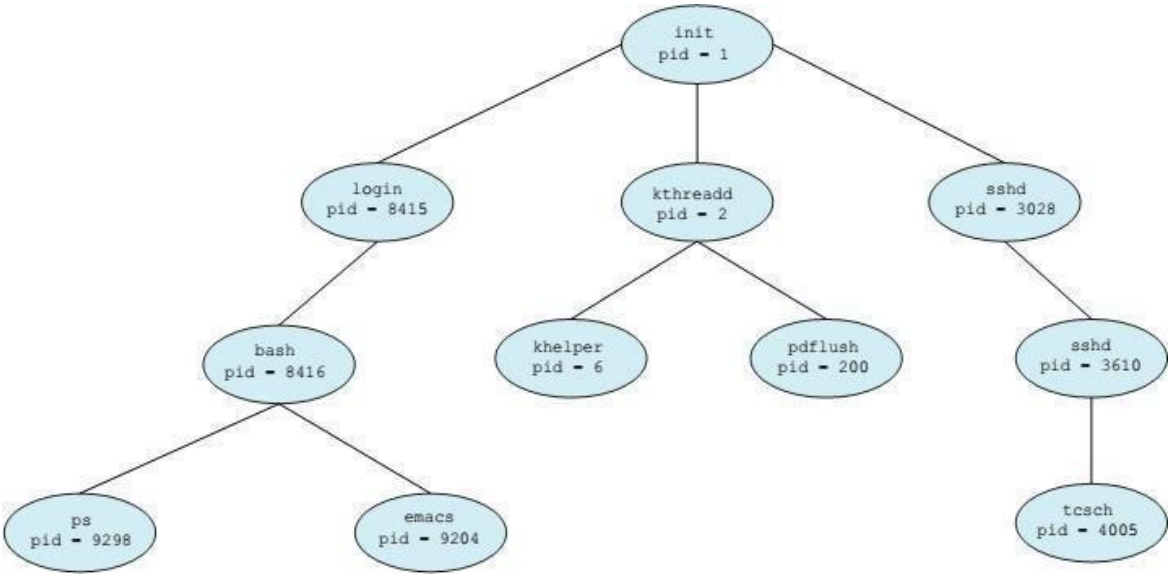
**Operations on Processes**

1. Process Creation
2. Process Termination

**Process Creation**

- During the execution of a process in its lifetime, a process may create several new processes.
- The creating process is called a parent process and the new processes are called children process.
- Each of these new processes may create other processes forming a **tree** of processes.
- Operating system identifies processes according to the process **identifier** (**pid**).
- Pid provides an unique integer number for each process in the system.
- Pid can be used as an index to access various attributes of a process within the kernel.

The below figure shows the process tree for the Linux OS that shows the name of each process and its pid. In Linux the process is called a task.




- The init process always has a pid of 1. The init process serves as the root parent process for all user processes.
- Once the system has booted, the init process can also create various user processes, such as a web or print server, an ssh server etc.
- kthreadd and sshd are child processes of init.
- The kthreadd process is responsible for creating additional processes that perform tasks on behalf of the kernel.
- The sshd process is responsible for managing clients that connect to the system by using a secure shell (ssh).

**ps** command is used to obtain a list of processes:

**ps –el**

The command will list complete information for all processes currently active in the system.

- When a process creates a child process, that child process will need certain resources such as CPU time, memory, files, I/O devices to accomplish its task.
- A child process may be able to obtain its resources directly from the operating system or it may be constrained to a subset of the resources of the parent process.
- The parent may have to partition its resources among its children or it may be able to share some resources such as memory or files among several of its children.
- Restricting a child process to a subset of the parent's resources prevents any process from overloading the system by creating too many child processes.

When a process creates a new process there exist two possibilities for execution:

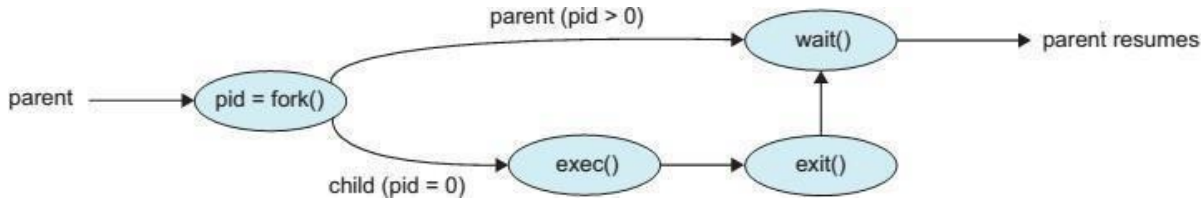
1. The parent continues to execute concurrently with its children.
2. The parent waits until some or all of its children have terminated.

There are also two address-space possibilities for the new process:

1. The child process is a duplicate of the parent process (i.e) it has the same program and data as the parent.
2. The child process has a new program loaded into it.hg

**Process System calls in Unix/ Linux: fork( ), exec( ), wait( ), exit( )**

- **fork( )**: In UNIX OS a new process is created by the **fork( )** system call.
- The new process consists of a copy of the address space of the original process. This mechanism allows the parent process to communicate easily with its child process.
- Both the parent and the child processes continue execution at the instruction after the fork( ).
- For the new child process (i.e. Child Process) the return code for the fork( ) is zero.
- The nonzero process identifier of the child is returned to the parent.
- **exec( )**: After a fork( ) system call, one of the two processes typically uses the **exec( )** system call to replace the process's memory space with a new program.
- The exec( ) system call loads a binary file into memory and starts its execution.
- In this way, the two processes are able to communicate and then go their separate ways.
- **wait( ):** The parent can create more children or if the parent has nothing else to do while the child process is running then the parent process can issue a **wait( )** system call to move itself out of the Ready Queue until the child process terminates.
- The call to exec( ) overlays the process's address space with a new program or the call to exec( ) does not return control unless an error occurs.




**Program for Creating a separate process using the UNIX fork( ) system call**

```
#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);
                return 0;}                                    }
       }
       else {
              /* parent process */
              /*parent will wait for the
              child to complete */
              wait(NULL);
              printf("ChildComplete");}
```

The above C program shows the UNIX system calls fork, exec, wait. Two different processes are running copies of the same program.

- The only difference is that the value of pid for the child process is zero, while the value of pid for the parent is an integer value greater than zero (i.e. the actual pid of the child process).
- The child process inherits privileges and scheduling attributes from the parent as well as certain resources such as open files.
- The child process then overlays its address space with the UNIX command /bin/ls (used to get a directory listing) using the execlp( ) system call (execlp( ) is a version of the exec( ) system call).
- The parent waits for the child process to complete with the wait( ) system call.
- When the child process completes by either implicitly or explicitly invoking exit( ), the parent process resumes from the call to wait( ), where it completes using the exit( ) system call.

**Process Termination: exit( )**

- A process terminates when it finishes executing its final statement and asks the operating system to delete it by using the **exit( )** system call.
- The process may return a status value to its parent process via the wait( ) system call.
- All the resources of the process including physical and virtual memory, open files and I/O buffers are deallocated by the operating system.

A parent may terminate the execution of one of its children for a variety of reasons such as:

1. The child has exceeded its usage of some of the resources that it has been allocated.
2. The task assigned to the child is no longer required.
3. The parent is exiting and the operating system does not allow a child to continue if its parent terminates.

**Cascading Termination**

If a parent process terminates either normally or abnormally then all its children must also be terminated is referred as Cascading Termination. It is normally initiated by the operating system.

In Linux and UNIX systems, a process can be terminate by using the exit( ) system call providing an exit status as a parameter:

```
/* exit with status 1 */
exit(1);
```

Under normal termination, exit( ) may be called either directly (i.e. exit(1)) or indirectly ( i.e. by a return statement in main( ) ).

A parent process may wait for the termination of a child process by using the wait( ) system call. The wait( ) system call is passed a parameter that allows the parent to obtain the exit status of the child. This system call also returns the process identifier of the terminated child so that the parent can tell which of its children has terminated:

```
pid_t pid;
int status;
pid = wait(&status);
```

**Zombie process**

A process that has terminated but whose parent has not yet called wait( ) is known as a **zombie** process.

- When a process terminates, its resources are deallocated by the operating system. Its entry in the process table must remain there until the parent calls wait( ), because the process table contains the process's exit status.
- Once the parent calls wait( ), the process identifier of the zombie process and its entry in the process table are released.

**Orphan Processes**

If a parent did not invoke wait( ) and instead terminated, thereby leaving its child processes as **orphans** are called Orphan processes.

- Linux and UNIX address this scenario by assigning the init process as the new parent to orphan processes.
- The init process periodically invokes wait( ), thereby allowing the exit status of any orphaned process to be collected and releasing the orphan's process identifier and process-table entry.

## 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 single-processor system, only one process can run at a time. Others must wait until the

CPU is free and can be rescheduled.

- The CPU will sit idle and wait for a process that needs an I/O operation to complete. If the I/O operation completes then only the CPU will start executing the process. A lot of CPU time has been wasted with this procedure.
- The objective of multiprogramming is to have some process running at all times to maximize CPU utilization.
- When several processes are in main memory, if one process is waiting for I/O then the operating system takes the CPU away from that process and gives the CPU to another process. Hence there will be no wastage of CPU time.

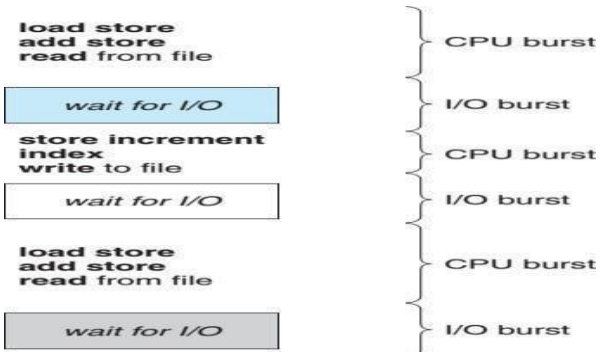
**Concepts of CPU Scheduling**

1. CPU–I/O Burst Cycle
2. CPU Scheduler
3. Preemptive Scheduling
4. Dispatcher

**CPU–I/O Burst Cycle**

Process execution consists of a **cycle** of CPU execution and I/O wait.

- Process execution begins with a **CPU burst**. That is followed by an **I/O burst.** Processes alternate between these two states.
- The final CPU burst ends with a system request to terminate execution.
- Hence the **First cycle** and **Last cycle** of execution must be CPU burst.




**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 **Short-Term Scheduler** or **CPU scheduler**.

**Preemptive Scheduling**

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

1. When a process switches from the running state to the waiting state.
   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.
   Example: when an interrupt occurs
3. When a process switches from the waiting state to the ready state.
   Example: at completion of I/O.
4. When a process terminates.

For situations 2 and 4 are considered as **Preemptive scheduling** situations. Mach OS X, WINDOWS 95 and all subsequent versions of WINDOWS are using Preemptive scheduling.

## Dispatcher

The dispatcher is the module that gives control of the CPU to the process selected by the short-term scheduler. Dispatcher function involves:

1. Switching context
2. Switching to user mode
3. Jumping to the proper location in the user program to restart that program.

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

Many criteria have been suggested for comparing CPU-scheduling algorithms:

- **CPU utilization:** CPU must be kept as busy as possible. CPU utilization can range from 0 to 100 percent. In a real system, it should range from 40 to 90 percent.
- **Throughput:** The number of processes that are completed per time unit.
- **Turn-Around Time:** It is the interval from the time of submission of a process to the time of completion. Turnaround time is the sum of the periods spent waiting to get into memory, waiting in the ready queue, executing on the CPU and doing I/O.
- **Waiting time:** It is the amount of time that a process spends waiting in the ready queue.
- **Response time:** It is the time from the submission of a request until the first response is produced. Interactive systems use response time as its measure.

**Note:** It is desirable to maximize CPU utilization and Throughput and to minimize Turn-Around Time, Waiting time and Response time.

## CPU SCHEDULING ALGORITHMS

CPU scheduling deals with the problem of deciding which of the processes in the ready queue is to be allocated to the CPU. Different CPU-scheduling algorithms are:

1. First-Come, First-Served Scheduling (FCFS)
2. Shortest-Job-First Scheduling (SJF)
3. Priority Scheduling
4. Round Robin Scheduling
5. Multilevel Queue Scheduling
6. Multilevel Feedback Queue Scheduling

**Gantt Chart** is a bar chart that is used to illustrate a particular schedule including the start and finish times of each of the participating processes.

### First-Come, First-Served Scheduling (FCFS)

In FCFS, the process that requests the CPU first is allocated the CPU first.

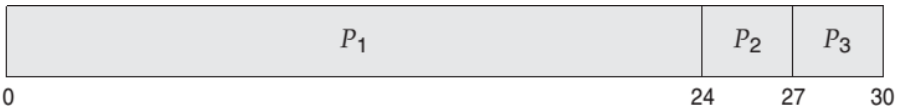
- FCFS scheduling algorithm is Non-preemptive.
- Once the CPU has been allocated to a process, it keeps the CPU until it releases the CPU.
- FCFS can be implemented by using FIFO queues.
- When a process enters the ready queue, its PCB is linked onto the tail of the queue.
- When the CPU is free, it is allocated to the process at the head of the queue.

- The running process is then removed from the queue.

**Example:1** Consider the following set of processes that arrive at time 0. The processes are arrived at in the order P1, P2, P3, with the length of the CPU burst given in milliseconds.

| Process | Burst Time |
|---|---|
| P1 | 24 |
| P2 | 3 |
| P3 | 3 |

Gantt Chart for FCFS is:



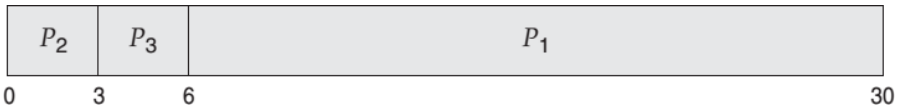

The average waiting time under the FCFS policy is often quite long.

- The waiting time is 0 milliseconds for process *P*1, 24 milliseconds for process *P*2 and 27 milliseconds for process *P*3.
- Thus, the average waiting time is (0 + 24 + 27)/3 = 17 milliseconds.

**Convoy Effect in FCFS**

Convoy effect means, when a big process is executing in CPU, all the smaller processes must have to wait until the big process execution completes. This will affect the performance of the system.

**Example:2** Let us consider the same example above but with the processes arriving in the order P2, P3, P1.




The processes coming at P2, P3, P1 the average waiting time (6 + 0 + 3)/3 = 3 milliseconds whereas the processes come in the order P1, P2, P3 the average waiting time is 17 milliseconds.

**Disadvantage of FCFS:**

FCFS scheduling algorithm is Non-preemptive, it allows one process to keep CPU for a long time. Hence it is not suitable for time sharing systems.

**Shortest-Job-First Scheduling (SJF)**

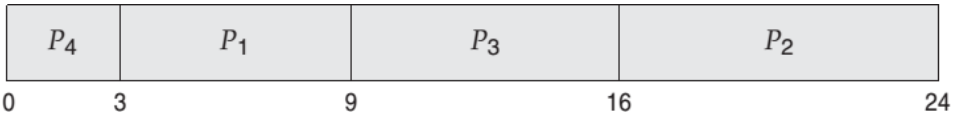
The SJF algorithm is defined as **"**when the CPU is available, it is assigned to the process that has the smallest next CPU burst**".** If the next CPU bursts of two processes are the same, FCFS scheduling is used between two processes.

SJF is also called 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.

**Example:** Consider the following processes and CPU burst in milliseconds:

| Process | Burst Time |
|---|---|
| P1 | 6 |
| P2 | 8 |
| P3 | 7 |
| P4 | 3 |

**Gantt Chart of SJF algorithm:**




**Waiting Time for Processes:**

| Process | Burst Time (ms) | Waiting Time |
|---|---|---|
| P1 | 6 | 3 |
| P2 | 8 | 16 |
| P3 | 7 | 9 |
| P4 | 3 | 0 |
| Average Waiting Time | | 7 ms |

- By looking at the above table the average waiting time by using SJF algorithm is 7ms.
- SJF gives the minimum average waiting time for a given set of processes. SJF is optimal.
- The average waiting time decreases because moving a short process before a long process decreases the waiting time of the short process more than it increases the waiting time of the long process.

**Difficulty with SJF**

The difficulty with the SJF algorithm is "knowing the length of the next CPU request". With Short-Term Scheduling, there is no way to know the length of the next CPU burst. It is not implemented practically.

**Solution for the difficulty**

One approach to this problem is to try to approximate SJF scheduling.

- We may not know the length of the next CPU burst, but we may be able to predict its value. We expect that the next CPU burst will be similar in length to the previous ones.
- By computing an approximation of the length of the next CPU burst, we can pick the process with the shortest predicted CPU burst.
- The next CPU burst is generally predicted as an **Exponential Average** of the measured lengths of previous CPU bursts.

The following formula defines the Exponential average:

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n$$

**$t_n$** be the length of the nth CPU burst (i.e. contains the most recent information).

$\tau_n$ stores the past history.

$\tau_{n+1}$ be our predicted value for the next CPU burst.

**α** controls the relative weight of recent and past history in our prediction ($0 \leq \alpha \leq 1$)

- If **α=0,** $\tau_{n+1} = \tau_n$ then **,** recent history has no effect
- If **α=1** then $\tau_{n+1} = t_n$**,** only the most recent CPU burst matters.
- If **α = 1/2**, so recent history and past history are equally weighted.

**Shortest Remaining Time First Scheduling (SRTF)**

SRTF is the preemptive SJF algorithm.

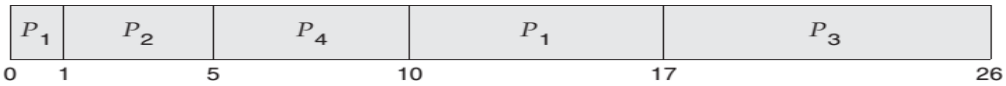
- A new process arrives at the ready queue, while a previous process is still executing.

- The next CPU burst of the newly arrived process may be shorter than the currently executing process.
- SRTF will preempt the currently executing process and execute the shortest job.

Consider the four processes with arrival times and burst times in milliseconds:

| Process | Arrival time | Burst Time (ms) |
|---|---|---|
| P1 | 0 | 8 |
| P2 | 1 | 4 |
| P3 | 2 | 9 |
| P4 | 3 | 5 |

**Gantt Chart for SRTF**




- Process P1 is started at time 0, since it is the only process in the queue.
- Process P2 arrives at time 1. The remaining time for process P1 (7 milliseconds) is larger than the time required by process P2 (4 milliseconds), so process P1 is preempted and process P2 is scheduled.
- The average waiting time **= 26/4 = 6.5 milliseconds.**

## Priority Scheduling

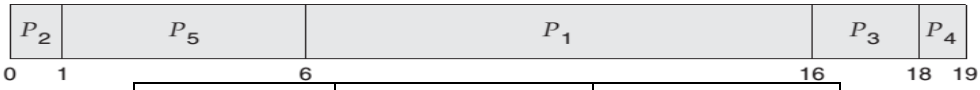
A priority is associated with each process and the CPU is allocated to the process with the highest priority. Equal-priority processes are scheduled in FCFS order.

- An SJF algorithm is a special kind of priority scheduling algorithm where small CPU bursts will have higher priority.
- Priorities can be defined based on time limits, memory requirements, the number of open files etc.

**Example:** Consider the following processes with CPU burst and Priorities. All the processes arrive at time t=0 in the same order. Low numbers are having higher priority.

| Process | Burst time (ms) | Priority |
|---|---|---|
| P1 | 10 | 3 |
| P2 | 1 | 1 |
| P3 | 2 | 4 |
| P4 | 1 | 5 |
| P5 | 5 | 2 |

**Gantt chart for Priority Scheduling:**




| Process | Burst time (ms) | Waiting Time |
|---|---|---|
| P1 | 10 | 6 |
| P2 | 1 | 0 |
| P3 | 2 | 16 |
| P4 | 1 | 18 |
| P5 | 5 | 1 |
| Average Waiting Time | | 8.2 ms |

Priority scheduling can be either **Preemptive or Non-preemptive**.
A **Preemptive Priority** Scheduling algorithm will preempt the CPU if the priority of the newly arrived process is higher than the priority of the currently running process.

**Problem: Starvation or Indefinite Blocking**

- In priority Scheduling when there is a continuous flow of higher priority processes to the ready queue then all the lower priority processes must have to wait for the CPU until all the higher priority processes execution completes.
- This leads to lower priority processes blocked from getting CPU for a long period of time. This situation is called Starvation or Indefinite blocking.
- In the worst case indefinite blocking may take years to execute the process.

**Solution: Aging**

Aging involves gradually increasing the priority of processes that wait in the system for a long time.

**Round-Robin Scheduling (RR)**

Round-Robin (RR) scheduling algorithm is designed especially for Time Sharing systems.

- RR is similar to FCFS scheduling, but preemption is added to enable the system to switch between processes.
- A small unit of time called a **Time Quantum** or **Time Slice** is defined. A time quantum is generally from 10 to 100 milliseconds in length.
- The ready queue is treated as a **Circular queue**. New processes are added to the tail of the ready queue.
- The CPU scheduler goes around the ready queue by allocating the CPU to each process for a time interval of up to 1 time quantum and dispatches the process.
- If a process CPU burst exceeds 1 time quantum, that process is preempted and is put back in the ready queue.

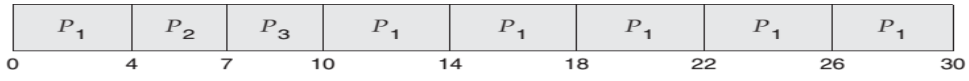
In RR scheduling one of two things will then happen.

1. The process may have a CPU burst of less than 1 time quantum. The process itself will release the CPU voluntarily. The scheduler will then proceed to the next process in the ready queue.
2. If the CPU burst of the currently running process is longer than 1 time quantum, the timer will go off and will cause an interrupt to the operating system. A context switch will be executed and the process will be put at the tail of the ready queue. The CPU scheduler will then select the next process in the ready queue.

Consider the following set of processes that arrive at time 0 and the processes are arrived at in the order P1, P2, P3 and Time Quanta=4.

| Process | Burst Time |
|---|---|
| P1 | 24 |
| P2 | 3 |
| P3 | 3 |

**Gantt chart of Round Robin Scheduling**



- If we use a time quantum of 4 milliseconds, then process *P*1 gets the first 4 milliseconds.
- Since it requires another 20 milliseconds, it is preempted after the first quantum and the CPU is given to the next process in the queue, process *P*2.
- CPU burst of Process *P*2 is 3, so it does not need 4 milliseconds then it quits before its time quantum expires. The CPU is then given to the next process *P*3.
- Once each process has received 1 time quantum, the CPU is returned to process *P*1 for an additional time quantum.

The average waiting time under the RR policy is often long.

- *P*1 waits for 6 milliseconds (10 - 4), *P*2 waits for 4 milliseconds and *P*3 waits for 7 milliseconds. Thus, the average waiting time is 17/3 = 5.66 milliseconds.

The performance of the RR algorithm depends on the size of the Time Quantum.

- If the time quantum is extremely large, the RR policy is the same as the FCFS policy.
- If the time quantum is extremely small (i.e. 1 millisecond) the RR approach can result in a large number of context switches.
- The time taken for context switch value should be a small fraction of Time quanta then the performance of the RR will be increased.

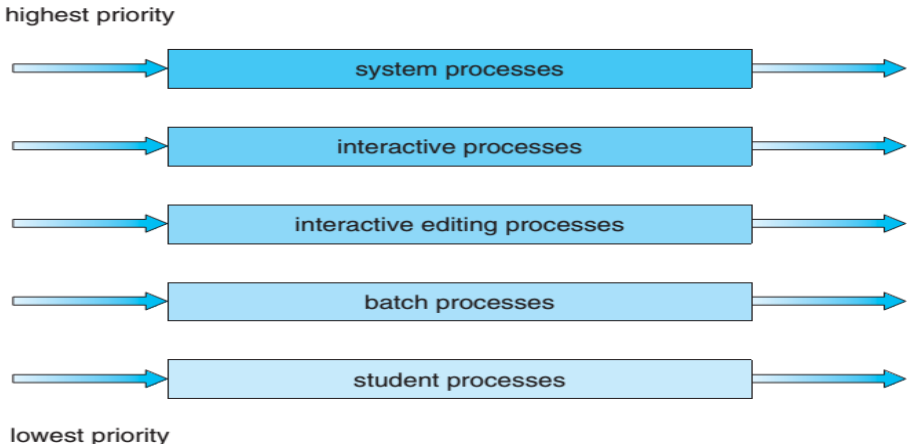
**Note:** A rule of thumb is that 80 percent of the CPU bursts should be shorter than the time quantum.

**Multi-Level Queue Scheduling (MLQ)**

In the Multilevel Queue Scheduling algorithm the processes are classified into different groups.

- A Multilevel queue scheduling partitions the ready queue into several separate queues.
- The processes are permanently assigned to one queue based on memory size, process priority or process type. Each queue has its own scheduling algorithm.

**Example:** Foreground processes have highest priority over background processes and these processes have different response times hence it needs different scheduling.




The above figure shows Multi-level queue scheduling algorithm with five queues, listed below in order of priority:

1. System processes
2. Interactive processes
3. Interactive editing processes
4. Batch processes
5. Student processes

Each queue has absolute priority over lower-priority queues.

- No lower level queue processes will start executing unless all the processes in the higher level queue are empty.
  **Example:** The interactive processes start executing only when all the processes in the system queue are empty.
- If a lower priority process is executing and a higher priority process enters into the queue then a lower priority process will be preempted and starts executing a higher priority process.
  **Example:** If a system process entered the ready queue while an interactive process was running, the interactive process would be preempted.

**Disadvantage: Starvation of Lower level queue**

The multilevel queue scheduling algorithm is inflexible.

- The processes are permanently assigned to a queue when they enter the system. Processes are not allowed to move from one queue to another queue.
- There is a chance that lower level queues will be in starvation because unless the higher level queues are empty no lower level queues will be executing.
- If at any instant of time if there is a process in higher priority queue then there is no chance that lower level process can be executed eternally.

Multilevel Feedback Queue Scheduling is used to overcome the problem of Multi-level queue scheduling.

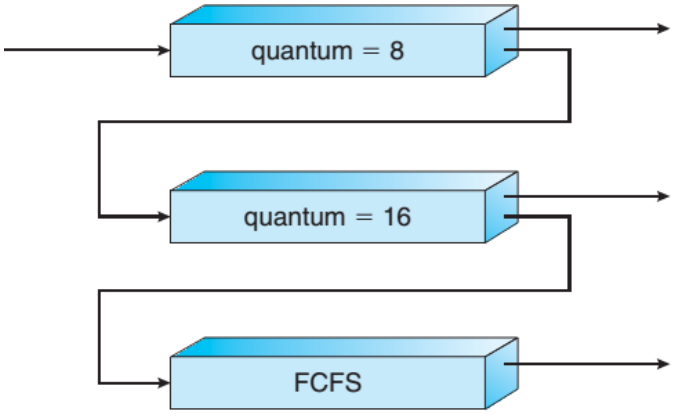
**Multilevel Feedback Queue Scheduling (MLFQ)**

Multilevel feedback queue scheduling algorithm allows a process to move between queues.

- Processes are separated according to the characteristics of their CPU bursts.
- If a process uses too much CPU time, it will be moved to a lower-priority queue.
- A process that waits too long in a lower-priority queue moved to a higher-priority queue.
- This form of aging prevents starvation.

Consider a multilevel feedback queue scheduler with three queues: queue0, queue1, queue2.

- The scheduler first executes all processes in queue0 then queue1 and then queue2.
- Only when queue and queue1 is empty, the scheduler will execute processes in queue2.
- A process that arrives for queue1 will preempt a process in queue2. A process in queue1 will in turn be preempted by a process arriving for queue0.



- A process entering the ready queue is put in queue0. A process in queue 0 is given a time quantum of 8ms. If it does not finish within this time, it is moved to the tail of queue 1.
- If queue 0 is empty, the process at the head of queue1 is given a quantum of 16ms. If it does not complete, it is preempted and is put into queue2.
- Processes in queue 2 are run on an FCFS basis but are run only when queues 0 and 1 are empty.
- This scheduling algorithm gives highest priority to any process with a CPU burst of 8ms or less. Such a process will quickly get the CPU and finish its CPU burst and go off to its next I/O burst.
- Processes that need more than 8ms but less than 24ms are also served quickly, although with lower priority than shorter processes.
- Long processes automatically sync to queue2 and are served in FCFS order with any CPU cycles left over from queues0 and queue1.

A Multi-Level Feedback queue scheduler is defined by the following parameters:

- The number of queues.
- The scheduling algorithm for each queue.
- The method used to determine when to upgrade a process to a higher priority queue.
- The method used to determine when to demote a process to a lower priority queue.
- The method used to determine which queue a process will enter when that process needs service.

## THREAD SCHEDULING

Threads can be divided into two types: Kernel level threads and User level threads.

- Kernel-level threads are being scheduled by the operating system.
- User-level threads are managed by a **Thread Library** and the kernel is unaware of them.
- User-level threads must be mapped to an associated kernel-level thread to run on a CPU

**Contention scope**

- The thread library schedules user-level threads to run on an available **Light Weight Process**. This scheme is known as **Process-Contention Scope (PCS)**. There will be a competition for the CPU among threads belonging to the same process.
- **PCS** is done according to priority. The scheduler selects the runnable thread with the highest priority to run. User-level thread priorities are set by the programmer and are not adjusted by the thread library.
- PCS will preempt the thread currently running in favor of a higher-priority thread.
- To decide which kernel-level thread to schedule onto a CPU, the kernel uses **System-Contention Scope (SCS)**. Competition for the CPU with SCS scheduling takes place among all threads in the system.
- Windows, Linux and Solaris are the systems scheduled threads using only SCS.

## MULTIPLE-PROCESSOR SCHEDULING

Scheduling process will become complex with multiple CPU structures but Load Sharing is possible with multiple CPU structures.

In multiple processor systems, we can use any available processor to run any process in the queue.

**Multiprocessor Scheduling Approaches**

There are two approaches to multiprocessing: **Asymmetric** and **Symmetric** Multiprocessing.

- In **Asymmetric Multiprocessing**, Master and Worker relationships exist. The master server is a single processor that handles the activities related to all scheduling decisions, I/O processing and other system activities. The other processors execute only user code.
- Asymmetric multiprocessing is simple because only one processor accesses the system data structures, reducing the need for data sharing.
- In **Symmetric Multiprocessing (SMP)** each processor is self-scheduling. All processes may be in a common ready queue or each processor may have its own private ready queue processes.
- Scheduling proceeds by having the scheduler for each processor examine the ready queue and select a process to execute.
- When multiple processors try to access and update a common data structure, the scheduler must be programmed carefully.
- Two separate processors do not choose to schedule the same process and that processes are not lost from the queue.

**Processor Affinity**

The Process Affinity is **"**to make a process run on the same CPU it ran on last time**"**.

- The processor cache contains the data that is most recently accessed by the process.
- If the process migrates from one processor to another processor, the contents of cache memory must be invalidated for the first processor and the cache for the second processor must be entered again.
- Because of the high cost of invalidating and re-entering caches, most SMP systems try to avoid migration of processes from one processor to another and instead attempt to keep a process running on the same processor.

Processor affinity can be implemented in two ways: Soft affinity and Hard affinity.

- **Soft affinity:** The operating system will attempt to keep a process on a single processor, but it is possible for a process to migrate between processors.
- **Hard affinity**: Some systems provide system calls that support **Hard Affinity**, thereby allowing a process to specify a subset of processors on which it may run.

**Load Balancing**

Load balancing attempts to keep the workload evenly distributed across all processors in an SMP system.

Load balancing is necessary only on systems where each processor has its own private queue of processes to execute.

There are two approaches to load balancing: **Push Migration** and **Pull Migration**.

- **Push migration:** A specific process periodically checks the load on each processor. If the task finds an imbalance then it evenly distributes the load by moving (pushing) processes from overloaded processors to idle or less-busy processors.
- **Pull migration:** It occurs when an idle processor pulls a waiting process from a busy processor.

**Multicore Processors**

In a multicore processor each core acts as a separate processor. Multicore processors may complicate scheduling issues.

- When a processor accesses memory, it spends a significant amount of time waiting for the data to become available. This waiting time is called a Memory **Stall**.
- Memory Stall may occur for several reasons for example Cache miss.
- In order to avoid memory stall, many recent hardware designs have implemented multithreaded processor cores in which two or more hardware threads are assigned to each core. That way, if one thread stalls while waiting for memory, the core can switch to another thread.

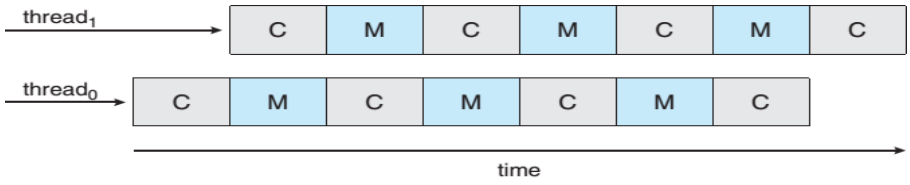



**Figure 6.11** Multithreaded multicore system.

- The execution of thread0 and the execution of thread 1 are interleaved on a dual-threaded processor core.
- From an operating-system perspective, each **Hardware Thread** appears as a **Logical Processor** that is available to run a software thread.
- Thus, on a **Dual**-threaded, **Dual**-core system, **Four** logical processors are presented to the operating system.

There are two ways to multithread a processing core: **Coarse-grained** and **Fine-grained**

**Coarse-Grained Multithreading:**

- A thread executes on a processor until a long-latency event such as a memory stall occurs.
- The processor must switch to another thread to begin execution, because of the delay caused by the long-latency event.
- The cost of switching between threads is high, since the instruction pipeline must be flushed before the other thread can begin execution on the processor core.
- Once this new thread begins execution, it begins filling the pipeline with its instructions.

**Fine-grained (or) Interleaved Multithreading:**

- Thread switching done at the boundary of an instruction cycle.
- The architectural design of fine-grained systems includes logic for thread switching. As a result, the cost of switching between threads is small.