Module 2

PROCESS MANAGEMENT

Process

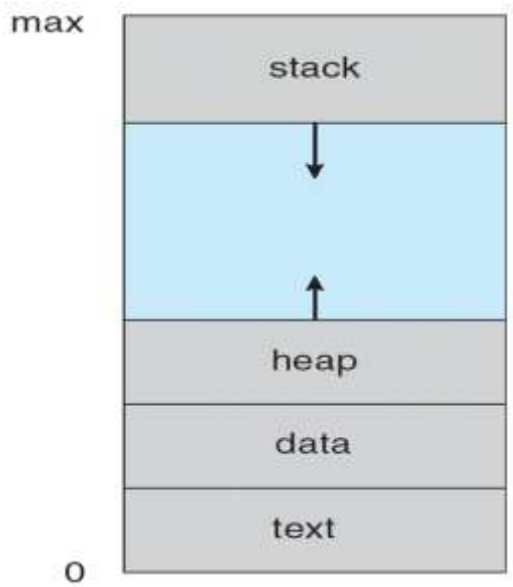
A program is a set of statements or instructions which collectively implements a task.

A process is a program being executed.

Program resides in secondary memory.

Process resides in primary memory.

The memory allocated by the operating system for a process consists of four parts as shown in following figure.



The text part contains instructions or statements of the process.

Data part contains global variables.

Stack contains temporary data like function parameters, return values and so on.

Heap part contains the objects that are dynamically created during execution of process.

Process States

A process at any particular time will be in any one of the following states

1) New - The process is about to be created but not yet created. It is the program that is present in secondary memory that will be picked up by the Operating System to create the process.

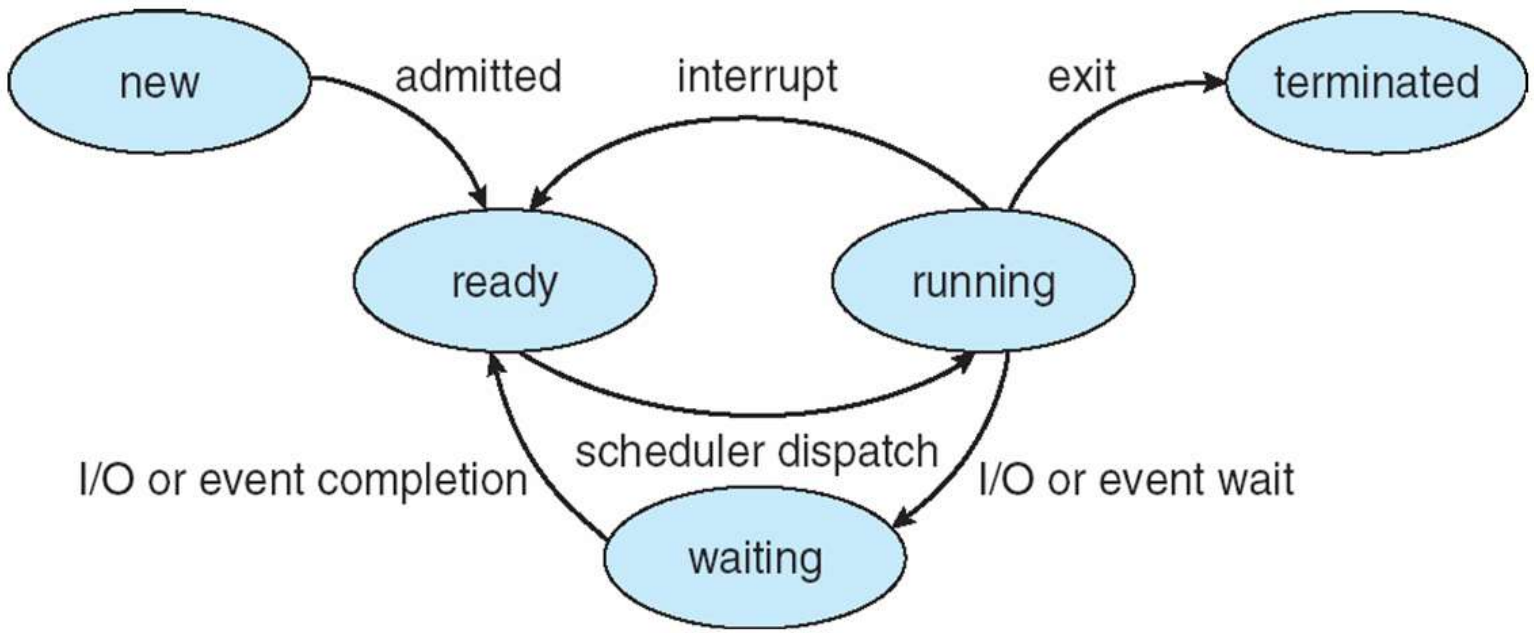
2) Ready - The process is loaded into the main memory. The process here is ready to run and is waiting to get the CPU time for its execution.

3) Running – The process is executing.

4) Waiting – The process requests access to I/O or needs input from the user. The process continues to wait in the main memory and does not require CPU.

5) Exit – The execution of process is completed. The resources allocated to the process will be released or deallocated.

The change in state of a process is indicated through the following diagram



When the process is ready for execution on allocation of CPU then the process moves from new state to ready state.

When CPU is allocated to the process then the process moves from ready state to running state.

During execution of the process:

1) If the process is completed then the process moves from running state to exit state.

2) If any i/o operation is requested or the process waits for an event then the process moves from running state to waiting state.

3) If the allocated time is over or an interrupt occurs then the process moves from running state to ready state.

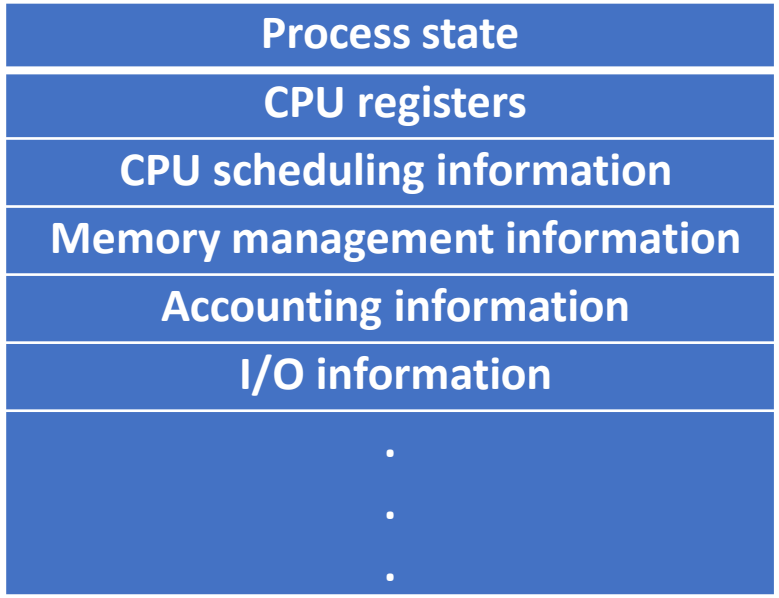
When the requested i/o operation is completed or the event is completed then the process moves from waiting state to ready state.

Process Control Block (PCB)

Operating system creates a separate process control block for each process that is running in the computer system.

Process control block contains information about the process.

The information stored in the process control block of a process is:



Process state: indicates current state of the process.

CPU registers: indicates the values stored in the registers.

CPU scheduling information: indicates scheduling information like priority of process.

Memory management information: indicates the starting and ending positions or addresses of process in the RAM.

Accounting information: indicates process id, amount of CPU time required and so on.

I/O status information: indicates the list of i/o devices allocated to the process, the list of open files and so on.

Context switch

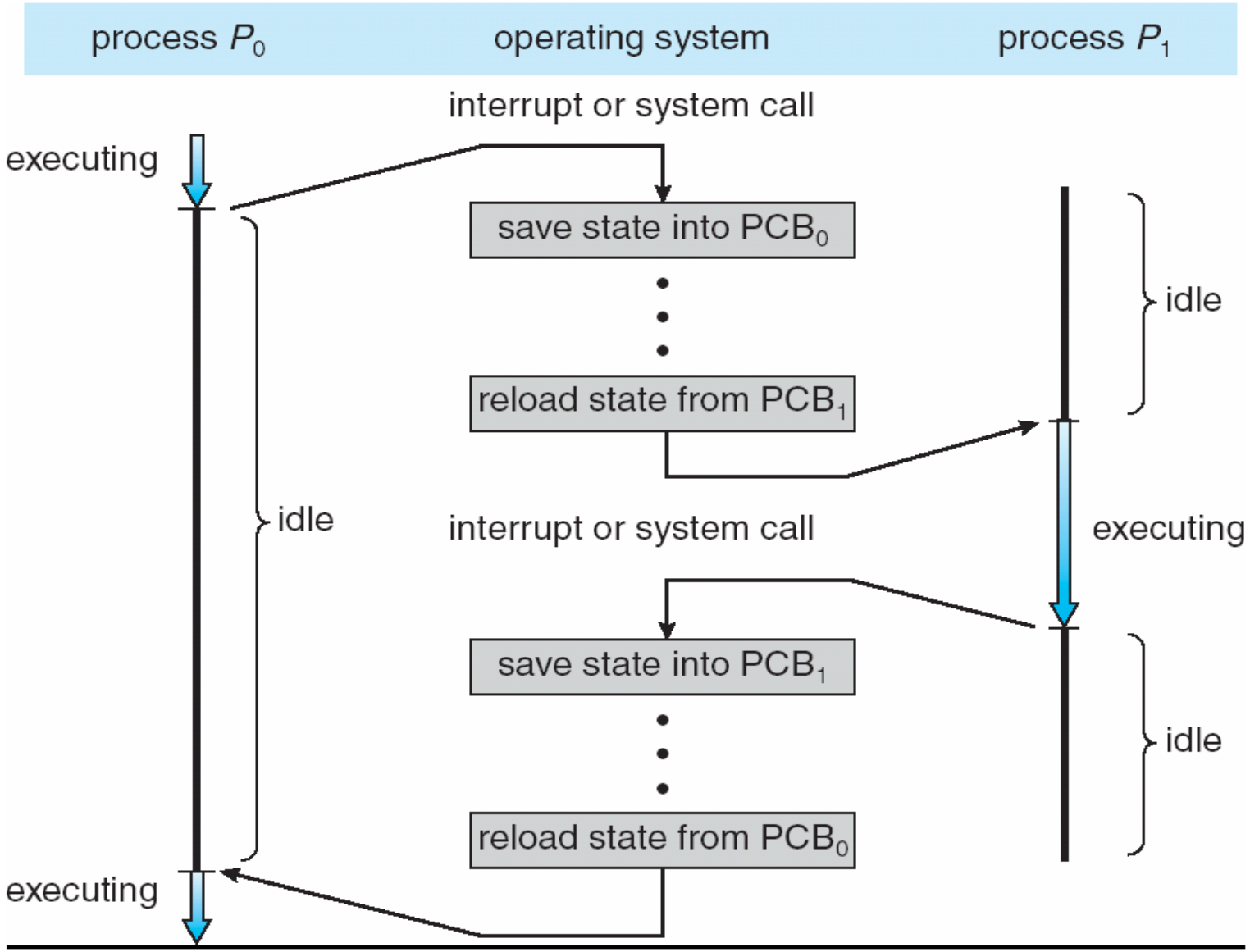
Context switch is switching the CPU from one process to other process.

Operating system switches the CPU from the current process to another process when:

1) The execution of current process is completed
2) The execution of current process is suspended due to some I/O operation request
3) The allotted time for the current process is over

When the Operating System switches the CPU from one process to other process then the Operating System has to update the PCBs of the processes.

The following diagram shows state change in process control block when context switch occurs.


process P_0
operating system
process P_1
interrupt or system call
executing
save state into PCB_0
reload state from PCB_1
idle
idle
interrupt or system call
executing
save state into PCB_1
reload state from PCB_0
idle
executing

Initially CPU is allocated to process P_0.

While executing process P_0, if process P_0 invokes a system call or requests any i/o operation or an interrupt occurs then

1) the execution of process P_0 is suspended
2) the state of process P_0 is saved into PCB_0
3) the state of process P_1 is reloaded from PCB_1
4) the CPU is allocated to process P_1.

While executing process P_1, if process P_1 invokes a system call or requests any i/o operation or an interrupt occurs then

1) the execution of process P_1 is suspended
2) the state of process P_1 is saved into PCB_1
3) the state of process P_0 is reloaded from PCB_0
4) the CPU is allocated to process P_0.

Process Scheduling

To increase the utilization of CPU, the operating system loads a number of programs at a time into RAM.

When number of programs are ready for execution then the operating system has to decide an order for executing the programs (i.e. the operating system has to schedule the execution of programs).

Scheduling queues

Operating system maintains two types of queues

1) Ready queue
2) Device queues

Ready queue

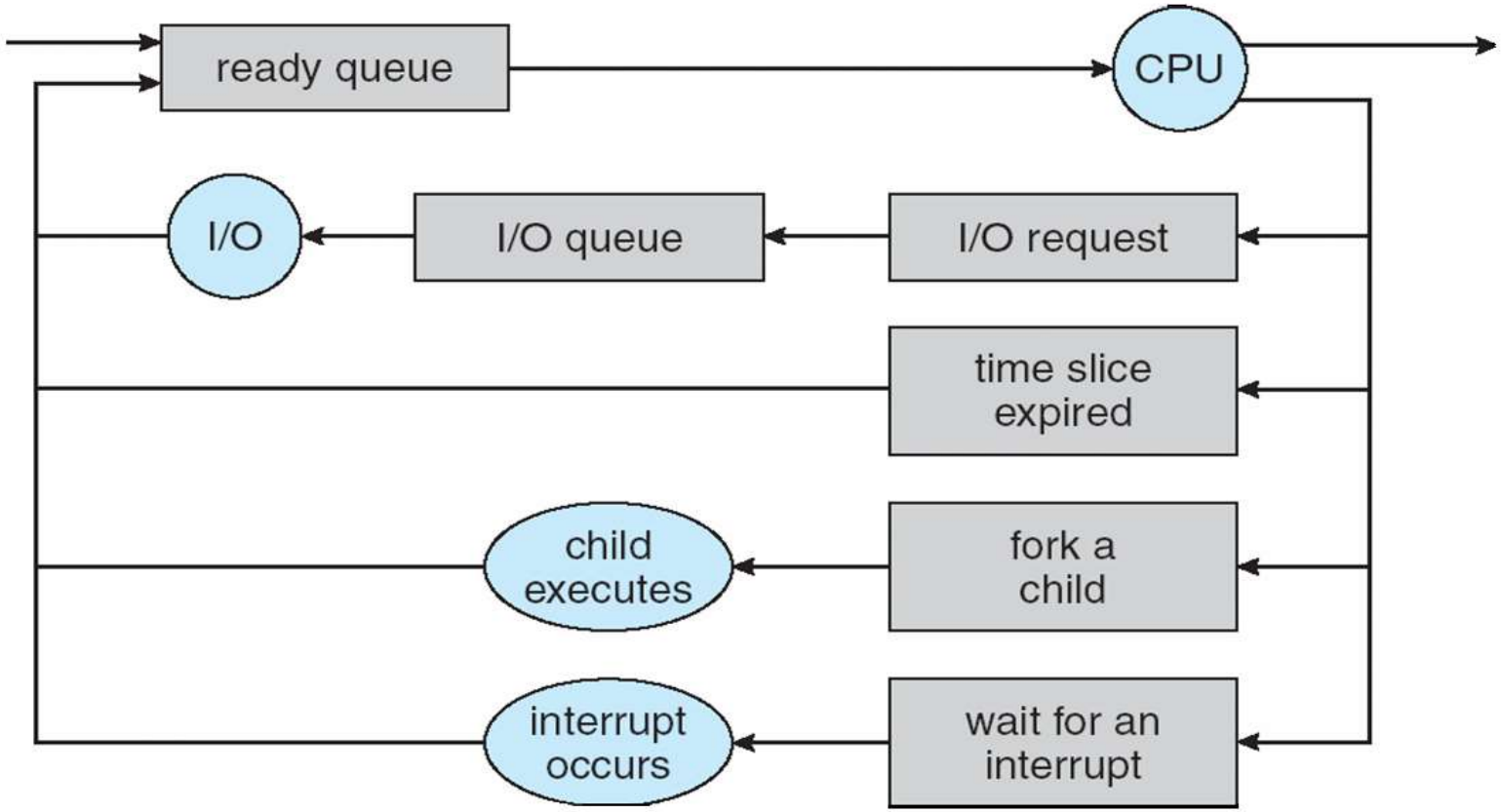
The ready queue contains the PCBs of processes that are ready for execution.

Device queue

A device queue is maintained for each device. The device queue of a device contains the PCBs of the processes that are waiting for that device.

Queuing diagram

The queuing diagram shows how a process moves between different queues during its life time.



In the queuing diagram, each rectangle represents a queue and each circle represents a resource.

When a process enters into the system then it is put into ready queue.

A process waits in the ready queue until the CPU is allocated to the process.

When CPU is allocated to the process then the execution of the process begins.

During execution of the process:

1) **The process may request for any i/o operation.**

In this case, execution of the process is suspended and it is put into device queue of the device for which it made the request.

The process waits in device queue till the completion of the i/o operation.

After the completion of i/o operation, the process is put into the ready queue.

2) **The allocated time slice is completed.**

In this case, execution of the process is suspended and is put into the ready queue.

3) **The process may create a child process.**

In this case, execution of the process is suspended and the process waits for the completion of child process.

After completion of child process, the process is put into the ready queue.

4) **An interrupt may be raised.**

In this case, execution of the process is suspended and the process waits for completion of processing of the interrupt.

After processing the interrupt, the process is put into ready queue.

Schedulers

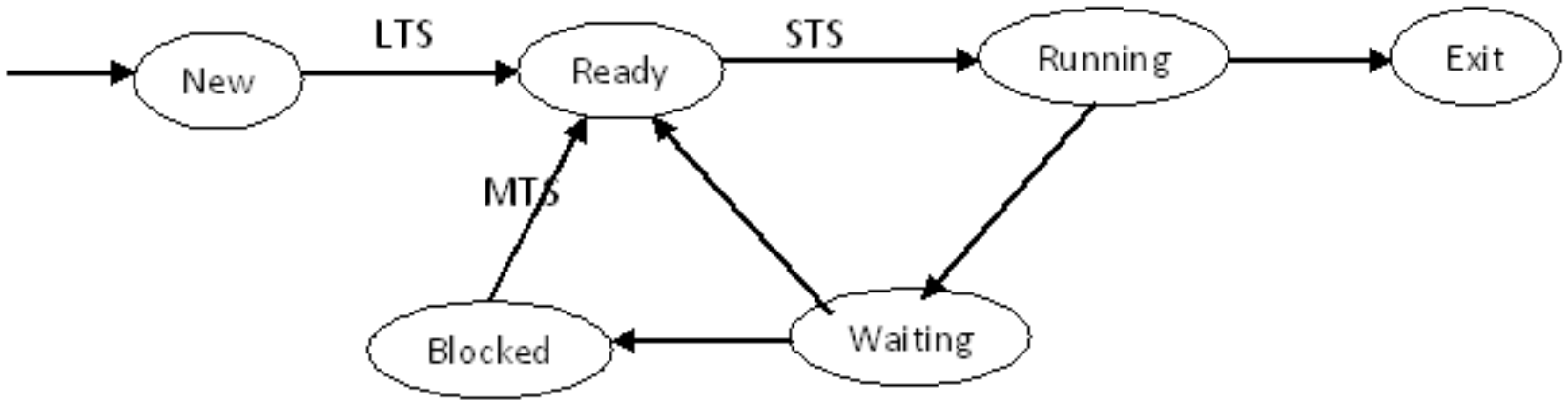
A process moves around different queues during its life time.

The operating system uses different types of schedulers to select processes form these queues.

Different schedulers used by the operating system are:

1) Long Term Scheduler (LTS)
2) Medium Term Scheduler (MTS)
3) Short Term Scheduler (STS) or CPU scheduler

The following process state diagram shows when the operating system activates these schedulers.



When a process requests any i/o operation during its execution then the process moves to the waiting state.

A waiting process is in the RAM.

When number of processes in the RAM are in waiting state then the operating system moves some of the waiting processes from RAM to hard disk in order to load new processes into RAM.

When a waiting process is moved from RAM to hard disk then the process is said to be in the blocked state.

After completion of the i/o operation, the process goes to the ready state from either the waiting or the blocked state.

Long term Scheduler

Long term scheduler selects one process (program) from the list of new processes (programs) in the hard disk and loads that process into RAM.

Medium term scheduler

Medium term scheduler selects one process from the list of waiting processes in the hard disk and loads that process into RAM.

Short term scheduler or CPU scheduler

Short term scheduler selects one process from the ready queue and allocates the CPU to that process.

CPU scheduler uses a **Dispatcher** module.

The Dispatcher module switches the CPU to the process selected from the ready queue.

The time required to switch the CPU to the selected process is called Dispatching Latency.

Short term scheduler uses various scheduling algorithms (CPU scheduling algorithms) for selecting a process from the ready queue.

The CPU scheduling algorithms are divided into two categories

1) Preemptive
2) Non-preemptive

In preemptive scheduling, the CPU can be switched from current process to other process forcibly.

In non-preemptive scheduling, the CPU cannot be switched from current process to other process until the current process releases the CPU.

Scheduling Criteria

Parameters used to evaluate the performance of CPU scheduling algorithms.

The different scheduling criteria are:

CPU utilization: the percentage of time for which the CPU is busy.

Throughput: the number of processes completed per unit time.

Turnaround time: difference between the time at which the process has arrived into system and the time at which the process has completed its execution.

turnaround time=completion time-arrival time

Waiting time: the sum of periods for which the process is waiting in the ready queue.

waiting time=turnaround time-burst time

Response time: difference between the time at which the process has arrived into system and the time at which the first response has come out from the process.

A good scheduling algorithm should maximize CPU utilization, throughput and minimize turnaround time, waiting time and response time.

CPU scheduling algorithms

1) First Come First Serve (FCFS)
2) Shortest Job First (SJF)
3) Priority
4) Round Robin (RR)
5) Multilevel Queue
6) Multilevel Feedback Queue

First Come First Serve (FCFS) scheduling algorithm

FCFS is non-preemptive scheduling algorithm.

With FCFS scheduling, the processes are executed in the order in which they enter into the system.

Consider the following set of processes

Process	Burst time	Arrival time
P1	8	0
P2	5	0
P3	3	0
P4	6	0

The order of execution of these processes with FCFS is indicated with following Gantt chart

Gantt chart:

Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	8-0=8	8-8=0
P2	5	0	13-0=13	13-5=8
P3	3	0	16-0=16	16-3=13
P4	6	0	22-0=22	22-6=16

The average waiting time is (0+8+13+16)/4=9.25

Ex:

Process	Burst time	Arrival time
P1	8	0
P2	5	1
P3	3	2
P4	6	4

The order of execution of these processes with FCFS is indicated with following Gantt chart

Gantt chart:

Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	8-0=8	8-8=0
P2	5	1	13-1=12	12-5=7
P3	3	2	16-2=14	14-3=11
P4	6	4	22-4=18	18-6=12

The average waiting time is (0+7+11+12)/4=7.5

Advantages:

1) Simple and easy to implement.

Disadvantages:

1) Not suitable for time sharing operating systems.
2) Average waiting time is high.

Shortest Job First (SJF) scheduling algorithm

SJF has two versions: preemptive and non-preemptive.

With SJF algorithm, the process with least burst time is executed first.

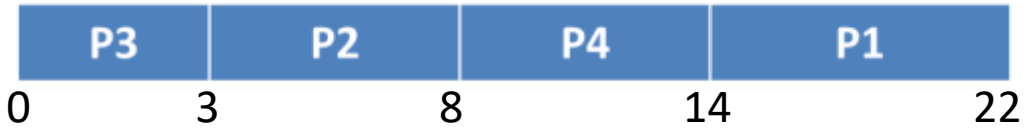
If the burst time of two or more processes is same then the processes are executed in FCFS order.

Non-preemptive SJF

Process	Burst time	Arrival time
P1	8	0
P2	5	0
P3	3	0
P4	6	0

The order of execution of these processes with non-preemptive SJF is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	22-0=22	22-8=14
P2	5	0	8-0=8	8-5=3
P3	3	0	3-0=3	3-3=0
P4	6	0	14-0=14	14-6=8

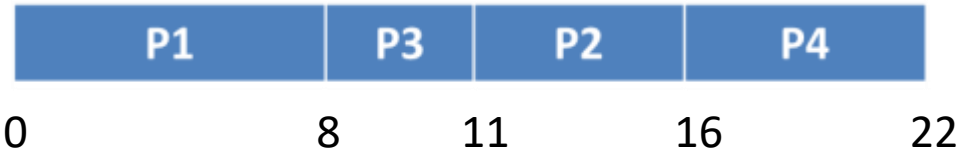
The average waiting time is (14+3+0+8)/4=6.25

Ex:

Process	Burst time	Arrival time
P1	8	0
P2	5	1
P3	3	2
P4	6	4

The order of execution of these processes with non-preemptive SJF is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	8-0=8	8-8=0
P2	5	1	16-1=15	15-5=10
P3	3	2	11-2=9	9-3=6
P4	6	4	22-4=18	18-6=12

The average waiting time is (0+10+6+12)/4=7

Preemptive SJF

With preemptive SJF, current process is allowed to execute till the arrival of next process.

At the arrival of next process, CPU is allocated to the process with shortest remaining burst time.

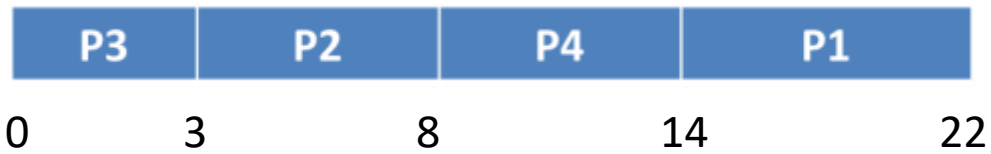
Another name of preemptive SJF is “Shortest Remaining Time First” (SRTF).

For example, consider the following set of processes

Process	Burst time	Arrival time
P1	8	0
P2	5	0
P3	3	0
P4	6	0

The order of execution of these processes with preemptive SJF is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	22-0=22	22-8=14
P2	5	0	8-0=8	8-5=3
P3	3	0	3-0=3	3-3=0
P4	6	0	14-0=14	14-6=8

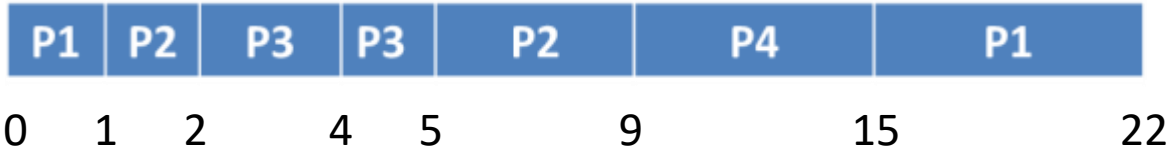
The average waiting time is (14+3+0+8)/4=6.25

Ex:

Process	Burst time	Arrival time
P1	8	0
P2	5	1
P3	3	2
P4	6	4

The order of execution of these processes with preemptive SJF is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	22-0=22	22-8=14
P2	5	1	9-1=8	8-5=3
P3	3	2	5-2=3	3-3=0
P4	6	4	15-4=11	11-6=5

The average waiting time is (14+3+0+5)/4=5.5

Advantages:

Compared to FCFS, average waiting time is less.

Disadvantages:

It can be used only when the burst times of processes are known in advance.

Generally, the burst times of processes are not available.

Priority scheduling algorithm

Priority scheduling also has two versions: preemptive and non-preemptive.

With priority algorithm, the process with highest priority is executed first.

If the priority of two or more processes is same then the processes are executed in FCFS order.

The priorities of processes are generally indicated as 1, 2, 3 and so on.

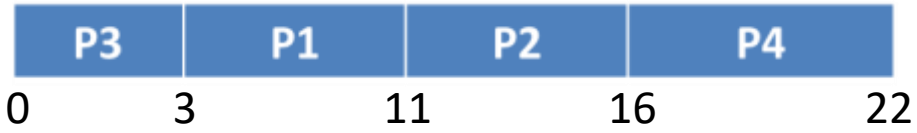
Lower number indicates highest priority.

Non-preemptive Priority

Process	Burst time	Arrival time	Priority
P1	8	0	2
P2	5	0	3
P3	3	0	1
P4	6	0	4

The order of execution of these processes with non-preemptive Priority is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	11-0=11	11-8=3
P2	5	0	16-0=16	16-5=11
P3	3	0	3-0=3	3-3=0
P4	6	0	22-0=22	22-6=16

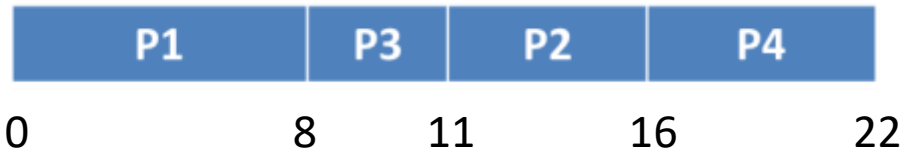
The average waiting time is (3+11+0+16)/4=7.5

Ex:

Process	Burst time	Arrival time	Priority
P1	8	0	2
P2	5	1	3
P3	3	2	1
P4	6	4	4

The order of execution of these processes with non-preemptive Priority is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	8-0=8	8-8=0
P2	5	1	16-1=15	15-5=10
P3	3	2	11-2=9	9-3=6
P4	6	4	22-4=18	18-6=12

The average waiting time is (0+10+6+12)/4=7

Preemptive Priority

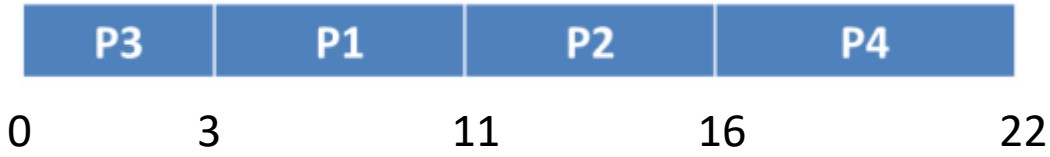
With Preemptive Priority, current process is allowed to execute until the arrival of next process.

At the arrival of next process, CPU is allocated to the process with highest priority.

Process	Burst time	Arrival time	Priority
P1	8	0	2
P2	5	0	3
P3	3	0	1
P4	6	0	4

The order of execution of these processes with preemptive Priority is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	11-0=11	11-8=3
P2	5	0	16-0=16	16-5=11
P3	3	0	3-0=3	3-3=0
P4	6	0	22-0=22	22-6=16

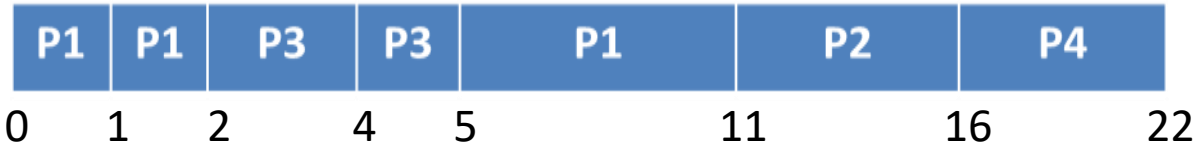
The average waiting time is (3+11+0+16)/4=7.5

Ex:

Process	Burst time	Arrival time	Priority
P1	8	0	2
P2	5	1	3
P3	3	2	1
P4	6	4	4

The order of execution of these processes with preemptive Priority is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	11-0=11	11-8=3
P2	5	1	16-1=15	15-5=10
P3	3	2	5-2=3	3-3=0
P4	6	4	22-4=18	18-6=12

The average waiting time is (3+10+0+12)/4=6.25

Disadvantages:

A process may continuously wait for the CPU. This situation is called starvation.

If there is a continuous flow of higher priority processes into the system then the lower priority processes will never get the CPU.

So, the lower priority processes will wait continuously.

A solution to the problem of starvation is aging.

Aging is increasing the priority of processes which have been waiting for long time.

Round Robin (RR) scheduling algorithm

Round robin algorithm is designed for time sharing operating systems.

RR is similar to FCFS.

RR is preemptive scheduling algorithm.

A time quantum or time slice is used.

The time quantum is generally from 10 to 100 milliseconds.

With RR, the processes are executed in FCFS order and each process is allowed to execute for the time which is specified by quantum time.

If the process is completed within the time specified by quantum time then it will be taken out from the ready queue.

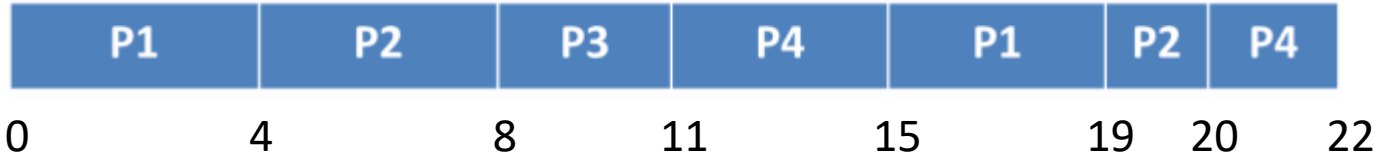
Otherwise, it will be added at the end of ready queue.

Process	Burst time	Arrival time
P1	8	0
P2	5	0
P3	3	0
P4	6	0

quantum time=4

The order of execution of these processes with RR is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	19-0=19	19-8=11
P2	5	0	20-0=20	20-5=15
P3	3	0	11-0=11	11-3=8
P4	6	0	22-0=22	22-6=16

The average waiting time is (11+15+8+16)/4=12.5

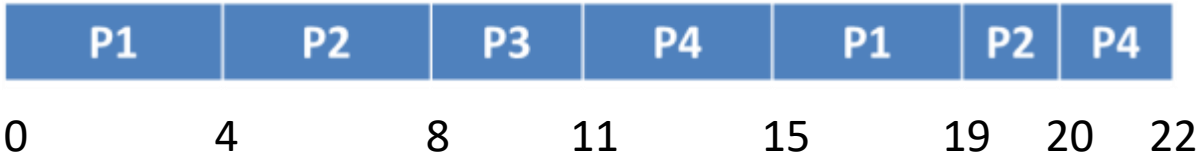
Ex:

Process	Burst time	Arrival time
P1	8	0
P2	5	1
P3	3	2
P4	6	4

Quantum time=4

The order of execution of these processes with RR is indicated with following Gantt chart

Gantt chart:



Process	Burst time	Arrival time	Turnaround time	Waiting time
P1	8	0	19-0=19	19-8=11
P2	5	1	20-1=19	19-5=14
P3	3	2	11-2=9	9-3=6
P4	6	4	22-4=18	18-6=12

The average waiting time is (11+14+6+12)/4=10.75

Advantages:

1) All processes are given equal priority.

Disadvantages:

1) The average waiting time is high.

2) If quantum time is less then more number of context switches will occur. More number of context switches leads to wastage of time.

3) If quantum time is high then the processes have to wait for more time.

Multilevel Queue Scheduling

In multilevel queue scheduling, number of ready queues are maintained.

Initially, the processes are distributed to ready queues based on some property of processes like burst time, priority and so on.

As an example, the processes with small burst time are placed in first ready queue, the processes with larger burst time are placed in last ready queue.

Different scheduling algorithms can be used to execute the processes in different queues.

Initially, CPU is allocated to ready queue1 and the processes in ready queue1 are executed in the order specified by corresponding scheduling algorithm.

After completion of all processes in ready queue1, CPU is allocated to ready queue2.

The processes in ready queue2 are executed in the order specified by corresponding scheduling algorithm.

After completion of all processes in ready queue2, CPU is allocated to ready queue3.

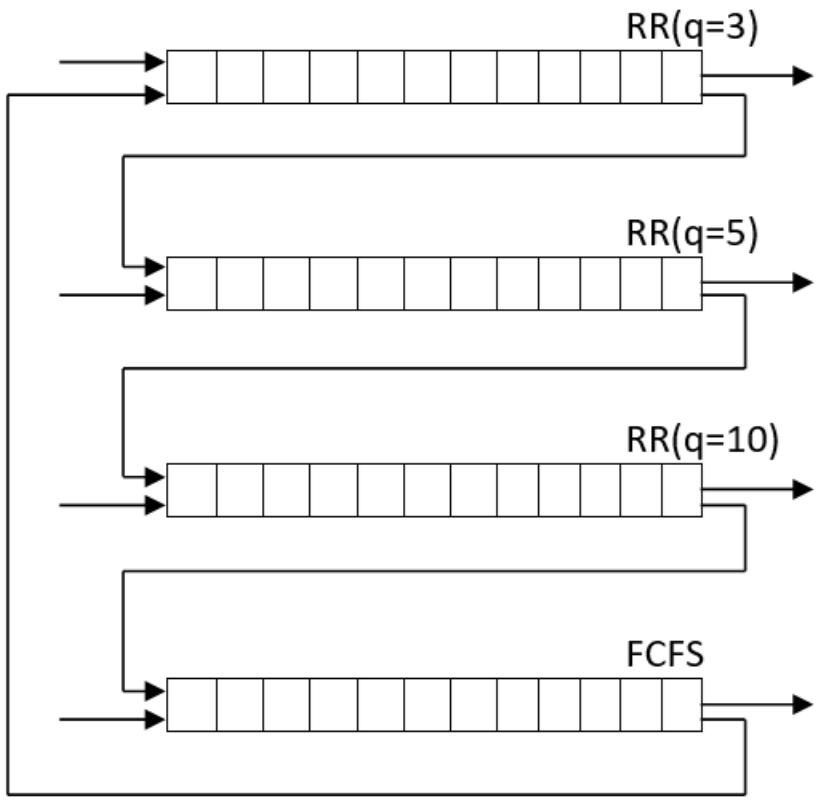
This procedure is repeated till the last queue is reached.

Priority will be given to the processes in higher level queues.

While executing any process in ready queue2, if any new process arrives into ready queue1 then the process in ready queue2 is preempted and the CPU is switched to the process arrived into ready queue1.

Similarly, while executing any process in ready queue3, if any new process arrives into either ready queue1 or ready queue2 then the process in ready queue3 is preempted and the CPU is switched to the process arrived into ready queue1 or ready queue2.

Multilevel Feedback Queue Scheduling



In multilevel feedback queue scheduling, number of ready queues are maintained.

Initially, all processes are placed in ready queue1.

Different scheduling algorithms can be used to execute processes in different queues.

Initially CPU is allocated to ready queue1.

The processes in ready queue1 are executed in the order specified by corresponding scheduling algorithm.

After completion of all processes in ready queue1, the CPU is allocated to ready queue2.

The processes in ready queue2 are executed in the order specified by corresponding scheduling algorithm.

After completion of all processes in ready queue1 and ready queue2, the CPU is allocated to ready queue3.

This procedure is repeated till the last ready queue is reached.

Priority will be given to the processes in higher level queues.

While executing any process in ready queue2, if any new process arrives into ready queue1 then the process in ready queue2 is preempted and the CPU is switched to the process arrived into ready queue1.

Similarly, while executing any process in ready queue3, if any new process arrives into either ready queue1 or ready queue2 then the process in ready queue3 is preempted and the CPU is switched to the process arrived into ready queue1 or ready queue2.

If a process in ready queue1 is not completed then it will be moved to ready queue2.

If a process in ready queue2 is not completed then it will be moved to ready queue3.

If a process in last ready queue is not completed then it will be moved to ready queue1.

Operations on Processes

There are two basic operations on processes:

1) Process creation
2) Process termination

Process Creation

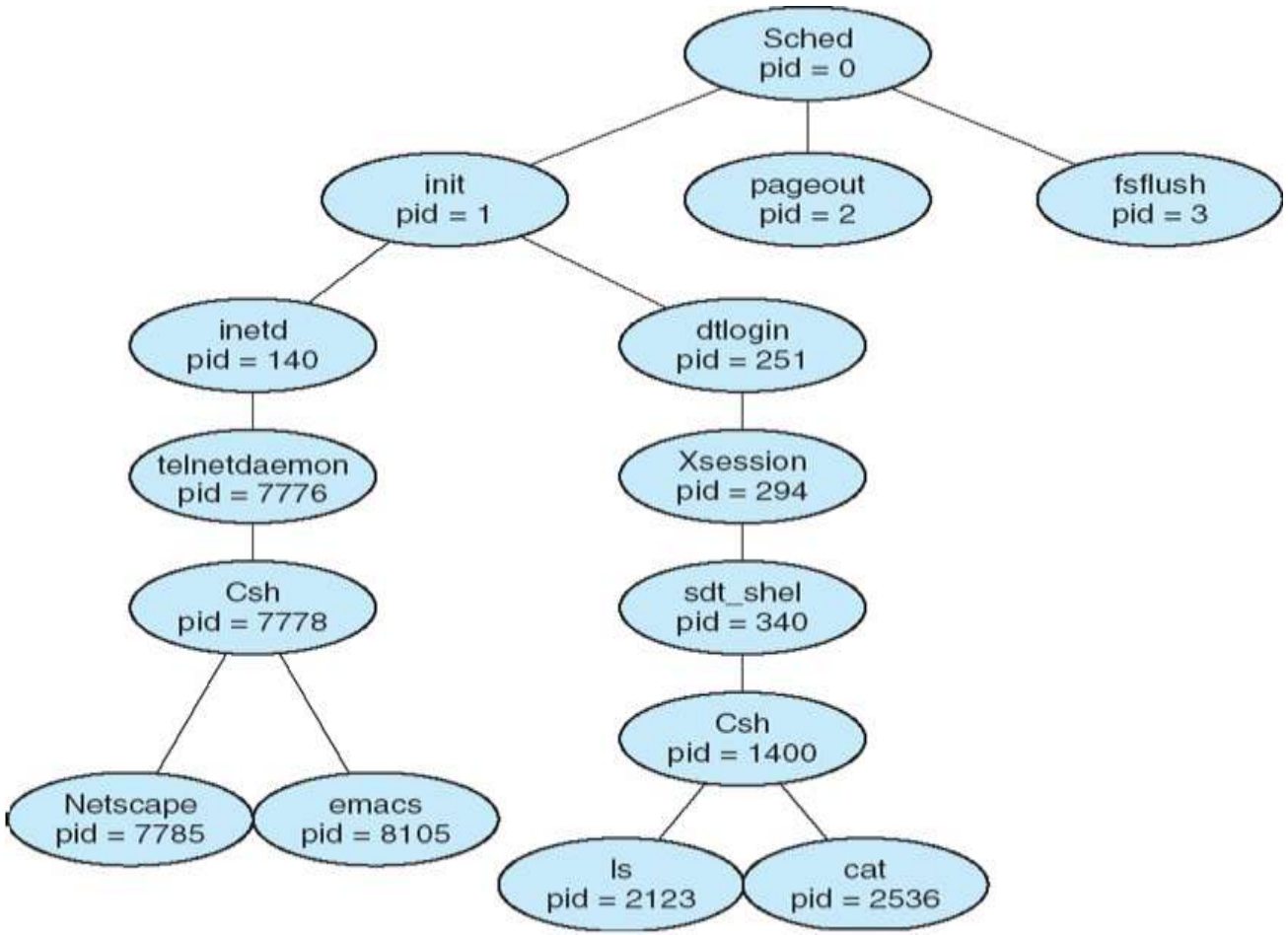
A process may create several new processes during its execution.

The process which creates new processes is called the parent process and the created processes are called the child processes.

Each child process may create other processes.

This creation leads to formation of a tree of processes.

Each process is associated with a unique integer number called process identifier which is used to identify the processes.


Sched
pid = 0
init
pid = 1
pageout
pid = 2
fsflush
pid = 3
inetd
pid = 140
dtlogin
pid = 251
telnetdaemon
pid = 7776
Xsession
pid = 294
Csh
pid = 7778
sdt_shel
pid = 340
Csh
pid = 1400
Netscape
pid = 7785
emacs
pid = 8105
ls
pid = 2123
cat
pid = 2536

Each process requires some resources.

A child process obtains its required resources in any one of the following ways:

1) Directly from the operating system
2) From its parent process

The parent process has to distribute some resources and share some resources among its child processes.

In addition to resources, the parent process may pass some data to its child processes.

For example, if a child process is created for displaying an image file on the monitor then the parent process has to pass the address of file to the child process.

The child process may be a duplicate of the parent process (child has the same program and data as parent) or the child has a new program.

When a parent process creates a child process then the parent and child processes can execute concurrently or the parent process waits for the completion of some or all of its child processes.

In UNIX operating system, the fork() system call is used to create a new process.

Fork() System Call

Fork() system call is used for creating a new process.

The process which invokes the fork() system call is called the parent process.

The newly created process is called the child process.

Both processes (parent and child) will run concurrently.

After a new child process is created, both processes will execute the next instruction following the fork() system call.

Separate copy of the variables is maintained in parent and child processes.

Changes made to the values of variables by parent process will not be reflected in the child process and vice versa.

Fork system call takes no parameters and returns an integer value.

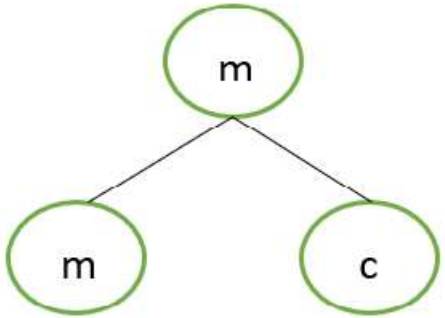
Below are different values returned by fork().

Negative Value: creation of a child process was unsuccessful.
Zero: returned to the newly created child process.
Positive value: returned to parent process. The value contains process ID of newly created child process.

Predict the output of the following program

```
#include<stdio.h>
#include<sys/types.h>
#include<unistd.h>
int main()
{
        fork();
        printf("Hello world!\n");
        return 0;
}
```

Process hierarchy



Output:

```
Hello world!
Hello world!
```

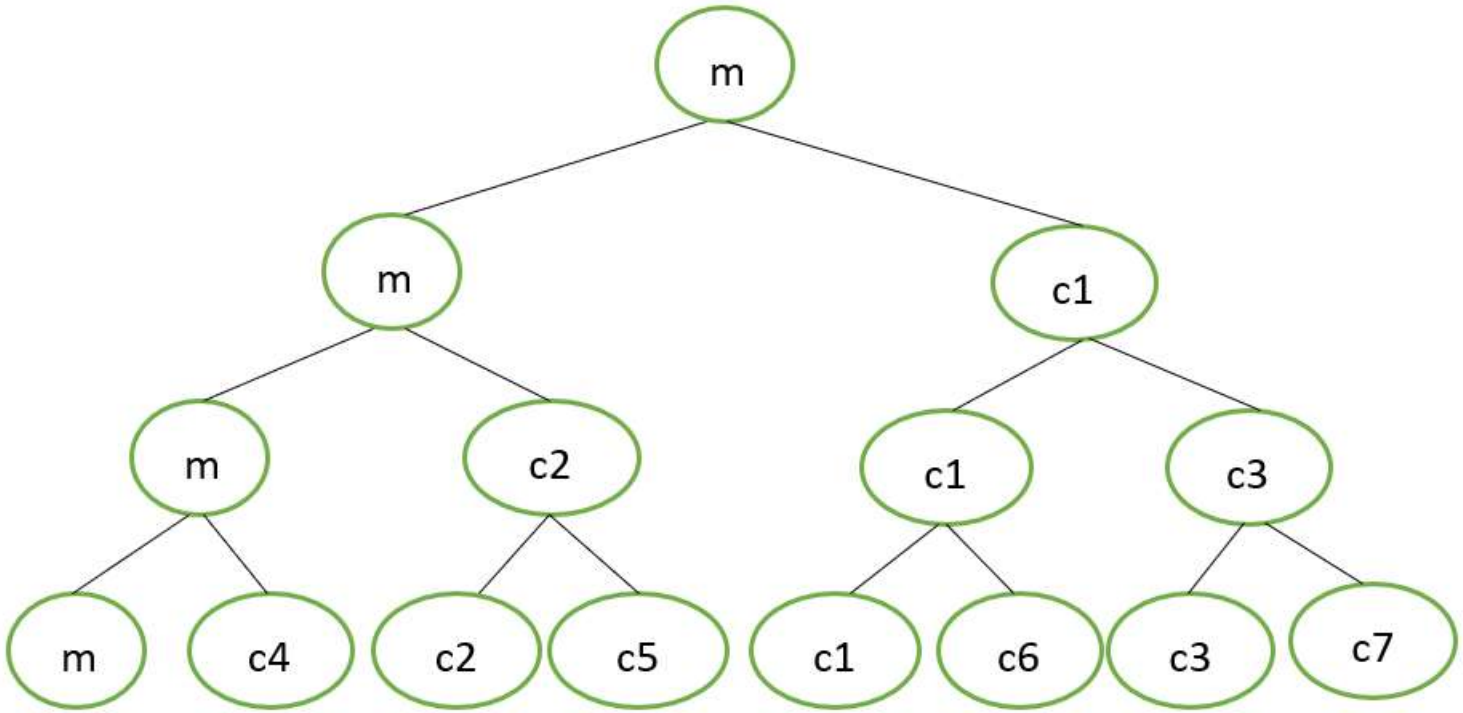
Calculate the number of times hello is printed

```
#include<stdio.h>
#include<sys/types.h>
#include<unistd.h>
int main()
{
        fork();
        fork();
        fork();
        printf("hello\n");
        return 0;
}
```

Output:

```
hello
hello
hello
hello
hello
hello
hello
hello
```

Process hierarchy



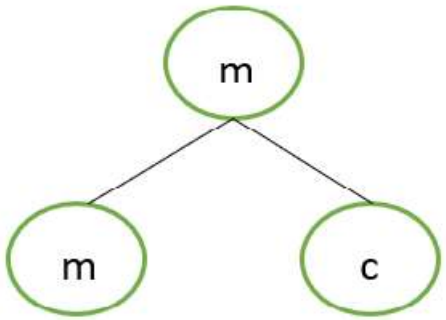
Predict the output of the following program

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

void forkexample()
{
        if (fork() == 0)
                printf("Hello from Child!\n");

        else
                printf("Hello from Parent!\n");
}
int main()
{
        forkexample();
        return 0;
}
```

Process hierarchy



Output:

```
Hello from Child!
Hello from Parent!

(or)

Hello from Parent!
Hello from Child!
```

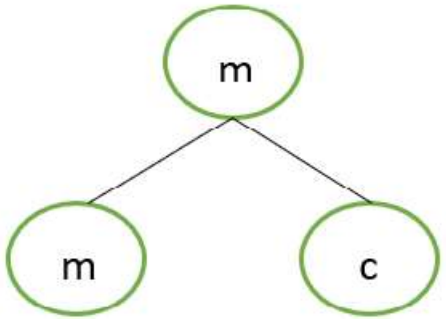
Predict the output of the following program

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

void forkexample()
{
        int x = 1;

        if (fork() == 0)
                printf("Child has x = %d\n", ++x);
        else
                printf("Parent has x = %d\n", --x);
}
int main()
{
        forkexample();
        return 0;
}
```

Process hierarchy



Output:

```
Parent has x = 0
Child has x = 2

(or)

Child has x = 2
Parent has x = 0
```

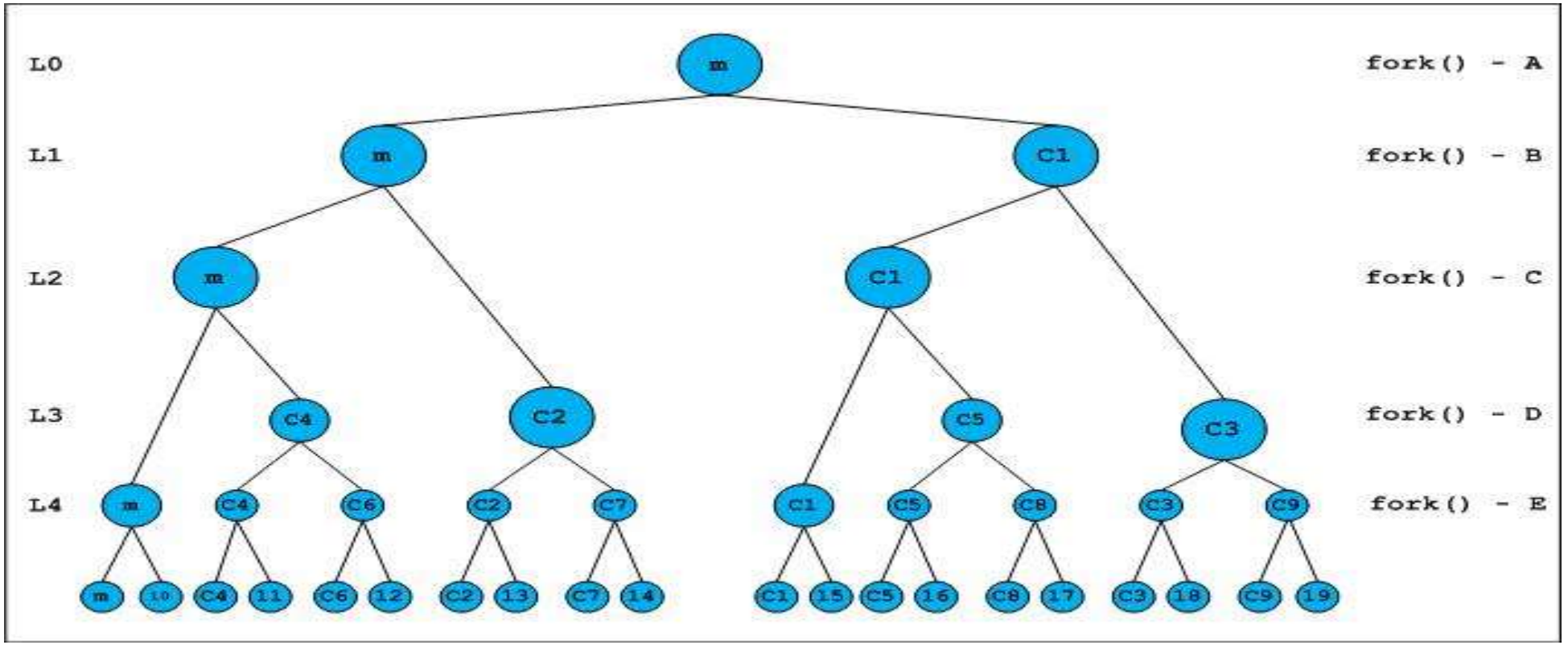
Predict output of below program

```
#include<stdio.h>
#include<sys/types.h>
#include<unistd.h>
int main()
{
        fork();
        ((fork() && fork()) || fork());
        fork();

        printf("forked\n");
        return 0;
}
```

```
#include<stdio.h>
int main()
{
        fork(); /* A */
        (( fork()  /* B */ && fork()  /* C */ ) ||  fork(); /* D */ )
        fork(); /* E */
        printf("forked\n");
        return 0;
}
```

Process hierarchy



Output:

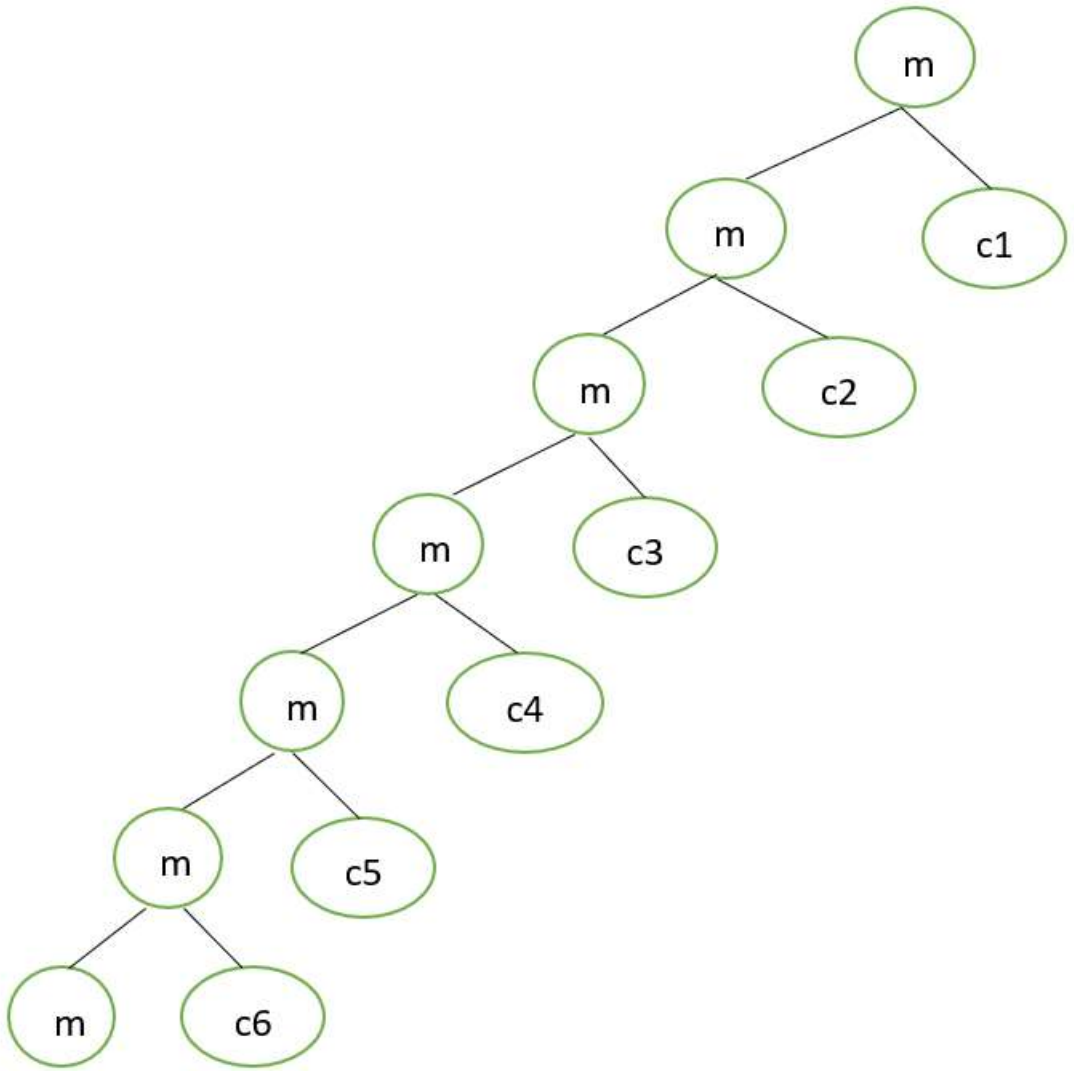
```
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
Forked
forked
```

How many times **fork()** is invoked in the following program?

```
void main()
{
        int i = 0;
        for (i = 0; fork();i++)
        {
                if(i == 5)
                {
                        exit(0);
                }
        }
}
```

6 times

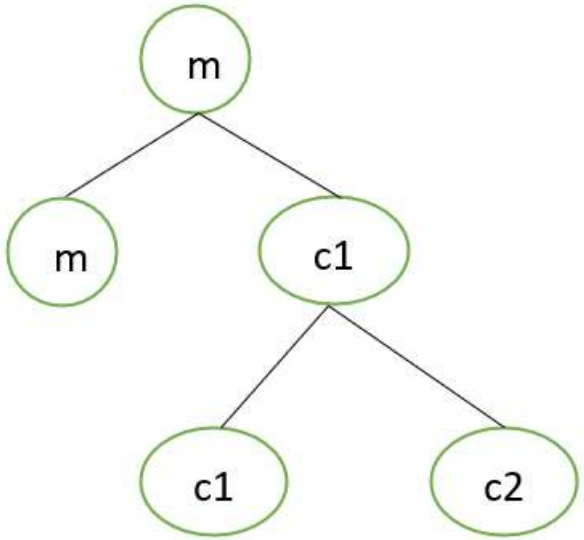
Process hierarchy



Mention the process hierarchy and output.

```
main()
{
    print("a\n");
    if(fork() == 0)
    {
            print("b\n");
            if(fork() == 0)
            {
                    print("c\n");
                    exit();
            }
            print("d\n");
            print("e\n");
            exit();
    }
    print("f\n");
    print("g\n");
    exit();
}
```

Process hierarchy



Output:

a
f
g
b
d
e
c

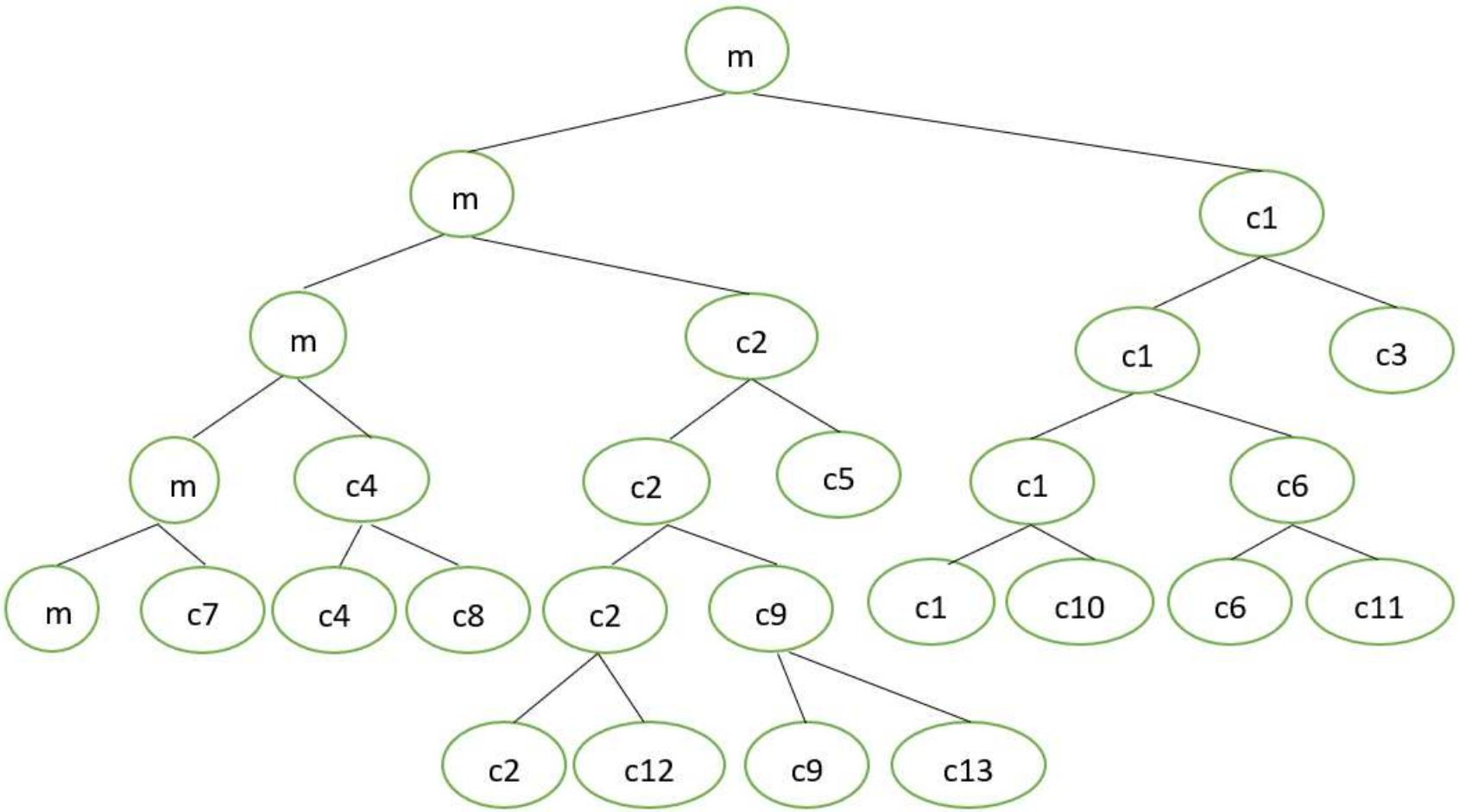
Draw the process hierarchy to represent the process creation and mention how many times “OS” will be printed.

```
void main()
{
        if(fork() && fork() || fork())
        {
                fork();
                fork();
                print(“OS”);
        }
}
```

Output:

OS
OS
OS
OS
OS
OS
OS
OS
OS
OS
OS
OS
OS
OS

Process hierarchy



Process Termination

A process terminates when the last statement of the process is executed.

When a process terminates, it informs to its parent about its completion.

The operating system releases all resources from the completed process.

A parent process may terminate its child process when the child process uses its allocated resources for long time (or) the task executed by the child process is no longer required (or) the parent is exiting.

Some operating systems do not allow a child process to exist when the parent process is terminated.

In this case, when the parent process terminates then the operating system terminates all children of the process.

This type of termination is called **cascading termination**.

Inter-process Communication

In a computer system, number of processes may be executing concurrently.

A process is called **independent** if it is not communicating with any other process.

A process is called **cooperating** if it is communicating with any other process.

Processes must communicate for

Sharing resources: for example, if two or more processes require data from same file (resource).

Speeding up the computation:

when a program has to be completed in less time then the program is divided into number of parts and the parts are executed concurrently on the processors (processing units) of the system.

The parts must communicate with each other as they belong to the same program.

Two methods are used for implementing inter-process communication

1) Shared memory
2) Message passing

Shared Memory

A region of memory shared by processes is created.

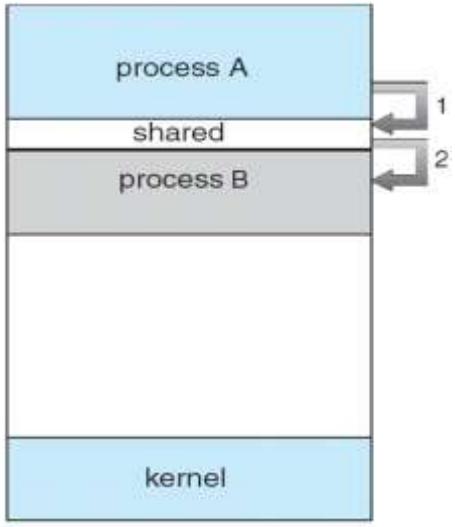
The processes can exchange information by reading and writing data to the shared memory.

A process creates the shared memory segment.

Any process which wants to communicate with the process creating the shared memory must attach the shared memory to its address space.

Generally, the operating system prevents one process from accessing other process memory.

This restriction is omitted in the shared memory method.



Producer – consumer problem

In this problem, there are two processes: **producer** and **consumer**.

There is a **buffer** for storing items.

The producer process stores items into the buffer and the consumer process takes items from the buffer.

Two pointers (**in** and **out**) are maintained for the buffer.

The in pointer points to the next free slot in the buffer and out pointer points to the slot from which item can be taken out from the buffer.

A variable called '**count**' indicates the number of items in the buffer.

The buffer, **sizeofbuffer** and count must be stored in shared memory as these are accessed by both processes.

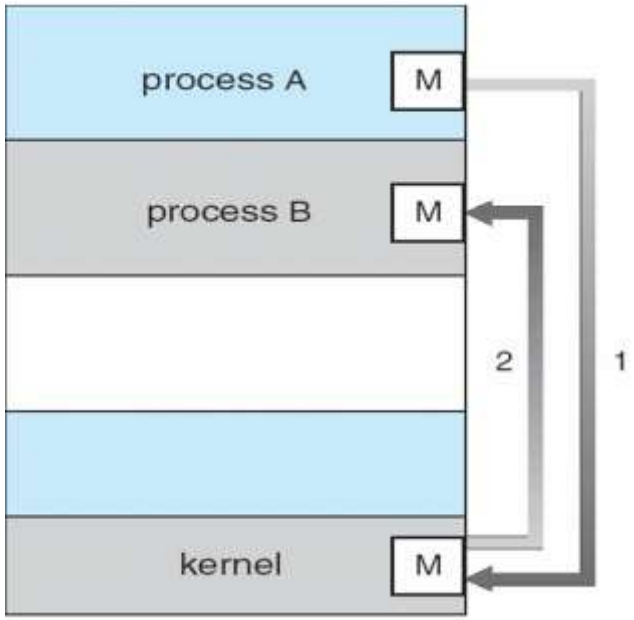
The producer process has to wait until a free slot is available in the buffer.

The consumer process has to wait until an item is available in the buffer.

Using shared memory, large amount of data can be exchanged between processes in less time.

Message passing

With message passing, processes can communicate by exchanging short messages.



Two operations called **send(message), receive(message)** and a **communication link** are used for exchanging the messages.

The following three issues need to be considered.

1) Naming
2) Synchronization
3) Buffering

1) Naming

A direct communication link or an indirect communication link is used between the communicating processes.

Direct Communication:

With direct communication, the sender process has to mention the name of receiver process.

Similarly, the receiver process has to mention the name of sender process.

The syntax of send and receive operations is

send(P, message) - sends a message to process P.
receive(Q, message) - receives a message from process Q.

In Direct Communication:

1) A communication link is established between every pair of processes that want to communicate.
2) A link is associated with exactly two processes.
3) There exists exactly one link between every pair of processes.

Indirect communication:

The processes can communicate by sending and receiving messages from mailboxes.

The syntax of send and receive operations is

send(A, message) – sends a message to mailbox A.
receive(A, message) – receives a message from mailbox A.

In Indirect Communication:

1) A link is established between a pair of processes if both processes have a shared mailbox.
2) There exists more number of links between a pair of processes.

2) Synchronization

Communication between processes takes place through calls to send() and receive() operations.

Message passing is either **blocking** or **non blocking** – also known as synchronous and asynchronous.

Blocking send: the sending process is blocked until the message is received by the receiver or mailbox.

Non blocking send: the sending process continues its operations after sending the message.

Blocking receive: the receiver blocks until it receive the message.

Non blocking receive: the receiver does not block for the message to receive.

The sender and receiver can use any combination of send() and receive() operations.

3) Buffering

In both direct and indirect communication, the messages are stored in a buffer.

Three types of buffers can be used

Buffer with zero capacity: in this case, the sender must block until the receiver receives the message.

Buffer with bounded capacity: the buffer has a finite length. In this case, the sender can continue its execution after sending a message if the buffer is not full.

Buffer with unbounded capacity: the buffer has infinite capacity. In this case, the sender never blocks.

If the processes running in different systems want to communicate then message passing is easier to implement than shared memory.

Message passing allows exchanging of small amounts of data.

It takes more time to exchange messages as messages are exchanged through kernel.

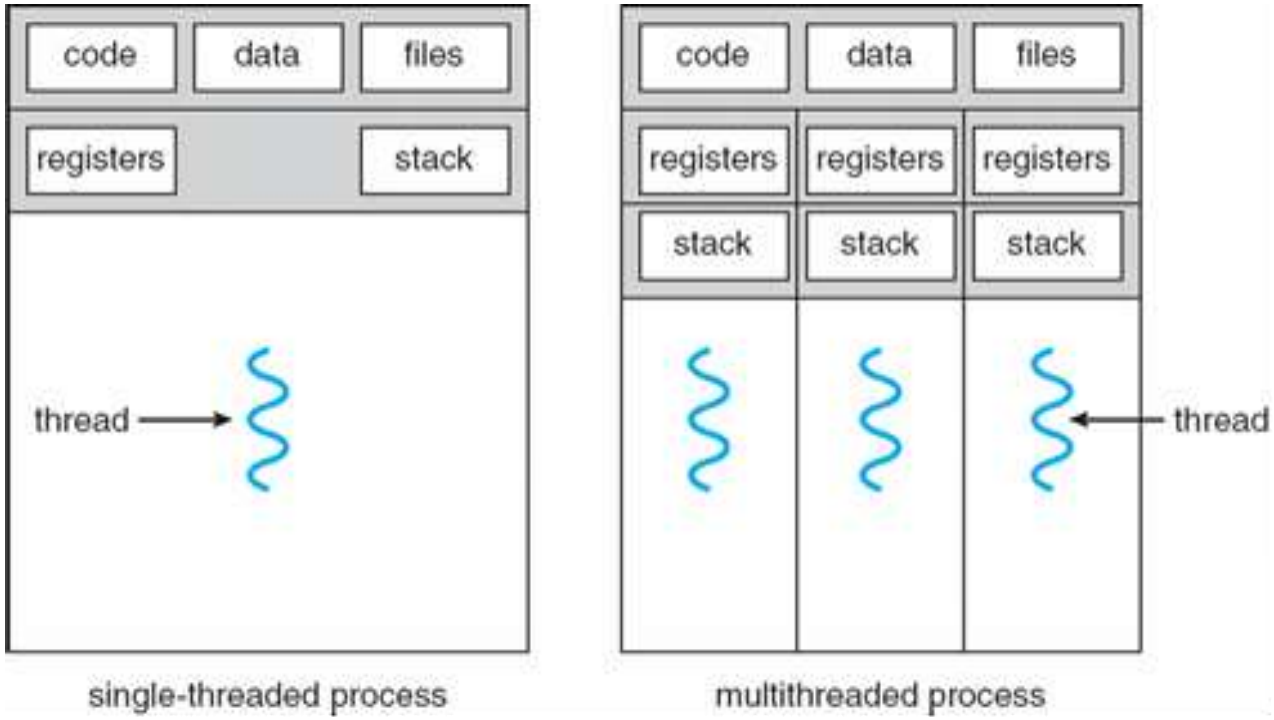
Multithreaded Programming

A thread is part of a process.

A single threaded process can perform only one task at a time.

A multithreaded process can perform number of tasks at a time.

The following figure shows the difference between a single threaded process and a multithreaded process.



A thread is associated with a program counter, a set of registers and a stack.

The threads belonging to a process shares the code, data and resources of the process.

Most of the software running on modern computer systems are multithreaded.

The threads of a process may be performing different tasks or same task.

For example, in a word processor, a thread displays graphics, a thread responds to key strokes and a thread checks spelling and grammar.

In a web server, there are number of threads one for each client request.

When a client makes a request, a thread is created by the server for processing that request.

Most operating system kernels are multithreaded.

Number of threads is running in the kernel.

Each thread implements a functionality of the operating system.

Benefits of multithreaded programs

1) Responsiveness

In a single threaded process, if the thread blocks then the user does not get response.

In a multithreaded process, if one or more threads are blocked then the user gets response from other threads of the process.

Multithreading increases responsiveness to the user.

2) Resource sharing

In multithreading, all threads of a process shares resources allocated to that process automatically.

3) Economy

Creating a process is costly.

The operating system has to allocate number of resources to a process when it creates a process.

When a thread is created no need to allocate resources for the thread as the thread shares resources of the process in which it is created.

Process switching is costly compared to thread switching.

4) Scalability

In a multiprocessor system, a single threaded process can use only one processor.

A multithreaded process can use all processors for running the threads in parallel.

Multithreading models

Two types of threads can be found in the computer system: User threads and Kernel threads

User threads (threads created in an application program) are created and managed by user.

User level threads are fast.

Creation of user level threads and switching between user level threads is easy.

Kernel threads (threads created in kernel) are managed by the operating system.

Kernel level threads are slower compared to user level threads due to management overhead.

Creation of kernel level threads and switching between kernel level threads is costly and time consuming.

A kernel level thread provide services to one or more user level threads.

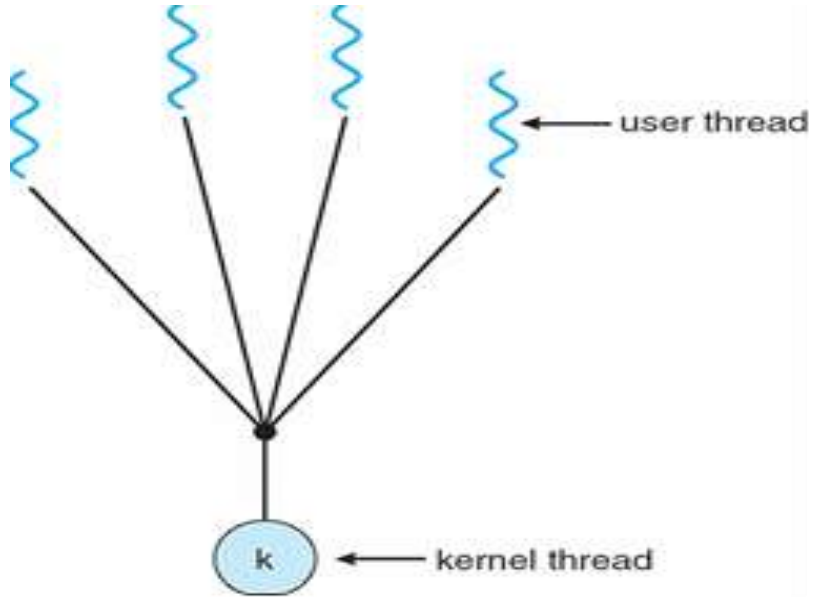
Multithreading models indicate the relationship between user and kernel threads.

There are three types of models

1) Many-to-One model
2) One-to-One model
3) Many-to-Many model

1) Many-to-One model

Number of user threads is mapped to one kernel thread as shown in following figure.



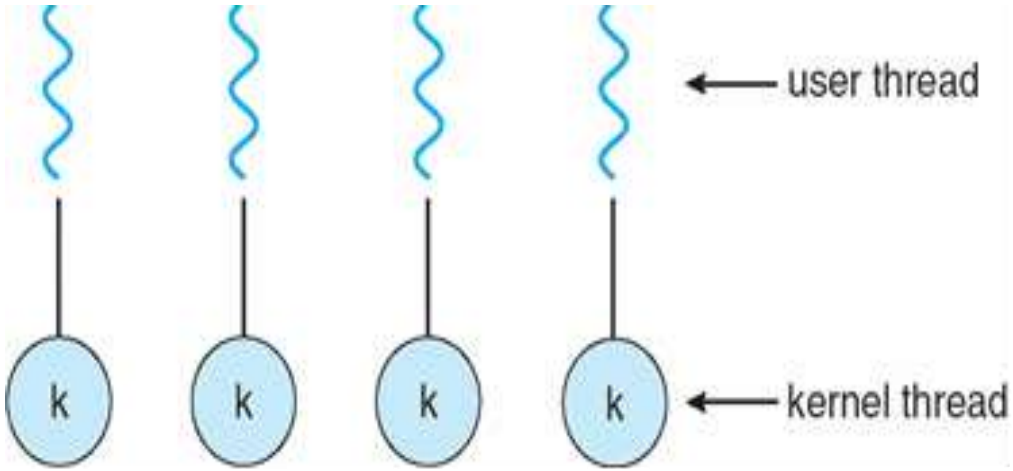
The kernel thread provide services to only one user thread at a time.

If the kernel thread is blocked then the entire user process is blocked.

It is not possible to run user threads in parallel.

2) One-to-One model

Each user thread is mapped to a kernel thread as shown in following figure.



The user process is not blocked when one thread makes a blocking system call.

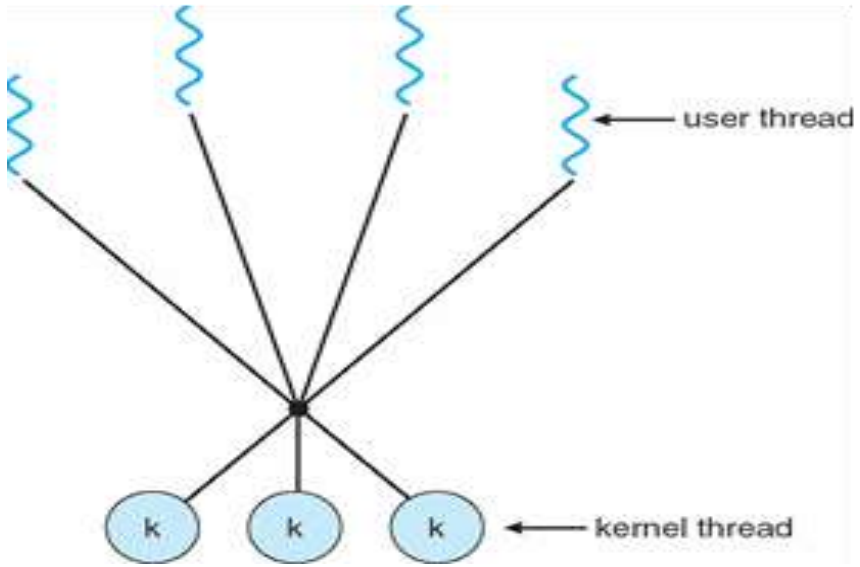
All user threads can run in parallel on multiple processors.

A drawback with this method is:

Creation of a user thread results in creation of a kernel thread.

3) Many-to-Many model

The user threads are mapped to less or equal number of kernel threads as shown in following figure



The user threads can run in parallel on multiple processors.

The user can create any number of user threads.

When a thread makes a blocking system call, the kernel can schedule another thread for execution.

One variation of many-to-many model is **two-level model**.

In two-level model, user threads are mapped to less or equal number of kernel threads and a user thread can be bound to a kernel thread.