Process Communication, Critical Section Problem, Solution to Critical Section Problem : Semaphores – Binary and Counting Semaphores, WAIT & SIGNAL Operations and their implementation. Deadlocks: Deadlock Problems, Characterization, Prevention, Avoidance, Recovery.

Process Synchronization

When two or more process cooperates with each other, their order of execution must be preserved otherwise there can be conflicts in their execution and inappropriate outputs can be produced.

A cooperative process is the one which can affect the execution of other process or can be affected by the execution of other process. Such processes need to be synchronized so that their order of execution can be guaranteed.

The procedure involved in preserving the appropriate order of execution of cooperative processes is known as Process Synchronization. There are various synchronization mechanisms that are used to synchronize the processes.

Race Condition

A Race Condition typically occurs when two or more threads try to read, write and possibly make the decisions based on the memory that they are accessing concurrently.

Critical Section

The regions of a program that try to access shared resources and may cause race conditions are called critical section. To avoid race condition among the processes, we need to assure that only one process at a time can execute within the critical section.

The Critical Section Problem

Critical Section is the part of a program which tries to access shared resources. That resource may be any resource in a computer like a memory location, Data structure, CPU or any IO device.

The critical section cannot be executed by more than one process at the same time; operating system faces the difficulties in allowing and disallowing the processes from entering the critical section.

The critical section problem is used to design a set of protocols which can ensure that the Race condition among the processes will never arise.

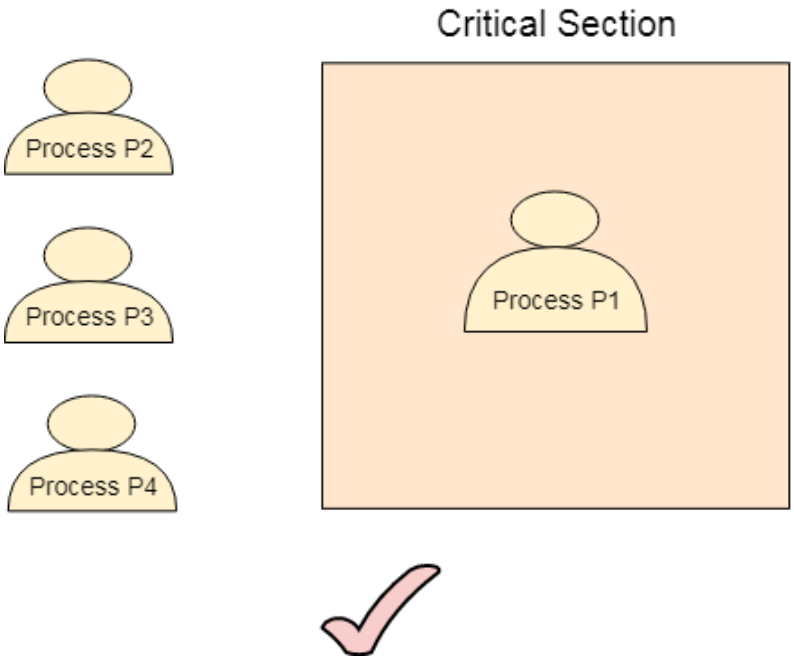
In order to synchronize the cooperative processes, our main task is to solve the critical section problem. We need to provide a solution in such a way that the following conditions can be satisfied.

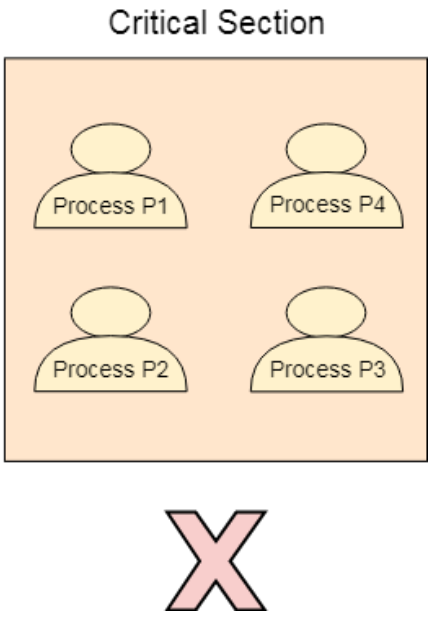
Requirements of Synchronization mechanisms.

Primary

1. Mutual Exclusion

Our solution must provide mutual exclusion. By Mutual Exclusion, we mean that if one process is executing inside critical section then the other process must not enter in the critical section.





2. Progress

   Progress means that if one process doesn't need to execute into critical section then it should not stop other processes to get into the critical section.

   Secondary

   Bounded Waiting

   We should be able to predict the waiting time for every process to get into the critical section. The process must not be endlessly waiting for getting into the critical section.

Introduction to semaphore

To get rid of the problem of wasting the wake-up signals, Dijkstra proposed an approach which involves storing all the wake-up calls. Dijkstra states that, instead of giving the wake-up calls directly to the consumer, producer can store the wake-up call in a variable. Any of the consumers can read it whenever it needs to do so.

Semaphore is simply a variable that is non-negative and shared between threads. A semaphore is a signaling mechanism, and a thread that is waiting on a semaphore can be signaled by another thread. It uses two atomic operations, 1)wait, and 2) signal for the process synchronization.

A semaphore either allows or disallows access to the resource, which depends on how it is set up.

Characteristic of Semaphore

Here, are characteristic of a semaphore:

- It is a mechanism that can be used to provide synchronization of tasks.
- It is a low-level synchronization mechanism.
- Semaphore will always hold a non-negative integer value.
- Semaphore can be implemented using test operations and interrupts, which should be executed using file descriptors.

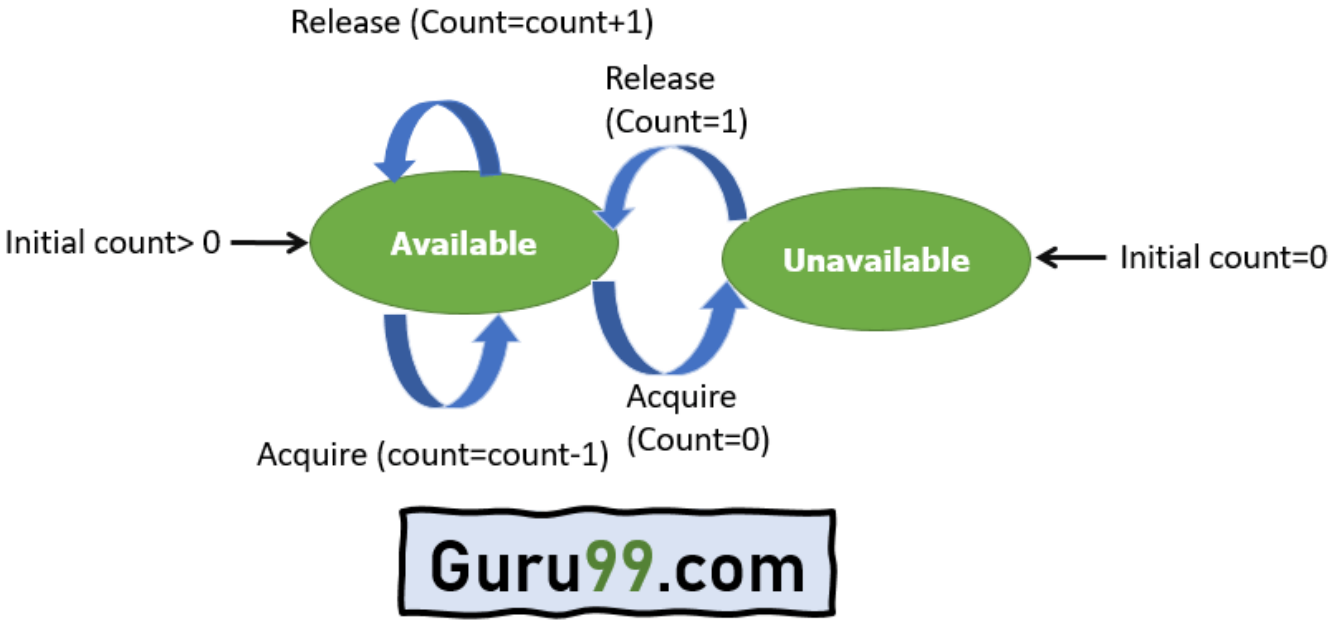
Types of Semaphores

The two common kinds of semaphores are

- Counting semaphores
- Binary semaphores.

Counting Semaphores

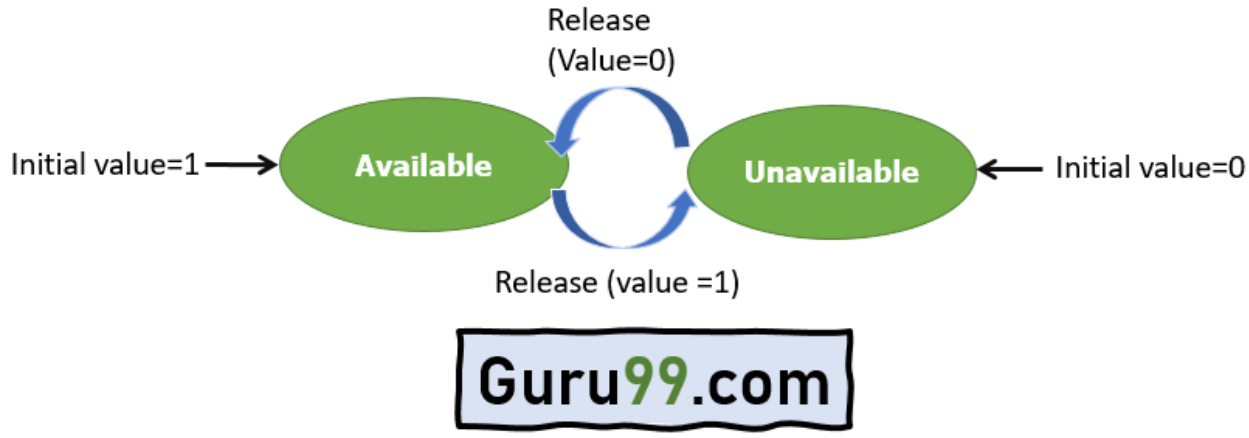
This type of Semaphore uses a count that helps task to be acquired or released numerous times. If the initial count = 0, the counting semaphore should be created in the unavailable state.



However, If the count is > 0, the semaphore is created in the available state, and the number of tokens it has equals to its count.

Binary Semaphores

The binary semaphores are quite similar to counting semaphores, but their value is restricted to 0 and 1. In this type of semaphore, the wait operation works only if semaphore = 1, and the signal operation succeeds when semaphore= 0. It is easy to implement than counting semaphores.



Example of Semaphore

The below-given program is a step by step implementation, which involves usage and declaration of semaphore.

```
Shared var mutex: semaphore = 1;

Process i

   begin

   .

   .

   P(mutex);

   execute CS;

   V(mutex);

   .

   .

   End;
```

Wait and Signal Operations in Semaphores

Both of these operations are used to implement process synchronization. The goal of this semaphore operation is to get mutual exclusion.

Wait for Operation

This type of semaphore operation helps you to control the entry of a task into the critical section. However, If the value of wait is positive, then the value of the wait argument X is decremented. In the case of negative or zero value, no operation is executed. It is also called P(S) operation.

After the semaphore value is decreased, which becomes negative, the command is held up until the required conditions are satisfied.

```
wait(S)

{

   while (S<=0);

   S--;

}
```

Signal operation

This type of Semaphore operation is used to control the exit of a task from a critical section. It helps to increase the value of the argument by 1, which is denoted as V(S).

```
signal(S)
{

   S++;
}
```

Advantages of Semaphores

Here, are pros/benefits of using Semaphore:

- It allows more than one thread to access the critical section
- Semaphores are machine-independent.
- Semaphores are implemented in the machine-independent code of the microkernel.
- They do not allow multiple processes to enter the critical section.
- As there is busy waiting in semaphore, there is never a wastage of process time and resources.
- They are machine-independent, which should be run in the machine-independent code of the microkernel.
- They allow flexible management of resources.

Disadvantage of semaphores

Here, are cons/drawback of semaphore

- One of the biggest limitations of a semaphore is priority inversion.
- The operating system has to keep track of all calls to wait and signal semaphore.
- Their use is never enforced, but it is by convention only.
- In order to avoid deadlocks in semaphore, the Wait and Signal operations require to be executed in the correct order.
- Semaphore programming is a complicated, so there are chances of not achieving mutual exclusion.

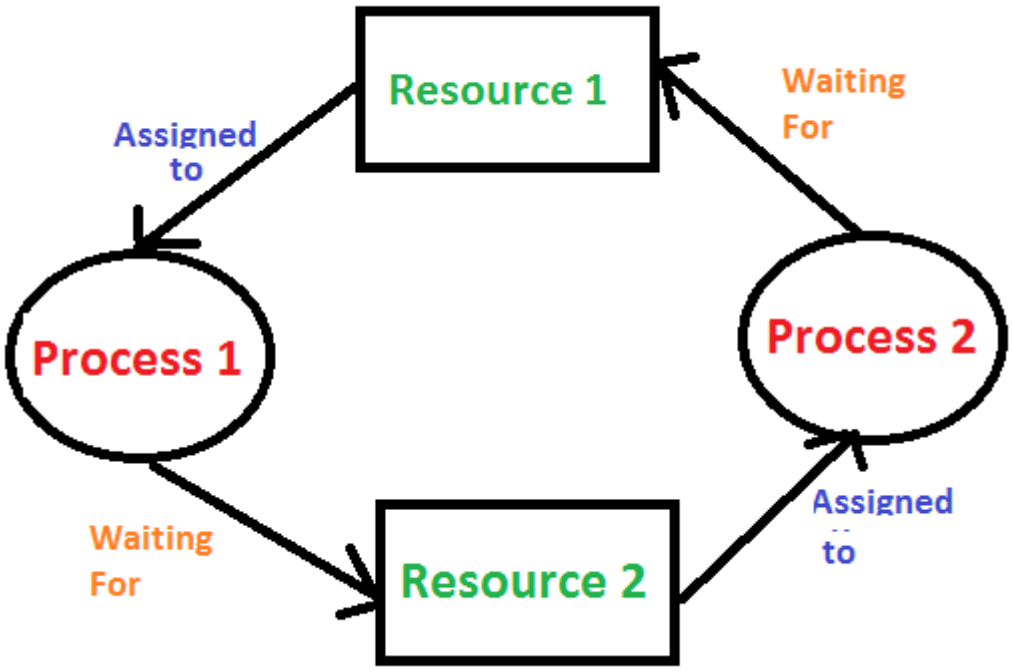
- It is also not a practical method for large scale use as their use leads to loss of modularity.
- Semaphore is more prone to programmer error.
- It may cause deadlock or violation of mutual exclusion due to programmer error.

Deadlock in Operating System

A process in operating systems uses different resources and uses resources in following way.

1) Requests a resource
2) Use the resource
2) Releases the resource

Deadlock is a situation where a set of processes are blocked because each process is holding a resource and waiting for another resource acquired by some other process.
Consider an example when two trains are coming toward each other on same track and there is only one track, none of the trains can move once they are in front of each other. Similar situation occurs in operating systems when there are two or more processes hold some resources and wait for resources held by other(s). For example, in the below diagram, Process 1 is holding Resource 1 and waiting for resource 2 which is acquired by process 2, and process 2 is waiting for resource 1.



Deadlock can arise if following four conditions hold simultaneously (Necessary Conditions)
Mutual Exclusion: One or more than one resource are non-sharable (Only one process can use at a time)
Hold and Wait: A process is holding at least one resource and waiting for resources.
No Preemption: A resource cannot be taken from a process unless the process releases the resource.
Circular Wait: A set of processes are waiting for each other in circular form.

Methods for handling deadlock
There are three ways to handle deadlock
1) Deadlock prevention or avoidance: The idea is to not let the system into deadlock state.
One can zoom into each category individually, Prevention is done by negating one of above mentioned necessary conditions for deadlock.
Avoidance is kind of futuristic in nature. By using strategy of "Avoidance", we have to make an assumption. We need to ensure that all information about resources which process WILL need are known to us prior to execution of the process. We use Banker's algorithm (Which is in-turn a gift from Dijkstra) in order to avoid deadlock.

2) Deadlock detection and recovery: Let deadlock occur, then do preemption to handle it once occurred.

3) Ignore the problem all together: If deadlock is very rare, then let it happen and reboot the system. This is the approach that both Windows and UNIX take.

Deadlock Prevention And Avoidance

Deadlock Characteristics

As discussed in the previous post, deadlock has following characteristics.

Mutual Exclusion

Hold and Wait

No preemption

Circular wait

Deadlock Prevention

We can prevent Deadlock by eliminating any of the above four conditions.

Eliminate Mutual Exclusion.

It is not possible to dis-satisfy the mutual exclusion because some resources, such as the tape drive and printer, are inherently non-shareable.

Eliminate Hold and wait.

Allocate all required resources to the process before the start of its execution, this way hold and wait condition is eliminated but it will lead to low device utilization. for example, if a process requires printer at a later time and we have allocated printer before the start of its execution printer will remain blocked till it has completed its execution.

The process will make a new request for resources after releasing the current set of resources. This solution may lead to starvation.

Eliminate No Preemption.

Preempt resources from the process when resources required by other high priority processes.

Eliminate Circular Wait

Each resource will be assigned with a numerical number. A process can request the resources increasing/decreasing. order of numbering.

For Example, if P1 process is allocated R5 resources, now next time if P1 ask for R4, R3 lesser than R5 such request will not be granted, only request for resources more than R5 will be granted.

Deadlock Avoidance

Deadlock avoidance can be done with Banker's Algorithm.

Banker's Algorithm

Bankers's Algorithm is resource allocation and deadlock avoidance algorithm which test all the request made by processes for resources, it checks for the safe state, if after granting request system remains in the safe state it allows the request and if there is no safe state it doesn't allow the request made by the process.

Banker's Algorithm in Operating System

The banker's algorithm is a resource allocation and deadlock avoidance algorithm that tests for safety by simulating the allocation for predetermined maximum possible amounts of all resources, then makes an "s-state" check to test for possible activities, before deciding whether allocation should be allowed to continue.

Following **Data structures** are used to implement the Banker's Algorithm:

Let **'n'** be the number of processes in the system and **'m'** be the number of resources types.

Available :

- It is a 1-d array of size **'m'** indicating the number of available resources of each type.

- Available[j] = k means there are **'k'** instances of resource type $\mathbf{R_j}$

Max :

- It is a 2-d array of size '**n*m'** that defines the maximum demand of each process in a system.
- Max[i, j] = k means process $\mathbf{P_i}$ may request at most **'k'** instances of resource type $\mathbf{R_j}$.

Allocation :

- It is a 2-d array of size **'n*m'** that defines the number of resources of each type currently allocated to each process.
- Allocation[i, j] = k means process $\mathbf{P_i}$ is currently allocated **'k'** instances of resource type $\mathbf{R_j}$

Need :

- It is a 2-d array of size **'n*m'** that indicates the remaining resource need of each process.
- Need [i, j] = k means process $\mathbf{P_i}$ currently need **'k'** instances of resource type $\mathbf{R_j}$

for its execution.

- Need [i, j] = Max [i, j] – Allocation [i, j]

$Allocation_i$ specifies the resources currently allocated to process P_i and $Need_i$ specifies the additional resources that process P_i may still request to complete its task.
Banker's algorithm consists of Safety algorithm and Resource request algorithm

Safety Algorithm
The algorithm for finding out whether or not a system is in a safe state can be described as follows:

1) Let Work and Finish be vectors of length 'm' and 'n' respectively.
Initialize: Work = Available
Finish[i] = false; for i=1, 2, 3, 4….n

2) Find an i such that both
a) Finish[i] = false
b) $Need_i$ <= Work
if no such i exists goto step (4)
3) Work = Work + Allocation[i]
Finish[i] = true
goto step (2)

4) if Finish [i] = true for all i
then the system is in a safe state

Resource-Request Algorithm

Let $Request_i$ be the request array for process P_i. $Request_i[j] = k$ means process P_i wants k instances of resource type R_j. When a request for resources is made by process P_i, the following actions are taken:

1) If $Request_i <= Need_i$

Goto step (2) ; otherwise, raise an error condition, since the process has exceeded its maximum claim.

2) If $Request_i <= Available$

Goto step (3); otherwise, P_i must wait, since the resources are not available.

3) Have the system pretend to have allocated the requested resources to process Pi by modifying the state as follows:

Available = Available – Requesti

$Allocation_i = Allocation_i + Request_i$

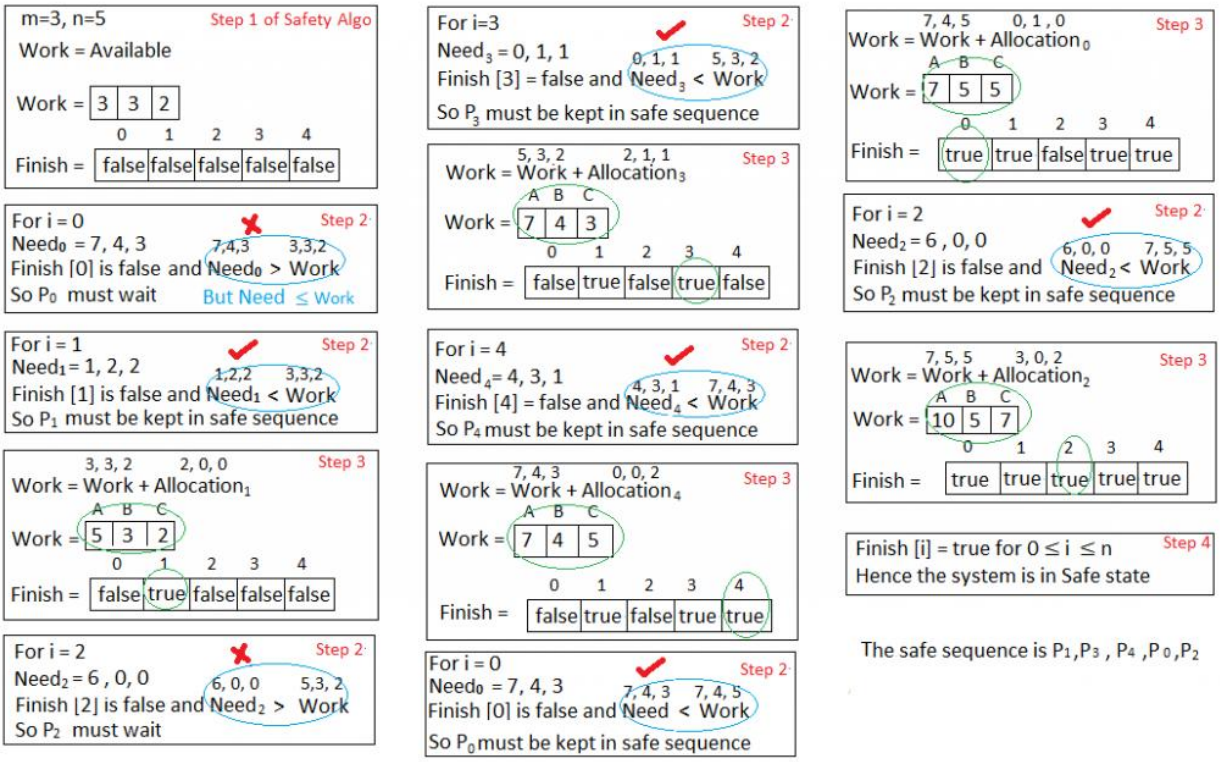
$Need_i = Need_i – Request_i$

Process	Allocation	Max	Available
	A B C	A B C	A B C
P_0	0 1 0	7 5 3	3 3 2
P_1	2 0 0	3 2 2	
P_2	3 0 2	9 0 2	
P_3	2 1 1	2 2 2	
P_4	0 0 2	4 3 3	

Need [i, j] = Max [i, j] – Allocation [i, j]

So, the content of Need Matrix is:

Process	Need		
	A	B	C
P_0	7	4	3
P_1	1	2	2
P_2	6	0	0
P_3	0	1	1
P_4	4	3	1



Reference:

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