Process Synchronization

Process Synchronization means sharing system resources by processes in a such a way that, Concurrent access to shared data is handled thereby minimizing the chance of inconsistent data. Maintaining data consistency demands mechanisms to ensure synchronized execution of cooperating processes.

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

processes are categorized as one of the following two types:

- **Independent Process** : Execution of one process does not affects the execution of other processes.

- **Cooperative Process** : Execution of one process affects the execution of other processes.

Process synchronization problem arises in the case of Cooperative process also because resources are shared in Cooperative processes.

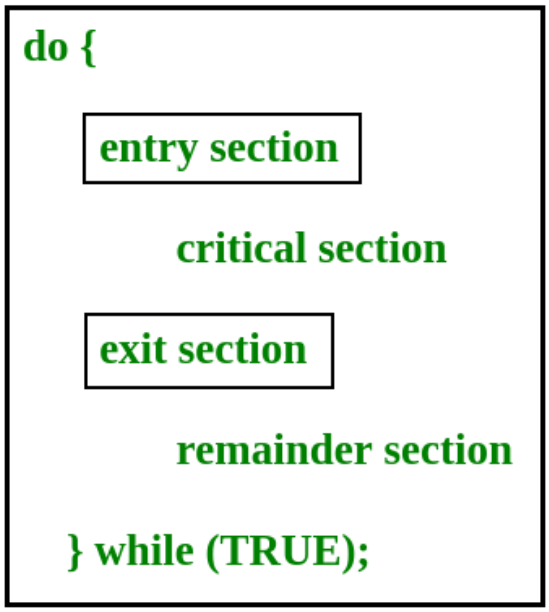
Race Condition

When more than one processes are executing the same code or accessing the same memory or any shared variable in that condition there is a possibility that the output or the value of the shared variable is wrong so for that all the processes doing race to say that my output is correct this condition known as race condition.

Several processes access and process the manipulations over the same data concurrently, then the outcome depends on the particular order in which the access takes place.

Critical Section Problem

Critical section is a code segment that can be accessed by only one process at a time. Critical section contains shared variables which need to be synchronized to maintain consistency of data variables. In the entry section, the process requests for entry in the **Critical Section.**



Any solution to the critical section problem must satisfy three requirements:

- **Mutual Exclusion** : If a process is executing in its critical section, then no other process is allowed to execute in the critical section.
- **Progress** : If no process is executing in the critical section and other processes are waiting outside the critical section, then only those processes that are not executing in their remainder section can participate in deciding which will enter in the critical section next, and the selection can not be postponed indefinitely.
- **Bounded Waiting** : A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.

Classical problems of Synchronization

1. **The Producer-Consumer problem**

The Producer-Consumer problem is a classic problem this is used for multi-process synchronization i.e. synchronization between more than one processes.

In the producer-consumer problem, there is one Producer that is producing something and there is one Consumer that is consuming the products produced by the Producer. The producers and consumers share the same memory buffer that is of fixed-size.

The job of the Producer is to generate the data, put it into the buffer, and again start generating data. While the job of the Consumer is to consume the data from the buffer.

The following are the problems that might occur in the Producer-Consumer:

- The producer should produce data only when the buffer is not full. If the buffer is full, then the producer shouldn't be allowed to put any data into the buffer.
- The consumer should consume data only when the buffer is not empty. If the buffer is empty, then the consumer shouldn't be allowed to take any data from the buffer.
- The producer and consumer should not access the buffer at the same time.

2. **Readers Writer Problem**

There is a shared resource which should be accessed by multiple processes. There are two types of processes in this context. They are **reader** and **writer**. Any number of **readers** can read from the shared resource simultaneously, but only one **writer** can write to the shared resource. When a **writer** is writing data to the resource, no other process can access the resource. A **writer** cannot write to the resource if there are non zero number of readers accessing the resource at that time.

3. **The dining philosophers problem**

   It states that there are 5 philosophers sharing a circular table and they eat and think alternatively. There is a bowl of rice for each of the philosophers and 5 chopsticks. A philosopher needs both their right and left chopstick to eat. A hungry philosopher may only eat if having both chopsticks.

Semaphores

Semaphore is simply a variable which is non-negative and shared between threads. This variable is used to solve the critical section problem and to achieve process synchronization in the multiprocessing environment.

Semaphores are of two types:

1. **Binary Semaphore –** This is also known as mutex lock. It can have only two values – 0 and 1. Its value is initialized to 1. It is used to implement the solution of critical section problem with multiple processes.
2. **Counting Semaphore –** Its value can range over an unrestricted domain. It is used to control access to a resource that has multiple instances.

In very simple words, semaphore is a variable which can hold only a non-negative Integer value, shared between all the threads, with operations wait and signal

The classical definitions of **wait** and **signal** are:

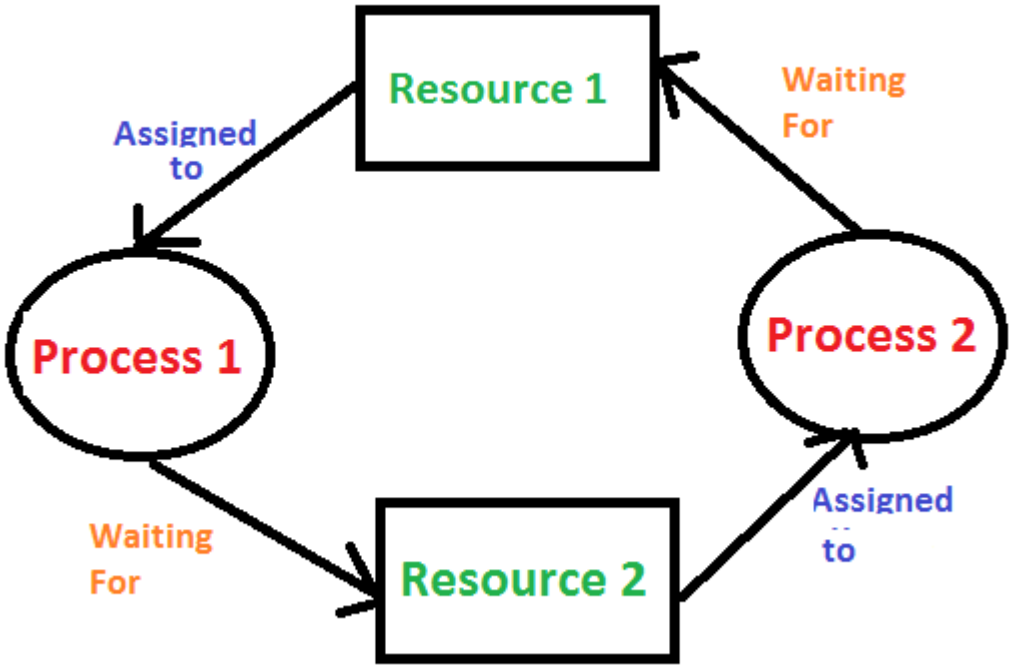
- **Wait**: Decrements the value of its argument S, as soon as it would become non-negative(greater than or equal to 1).
- **Signal**: Increments the value of its argument S, as there is no more process blocked on the queue.

Properties of Semaphores

1. It's simple and always have a non-negative Integer value.
2. Works with many processes.
3. Can have many different critical sections with different semaphores.
4. Each critical section has unique access semaphores.
5. Can permit multiple processes into the critical section at once, if desirable.

Deadlock in Operating System

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)

1. Mutual Exclusion: One or more than one resource are non-sharable (Only one process can use at a time)

2. Hold and Wait: A process is holding at least one resource and waiting for resources.

3. No Preemption: A resource cannot be taken from a process unless the process releases the resource.

4. 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.

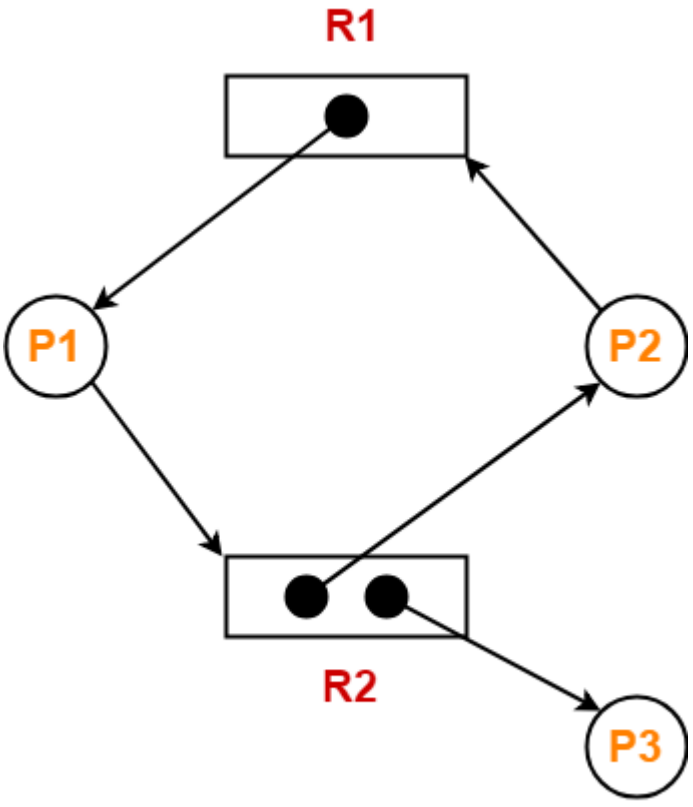
One can zoom into each category individually, Prevention is done by negating one of above mentioned necessary conditions for deadlock.

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.

Resource Allocation Graph (RAG) in Operating System

- Resource Allocation Graph (RAG) is a graph that represents the state of a system pictorially.
- There are two components of RAG- Vertices and Edges.



Resource Allocation Graph

Deadlock Detection-

Using Resource Allocation Graph, it can be easily detected whether system is in a **Deadlock** state or not.

The rules are-

Rule-01:

In a Resource Allocation Graph where all the resources are single instance,

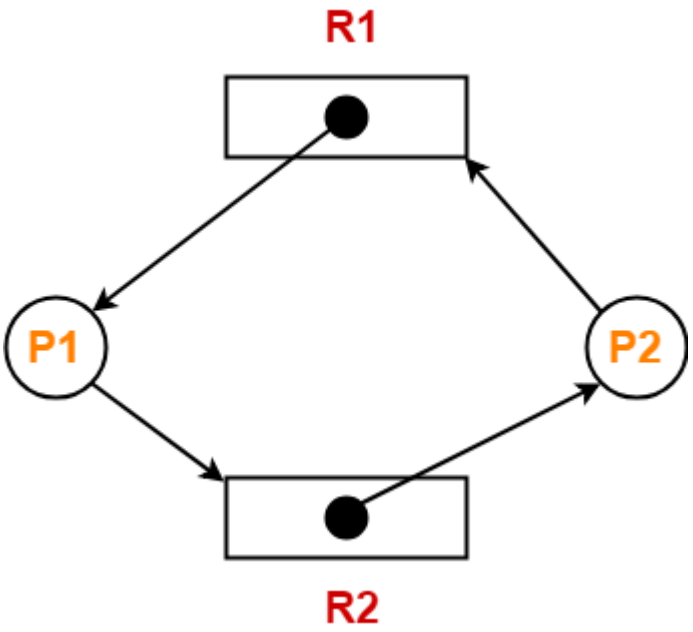
- If a cycle is being formed, then system is in a deadlock state.
- If no cycle is being formed, then system is not in a deadlock state.

Rule-02:

In a Resource Allocation Graph where all the resources are **NOT** single instance,

- If a cycle is being formed, then system may be in a deadlock state.
- **Banker's Algorithm** is applied to confirm whether system is in a deadlock state or not.
- If no cycle is being formed, then system is not in a deadlock state.
- Presence of a cycle is a necessary but not a sufficient condition for the occurrence of deadlock.

Consider the resource allocation graph in the figure-

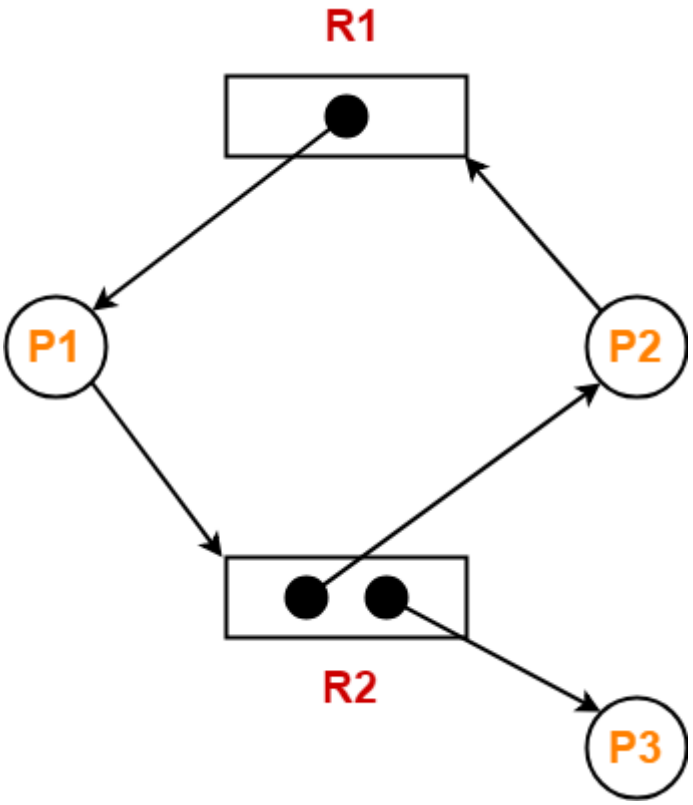


Find if the system is in a deadlock state otherwise find a safe sequence.

Solution-

- The given resource allocation graph is single instance with a cycle contained in it.
- Thus, the system is definitely in a deadlock state.

Consider the resource allocation graph in the figure-



Find if the system is in a deadlock state otherwise find a safe sequence.

Solution-

- The given resource allocation graph is multi instance with a cycle contained in it.
- So, the system may or may not be in a deadlock state.

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

$Allocation_i$ = $Allocation_i$ + $Request_i$

$Need_i$ = $Need_i$– $Request_i$

Note : Example numerical of banker's algorithm – refer my you tube channel banker's algorithm example.