UNIT 3:
Process Synchronization and Deadlock

Introduction of Process Synchronization

Process Synchronization is the coordination of execution of multiple processes in a multi-process system to ensure that they access shared resources in a controlled and predictable manner. It aims to resolve the problem of race conditions and other synchronization issues in a concurrent system.

The main objective of process synchronization is to ensure that multiple processes access shared resources without interfering with each other, and to prevent the possibility of inconsistent data due to concurrent access. To achieve this, various synchronization techniques such as semaphores, monitors, and critical sections are used.

In a multi-process system, synchronization is necessary to ensure data consistency and integrity, and to avoid the risk of deadlocks and other synchronization problems. Process synchronization is an important aspect of modern operating systems, and it plays a crucial role in ensuring the correct and efficient functioning of multi-process systems.

On the basis of synchronization, processes are categorized as one of the following two types:

- **Independent Process**: The execution of one process does not affect the execution of other processes.
- **Cooperative Process**: A process that can affect or be affected by other processes executing in the system.

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

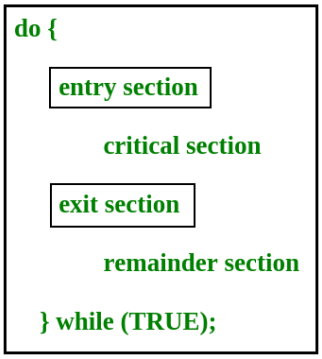
Race Condition:

When more than one process is 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 the race

to say that my output is correct this condition known as a 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. A race condition is a situation that may occur inside a critical section. This happens when the result of multiple thread execution in the critical section differs according to the order in which the threads execute. Race conditions in critical sections can be avoided if the critical section is treated as an atomic instruction. Also, proper thread synchronization using locks or atomic variables can prevent race conditions.

Critical Section Problem:

A critical section is a code segment that can be accessed by only one process at a time. The critical section contains shared variables that need to be synchronized to maintain the consistency of data variables. So the critical section problem means designing a way for cooperative processes to access shared resources without creating data inconsistencies.



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.

Semaphores:

A semaphore is a signaling mechanism and a thread that is waiting on a semaphore can be signaled by another thread. This is different than a mutex as the mutex can be signaled only by the thread that is called the wait function.

A semaphore uses two atomic operations, wait and signal for process synchronization. A Semaphore is an integer variable, which can be accessed only through two operations wait() and signal().
There are two types of semaphores: Binary Semaphores and Counting Semaphores.

- **Binary Semaphores:** They can only be either 0 or 1. They are also known as mutex locks, as the locks can provide mutual exclusion. All the processes can share the same mutex semaphore that is initialized to 1. Then, a process has to wait until the lock becomes 0. Then, the process can make the mutex semaphore 1 and start its critical section. When it completes its critical section, it can reset the value of the mutex semaphore to 0 and some other process can enter its critical section.
- **Counting Semaphores:** They can have any value and are not restricted over a certain domain. They can be used to control access to a resource that has a limitation on the number of simultaneous accesses. The semaphore can be initialized to the number of instances of the resource. Whenever a process wants to use that resource, it checks if the number of remaining instances is more than zero, i.e., the process has an instance available. Then, the process can enter its critical section thereby decreasing the value of the counting semaphore by 1. After the process is over with the use of the instance of the resource, it can leave the critical section thereby adding 1 to the number of available instances of the resource.

Advantages and Disadvantages:

Advantages of Process Synchronization:

- Ensures data consistency and integrity
- Avoids race conditions
- Prevents inconsistent data due to concurrent access
- Supports efficient and effective use of shared resources

Disadvantages of Process Synchronization:

- Adds overhead to the system
- Can lead to performance degradation

- Increases the complexity of the system
- Can cause deadlocks if not implemented properly.

Monitors in Process Synchronization

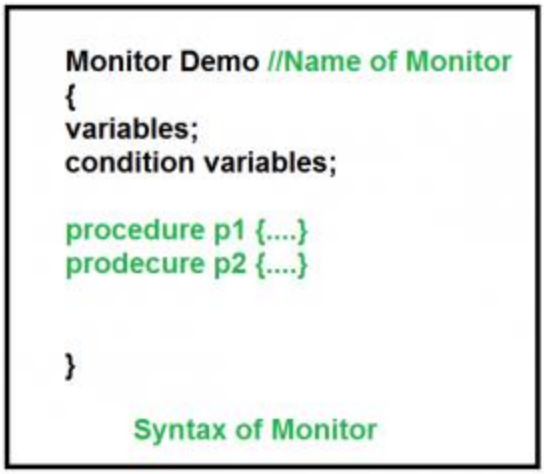
Monitors are a higher-level synchronization construct that simplifies process synchronization by providing a high-level abstraction for data access and synchronization. Monitors are implemented as programming language constructs, typically in object-oriented languages, and provide mutual exclusion, condition variables, and data encapsulation in a single construct.

1. A monitor is essentially a module that encapsulates a shared resource and provides access to that resource through a set of procedures. The procedures provided by a monitor ensure that only one process can access the shared resource at any given time, and that processes waiting for the resource are suspended until it becomes available.
2. Monitors are used to simplify the implementation of concurrent programs by providing a higher-level abstraction that hides the details of synchronization. Monitors provide a structured way of sharing data and synchronization information, and eliminate the need for complex synchronization primitives such as semaphores and locks.
3. The key advantage of using monitors for process synchronization is that they provide a simple, high-level abstraction that can be used to implement complex concurrent systems. Monitors also ensure that synchronization is encapsulated within the module, making it easier to reason about the correctness of the system.

However, monitors have some limitations. For example, they can be less efficient than lower-level synchronization primitives such as semaphores and locks, as they may involve additional overhead due to their higher-level abstraction. Additionally, monitors may not be suitable for all types of synchronization problems, and in some cases, lower-level primitives may be required for optimal performance.

The monitor is one of the ways to achieve Process synchronization. The monitor is supported by programming languages to achieve mutual exclusion between processes. For example Java Synchronized methods. Java provides wait() and notify() constructs.

1. It is the collection of condition variables and procedures combined together in a special kind of module or a package.
2. The processes running outside the monitor can’t access the internal variable of the monitor but can call procedures of the monitor.
3. Only one process at a time can execute code inside monitors.



Syntax: **Condition Variables:** Two different operations are performed on the condition variables of the monitor.
Wait.

signal.

let say we have 2 condition variables **condition x, y; // Declaring variable Wait operation** x.wait() : Process performing wait operation on any condition variable are suspended. The suspended processes are placed in block queue of that condition variable. **Note:** Each condition variable has its unique block queue. **Signal operation** x.signal(): When a process performs signal operation on condition variable, one of the blocked processes is given chance.
If (x block queue empty)

// Ignore signal

else

// Resume a process from block queue.

Advantages of Monitor: Monitors have the advantage of making parallel programming easier and less error prone than using techniques such as semaphore. **Disadvantages of Monitor:** Monitors have to be implemented as part of the programming language . The compiler must generate code for them. This gives the compiler the additional burden of having to know what operating system facilities are available to control access to critical sections in concurrent processes. Some languages that do support monitors are Java,C#,Visual Basic,Ada and concurrent Euclid

What is Deadlock in Operating System (OS)?

Every process needs some resources to complete its execution. However, the resource is granted in a sequential order.

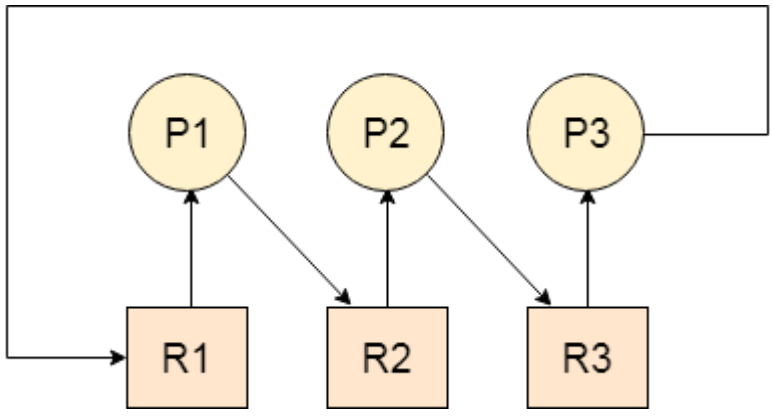
1. The process requests for some resource.
2. OS grant the resource if it is available otherwise let the process waits.
3. The process uses it and release on the completion.

A Deadlock is a situation where each of the computer process waits for a resource which is being assigned to some another process. In this situation, none of the process gets executed since the resource it needs, is held by some other process which is also waiting for some other resource to be released.

Let us assume that there are three processes P1, P2 and P3. There are three different resources R1, R2 and R3. R1 is assigned to P1, R2 is assigned to P2 and R3 is assigned to P3.

After some time, P1 demands for R1 which is being used by P2. P1 halts its execution since it can't complete without R2. P2 also demands for R3 which is being used by P3. P2 also stops its execution because it can't continue without R3. P3 also demands for R1 which is being used by P1 therefore P3 also stops its execution.

In this scenario, a cycle is being formed among the three processes. None of the process is progressing and they are all waiting. The computer becomes unresponsive since all the processes got blocked.



Difference between Starvation and Deadlock

Sr.	Deadlock	Starvation

1	Deadlock is a situation where no process got blocked and no process proceeds	Starvation is a situation where the low priority process got blocked and the high priority processes proceed.
2	Deadlock is an infinite waiting.	Starvation is a long waiting but not infinite.
3	Every Deadlock is always a starvation.	Every starvation need not be deadlock.
4	The requested resource is blocked by the other process.	The requested resource is continuously be used by the higher priority processes.
5	Deadlock happens when Mutual exclusion, hold and wait, No preemption and circular wait occurs simultaneously.	It occurs due to the uncontrolled priority and resource management.

Necessary conditions for Deadlocks

1. **Mutual Exclusion**

   A resource can only be shared in mutually exclusive manner. It implies, if two process cannot use the same resource at the same time.

2. **Hold and Wait**

   A process waits for some resources while holding another resource at the same time.

3. **No preemption**

   The process which once scheduled will be executed till the completion. No other process can be scheduled by the scheduler meanwhile.

4. **Circular Wait**

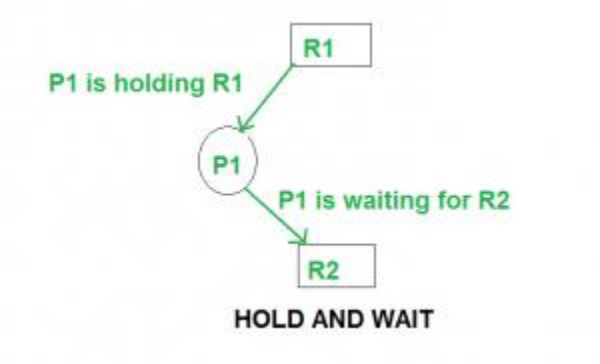
   All the processes must be waiting for the resources in a cyclic manner so that the last process is waiting for the resource which is being held by the first process.

Deadlock Prevention And Avoidance

Deadlock Prevention

We can prevent a 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 a printer at a later time and we have allocated a 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 are required by other high-priority processes.
Eliminate Circular Wait : Each resource will be assigned a numerical number. A process can request the resources to increase/decrease. order of numbering. For Example, if the P1 process is allocated R5 resources, now next time if P1 asks for R4, R3 lesser than R5 such a request will not be granted, only a request for resources more than R5 will be granted.
Detection and Recovery: Another approach to dealing with deadlocks is to detect and recover from them when they occur. This can involve killing one or more of the processes involved in the deadlock or releasing some of the resources they hold.

Deadlock Avoidance

Resource Allocation Graph

The resource allocation graph (RAG) is used to visualize the system's current state as a graph. The Graph includes all processes, the resources that are assigned to them, as well as the resources that each Process requests. Sometimes, if there are fewer processes, we can quickly spot a deadlock in the system by looking at the graph rather

than the tables we use in Banker's algorithm. Deadlock avoidance can also be done with Banker's Algorithm.

Banker's Algorithm

Bankers's Algorithm is a resource allocation and deadlock avoidance algorithm which test all the request made by processes for resources, it checks for the safe state, and after granting a 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.

Inputs to Banker's Algorithm

1. Max needs of resources by each process.
2. Currently, allocated resources by each process.
3. Max free available resources in the system.

The request will only be granted under the below condition

1. If the request made by the process is less than equal to the max needed for that process.
2. If the request made by the process is less than equal to the freely available resource in the system.

Timeouts: To avoid deadlocks caused by indefinite waiting, a timeout mechanism can be used to limit the amount of time a process can wait for a resource. If the help is unavailable within the timeout period, the process can be forced to release its current resources and try again later.

Example:

Total resources in system:
A B C D
6 5 7 6
The total number of resources are
Available system resources are:
A B C D
3 1 1 2
Available resources are
Processes (currently allocated resources):
A B C D
P1 1 2 2 1
P2 1 0 3 3
P3 1 2 1 0
Maximum resources we have for a process
Processes (maximum resources):
A B C D
P1 3 3 2 2
P2 1 2 3 4
P3 1 3 5 0

Need = Maximum Resources Requirement – Currently Allocated Resources.

Need = maximum resources - currently allocated resources.
Processes (need resources):

	A	B	C	D
P1	2	1	0	1
P2	0	2	0	1
P3	0	1	4	0

Deadlock Detection And Recovery

Deadlock detection and recovery is the process of detecting and resolving deadlocks in an operating system. A deadlock occurs when two or more processes are blocked, waiting for each other to release the resources they need. This can lead to a system-wide stall, where no process can make progress.

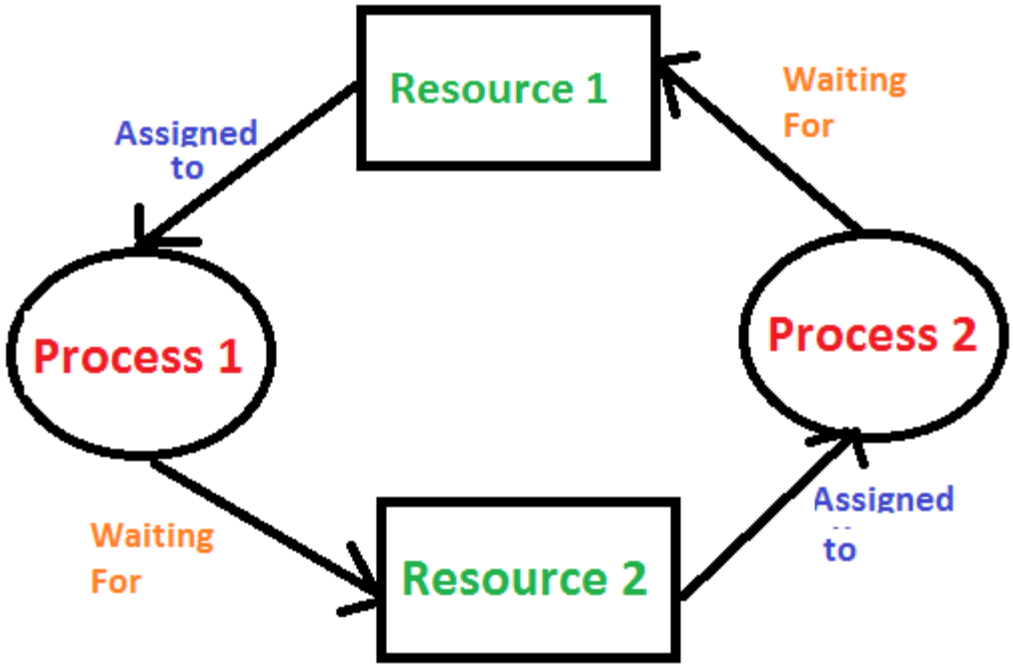
There are two main approaches to deadlock detection and recovery:

1. **Prevention**: The operating system takes steps to prevent deadlocks from occurring by ensuring that the system is always in a safe state, where deadlocks cannot occur. This is achieved through resource allocation algorithms such as the Banker's Algorithm.
2. **Detection and Recovery:** If deadlocks do occur, the operating system must detect and resolve them. Deadlock detection algorithms, such as the Wait-For Graph, are used to identify deadlocks, and recovery algorithms, such as the Rollback and Abort algorithm, are used to resolve them. The recovery algorithm releases the resources held by one or more processes, allowing the system to continue to make progress.

Difference Between Prevention and Detection/Recovery: Prevention aims to avoid deadlocks altogether by carefully managing resource allocation, while detection and recovery aim to identify and resolve deadlocks that have already occurred.
Deadlock detection and recovery is an important aspect of operating system design and management, as it affects the stability and performance of the system. The choice of deadlock detection and recovery approach depends on the specific requirements of the system and the trade-offs between performance, complexity, and risk tolerance. The operating system must balance these factors to ensure that deadlocks are effectively detected and resolved.

In the previous post, we discussed Deadlock Prevention and Avoidance. In this post, the Deadlock Detection and Recovery technique to handle deadlock is discussed.
Deadlock Detection :
1. If resources have a single instance –
In this case for Deadlock detection, we can run an algorithm to check for the cycle in

the Resource Allocation Graph. The presence of a cycle in the graph is a sufficient condition for deadlock.



In the above diagram, resource 1 and resource 2 have single instances. There is a cycle R1 → P1 → R2 → P2. So, Deadlock is Confirmed.

2. If there are multiple instances of resources –
Detection of the cycle is necessary but not a sufficient condition for deadlock detection, in this case, the system may or may not be in deadlock varies according to different situations.

3. Wait-For Graph Algorithm –
The Wait-For Graph Algorithm is a deadlock detection algorithm used to detect deadlocks in a system where resources can have multiple instances. The algorithm works by constructing a Wait-For Graph, which is a directed graph that represents the dependencies between processes and resources.

Deadlock Recovery :
A traditional operating system such as Windows doesn't deal with deadlock recovery as it is a time and space-consuming process. Real-time operating systems use Deadlock recovery.

1. **Killing the process –**
   Killing all the processes involved in the deadlock. Killing process one by one. After

killing each process check for deadlock again and keep repeating the process till the system recovers from deadlock. Killing all the processes one by one helps a system to break circular wait conditions.

2. **Resource Preemption –**
   Resources are preempted from the processes involved in the deadlock, and preempted resources are allocated to other processes so that there is a possibility of recovering the system from the deadlock. In this case, the system goes into starvation.
3. **Concurrency Control –** Concurrency control mechanisms are used to prevent data inconsistencies in systems with multiple concurrent processes. These mechanisms ensure that concurrent processes do not access the same data at the same time, which can lead to inconsistencies and errors. Deadlocks can occur in concurrent systems when two or more processes are blocked, waiting for each other to release the resources they need. This can result in a system-wide stall, where no process can make progress. Concurrency control mechanisms can help prevent deadlocks by managing access to shared resources and ensuring that concurrent processes do not interfere with each other.

ADVANTAGES OR DISADVANTAGES:

Advantages of Deadlock Detection and Recovery in Operating Systems:

1. **Improved System Stability:** Deadlocks can cause system-wide stalls, and detecting and resolving deadlocks can help to improve the stability of the system.
2. **Better Resource Utilization:** By detecting and resolving deadlocks, the operating system can ensure that resources are efficiently utilized and that the system remains responsive to user requests.
3. **Better System Design**: Deadlock detection and recovery algorithms can provide insight into the behavior of the system and the relationships between processes and resources, helping to inform and improve the design of the system.

Disadvantages of Deadlock Detection and Recovery in Operating Systems:

1. **Performance Overhead:** Deadlock detection and recovery algorithms can introduce a significant overhead in terms of performance, as the system must regularly check for deadlocks and take appropriate action to resolve them.
2. **Complexity:** Deadlock detection and recovery algorithms can be complex to implement, especially if they use advanced techniques such as the Resource Allocation Graph or Timestamping.

3. **False Positives and Negatives:** Deadlock detection algorithms are not perfect and may produce false positives or negatives, indicating the presence of deadlocks when they do not exist or failing to detect deadlocks that do exist.
4. **Risk of Data Loss**: In some cases, recovery algorithms may require rolling back the state of one or more processes, leading to data loss or corruption.

Overall, the choice of deadlock detection and recovery approach depends on the specific requirements of the system, the trade-offs between performance, complexity, and accuracy, and the risk tolerance of the system. The operating system must balance these factors to ensure that deadlocks are effectively detected and resolved.

Handling Deadlocks

Methods of handling deadlocks: There are four approaches to dealing with deadlocks.

1. Deadlock Prevention
2. Deadlock avoidance (Banker's Algorithm)
3. Deadlock detection & recovery
4. Deadlock Ignorance (Ostrich Method)

These are explained below.

1. Deadlock Prevention: The strategy of deadlock prevention is to design the system in such a way that the possibility of deadlock is excluded. The indirect methods prevent the occurrence of one of three necessary conditions of deadlock i.e., mutual exclusion, no pre-emption, and hold and wait. The direct method prevents the occurrence of circular wait. **Prevention techniques – Mutual exclusion –** are supported by the OS. **Hold and Wait –** the condition can be prevented by requiring that a process requests all its required resources at one time and blocking the process until all of its requests can be granted at the same time simultaneously. But this prevention does not yield good results because:

- long waiting time required
- inefficient use of allocated resource
- A process may not know all the required resources in advance

No pre-emption – techniques for 'no pre-emption are'

- If a process that is holding some resource, requests another resource that can not be immediately allocated to it, all resources currently being held are released and if necessary, request again together with the additional resource.
- If a process requests a resource that is currently held by another process, the OS may pre-empt the second process and require it to release its resources. This works only if both processes do not have the same priority.

Circular wait One way to ensure that this condition never holds is to impose a total ordering of all resource types and to require that each process requests resources in

increasing order of enumeration, i.e., if a process has been allocated resources of type R, then it may subsequently request only those resources of types following R in ordering.

2. Deadlock Avoidance: The deadlock avoidance Algorithm works by proactively looking for potential deadlock situations before they occur. It does this by tracking the resource usage of each process and identifying conflicts that could potentially lead to a deadlock. If a potential deadlock is identified, the algorithm will take steps to resolve the conflict, such as rolling back one of the processes or pre-emptively allocating resources to other processes. The Deadlock Avoidance Algorithm is designed to minimize the chances of a deadlock occurring, although it cannot guarantee that a deadlock will never occur. This approach allows the three necessary conditions of deadlock but makes judicious choices to assure that the deadlock point is never reached. It allows more concurrency than avoidance detection A decision is made dynamically whether the current resource allocation request will, if granted, potentially lead to deadlock. It requires knowledge of future process requests. Two techniques to avoid deadlock :

1. Process initiation denial
2. Resource allocation denial

Advantages of deadlock avoidance techniques:

- Not necessary to pre-empt and rollback processes
- Less restrictive than deadlock prevention

Disadvantages :

- Future resource requirements must be known in advance
- Processes can be blocked for long periods
- Exists a fixed number of resources for allocation

Banker's Algorithm:

The Banker's Algorithm is based on the concept of resource allocation graphs. A resource allocation graph is a directed graph where each node represents a process, and each edge represents a resource. The state of the system is represented by the current allocation of resources between processes. For example, if the system has three processes, each of which is using two resources, the resource allocation graph would look like this:

Processes A, B, and C would be the nodes, and the resources they are using would be the edges connecting them. The Banker's Algorithm works by analyzing the state of the system and determining if it is in a safe state or at risk of entering a deadlock.

To determine if a system is in a safe state, the Banker's Algorithm uses two matrices: the available matrix and the need matrix. The available matrix contains the amount of each resource currently available. The need matrix contains the amount of each resource required by each process.

The Banker's Algorithm then checks to see if a process can be completed without overloading the system. It does this by subtracting the amount of each resource used by the process from the available matrix and adding it to the need matrix. If the result is in a safe state, the process is allowed to proceed, otherwise, it is blocked until more resources become available.

The Banker's Algorithm is an effective way to prevent deadlocks in multiprogramming systems. It is used in many operating systems, including Windows and Linux. In addition, it is used in many other types of systems, such as manufacturing systems and banking systems.

The Banker's Algorithm is a powerful tool for resource allocation problems, but it is not foolproof. It can be fooled by processes that consume more resources than they need, or by processes that produce more resources than they need. Also, it can be fooled by processes that consume resources in an unpredictable manner. To prevent these types of problems, it is important to carefully monitor the system to ensure that it is in a safe state.

3. Deadlock Detection: Deadlock detection is used by employing an algorithm that tracks the circular waiting and kills one or more processes so that the deadlock is removed. The system state is examined periodically to determine if a set of processes is deadlocked. A deadlock is resolved by aborting and restarting a process, relinquishing all the resources that the process held.

- This technique does not limit resource access or restrict process action.
- Requested resources are granted to processes whenever possible.
- It never delays the process initiation and facilitates online handling.
- The disadvantage is the inherent pre-emption losses.

4. Deadlock Ignorance: In the Deadlock ignorance method the OS acts like the deadlock never occurs and completely ignores it even if the deadlock occurs. This method only applies if the deadlock occurs very rarely. The algorithm is very simple. It says " if the deadlock occurs, simply reboot the system and act like the deadlock never occurred." That's why the algorithm is called the **Ostrich Algorithm**.

Advantages:

- Ostrich Algorithm is relatively easy to implement and is effective in most cases.
- It helps in avoiding the deadlock situation by ignoring the presence of deadlocks.

Disadvantages:

- Ostrich Algorithm does not provide any information about the deadlock situation.
- It can lead to reduced performance of the system as the system may be blocked for a long time.
- It can lead to a resource leak, as resources are not released when the system is blocked due to deadlock.