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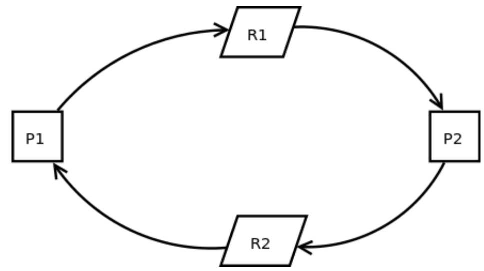
Deadlock

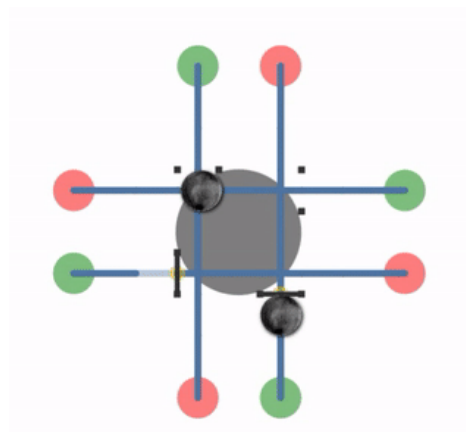
In concurrent computing, a **deadlock** is a state in which each member of a group is waiting for some other member to take action, such as sending a message or more commonly releasing a lock.[1] Deadlock is a common problem in multiprocessing systems, parallel computing, and distributed systems, where software and hardware locks are used to handle shared resources and implement process synchronization.[2]



Both processes need resources to continue execution. *P1* requires additional resource *R1* and is in possession of resource *R2*, *P2* requires additional resource *R2* and is in possession of *R1*; neither process can continue.

In an operating system, a deadlock occurs when a process or thread enters a waiting state because a requested system resource is held by another waiting process, which in turn is waiting for another resource held by another waiting process. If a process is unable to change its state indefinitely because the resources requested by it are being used by another waiting process, then the system is said to be in a deadlock.[3]

In a communications system, deadlocks occur mainly due to lost or corrupt signals rather than resource contention.[4]



Four processes (blue lines) compete for one resource (grey circle), following a right-before-left policy. A deadlock occurs when all processes lock the resource simultaneously (black lines). The deadlock can be resolved by breaking the symmetry.

Contents

Necessary conditions

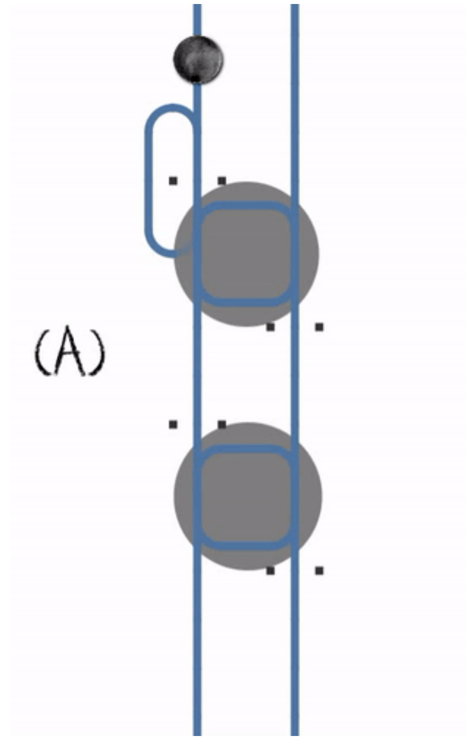
A deadlock situation on a resource can arise if and only if all of the following conditions hold simultaneously in a system:[5]

1. *Mutual exclusion:* At least one resource must be held in a non-shareable mode. Otherwise, the processes would not be prevented from using the resource when necessary. Only one process can use the resource at any given instant

of time.[6]

2. *Hold and wait* or *resource holding:* a process is currently holding at least one resource and requesting additional resources which are being held by other processes.
3. *No preemption:* a resource can be released only voluntarily by the process holding it.
4. *Circular wait:* each process must be waiting for a resource which is being held by another process, which in turn is waiting for the first process to release the resource. In general, there is a set of waiting processes, $P = \{P_1, P_2, \ldots, P_N\}$, such that P_1 is waiting for a resource held by P_2, P_2 is waiting for a resource held by P_3 and so on until P_N is waiting for a resource held by P_1.[3][7]

These four conditions are known as the *Coffman conditions* from their first description in a 1971 article by Edward G. Coffman, Jr.[7]



Two processes competing for two resources in opposite order.
(A) A single process goes through.
(B) The later process has to wait.
(C) A deadlock occurs when the first process locks the first resource at the same time as the second process locks the second resource.
(D) The deadlock can be resolved by cancelling and restarting the first process.

Deadlock handling

Most current operating systems cannot prevent deadlocks.[8] When a deadlock occurs, different operating systems respond to them in different non-standard manners. Most approaches work by preventing one of the four Coffman conditions from occurring, especially the fourth one.[9] Major approaches are as follows.

Ignoring deadlock

In this approach, it is assumed that a deadlock will never occur. This is also an application of the Ostrich algorithm.[9][10] This approach was initially used by MINIX and UNIX.[7] This is used when the time intervals between occurrences of deadlocks are large and the data loss incurred each time is tolerable.

Detection

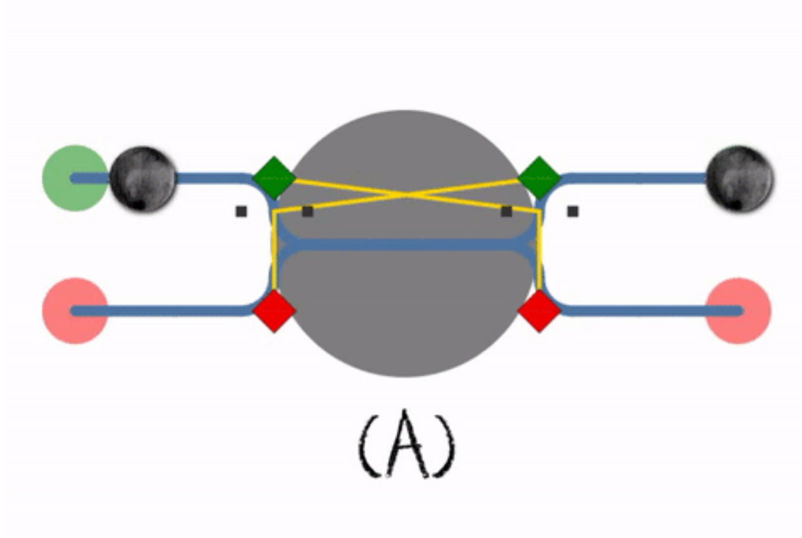
Under the deadlock detection, deadlocks are allowed to occur. Then the state of the system is examined to detect that a deadlock has occurred and subsequently it is corrected. An algorithm is employed that tracks resource allocation and process states, it rolls back and restarts one or more of the processes in order to remove the detected deadlock. Detecting a deadlock that has already occurred is easily possible since the resources that each process has locked and/or currently requested are known to the resource scheduler of the operating system.[10]

After a deadlock is detected, it can be corrected by using one of the following methods:

1. *Process termination:* one or more processes involved in the deadlock may be aborted. One could choose to abort all competing processes involved in the deadlock. This ensures that deadlock is resolved with certainty and speed. But the expense is high as partial computations will be lost. Or, one could choose to abort one process at a time until the deadlock is resolved. This approach has high overhead because after each abort an algorithm must determine whether the system is still in deadlock. Several factors must be considered while choosing a candidate for termination, such as priority and age of the process.
2. *Resource preemption:* resources allocated to various processes may be successively preempted and allocated to

other processes until the deadlock is broken.[11]

Prevention



(A) Two processes competing for one resource, following a first-come, first-served policy. (B) Deadlock occurs when both processes lock the resource simultaneously. (C) The deadlock can be *resolved* by breaking the symmetry of the locks. (D) The deadlock can be *prevented* by breaking the symmetry of the locking mechanism.

Deadlock prevention works by preventing one of the four Coffman conditions from occurring.

- Removing the *mutual exclusion* condition means that no process will have exclusive access to a resource. This proves impossible for resources that cannot be spooled. But even with spooled resources, deadlock could still occur. Algorithms that avoid mutual exclusion are called non-blocking synchronization algorithms.
- The *hold and wait* or *resource holding* conditions may be removed by requiring processes to request all the resources they will need before starting up (or before embarking upon a particular set of operations). This advance knowledge is frequently difficult to satisfy and, in any case, is an inefficient use of resources. Another way is to require processes to request resources only when it has none. Thus, first they must release all their currently held resources before requesting all the resources they will need from scratch. This too is often impractical. It is so because resources may be allocated and remain unused for long periods. Also, a process requiring a popular resource may have to wait indefinitely, as such a resource may always be allocated to some process, resulting in resource starvation.[12] (These algorithms, such as serializing tokens, are known as the *all-or-none algorithms*.)
- The *no preemption* condition may also be difficult or impossible to avoid as a process has to be able to have a resource for a certain amount of time, or the processing outcome may be inconsistent or thrashing may occur. However, inability to enforce preemption may interfere with a *priority* algorithm. Preemption of a "locked out" resource generally implies a rollback, and is to be avoided, since it is very costly in overhead. Algorithms that allow preemption include lock-free and wait-free algorithms and optimistic concurrency control. If a process holding some resources and requests for some another resource(s) that cannot be immediately allocated to it, the condition may be removed by releasing all the currently being held resources of that process.
- The final condition is the *circular wait* condition. Approaches that avoid circular waits include disabling interrupts during critical sections and using a hierarchy to determine a partial ordering of resources. If no obvious hierarchy exists, even the memory address of resources has been used to determine ordering and resources are requested in the increasing order of the enumeration.[3] Dijkstra's solution can also be used.

Livelock

A *livelock* is similar to a deadlock, except that the states of the processes involved in the livelock constantly change with regard to one another, none progressing.

The term was defined formally at some time during the 1970s. An early sighting in the published literature is in Babich's 1979 article on program correctness.[13] Livelock is a special case of resource starvation; the general definition only states that a specific process is not progressing.[14]

Livelock is a risk with some algorithms that detect and recover from *deadlock*. If more than one process takes action, the deadlock detection algorithm can be repeatedly triggered. This can be avoided by ensuring that only one process (chosen arbitrarily or by priority) takes action.[15]

Distributed deadlock

Distributed deadlocks can occur in distributed systems when distributed transactions or concurrency control is being used. Distributed deadlocks can be detected either by constructing a global wait-for graph from local wait-for graphs at a deadlock detector or by a distributed algorithm like edge chasing.

Phantom deadlocks are deadlocks that are falsely detected in a distributed system due to system internal delays but don't actually exist. For example, if a process releases a resource *R1* and issues a request for *R2*, and the first message is lost or delayed, a coordinator (detector of deadlocks) could falsely conclude a deadlock (if the request for *R2* while having *R1* would cause a deadlock).

See also

- Banker's algorithm
- Catch 22
- Circular reference
- Dining philosophers problem
- File locking
- Gridlock (in vehicular traffic)
- Hang
- Impasse
- Infinite loop
- Turn restriction routing
- Linearizability
- Model checker can be used to formally verify that a system will never enter a deadlock
- Ostrich algorithm
- Priority inversion
- Race condition
- Sleeping barber problem
- Stalemate
- Readers-writer lock
- Synchronization

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Further reading

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External links

- "Advanced Synchronization in Java Threads (http://www.onjava.com/pub/a/onjava/2004/10/20/threads2.html)" by Scott Oaks and Henry Wong
- Deadlock Detection Agents (https://web.archive.org/web/20050504052535/http://www-db.in.tum.de/research/projects/dda.html)
- DeadLock at the Portland Pattern Repository
- Etymology of "Deadlock" (http://www.etymonline.com/index.php?term=deadlock)