6.8 Liveness

One consequence of using synchronization tools to coordinate access to critical sections is the possibility that a process attempting to enter its critical section will wait indefinitely. Recall that in Section 6.2, we outlined three criteria that solutions to the critical-section problem must satisfy. Indefinite waiting violates two of these—the progress and bounded-waiting criteria.

Liveness refers to a set of properties that a system must satisfy to ensure that processes make progress during their execution life cycle. A process waiting indefinitely under the circumstances just described is an example of a "liveness failure."

There are many different forms of liveness failure; however, all are generally characterized by poor performance and responsiveness. A very simple example of a liveness failure is an infinite loop. A busy wait loop presents the *possibility* of a liveness failure, especially if a process may loop an arbitrarily long period of time. Efforts at providing mutual exclusion using tools such as mutex locks and semaphores can often lead to such failures in concurrent programming. In this section, we explore two situations that can lead to liveness failures.

6.8.1 Deadlock

The implementation of a semaphore with a waiting queue may result in a situation where two or more processes are waiting indefinitely for an event that can be caused only by one of the waiting processes. The event in question is the execution of a `signal()` operation. When such a state is reached, these processes are said to be **deadlocked**.

To illustrate this, consider a system consisting of two processes, P_0 and P_1, each accessing two semaphores, `S` and `Q`, set to the value 1:

P_0	P_1
`wait(S);`	`wait(Q);`
`wait(Q);`	`wait(S);`
.	.
.	.
.	.
`signal(S);`	`signal(Q);`
`signal(Q);`	`signal(S);`

Suppose that P_0 executes `wait(S)` and then P_1 executes `wait(Q)`. When P_0 executes `wait(Q)`, it must wait until P_1 executes `signal(Q)`. Similarly, when P_1 executes `wait(S)`, it must wait until P_0 executes `signal(S)`. Since these `signal()` operations cannot be executed, P_0 and P_1 are deadlocked.

We say that a set of processes is in a deadlocked state when *every process in the set is waiting for an event that can be caused only by another process in the set*. The "events" with which we are mainly concerned here are the acquisition and release of resources such as mutex locks and semaphores. Other types of events may result in deadlocks, as we show in more detail in Chapter 8. In that chapter, we describe various mechanisms for dealing with the deadlock problem, as well as other forms of liveness failures.

6.8.2 Priority Inversion

A scheduling challenge arises when a higher-priority process needs to read or modify kernel data that are currently being accessed by a lower-priority process—or a chain of lower-priority processes. Since kernel data are typically protected with a lock, the higher-priority process will have to wait for a lower-priority one to finish with the resource. The situation becomes more complicated if the lower-priority process is preempted in favor of another process with a higher priority.

As an example, assume we have three processes—L, M, and H—whose priorities follow the order $L < M < H$. Assume that process H requires a semaphore S, which is currently being accessed by process L. Ordinarily, process H would wait for L to finish using resource S. However, now suppose that process M becomes runnable, thereby preempting process L. Indirectly, a process with a lower priority—process M—has affected how long process H must wait for L to relinquish resource S.

This liveness problem is known as **priority inversion**, and it can occur only in systems with more than two priorities. Typically, priority inversion is avoided by implementing a **priority-inheritance protocol**. According to this protocol, all processes that are accessing resources needed by a higher-priority process inherit the higher priority until they are finished with the resources in question. When they are finished, their priorities revert to their original values. In the example above, a priority-inheritance protocol would allow process L to temporarily inherit the priority of process H, thereby preventing process M from preempting its execution. When process L had finished using resource S, it would relinquish its inherited priority from H and assume its original priority. Because resource S would now be available, process H—not M—would run next.

6.9 Evaluation

We have described several different synchronization tools that can be used to solve the critical-section problem. Given correct implementation and usage, these tools can be used effectively to ensure mutual exclusion as well as address liveness issues. With the growth of concurrent programs that leverage the power of modern multicore computer systems, increasing attention is being paid to the performance of synchronization tools. Trying to identify when to use which tool, however, can be a daunting challenge. In this section, we present some simple strategies for determining when to use specific synchronization tools.

The hardware solutions outlined in Section 6.4 are considered very low level and are typically used as the foundations for constructing other synchronization tools, such as mutex locks. However, there has been a recent focus on using the CAS instruction to construct **lock-free** algorithms that provide protection from race conditions without requiring the overhead of locking. Although these lock-free solutions are gaining popularity due to low overhead