Deadlocks

In a multiprogramming environment, several processes may compete for a finite number of resources. A process requests resources; if the resources are not available at that time, the process enters a waiting state. Sometimes, a waiting process is never again able to change state, because the resources it has requested are held by other waiting processes. This situation is called a **deadlock**. We discussed this issue briefly in Chapter 5 in connection with semaphores.

Perhaps the best illustration of a deadlock can be drawn from a law passed by the Kansas legislature early in the 20th century. It said, in part: "When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up again until the other has gone."

In this chapter, we describe methods that an operating system can use to prevent or deal with deadlocks. Although some applications can identify programs that may deadlock, operating systems typically do not provide deadlock-prevention facilities, and it remains the responsibility of programmers to ensure that they design deadlock-free programs. Deadlock problems can only become more common, given current trends, including larger numbers of processes, multithreaded programs, many more resources within a system, and an emphasis on long-lived file and database servers rather than batch systems.

Bibliographical Notes

Most research involving deadlock was conducted many years ago. [Dijkstra (1965)] was one of the first and most influential contributors in the deadlock area. [Holt (1972)] was the first person to formalize the notion of deadlocks in terms of an allocation-graph model similar to the one presented in this chapter. Starvation was also covered by [Holt (1972)]. [Hyman (1985)] provided the deadlock example from the Kansas legislature. A study of deadlock handling is provided in [Levine (2003)].

The various prevention algorithms were suggested by [Havender (1968)], who devised the resource-ordering scheme for the IBM OS/360 system. The banker's algorithm for avoiding deadlocks was developed for a single resource

type by [Dijkstra (1965)] and was extended to multiple resource types by [Habermann (1969)].

The deadlock-detection algorithm for multiple instances of a resource type, which is described in Section 7.6.2, was presented by [Coffman et al. (1971)].

[Bach (1987)] describes how many of the algorithms in the traditional UNIX kernel handle deadlock. Solutions to deadlock problems in networks are discussed in works such as [Culler et al. (1998)] and [Rodeheffer and Schroeder (1991)].

The witness lock-order verifier is presented in [Baldwin (2002)].

Bibliography

[Bach (1987)] M. J. Bach, *The Design of the UNIX Operating System*, Prentice Hall (1987).

[Baldwin (2002)] J. Baldwin, "Locking in the Multithreaded FreeBSD Kernel", *USENIX BSD* (2002).

[Coffman et al. (1971)] E. G. Coffman, M. J. Elphick, and A. Shoshani, "System Deadlocks", *Computing Surveys*, Volume 3, Number 2 (1971), pages 67–78.

[Culler et al. (1998)] D. E. Culler, J. P. Singh, and A. Gupta, *Parallel Computer Architecture: A Hardware/Software Approach*, Morgan Kaufmann Publishers Inc. (1998).

[Dijkstra (1965)] E. W. Dijkstra, "Cooperating Sequential Processes", Technical report, Technological University, Eindhoven, the Netherlands (1965).

[Habermann (1969)] A. N. Habermann, "Prevention of System Deadlocks", *Communications of the ACM*, Volume 12, Number 7 (1969), pages 373–377, 385.

[Havender (1968)] J. W. Havender, "Avoiding Deadlock in Multitasking Systems", *IBM Systems Journal*, Volume 7, Number 2 (1968), pages 74–84.

[Holt (1972)] R. C. Holt, "Some Deadlock Properties of Computer Systems", *Computing Surveys*, Volume 4, Number 3 (1972), pages 179–196.

[Hyman (1985)] D. Hyman, *The Columbus Chicken Statute and More Bonehead Legislation*, S. Greene Press (1985).

[Levine (2003)] G. Levine, "Defining Deadlock", *Operating Systems Review*, Volume 37, Number 1 (2003).

[Rodeheffer and Schroeder (1991)] T. L. Rodeheffer and M. D. Schroeder, "Automatic Reconfiguration in Autonet", *Proceedings of the ACM Symposium on Operating Systems Principles* (1991), pages 183–97.