The scene depicted is set during the late Cretaceous period in the western United States. A *Tyrannosaurusrex* threatens a *Staurikosaurus* while a small varanid lizard is safe in a jumble of rocks. A small herd of *Ornithomimus* stays out of the way in the background while *Pterosaurs* circle in flight above. The massive *Alamosaurus* seems unconcerned by the confrontation.

To *my parents, Wira and Mietek,*
and my children, Lemor, Sivan, and Aaron.

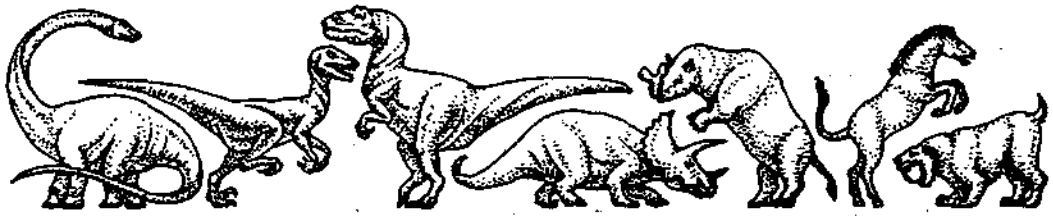
Avi Silberschatz

To Carla, Gwendolyn, and Owen

Peter Galvin

OPERATING SYSTEM CONCEPTS

Fifth Edition



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PREFACE

Operating systems are an essential part of any computer system. Similarly, a course on operating systems is an essential part of any computer-science education. This book is intended as a text for an introductory course in operating systems at the junior or senior undergraduate level, or at the first-year graduate level. It provides a clear description of the *concepts* that underlie operating systems.

In this book, we do not concentrate on any particular operating system or hardware. Instead, we discuss fundamental concepts that are applicable to a variety of systems. We present a large number of examples that pertain specifically to UNIX and to other popular operating systems. In particular, we use Sun Microsystem's Solaris 2 operating system, a version of UNIX, which recently has been transformed into a modern operating system with support for threads at the kernel and user levels, symmetric multiprocessing, and real-time scheduling. Other examples used include Microsoft MS-DOS, Windows, and Windows NT, Linux, IBM OS/2, the Apple Macintosh Operating System, and DEC VMS and TOPS-20.

Prerequisites

As prerequisites, we assume that the reader is familiar with general computer organization and with a high-level language, such as Pascal. The hardware topics required for an understanding of operating systems are included in Chapter 2. We use pseudo-Pascal notation for code examples, but the algo-

rithms can be understood by people who do not have a thorough knowledge of Pascal.

Content of this Book

The text is organized in seven major parts:

- Overview (Chapters 1 to 3). These chapters explain what operating systems *are*, what they *do*, and how they are *designed* and *constructed*. They explain how the concept of an operating system has developed, what the common features of an operating system are, what an operating system does for the user, and what it does for the computer-system operator. The presentation is motivational, historical, and explanatory in nature. We have avoided a discussion of how things are done internally in these chapters. Therefore, they are suitable for individuals or for students in lower-level classes who want to learn what an operating system is, without getting into the details of the internal algorithms. Chapter 2 covers the hardware topics that are important to an understanding of operating systems. Readers well-versed in hardware topics, including I/O, DMA, and hard-disk operation, may chose to skim or skip this chapter.

- Process management (Chapters 4 to 7). The process concept and concurrency are at the heart of modern operating systems. A *process* is the unit of work in a system. Such a system consists of a collection of *concurrently* executing processes, some of which are operating-system processes (those that execute system code), and the rest of which are user processes (those that execute user code). These chapters cover various methods for process scheduling, interprocess communication, process synchronization, and deadlock handling. Also included under this topic is a discussion of threads.

- Memory and storage management (Chapters 8 to 11). A process must be in main memory (at least partially) during execution. To improve both the utilization of CPU and the speed of its response to its users, the computer must keep several processes in memory. There are many different memory-management schemes. These schemes reflect various approaches to memory management, and the effectiveness of the different algorithms depends on the particular situation. Since main memory is usually too small to accommodate all data and programs, and since it cannot store data permanently, the computer system must provide secondary storage to back up main memory. Most modern computer systems use disks as the primary on-line storage medium for information (both programs and data). The file system provides the mechanism for on-line storage of and access to both data and programs residing on the disks. These chapters deal

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