



1-Introduction

An **operating system** is a program that manages a computer's hardware. It also provides a basis for application programs and acts as an intermediary between the computer user and the computer hardware. An amazing aspect of operating systems is how they vary in accomplishing these tasks. Mainframe operating systems are designed primarily to optimize utilization of hardware. Personal computer (PC) operating systems support complex games, business applications, and everything in between. Operating systems for mobile computers provide an environment in which a user can easily interface with the computer to execute programs. Thus, some operating systems are designed to be **convenient**, others to be **efficient**, and others to be some combination of the two.

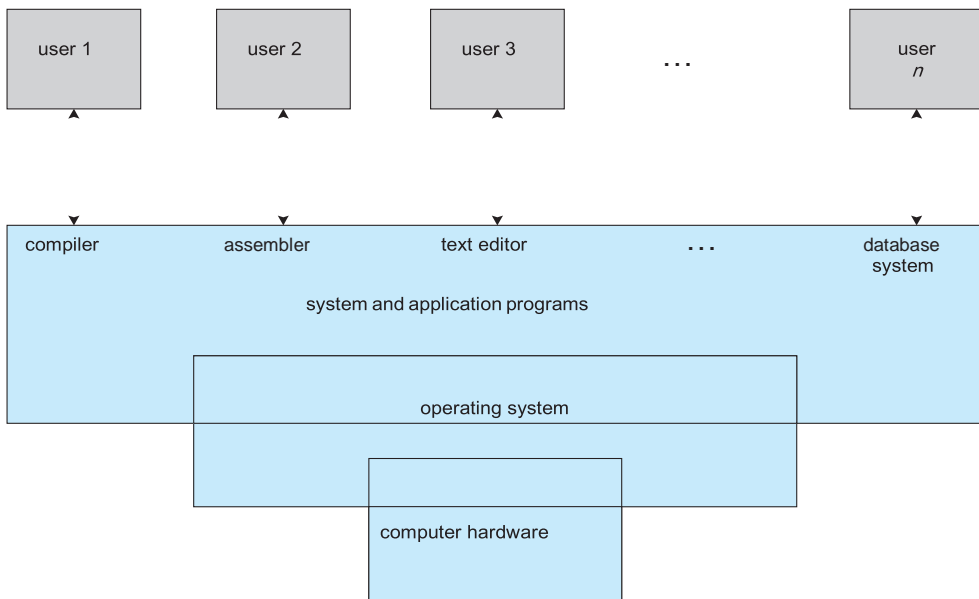


Figure 1.1 Abstract view of the components of a computer system.

1.1 What Operating Systems Do

We begin our discussion by looking at the operating system's role in the overall computer system. A computer system can be divided roughly into four components: the **hardware**, the **operating system**, the **application programs**, and the **users** (Figure 1.1).

The **hardware**—the **central processing unit (CPU)**, the **memory**, and the **input/output (I/O) devices**—provides the basic computing resources for the system. The **application programs**—such as word processors, spreadsheets, compilers, and Web browsers—define the ways in which these resources are used to solve users' computing problems. The operating system controls the hardware and coordinates its use among the various application programs for the various users.

1.1.1 Computer-System Operation

A modern general-purpose computer system consists of one or more CPUs and a number of device controllers connected through a common bus that provides access to shared memory (Figure 1.2). Each device controller is in charge of a specific type of device (for example, disk drives, audio devices, or video displays). The CPU and the device controllers can execute in parallel, competing for memory cycles. To ensure orderly access to the shared memory, a memory controller synchronizes access to the memory.

For a computer to start running—for instance, when it is powered up or rebooted—it needs to have an initial program to run. This initial program, or **bootstrap program**, tends to be simple. Typically, it is stored within the computer hardware in read-only memory (**ROM**) or electrically erasable programmable read-only memory (**EEPROM**), known by the general term **firmware**. It initializes all aspects of the system, from CPU registers to device controllers to memory contents. The bootstrap program must know how to load the operating system and how to start executing that system. To accomplish this goal, the bootstrap program must locate the operating-system kernel and load it into memory.

Once the kernel is loaded and executing, it can start providing services to the system and its users. Some services are provided outside of the kernel, by system programs that are loaded into memory at boot time to become **system processes**, or **system daemons** that run the entire time the kernel is running. On UNIX, the first system process is “init,” and it starts many other daemons. Once this phase is complete, the system is fully booted, and the system waits for some event to occur.

The occurrence of an event is usually signaled by an **interrupt** from either the hardware or the software. Hardware may trigger an interrupt at

any time by sending a signal to the CPU, usually by way of the system bus. Software may trigger an interrupt by executing a special operation called a **system call** (also called a **monitor call**).

When the CPU is interrupted, it stops what it is doing and immediately transfers execution to a fixed location. The fixed location usually contains the starting address where the service routine for the interrupt is located. The interrupt service routine executes; on completion, the CPU resumes the interrupted computation.

Interrupts are an important part of a computer architecture. Each computer design has its own interrupt mechanism, but several functions are common. The interrupt must transfer control to the appropriate interrupt service routine. The straightforward method for handling this transfer would be to invoke a generic routine to examine the interrupt information. The interrupt routine is called indirectly through the table, with no intermediate routine needed. Generally, the table of pointers is stored in low memory (the first hundred or so locations). These locations hold the addresses of the interrupt service routines for the various devices. *This array, or **interrupt vector**, of addresses is then indexed by a unique device number, given with the interrupt request, to provide the address of the interrupt service routine for the interrupting device.* Operating systems as different as Windows and UNIX dispatch interrupts in this manner.

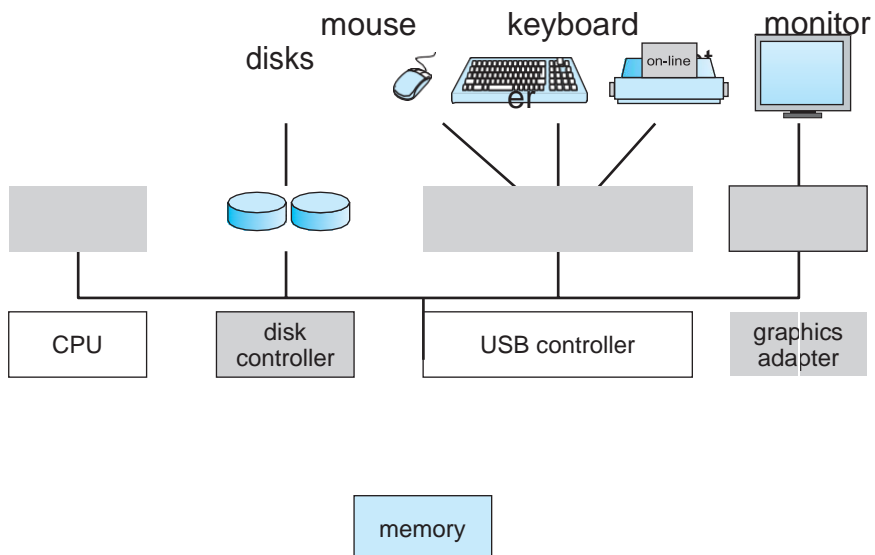


Figure 1.2 A modern computer system.

STORAGE DEFINITIONS AND NOTATION

The basic unit of computer storage is the **bit**. A bit can contain one of two values, 0 and 1. All other storage in a computer is based on collections of bits. Given enough bits, it is amazing how many things a computer can represent: numbers, letters, images, movies, sounds, documents, and programs, to name a few. A **byte** is 8 bits, and on most computers it is the smallest convenient chunk of storage. For example, most computers don't have an instruction to move a bit but do have one to move a byte. A less common term is **word**, which is a given computer architecture's native unit of data. A word is made up of one or more bytes. For example, a computer that has 64-bit registers and 64-bit memory addressing typically has 64-bit (8-byte) words. A computer executes many operations in its native word size rather than a byte at a time. Computer storage, along with most computer throughput, is generally measured and manipulated in bytes and collections of bytes. A Computer manufacturer often round off these numbers and say that a megabyte is 1 million bytes and a gigabyte is 1 billion bytes. Networking measurements are an exception to this general rule; they are given in bits (because networks move data a bit at a time).

Storage Structure 1.1.1

The CPU can load instructions only from memory, so any programs to run must be stored there. General-purpose computers run most of their programs from rewritable memory, called main memory (also called **random-access memory**, or **RAM**). Main memory commonly is implemented in a semiconductor technology called **dynamic random-access memory (DRAM)**.

Computers use other forms of memory as well. We have already mentioned read-only memory, ROM) and electrically erasable programmable read-only memory, EEPROM). Because ROM cannot be changed, only static programs, such as the bootstrap program described earlier, are stored there. The immutability of ROM is of use in game cartridges. EEPROM can be changed but cannot be changed frequently and so contains mostly static programs. For example, smartphones have EEPROM to store their factory-installed programs.

All forms of memory provide an array of bytes. Each byte has its own address. Interaction is achieved through a sequence of load or store instructions to specific memory addresses. The load instruction moves a byte or word from main memory to an internal register within the CPU, whereas the store instruction moves the content of a register to main memory. Aside from explicit loads and stores, the CPU automatically loads instructions from main memory for execution.

A typical instruction–execution cycle, as executed on a system with a **von Neumann architecture**, first fetches an instruction from memory and stores that instruction in the **instruction register**. The instruction is then decoded and may cause operands to be fetched from memory and stored in some internal register. After the instruction on the operands has been executed, the result may be stored back in memory. Notice that the memory unit sees only a stream of memory addresses. It does not know how they are generated (by the instruction counter, indexing, indirection, literal addresses, or some other means) or what they are for (instructions or data). Accordingly, we can ignore *how* a memory address is generated by a program. We are interested only in the sequence of memory addresses generated by the running program.

Ideally, we want the programs and data to reside in main memory permanently. This arrangement usually is not possible for the following two reasons:

1. Main memory is usually too small to store all needed programs and data permanently.
2. Main memory is a **volatile** storage device that loses its contents when power is turned off or otherwise lost.

Thus, most computer systems provide **secondary storage** as an extension of main memory. The main requirement for secondary storage is that it be able to hold large quantities of data permanently.

The most common secondary-storage device is a **magnetic disk**, which provides storage for both programs and data. Most programs (system and application) are stored on a disk until they are loaded into memory. Many programs then use the disk as both the source and the destination of their processing. Hence, the proper management of disk storage is of central importance to a computer system, as we discuss in Chapter 10.

In a larger sense, however, the storage structure that we have described—consisting of registers, main memory, and magnetic disks—is only one of many possible storage systems. Others include cache memory, CD-ROM, magnetic tapes, and so on. Each storage system provides the basic functions of storing a datum and holding that datum until it is retrieved at a later time. The main differences among the various storage systems lie in speed, cost, size, and

volatility.

The wide variety of storage systems can be organized in a hierarchy (Figure 1.4) according to speed and cost. The higher levels are expensive, but they are fast. As we move down the hierarchy, the cost per bit generally decreases, whereas the access time generally increases. This trade-off is reasonable; if a given storage system were both faster and less expensive than another—other properties being the same—then there would be no reason to use the slower, more expensive memory.

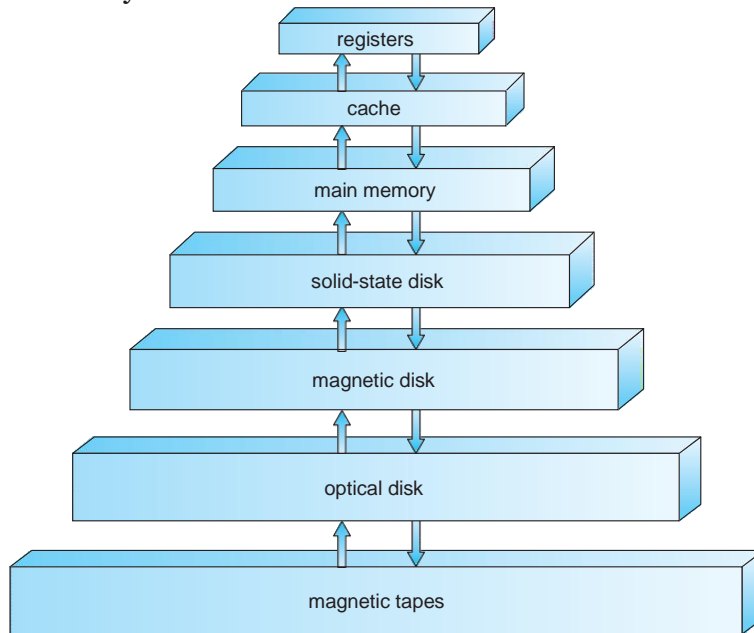


Figure 1.4 Storage-device hierarchy.

now that magnetic tape and **semiconductor memory** have become faster and cheaper. The top four levels of memory in Figure 1.4 may be constructed using semiconductor memory.

Solid-state disks have several variants but in general are faster than magnetic disks and are nonvolatile. One type of solid-state disk stores data in a large DRAM array during normal operation but also contains a hidden magnetic hard disk and a battery for backup power. If external power is interrupted, this solid-state disk's controller copies the data from RAM to the magnetic disk. When external power is restored, the controller copies the data back into RAM. Another form of solid-state disk is flash memory, which is popular in cameras and **personal digital assistants (PDAs)**, in robots, and increasingly for storage on general-purpose computers. Flash memory is slower than DRAM but needs no power to retain its contents. Another form of nonvolatile storage is **NVRAM**, which is DRAM with battery backup power. This memory can be as fast as

DRAM and (as long as the battery lasts) is nonvolatile.

The design of a complete memory system must balance all the factors just discussed: it must use only as much expensive memory as necessary while providing as much inexpensive, nonvolatile memory as possible. Caches can be installed to improve performance where a large disparity in access time or transfer rate exists between two components.

1.8.1 File-System Management

File management is one of the most visible components of an operating system. Computers can store information on several different types of physical media. Magnetic disk, optical disk, and magnetic tape are the most common. Each of these media has its own characteristics and physical organization. Each medium is controlled by a device, such as a disk drive or tape drive, that also has its own unique characteristics. These properties include access speed, capacity, data-transfer rate, and access method (sequential or random).

A file is a collection of related information defined by its creator. Commonly, files represent programs (both source and object forms) and data. Data files may be numeric, alphabetic, alphanumeric, or binary. Files may be free-form (for example, text files), or they may be formatted rigidly (for example, fixed fields). Clearly, the concept of a file is an extremely general one.

The operating system implements the abstract concept of a file by managing mass-storage media, such as tapes and disks, and the devices that control them. In addition, files are normally organized into directories to make them easier to use. Finally, when multiple users have access to files, it may be desirable to control which user may access a file and how that user may access it (for example, read, write, append).

The operating system is responsible for the following activities in connection with file management:

- Creating and deleting files
- Creating and deleting directories to organize files
- Supporting primitives for manipulating files and directories
- Mapping files onto secondary storage
- Backing up files on stable (nonvolatile) storage media

File-management techniques are discussed in Chapters 11 and 12.

1.8.2 Mass-Storage Management

As we have already seen, because main memory is too small to accommodate all data and programs, and because the data that it holds are lost when power is lost, the computer system must provide

secondary storage to back up main memory. Most modern computer systems use disks as the principal on-line storage medium for both programs and data. Most programs—including compilers, assemblers, word processors, editors, and formatters—are stored on a disk until loaded into memory. They then use the disk as both the source and destination of their processing. Hence, the proper management of disk storage is of central importance to a computer system. The operating system is responsible for the following activities in connection with disk management:

- Free-space management
- Storage allocation
- Disk scheduling

Because secondary storage is used frequently, it must be used efficiently. The entire speed of operation of a computer may hinge on the speeds of the disk subsystem and the algorithms that manipulate that subsystem.

Techniques for secondary and tertiary storage management are discussed in Chapter 10.

1.8.3 Caching

Caching is an important principle of computer systems. Here's how it works. Information is normally kept in some storage system (such as main memory). As it is used, it is copied into a faster storage system—the cache—on a temporary basis. When we need a particular piece of information, we first check whether it is in the cache. If it is, we use the information directly from the cache. If it is not, we use the information from the source, putting a copy in the cache under the assumption that we will need it again soon.

In addition, internal programmable registers, such as index registers, provide a high-speed cache for main memory. The programmer (or compiler) implements the register-allocation and register-replacement algorithms to decide which information to keep in registers and which to keep in main memory.

Other caches are implemented totally in hardware. For instance, most systems have an instruction cache to hold the instructions expected to be executed next. Without this cache, the CPU would have to wait several cycles while an instruction was fetched from main memory. For similar reasons, most systems have one or more high-speed data caches in the memory hierarchy. We are not concerned with these hardware-only caches in this text, since they are outside the control of the operating system.

Main memory can be viewed as a fast cache for secondary storage, since data in secondary storage must be copied into main memory for use and data must be in main memory before being moved to secondary storage for safekeeping. The file-

system data, which resides permanently on secondary storage, may appear on several levels in the storage hierarchy.

At the highest level, the operating system may maintain a cache of file-system data in main memory. In addition, solid-state disks may be used for high-speed storage that is accessed through the file-system interface. The bulk of secondary storage is on magnetic disks. The magnetic-disk storage, in turn, is often backed up onto magnetic tapes or removable disks to protect against data loss in case of a hard-disk failure. Some systems automatically archive old file data from secondary storage to tertiary storage, such as tape jukeboxes, to lower the storage cost (see Chapter 10).

Level	1	2	3	4	5
Name	registers	cache	main memory	solid state disk	magnetic disk
Typical size	< 1 KB	< 16MB	< 64GB	< 1 TB	< 10 TB
Implementation technology	custom memory with multiple ports CMOS	on-chip or off-chip CMOS SRAM	CMOS SRAM	flash memory	magnetic disk
Access time (ns)	0.25 - 0.5	0.5 - 25	80 - 250	25,000 - 50,000	5,000,000
Bandwidth (MB/sec)	20,000 - 100,000	5,000 - 10,000	1,000 - 5,000	500	20 - 150
Managed by	compiler	hardware	operating system	operating system	operating system
Backed by	cache	main memory	disk	disk	disk or tape

Figure 1.11 Performance of various levels of storage.

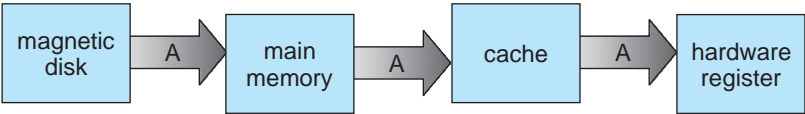


Figure 1.12 Migration of integer A from disk to register.

1.8.4 I/O Systems

One of the purposes of an operating system is to hide the peculiarities of specific hardware devices from the user. For example, in UNIX, the peculiarities of I/O

devices are hidden from the bulk of the operating system itself by the **I/O subsystem**. The I/O subsystem consists of several components:

- A memory-management component that includes buffering, caching, and spooling
- A general device-driver interface
- Drivers for specific hardware devices

Only the device driver knows the peculiarities of the specific device to which it is assigned.

system components, manages devices, transfers data, and detects I/O completion.