

Chapter 7

Device Management

At a Glance

Instructor's Manual Table of Contents

- Overview
- Objectives
- Teaching Tips
- Quick Quizzes
- Class Discussion Topics
- Additional Projects
- Additional Resources
- Key Terms

Lecture Notes

Overview

The Device Manager manages every peripheral device of the system. It must maintain a delicate balance of supply and demand, balancing the system's finite supply of devices with users' infinite demand for them. Device management involves four basic functions, which are discussed in this chapter.

This chapter begins by explaining the three different categories of devices: dedicated, shared, and virtual. An explanation of different types of sequential and direct access media follows. The concepts of blocking and buffering and the critical components of the I/O subsystem are presented next. This is followed by a discussion and comparison of the strengths and weaknesses of common seek strategies. The chapter concludes with a comprehensive presentation of RAID.

Learning Objectives

After completing this chapter, the student should be able to describe:

- Features of dedicated, shared, and virtual devices
- Differences between sequential and direct access media
- Concepts of blocking and buffering and how they improve I/O performance
- Roles of seek time, search time, and transfer time in calculating access time
- Differences in access times in several types of devices
- Critical components of the input/output subsystem, and how they interact
- Strengths and weaknesses of common seek strategies, including FCFS, SSTF, SCAN/LOOK, C-SCAN/C-LOOK, and how they compare
- Different levels of RAID and what sets each apart from the others

Teaching Tips

Types of Devices

1. Review the role of the Device Manager, noting that the component must manage every peripheral device in the system. It does this by balancing the finite supply of devices with the user's infinite requests for them. Outline the four basic functions of device management that will be explained in this chapter.
 - a. Device status monitoring
 - b. Enforcing preset policies determining the process to get a device and for how long
 - c. Allocating the devices
 - d. Deallocating the devices at two levels (process level and job level)

2. Review the three categories of peripheral devices that the Device Manager must control: dedicated, shared, and virtual. Point out that the difference between these device types involves two items: device characteristics and device manager oversight.
3. Describe dedicated devices, emphasizing that they are assigned to only one job at a time and that the device serves the job until it completes its execution or explicitly releases the device. Point out the disadvantage of dedicated devices, which is that they must be allocated to a single user for the duration of a job's execution.
4. Describe shared devices, emphasizing that they are assigned to several processes at a time. Provide an example: DASD. Point out that the disadvantage of shared DASD devices is that the requests are interleaved and they must be carefully controlled by the Device Manager. Note that policies for conflict resolution are necessary.
5. Describe virtual devices, emphasizing that they are a combination of dedicated and shared devices. In effect, dedicated devices are transformed into shared devices. Provide an example such as the printer. Discuss their advantages, such as improving performance and device use by converting one physical device into several virtual devices. Discuss how spooling is used to speed up slow dedicated printing devices. Be sure to explain USB controllers, a virtual device that has become important in recent years.
6. Outline two categories of storage media: sequential access media and direct access storage devices (DASD). Compare the vast difference in speed and sharability of these media.

Teaching Tip	Refer to the following link for more information about USB controllers: www.usbman.com/USB%20%20News.htm
---------------------	---

Sequential Access Storage Media

1. Explain the important features of magnetic tape, such as how records are stored serially on magnetic tapes, the factors that determine the length of a record, and how records are accessed on a magnetic tape.
2. Use Figure 7.1 on page 208 in the text to demonstrate how long it takes to access a single record on a tape. Discuss the details of tape density, noting it is the number of characters that can be recorded per inch. Provide some examples. Explain the mechanics of reading and writing to a tape.
3. Discuss the processes of storing records individually and in blocks. Make sure the students understand the terms *interrecord gap* (IRG), *interblock gap* (IBG), and *transfer rate*.
4. Use Figure 7.2 and Figure 7.3 on pages 207 and 208 of the text to explain each type of storage. Explain how blocking results in efficient recording of tapes.

5. Discuss the advantages and disadvantages of storing records in blocks.
6. Discuss the advantages of magnetic tape. Discuss how long it takes to access a block or record on a magnetic tape and the factors that influence access time. Use Table 7.1 on page 210 in the text to point out that access times can vary widely. This makes magnetic tape a poor medium for routine secondary storage except for files with very high sequential activity.

Direct Access Storage Devices

1. Provide an overview of direct access storage devices (DASD), which can directly read or write to a specific place on a disk.
2. Outline four different categories of DASD: magnetic disks, optical discs, flash memory, and magneto-optical disks. Point out that there are two types of magnetic disks: fixed-head magnetic disk storage and movable-head magnetic disk storage. Compare magnetic tape to DASD in terms of access time. The variance in access time in DASD is not as wide as that found in magnetic tape; however, the location of the specific record does have a direct effect on DASD access time.

Fixed-Head Magnetic Disk Storage

1. Provide students with an overview of fixed-head magnetic disk storage. Describe its similar features to a CD or DVD as well as its formatting features. Discuss how data is recorded and present the advantages and disadvantages of this media.
2. Use Figure 7.4 on page 211 in the text to illustrate the fixed-head disk pictorially.

Movable-Head Magnetic Disk Storage

1. Provide students with an overview of movable-head magnetic disk storage. Describe its features in terms of likeliness to a computer hard drive. Discuss how it has one read/write head that floats over each surface of each disk. Note that the disk may be a single platter or part of a disk pack platter. Describe a disk pack platter.
2. Use Figure 7.5 on page 212 in the text to illustrate the movable-head disk pack pictorially.
3. Refer the student to Figure 7.6 on page 212 in the text for a more detailed image describing the read/write process of a hard drive.

Teaching Tip

Read about current research at the IBM Almaden Research Center in the area of magnetic tape storage exploring:

www.almaden.ibm.com/st/magnetism/magnetic_storage/tape

Optical Disc Storage

1. Discuss how optical disc technology was made possible with the advent of laser technology and the success of the audio CD.
2. The magnetic disk differs from the optical disc in many ways. Examples include the design of the disc track and sectors, as well as the use of constant angular velocity (CAV). Use Figure 7.7 on page 213 in the text to illustrate these differences.
3. The optical disc has several features worth mentioning: a single spiraling track of same-sized sectors; same-size sectors regardless of their locations, and the adjustment of the disc drive spin to compensate for the sector's location on the disc (constant linear velocity, or CLV). Explain each of these. Use Figure 7.8 on page 214 in the text to illustrate these features.
4. Discuss two important performance measures: sustained data-transfer rate and average access time. Point out a third important feature of optical disc drives: cache size. While not a speed measurement, cache size has a substantial impact on perceived performance because it acts as a buffer by transferring blocks of data from the disc.
5. Describe the details of CD-ROM (read-only memory) optical technology discs. Note that the major difference between an audio CD and a CD-ROM is that CD-ROM drives are sturdier and have rigorous error-correction methods to make sure that data transferred from the disc to main memory is correct. Describe how data is recorded on CD-ROM and the various speed classifications.
6. Describe the details of CD-Recordable Technology (CD-R) optical technology discs. Note that this technology requires a more expensive controller than the CD-ROM drives because the user may write once to the disc. Discuss the composition of the CD-R disc and describe how the data is recorded. Note that it cannot be erased after it is recorded (it can only be read).
7. Describe the details of CD-Rewritable Technology (CD-RW) optical technology discs. Note that this technology uses phase change technology to write, change, and erase data. Describe the CD-RW disc recording layers and how data is recorded and erased.
8. Describe the details of DVD Technology (DVD-ROM) optical technology discs. Note their similarity in design to CD-ROMs. Point out that the major difference is the much greater amount of data a DVD can hold and the use of red lasers. Describe the advantages of compression technology and mention the flexibility provided by DVD-R and DVD-RW technologies.

**Teaching
Tip**

Learn more about optical storage at the Optical Storage Technology Association (OSTA) Organization home page: www.osta.org/index.htm

Magneto-Optical Storage

1. Provide students with an overview of magneto-optical (MO) storage, which combines magnetic and optical disk technology. Provide a comparison to magnetic storage by noting that MO disks read and write similarly; however, the MO disks store significantly more data (several GBs). Their access rate is faster than that of a floppy disk but slower than that of hard drives. The greatest advantage for a MO disk over a magnetic disk is that the MO disk is much hardier.
2. Explain the read/write process for magneto-optical devices.

Flash Memory Storage

1. Provide students with an overview of flash memory, which is a removable medium that emulates RAM, but stores data securely even when it is removed from its power source.
2. Discuss how data is stored and erased in this type of device. Outline different configurations of flash memory, such as compact flash, smart cards, and memory sticks. Discuss their advantages and disadvantages.

Teaching Tip	Refer to the following link for more information about flash memory storage: www.dansdata.com/flashcomp.htm
---------------------	--

DASD Access Times

1. Explain the three factors that contribute to the time required to access a file: seek time, search time, and transfer time.

Fixed-Head Devices

1. Discuss how a fixed-head device accesses a record and the factors involved. Point out that in the case of fixed-head devices, access time depends on search time and transfer time only. Note that because DASDs rotate continuously, there are three basic positions for the requested record in relation to the position of the read/write head. Also, point out that because there is little variance in access, DASDs are good for files with low activity or for users who access records in a random fashion.
2. Use Figure 7.9 and Table 7.2 on page 219 to illustrate these points. Discuss also how blocking results in minimizing the access time.

Movable-Head Devices

1. Point out that in the case of movable-head devices, access time is the sum of all three factors. Seek time is the third element and represents the time to move the arm into position over the proper track. Note that the maximum seek time is typically 50 ms.

2. Use Table 7.3 on page 212 to illustrate access time differences.
3. Point out that movable-head DASDs are much more common than fixed-head DASDs because they are less costly and have larger capacities, although their retrieval time is longer.

Quick Quiz 1

1. Which of the following are direct access storage devices? (Choose all that apply.)
 - a. Punch cards
 - b. Fixed-head magnetic disk storage
 - c. Magnetic tape
 - d. Magneto-optical (MO) discAnswer: b and d
2. Which of the following storage devices uses phase change technology to write data?
 - a. Magneto-optical (MO) disc
 - b. CD-R discs
 - c. CD-RW discs
 - d. Magnetic disksAnswer: c
3. _____, also known as rotational delay, is the time it takes to rotate the DASD until the requested record is moved under the read/write head.
Answer: Search time

Components of the I/O Subsystem

1. Provide students with an overview of the configuration of an I/O subsystem by referring to the mythical “Flynn Taxicab Company” described on page 211 in the text and articulated pictorially using Figure 7.10 on page 222 in the text.
2. Explain the functions of each I/O subsystem component including channels, control units, and devices. Point out that the I/O channel keeps up with I/O requests from the CPU, passes them down the line to the appropriate control unit, and synchronizes the fast speed of CPU with the slow speed of the I/O device.
3. Point out that the entire path must be available when an I/O command is initiated. Outline the information that is passed from the CPU to a channel at the start of an I/O command. Use Figure 7.11 on page 224 in the text to clarify these points.
4. Discuss how an I/O subsystem configuration with multiple paths increases both flexibility and reliability. Use Figure 7.12 on page 224 in the text to clarify this point.

Communication Among Devices

1. Outline three problems that must be resolved in order for the Device Manager to run efficiently under the demanding conditions of a busy computer system. It needs to know which components are busy and which are free; it must be able to accommodate the requests that come in during heavy I/O traffic; and it must accommodate the disparity of speeds between the CPU and the I/O devices.
2. Discuss, using examples, how each unit in an I/O subsystem can finish its operation independently from the others.
3. Discuss the structure of a hardware flag and how it is used to test whether or not a device has completed an operation. Discuss two methods of testing the flag by the CPU, namely by polling and using interrupts. Discuss the pros and cons of each method. Point out that the use of interrupts is a more efficient way to test a flag.
4. Discuss the direct memory access (DMA) technique that allows a control unit to access main memory directly and transfer data without the intervention of the CPU. Point out that this technique is used for high-speed devices such as disks.
5. Point out that without DMA, the CPU is responsible for the physical movement of data between main memory and the device, a time-consuming task that results in significant overhead and decreased CPU utilization.
6. Discuss the roles of buffers, which are temporary storage areas residing in main memory, channels, and control units. Provide an example of their usefulness when blocked records are either read from or written to an I/O device.
7. Explain how double buffering helps to minimize the idle time for devices and to maximize their throughput. Use the example in Figure 7.13 on page 227 in the text to illustrate this point.

Management of I/O Requests

1. Describe the main tasks of each of the three software components that manage I/O requests in an I/O subsystem, namely, the I/O traffic controller, I/O scheduler, and I/O device handler.
2. Point out that the I/O traffic controller maintains a database containing the status and connections for each unit in the I/O subsystem, as shown in Table 7.4 on page 228 in the text.
3. Remind students of the job of the Process Scheduler, because the I/O scheduler carries out a similar task. However, I/O requests are typically not preempted.

Device Handler Seek Strategies

1. Provide students with an overview of device handler seek strategies, which are predetermined policies used by device handlers to determine the order in which processes get the device. Point out that their goal is to keep seek time to a minimum.
2. Outline commonly used seek strategies, such as first-come, first-served (FCFS); shortest seek time first (SSTF); and SCAN and its variations LOOK, N-Step SCAN, C-SCAN, and C-LOOK.
3. Outline general goals of every scheduling algorithm, such as to minimize arm movement, to minimize mean response time, and to minimize the variance in response time.
4. Explain the first-come, first-served (FCFS) strategy, using an example as shown in Figure 7.14 on page 229 in the text. Point out that on average, it does not meet any of the three goals of a seek strategy, and its disadvantages include extreme arm movement.
5. Explain the shortest seek time first strategy, using an example as shown in Figure 7.15 on page 230 in the text. Point out that this strategy minimizes overall seek time; however, it postpones traveling to those areas that are out of the way.
6. Explain the SCAN strategy, which uses a directional bit to indicate whether the arm is moving toward the center of the disk or away from it. Point out that in this technique, the algorithm moves the arm methodically from the outer to the inner track, servicing every request in its path. When it reaches the innermost track, it reverses direction and moves toward the outer tracks, again servicing every request in its path.
7. Explain the LOOK strategy, using an example as shown in Figure 7.16 on page 231 in the text. Point out that this is the most common variation of SCAN. In this strategy, the arm does not necessarily go all the way to either edge unless there are requests, hence eliminating the possibility of indefinite postponement.
8. Describe the N-Step SCAN, C-SCAN (Circular SCAN), and C-LOOK strategies, pointing out their advantages and disadvantages.

Search Strategies: Rotational Ordering

1. Provide students with an overview of rotational ordering, which is a strategy to optimize search times by ordering the requests once the read/write heads have been positioned.
2. Explain how the amount of time wasted due to rotational delay can be reduced by arranging requests so that the first sector requested on the second track is the next number higher than the one just served. Use Figure 7.17, Table 7.5, and Table 7.6 on pages 233 and 234 in the text to illustrate this point.

Teaching Tip	Although nothing can be done to improve the time spent moving the read/write head because of its hardware-dependency, the amount of time wasted due to rotational delay can be reduced. If the requests are ordered within each track so that the first sector requested on the second track is the next number higher than the one just served, rotational delay will be minimized, as shown in Table 7.6.
---------------------	---

RAID

1. Provide students with an overview of the concept of RAID. Explain that RAID stands for Redundant Array of Independent Disks. Explain that RAID is a set of physical disk drives that are viewed as a single logical unit by the operating system. Point out that RAID assumes that several smaller-capacity disk drives are preferable to a few large-capacity disk drives, which provides improved data recovery and introduces redundancy to help systems recover from hardware failure.
2. Use Figure 7.18 on page 235 in the text to describe pictorially a typical disk array configuration. Discuss the role of the RAID controller and note how data is divided into segments called strips. Point out that a set of consecutive strips across disks is called a stripe.
3. Note that there are seven primary levels of RAID numbered Level Zero to Level Six. Emphasize this is not a hierarchy, but instead denotes different types of configurations and error correction capabilities.
4. Use Table 7.7 on page 236 in the text to introduce the seven primary levels and to summarize the RAID levels and their error correction capabilities.

Level Zero

1. Explain what RAID Level Zero is and how it works. Note that it uses data striping without parity and error correction. Emphasize that RAID Level Zero does not provide error correction. Also, explain the ramifications of this failure. Describe the benefits of RAID Level Zero and the types of data configurations that are best suited for it.
2. Use Figure 7.19 on page 237 in the text to describe a typical RAID Level Zero configuration pictorially.

Level One

1. Explain what RAID Level One is and how it works. Note that it also uses data striping and is called mirrored because it provides redundancy (has a duplicate set of all data in a mirrored array of disks). This redundancy provides backup for the data in the system in the event of a disk hardware failure. Describe the advantage (data can be retrieved from either mirror) and disadvantages (twice as much work and more expensive) of this level of RAID and what types of data configurations are best suited for it .

2. Use Figure 7.20 on page 237 in the text to describe pictorially a typical RAID Level One configuration.

Level Two

1. Explain what RAID Level Two is and how it works. Note that it uses very small stripes and a Hamming code to provide error detection and correction, or redundancy. Note that a Hamming code is an algorithm that adds extra redundant bits to the data, and it is therefore able to correct single-bit errors and detect double-bit errors. Describe the expense in implementing RAID Level Two.
2. Use Figure 7.21 on page 238 in the text to describe a typical RAID Level Two configuration pictorially.

Level Three

1. Explain what RAID Level Three is and how it works. Note that it is a modified version of RAID Level Two. Note that it only requires one disk for redundancy, and only one parity bit is computed for each strip. Describe the advantages and disadvantages in implementing RAID Level Three.
2. Use Figure 7.22 on page 239 in the text to describe a typical RAID Level Three configuration pictorially.

Level Four

1. Explain what RAID Level Four is and how it works. Note that it uses the same striping scheme as that found in Levels Zero and One. The difference is that it computes parity for each strip and then stores these parities in the corresponding strip in the designated parity disk. Describe the advantages and disadvantages in implementing RAID Level Four.
2. Use Figure 7.23 on page 239 in the text to describe pictorially a typical RAID Level Four configuration.

Level Five

1. Explain what RAID Level Five is and how it works. Note that it is a modified version of RAID Level Four. The difference is that instead of designating one disk for storing parities, Level Five distributes the parity strips across the disks. This is important because it eliminates the bottleneck created in Level Four. Describe the disadvantages in implementing RAID Level Five in that regenerating data from a failed drive is more complicated.
2. Use Figure 7.24 on page 239 in the text to describe a typical RAID Level Five configuration pictorially.

Level Six

1. Explain what RAID Level Six is and how it works. Note that RAID Level Six provides an extra degree of error detection and correction because it requires two different parity calculations. The first is the calculation used in Levels Four and Five. The second is an independent data-check algorithm. Describe the advantages and disadvantages in implementing RAID Level Six.
2. Use Figure 7.25 on page 240 in the text to describe a typical RAID Level Six configuration pictorially.

Nested RAID Levels

1. Describe nested RAID Levels and how they work.
2. Use Table 7.8 on page 240 in the text to describe pictorially common nested RAID configurations. Emphasize to the students that Nested Level “01” and Nested Level “03” are not the same as RAID Level One (1) and RAID Level Three (3).
3. Use Figure 7.26 on page 241 in the text to describe pictorially a typical RAID Level Ten configuration.

Teaching Tip	Refer to the following Web site to learn more about RAID: www.redhat.com/docs/manuals/linux/RHL-7-Manual/ref-guide/ch-raid.html
---------------------	---

Teaching Tip	Refer to the following Web site for the Device Management API for Windows and Linux Operating Systems Library Reference: www.intel.com/design/network/manuals/telecom/hmp12lin/pdf/files/device_mgmt_api_v2.pdf
---------------------	--

Quick Quiz 2

1. Which of the following components performs the actual transfer of data and processes the device interrupts?
 - a. I/O traffic controller
 - b. I/O device handler
 - c. I/O scheduler
 - d. I/O traffic handler

Answer: b

2. Which of the following strategies uses a directional bit to indicate whether the arm is moving toward the center of the disk or away from it?
 - a. FCFS
 - b. SSTF
 - c. SCAN
 - d. RAIDAnswer: c

3. The _____ is an algorithm that adds redundant bits to the data and is therefore able to correct single-bit errors and detect double-bit errors.
Answer: Hamming code

Class Discussion Topics

1. Have student discuss different types of direct access storage devices. Which type of DASD do they prefer for storing records and why?
2. Have students discuss different types of device handler seek strategies. Which strategy do they think is the best? Why? Can they generalize their statement or does it depend on a particular computing system? Do they think it is better to use a combination of more than one scheme? If yes, then how?

Additional Projects

1. Have students research how to create a RAID-5 volume on a remote Windows 2000 Server-based computer from a Windows XP Professional-based computer.
2. Have students do research to compile a list of various flash memory devices available today in the market. Have them include the key features along with approximate prices for each type.

Additional Resources

Intel.com:

www.intel.com/

Sun Microsystems:

www.sun.com/

Sun Microsystems Storagetek:

www.sun.com/storagetek/

IBM.com:

www.ibm.com/

Microsoft.com:

www.microsoft.com

Western Digital:

www.wdc.com/en/

Key Terms

- **Access time:** the total time required to access data in secondary storage.
- **Blocking:** a storage-saving and I/O-saving technique that groups individual records into a block that's stored and retrieved as a unit.
- **Buffers:** temporary storage areas residing in main memory, channels, and control units.
- **Channel Status Word (CSW):** a data structure that contains information indicating the condition of the channel, including three bits for the three components of the I/O subsystem, one each for the channel, control unit, and device.
- **C-LOOK:** a scheduling strategy for direct access storage devices that's an optimization of C-SCAN.
- **C-SCAN:** a scheduling strategy for direct access storage devices that's used to optimize seek time. It's an abbreviation for circular-SCAN.
- **Cylinder:** a concept that describes a virtual tube that is formed when two or more read/write heads are positioned at the same track, at the same relative position, on their respective surfaces.
- **Dedicated device:** a device that can be assigned to only one job at a time; it serves that job for the entire time the job is active.
- **Direct access storage device (DASD):** any secondary storage device that can directly read or write to a specific place. Sometimes called a random access storage device.
- **Direct memory access (DMA):** an I/O technique that allows a control unit to access main memory directly and transfer data without the intervention of the CPU.
- **First-come, first-served (FCFS):** the simplest scheduling algorithm for direct access storage devices that satisfies track requests in the order in which they are received.
- **Flash memory:** a type of nonvolatile memory used as a secondary storage device that can be erased and reprogrammed in blocks of data.
- **Hamming code:** an error-detecting and error-correcting code that greatly improves the reliability of data, named after mathematician Richard Hamming, its inventor.
- **I/O channel:** a specialized programmable unit placed between the CPU and the control units, which synchronizes the fast speed of the CPU with the slow speed of the I/O device and vice versa, making it possible to overlap I/O operations with CPU operations.
- **I/O channel program:** the program that controls the channels.
- **I/O control unit:** the hardware unit containing the electronic components common to one type of I/O device, such as a disk drive.
- **I/O device handler:** the module that processes the I/O interrupts, handles error conditions, and provides detailed scheduling algorithms that are extremely device dependent.
- **I/O scheduler:** one of the modules of the I/O subsystem that allocates the devices, control units, and channels.

- **I/O subsystem:** a collection of modules within the operating system that controls all I/O requests.
- **I/O traffic controller:** one of the modules of the I/O subsystem that monitors the status of every device, control unit, and channel.
- **Interrecord gap (IRG):** an unused space between records on a magnetic tape. It facilitates the tape's start/stop operations.
- **Interrupt:** a hardware signal that suspends execution of a program and activates the execution of a special program known as the interrupt handler.
- **Lands:** flat surface areas on the reflective layer of a CD or DVD. Each land is interpreted as a 1. Contrasts with pits, which are interpreted as 0s.
- **LOOK:** a scheduling strategy for direct access storage devices that's used to optimize seek time. Sometimes known as the elevator algorithm.
- **Magneto-optical (MO) disk drive:** a data storage drive that uses a laser beam to read and/or write information recorded on magneto-optical disks.
- **N-step SCAN:** a variation of the SCAN scheduling strategy for direct access storage devices that's used to optimize seek times.
- **Parity bit:** an extra bit added to a character, word, or other data unit and used for error checking. It is set to either 0 or 1 so that the sum of the one bits in the data unit is always even, for even parity, or odd for odd parity, according to the logic of the system.
- **Pits:** tiny depressions on the reflective layer of a CD or DVD. Each pit is interpreted as a 0. Contrasts with lands, which are interpreted as 1s.
- **RAID:** acronym for redundant array of independent disks; a group of hard disks controlled in such a way that they speed read access of data on secondary storage devices and aid data recovery.
- **Rotational ordering:** an algorithm used to reorder record requests within tracks to optimize search time.
- **SCAN:** a scheduling strategy for direct access storage devices that's used to optimize seek time. The most common variations are N-step SCAN and C-SCAN.
- **Search:** algorithm used to optimize search time in DASD.
- **Search time:** the time it takes to rotate the disk from the moment an I/O command is issued until the requested record is moved under the read/write head. Also known as rotational delay.
- **Seek strategy:** a predetermined policy used by the I/O device handler to optimize seek times.
- **Seek time:** the time required to position the read/write head on the proper track from the time the I/O request is issued.
- **Sequential access medium:** any medium that stores records only in a sequential manner, one after the other, such as magnetic tape.
- **Shared device:** a device that can be assigned to several active processes at the same time.
- **Shortest seek time first (SSTF):** a scheduling strategy for direct access storage devices that's used to optimize seek time. The track requests are ordered so the one closest to the currently active track is satisfied first and the ones farthest away are made to wait.
- **Storage:** the place where data is stored in the computer system. Secondary storage is nonvolatile media, such as disks and flash memory. Primary storage is main memory.
- **Stripe:** a set of consecutive strips across disks; the strips contain data bits and sometimes parity bits depending on the RAID level.
- **Track:** a path on a storage medium along which data is recorded.
- **Transfer rate:** the rate at which data is transferred from sequential access media.

- **Transfer time:** the time required for data to be transferred between secondary storage and main memory.
- **Universal serial bus (USB) controller:** the interface between the operating system, device drivers, and applications that read and write to devices connected to the computer through the USB port. Each USB port can accommodate up to 127 different devices.
- **Virtual device:** a dedicated device that has been transformed into a shared device through the use of spooling techniques.