KEY POINTS

- **The computer system's I/O architecture is its interface to the outside world. This architecture provides a systematic means of controlling interaction with the outside world and provides the operating system with the information it needs to manage I/O activity effectively.**
- **There are three principal I/O techniques: programmed I/O, in which I/O occurs under the direct and continuous control of the program requesting the I/O operation; interrupt-driven I/O, in which a program issues an I/O command and then continues to execute, until it is interrupted by the I/O hardware to signal the end of the I/O operation; and direct memory access (DMA), in which a specialized I/O processor takes over control of an I/O operation to move a large block of data.**
- **Two important examples of external I/O interfaces are FireWire and InfiniBand.**

In addition to the processor and a set of memory modules, the third key element of a computer system is a set of I/O modules. Each module interfaces to the system bus or central switch and controls one or more peripheral devices. An I/O module is not simply a set of mechanical connectors that wire a device into the system bus. Rather, the I/O module contains logic for performing a communication function between the peripheral and the bus.

The reader may wonder why one does not connect peripherals directly to the system bus. The reasons are as follows:

- There are a wide variety of peripherals with various methods of operation. It would be impractical to incorporate the necessary logic within the processor to control a range of devices.
- The data transfer rate of peripherals is often much slower than that of the memory or processor. Thus, it is impractical to use the high-speed system bus to communicate directly with a peripheral.
- On the other hand, the data transfer rate of some peripherals is faster than that of the memory or processor. Again, the mismatch would lead to inefficiencies if not managed properly.
- Peripherals often use different data formats and word lengths than the computer to which they are attached.

Thus, an I/O module is required. This module has two major functions (Figure 7.1):

- Interface to the processor and memory via the system bus or central switch
- Interface to one or more peripheral devices by tailored data links

We begin this chapter with a brief discussion of external devices, followed by an overview of the structure and function of an I/O module. Then we look at the

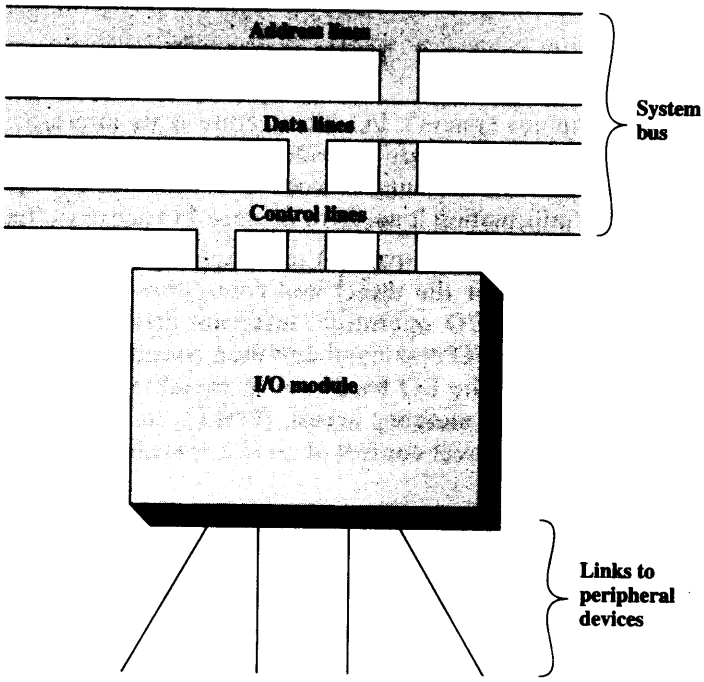

Figure 7.1 Generic Model of an I/O Module

various ways in which the I/O function can be performed in cooperation with the processor and memory: the internal I/O interface. Finally, we examine the external I/O interface, between the I/O module and the outside world.

7.1 EXTERNAL DEVICES

I/O operations are accomplished through a wide assortment of external devices that provide a means of exchanging data between the external environment and the computer. An external device attaches to the computer by a link to an I/O module (Figure 7.1). The link is used to exchange control, status, and data between the I/O module and the external device. An external device connected to an I/O module is often referred to as a *peripheral device* or, simply, a *peripheral.*

We can broadly classify external devices into three categories:

- **Human readable:** Suitable for communicating with the computer user
- **Machine readable:** Suitable for communicating with equipment
- **Communication:** Suitable for communicating with remote devices

Examples of human-readable devices are video display terminals (VDTs) and printers. Examples of machine-readable devices are magnetic disk and tape systems, and sensors and actuators, such as are used in a robotics application. Note that we are viewing disk and tape systems as I/O devices in this chapter, whereas in Chapter 6 we viewed them as memory devices. From a functional point of view, these devices are

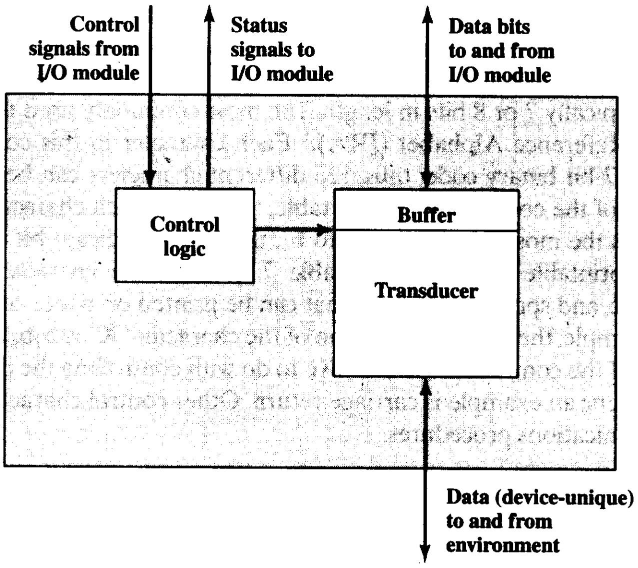

Figure 7.2 Block Diagram of an External Device

part of the memory hierarchy, and their use is appropriately discussed in Chapter 6. From a structural point of view, these devices are controlled by I/O modules and are hence to be considered in this chapter.

Communication devices allow a computer to exchange data with a remote device, which may be a human-readable device, such as a terminal, a machine-readable device, or even another computer.

In very general terms, the nature of an external device is indicated in Figure 7.2. The interface to the I/O module is in the form of control, data, and status signals. *Control signals* determine the function that the device will perform, such as send data to the I/O module (INPUT or READ), accept data from the I/O module (OUTPUT or WRITE), report status, or perform some control function particular to the device (e.g., position a disk head). *Data* are in the form of a set of bits to be sent to or received from the I/O module. *Status signals* indicate the state of the device. Examples are READY/NOT-READY to show whether the device is ready for data transfer.

Control logic associated with the device controls the device's operation in response to direction from the I/O module. The *transducer* converts data from electrical to other forms of energy during output and from other forms to electrical during input. Typically, a buffer is associated with the transducer to temporarily hold data being transferred between the I/O module and the external environment; a buffer size of 8 to 16 bits is common.

The interface between the I/O module and the external device will be examined in Section 7.7. The interface between the external device and the environment is beyond the scope of this book, but several brief examples are given here.

Keyboard/Monitor

The most common means of computer/user interaction is a keyboard/monitor arrangement. The user provides input through the keyboard. This input is then transmitted to

Table 7.2 Continued

SI (Shift In): Indicates that the code combinations that follow shall be interpreted according to the standard character set.	**CAN (Cancel):** Indicates that the data that precedes it in a message or block should be disregarded (usually because an error has been detected).
DEL (Delete): Used to obliterate unwanted characters; for example by overwriting.	**EM (End of Medium):** Indicates the physical end of a tape or other medium, or the end of the required or used portion of the medium.
SP (Space): A nonprinting character used to separate words, or to move the printing mechanism or display cursor forward by one position.	**SUB (Substitute):** Substituted for a character that is found to be erroneous or invalid.
	ESC (Escape): A character intended to provide code extension in that it gives a specified number of continuously following characters an alternate meaning.

For keyboard input, when the user depresses a key, this generates an electronic signal that is interpreted by the transducer in the keyboard and translated into the bit pattern of the corresponding IRA code. This bit pattern is then transmitted to the I/O module in the computer. At the computer, the text can be stored in the same IRA code. On output, IRA code characters are transmitted to an external device from the I/O module. The transducer at the device interprets this code and sends the required electronic signals to the output device either to display the indicated character or perform the requested control function.

Disk Drive

A disk drive contains electronics for exchanging data, control, and status signals with an I/O module plus the electronics for controlling the disk read/write mechanism. In a fixed-head disk, the transducer is capable of converting between the magnetic patterns on the moving disk surface and bits in the device's buffer (Figure 7.2). A moving-head disk must also be able to cause the disk arm to move radially in and out across the disk's surface.

7.2 I/O MODULES

Module Function

The major functions or requirements for an I/O module fall into the following categories:

- Control and timing
- Processor communication
- Device communication
- Data buffering
- Error detection

During any period of time, the processor may communicate with one or more external devices in unpredictable patterns, depending on the program's need for I/O.