Technology Guides

Technology Guide 1

Hardware

T1.1 What Is a Computer System?

Computer hardware is composed of the following components: central processing unit (CPU), input devices, output devices, primary storage, secondary storage, and communication devices. (These devices are described in Technology Guide 4.) Each of the hardware components plays an important role in computing. The **input devices** accept data and instructions and convert them to a form that the computer can understand. The **output devices** present data in a form people can understand. The **CPU** manipulates the data and controls the tasks done by the other components. The **primary storage** (internal storage) temporarily stores data and program instructions during processing. It also stores intermediate results of the processing. The **secondary storage** (external) stores data and programs for future use. Finally, the **communication devices** provide for the flow of data from external computer networks (e.g., Internet, intranets) to the CPU, and from the CPU to computer networks. A schematic view of a computer system is shown in Figure T1.1.

REPRESENTING DATA, PICTURES, TIME, AND SIZE IN A COMPUTER

ASCII. Today's computers are based on integrated circuits (chips), each of which includes millions of subminiature transistors that are interconnected on a small (less than 1-inch-square) chip area. Each transistor can be in either an "on" or "off" position.

The "on-off" states of the transistors are used to establish a binary 1 or 0 for storing one **binary digit,** or **bit.** A sufficient number of bits to represent specific characters—letters, numbers, and special symbols—is known as a **byte,** usually 8 bits. Because a bit has only two states, 0 or 1, the bits comprising a byte can represent any of 2^8, or 256, unique characters. Which character is represented depends upon the bit combination or coding scheme used. The two most commonly used coding schemes are **ASCII (American National Standard Code for Information Interchange),** pronounced "ask-ee," and **EBCDIC (Extended Binary Coded Decimal Interchange Code),** pronounced "ebsa-dick." EBCDIC was developed by IBM and is used primarily on large, mainframe computers. ASCII has emerged as the standard coding scheme for microcomputers. These coding schemes, and the characters they present, are shown in Figure T1.2. In addition to characters, it is possible to represent commonly agreed-upon symbols in a binary code. For example, the plus sign (+) is 00101011 in ASCII.

The 256 characters and symbols that are represented by ASCII and EBCDIC codes are sufficient for English and Western European languages but are not large enough for Asian and other languages that use different alphabets. **Unicode** is a

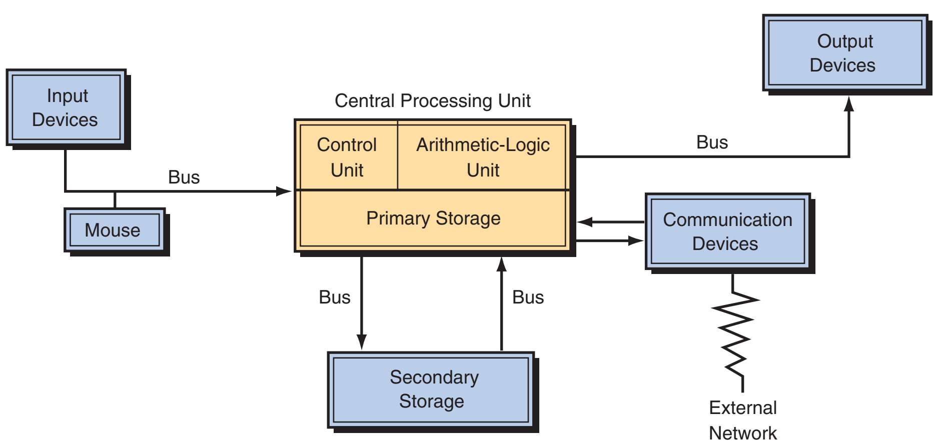


Figure T1.1 The components of computer hardware. A "bus" is a connecting channel.

Character	EBCDIC Code	ASCII Code	Character	EBCDIC Code	ASCII Code
A	11000001	10100001	S	11100010	10110011
B	11000010	10100010	T	11100011	10110100
C	11000011	10100011	U	11100100	10110101
D	11000100	10100100	V	11100101	10110110
E	11000101	10100101	W	11100110	10110111
F	11000110	10100110	X	11100111	10111000
G	11000111	10100111	Y	11101000	10111001
H	11001000	10101000	Z	11101001	10111010
I	11001001	10101001	0	11110000	01010000
J	11010001	10101010	1	11110001	01010001
K	11010010	10101011	2	11110010	01010010
L	11010011	10101100	3	11110011	01010011
M	11010100	10101101	4	11110100	01010100
N	11010101	10101110	5	11110101	01010101
O	11010110	10101111	6	11110110	01010110
P	11010111	10110000	7	11110111	01010111
Q	11011000	10110001	8	11111000	01011000
R	11011001	10110010	9	11111001	01011001

Figure T1.2 Internal computing coding schemes.

16-bit code that has the capacity to represent more than 65,000 characters and symbols. The system employs the codes used by ASCII and also includes other alphabets (such as Cyrillic and Hebrew), special characters (including religious symbols), and some of the "word writing" symbols used in various Asian countries.

Representing Pictures. Pictures are represented by a grid overlay of the picture. The computer measures the color (or light level) of each cell of the grid. The unit measurement of this is called a **pixel.** Figure T1.3 shows a pixel representation of the letter *A* and its conversion to an input code.

Representing Time and Size of Bytes. Time is represented in fractions of a second. The following are common measures of time:

- **Millisecond** = 1/1000 second
- **Microsecond** = 1/1,000,000 second
- **Nanosecond** = 1/1,000,000,000 second
- **Picosecond** = 1/1,000,000,000,000 second

Size is measured by the number of bytes. Common measures of size are:

- **Kilobyte** = 1,000 bytes (actually 1,024)
- **Megabyte** = 1,000 kilobytes = 10^6 bytes
- **Gigabyte** = 10^9 bytes
- **Terabyte** = 10^{12} bytes

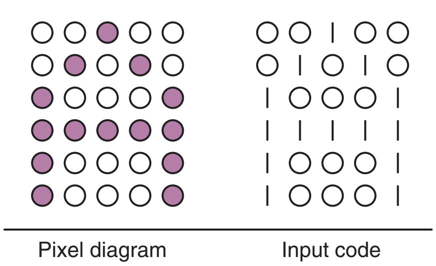


Figure T1.3 Pixel representation of the letter *A*.

- **Petabyte** = 10^{15} bytes
- **Exabyte** = 10^{18} bytes
- **Zettbyte** = 10^{21} bytes
- **Yottabyte** = 10^{24} bytes

T1.2 The Evolution of Computer Hardware

Computer hardware has evolved through four stages, or generations, of technology. Each generation has provided increased processing power and storage capacity, while simultaneously exhibiting decreases in costs (see Table T1.1). The generations are distinguished by different technologies that perform the processing functions.

The *first generation* of computers, from 1946 to about 1956, used *vacuum tubes* to store and process information. Vacuum tubes consumed large amounts of power, generated much heat, and were short-lived. Therefore, first-generation computers had limited memory and processing capability.

The *second generation* of computers, 1957–1963, used **transistors** for storing and processing information. Transistors consumed less power than vacuum tubes, produced less heat, and were cheaper, more stable, and more reliable. Second-generation computers, with increased processing and storage capabilities, began to be more widely used for scientific and business purposes.

Third-generation computers, 1964–1979, used **integrated circuits** for storing and processing information. Integrated circuits are made by printing numerous small transistors on silicon chips. These devices are called *semiconductors*. Third-generation computers employed software that could be used by nontechnical people, thus enlarging the computer's role in business.

Early to middle *fourth-generation* computers, 1980–1995, used **very large-scale integrated (VLSI) circuits** to store and process information. The VLSI technique allows the installation of hundreds of thousands of circuits (transistors and other components) on a small chip. With **ultra-large-scale integration (ULSI),** 100 million transistors could be placed on a chip. These computers are inexpensive and widely used in business and everyday life.

Late *fourth-generation computers,* 2001 to the present, use **grand-scale integrated (GSI) circuits** to store and process information. With GSI, 1,000 million transistors can be placed on a chip.

The first four generations of computer hardware were based on the *Von Neumann architecture,* which processed information sequentially, one instruction at a time. The fifth generation of computers uses **massively parallel processing** to

TABLE T1.1 Hardware Generations

	Generations					
Feature	**1st**	**2nd**	**3rd**	**4th (early)**	**4th (1988)**	**4th (2001)**
Circuitry	Vacuum tubes	Transistors	Integrated circuits	LSI and VLSI	ULSI	GSI
Primary storage	2 KB	64 KB	4 MB	16 MB	64 MB	128 MB
Cycle times	100 millisecs	10 microsecs	500 nanosecs	800 picosecs	2,000 picosecs	333 MHz
Average cost	$2.5 million	$250 thousand	$25 thousand	$2.5 thousand	$2.0 thousand	$1.5 thousand

process multiple instructions simultaneously. Massively parallel computers use flexibly connected networks linking thousands of inexpensive, commonly used chips to address large computing problems, attaining supercomputer speeds. With enough chips networked together, massively parallel machines can perform more than a trillion floating point operations per second—a teraflop. A *floating point operation (flop)* is a basic computer arithmetic operation, such as addition or subtraction, on numbers that include a decimal point.

T1.3 Types of Computers

Computers are distinguished on the basis of their processing capabilities.

SUPERCOMPUTERS

A supercomputer.

Supercomputers are the computers with the most processing power (see photo). The primary application of supercomputers has been in scientific and military work, but their use is growing rapidly in business as their prices decrease. Supercomputers are especially valuable for large simulation models of real-world phenomena, where complex mathematical representations and calculations are required, or for image creation and processing. Supercomputers are used to model the weather for better weather prediction, to test weapons nondestructively, to design aircraft (e.g., the Boeing 777) for more efficient and less costly production, and to make sequences in motion pictures (e.g., *Jurassic Park*).

Supercomputers use the technology of **parallel processing.** However, in contrast to neural computing, which uses massively parallel processing, supercomputers use noninterconnected CPUs. The difference is shown in Figure T1.4. Parallel processing is also used in smaller computers where 2 to 64 processors are common.

Silicon Graphics (SGI) has added the equivalent of dozens of supercomputer nodes into a single blade by leveraging the inherent parallelism of the Field-Programmable Gate Array (FPGA) technology. According to SGI, the RASC RC100 computation blade, built with dual Xilinx Virtex 4 FPGAs, can accelerate the performance of many HPC applications by orders of magnitude over conventional systems at a far lower cost and much smaller footprint. Based on SGI's RASC (Reconfigurable Application-Specific Computing) technology, the new RC100 blade is designed for customers whose applications spend most of their time working on a set of specific routines or algorithms. By accelerating those routines, RASC technology can significantly improve the performance of the overall application (*Computer Technology Review,* 2006f).

A mainframe computer.

MAINFRAMES

Mainframes are not as powerful and generally not as expensive as supercomputers. Large corporations, where data processing is centralized and large databases are maintained, often use mainframe computers. Applications that run on a mainframe can be large and complex, allowing for data and information to be shared throughout the organization.

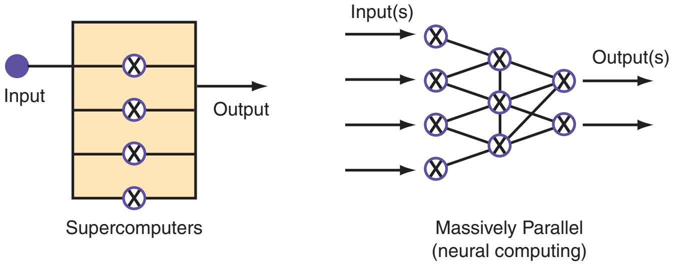


Figure T1.4 Supercomputers vs. neural computing. (X is a CPU.)

MIDRANGE COMPUTERS

Midrange computers includes *minicomputers* and *servers*.

Minicomputers. **Minicomputers** are smaller and less expensive than mainframe computers. Minicomputers are usually designed to accomplish specific tasks such as process control, scientific research, and engineering applications. Larger companies gain greater corporate flexibility by distributing data processing with minicomputers in organizational units instead of centralizing computing at one location. These minicomputers are connected to each other and often to a mainframe through telecommunication links.

Servers. **Servers** typically support computer networks, enabling users to share files, software, peripheral devices, and other network resources. Servers have large amounts of primary and secondary storage and powerful CPUs. Organizations with heavy e-commerce requirements and very large Web sites are running their Web and e-commerce applications on multiple servers in *server farms*. Server farms are large groups of servers maintained by an organization or by a commercial vendor and made available to customers. As companies pack greater numbers of servers in their server farms, they are using pizza-box-size servers called *rack servers* that can be stacked in racks. These computers run cooler, and therefore can be packed more closely, requiring less space. To further increase density, companies are using a server design called a blade. A *blade* is a card about the size of a paperback book on which memory, processor, and hard drives are mounted.

Computer vendors originally developed workstations to provide the high levels of performance demanded by technical users such as designers. **Workstations** are typically based on RISC (reduced instruction set computing) architecture and provide both very-high-speed calculations and high-resolution graphic displays. These computers have found widespread acceptance within the scientific community and, more recently, within the business community.

Workstation applications include electronic and mechanical design, medical imaging, scientific visualization, 3-D animation, and video editing. By the second half of the 1990s, many workstation features were commonplace in PCs, blurring the distinction between workstations and personal computers.

Virtual servers make it possible to place multiple applications on a single physical server, yet run each within its own operating system environment, known as a virtual machine. So, when one virtual server crashes or is rebooted, the others continue operating without interruption. Early virtual machines appeared on IBM mainframes back in the 1960s. A virtual server permits two or more applications to run on a single physical unit. Each application has its own operating system and hardware, all wrapped in a "virtual machine" that itself runs on the virtual server. The server can be software- or hardware-based (Carr, 2006). Advanced Micro Devices Inc. and Intel Corp. began offering virtualization technologies built into their chips in 2006. Hardware running these chips will support virtual machines more efficiently by allowing systems to be partitioned and able to run multiple operating systems.

Blade Server. A blade is one component in a system and blades could be individual servers that plug into a single cabinet or individual port cards that add connectivity to a switch. A blade is typically a hot swappable hardware device.

A blade server is a server architecture that houses multiple server modules (blades) in a single chassis. It is widely used in datacenters to save space and improve system management. Either self-standing or rack mounted, the chassis provides the power supply, and each blade has its own CPU, memory, and hard disk.

Blade servers generally provide their own management systems and may include a network or storage switch.

With enterprise-class blade servers, disk storage is external, and the blades are diskless. This approach allows for more efficient failover because applications are not tied to specific hardware and a particular instance of the operating system. The blades are anonymous and interchangeable.

MICROCOMPUTERS

Microcomputers, also called *personal computers (PCs)*, are the smallest and least expensive category of general-purpose computers. **Notebook computers** are small, easily transportable, lightweight microcomputers that fit easily into a briefcase.

Notebooks are allowing users to have access to processing power and data without being bound to an office environment.

MOBILE DEVICES

Platforms for computing and communications include such **mobile devices** as **personal digital assistants (PDAs)** or *handheld personal computers*. Another platform is mobile phone handsets with wireless and Internet access capabilities. Usually, such devices would use a micro version of a desktop operating system, such as Pocket PC, Symbian, or Palm OS.

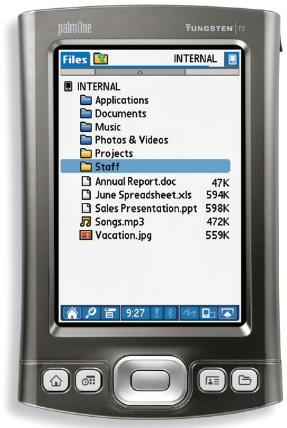
Table T1.2 describes the various types of mobile devices. In general, mobile devices have the following characteristics:

- They cost much less than PCs.
- Their operating systems are simpler than those on a desktop PC.
- They provide good performance at specific tasks but do not replace the full functions of a PC.
- They provide both computer and/or communications features.
- They offer a Web portal that is viewable on a screen.

TABLE T1.2 Mobile Devices and their Uses

Device	Description and Use
Handheld companions	Devices with a core functionality of accessing and managing data; designed as supplements to notebooks or PCs
PC companions	Devices primarily used for personal information management (PIM), e-mail, and light data-creation capabilities
Personal companions	Devices primarily used for PIM activities and data-viewing activities
Classic PDAs	Handheld units designed for PIM and vertical data collection
Smart phones	Emerging mobile phones with added PDA, PIM, data, e-mail or messaging creation/service capabilities
Vertical application devices	Devices with a core functionality of data access, management, creation, and collection; designed for use in vertical markets*
Pen tablets	Business devices with pen input and tablet form for gathering data in the field or in a mobile situation
Pen notepads	Pen-based for vertical data collection applications
Keypad handhelds	Business devices with an alphanumeric keypad used in specialized data-collection applications

*Vertical markets refer to specific industries, such as manufacturing, finance, healthcare, etc.



A palmOne Tungsten PDA. (Tungsten T5 is a trademark of palmOne, Inc.)

Personal Digital Assistant. A **PDA** is a palmtop computer that combines a processor with a multitasking operating system using a pen (stylus) for handwriting recognition rather than keyboard input (see photo). Some PDAs enable users to communicate via fax, electronic mail, and paging, or to access online services.

Expansion slots enable the addition of Secure Digital card, CompactFlash, Springboard, and Memory Stick.

Some products combine PDA and cell phones (smart phones). These include Audiovox's Maestro PDA1032C, Handspring's Treo 180, Motorola's Accompli 009, Nokia's 9290 Communicator, and Sony Ericsson's P900. Some of them have extra features of connection cable, e-mail, Web-browsing apps, speakerphone, headset, jog dial, keyboard, digital voice, and call recorder.

PDAs from Palm, Inc. have emerged as a solid wireless communications tool. The Palm^{TM} VIIx handheld features a built-in modem that allows users to wirelessly connect to the Internet, plus send and receive e-mail. To view Web content, the Palm VIIx handheld uses technology the company calls "Web clipping." Web clipping is an efficient way for people on the move to access Web information without a PC. Users can download Web-clipping applications to get stock quotes, sports scores, today's headlines, and tomorrow's weather.

New features are being added to PDAs every year. Sony's Clie PEG N710C model, for example, can play MP3 and digitally protected ATRAC3 audio. So-called "all-in-one" PDAs are personal digital assistants coupled with mobile phone functions. Example of products in this category are HP's Jornada 928 WD, Palm's Tungsten W, and Sony-Ericsson P900.

Some mobile devices offer mapping capabilities using GPS. **Global positioning systems,** long used by sailors, hikers, private pilots, and soldiers, are making their way into PDAs. To use GPS, you need to have a mapping software plus a GPS module that connects to your device via USB, PC Card, CompactFlash, or a dedicated clip-on module. Some models can let you type in your destination on the touch-sensitive LCD panel and it calculates the route in just a few seconds.

Wi-Fi. The spread of wireless fidelity, or **Wi-Fi,** has had a huge impact on the ability to connect to the Internet via one's laptop or other mobile computing device. The term Wi-Fi comes from the wireless networking standard 802.11b (now 802.11j) that has become a standard feature for most laptops and PDAs. It allows people on the move the convenience of finding a hot spot to download and reply to e-mails anywhere and at any time. HP's iPAQ 5450 is the first handheld that has both wireless local area network (WLAN) and Bluetooth connectivity. It also has a built-in fingerprint security scanner—a small bar just beneath the navigation button over which the user swipes his finger to be identified.

The 802.11j specification is an addition to the 802.11 family of standards for wireless local area networks (WLANs) that incorporates Japanese regulatory extensions to the 802.11a standard. It is to add channels in the radio-frequency (RF) band of 4.9 GHz to 5.0 GHz. Certain changes are proposed that can satisfy Japanese legal requirements concerning wireless transmitter output power, operational modes, channel arrangements, and spurious emission levels. WLANs using 802.11j provide speeds up to 54 Mbps, and employ orthogonal frequency division multiplexing (OFDM) (*Searchmobilecomputing.com,* 2006).

Early in 2006, a new standard of 802.11n Draft 1.0 had been confirmed. Its performance can be up to 650 percent faster than an 802.11g wireless connection.

Tablet PC. **Tablet PC** technology runs touch-sensitive displays that you can tap with a pen, forgoing a mouse or touch pad. A tablet PC can put the full power of

Windows XP Professional in a laptop computer that's as simple as a pad and pen. There you can write, draw, and erase directly on the screen, plus you can run your favorite Windows XP compatible applications. It is a good compliment to a full keyboard but cannot be a keyboard replacement. Two products in this category include Fujitsu's FMV Stylistic line and Acer TravelMate C110. The EMR pen of the Acer model and Microsoft's linking technology enable natural handwriting as a form of input, and wireless connectivity enhances user mobility in the office and on the road.

Tablet PC technology is becoming more mature. The so-called "ink features" (ability to write on the tablet's screen) are good for taking notes and especially useful for sketching. Drawing with a pen is simply more natural than with a mouse. The vertical orientation of a tablet and special buttons for moving up and down on a page make it better than a conventional notebook display for reading electronic books and magazines, using software like Microsoft Reader.

Getting online content onto offline devices is popular. There are several options for the "tabletzines" market, for example: LinkPath enables more than 50 B2B publications to work well on tablet PCs; Microsoft will be making tools available to help publishers move their print products into tablet PC-sized formats via Internet Explorer; Newsstand has a free reader software for its magazines and newspapers that works with Tablet stylus for navigation. Zinio, a distributor of digital magazines, improved the digital technology so that the tablet user can quickly download content via broadband Internet connection and Wi-Fi network.

Web Pads. **Web pads** (also called *Web tablets*) are the second generation of tablet PCs. Its unique purpose is to fulfill the vision of the home computer as a powerful, easy-to-use machine that is always at hand and at the ready. It can run nearly all Windows applications, has a big and bright touch-sensitive screen, and has built-in 802.11b wireless networking. Except those text-entry-focused applications where a notebook PC is better, Web pads are the best pervasive devices.

Other New Mobile Computing and Wireless Devices. The variety of new mobile computing devices is astonishing. For example, PC-Ephone is a CDMA mobile phone along with an MP3 player and an MPEG movie player. It is the first to have a stylus wireless handset using Bluetooth technology. It runs the Windows CE operating system including Internet Explorer, e-mail, and pocket versions of Word and Excel.

Ericsson T20e (*ericsson.com*) enables owners to talk with friends via electronic messages in Web chat rooms. Plug in Ericsson's MP3 player or connect to Ericsson's FM radio to listen to radio programs wherever available.

Tiqit (*tiqit.com*) is a fully functioning PC in a package not much bigger than a PDA. It has a built-in 4-inch-diagonal, 640×480 touch-sensitive screen and a thumb keyboard. Processor is NS Geode 300 MHz, 256 Mb RAM, 15 Gb hard disk. It can run in Windows XP. It can attach a USB keyboard and an external monitor.

Several other new wireless communications products are appearing on the market. For example, 24 GHz wireless Ethernet bridges can turn an Ethernet port into a Wi-Fi connection, making nearly any device—Xbox, PlayStation 2, and laser printer—wireless ready. Bluetooth uses the 2.4 GHz for data transfer but its maximum range is 30 feet, limiting it to gadget-to-gadget communication; examples of products that use Bluetooth include 3COM's Wireless Bluetooth Adapter, Socket's Bluetooth GPS Receiver, Jabra's Freespeak Bluetooth Headset, and Pico's Picoblue Internet Access Point. Xircom SpringPort Wireless Ethernet Module can support Handspring Visor to the standard wireless networking technology. It is 802.11b compliant and lets you check e-mail and access the Internet with minimal effort. The connection range is typically 100 feet indoors and 300 feet outdoors with no obstructions for full-speed network operation.

Embedded Computers. **Embedded computers** are placed inside other products to add features and capabilities. For example, the average mid-sized automobile has more than 3,000 embedded computers that monitor every function from braking to engine performance to seat controls with memory.

Active Badges. **Active badges** can be worn as ID cards by employees who wish to stay in touch at all times while moving around the corporate premises. The clip-on badge contains a microprocessor that transmits its location to the building's sensors, which send that information to a computer. When someone wants to contact the badge wearer, the phone closest to the person is identified automatically. When badge wearers enter their offices, their badge identifies them and logs them on to their personal computers. This technology has been used by some primary schools in Japan to trace the schoolchildren's activities. It is also used in some healthcare facilities to trace the movement of patients.

Memory Buttons. **Memory buttons** are nickel-sized devices that store a small database relating to whatever it is attached to. These devices are analogous to a bar code, but with far greater informational content and a content that is subject to change. Each button carries a unique serial number. Because no two buttons can ever have the same registration number, they can be used for various identification purposes (objects, people, etc.), also for automated password entry and many other applications (e.g., estate management patrol, etc.).

Smart Cards. An even smaller form of mobile computer is the **smart card,** which has resulted from the continuing shrinkage of integrated circuits. Similar in size and thickness to ordinary plastic credit cards, smart cards contain a small CPU, memory, and an input/output device that allow these "computers" to be used in everyday activities such as person identification and banking.

Uses for smart cards are appearing rapidly. People are using them as checkbooks; a bank ATM (automatic teller machine) can "deposit money" into the card's memory for "withdrawal" at retail stores (see Chapter 6). Smart cards are being used to transport data between computers, replacing floppy disks. Adding a small transmitter to a smart card can enable them to work like active badges, allowing businesses to locate any employee and automatically route phone calls to the nearest telephone.

OTHER TYPES OF COMPUTERS

The computers described so far in this section are considered "smart" computers which have intelligence coming from their built-in microprocessor and memory. However, mainframe and midrange computers also can use *dumb terminals*, which are basically input/output devices, without processing capabilities. However, as time has passed, these terminals, which are called *X terminals*, have also come to be used for limited processing. Two extensions of these terminals are discussed here.

Network Computers. A **network computer (NC),** also called a *thin computer*, is a desktop terminal that does not store software programs or data permanently. Similar to a dumb terminal, the NC is simpler and cheaper than a PC and easy to maintain. Users can download software or data they need from a server on a mainframe over an intranet or the Internet. There is no need for hard disks, floppy disks, CD-ROMs, and their drives. The central computer can save any material for the user.

The NCs provide security as well. However, users are limited in what they can do with the terminals.

Windows-Based Terminals (WBTs). **Windows-based terminals (WBTs)** are a subset of the NC. Although they offer less functionality than PCs, WBTs reduce maintenance and support costs and maintain compatibility with Windows operating systems. WBT users access Windows applications on central servers as if those applications were running locally. As with the NC, the savings are not only in the cost of the terminals, but mainly from the reduced support and maintenance cost. The WBT is used by some organizations as an alternative to NCs. However, because the NCs use Java and HTML languages, they are more flexible and efficient and less expensive to operate than a WBT.

T1.4 The Microprocessor and Primary Storage

MICROPROCESSORS

The **central processing unit (CPU)** is the center of all computer-processing activities, where all processing is controlled, data are manipulated, arithmetic computations are performed, and logical comparisons are made. The CPU consists of the control unit, the arithmetic-logic unit (ALU), and the primary storage (or main memory). Because of its small size, the CPU is also referred to as a *microprocessor.*

How a Microprocessor Works. The CPU operates like a tiny factory. Inputs come in and are stored until needed, at which point they are retrieved and processed and the output is stored and then delivered somewhere. Figure T1.5 illustrates this process, which works as follows:

- The inputs are data and brief instructions about what to do with the data. These instructions come from software in other parts of the computer. Data might be entered by the user through the keyboard, for example, or read from a data file in another part of the computer. The inputs are stored in registers until they are sent to the next step in the processing.
- Data and instructions travel in the chip via electrical pathways called *buses*. The size of the bus—analogous to the width of a highway—determines how much information can flow at any time.

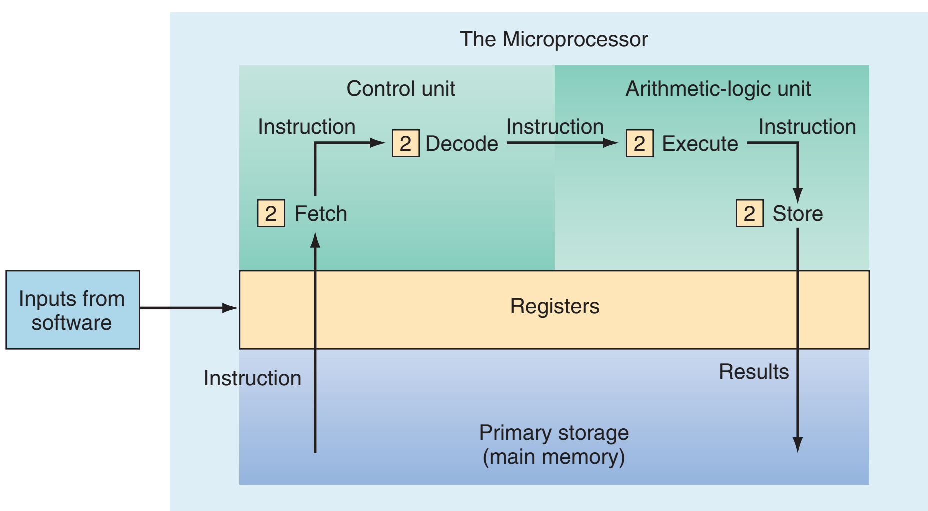


Figure T1.5 How the CPU works.

- The control unit directs the flow of data and instructions within the chip.
- The arithmetic-logic unit (ALU) receives the data and instructions from the registers and makes the desired computation. These data and instructions have been translated into *binary form*, that is, only 0s and 1s. The CPU can process only binary data.
- The data in their original form and the instructions are sent to storage registers and then are sent back to a storage place outside the chip, such as the computer's hard drive (discussed below). Meanwhile, the transformed data go to another register and then on to other parts of the computer (to the monitor for display, or to be stored, for example).

This cycle of processing, known as a **machine instruction cycle,** occurs millions of times per second or more. The speed of a chip, which is an important benchmark, depends on four things: the clock speed, the word length, the data bus width, and the design of the chip.

1. The **clock,** located within the control unit, is the component that provides the timing for all processor operations. The beat frequency of the clock (measured in megahertz [MHz] or millions of cycles per second) determines how many times per second the processor performs operations. In 2001, PCs with Pentium 4, Pentium III, P6, PowerPC, or Alpha chips are running at 700 MHz to 1.5 GHz. In 2006, a PC can be as fast as 3.73 GHz.

   The preset speed of the clock that times all chip activities, measured in megahertz (MHz), millions of cycles per second, and gigahertz (GHz), billions of cycles per second. The faster the **clock speed,** the faster the chip. (For example, all other factors being equal, a 1.0 GHz chip is twice as fast as a 500 MHz chip.)
2. The **word length,** which is the number of bits (0s and 1s) that can be processed by the CPU at any one time. The majority of current chips handle 32-bit word lengths, and the Pentium 4 is designed to handle 64-bit word lengths. Therefore, the Pentium 4 chip processes 64 bits of data in one machine cycle. The larger the word length, the faster the chip. Newer chips handle 128-bit words.
3. The **bus width.** The wider the *bus* (the physical paths down which the data and instructions travel as electrical impulses), the more data can be moved and the faster the processing. A processor's *bus bandwidth* is the product of the width of its bus (measured in bits) times the frequency at which the bus transfers data (measured in megahertz). For example, Intel's Pentium 4 processor uses a 64-bit bus that runs at 400 MHz. That gives it a peak bandwidth of 3.2 gigabits per second.
4. The physical design of the chip. Going back to our "tiny factory" analogy, if the "factory" is very compact and efficiently laid out, then "materials" (data and instructions) do not have far to travel while being stored or processed. We also want to pack as many "machines" (transistors) into the factory as possible. The distance between transistors is known as **line width.** Historically, line width has been expressed in microns (millionths of a meter), but as technology has advanced, it has become more convenient to express line width in nanometers (billionths of a meter). Currently, most CPUs are designed with 180-nanometer technology (0.18 microns), but chip manufacturers are moving to 130-nanometer technology (0.13 microns). The smaller the line width, the more transistors can be packed onto a chip, and the faster the chip.

Running a Program on a Computer. To see how a program is run on a computer, look at Figure T1.6. A computer program can be stored on a disk or on the hard drive

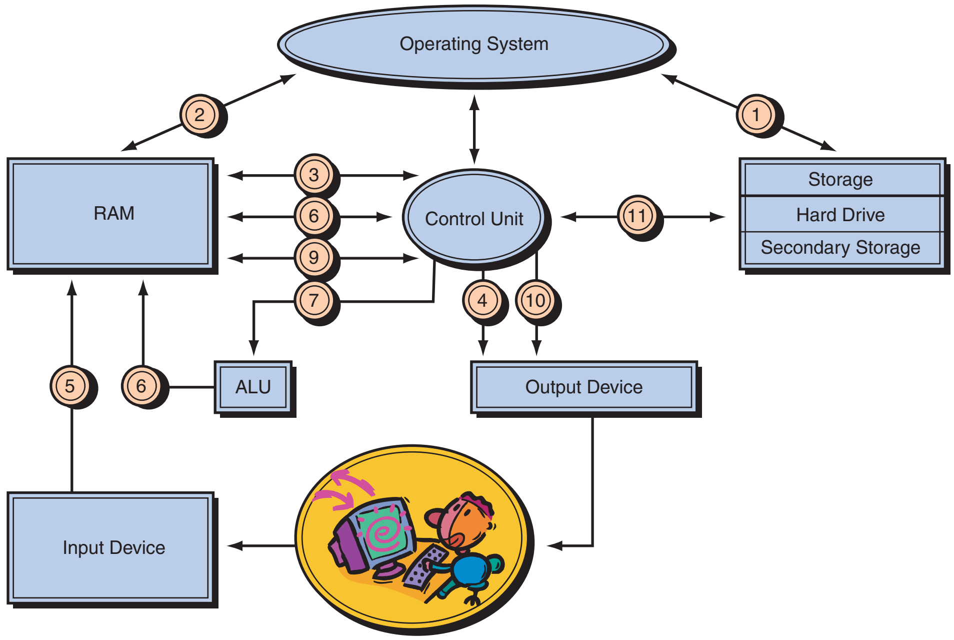


Figure T1.6 Running a program on a computer.

(drive "C"). To run this program, the operating system will retrieve the program from its location (step 1 in the figure) and place it into the RAM (step 2). Then the control unit "fetches" the first instruction in the program from the RAM (step 3) and acts upon it (e.g., send a message to the user, via an output device, to enter a number, or say "yes" or "no"; step 4). Once the message is answered (step 5) (e.g., via an input device), it is stored in the RAM. This concludes the first instruction. Then the control unit "fetches" the second instruction (step 6), and the process continues on and on.

If one of the instructions calls for some computation, the control unit sends it, together with any relevant data stored in the RAM, to the arithmetic logic unit (ALU) (step 7). The ALU executes the processing and returns the results to the RAM (step 8). The control unit then "fetches" one more instruction (step 9), which tells what to do with the result—e.g., display it (step 10) or store it on the hard drive (step 11).

When instructions are "fetched," they are decoded. The computer can process large numbers of instructions per second, usually millions. Therefore, we measure the speed of computers by "millions of instructions per minute," or MIPS.

Getting More Performance. There are four broad categories of microprocessor architecture: *complex instruction set computing* (CISC), *reduced instruction set computing (RISC), very long instruction word* (VLIW), and the newest category, *explicitly parallel instruction computing* (EPIC). Most chips are designated as CISC and have very comprehensive instructions, directing every aspect of chip functioning. RISC chips eliminate rarely used instructions. Computers that use RISC chips (for example, a workstation devoted to high-speed mathematical computation) rely on their software to contain the special instructions. VLIW architectures reduce the number of instructions on a chip by lengthening each instruction. With EPIC architectures, the processor can execute certain program instructions in parallel. Intel's Pentium 4 is the first implementation of EPIC architecture.

In addition to increased speeds and performance, Moore's Law has had an impact on costs. For example, in 1998, a personal computer with a 16-MHz Intel 80386 chip, one megabyte of RAM (discussed later in this Tech Guide), a 40-megabyte hard disk (discussed later in this Tech Guide), and a DOS 3.31 operating system cost $5,200. In

2004, a personal computer with a 3-GHz Intel Pentium 4 chip, 512 megabytes of RAM, an 80-gigabyte hard disk, and the Windows XP operating system cost less than $1,000 (without the monitor).

Conventional microchip manufacturing requires light to shine through a stencil of the circuit pattern. This light travels through lenses which focus the pattern onto a silicon wafer covered with light-sensitive chemicals. When the wafer is coated with acid, the desired circuitry emerges from the silicon. Smaller circuits require shorter wavelengths of light. Current technology uses light waves about 240 nanometers long (called deep ultraviolet light) to create circuits about 100 nanometers wide. However, smaller wavelengths won't work because conventional lenses absorb them. Now, the scientists have made use of extreme ultraviolet light (EUV), with wavelengths from 10 to 100 nanometers, so that circuit could shrink in width to 10 nanometers. The result is microprocessors with 100 times more powerful can be made.

Although organizations certainly benefit from microprocessors that are faster, they also benefit from chips that are less powerful but can be made very small and inexpensive. **Microcontrollers** are chips that are embedded in countless products and technologies, from cellular telephones to toys to automobile sensors. Microprocessors and microcontrollers are similar except that microcontrollers usually cost less and work in less-demanding applications. Thus, the scientific advances in CPU design affect many organizations on the product and service side, not just on the internal CBIS side.

Lucent Technologies has built a transistor in which the layer that switches currents on and off is only one molecule thick. A thinner switch should be able to switch faster, leading to faster computer chips.

Parallel Processing. A computer system with two or more processors is referred to as a **parallel processing system.** Today, some PCs have 2 to 4 processors while workstations have 20 or more. Processing data in parallel speeds up processing. Larger computers may have a hundred processors. For example, IBM is building a supercomputer for the U.S. Energy Department with 8,192 processors working in tandem and able to execute 10 trillion calculations per second (about 150,000 times faster than the 1999 PC). As described earlier, systems with large numbers of processors are called *massively parallel processor* (MPP) systems. They are related to neural computing and complex scientific applications.

Computer Architecture. The arrangement of the components and their interactions is called computer *architecture*. Computer architecture includes the instruction set and the number of the processors, the structure of the internal buses, the use of caches, and the types and arrangements of input/output (I/O) device interfaces.

Every processor comes with a unique set of operational codes or commands that represent the computer's instruction set. An **instruction set** is the set of machine instructions that a processor recognizes and can execute. Today, two instruction set strategies, **complex instruction set computer (CISC)** and **reduced instruction set computer (RISC),** dominate the processor instruction sets of computer architectures. These two strategies differ by the number of operations available and how and when instructions are moved into memory.

A *CISC processor* contains more than 200 unique coded commands, one for virtually every type of operation. The CISC design goal is for its instruction set to look like a sophisticated programming language. Inexpensive hardware can then be used to replace expensive software, thereby reducing the cost of developing software. The penalty for this ease of programming is that CISC processor–based computers have increased architectural complexity and decreased overall system performance. In spite of these drawbacks, most computers still use CISC processors.

The other, most recent approach is *RISC processors*, which eliminate many of the little-used codes found in the complex instruction set. Underlying RISC design is the claim that a very small subset of instructions accounts for a very large percentage of all instructions executed. The instruction set, therefore, should be designed around a few simple "hardwired" instructions that can be executed very quickly. The rest of the needed instructions can be created in software.

The Arithmetic-Logic Unit. The **arithmetic-logic unit** performs required arithmetic and comparisons, or logic, operations. The ALU adds, subtracts, multiplies, divides, compares, and determines whether a number is positive, negative, or zero. All computer applications are achieved through these six operations. The ALU operations are performed sequentially, based on instructions from the control unit. For these operations to be performed, the data must first be moved from the storage to the arithmetic registers in the ALU. **Registers** are specialized, high-speed memory areas for storing temporary results of ALU operations as well as for storing certain control information.

PRIMARY STORAGE

Primary storage, or **main memory,** stores data and program statements for the CPU. It has four basic purposes:

1. To store data that have been input until they are transferred to the ALU for processing
2. To store data and results during intermediate stages of processing
3. To hold data after processing until they are transferred to an output device
4. To hold program statements or instructions received from input devices and from secondary storage

Primary storage utilizes **integrated circuits.** These circuits are interconnected layers of etched semiconductor materials forming electrical transistor memory units with "on-off" positions that direct the electrical current passing through them. The on-off states of the transistors are used to establish a binary 1 or 0 for storing one binary digit, or bit.

The Role of "Buses." Instructions and data move between computer subsystems and the processor via communications channels called buses. A **bus** is a channel through which data are passed in electronic form. Three types of buses link the CPU, primary storage, and the other devices in the computer system. The **data bus** moves data to and from primary storage. The **address bus** transmits signals for locating a given address in primary storage. The **control bus** transmits signals specifying whether to "read" or "write" data to or from a given primary storage address, input device, or output device.

The capacity of a bus, called **bus width,** is defined by the number of bits they carry at one time.

The Control Unit. The **control unit** reads instructions and directs the other components of the computer system to perform the functions required by the program. It interprets and carries out instructions contained in computer programs, selecting program statements from the primary storage, moving them to the instruction registers in the control unit, and then carrying them out. It controls input and output devices and data-transfer processes from and to memory. The control unit does not actually change or create data; it merely directs the data flow within the CPU. The control unit can process only one instruction at a time, but it can execute instructions so quickly (millions per second) that it can appear to do many different things simultaneously.

The series of operations required to process a single machine instruction is called a **machine cycle.** Each machine cycle consists of the *instruction cycle*, which sets up circuitry to perform a required operation, and the *execution cycle*, during which the operation is actually carried out.

Categories of Memory. There are two categories of memory: the *register*, which is part of the CPU and is very fast, and the **internal memory chips,** which reside outside the CPU and are slower. A register is circuitry in the CPU that allows for the fast storage and retrieval of data and instructions during the processing. The control unit, the CPU, and the primary storage all have registers. Small amounts of data reside in the register for very short periods, prior to their use.

The **internal memory** is used to store data just before they are processed by the CPU. Immediately after the processing it comprises two types of storage space: RAM and ROM.

Random-Access Memory. **Random-access memory (RAM)** is the place in which the CPU stores the instructions and data it is processing. The larger the memory area, the larger the programs that can be stored and executed.

With the newer computer operating system software, more than one program may be operating at a time, each occupying a portion of RAM. Most personal computers as of 2006 needed 512 megabytes to 1 gigabyte of RAM to process "multimedia" applications, which combine sound, graphics, animation, and video, thus requiring more memory.

The advantage of RAM is that it is very fast in storing and retrieving any type of data, whether textual, graphical, sound, or animation-based. Its disadvantages are that it is relatively expensive and volatile. This volatility means that all data and programs stored in RAM are lost when the power is turned off. To lessen this potential loss of data, many of the newer application programs perform periodic automatic "saves" of the data.

Many software programs are larger than the internal, primary storage (RAM) available to store them. To get around this limitation, some programs are divided into smaller blocks, with each block loaded into RAM only when necessary. However, depending on the program, continuously loading and unloading **blocks** can slow down performance considerably, especially since secondary storage is so much slower than RAM. As a compromise, some architectures use high-speed **cache memory** as a temporary storage for the most frequently used blocks. Then the RAM is used to store the next most frequently used blocks, and secondary storage (described later) for the least used blocks.

There are two types of cache memory in the majority of computer systems—Level 1 (L1) cache is located in the processor, and Level 2 (L2) cache is located on the motherboard but not actually in the processor. L1 cache is smaller and faster than L2 cache. Chip manufacturers are now designing chips with L1 cache and L2 cache in the processor and Level 3 (L3) cache on the motherboard.

Since cache memory operates at a much higher speed than conventional memory (i.e., RAM), this technique greatly increases the speed of processing because it reduces the number of times the program has to fetch instructions and data from RAM and secondary storage.

Dynamic random access memories (DRAMs) are the most widely used RAM chips. These are known to be volatile since they need to be recharged and refreshed hundreds of times per second in order to retain the information stored in them.

Synchronous DRAM (SDRAM) is a relatively new and different kind of RAM. SDRAM is rapidly becoming the new memory standard for modern PCs. The reason is that its synchronized design permits support for the much higher bus speeds that have started to enter the market.

Read-Only Memory. **Read-only memory (ROM)** is that portion of primary storage that cannot be changed or erased. ROM is *nonvolatile*; that is, the program instructions are continually retained within the ROM, whether power is supplied to the computer or not. ROM is necessary to users who need to be able to restore a program or data after the computer has been turned off or, as a safeguard, to prevent a program or data from being changed. For example, the instructions needed to start, or "boot," a computer must not be lost when it is turned off.

Programmable read-only memory (PROM) is a memory chip on which a program can be stored. But once the PROM has been used, you cannot wipe it clean and use it to store something else. Like ROMs, PROMs are nonvolatile.

Erasable programmable read-only memory (EPROM) is a special type of PROM that can be erased by exposing it to ultraviolet light.

Other Memory Measures. Several other types of memories are on the market. Notable are the fast static RAM (SRAM) chips and the Flash Memory. **SRAM** costs more than DRAM but has a higher level of performance, making SRAM the preferred choice for performance-sensitive applications, including the external L2 and L3 caches that speed up microprocessor performance. **Flash memory** is another form of rewritable ROM storage. This technology can be built into a system or installed on a personal computer card (known as a *flash card*). These cards, though they have limited capacity, are compact, portable, and require little energy to read and write. Flash memory via flash cards is very popular for small portable technologies such as cellular telephones, digital cameras, handheld computers, and other consumer products.

A kind of new memory chip, called **M-RAM,** can maintain data securely without a constant source of power. "M" means magnetic that uses minuscule magnets rather than electric charges to store the 0s and 1s of binary data. M-RAM has significant advantage over D-RAM: In D-RAM, the bits that make up the 0s and 1s are stored as electric charges on the power-storage unit, the capacitor, which must be bathed in electricity every few nanoseconds to hold the charge; in contrast, M-RAM stores its bits magnetically, not as charges, so information will not leak away when there is no power, thus ideal for wireless and portable applications. Estimated investment in the research of this technology is over $50 million.

Staktek Holdings Inc., a provider of intellectual property and services for high-speed, high-capacity systems, offered the ArctiCore memory module, which utilizes 72 standard memory devices in an industry-standard module form factor. The new module, based on ArctiCore technology, is a Registered Dual In-Line Memory Module (RDIMM) designed for server and workstation applications. ArctiCore's high-density architecture enables placement of 72 cost-effective 512 Mb memory devices on a module that meets the applicable JEDEC specifications for RDIMM dimensions. This mounting efficiency results in a total module capacity of 4 Gb of memory. With the memory structured in a 4-rank organization, many applications experience increased system performance when compared to a 2-rank memory module of the same capacity (*Computer Technology Review,* 2006g).

T1.5 Input/Output Devices

The input/output (I/O) devices of a computer are not part of the CPU, but are channels for communicating between the external environment and the CPU. Data and instructions are entered into the computer through **input devices,** and processing results are provided through **output devices.** Widely used I/O devices are the cathode-ray tube (CRT) or visual display unit (VDU), magnetic storage media, printers, keyboards, "mice," and image-scanning devices.

I/O devices are controlled directly by the CPU or indirectly through special processors dedicated to input and output processing. Generally speaking, I/O devices are subclassified into *secondary storage devices* (primarily disk and tape drives) and *peripheral devices* (any input/output device that is attached to the computer).

SECONDARY STORAGE

Secondary storage is separate from primary storage and the CPU, but directly connected to it. An example would be the 3.5-inch disk you place in your PC's A-drive. It stores the data in a format that is compatible with data stored in primary storage, but secondary storage provides the computer with vastly increased space for storing and processing large quantities of software and data. Primary storage is volatile, contained in memory chips, and very fast in storing and retrieving data. In contrast, secondary storage is nonvolatile, uses many different forms of media that are less expensive than primary storage, and is relatively slower than primary storage. Secondary storage media include magnetic tape, magnetic disk, magnetic diskette, optical storage, and digital videodisk.

Magnetic Tape. **Magnetic tape** is kept on a large open reel or in a small cartridge or cassette. Today, cartridges and cassettes are replacing reels because they are easier to use and access. The principal advantages of magnetic tape are that it is inexpensive, relatively stable, and long lasting, and that it can store very large volumes of data. A magnetic tape is excellent for backup or archival storage of data and can be reused. The main disadvantage of magnetic tape is that it must be searched from the beginning to find the desired data. This process is called *sequential access.* The magnetic tape itself is fragile and must be handled with care. Magnetic tape is also labor intensive to mount and dismount in a mainframe computer. Magnetic tape storage often is used for information that an organization must maintain, but uses rarely or does not need immediate access to. Industries with huge numbers of files (e.g., insurance companies) use magnetic tape systems. Modern versions of magnetic tape systems use cartridges and often a robotic system that selects and loads the appropriate cartridge automatically. There are also some tape systems, like digital audio tapes (DAT), for smaller applications such as storing copies of all the contents of a personal computer's secondary storage ("backing up" the storage).

Magnetic Disks. **Magnetic disks,** also called **hard disks** (see photo), alleviate some of the problems associated with magnetic tape by assigning specific address locations for data, so that users can go directly to the address without having to go

A hard disk drive.

through intervening locations looking for the right data to retrieve. This process is called *direct access*. Most computers today rely on hard disks for retrieving and storing large amounts of instructions and data in a nonvolatile and rapid manner. The hard drives of 2006 microcomputers provide 80 to 500 gigabytes of data storage.

A hard disk is like a phonograph containing a stack of metal-coated platters (usually permanently mounted) that rotate rapidly. Magnetic read/write heads, attached to arms, hover over the platters. To locate an address for storing or retrieving data, the head moves inward or outward to the correct position, then waits for the correct location to spin underneath.

The speed of access to data on hard-disk drives is a function of the rotational speed of the disk and the speed of the read/write heads. The read/write heads must position themselves, and the disk pack must rotate until the proper information is located. Advanced disk drives have access speeds of 8 to 12 milliseconds.

Magnetic disks provide storage for large amounts of data and instructions that can be rapidly accessed. Another advantage of disks over reel is that a robot can change them. This can drastically reduce the expenses of a data center. Storage Technology is the major vendor of such robots. The disks' disadvantages are that they are more expensive than magnetic tape and they are susceptible to "disk crashes."

A modern personal computer typically has many gigabytes (some more than 100 gigabytes) of storage capacity in its internal hard drive. Data access is very fast, measured in milliseconds. For these reasons, hard disk drives are popular and common. Because they are somewhat susceptible to mechanical failure, and because users may need to take all their hard drive's contents to another location, many users like to back up their hard drive's contents with a portable hard disk drive system, such as Iomega's Jaz.

In contrast to large, fixed disk drives, one current approach is to combine a large number of small disk drives, each with 10- to 40-gigabyte capacity, developed originally for microcomputers. These devices are called **redundant arrays of inexpensive disks (RAID).** Because data are stored redundantly across many drives, the overall impact on system performance is lessened when one drive malfunctions. Also, multiple drives provide multiple data paths, improving performance. Finally, because of manufacturing efficiencies of small drives, the cost of RAID devices is significantly lower than the cost of large disk drives of the same capacity.

To take advantage of the new, faster technologies, *disk-drive interfaces* must also be faster. Most PCs and workstations use one of two high-performance disk-interface standards: **Enhanced Integrated Drive Electronics (EIDE)** or **Small Computer Systems Interface (SCSI).** EIDE offers good performance, is inexpensive, and supports up to four disks, tapes, or CD-ROM drives. The latest version is called Serial ATA (SATA). For details, refer to *serialata.org.* SCSI drives are more expensive than EIDE drives, but they offer a faster interface and support more devices. SCSI interfaces are therefore used for graphics workstations, server-based storage, and large databases.

SCSI held more than 80 percent of the market in storage I/O. The successor to SCSI, Serial Attached SCSI (SAS), is rapidly replacing legacy SCSI as the leadership storage technology. (*Computer Technology Review,* 2006c).

Hard disks are not practical for transporting data of instructions from one personal computer to another. To accomplish this task effectively, developers created the **magnetic diskette.** (These diskettes are also called "floppy disks," a name first given the very flexible 5.25-inch disks used in the 1980s and early 1990s.) The magnetic diskette used today is a 3.5-inch, removable, somewhat flexible magnetic platter encased in a plastic housing. Unlike the hard disk drive, the read/write head of the diskette drive actually touches the surface of the disk. As a result, the speed of the drive is much slower, with an accompanying reduction in data transfer rate. However, the diskettes themselves are very inexpensive, thin enough to be mailed, and able to store relatively large amounts of data. A standard high-density disk contains 1.44 megabytes. **Zip disks** are larger than conventional floppy disks, and about twice as thick. Disks formatted for zip drives contain up to 35 Gb (or 90 Gb in compressed mode).

Imation Corp. offered the 4 Gb drive. The Imation Micro Hard Drive also has a tiny hard disk drive, a Toshiba invention measuring less than one inch in diameter, that stores 4 Gb of information (*Computer Technology Review,* 2006b).

The Seagate Portable Hard Drive has storage capacity to 160 Gb, which is 30 percent over the current standard while maintaining the same compact footprint. For data-intensive applications such as video editing or massive data transfers, the Seagate Pushbutton Backup Hard Drive now backs up and transfers data five times faster than existing storage devices, by taking 3 Gb/s Serial ATA out of the box. The Seagate 500 Gb eSATA Pushbutton Backup Hard Drive provides external data backup and protection with speeds up to a 300 Mb/s or 3 Gb/s interface rate—up to five times faster than existing external storage solutions such as USB 2.0 and 1394a (*Computer Technology Review,* 2006d.)

IBM has invented a new disk drive technology by combining two layers of magnetic material and a three-atom-thick filling to create a disk drive that can hold 27 gigabits per square inch. The two magnetic layers are separated by ruthenium, a nonmagnetic material. The three-layer coating is thicker than current coatings and more stable. The ruthenium layer forces the adjacent layers to have opposite magnetic orientations, allowing data to be written on the top layer at higher densities. NEC is working on a technology to revolutionize storage capacity to 1 Tb per square inch. This technology would make use of a newly developed material that exhibits a property called "extraordinary magneto-resistance" (EMR). When applied to the read heads of disk drives, EMR allows for more sensitivity when reading magnetic information on the spinning hard disk; thus the actual disk platter can be jammed with more information.

Iomega has developed StorCenter Pro NAS 400r Series with 1 terabyte (Tb) expansion chassis. Companies can select the appropriate StorCenter Pro NAS 400r series server for their current needs (native capacity ranges from 640 Gb to 1.6 Tb), and as storage needs grow, they can add additional 1 Tb via a 400e expansion chassis unit as needed (1 Tb at a time). Users can add up to 3.0 Tb to the original NAS 400r series server, all managed under the 400r series server's Windows Storage Server 2003 operating system license (*Computer Technology Review,* 2006a).

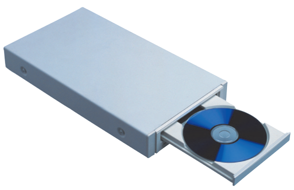
Intel Robson Cache. Since the evolution of Intel's Dual Core technology, conventional hard disk technology has reached its limitations, which are mostly mechanical in nature. On the other hand, semiconductor technology (e.g., DRAM, SRAM) also has its limitations, like low capacity. As a result, the new secondary storage technology, called Intel Robson Cache, was invented. This technology makes use of NAND's architecture—flash memory with capacity from 64 Mb to 4 Gb mountable on the motherboard or in the form of a mini-PCI-E module.

Optical Storage Devices. **Optical storage devices** have extremely high storage density. Typically, much more information can be stored on a standard 5.25-inch optical disk than on a comparably sized floppy (about 400 times more). Since a highly focused laser beam is used to read/write information encoded on an optical disk, the information can be highly condensed. In addition, the amount of physical disk space needed to record an optical bit is much smaller than that usually required by magnetic media.

Another advantage of optical storage is that the medium itself is less susceptible to contamination or deterioration. First, the recording surfaces (on both sides of the disk) are protected by two plastic plates, which keep dust and dirt from contaminating the surface. Second, only a laser beam of light, not a flying head, comes in contact with the recording surface; the head of an optical disk drive comes no closer than 1 mm from the disk surface. Optical drives are also less fragile, and the disks themselves may easily be loaded and removed. In addition, optical disks can store much more information, both on a routine basis and also when combined into storage systems.

Optical disk storage systems can be used for large-capacity data storage. These technologies, known as **optical jukeboxes,** store many disks and operate much like the automated phonograph record changers for which they are named.

Types of optical disks include compact disk read-only memory (CD-ROM), digital video disk (DVD), and fluorescent multilayer disk (FMD-ROM).


A CD-ROM inside a drive.

Compact Disk Read-Only Memory. **Compact disk read-only memory (CD-ROM) disks** have high capacity, low cost, and high durability (see photo). CD-ROM technology is very effective and efficient for mass-producing many copies of large amounts of information that do not need to be changed, for example, encyclopedias, directories, and online databases. However, because it is a read-only medium, the CD-ROM can be only read and not written on. **Compact disk, rewritable (CD-RW)** adds rewritability to the recordable compact disk market, which previously had offered only write-once CD-ROM technology.

Digital Video Disk (DVD). **DVD** is a relatively new storage disk that offers higher quality and denser storage capabilities. In 2003, the disk's maximum storage capacity is 40 Gbytes, which is sufficient for storing about five movies. It includes superb audio (six-track vs. the two-track stereo). Like CDs, DVD comes as DVD-ROM (read-only) and DVD-RAM (rewritable). Rewritable DVD-RAM systems offer a capacity of 4.7 Gb on one side, 4.7 Gb on two sides. In fact, DVD specification supports disks with capacities of from 4.7 Gb to 17 Gb and access rates of 600 Kbps to 1.3 Mbps.

Sony Electronics has developed its 25 Gb single-layer and 50 Gb dual-layer Blu-ray disc recording media with AccuCORE technology. Sony's AccuCORE technology, which was first integrated into recordable DVD media, has been reengineered for Blu-ray discs to deliver enhanced reliability and durability. Its features include: scratch guard, archival reliability, stable writing, and temperature durability. Sony's Blu-ray media also support 2 × recording speed, which provides a high data transfer rate up to 72 Mbps, making it ideal for high-definition video recording and data storage applications. Users could edit high-definition video shot on a Sony HDV camcorder on a Blu-ray-enabled computer, then burn it onto Blu-ray disc media, and play it back on a Blu-ray disc player (*Computer Technology Review,* 2006e).

Fluorescent Multilayer Disk (FMD-ROM). **FMD-ROM** is a new optical storage technology that greatly increases storage capacity. The idea of using multiple layers on an optical disk is not new, as DVDs currently support two layers. However, by using a new fluorescent-based optical system, FMDs can support 20 layers or more. FMDs are clear disks; in the layers are fluorescent materials that give off light. The presence or absence of these materials tells the drive whether there is information there or not. All layers of an FMD can be read in parallel, thereby increasing the data transfer rate.

Expandable Storage. **Expandable storage devices** are removable disk cartridges. The storage capacity ranges from 100 megabytes to several gigabytes per cartridge, and the access speed is similar to that of an internal hard drive. Although more expensive than internal hard drives, expandable storage devices combine hard disk storage capacity and diskette portability. Expandable storage devices are ideal for backup of the internal hard drive, as they can hold more than 80 times as much data and operate five times faster than existing floppy diskette drives.

Memory PC Card. *Memory PC cards* (also known as *memory sticks*) expand the amount of available memory. They have been widely used, particularly in portable devices like PDAs and smart phones. There are a number on the market: HP's Compact Flash Card, IBM Micro Driver, Smart Media Card, Secure Digital Card, Multi Media Card, Memory Stick, and Memory Stick Pro.

Summary. Table T1.3 summarizes the major secondary storage devices, their advantages, limitations, and applications.

TABLE T1.3 Secondary Storage

Type	Advantages	Disadvantages	Application
Magnetic Storage Devices			
Magnetic tape	Lowest cost per unit stored.	Sequential access means slow retrieval speeds.	Corporate data archiving.
Hard drive	Relatively high capacity and fast retrieval speed.	Fragile; high cost per unit stored.	Personal computers through mainframes.
RAID	High capacity; designed for fault tolerance and reduced risk of data loss; low cost per unit stored.	Expensive, semipermanent installation.	Corporate data storage that requires frequent, rapid access.
SAN	High capacity; designed for large amounts of enterprise data.	Expensive.	Corporate data storage that requires frequent, rapid access.
NAS	High capacity; designed for large amounts of enterprise data.	Expensive.	Corporate data storage that requires frequent, rapid access.
Magnetic diskettes	Low cost per diskette, portability.	Low capacity; very high cost per unit stored; fragile.	Personal computers.
Memory cards	Portable; easy to use; less failure-prone than hard drives.	Expensive.	Personal and laptop computers.
Memory sticks	Extremely portable and easy to use.	Relatively expensive.	Consumer electronic devices; moving files from portable devices to desktop computers.
Expandable storage	Portable; high capacity.	More expensive than hard drives.	Backup of internal hard drive.
Optical Storage Devices			
CD-ROM	High capacity; moderate cost per unit stored; high durability.	Slower retrieval speeds than hard drives; only certain types can be rewritten.	Personal computers through corporate data storage.
DVD	High capacity; moderate cost per unit stored.	Slower retrieval speeds than hard drives.	Personal computers through corporate data storage.
FMD-ROM	Very high capacity; moderate cost per unit stored.	Faster retrieval speeds than DVD or CD-ROM; slower retrieval speeds than hard drives.	Personal computers through corporate data storage.

PERIPHERAL INPUT DEVICES

Users can command the computer and communicate with it by using one or more **input devices.** Each input device accepts a specific form of data. For example, keyboards transmit typed characters, and handwriting recognizers "read" handwritten characters. Users want communication with computers to be simple, fast, and error free. Therefore, a variety of input devices fits the needs of different individuals and applications (see Table T1.4). Some of these devices are shown in Figure T1.7 together with their usage.

Keyboards. The most common input device is the *keyboard*. The keyboard is designed like a typewriter but with many additional special keys. Most computerusers utilize keyboards regularly. Unfortunately, a number of computer users have developed repetitive stress injury, which they allege comes from excessive use of poorly designed keyboards. As a result, new keyboards have been developed that are ergonomically designed. For example, some keyboards are now "split" in half, loosely approximating the natural angle of the arms and wrists (see photo).

Of the many attempts to improve the keyboard, one of the most interesting is the DataHand (*datahand.com*) keyboard, which consists of two unattached pads. Rather than a conventional array of keys, this device has touch-sensitive receptacles (or finger wells) for the fingers and thumbs. Each finger well allows five different commands, which are actuated by touching one of the sides or the bottom of the finger wells. Complex commands can be programmed so that a single flick of the finger can be used to enter frequently used sequences of commands or chunks of data. In 2004, wireless keyboards became quite popular. They use radio frequency (RF), which is more accurate than infrared.

TABLE T1.4 Representative Input Devices

Categories	Examples
Keying devices	• Punched card reader • Keyboard • Point-of-sale (POS) terminal
Pointing devices *(devices that point to objects on the computer screen)*	• Mouse (including rollerballs and trackballs) • Touch screen • Touchpad (or trackpad) • Light pen • Joy stick
Optical character recognition *(devices that scan characters)*	• Bar code scanner (e.g., at POS) • Optical character reader • Wand reader • Cordless reader • Optical mark reader
Handwriting recognizers	• Pen
Voice recognizers *(data are entered by voice)*	• Microphone
Other devices	• Magnetic ink character readers • Digital cameras • Automated teller machines (ATMs) • Smart cards • Digitizers (for maps, graphs, etc.) • RFID

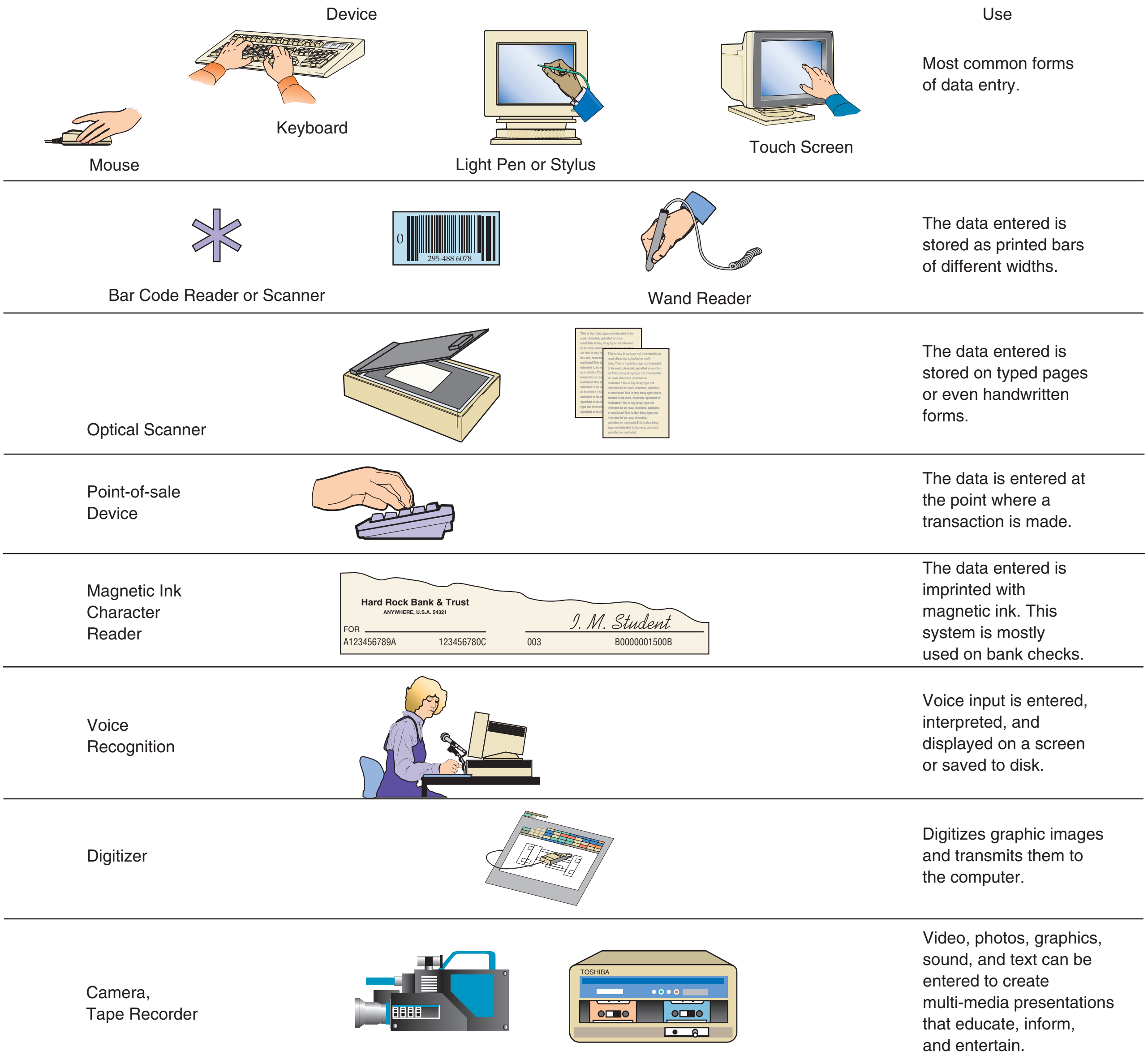


Figure T1.7 Typical input devices. Each input device reads a different form of data for processing by the CPU. (*Source: Computing in the Information Age*, Stern and Stern, 1993, p. 172. Copyright © 1993 John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

As the popularity of PDAs has grown, manufacturers have developed keyboards to be used with these devices. A Universal IR Wireless Keyboard, called Targus (*targus.com*), works with most popular PDAs like Palm, Pocket PC PDAs, and Palm/PPC based PDA/cell phones, and smart phones. It works with applications that support text input. Another manufacturer, Logitech (*logitech.com*), has made two keyboards used in conjunction with Palm PDAs, KeyCase and TypeAway.

Virtual Keyboard, developed by VKB, uses laser technology to project an image of a keyboard to a sensor in front that can detect finger strokes. It can be used to replace a computer mouse or telephone keypad. This futuristic device will enable

An ergonomic "split" keyboard.

computer users to key in data from any place, without need to have a physical keyboard with them.

Mice and Trackballs. The computer *mouse* is a handheld device used to point a cursor at a desired place on the screen, such as an icon, a cell in a table, an item in a menu, or any other object. Once the arrow is placed on an object, the user clicks a button on the mouse, instructing the computer to take some action. The use of the mouse reduces the need to type in information or use the slower arrow keys.

Special types of mouses are *rollerballs* and *trackballs*, used in many portable computers. A new technology, called *glide-and-tap*, allows fingertip cursor control in laptop computers.

A variant of the mouse is the **trackball,** which is often used in graphic design. The user holds an object much like a mouse, but rather than moving the entire device to move the cursor (as with a mouse), he or she rotates a ball that is built into the top of the device. Portable computers have some other mouselike technologies, such as the glide-and-tap pad, used in lieu of a mouse. Many portables also allow a conventional mouse to be plugged in when desired.

Another variant of the mouse, the **optical mouse,** replaces the ball, rollers, and wheels of the mechanical mouse with a light, lens, and a camera chip. It replicates the action of a ball and rollers by taking photographs of the surface it passes over, and comparing each successive image to determine where it is going.

The **pen mouse** resembles an automobile stick shift in a gear box. Moving the pen and pushing buttons on it perform the same functions of moving the cursor on the screen as a conventional pointing device.

Touch Screens. An alternative to the mouse or other screen-related devices is a *touch screen*. **Touch screens** are a technology that divides a computer screen into different areas. Users simply touch the desired area (often buttons or squares) to trigger an action. Touch screens are often found in computer kiosks and other such applications.

Stylus. A **stylus** is a pen-style device that allows the user either to touch parts of a predetermined menu of options (as with a wearable computer, discussed above) or to handwrite information into the computer (as with some PDAs). The technology may respond to pressure of the stylus, or the stylus can be a type of light pen that emits light that is sensed by the computer.

Joysticks. *Joysticks* are used primarily at workstations that can display dynamic graphics. They are also used in playing video games. The joystick moves and positions the cursor at the desired object on the screen.

Joysticks have been developed to include many features. Essential Reality's P5 Glove was designed in gaming, scientific visualization, animation, CAD, virtual reality (VR), industrial design, and Web browsing. It is a handheld glove that contains electronics that can read how users move their fingers and then use that information to carry out commands on the screen.

Electronic Forms. **Electronic forms** provide a standardized format whose headings serve as prompts for the input. In **form interaction,** the user enters data or commands into predesignated spaces (fields) in a form. The computer may produce some output after input is made, and the user may be requested to continue the form interaction process. Electronic forms can alleviate many of the resource-intensive steps of processing forms, making traditional typesetting and printing unnecessary. Finally, processing centers do not need to rekey data from paper-based forms, since the data remain in electronic format throughout the process.

Whiteboard. A **whiteboard** is an area on a display screen that multiple users can write or draw on. Whiteboards are a principal component of teleconferencing applications because they enable visual as well as audio communication.

Source Data Automation. *Source data automation* captures data in computer-readable form at the moment the data are created. Point-of-sale systems, optical barcodes and code scanners, other optical character recognition devices, handwriting recognizers, voice recognizers, digitizers, and cameras are examples of source data automation. Source data automation devices eliminate errors arising from humans keyboarding data and allow for data to be captured directly and immediately, with built-in error correction. The major devices are described below.

Point-of-Sale Terminals. Many retail organizations utilize **point of sale (POS) terminals.** The POS terminal has a specialized keyboard. For example, the POS terminals at fast-food restaurants include all the items on the menu, sometimes labeled with the picture of the item. POS terminals in a retail store are equipped with a barcode scanner that reads the barcoded sales tag. POS devices increase the speed of data entry and reduce the chance of errors. POS terminals may include many features such as scanner, printer, voice synthesis (which pronounces the price by voice), and accounting software.

Barcode Scanner. **Barcode scanners** scan the black-and-white bars written in the *Universal Product Code* (UPC) (see photo). This code specifies the name of the product and its manufacturer (product ID). Then a computer finds in the database the price equivalent to the product's ID. Barcodes are especially valuable in high-volume processing where keyboard energy is too slow and/or inaccurate. Applications include supermarket checkout, airline baggage stickers, and transport companies' packages (Federal Express, United Parcel Service, and the U.S. Postal Service). The **wand reader** is a special handheld barcode reader that can read codes that are also readable by people.

Radio Frequency Identification (RFID) Tag. *Radio frequency identification* (RFID) is a system of technologies that use radio waves to automatically identify people or objects. The unique information (usually a serial number) is stored on a microchip (tag) that is attached to an antenna, which can transmit to a nearby reader. The reader would then convert the radio waves from the RFID tag into digital information for the computer to use.

A POS terminal, which reads Universal Product Codes (UPCs).

Optical Mark Reader. An **optical mark reader** is a special scanner for detecting the presence of pencil marks on a predetermined grid, such as multiple-choice test answer sheets.

Magnetic Ink Character Readers. Similarly, **magnetic ink character readers (MICRs)** are used chiefly in the banking industry. Information is printed on checks in magnetic ink that can be read by the MICR technology, thus helping to automate and greatly increase the efficiency of the check-handling process.

Optical Character Reader (or Optical Scanner). With an **optical character reader (OCR),** source documents such as reports, typed manuscripts, and books can be entered directly into a computer without the need for keying. An OCR converts text and images on paper into digital form and stores the data on disk or other storage media. OCRs are available in different sizes and for different types of applications.

The publishing industry was the leading user of optical scanning equipment. Publishers scan printed documents and convert them to electronic databases that can be referenced as needed. Similarly, they may scan manuscripts instead of retyping them in preparation for the process that converts them into books and magazines. Considerable time and money are saved, and the risk of introduction of typographical errors is reduced.

Handwriting Recognizers. Handwriting recognition is supported by technologies such as expert systems and neural computing and is available in some pen-based computers.

Scanners that can interpret handwritten input are subject to considerable error. To minimize mistakes, handwritten entries should follow very specific rules. Some scanners will flag handwritten entries that they cannot interpret or will automatically display for verification all input that has been scanned. Because handwritten entries are subject to misinterpretation and typed entries can be smudged, misaligned, and/or erased, optical scanners have an error rate much higher than the error rate for keyed data.

Pen-based input devices transform the letters and numbers written by users on the tablet into digital form, where they can be stored or processed and analyzed. At present, pen-based devices cannot recognize free-hand writing very well, so users must print letters and numbers in block form.

For example, Logitech's io_2 pen has a bulky and cigar-like body that has an optical sensor which captures your handwriting as you write. It can store pages of your scribbles and uses USB cradle to turn your digital scrawl into Microsoft Word or Outlook documents, on-screen sticky notes. It requires special digital paper.

Voice Recognizers. The most natural way to communicate with computers is by voice. **Voice recognition devices** convert spoken words into digital form. Voice recognition devices work fast, free the user's hands, and result in few entry errors. They also allow people with visual or other disabilities to communicate with computers. When voice technology is used in combination with telephones, people can call their computers from almost any location. While voice technologies have certain limitations such as size of the vocabulary, they are rapidly being improved. Because voice recognition uses so-called "natural language" (as opposed to created machine language), the process of communicating with voice recognizers is called **natural language processing.**

Recognizing words is fairly easy, but understanding the content of sentences and paragraphs is much more difficult. To understand a natural language inquiry, a computer must have sufficient knowledge to analyze the input in order to interpret it. This knowledge includes linguistic knowledge about words, domain knowledge, common-sense knowledge, and even knowledge about users and their goals.

Digitizers. **Digitizers** are devices that convert drawings made with a pen on a sensitized surface to machine-readable input. As drawings are made, the images are transferred to the computer. This technology is based on changes in electrical charges that correspond to the drawings. Designers, engineers, and artists use digitizers.

Sensors. **Sensors** are extremely common technologies embedded in other technologies. They collect data directly from the environment and input them into a computer system. Examples might include your car's airbag activation sensor or fuel mixture/pollution control sensor, inventory control sensors in retail stores, and the myriad types of sensors built into a modern aircraft.

Digital Cameras. Regular video cameras can be used to capture pictures that are digitized and stored in computers. Special **digital cameras** are used to transfer pictures and images to storage on a memory card, floppy diskette, small hard drive, or CD-ROM. A digital camera can take photos and load them directly from the camera, digitally, to a main storage or secondary storage device.

Digital cameras use a *charge-coupled device* (CCD) instead of film. Once you take pictures you can review, delete, edit, and save images. You can capture sound or text annotations and send the results to a printer using infrared, Bluetooth, or picbridge technology. You can zoom or shrink images and interface with other devices. Images can be transmitted from the camera to a PC, printer, or other cameras, even via telephone lines. Digital cameras work with or without computers.

In addition to instant prints, you can do many other things with your digital camera. For example, in presentations you can stop scribbling notes and can instead digitally capture the teacher's (presenter's) notes, slides, and other visual exhibits. When linked to the Internet, and using special software such as Microsoft's Net-Meeting, such a system can be used to conduct desktop videoconferencing.

Universal Serial Bus (USB). This is a low-cost interfacing port for computer peripherals. USB 1.1 has a maximum transfer rate of 12 Mbps that cannot fulfill some speedy peripherals like external hard drives. USB 2.0 has a maximum transfer rate of 480 Mbps, which is 40 times faster than USB 1.1. It is faster than its competitor IEEE 1394 that has maximum transfer rate of 400 mbps. Table T1.5 shows the USB performance tests.

The output generated by a computer can be transmitted to the user via several devices and media. The presentation of information is extremely important in

TABLE T1.5 USB Performance Tests

USB 2.0 vs. USB 1.1 Real-World Transfers	Hard Drive Tests		CD-RW Drive Tests		Scanner Tests	
	Copy files & folders	Photoshop 6.0.1	Digital audio	Write to CD-R	1,600 dpi image	300 dpi image
Average of five USB 2.0 cards in second	0:58	4:24	1:38	4:03	6:44	0:15
USB 1.1 in second	12:13	37:19	6:32	20:10	13:42	0:26
Performance gain	12.6 X	8.5 X	4 X	5 X	2 X	1.7 X

Source: PC World.

encouraging users to embrace computers. The major output devices are shown in Figure T1.8 and are discussed next.

An LCD monitor.

Monitors. The data entered into a computer can be visible on the computer **monitor,** which is basically a video screen that displays both input and output (see photo). Monitors come in different sizes, ranging from inches to several feet. The major benefit is the interactive nature of the device.

Light-Emitting Polymer. *Light-emitting polymer* (LEP), developed by Cambridge Display Technology (*cdtltd.co.uk*), refers to a display technology in which plastics are made to conduct electricity and under certain conditions to emit light. They are constructed by applying a thin film of the light-emitting polymer onto a glass or plastic substrate coated with a transparent, indium tin oxide electrode. An aluminum electrode is sputtered or evaporated on top of the polymer. Application of an electric field between the two electrodes results in emission of light from the polymer. Unlike liquid crystal or plasma displays, which require thin film processing on two glass plates, LEPs can be fabricated on one sheet of glass or plastic, which in

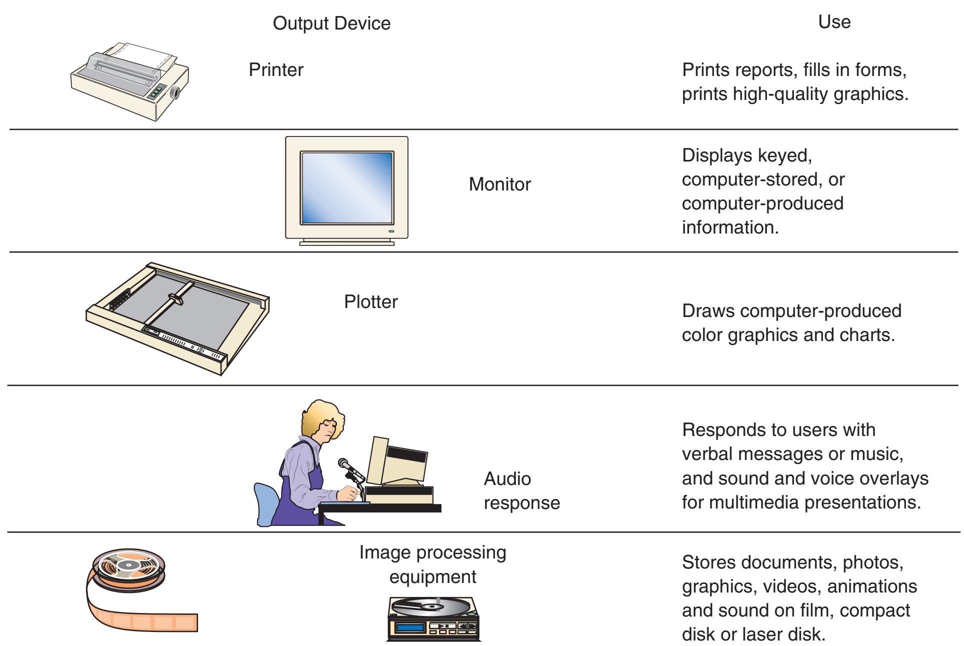


Figure T1.8 Representative output devices and their use. (*Source: Computing in the Information Age*, Stern and Stern 1993, p. 199. Copyright © 1993 John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

turn greatly simplifies manufacturing and reduces component cost. Their advantages are fast response time, switching at low voltage, and the intensity of light is proportional to current.

Organic Light-Emitting Diodes. **Organic light-emitting diodes (OLEDs)** provide displays that are brighter, thinner, lighter, and faster than liquid crystal displays (LCDs). Compared to LCDs, OLEDs take less power to run, offer higher contrast, look equally bright from all angles, handle video, and are cheaper to manufacture. OLEDs do face technical obstacles with color. If you leave OLEDs on for a month or so, the color becomes very nonuniform. However, OLEDs are probably good enough right now for cell phones, which are typically used for 200 hours per year and would likely be replaced before the colors start to fade. But such performance is not adequate for handheld or laptop displays, for which several thousand hours of life are required.

Organic light-emitting diodes (OLEDs) are based on something called *electroluminescence*. Certain organic materials emit light when an electric current passes through them. If such materials are sandwiched between two electrodes, a display can be obtained. Besides using less electricity than LCDs, OLEDs are easier to manufacture, the materials to manufacture them are cheaper, and their displays are brighter with better color saturation and a wider viewing angle.

Impact Printers. **Impact printers** use some form of striking action to press a carbon or fabric ribbon against paper to create a character. The most common impact printers are the dot matrix, daisy wheel, and line printers. Line printers print one line at a time; therefore, they are faster than one-character type printers. Impact printers have even been produced for portable uses. There is a portable printer, for example, that can print barcode labels conveniently.

Nonimpact Printers. **Nonimpact printers** overcome the deficiencies of impact printers. There are different types of nonimpact printers: laser, thermal, ink-jet. **Laser printers** (see photo) contain high-quality devices that use laser beams to write information on photosensitive drums, whole pages at a time; then the paper passes over the drum and picks up the image with toner. Because they produce print-quality text and graphics, and do so quickly, laser printers are used in desktop publishing and in reproduction of artwork. **Thermal printers** create whole characters on specially treated paper that responds to patterns of heat produced by the printer. For example, SiPix's Pocket Printer A6 does not need ink cartridges or ribbons, but instead uses thermal technology to print by heating coated paper. **Ink-jet printers** shoot tiny dots of ink onto paper. Sometimes called *bubble jet,* they are relatively

Laser printer.

inexpensive, and are especially suited for low-volume graphical applications when different colors of ink are required. **Digital color copiers** are now so powerful that they can produce everything from coupons and posters to brochures. If loaded with additional print controller, the digital color copier can be a color printer or scanner.

Plotters. **Plotters** are printing devices using computer-driven pens for creating high-quality black-and-white or color graphic images—charts, graphs, and drawings. They are used in complex, low-volume situations such as engineering and architectural drawing, and they come in different types and sizes.

Voice Output. Some devices provide output via voice—**synthesized voice.** This term refers to the technology by which computers "speak." The synthesis of voice by computer differs from a simple playback of a prerecorded voice by either analog or digital means. As the term "synthesis" implies, the sounds that make up words and phrases are electronically constructed from basic sound components and can be made to form any desired voice pattern. The quality of synthesized voice is currently very good, and relatively inexpensive.

Multimedia. **Multimedia** refers to a group of human–machine communication media, some of which can be combined in one application. In information technology, an interactive multimedia approach involves the use of computers to improve human–machine communication by using a combination of media. The construction of a multimedia application is called *authoring*. Multimedia also merges the capabilities of computers with television sets, VCRs, CD players, DVD players, video and audio recording equipment, and music and gaming technologies.

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