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

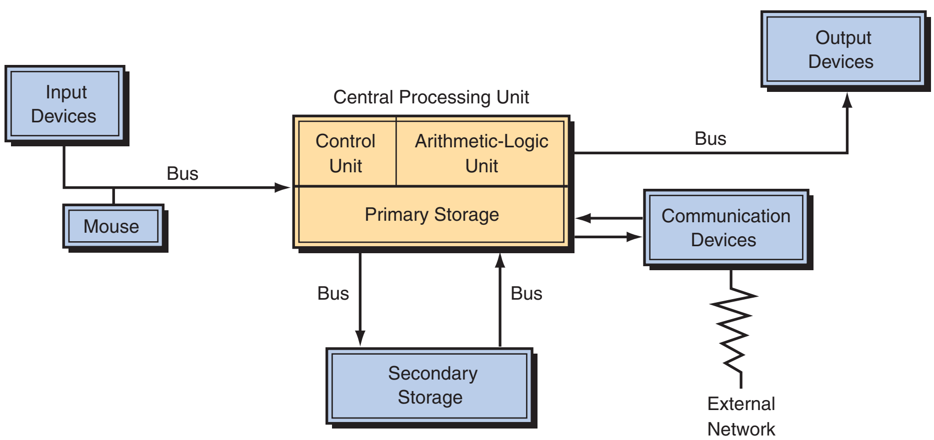


FIGURE T1.1 The components of computer hardware. A "bus" is a connecting channel.

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.

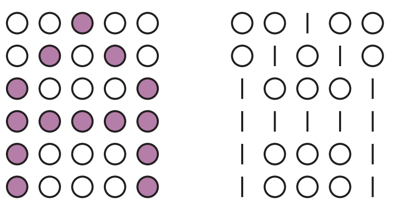
commonly agreed-upon symbols in a binary code. For example, the plus sign (+) is 00101011 in ASCII.

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 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



Pixel diagram Input code

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

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
- **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.

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

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 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.

Future Generations of Computers

Two major innovations are in experimental stages: DNA computers and optical computers.

DNA COMPUTERS. DNA is an acronym for deoxyribonucleic acid, the component of living matter that contains the genetic code. Scientists are now experimenting with *DNA computing*, which takes advantage of the fact that information can be written onto individual DNA molecules. The information uses the alphabet of four bases that all living organisms use to record genetic information. A DNA computation is done by coding a problem into the alphabet and then creating conditions under which DNA molecules are formed that encode all possible solutions of a problem. The process produces billions of molecules encoding wrong answers, and a few encoding the right one. Modern molecular genetics has chemical procedures that can reliably isolate the few DNA molecules encoding the correct answer from all the others.

DNA computers process in parallel and are potentially twice as fast as today's fastest supercomputers. In addition, storage on DNA computers is vastly improved. Modern storage media store information at a density of one bit per 1,012 nanometers (one billionth of a meter), whereas DNA computers have storage densities of one bit per cubic nanometer, a trillion times less space.

Nanotechnology is a hybrid science that refers to the modeling, measurement, and manipulation of matter on the nano-scale—1 to 100 nanometers across. Nanotech is producing materials with novel and useful properties. Molecular electronics will become the first major application of nanotechnology. Intel and IBM have stated that silicon circuitry is reaching its limits, and proof-of-concept experiments have demonstrated the potential of nano-scale electronics since nano-electronics would turn a single molecule into a switch, conductor, or other circuit element.

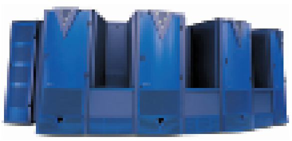
OPTOELECTRONIC COMPUTERS. Scientists are working on a machine that uses beams of light instead of electrons. These so-called *optoelectronic computers* are expected to process information several hundred times faster than current computers.

QUANTUM COMPUTING. Researchers are looking into using the basic quantum states of matter as a fundamental unit of computing. If successful, quantum computers will be millions of times faster than today's supercomputers. It will take at least 10 years before we see such a computer. Major research efforts are underway at IBM, NEC, the University of Kansas, and D-Ware Systems. See Kaihla (2004) for details.

T1.3 Types of Computers

Computers are distinguished on the basis of their processing capabilities. Computers with the most processing power are also the largest and most expensive.

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 generally operate 4 to 10 times faster than the next-most-powerful computer class, the mainframe. In 2004, supercomputers were able to compute one trillion operations per second, reaching close to 23,000 gigaflop. This represented a 1,000-fold speed increase over 1990's most powerful computers. Also, in 2004, the prices of supercomputers range from $100,000 to $15 million or more.

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 today in smaller computers where 2 to 64 processors are common.

The development of massively parallel computers has led some people to confuse these computers with supercomputers. The **massively parallel computers** are a relatively new type of computer that uses a large number of processors. As described earlier, the processors divide up and independently work on small chunks of a large problem. Modern problems in science and engineering, such as structural engineering, fluid mechanics, and other large-scale physical simulations, rely on high-performance computing to make progress. These problems are so enormous as to swamp the computational power of conventional computers, so massively parallel computers must be used. In 2001, the prices of massively parallel computers range from $100,000 to $4 million or more.

Mainframes

Mainframes are not as powerful and generally not as expensive as supercomputers. Large corporations, where data processing is centralized and large

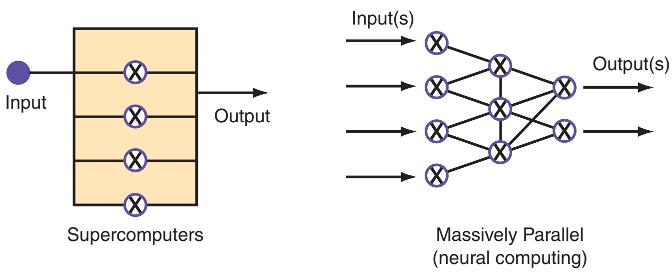


FIGURE T1.4 Supercomputers vs. neural computing. (X is a CPU.)

A mainframe computer.

databases are maintained, most 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. In 2004, a mainframe system has up to several gigabytes of *primary storage*. Online and offline *secondary storage* uses high-capacity magnetic and optical storage media with capacities in the terabyte range. Several hundreds or even thousands of online computers can be linked to a mainframe. Also, in 2004, mainframes were priced as high as $5 million. Today's most advanced mainframes perform at more than 3,300 MIPs and can handle over 1 billion transactions per day.

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. The minicomputer is also able to meet the needs of smaller organizations that would rather not utilize scarce corporate resources by purchasing larger computer systems.

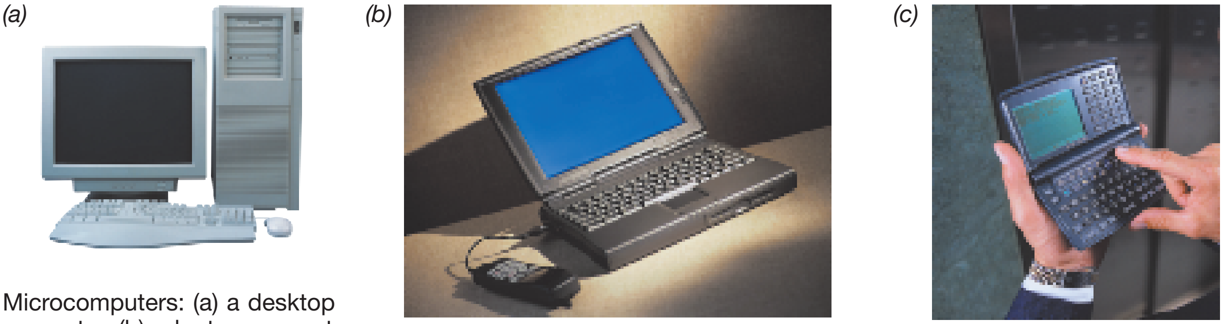
SERVERS. **Servers** typically support computer networks, enabling users to share files, software, peripheral devices, and other network resources. Servers have large amounts of primary and secondary storage and powerful CPUs. Organizations with heavy e-commerce requirements and very large Web sites 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.

Microcomputers

Microcomputers, also called *micros* or *personal computers (PCs)*, are the smallest and least expensive category of general-purpose computers. In general, modern microcomputers have between 64 and 1 gigabyte of primary storage, one 3.5-inch floppy drive, a CD-ROM (or DVD) drive, and up to 100 gigabyte or more of secondary storage. They may be subdivided into five classifications



Microcomputers: (a) a desktop computer, (b) a laptop computer, and (c) a laptop notebook computer.

based on their size: desktops, thin clients, laptops, notebooks, and mobile devices (see photos above). We'll look at the first four in this section and at mobile devices in a separate section that follows.

The **desktop personal computer** is the typical, familiar microcomputer system. It is usually modular in design, with separate but connected monitor, keyboard, and CPU. **Thin-client systems** are desktop computer systems that do not offer the full functionality of a PC. Compared to a PC, thin clients are less complex, particularly because they lack locally installed software, and thus are easier and less expensive to operate and support than PCs. One type of thin client is the *terminal,* allowing the user to only access an application running on a server. Another type of thin client is a **network computer,** which is a system that provides access to Internet-based applications via a Web browser and can download software, usually in the form of Java applets. **Laptop computers** are small, easily transportable, lightweight microcomputers that fit easily into a briefcase.

Notebooks are smaller laptops (also called *mini-laptops*), but sometimes are used interchangeably with laptops. Laptops and notebooks are designed for maximum convenience and transportability, allowing users to have access to processing power and data without being bound to an office environment. A notebook computer's Universal Serial Bus (USB) port is very useful in attaching some useful "gismos." For example, a product called "FlyFan USB Fan" from Kensington Corporation (*kensington.com*) is a mini-fan that hooks into the USB port with a shaft that snakes around to shoot cool air in your face while you work. Another product, "FlyLight Notebook USB Light," has an LED light beaming a direct glow onto your keyboard. Both products' power consumption is not so large: just 5 minutes and 1.5 minutes per hour of notebook power, respectively.

Manufacturers are developing features for notebooks to make them even more useful. The Xentex Flip-Pad Voyager notebook, for example, has two 13.3-inch LCDs which stand side by side in portrait mode. These dual screens can be used as a single huge display or as two independent monitors; one screen pivots 180 degrees to make presentation easier. The notebook is 19.5 inches long, 14 inches wide, and only 3.2 inches thick. It weighs 12.6 pounds with two batteries.

Mobile Devices

Emerging platforms for computing and communications include such **mobile devices** as handheld computers, often called **personal digital assistants (PDAs)** or *handheld personal computers*. Another quickly emerging platform is

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

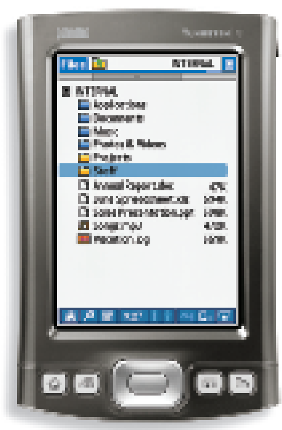
*Vertical markets refer to specific industries, such as manufacturing, finance, healthcare, etc.

mobile phone handsets with new wireless and Internet access capabilities formerly associated with PDAs. Usually, such devices would use a micro version of a desktop operating system, such as Pocket PC, Symbian, or Palm OS.

Other emerging platforms are consumer electronics devices (such as game consoles and even robots such as Sony's SDR-4X that can walk around with bumping into things, recognize faces and voices with its two built-in color cameras and its seven microphones) that are expanding into computing and telecommunications. Mobile devices are becoming more popular and more capable of augmenting, or even substituting for, desktop and notebook computers.

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.



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

PERSONAL DIGITAL ASSISTANT. A **personal digital assistant (PDA)** is a palmtop computer that combines a fast processor with a multitasking operating system using a pen (stylus) for handwriting recognition rather than keyboard input (see photo). PDAs differ from other personal computers in that they are usually specialized for individual users. The PDA may be thought of as a computing appliance, rather than a general-purpose computing device. In 2003, PDAs typically weigh under a pound and are priced from $150 to $500. Some PDAs enable users to communicate via fax, electronic mail, and paging, or to access online services. PDAs are very popular for special applications.

There are several basic PDAs including HandEra's 330, Handspring's Visor Neo, Handspring's Visor Pro, Palm's M125, and Sony's Clie PEG-T415 (as of spring 2003). They are run on operating systems of Palm OS. The prices for the basic PDAs range from \$150 to \$299, with memory capacity from 8MB to 32MB. Screen sizes are from 1.6 × 1.6 to 2.9 × 2.2 with resolutions from 160 × 160 to 320 × 320. For more advanced PDAs, which offer more color and power, choices include Casio's Cassiopeia E-200, Compaq's IPaq Pocket PC H3850, Handspring's Visor Prism, the HP Jornada 565, Palm's M505, and Toshiba's Pocket PC E570. They are run on operating systems of Palm OS and Pocket PC 2002. Their prices range from \$265 to \$569 with memory capacity from 8MB to 128MB. Screen sizes are from 2.2 × 2.2 to 3.0 × 2.3 with resolutions from 160 × 160 to 240 × 320. 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. Their prices range from \$399 to \$700, with memory capacity from 1MB to 40MB. Screen sizes are from 1.3 × 1.3 to 2.8 × 2.3 with resolutions from 160 × 160 to 640 × 200. 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™ 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 Tunsten 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 7-inch LCD panel and it calculates the route in just a few seconds. For example, Garmin International has developed a new PDA called iQue 3600 that allows users to chart a course to anyone in their computerized address book, with the device providing vocal turn-by-turn directions to the destination. It runs on Palm 5.0 operating system and has a small fold-down GPS antenna, electronic mapping, electronic route calculation and turn-by-turn voice guidance. It uses a system of 24 satellites to show a user's precise location: combined with mapping technology, they show a person's location anywhere in the world.

WI-FI. Over the last ten years, laptop computers have enabled people to carry their computing devices with them as they travel. Now, as discussed in Chapter 6, the spread of wireless fidelity, or **Wi-Fi** as it is popularly called, is beginning to have 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 802.11g) 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.

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.

An example of the use of Tablet PC: ViewSonic's ViewPad 1000s (based on Microsoft's Tablet PC operating system and the Internet, and combined with an 802.11b wireless connection) allow patrons at Seahawk Stadium to check their e-mail and surf the Web. T-Mobile Sidekick II was the 2003 World Class Product of the Year PDA; Sidekick's intuitive menus lets you easily navigate your e-mail and use Instant Messenger.

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.

The handwriting recognizer of the Tablet PC is now nearly flawless; it can even recognize young kids' handwriting, even with misspellings. In fact, it can correct errors as soon as the writer completes a word. The Tablet PC is now lighter, just 1.8 kg, and it can include communication media (e.g., USB port, Ethernet, Wi-Fi wireless networking). It is easier to hold and read.

Getting online content onto offline devices is becoming increasing popular. There are several options for the "tabletzines" market, for example: LinkPath enables more than 50 B2B publication 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.

Tigit (*tigit.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 300MHz, 256MB RAM, up to 20GB 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, 54G routers uses 802.11g, which is five times faster than 802.11b. In addition, 24GHz 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 2.4GHz 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.

WEARABLE COMPUTING. **Wearable computers** are designed to be worn and used on the body. This new technology has so far been aimed primarily at niche markets in industry rather than at consumers. Industrial applications of wearable computing include systems for factory automation, warehouse management, and performance support, such as viewing technical manuals and diagrams while building or repairing something. The technology is already widely used in diverse industries such as freight delivery, aerospace, securities trading, and law enforcement. Governments have been examining such devices for military uses. Medical uses include devices that monitor heart rhythms, and a "watch" that would monitor the blood sugar of diabetics.

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 (and its wearer's) 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.

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 5). 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 NC's cost in 2003 is $200 to $500. At the same time, simple PCs are selling for $500 to $700. Since the price advantage is not so large, the future of NCs is not clear. However, there is a potentially substantial saving in the maintenance cost. 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, on a basic level, 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.
- 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).

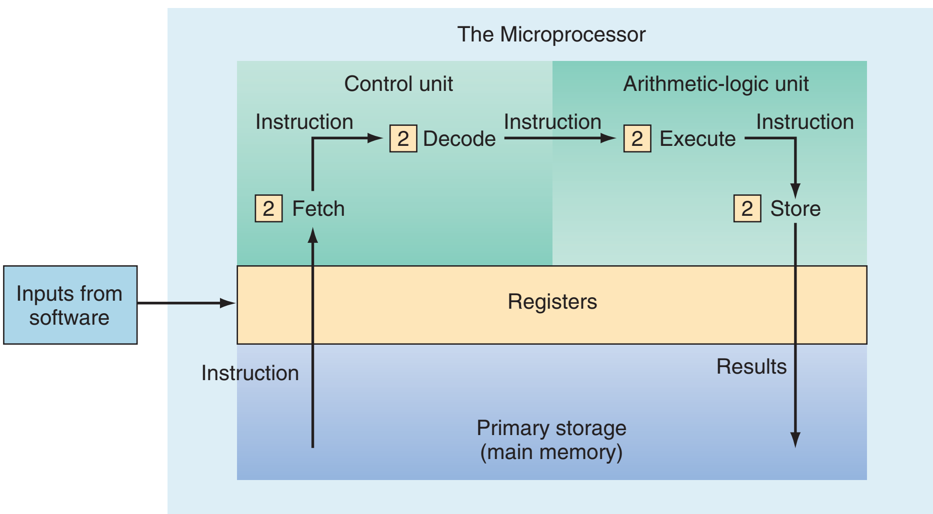


FIGURE T1.5 How the CPU works.

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 2004, a PC can be as fast as 3.2 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 (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.

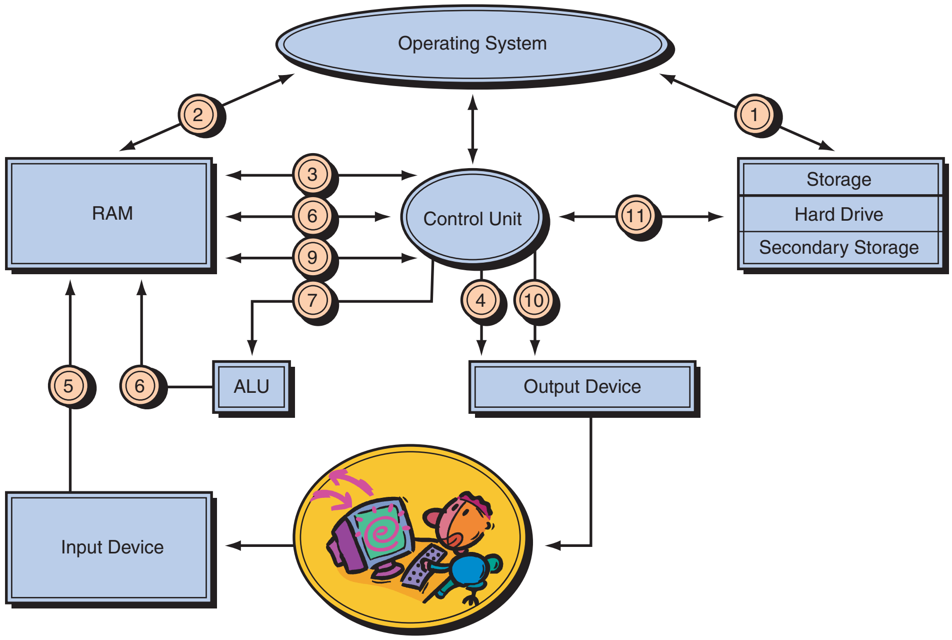


FIGURE T1.6 Running a program on a computer.

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.

MOORE'S LAW AND A CHIP'S PERFORMANCE. In Chapters 1 and 13, we described Moore's Law—Gordon Moore's 1965 prediction that microprocessor complexity would double approximately every two years. The advances predicted from Moore's Law come mainly from the following changes:

- Increasing miniaturization of transistors.
- Making the physical layout of the chip's components as compact and efficient as possible (decreasing line width).
- Using materials for the chip that improve the *conductivity* (flow) of electricity. The traditional silicon is a semiconductor of electricity—electrons can flow through it at a certain rate. New materials such as *gallium arsenide* and *silicon germanium* allow even faster electron travel and some additional benefits, although they are more expensive to manufacture than silicon chips.
- Targeting the amount of basic instructions programmed into the chip.

In the Intel 2002 Developer Forum, R. Gelsinger, a vice president at Intel, indicated that Intel's new 90-nanometer fabrication processes and cutting-edge research in extreme ultraviolet lithography will help to extend Moore's Law for many years.

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.

THE EVOLUTION OF MICROPROCESSING. The four factors cited earlier—clock speed, word length, bus width, and line width–make it difficult to compare the speeds of different processors. As a result, Intel and other chip manufacturers have developed a number of benchmarks to compare processor speeds. Table T1.3 shows the evolution of the microprocessor from the introduction of the 4004 in 1971 to 2001's Pentium 4 microprocessors. Over the thirty years, microprocessors have become dramatically faster, more complex, and denser, with increasing numbers of transistors embedded in the silicon wafer. As the transistors are packed closer together and the physical limits of silicon are approached, scientists are developing new technologies that increase the processing power of chips.

Chips are now being manufactured using gallium arsenide (GaAs), a semiconductor material inherently much faster than silicon. (Electrons can move through GaAs five times faster than they can move through silicon.) GaAs chips are more difficult to produce than silicon chips, resulting in higher prices. However, chip producers are perfecting manufacturing techniques that will result in a decrease in the cost of GaAs chips.

The Intel Pentium 4 processor introduces a new generation of processing power with Intel NetBurst microarchitecture. It maximizes the performance of cutting-edge technologies such as digital video and online 3-D gaming, and has an innovative design capable of taking full advantage of emerging Web technologies. The chip's all-new internal design includes a rapid execution engine and a 400 MHz system bus in order to deliver a higher level of performance.

A prototype *plasma-wave chip* has been developed that transmits signals as waves, not as packets of electrons as current chips do. Developers use an analogy with sound. Sound travels through the air as waves, not as batches of air molecules that

TABLE T1.3 Evolution of Microprocessors

Chip	Introduction Date	Clock Speed	Bus Width	Number of Transistors	Addressable Memory
4004	11/71	108 KHz	4 bits	2,300	640 bytes
8008	4/72	108 KHz	8 bits	3,500	16 Kbytes
8080	4/74	2 MHz	8 bits	6,000	64 Kbytes
8086	6/78	5–10 MHz	16 bits	29,000	1 Mbyte
80286	2/82	8–12 MHz	16 bits	134,000	16 Mbytes
80386 DX	10/85	16–33 MHz	16 bits	275,000	1 Gbyte
80386 SX	6/88	16–20 MHz	16 bits	275,000	1 Gbyte
80486 DX	4/89	25–50 MHz	32 bits	1.2 M	4 Gbytes
80486 SX	4/91	16–33 MHz	32 bits	1.185 M	4 Gbytes
Pentium	3/93	60–166 MHz	32 bits	3.1 M	4 Gbytes
Pentium Pro	3/95	150–200 MHz	32 bits	5.5 M	4 Gbytes
Pentium II	1996	233–300 MHz	32 bits	5.5 M	4 Gbytes
P6	1997	up to 400 MHz	32 bits	7.5 M	4 Gbytes
Merced (IA64)	1998/99	500–600 MHz	64 bits	9 M	4–8 Gbytes
Pentium III	1999	450–600 MHz	64 bits	9.5 M	10–12 Gbytes
Itanium (Merced)	2000	800–1,000 MHz	64 bits	25 M	16 Gbytes
Pentium 4	2001	1.3–1.5 GHz	64 bits	42 M	4–64 Gbytes
Itanium II	2002	1.4–2.2 GHz	128 bits	410 M	1 Terabyte

leave one person's mouth and enter another's ear. If sound worked in that fashion, there would be a long delay while the sound-carrying molecules negotiated their way through the other air molecules. The new chips have the potential of operating speeds in the gigahertz range, or billions of cycles per second.

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 in today's microcomputers 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 (or shared data path) 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 most common PC in 2004 was 128 bits.) Bus speeds are also important, currently averaging about 533 megahertz (MHz).

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 2004 needed 64 to 512 megabytes 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 chips, 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.

T1.5 INPUT/OUTPUT DEVICES

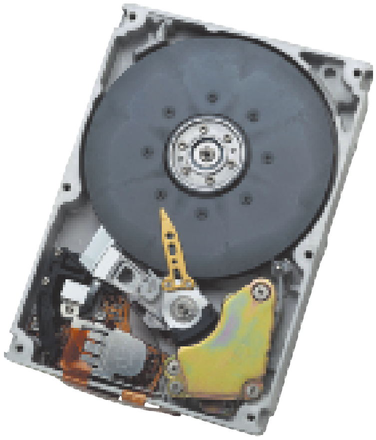
The input/output (I/O) devices of a computer are not part of the CPU, but are channels for communicating between the external environment and the CPU. Data and instructions are entered into the computer through **input devices,** and processing results are provided through **output devices.** Widely 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



A hard disk drive.

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 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 2004 microcomputers provide 40 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.

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 (a subsidiary of 3M) has developed several portable high-capacity hard disks. Capacities range from 20 GB to 60 GB using USB 1.1, 2.0 or IEEE1394 as interface. It does not need any external power. It is lightweight and small in size.

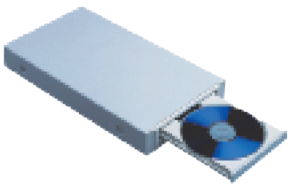
IBM has invented a new disk drive technology by combining two layers of magnetic material and a three-atom-thick filling to create a disk drive that can hold 27 gigabits per square inch. The two magnetic layers are separated by ruthenium, a nonmagnetic material. The three-layer coating is thicker than 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. Capacity is expected to be 1 terabit per square inch. (Current 2.5-inch hard disks have a recording density of about 26 gigabits per square inch.) NEC is working on a technology to revolutionize storage capacity to 1TB 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.

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 are already on the market, offering a capacity of 8.5 GB on one side, 17 GB on two sides.

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 T1.4 summarizes the major secondary storage devices, their advantages, limitations, and applications.

TABLE T1.4 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 T1.5). 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 computer-users 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

TABLE T1.5 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 • Automatic teller machines (ATM) • Smart cards • Digitizers (for maps, graphs, etc.) • RFID

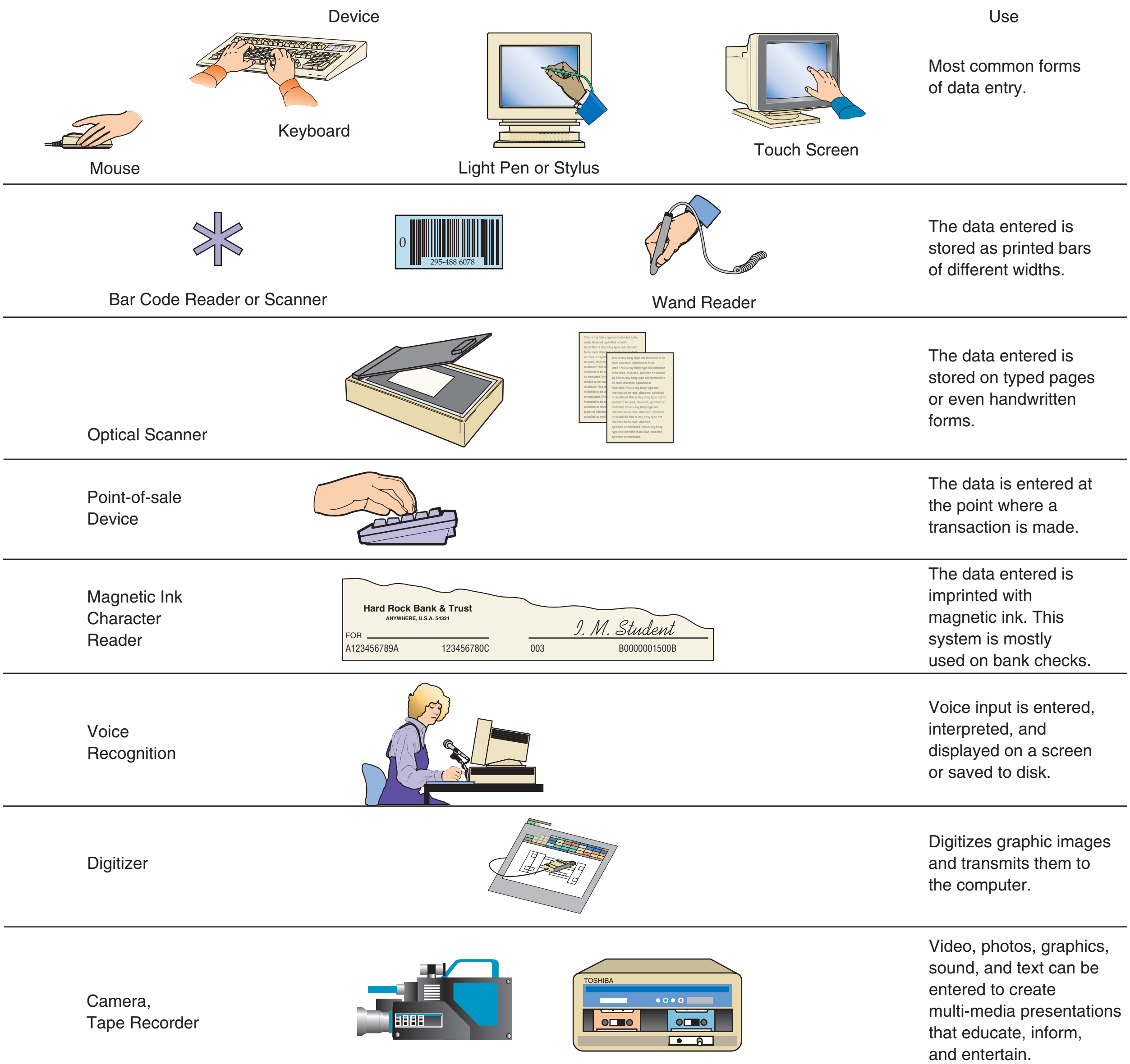


FIGURE T1.7 Typical input devices. Each input device reads a different form of data for processing by the CPU. (*Source: Computing in the Information Age,* Stern and Stern, 1993, p. 172. Copyright © 1993 John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

commands or chunks of data. In 2004, wireless keyboards became quite popular. They use radio frequency (RF), which is more accurate than infrared.

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.

An ergonomic "split" keyboard.

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 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 hand-held glove that contains electronics that can read how users move their fingers and then use that information to carry out commands on the screen.

MICROPHONES. A **microphone** is becoming a popular data-input device as voice-recognition software improves and people can use microphones to dictate to the computer. These are also critical technologies for people who are physically challenged and cannot use the more common input devices.

AUTOMATED TELLER MACHINES. *Automated teller machines (ATMs)* are interactive input/output devices that enable people to obtain cash, make deposits, transfer funds, and update their bank accounts instantly from many locations. ATMs can handle a variety of banking transactions, including the transfer of funds to specified accounts. One drawback of ATMs is their vulnerability to computer crimes and to attacks made on customers as they use outdoor ATMs.

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 bar-codes 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 bar-code scanner that reads the bar-coded 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.

BAR CODE SCANNER. **Bar code 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. Bar codes 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 bar code 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.

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.

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

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. Today's scanners are good at "reading" typed or published material, but they are not very good at handwriting recognition. 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. In 2003, voice recognizers have a vocabulary of 200,000 to 350,000 words (e.g., Via Voice from IBM and Naturally Speaking from Dragon Systems). 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** (see photo) 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 NetMeeting, such a system can be used to conduct desktop videoconferencing.

MOBILE VIDEOPHONE. A **mobile videophone** has a large color screen and a built-in video camera, enabling a user to hold a video call with another person also equipped with a videophone. Orange's Mobile Videophone, for example, can offer a third-generation service on a second-generation network. It has two images on screen, showing both the caller and the recipient. Its weight is about twice the weight of a mobile phone.

A digital video camera.

TABLE T1.6 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.

UNIVERSAL SERIAL BUS (USB) 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 T1.6 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 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.

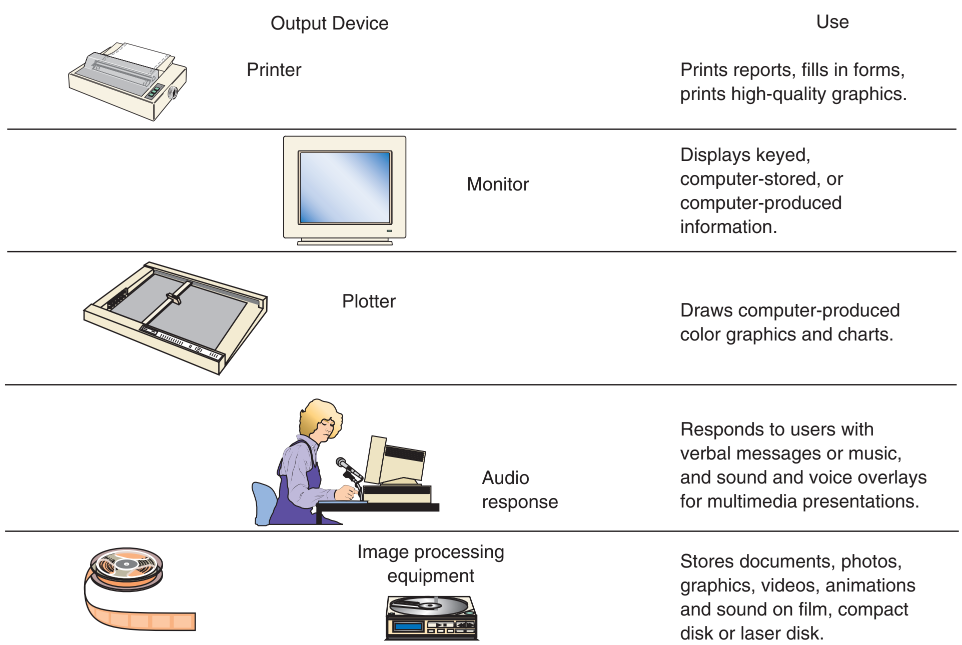


FIGURE T1.8 Representative output devices and their use. (*Source: Computing in the Information Age*, Stern and Stern 1993, p. 199. Copyright © 1993 John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

Monitors employ the *cathode ray tube (CRT)* technology, in which an electronic "gun" shoots a beam of electrons to illuminate the pixels on the screen. CRTs typically are 21-inch or smaller. The more pixels on the screen, the higher the resolution. Portable computers use a float screen consisting of a *liquid crystal display (LCD)*. LCDs, invented in 1963, have become the standard display for everything from watches to laptop computers. In 2004, prices of large LCD screens dropped sharply, making such screens popular. *Gas plasma monitors* offer larger screen sizes (more than 36 inches) and higher display quality than LCD monitors but are much more expensive.

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 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.

RETINAL SCANNING DISPLAYS. As people increasingly use mobile devices, many are frustrated with the interfaces, which are too small, too slow, and too awkward to process information effectively. As a result, Web sites become unusable, e-mails are constrained, and graphics are eliminated. One solution does away with screens altogether. A firm named Microvision projects an image, pixel by pixel, directly onto a viewer's retina. This technology, called **retinal scanning displays (RSDs),** is used in a variety of work situations, including medicine, air traffic control, and controls of industrial machines. RSDs can also be used in dangerous situations, for example, giving firefighters in a smoke-filled building a floor plan.

IMPACT PRINTERS. Like typewriters, **impact printers** use some form of striking action to press a carbon or fabric ribbon against paper to create a character. The

Laser printer.

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.

However, impact printers tend to be slow and noisy, cannot do high-resolution graphics, and are often subject to mechanical breakdowns. They have largely been replaced by nonimpact printers, except where multi-ply copies are needed.

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 above) 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 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.

MULTIFUNCTION DEVICES. **Multifunction devices** combine a variety of input and output technologies and are particularly appropriate for home offices. The technologies include fax, printer, scanner, copy machine, and answering machine. Depending on how much one wishes to invest and one's needs, any combination can be found in a single cost-effective machine.

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. Communications media are listed in Table T1.7. The multimedia software is described in Technology Guide 2.

TABLE T1.7 Communications Media

Computer
- CRT and terminals
- CD-ROM
- Computer interactive videodisc
- Digital video interactive
- Compact disc interactive
- Telnet
- Computer fax
- E-mail
- FTP
- Chats
- DVD
- Computer simulation
- Teletext/videotext
- Intelligent tutoring system
- Hypertext
- Image digitizing
- Scanners
- Screen projection
- Object-oriented programming

Motion image
- Videodisc (cassette)
- Motion pictures
- Broadcast television
- Teleconference/videoconference
- Web casting
- Satellite
- Digital drawing pads
- Animation
- Virtual reality

Projected still visuals
- Slide
- Overhead

Graphic materials
- Pictures
- Printed job aids
- Visual display

Audio
- Tape/cassette/record
- Teleconference/audioconference
- Sound digitizing
- Microphone
- Compact disc
- Music
- Voice over IP
- Audiographic

Text
- Printouts

Source: Based on P. Chao, et al., "Using Expert Systems Approaches to Solve Media Selection Problems: Matrix Format," *Proceedings of the Association of Computer Interface Systems*, November 1990, IEEE.

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