16th Edition

Understanding Computers

Today and Tomorrow

Comprehensive

Chapter 2
The System Unit, Processing, and Memory

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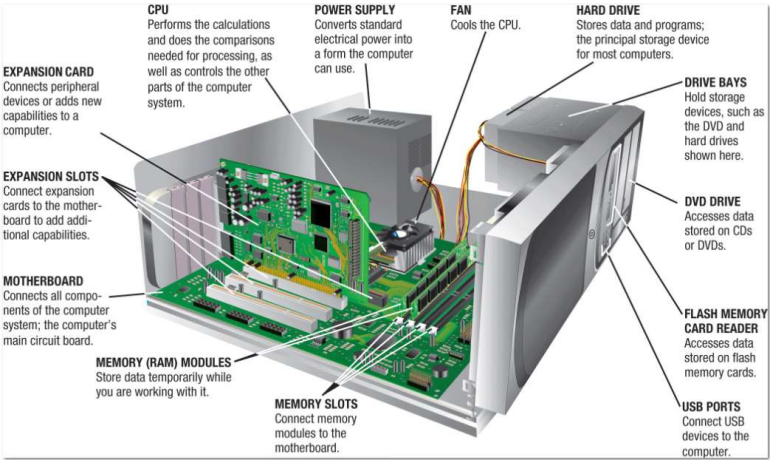
Inside the System Unit

- The **system unit** is the main case of a computer or mobile device
  - Houses the processing hardware for a computer
  - Also contains other components, such as storage devices, the power supply, cooling hardware, one or more processors, several types of memory, and interfaces to peripheral devices
  - Interconnected through sets of wires called buses on the motherboard

Inside a Desktop System Unit

FIGURE 2-7
Inside a desktop system unit.



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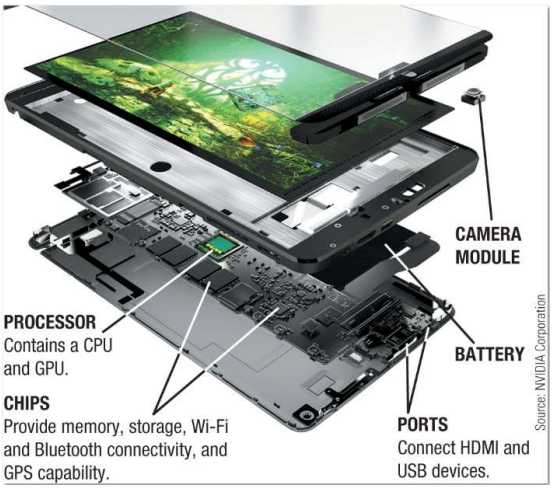
Inside a Tablet System Unit

FIGURE 2-8
Inside a tablet system unit.



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The Motherboard

- The **motherboard** is a circuit board consisting of computer chips, also called integrated circuits (ICs)
  - ICs contain interconnected components (such as transistors) to perform particular functions
  - All devices connect via a wired or wireless connection to the motherboard
  - External devices connect by plugging into a port
    - The port is either built directly into the motherboard or created via an expansion card
  - Wireless external devices use either a transceiver or wireless networking technology

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The Power Supply and Drive Bays

- The power supply connects to the motherboard to deliver electricity
- Portable computers use a rechargeable battery pack
  - Built-in batteries more difficult and expensive to replace, resulting in electronic waste (e-waste)
- Drive bays are rectangular metal racks inside the system unit that house storage devices
  - Hard drive, CD/DVD drive, flash memory card reader
  - Storage devices also connect to the motherboard

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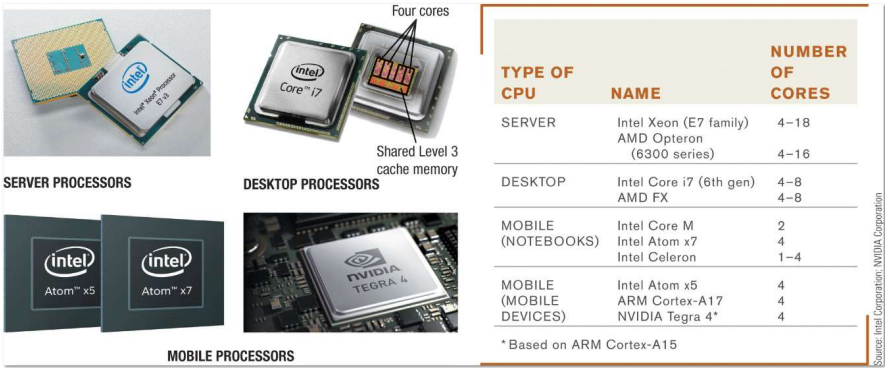
Processors and the CPU

- A **processor** consists of circuitry and components packaged together and connected directly to the motherboard
- The **CPU (central processing unit)** does the vast majority of processing for a computer
  - Called a microprocessor when talking about personal computers
  - Typically designed for a specific type of computer
    - Desktops, servers, and some notebook PCs use Intel or Advanced Micro Devices (AMD) processors
    - Portable computers and mobile devices often use Intel or AMD mobile processors or an ARM processor instead

CPU Cores

- **Multi-core CPUs** contain the processing components (cores) of multiple independent processors in a single CPU
- **Dual-core CPUs** contain two cores
- **Quad-core CPUs** contains four cores
- Multi-core processors allow computers to work on more than one task at a time
  - They also typically use slower cores than single-core CPUS so have fewer heat problems

Examples of CPUs



TYPE OF CPU	NAME	NUMBER OF CORES
SERVER	Intel Xeon (E7 family)	4–18
	AMD Opteron (6300 series)	4–16
DESKTOP	Intel Core i7 (6th gen)	4–8
	AMD FX	4–8
MOBILE (NOTEBOOKS)	Intel Core M	2
	Intel Atom x7	4
	Intel Celeron	1–4
MOBILE (MOBILE DEVICES)	Intel Atom x5	4
	ARM Cortex-A17	4
	NVIDIA Tegra 4*	4

*Based on ARM Cortex-A15

FIGURE 2-9
CPU examples.

The GPU

- The **GPU (graphics processing unit)** takes care of the processing needed to display images (including still images, animations) on the screen
  - Can be located on the motherboard, on a video graphics board, or in the CPU package
  - Mobile processors often integrate other capabilities into the processor package (system-on-a-chip (SoC))

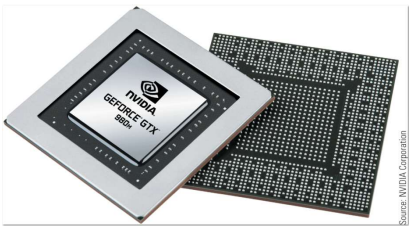


FIGURE 2-10
A GPU.

Processing Speed

- Processing speed can be measured by the CPU's clock speed
  - Rated in megahertz (MHz) or gigahertz (GHz)
  - Higher CPU clock speed = more instructions processed per second
  - Alternate measure of processing speed is the number of instructions a CPU can process per second
    - Megaflops (millions), gigaflops (billions), teraflops (trillions)
  - Benchmark tests can be used to evaluate overall processing speed

Word Size and Cache Memory

- A computer word is the amount of data that a CPU can manipulate at one time
  - In the past, CPUs used 32-bit words (referred to as 32-bit processors); today, most CPUs are 64-bit processors
- **Cache memory** is a special group of very fast circuitry usually built into the CPU (internal cache memory)
  - More cache memory typically means faster processing
  - Cache memory level numbers indicate the order in which the various levels of cache are accessed by the CPU
    - Level 1 is fastest, then Level 2, then Level 3

Bus Width, Bus Speed, and Bandwidth

- A **bus** is an electronic path over which data can travel
  - Found inside the CPU and on the motherboard
  - Bus width is the number of wires in the bus over which data can travel
    - A wider bus allows more data to be transferred at one time
- Bus width and bus speed together determine the bus's **bandwidth** (the amount of data that can be transferred via the bus in a given time period)
- The amount of data actual transferred under real-life conditions is called **throughput**

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Example of Bus Width

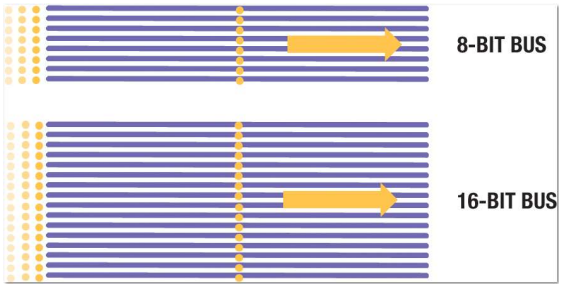

FIGURE 2-11
Bus width. A wider bus can transfer more data at one time than a narrower bus.

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Memory

- **Memory** refers to chip-based storage, or locations that a computer uses to store data on a temporary basis
  - **Volatile** memory (content is erased when the device is shut off)
  - **Non-volatile** memory (content is retained when the device is shut off)
- **Random access memory (RAM)** is the computer's main memory or system memory
  - Stores essential parts of operating system, programs, and data the computer is currently using
  - Consists of electronic circuits etched onto chips
    - Mobile devices typically use embedded memory chips
    - Servers and personal computers use circuit boards called memory modules plugged into the motherboard

Inserting RAM Memory Modules

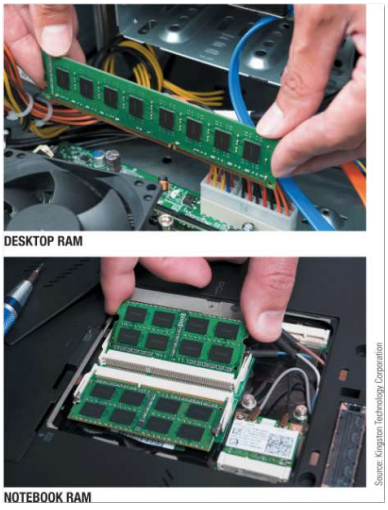

FIGURE 2-12
Inserting RAM memory modules.

Characteristics of RAM

- Volatile
- Measured in bytes (amount dependent on CPU and operating system)
- Most personal computers use SDRAM
- Double-Data Rate (DDR) RAM sends data twice as often as ordinary SDRAM or prior versions of RAM
  - DDR2, DDR3, DDR4
- Dual-channel memory architecture has two paths that go to and from memory; tri-channel (three paths) and quad-channel (four paths) memory architecture used for higher performance

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Memory Addressing

- Each location in memory has an address
  - Usually stored in one or more consecutive addresses, depending on its size
- Computer system sets up and maintains directory tables to facilitate retrieval of the data

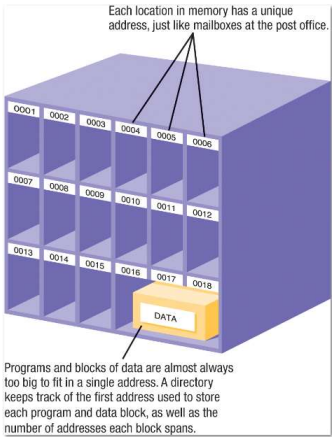

FIGURE 2-13
Memory addressing.

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Registers and ROM

- **Registers** are high-speed memory locations built into the CPU
  - Used to store data and intermediary results during processing
  - Fastest type of memory
- **ROM (read-only memory)** consists of non-volatile chips located on the motherboard into which data or programs have been permanently stored
  - Retrieved by the computer when needed
  - Being replaced with flash memory

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Flash Memory

- **Flash memory** consists of nonvolatile memory chips that can be used for storage
  - Have begun to replace ROM for storing system information (BIOS)
  - Stores firmware for personal computers and other devices
  - Built into many types of devices (tablets, smartphones, and digital cameras) for user storage
  - Built into some storage devices (solid-state hard drives, USB flash drives, etc.)

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Fans, Heat Sinks, and Other Cooling Components

- Fans are used on most personal computers to help cool the CPU and system unit
  - Heat is an ongoing problem for CPU and computer manufacturers
    - Can damage components
    - Cooler chips run faster
- Heat sinks are small components typically made out of aluminum with fins that help to dissipate heat
- Some portable computers and virtually all mobile devices don't include a fan; instead thermal transfer materials are used to spread out the heat generated

Other Types of Cooling Systems

- Liquid cooling systems
  - Cool the computer with liquid-filled tubes
- Immersion cooling
  - Hardware is actually submerged into units filled with a liquid cooling solution
- Notebook cooling stand
  - Cools the underside of a notebook computer
- Other cooling methods, such as ion pump cooling systems, are under development

Examples of Computer Cooling Methods

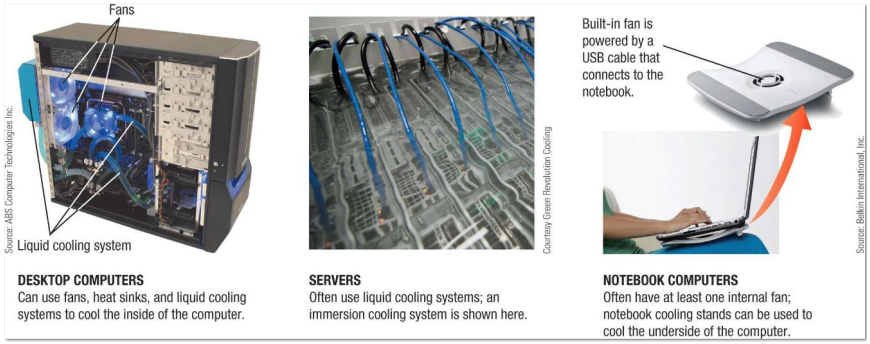


FIGURE 2-14
Computer cooling methods.

Expansion Slots and Expansion Cards

- An **expansion slot** is a location on the motherboard into which expansion cards are inserted
- An **expansion card** is a circuit board inserted into an expansion slot
  - Used to add additional functionality or to attach a peripheral device
- Smaller devices may integrate capabilities directly into the device
- USB adapters can be used with portable computers and some mobile devices

Examples of Expansion Cards and Adapters

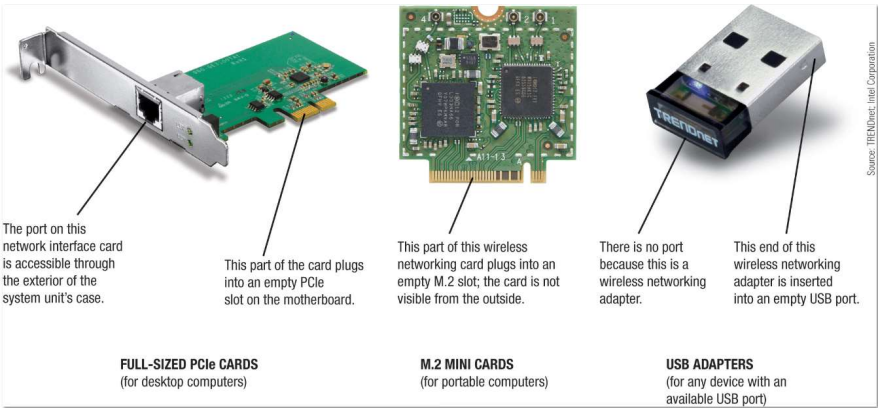


FIGURE 2-15
Expansion cards and adapters.

Buses

- A **bus** is an electronic path within a computer over which data travels
  - Located within the CPU and etched onto the motherboard
- An **expansion bus** connects the CPU to peripheral (typically input and output) devices
- The **memory bus** connects the CPU directly to RAM
- The **frontside bus (FSB)** connects the CPU to the chipset that connects the CPU to the rest of the bus architecture

Examples of Buses and Expansion Slots

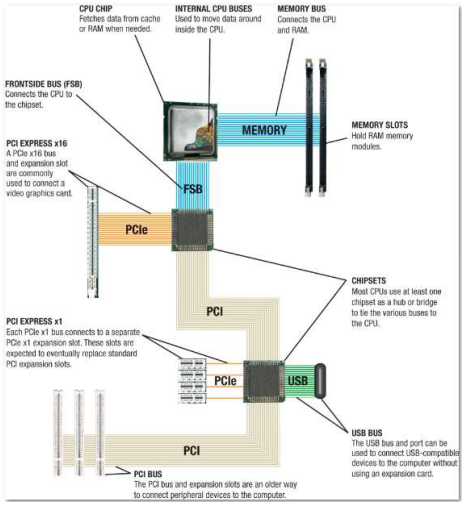


FIGURE 2-16
Buses and expansion slots.
Buses transport data from one component to another.

PCI, PCIe, and USB

- The PCI bus used to be the most common type of expansion bus
- Today, **PCI Express (PCIe)** buses are more common
  - PCIe x16 is a 16-bit bus and is used to connect monitors to a computer
  - PCIe x1 is a 1-bit bus and is used to connect other peripherals
  - PCIe buses are extremely fast
- A **universal serial bus (USB)** connects USB devices to a computer
  - 127 different devices can connect via a single USB port
  - Extremely versatile

Ports and Connectors

- A **port** is a connector on the exterior of a computer's system unit to which a device may be attached
  - Typical desktop computer ports HDMI to connect a monitor (VGA and Digital Video Interface (DVI) are older standards)
  - Network ports connect a device to a wired network
  - USB ports connect USB devices; can be USB-C
  - Others include IrDA and Bluetooth ports, flash memory card slots, audio ports, eSATA ports, and Thunderbolt ports (Apple)
  - Most computers support the Plug and Play standard
  - USB and Thunderbolt devices are hot-swappable

Examples of Typical Ports and Connectors

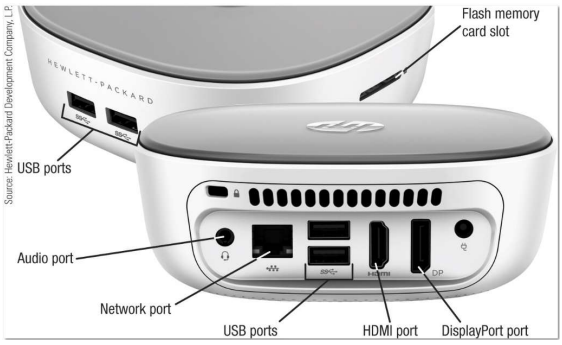


FIGURE 2-17
Typical ports.

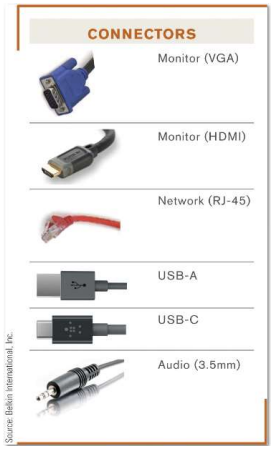
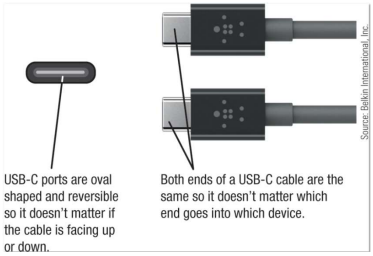


FIGURE 2-18
Typical connectors.

How It Works

USB-C

- Both ends of a USB-C cable are the same
  - Traditional USB cables have two different connectors:
    - USB-A and USB-B
- Very fast
- Can charge and power portable computers
- Many types of adapters and multiport adapter cables available



USB-C ports are oval shaped; cables are reversible and interchangeable.

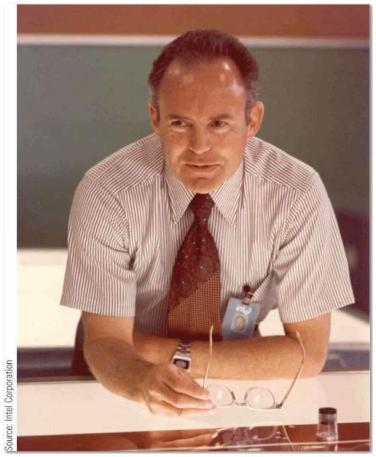
How the CPU Works

- The CPU (central processing unit) consists of a variety of circuitry and components packaged together
  - The transistor is the key element of the microprocessor
    - Made of semi-conductor material that controls the flow of electrons inside a chip
    - Today's CPUs contain hundreds of millions of transistors; the number doubles about every 18 months (Moore's Law)
  - Electronic impulses move from one part of the CPU to another to process data
  - The architecture and components included in a CPU (referred to as microarchitecture) vary from processor to processor

Inside the Industry

Moore's Law

- In 1965, Gordon Moore predicted that the number of transistors per square inch on chips had doubled every two years and that trend would continue
- Moore's Law is still relevant today for processors as well as other computer components



George Moore (1970)

CPU Core Components

- The **arithmetic/logic unit (ALU)** performs arithmetic involving integers and logical operations
- The **floating point unit (FPU)** performs decimal arithmetic
- The **control unit** coordinates and controls activities within a CPU core
- The **prefetch unit** attempts to retrieve data and instructions before they are needed for processing in order to avoid delays

CPU Core Components (cont'd)

- The **decode unit** translates instructions from the prefetch unit so that they are understood by the control unit, ALU, and FPU
- The registers and internal cache memory store data and instructions needed by the CPU
- The **bus interface unit** allows the core to communicate with other CPU components

Inside a CPU Core

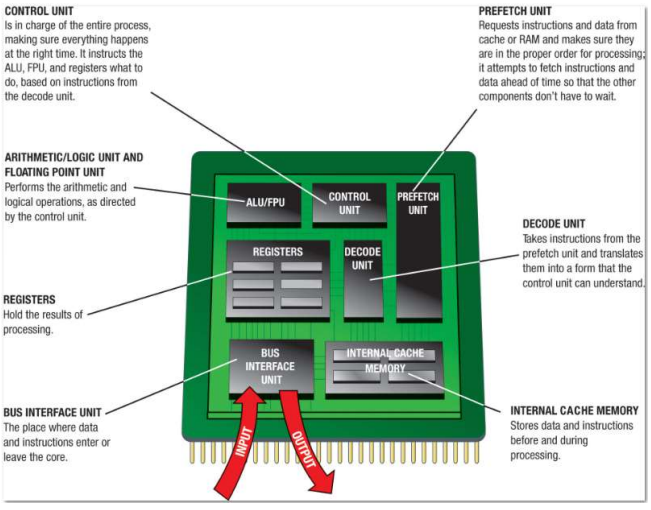


FIGURE 2-21
Inside a CPU core.

The System Clock

- The **system clock** is a timing mechanism within the computer system that synchronizes the computer's operations
  - Located on the motherboard
  - Sends out a signal on a regular basis to all computer components
  - Each signal is a cycle
  - Number of cycles per second is measured in hertz (Hz)
  - One megahertz = one million ticks of the system clock

Clock Speed

- Computers can run at a multiple or fraction of the system clock speed
  - Many PC system clocks run at 200 MHz; all devices run at a fraction or multiplier of the clock speed
  - A CPU clock speed of 2 GHz means the CPU clock "ticks" 10 times during each system clock tick
  - During each CPU clock tick, one or more pieces of microcode are processed
  - A CPU with a higher clock speed processes more instructions per second than the same CPU with a lower CPU clock speed

The Machine Cycle

- A **machine cycle** occurs whenever the CPU processes a single piece of microcode
  - It consists of four operations:
    - Fetch
    - Decode
    - Execute
    - Store

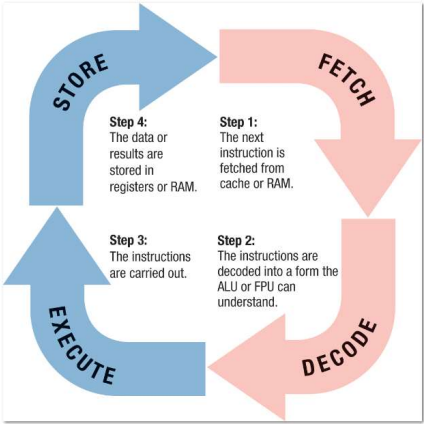


FIGURE 2-22
A machine cycle. A machine cycle is typically accomplished in four steps.

Making Computers Faster and Better Now and in the Future

- Improving the Performance of Your System Today
  - Add more memory
  - Perform system maintenance
    - Uninstall programs properly
    - Remove unnecessary programs from the Startup list
    - Place unneeded large files on external storage
    - Delete temporary files
    - Error-check your hard drive
    - Scan for viruses and spyware
    - Clean out the dust

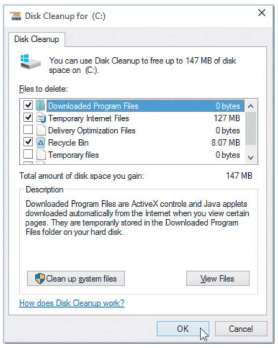


FIGURE 2-24
Windows Disk Cleanup. Can help free up room on your hard drive.

Making Computers Faster and Better Now and in the Future

- Buy a larger or second hard drive
  - Can be internal or external
  - Move files from your primary drive to make it faster
- Upgrade your Internet connection
  - Various types of connections and speeds are available
- Upgrade your video graphics card
  - PCs with integrated graphics can typically have a graphics card added
  - Graphics cards can be upgraded if needed
  - Some notebooks switch to integrated graphics when using battery power to extend battery life

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Making Computers Faster and Better Now and in the Future

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Strategies for Making Faster and Better Computers

- **Pipelining** allows multiple instructions to be processed at one time
- Multiprocessing/Parallel Processing
- Improved Architecture
- Improved Materials
- Nanotechnology
- Quantum Computing

Terascale/Exascale Computing

- High-performance computing (HPC)
  - **Terascale computing** is the ability of a computer to process one trillion floating point operations per second (teraflops)
    - Research is focusing on creating multi-core processors with tens to hundreds of cores used in conjunction with multithreaded hardware and software to achieve teraflop performance
  - The next development is expected to be **exascale computing** that can process data at exaflop (1,000 petaflops) speeds

Storage System Characteristics

- A storage system consists of a storage medium and a storage device
  - The **storage medium** is the hardware where data is stored
    - DVD disc, flash memory card, etc.
  - The **storage device** is the hardware into which the storage medium is inserted
    - DVD drive, flash memory card reader, etc.
    - Can be internal, external, or remote
    - Storage devices are typically identified by letter
  - Some storage media is removable; some is not

Volatility and Random vs. Sequential Access

- Volatility
  - Storage media are nonvolatile and, therefore, is used for data to be saved for later use
- Random vs. sequential access
  - Random access (direct access) allows data to be retrieved from any location on the storage medium
    - Virtually all storage devices use random access
  - Sequential access means that retrieval of data can occur only in the order in which it was physically stored on the storage medium; for example, a magnetic tape drive

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Logical vs. Physical Representation and Types of Storage Technologies Used

- Logical file representation
  - Individuals view a document stored as one complete unit in a particular folder on a particular drive
- Physical file representation
  - Computers access a particular document stored on a storage medium using its physical location or locations
- Types of storage technology
  - Magnetic (conventional hard drives)
  - Optical (optical discs)
  - Electrons (flash memory media)

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Hard Drives

- A **hard drive** stores most programs and data for a personal computer
  - Can be internal or external
  - Available with built-in encryption that limits access to only authorized users

FIGURE 3-3
Encrypted hard drives. The data stored on these external hard drives is accessed via a fingerprint scan (left) or PIN (right).

Magnetic Hard Drives

- A **magnetic hard drive** or **hard disk drive (HDD)** contains particles on the metal disks inside the drive that are magnetized to represent the data's 0s and 1s

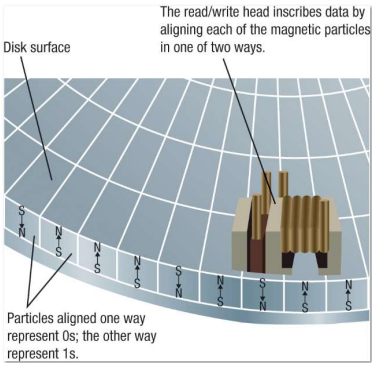

FIGURE 3-4
Storing data on magnetic disks.

Magnetic Hard Drives (cont'd)

- One or more metal hard disks are permanently sealed inside the drive along with an access mechanism and read/write heads

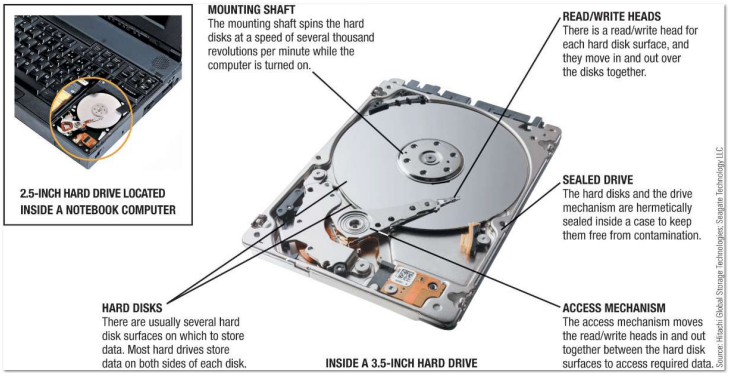

FIGURE 3-5
Magnetic hard drives.

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Hard Disk Organization

- **Tracks** are concentric paths on the disk where data is recorded
- **Sectors** are small pieces of a track
- **Clusters** consist of one or more sectors
  - Smallest addressable area of a disk
- **Cylinders** are a collection of tracks located in the same location on a set of hard disk surfaces

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Examples of Tracks, Sectors, Clusters, and Cylinders

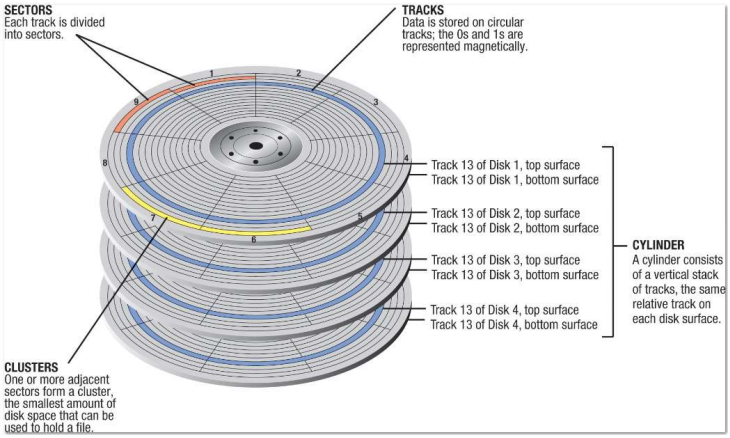

FIGURE 3-6
Magnetic hard disks are organized into tracks, sectors, clusters, and cylinders.

Solid-State Drives (SSDs)

- A **solid-state drive (SSD)** uses flash memory technology to store data
  - Uses less power and has no moving parts
  - Much faster than magnetic hard drives, but more expensive
  - The norm for netbooks, mobile devices, and other portable devices

FIGURE 3-7
Solid-state drives (SSDs). Contain only flash memory.

Hard Drive Speed and Disk Caching

- **Disk access time** is the total time that it takes for a hard drive to read or write data
  - Consists of seek time, rotational delay, and data movement time
  - SSDs don't require seek time or rotational delays
- **Disk cache** consists of memory used in conjunction with a magnetic hard drive to improve system performance
  - Typically consists of RAM-based disk cache located inside the hard drive case
  - Can speed up performance and save battery life

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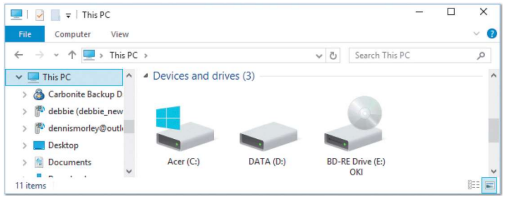
Hard Drive Partitioning

- Partitioning divides the physical capacity of a single drive logically into separate areas, called partitions
  - Each partition functions as an independent hard drive
  - Referred to as logical drives
  - Increases efficiency (smaller drives use smaller clusters)
- Partitions are used to create:
  - A recovery partition
  - A new logical drive for data
  - A dual boot system

FIGURE 3-10
Hard drive partitions.



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Optical Discs

- **Optical discs** are thin circular plastic discs
  - Are read from and written to using laser beams
  - Are commonly used for software delivery
  - Divided into sectors like magnetic discs but use a single spiral track (groove)
  - Have a relatively large capacity and are durable
  - Used for backup purposes and for storing and transporting music, photos, video, etc.

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Representing Data on an Optical Disc

- Pits and lands are used to represent 1s and 0s
- The transition between a pit and a land represents a 1; no transition represents a 0
- Read-only optical disc
  - Surface of disc is molded or stamped to represent data
- Recordable or rewritable disc
  - The reflectivity of the disc is changed using a laser beam to represent the data
  - Different types of optical discs use different types of laser beams

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How Recorded Optical Discs Work

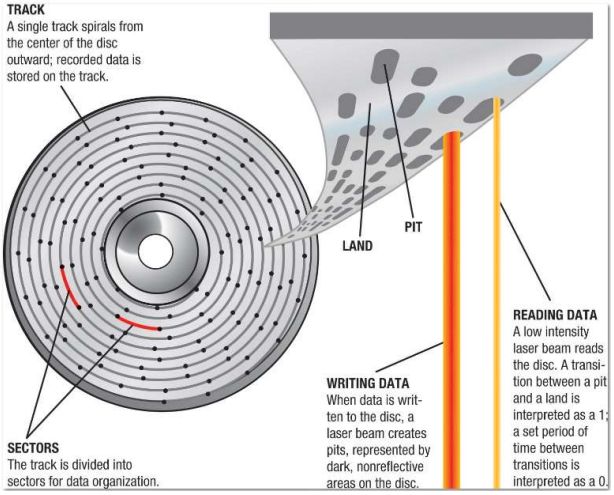

FIGURE 3-11
How recorded optical discs work.

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Summary of Optical Discs

TYPE OF DISC	CAPACITY	USED FOR
CD	700 MB	Audio music delivery; custom CDs containing music, photos, etc.
DVD DVD-DL	4.7 GB 8.5 GB	Movie and software delivery; custom DVDs containing videos, music, photos, etc.
BD BD-DL	25 GB 50 GB	Primarily movie delivery
BDXL (3 layers) BDXL (4 layers)	100 GB 128 GB	Primarily video archiving
Ultra HD (4K) (2 layers) Ultra HD (4K) (3 layers)	66 GB 100 GB	Primarily 4K movie delivery

FIGURE 3-14
Summary of optical discs.

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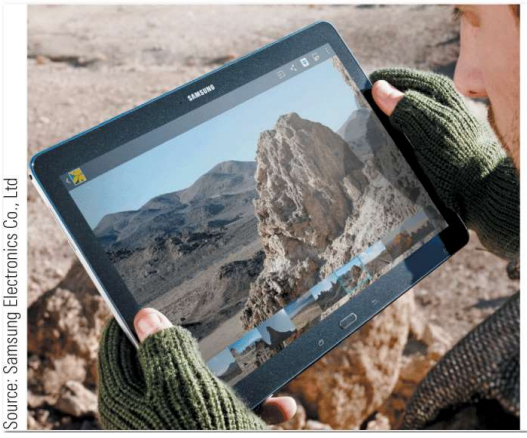
Flash Memory Storage Systems

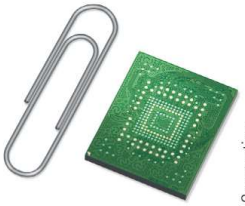
- **Flash memory** is a chip-based storage medium that represents data using electrons
  - Used in a variety of storage systems
- **Embedded flash memory** refers to flash memory chips embedded into products
  - Smartphones, tablets, smart watches, and even sunglasses and wristwatches
  - Usually the primary storage for mobile devices such as tablets and smartphones

Examples of Embedded Flash Memory



Source: Samsung Electronics Co., Ltd

This tablet contains 64 GB of embedded flash memory.



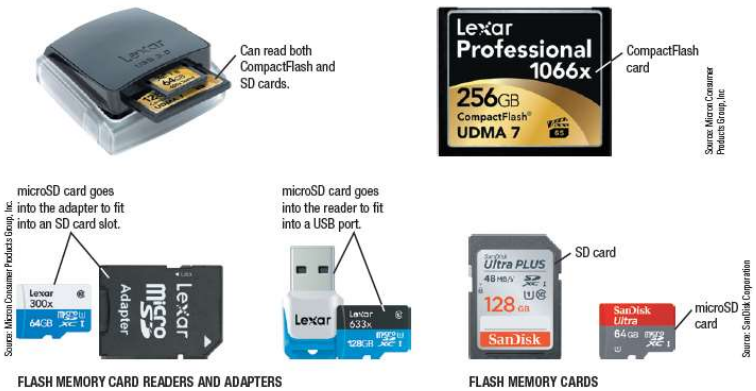
Source: SanDisk Corporation

An embedded flash memory chip.

Flash Memory Cards and Readers

- A **flash memory card** is a small card containing one or more flash memory chips, a controller chip, and metal contacts to connect the card to the device or reader being used
  - Available in a variety of formats; these formats are not interchangeable
  - Secure Digital (SD) is one of the most widely used types of flash memory media
  - Most common type of storage media for digital cameras, smartphones, and other portable devices
- Many devices today have a built-in flash memory card reader; an external reader via USB port is also used
- Adapters allow the use of smaller flash memory cards in a larger slot of the same type (microSD to SD, etc.)

Examples of Flash Memory Cards, Readers, and Adapters



FLASH MEMORY CARD READERS AND ADAPTERS

FLASH MEMORY CARDS

FIGURE 3-16
Flash memory cards, readers, and adapters.

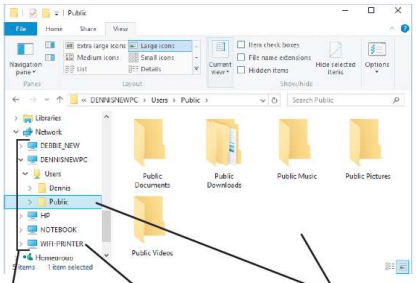
USB Flash Drives

- **USB flash drives** (USB drives or flash drives) consist of flash memory media integrated into a self-contained unit that plugs into and is powered by a USB port
  - Designed to be very small and very portable
  - Available in a host of formats
    - Low-profile drives, custom shapes, micro drives, etc.
  - Can be built into a consumer product
  - Additional related hardware becoming available
    - USB duplicator systems

Other Types of Storage Systems

- Remote storage refers to using a storage device that is not connected directly to the user's computer
- **Network storage:** Using a storage device via a local network
  - Works in much the same way as using local storage
  - **Network attached storage (NAS)** devices are high performance storage systems connected individually to a network
  - A **storage area network (SAN)** consist of separate network of hard drives or other storage devices that are attached to the main network

Examples of Network Storage



LOCAL NETWORKS
Network devices appear and are accessed in a manner similar to local resources.

NETWORK ATTACHED STORAGE (NAS) DEVICES
This NAS device holds up to 12 TB of data on two magnetic hard drives.

FIGURE 3-19
Network storage.

Cloud Storage

- **Cloud storage** (**online storage**) is accessed via the Internet
  - Cloud applications (Flickr, Facebook, Google Docs, etc.)
  - Online storage sites (Box, Dropbox, OneDrive, etc.)
  - Growing in importance because more and more applications are Web-based
  - Increasingly used for backup purposes
  - Files can be synched between PC and cloud storage
  - Many online storage sites offer some free storage
  - Business cloud storage is available; businesses can also create private clouds

Example of Cloud Storage

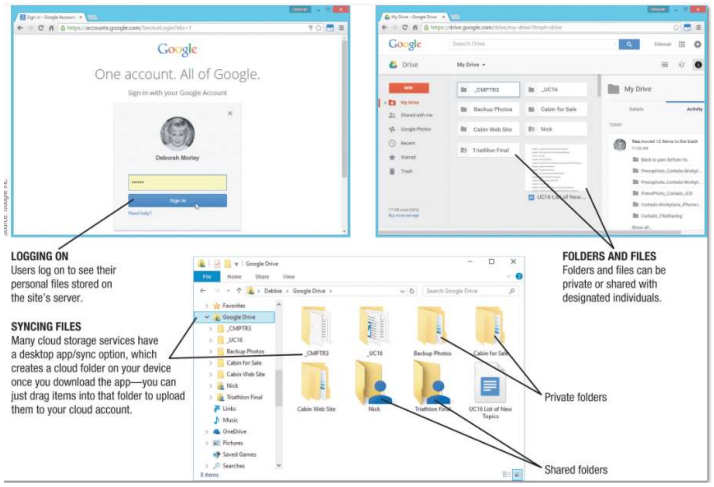


FIGURE 3-20
Cloud storage.

Smart Cards

- A **smart card** is a credit card-sized piece of plastic that contains some computer circuitry (processor, memory, and storage)
  - Stores a small amount of data (about 64 KB or less)
  - Commonly used to store prepaid amounts of digital cash or personal information
  - Smart card readers are built into or attached to a computer, door lock, vending machine, or other device
  - Some smart cards store biometric data
  - Use of mobile smart cards is an emerging trend

Examples of Uses for Smart Cards

FIGURE 3-21
Uses for smart cards.

Storage Systems for Large Computer Systems

- Business storage needs are growing exponentially
  - Digital data produced is expected to double every two years through 2020
- A storage server contains multiple high-speed hard drives
  - Larger than typical NASs
  - Usually contain drawers of hard drives
  - Typically use fast Fibre Channel or iSCSI connections
  - Scalable so that more hard drives can be added as needed
  - Can use magnetic and/or SSD drives

Example of a Large Storage Systems

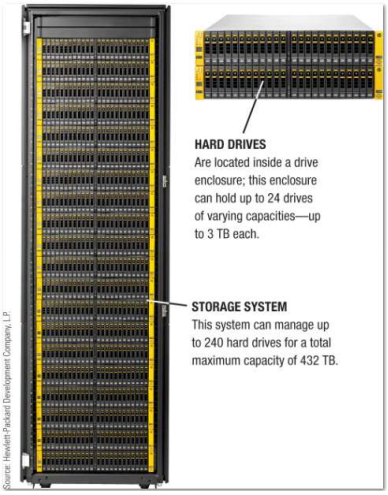


FIGURE 3-22
Large storage systems. Large storage systems are usually scalable so additional hard drives can be added as needed.

RAID

- **RAID** (**redundant arrays of independent discs**) is a method of storing data on two or more hard drives that work together to record redundant copies
  - Used to protect critical data on large storage systems
  - Helps to increase fault tolerance
  - Different levels of RAID:
    - RAID 0 = disk striping (spread files over two or more hard drives)
    - RAID 1 = disk mirroring (duplicate copy)
    - Other levels use a combination or striping and mirror

Two Primary RAID Techniques

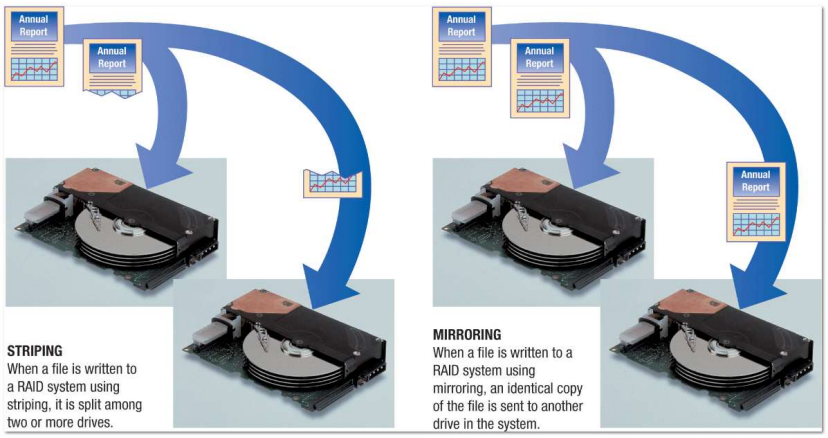


FIGURE 3-23
RAID. Two primary RAID techniques are striping and mirroring.

Newer RAID Systems

- New storage systems are easier to set up and maintain so dedicated RAID personnel are not needed
  - For example, the Drobo system:
    - Connects to a computer or a network via a USB cable
    - Contains drive bays into which hard drives can be inserted
    - Has capacity and status indicators – drives can be inserted and removed as needed

FIGURE 3-24
A Drobo storage system.

Evaluating Your Storage Alternatives

- Product characteristics to consider:
  - Speed, compatibility, storage capacity, convenience, and portability
- Each storage alternative normally involves trade-offs
- Research which devices and media are most appropriate to your personal devices
- All computers need at least one convenient USB port
- Mobile device users
  - Fewer options for storage alternatives
  - Require appropriate wireless connectivity