15th Edition

Understanding Computers

Today and Tomorrow

Comprehensive

Chapter 2

The Systems Unit: Processing and Memory

updated by

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Learning Objectives

1. Understand how data and programs are represented to a computer and be able to identify a few of the coding systems (Text in ASCII, EBCDIC,..) used to accomplish this.
2. Explain the functions of the hardware components commonly found inside the system unit, such as the CPU (Central Processing Unit), GPU (Graphics Processing Unit), memory, buses, and expansion cards.
3. Describe how peripheral devices or other hardware can be added to a computer.
4. Understand how a computer's CPU and memory components process program instructions and data.

Learning Objectives

5. Name and evaluate several strategies that can be used today for speeding up the operations of a computer.
6. List some processing technologies that may be used in future computers.

Overview

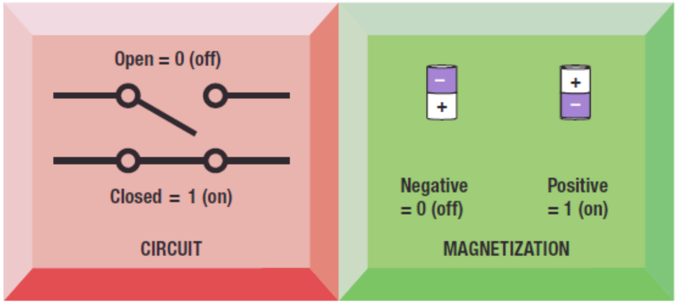
- Explain how computers represent data and program instructions.
- Explain how the CPU and memory are arranged with other components inside the system unit.
- Explain how a CPU performs processing tasks.
- Identify strategies that can be used today to create faster and better computers in the future.

Data and Program Representation

- Digital Data Representation
  - Coding Systems
    - Used to represent data and programs in a manner understood by the computer
  - Digital Computers
    - Can only understand two states, off and on (0 and 1)
  - Digital Data Representation
    - The process of representing data in digital form so it can be understood by a computer

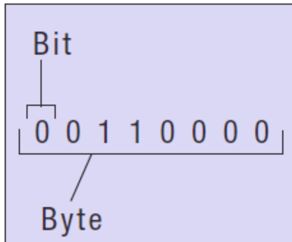
FIGURE 2-1

Ways of representing 0 and 1. Binary computers recognize only two states—off and on—usually represented by 0 and 1.



Digital Data Representation

– Bit
  - The smallest unit of data that a binary computer can recognize (a single 1 or 0)
– Byte = 8 bits
  - Byte terminology used to express the size of documents and other files, programs, etc.



Abbreviation	Approximate Size
KB	1 thousand bytes
MB	1 million bytes
GB	1 billion bytes
TB	1 trillion bytes
PB	1,000 terabytes
EB	1,000 petabtyes
ZB	1,000 exabytes
YB	1,000 zettabytes

FIGURE 2-2
Bits and bytes. Document size, storage capacity, and memory capacity are all measured in bytes.

– Prefixes are often used to express larger quantities of bytes: kilobyte (KB), megabyte (MB), gigabyte (GB), terabyte (TB), petabyte (PB), exabyte (EB), zettabyte (ZB), yottabyte (YB).

Representing Numerical Data

- The Binary Numbering System
  - Numbering system
    - A way of representing numbers
  - Decimal numbering system
    - Uses 10 digits (0-9)
  - Binary numbering system
    - Uses only two digits (1 and 0) to represent all possible numbers
  - In both systems, the position of the digits determines the power to which the base number (such as 10 or 2) is raised

Representing Numerical Data

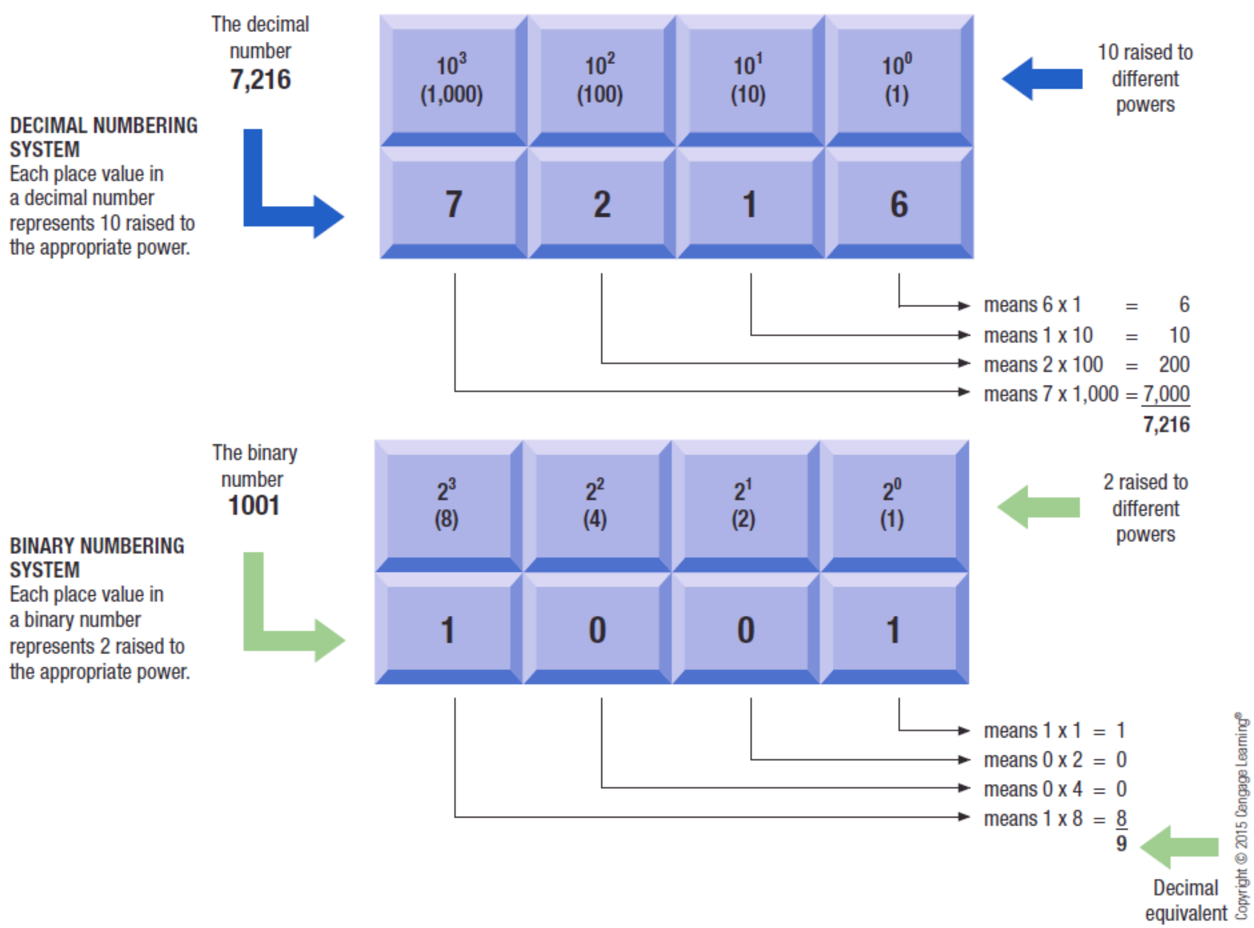


FIGURE 2-3
Examples of using the decimal and binary numbering systems.

Coding Systems for Text-Based Data

- ASCII (American Standard Code for Information Interchange)
  - Coding system traditionally used with personal computers
- EBCDIC (Extended Binary-Coded Decimal Interchange Code)
  - Developed by IBM, primarily for mainframes

CHARACTER	ASCII
0	00110000
1	00110001
2	00110010
3	00110011
4	00110100
5	00110101
A	01000001
B	01000010
C	01000011
D	01000100
E	01000101
F	01000110
+	00101011
!	00100001
#	00100011

FIGURE 2-4
Some extended ASCII code examples.

Coding Systems for Text-Based Data

- Unicode
  - Newer code (32 bits per character is common)
  - Universal coding standard designed to represent text-based data written in any ancient or modern language
  - Replacing ASCII as the primary text-coding system

FIGURE 2-5
Unicode. Many characters, such as these, can be represented by Unicode but not by ASCII or EBCDIC.

Coding Systems for Other Types of Data

- Graphics Data (still images such as photos or drawings)
  - Bitmapped images
    - Image made of up of a grid of small dots called pixels
    - Monochrome graphic can only be one of two colors
      - Requires just one bit for color storage
    - Images with more than two colors
      - Can use 4, 8, or 24 bits to store the color data for each pixel
  - More bits = more colors

Coding Systems for Other Types of Data

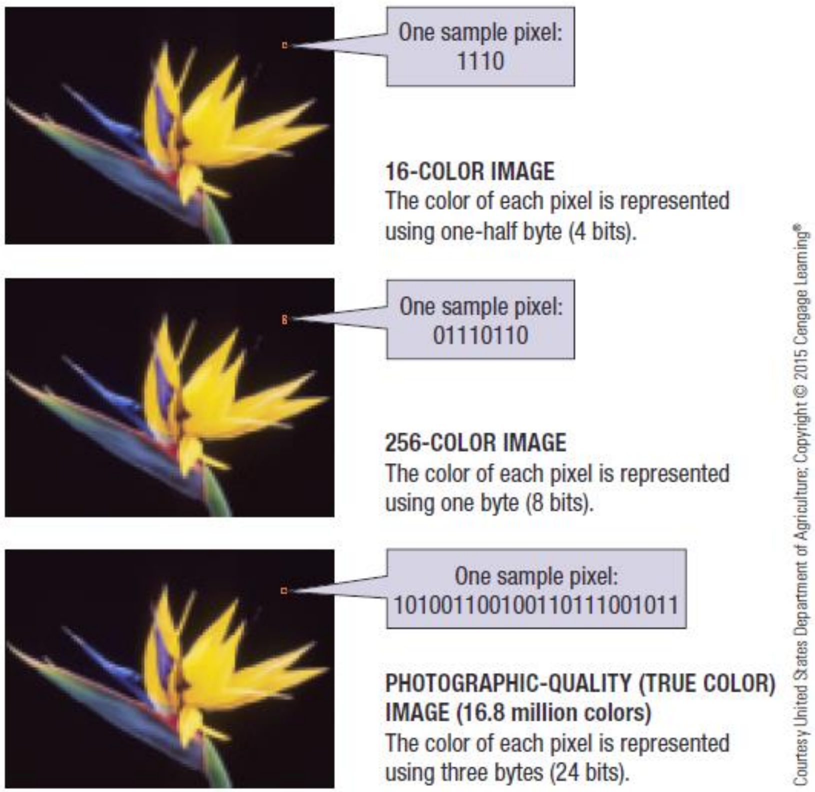


FIGURE 2-6

Representing graphics data. With bitmapped images, the color of each pixel is represented by bits; the more bits used, the better the image quality.

Coding Systems for Other Types of Data

- Audio Data
  - Must be in digital form in order to be stored on or processed by a computer
  - Often compressed when sent over the Internet
    - MP3 files are 10 times smaller than their uncompressed digital versions
    - Download more quickly and take up less storage space
- Video Data
  - Displayed using a collection of frames, each frame contains a still image
  - Amount of data can be substantial, but can be compressed

Representing Software Programs

- Machine language
  - Binary-based language for representing computer programs the computer can execute directly
  - Early programs were written in machine language
  - Today's programs still need to be translated into machine language in order to be understood by the computer

Quick Quiz

1. Another way to say “one million bytes” is
   a. one kilobyte
   b. one gigabyte
   c. one megabyte
2. True or False: MP3 files are stored using 0s and 1s.
3. The _______________ numbering system is used by computers to perform mathematical computations.

Answers:

1) c; 2) True; 3) binary

Inside the System Unit

- System Unit
  - The main case of a computer
  - Houses the processing hardware for a computer
  - Also contains storage devices, the power supply, and cooling fans
  - Houses processor, memory, interfaces to connect to peripheral devices (printers, etc), and other components
  - With a desktop computer, usually looks like a rectangular box

Inside the System Unit

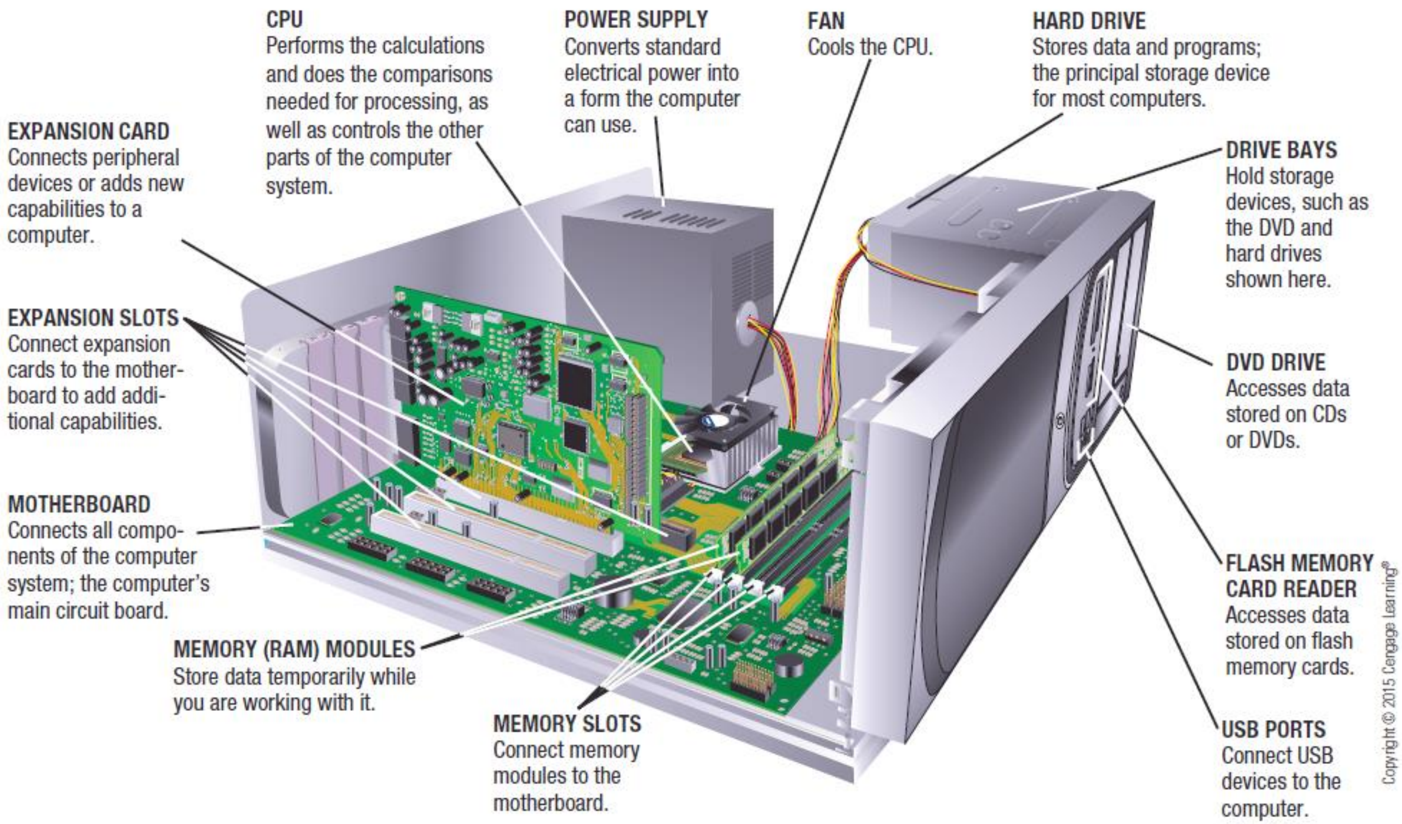


FIGURE 2-7

Inside a typical system unit. The system unit houses the CPU, memory, and other important pieces of hardware.

Inside the System Unit

- The Motherboard
  - Computer Chip
    - Very small pieces of silicon or other semi-conducting material onto which integrated circuits are embedded
  - Circuit Board
    - A thin board containing computer chips and other electronic components
  - System Board
    - The main circuit board inside the system unit to which all devices must connect

Inside the System Unit

- External devices (monitors, keyboards, mice, printers)
- Wireless devices (e.g., Bluetooth)
- Power Supply
  - Connects to the motherboard to deliver electricity (personal computer)
  - Portable computers use rechargeable battery pack
    - Nonremovable batteries more difficult and expensive to replace

Inside the System Unit

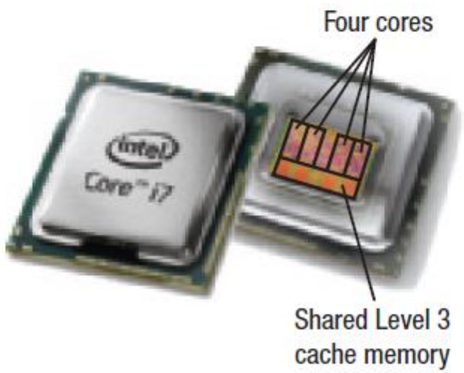
- Drive Bays
  - Rectangular metal racks inside the system unit that house storage devices
    - Hard drive, CD/DVD drive, flash memory card reader
    - Connected to the motherboard with a cable

- Processors
  - The CPU (Central Processing Unit)
    - Circuitry and components packaged together and connected directly to the motherboard
    - Does most of the processing for a computer
    - A.k.a. processor; called a microprocessor when talking about personal computers

Inside the System Unit

- Dual-core CPU
  - Contains the processing components (cores) of two separate processors on a single CPU
- Quad-core CPU
  - Contains four cores
- Multi-core processors allow computers to work on more than one task at a time
- Typically, different CPUs for desktop computers, portable computers, servers, mobile devices, consumer devices, etc.
  - Personal computer CPU often made by Intel or AMD
  - Media tablets and mobile phones use processors made by other companies such as ARM

Inside the System Unit



DESKTOP PROCESSORS

MOBILE PROCESSORS

TYPE OF CPU	NAME	NUMBER OF CORES	CLOCK SPEED	TOTAL CACHE MEMORY
SERVER	Intel Xeon (E7 family)	6–10	1.73–2.66 GHz	18–30 MB
	AMD Opteron (6300 series)	4–16	1.8–3.5 GHz	20–32 MB
DESKTOP	Intel Core i7 (3rd gen)	4–6	2.5–3.6 GHz	8–12 MB
	AMD FX	4–8	3.1–4.2 GHz	8–16 MB
MOBILE (NOTEBOOKS)	Intel Core i7 Mobile (3rd gen)	2–4	1.06–3.0 GHz	4–8 MB
	AMD Athlon II Neo	1–2	1.3–1.7 GHz	1–2 MB
MOBILE (MOBILE DEVICES)	ARM Cortex-A9	1–4	800 MHz–2 GHz	up to 2 MB
	ARM Cortex-A15	1–4+	1–2 GHz	up to 4 MB
	NVIDIA Tegra 4*	4	1.9 GHz	2 MB

*Based on ARM Cortex-A15

FIGURE 2-8
CPU examples and characteristics.

Inside the System Unit

- 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, on in the CPU package

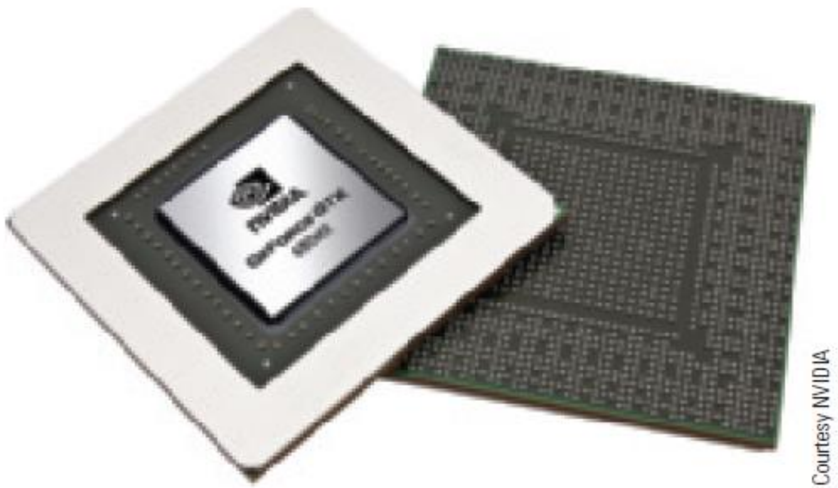


FIGURE 2-9
A GPU.

How It Works Box

GPUs and *Transformers: The Ride 3D* at Universal Studios

- Uses a 2,000 foot-long track, 14 huge screens, and 34 projectors
- Motion is synchronized with the action
- Images are 3D, 4K
- Used GPUs to see 3D animations in real time as they were being developed

Inside the System Unit

- Processing Speed
  - CPU clock speed is one measurement of processing 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

Inside the System Unit

- Word Size
  - The amount of data that a CPU can manipulate at one time
  - Typically 32 or 64 bits
- Cache Memory
  - Special group of very fast memory chips located on or close to the CPU
  - Level 1 is fastest, then Level 2, then Level 3
  - More cache memory typically means faster processing
  - Usually internal cache (built into the CPU)

Inside the System Unit

- 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

Inside the System Unit

- Bus width and speed determine the throughput or bandwidth of the bus
  - The amount of data that can be transferred by the bus in a given time period

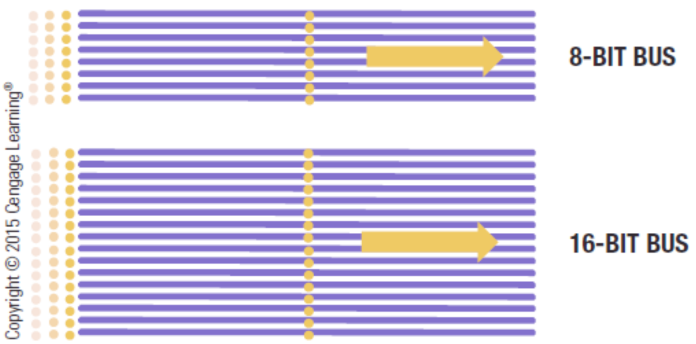


FIGURE 2-10

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

Memory

- Memory
  - Refers to chip-based storage located inside the system unit
  - Storage refers to the amount of long-term storage available to a computer
  - Random Access Memory (RAM)
    - Computer’s main memory
    - Consists of chips arranged on a circuit board called a memory module which are plugged into the motherboard
    - Stores essential parts of operating system, programs, and data the computer is currently using

Memory

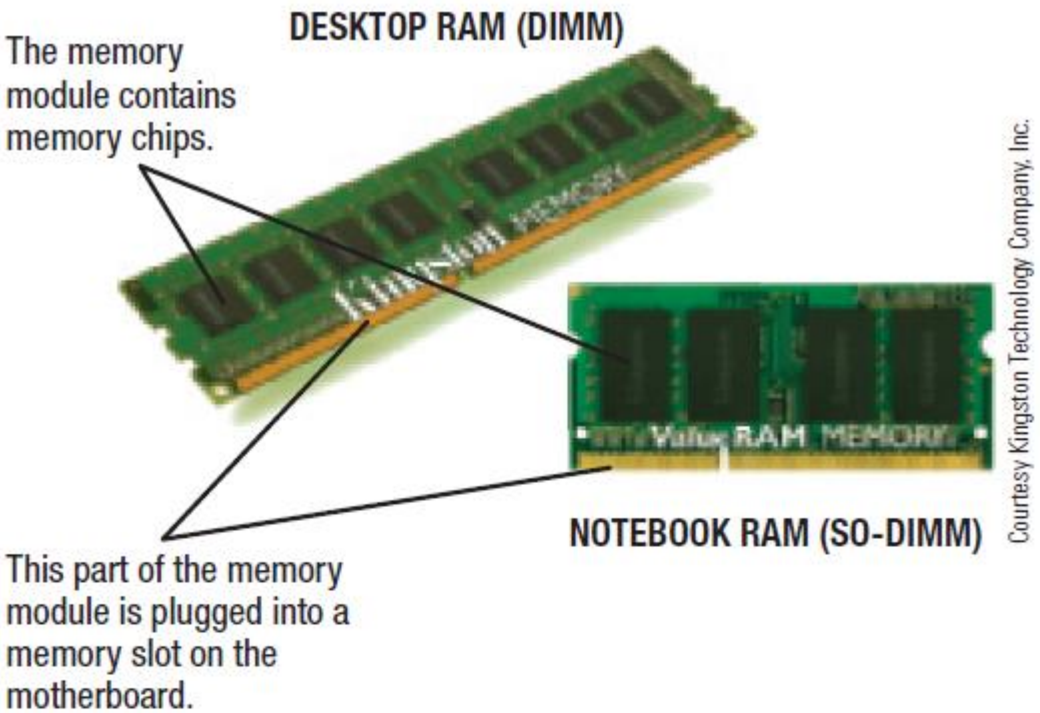


FIGURE 2-11

RAM memory modules.

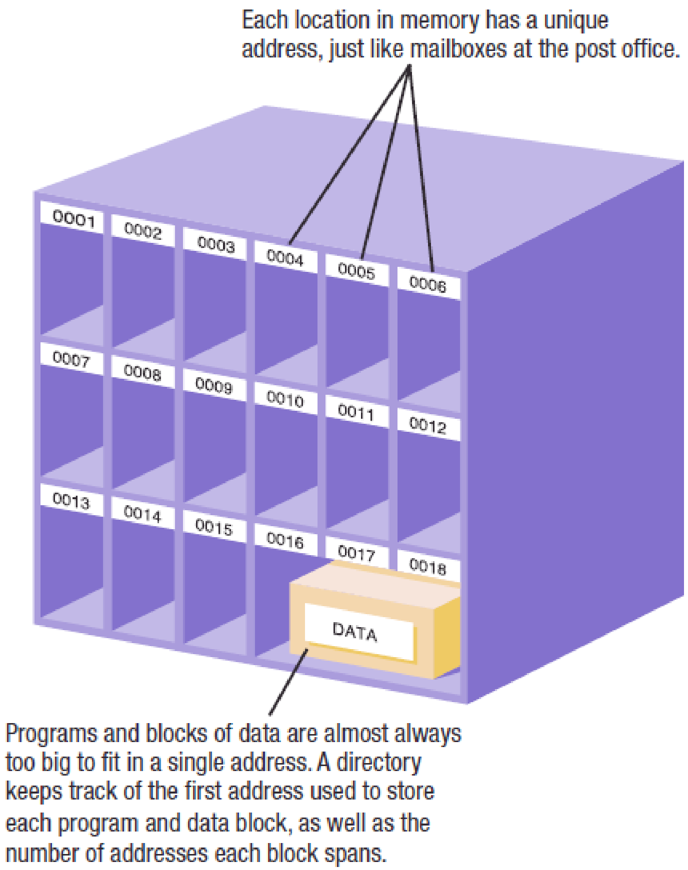
Memory

- Volatile
  - RAM content lost when the computer is shut off
  - ROM and flash memory are non-volatile
- Measured in bytes
  - Amount installed depends on the CPU and operating system being used
- Most personal computers use SD-RAM
- MRAM and PRAM - non-volatile RAM under development

Memory

- Each location in memory has an address
  - Each location typically holds one byte
  - Computer system sets up and maintains directory tables to facilitate retrieval of the data

FIGURE 2-12
Memory addressing.



Memory

- Registers
  - High-speed memory built into the CPU
  - Used to store data and intermediary results during processing
  - Fastest type of memory
- ROM (read-only memory)
  - 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

Memory

- Flash Memory
  - Nonvolatile memory chips that can be used for storage
  - Have begun to replace ROM for storing system information
  - Now stores firmware for personal computers and other devices
  - Built into many types of devices (media tablets, mobile phones, and digital cameras) for user storage

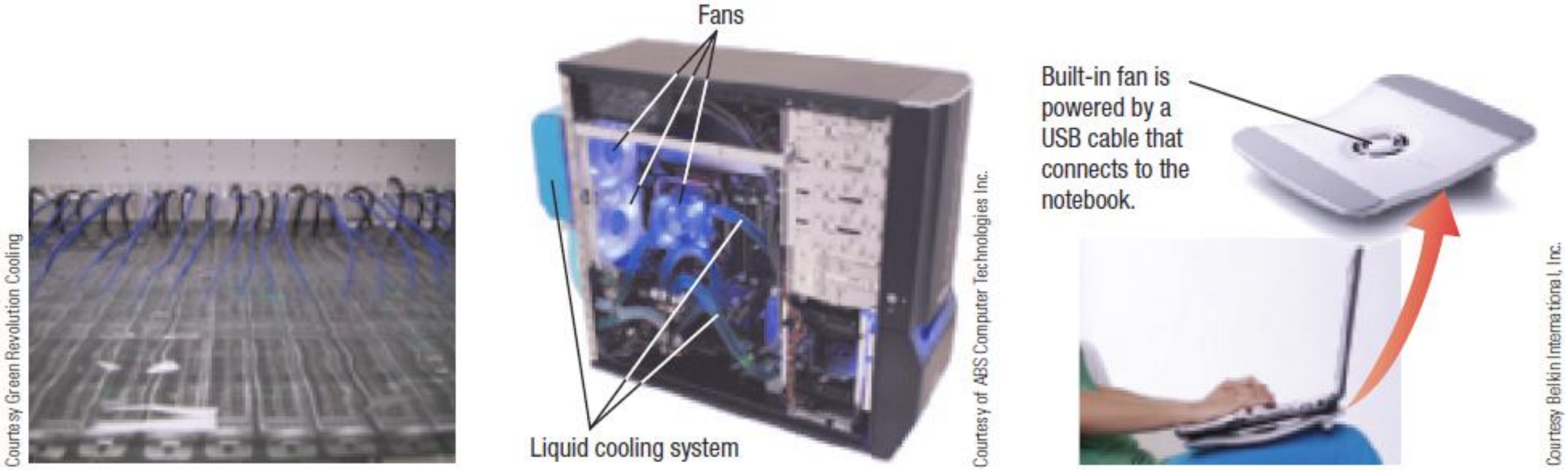
Cooling Components

- Fans
  - Fans 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
  - Small components typically made out of aluminum with fins that help to dissipate heat

Cooling Components

- 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

Cooling Components



SERVERS
Often use liquid cooling systems; an immersion cooling system is shown here.

DESKTOP COMPUTERS
Can use fans, heat sinks, and liquid cooling systems to cool the inside of the computer.

NOTEBOOK COMPUTERS
Typically have at least one internal fan; notebook cooling stands can be used to cool the underside of the computer.

FIGURE 2-13
Computer cooling methods.

Expansion

- Expansion Slots, Expansion Cards, and ExpressCard Modules
  - Expansion Slot
    - A location on the motherboard into which expansion cards are inserted
  - Expansion Card
    - A circuit board inserted into an expansion slot
    - Used to add additional functionality or to attach a peripheral device
  - ExpressCard Modules
    - Designed to add additional functionality to notebooks

Expansion

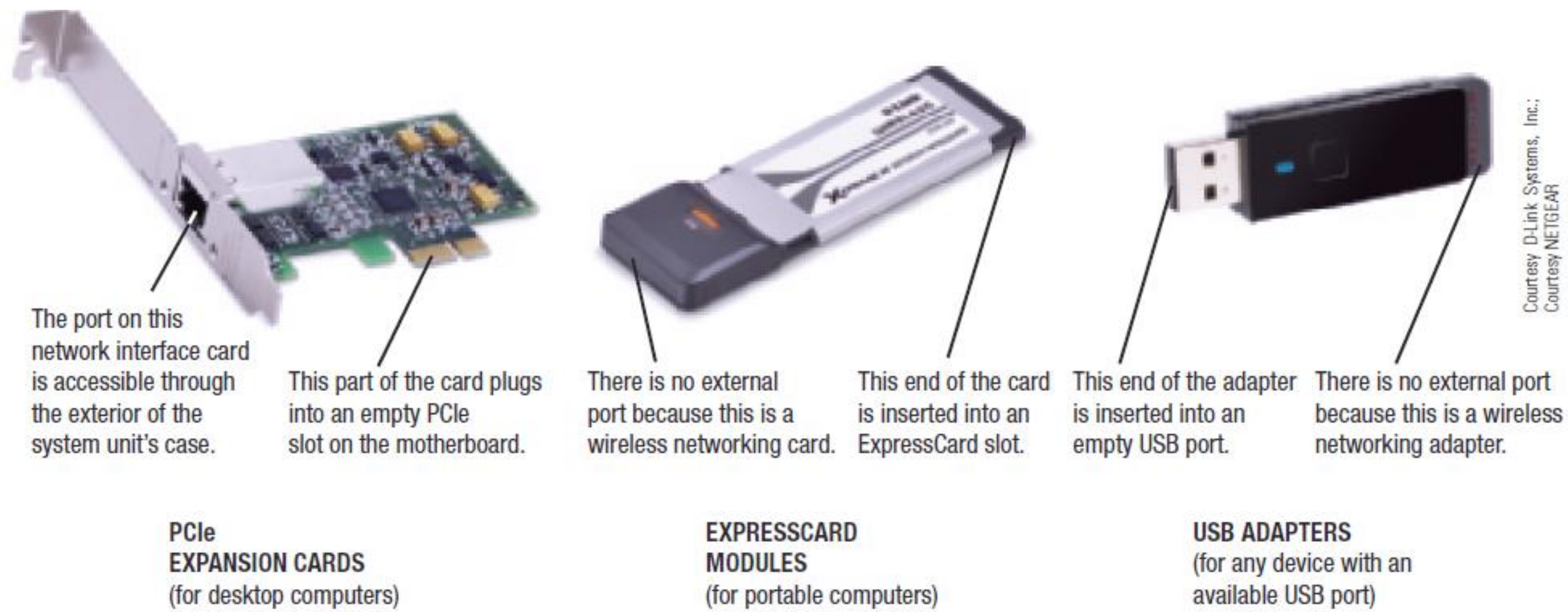


FIGURE 2-14

Types of expansion.

Buses

- Bus
  - An electronic path within a computer over which data travels
    - Located within the CPU and etched onto the motherboard
  - Expansion Bus
    - Connects the CPU to peripheral (typically input and output) devices
  - Memory Bus
    - Connects CPU directly to RAM
  - Frontside Bus (FSB)
    - Connects CPU to the chipset that connects the CPU to the rest of the bus architecture

Buses

- PCI (peripheral component interconnect) and PCI Express (PCIe) Bus
  - PCI has been one of the most common types
  - Today, PCI Express bus, which is extremely fast, has replaced the PCI bus
- Universal Serial Bus (USB)
  - Extremely versatile
  - Allows 127 different devices to connect to a computer via a single USB port
- FireWire Bus
  - Developed by Apple to connect multimedia devices to a computer

Ports and Connectors

- Port
  - A connector on the exterior of a computer's system unit to which a device may be attached
  - Typical desktop computer ports include:
    - Power connector, Firewire, VGA monitor, Network, USB, Audio, and HDMI
  - Others include IrDA and Bluetooth ports, eSATA ports, Thunderbolt ports (Apple devices)
  - Most computers support the Plug and Play standard

Ports and Connectors

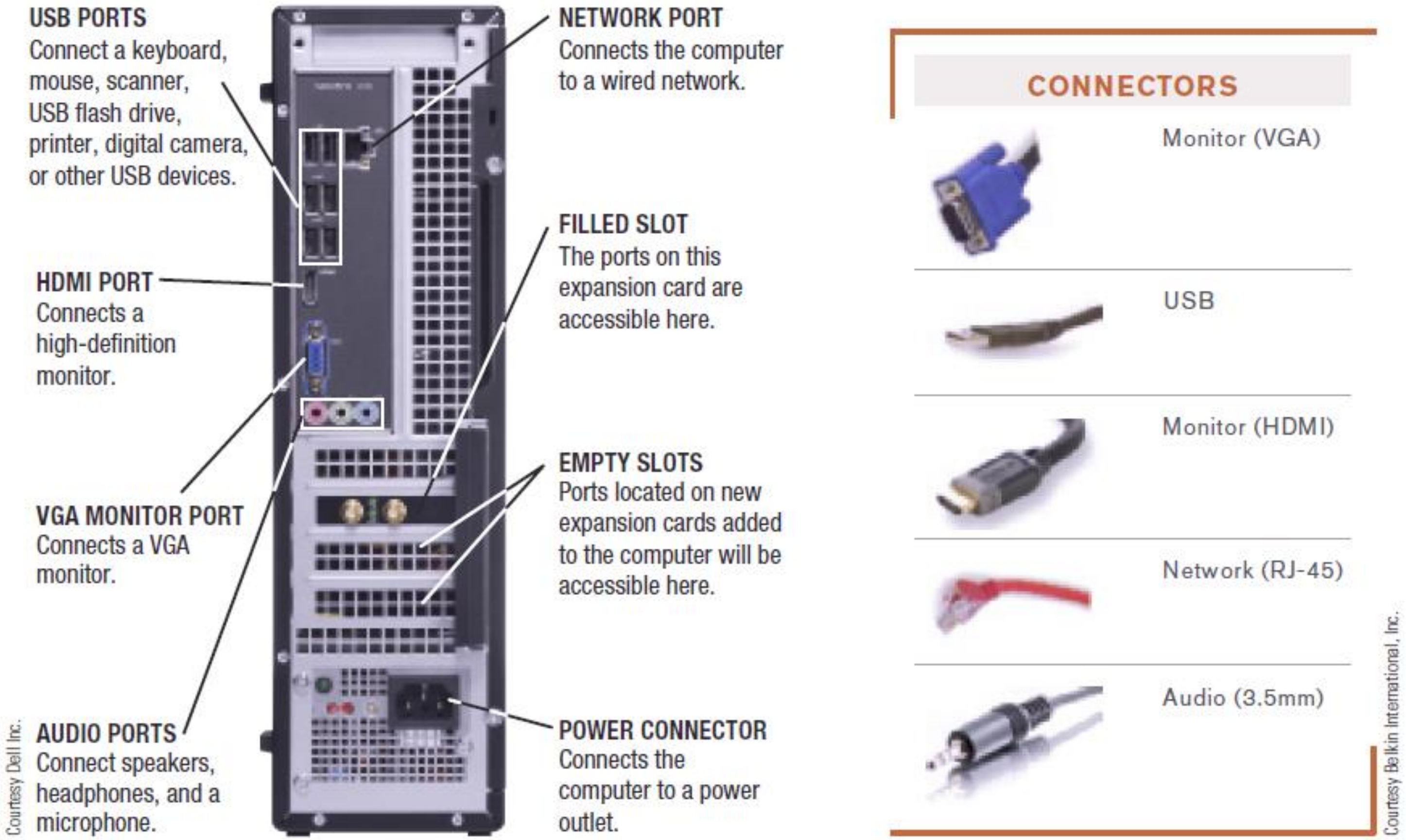


FIGURE 2-16
Typical ports for desktop computers and examples of connectors.

Ports and Connectors

- Portable computers have ports similar to desktop computers, but often not as many
- Smartphones and mobile devices have more limited expansion capabilities
  - Usually have a USB port, HDMI port, and/or flash memory card slot
  - Flash memory cards often use the Secure Digital (SD) format
  - MiniSD and microSD cars are smaller than regular SD cards

Ports and Connectors

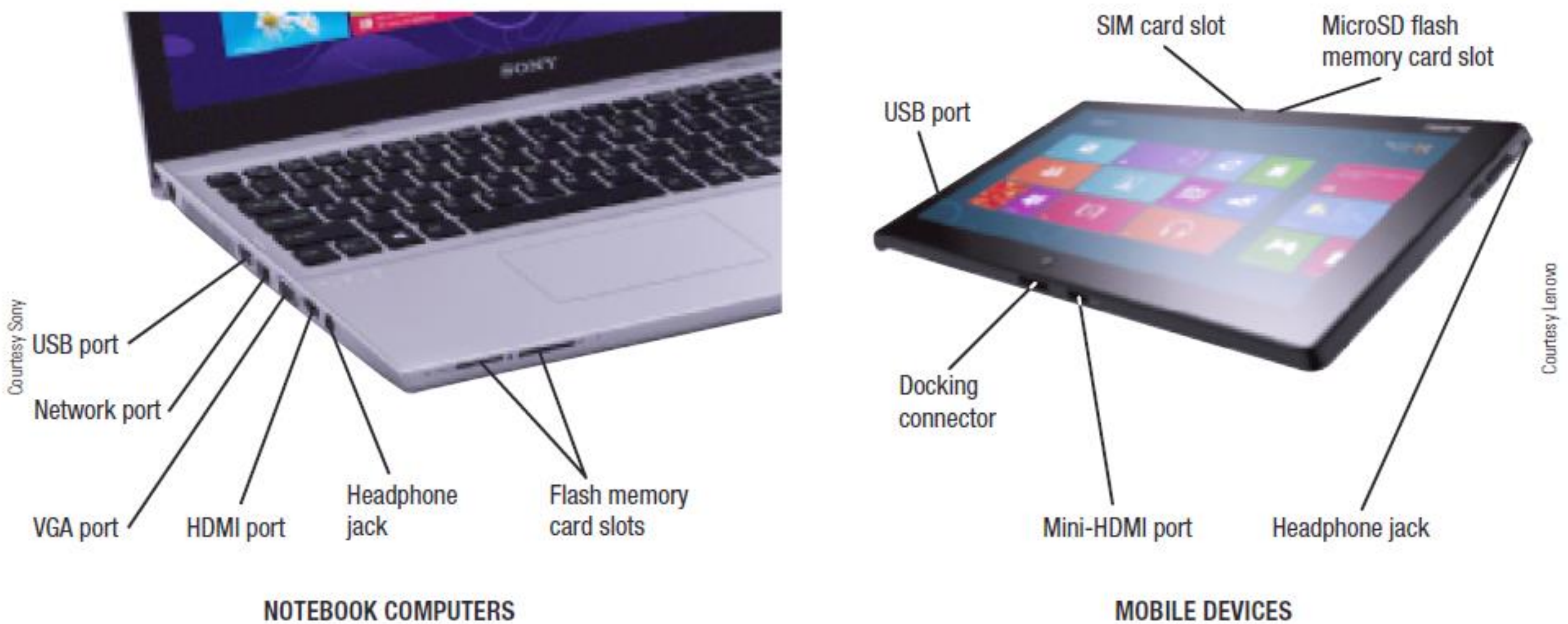


FIGURE 2-18

Typical ports for portable computers.

Trend Box

Tablet Docks

- Used to help with tablet productivity
- Some are just a stand
- Many include a keyboard
- Some include ports (USB, monitor, etc.) to connect peripherals
- Some contain a battery

Quick Quiz

1. Which type of memory is erased when the power goes out?
   a. ROM
   b. RAM
   c. flash memory
2. True or False: The CPU can also be called the motherboard.
3. A(n) electronic path within a computer over which data travels is called a(n) ______________.

Answers:

1) b; 2) False; 3) bus

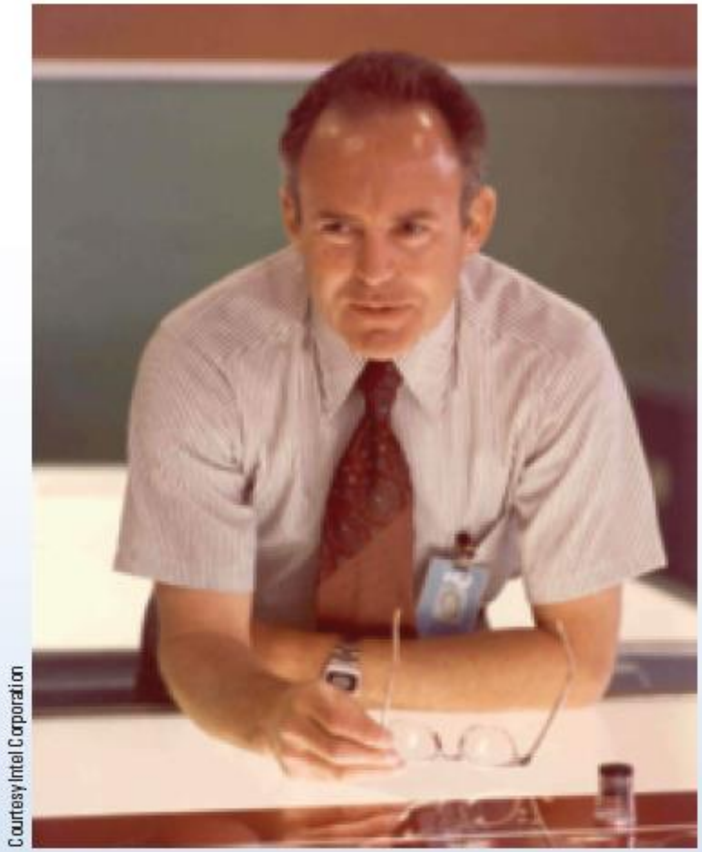
How the CPU Works

- CPU (Central Processing Unit)
  - Consists of a variety of circuitry and components packaged together
  - Transistor: Key element of the microprocessor
    - Made of semi-conductor material that acts like a switch controlling 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)

Inside the Industry Box

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



Gordon Moore (1970).

How the CPU Works

- Typical CPU Components
  - Arithmetic/Logic Unit (ALU)
    - Performs arithmetic involving integers and logical operations
  - Floating Point Unit (FPU)
    - Performs decimal arithmetic
  - Control Unit
    - Coordinates and controls activities within a CPU core
  - Prefetch Unit
    - Attempts to retrieve data and instructions before they are needed for processing in order to avoid delays

How the CPU Works

- Decode Unit
  - Translates instructions from the prefetch unit so they are understood by the control unit, ALU, and FPU
- Registers and Internal Cache Memory
  - Store data and instructions needed by the CPU
- Bus Interface Unit
  - Allows the core to communicate with other CPU components

How the CPU Works

CONTROL UNIT
Is in charge of the entire process, making sure everything happens at the right time. It instructs the ALU, FPU, and registers what to do, based on instructions from the decode unit.

PREFETCH UNIT
Requests instructions and data from cache or RAM and makes sure they are in the proper order for processing; it attempts to fetch instructions and data ahead of time so that the other components don't have to wait.

ARITHMETIC/LOGIC UNIT AND FLOATING POINT UNIT
Performs the arithmetic and logical operations, as directed by the control unit.

REGISTERS
Hold the results of processing.

DECODE UNIT
Takes instructions from the prefetch unit and translates them into a form that the control unit can understand.

BUS INTERFACE UNIT
The place where data and instructions enter or leave the core.

INTERNAL CACHE MEMORY
Stores data and instructions before and during processing.

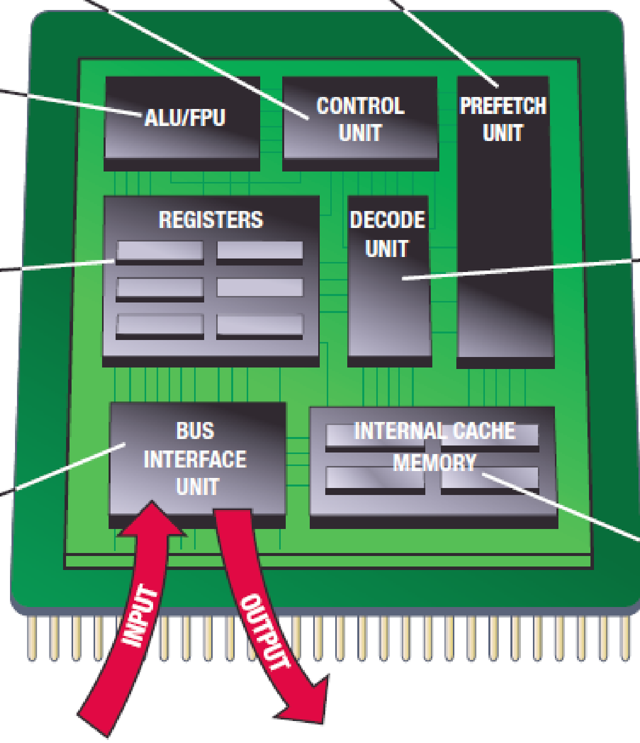


FIGURE 2-19
Inside a CPU core.

The System Clock and the Machine Cycle

- System Clock
  - Small quartz crystal on the motherboard
  - Timing mechanism within the computer system that synchronizes the computer’s operations
    - 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

The System Clock and the Machine Cycle

- Many PC system clocks run at 200 MHz
- Computers can run at a multiple or fraction of the system 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 System Clock and the Machine Cycle

- Machine Cycle
  - The series of operations involved in the execution of a single machine level instructi

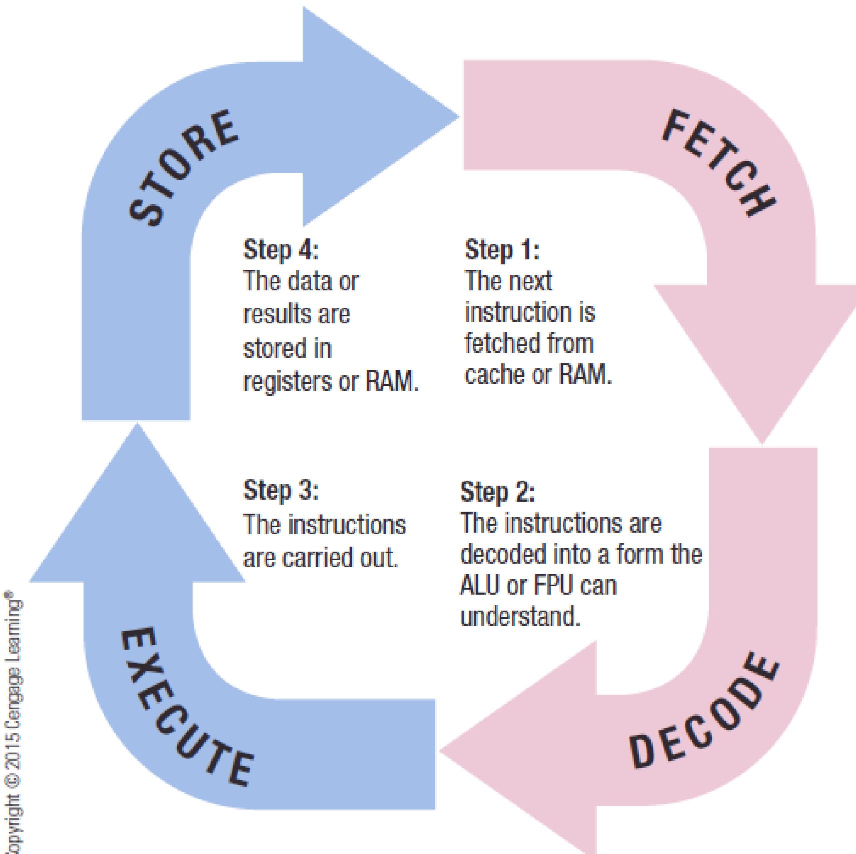


FIGURE 2-20

A machine cycle.

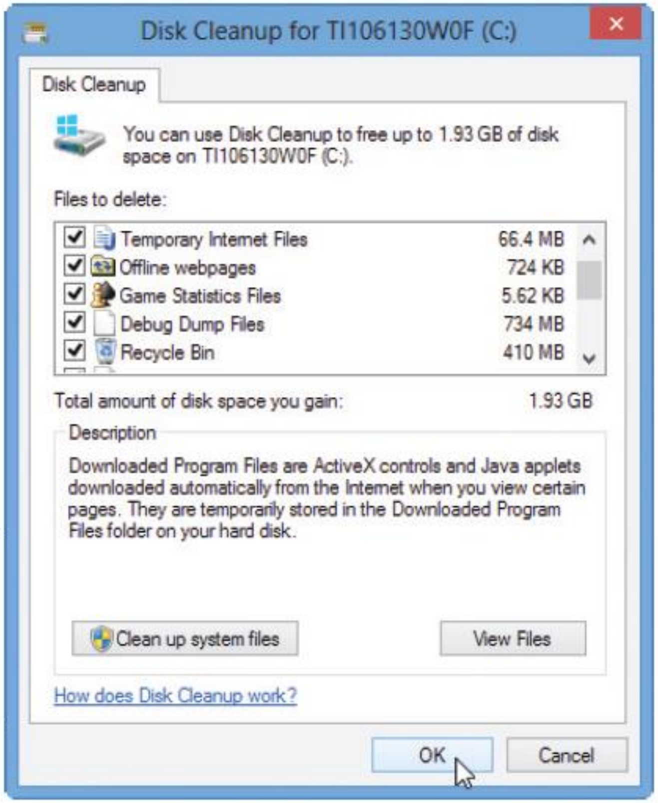
A machine cycle is typically accomplished in four steps.

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
    - Consider placing large files not needed on a regular basis on external storage
    - Delete temporary files

FIGURE 2-22

Windows Disk Cleanup. Running the Disk Cleanup program can help free up room on your hard drive.



Making Computers Faster and Better Now and in the Future

    - Error check and defrag the hard drive periodically
    - Scan for viruses and spyware continually
    - Clean out dust once or twice a year
- Buy a larger or second hard drive
- Upgrade your Internet connection
- Upgrade your video graphics card

Making Computers Faster and Better Now and in the Future

- Strategies for Making Faster and Better Computers
  - Improved Architecture
    - Smaller components, faster bus speeds, multiple CPU cores, support for virtualization
  - Improved Materials
    - Flexible electronic components
      - Copper, high-k, graphene chip

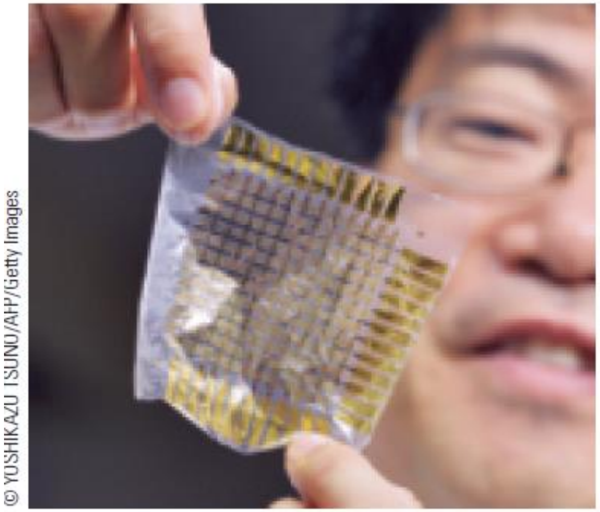
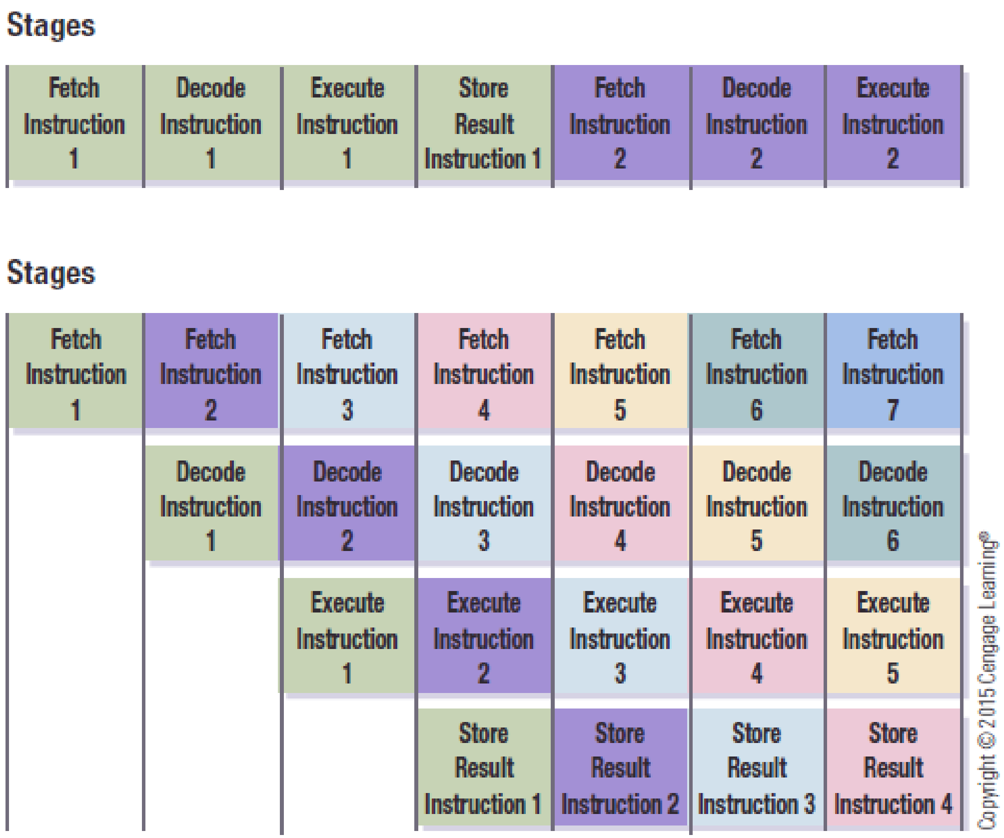


FIGURE 2-23
Flexible electronics.

Making Computers Faster and Better Now and in the Future

- Pipelining
  - Allows multiple instructions to be processed at one time
- Multiprocessing and Parallel Processing
  - Use multiple processors to speed up processing

Making Computers Faster and Better Now and in the Future



WITHOUT PIPELINING
Without pipelining, an instruction finishes an entire machine cycle before another instruction is started.

WITH PIPELINING
With pipelining, a new instruction is started when the preceding instruction moves to the next stage of the pipeline.

FIGURE 2-24
Pipelining. Pipelining streamlines the machine cycle by executing different stages of multiple instructions at the same time so that the different parts of the CPU are idle less often.

Future Trends

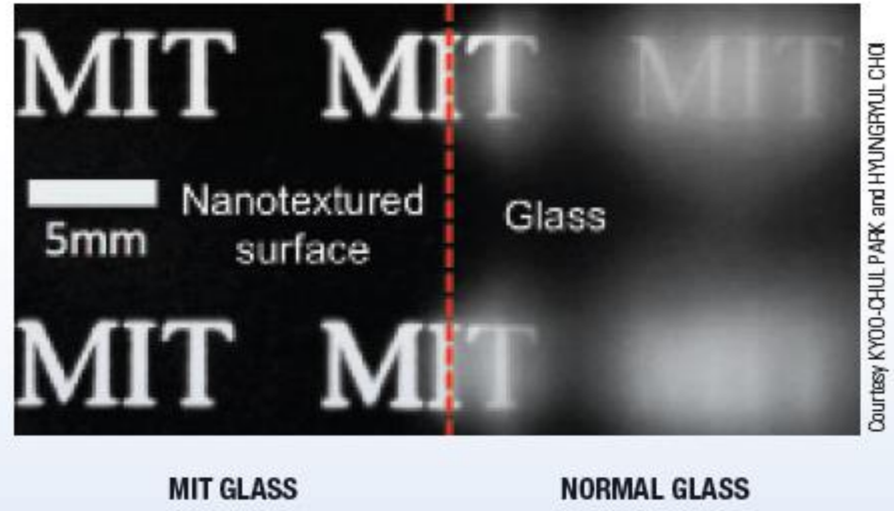
- Nanotechnology
  - The science of creating tiny computers and components less than 100 nanometers in size
  - Carbon nanotubes (CNTs) used in many products today
  - Nanofilters and nanosensors
  - Future applications may be built by working at the individual atomic and molecular levels

FIGURE 2-25
Carbon nanotubes. This light bulb is powered and held in place by two carbon nanotube fibers.

Technology and You Box

"Magic" Glass

- MIT has developed nano-sized conical patterns on the surface of glass to eliminated its reflective properties
- Glass resists fogging and is self-cleaning
- Possible uses:
  - Smartphone screens
  - Eyeglasses
  - TVs
  - Car windshieds
  - Building windows



MIT "magic" glass vs. normal glass. The normal half of this piece of glass (right) can fog up and produce glare; the MIT glass half (left) remains clear.

Future Trends

- Quantum Computing
  - Applies the principles of quantum physics and quantum mechanics to computers
  - Utilizes atoms or nuclei working together as quantum bits (qubits)
  - Qubits function simultaneously as the computer’s processor and memory and can represent more than two states
  - Expected to be used for specialized applications, such as encryption and code breaking

Future Trends

- Optical Computing
  - Uses light, from laser beams or infrared beams, to perform digital computations
  - Opto-electronic computers use both optical and electronic components
- Silicon Photonics
  - The process of making optical devices using silicon manufacturing techniques
    - Possible low-cost solution to future data-intensive computing applications—telemedicine, cloud data centers

Future Trends

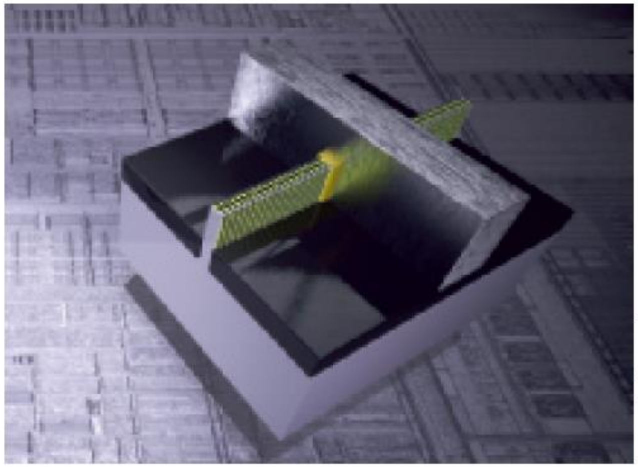
- Tera-Scale Computing
  - The ability to process one trillion floating-point operations per second (teraflops)
  - Terascale research is focusing on creating multi-core processors with tens to hundreds of cores
  - Intel has created a Single-chip Cloud Computer which contains 48 cores on one silicon chip
  - Expected to be needed for future applications

Future Trends

- 3D Chips
  - Contain transistors that are layered to cut down on the surface area required
  - Created by layering individual silicon wafers on top of one another
  - Being used with memory, flash memory, and CPUs

FIGURE 2-28

3D chips. In this 3D transistor, the electrical current (represented by the yellow dots) flows on three sides of a vertical fin.



Courtesy Intel Corporation

Quick Quiz

1. Optical computers use which of the following to transmit and process data?
   a. Liquid
   b. Light
   c. Silicon
2. True or False: If your computer is running slowly, adding more memory might speed it up.
3. A quantum bit is known as a(n) ____________________.

Answers:

1) b; 2) True; 3) qubit

Summary

- Data and Program Representation
- Inside the System Unit
- How the CPU Works
- Making Computers Faster and Better Now and in the Future