THE SYSTEMS UNIT: PROCESSING AND MEMORY

Application of Information and Communication Technologies

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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 used to accomplish this.
2. Explain the functions of the hardware components commonly found inside the system unit, such as the CPU, memory, buses, and expansion cards.
3. Describe how new peripheral devices or other hardware can be added to a computer.
4. Understand how the computer system's CPU and memory components process program instructions and data.
5. Name and evaluate several strategies that can be used today for speeding up the operations of a computer.
6. List some technologies that may be used in the future computers.

Overview

- This chapter covers:
  - 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

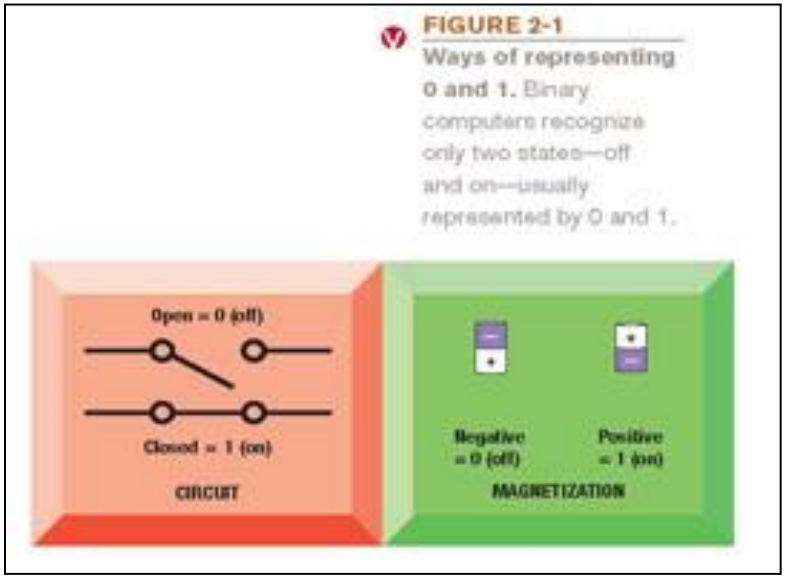
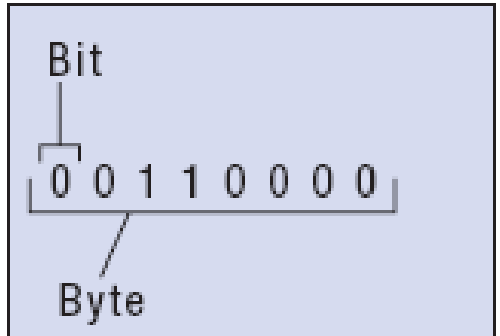


FIGURE 2-1
Ways of representing 0 and 1. Binary computers recognize only two states—off and on—usually represented by 0 and 1.

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.
- Prefixes are often used to express larger quantities of bytes: kilobyte (KB), megabyte (MB), gigabyte (GB), terabyte (TB), etc.

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



Abbreviation	Approximate Size
KB	1 thousand bytes
MB	1 million bytes
GB	1 billion bytes
TB	1 trillion bytes
PB	1,000 terabytes

Representing Numerical Data

- The Binary Numbering System
  - Numbering system
    - A way of representing numbers
  - Decimal numbering system
    - Uses 10 symbols (0-9)
  - Binary numbering system
    - Uses only two symbols (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

The Binary Numbering System

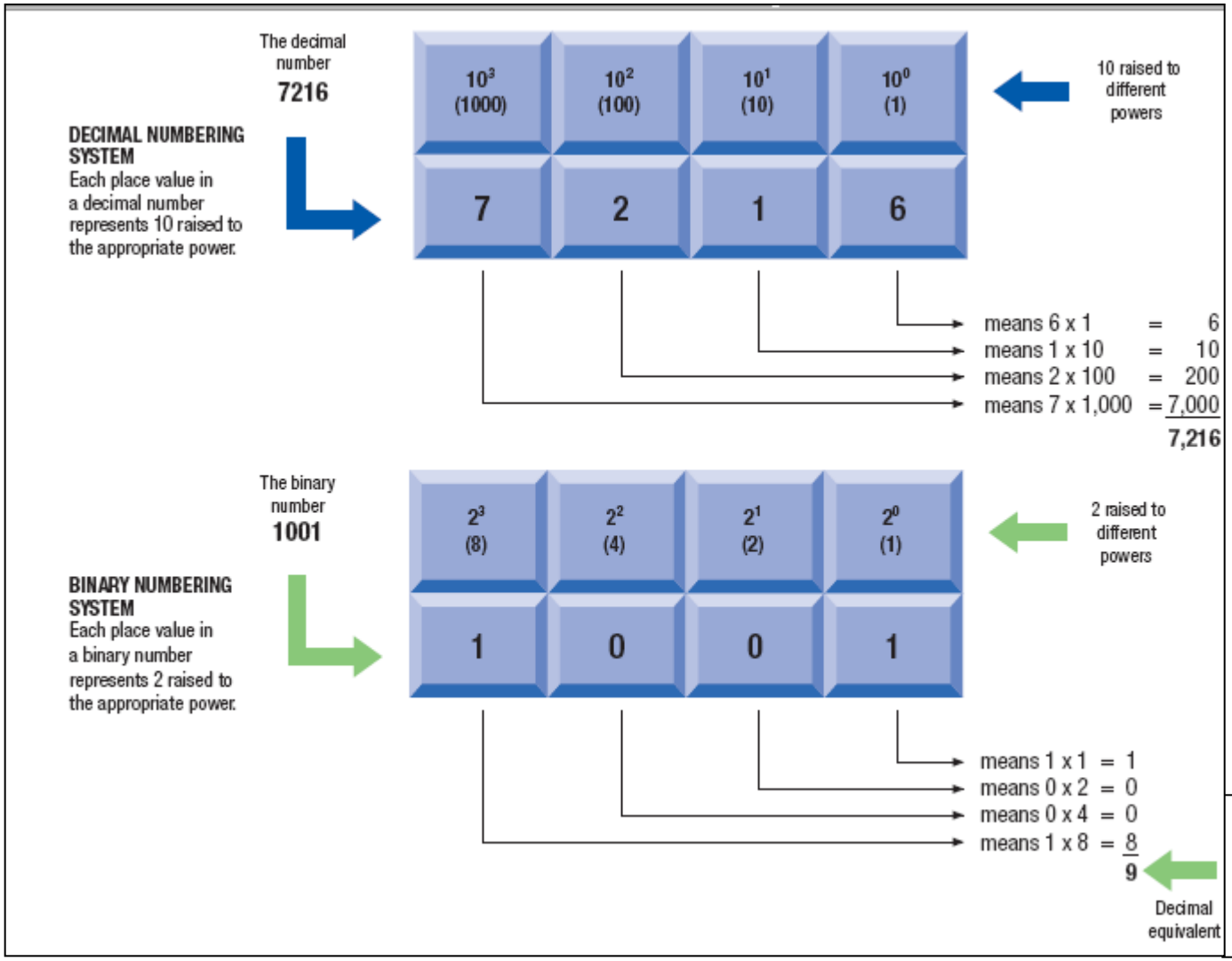


FIGURE 2-3
Examples of using the decimal and binary numbering systems.

Coding Systems for Text-Based Data

- ASCII and EBCDIC
  - 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 mainframe use

CHARACTER	ACSII
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

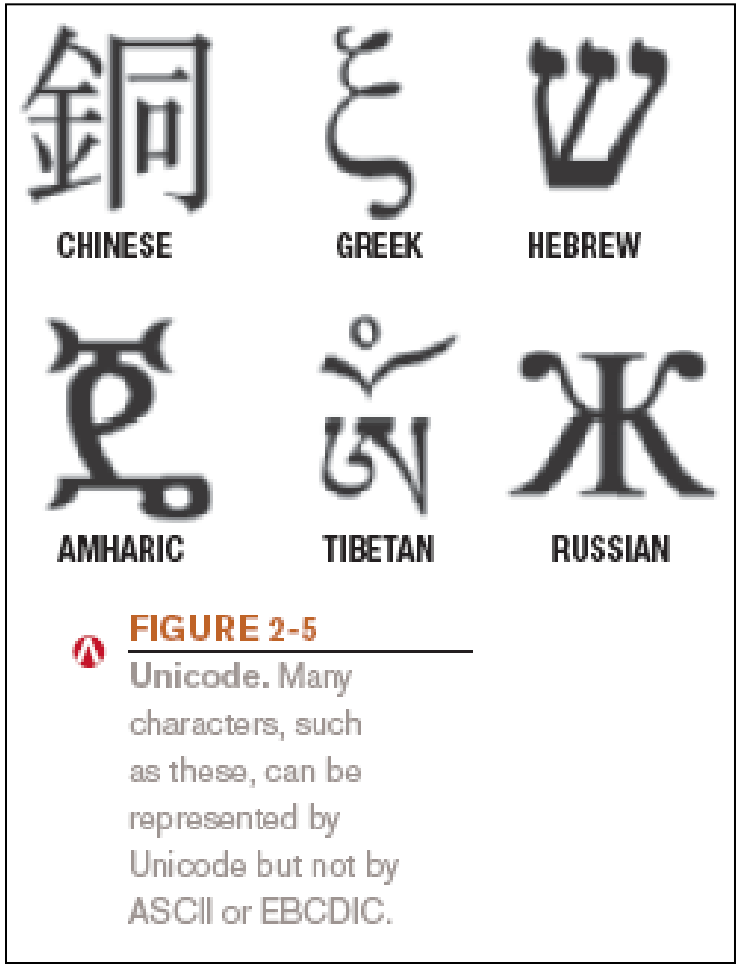


FIGURE 2-5
Unicode. Many characters, such as these, can be represented by Unicode but not by ASCII or EBCDIC.

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

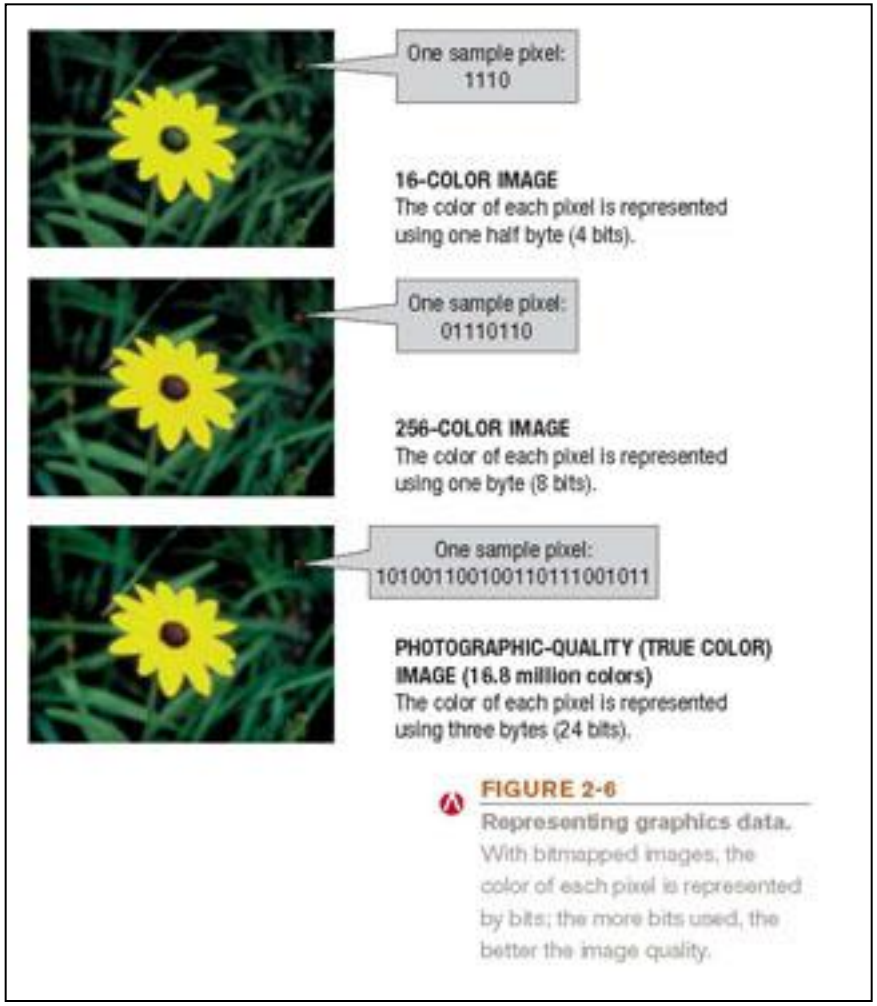


FIGURE 2-6
Representing graphics data. With bitmapped images, the color of each pixel is represented by bits; the more bits used, the better the image quality.

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
- 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
- Most programs are written in other programming languages
  - Language translators are used to translating the programs into machine language

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 the CPU, memory, interfaces to connect to peripheral devices (printers, etc), and other components such as CD/DVD drives
  - With a desktop computer, usually looks like a rectangular box

Inside the System Unit

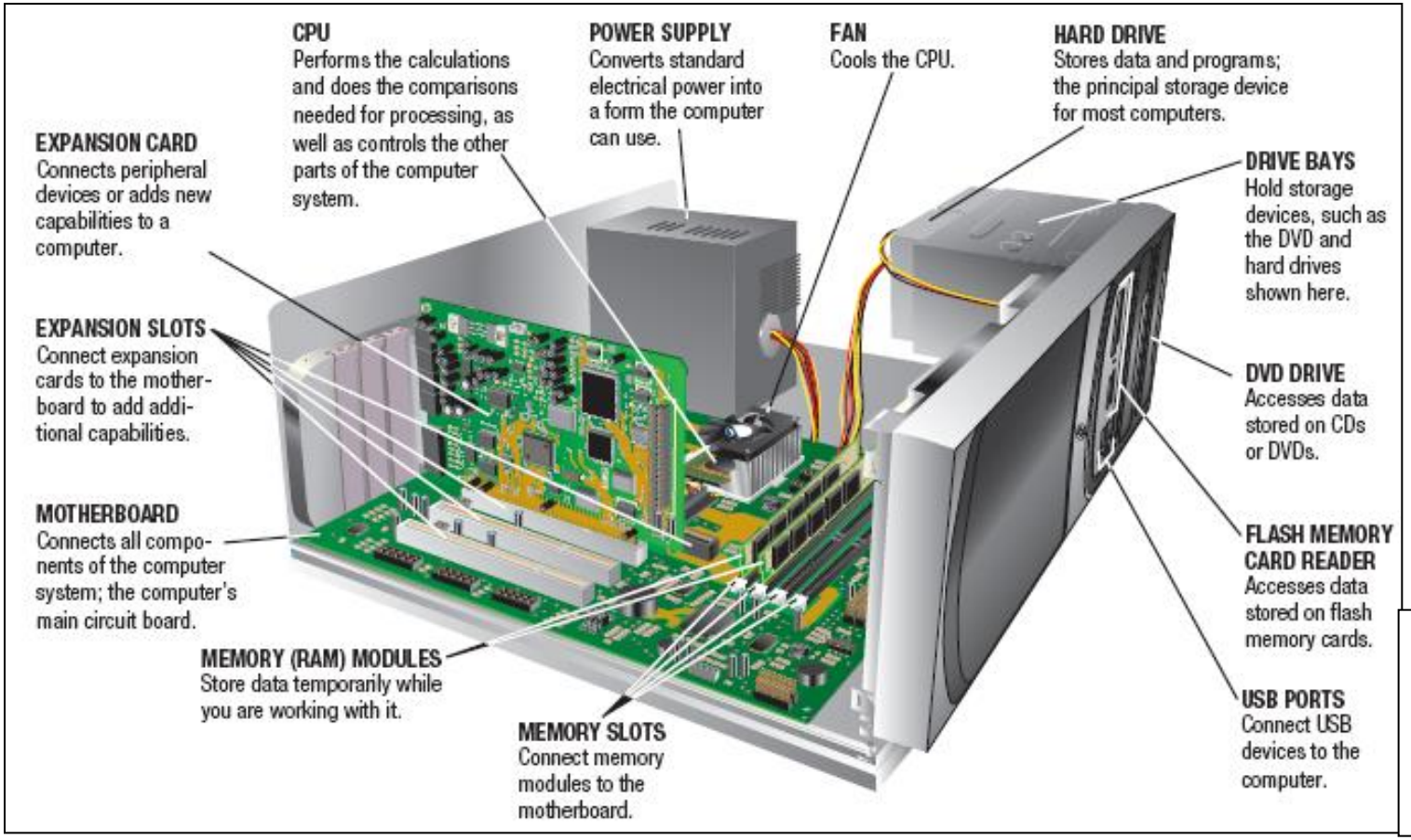


FIGURE 2-7
Inside a typical system unit. The system unit houses the CPU, memory, and other important pieces of hardware.

Inside the System Unit

- The Motherboard
  - Computer chip
    - A very small piece 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
  - External devices (monitors, keyboards, mice, printers) typically connect by plugging into a port exposed through the exterior of the system unit
  - Wireless devices connect through a transceiver or wireless networking technology (like Bluetooth)

Inside the System Unit

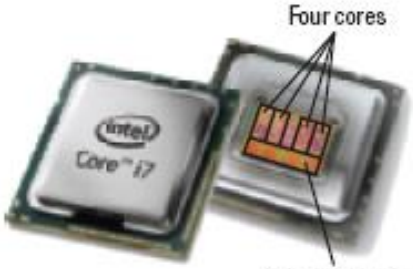
- Drive Bays
  - Rectangular metal racks inside the system unit that house storage devices
    - Hard drive, CD/DVD drive, flash memory card reader
    - Connected to the motherboard with a cable
- Processors
  - The CPU (Central Processing Unit)
    - Circuitry and components packaged together and connected directly to the motherboard
    - Does the vast majority of processing for a computer
    - Also called 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

The CPU

FIGURE 2-8
CPUs. CPUs today typically have multiple cores.



DESKTOP PROCESSORS
Typically have 2 to 4 cores and are designed for performance.

SERVER AND WORKSTATION PROCESSORS
Typically have at least 4 cores and are designed for very high performance.

NOTEBOOK PROCESSORS
Typically have 2 to 4 cores and are designed for performance and increased battery life.

NETBOOK PROCESSORS
Typically have 1 to 2 cores, are small in size, and are designed for extended battery life.

The CPU

TYPE OF PROCESSOR	NAME	NUMBER OF CORES	CLOCK SPEED	TOTAL CACHE MEMORY		
				LEVEL 1	LEVEL 2	LEVEL 3
DESKTOP	Intel Core i7	4	2.66–3.33 GHz	64 KB*	256 KB*	8 MB
	AMD Phenom II	2–4	2.4–3.2 GHz	128 KB*	512 KB*	4–6 MB
SERVER/ WORKSTATION	Intel Xeon (5500 series)	2 or 4	1.86–3.2 GHz	64 KB*	256 KB*	4–8 MB
	AMD Opteron (3rd generation)	4 or 6	2.0–3.1 GHz	128 KB*	512 KB*	6 MB
NOTEBOOK	Intel Core 2 Mobile	1, 2, or 4	1.06–3.06 GHz	64 KB*	1–12 MB	none
	AMD Turion X2 Mobile	2	2.0–2.5 GHz	128 KB*	1–2 MB*	none
NETBOOK	Intel Atom	1–2	800 MHz–2 GHz	56 KB*	512 KB*	none
	AMD Athlon Neo	1	1.6 MHz	128 KB*	512 KB*	none

*Per core

FIGURE 2-9
Some examples of current Intel and AMD CPUs.

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

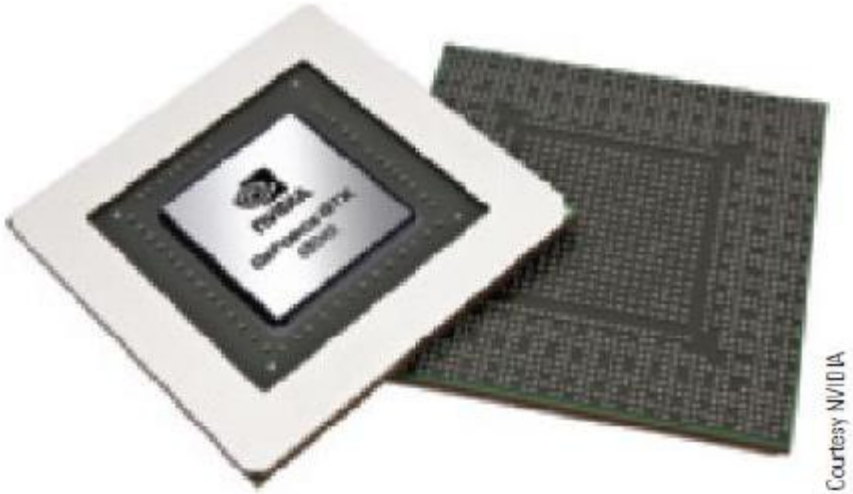


FIGURE 2-9
A GPU.

Processing Speed

- CPU clock speed: One measurement of processing speed
  - Measured 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, gigaflops, teraflops
- Benchmark tests: Can be used to evaluate overall processing speed

Word Size and Cache Memory

- 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)
  - Often some cache dedicated to each core; may also have some shared cache accessible by any core

Bus Width, Bus Speed, and Bandwidth

- Bus
  - An electronic path over which data can travel
  - Found inside the CPU and on the motherboard
- Bus width
  - The number of wires in the bus over which data can travel
  - 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

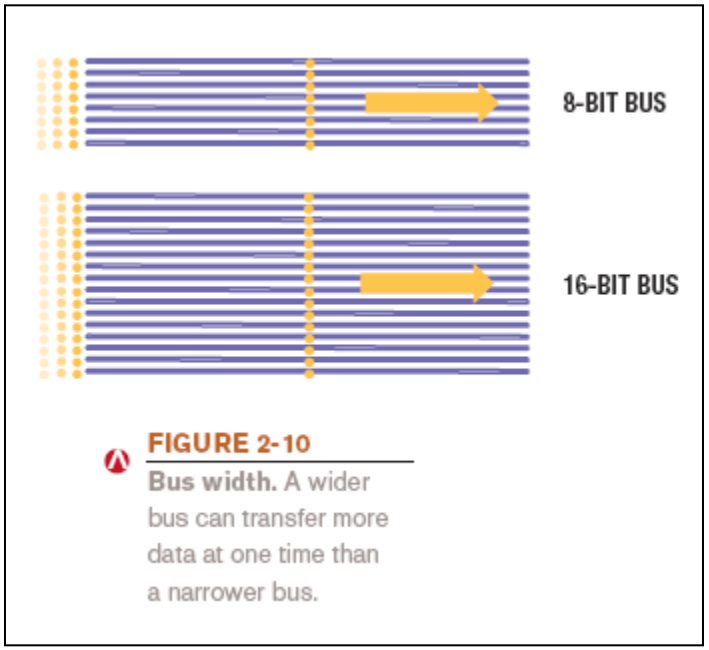


FIGURE 2-10
Bus width. A wider bus can transfer more data at one time than a narrower bus.

Memory

- Refers to chip-based storage located inside the system unit
- Storage refers to the amount of long-term storage available to a computer, refers to chip-based storage
- RAM (random access memory): Computer's main memory
  - Consists of chips arranged on a circuit board called a memory module plugged into the motherboard
  - Stores essential parts of an operating system, programs, and data the computer is currently using
  - Adequate RAM is needed to run programs
  - Volatile: Contents of RAM is lost when the computer is shut off
  - Most personal computers use SD-RAM
  - 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

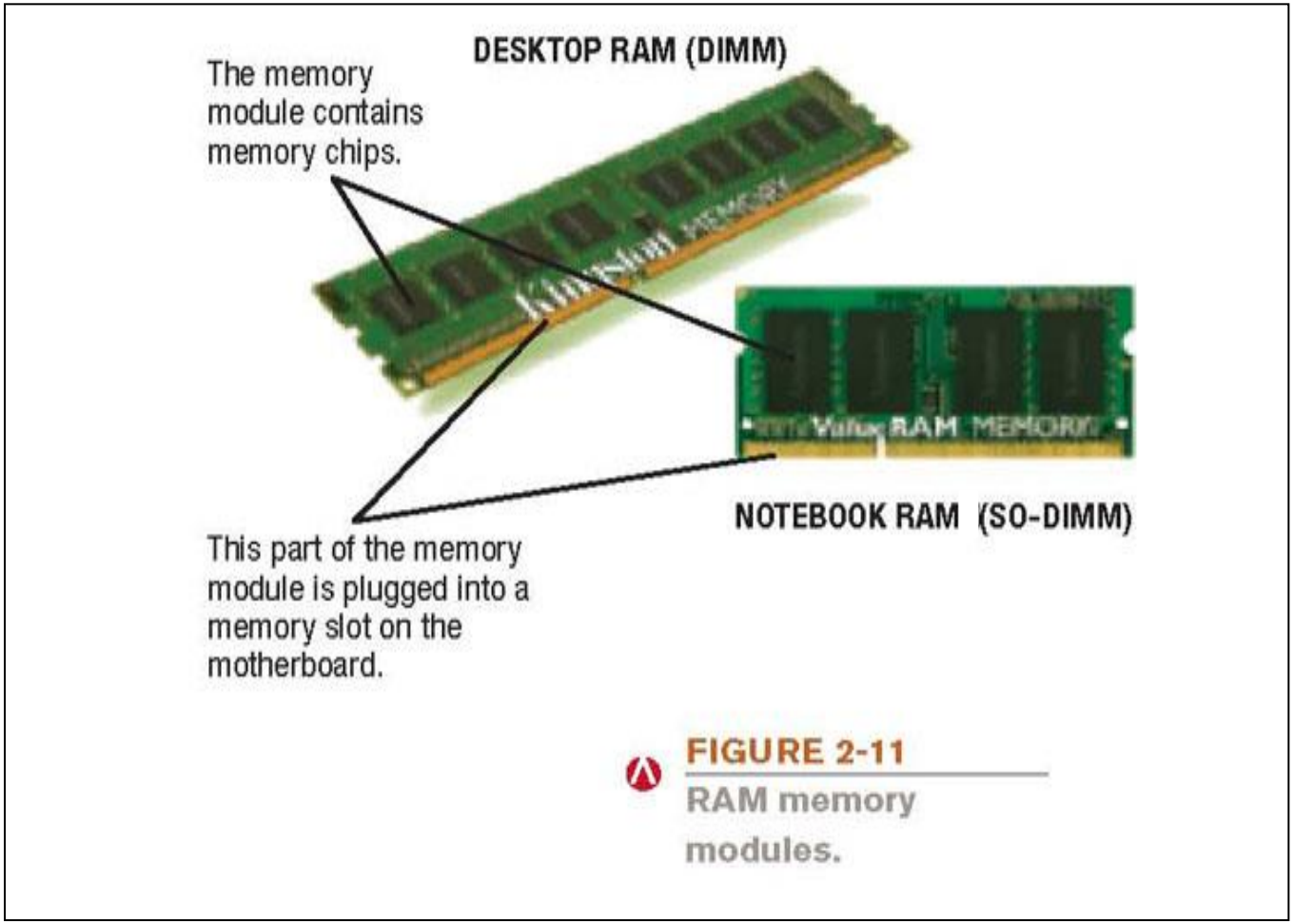
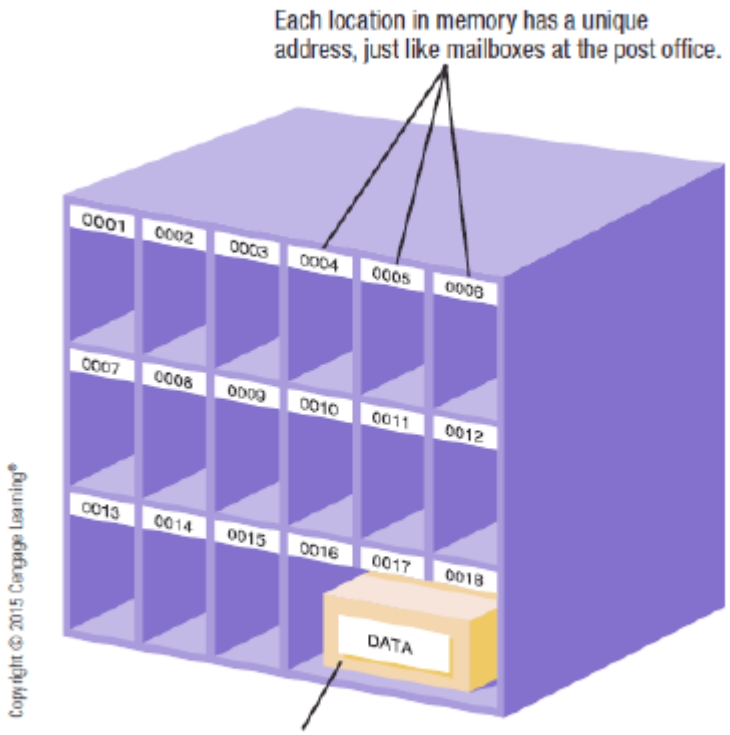


FIGURE 2-11
RAM memory modules.

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 for firmware
- Flash memory:
  - Type of 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

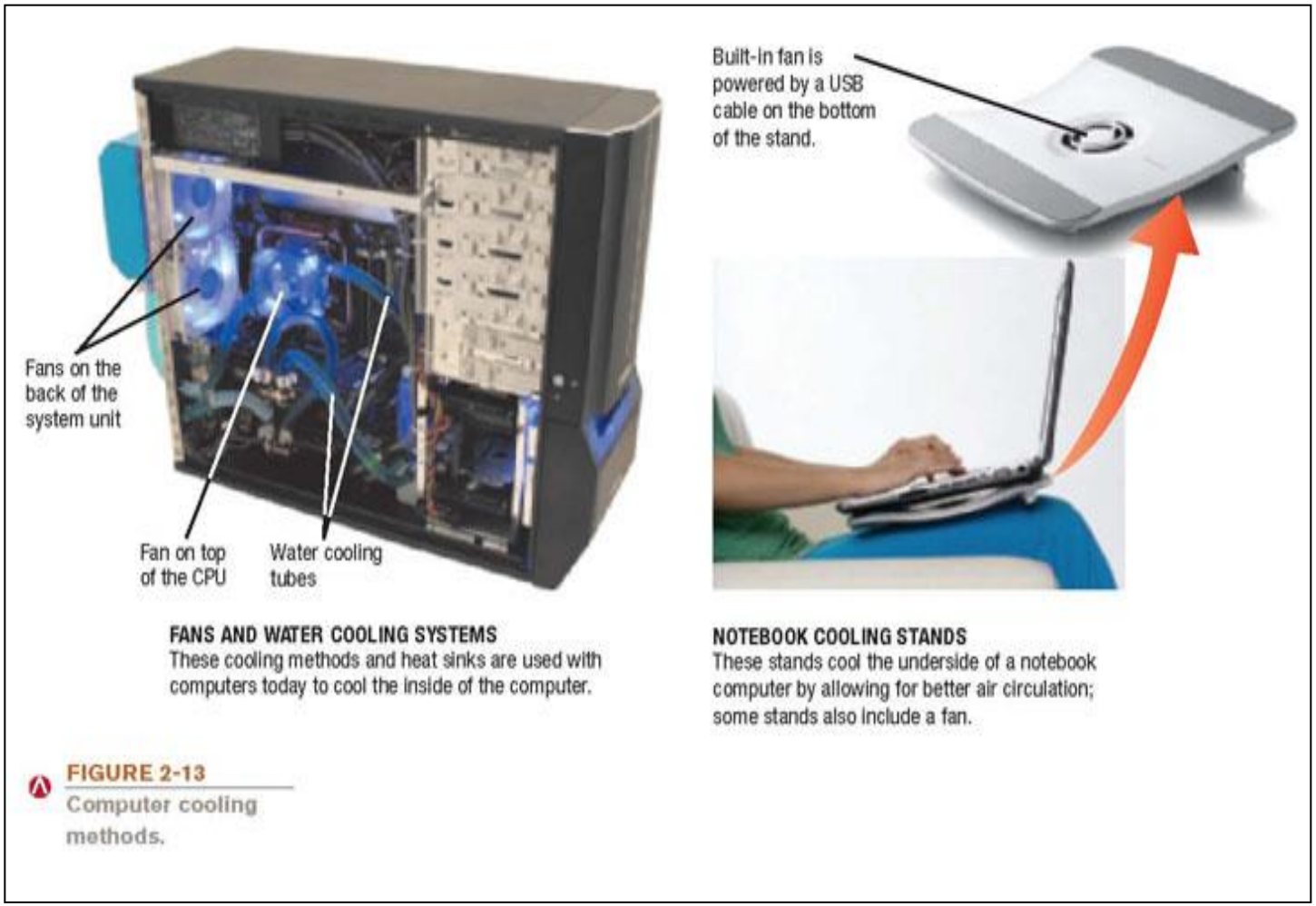
- Fans
  - Fans used on most personal computers to help cool the CPU and system unit
  - Heat is an ongoing problem for CPU and computer manufacturers
    - Can damage components
    - Cooler chips run faster
- Heat Sinks
  - Small components typically made out of aluminum with fins that help to dissipate 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

Fans, Heat Sinks, and Other Cooling Components



FANS AND WATER COOLING SYSTEMS
These cooling methods and heat sinks are used with computers today to cool the inside of the computer.

NOTEBOOK COOLING STANDS
These stands cool the underside of a notebook computer by allowing for better air circulation; some stands also include a fan.

FIGURE 2-13
Computer cooling methods.

Expansion

- Expansion Slots, Expansion Cards, and Express Card 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
- Express Card 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

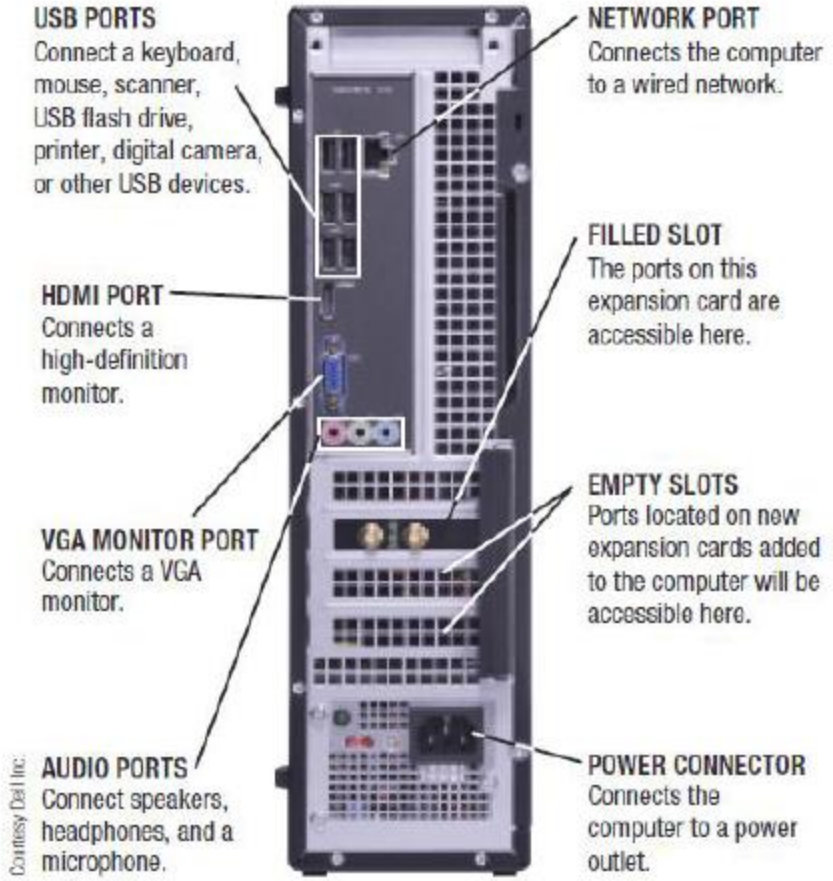
Buses

- PCI 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



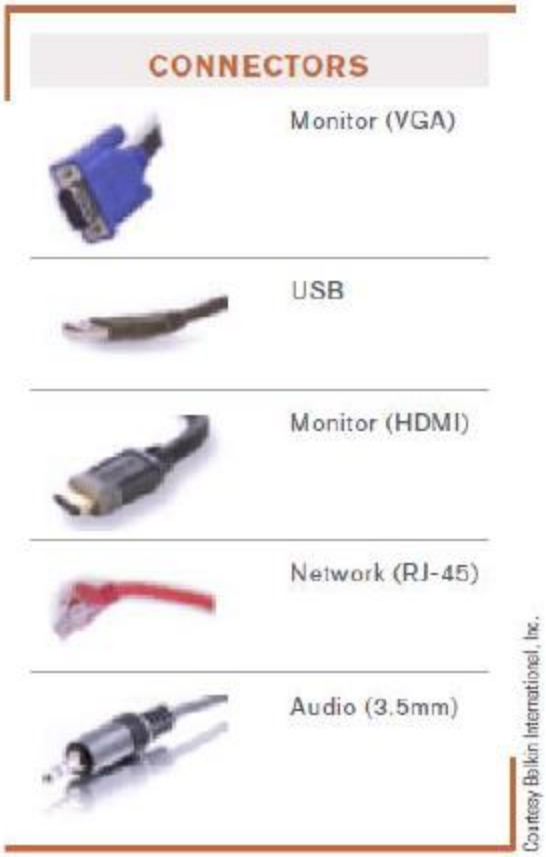


FIGURE 2-16
Typical ports for desktop computers and examples of connectors.

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

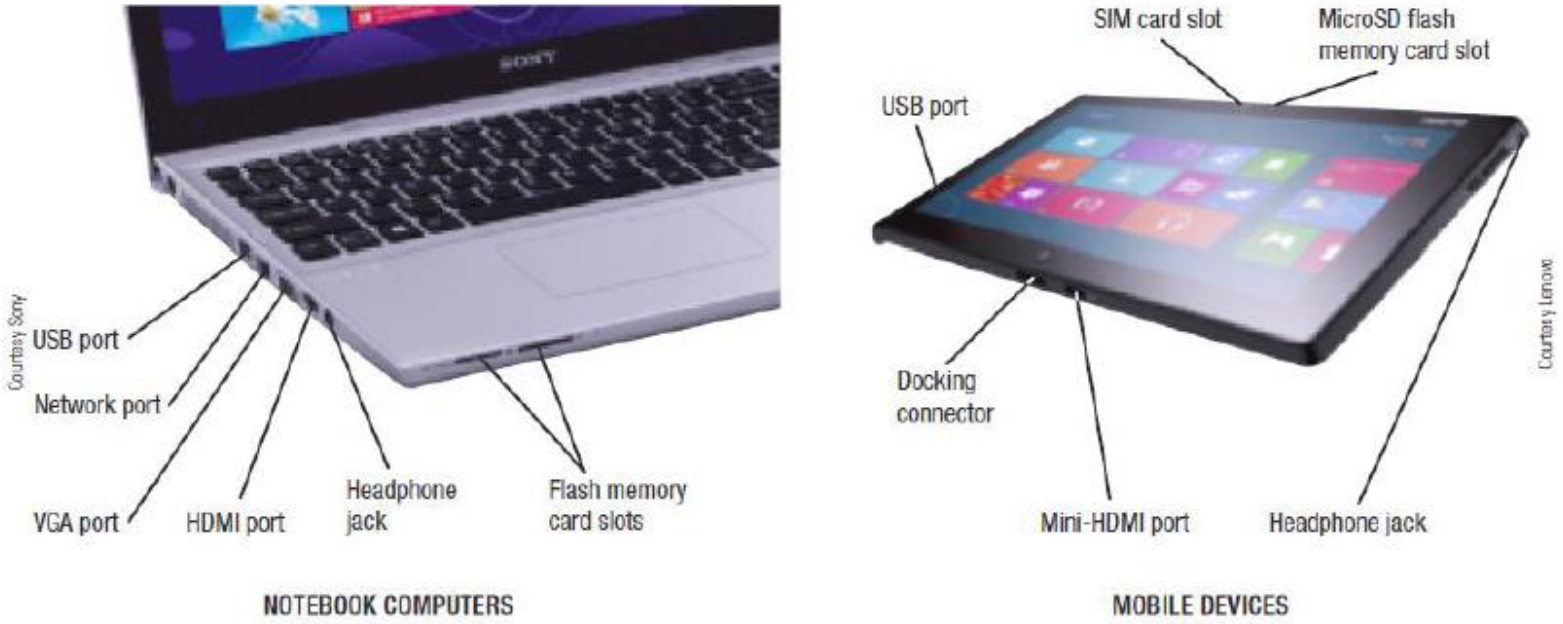


FIGURE 2-18
Typical ports for portable computers.

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:

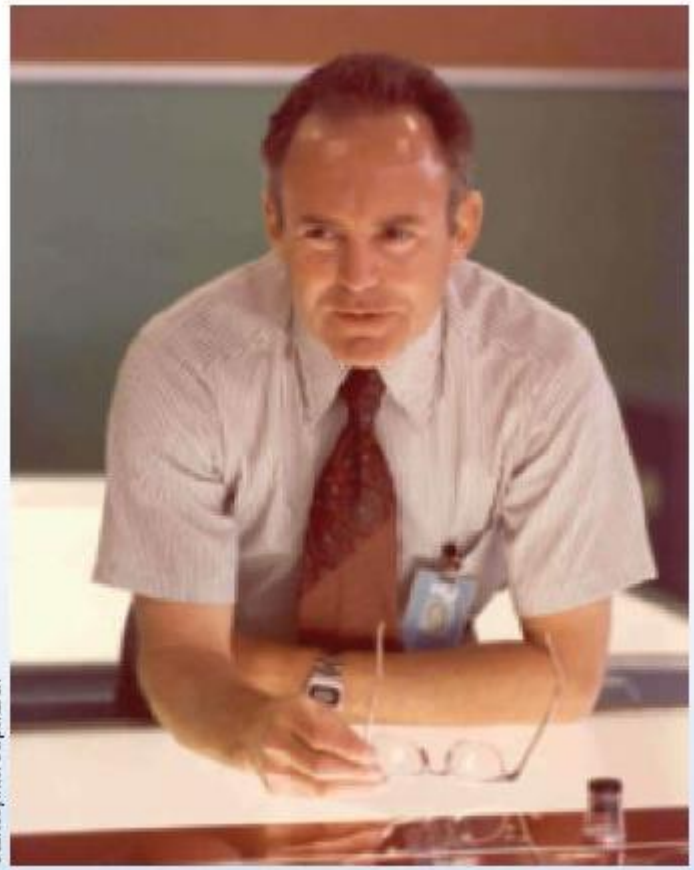
1) b; 2) False; 3) bus

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

Typical CPU Components

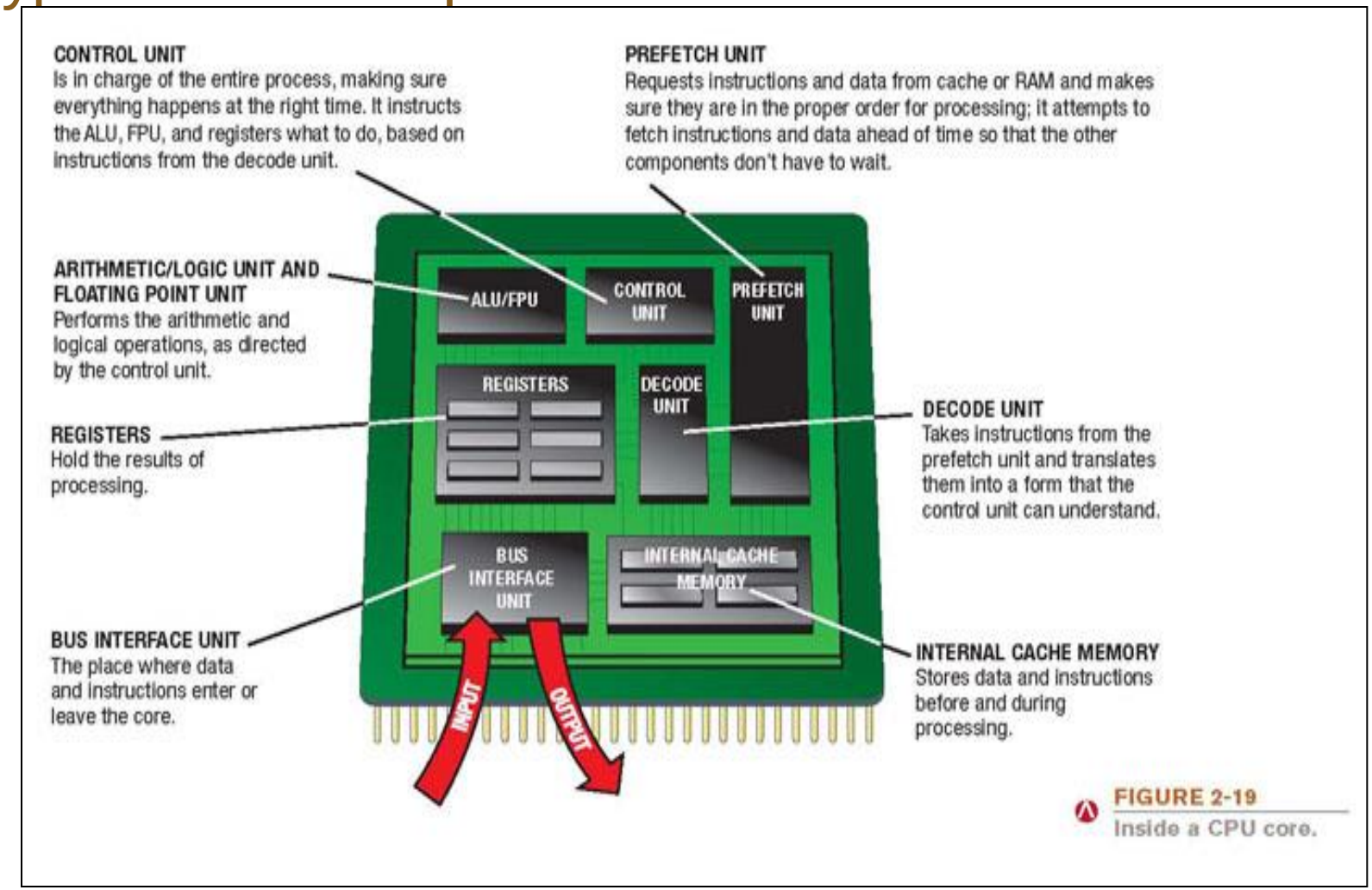


FIGURE 2-19
Inside a CPU core.

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 instruction
  - Fetch: The program instruction is fetched
  - Decode: The instructions are decoded so the control unit, ALU, and FPU can understand them
  - Execute: The instructions are carried out
  - Store: The original data or the result from the ALU or FPU execution is stored in the CPU's registers

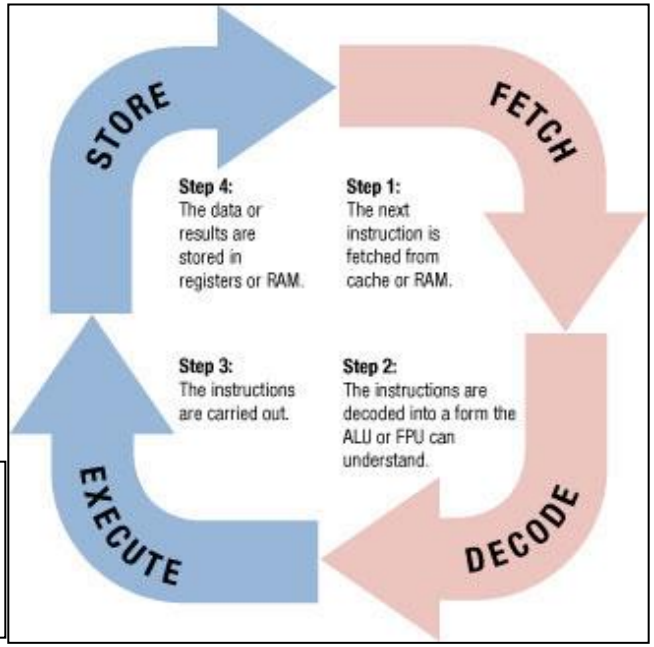


FIGURE 2-20
A machine cycle.
A machine cycle is typically accomplished in four steps.

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 regularly on external storage
    - Delete temporary files
    - 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

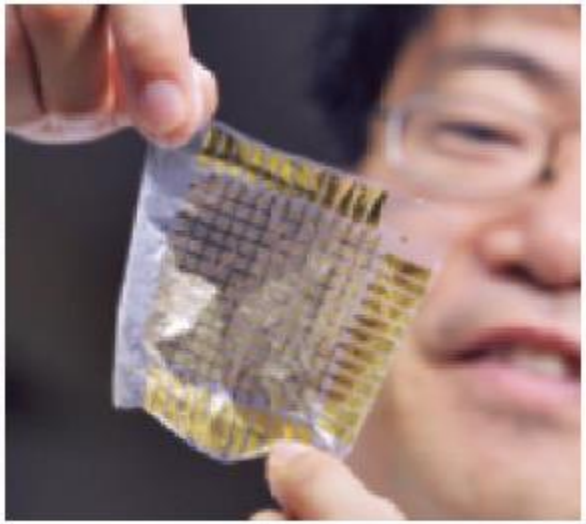
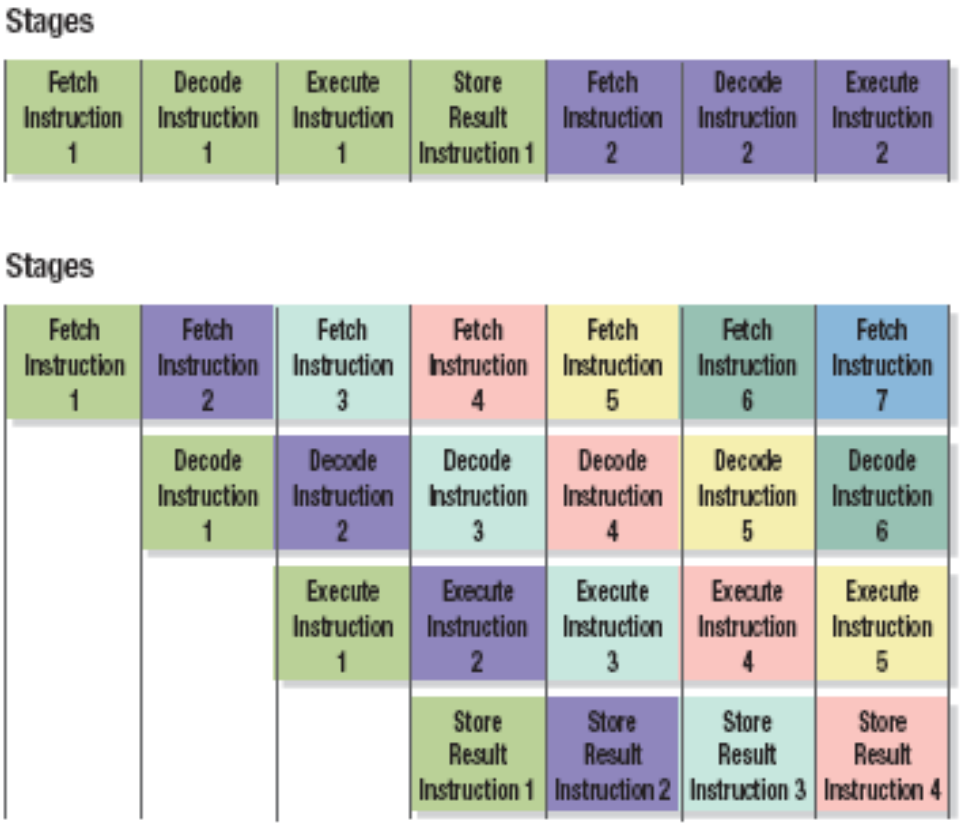


FIGURE 2-23
Flexible electronics.

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 the processing

Pipelining



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.

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

FIGURE 2-26
Quantum computers. The vial of liquid shown here contains the 7-qubit computer used by IBM researchers in 2001 to perform the most complicated computation by a quantum computer to date—factoring the number 15.

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

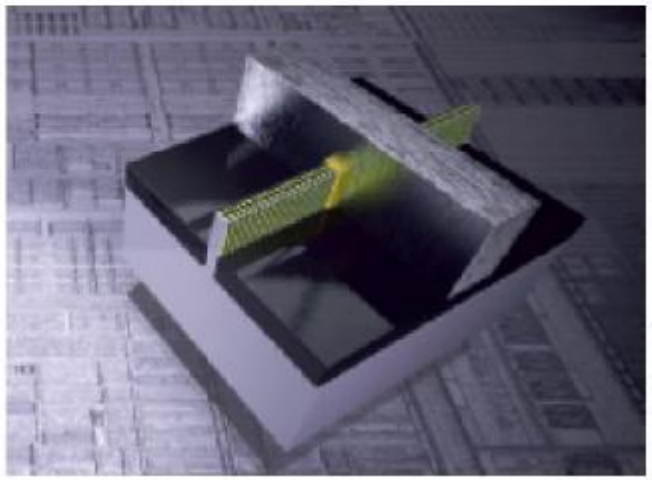
Future Trends

- 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 require
  - 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

Credit

- This lecture notes are based on the following resources:

- **Chapter 2,** Understanding Computers: Today and Tomorrow by Deborah Morley and Charles S. Parker,