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Information Systems: Hardware

- What is a Computer System?
- The Evolution of Computer Hardware
- Types of Computers
- The Microprocessor and Primary Storage
- Input/Output Devices

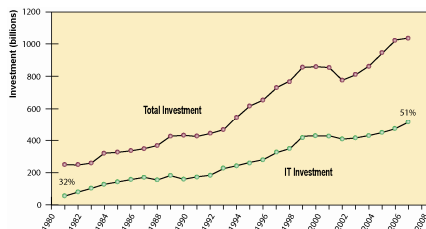
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Learning Objectives

- Recognize major components of an electronic computer.
- Understand how the different components work.
- Know the functions of peripheral equipment.
- Be able to classify computers into major categories, and identify their strengths and weaknesses.
- Be able to identify and evaluate key criteria when deciding what computers to purchase.

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Information Technology Capital Investment

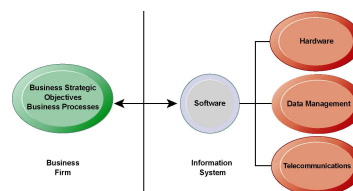


- Information technology investment, defined as hardware, software, and communications equipment, grew from 32% to 51% between 1980 and 2008.

Source: Based on data in U.S. Department of Commerce, Bureau of Economic Analysis, *National Income and Product Accounts*, 2008.

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Interdependence Between Organizations and IT

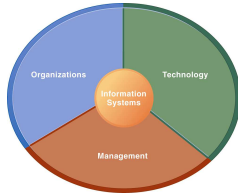


- In contemporary systems there is a growing interdependence between a firm's information systems and its business capabilities.
- Changes in strategy, rules, and business processes increasingly require changes in hardware, software, databases, and telecommunications.

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Information Systems Are More Than Computers

- Using information systems effectively requires an understanding of the
 - organization,
 - management, and
 - information technology shaping the systems.
- An information system creates value for the firm as an organizational and management solution to challenges posed by the environment.



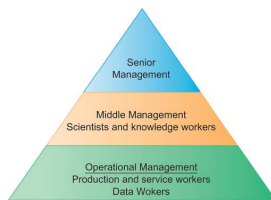
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Organizational dimension of information systems

- Hierarchy of authority, responsibility
 - Senior management
 - Middle management
 - Operational management
 - Knowledge workers
 - Data workers
 - Production or service workers

Levels in a Firm

- Business organizations are hierarchies consisting of three principal levels:
 - senior management,
 - middle management,
 - operational management.



- Information systems serve each of these levels.
- Scientists and knowledge workers often work with middle management.

Organizational dimension of information systems

- Separation of business functions
 - Sales and marketing
 - Human resources
 - Finance and accounting
 - Manufacturing and production
- Unique business processes
- Unique business culture
- Organizational politics

Management dimension of information systems

- Managers set organizational strategy for responding to business challenges
- In addition, managers must act creatively:
 - Creation of new products and services
 - Occasionally re-creating the organization

Technology dimension of information systems

- Computer hardware and software
- Data management technology
- Networking and telecommunications technology
 - Networks, the Internet, intranets and extranets, World Wide Web
- IT infrastructure: provides platform that system is built on

The Central Tool of Modern Information Systems

- Computers
- Four Basic Functions of Computers
 - Data processing
 - Data movement
 - Data storage
 - Control

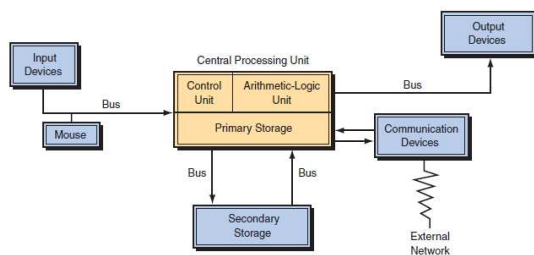
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What is a Computer System?

- Computer hardware is composed of the following components:
 - Central processing unit (CPU),
 - for data processing
 - Input/output (I/O) devices
 - for data movement,
 - Memory
 - for data storage,
 - System interconnection.
- Each of the hardware components plays an important role in computing.

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What is a Computer System?



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What is a Computer System?

- CPU
 - manipulates the data and controls the tasks done by the other components.
- Input devices
 - accept data and instructions and convert them to a form that the computer can understand.
- Output devices
 - present data in a form people can understand.

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What is a Computer System?

- **Primary storage (internal storage)**
 - temporarily stores data and program instructions during processing.
 - It also stores intermediate results of the processing.
- **Secondary storage (external)**
 - stores data and programs for future use. Finally,
- **Communication devices**
 - provide for the flow of data from external computer networks the CPU, and from the CPU to computer networks.

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

- Computers are based on integrated circuits (chips) including millions of transistors
 - Each transistor can be in either an “on” or an “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.

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

- 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), and **EBCDIC** (Extended Binary Coded Decimal Interchange Code),
 - EBCDIC was developed by IBM and is used primarily on large, mainframe computers.

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

- **ASCII** has emerged as the standard coding scheme for microcomputers.
- In addition to characters, it is possible to represent commonly agreed-upon symbols in a binary code.
 - For example, the plus sign (+) is 00101011 in ASCII.
- The 256 characters and symbols that are represented by ASCII and EBCDIC codes are sufficient for English and Western European languages but are not large enough for Asian and other languages that use different alphabets.
- **Unicode** is a 16-bit code that has the capacity to represent more than 65,000 characters and symbols.

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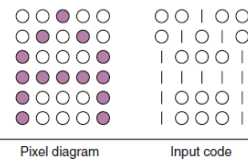
REPRESENTING DATA, PICTURES, TIME, AND SIZE IN A COMPUTER

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

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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 shows a pixel representation of the letter A and its conversion to an input code.



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Representing Time

- Time is represented in fractions of a second.
 - 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

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Representing Size of Bytes

- Size is measured by the number of bytes.
 - 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
 - ZettaByte = 10^{21} bytes
 - YottaByte = 10^{24} bytes

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Measurement for performance and capacity

	performance	capacity
– Kilo	= 10^3	= 2^{10}
– Mega	= 10^6	= 2^{20}
– Giga	= 10^9	= 2^{30}
– Tera	= 10^{12}	= 2^{40}
– Peta	= 10^{15}	= 2^{50}
– Exa	= 10^{18}	= 2^{60}
– Zetta	= 10^{21}	= 2^{70}
– Yotta	= 10^{24}	= 2^{80}

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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
- The generations are distinguished by different technologies that perform the processing functions.

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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.
- had limited memory and processing capability.

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Second-generation of computers

- From 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.

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Third-generation of computers

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

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Fourth-generation of computers

- Early to middle 4th-generation computers, 1980–1995,
- used very large-scale integrated (VLSI) circuits to store and process information.
- 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.

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Fourth-generation of computers

- Late 4th-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.

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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.

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Feature	Generations					
	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 milliseconds	10 microseconds	500 nanoseconds	800 picoseconds	2,000 picoseconds	333 MHz
Average cost	\$2.5 million	\$250 thousand	\$25 thousand	\$2.5 thousand	\$2.0 thousand	\$1.5 thousand

- 2010
 - Primary storage: ~ 2 GB
 - Cycle time: ~ 2 GHz
 - Average cost : ~ \$1.0 thousand

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Types of Computers

- Computers are distinguished on the basis of their processing capabilities.
 - Supercomputers
 - Mainframes
 - Minicomputers
 - Servers
 - Workstations
 - Microcomputers
 - Notebook computers
 - Mobile computing devices
 - Wearable computers

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Supercomputers

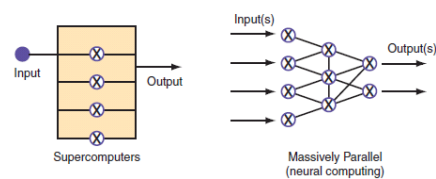
- computers with the most processing power.
- primary application: scientific and military work.
- valuable for large simulation models of real-world phenomena, where complex mathematical representations and calculations are required, or for image creation and processing.
 - used to model the weather 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*).

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Supercomputers

- use parallel processing technology.
 - supercomputers use noninterconnected CPUs
- neural computing, which uses massively parallel processing,

Supercomputers vs. neural computing.



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Cray-1

- The first Cray computer was developed by a team lead by the legendary Seymour Cray.
- It was a freon-cooled 64-bit system running at 80 MHz with 8 megabytes of RAM.
- Careful use of vector instructions could yield a peak performance of 250 megaflops.
- Together with its freon cooling system, the first model of the Cray-1 (Cray-1A) weighed 5.5 tons and was delivered to the Los Alamos National Laboratory in 1976.

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Cray-1



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IBM Roadrunner

- Capable of 1.71 petaflops
 - world's fastest computer since June 2008.
- It has 12,960 IBM PowerXCell 8i processors operating at 3.2 GHz and 6,480 dual-core AMD Opteron processors operating at 1.8 GHz,
 - a total of 130,464 processor cores.
- It also has more than 100 terabytes of RAM.
- 216 System x3755 I/O nodes
- 26 288-port ISR2012 Infiniband 4x DDR switches
- 2.35 MW power

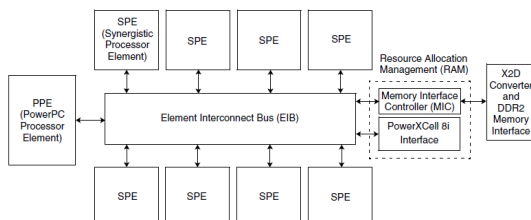
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IBM Roadrunner



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PowerXCell 8i Overview



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Mainframes

- are not as powerful and generally not as expensive as supercomputers.
- used mainly by large organizations for critical applications, typically bulk data processing such as census, industry and consumer statistics, ERP, and financial transaction processing.
- The term originally referred to the large cabinets that housed the central processing unit and main memory of early computers.
- Later the term was used to distinguish high-end commercial machines from less powerful units.

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Mainframes

- A mainframe has 1 to 16 CPU's (modern machines more)
- Memory ranges from 128 Mb over 8 Gigabyte on line RAM
- Its processing power ranges from 80 over 550 MIPS
- It has often different cabinets for
 - Storage, I/O, RAM
- Separate processes (program) for
 - task management
 - program management
 - job management
 - serialization
 - catalogs
 - inter address space
 - communication

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ENIAC

CPU:	17,468 vacuum tubes, 70,000 resistors, 10,000 capacitors, 1,500 relays, and 6,000 manual switches
CPU speed	ENIAC could execute 5,000 additions, 357 multiplications, and 38 divisions in one second
introduced	1946
OS	hard wired
initial price	total cost approximately \$500,000
footprint	167,3 m2
energy consumption	180 kW

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IBM eServer zSeries 890

- Introduced in 2004
- can host up to 32 GBytes of memory.
- The four PCI-X Crypto Coprocessor.
- can run several operating systems at the same time including z/OS, OS/390®, z/VM®, VM/ESA®, VSE/ESA, TPF and Linux for zSeries and Linux for S/390®.
- The z890 is upgradeable within z890 family and can also upgrade to z990 from select z890 configurations.

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Minicomputers

- smaller and less expensive than mainframes.
- 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.
- They are connected to each other and often to a mainframe through telecommunication links.

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Minicomputers

- introduced in the early 1960s
- Digital Equipment Corporation developed the PDP-1 minicomputer in 1960, and the PDP-8 virtually conquered the market in a sweep and sold over 40,000 units.
- In time some 200 companies produced this type of minicomputers.
- DEC got at the top of the market with the PDP-11, and with the VAX 11/780 system.

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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](#).

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Server farms

- 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.

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Workstations

- originally developed to provide the high levels of performance demanded by technical users such as designers.
- based on RISC architecture and provide both very-high-speed calculations and high-resolution graphic displays.
- found widespread acceptance within the scientific community and, more recently, within the business community.
- applications include electronic and mechanical design, medical imaging, scientific visualization, 3-D animation, and video editing.

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Microcomputers

- also called personal computers (PCs),
- are the smallest and least expensive category of general-purpose computers.

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Notebook computers

- small, easily transportable, lightweight microcomputers
- fit easily into a briefcase.
- Notebooks are allowing users to have access to processing power and data without being bound to an office environment.
- Laptop
- Netbook

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Mobile computing devices

- PDAs or handheld personal computers.
- mobile phone handsets with wireless and internet access capabilities.
- use a micro version of a desktop OS, such as Pocket PC, Symbian, or Palm OS.
- Mobile devices have the following characteristics:
 - They cost much less than PCs.
 - Their OS 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.

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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, and 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.

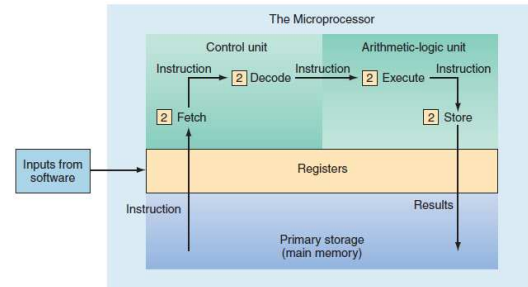
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Wearable computers

- computers that are worn on the body.
 - used in behavioral modeling, health monitoring systems, information technologies and media development.
- useful for applications that require computational support while the user's hands, voice, eyes, arms or attention are actively engaged with the physical environment.
- "Wearable computing" is an active topic of research,
 - user interface design, augmented reality, pattern recognition, use of wearables for specific applications or disabilities, electronic textiles and fashion design.

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Microprocessor and Primary Storage



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central processing unit (CPU)

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

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How a Microprocessor Works

- 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.
- 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.

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How a Microprocessor Works

- 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 control unit directs the flow of data and instruction 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.

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How a Microprocessor Works

- The data and the instructions are sent to storage registers and are then sent back to a storage place outside the chip, such as the hard drive.
- Meanwhile, the transformed data go to another register and then on to other parts of the computer.
- This cycle processing, known as a machine instruction cycle, occurs millions of times or more per second.
- 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.

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How a Microprocessor Works

- **Clock** is located within the control unit
 - 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.
- **Word length** is the number of bits that can be processed by the CPU at any one time.
- **Bus width.**
 - The wider the bus, the more data can be moved and the faster the processing.

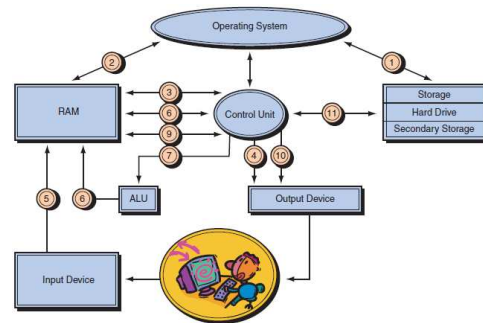
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How a Microprocessor Works

- **Physical design of the chip.**
- 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).

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Running a Program on a Computer



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Running a Program on a Computer

- 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 (step 4).
 - Once the message is answered (step 5), 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

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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—for example, display it (step 10) or store it on the hard drive (step 11).

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Running a Program on a Computer

- 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 (MIPS)**.

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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 hundreds of processors.

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Computer Architecture/Organization

- 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.

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- 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.

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Comprehensive classification

- Complex instruction set computer (CISC)
- Reduced instruction set computer (RISC)
- Minimal instruction set computer (MISC)
- One instruction set computer (OISC)
- No-instruction-set-computer (NISC)
- Zero Instruction Set Computer (ZISC)
- Very long instruction word (VLIW) computer

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CISC

- 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.

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RISC

- The other 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.

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Minimal Instruction Set Computer

- a processor architecture with a very small number of basic operations and corresponding opcodes.
 - stack based rather than register based (stack machine)
 - smaller instruction set, a smaller and faster instruction decode unit, and overall faster operation of individual instructions.
- The downside is that instructions tend to have more sequential dependencies, reducing instruction-level parallelism.
- MISC architectures have much in common with the Fortran programming language, and the Java Virtual Machine.
- Probably the most commercially successful MISC was the **INMOS transputer**.

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one instruction set computer

- sometimes called an **ultimate reduced instruction set computer (URISC)**,
- an abstract machine that uses only one instruction
- With a judicious choice for the single instruction and given infinite resources, an OISC is capable of being a universal computer in the same manner as traditional computers that have multiple instructions.
- OISCs have been recommended as aids in teaching computer architecture and have been used as computational models in structural computing research.

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No-instruction-set-computer

- a new architecture and compiler technology for designing custom processors and hardware accelerators.
- operation scheduling and hazard handling are done by a compiler.
- does not have any predefined instruction set or microcode.
- The compiler generates nanocodes which directly control functional units, registers and multiplexers of a given datapath. The benefits of NISC technology are:
 - **Simpler controller: no hardware scheduler, no instruction decoder**
 - **Better performance: more flexible architecture, better resource utilization**
 - **Easier to design: no need for designing instruction-sets**

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Zero Instruction Set Computer

- a chip technology based on pure pattern matching and absence of (micro-) instructions in the classical sense.
- ZISC is a technology based on ideas from artificial neural networks and massively hardwired parallel processing.
- The parallelism is the key to the speed of ZISC systems, which eliminate the step of serial loading and comparing the pattern for each location.
- Another key factor is ZISC's scalability:
 - a ZISC network can be expanded by adding more ZISC devices without suffering a decrease in recognition speed.
 - Today's ZISC chip contains 78 neurons per chip and can find a match among 1,000,000 patterns in one second operating at less than 50 MHz.
- Practical uses of ZISC technology focus on pattern recognition, information retrieval (data mining), security and similar tasks.

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Very long instruction word

- **VLIW** refers to a CPU architecture designed to take advantage of instruction level parallelism.
- executes operations in parallel based on a fixed schedule determined when programs are compiled.
- Since determining the order of execution of operations (including which operations can execute simultaneously) is handled by the compiler, the processor does not need the scheduling hardware
- VLIW CPUs offer significant computational power with less hardware complexity (but greater compiler complexity)
- VLIW instruction encodes multiple operations;
 - if a VLIW device has five execution units, then a VLIW instruction for that device would have five operation fields, each field specifying what operation should be done on that corresponding execution unit.
- To accommodate these operation fields, VLIW instructions are usually at least 64 bits wide.

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Arithmetic-Logic Unit

- ALU performs required arithmetic and operations.
 - adds, subtracts, multiplies, divides, compares, and determines whether a number is positive, negative, or zero.
- 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 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.

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Primary storage (main memory)

- stores data and program statements for the CPU.
- It has four basic purposes:
 - To store data that have been input until they are transferred to the ALU for processing
 - To store data and results during intermediate stages of processing
 - To hold data after processing until they are transferred to an output device
 - To hold program statements or instructions received from input devices and from secondary storage

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Buses

- A bus is a communication channel through which instructions and data move between computer subsystems and the processor
- Three types of buses link the CPU, primary storage, and the other devices in the computer system.
 - data bus moves data to and from primary storage.
 - address bus transmits signals for locating a given address in primary storage.
 - 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 it carries at one time.

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Control Unit

- reads instructions and directs the other components of the computer system to perform the functions required by the program.
- interprets and carries out instructions contained in computer programs, selecting program statements from the memory, moving them to the IR in the control unit, and then carrying them out.
- It controls I/O devices and data-transfer processes from and to memory.
- 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.**

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Input/Output Devices

- 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)
 - peripheral devices (any input/output device that is attached to the computer).

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Secondary storage

- Magnetic disc
- Magnetic tape
- Compact disc
- Digital Video Disk (DVD)
- Memory PC Card
- USB memory
-

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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.

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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.

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Representative input devices

Categories	Examples
Keying devices	<ul style="list-style-type: none"> Punched card reader Keyboard Point-of-sale (POS) terminal
Pointing devices <i>(devices that point to objects on the computer screen)</i>	<ul style="list-style-type: none"> Mouse (including rollerballs and trackballs) Touch screen Touchpad (or trackpad) Light pen Joy stick
Optical character recognition <i>(devices that scan characters)</i>	<ul style="list-style-type: none"> Bar code scanner (e.g., at POS) Optical character reader Wand reader Cordless reader Optical mark reader
Handwriting recognizers Voice recognizers <i>(data entered by voice)</i>	<ul style="list-style-type: none"> Pen Microphone
Other devices	<ul style="list-style-type: none"> Magnetic ink character readers Digital cameras Automated teller machines (ATMs) Smart cards Digitizers (for maps, graphs, etc.) RFID

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Device | **Use**

Mouse | Keyboard | Light Pen or Stylus | Touch Screen | Most common forms of data entry.

Bar Code Reader or Scanner | Wand Reader | The data entered are stored as printed bars of different widths.

Optical Scanner | Point-of-sale Device | The data entered are stored on typed pages or even handwritten forms.

Point-of-sale Device | The data are entered at the point where a transaction is made.

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Magnetic Ink Character Reader | The data entered are imprinted with magnetic ink. This system is mostly used on bank checks.

Voice Recognition | Voice input is entered, interpreted, and displayed on a screen or saved to disk.

Digitizer | Graphic images are digitized and transmitted to the computer.

Camera, Tape Recorder | Video, photos, graphics, sound, and text can be entered to create multimedia presentations that educate, inform, and entertain.

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Output devices

Output Device | **Use**

Printer | Prints reports, files in forms, prints high-quality graphics.

Monitor | Displays keyed, computer-stored, or computer-produced information.

Plotter | Draws computer-produced color graphics and charts.

Audio response | Responds to users with verbal messages or music, and sound and voice overlays for multimedia presentations.

Image processing equipment | Stores documents, photos, graphics, videos, animations and sound on film, compact disk or laser disk.

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