The Central Processing Unit:

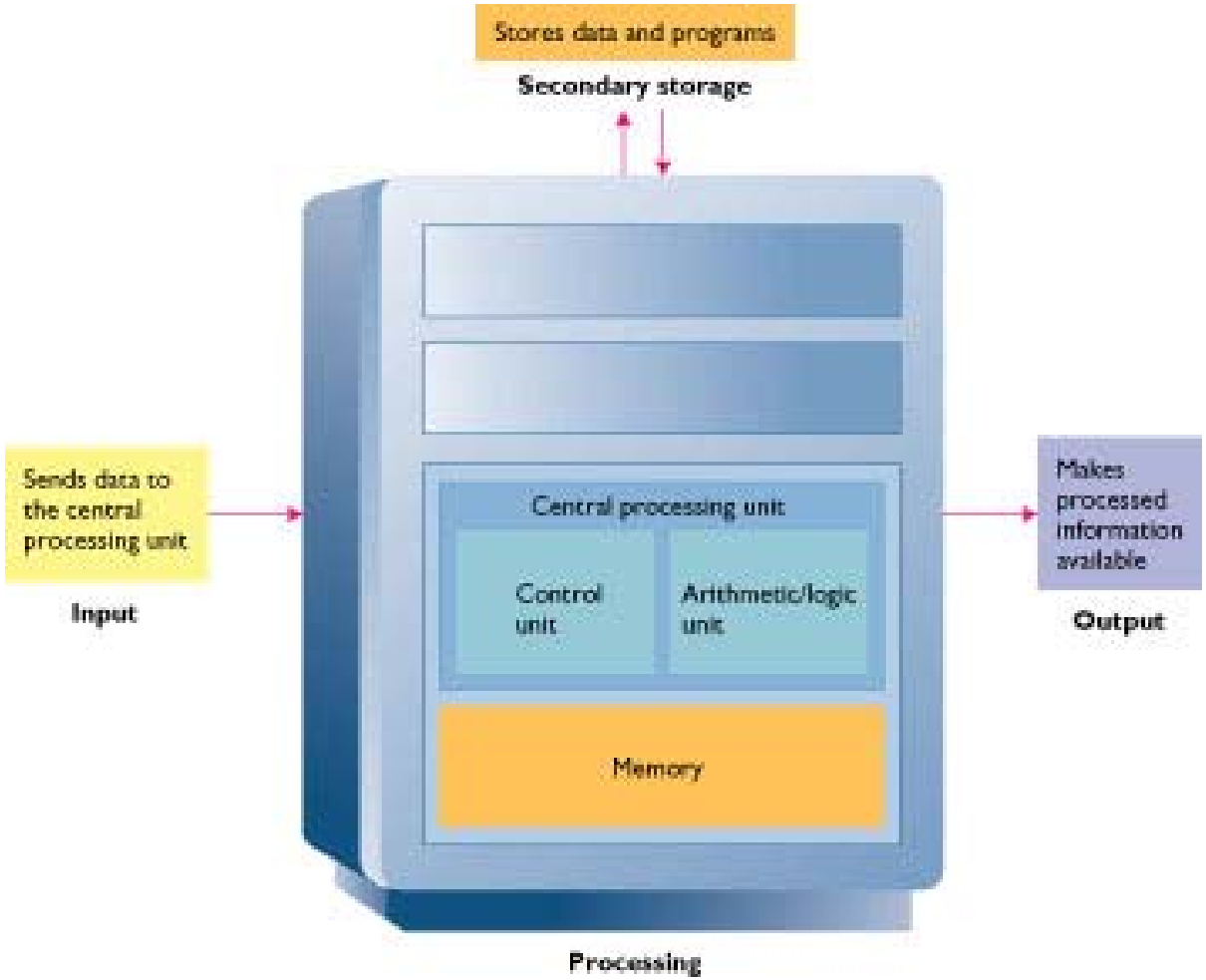
What Goes on Inside the Computer

Chapter 4

Objectives

- Identify the components of the central processing unit and how they work together and interact with memory
- Describe how program instructions are executed by the computer
- Explain how data is represented in the computer
- Describe how the computer finds instructions and data
- Describe the components of a microcomputer system unit's motherboard
- List the measures of computer processing speed and explain the approaches that increase speed

The CPU


Stores data and programs
Secondary storage
Sends data to the central processing unit
Input
Central processing unit
Control unit
Arithmetic/logic unit
Memory
Makes processed information available
Output
Processing

The CPU

- Complex set of electronic circuitry
- Control center
- Set of electronic circuitry that executes stored program instructions
- Two parts
  - Control Unit (CU)
  - Arithmetic Logic Unit (ALU)

Control Unit: *CU*

- Part of the hardware that is in-charge
- Directs the computer system to execute stored program instructions
- Must communicate with memory and ALU
- Sends data and instructions from secondary storage to memory as needed

Arithmetic Logic Unit

- Executes all arithmetic and logical operations
- Arithmetic operations
  - Addition, subtraction, multiplication, division
- Logical operations
  - Compare numbers, letters, or special characters
  - Tests for one of three conditions
    - Equal-to condition
    - Less-than condition
    - Greater-than condition

Data Storage and the CPU

- Two types of storage:
  - Primary storage (memory)
    - Stores data temporarily
    - CPU refers to it for both program instructions and data
  - Secondary storage
    - Long-term storage
    - Stored on external medium, such as a disk

The CPU and Memory

- CPU cannot process data from disk or input device
  - It must first reside in memory
  - Control unit retrieves data from disk and moves it into memory
- Items sent to ALU for processing
  - Control unit sends items to ALU, then sends back to memory after processing
- Data and instructions held in memory until sent to an output or storage device or program is shut down

Registers

Special-purpose

High-speed

Temporary storage

Located inside CPU

Instruction register
Holds instruction currently being executed

Status Register
Holds status of ALU operations

Data register

Holds data waiting to be processed

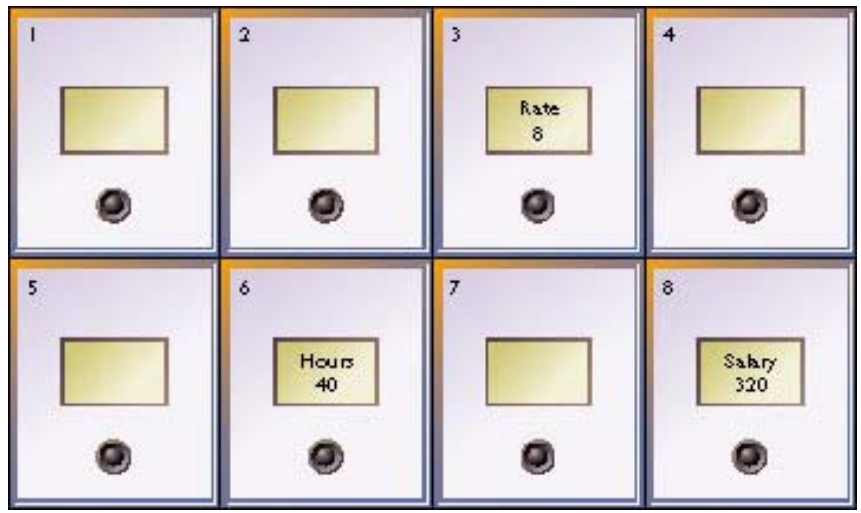
Holds results from processing

Memory

- Also known as primary storage and main memory
  - Often expressed as random-access memory (RAM)
  - Not part of the CPU
- Holds data and instructions for processing
- Stores information only as long as the program is in operation

Memory Addresses

- Each memory location has an address
  - A unique number, much like a mailbox
- May contain only one instruction or piece of data
  - When data is written back to memory, previous contents of that address are destroyed
- Referred to by number
  - Programming languages use a symbolic (named) address, such as Hours or Salary



Data Representation

- Computers understand two things: on and off
- Data represented in binary form
  - Binary (base 2) number system
  - Contains only two digits, 0 and 1
    - Corresponds to two states, on and off

BINARY EQUIVALENT OF DECIMAL NUMBERS 0–15

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Representing Data

- Bit
- Byte
- Word

Bit

- Short for binary digit
  - Two possible values: 0 and 1
  - Can never be empty
- Basic unit for storing data
  - 0 means off, 1 means on

Byte

- A group of 8 bits
  - Each byte has 256 (2^8) possible values
- For text, stores one character
  - Can be letter, digit, or special character
- Memory and storage devices measured in number of bytes

Word

- The number of bits the CPU processes as a unit
  - Typically a whole number of bytes
  - The larger the word, the more powerful the computer
  - Personal computers typically 32 or 64 bits in length

Storage Sizes

- Kilobyte: 1024 (2^{10}) bytes
  - Memory capacity of older personal computers
- Megabyte: roughly one million (2^{20}) bytes
  - Personal computer memory
  - Portable storage devices (diskette, CD-ROM)
- Gigabyte: roughly one billion (2^{30}) bytes
  - Storage devices (hard drives)
  - Mainframe and network server memory
- Terabyte: roughly one trillion (2^{40}) bytes
  - Storage devices on very large systems

Executing Programs

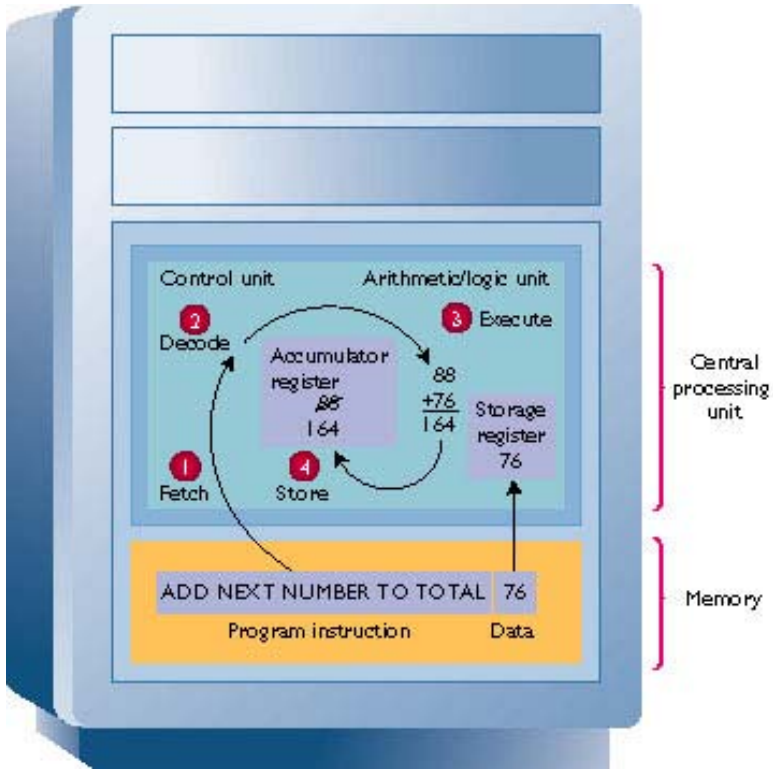
- Fetch
  - CU gets an instruction
- Decode
  - CU decodes the instruction
- Execute
  - CU notifies the appropriate part of hardware to take action
  - Control is transferred to the appropriate part of hardware
  - Task is performed
- Store
- Control is returned to the CU

How the CPU Executes Instructions

- Four steps performed for each instruction
  - Machine cycle: the amount of time needed to execute an instruction
  - Personal computers execute in less than one millionth of a second
  - Supercomputers execute in less than one trillionth of a second
- Each CPU has its own instruction set
  - those instructions that CPU can understand and execute

The Machine Cycle

- The time required to retrieve, execute, and store an operation
- Components
  - Instruction time
  - Execution time
- System clock synchronizes operations



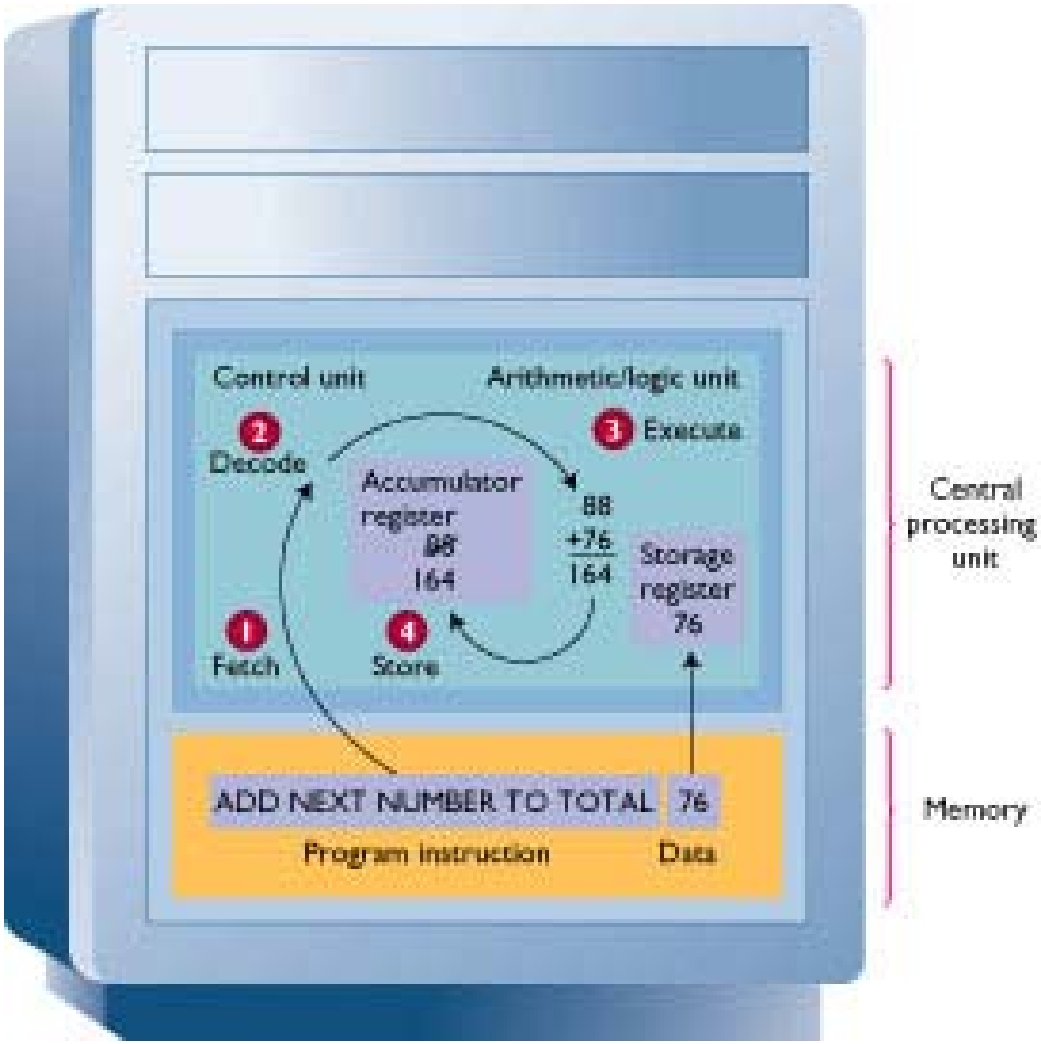
Instruction Time

- Also called I-time
- Control unit gets instruction from memory and puts it into a register
- Control unit decodes instruction and determines the memory location of needed data

Execution Time

- Control unit moves data from memory to registers in ALU
  - ALU executes instruction on the data
- Control unit stores result of operation in memory or in a register

Machine Cycle - Example



System Clock

- System clock produces pulses at a fixed rate
- Each Machine Cycle is one or more clock pulses
- One program instruction may actually be several instructions to the CPU
- Each CPU instruction will take one machine cycle
- CPU has an instruction set – instructions that it can understand and process
  - Different CPUs have unique instruction sets
    - Different types non-compatible (ie, Apple vs Intel)

Example

- get instruction from address location 2110
- decipher instruction → Z = X + Y
- mov X into register A (the accumulator)
- mov Y into register B
- add register B to register A
  - Result stays in accumulator
- store result in memory location symbolically addressed by Z

Coding Schemes

- Provide a common way of representing a character of data
  - Needed so computers can exchange data
- Common Schemes
  - ASCII
  - EBCDIC
  - Unicode

ASCII

- Stands for American Standard Code for Information Interchange
- Most widely used standard
- Used on virtually all personal computers

EBCDIC

- Extended Binary Coded Decimal Interchange Code
  - Used primarily on IBM and IBM-compatible mainframes

Unicode

- Designed to accommodate alphabets of more than 256 characters
- Uses 16 bits to represent one character
  - 65,536 possible values
- Requires twice as much space to store data

The System Unit

- Houses the electronic components of the computer system
  - Motherboard
  - Storage devices

Motherboard

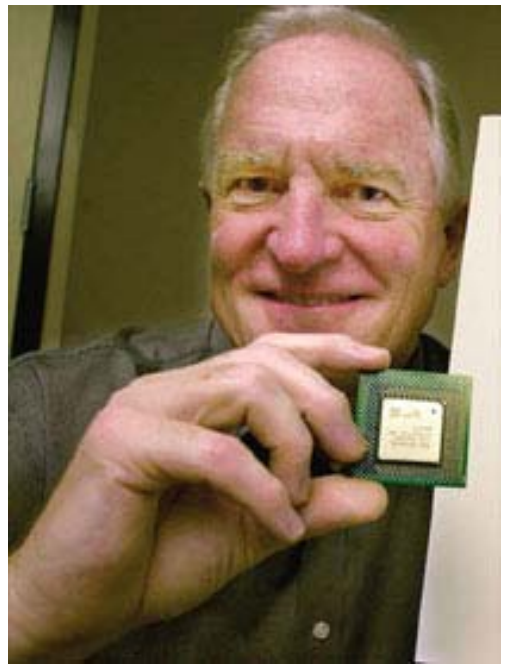
- Flat circuit board that holds the computer circuitry
  - Central processing unit (microprocessor) is most important component

Storage Devices

- Long-term storage of memory
  - Data not lost when computer shut down
- Examples include hard drive, diskette, DVD-ROM

Microprocessor

- Central processing unit etched on silicon chip
- Contain tens of millions of tiny transistors
- Key components:
  - Central processing unit
  - Registers
  - System clock



Transistors

- Electronic switches that may or may not allow electric current to pass through
  - If current passes through, switch is on, representing a 1 bit
  - Otherwise, switch is off, representing a 0 bit

Types of Chips

- Intel makes a family of processors
  - Pentium III and Pentium4 processors in most PCs
  - Celeron processor sold for low-cost PCs
  - Xeon and Itanium for high-end workstations and network servers
- Other processors
  - Cyrix and AMD make Intel-compatible microprocessors
  - PowerPC chips used primarily in Macintosh computers
  - Compaq's Alpha microprocessor used in high-end servers

Memory Components

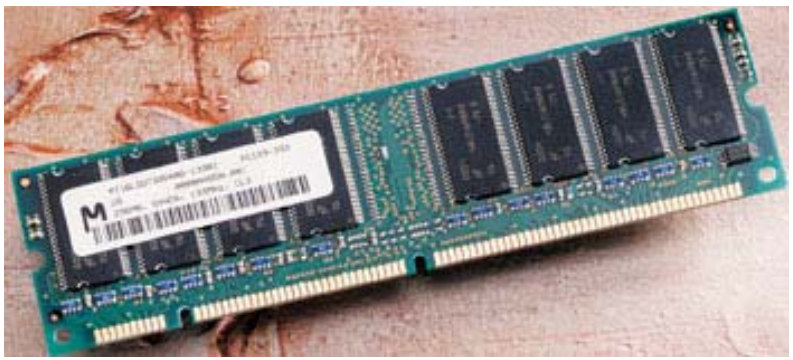
- Semiconductor Memory
- RAM and ROM
- Flash Memory

Semiconductor Memory

- Used by most modern computers
  - Reliable, inexpensive, and compact
  - Volatile: requires continuous electric current
    - If the current is interrupted, data is lost
  - Complementary Metal Oxide Semiconductor (CMOS)
    - Retains information when power is shut down
    - Used to store information needed when the computer boots

Random Access Memory

- Data can be accessed randomly
  - Memory address 10 can be accessed as quickly as memory address 10,000,000



- Types:
  - Static RAM (SRAM)
  - Dynamic RAM (DRAM)
- Packaged on circuit boards
  - Single in-line memory modules (SIMMS)
  - Dual in-line memory modules (DIMMS)

Static RAM

- Retains its contents with intervention from CPU
- Faster and more expensive than DRAM
- Typically used for Level 2 cache

Dynamic RAM

- Must be continuously refreshed by CPU or it loses its contents
- Used for personal computer memory
  - Synchronous DRAM (SDRAM): faster type of DRAM used today
  - Rambus DRAM (RDRAM): faster than SDRAM, will become more commonly used as price declines

Read-Only Memory

- Contains programs and data permanently recorded into memory at the factory
  - Cannot be changed by user
  - Not volatile: contents do not disappear when power is lost
- Programmable ROM (PROM) chips
  - Some instructions on chip can be changed

Flash Memory

- Nonvolatile RAM
  - Used in cellular phones, digital cameras, and some handheld computers
  - Flash memory chips resemble credit cards
  - Smaller than disk drive and require less power

The System Bus

- Parallel electrical paths that transport data between the CPU and memory
- Bus width
  - The number of electrical paths to carry data
  - Measured in bits
- Bus speed
  - Measured in megahertz (MHz)

Bus Width

- Typically the same as CPU's word size
- With a larger bus size, CPU can:
  - Transfer more data at a time
    - Makes computer faster
  - Reference larger memory address numbers
    - Allows for more memory
  - Support a greater number and variety of instructions

Bus Speed

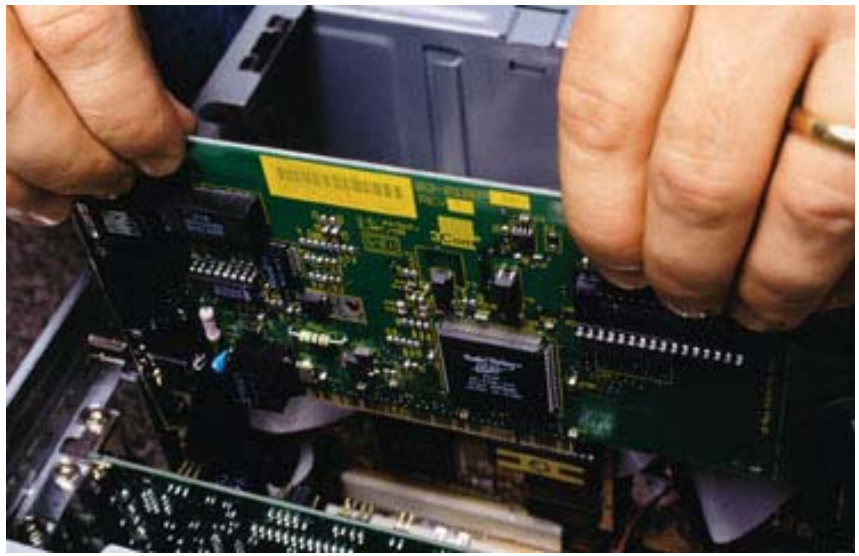
- The faster the bus speed, the faster data travels through the system
- Personal computers have bus speeds of 400 or 533 MHz

Expansion Buses

- Add peripheral devices to system
- Expansion board
- Port
- Common expansion buses

Expansion Boards

- Connect to expansion slots on motherboard
  - Used to connect peripheral devices



Ports

- External connectors to plug in peripherals such as printers
- Two types of ports
  - Serial: transmit data one bit at a time
    - Used for slow devices such as the mouse and keyboard
  - Parallel: transmit groups of bits together side-by-side
    - Used for faster devices such as printers and scanners

Common Expansion Buses and Ports

- Industry Standard Architecture (ISA) bus
  - Used for slow devices such as the mouse and modem
- Peripheral Component Interconnect (PSI) bus
  - Used for faster devices such as hard disks
- Accelerated Graphics Port (AGP)
  - Provides faster video performance
- Universal Serial Bus (USB) port
  - Allows you to convert many devices in a series into the USB port
- IEEE 1394 bus
  - A high-speed bus normally used to connect video equipment
- PC Card bus
  - Used on laptops to plug in a credit-card sized device

Computer Processing Speeds

- Instruction speeds measured in fractions of seconds
  - Millisecond: one thousandth of a second
  - Microsecond: one millionth of a second
  - Nanosecond: one billionth of a second
    - Modern computers have reached this speed
  - Picosecond: one trillionth of a second

Microprocessor Speeds

- Measure of system clock speed
  - How many electronic pulses the clock produces per second
  - Usually expressed in gigahertz (GHz)
    - Billions of machine cycles per second
    - Some old PCs measured in megahertz (MHz)
- Comparison of clock speed only meaningful between identical microprocessors

Other Performance Measures

- Millions of Instructions per Second (MIPS)
  - High-speed personal computers can perform over 500 MIPS
  - Typically a more accurate measure of performance than clock speed
- Megaflop: one million floating-point operations
  - Measures ability of computer to perform complex mathematical operations

Cache

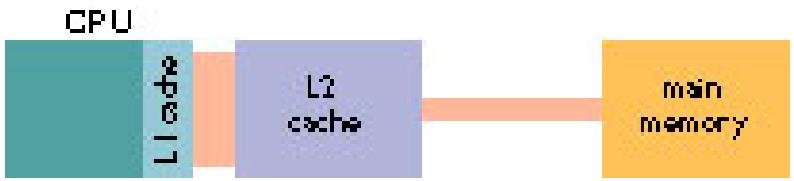
- A temporary storage area
  - Speeds up data transfer within computer
- Memory cache
- Processor cache

Memory Cache

- A small block of high-speed memory
  - Stores most frequently and most recently used data and instructions
- Microprocessor looks for what it needs in cache first
  - Transferred from cache much faster than from memory
  - If not in cache, control unit retrieves from memory
    - The more cache “hits” the faster the system performance

Processor Cache

- Internal (Level 1) cache built into microprocessor
  - Fastest access, but highest cost
- External (Level 2) cache on separate chip
  - Incorporated into processor on some current microprocessors



RISC Technology

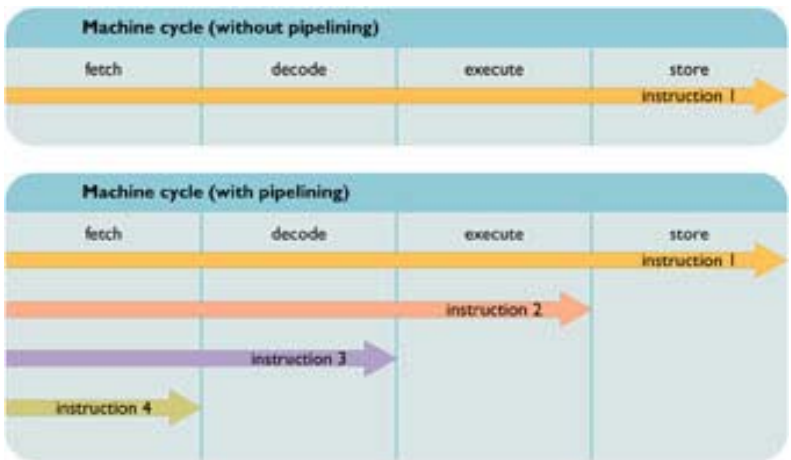
- Reduced Instruction Set Computing
  - Uses a small subset of instructions
  - Fewer instructions increases speed
  - Drawback: complex operations have to be broken down into a series of smaller instructions
- Traditional processors use Complex Instruction Set Computing (CISC)

Parallel Processing and Pipelining

- Pipelining
  - A variation of traditional serial processing
- Parallel Processing
  - Using multiple processors at once

Pipelining

- Feeds a new instruction into CPU at each step of the machine cycle
  - Instruction 2 fetched when instruction 1 is being decoded, rather than waiting until cycle is complete



Parallel Processing

- Control processor divides problem into parts
  - Each part sent to separate processor
  - Each processor has its own memory
  - Control processor assembles results
- Some computers using parallel processing operate in terms of teraflops: trillions of floating-point instructions per second

Memory: *Many Names*

Primary storage

Primary memory

Main storage

Internal storage

Main memory