MicroProcessor

- A **microprocessor** is a single, very-large-scale-integration (VLSI) chip that contains many digital circuits that perform arithmetic, logic, communication, and control functions.
- When a microprocessor is packaged on a printed circuit board with other components, such as interface and memory chips, the resulting assembly is referred to as a **microcomputer** or **single-board computer.** The overall architecture of a typical microcomputer system using a microprocessor is illustrated in Figure 10.1 .
- The microprocessor, (also called the **central processing unit** (CPU) or **microprocessor unit** (MPU), is where the primary computation and system control operations occur.
- **Arithmetic logic unit** (ALU) within the CPU executes mathematical functions on data structured as binary words.
- **Word:** an ordered set of bits, usually 8, 16, 32, or 64 bits long.
- The instruction decoder interprets instructions fetched sequentially from memory by the control unit and stored in the instruction register.

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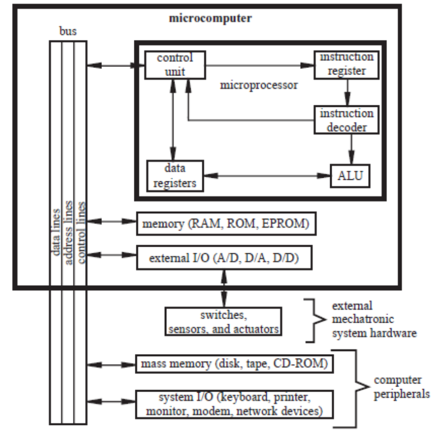
Figure 10.1 Microcomputer architecture.



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- Each instruction is a set of coded bits that commands the ALU to perform bit manipulation, such as binary addition and logic functions, on words stored in the CPU data registers.
- The ALU results are also stored in data registers and then transferred to memory by the control unit.
- **Bus:** a set of shared communication lines that serves as the central nervous system of the computer.
  - Data, address, and control signals are shared by all system components via the bus.
  - Each component connected to the bus communicates information to and from the bus via its own bus controller.
- The data lines, address lines, and control lines allow a specific component to access data addressed to that component.
- **Data lines:** used to communicate words to and from data registers in the various system components such as memory, CPU, and input/output (I/O) peripherals.

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- **Address lines:** used to select devices on the bus or specific data locations within memory.
  - Devices usually have a combinational logic address decoder circuit that identifies the address code and activates the device.
- **Control lines:** transmit read and write signals, the system clock signal, and other control signals such as system interrupts.
- **Memory:** Different types of memory include
  - **Read-only memory** (ROM): used for permanent storage of data that the CPU can read, but the CPU cannot write data to ROM.
    - ROM does not require a power supply to retain its data and therefore is called nonvolatile memory.
  - **Random access memory** (RAM): can be read from or written to at any time, provided power is maintained.
    - The data in RAM is considered volatile because it is lost.
    - There are two main types of RAM: **static RAM** (SRAM), which retains its data in flip-flops as long as the memory is powered, and

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  - **Dynamic RAM** (DRAM), which consists of capacitor storage of data that must be refreshed (rewritten) periodically because of charge leakage.
- **Erasable-programmable ROM** (EPROM): Data stored in an EPROM can be erased with ultraviolet light applied through a transparent quartz window on top of the EPROM IC.
  - Then new data can be stored on the EPROM.
  - Another type of EPROM is **electrically erasable (EEPROM).**
  - Data in EEPROM can be erased electrically and rewritten through its data lines without the need for ultraviolet light.
- Because data in RAM are volatile, ROM, EPROM, EEPROM, and peripheral mass memory storage devices such as magnetic, optical, and solid-state drives are sometimes needed to provide permanent data storage.

MicroProcessor

- Communication to and from the microprocessor occurs through I/O devices connected to the bus.
- External computer peripheral I/O devices include
  - keyboards,
  - printers,
  - displays, and
  - network devices.
- For mechatronic applications,
  - analog-to-digital (A/D),
  - digital-to-analog (D/A), and
  - digital I/O (D/D) devices provide interfaces to
    - switches,
    - sensors, and
    - actuators.

MicroController

- There are two branches of the microprocessor.
- One branch supports CPUs for the PC and workstation industry, where the main constraints are high speed and large word size (32 and 64 bits).
- The other branch includes **microcontroller**
  - single IC containing specialized circuits and functions that are applicable to mechatronic system design.
  - It contains a
    - microprocessor,
    - memory,
    - I/O capabilities, and other on-chip resources.
  - It is basically a microcomputer on a single IC.
  - Examples of microcontrollers are
    - Microchip's PIC,
    - Motorola's 68HC11, and
    - Intel's 8096.

MicroController

- Factors that have driven development of the microcontroller are
  - low cost,
  - versatility,
  - ease of programming, and
  - small size.
- Microcontrollers are attractive in mechatronic system design because their small size and broad functionality allow them to be physically embedded in a system to perform all of the necessary control functions.

Uses:

- used in a wide array of applications including
  - home appliances,
  - entertainment equipment,
  - telecommunication equipment,
  - automobiles, trucks, airplanes, toys, and office equipment.

MicroController

- All these products involve devices that require some sort of intelligent control based on various inputs.
- For example,
  - the microcontroller in a microwave oven monitors the control panel for user input, updates the graphical displays when necessary, and controls the timing and cooking functions.
  - In an automobile, there are many microcontrollers to control various subsystems, including cruise control, antilock braking, ignition control, keyless entry, air and fuel flow etc.
  - An office copy machine controls actuators to feed paper, uses photo sensors to scan a page, sends or receives data via a network connection, and provides a user interface complete with menu-driven controls.
  - A toy robot dog has various sensors to detect inputs from its environment (e.g., bumping into obstacles, being patted on the head, light and dark, voice commands), and an onboard microcontroller actuates motors to mimic actual dog behavior (e.g., bark, sit, and walk) based on this input.

MicroController

- The components of a microcontroller include the CPU, RAM, ROM, digital I/O ports, a serial communication interface, timers, analog-to-digital (A/D) converters, and digital-to-analog (D/A) converters.
- The CPU executes the software stored in ROM and controls all the microcontroller components.
- Microcontroller manufacturers offer programming devices that can download compiled machine code from a PC directly to the EEPROM of the micro-controller, usually via the PC serial port and special-purpose pins on the microcontroller.

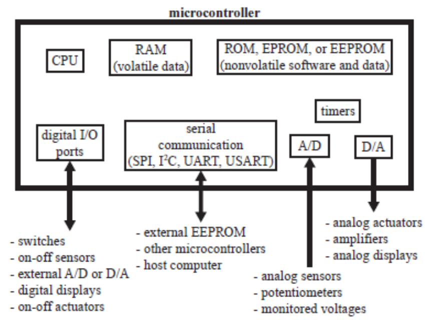

Figure 10.2 Components of a typical full-featured microcontroller.

MicroController

- There are various standards or protocols for serial communication, e.g.
  - SPI (serial peripheral interface),
  - I^2 C (interintegrated circuit),
  - UART (universal asynchronous receiver-transmitter), and
  - USART (universal synchronous-asynchronous receiver-transmitter).
- The A/D converter allows the microcontroller to convert an external analog voltage (e.g., from a sensor) to a digital value that can be processed or stored by the CPU.
- The D/A converter allows the microcontroller to output an analog voltage to a nondigital device (e.g., a motor amplifier).
- Onboard timers are usually provided to help create delays or ensure events occur at precise time intervals (e.g., reading the value of a sensor).
- Microcontrollers typically have less than 1 kilobyte to several tens of kilobytes of program memory.

MicroController: Memory

- The memory of a microcomputer, microprocessor, or microcontroller stores both data and instructions.
- Instructions need to move sequentially through the CPU to be decoded and executed.
- Data can be read from memory by the CPU or written in memory by the CPU.
- Therefore, the way that memory is organized and the way it communicates with the CPU determines the performance of the device.
- The two generic hardware models for memory structure are called
  - Von Neumann and
  - Harvard architectures.

MicroController: Memory

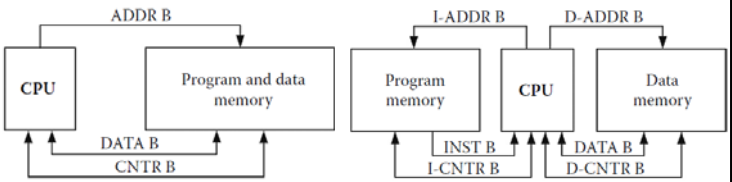

Figure 10.3 (a) von Neumann and (b) Harvard architectures.

- The von Neumann architecture uses a single memory to store instructions and data.
  - This means that one unique address bus can access program instructions and data.
  - Also, a unique data bus can transmit program instructions and data.

MicroController: Memory

- The CPU sends the same control signal to read data or to read an instruction.
- There are no independent data or instructions control signals.
- Although ROM is used for instruction storage and RAM is used for data storage, the CPU is not concerned with this distinction and treats them the same way.
- From the CPU point of view, both ROM and RAM make up a single memory block to which the CPU sends control signals for addresses and data.

- Harvard architecture uses different memories to store instructions and data.
  - The program memory has its own address bus (instruction address bus), its own data bus (more properly called an instruction bus), and its own control bus.
  - Data memory has its own address bus, data bus, and control bus independent from the instruction buses.
  - The program memory can only be read when data memory can be read and written.

MicroController: Memory

- The von Neumann architecture uses fewer lines than the Harvard architecture, thus making a much simpler connection between CPU and memory.
  - However, this structure does not allow simultaneous handling of data and instructions because there is only one bus.
  - On the other hand, because it has different buses, Harvard architecture allows the handling of data and instructions simultaneously.
  - This gives Harvard architecture an advantage in the speed of execution of programs.

MicroController: PIC

- The five pins RA0 through RA4 are digital I/O pins collectively referred to as **PORTA**
- The eight pins RB0 through RB7 are digital I/O pins collectively referred to as **PORTB.**
- In total, there are 13 I/O lines, called **bidirectional** lines because each can be individually configured in software as an input or output.

Interrupt

- An **interrupt** occurs when a specially designated input changes state.
- When this happens, normal program execution is suspended while a special interrupt handling portion of the program is executed. On the PIC16F84, pins RB0 and RB4 through RB7 can be configured as interrupt inputs.

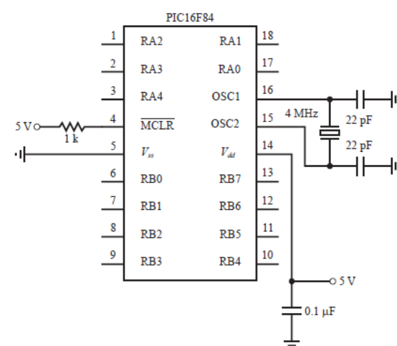

Figure 10.4 PIC16F84 pin-out and required external components.

MicroController: PIC

- Power and ground are connected to the PIC through pins V_{dd} and V_{ss}
  - The *dd* and *ss* subscripts refer to the drain and source notation used for MOS transistors.
  - The voltage levels (e.g., V_{dd} 5 V and V_{ss} 0 V) can be provided using a DC power supply or batteries (e.g., four AA batteries in series or a 9 V battery connected through a voltage regulator).

Reset

- The master clear pin (MCLR) is active low and provides a reset feature. Grounding this pin causes the PIC to reset and restart the program stored in EEPROM.
  - This pin must be held high during normal program execution.
- To provide a manual reset feature to a PIC design, we can add a normally open (NO) pushbutton switch. Closing the switch grounds the pin and causes the PIC to reset.

MicroController: PIC

Clock

- The PIC **clock** frequency can be controlled using different methods, including an external RC circuit, an external clock source, or a clock crystal.
- In Figure 10.4 , we show the use of a clock crystal to provide an accurate and stable clock frequency at relatively low cost.
- The clock frequency is set by connecting a 4-MHz crystal across the OSC1 and OSC2 pins with the 22 pF capacitors grounded as shown in Figure 10.4 .