Applications of μC
Topic-1. Introduction to Embedded Systems

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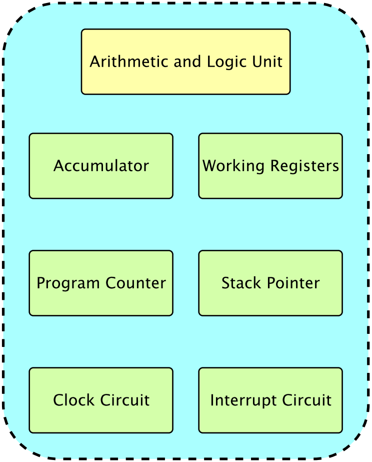
Microprocessor and Microcontroller

Microprocessor and microcontrollers are stemmed up from the same basic idea of computing, then what is the difference between them? Let us explore.

Microprocessor

A microprocessor is general purpose digital computer popularly known as central processing unit (CPU), essentially consists of arithmetic and logic unit (ALU), program counter (PC), stack pointer (SP) and some general purpose registers. e.g. Intel's 8085, Motorola's 68000, Zilog's Z80 etc.

To make a complete microcomputer system, one needs to add memory chips, I/O devices with appropriate interface and may be interrupt controllers, timers, direct memory access (DMA), Universal asynchronous receiver/transmitter (UART) etc. as per need.

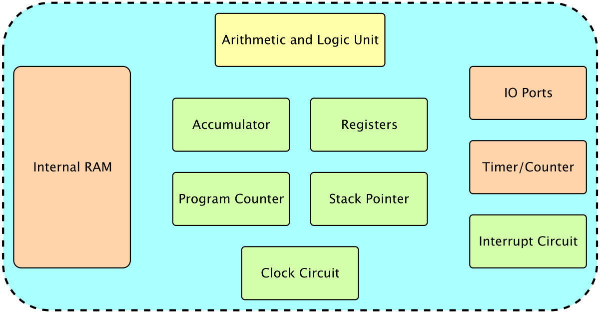


Block diagram of microprocessor

Microcontroller

A microcontroller is a computer-on-a-chip or a single-chip computer.The device may be used to control objects, processes, or events. Another term to describe a microcontroller is embedded controller, because the microcontroller and its support circuits are often built into, or embedded in, the devices they control. e.g. Intel's 8051, Motorola's 68HC11, Zilog's Z8 etc.

Both, microprocessors and microcontrollers contain a central processing unit (CPU). The CPU executes instructions that perform the basic logic, math, and data-moving functions of a computer.
However, a microcontroller is a single-chip computer because it contains memory and I/O interfaces in addition to the CPU unlike microprocessor.



Block diagram of microcontroller

Evolution of Microprocessors: First generation microprocessors

- In 1971, Intel Corporation introduced the first microprocessor as a result of designing a calculator chip. It was named as 4004.
- There were three other microprocessors in the market during 1971-73
  - Rockwell International's PPS-4 (4 bits)
  - Intel's 8008 (8 bits)
  - National Semiconductor's IMP-16 (16 bits)
- They were fabricated using PMOS technology for low cost with low output currents but slow speed.
- They were not compatible with TTL devices.

Second generation microprocessors

- During 1974-1978, very efficient 8 – bit microprocessors based on NMOS technology which provided higher density, high speed operation than PMOS and also were TTL compatible.
- Some of the popular processors were
  - Intel's 8085
  - Zilog's Z80
  - Motorola's 6800 and 6809

Third generation microprocessors

- Third generation of microprocessors (1979 – 80) is dominated by 16 – bits microprocessors.
- They were designed using HMOS technology as it's Speed-power-product was four times better than that of NMOS.
- HMOS can accommodate twice the circuit density compared to NMOS
- Some of the popular processors were
  - Intel's 8086/80186/80286
  - Motorolla's 68000/68010

Fourth generation microprocessors

- 1981 – 1995 era has marked the beginning of 32 bits microprocessors.
- They were fabricated using low-power version of the HMOS technology called HCMOS.
    - Intel introduced 80386.
    - Motorola introduced 68020/68030.
    - Later Motorola introduced 32-bit RISC processors called MC88100.

Fifth generation and higher

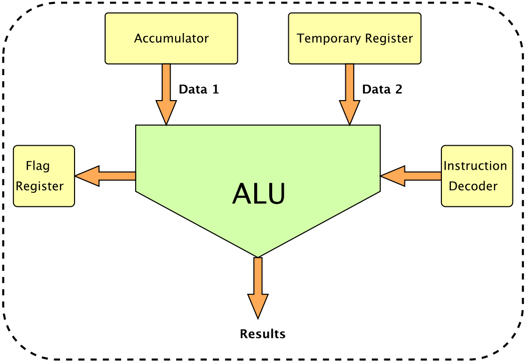
- Since 1996 emphasis is on introducing chips that carry on-chip functionalities and improvements in the speed of memory and I/O devices
- Introduction of 64-bit microprocessors.
- Working with up to 3.5GHz speed.
- Intel launched multi-core processors ranging from Pentium, Celeron to the current i-core generation 4.
- AMD has popular Athelon series which took credit to break 1Ghz speed barrier in processor industry.
- Numerous processors are availbale in this generation.

A brief introduction to microprocessor architecture

- A microprocessor is said to be *n*-bit microprocessor when it has *n*-bit ALU. e.g. Intel's 8085 is 8-bit microprocessor as its ALU processes 8-bit data.
- Usually the size of data bus of the CPU is equal to the size of ALU.
- Basic building blocks of any Microprocessor are
  - ALU
  - CPU registers such as accumulator and flag register (Part of ALU), general purpose registers, memory pointers (such as program counter and stack pointer)
  - Instruction registers and Instruction decoder
  - System buses such as data bus, address bus and control signals.

Arithmetic and logic unit (ALU)

- ALU is like a simple pocket calculator.
- It can perform arithmetic operations like add, subtract, multiply, divide and do various logical operations such as AND, OR, XOR.
- ALU works together with two resisters one an accumulator and a temporary register.
- As per the instruction from the instruction decoder, it performs arithmetic or logical operation.
- The result of the processing is over-written in the accumulator.
- Result conditions such as carry, sign, zero etc. are stored in flag register, which may be used in program to jump during the execution.



Typical Arithmetic and Logic Unit

CPU registers

Usually there are three types of registers in CPU.

- Working registers (Accumulator and Flag Register):
  - Accumulator essentially is one of the operands in arithmetic and logical instructions and result of the operation is always stored in accumulator.
  - The condition of result in accumulator is reflected in a Flag register. e.g. if the result in accumulator is zero, then zero flag bit in flag register is set else reset.
  - Flag condition is usually used to change to sequence of execution of instructions conditionally.

D7							D0
S	Z		AC		P		CY

Flag register of 8085 microprocessor

- General purpose registers: They are used to store the data required for the various operations to be performed in ALU. In some 8-bit processors they are paired in a specific manner to perform some 16-bit operations. e.g. in 8085 there are six 8-bit general purpose registers namely B, C, D, E, H and L. They can be paired as BC, DE and HL to perform some 16-bit operations.
- Memory Pointers: Usually there are two types of memory pointers, one is Stack pointer (SP) and other is Program Counter (PC).

- Stack pointer (SP) : When the general purpose registers are not enough to hold the data, it is stored in the defined read/write memory called as Stack.
  Stack pointer is used to point the defined read/write memory (Stack) during the program execution.
  Stack pointer holds the address of the data to be fetched/stored and decremented after every time data is stored and incremented as data is fetched.
- Program counter (PC): The purpose of this register is to sequence the execution of instructions. This register holds the address of the instruction to be fetched into the instruction decoder and incremented in every machine cycle.

Instruction decoder

- Instruction register:
  - It is just a small memory able to store one byte of information. This information is an instruction for the microprocessor to carry out.
  - The information is latched into the instruction register to release the internal data bus for other purposes.
- Instruction decoder:
  - It is the part of the microprocessor that is able to actually carry out an instruction. It identifies the instruction by comparing its binary code with an internally stored list.
  - Once it has located the instruction, it follows a built-in program designed into the microprocessor by the manufacturer and details all the necessary steps to complete any instruction of which it is capable.

System Buses

There are three types of buses Address bus, Data bus and Control bus.

- Address bus: The address bus carries addresses and is a one-way bus from the microprocessor to the memory or other devices. The number of lines that form the address bus determines the addressing capacity of the processor. e.g. processor with 16 address lines is capable of addressing $2^{16} = 65536 = 64K$ of memory.
- Data bus: The data bus is a two-way bus carrying data around the system. Information going into the microprocessor and results coming out is done via data bus.
- Control bus: The control bus is just a bunch of all the other necessary lines that carries signal from chip select and read/write pins to define the kind of operation among peripherals and microprocessor.

Processor architecture types

There are two basic types of architecture: Harvard and Von Neumann. Microcontrollers most often use a Harvard or a modified Harvard-based architecture, while microprocessors usually follow the Von Neumann architecture.

- Von Neumann architecture–
  - Von Neumann architecture has a single, common memory space where both program instructions and data are stored.
  - There is a single data bus which fetches both instructions and data.
  - The advantage to this architecture lies in its simplicity and economy.
- Harvard architecture–
  - Harvard architecture computers have separate memory areas for program instructions and data.
  - There are two or more internal data buses which allow simultaneous access to both instructions and data.
  - Speed of execution is higher, but at the cost of more hardware complexity.

CISC and RISC computer architectures

Complex Instruction Set Computers (CISC)–

- Complex architecture of computer with larger instruction sets, more addressing modes, more computational power of the individual instructions, more specialized registers.
- Recent machines fall in this category.
- The CISC design approach reduces the number of instructions in the program by providing special instructions that are able to perform complex operations.
- Thus development time for the software systems for the the CISC machines is less than RISC machines.

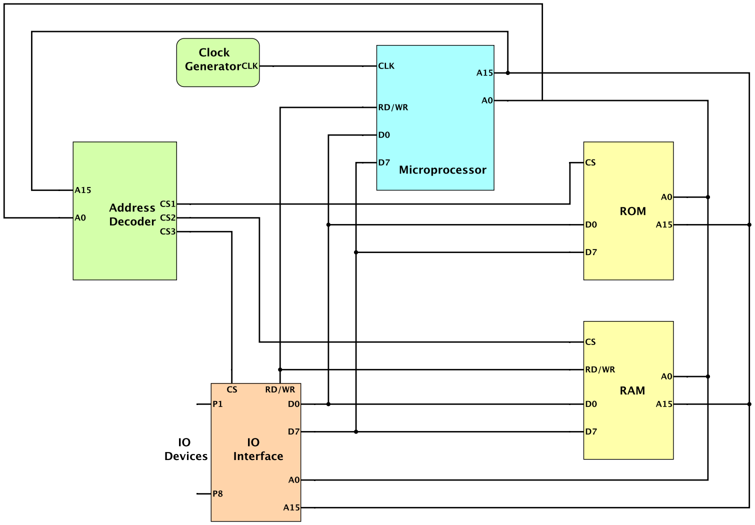
Reduced Instruction Set Computers (RISC)–

- The design philosophy of the RISC architecture says to add only those instructions to the instruction set that result in a performance gain.
- The common characteristics shared by most of these designs are a limited and simple instruction set, on-chip cache memories (or a large number of registers), a compiler to maximize the use of registers and thereby minimize main memory accesses, and emphasis on optimizing the instruction pipeline.
- Contrast to CISC, the RISC design approach reduces the average number of clock cycles required to execute an instruction.
- Due to the large register set, the register allocation scheme is more complex. This increases the complexity of the compiler.
- Therfore the main disadvantage of a RISC architecture is the necessity of writing a good compiler.
- The development time for the software systems for the RISC machine is longer than for the CISC.

Microprocessor based system

- Program to run the microprocessor based system with I/O's is usally burned in ROM.
- For any microprocessor-based system some RAM is needed. Even if the microprocessor-based system is controlling an oven, we still need the RAM to vary the instructions to change the temperature, the time cycle, the fan speed. etc.
- In the minimal microprocessor based system, processor is controlling the operation of three chips: ROM, RAM and I/O.
- To control the flow of information it needs to send chip select and read/write information along the control bus.
- All the peripheral share the same address and data buses, address decoder is used to select the specific peripheral via chip select (CS) signal.

Microprocessor based system



A basic block diagram of microprocessor based system

Flow of operation in microprocessor based system

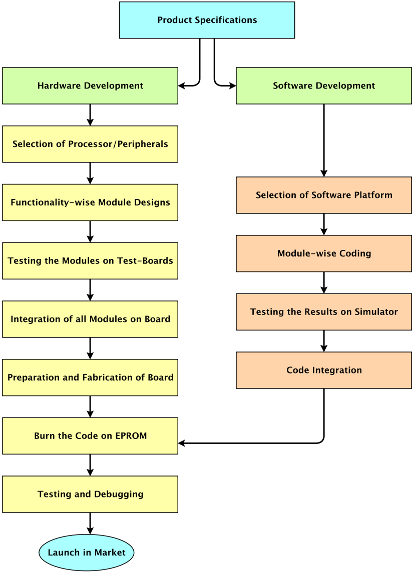
To demonstrate the operation of μP based system, we can ask it to perform a simple task.

- Send the number 4EH in the RAM at address 2000H.
- PC places the address of the instruction stored in ROM on the address bus.
- The address is applied to the ROM, RAM, I/O controller as well as the address decoder. This will not cause any problems because all the chip selects are disabled at the moment.
- The address decoder enables the chip select signal as per the address of the ROM location.
- The data byte from the ROM is stored in the specified CPU register.
- The address of RAM location 2000H is placed on address bus and then it is enabled by address decoder.

- The data byte 4EH is placed on the data bus.
- μP generates write signal.
- As only RAM is enabled, as soon as write signal is received by the RAM, the data byte 4EH is placed in 2000H.
- In the same manner, I/O are communicated.

Microprocessor based system development cycle

- Product specifications: List out the desired product specifications.
- Modelling the system: There are two aspects of the system, an hardware selection (system architecture) and software model that determines the behaviour of the system.


Product Specifications
Hardware Development
Software Development
Selection of Processor/Peripherals
Functionality-wise Module Designs
Testing the Modules on Test-Boards
Integration of all Modules on Board
Preparation and Fabrication of Board
Burn the Code on EPROM
Testing and Debugging
Launch in Market
Selection of Software Platform
Module-wise Coding
Testing the Results on Simulator
Code Integration

- Hardware development cycle
  - Selection of microprocessor/microcontroller and peripherals for the optimal performance of the system.
  - Segregate the systems into modules like serial communication, I/O control, interrupt based timer operations etc.
  - Test each module on the development board (prototyping) and fix the bugs if any.
  - Integrate all the modules.
  - Prepare schematic and PCB for necessary hardware.
  - Burn the software which has gone through software development cycle simultaneously into the EPROM.
  - Test the end product, fix the bugs if any.
  - Launch in market.

- Software development cycle
  - Select the software platform, simulator, cross-compiler and ROM burning tool.
  - Coding for each of the modules.
  - Test each code to run module in simulation.
  - Integrate all the codes.
  - Simulate the complete software platform.
  - Burn the software into the EPROM.
  - Test the end product, fix the bugs if any.
  - Launch in market.

That's the end of TOPIC-1 !