AMERICAN INTERNATIONAL UNIVERSITY – BANGLADESH(AIUB)

Where leaders are created

Fundamentals of Microprocessor and Embedded system

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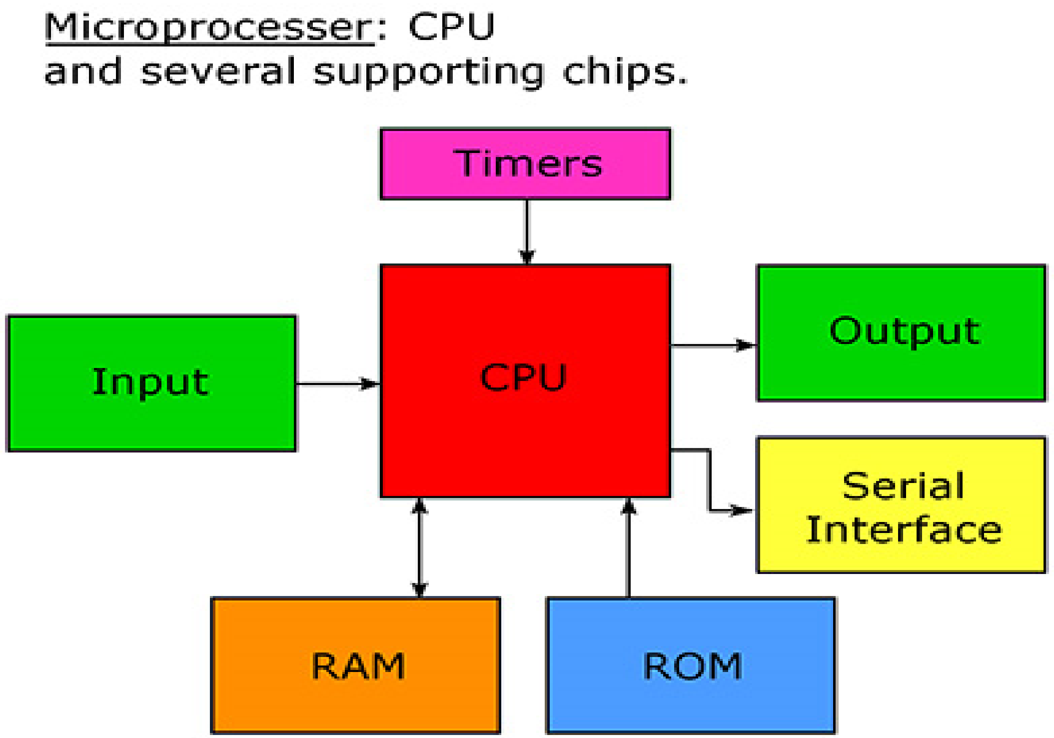
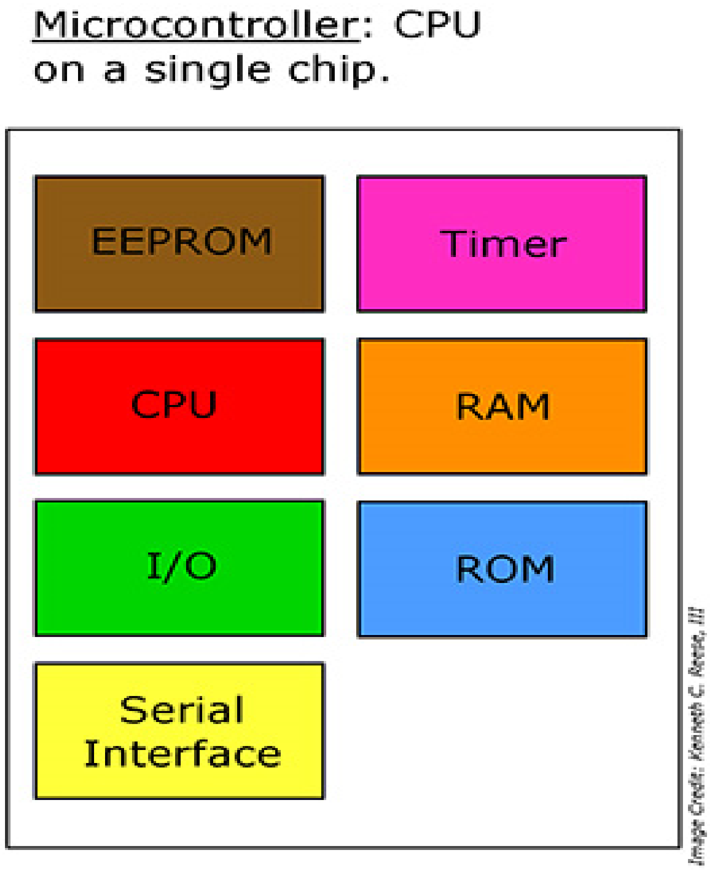
Some important Differences : Microprocessor vs. Microcontroller



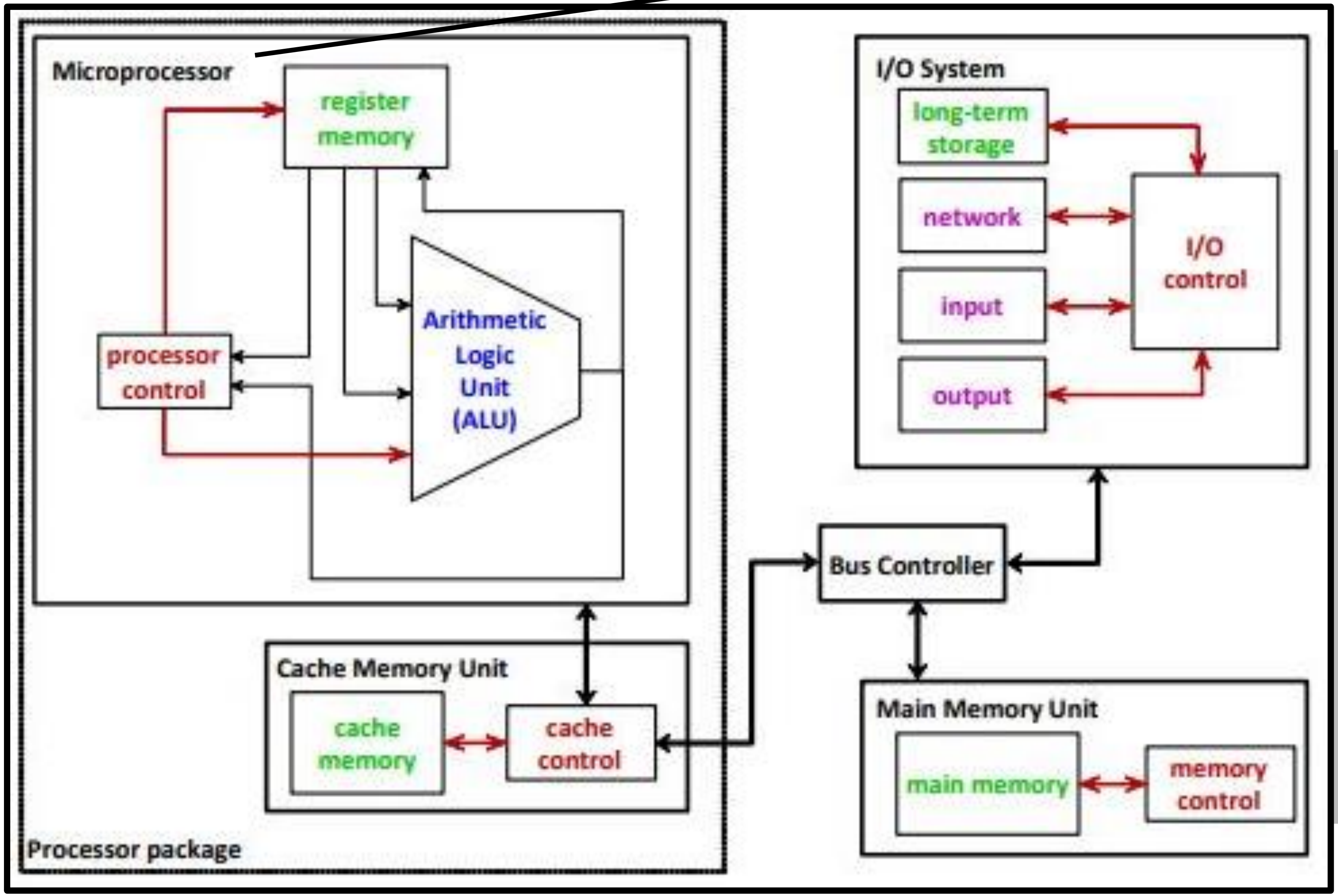
It is only a processor, so memory and I/O components need to be connected externally



Microcontroller has a processor along with internal memory and I/O components.

Some important Differences…

***CPU consisting of ALU, registers etc.**



Some important Differences :

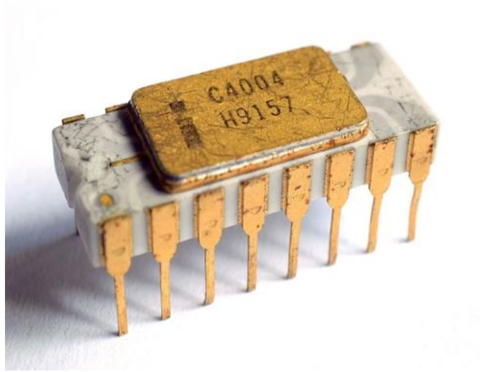
Microprocessor	Microcontroller
Microprocessor is the **heart** of Computer system.	Microcontroller is the **heart** of an embedded system.
It is only a processor (consisting of ALU, registers etc.), so memory and I/O components need to be connected externally	Microcontroller has a processor along with internal memory and I/O components.
Memory and I/O has to be connected externally, so the circuit becomes large.	Memory and I/O are already present, and the internal circuit is small.
You can't use it in compact systems	You can use it in compact systems.
Cost of the entire system is high	Cost of the entire system is low
Due to external components, the total power consumption is high. Therefore, it is not ideal for the devices running on stored power like batteries.	As external components are low, total power consumption is less. So, it can be used with devices running on stored power like batteries.
It is mainly used in personal computers.	It is used mainly in a washing machine, MP3 players, and embedded systems.

Some important Differences :

Microprocessor	Microcontroller
It is a central processing unit on a single silicon-based integrated chip.	It is a byproduct of the development of microprocessors with a CPU along with other peripherals.
It has no RAM, ROM, Input-Output units, timers, and other peripherals on the chip.	It has a CPU along with RAM, ROM, and other peripherals embedded on a single chip.
It uses an external bus to interface to RAM, ROM, and other peripherals.	It uses an internal controlling bus.
Microprocessor-based systems can run at a very high speed because of the technology involved.	Microcontroller based systems run up to 200MHz or more depending on the architecture.
It’s used for general purpose applications that allow you to handle loads of data.	It’s used for application-specific systems.
It’s complex and expensive, with a large number of instructions to process.	It’s simple and inexpensive with less number of instructions to process.

Evolution of Microprocessor(4-bit to 8-bit)

- Intel 4004 (4-bit)
  - 4 bit microprocessor
  - Able to address 4096 4-bit wide memory
  - Instruction set contained 45 instructions
  - It was fabricated by PMOS technology
  - Instruction execution rate was 50 KIPs.
- Intel 4040 (4-bit)
  - Updated version of 4004
  - Use: microwave systems, small control system and calculator



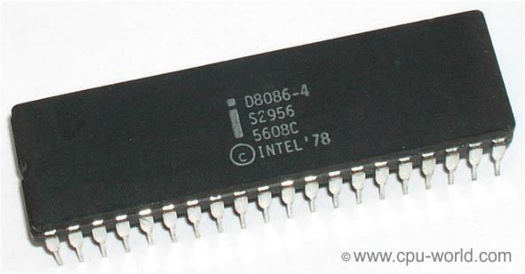
Intel 4004

- Intel 8008
  - 8 bit microprocessor
  - 16 K bytes memory
  - 48 instructions
- Intel 8080
  - 500,000 IPS
  - 64K bytes memory
- Intel 8085
  - In 1977, Intel Corporation introduced the last 8 bit microprocessor.
  - Execution rate 769,230 per seconds
  - Main advantage was internal clock and higher clock frequency.

* IPS means instructions Per Second

Evolution of Microprocessor(16-bit to 32-bit)

- 8086/8088
  - 2.5 MIPs
  - 1 M byte memory
  - 6 byte instruction cache or queue that pre-fetch a few instructions before execution.
- 80286
  - 4 MIPs
  - 16 Mbyte memory
  - Almost identical to 8086



8 bit microprocessors (8086)

- 80386
  - First 32 bit microprocessor
  - 32 bit data and 32 bit memory address
  - 4 G bytes memory
  - It included hardware circuitry for memory management
- 80486
  - 8K byte cache memory
  - Half cycle instruction execution

Evolution of Microprocessor (contd…)

- Pentium
  - 4 G byte memory, 8 K byte data cache and 8K byte instruction cache
  - Data bus 64 bit
  - Multimedia execution instructions or MMX
  - Dual integer processors
  - The Pentium simultaneously executes two independent instructions using superscalar technology.
  - Jump prediction technology of Pentium, speeds the execution of programs that includes loop.
  - Floating point processor process floating point data.

- Pentium Pro
  - 21 million transistors, 3 integer units, one floating point unit.
  - 16 K byte level 1 cache (8K byte for data and 8K byte for instructions) and 256 K level 2 caches
  - 3 execution engines can be configured for 64 G byte memory and it is used with windows NT operating systems for server applications.

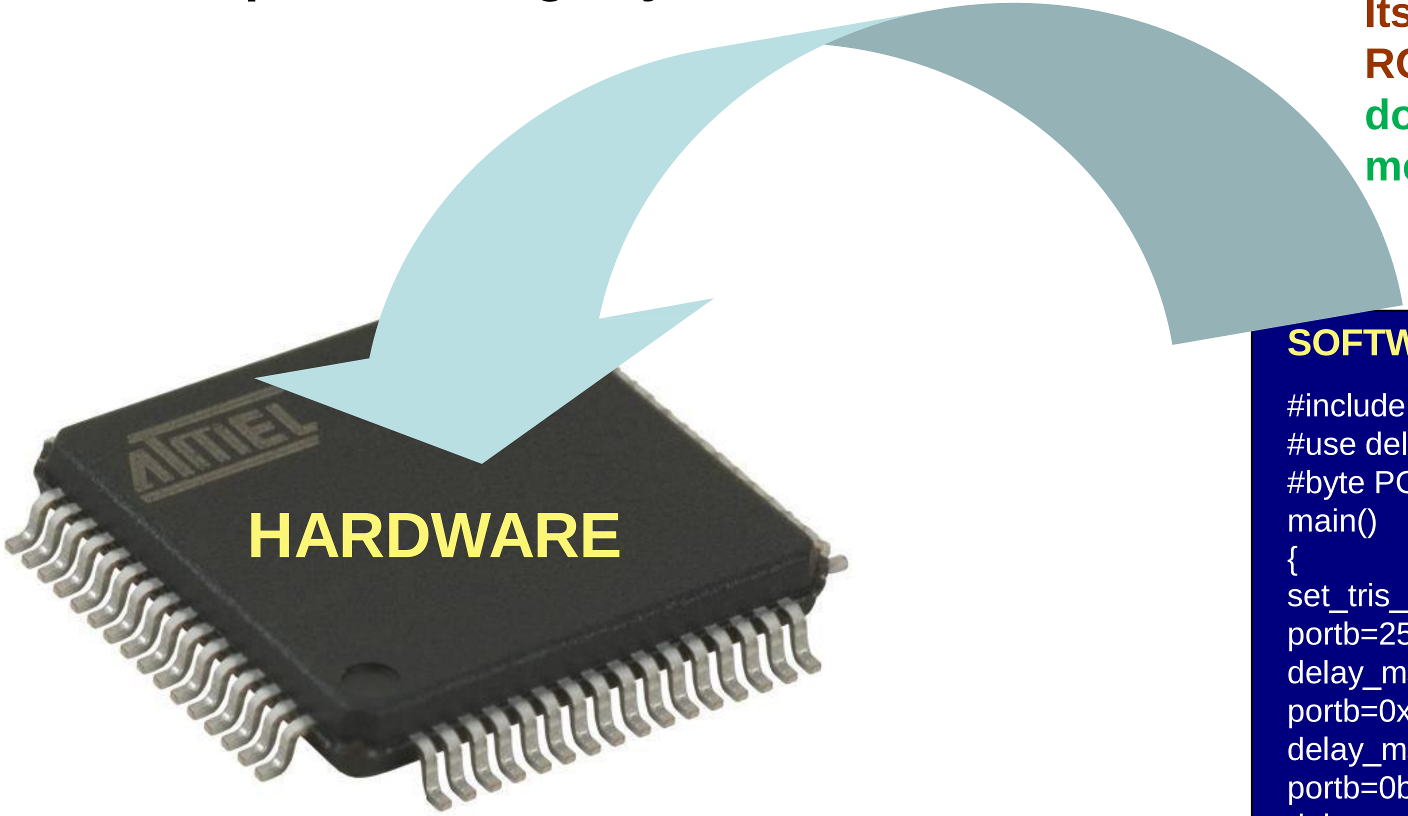
Types of Computer

- Mainframe
  - The largest and most powerful computer
  - They are designed to work at a very high speed
  - Large data words, typically 64 bits or greater
  - They have massive amount of memory
  - Used in military defense control, business data processing, computer graphic display.
  - Example : IBM 4381
- Super Computer
  - The fastest and more powerful mainframes are called Super Computer.
  - Example: Cray Y-MP/832
  - Used by largest firms, government agencies and universities
  - Tianhe-2 or TH-2 is a 33.86-petaflop (PFLOPS) supercomputer located in National Supercomputer Center in Guangzhou, China
- Mini Computer
  - Scaled-down version of mainframe computer
  - Runs slowly, works with smaller data word
  - Does not have as much memory as mainframe
  - Used in scientific research and industrial control
- Micro Computer
  - Small Computer
  - CPU is usually a single microprocessor
  - Example : Desktop, Laptop, Palmtop

Embedded System

An embedded system is **a microprocessor-based computer hardware system with software that is designed** to perform a dedicated function**, either as an independent system or as a part of a large system**.

Its software embeds in ROM (Read Only Memory). It does not need secondary memories as in a computer

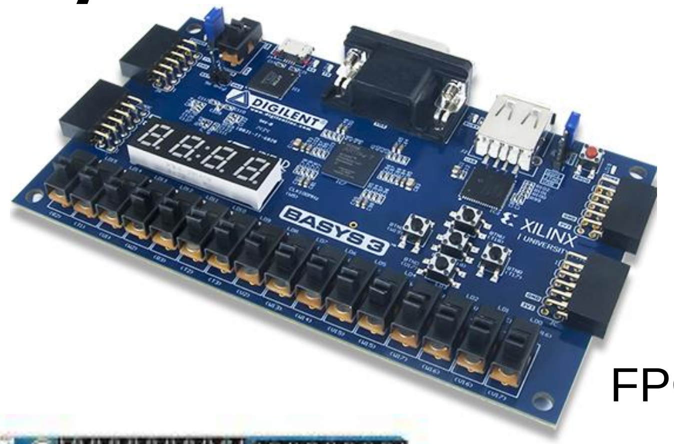


SOFTWARE PROGRAM

```
#include <16f876a.h>
#use delay (clock=20000000)
#byte PORTB=6
main()
{
set_tris_b(0);
portb=255;        //decimal
delay_ms(1000);
portb=0x55;       //hexadecimal
delay_ms(1000);
portb=0b10101010; //binary
delay_ms(500);
}
```

Widely Used Boards in Embedded Systems

Field –programmable gate arrays (FPGA) form custom embedded systems at gate level. Therefore it cannot be programmed rather FPGA system has to be constructed by a hardware description language such as Verilog and VHDL.



FPGA Board

Microcontrollers form embedded systems as those can be programmed in assembly or high level language to perform operations. Most well known microcontrollers are Arduino and RISC or ARM Cortex based ones having limited computation power and memory .

Arduino UNO

Microprocessors form embedded systems where Linux operating system can control and organize operations . This also leads to Graphical User Interface (GUI) usage as well. Microprocessors have fairly high memory and computation power compared to microcontrollers. Popular microprocessor based embedded systems are Raspberry Pi family.

Raspberry Pie

New hardware Options emerged for embedded systems are as follows:

1) STMicroelectronics offered joint usage of microcontroller (Arm Cortex A) and microprocessor (Cortex M CPUs.
2) Development boards consisting of graphical processing units (GPU) allow parallel processing via high-level programming languages.
3) Recent advances in deep learning and neural networks also led to devices consisting of neural processing units (NPU or TPU) dedicated to neural network implementations.

New hardware Options emerged for embedded systems are as follows:

- At present, some of the popular microcontroller families in the market are:
  - ATMega family: ATMega328P, ATMega32
  - Pic-chips: Pic24, Pic33 etc
  - ARM processors: Raspberry Pi, TM4C chips, STM32 F401, Mobile SoC
- In Bangladesh, ATMega based Arduino boards have gained wide popularity due to easy availability and low price. We are going to mostly focus on the **ATMega328P microcontroller-based Arduino board** during midterm.
- **ATMega328P** is based on Microchip picoPower® 8-bit AVR® **RISC-based** microcontroller. **RISC-V** is an **open-source architecture**, whereas **ARM** is **proprietary**. This means that any designer who wants to include an ARM CPU into their design (for example, a SoC) must pay royalties to ARM Holdings. RISC-V, on the other hand, is open-source and does not require any royalties or licensing

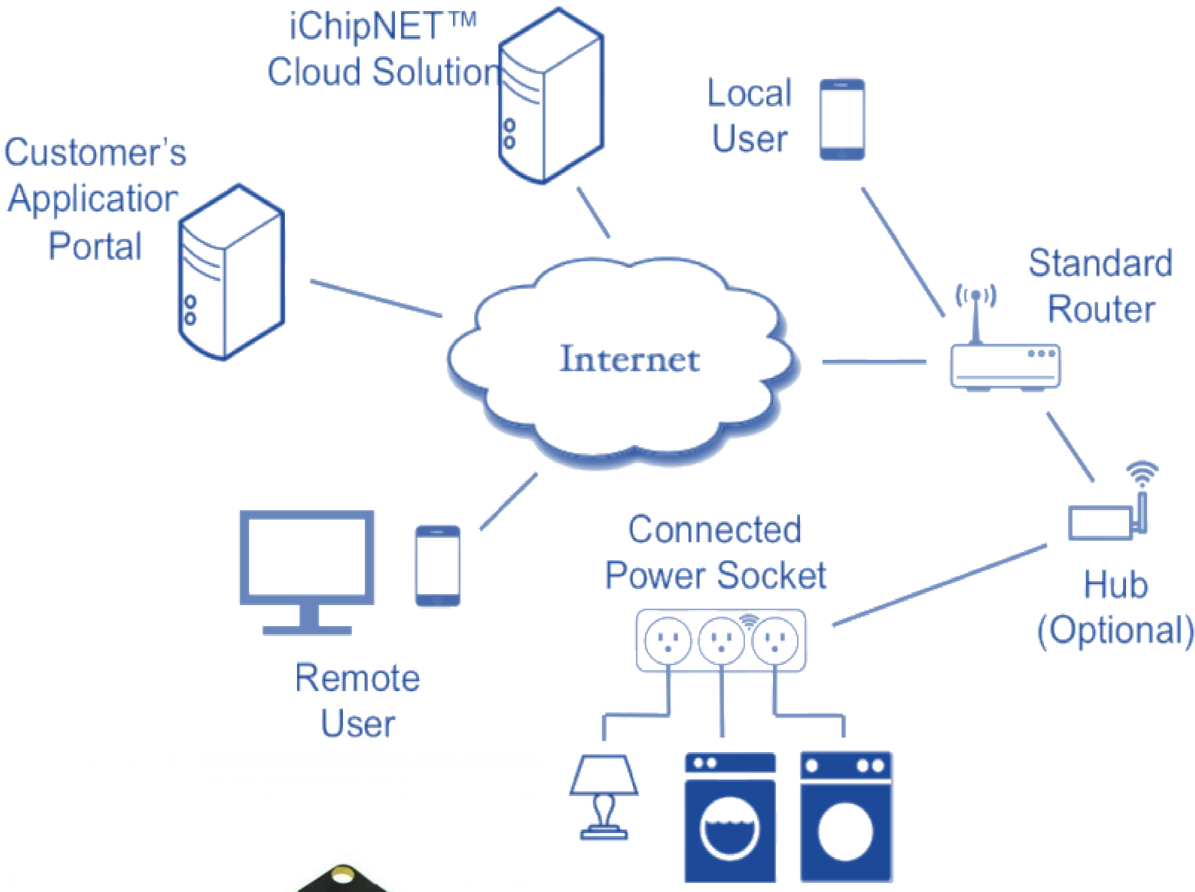
Internet of Things (IoT)

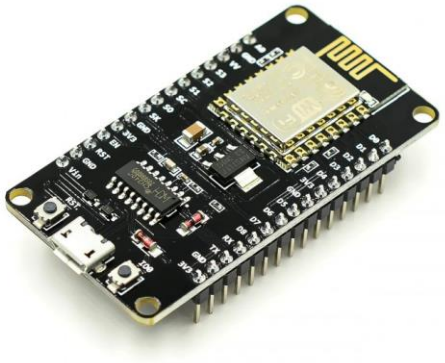
- A network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, actuators, and connectivity, enabling these objects to connect and exchange data.

- Inter-networking of embedded devices, sensors and computers

- Can collect and distribute large amount of data

- Connected devices:
  - ❖ Only need to be connected to a network
  - ❖ Need to be individually addressable
  - ❖ Do not necessarily need to be connected to the public internet

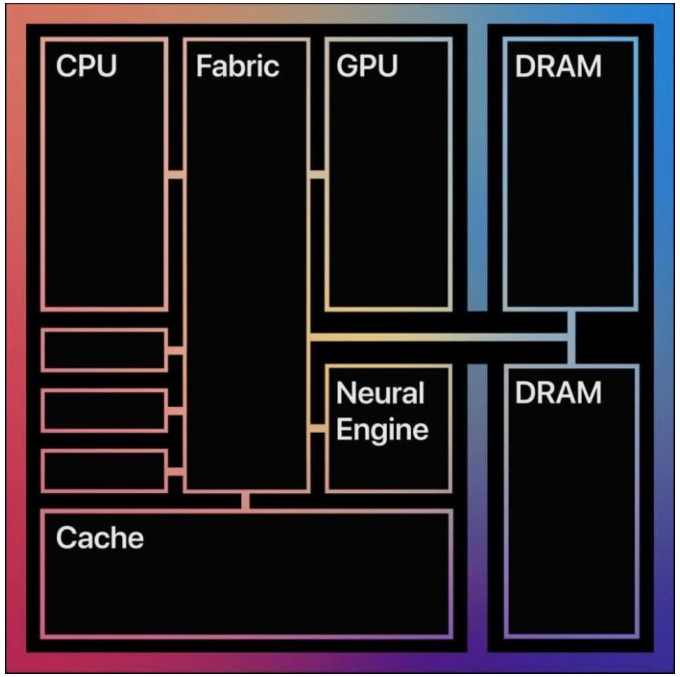




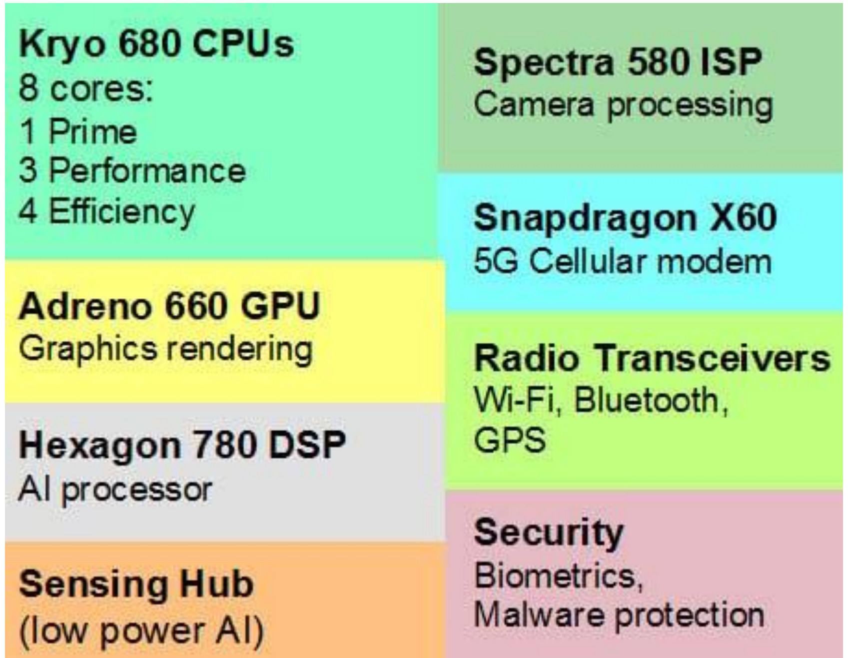
Node MCU ESP8266

System on Chip (SoC)

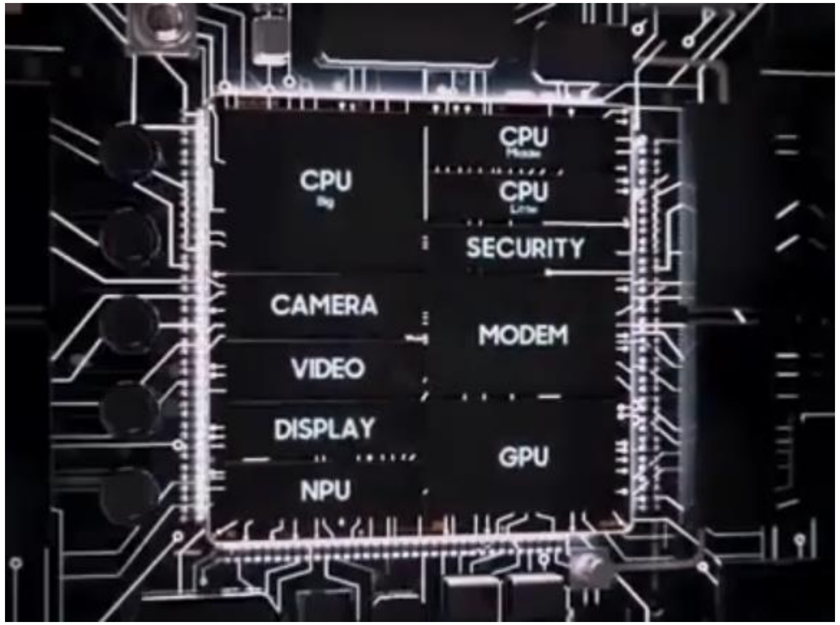
A System on Chip (SoC) is an integrated circuit that integrates most or all components of a computer or other electronic system. These components almost always include a central processing unit (**CPU**), **memory interfaces**, **on-chip input/output devices**, input/output interfaces, and **secondary storage interfaces**, often alongside other components such as **radio modems** and a graphics processing unit (**GPU**) – all on a single substrate or microchip. It may contain **digital, and also analog, mixed-signal**, and often radio frequency signal processing functions.



Apple M1 SoC



Qualcomm Snapdragon 888 SoC



Samsung's Exynos 9820 SoC

Real-life Examples of embedded systems:

Exceptionally versatile and adaptable, embedded systems can be found in all smart devices today. It is difficult to find a single portion of modern life that doesn't involve this technology. Here are some of the real-life examples of embedded system applications.

Automatic fare collection(AFC)

ATM systems

Factory robots

Medical devices

Self-service kiosks

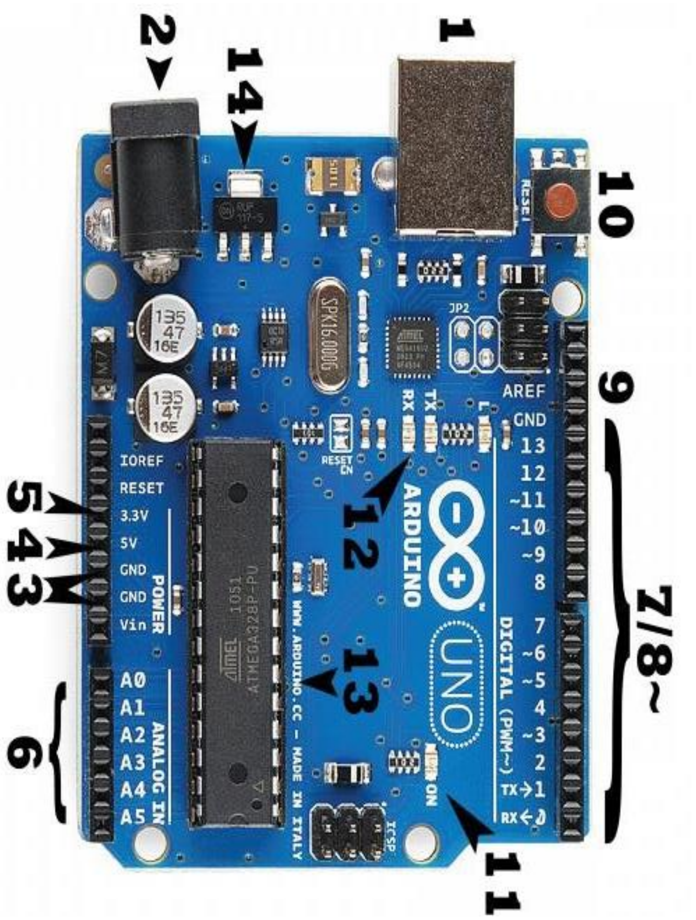
Electric vehicle charging stations


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

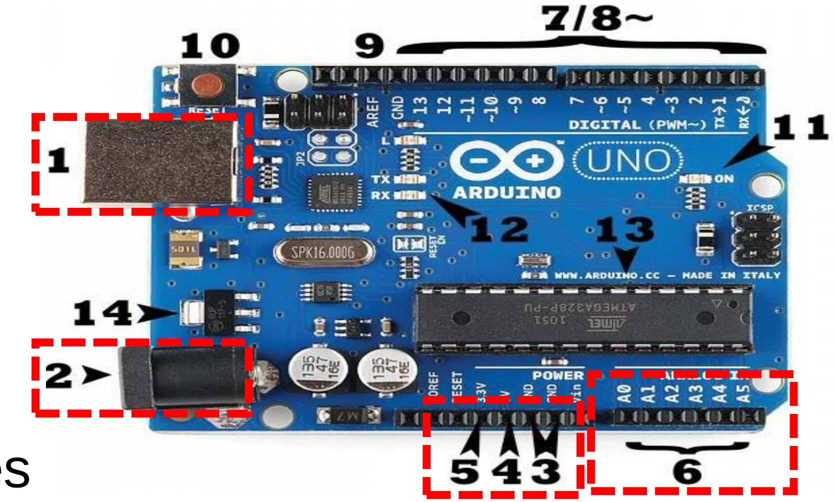
Architecture
of
Modern Microcontroller

Basics Features of Arduino UNO

- Consists of:
  - A programmable microcontroller (ATMega328) and
  - Integrated Design Environment or IDE
- Uses a computer to write and upload code (written in the easier version of C++) to the microcontroller
- Doesn’t need any additional programmer/burner
- Operating voltage ranges from 1.8 V to 5.5 V
- Digital pins: 14 (of which 6 provides PWM output)
- DC Current per I/O pin: 20 mA



Arduino UNO Pin Configuration



1. Power (USB/Barrel Jack)
Every Arduino board needs a power source through a USB cable coming from your computer **(1)** or a wall power supply that is terminated in a barrel jack **(2)**.

Pins (5V, 3.3V, GND, Analog, Digital, PWM, AREF):

GND (3): Short for 'Ground' and **5V (4) & 3.3V (5)**: used as supplies 5 volts of power, and the 3.3V pin supplies 3.3 volts of power.

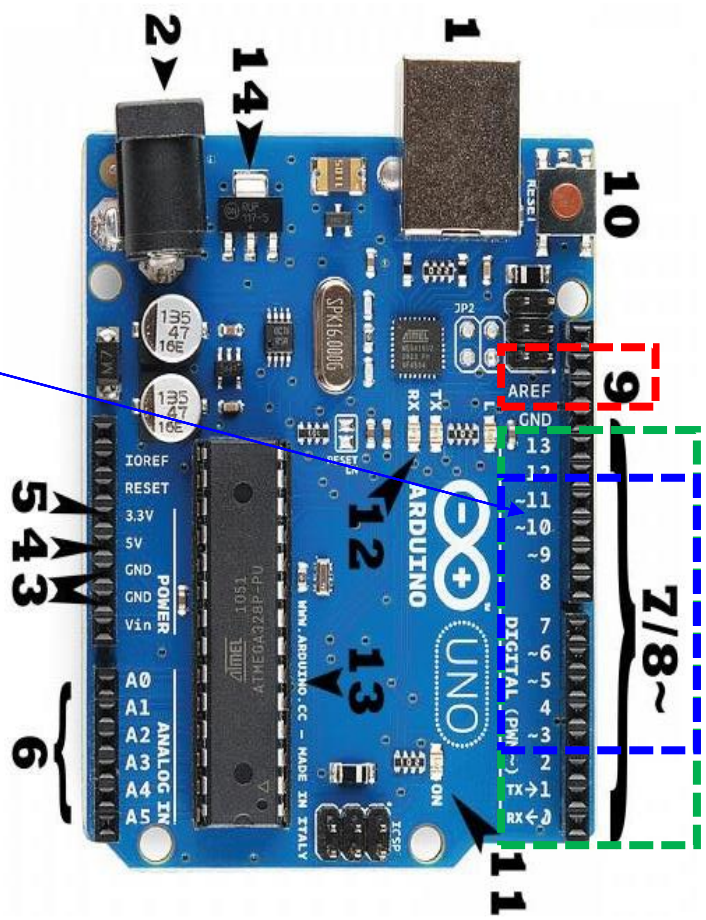
Analog Pins (6): The area of pins under the 'Analog In' label (A0 through A5 on the UNO) are Analog Input pins. These pins can read the signal from an analog sensor (like a temperature sensor) and convert it into a digital value that we can read.

Arduino UNO Pin Configuration

Digital (7): Across from the analog pins are the digital pins (0 through 13 on the UNO).

PWM (8): You may have noticed the tilde (~) sign next to some of the digital pins (3, 5, 6, 9, 10, and 11 on the UNO). These pins act as Pulse Width Modulation (PWM, think of these pins as being able to simulate analog output (like fading an LED in and out).

AREF (9): Analog reference input voltage pin to convert it into digital. It specifies the top value for the input range, and consequently each discrete step in the converted output. Most of the time you can leave this pin alone.



Arduino UNO Pin Configuration

Reset Button: Pushing it will temporarily connect the reset pin to ground and restart any code that is loaded on the Arduino.

Power LED indicator (11): If this light doesn't turn on, there's a good chance something is wrong. Time to re-check your circuit.

TX RX LEDs (12): These LEDs will give us some nice visual indications whenever our Arduino is receiving or transmitting data (for example, when we are loading a new program onto the board).

Main IC (Integrated Circuit) (13): The main IC on the Arduino is the ATmega328 microcontroller of the ATMEL company., where we have to upload the code.

Voltage Regulator: The voltage regulator **(14)** is used to control the amount of voltage that is let into the Arduino board. But Arduino should not be power by more than 20 V.

Example of a Modern Microcontroller: ATmega328

ATmega-328 is basically an Advanced Virtual RISC (AVR) micro-controller.

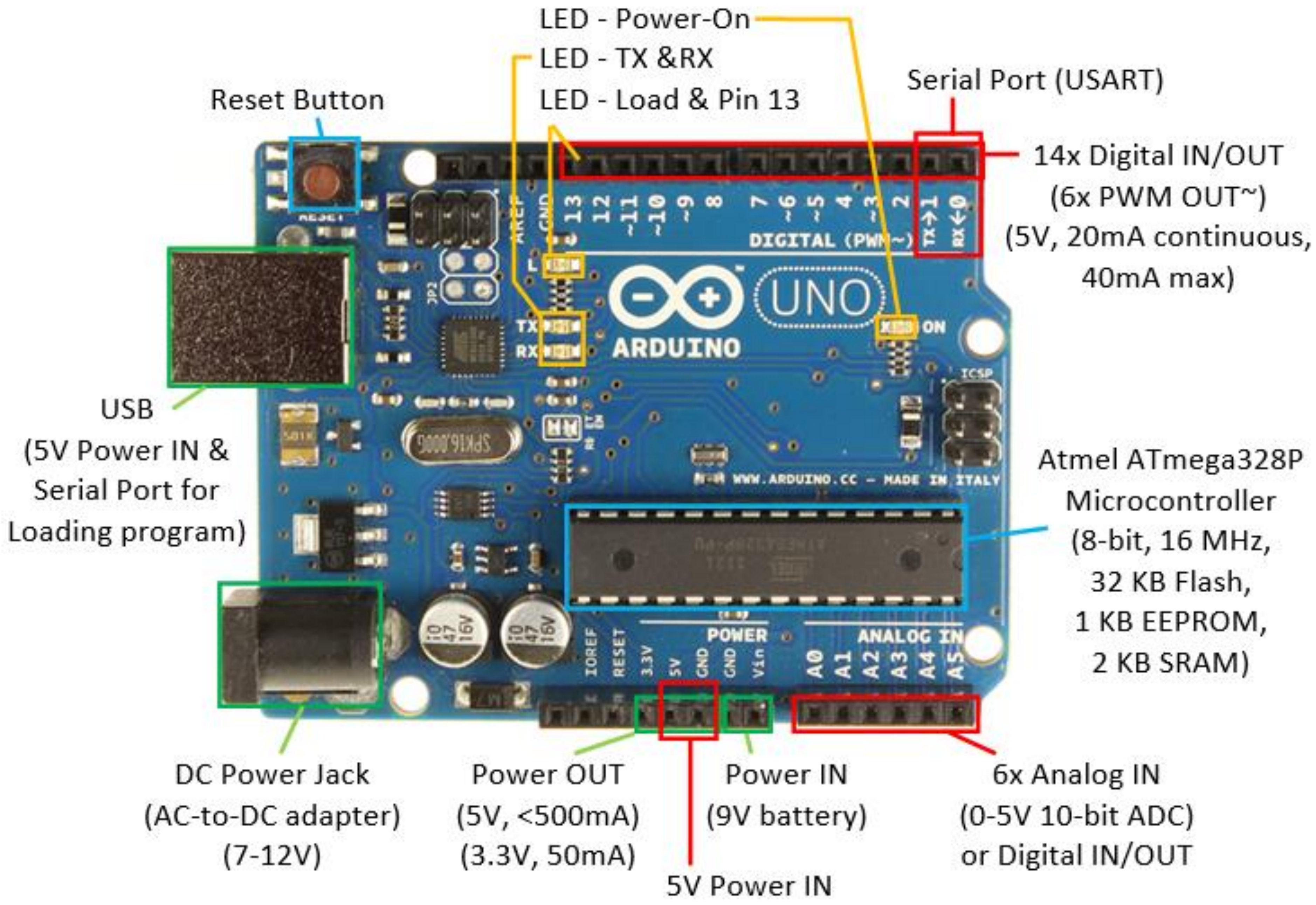
ATmega-328 has **32 KB internal built in memory**.

- ATmega328 supports the data up to **eight (8) bits and have 28 Pins.** AVR Microcontroller, manufactured by Microchip, follows RISC Architecture and **has a flash type program memory of 32 KB**.
- ATmega328 has **1 KB Electrically Erasable Programmable Read Only Memory (EEPROM)**. For a EEPROM, if the electric supply is removed from the micro-controller it can store the data. After providing electric supply it can provide previous results.
- ATmega328 has **2 KB Static Random Access Memory** (SRAM).
- It has **8 Pin for ADC operations**, which all combines to form Port A (PA0-PA7).

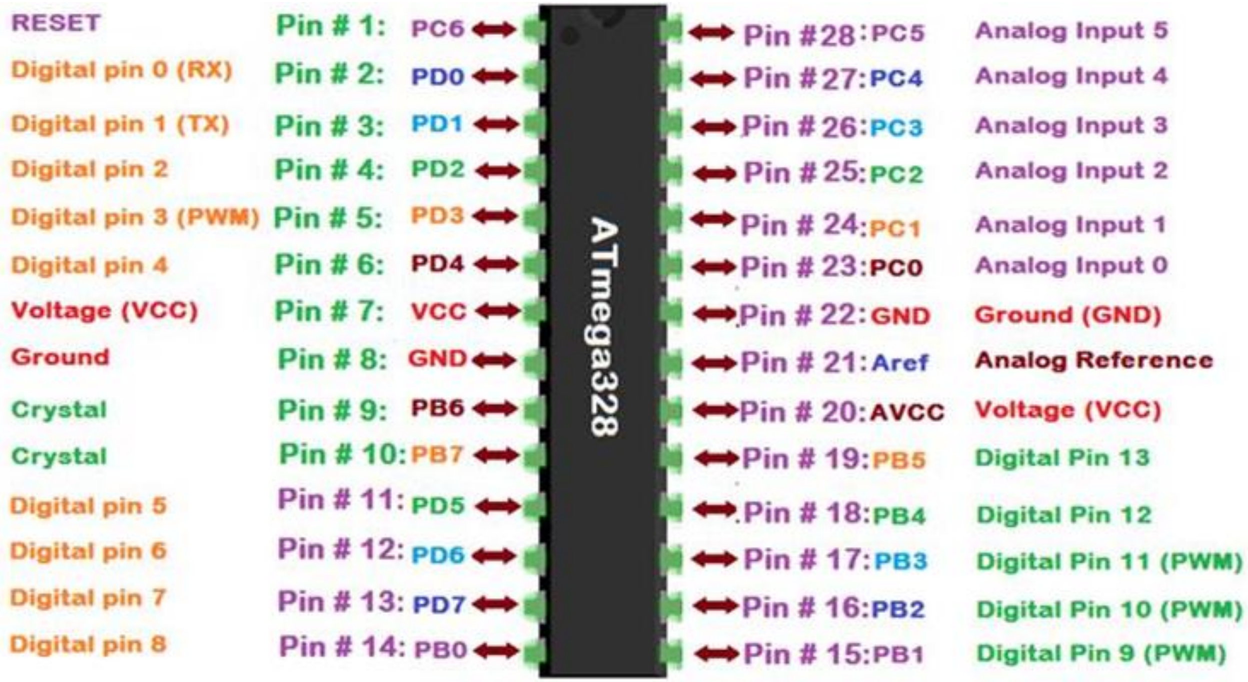
Example of a Modern Microcontroller: ATmega328

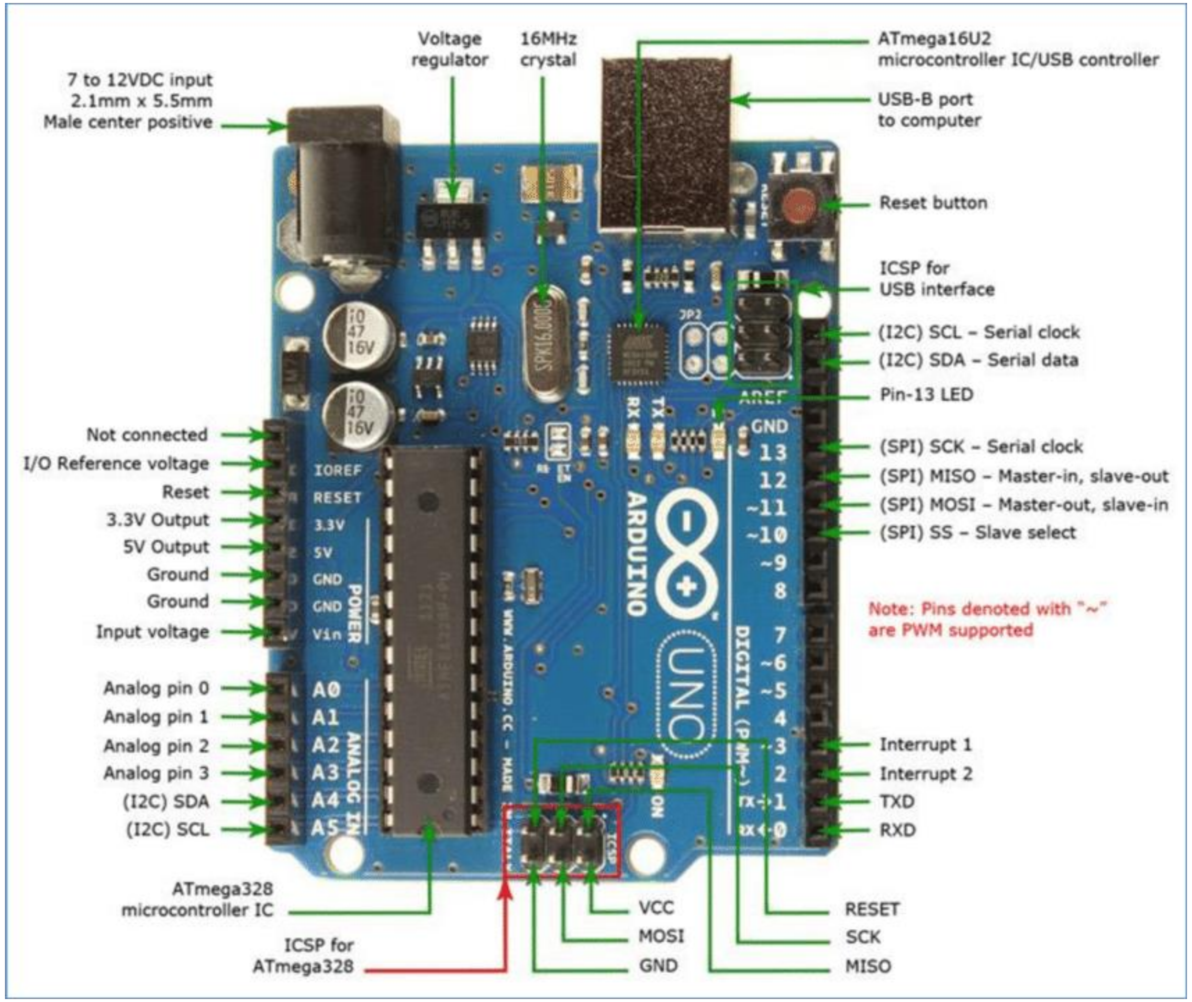
- It also has 3 built in Timers, two of them are 8 Bit timers while the third one is 16-Bit Timer.
- Arduino UNO is based on Atmega328 Microcontroller. It is UNO's heart.
- It operates ranging from 3.3 V to 5.5 V but normally we use 5 V as a standard.
- Its excellent features include the cost efficiency, low power dissipation, programming lock for security purposes, real timer counter with separate oscillator.
- It is normally used in Embedded System applications.
- Moreover, ATmega328 has several different features which makes it the most popular device in today's market. These features consist of advanced RISC architecture, good performance, 6 PWM pins, programmable Serial USART, programming lock for software security, throughput up to 20 MIPS etc.

Overview of Arduino UNO Board



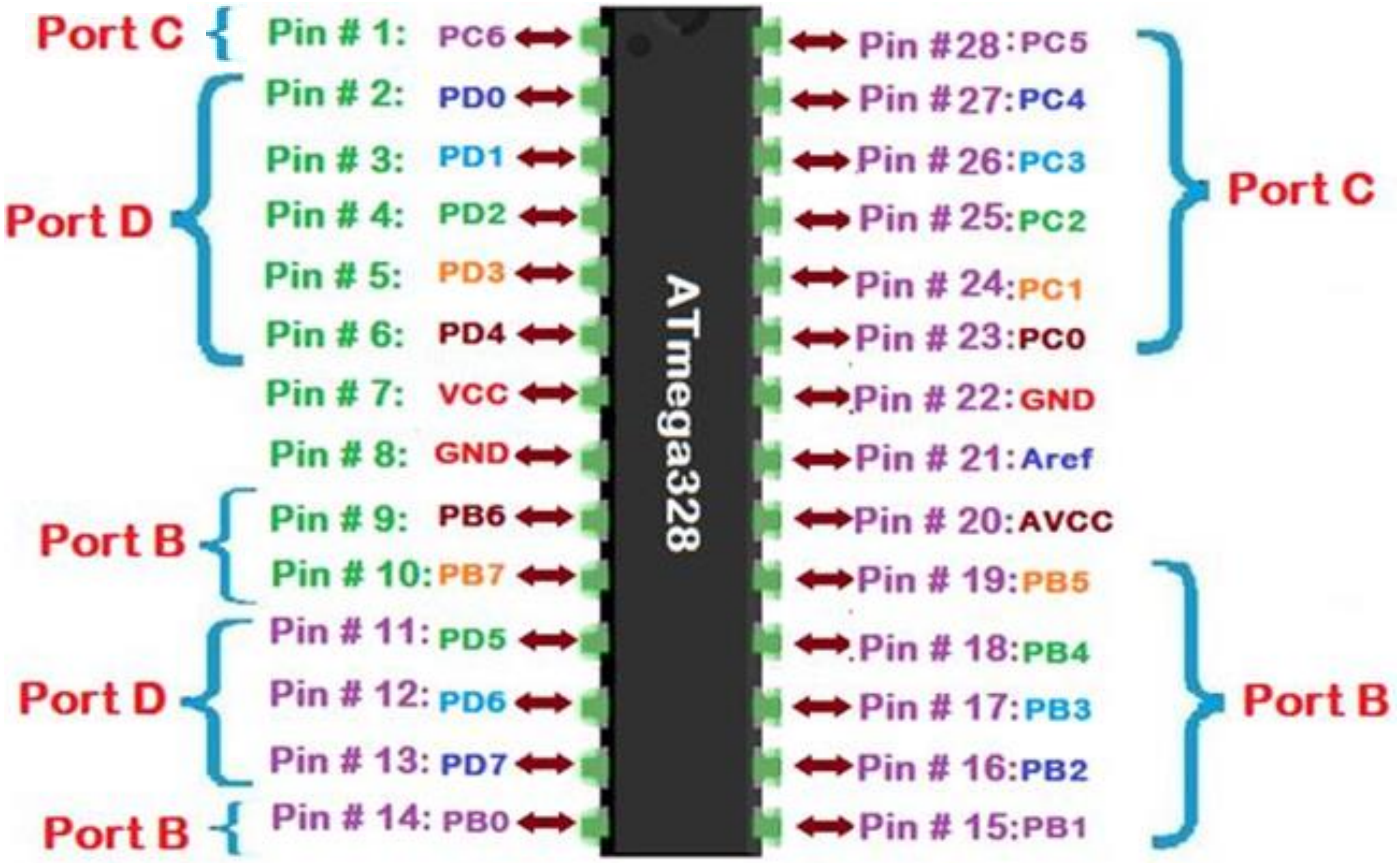
Arduino ATmega328 Pin Configuration





Arduino board and ATmega328 pin Mapping

Arduino ATmega328 Port Configuration



Arduino ATmega328 Pin Description

Functions associated with the pins must be known in order to use the device appropriately:

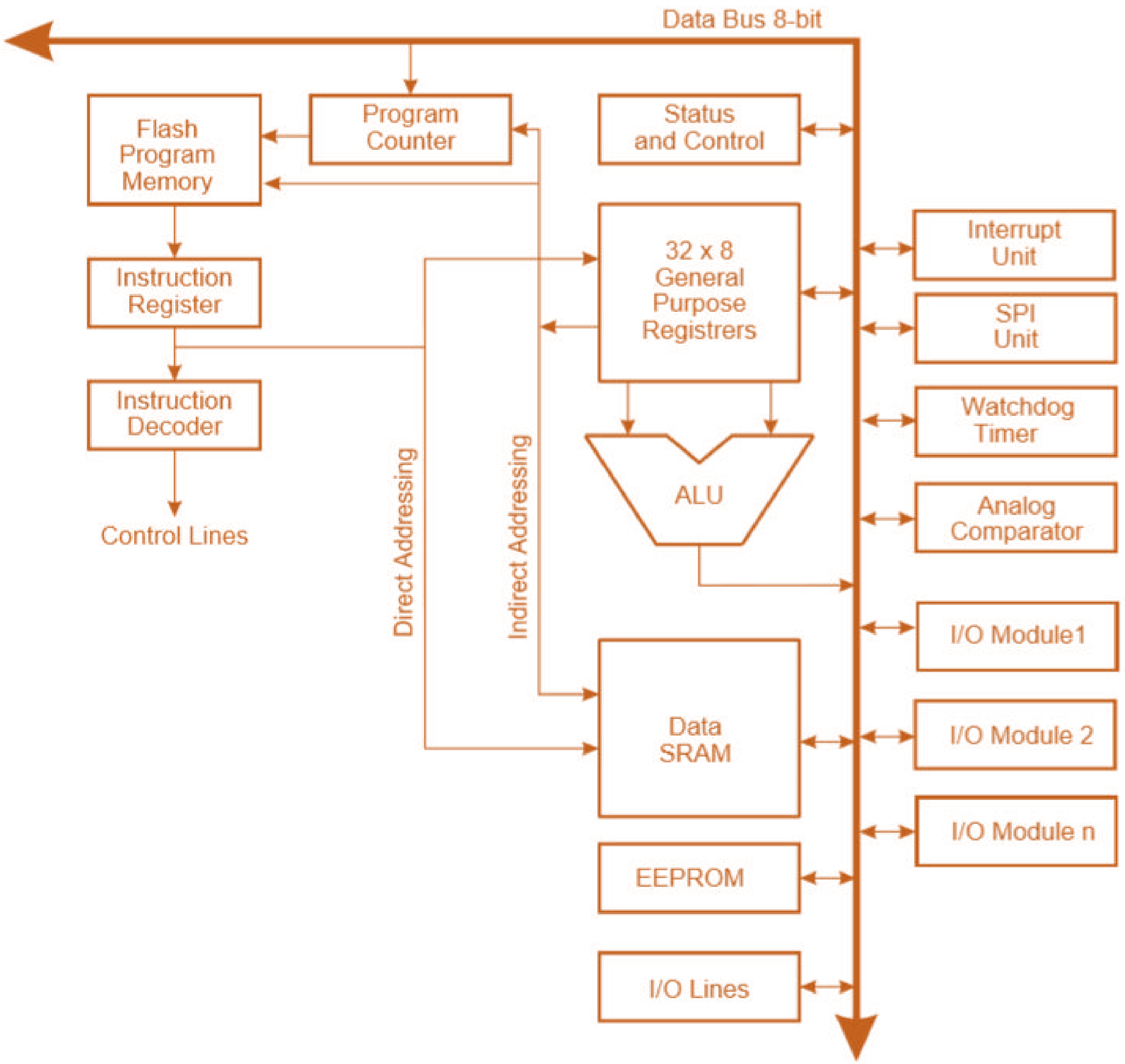
- VCC is a digital voltage supply.
- AVCC is a supply voltage pin for analog to digital converter.
- GND denotes Ground and it has a 0V.

ATmega-328 pins are divided into different ports which are given in detail below:

- ✓ Port A consists of the pins from PA0 to PA7. **These pins serve as analog input to convert from analog to digital. Port A** acts as **an eight (8) bit bidirectional input/output port** if ADC is not required.
- ✓ Port B consists of the pins from PB0 to PB7. This port is an **8 bit bidirectional port having an internal pull-up resistor.**
- ✓ Port C consists of the pins from PC0 to PC7. The **output buffers of port C has symmetrical drive characteristics with source capability as well high sink.**
- ✓ Port D consists of the pins from PD0 to PD7. It is also **an 8 bit input/output port having an internal pull-up resistor.**
- ✓ AREF is an **analog reference pin for analog to digital converter**.

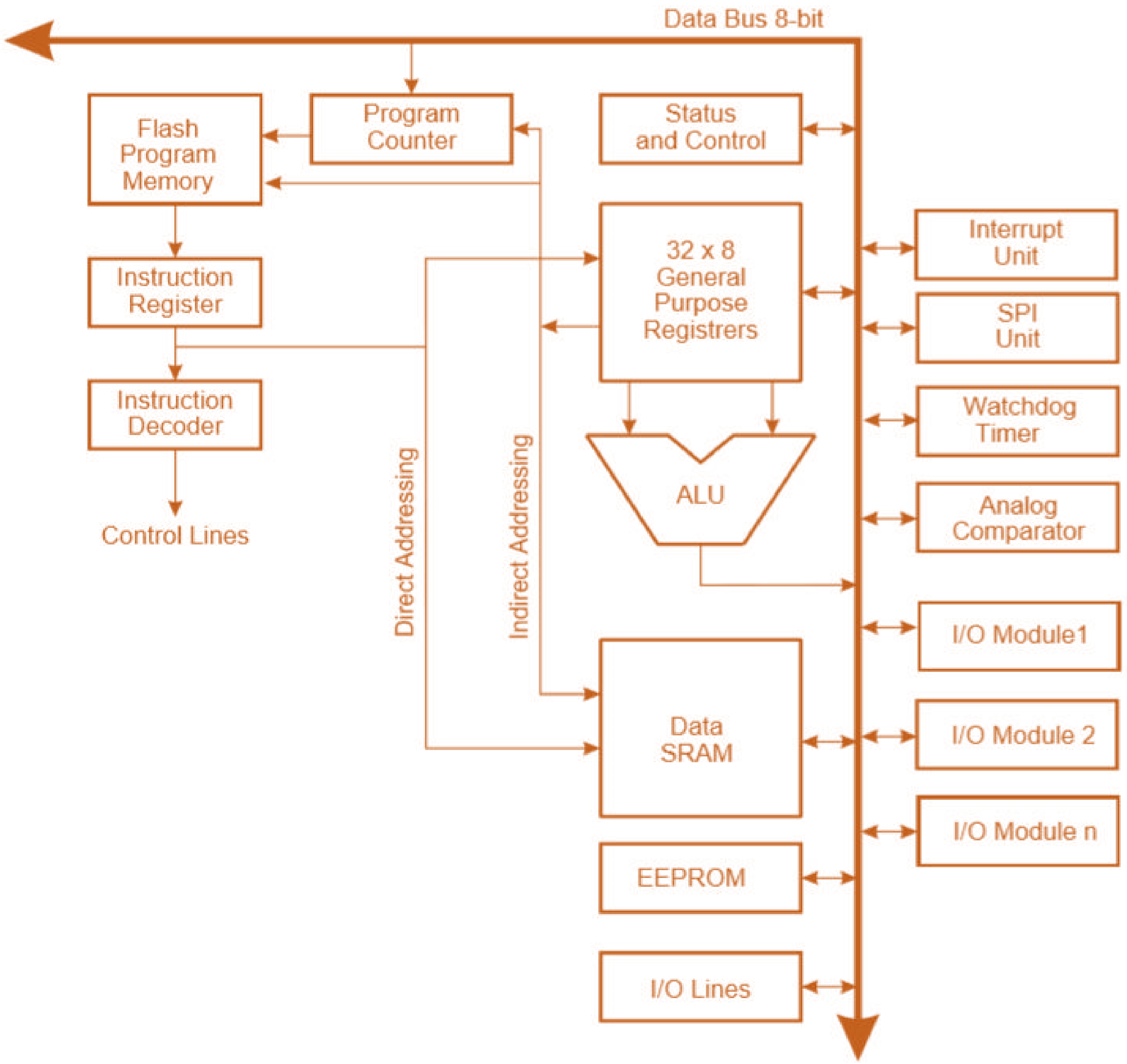
Internal Architecture of ATmega328

1. The ATmega328/P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC (reduced instruction set computer) architecture.
2. The clock is controlled by an external 16 MHz Crystal Oscillator.
3. The data is uploaded in serial via the port.
4. Instructions are sent to instruction register and it decodes the instructions on the same clock pulse.
5. In general purpose registers the registers are of 8-bit (used to store data for normal calculations and results) but there are 3 16-bit registers also (used to store data of timer counter).



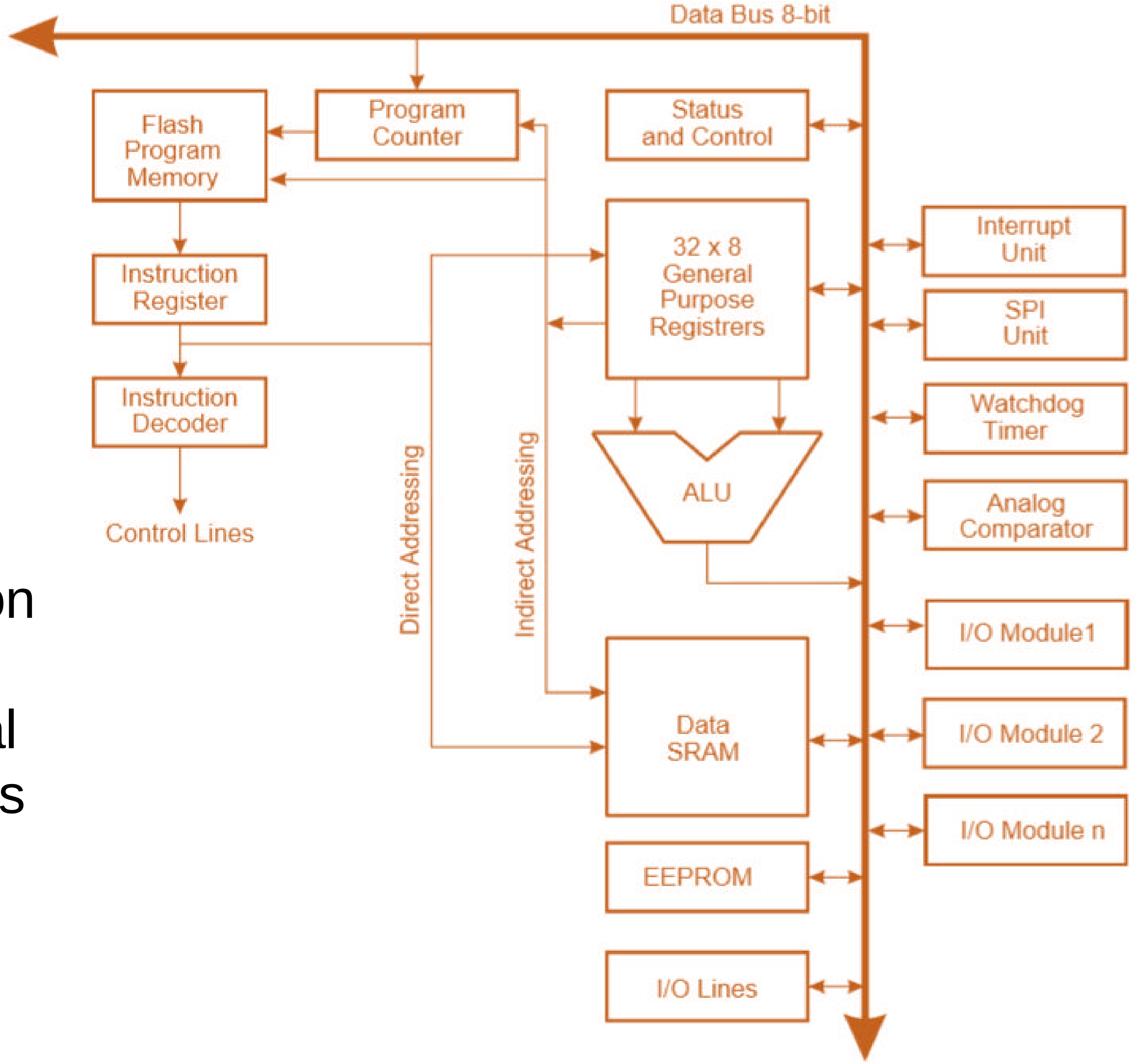
Internal Architecture of ATmega328

6. EEPROM stores data permanently even if the power is cut out.
7. Interrupt Unit checks whether there is an interrupt for the execution of instruction to be executed in ISR (Interrupt Service Routine).
8. Serial Peripheral Interface (SPI) is used to send data between microcontroller and small peripherals such as Camera, Display, SD cards, etc. It uses separate clock and data lines, along with a select line to choose the device you wish to talk to.
9. Watchdog timer is used to detect and recover from MCU malfunctioning when the system hangs or freezes due to errors in the code written or due to conditions that may arise due to hardware issues.



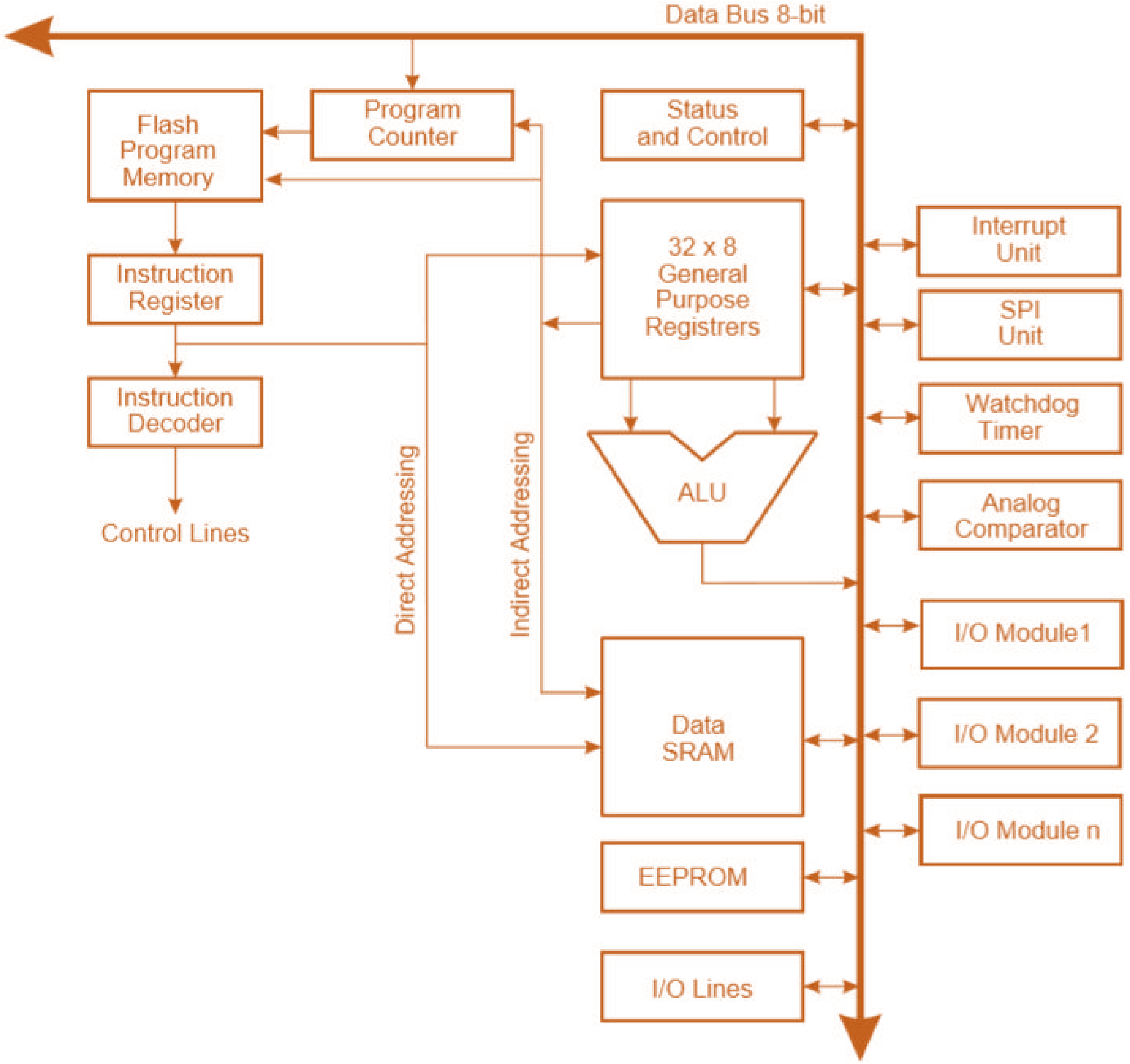
Internal Architecture of ATmega328

10. Analog comparator compares the input values on the positive and negative pin, when the value of positive pin is higher the output is set.
11. Status and control is used to control the flow of execution of commands by checking other blocks inside the CPU at regular intervals.
12. ALU (Arithmetic and Logical Unit): The high performance AVR ALU operates in direct connection with the all 32 general purpose registers. Within a single clock cycle, arithmetic operations b/w general purpose registers are executed. The ALU operations are divided into 3 main categories– arithmetic, logical and bit-function.



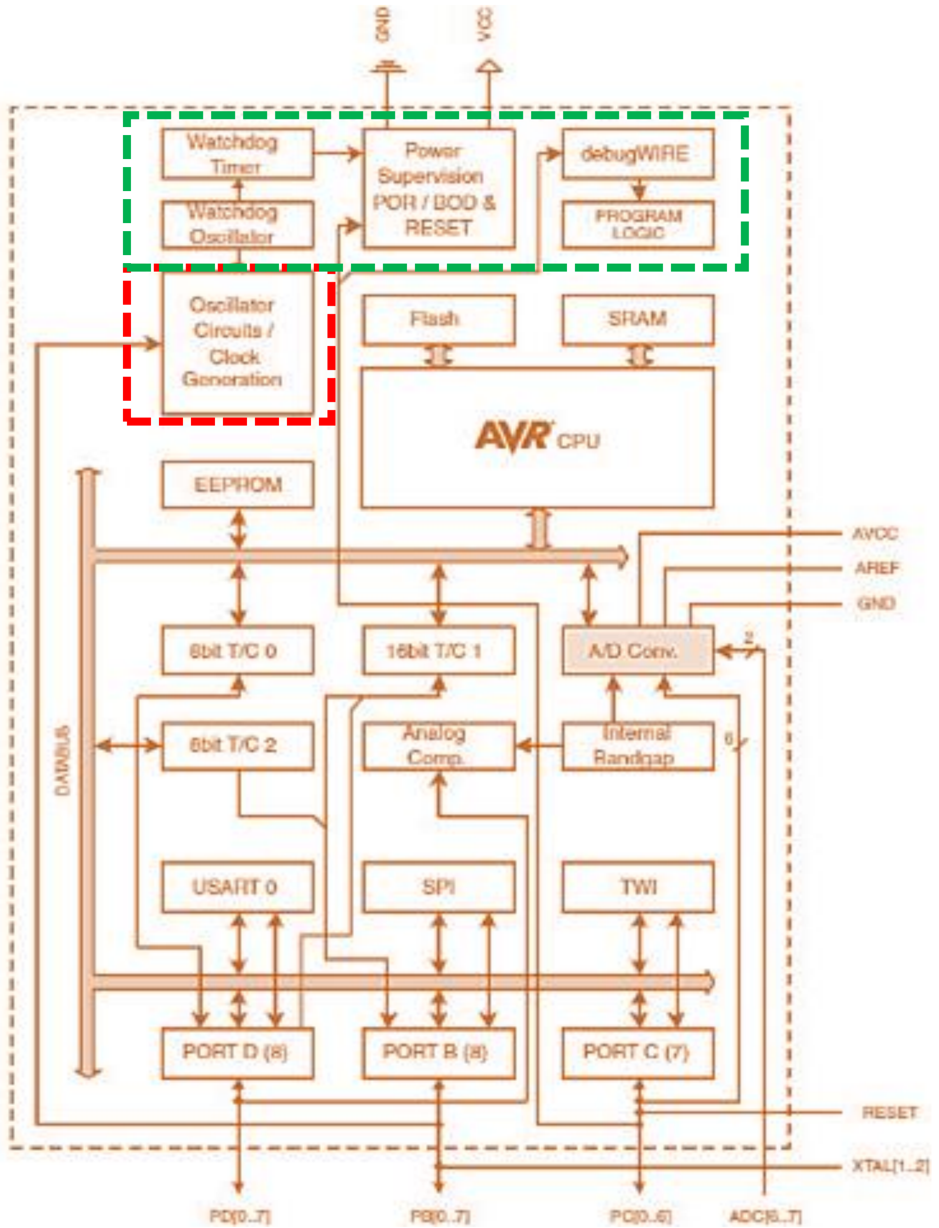
Internal Architecture of ATmega328

10. I/O pins The digital inputs and outputs (digital I/O) on the Arduino are what allow you to connect the Arduino sensors, actuators, and other ICs. Learning how to use them will allow you to use the Arduino to do some really useful things, such as reading switch inputs, lighting indicators, and controlling relay outputs.



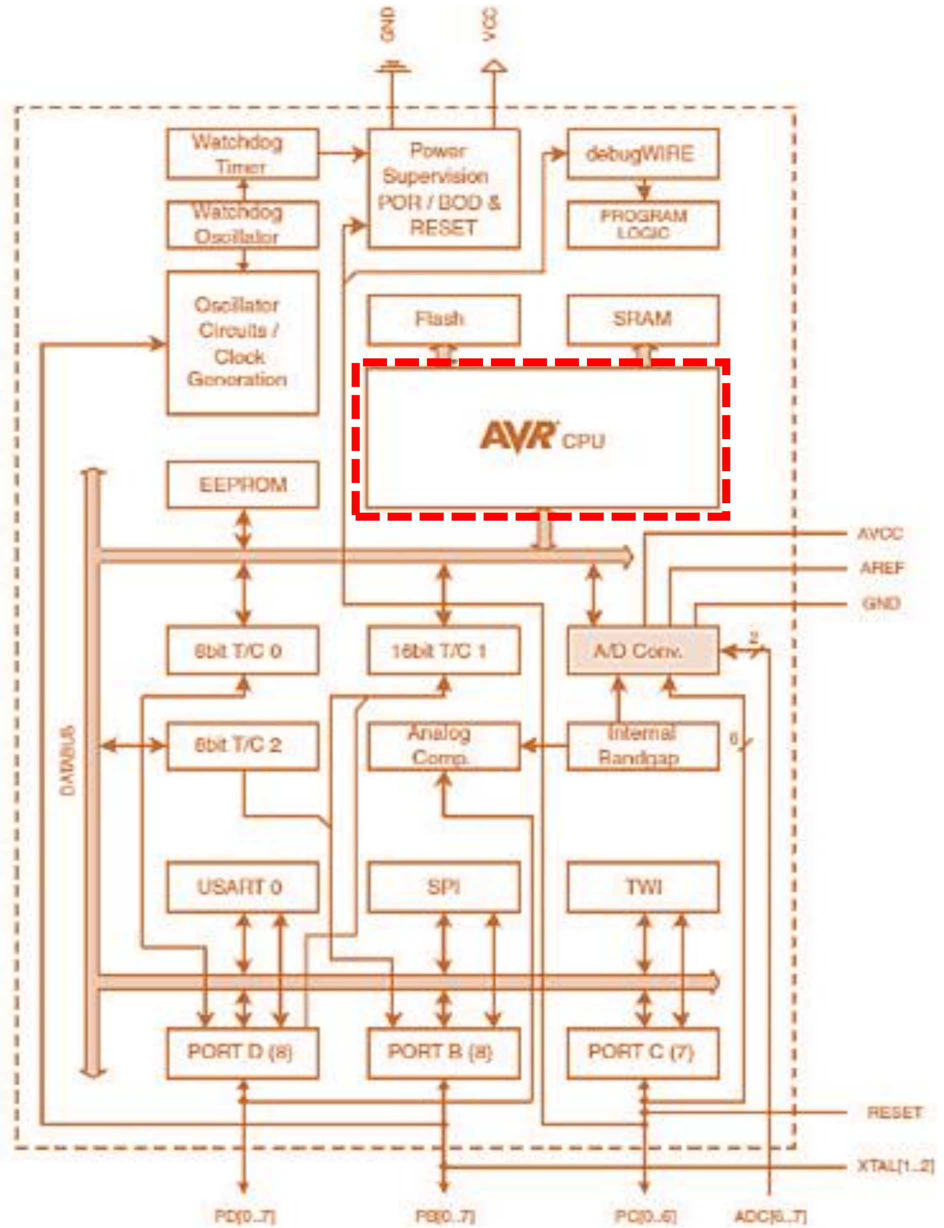
Internal Architecture of AVR

- 6 different oscillators to serve as clock sources
- 5 different clock outputs from the AVR clock control Unit
- CPU clock routed to part of the system concerned with the operation of AVR core
- I/O clock used by most I/O modules
- Flash clock controls operation of the flash interface
- Asynchronous timer clock allows asynchronous timer/counter to be clocked directly by external clock
- ADC Clock is dedicated to the ADC module



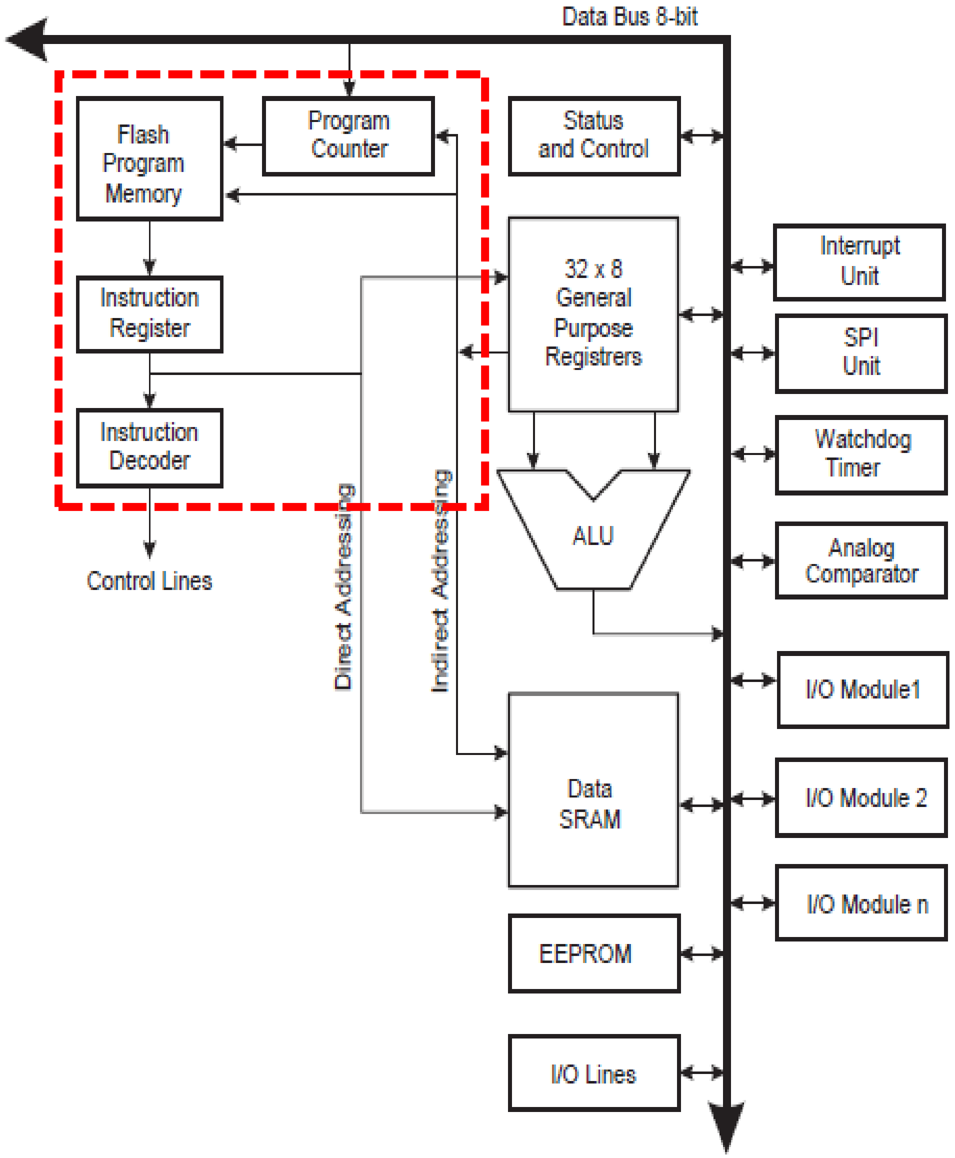
Internal Architecture of AVR

- CPU is the Central Processing Unit
- The main function of the CPU core is to ensure correct program execution.
- The CPU must therefore be able to access memories, perform calculations, control peripherals, and handle interrupts.
- In order to maximize performance and parallelism, the AVR uses a Harvard architecture – with separate memories and buses for program and data.



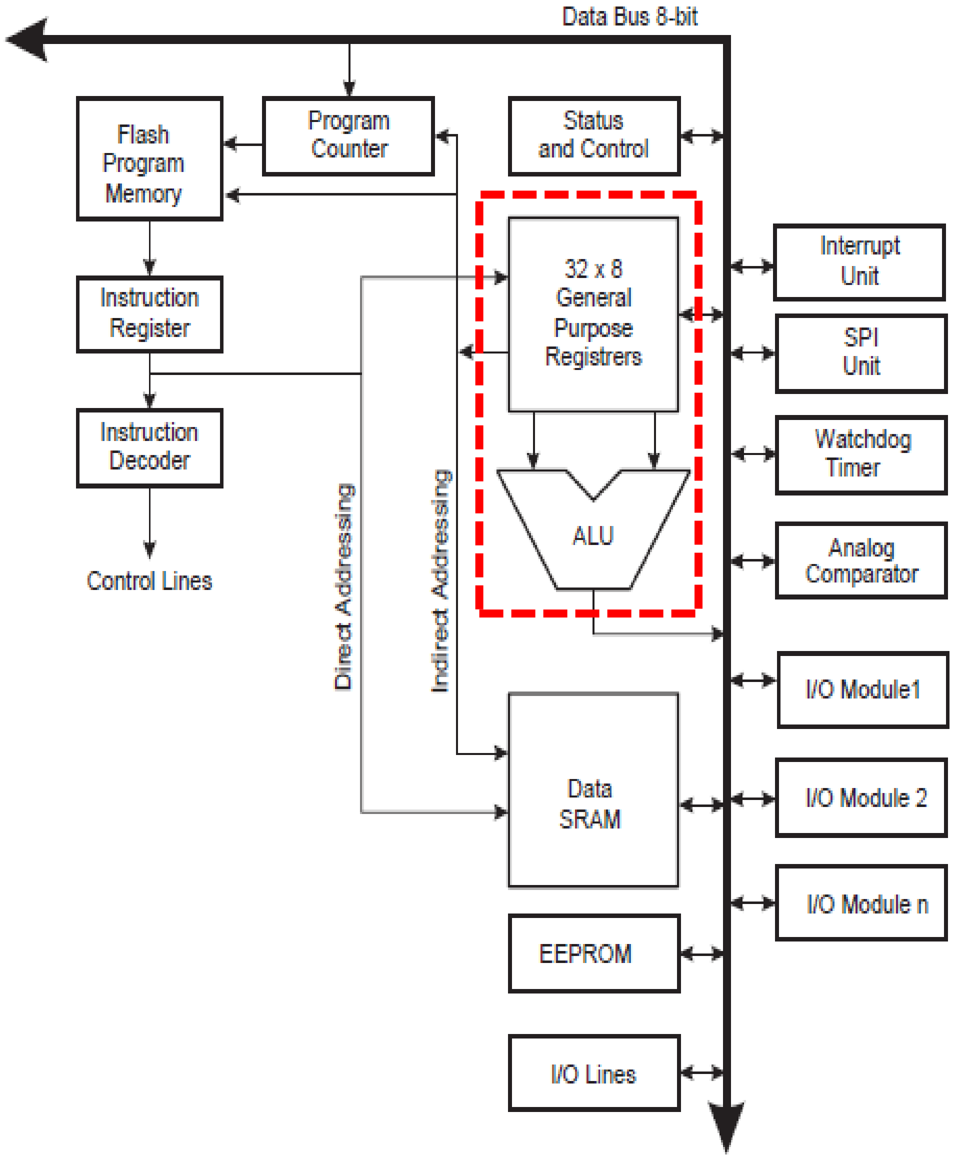
Instruction Fetch and Decode

- Separate memories and busses for program and data (Harvard Architecture)
- Instructions in program memory are executed with single-level pipelining
- The next instruction is pre-fetched from program memory while previous instruction is being executed
- Instructions are executed every clock cycle
- Program counter points towards the next instruction to be executed



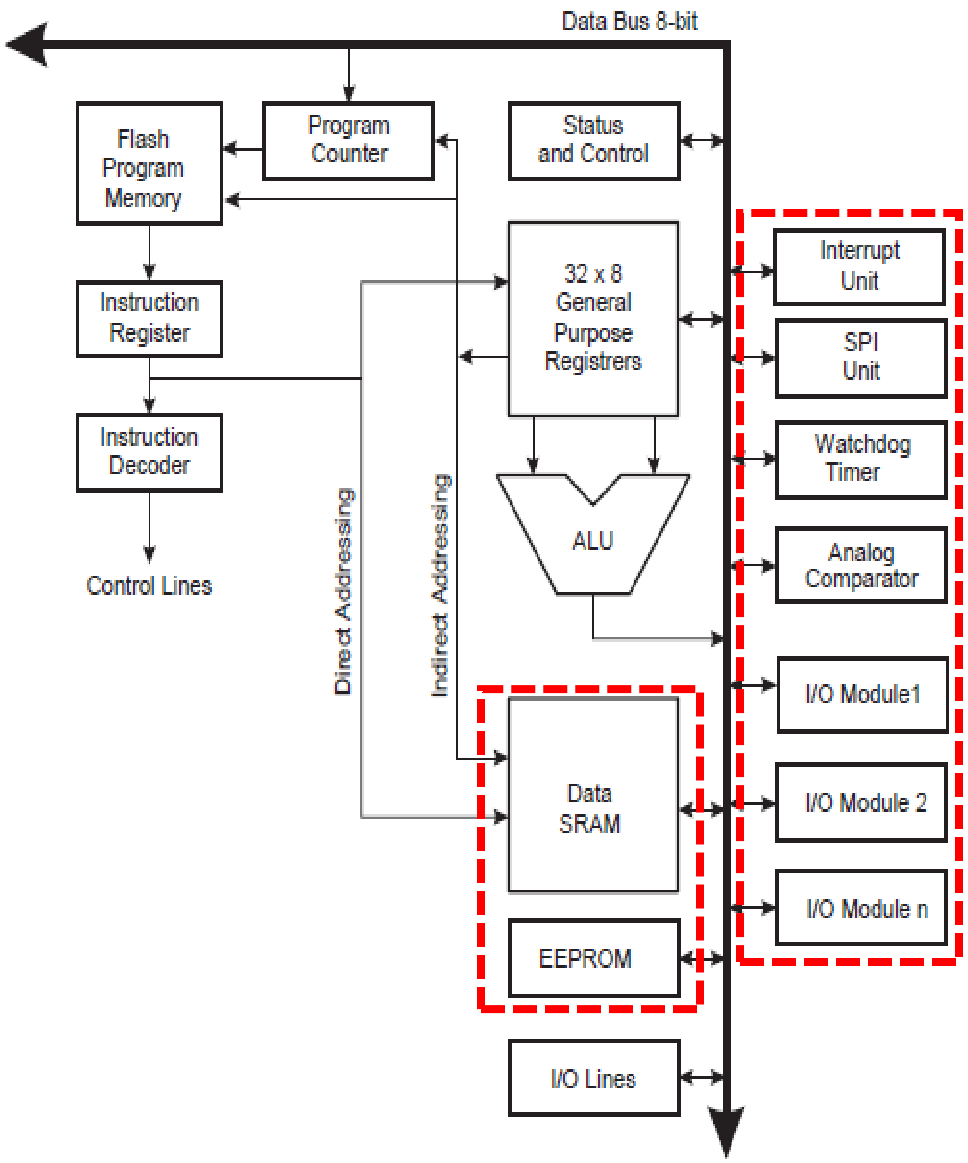
ALU Instructions

- ALU supports both arithmetic and logic operations between:
  - Registers
  - A constant and a register
- Single register operations can also be executed
- Status register updated after arithmetic operations to reflect information about the operation
- In typical ALU operations, in a single clock cycle:
  - Operation is executed
  - Result is stored back in the register



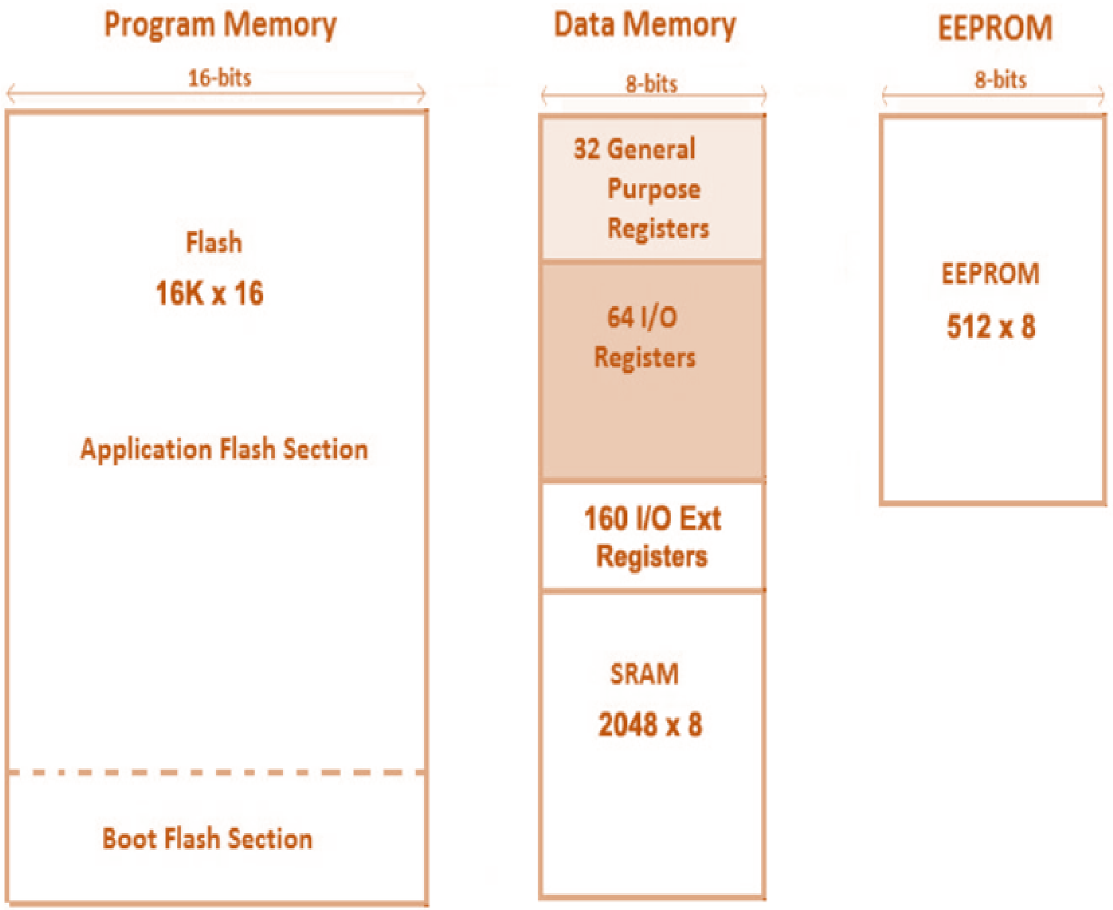
I/O and Special Functions

- When used as general digital I/O ports, all AVR ports have true read-modify-write functionality.
- General digital I/O pins are:
  - Bi-directional
  - Optional internal pull-ups
  - When configured as an input pin, pull up resistor is activated
  - When configured as an output pin, pull up resistor is turned off
- Most digital I/O pins have alternate functions



ATmega328 Memory

- ATmega 328 has **three types of memories:**
  - **Flash Memory (Program Memory)** has **32 KB** capacity. It has an address of 15 bits. It is a non volatile memory. It used for permanent saving program (CODE) being executed. The AVR executes programs stored in program memory only.
  - SRAM stands for **Static Random Access Memory. It is also called Data Memory. It has 2 KB capacity.** It is a volatile memory i.e. data will be removed after removing the power supply.
  - EEPROM stands for Electrically Erasable Programmable Read Only Memory. **It has 1 KB capacity. It has a long term data.**



ATmega328 General Purpose Registers

- ATmega-328 has thirty two **(32) General Purpose Registers (GPR).**
- All these registers are the **part of Static Random Access Memory (SRAM).**
- These **GPRs** are 8-bit in size.
- Most instructions operating on the Register file:
  - ✓ Have direct access to all registers
  - ✓ Most are single clock cycle execution

7 0	Addr.
R0	0x00
R1	0x01
R2	0x02
...	
R13	0x0D
R14	0x0E
R15	0x0F
R16	0x10
R17	0x11
...	
R26	0x1A
R27	0x1B
R28	0x1C
R29	0x1D
R30	0x1E
R31	0x1F

Thanks for attending….

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