

# AVR Microcontroller Architecture

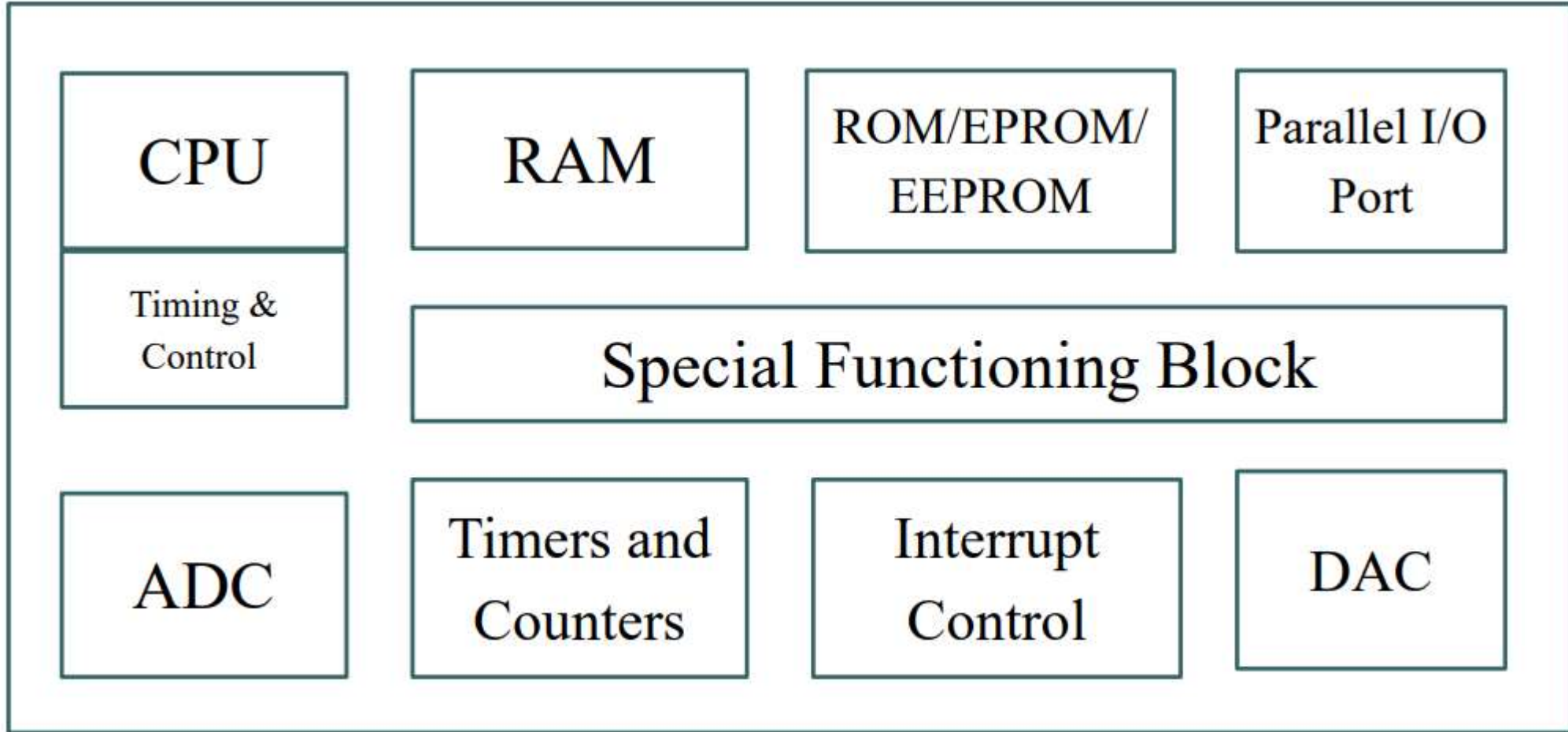
Advanced Virtual RISC

RISC (**Reduced Instruction Set Computer**) is a microprocessor design that performs fewer computer instructions at higher speeds.

## Introduction to microcontroller :

- A microcontroller is a small and low-cost microcomputer, which is designed to perform the specific tasks of embedded systems like displaying microwave's information, receiving remote signals, etc.
- Microcontroller is a compressed micro computer manufactured to control the functions of embedded systems in office machines, robots, home appliances, motor vehicles, and a number of other gadgets. A microcontroller is comprises components like – memory, peripherals and most importantly a processor.
- Microcontroller is also known as “Computer-on-a-Chip”.
- It is named so, because not only the CPU, but RAM, ROM, I/O ports, Timer/Counter, Serial I/Os all are put together on a single microcontroller chip.
- A microcontroller also called an embedded controller because the microcontroller and its support circuits are often built into, or embedded in, the devices they control. ☐ A microcontroller is available in different word lengths like microprocessors (4bit, 8bit, 16bit, 32bit, 64bit and 128-bit microcontrollers are available today).

## Block Diagram of Microcontroller



# Memory

- Memory spaces such as RAM, ROM, EPROM or EEPROM are there to store data and programs.
- For data storage, volatile memory RAM is used while for the program and operating parameter storage ROM and other memory spaces are used.
- A microcontroller usually has a certain amount of RAM and ROM (EEPROM, EPROM, etc) or flash memories for storing program source codes.

# Timers/counters

- This is the one of the useful function of a microcontroller.
- A microcontroller may have more than one timer and counters.
- The timers and counters provide all timing and counting functions inside the microcontroller.
- The major operations of this section are performed clock functions, modulations, pulse generations, frequency measuring, making oscillations, etc.
- This also can be used for counting external pulses.
- There is a watchdog timer. A watchdog timer is a portion of hardware that can be used to automatically detect software anomalies/malfunctions and reset the processor if any occur

# Parallel input/output ports

- Parallel input/output ports are mainly used to drive/interface various devices such as LCD'S, LED'S, printers, memories, etc to a microcontroller.

# Serial ports

- Serial ports provide various serial interfaces between a microcontroller and other peripherals like parallel ports.

# Interrupt control

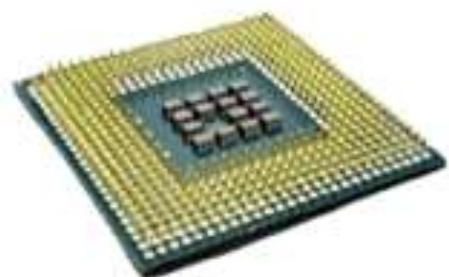
- The interrupt control used for providing interrupt (delay) for a working program.
- The interrupt may be external (activated by using interrupt pin) or internal (by using interrupt instruction during programming).

## Special functioning block

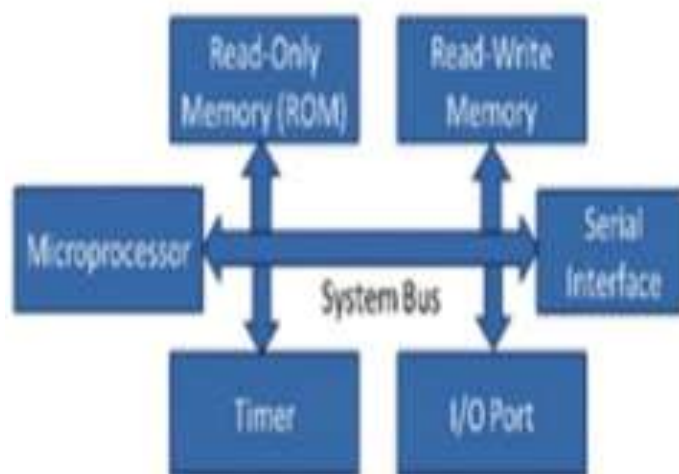
- Some microcontrollers used only for some special applications (e.g. space systems and robotics) these controllers containing additional ports to perform such special operations.
- This considered as special functioning block.

## Advantages of microcontroller

- The main advantages of microcontrollers are given.
- Microcontrollers act as a microcomputer without any external digital parts.
- As the higher integration inside microcontroller reduces cost and size of the system.
- Usage of a microcontroller is simple, easy to troubleshoot and system maintaining.
- Most of the pins are programmable by the user for performing different functions.
- Easily interface additional RAM, ROM, I/O ports.
- Low time required for performing operations.



# Microprocessor vs Microcontroller

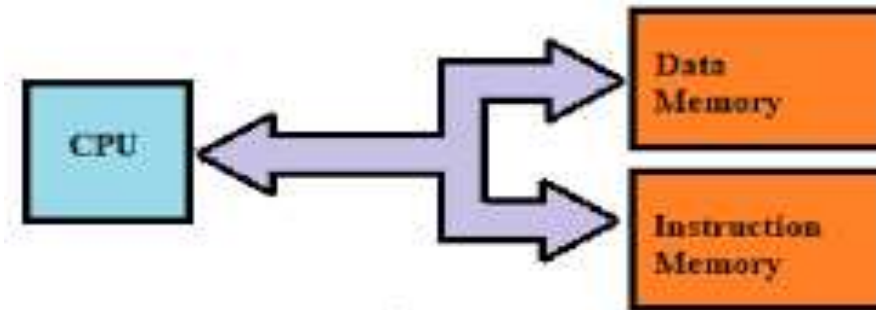


Microcontroller	Read-Only Memory	Read-Write Memory
Timer	I/O Port	Serial Interface

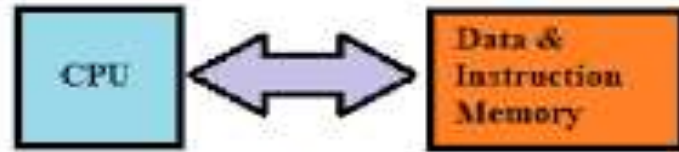
## Comparison between microprocessor and microcontroller

Sr. No.	Microprocessors	Microcontroller
1	It is only a general purpose computer CPU	It is a microcomputer itself
2	Memory, I/O ports, timers, interrupts are not available inside the chip	All are integrated inside the microcontroller chip
3	Systems become bulkier and expensive.	Make the system simple, economic and compact
4	Microprocessors have many opcodes for moving the data from external memory to CPU.	Microcontrollers have one or two opcodes for moving the data.
5	Higher accessing time required	Low accessing time
6	Very few number of bit handling instructions	Many bit handling instructions
7	Very few pins are programmable	Most of the pins are programmable
8	Widely Used in modern PC and laptops	widely used in small control systems and dedicated applications

- a) Harvard Architecture, b) Von Neumann Architecture



a)



b)

## Applications of microcontroller

### **1. Consumer Electronics Products:**

- Toys, Cameras, Robots, Washing Machine, Microwave Ovens etc. [any automatic home appliance]

### **2. Instrumentation and Process Control:**

- Oscilloscopes, Multi-meter, Leakage Current Tester, Data Acquisition and Control etc.

### **3. Medical Instruments:**

- ECG machine, Electronic Cardiac Monitor, Blood gas analyzer, Blood Glucose Monitor, MRI Machine etc.

### **4. Communication:**

- Cell Phones, Telephone Sets, Answering Machines etc.

### **5. Office Equipment:**

- Fax, Printers, etc.

### **6. Multimedia Application:**

- Mp3 Player, PDAs, optical players, digital camcorders etc.

### **7. Automobile:**

- Speedometer, Auto-breaking system etc.

### **8. Robotics:**

- Domestic or household robots, Industrial robots, Medical robots, Service robots, Military robots, Entertainment robots, Space robots,

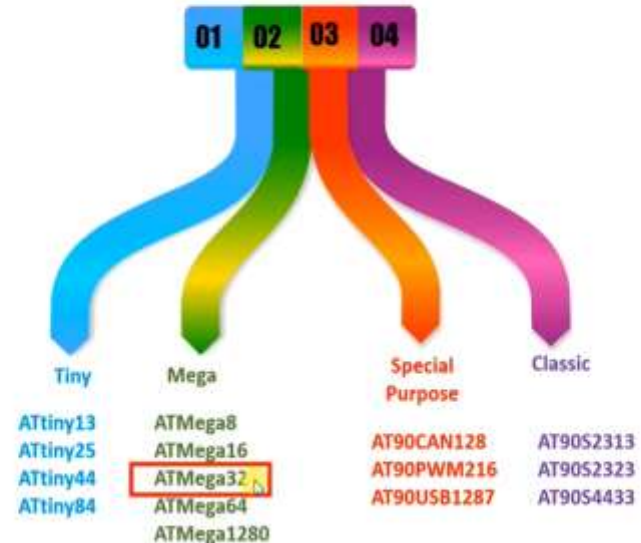
# Introduction to AVR

- AVR MCUs are extremely popular MCUs used in various application specially in project prototyping and embedded devices.
- AVR is a **8-bit RISC architecture** (Reduced Instruction Set Computing) microcontroller in market since 1996 which is having on-chip programmable flash memory, SRAM, IO data space & EEPROM.
- AVR is the first MCU in market which has on-chip flash storage.

## Introduction to AVR Family

- ❖ Developed by Atmel corporation in 1996 and acquired by Microchip Technology in 2016.
- ❖ Advance Virtual Risc or Alf and Vegard Risc
- ❖ AVR is an 8 bit RISC based single chip microprocessor with Harvard architecture
- ❖ It has Code ROM, Data ROM (EEPROM), RAM, I/O and Timers
- ❖ Supports some serial interfaces such as CAN, I2C, SPI, USB, USART.

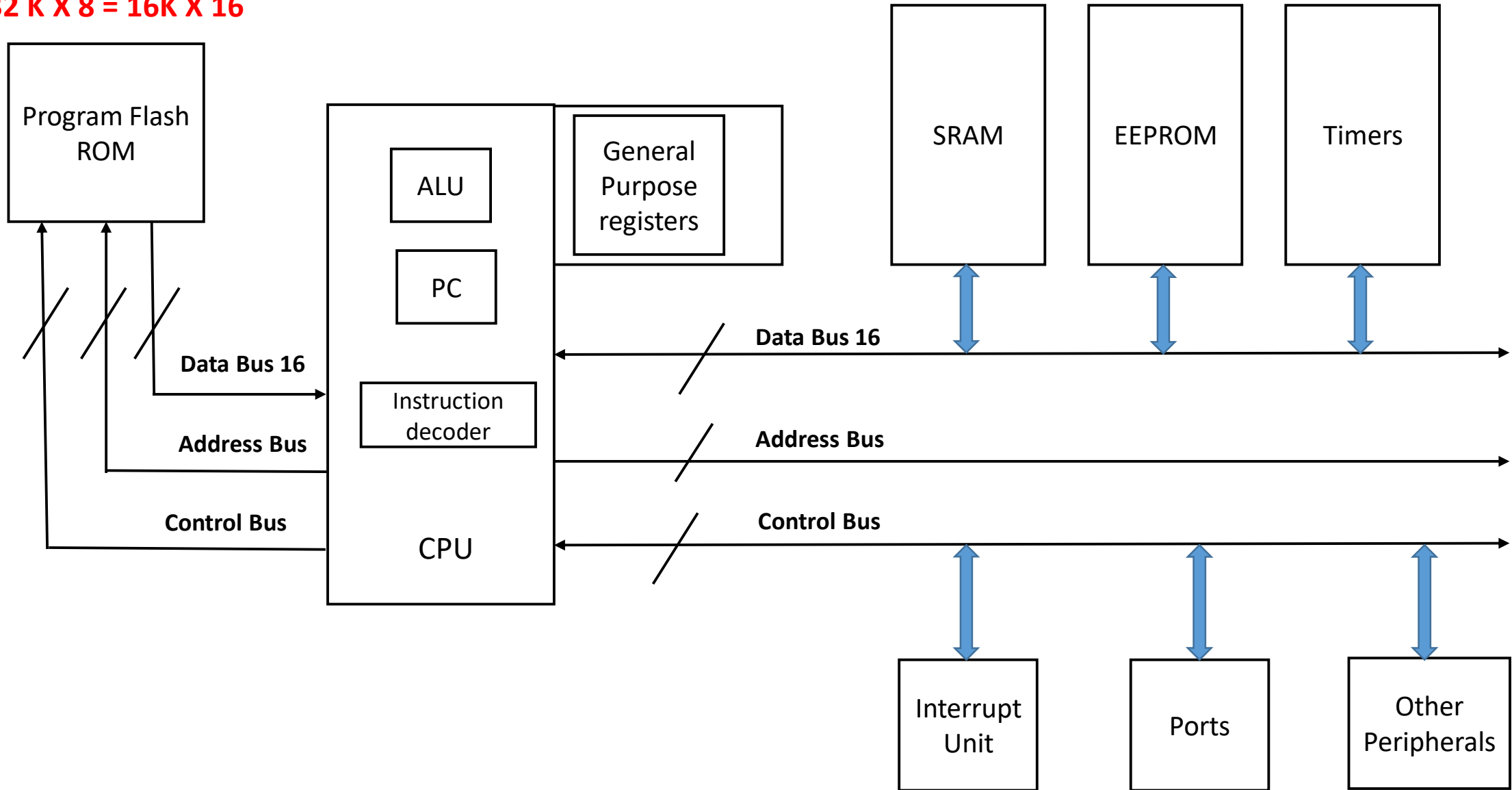
## AVR Family Classification



# AVR architectural overview :

ATmega 32

32 K X 8 = 16K X 16



## AVR architectural overview :

**Data BUS 8 bit :** Its an 8-bit parallel data lines by which the data travels inside the MCU (NOTE: this is the reason why AVR is an 8-bit MCU).

**ALU:** Arithmetic Logic Unit, the core/heart of the entire system where typically all commands get executed.

**Data SRAM:** It basically pretty similar to the RAM (Random access memory) we see inside our computers.

**EEPROM:** (Electrically Erasable Programmable Read Only Memory) its very similar to another component in our computer namely Hard Disk, i.e. a permanent storage.

**I/O lines:** These are the bunch of registers which is used as a switches or controls for different features of AVR.

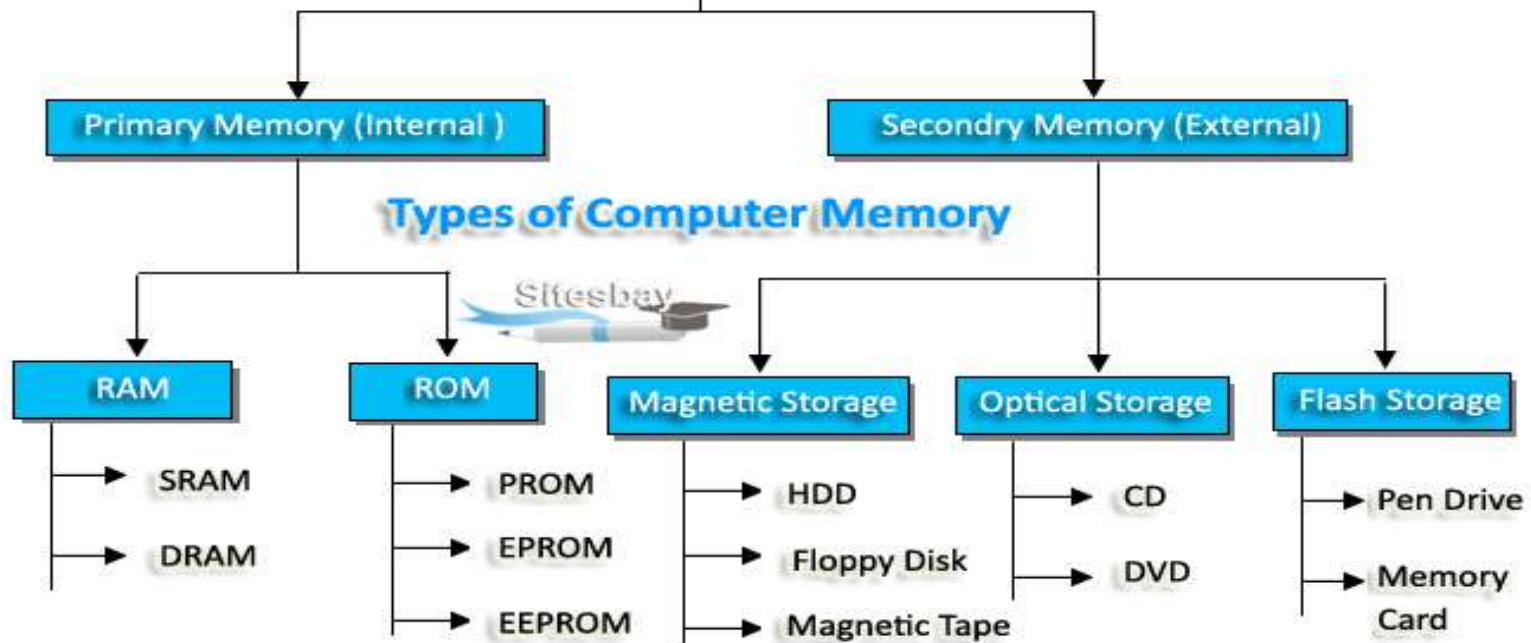
**32X8 GPR (General Purpose Registers):** This are 32 registers each having 8-bit which is a general storage space for data. But, remember, SRAM is also a temporary storage but these registers have some specialty among all.

**Status & Control :** A couple of registers which are very special to the MCU & to us also.

**Program Counter:** This is a register which has a responsibility to track the position of the program that is currently executing.

**Flash Memory:** It is also a permanent storage but its only for storing the program we write to it.

**Instruction Register & Decoder:** These are import for the MCU but not too much to us.



## Features of Atmega32

- 2 Kilo bytes of internal Static RAM
- 32 X 8 general working purpose registers
- 32 Kilo bytes of in system self programmable flash program memory.
- 1024 bytes EEPROM
- Programmable serial USART
- 8 Channel, 10 bit ADC
- One 16-bit timer/counter with separate prescaler, compare mode and capture mode.
- Available in 40 pin DIP, 44-pad QFN/MLF and 44-lead QTFP
- QFP (Quad Flat Package) and QFN (Quad Flat No-leads) packages. Thin Quad Flat Package (TQFP)
- Two 8-bit timers/counters with separate prescalers and compare modes
- 32 programmable I/O lines
- In system programming by on-chip boot program
- Master/slave SPI serial interface
- Programmable watch dog timer with separate on-chip oscillator

# Memory Organization of ATmega 32

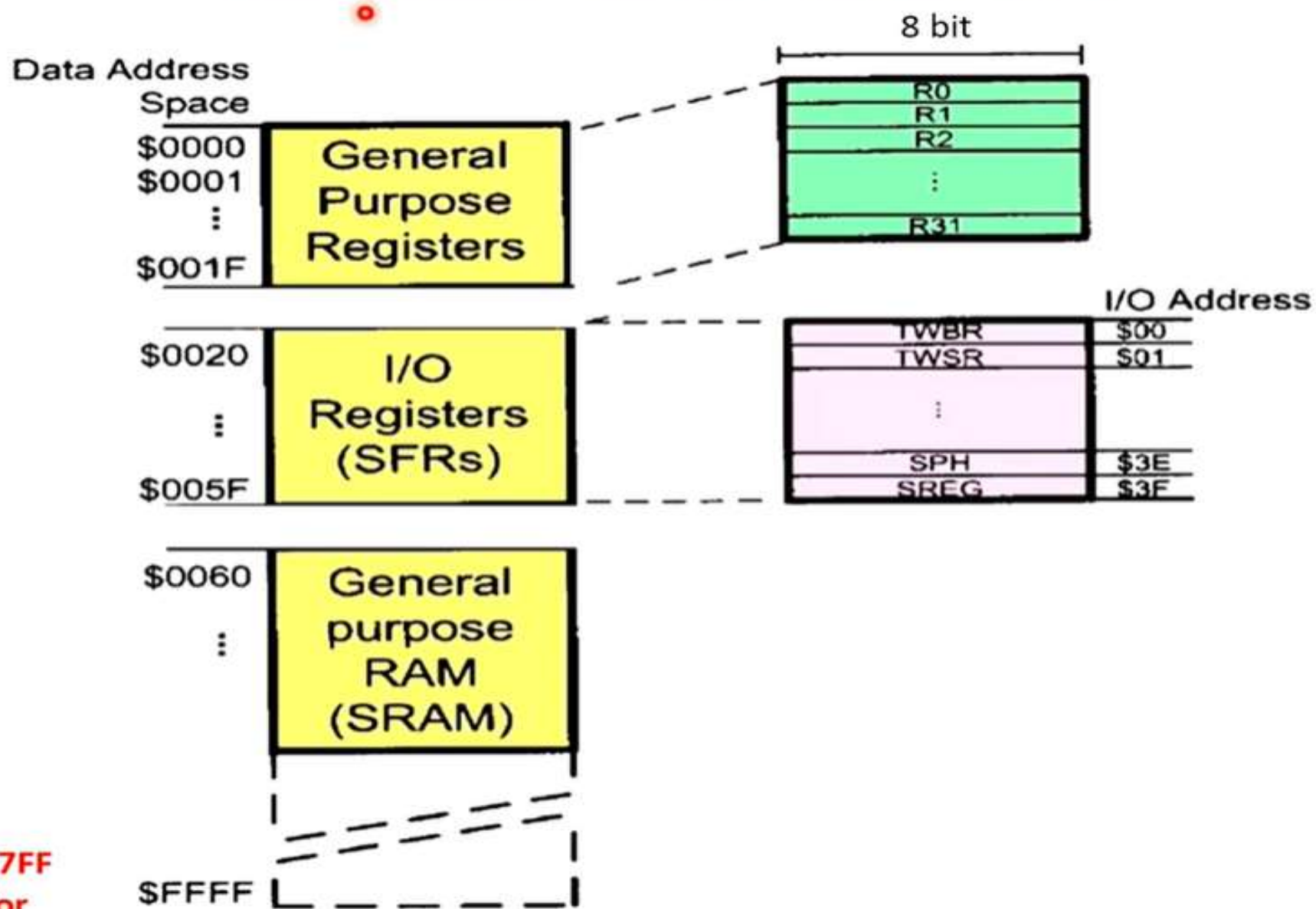
## General Purpose Registers of ATmega32



RAM  
(32KB)

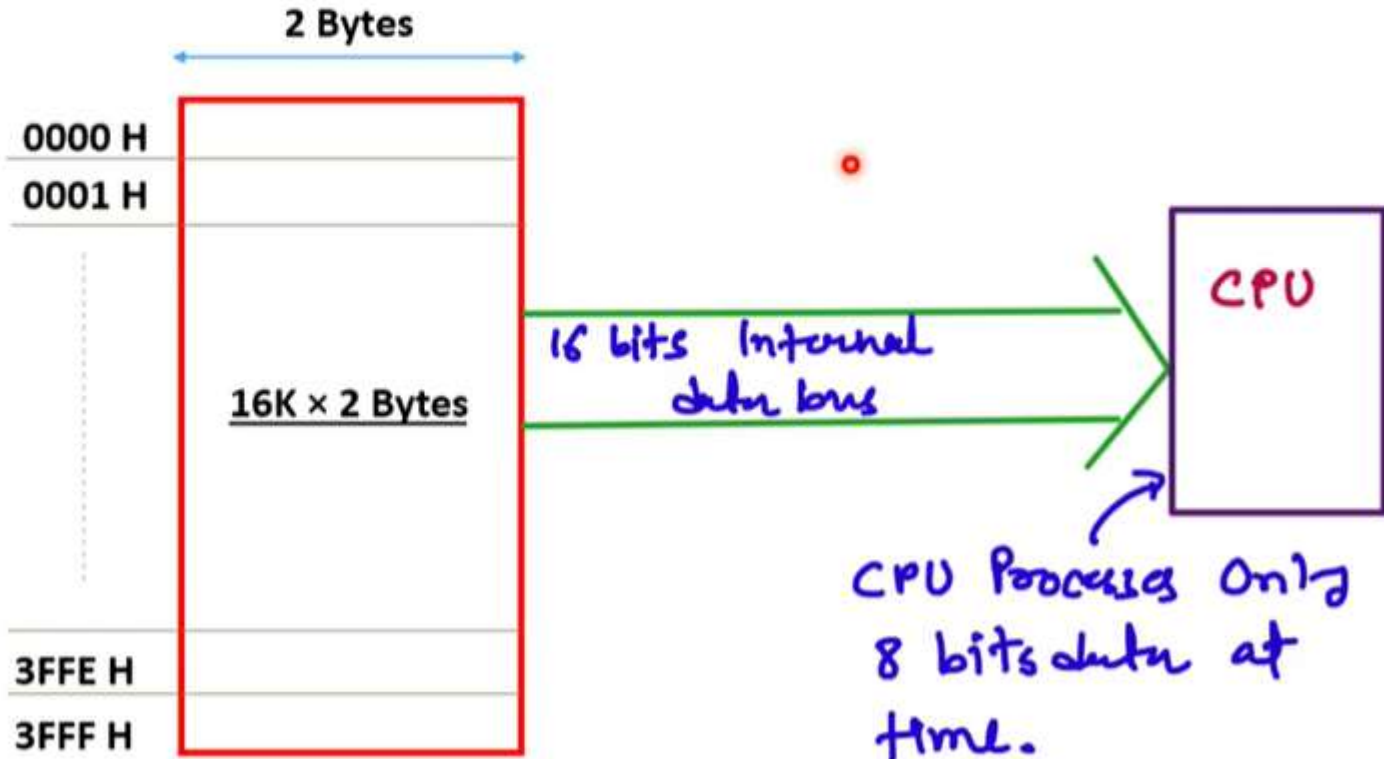
ROM  
(32KB)

# RAM Architecture of Atmega32 (2Kb)



**\$07FF**  
for  
**ATmega32**

# ROM Architecture of ATmega32 (32Kb)



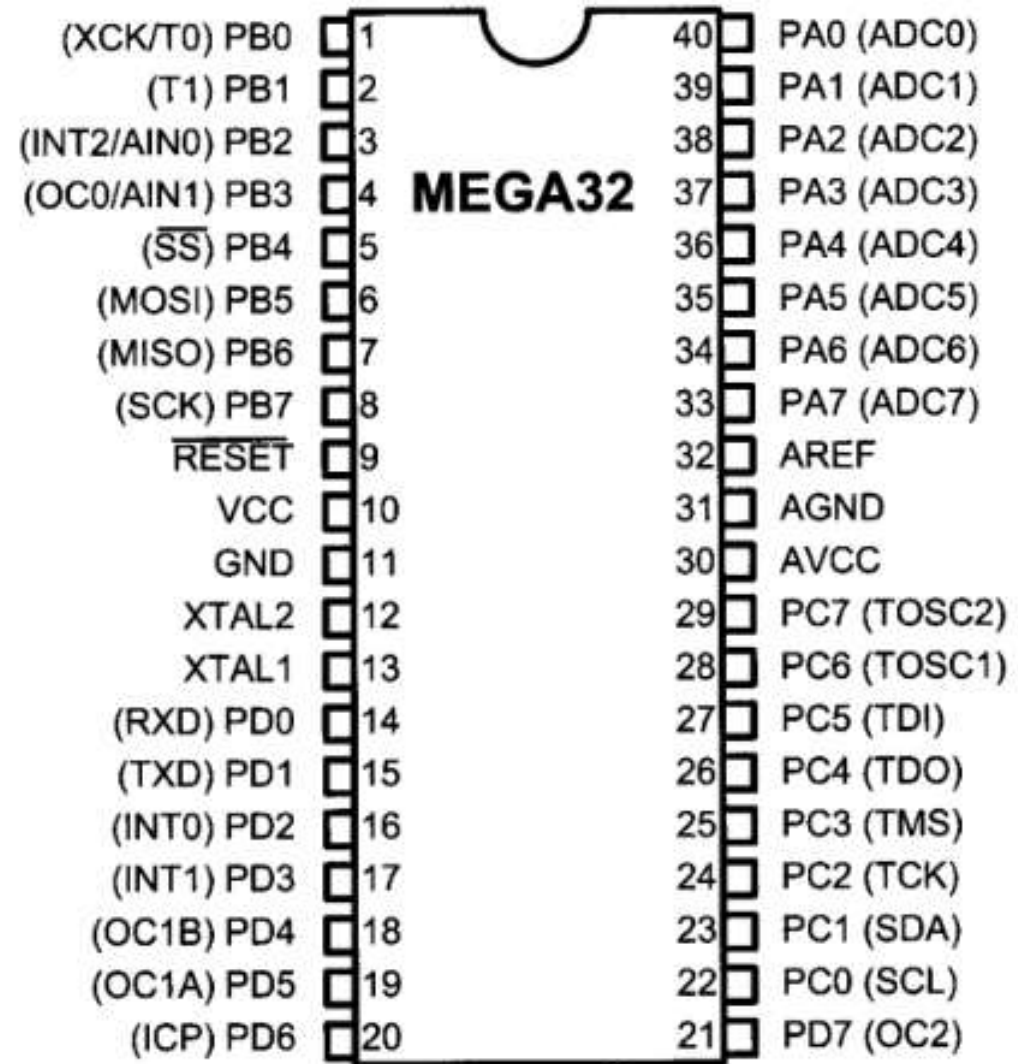
## AVR I/O Port Programming

- In AVR microcontroller family, there are many ports available for I/O operations, depending on which family microcontroller you choose.
- For the ATmega32 40-pin chip 32 Pins are available for I/O operation. The four ports PORTA, PORTB, PORTC, and PORTD are programmed for performing desired operation.

The number of ports in AVR family varies depending on number of pins available on chip.

Pins	8-pin	28-pin	40-pin	64-pin	100-pin
Chip	ATtiny25/45/85	ATmega8/48/88	ATmega32/16	ATmega64/128	ATmega1280
Port A			X	X	X
Port B	6 bits	X	X	X	X
Port C		7 bits	X	X	X
Port D		X	X	X	X
Port E				X	X
Port F				X	X
Port G				5 bits	6 bits
Port H					X
Port J					X
Port K					X
Port L					X

**Note:** X indicates that the port is available.



# Memory Organization of Atmega32

## **1. Flash Memory (Program Memory):**

- The ATmega32 typically comes with 32 KB of Flash memory.
- Flash memory is where the program code is stored. It's non-volatile, meaning the code remains even when power is removed.
- Flash memory is organized into 16-bit words.

## **2. SRAM (Static Random Access Memory):**

- The ATmega32 has 2 KB of SRAM.
- SRAM is used for storing variables, intermediate results, and stack data during program execution.
- Unlike Flash memory, SRAM is volatile and loses its content when power is removed.

## **3. EEPROM (Electrically Erasable Programmable Read-Only Memory):**

- The ATmega32 features 1 KB of EEPROM.
- EEPROM is non-volatile memory that can be written to and read from by the AVR microcontroller during program execution.
- It's commonly used for storing non-volatile data that needs to be retained even when the power is turned off, such as configuration settings or small amounts of user data.

## **4. I/O Registers:**

- These are memory-mapped registers used for interfacing with peripherals and controlling the microcontroller's operation.
- I/O Registers control various aspects of the microcontroller, including GPIO (General Purpose Input/Output), timers, UART, SPI, and other peripherals.
- They are often used for configuring and controlling the behavior of the microcontroller's peripherals.

## **5. Special Function Registers (SFRs):**

- These registers provide control and status information for the CPU and peripherals.
- SFRs are used to configure the operation of the microcontroller, control interrupts, and manage power-saving modes.
- They also include status flags and control bits for various functions of the microcontroller.

The 40-pin AVR has four ports for using any of the ports as an input or output port, it must be accordingly programmed. In AVR microcontroller not all ports have 8 pins. For example:-in the ATmega8, Port C has 7 pins.

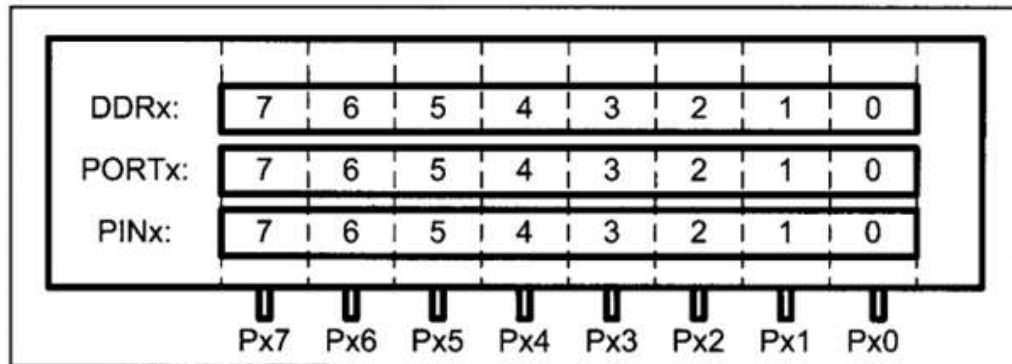
The Registers Addresses for ATmega32 Ports is given below:

Each port in AVR microcontroller has three I/O registers associated with it. They are designated as PORTx, DDRx and PINx. For example: - in case of Port B we have PORTB, DDRB, and PINB. Here **DDR stands for Data Direction Registers, and PIN stands for Port Input pins.**

Each of I/O registers is 8 bits wide, and each port has a maximum of 8 pins, therefore each bit of I/O registers affects one of the pins.

For accessing I/O registers associated with the ports the common relationship between the registers and the pins of AVR microcontroller is used.

The relation between the Registers and the Pins of AVR is shown below:



**Table 4-2: Register Addresses for ATmega32 Ports**

Port	Address	Usage
PORTA	\$3B	output
DDRA	\$3A	direction
PINA	\$39	input
PORTB	\$38	output
DDRB	\$37	direction
PINB	\$36	input
PORTC	\$35	output
DDRC	\$34	direction
PINC	\$33	input
PORTD	\$32	output
DDRD	\$31	direction
PIND	\$30	input

# Microcontroller

- A microcontroller (MCU) is a small computer on a single integrated circuit that is designed to control specific tasks within electronic systems. It combines the functions of a central processing unit (CPU), memory, and input/output interfaces, all on a single chip.
- Microcontrollers are widely used in embedded systems, such as home appliances, automotive systems, medical devices, and industrial control systems.
- They are also used in consumer electronics products, such as gaming systems, digital cameras, and audio players.
- A typical microcontroller consists of a processor core, volatile and non-volatile memory, input/output peripherals, and various communication interfaces. The processor core is responsible for executing instructions and controlling the other components of the microcontroller. The memory is used to store data and program code, while the input/output peripherals are used to interact with the external environment

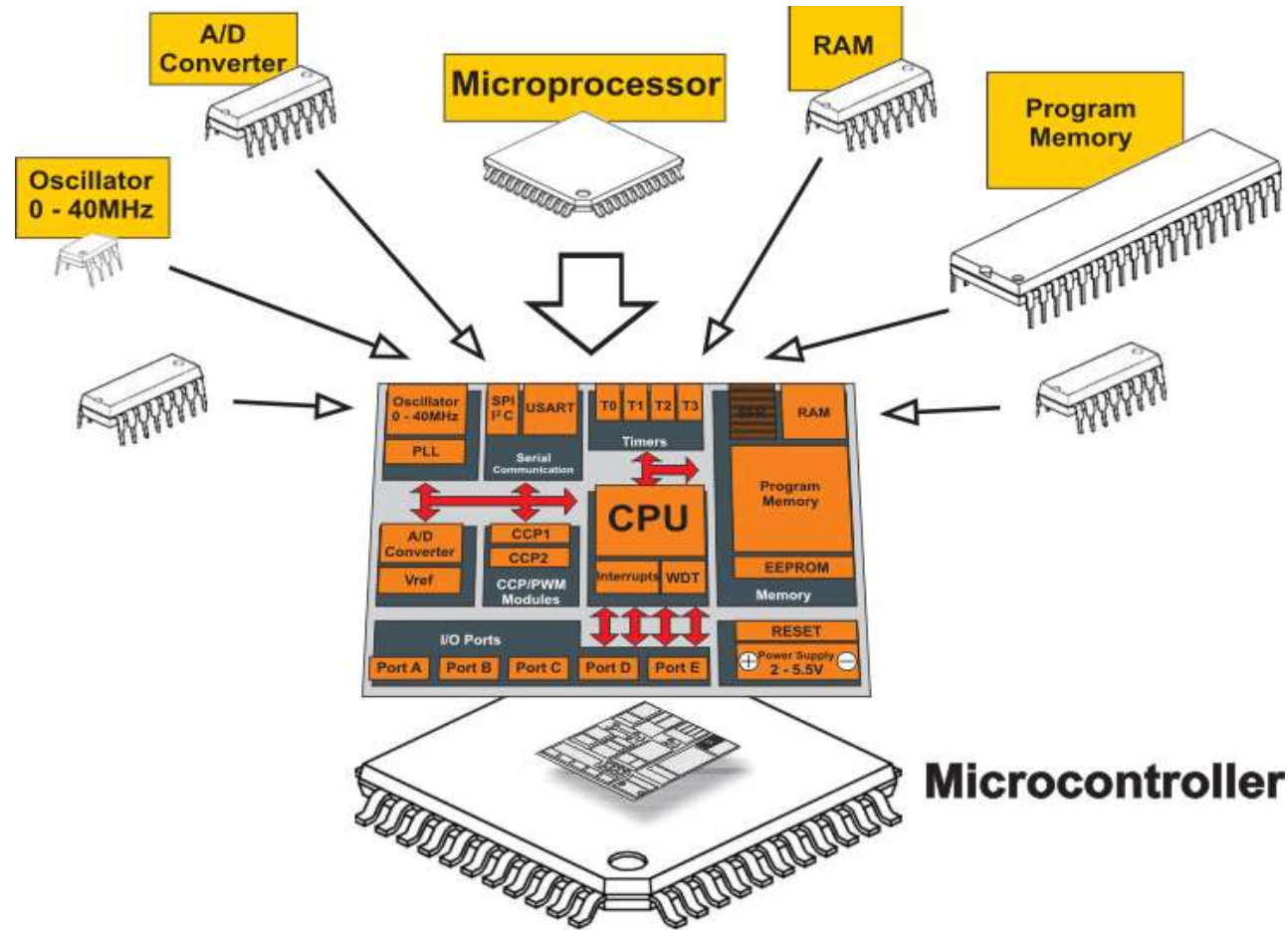
Microcontroller was first designed by Michael Cochran and Gary Boone.

C and assembly languages are used for programming a microcontroller but the HEX File is in machine language which actually gets uploaded in Microcontrollers.

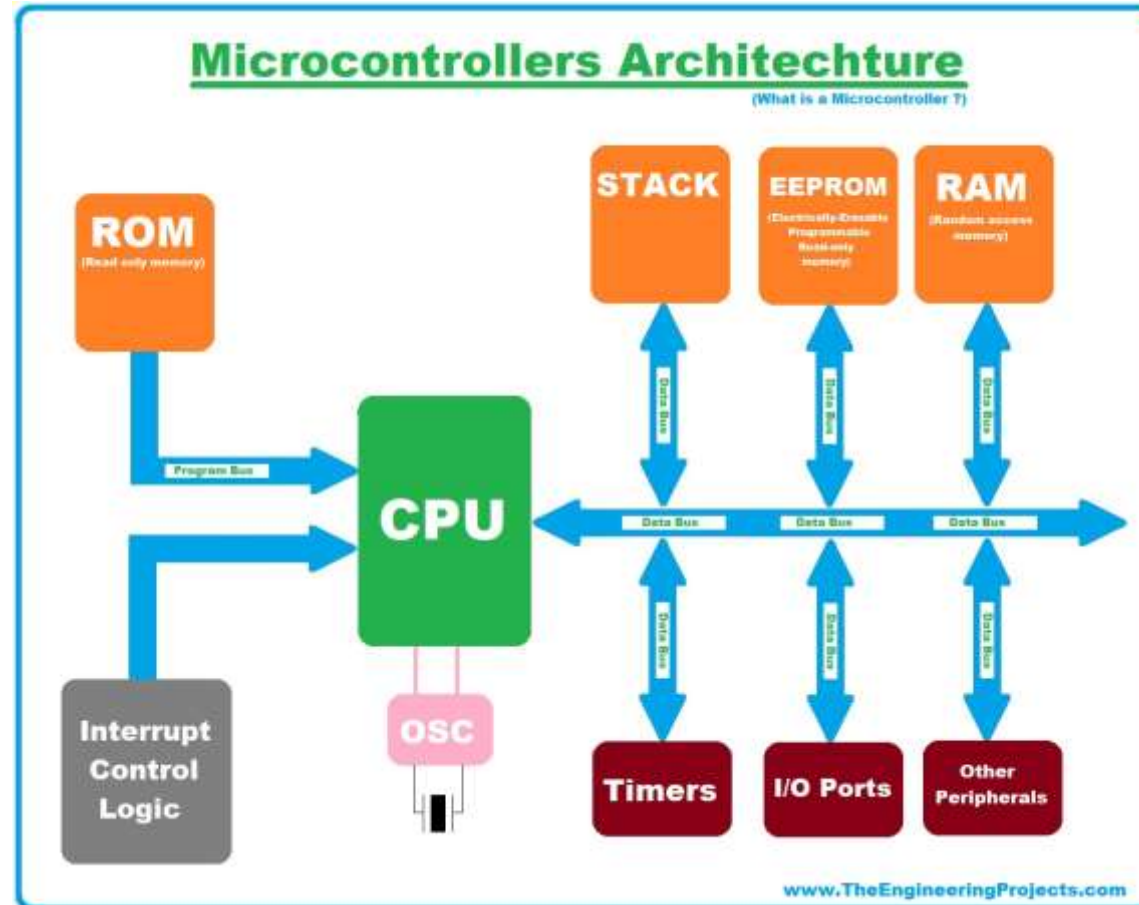
There are also other languages available for programming a microcontroller , start with assembly language as it provides a clear concept about microcontroller's architecture.

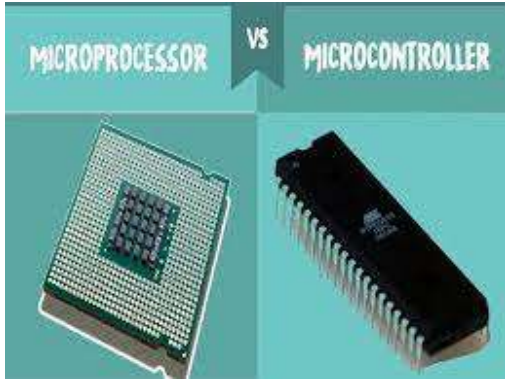
Below image shows few of the most commonly used Microcontrollers





# Microcontrollers Architecture





## Difference between Microprocessor and Microcontroller

### Microcontroller

Microcontrollers are used to execute a single task within an application.

Its designing and hardware cost is low.

Easy to replace.

It is built with CMOS technology, which requires less power to operate.

It consists of CPU, RAM, ROM, I/O ports.

### Microprocessor

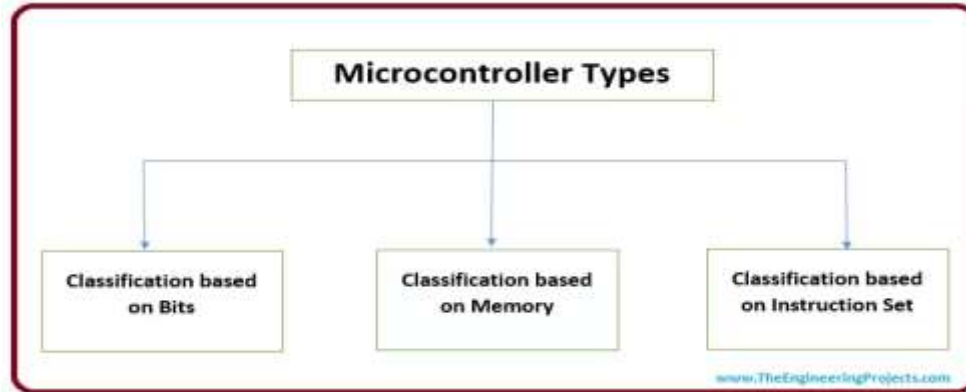
Microprocessors are used for big applications.

Its designing and hardware cost is high.

Not so easy to replace.

Its power consumption is high because it has to control the entire system.

It doesn't consist of RAM, ROM, I/O ports. It uses its pins to interface to peripheral devices.



## Bit

Based on bit configuration, the microcontroller is further divided into three categories.

- 8-bit microcontroller** – This type of microcontroller is used to execute arithmetic and logical operations like addition, subtraction, multiplication division, etc. For example, Intel 8031 and 8051 are 8 bits microcontroller.

- 16-bit microcontroller** – This type of microcontroller is used to perform arithmetic and logical operations where higher accuracy and performance is required. For example, Intel 8096 is a 16-bit microcontroller.

- 32-bit microcontroller** – This type of microcontroller is generally used in automatically controlled appliances like automatic operational machines, medical appliances, etc.

## Memory

- Based on the memory configuration, the microcontroller is further divided into two categories.
- **External memory microcontroller** – This type of microcontroller is designed in such a way that they do not have a program memory on the chip. Hence, it is named as external memory microcontroller. For example: Intel 8031 microcontroller.
- **Embedded memory microcontroller** – This type of microcontroller is designed in such a way that the microcontroller has all programs and data memory, counters and timers, interrupts, I/O ports are embedded on the chip. For example: Intel 8051 microcontroller.

## Instruction Set

- Based on the instruction set configuration, the microcontroller is further divided into two categories.
- **CISC** –Complex Instruction Set Computer, CISC architecture reduces the number of instructions per program while increasing the number of cycles per instruction.
- **RISC** – RISC stands for Reduced Instruction Set Computers. the RISC architecture reduces the cycles per instruction while increasing the number of instructions per program..

# Applications of Microcontrollers

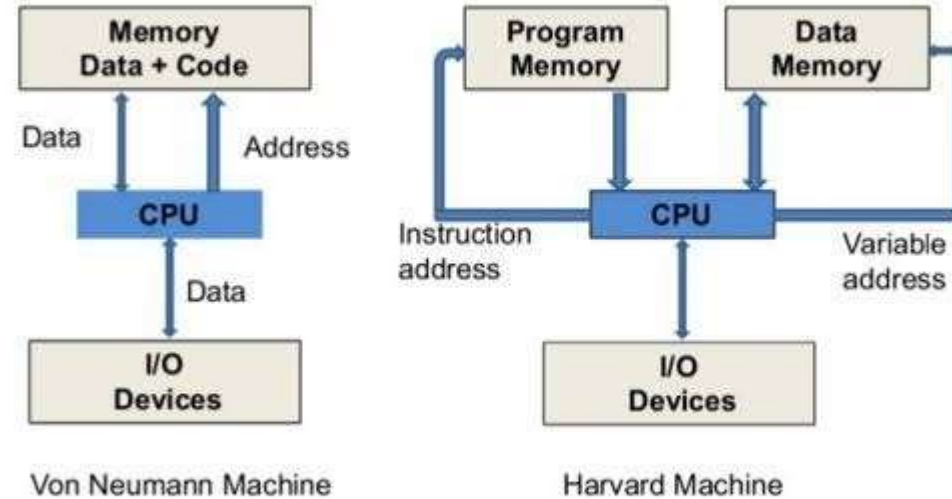
- Applications of Microcontrollers
- Microcontrollers are widely used in various different devices such as –
- Light sensing and controlling devices like LED.
- Temperature sensing and controlling devices like microwave oven, chimneys.
- Fire detection and safety devices like Fire alarm.
- Measuring devices like Volt Meter.

# Issues in Microcontroller :

- some of the most common issues that can arise with microcontrollers:
- **Timing Issues:** Microcontrollers rely on precise timing to execute instructions and perform tasks. Any issues with timing can cause errors and malfunctions, which can be difficult to diagnose and fix.
- **Power Issues:** Microcontrollers require a stable and consistent power supply to operate correctly. Any fluctuations or disruptions in the power supply can cause the microcontroller to malfunction or fail.
- **Heat Issues:** Microcontrollers generate heat during operation, and excessive heat can damage the device or cause it to malfunction. Heat issues can be caused by poor design, inadequate cooling, or high ambient temperatures.
- **Noise Issues:** Microcontrollers can be affected by electromagnetic interference (EMI) and radio frequency interference (RFI) from other electronic devices, which can cause errors and malfunctions.
- **Code Issues:** The programming code used to control the microcontroller can contain errors and bugs, which can cause the device to malfunction or fail.
- **Security Issues:** Microcontrollers can be vulnerable to security breaches, including unauthorized access, data theft, and malware attacks.
- **Compatibility Issues:** Microcontrollers may not be compatible with other electronic components or devices, which can cause errors and malfunctions.
-

- Examples of Von – Neumann Architecture: ARM 7 and Pentium Processors etc. Examples of Harvard Architecture: 8051, ARM 9, AVR by Atmel Corporation and PIC microcontrollers by microchip Technology

## Von Neumann vs. Harvard Architecture

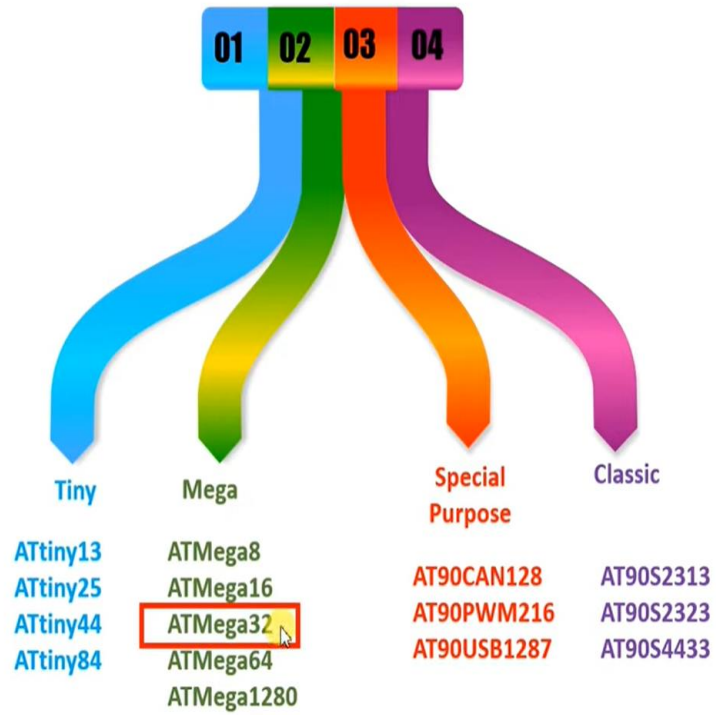


# Introduction to AVR Family

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- ❖ Advance Virtual Risc or Alf and Vegard Risc
- ❖ AVR is an 8 bit RISC based single chip microprocessor with Harvard architecture
- ❖ It has Code ROM, Data ROM (EEPROM), RAM, I/O and Timers
- ❖ Supports some serial interfaces such as CAN, I2C, SPI, USB, USART.



# AVR Family Classification

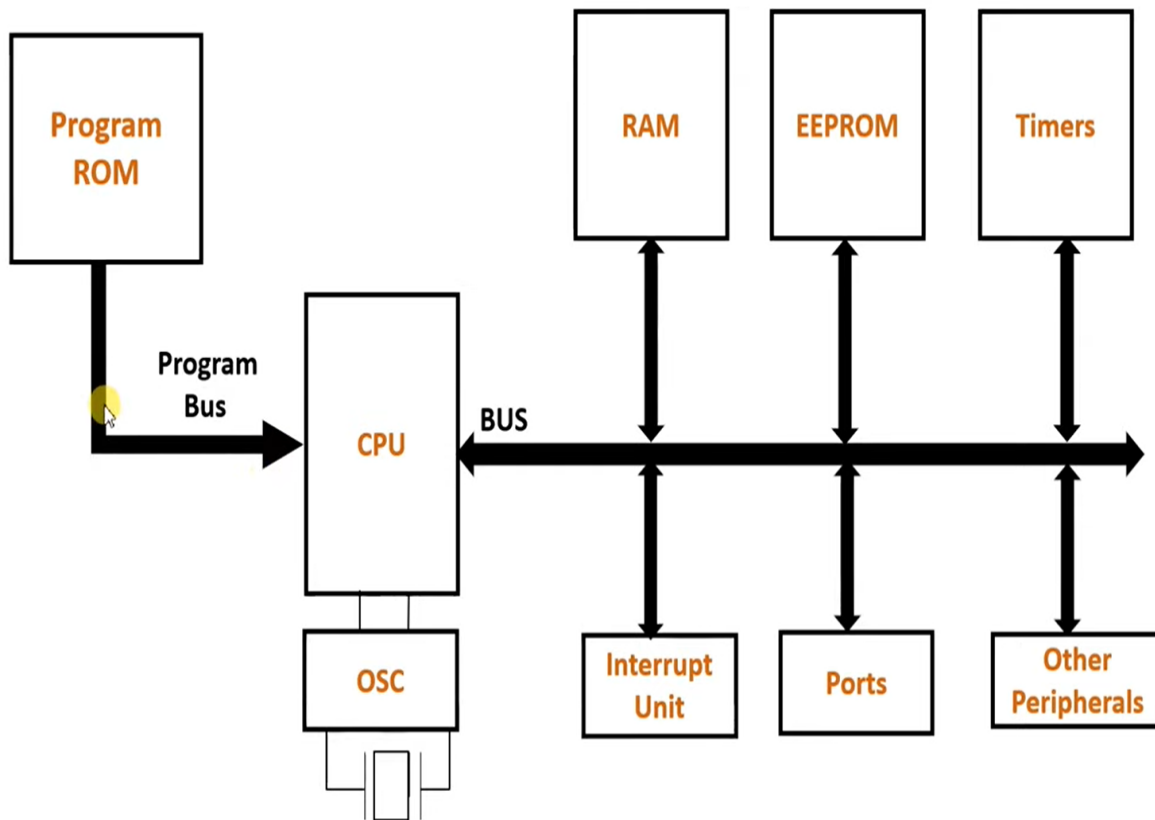


## Some members of Mega AVR family

Part Number	Code ROM	DATA RAM	DATA EPROM	I/O pins	ADC	Timers	Pin numbers & Packages
ATmega8	8K	1K	0.5K	23	8	3	TQFP32,PDIP28
ATmega16	16K	1K	0.5K	32	8	3	TQFP44,PDIP40
Atmega32	32K	2K	1K	32	8	3	TQFP44,PDIP40



# Simplified View of an AVR Microcontroller



## Program ROM

- Used to store program
- 8MB of ROM space
- ROM size vary from 1K to 256KB for different family

## AVR Microcontroller data RAM and EEPROM

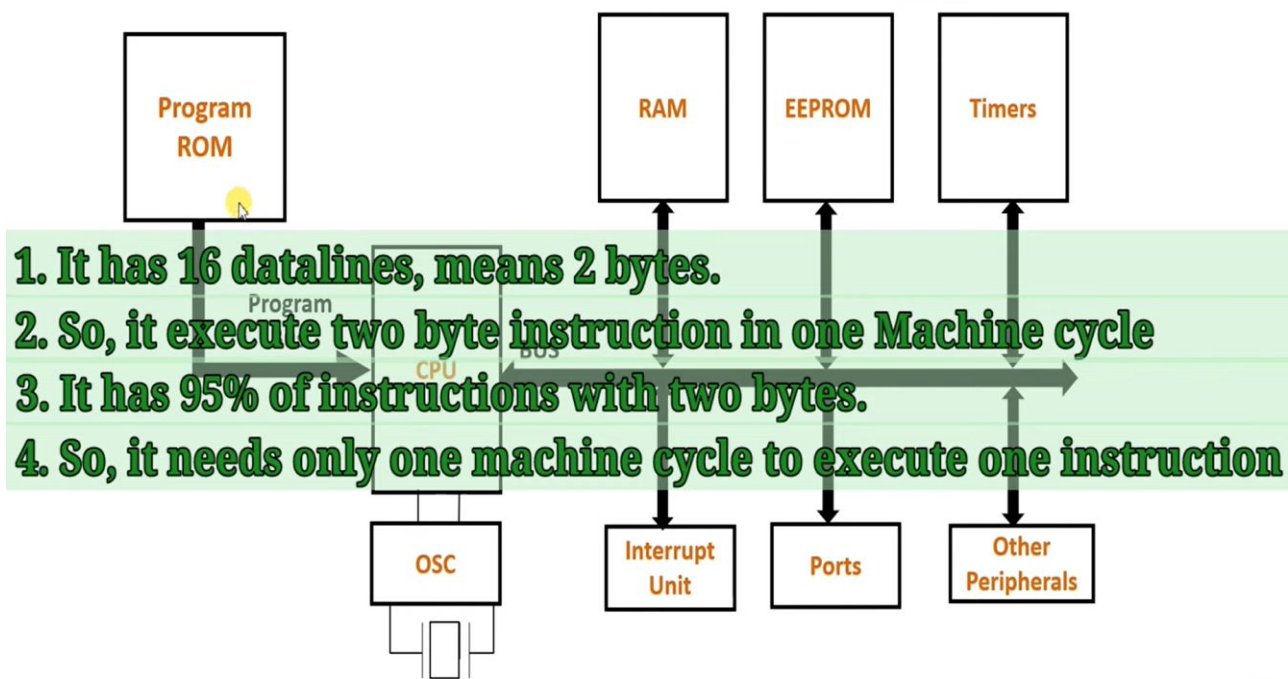
- Used to store data
- Max of 64KB of data RAM space
- Data RAM has three components: General purpose registers, I/O memory and Internal SRAM
- EPROM is used to store critical data that does not change often.

## AVR Microcontroller I/O pins

- 3-86 pins for I/O.
- I/O pins depends on the number of pins in package.

- Pins for AVR package 8 to 100
- AVR Microcontroller Peripherals
- AVR comes with ADC, Timers and USART as standard peripherals

## Simplified View of an AVR Microcontroller



1. It has 16 datalines, means 2 bytes.
2. So, it execute two byte instruction in one Machine cycle
3. It has 95% of instructions with two bytes.
4. So, it needs only one machine cycle to execute one instruction

## Companies that produce widely used 8 bit microcontrollers

Company	Web Site	Architecture
Atmel	<a href="http://www.atmel.com">http://www.atmel.com</a>	AVR and 8051
Microchip	<a href="http://www.microchip.com">http://www.microchip.com</a>	PIC16xxx/18xxx

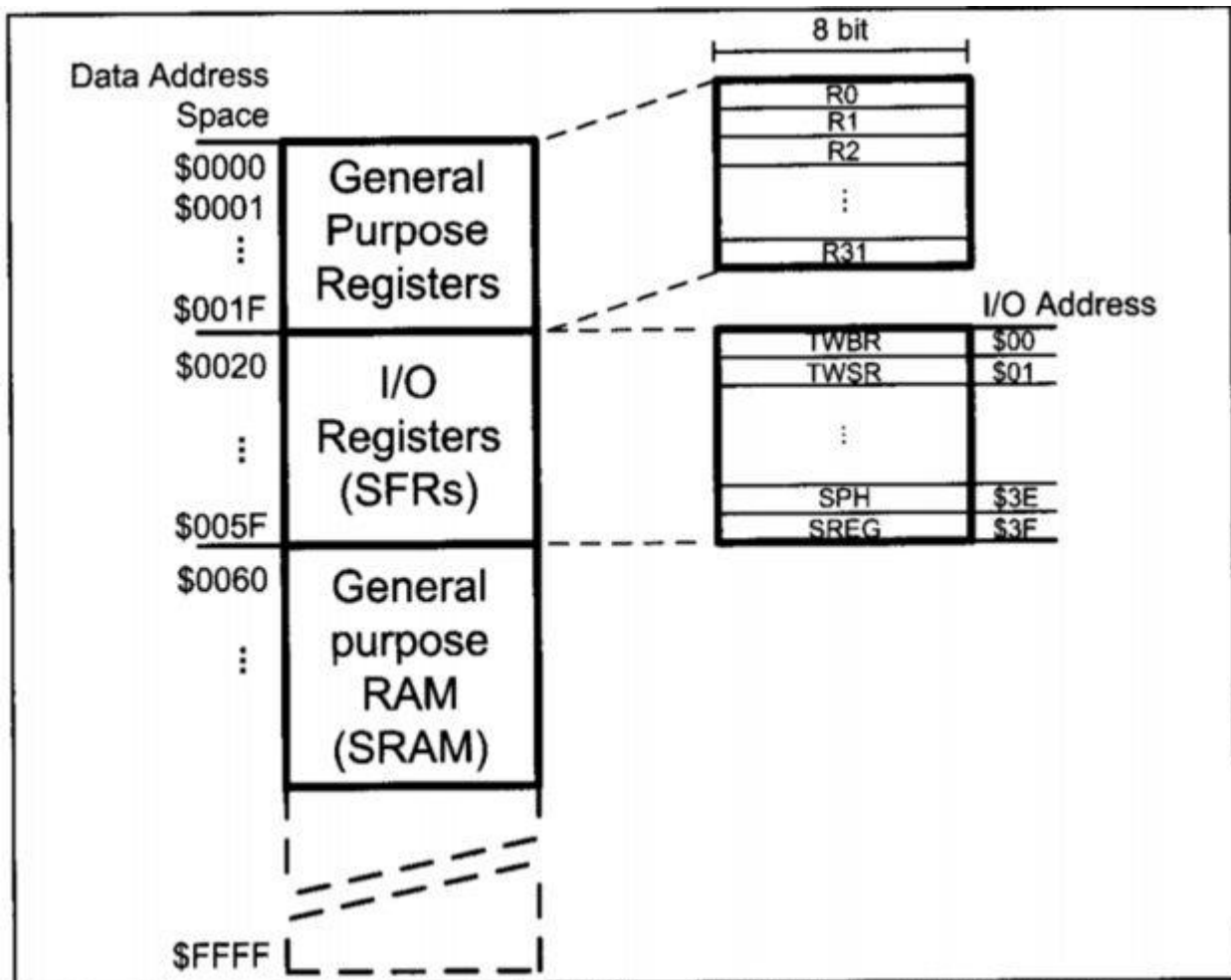


Figure 2-3. The Data Memory for AVR with No Extended I/O Memory

# ATmega32-8 Bit AVR MicroController

- The AVR microController is based on the advanced Reduced Instruction Set Computer (RISC) architecture.
- ATmega32 microController is a low power CMOS technology based controller. Due to RISC architecture AVR microcontroller can execute 1 million of instructions per second if cycle frequency is 1 MHz provided by crystal oscillator.



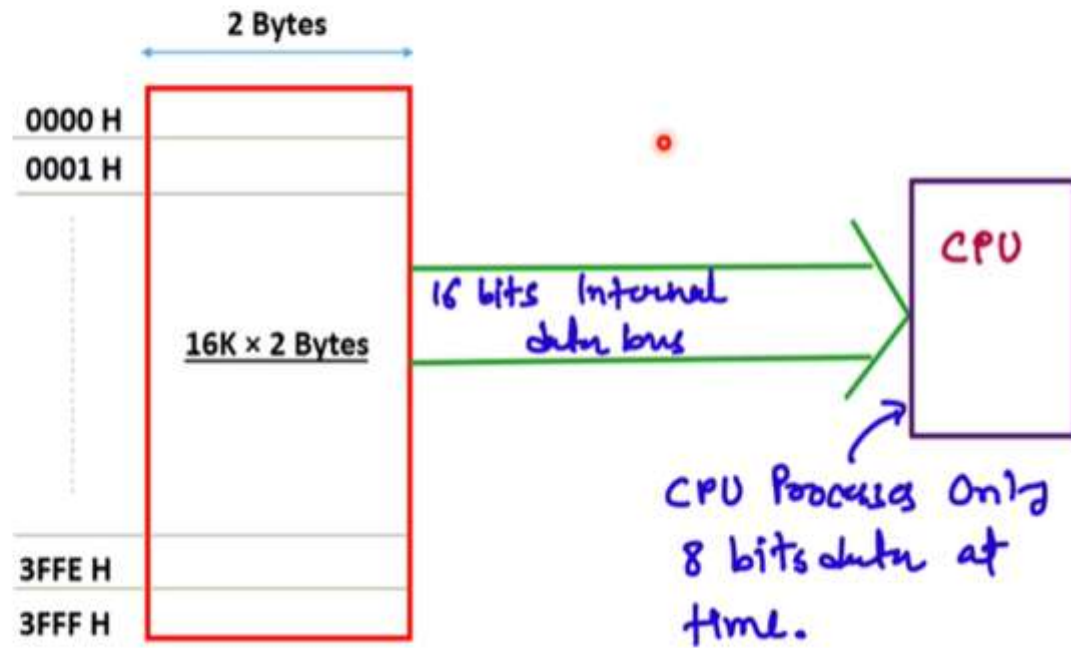
# Key Features:

- 2 Kilo bytes of internal Static RAM
- 32 X 8 general working purpose registers
- 32 Kilo bytes of in system self programmable flash program memory.
- 1024 bytes EEPROM
- Programmable serial USART
- 8 Channel, 10 bit ADC
- One 16-bit timer/counter with separate prescaler, compare mode and capture mode.
- Available in 40 pin DIP, 44-pad QFN/MLF and 44-lead QTFP
- Two 8-bit timers/counters with separate prescalers and compare modes
- 32 programmable I/O lines
- In system programming by on-chip boot program
- Master/slave SPI serial interface
- 4 PWM channels
- Programmable watch dog timer with separate on-chip oscillator

# Special Microcontroller Features:

- External and internal interrupt sources
- Six sleep modes: Idle, ADC noise reduction, power-save, power-down, standby and extended standby.
- Power on reset and programmable brown-out detection.
- Internal calibrated RC oscillator

## ROM Architecture of ATmega32 (32Kb)



## Memory Organization of Atmega32

### **1.Flash Memory (Program Memory):**

- The ATmega32 typically comes with 32 KB of Flash memory.
- Flash memory is where the program code is stored. It's non-volatile, meaning the code remains even when power is removed.
- Flash memory is organized into 16-bit words.

### **2.SRAM (Static Random Access Memory):**

- The ATmega32 has 2 KB of SRAM.
- SRAM is used for storing variables, intermediate results, and stack data during program execution.
- Unlike Flash memory, SRAM is volatile and loses its content when power is removed.

### **3.EEPROM (Electrically Erasable Programmable Read-Only Memory):**

- The ATmega32 features 1 KB of EEPROM.
- EEPROM is non-volatile memory that can be written to and read from by the AVR microcontroller during program execution.
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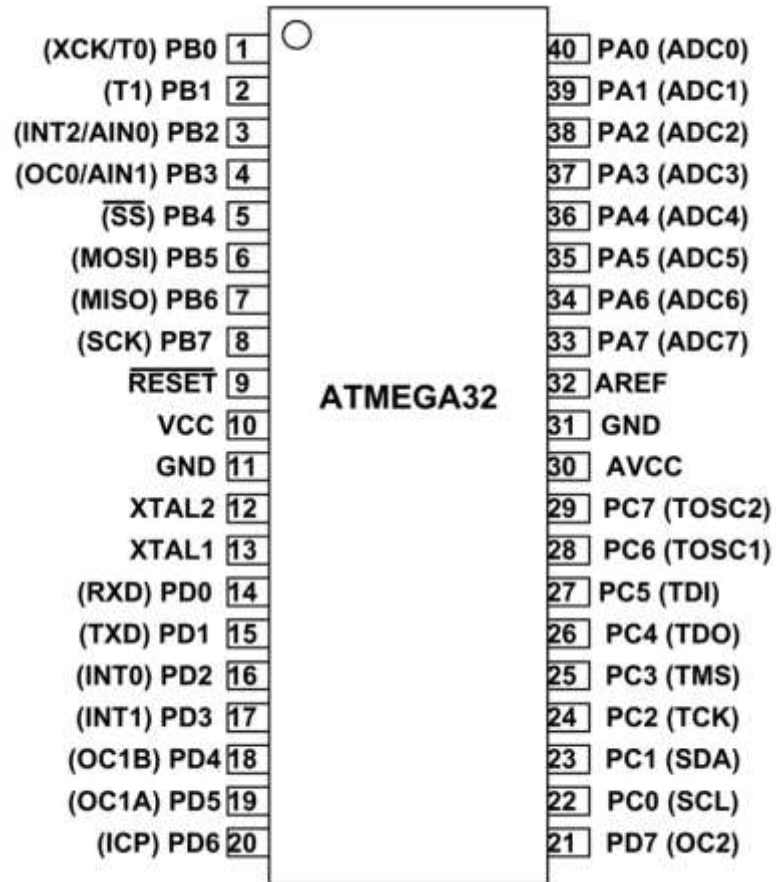
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### **5.Special Function Registers (SFRs):**

- These registers provide control and status information for the CPU and peripherals.
- SFRs are used to configure the operation of the microcontroller, control interrupts, and manage power-saving modes.
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# PIN diagram Of AVR Atmega32



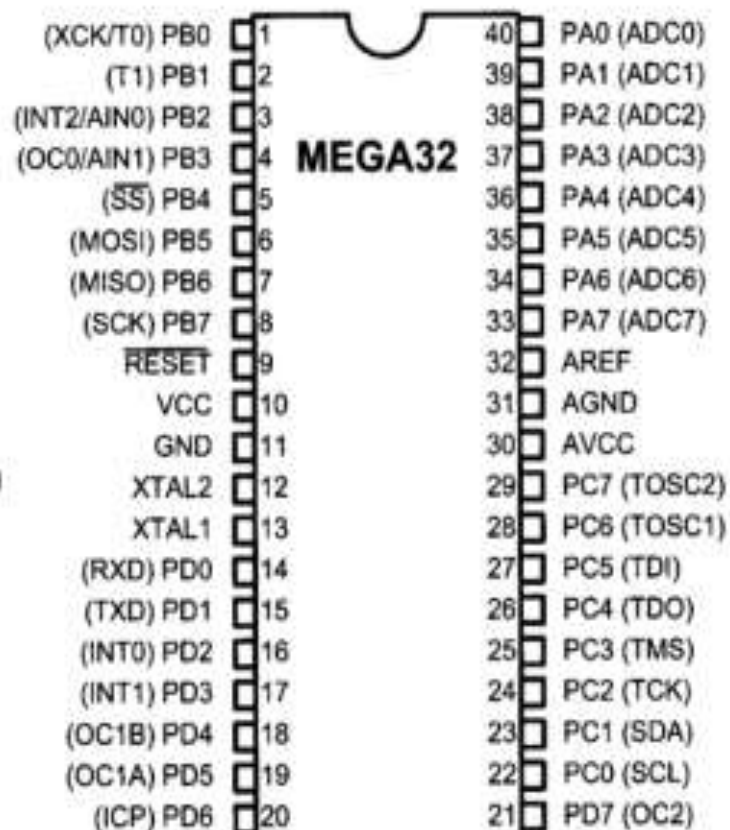
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Pins	8-pin	28-pin	48-pin	64-pin	100-pin
Chip	ATtiny25/45/85	ATmega8/48/88	ATmega32/16	ATmega64/128	ATmega1280
Port A			X	X	X
Port B	6 bits	X	X	X	X
Port C		7 bits	X	X	X
Port D		X	X	X	X
Port E				X	X
Port F				X	X
Port G				5 bits	6 bits
Port H					X
Port J					X
Port K					X
Port L					X

**Note:** X indicates that the port is available.



The ATmega32 microcontroller is part of the AVR family and is widely used in embedded systems. Its memory organization includes several distinct types of memory: Flash memory, SRAM, EEPROM, and special function registers. Here's an overview of its memory organization:

## Memory Organization of ATmega32

1. **Flash Memory (Program Memory):**
  - **Size:** 32 KB
  - **Type:** Non-volatile memory
  - **Function:** This memory is used to store the program code that runs on the microcontroller. The code remains intact even when power is lost. It can be programmed using ISP (In-System Programming).
  - **Access:** It can be accessed in byte or page mode.
2. **SRAM (Static Random-Access Memory):**
  - **Size:** 2 KB
  - **Type:** Volatile memory
  - **Function:** SRAM is used for temporary storage of variables, stack, and data during program execution. The data in SRAM is lost when the microcontroller is powered off.
  - **Structure:** It is organized into 32 registers (R0 to R31) that can be used for general purposes, along with additional memory locations.
3. **EEPROM (Electrically Erasable Programmable Read-Only Memory):**
  - **Size:** 1 KB
  - **Type:** Non-volatile memory
  - **Function:** EEPROM is used to store data that must be retained even when the microcontroller is powered off, such as configuration settings or calibration data. It can be written to and erased while in-circuit.
  - **Access:** It can be accessed byte-wise.
4. **I/O Registers (Special Function Registers):**
  - **Size:** 64 bytes
  - **Type:** Volatile memory
  - **Function:** These registers are used to control and monitor the operation of the microcontroller's peripherals, including timers, ADCs, and communication interfaces.
  - **Structure:** The registers are mapped into the I/O memory space, with addresses from 0x00 to 0x3F.
5. **Peripheral Registers:**
  - These are specialized registers associated with the microcontroller's hardware features, such as timers, ADCs, UART, etc. Each peripheral has its own set of registers for configuration and control.

## Memory Map of ATmega32

Here's a simplified representation of the memory organization:

```
scss
Copy code
+-----+
|      Flash Memory      |  0x0000 - 0x7FFF (32 KB)
| (Program Storage Area) |
```

SRAM (Data Storage Area)	0x0100 - 0x01FF (2 KB)
EEPROM (Data Storage Area)	0x0000 - 0x03FF (1 KB)
I/O Registers (Peripheral Control)	0x0000 - 0x003F (64 bytes)

## Summary of Memory Types

- **Flash Memory:** For program storage, non-volatile, 32 KB.
- **SRAM:** For data storage during execution, volatile, 2 KB.
- **EEPROM:** For persistent data storage, non-volatile, 1 KB.
- **I/O Registers:** For controlling peripherals, volatile, 64 bytes.

## Conclusion

Understanding the memory organization of the ATmega32 is crucial for effective programming and resource management in embedded systems. Each memory type has specific uses, and knowing how to optimize their use can enhance the performance and efficiency of the application.

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