

# Chapter-4

**Mandip Rai**

# Microprocessor and Microcontroller

| Feature                      | Microprocessor  | Microcontroller  |
|------------------------------|---|--|
| <b>Definition</b>            | A Si chip representing a CPU, which is capable of performing arithmetic as well as logical operations according to a pre-defined set of instructions.               | Is a highly integrated chip that contains a CPU, scratchpad RAM, special and general purpose register arrays, on chip ROM/FLASH memory for program storage, timer & interrupt control units and dedicated I/O ports. |
| <b>Internal Components</b>   | CPU is stand-alone, RAM, ROM, I/O, timer are separate   | CPU, RAM, ROM, I/O and timer are all on a single chip  |
| <b>Dependency</b>            | Is a dependent unit. It requires the combination of other chip like timers, program and data memory chips, interrupt controllers, etc. for functioning              | Is a self-contained unit & it doesn't require external interrupt controller, timer, UART (Universal Asynchronous Receiver Transmitter), etc. for its functioning   |
| <b>Design Purpose</b>        | Most of the time general purpose in design and operation  | Mostly application-oriented or domain-specific   |
| <b>Target Market</b>         | Targeted for high end market where performance is important   | Targeted for embedded market where performance is not so critical.   |
| <b>I/O Ports</b>             | Doesn't contain a built-in I/O port. The I/O port functionality needs to be implemented with the help of external programmable peripheral interface chips like 8255 | Most of the processors contain multiple built-in I/O ports which can be operated as a single 8 or 16 or 32 bit port or as individual port pins   |
| <b>Power Saving Features</b> | Limited power saving options compared to microcontrollers   | Includes lots of power saving features.  |

# Selection Criteria

## **1. Feature Set Requirements**

- Interface needs (UART, SPI, I2C, USB)
- Number of I/O ports required by application
- Quantity of timers/counters needed
- Built-in ADC/DAC hardware requirements
- Required processing performance level

## **2. Speed of Operation**

- Clock cycles per instruction execution
- Maximum supported clock frequency
- Impact on overall controller performance

## **3. Code Memory Capacity**

- Sufficient on-chip ROM/Flash memory
- Must accommodate compiled hex code
- Especially important for high-level language applications (C, etc.)

## **4. Data Memory Capacity**

- Adequate on-chip RAM for:
  - Runtime variables
  - Data structures
  - Temporary storage

# Selection Criteria

## **5. Development Support**

- Availability of manufacturer-provided tools:
  - Cost-effective development kits
  - Sample applications
  - Debugging tools
- Third-party tool compatibility
- Technical support quality

## **6. Availability (Lead Time)**

- Time between purchase order and delivery
- Supply chain reliability
- Alternative sourcing options

## **7. Power Consumption**

- Must be minimized for:
  - Smaller power supply designs
  - Reduced cooling requirements
- Should support:
  - Idle modes
  - Power-down modes
- Impacts overall system: Size, Complexity, Cost

## **8. Cost Considerations**

- Must fit target market price range
- Balance between features and affordability
- Remember: End product must maintain profitability
- High-tech features may not always justify higher cost

## **Microprocessor Application**

- Desktop/laptop computers
- Cloud servers and data centers
- High-end smartphones
- Gaming consoles
- AI/ML processing systems
- Workstations for video editing
- Supercomputers
- Network routers/switches

## **Microcontroller Application**

- Home appliances (washing machines)
- Automotive control systems
- Industrial automation
- Medical devices
- Smart sensors/IoT devices
- Consumer electronics (TV remotes)
- Robotics control
- Wearable devices

# Atmega328

- ATmega328 is an 8-bit, 28-Pin AVR Microcontroller, manufactured by Microchip, follows RISC Architecture and has a flash-type program memory of 32KB.
- Atmega328 is the microcontroller, used in basic Arduino boards i.e Arduino UNO, Arduino Pro Mini and Arduino Nano.
- It has an EEPROM memory of 1KB and its SRAM memory is 2KB.
- It has 8 Pins for ADC operations, which all combine to form PortA ( PA0 - PA7 ).
- It also has 3 built-in Timers, two of them are 8 Bit timers while the third one is 16-Bit Timer.
- It operates ranging from 3.3V to 5.5V but normally we use 5V as a standard.
- Its excellent features include cost-efficiency, low power dissipation, programming lock for security purposes, real timer counter with separate oscillator.
- It's normally used in Embedded Systems applications.

**Atmega328 IC**



| Feature                     | Specification                       | Feature               | Specification                    |
|-----------------------------|-------------------------------------|-----------------------|----------------------------------|
| <b>No. of Pins</b>          | 28                                  | <b>ADC</b>            | 10-bit, 8 channels               |
| <b>CPU</b>                  | 8-bit RISC AVR                      | <b>PWM Pins</b>       | 6                                |
| <b>Operating Voltage</b>    | 1.8V – 5.5V                         | <b>Comparator</b>     | 1 (Analog)                       |
| <b>Program Memory</b>       | 32KB Flash                          | <b>Packages</b>       | 8-pin PDIP, 32-TQFP, 28/32-QFN   |
| <b>SRAM</b>                 | 2048 Bytes                          | <b>Oscillator</b>     | Up to 20 MHz                     |
| <b>EEPROM</b>               | 1024 Bytes                          | <b>Timers</b>         | 8-bit (x2), 16-bit (x1)          |
| <b>Power Management</b>     | BOD, Power-on Reset, Power-Up Timer | <b>I/O Pins</b>       | 23                               |
| <b>Manufacturer</b>         | Microchip                           | <b>SPI</b>            | Yes                              |
| <b>I<sup>2</sup>C (TWI)</b> | Yes                                 | <b>Watchdog Timer</b> | Yes                              |
| <b>USART</b>                | Yes                                 | <b>Reset</b>          | Yes                              |
| <b>Temp. Range</b>          | -40°C to +85°C                      | <b>USI</b>            | Yes (Universal Serial Interface) |

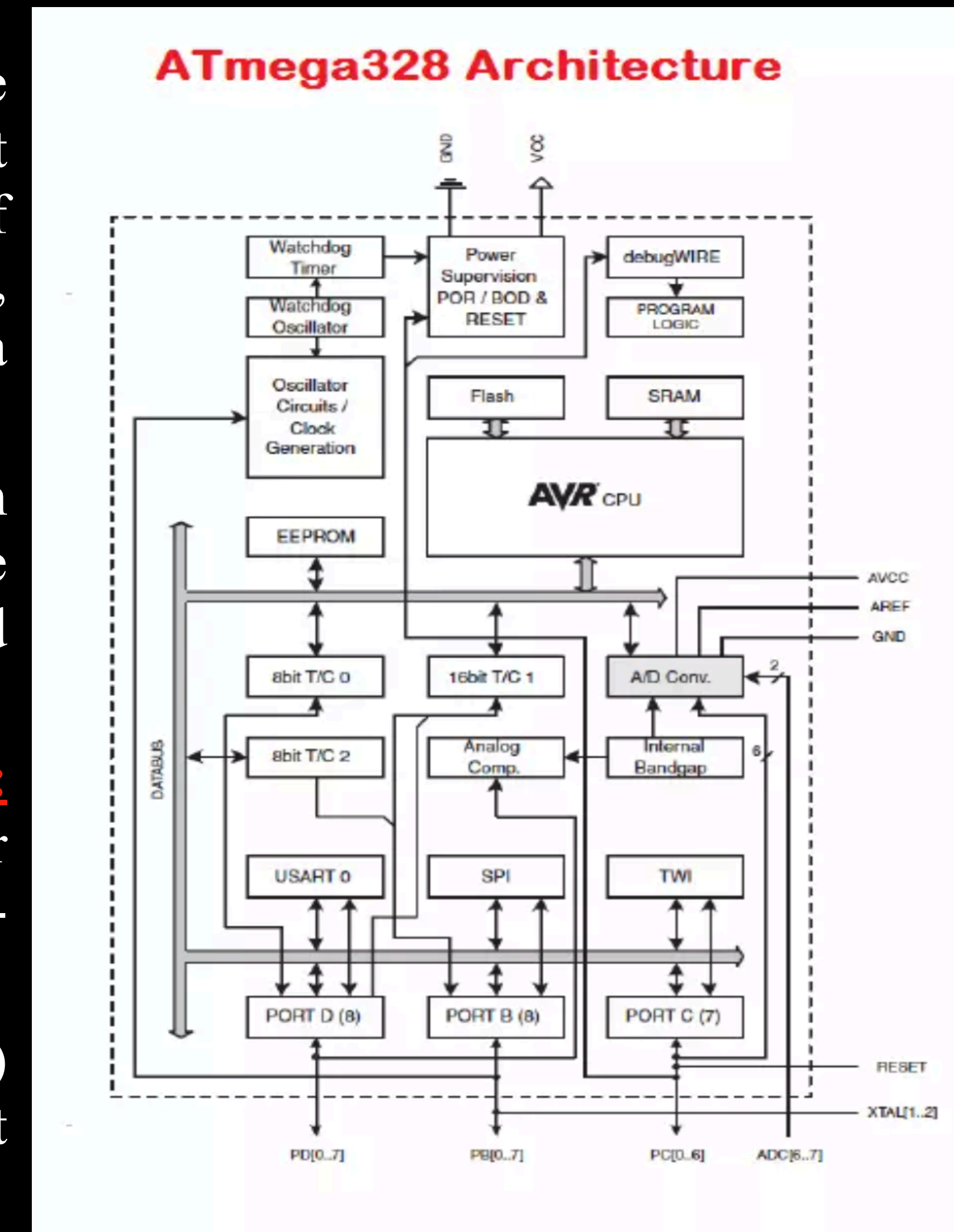
# Architecture

**1. AVR CPU (Central Processing Unit):** The AVR CPU is the core of the ATmega328 microcontroller. It follows an 8-bit RISC (Reduced Instruction Set Computing) architecture, which allows for efficient and fast execution of instructions. The CPU fetches instructions from Flash memory, decodes them, and performs arithmetic, logic, and control operations. It also manages data movement between registers, SRAM, and peripherals.

**2. Flash Memory (Program Memory):** The Flash memory (32KB in ATmega328) stores the firmware or program code. It is non-volatile, meaning the data remains even when power is removed. The Flash can be reprogrammed thousands of times, making it ideal for development and firmware updates.

**3. EEPROM (Electrically Erasable Programmable Read-Only Memory):** The EEPROM (1KB in ATmega328) is used to store data that must persist after power cycles (e.g., calibration values, user settings). Unlike Flash, it allows byte-level read/write operations, making it useful for small, frequently updated data.

**4. SRAM (Static Random-Access Memory):** The SRAM (2KB in ATmega328) is volatile memory used for temporary data storage during program execution. It holds variables, stack data, and dynamic memory allocations.



**5. Oscillator/Clock Generation:** The microcontroller requires a clock signal to synchronize operations. The Oscillator/Clock Generation circuit can derive timing from:

- An external crystal oscillator (e.g., 16MHz in Arduino Uno).
- An internal RC oscillator (8MHz by default).
- An external clock signal.

**6. Watchdog Timer (WDT) & Oscillator:** The Watchdog Timer (WDT) is a safety feature that resets the microcontroller if the software gets stuck (e.g., due to an infinite loop). It runs on an independent Watchdog Oscillator (typically 128kHz) to ensure operation even if the main clock fails.

**7. 8-bit Timer/Counters (TC0 & TC2):** The ATmega328 has three timers (two 8-bit and one 16-bit, though only TC0 and TC2 are shown here). These can be used for:

- PWM (Pulse-Width Modulation) generation (e.g., motor control, LED dimming).
- Waveform generation (e.g., square, sawtooth).
- Event counting (e.g., measuring sensor pulses).

**8. USART0 (Universal Synchronous/Asynchronous Receiver/Transmitter):** The USART enables serial communication (UART mode) with devices like:

- PCs (via USB-to-serial converters).
- GPS modules, Bluetooth modules, etc.

It supports full-duplex communication (simultaneous transmit and receive).

## **9. TWI (Two-Wire Interface, I<sup>2</sup>C-Compatible)**

The TWI (I<sup>2</sup>C) interface allows communication with multiple peripherals (e.g., sensors, EEPROMs) using just two wires (SDA & SCL). It supports multi-master and slave modes.

## **10. Analog Comparator & ADC (Analog-to-Digital Converter)**

- Analog Comparator: Compares two input voltages and triggers an interrupt if one exceeds the other.
- ADC (10-bit, 6-channel): Converts analog signals (e.g., from sensors) to digital values for processing.

**11. Internal Band-gap Reference:** A stable voltage reference ( $\sim 1.1\text{V}$ ) used by the ADC and Analog Comparator for accurate measurements, independent of supply voltage fluctuations.

**12. I/O Ports (PORT B, PORT D, PORT C):** The ATmega328 has 23 programmable I/O pins grouped into three ports:

- PORT B (8 pins): Digital I/O, PWM, SPI.
- PORT D (8 pins): Digital I/O, USART, interrupts.
- PORT C (7 pins): Analog inputs (ADC), I<sup>2</sup>C.

## **13. Power Supervision (Brown-Out Detection & Reset):**

- BOD (Brown-Out Detector): Resets the MCU if voltage drops below a safe threshold (e.g., 2.7V or 4.3V, configurable).
- Reset Circuit: Ensures a clean startup by holding the MCU in reset until the power supply stabilizes.

# Pin Configuration

## Power and System Pins:

Pin 1 (PC6/RESET): Active-low reset input (must be pulled high for normal operation)

Pin 7 (VCC): Main 5V power supply input

Pin 8 (GND): Ground connection

Pin 20 (AVCC): Dedicated power for ADC (should connect to VCC via filter)

Pin 21 (AREF): Reference voltage input for analog conversions

Pin 22 (GND): Additional ground connection

## Port D Pins (Digital I/O with Special Functions):

Pin 2 (PD0): Digital I/O, USART Receive (RX) for serial communication

Pin 3 (PD1): Digital I/O, USART Transmit (TX) for serial communication

Pin 4 (PD2): Digital I/O with External Interrupt 0 capability

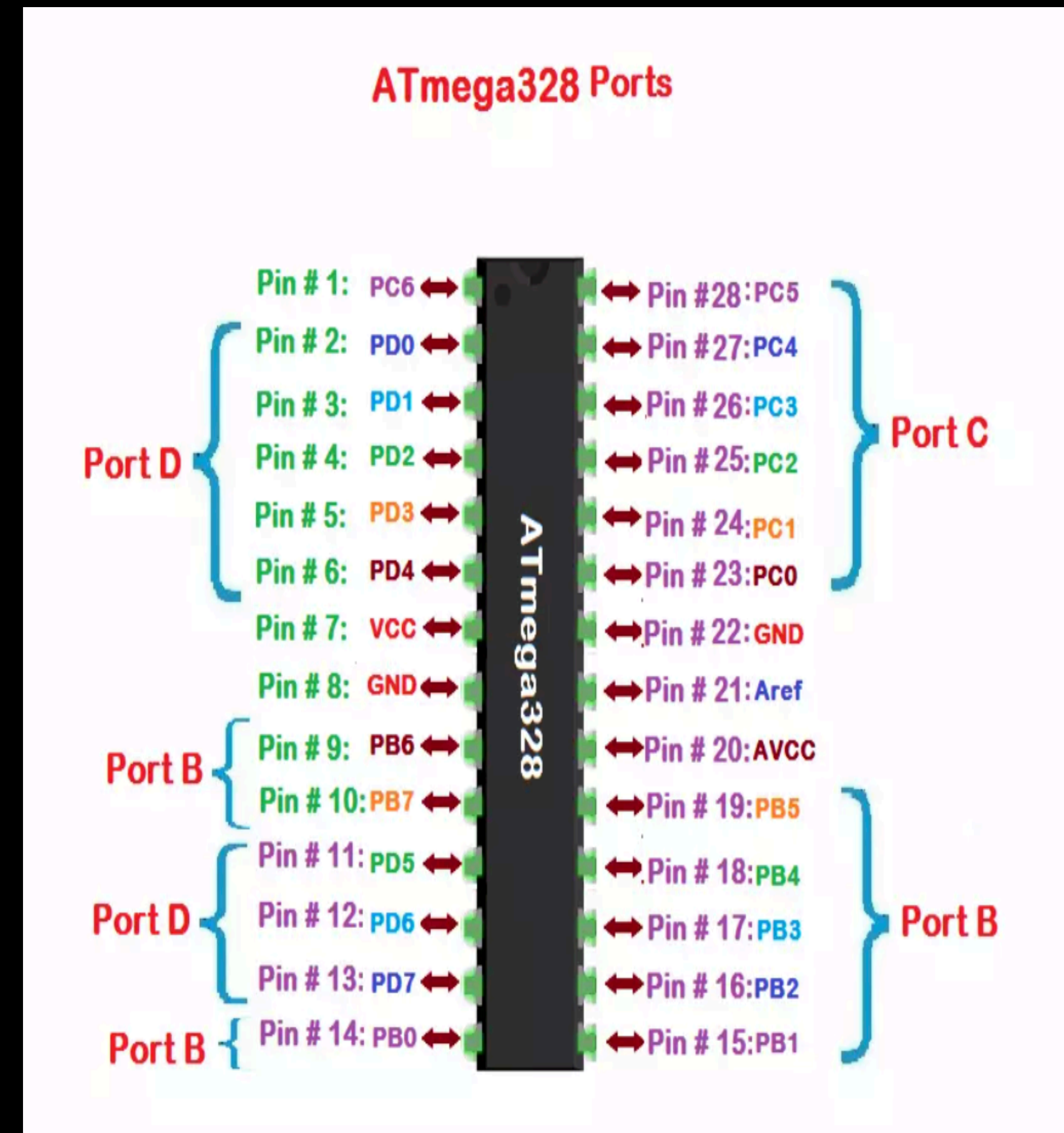
Pin 5 (PD3): Digital I/O with External Interrupt 1 and PWM output

Pin 6 (PD4): General purpose digital I/O

Pin 11 (PD5): Digital I/O with PWM output

Pin 12 (PD6): Digital I/O with PWM output

Pin 13 (PD7): General purpose digital I/O



### **Port B Pins (Digital I/O with SPI and Timer Functions):**

Pin 9 (PB6): Digital I/O, can connect to crystal oscillator (XTAL1)

Pin 10 (PB7): Digital I/O, can connect to crystal oscillator (XTAL2)

Pin 14 (PB0): Digital I/O with PWM output

Pin 15 (PB1): Digital I/O with PWM output

Pin 16 (PB2): Digital I/O, SPI Slave Select (SS)

Pin 17 (PB3): Digital I/O, SPI Master Out Slave In (MOSI) with PWM

Pin 18 (PB4): Digital I/O, SPI Master In Slave Out (MISO)

Pin 19 (PB5): Digital I/O, SPI Serial Clock (SCK)

### **Port C Pins (Analog Input and I<sup>2</sup>C):**

Pin 23 (PC0): Analog Input ADC0 or digital I/O

Pin 24 (PC1): Analog Input ADC1 or digital I/O

Pin 25 (PC2): Analog Input ADC2 or digital I/O

Pin 26 (PC3): Analog Input ADC3 or digital I/O

Pin 27 (PC4): Analog Input ADC4 or digital I/O, I<sup>2</sup>C Serial Data (SDA)

Pin 28 (PC5): Analog Input ADC5 or digital I/O, I<sup>2</sup>C Serial Clock (SCL)

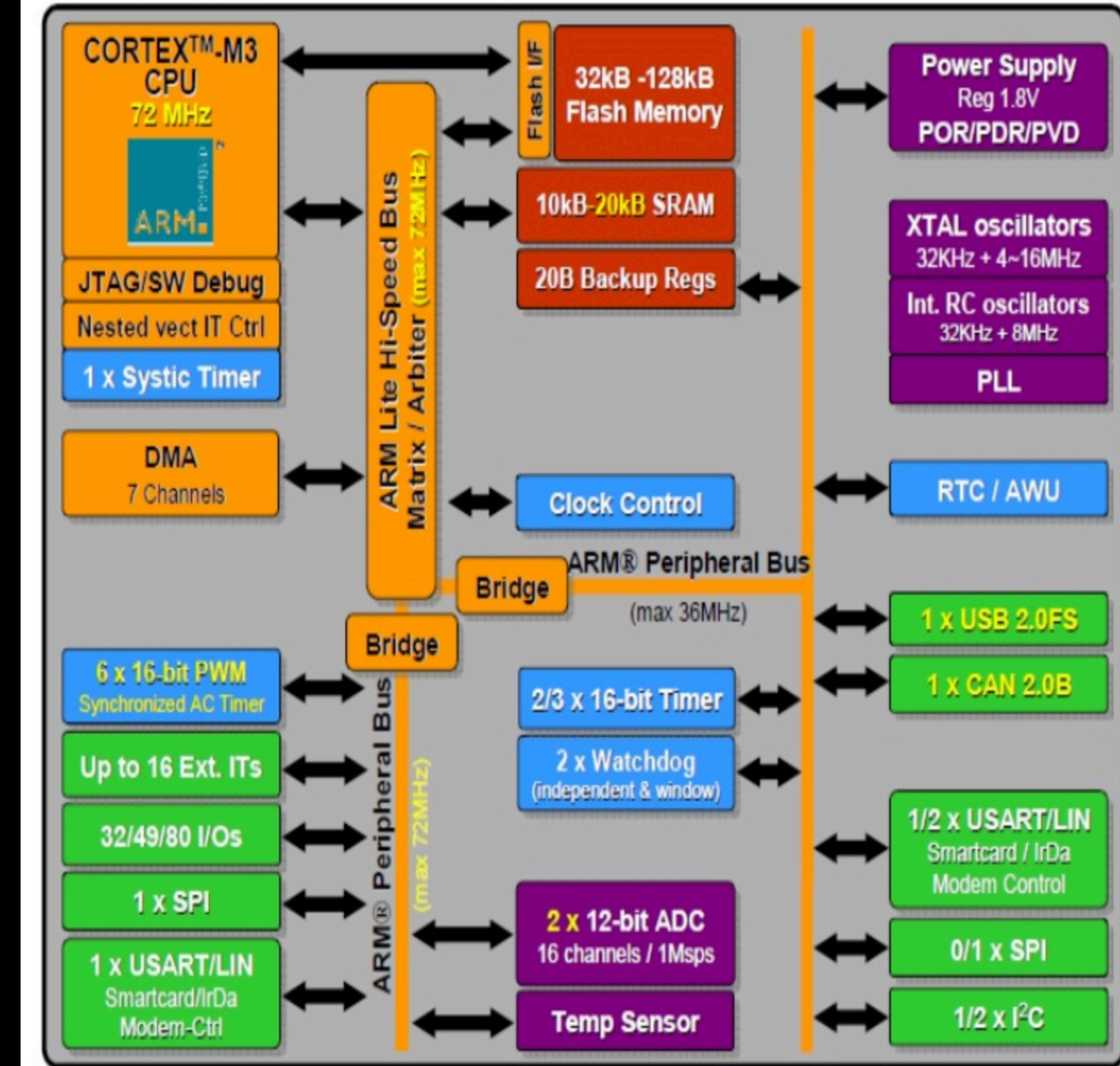
# STM32

## Core and Control Block

- Cortex-M3 CPU @ 72 MHz:  
A powerful 32-bit ARM core designed for high performance and low power. It supports:
  - Nested Vectored Interrupt Controller (NVIC): For fast and prioritized interrupt handling.
  - SysTick Timer: A dedicated system timer used for OS tick generation or simple delays.
  - JTAG/SW Debug Interface: For debugging and programming.

## Memory

- Flash Memory (32 KB – 128 KB):  
Non-volatile memory for storing code and constants.
- SRAM (10 KB – 20 KB):  
Volatile memory for data and stack.
- Backup Registers (20 Bytes):  
Used to retain small amounts of data during power loss or in low-power mode.



## **Clock & Power Management**

- **Power Supply (Reg 1.8V):**  
Core operates at 1.8V via internal voltage regulation.
- **Power-on Reset (POR), Power-down Reset (PDR), Programmable Voltage Detector (PVD):**  
Protects against undervoltage conditions.
- **Clock Sources:**
  - XTAL Oscillators: 32 KHz (for RTC), 4–16 MHz (main system clock).
  - Internal RC Oscillators: 32 KHz + 8 MHz for startup or low-accuracy applications.
  - PLL: Used to multiply frequency for faster CPU/system operation.
- **RTC / AWU: Real-Time Clock and Auto Wake-Up from low-power modes.**

## **Peripherals and I/O**

- **ARM Peripheral Bus (max 36 MHz):**  
Connects slower peripherals to the CPU and memory.
- **ARM Lite Hi-Speed Bus (max 72 MHz):**  
For high-performance access like DMA and flash.
- **DMA (7 Channels):**  
Transfers data between peripherals/memory without CPU load.

## **Timers**

- **6 × 16-bit PWM Timers:**  
Synchronized timers used for generating PWM signals, useful in motor control or lighting.
- **2/3 × 16-bit General-Purpose Timers**
- **2 × Watchdog Timers:**
  - **Independent and Windowed Watchdog:** Ensures system stability.

## **Communication Interfaces**

- **USART/LIN (1 full + 1/2):**  
UART communication with LIN (Local Interconnect Network) support.
- **SPI (1 full + 0/1 additional):**  
Serial Peripheral Interface for fast synchronous communication.
- **I2C (1/2 interfaces):**  
For connecting low-speed peripherals like EEPROMs, sensors.
- **CAN 2.0B (1 interface):**  
Used in automotive and industrial applications.
- **USB 2.0 Full-Speed (1 interface):**  
Allows the STM32 to act as a USB device (keyboard, mouse, etc.).

## I/O Capabilities

- **32 / 49 / 80 I/O Pins:**

Depending on the package, with alternate functions for peripherals.

- **Up to 16 External Interrupts:**

Allows hardware event detection on I/O pins.

## Analog Features

- **2 × 12-bit ADC (16 channels, 1Msps):**

Fast and high-resolution analog-to-digital conversion for sensors.

- **Temperature Sensor:**

On-chip sensor for temperature monitoring.