Chapter 4: Elements of IoT
Introduction to Sensors, Actuators, Transducers and their types

1. Introduction

In the **Internet of Everything (IoE)** and **Internet of Things (IoT)**, devices interact with the **physical environment**.

This interaction requires:

- **Sensors** → to sense physical quantities.
- **Transducers** → to convert one form of energy into another.
- **Actuators** → to perform real-world actions.

Together, they create a **closed loop system**:
Physical Environment → Sensors → Processing Unit → Actuators → Physical Environment

2. Sensors

Definition

A **sensor** is a device that **detects physical, chemical, or biological parameters** and converts them into a measurable electrical signal.

Working Principle

1. Physical quantity (e.g., temperature, pressure, light) changes a property of the sensor.
2. This change is converted into an electrical signal (voltage, current, resistance, or frequency).
3. The signal is further processed by a controller (e.g., Arduino, Raspberry Pi).

Characteristics of Sensors

- **Sensitivity** → How much the output changes per unit change in input.
- **Accuracy** → How close measurement is to the true value.
- **Resolution** → Smallest detectable change.
- **Range** → Minimum to maximum measurable limit.
- **Response Time** → Time taken to respond to changes.

Types of Sensors

1. **Temperature Sensors**

    - Thermocouples, RTDs, Thermistors, IC sensors (LM35).
    - Example: Smart thermostat.

2. **Proximity Sensors**
    - IR sensor, Ultrasonic sensor, Capacitive/Inductive sensors.
    - Example: Automatic doors, parking sensors.
3. **Light Sensors**
    - LDR, Photodiode, Phototransistor.
    - Example: Street lights turning ON/OFF automatically.
4. **Motion & Position Sensors**
    - PIR sensor (detects human motion), Accelerometer, Gyroscope.
    - Example: Fitness trackers, robotics.
5. **Gas & Chemical Sensors**
    - MQ-series sensors, pH sensors.
    - Example: Air quality monitoring, alcohol detectors.
6. **Pressure Sensors**
    - Barometric pressure sensors, Piezoelectric sensors.
    - Example: Weather monitoring, tire pressure systems.

3. Transducers

Definition

A **transducer** is a device that **converts one form of energy into another**.

- **All sensors are transducers**, but not all transducers are sensors.

□ Example:

- Microphone (Sound → Electrical signal) → **Sensor Transducer**.
- Loudspeaker (Electrical signal → Sound) → **Actuator Transducer**.

Types of Transducers

1. **Input Transducers (Sensors)**
    - Convert physical quantity → electrical signal.
    - Examples: Thermocouple, Light Dependent Resistor Sensor, Microphone.
2. **Output Transducers (Actuators)**
    - Convert electrical signal → physical action.
    - Examples: Motor, Speaker, Bulb.

3. **Active Transducers** (Self-generating)
    - Generate their own electrical signal without external power.
    - Examples: Thermocouple.
4. **Passive Transducers** (Require external power)
    - Output signal depends on external excitation.
    - Examples: Resistance Temperature Detector Sensor, LDR, Strain gauge.

4. Actuators

Definition

An **actuator** is a device that **converts an electrical signal into mechanical movement, heat, sound, or other physical actions**.

□ It is the **“action” part** of IoE systems.

Working Principle

1. Controller generates an electrical control signal.
2. Actuator converts that signal into a physical action.
3. Action modifies the environment (e.g., fan ON, valve open).

Characteristics of Actuators

- **Precision** → How accurately it performs an action.
- **Speed** → How quickly it responds.
- **Force/Torque** → Mechanical power generated.
- **Control Method** → On/Off, Analog, or Digital control.

Types of Actuators

1. **Electrical Actuators**
    - DC Motors, Stepper Motors, Servo Motors, Solenoids.
    - Example: Robotics, Printers.
2. **Hydraulic Actuators**
    - Use pressurized fluid.
    - Example: Excavators, aircraft brakes.
3. **Pneumatic Actuators**
    - Use compressed air.
    - Example: Automation systems, factory machinery.
4. **Thermal Actuators**
    - Convert heat into movement.

    - Example: Bimetallic strips in thermostats.

5. **Piezoelectric Actuators**
    - Use piezoelectric effect to generate small precise movements.
    - Example: Precision instruments, ultrasonic devices.

Example Flow in IoE System

Smart Home Fan Control

- **Sensor:** Temperature sensor measures room heat.
- **Transducer:** Converts heat into electrical voltage signal.
- **Processor:** Microcontroller compares temperature with threshold.
- **Actuator:** DC motor turns ON the fan to cool the room.

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Arduino following models:

1.Arduino Uno(R3)

2.Arduino Mega (R3)

3.Arduino Nano

4.Arduino Leonardo

5.Arduino Due

6.LilyPad Arduino

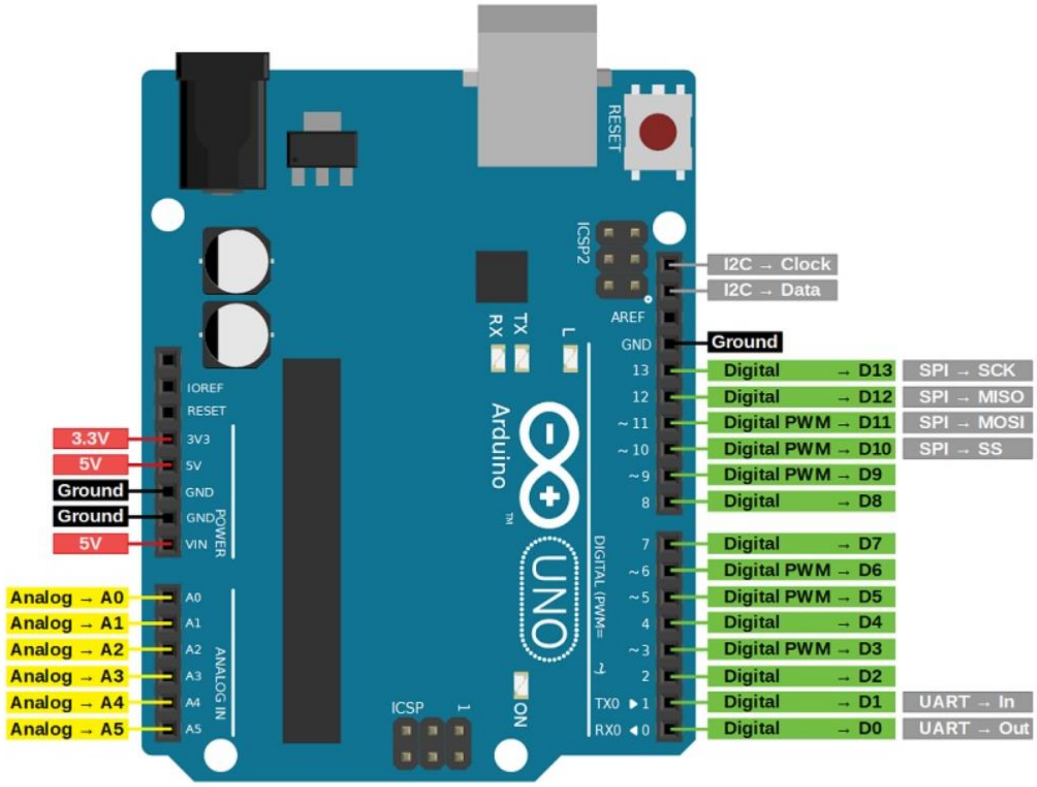
7.Arduino Micro

8.Arduino Pro Mini

Arduino boards, such as the popular Arduino Uno, are built around a microcontroller and feature a standardized pin configuration to facilitate interaction with external components.

Arduino Pin Configuration (Example: Arduino Uno):

Arduino Uno (R3)



Vin: This is the input voltage pin of the Arduino board used to provide input supply from an external power source.

5V: This pin of the Arduino board is used as a regulated power supply voltage and it is used to give supply to the board as well as onboard components.

3.3V: This pin of the board is used to provide a supply of 3.3V which is generated from a voltage regulator on the board

GND: This pin of the board is used to ground the Arduino board.

Reset: This pin of the board is used to reset the microcontroller. It is used to Resets the microcontroller.

Analog Pins: The pins A0 to A5 are used as an analog input and it is in the range of 0-5V.

Digital Pins: The pins 0 to 13 are used as a digital input or output for the Arduino board.

Serial Pins: These pins are also known as a UART pin. It is used for communication between the Arduino board and a computer or other devices. The transmitter pin number 1 and receiver pin number 0 is used to transmit and receive the data resp.

External Interrupt Pins: This pin of the Arduino board is used to produce the External interrupt and it is done by pin numbers 2 and 3.

PWM Pins: This pins of the board is used to convert the digital signal into an analog by varying the width of the Pulse. The pin numbers 3,5,6,9,10 and 11 are used as a PWM pin.

SPI Pins: This is the Serial Peripheral Interface pin, it is used to maintain SPI communication with the help of the SPI library. SPI pins include:

1.SS: Pin number 10 is used as a Slave Select

2.MOSI: Pin number 11 is used as a Master Out Slave In

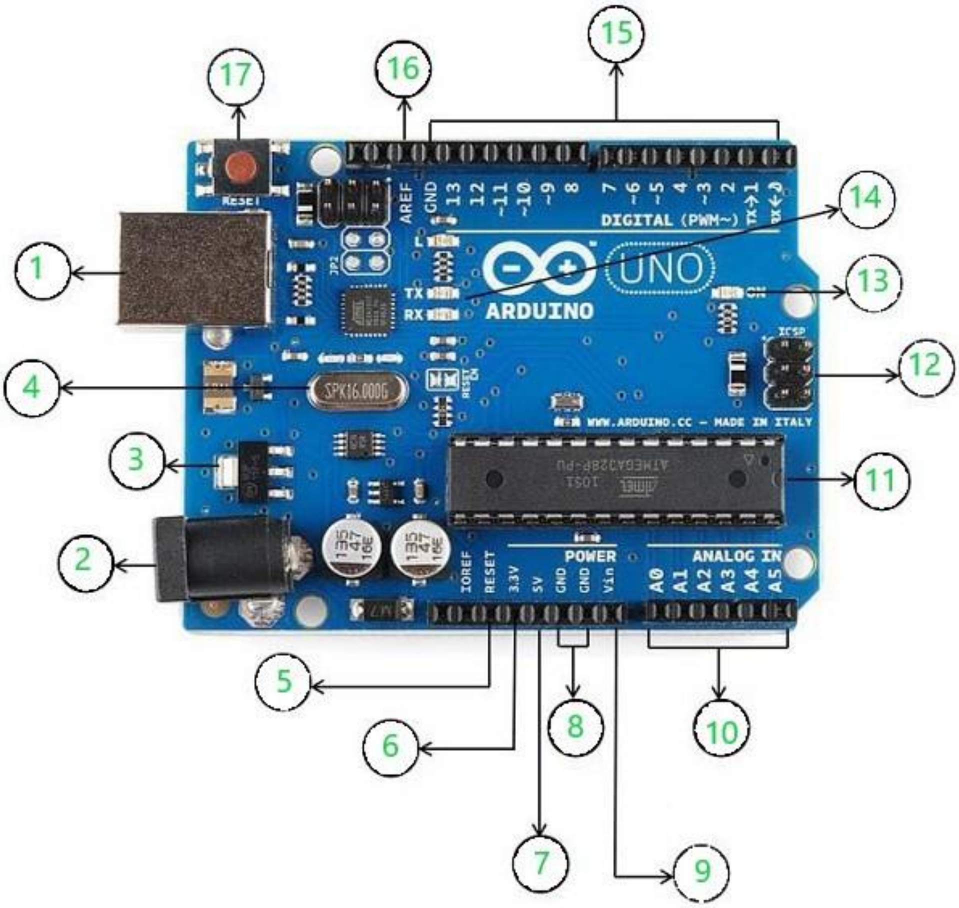
3.MISO: Pin number 12 is used as a Master In Slave Out

4.SCK: Pin number 13 is used as a Serial Clock

LED Pin: The board has an inbuilt LED using digital pin-13. The LED glows only when the digital pin becomes high.

AREF Pin: This is an analog reference pin of the Arduino board. It is used to provide a reference voltage from an external power supply.

Android Architecture



1.USB: can be used for both power and communication with the IDE

2.Barrel Jack: used for power supply

3.Voltage Regulator: regulates and stabilizes the input and output voltages

4.Crystal Oscillator: keeps track of time and regulates processor frequency

5.Reset Pin: can be used to reset the Arduino Uno

6.3.3V pin: can be used as a 3.3V output

7.5V pin: can be used as a 5V output

8.GND pin: can be used to ground the circuit

9.Vin pin: can be used to supply power to the board

10.Analog pins(A0-A5): can be used to read analog signals to the board

11.Microcontroller(ATMega328): the processing and logical unit of the board

12.ICSP pin: a programming header on the board also called SPI

13.Power indicator LED: indicates the power status of the board

14.RX and TX LEDs: receive(RX) and transmit(TX) LEDs, blink when sending or receiving serial data respectively

15.Digital I/O pins: 14 pins capable of reading and outputting digital signals; 6 of these pins are also capable of PWM

16.AREF pins: can be used to set an external reference voltage as the upper limit for the analog pins

17.Reset button: can be used to reset the board

How it Works

1. **Programming:**

   A program (sketch), written in a C++ based language, is uploaded to the Arduino's flash memory via the USB connection.
2. **Execution:**

   When powered on, the microcontroller reads the code from the flash memory and begins executing the instructions.
3. **Interaction:**

The program uses the I/O pins to interact with the outside world, reading digital or analog inputs and sending digital outputs to control other devices.

4. **Temporary Data:**

   Data generated or needed during program execution is temporarily stored in the SRAM.
5. **Persistent Data:**
   Data that needs to survive a power cycle (like settings or calibration values) is stored in the EEPROM.

Devices and Platforms, Ports, and Arduino Interfacing

1. Devices and Platforms in IoT/IoE

Devices

- **Definition**: Hardware components that sense, process, and act in an IoT system.
- **Examples**:
  - **Sensors**: Temperature, motion, gas, humidity sensors.
  - **Actuators**: Motors, relays, solenoids, LEDs, speakers.
  - **Edge Devices**: Arduino, Raspberry Pi, ESP32, NodeMCU.

Platforms

- **Definition**: Software environment that connects devices, collects data, and provides services such as analytics, storage, and visualization.
- **Types**:
  1. **Device-level Platforms** – Arduino IDE, Raspberry Pi OS.
  2. **Cloud Platforms** – AWS IoT, Google Cloud IoT, Azure IoT Hub.
  3. **Open-source IoT Platforms** – ThingsBoard, Node-RED, Kaa IoT.

Device = hardware that collects/acts.
Platform = software/cloud that manages and processes data.

2. Concept of Digital and Analog Ports

Ports in Microcontrollers

- **Port** = Physical interface (pin) on a microcontroller used to send/receive data.
- Classified as **digital** or **analog**.

Digital Ports

- Accept or output only **two states**:
  - 0 → LOW (0V)
  - 1 → HIGH (5V on Arduino UNO, 3.3V on some boards)
- Used for ON/OFF control.
- **Examples**:
  - Button press (pressed = HIGH, not pressed = LOW).
  - LED (ON = HIGH, OFF = LOW).
- **Arduino Digital Pins**: D0 – D13 on Arduino UNO.
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Analog Ports

- Accept **range of values**, not just 0 or 1.
- Measure continuous signals (0V → 5V).
- Microcontroller uses **ADC (Analog-to-Digital Converter)** to convert analog voltage into digital values (0–1023 for Arduino UNO).
- **Examples**:
  - Temperature sensor (LM35: 0.01V per °C).
  - Light sensor (LDR gives variable resistance).
- **Arduino Analog Pins**: A0 – A5 on Arduino UNO.

3. Arduino Interfacing Board

What is Arduino?

- Open-source **microcontroller board** used for **prototyping** and **IoT projects**.
- Uses **Arduino IDE** for programming (C/C++ based).
- Features:
  - USB interface for power and programming.
  - GPIO pins (digital + analog).

- Works with sensors, actuators, displays, and communication modules (WiFi, Bluetooth, GSM).

Example: Arduino with Sensor and Actuator

- **Sensor (Input)**: LDR connected to Analog pin A0.
- **Processor**: Arduino reads light level.
- **Actuator (Output)**: LED connected to Digital pin D9.
- **Function**: LED turns ON when room is dark.

Types of Arduino Boards

1.Arduino Uno(R3)

2.Arduino Mega (R3)

3.Arduino Nano

4.Arduino Leonardo

5.Arduino Due

6.LilyPad Arduino

7.Arduino Micro

8.Arduino Pro Mini

Arduino boards differ mainly in **microcontroller**, **size**, **number of input/output pins**, **connectivity options**, and **applications**.

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1. **Arduino Uno**

- **Microcontroller:** ATmega328P
- **Operating Voltage:** 5V
- **Digital I/O Pins:** 14 (6 can be PWM)
- **Analog Input Pins:** 6
- **Flash Memory:** 32 KB
- **Best For:** Beginners, learning, and small IoT projects
- **Special Note:** Most popular and widely supported board.

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2. **Arduino Nano**
    - **Microcontroller:** ATmega328P
    - **Operating Voltage:** 5V (3.3V also available in some versions)
    - **Digital I/O Pins:** 22 (6 PWM)
    - **Analog Input Pins:** 8
    - **Flash Memory:** 32 KB
    - **Size:** Very small, breadboard-friendly
    - **Best For:** Compact projects, wearable devices.

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3. **Arduino Mega 2560**
    - **Microcontroller:** ATmega2560
    - **Operating Voltage:** 5V
    - **Digital I/O Pins:** 54 (15 PWM)
    - **Analog Input Pins:** 16
    - **Flash Memory:** 256 KB
    - **Best For:** Complex projects needing many sensors/actuators (e.g., robotics, automation).

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4. **Arduino Leonardo**
    - **Microcontroller:** ATmega32u4
    - **Operating Voltage:** 5V
    - **Digital I/O Pins:** 20
    - **Analog Input Pins:** 12
    - **Flash Memory:** 32 KB
    - **Special Feature:** Can emulate a **keyboard or mouse** (USB HID device).
    - **Best For:** Human-computer interaction projects.

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5. **Arduino Due**
    - **Microcontroller:** Atmel SAM3X8E ARM Cortex-M3 (32-bit)
    - **Operating Voltage:** 3.3V (⚠ not 5V tolerant)
    - **Digital I/O Pins:** 54 (12 PWM)

- **Analog Input Pins:** 12
- **Flash Memory:** 512 KB
- **Best For:** High-performance computing, IoT gateways, and real-time processing.

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6. **Arduino Micro**
   - **Microcontroller:** ATmega32u4
   - **Operating Voltage:** 5V
   - **Digital I/O Pins:** 20
   - **Analog Input Pins:** 12
   - **Flash Memory:** 32 KB
   - **Size:** Smaller than Leonardo, breadboard compatible
   - **Best For:** Wearable and compact projects.

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7. **Arduino Pro Mini**
   - **Microcontroller:** ATmega328P
   - **Operating Voltage:** 3.3V or 5V (depending on model)
   - **Digital I/O Pins:** 14 (6 PWM)
   - **Analog Input Pins:** 8
   - **Flash Memory:** 32 KB
   - **Special Note:** No USB port (needs FTDI programmer).
   - **Best For:** Low-power embedded projects.

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8. **Arduino LilyPad**
   - **Microcontroller:** ATmega328P
   - **Operating Voltage:** 3.3V or 5V
   - **Digital I/O Pins:** 14
   - **Analog Input Pins:** 6
   - **Flash Memory:** 32 KB
   - **Special Feature:** Designed for **e-textiles & wearables**, sewable with conductive thread.

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9. **Arduino MKR Series** (e.g., MKR1000, MKR WiFi 1010, MKR GSM 1400)
    - **Microcontrollers:** ARM Cortex-M0 SAMD21
    - **Operating Voltage:** 3.3V
    - **Connectivity Options:** WiFi, GSM, LoRa, NB-IoT (depending on variant)
    - **Best For:** IoT and wireless communication projects.

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10. **Arduino Portenta Series** (e.g., Portenta H7)
    - **Microcontrollers:** Dual-core ARM Cortex-M7 + Cortex-M4
    - **Connectivity:** WiFi, Bluetooth, IoT-ready
    - **Best For:** AI, machine learning at the edge, advanced industrial IoT.

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11. **Arduino Esplora**
    - **Microcontroller:** ATmega32u4
    - **Built-in Sensors:** Joystick, light sensor, temperature sensor, accelerometer, microphone
    - **Special Feature:** Comes with ready sensors and actuators for experimentation
    - **Best For:** Education, gaming, prototyping without external components.

Different Arduino Model

Model	Launch Year	Microcontroller	Clock Speed	Flash Memory	SRAM	I/O Pins (Digital / Analog)	USB / Communication	Notable Features / Use Cases
Arduino Nano	2008	ATmega328P	16 MHz	32 KB	2 KB	14 (6 PWM) / 8	Mini USB	Compact Uno alternative, breadboard friendly
Arduino Uno R3	2010	ATmega328P	16 MHz	32 KB	2 KB	14 (6 PWM) / 6	USB Type-B	Most popular, beginner-friendly, ideal for basic projects & education
Arduino Mega 2560	2010	ATmega2560	16 MHz	256 KB	8 KB	54 (15 PWM) / 16	USB Type-B	Large I/O count, used for robotics, automation, 3D printers
Arduino Leonardo	2012	ATmega32U4	16 MHz	32 KB	2.5 KB	20 (7 PWM) / 12	Micro USB	Built-in USB communication – acts as mouse/keyboard
Arduino Due	2012	Atmel SAM3X8E (ARM Cortex-M3)	84 MHz	512 KB	96 KB	54 (12 PWM) / 12	Micro USB	32-bit ARM processor, faster & powerful for advanced projects
Arduino Micro	2013	ATmega32U4	16 MHz	32 KB	2.5 KB	20 (7 PWM) / 12	Micro USB	Miniature version of Leonardo, good for wearable/portable projects
Arduino MKR1000 (WiFi)	2016	SAMD21 (ARM Cortex-M0+)	48 MHz	256 KB	32 KB	22 (12 PWM) / 7	Micro USB + Wi-Fi	IoT-ready board with built-in Wi-Fi
Arduino MKR Zero	2017	SAMD21	48 MHz	256 KB	32 KB	22 (12 PWM) / 7	Micro USB	Supports SD card, good for data logging & audio
Arduino Nano Every	2019	ATmega4809	20 MHz	48 KB	6 KB	22 (6 PWM) / 8	Micro USB	Upgraded Nano – more RAM, flash, faster speed
Arduino Nano 33 IoT	2019	SAMD21 + NINA-W102	48 MHz	256 KB	32 KB	14 (PWM) / 8	Micro USB + Wi-Fi + BT	IoT + BLE + sensor support in compact size
Arduino Portenta H7	2020	Dual-core ARM Cortex-M7 + M4	480 + 240 MHz	2 MB	1 MB	160+	USB-C	Industrial-grade performance, AI/ML capable, edge computing
Arduino Giga R1 WiFi	2023	STM32H747XI Dual ARM Cortex-M7 + M4	480 + 240 MHz	2 MB	1 MB	76 (12 analog)	USB-C + Wi-Fi + BT	High-end board for robotics, multimedia, and AI

Raspberry Pi – Introduction

- **Raspberry Pi (Rpi)** is a **low-cost, credit card-sized single-board computer** developed by the **Raspberry Pi Foundation (UK)** to promote computer education and DIY electronics.
- It can perform most functions of a desktop computer — like browsing, coding, and connecting sensors and devices.
- Commonly used for **IoT projects, robotics, automation, and embedded systems**

What is Raspberry Pi?

Raspberry Pi is defined as a minicomputer the size of a credit card that is interoperable with any input and output hardware device like a monitor, a television, a mouse, or a keyboard – effectively converting the set-up into a full-fledged PC at a low cost.

The first generation of computers came as massive processing systems built with vacuum tube technology. Over the years, more compact and less expensive versions of what a computer would come to look like sprung up. Today, we have minicomputer gadgets such as smartphones in our pockets. Even though computers have become so commonplace, they are still not widely accessible in developing countries. This imbalance in access to computers and programming technology led to the development and creation of the Raspberry Pi computer.

Raspberry Pi is a small, low-cost, single-board computer the size of a credit card that allows people from different backgrounds and levels of expertise to experience and learn to compute. It is an enhanced motherboard developed in the United Kingdom by the Raspberry Pi foundation, now widely accepted as a part of evolving computer technology. The minicomputer can connect with other peripheral hardware devices such as a keyboard, mouse, and monitor.

One can use Raspberry Pi for various purposes, including learning programming languages and orchestrating network management. It is multifunctional and gained even more popularity in the past few years than initially projected.

Key Features:

- ARM-based processor
- HDMI, USB, Ethernet, Wi-Fi, Bluetooth
- GPIO pins for hardware interfacing
- Runs Linux-based OS (e.g., Raspberry Pi OS, Ubuntu, etc.)

How does Raspberry Pi work?

Raspberry Pi is a programmable device. It comes with all the critical features of the motherboard in an average computer but without peripherals or internal storage. To set up the Raspberry computer, you will need an SD card inserted into the provided space. The SD card should have the operating system installed and is required for the computer to boot. Raspberry computers are compatible with Linux OS. This reduces the amount of memory needed and creates an environment for diversity.

After setting up the OS, one can connect Raspberry Pi to output devices like computer monitors or a High-Definition Multimedia Interface (HDMI) television. Input units like mouse or keyboards should also be connected. This minicomputer's exact use and applications depend on the buyer and can cover many functions.

Comparison of Various Raspberry Pi Models

Model (Year)	Processor	RAM	USB / Ethernet	Wireless	GPIO	Notable Features / Highlights
Raspberry Pi 1 (2012)	700 MHz ARM11	256–512 MB	USB 2.0 / Ethernet	No	26 → 40 (B+)	First model; baseline for future boards
Raspberry Pi 2 B (2015)	Quad-core 900 MHz ARM Cortex-A7	1 GB	USB 2.0 / Ethernet	No	40	Improved speed and performance
Raspberry Pi Zero / Zero W (2015)	1 GHz ARM11	512 MB	Micro USB	No / Wi-Fi + BT 4.0 (Zero W)	40	Ultra-compact, low-cost board for IoT
Raspberry Pi 3 B / B+ (2016 / 2018)	Quad-core 1.2 – 1.4 GHz ARM Cortex-A53	1 GB	USB 2.0 / Ethernet	Wi-Fi + BT 4.1	40	Wireless connectivity, low power use
Raspberry Pi 4 B (2019)	Quad-core 1.5 GHz ARM Cortex-A72	2–8 GB	USB 3.0 / Gigabit Ethernet	Wi-Fi + BT 5.0	40	Dual 4K display, high performance
Raspberry Pi 400 (2020)	Quad-core 1.8 GHz ARM Cortex-A72	4 GB	USB 3.0 / Ethernet	Wi-Fi + BT 5.0	40	Built into keyboard; ideal for classrooms

Evolution Highlights

- **Memory growth:** 256 MB → 8 GB
- **Connectivity evolution:** Ethernet → Wi-Fi + Bluetooth → USB 3.0 & Gigabit
- **Processing power:** Single-core → Quad-core → High-speed Cortex-A72
- **Form factors:** Standard boards → ultra-compact (Zero) → all-in-one keyboard (Pi 400)
- **Recommended Uses:**
- Pi Zero: Mini IoT projects
- Pi 1 / 2: Beginners & learning kits
- Pi 3: IoT, home automation, robotics
- Pi 4 / 400: Advanced projects, classrooms, desktop computing

Architecture of Raspberry pi :

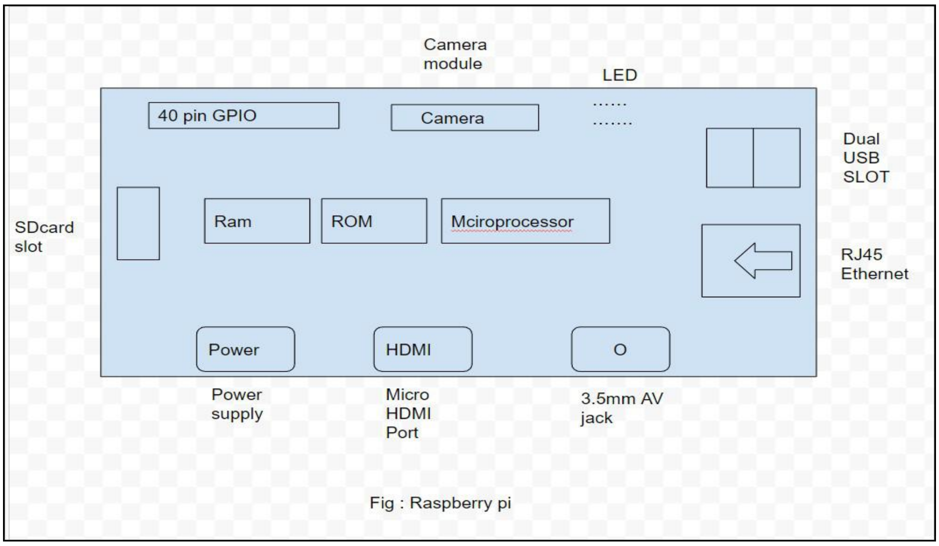
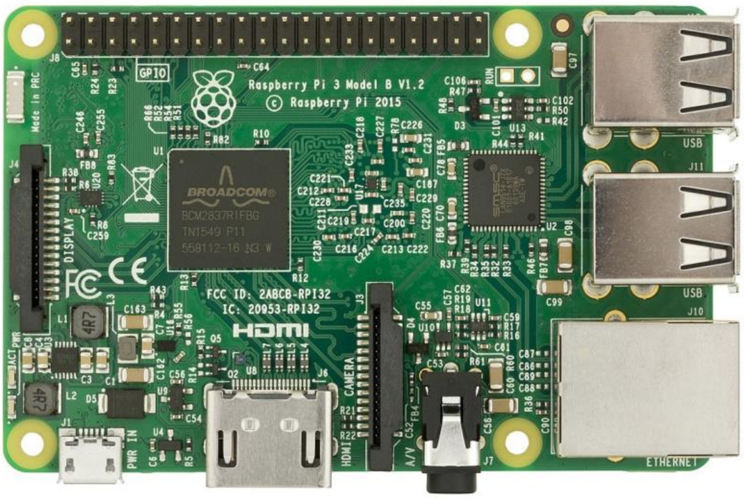


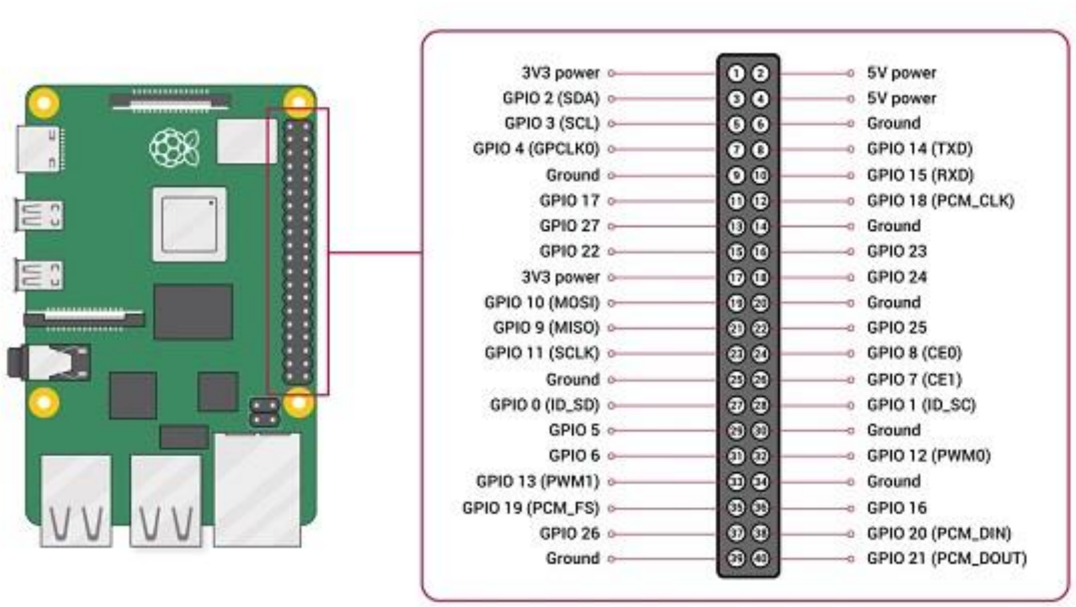
Fig : Raspberry pi



On-board Components of Raspberry Pi

Component	Function
Processor (CPU + GPU)	Broadcom BCM2835 system on chip which is an ARM processor and Video core graphics unit
RAM	Temporary memory for processing tasks
USB Ports	Connect keyboard, mouse, storage
HDMI Port	Display output to monitor
Ethernet Port / Wi-Fi Module	Network connectivity
Audio Jack	Sound output
Camera Serial Interface (CSI)	Connect camera module
Display Serial Interface (DSI)	Connect touch/display module
GPIO Header	Interfacing sensors, actuators
MicroSD Slot	Storage for OS and files
Power Supply Port (USB-C / micro-USB)	5V DC input
LED Indicators	Power and activity status

Raspberry Pi Pin Description (40-Pin GPIO Header)



The **Raspberry Pi GPIO header** provides a **flexible interface** for connecting sensors, actuators, and other devices. Most modern Raspberry Pi models (Pi 2, 3, 4, 400) use a **40-pin layout**.

Pin Types & Functions

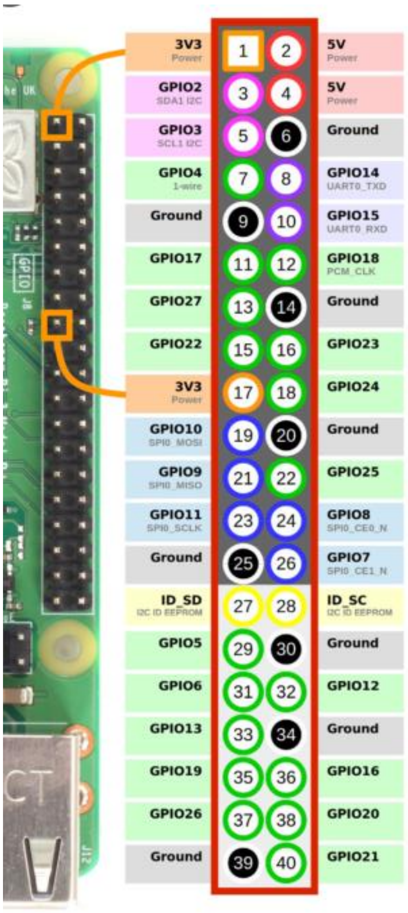
Pin Type	Pin Numbers	Function / Description
Power Pins	1, 2, 4, 17	3.3V (1,17), 5V (2,4)
Ground (GND)	6, 9, 14, 20, 25, 30, 34, 39	Common ground for circuits
General Purpose I/O (GPIO)	3–27 (26 GPIO pins)	Digital input/output; programmable for sensors, LEDs, motors
UART (Serial Communication)	8 (TX), 10 (RX)	Transmit/Receive serial data
I2C (Inter-Integrated Circuit)	3 (SDA), 5 (SCL)	Two-wire communication with I2C devices
SPI (Serial Peripheral Interface)	19 (MOSI), 21 (MISO), 23 (SCLK), 24 (CE0), 26 (CE1)	Fast communication with SPI devices
ID EEPROM Pins	27, 28	Used by HATs to identify hardware automatically
Other Pins	Various	Special functions like PCM (audio), PWM (motor control)

UART (Universal Asynchronous Receiver/Transmitter)

Type: Asynchronous serial communication
Number of Wires: 2 main wires (TX, RX)
Speed: Moderate (depends on baud rate, e.g., 9600, 115200 bps)

How it works:

- UART transmits data **asynchronously** (no clock line).
- Each device agrees on a **baud rate** (bits per second).
- Data is sent **bit by bit** with **start and stop bits** to indicate the beginning and end of a byte.



- Error detection is usually done with **parity bits**

Typical Use Cases:

- PC-to-microcontroller communication (e.g., Arduino serial monitor).
- GPS modules, Bluetooth modules.
- Debugging purposes.

I2C (Inter-Integrated Circuit)

Type: Synchronous serial communication
Number of Wires: 2 main wires (SDA, SCL)
Speed: Standard: 100 kbps, Fast: 400 kbps, Fast+: 1 Mbps, High-Speed: 3.4 Mbps

How it works:

- I2C is **synchronous**, uses a **clock line (SCL)** to synchronize data.
- **SDA** is the data line.
- Devices have unique **addresses** (7-bit or 10-bit).
- **Master** initiates communication, **slave(s)** respond.
- Multiple devices can share the same bus.

Pinout:

- SDA: Serial Data
- SCL: Serial Clock
- Pull-up resistors are required on SDA and SCL.

Typical Use Cases:

- Sensors (temperature, humidity, accelerometers).
- EEPROM memory modules.
- OLED displays.

SPI (Serial Peripheral Interface)

Type: Synchronous serial communication
Number of Wires: Typically 4 (MISO, MOSI, SCLK, CS)
Speed: High speed (10 Mbps or more, depending on devices)

How it works:

- SPI is **synchronous**: data is coordinated with **clock line (SCLK)**.
- Master sends data to **MOSI** (Master Out, Slave In).
- Slave sends data to **MISO** (Master In, Slave Out).
- **CS (Chip Select)** selects which slave the master communicates with.
- Data is exchanged **full-duplex** (both directions simultaneously).

Pinout:

- MOSI: Master Out Slave In
- MISO: Master In Slave Out
- SCLK: Clock
- CS/SS: Chip Select/Slave Select

Typical Use Cases:

- High-speed sensors (ADC, DAC, accelerometers).
- SD cards.
- Flash memory modules.

Difference between Arduino and Raspberry Pi

Feature	Arduino	Raspberry Pi
Type	Microcontroller board	Mini computer (Single Board Computer)
Processor	Simple microcontroller (e.g., ATmega328P)	Powerful ARM-based processor (e.g., Quad-core Cortex-A)
Operating System	No OS (runs single program at a time)	Runs full OS (like Raspberry Pi OS – Linux-based)
Programming Language	C / C++ (Arduino IDE)	Python, C, Java, etc. (many languages supported)
Execution	Runs one loop program continuously	Can run multiple programs and multitask
Connectivity	Limited – USB, Serial, I2C, SPI	Full – USB, HDMI, Ethernet, Wi-Fi, Bluetooth
Memory (RAM)	Few KB (e.g., 2 KB on Uno)	512 MB – 8 GB depending on model
Storage	No storage (uses flash memory for program)	microSD card (acts as hard drive)
Power Requirement	Low (5V DC, few mA)	Higher (5V DC, ~2A)
GPIO Pins	For sensors and actuators	For sensors + can act as input/output + complex I/O
Best For	Hardware-level control (sensors, motors)	Complex projects needing OS, networking, display
Example Projects	LED control, temperature sensor, automation	Web server, media center, AI, IoT hub