Microcontrollers: Hardware and Software Architecture

IoT Spring 2024

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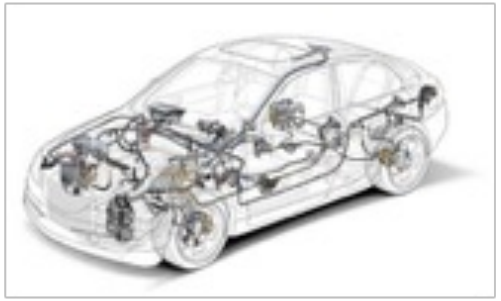
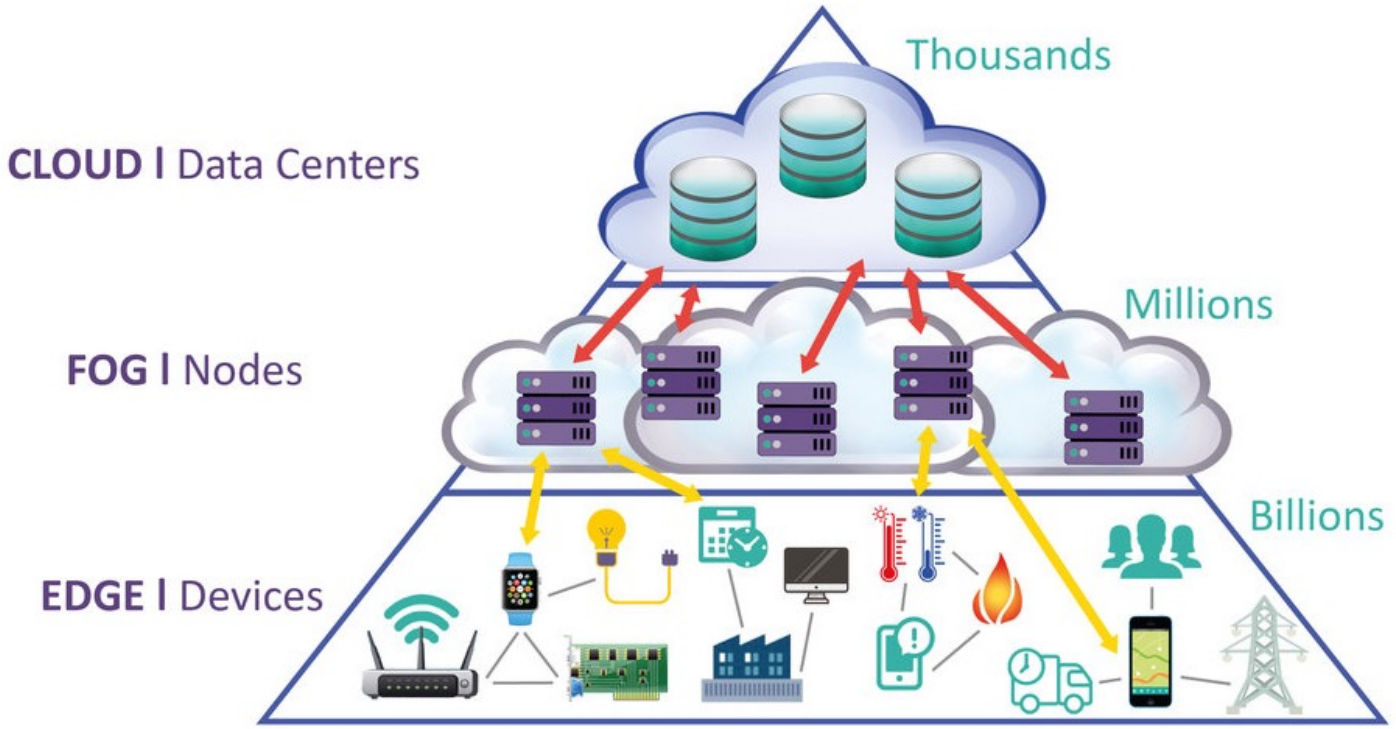
Ubiquitous Computing

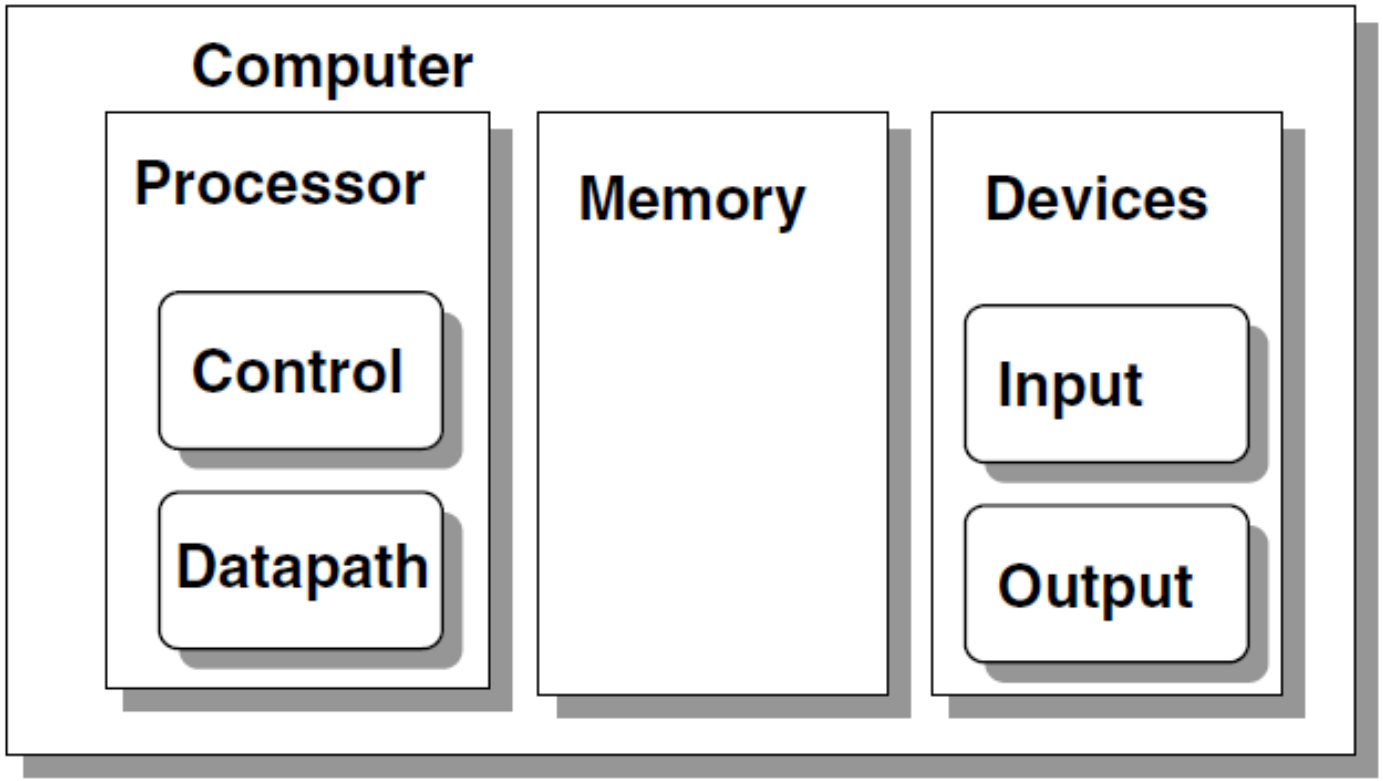


Edge, Fog and Cloud



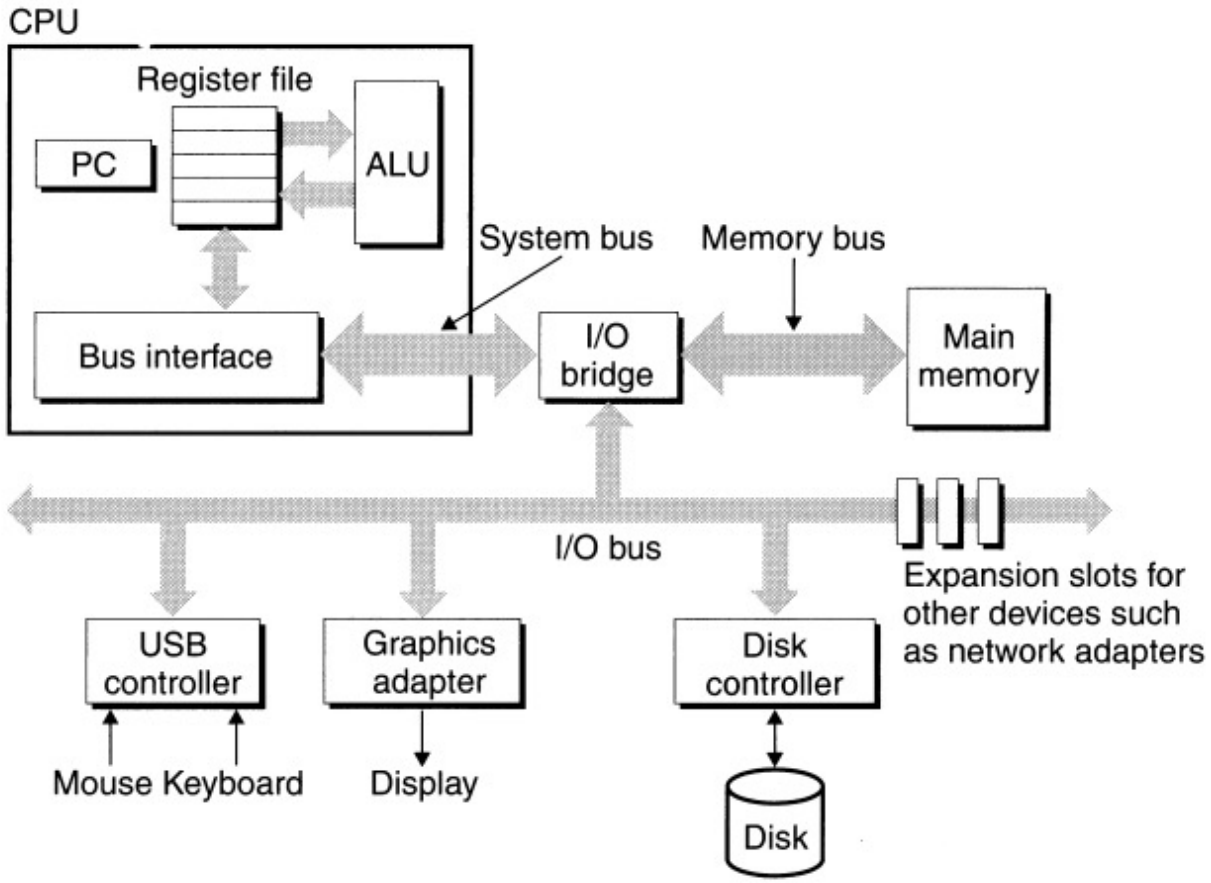
Source: https://leanbi.ch/en/blog/iot-and-predictive-analytics-fog-and-edge-computing-for-industries-versus-cloud-19-1-2018/

Hardware Organization of Computing Systems



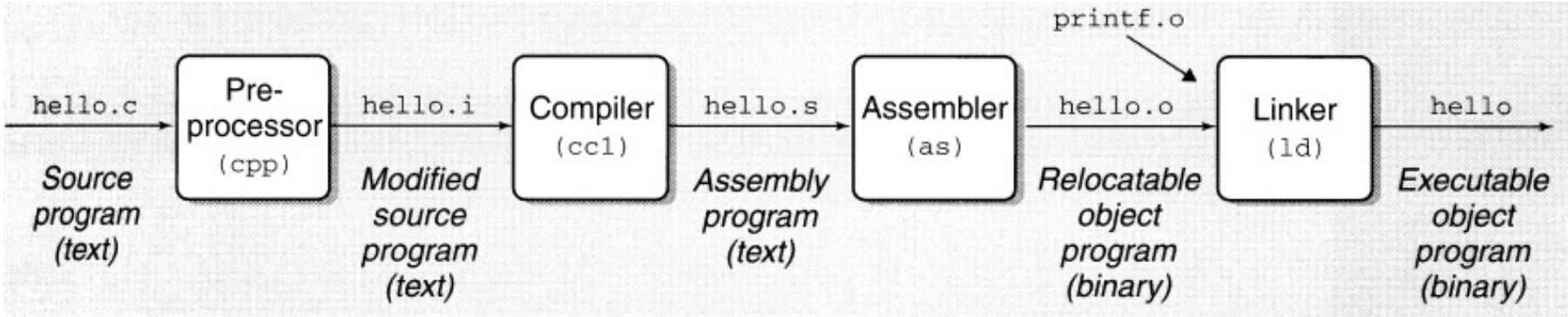
Source: Prof. Cheung's Course Notes (Imperial College, London)

Hardware Organization of Computing Systems

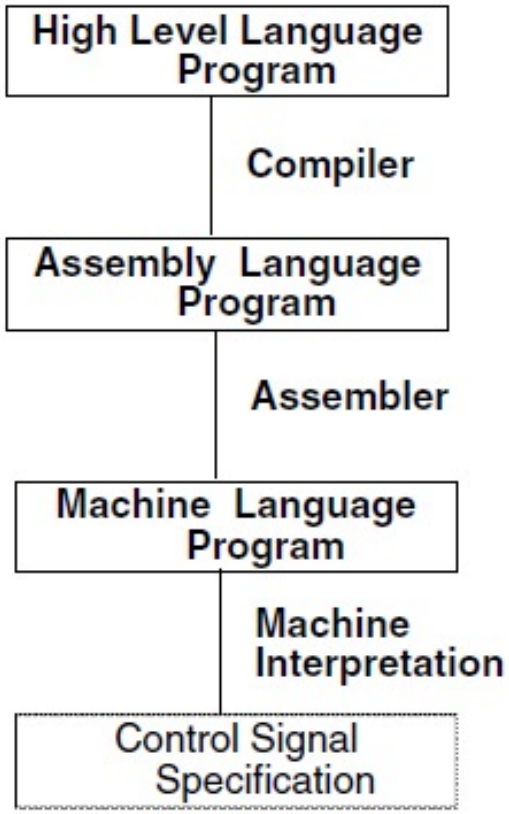


Source: RB&DO -1 (Randal E. Bryant & David O'Hallaron, 1st Ed)

Typical Compilation Sequence



Programming Abstractions and Compilers




```
temp := v[k];
v[k] := v[k+1];
v[k+1] := temp;
```

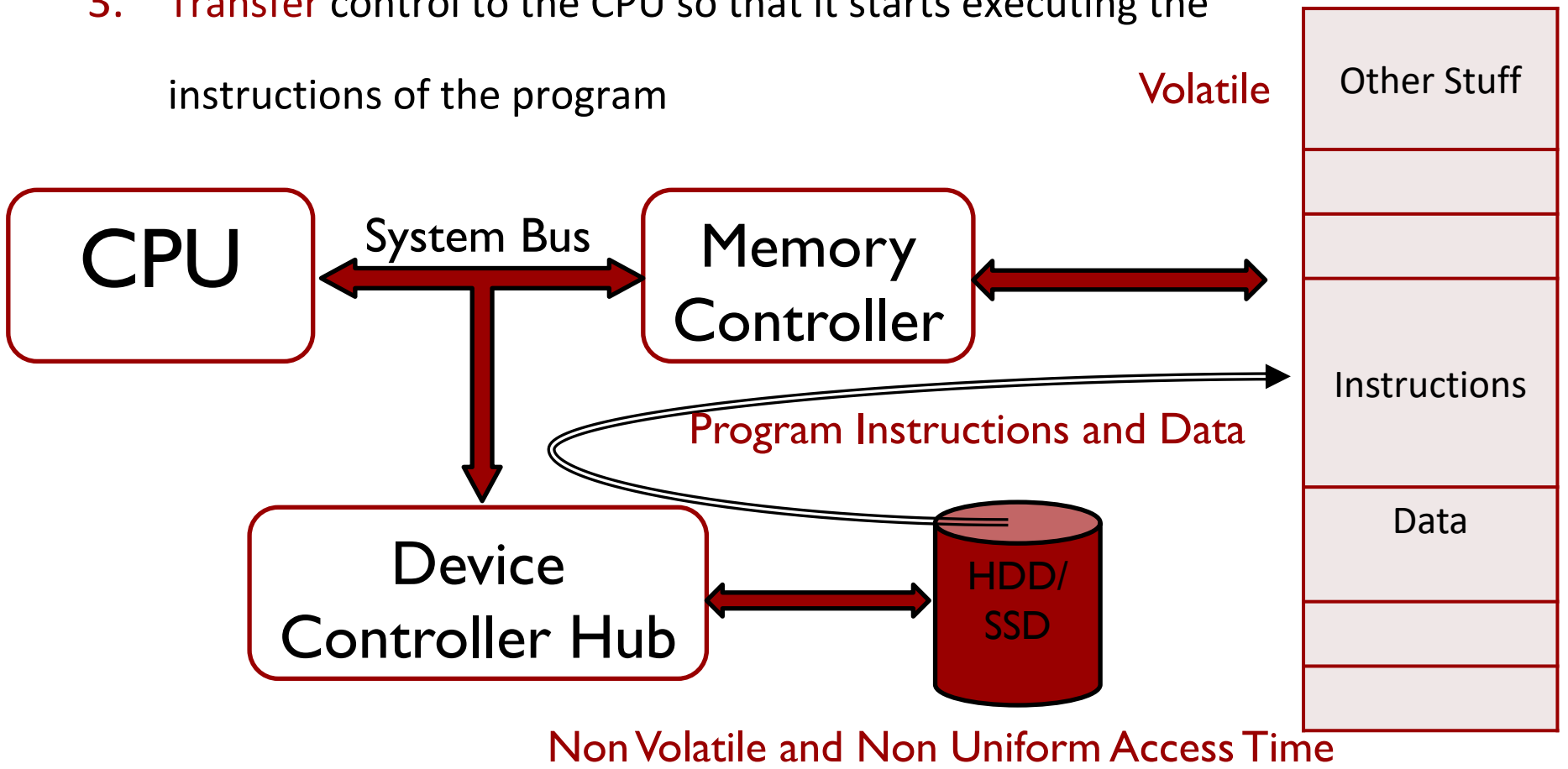
```
lw   $15, 0($2)
lw   $16, 4($2)
sw   $16, 0($2)
sw   $15, 4($2)
```

MIPS Assemble Language

```
0000 1001 1100 0110 1010 1111 0101 1000
1010 1111 0101 1000 0000 1001 1100 0110
1100 0110 1010 1111 0101 1000 0000 1001
0101 1000 0000 1001 1100 0110 1010 1111
```

Executing a Program

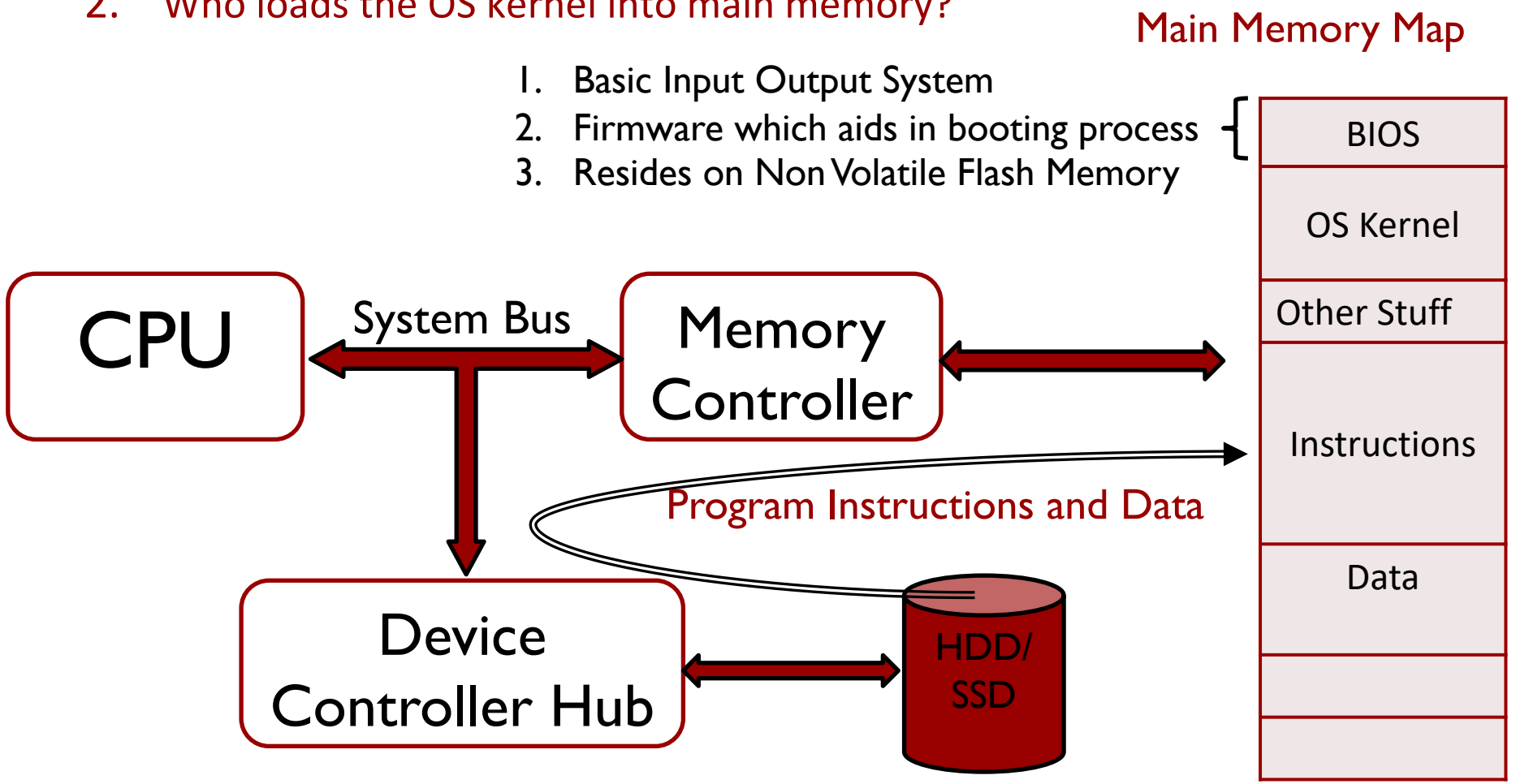
1. Initially Instructions and data of the program are present on the hard disk
2. Load main memory with the instructions and data of the program
3. Transfer control to the CPU so that it starts executing the instructions of the program



Loader

1. Who loads the program from the hard disk to main memory?
2. Who loads the OS kernel into main memory?

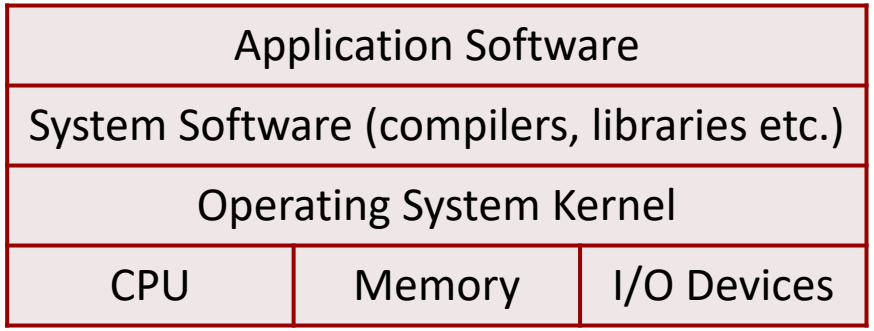
1. Basic Input Output System
2. Firmware which aids in booting process
3. Resides on Non Volatile Flash Memory



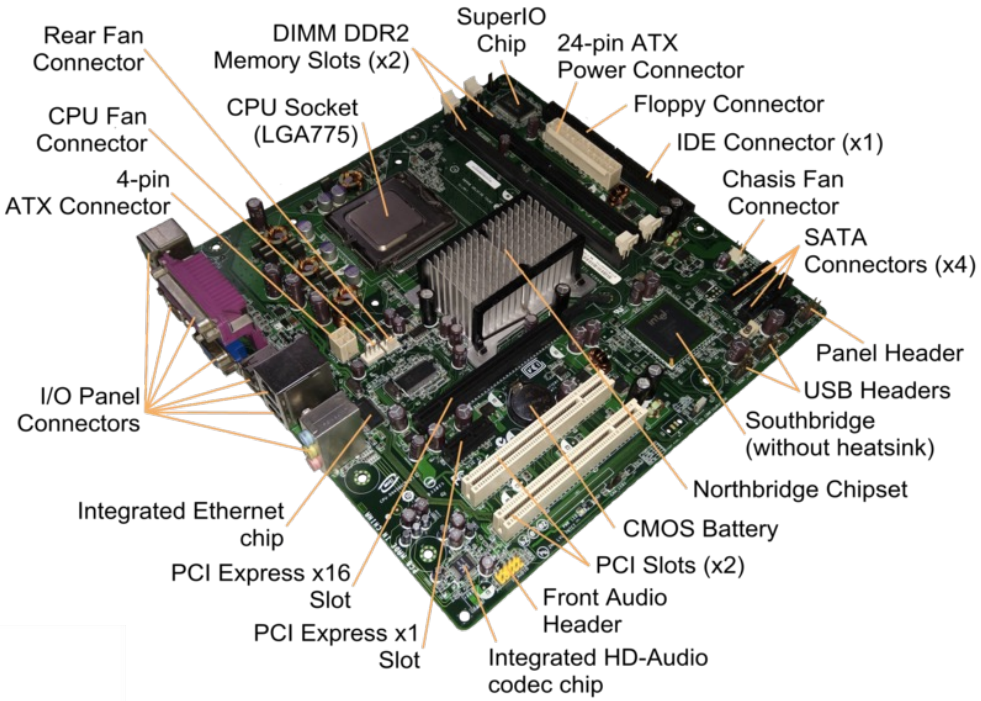
Components of a Computing System

Computing System consists of

1. **Hardware: CPU, Memory and I/O Devices**
2. **Software**
   a) System software
   b) Application software



CPU

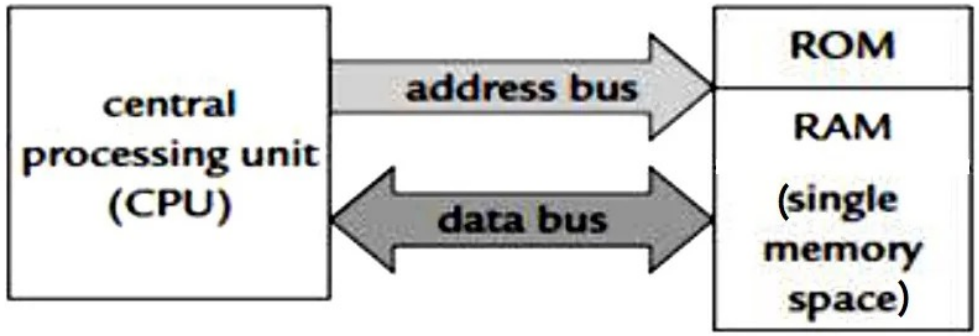


HDD

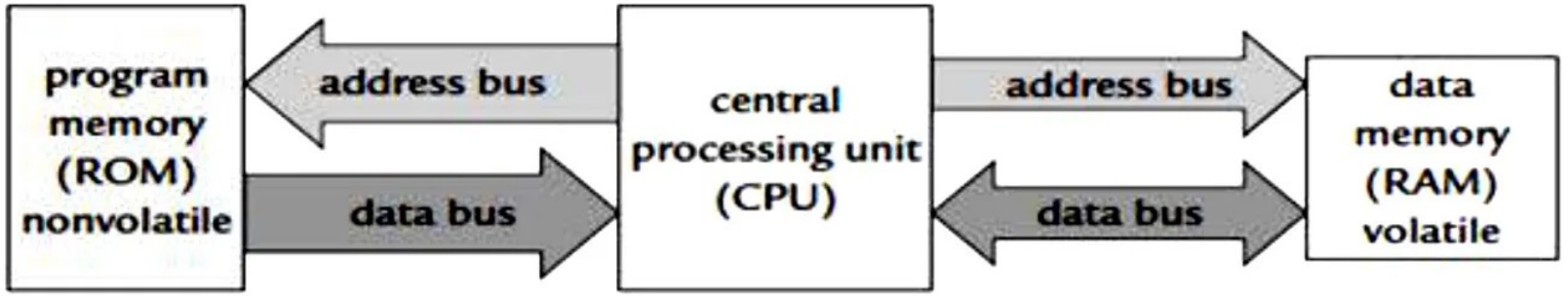
Main Memory

Von Neumann (Princeton) and Harvard Architectures

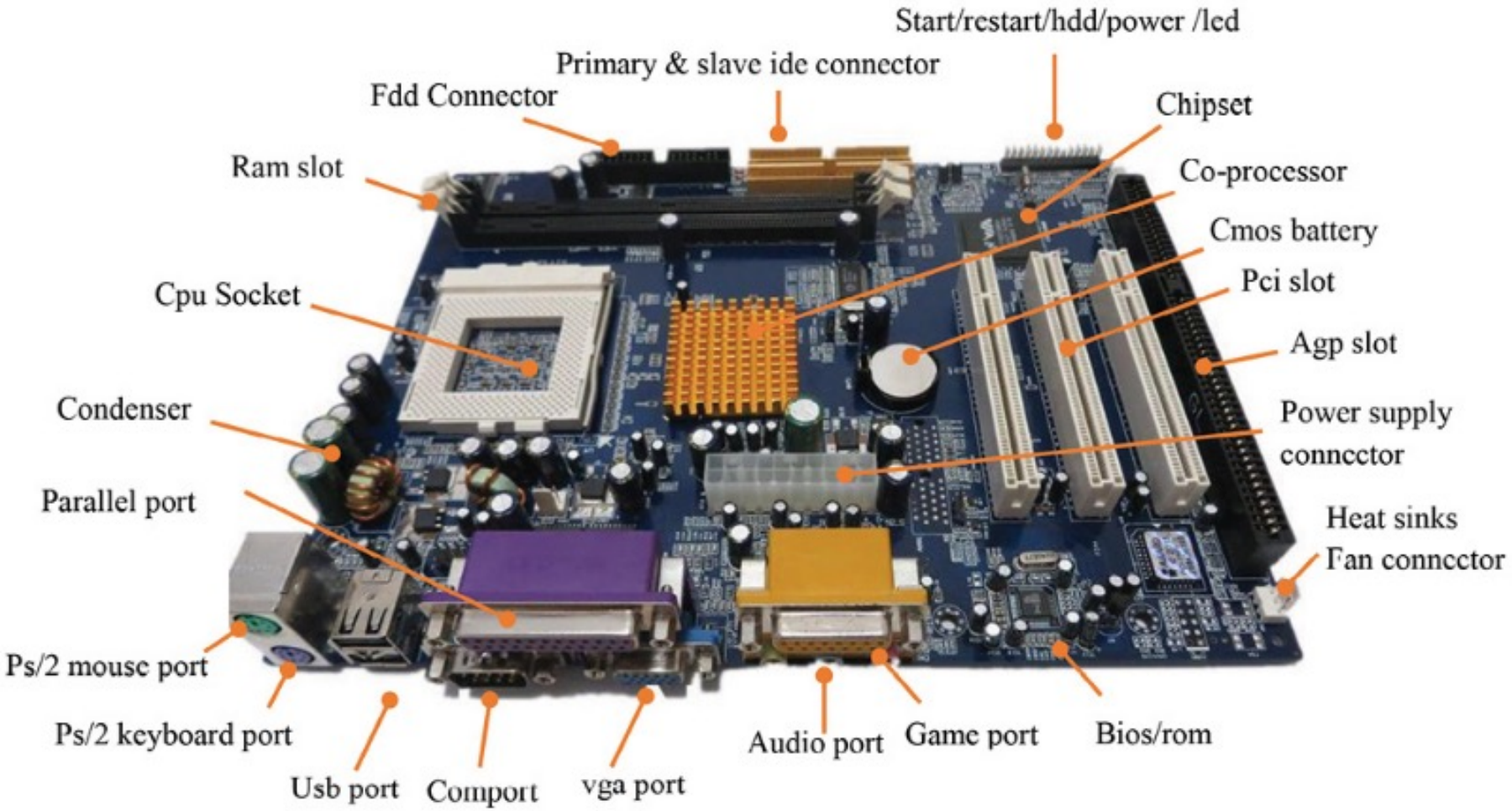
Von Neumann Architecture



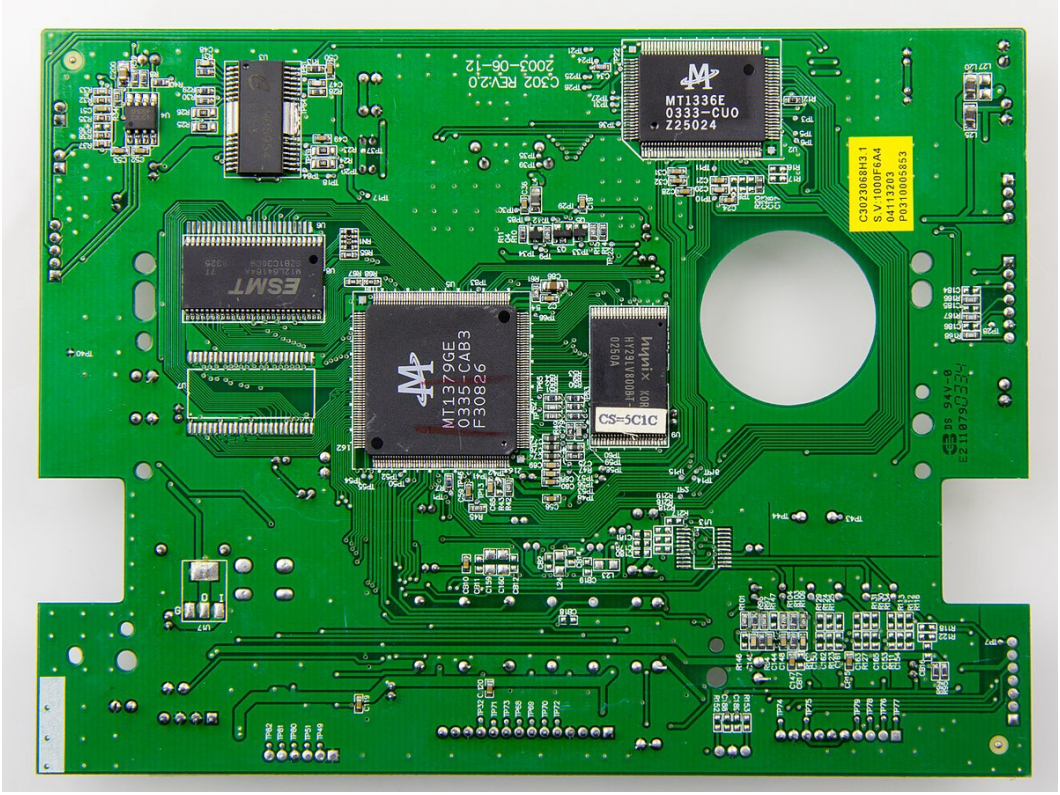
Harvard Architecture



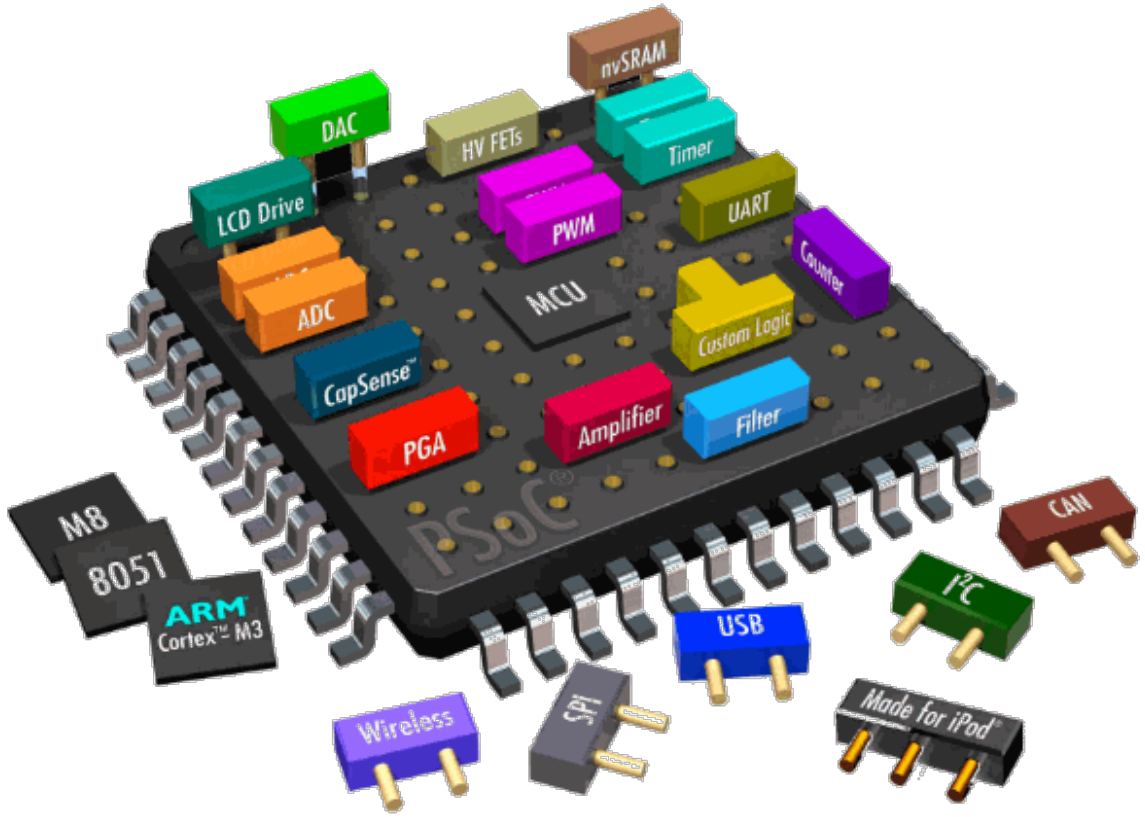
Close-up of Motherboard



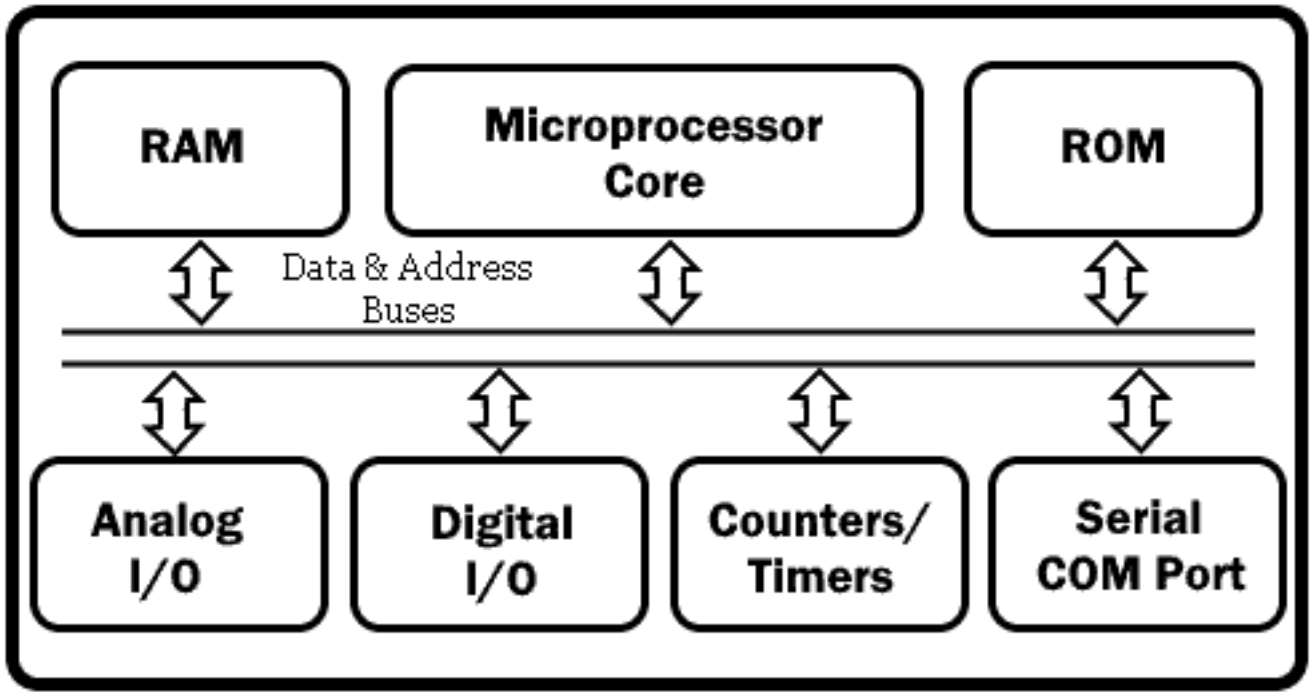
PCB based System Design



System-on-a-Chip

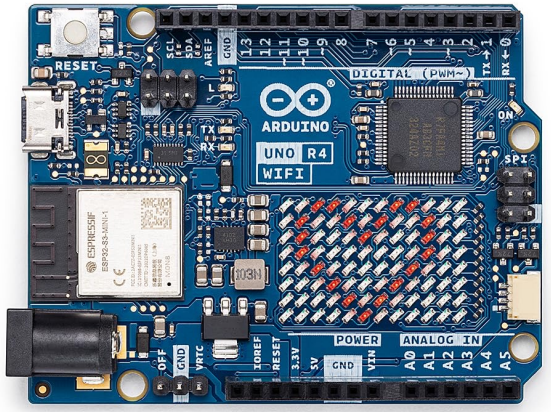


Microprocessor vs Microcontroller



Microcontroller

Arduno Uno



Variant	Microcontroller	Operating Voltage	Digital I/O Pins	Analog Input Pins	Flash Memory	SRAM	Clock Speed	Communication
Arduino Uno R3	ATmega328P	5V	14	6	32KB	2KB	16MHz	USB, UART
Arduino Uno WiFi	ATmega328P	5V	14	6	32KB	2KB	16MHz	USB, UART, WiFi
Arduino Uno Rev2	ATmega328PB	5V	14	6	32KB	2KB	16MHz	USB, UART
Arduino Uno WiFi Rev2	ATmega4809	5V	14	6	48KB	6KB	16MHz	USB, UART, WiFi

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Arduno Uno

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Feature	Uno R3	Uno WiFi Rev2	Nano Every	Nano 33 BLE
Microcontroller	ATmega328P	ATmega4809	ATmega4809	nRF52840
Operating Voltage	5V	5V	5V	3.3V
Input Voltage (recommended)	7-12V	7-12V	7-12V	3.3-5V
Input Voltage (limit)	6-20V	6-20V	6-20V	2.7-5.5V
Digital I/O Pins	14 (of which 6 provide PWM output)	14 (of which 11 provide PWM output)	14 (of which 6 provide PWM output)	14 (of which 8 provide PWM output)
Analog Input Pins	6	6	8	6
DC Current per I/O Pin	20 mA	20 mA	20 mA	15 mA
DC Current for 3.3V Pin	50 mA	50 mA	50 mA	N/A
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader	48 KB (ATmega4809)	48 KB (ATmega4809)	1 MB (nRF52840)
SRAM	2 KB (ATmega328P)	6 KB (ATmega4809)	6 KB (ATmega4809)	256 KB (nRF52840)
EEPROM	1 KB (ATmega328P)	256 bytes (ATmega4809)	256 bytes (ATmega4809)	N/A
Clock Speed	16 MHz	16 MHz	16 MHz	64 MHz
Length	68.6 mm	68.6 mm	45.0 mm	45.0 mm
Width	53.4 mm	53.4 mm	18.0 mm	18.0 mm
Weight	25 g	25 g	5 g	6 g
USB Connector	USB type B	Micro USB	Micro USB	Micro USB
Connectivity	None	WiFi, Bluetooth	None	Bluetooth Low Energy
Price	~$20	~$25	~$10	~$20

ESP32

Variant	Microcontroller	Operating Voltage	Digital I/O Pins	Analog Input Pins	Flash Memory	SRAM	Clock Speed	Communication	Wireless Features
ESP32 DevKitC	ESP32-D0WDQ6	3.3V	36	18	4MB	520KB	240MHz	Wi-Fi, Bluetooth	Wi-Fi 802.11 b/g/n, Bluetooth 4.2
ESP32-WROOM-32	ESP32-D0WDQ6	3.3V	38	23	4MB	520KB	240MHz	Wi-Fi, Bluetooth	Wi-Fi 802.11 b/g/n, Bluetooth 4.2
ESP32-WROOM-32D	ESP32-D0WDQ6	3.3V	38	23	4MB	520KB	240MHz	Wi-Fi, Bluetooth	Wi-Fi 802.11 b/g/n, Bluetooth 4.2
ESP32-PICO-D4	ESP32-PICO-D4	3.3V	39	23	4MB	520KB	240MHz	Wi-Fi, Bluetooth	Wi-Fi 802.11 b/g/n, Bluetooth 4.2
ESP32-S2 DevKitC	ESP32-S2-WROOM	3.3V	39	20	4MB	320KB	240MHz		

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ESP32

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Feature	ESP32-WROOM-32	ESP32-S2-WROOM	ESP32-S3-WROOM-1	ESP32-CAM
Microcontroller	Xtensa dual-core 32-bit LX6	Xtensa single-core 32-bit LX7	Xtensa dual-core 32-bit LX7	Xtensa single-core 32-bit LX6
Operating Voltage	3.0V-3.6V	2.3V-3.6V	2.3V-3.6V	5V
CPU Speed	Up to 240 MHz	Up to 240 MHz	Up to 240 MHz	Up to 160 MHz
Wi-Fi	802.11 b/g/n	802.11 b/g/n	802.11 b/g/n/a/ac	802.11 b/g/n
Bluetooth	4.2	None	5.0 (LE)	4.2
Flash Memory	4 MB	16 MB	16 MB	4 MB
RAM	520 KB	320 KB	384 KB	520 KB
GPIO Pins	34	43	44	9
ADC Channels	18	20	18	1
DAC Channels	2	2	2	None
I2C	2	2	2	1
SPI	3	4	4	1
UART	3	3	3	1
Camera Interface	None	None	None	Yes
Development Board	ESP32 DevKitC V4	ESP32-S2-Saola-1	ESP32-S3-DevKitC-1	ESP32-CAM
Price	~$5	~$4	~$8	~$7

Specification	ESP32	Arduino Uno
Microcontroller	ESP32-D0WDQ6 (varies by variant)	ATmega328P
Operating Voltage	3.3V	5V
Digital I/O Pins	Varies by variant (e.g., 36 or 38)	14
Analog Input Pins	Varies by variant (e.g., 18 or 23)	6
Flash Memory	4MB (varies by variant)	32KB
SRAM	520KB (varies by variant)	2KB
Clock Speed	240MHz	16MHz
Communication	Wi-Fi, Bluetooth	USB, UART
Wireless Features	Wi-Fi 802.11 b/g/n, Bluetooth 4.2	Not applicable
Additional Features	GPIO, SPI, I2C, ADC, DAC, PWM, etc.	GPIO, SPI, I2C, UART, ADC
Integrated WiFi/BT	Yes	No
Operating System	FreeRTOS (for some variants)	None
Cost	Varies by variant	Relatively Inexpensive

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Feature	Arduino Uno	ESP32
Microcontroller	ATmega328P (single-core, 16 MHz)	Xtensa LX6 (dual-core, up to 240 MHz)
Memory	2 KB SRAM, 32 KB flash	520 KB SRAM, 4 MB flash
Connectivity	No built-in Wi-Fi or Bluetooth (requires shields)	Built-in Wi-Fi and Bluetooth LE
Ease of Use	Beginner-friendly, extensive documentation	More complex, requires C++ knowledge for advanced features
Cost	~$20	~$5-10
Power Consumption	Lower	Higher, especially with Wi-Fi
Form Factor	Various sizes and pin layouts available	Various sizes and pin layouts available
Community Size	Larger	Growing rapidly

THANK YOU