พื้นฐานระบบไอโอที

Introduction to Internet of things (IoT)

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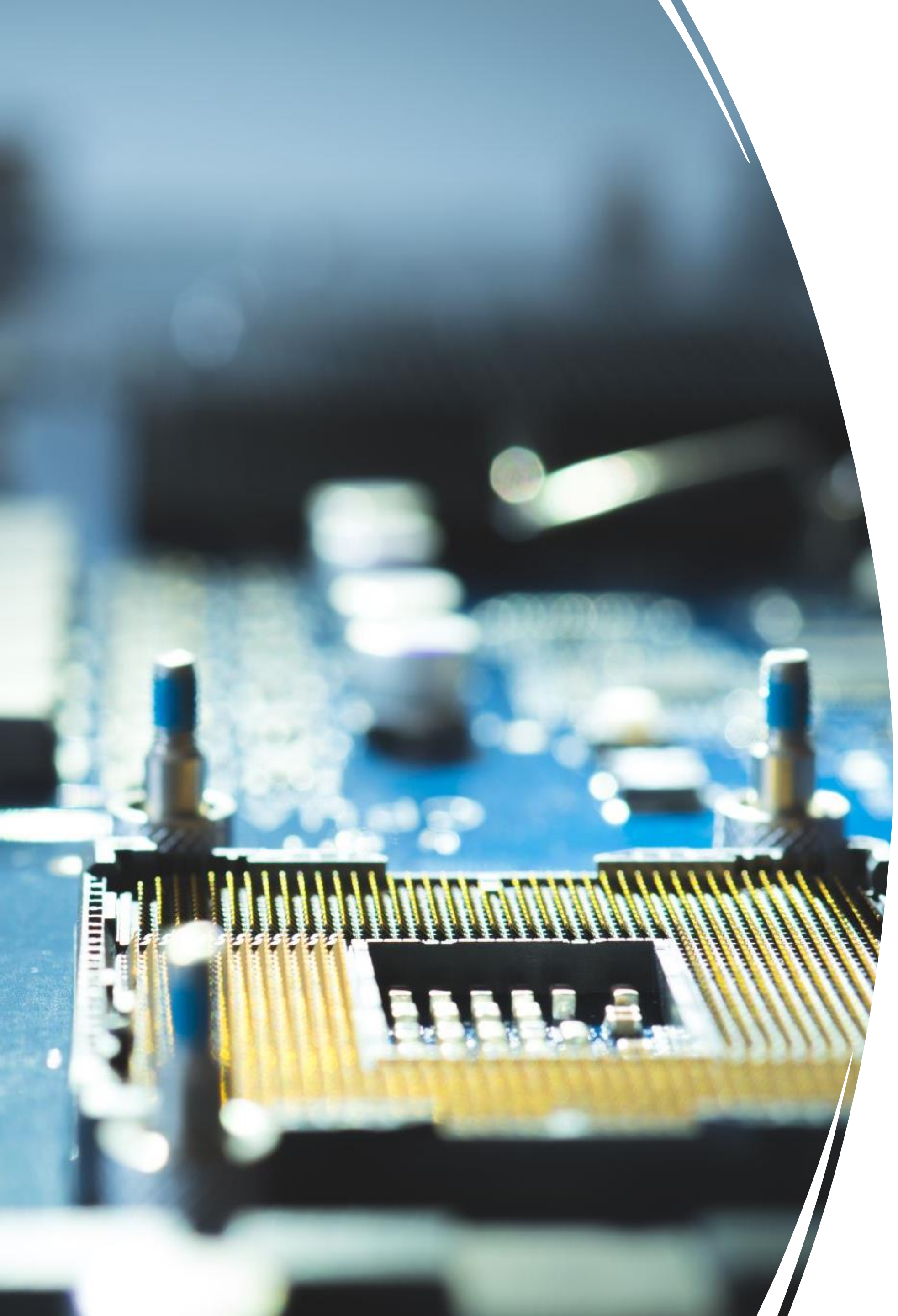
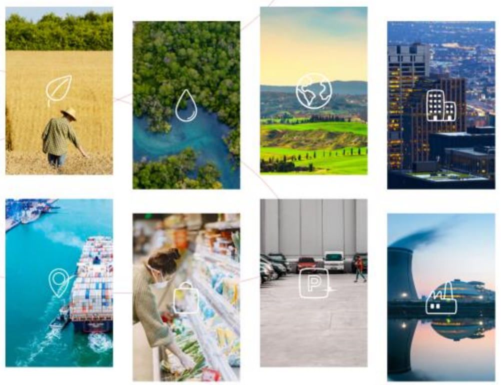
ภาควิชาวิศวกรรมคอมพิวเตอร์ (วิศวกรรมระบบไอโอทีและสารสนเทศ)

คณะวิศวกรรมศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง





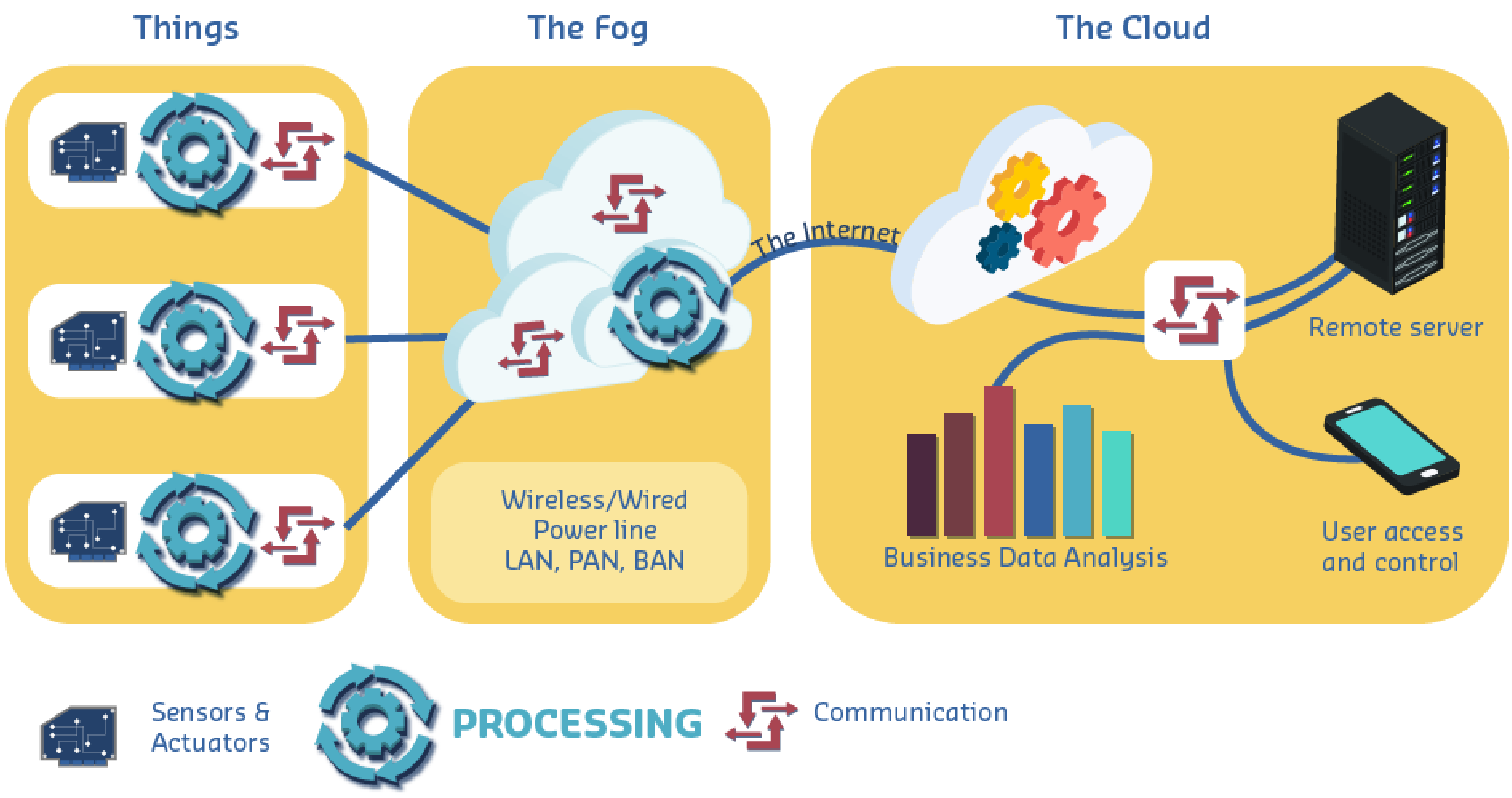
Lecture 5

IoT Device 3
Processor &
Embedded Systems

IoT Device Processors & Embedded Systems

IoT Device

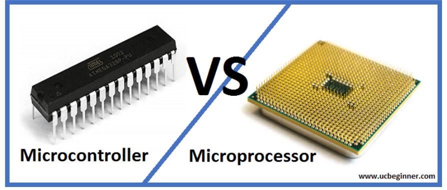
- Keep our course IoT diagram in mind, as we're going to be focusing on the Processing parts.



ระบบสมองกลฝังตัว (Embedded System)

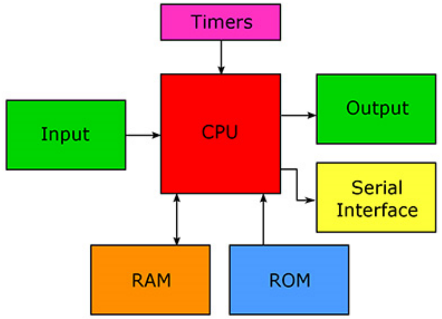
- คือ ระบบ (System) ที่ถูกนำไปฝังตัว (Embed) เพื่อใช้งานหรือประยุกต์ใช้งานตามวัตถุประสงค์ที่กำหนดไว้ เปรียบง่าย ๆ เสมือนการนำไปชิพหรือคอมพิวเตอร์จิ๋วไปฝังไว้ในอุปกรณ์ต่าง ๆ แล้วทำให้อุปกรณ์หรือระบบนั้น ๆ ฉลาดมากขึ้น หมายถึงสามารถควบคุม โปรแกรมมันได้ นั่นเอง
- เทคโนโลยีที่เลือกใช้สำหรับ Embedded System มีมากมาย ไม่ว่าจะเป็นไมโครคอนโทรลเลอร์ หรือไมโครโปรเซสเซอร์
- Embedded System นำไปสู่ IoT

Microcontroller vs Microprocessors

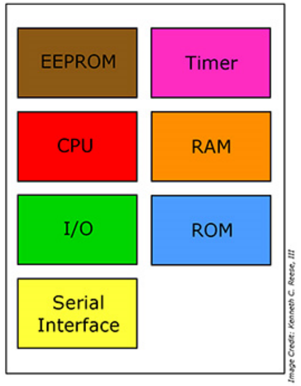


- Microprocessors can be thought of as more advanced embedded systems than microcontrollers.
- The main differences between a microprocessor and a microcontroller are:
- A **microcontroller** is **'all in one'**: the processor, RAM, and IO are all on the one chip - as such, you cannot (for instance) increase the amount of RAM available or the number of IO ports. The controlling bus is internal and not available to the board designer.
- A **microprocessor** generally does not have on-chip RAM, ROM, and few GPIO pins. It usually uses its pins as a bus to interface with RAM, ROM, serial ports, digital and analogue IO, etc. As such, it is expandable at the board level.

Microprocesser: CPU and several supporting chips.

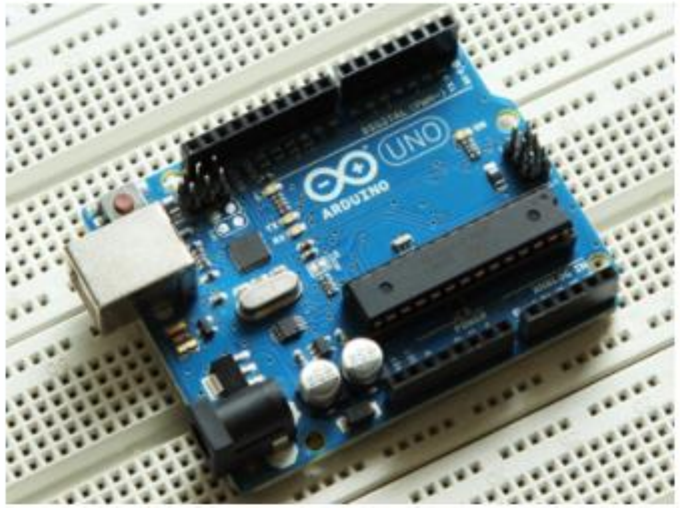


Microcontroller: CPU on a single chip.



What is in the device ?

- Most IoT systems utilize **microcontroller** units (MCUs) to collect data and transfer it to the processing units through the Internet.
- The advantages of using MCUs include:
    1. They are relatively simple, as MCUs do not require an operating system to function and are easy to interface with external components such as sensors.
    2. A MCU is usually sufficient to provide processing power and functionality in most IoT systems, thus making them economically viable for IoT applications.
    3. Due to their simplicity, MCUs are less vulnerable to security attacks.
- A **microprocessor** is a micro version of our computers, hence the name ‘microprocessor’.
- We can see that generally, if an application requires a form of Operating System, a microprocessor is normally used.
- A good example is our smartphones, which often use ARM microprocessors.

	Microcontroller	Microprocessor
Components	Processor, RAM, IO are all on the one chip	No RAM, ROM and IO pins
	Controlling bus is internal and cannot be changed	Interfaces to peripherals so board is expandable
Examples	 Ardiuno Uno *Img src: Image by [roelofse]*	 ARM processor *Img src: By Socram8888 [[CC BY 2.0]], from Wikimedia Commons*

https://www.youtube.com/watch?v=jKT4H0bstH8&feature=emb_title

Example Products

CPUs

Nike Hyperadapt
(self-lacing bluetooth shoes)
ARM Cortex M4 CPU

LG E8
(55-65" OLED TV)
LG α9 CPU

Amazon Echo Show
(smart speaker with screen)
ARM Cortex A8 CPU

Moverio BT-300
(smart glasses)
Intel Atom x5 CPU

Fitbit Ionic
(GPS smartwatch)
ARM Cortex A8 CPU

Microcontrollers

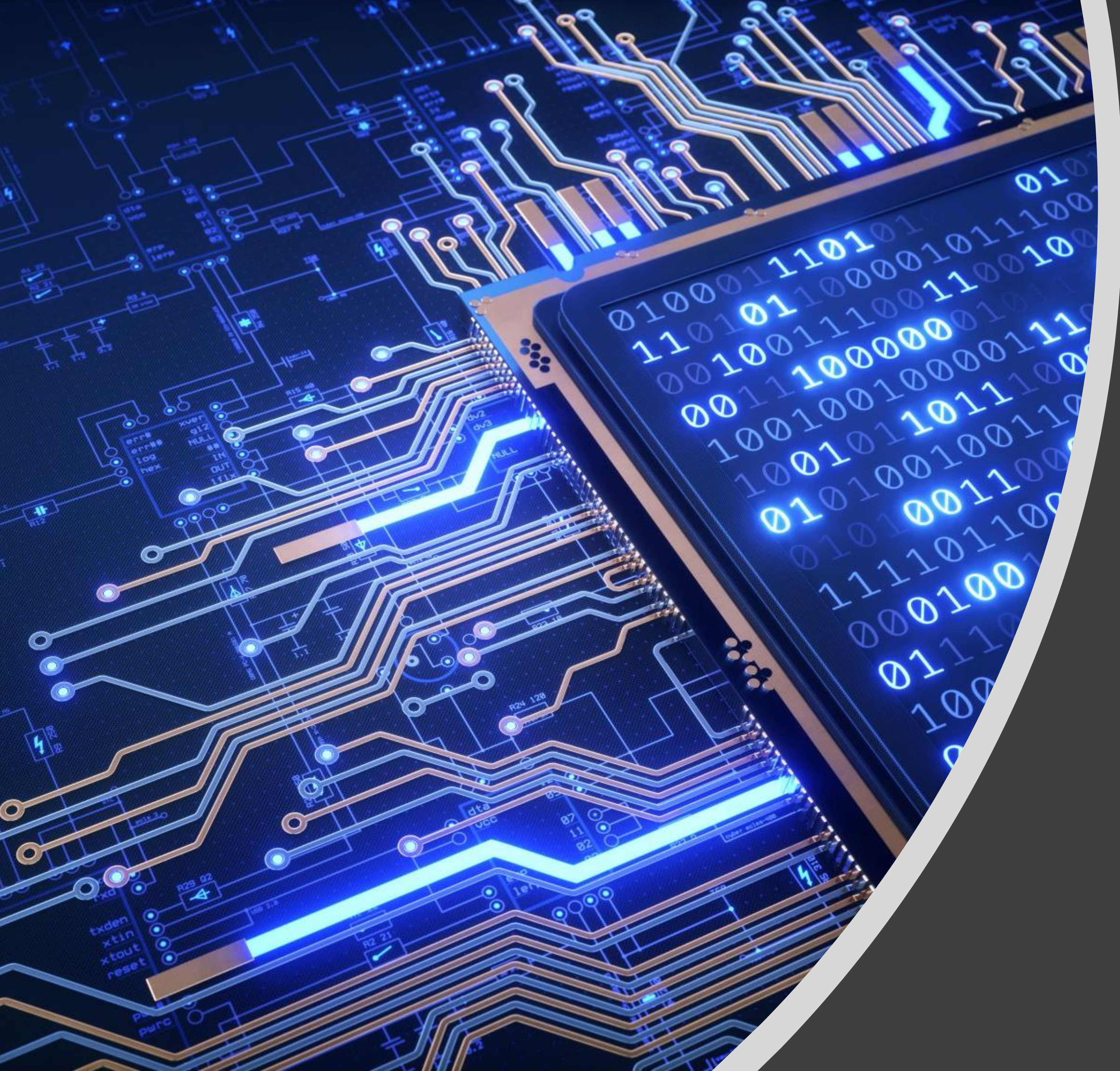
HTC Vive
(VR Goggles)
ARM Cortex M0

Parrot AR.Drone 2.0
(Drone)
Microchip PIC24

Honeywell Water Alarm
(Freeze/Leak detector)
Microchip PIC12

Pleo Smart Dinosaur
(AI Toy)
Toshiba TMP86FH47 8-bit

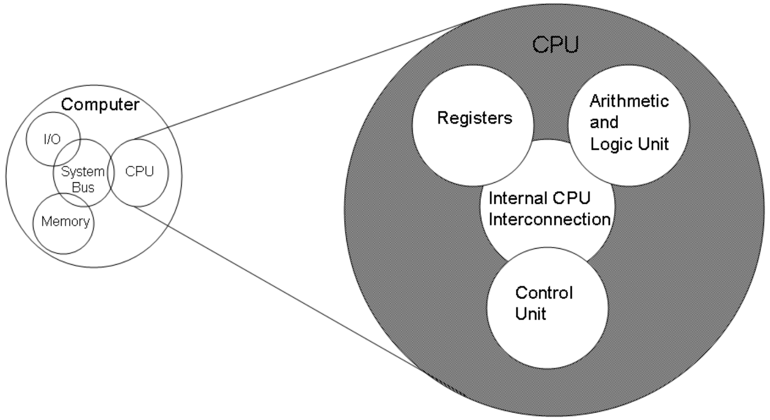
Amazon Fire TV
(digital media player)
TI MSP430F5435A

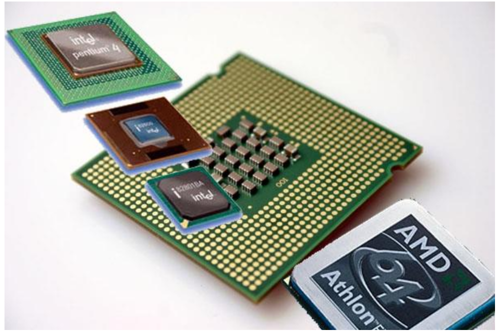


Microprocessor

หน่วยประมวลผลกลาง (Central Processing Unit : CPU)

- ซีพียูหรือหน่วยประมวลผลกลางจัดได้ว่าเป็นส่วนที่สำคัญที่สุดของคอมพิวเตอร์ เปรียบเสมือนเป็นสมองของเครื่องคอมพิวเตอร์ โดยทำหน้าที่ในการคำนวณค่าต่าง ๆ ตามคำสั่งที่ได้รับมอบหมาย และควบคุมการทำงานของส่วนประกอบอื่น ๆ ทั้งหมด ในระบบคอมพิวเตอร์
- CPU = Microprocessor
- **ประกอบด้วย**
  - ALU (Arithmetic Logic Unit : ALU) หน่วยคำนวณทางคณิตศาสตร์และลอจิกต่าง ๆ
  - CU (Control unit) หน่วยควบคุม ทำหน้าที่ควบคุมการทำงานต่างๆ ของหน่วยประมวลผล
  - Register เป็นพื้นที่สำหรับเก็บพักข้อมูล ชุดคำสั่ง ผลลัพธ์ และข้อมูลที่เกิดขึ้นขณะที่ซีพียูประมวลผลชั่วคราว





สถาปัตยกรรมของหน่วยประมวลผล (ซีพียู)

- สถาปัตยกรรมของซีพียูเป็นตัวบ่งบอกถึงลักษณะเฉพาะ และลักษณะการทำงานที่สำคัญของซีพียู อาจจะเรียกอีกแบบหนึ่งว่า “สถาปัตยกรรมชุดคำสั่ง” (ISA : Instruction Set Architecture)
- ลักษณะเฉพาะของซีพียูนี้กล่าวรวมไปถึง จำนวนและประเภทของรีจิสเตอร์, วิธีการกำหนดโหมดของแอ็ดเดรสของหน่วยความจำ และการออกแบบชุดคำสั่งต่าง ๆ (Instruction Sets)
- แบ่งออกเป็น 2 กลุ่มใหญ่ ๆ คือ CISC (Complex Instruction Set Computers) และ RISC (Reduced Instruction Set Computers)

CISC (Complex Instruction Set Computers)

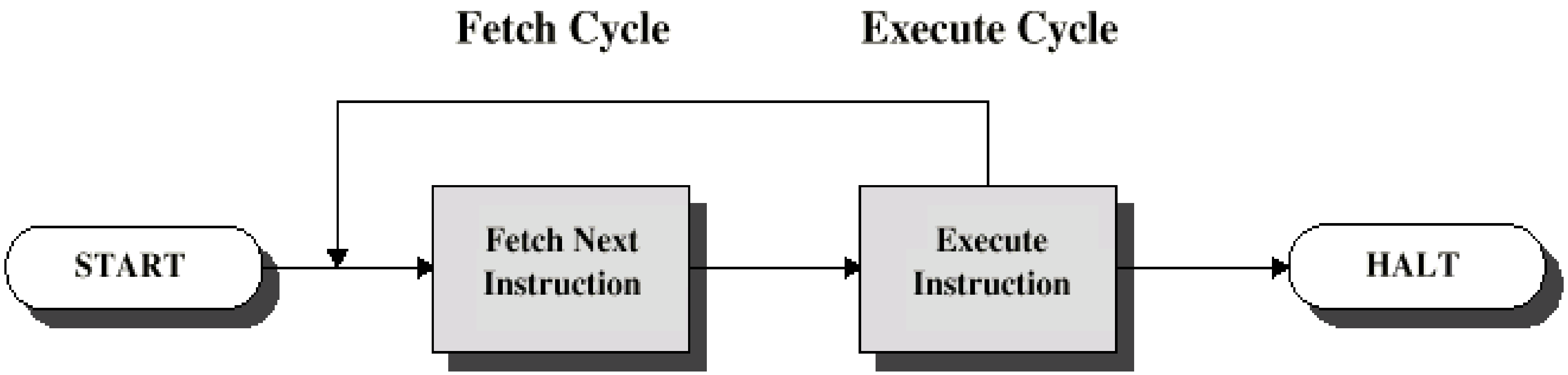
- สถาปัตยกรรม x86 เช่น intel, AMD ปัจจุบัน

RISC (Reduced Instruction Set Computers)

- smartphone, embedded device (ARM)

Instruction Cycle

- Fetch คือ CPU อ่านชุดคำสั่งจาก Memory เข้ามาเก็บไว้ใน Register
- Execute คือ ทำกระบวนการจาก instruction ว่าโปรแกรมให้ทำอะไร
- HALT จบการทำงานของโปรแกรม



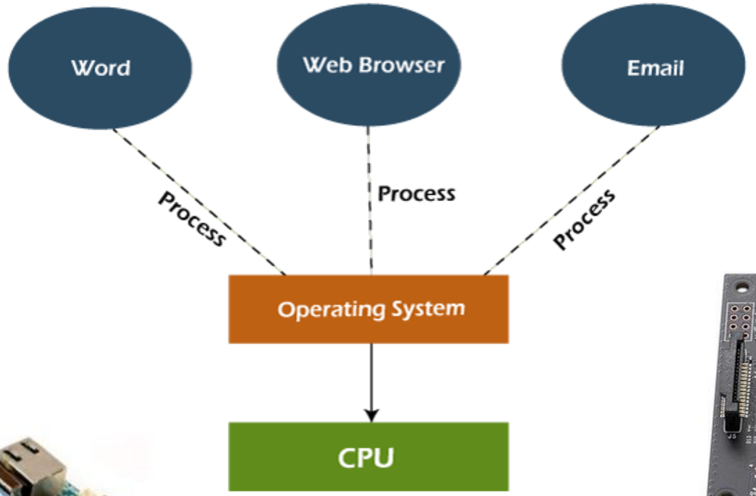
Benefits of CPUs (Microprocessor)

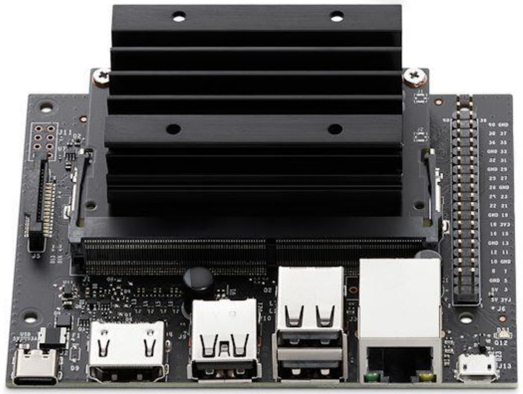
- Programmable circuits allow highly customizable logic in hardware
  - Enables explosion of sophistication
- Focused on digital applications
  - Easier to consolidate into a compact unit
- CPUs are great for many applications
  - Extremely flexible, high-speed
  - Can run operating systems, machine vision, NLP, etc.

Downsides of CPUs (Microprocessor)

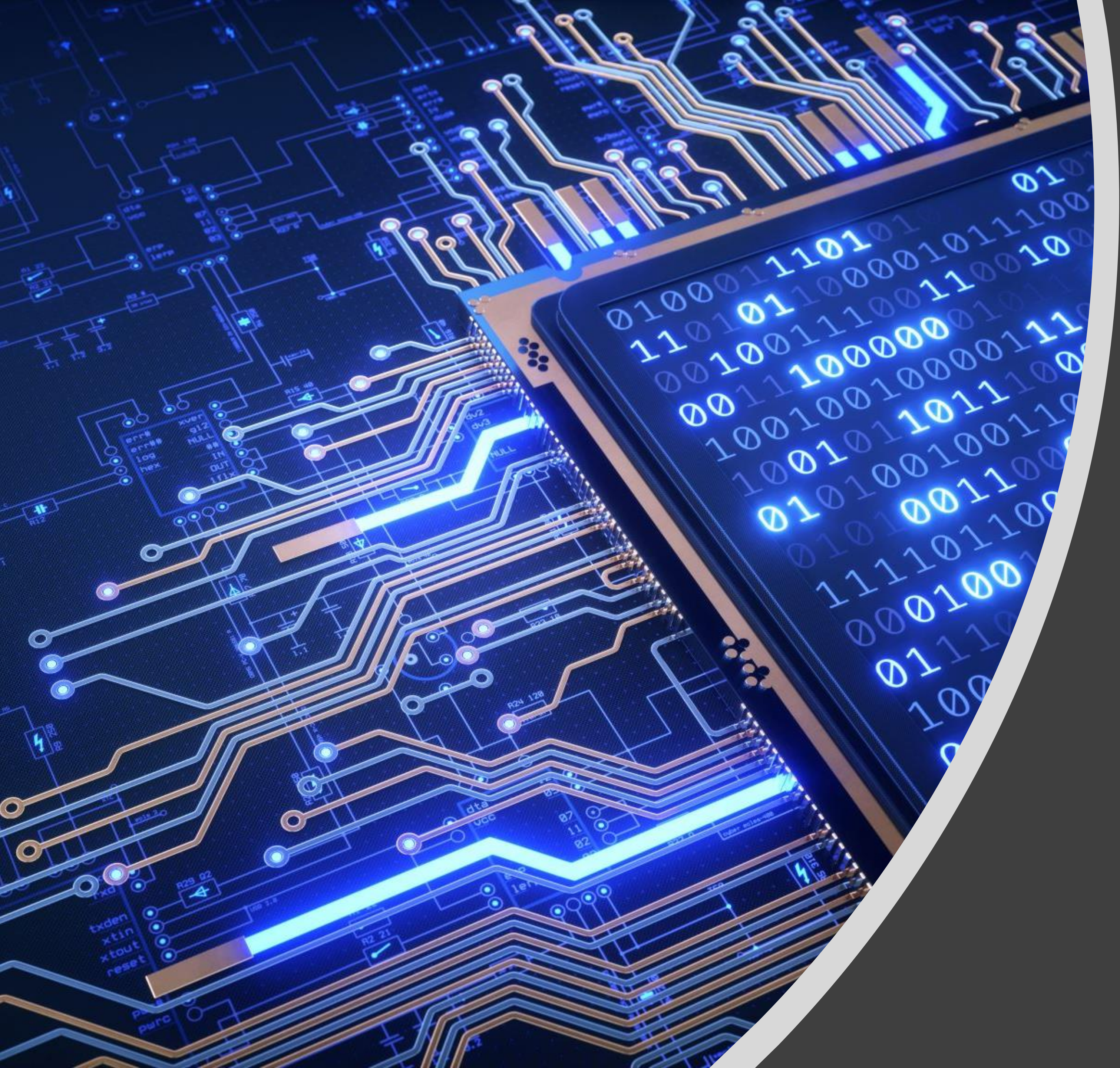
- However, hard to make them very cheaply
  - Hard to make general, powerful platforms also cheap
  - What do we do for ultra-cheap applications?
- Idea: make special-purpose CPUs
  - Architectures targeted toward specific uses
  - Only the capabilities you need →reduced costs

Single Board Computer





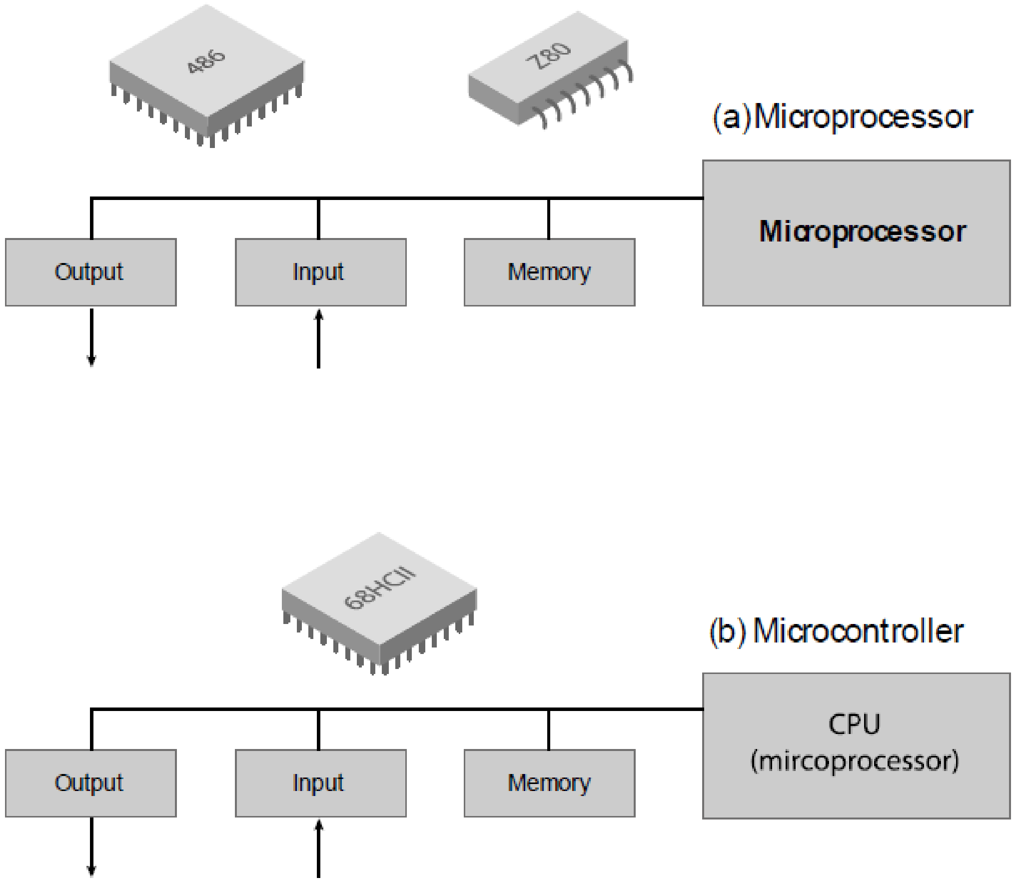
https://www.onesdr.com/best-single-board-computer/



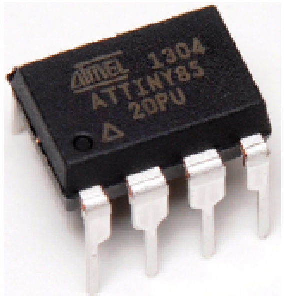
Microcontroller

Microcontrollers

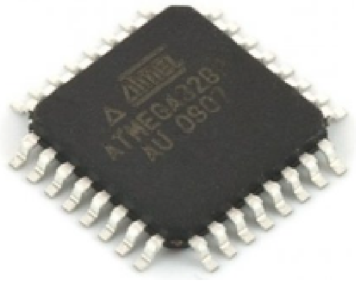
- A microcontroller is like a CPU, but:
- Lower-end design
  - Lower-performance (lower power usage/clockspeed)
  - Simpler (limited instruction set)
- Consolidated design
  - Memory, oscillator, I/O controllers, watchdog timers, are within chipset
- Special on-chip functions (peripherals)
  - Onboard DAC/ADC, PWM, NCO, programmable logic



Popular Microcontroller Cores



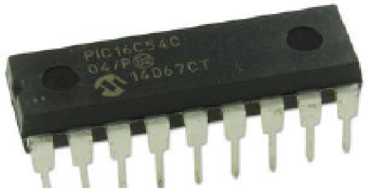
ATMEL TINYAVR
(low-end)



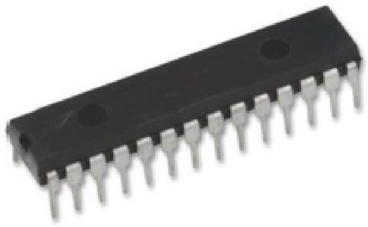
ATMEL MEGAAVR
(high-end)

ATMEL AVR

- RISC design. many single-cycle operations, 2-cycle multiply
- Strengths: many registers (32), good cycle efficiency
- Downsides: only one interrupt priority, slow clock speed compared to competition (up to 32 Mhz)
- Example chips: ATtiny85 (Arduino), ATtiny1616, ATmega328



Microchip PIC16
(lower-end)

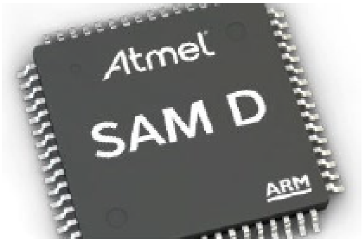


Microchip PIC24
(higher-end)

MICROCHIP PIC

- RISC design. 4T machine - 4 cycles fetch (plus 4 cycles execute)
- Strengths: many peripherals, historically very popular
- Downsides: only one register, no stack, lower-end chips have no on-chip debugging support, slow flash-load times. Falling out of favor for students/hobbyists.
- PIC32 uses 3rd party core (MIPS M4K)
- Example chips: PIC10, PIC12, PIC16, PIC18, PIC24, PIC32

Popular Microcontroller Cores



ATMEL SAM D10

Infineon XMC

ARM Cortex-M0

- 32-bit RISC. Entry level to ARM architecture. Rapidly gaining market share in <$1 market
- Strengths: 32 interrupt vectors, 4 interrupt priorities, full support for runtime exceptions. 13 registers.
- Downsides: low code density, lack of compatibility across vendor peripherals, complex peripherals, slow (12 cycle) interrupt latency
- Example chips: Infineon XMC-1100, Cypress PSOC 4000S

Nuvoton 8051

Infineon XC8XX

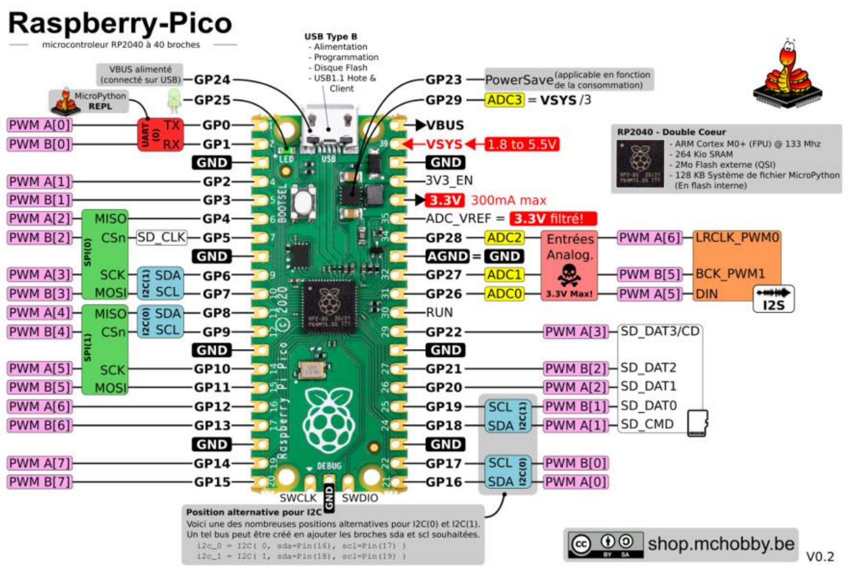
INTEL 8051

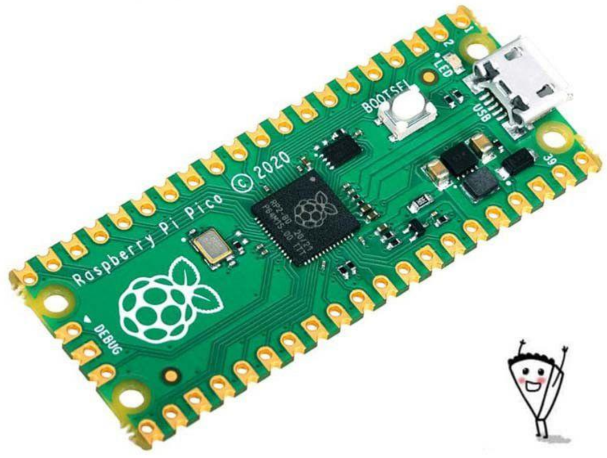
- Variable-length CISC instruction set, 32 registers, 2 interrupt priorities, 64KB program/RAM addressability. Widely-cloned architecture.
- Strengths: fast interrupts (good for real-time eg USB webcams and audio DSPs), fast clock speeds, historicallyextremely popular
- Downsides: only 8-bits, hard to compete with cheap 32-bit controllers. Simplicity can be a detriment with modern compilers. Falling out of favor.
- PIC32 uses 3rd party core (MIPS M4K)
- Example chips: STCmicro STC8, Silicon Labs EFM8, Nuvoton N76

	AVR	ARM	8051	PIC
Speed	1 clock/instruction cycle	1 clock/instruction cycle	12 clock/instruction cycle	4 clock/instruction cycle
Bus width	8/32 bit	32 bit mostly also available in 64 bit	8 bit for the standard core	8/16/32 bit
Manufacturer	Atmel	Apple, Nvidia, Qualcomm, Samsung Electronics, and TI	NXP, Atmel, Silicon Labs, Dallas, Cyprus, Infineon, etc	Microchip Average
Memory Architecture	Modified	Modified Harvard Architecture	Von Neumann Architecture	Harvard Architecture
Power Consumption	Low	Low	Average	Low
Community	Very Good	Vast	Vast	Very Good
Communication Protocols	UART, USART, SPI, I2C, (special purpose AVR support CAN, USB, Ethernet)	UART, USART, LIN, I2C, SPI, CAN, USB, Ethernet, 12S, DSP, SAI (serial audio interface), IrDA	UART, USART, SPI, I2C	PIC, UART, USART, LIN, CAN, Ethernet, SPI, I2S
Popular Microcontrollers	Atmega8, 16, 32, Arduino Community	LPC2148, ARM Cortex-M0 to ARM Cortex-M7, etc	AT89C51, P89v51, etc	PIC18fXX8, PIC16f88X, PIC32MXX
Memory	Flash, SRAM, EEPROM	Flash, SDRAM, EEPROM	ROM, SRAM, FLASH	SRAM, FLASH
Families	Tiny, Atmega, Xmega, Special purpose AVR	ARMv4, 5, 6, 7, and series	8051 variants	PIC16, PIC17, PIC18, PIC24, PIC32

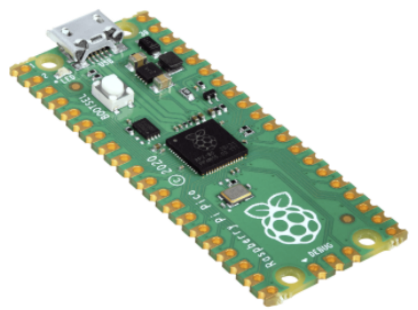
Raspberry Pi Pico : RP2040

- Below are the features of the RP2040 microcontroller:
- Dual ARM Cortex-M0+ @ 133MHz
- 264kB on-chip SRAM in six independent banks
- Support for up to 16MB of off-chip Flash memory via dedicated QSPI bus
- DMA controller
- Fully-connected AHB crossbar
- Interpolator and integer divider peripherals
- On-chip programmable LDO to generate core voltage
- 2 on-chip PLLs to generate USB and core clocks
- 30 GPIO pins, 4 of which can be used as analogue inputs
- Peripherals ◦ 2 UARTs ◦ 2 SPI controllers ◦ 2 I2C controllers ◦ 16 PWM channels ◦ USB 1.1 controller and PHY, with host and device support ◦ 8 PIO state machines

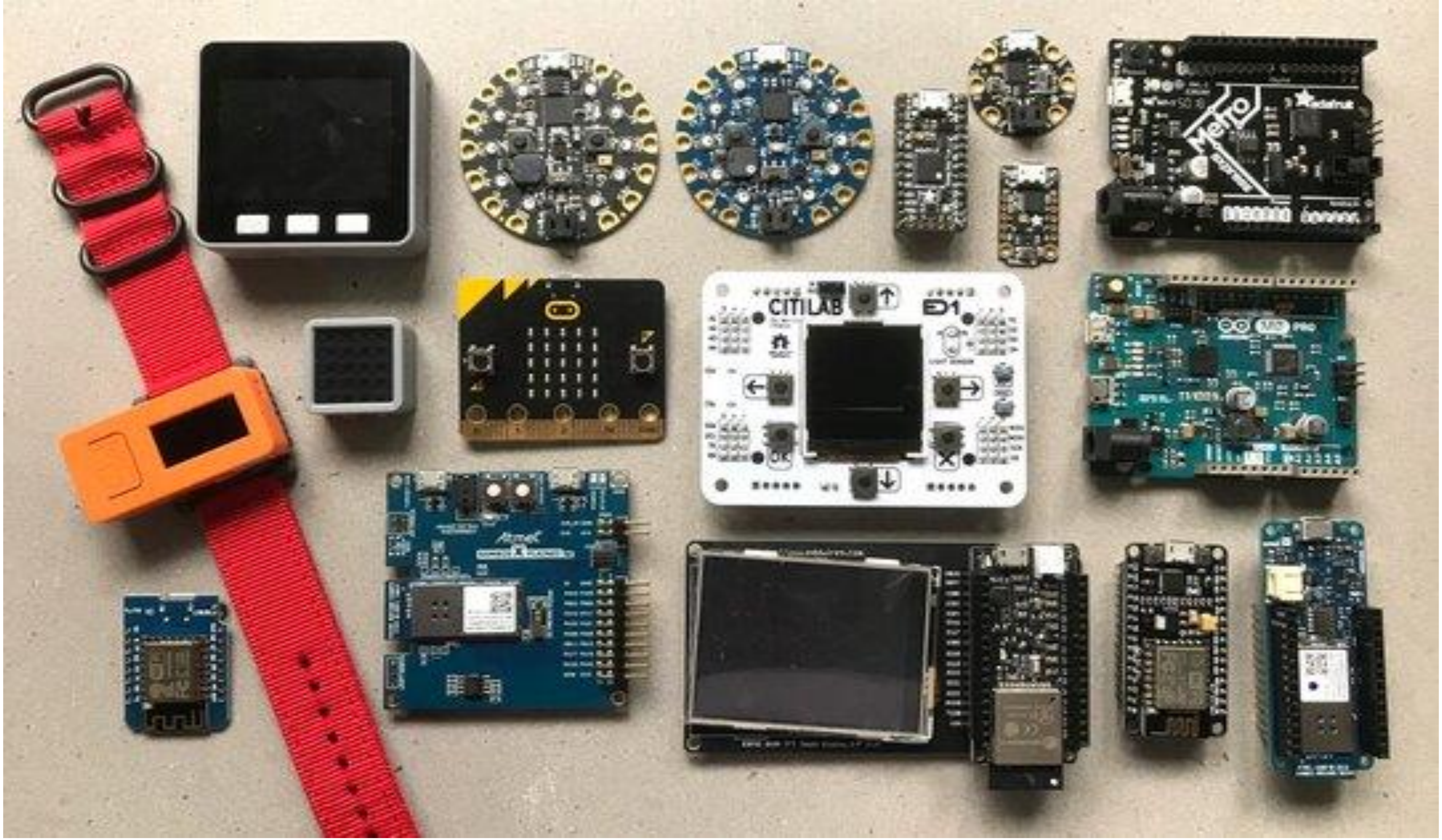




Raspberry Pi Pico vs Arduino UNO R3



Features/Specs	Raspberry Pi Pico	Arduino UNO R3
Microcontroller	RP2040	Atmega328P
Cores	**Dual-Core**	Single Core
Core Architecture	32-bit ARM Cortex-M0+	8-bit RISC
CPU Clock	48MHz, **upto 133MHz**	16MHz
RAM Size	**264 KByte** SRAM	2 KByte
Flash Size	**2 MByte** Q-SPI Flash	32 KByte
EEPROM	NO	**1 KByte**
Programming Language	MicroPython, C, C++	C alike, Arduino IDE
Board Power Input	5VDC via USB Micro B	5VDC via USB B
Alternative Board Power	2 - 5VDC via VSYS Pin (Pin 39)	7-12VDC via DC Barrel
MCU Voltage	3.3VDC	5VDC
GPIO Voltage	3.3VDC	5VDC
USB Interface	**USB 1.1 Device and Host**	External USB Serial IC
Program Loading	USB Micro B, USB Mass Storage	USB B, Virtual Serial Port
GPIO	**26** x Digital Input/Output (Total)	20 x Digital Input/Output (Total)
ADC	3 x 12-bit	**6** x 10-bit
UART	**2**	1 (Shared with USB Serial)
I^2C	**2**	1
SPI	**2**	1
PWM	**16**	6
On Board LED	1 x Programmable LED (GP25)	1 x Programmable LED (D13)
Header Pins	No	**Female Header Pre-soldered**
Retail Price (Exclude Tax and Shipping)	USD 4.00	USD 23.00


CITILAB
ED1
Metro

How to choose microcontroller ?

- Gather information of project such as Size of Project
- Number of Peripherals and Sensors Used
- Power Requirement/Operating Voltage
- Budget of Project
- Interfaces Requirement (like USB, SPI, I2C, UART etc),
- Make a Basic Hardware Block Diagram,)
- List down how many GPIO is needed (Number of I/O Pin)
- Analog to Digital Inputs (ADCs)
- PWMs
- Select the Right Architecture Needed i.e. or Bit Size(8-bit, 16-bit, 32-bit)
- Recognise Memory Requirement of project (RAM, Flash etc)

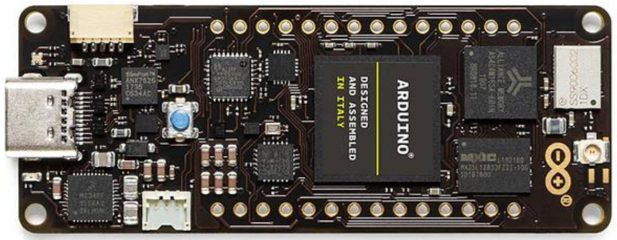
How to choose microcontroller ?

- **Frequency**: Speed at which the microcontroller will operate
- **Number of I/O pins** : Required ports and pins
- **RAM**: All the variables and arrays declared(DATA) in most MCUs
- **Flash Memory**: Whatever code you write goes here after compiling
- **Advanced Interfaces**: Advanced interfaces such as USB, CAN and Ethernet.
- **Working Voltage**: Working voltage of MCU such as 5V, 3.3V or Low voltage.
- **Target Connectors**: The connectors for ease of circuit design and size.
- **Development Environment**: IDE/Compiler/Interpreter/Assemblers ?
- **Price and Availability**
- **Package: TH or DIP ?**

Example

Name	Processor	Operating Voltage/Input Voltage	CPU Speed	Analog In/Out	Digital IO/PWM	EEPROM [KB]	SRAM [KB]	Flash [KB]	USB
Uno	ATmega328	5 V/7-12 V	16 Mhz	6/0	14/6	1	2	32	Regular
Due	AT91SAM3X8E	3.3 V/7-12 V	84 Mhz	12/2	54/12	-	96	512	2 Micro
Leonardo	ATmega32u4	5 V/7-12 V	16 Mhz	12/0	20/7	1	2.5	32	Micro
Mega 2560	ATmega2560	5 V/7-12 V	16 Mhz	16/0	54/15	4	8	256	Regular
Mega ADK	ATmega2560	5 V/7-12 V	16 Mhz	16/0	54/15	4	8	256	Regular
Micro	ATmega32u4	5 V/7-12 V	16 Mhz	12/0	20/7	1	2.5	32	Micro
Mini	ATmega328	5 V/7-9 V	16 Mhz	8/0	14/6	1	2	32	-
Nano	ATmega168 ATmega328	5 V/7-9 V	16 Mhz	8/0	14/6	0.512 1	1 2	16 32	Mini-B
Ethernet	ATmega328	5 V/7-12 V	16 Mhz	6/0	14/4	1	2	32	Regular
Esplora	ATmega32u4	5 V/7-12 V	16 Mhz	-	-	1	2.5	32	Micro
ArduinoBT	ATmega328	5 V/2.5-12 V	16 Mhz	6/0	14/6	1	2	32	-
Fio	ATmega328P	3.3 V/3.7-7 V	8 Mhz	8/0	14/6	1	2	32	Mini
Pro (168)	ATmega168	3.3 V/3.35-12 V	8 Mhz	6/0	14/6	0.512	1	16	-
Pro (328)	ATmega328	5 V/5-12 V	16 Mhz	6/0	14/6	1	2	32	-
Pro Mini	ATmega168	3.3 V/3.35-12 V 5 V/5-12 V	8 Mhz 16Mhz	6/0	14/6	0.512	1	16	-
LilyPad	ATmega168V ATmega328V	2.7-5.5 V/2.7-5.5 V	8 Mhz	6/0	14/6	0.512	1	16	-
LilyPad USB	ATmega32u4	3.3 V/3.8-5V	8 Mhz	4/0	9/4	1	2.5	32	Micro
LilyPad Simple	ATmega328	2.7-5.5 V/2.7-5.5 V	8 Mhz	4/0	9/4	1	2	32	-
LilyPad SimpleSnap	ATmega328	2.7-5.5 V/2.7-5.5 V	8 Mhz	4/0	9/4	1	2	32	-

High Performance Development Board



Datasheet is important

https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf

Atmel

ATmega328P

8-bit AVR Microcontroller with 32K Bytes In-System Programmable Flash

DATASHEET

Features

- High performance, low power AVR® 8-bit microcontroller
- Advanced RISC architecture
  - 131 powerful instructions – most single clock cycle execution
  - 32 × 8 general purpose working registers
  - Fully static operation
  - Up to 16MIPS throughput at 16MHz
  - On-chip 2-cycle multiplier
- High endurance non-volatile memory segments
  - 32K bytes of in-system self-programmable flash program memory
  - 1Kbytes EEPROM
  - 2Kbytes internal SRAM
  - Write/erase cycles: 10,000 flash/100,000 EEPROM
  - Optional boot code section with independent lock bits
    - In-system programming by on-chip boot program
    - True read-while-write operation
  - Programming lock for software security
- Peripheral features
  - Two 8-bit Timer/Counters with separate prescaler and compare mode
  - One 16-bit Timer/Counter with separate prescaler, compare mode, and capture mode
  - Real time counter with separate oscillator
  - Six PWM channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    - Temperature measurement
  - Programmable serial USART
  - Master/slave SPI serial interface
  - Byte-oriented 2-wire serial interface (Phillips I^2C compatible)
  - Programmable watchdog timer with separate on-chip oscillator
  - On-chip analog comparator
  - Interrupt and wake-up on pin change
- Special microcontroller features
  - Power-on reset and programmable brown-out detection
  - Internal calibrated oscillator
  - External and internal interrupt sources
  - Six sleep modes: Idle, ADC noise reduction, power-save, power-down, standby, and extended standby

Summary	Microprocessor	Microcontroller
Applications	Advanced data processing, video, computer vision, personal computers, fast communications, multi-core computation.	Embedded devices, control systems, smartphones, consumer electronics.
Processing Power	Higher	Lower
Memory	External - Flexible	Internal – Limited Size
Power Consumption	Higher	Lower
Size	Larger	Smaller
Price	Expensive	Cheaper
I/O	Need external peripherals with I/O pins	Programmable digital and analog I/O pins

Microcontroller vs Microprocessor

Other Kinds of Programmable Circuits

CPUs

Microcontrollers

FPGAs

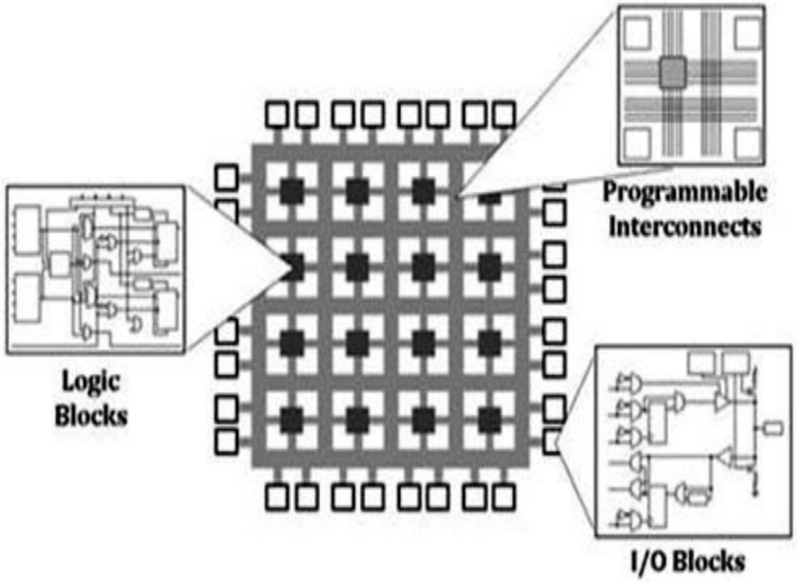
ASICs

GPUs

System on Chip (SoC)

FPGAs
(Field-Programmable Gate Arrays)

- FPGAs consist of a bunch of:
  - Programmable logic blocks –can be configured into logic gates (AND/XOR/NOT/etc.) or complex combinatorial functions
  - Interconnects to hook them together
- Many FPGAs can be reprogrammed after deployment (in the “field”)
  - Enables flexible “reconfigurable computing”
  - Can fix vulnerabilities/bugs post-deployment

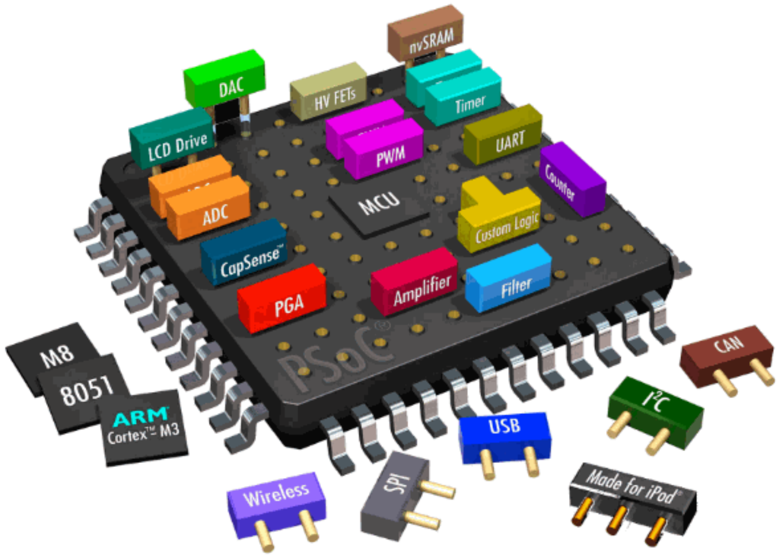


ASICs (Application-Specific Integrated Circuit)

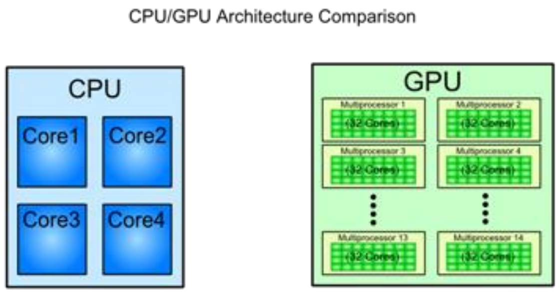
- Burn your design into silicon
  - 100s of millions of logic gates
  - Can include ROM, RAM, EEPROM, flash memory, and other large building block.
- Core logic not field-programmable, hard to update designs
  - May contain some reconfigurable logic
- ASICs (and FPGAs) used to implement CPUs/microcontrollers/etc.
  - Typical design: IP core CPU, digital signal processor, communication interfaces, memory
  - Non-recurring engineering (NRE) of millions of dollars
- Best for large production volumes, shared functionalities
- Key players: TSMC, GlobalFoundries, Samsung Semiconductor, Texas Instruments

SoCs (System on Chip)

- SoC=system on chip
- Basically pairs a CPU/microcontroller with other functions, on one chip
  - Tighter integration →better reliability, power savings, lower cost
- Paired functions: AI acceleration, machine vision, wireless communications, digital camera hardware/firmware, etc.



GPUs (Graphics Processing Unit)



Designed to rapidly manipulate and process images and video

- Many threads, like a highly parallel CPU (e.g., 480-1536 stream processors)

Commonly used in mobile phones, personal computers, game consoles, self-driving cars, drones, automated surveillance, etc.

Contains hardware implementations of important graphics functions.

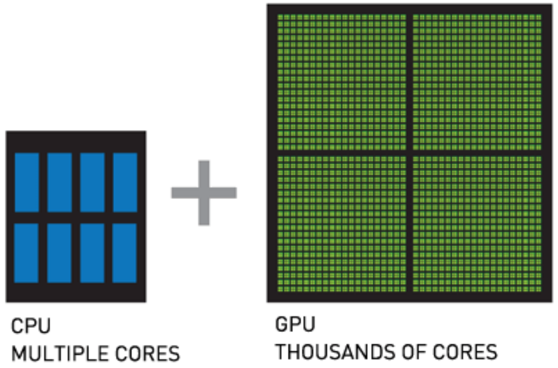
- Texture mapping, rendering polygons, rotation/translation of vertices, shading, special effects (chroma keying, bokeh, volumetric lighting)

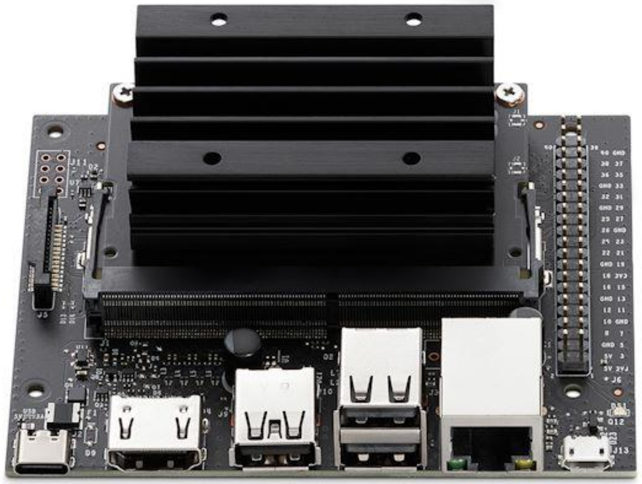
Non-graphics applications

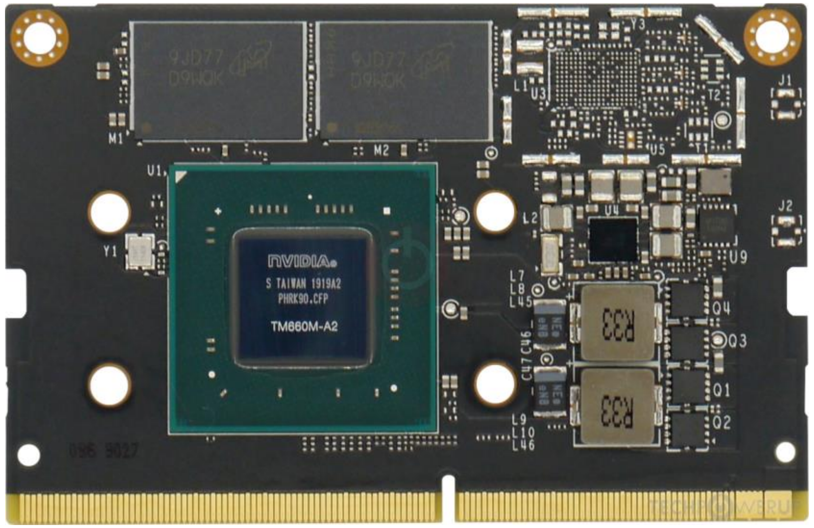
- Applications that can be parallelized work well: processing hashes (bitcoin mining), matrix operations, audio processing, machine learning, Deep learning, computer vision

•Key players: NVIDIA, Intel, AMD

CPU vs GPU : https://www.youtube.com/watch?v=1kypaBjJ-pg
Why GPU are used in ML : https://www.youtube.com/watch?v=XKOI9-G-wk8





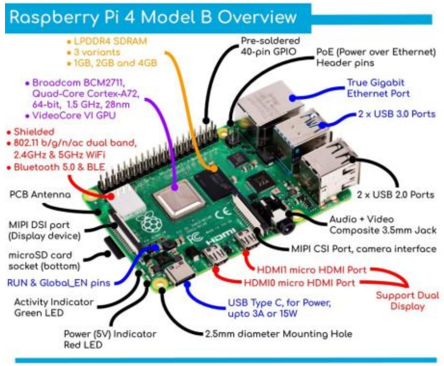


JETSON FAMILY SPECS

	JETSON NANO	JETSON TX2	JETSON XAVIER NX	JETSON AGX XAVIER
GPU	128-core NVIDIA Maxwell 0.5 TFLOPS (FP16)	256-core NVIDIA Pascal 1.3 TFLOPS (FP16)	384-core Volta 21 TOPS (INT8)	512-core Volta + NVDLA 10 TFLOPS (FP16) 32 TOPS (INT8)
CPU	4-core ARM A57	6-core Denver and A57 (2x) 2 MB L2	6-core Carmel ARM CPU (3x) 2 MB L2 + 4 MB L3	8-core Carmel ARM CPU (4x) 2 MB L2 + 4 MB L3
Memory	4 GB 64-bit LPDDR4 25.6 GB/s	4 GB 128-bit LPDDR4 51 GB/s 8 GB 128-bit LPDDR4 58 GB/s	8 GB 128-bit LPDDR4x 51.2 GB/s	16 GB 256-bit LPDDR4x 137 GB/s
Storage	16 GB eMMC	16 GB eMMC 32 GB eMMC	8 GB eMMC	32 GB eMMC
Encode	4K @ 30 (H.265)	4K @ 60 (H.265)	2x 4K @ 30 (H.265)	4x 4K @ 60 (H.265)
Decode	4K @ 60 (H.265)	2x 4K @ 60 (H.265)	2x 4K @ 60 (H.265)	6x 4K @ 60 (H.265)
Camera	12 (3x4 or 4x2) MIPI CSI-2 D-PHY 1.1 lanes (18 Gbps)	12 lanes MIPI CSI-2 D-PHY 1.2 (30 Gbps) C-PHY (41 Gbps)	12 lanes (3x4 or 6x2) MIPI CSI-2 D-PHY 1.2 (30 Gbps)	16 lanes MIPI CSI-2 8 lanes SLVS-EC D-PHY (40 Gbps) C-PHY (59 Gbps)
Mechanical	69.6 mm x 45 mm 260-pin edge connector	87 mm x 50 mm 400-pin connector	69.6 mm x 45 mm 260-pin edge connector	100 mm x 87 mm 699-pin connector
Software	NVIDIA JetPack SDK – Unified software release across all Jetson products			

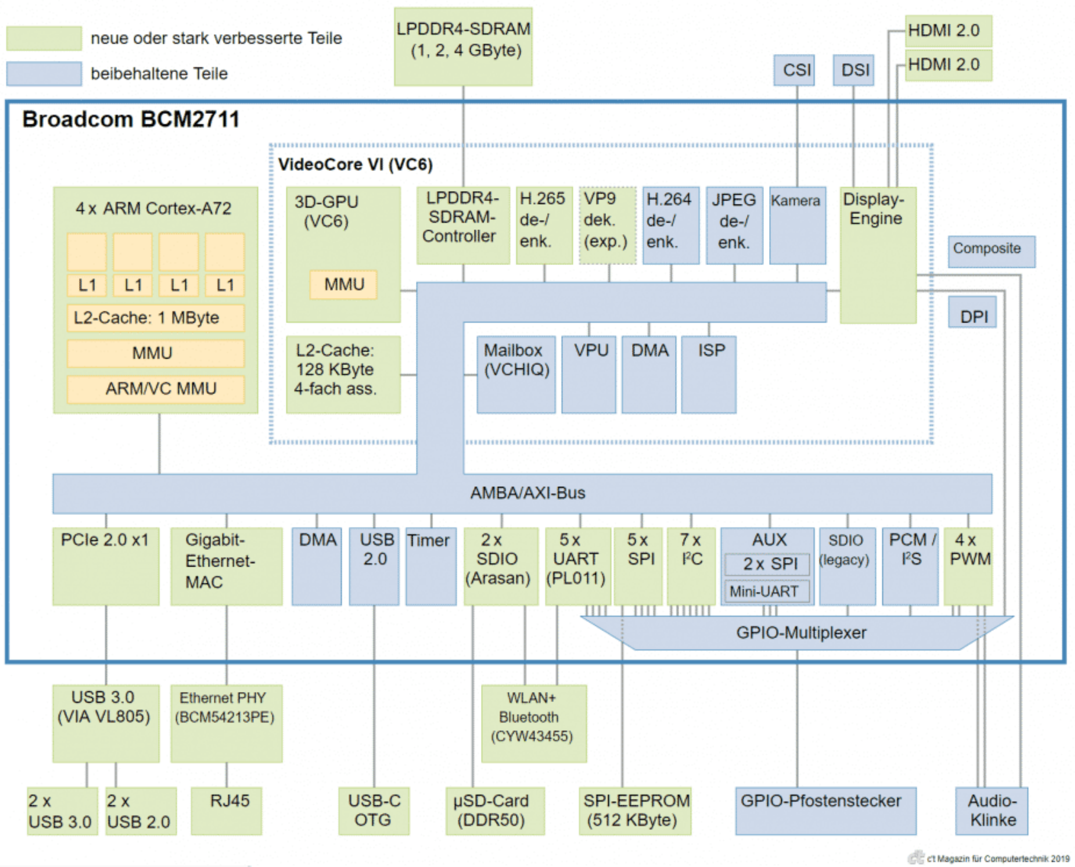
https://towardsdatascience.com/nvidia-jetson-nano-vs-google-coral-vs-intel-ncs-a-comparison-9f950ee88f0d

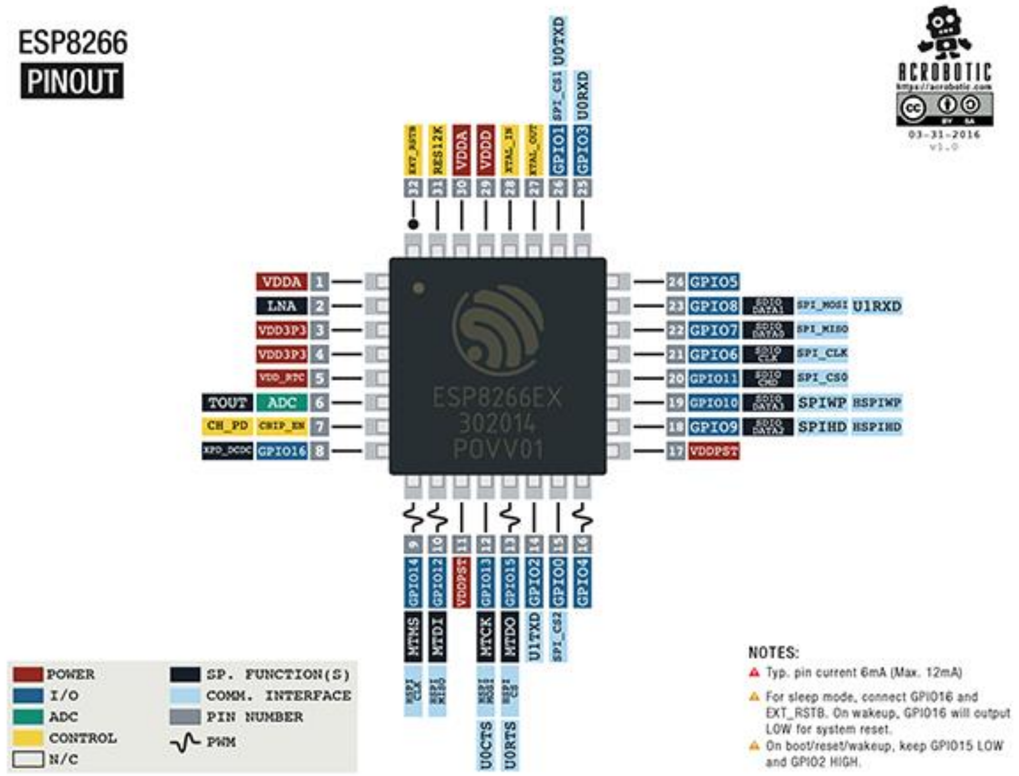
	[Raspberry Pi 4 B]()	[Raspberry Pi 3 Model A+]()	[Raspberry Pi 3 B+]()	[Raspberry Pi Zero WH]()
Image				
Release date	2019 Jun 24	2018 Nov 15	2018 Mar 14	2018 Jan 12
Description				Same as Raspberry Pi Zero W with header already soldered
Product details				
Price	US$35.00	US$25.00	US$35.00	US$15.00
SOC				
SOC Type	Broadcom BCM2711	Broadcom BCM2837B0	Broadcom BCM2837B0	Broadcom BCM2835
Core Type	Cortex-A72 (ARM v8) 64-bit	Cortex-A53 64-bit	Cortex-A53 64-bit	ARM1176JZF-S
No. Of Cores	4	4	4	1
GPU		VideoCore IV	VideoCore IV	VideoCore IV
CPU Clock	1.5 GHz	1.4 GHz	1.4 GHz	1 GHz
RAM	1 GB , 2 GB, 4 GB	512 MB DDR2	1 GB DDR2	512 MB
Wired Connectivity				
USB	✓ 2x USB3.0 + 2x USB2.0	✓ 1xUSB 2.0	✓ 4x USB2.0	✓ micro & micro OTG
Ethernet	✓ Gigabit	✗	✓ Gigabit - Over USB 2.0	✗
SATA Ports	✗	✗	✗	✗
HDMI port	✓ 2x micro HDMI	✓	✓	✓ mini
Analog Video Out	✓ shared with audio jack	✓ shared with audio jack	✓ shared with audio jack	✓ via unpopulated pin
Analog Audio Out	✓ 3.5mm jack	✓ 3.5mm jack	✓ 3.5mm jack	– HDMI audio
Analog Audio In	✗	✗	✗	✗
SPI	✓	✓	✓	✓
I2C	✓	✓	✓	✓
GPIO	✓	✓	✓	✓
LCD Panel	✓	✓	✓	✗
Camera	✓	✓	✓	✓
SD/MMC	✓ microSD	✓ microSD	✓ microSD	✓ microSD
Serial	–	–	– RX/TX UART	–
Wireless Connectivity (On-Board)				
Wi-Fi	✓ 2.4GHz and 5GHz 802.11 b/g/n/ac	✓ 2.4GHz and 5GHz 802.11 b/g/n/ac	✓ 2.4GHz and 5GHz 802.11 b/g/n/ac	✓ 802.11n
Bluetooth®	✓ 5.0	✓ 4.2, BLE	✓ 4.2, BLE	✓ 4.1
Dimensions				
Height	3.37 in (85.6 mm)	2.55 in (65 mm)	3.37 in (85.6 mm)	1.18 in (30 mm)
Width	2.22 in (56.5 mm)	2.20 in (56 mm)	2.22 in (56.5 mm)	2.55 in (65 mm)
Depth	0.43307 in (11 mm)	0.43307 in (11 mm)	0.66929 in (17 mm)	0.51181 in (13 mm)
Weight		1.02 oz (29 g)	1.58 oz (45 g)	0.42328 oz (12 g)
Power				
Power ratings			1.13 A @5V	180 mA
Power sources	USB-C	microUSB, GPIO	microUSB, GPIO	microUSB or GPIO
Power Over Ethernet	– with PoE Hat	✗	– with PoE Hat	✗

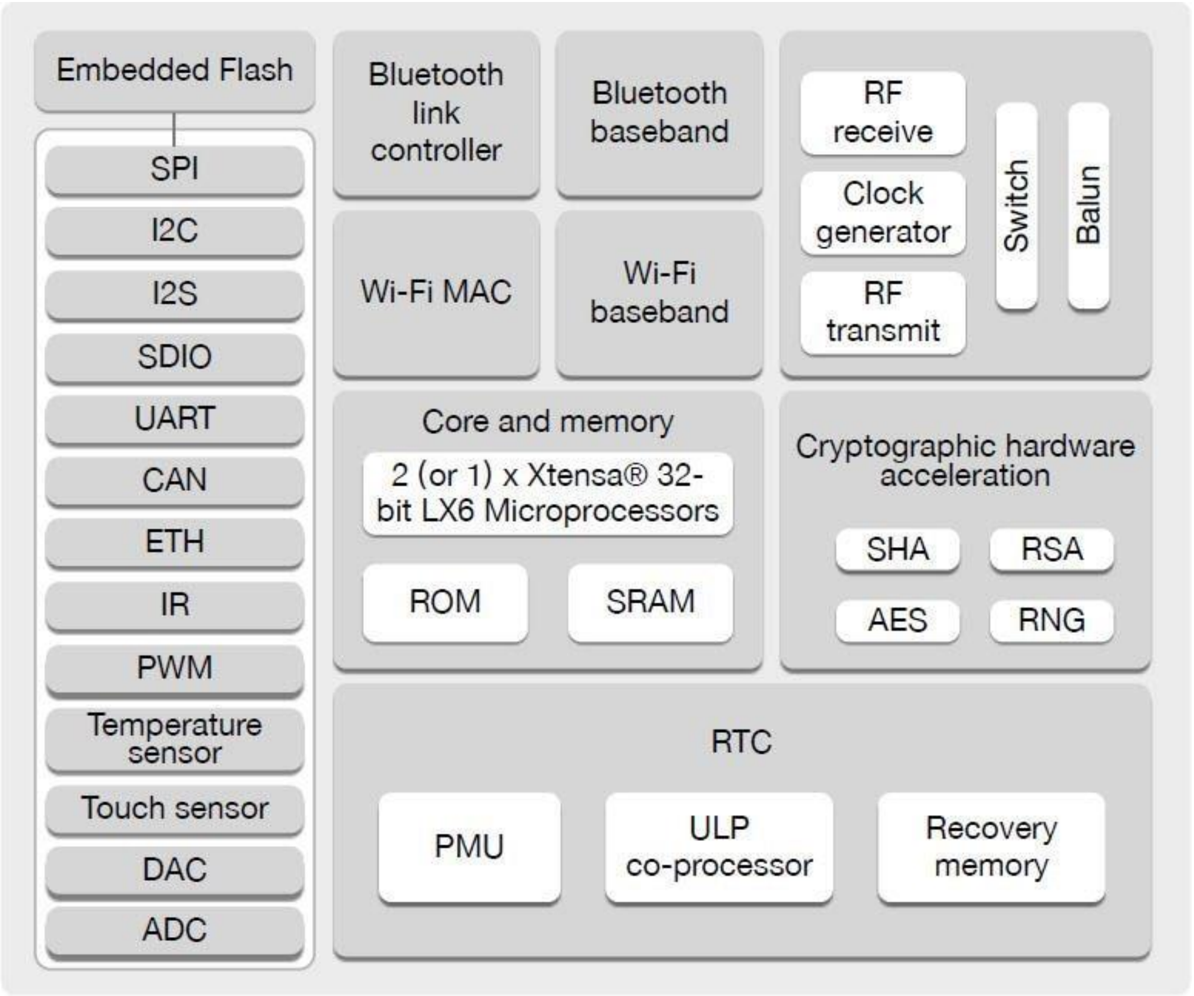


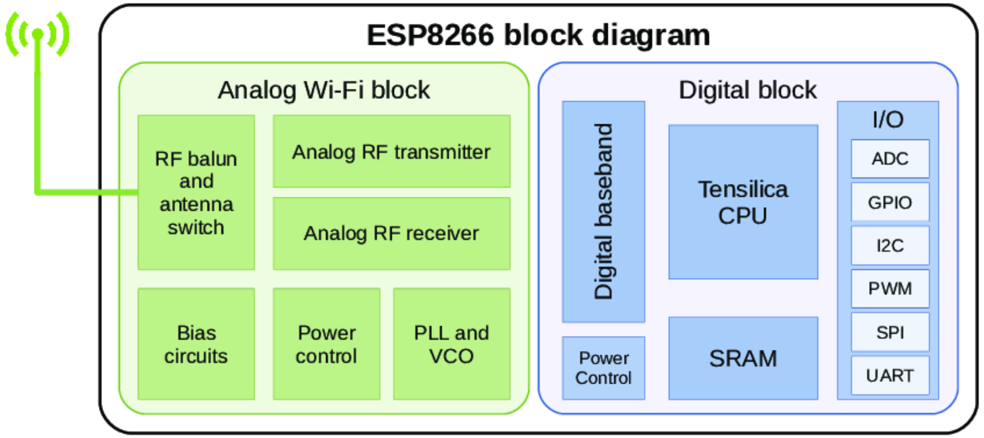
Herz des Raspberry Pi 4: Broadcom BCM2711

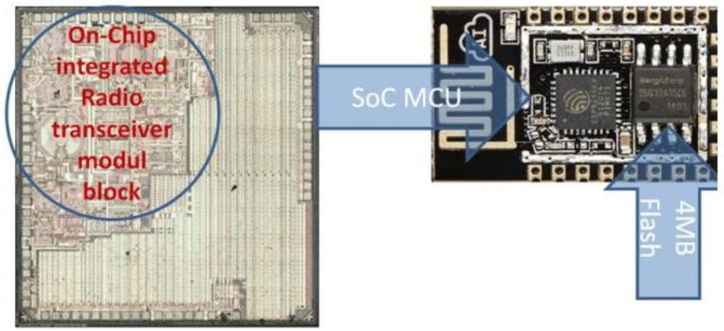
Das System-on-Chip (SoC) BCM2711 vereint nicht nur vier CPU-Kerne mit einer GPU, sondern enthält auch Controller für viele Schnittstellen.




ESP8266
PINOUT
ACROBOTIC
03-31-2016
ESP8266EX
302014
POVV01
VDDA
LNA
VDD3P3
VDD3P3
VDD_RTC
TOUT
ADC
CH_PD
CHIP_EN
GPIO16
GPIO5
GPIO8
GPIO7
GPIO6
GPIO11
GPIO10
GPIO9
VDDPST
U1RXD
SPIWP
HSPIWP
SPIHD
HSPIHD
GPIO1
GPIO3
U0TXD
U0RXD
GPIO14
GPIO12
VDDPST
GPIO13
GPIO15
GPIO2
GPIO0
GPIO4
MTMS
MTDI
MTCK
MTDO
U1TXD
U0CTS
U0RTS
POWER
I/O
ADC
CONTROL
N/C
SP. FUNCTION(S)
COMM. INTERFACE
PIN NUMBER
PWM
NOTES:
Typ. pin current 6mA (Max. 12mA)
For sleep mode, connect GPIO16 and EXT_RSTB. On wakeup, GPIO16 will output LOW for system reset.
On boot/reset/wakeup, keep GPIO15 LOW and GPIO2 HIGH.

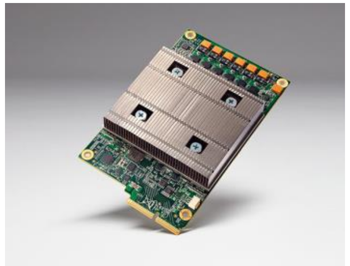

Embedded Flash
SPI
I2C
I2S
SDIO
UART
CAN
ETH
IR
PWM
Temperature sensor
Touch sensor
DAC
ADC
Bluetooth link controller
Bluetooth baseband
Wi-Fi MAC
Wi-Fi baseband
RF receive
Clock generator
RF transmit
Switch
Balun
Core and memory
2 (or 1) x Xtensa® 32-bit LX6 Microprocessors
ROM
SRAM
Cryptographic hardware acceleration
SHA
RSA
AES
RNG
RTC
PMU
ULP co-processor
Recovery memory


ESP8266 block diagram
Analog Wi-Fi block
RF balun and antenna switch
Analog RF transmitter
Analog RF receiver
Bias circuits
Power control
PLL and VCO
Digital block
Digital baseband
Tensilica CPU
I/O
ADC
GPIO
I2C
PWM
SPI
UART
Power Control
SRAM

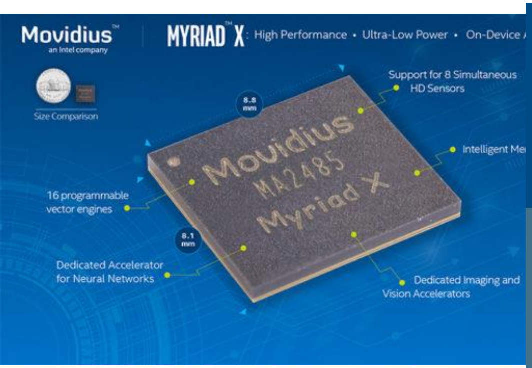

On-Chip integrated Radio transceiver modul block
SoC MCU
4MB Flash

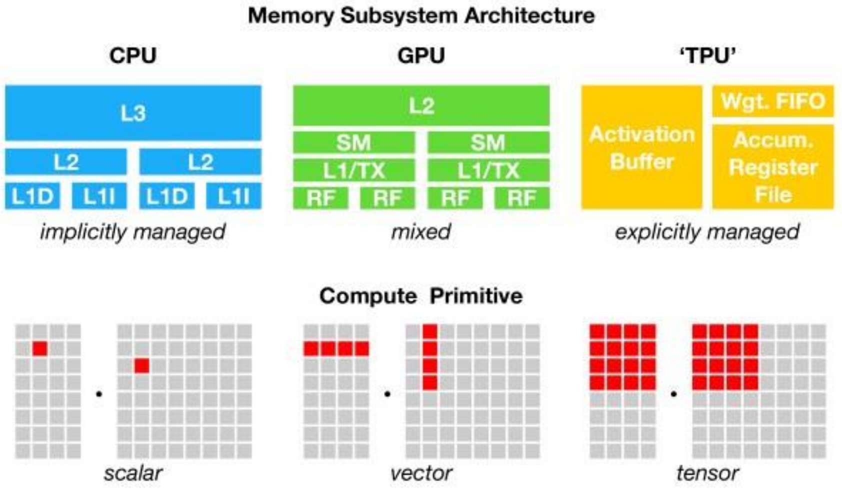

ESP32-D0WDQ6

Emerging Programmable Circuits



- **Vision Processing Unit (VPU)** –accelerates computer vision –Microsoft HoloLens, Movidius Myriad X, NVIDIA VLIW Vision Processor
- **Neural Network Processor (NNP)** –accelerates neural network machine learning –Google (Tensor Processing Unit), Intel (Nervana), AWS (Inferentia), Apple (Neural Engine)
- **Machine Learning Processor (MLP)** –general programmable platform for machine learning–ARM (Trillium), IBM (Power9)



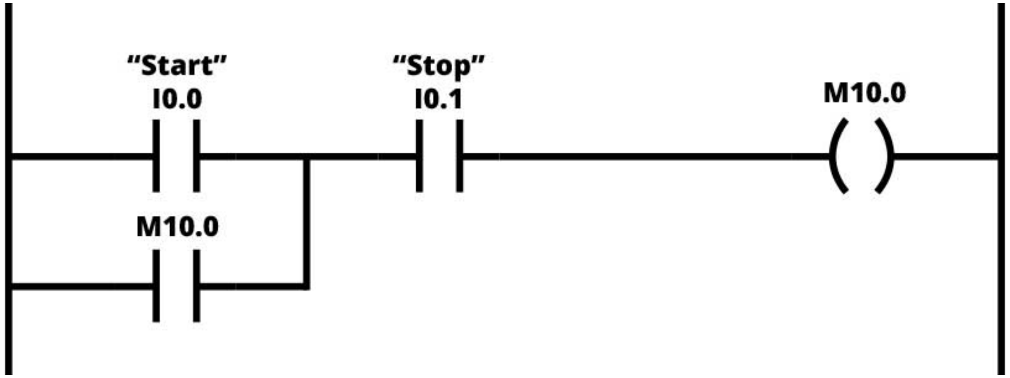


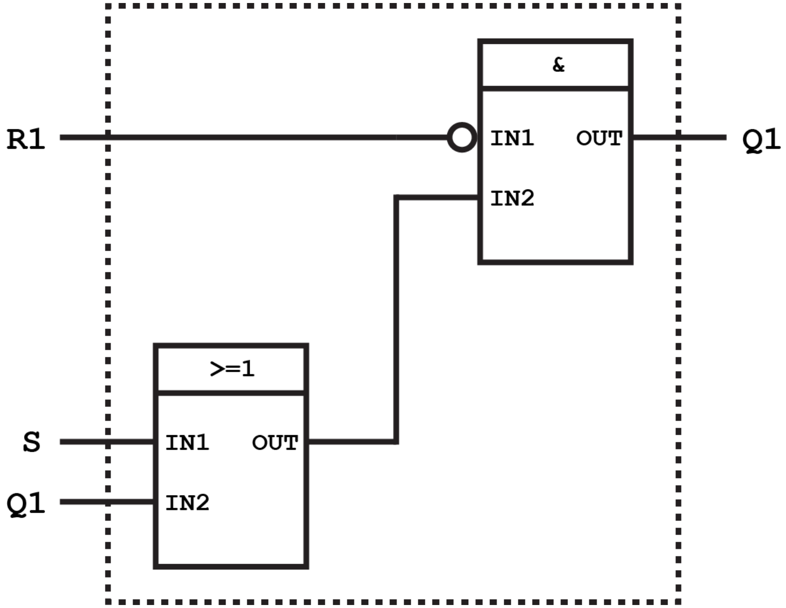
How to decide which to use?

Technology	When to use	Example applications
Microcontrollers	When you need to get really small, really power-efficient, or really low-cost, and don't need much compute power.	Main compute for Apple Watch Series 3 (ST Microelectronics ST33G1M2 32 bit MCU)
CPUs	When you need to run diverse applications or deal with larger memory or compute challenges.	Nest thermostat (Arm Cortex A8), Amazon Echo Show (Intel Atom x5)
FPGAs	When you benefit from parallelism or have need to reprogram logic in the field, and are at low production volumes. More expensive than ASICs.	Many (proprietary); smart automotive (eg plug-in hybrid), aerospace applications, prototyping ASICs.
ASICs	When you need and can afford to pay millions to fabricate your own chip. High production volumes.	Many (proprietary); edge devices, sensor/actuator control, etc.
GPUs	When your application is data-intense, and graphics-oriented, or can be transformed into a highly-parallel many-core problem (ML/AI).	Tesla Autopilot 2.0 ECU (Nvidia PX2 platform, which uses NVIDIA GP106 GPU)
SoC	When you need general and application-specific compute but also a compact size, your domain is one where there is an SoC and prices are low.	Samsung Galaxy smartphone (Exnyos 8 Octa SoC), Apple iPhone XS (Apple A12 Bionic ARM-Based)

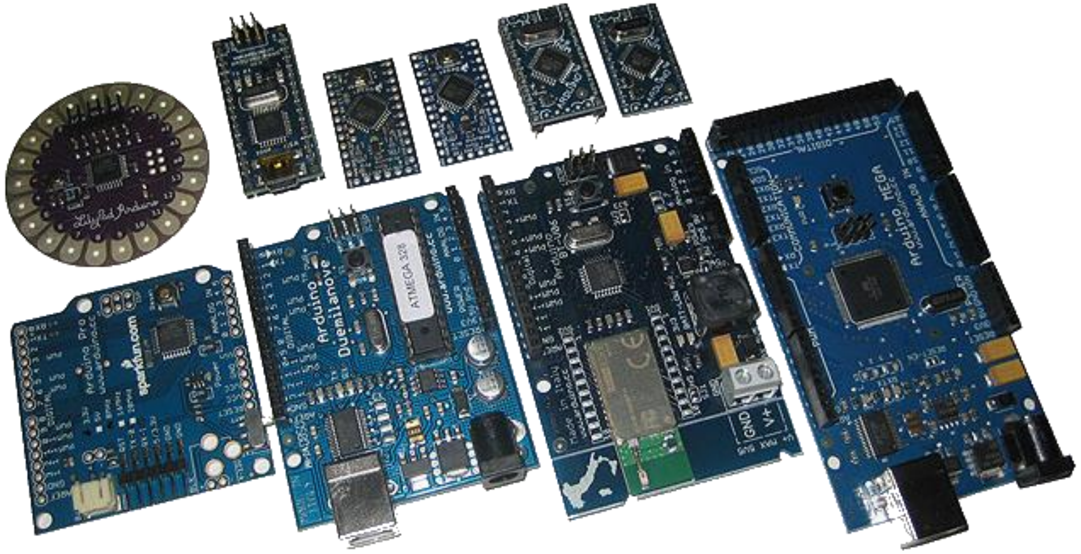
Controller in Industrial

- PLC : Programmable Logic Control
- ใช้งานตามยี่ห้อของผู้ผลิตอุปกรณ์นั้น ๆ
- มักใช้ภาษา Ladder หรือ Block ในการโปรแกรม

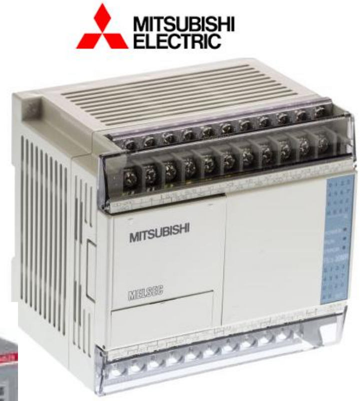




Arduino using in Industrial ?



VS



How to get embedded devices or sensors ?

- “บ้านหม้อ”
- Another Shop

How to get embedded devices or sensors ?

- Online Store (Thai Store)
    - Digikey, Cytron, RSOnline
    - Gravitech, allnewstep, thaieasyelec ฯลฯ
    - Aliexpress / Lazada / Shopee

References

- Lecture note on IoT Device, university of illinois at urbana-champaign.
- Google Cloud IIoT : https://developers.google.com/iot
- IoT System Design: Software and Hardware Integration : WasedaX
- IoT Sensors and Devices, CurtinX University
- https://circuitdigest.com/article/how-to-select-the-right-microcontroller-for-your-embedded-application
- https://www.arm.com/products/silicon-ip-cpu/ai-platform

อินเตอร์เน็ตในทุกสรรพสิ่ง

Internet of things