Embedded Platforms

CSE/ECE 475
ECE 542
2024

Some things to consider when selecting your platform

- Programmability and debugging tools
- External device and sensor interfaces and sufficient I/O pins
- Wireless (e.g., BTLE) and the location of antenna (internal or external)
- Power requirements (consumption, voltage requirements, etc)
- Compute power
- Storage (RAM, ROM, SSD)
- Environmental conditions
- Any special features like cryptography, supports tensorflow, have built in ml accelerators, etc

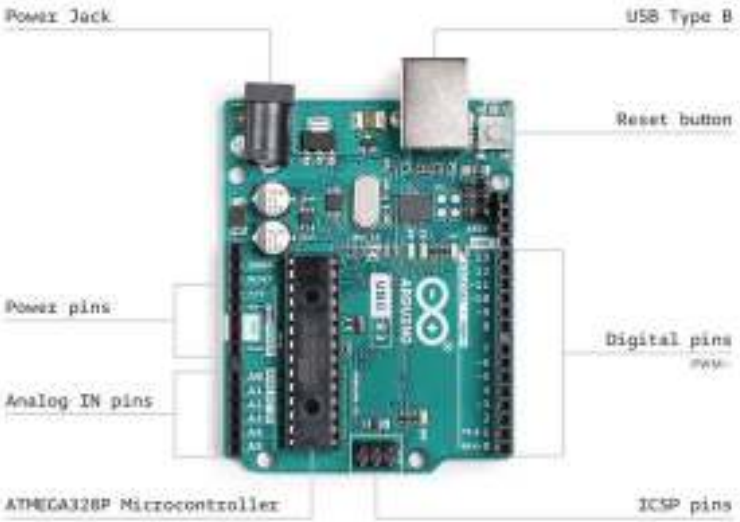
Arduino-Based Microcontrollers

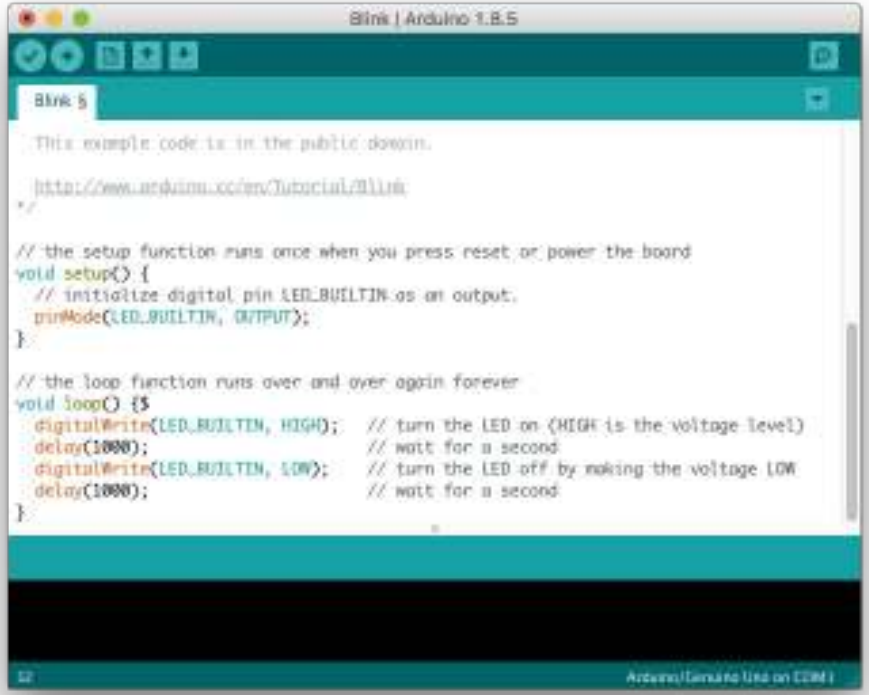
Why Arduino?

- **Cost** -- Cheap for prototyping
- **IDE** -- Cross-platform, very simple
- **Extensible** -- Can add AVR-C code directly into Arduino programs, open source libraries
- **Ready-to-use** -- Platforms already Arduino bootloader already flashed (so no need for ISP)
- **Open source hardware** -- Variety of different hardware configurations, shields, and compatible sensors available from a number of retailers
- **Large community** -- Lots and lots of docs, tutorials, and forums threads

Why not Arduino?

- **Cost** -- expensive, when building at volume
- **Non-custom** -- general-purpose boards limit your form factors and functions
- **Not memory-optimized** -- bootloader is large compared to some platforms, some libraries use unnecessarily large
- **Computationally inefficient** -- in some cases
- **Hardware-level access** abstracted with basic language
- **Limited debug capabilities** -- no code step, register inspection


Power Jack
USB Type B
Reset button
Power pins
Digital pins
Analog IN pins
ATMEGA328P Microcontroller
ICSP pins


Blink | Arduino 1.8.5
Blink §
This example code is in the public domain.
http://www.arduino.cc/en/Tutorial/Blink
*/
// the setup function runs once when you press reset or power the board
void setup() {
// initialize digital pin LED_BUILTIN as an output.
pinMode(LED_BUILTIN, OUTPUT);
}
// the loop function runs over and over again forever
void loop() {
digitalWrite(LED_BUILTIN, HIGH); // turn the LED on (HIGH is the voltage level)
delay(1000); // wait for a second
digitalWrite(LED_BUILTIN, LOW); // turn the LED off by making the voltage LOW
delay(1000); // wait for a second
}

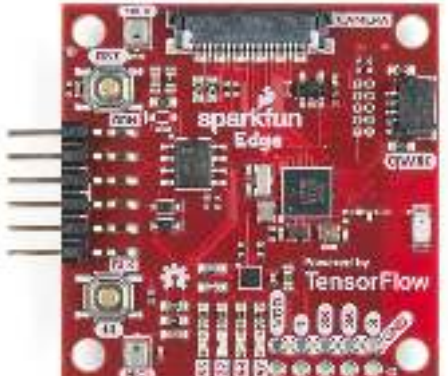
Small Form Factor Arduino Boards from Sparkfun/Adafruit

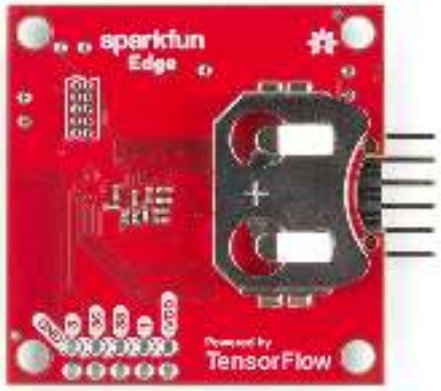
Sparkfun and Adafruit both have Arduino based dev kit ecosystems with good peripheral support. These are just two of the basic ones.

- SparkFun Qwiic Pro Micro - USB-C
  - https://www.sparkfun.com/products/15795
  - ATmega32U4
  - Can be 3.3V or 5V
  - Can plug into multiple peripherals offered from Sparkfun
- Adafruit Feather 32U4 Basic Proto
  - https://www.adafruit.com/product/2771
  - ATmega32U4
  - 3.3V
  - Different versions with wireless support (Wifi, BLE, LTE)

Sparkfun Edge Development Board

- Designed for low power machine learning
- Has lots of peripherals and connectors built in
  - Bluetooth
  - 3 Axis IMU
  - 2 Microphones
  - Connector for camera
- Low power - Can run off coin cell for 10 days
- Supports Arduino
- Not as common a platform as other dev boards though





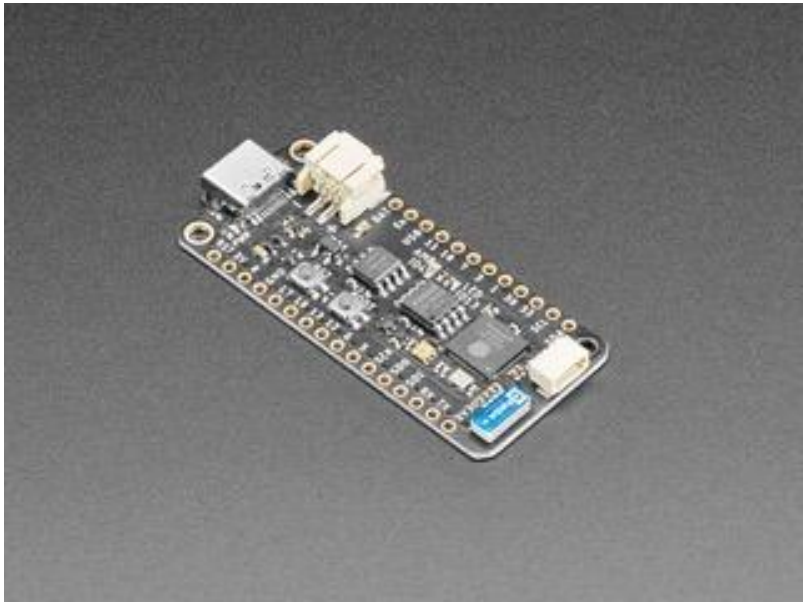
Other Arduino Kits

Teensy - Extremely powerful microcontrollers, small. https://www.pjrc.com/teensy/

Variety of Arduino shields available for added peripherals

Arduino Micro + Peripheral (Adafruit Feather Line)

Adafruit FeatherS2 - ESP32-S2 Feather Development Board
Micro + WiFi (integrated antenna)



Features & Specifications

- 32-bit 240 MHz single-core processor
- 16 MB SPI Flash
- 8 MB extra PSRAM
- 2.4 GHz Wi-Fi - 802.11b/g/n
- 3D Antenna
- 2x 700 mA 3.3 V LDO regulator
- Optimised power path for low-power battery usage
- LiPo battery management
- Power (red), Charge (orange) & IO13 (blue) LEDs
- 21x GPIO
- USB-C
- USB backfeed protection
- APA102 RGB LED (CLK IO45, DATA IO40)
- ALS-PT19 Ambient Light Sensor (IO14)
- QWIIC/STEMMA connector
- Feather format

Arduino Micro + Peripheral (Adafruit Feather Line)

Adafruit Feather M0 Adalogger
Mircro + SD Card for Data-logging applications
https://www.adafruit.com/product/2796

Features & Specifications

- 256KB of FLASH + 32KB of RAM
- No EEPROM
- 3.3V regulator with 500mA peak current output
- USB native support, comes with USB bootloader and serial port debugging
- You also get tons of pins - 20 GPIO pins
- Hardware Serial, hardware I2C, hardware SPI support
- 8 x PWM pins
- 10 x analog inputs
- 1 x 10-bit analog output (DAC)

Arduino Micro + Peripheral (Adafruit Feather Line)

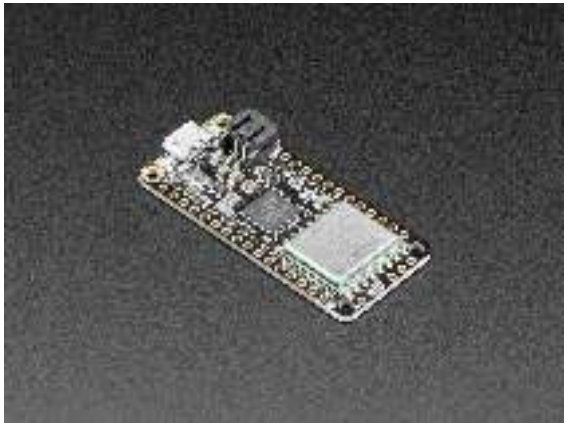
Adafruit Feather M4 Express - Featuring ATSAMD51 - ATSAMD51 Cortex M4
Slightly more powerful micro
https://www.adafruit.com/product/3857

Features & Specifications

- ATSAMD51 32-bit Cortex M4 core running at 120 MHz, 32-bit, 3.3V logic and power
    - Floating point support with Cortex M4 DSP instructions
    - 512 KB flash, 192 KB RAM
    - 2 MB SPI FLASH chip for storing files and CircuitPython code storage.
    - No EEPROM
    - 32.768 KHz crystal for clock generation & RTC
    - 3.3V regulator with 500mA peak current output
    - USB native support, comes with USB bootloader and serial port debugging
    - Built in crypto engines with AES (256 bit), true RNG, Pubkey controller
    - Tons of GPIO! 21 x GPIO pins with following capabilities:
        - Dual 1 MSPS 12 bit true analog DAC (A0 and A1) - can be used to play 12-bit stereo audio clips
        - Dual 1 MSPS 12 bit ADC (6 analog pins some on ADC1 and some on ADC2)
        - 6 x hardware SERCOM - Native hardware SPI, I2C and Serial all available
        - 16 x PWM outputs - for servos, LEDs, etc
        - I2S input and output
        - 8-bit Parallel capture controller (for camera/video in)
    - Built in 100mA lipoly charger with charging status indicator LED

Arduino Micro + Peripheral (Adafruit Feather Line)

Adafruit Feather M0 with RFM95 LoRa Radio - 900MHz - RadioFruit
Micro + LoRa
https://www.adafruit.com/product/3178



Features & Specifications

This Feather M0 LoRa Radio uses the extra space left over to add an RFM9x LoRa 868/915 MHz radio module. These radios are not good for transmitting audio or video, but they do work quite well for small data packet transmission when you need more range than 2.4 GHz (BT, BLE, WiFi, ZigBee).

- SX127x LoRa® based module with SPI interface
- Packet radio with ready-to-go Arduino libraries
- Uses the license-free ISM bands (ITU "Europe" @ 433MHz and ITU "Americas" @ 900MHz)
- +5 to +20 dBm up to 100 mW Power Output Capability (power output selectable in software)
- ~300uA during full sleep, ~120mA peak during +20dBm transmit, ~40mA during active radio listening.
- Simple wire antenna or spot for uFL connector

Arduino Micro + Peripheral (Adafruit Feather Line)

Adafruit Feather nRF52840 Sense
BLE + Micro + Sensors
https://www.adafruit.com/product/4516

Features & Specifications

A chorus of supporting sensors surround the module so you can do all sorts of environmental and motion sensing:

- ST Micro series 9-DoF motion - LSM6DS33 Accel/Gyro + LIS3MDL magnetometer
- APDS9960 Proximity, Light, Color, and Gesture Sensor
- PDM Microphone sound sensor
- SHT Humidity
- BMP280 temperature and barometric pressure/altitude

- ARM Cortex M4F (with HW floating point acceleration) running at 64MHz
- 1MB flash and 256KB SRAM
- Native Open Source USB stack - pre-programmed with UF2 bootloader
- Bluetooth Low Energy compatible 2.4GHz radio (Details available in the nRF52840 product specification)
- FCC / IC / TELEC certified module
- Up to +8dBm output power

TI MSP430

- Not as popular anymore, but you'll see these in many IoT products on the market
- 16-bit micro
- Ultra-low power
  - Great for sensing and battery powered applications
- More advanced, but closer to production
  - Large community and support
- Lots of dev board options
  - Launchpad
    - Each to interface with GIOs
    - Low-cost
  - EZ430
    - Small form factor
    - Low-power wireless options

Espressif Systems

Espressif Systems

- Low cost IoT development platform (~$20)
- Inbuilt WiFi
- 32 bit MCU
- Available in different form factors
- Arduino compatible
- Open Source IoT Development Framework

Image Source: Espressif Systems, Mouser Electronics

ESP8266 vs ESP32

- Single Core Processor operates up to 160Mhz
- Supports up to 17 GPIOs
- Communication Protocols: SPI, I2C, I2S, UART
- Single 10 bit ADC
- Currently priced at ~$6

- Single Core Processor operates up to 160Mhz
- Supports up to **22 GPIOs**
- Communication Protocols: SPI, I2C, I2S, UART, **USB OTG**
- Up to **six 12 bit** ADCs
- Currently priced at ~$2
- **Bluetooth 5, Built-in Sensors, Enhanced Storage & Security**

ESP32-S3

- Dual Core Processor
- Operates upto 240 MHz
- 512 KB SRAM, 384 KB ROM
- Complete WiFi Subsystem
- Bluetooth 5 a.k.a Bluetooth Low Energy
- Up to 45 GPIOs
- Temperature, Touch Sensors & LCD, Camera interfaces
- AI Acceleration support
- Ultra Low Power Core for low power modes of operation
- Cryptographic hardware accelerators that support AES-128/256, Hash, RSA, HMAC, digital signature, and secure boot

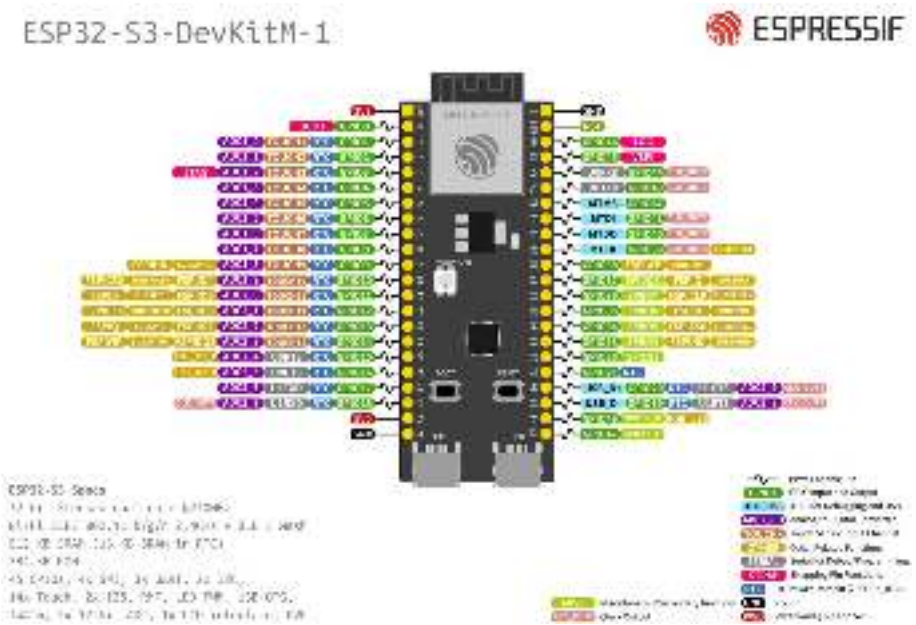
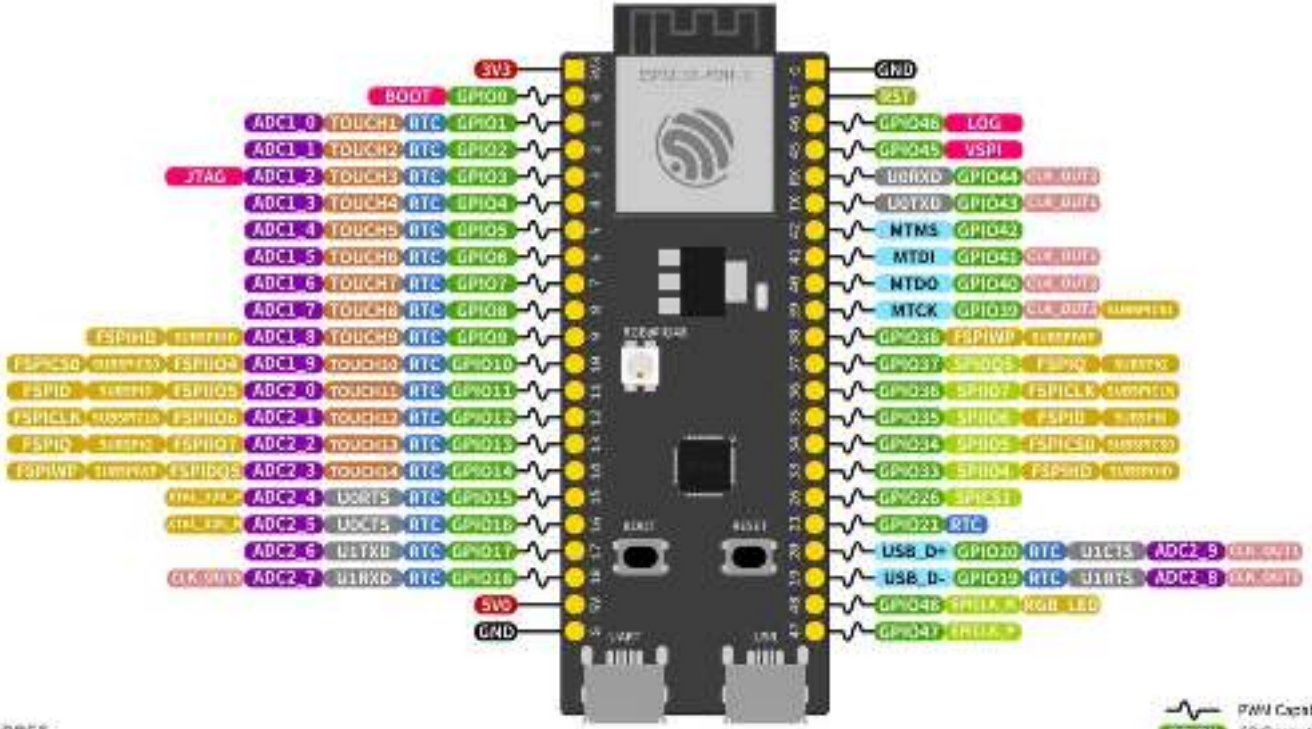


Image Source: Espressif Systems

ESP32-S3-DevKitM-1

ESPRESSIF



ESP32-S3 Specs

32-bit Xtensa® dual-core @240MHz

Wi-Fi IEEE 802.11 b/g/n 2.4GHz + BLE 5 Mesh

512 KB SRAM (16 KB SRAM in RTC)

384 KB ROM

45 GPIOs, 4x SPI, 3x UART, 2x I2C,

14x Touch, 2x I2S, RMT, LED PWM, USB-OTG,

TWAI®, 2x 12-bit ADC, 1x LCD interface, DVP

PWM Capable Pin

GPIOXX GPIO Input and Output

JTAG/USB JTAG for Debugging and USB

ADCX_CH Analog to Digital Converter

TOUCHX Touch Sensor Input Channel

OTHER Other Related Functions

SERIAL Serial for Debug/Programming

STRAP Strapping Pin Functions

RTC RTC Power Domain (VDD3P3_RTC)

MISC Miscellaneous/Secondary functions

GND Ground

CLK_OUTX Clock Output

PWR Power Rails (3V3 and 5V)

Alternative to ESP32?

NORDIC®
SEMICONDUCTOR

Nordic Semiconductor Offerings

- Hardware:
  - Low Power Cellular IoT
  - DECT NR+
  - WiFi
  - Bluetooth
  - Zigbee
- Software:
  - Desktop Development Tools
  - Mobile Apps
- Cloud Services:
  - Location
  - Firmware OTA Update

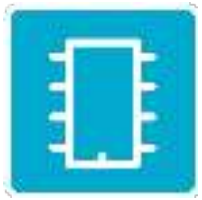


Image Source: Nordic Semi, Adafruit

nRF52840 Dongle

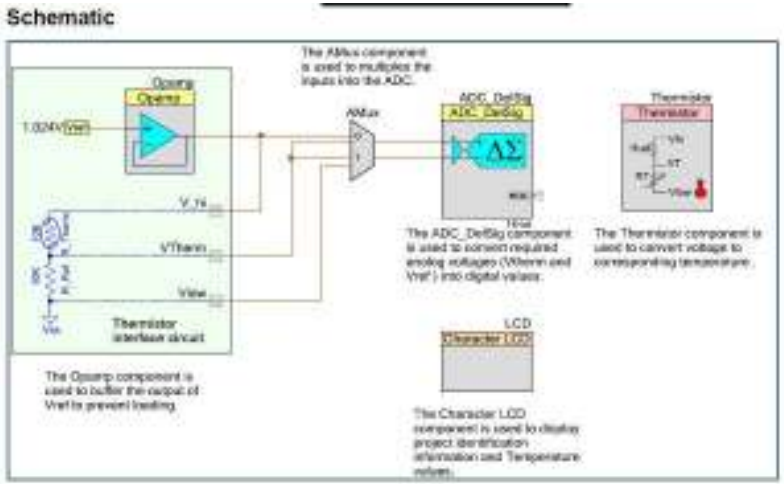
- 32 bit ARM-Cortex M4 up to 64MHz
- 1 MB Flash, 256 KB RAM
- Supports Bluetooth Low Energy (LE), Bluetooth mesh, Thread, Zigbee, NFC, 802.15.4, ANT and 2.4 GHz proprietary applications
- 15 GPIO pins
- SPI, UART, I2C, I2S, USB
- 1.7-5.5 V operation
- Focussed on Ultra Low Power applications
- ARM CryptoCell CC310 cryptographic accelerator
- Temperature Sensor
- Currently priced at $10

Image Source: Nordic Semi

PSoC

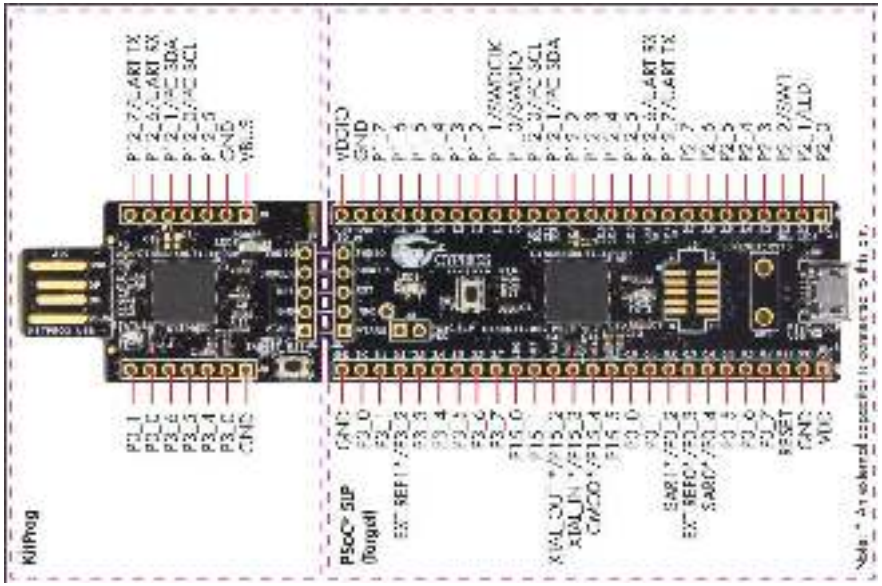
Infineon PSoC

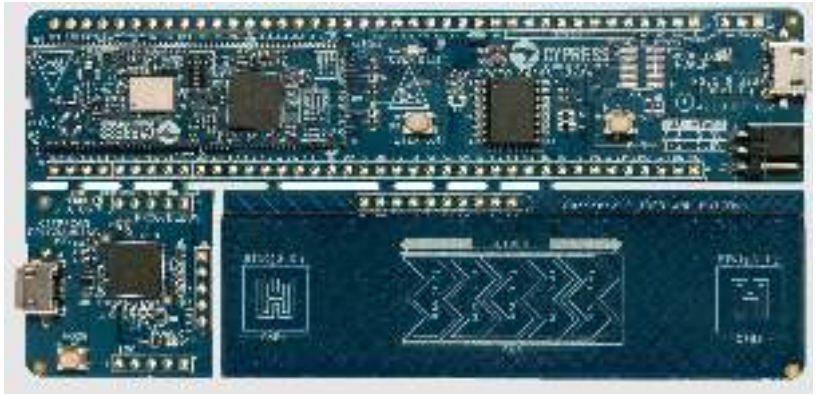
- Programmable System on Chip (PSoC)
- Arm Cortex-M Processors
- Complex Programmable Logic Device (CPLD)
  - Similar to FPGA
  - Verilog, LUTs, Digital Logic, etc.
- Analog Peripherals
  - Op Amps, PGAs, Mixers, etc.
- IDE Options
  - PSoC Creator
  - Modus Toolbox
  - IAR, Keil, Eclipse
- Excellent YouTube tutorials
- Highly configurable & flexible



PSoC 5 & 6

- PSoC 5LP
  - Mature Product
  - Cortex M3
  - Good blend between Analog and Digital
  - Inexpensive, easy to use protoboard.
- PSoC 6
  - Newest platform
  - Dual M4F and M0+ Cores
  - Higher performance
  - Digital and connectivity focused.





Raspberry Pi

Raspberry Pi

- Single-Board Computer
- System-on-chip processor
  - ARM CPU
  - GPU
- Embedded Linux
  - Default is Raspian
    - Based on Debian
- Wi-Fi, Ethernet, Bluetooth, HDMI, USB
- May be used as a standalone or “headless” computer
- 100’s of mW in power consumption
- No analog peripherals!
- GPIOs are kernel controlled

Raspberry Pi Zero & Zero W

- Zero
  - Basically older gen RPi in a smaller, stripped down format.
  - “$5 Computer”
  - Lowest power
  - To the right: RPi Zero with LoRa radio and OLED display. Used as a quick data logger.
- Zero W
  - Adds WiFi & Bluetooth
    - Increased power and cost

Raspberry Pi Pico

- Microcontroller Board
  - Different than other RPi's
    - Not a SBC
  - Based on RP2040 IC
    - Designed by RPi foundation
    - Dual Core Cortex-M0+
    - Programmable GPIO
    - ADC
    - MicroPython and C

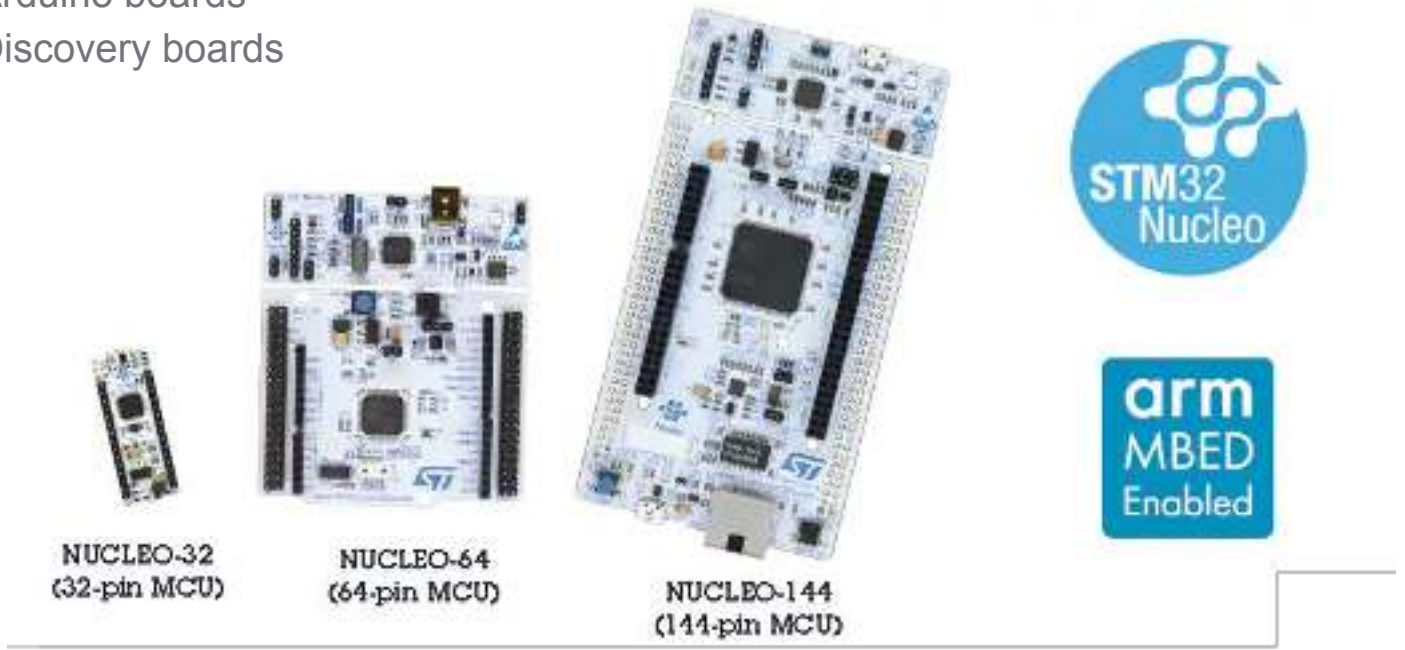
STM32

STM32 Arm MCUs

- Arm Cortex-M processor 32bit
- Clock rate up to 480MHz
- Combines high performance, real-time capabilities, digital signal processing, low-power operation, and connectivity
- Around $10 to $30
- Has various series:
  - High performance: STM32F
  - Mainstream: STM32G
  - Ultra-low-power: STM32L
  - Wireless: STM32WB/WL

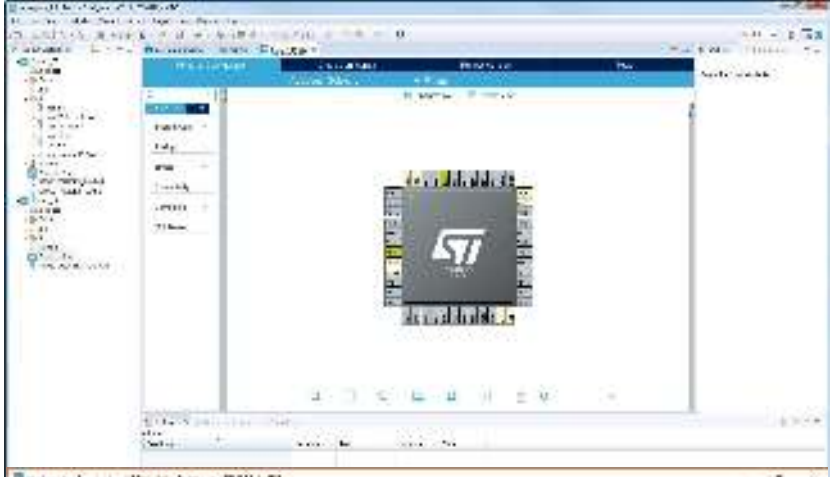
STM32 Arm MCUs

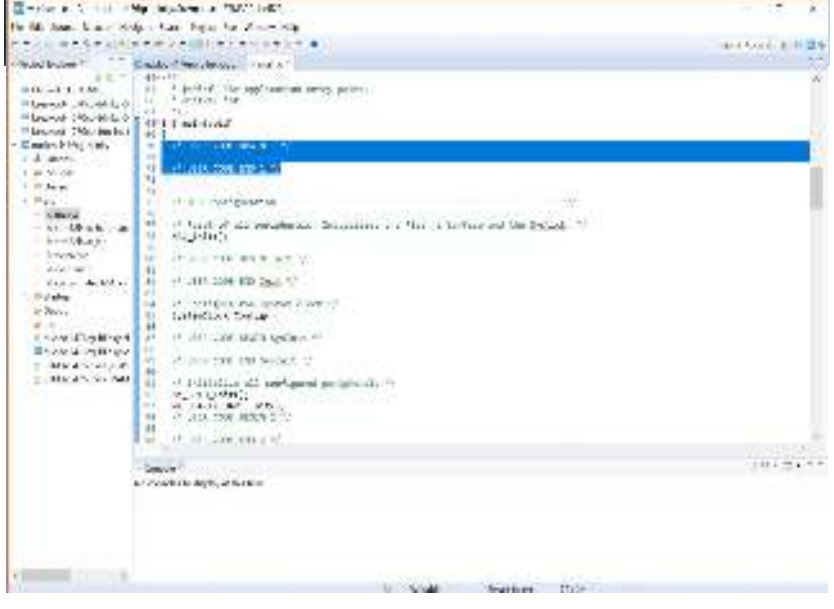
- Develop board:
  - Nucleo boards
  - Arduino boards
  - Discovery boards



STM32 Arm MCU Software

- Code portability in STM family
- STM32CubeMX
- STM32CubeIDE
- MBed – for Arm





Advanced Platforms

Qualcomm Snapdragon

- Full SOCs
- Power phones, tablets, and some laptops
- Huge industry utilities for mid to high end devices
- 1 core up to 1 GHz Scorpion or Cortex-A5 or ARM11
- GPU capabilities
- DSP: Hexagon QDSP5 at 350 MHz or Hexagon QDSP6 600 MHz
- Cellular modems
- Wifi/BT
- 45 or 65 nm manufacturing technology

Software Defined Radios

Software Defined Radios - prototyping wireless systems

- **HackRF**
  - 1 Mhz - 6 GHz half-duplex transceiver
  - Works with GNU Radio and other SDR platforms
  - Software gain and bandpass filters
  - Growing community and open-sourced hardware
  - ~$120 to ~$400

- **RTL2832U**-based Tuners
  - Very low-cost ~$30
  - Limited frequencies, but good for low frequency applications
  - Lots of sample source projects and growing community
    - https://www.rtl-sdr.com/

Software Defined Radios - prototyping wireless systems

- **BladeRF**
  - 47MHz to 6GHz range, 56MHz bandwidth
  - Works with GNU Radio and other SDR platforms
  - Auto gain control
  - 2x2 MIMO, 61.44MHz sampling rate
  - $500 ~ $900
  - https://www.nuand.com/

- **USRP**
  - Higher end product, expensive
  - Various frequency range available
  - Works with GNU Radio and other SDR platforms
  - Has a motherboard and a daughterboard
  - $3,000 ~ $20,000