SEMINAR ON STM32 MICROCONTROLLERS

UNIMORE

UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

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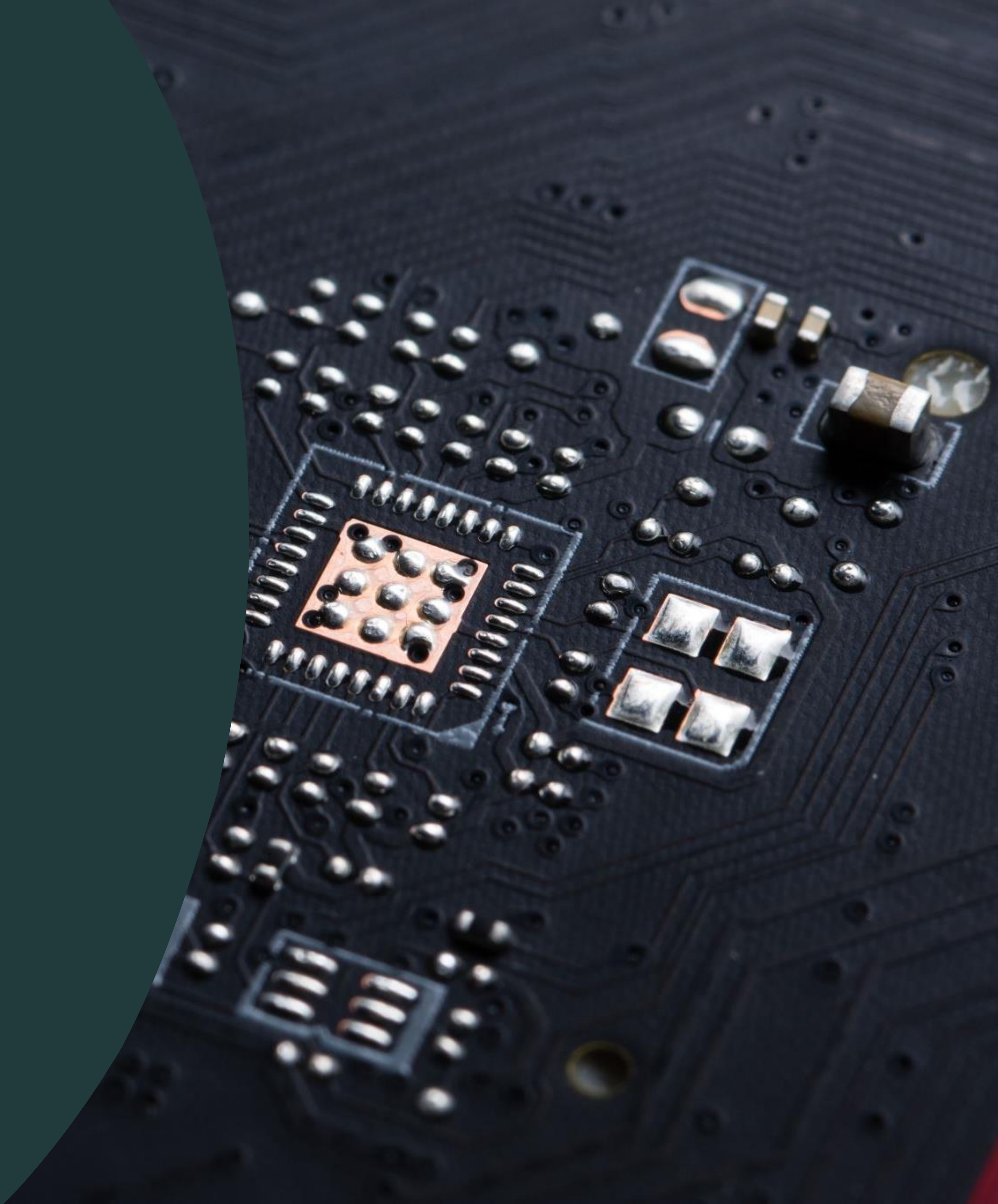
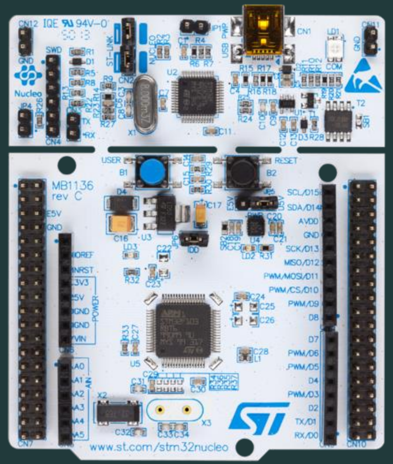
ST MICROELECTRONICS

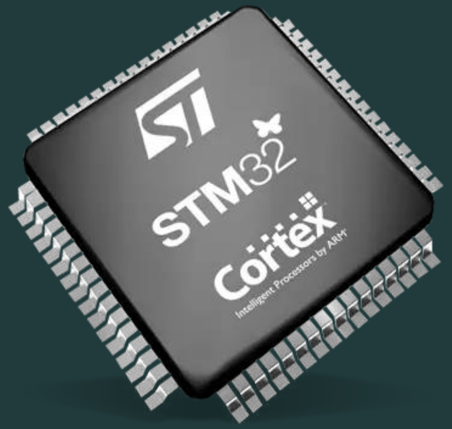
STM32 & ST Nucleo



What are STM32s and ST Cores?

- STM32s are a family of microcontrollers manufactured by ST Microelectronics.
- They are based on the ARM Cortex-M architecture
- ST Nucleos are DEVELOPMENT boards developed and supplied by ST
- Typically a circuit developed with ST Nucleo is designed and programmed, then the prototype PCB design is created





Where are STM32s being used?

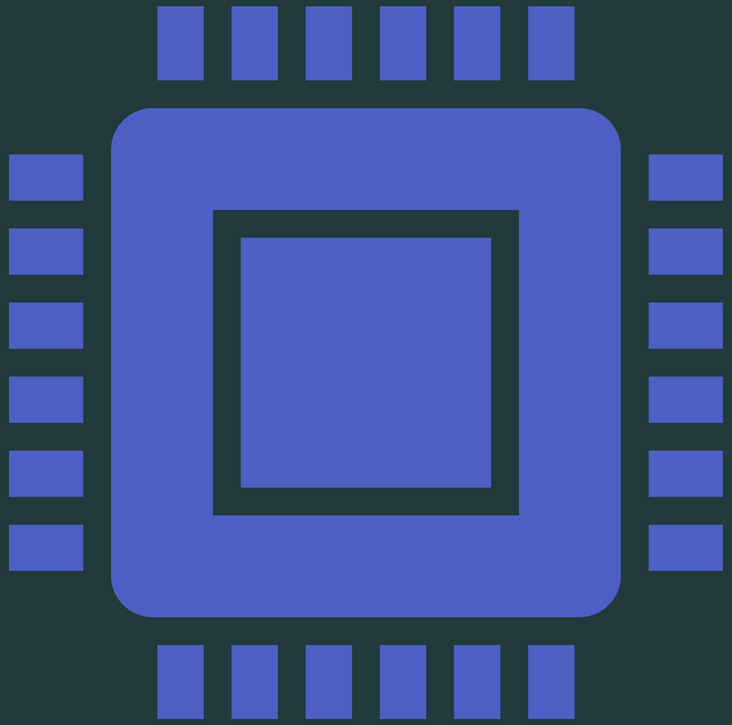
Typically, STM32s are used in industry. Some examples of industries may be:

- Industrial Automation
- Consumer Electronics
- Automotive
- Medical Industry
- Energy and Energy Management
- Aerospace and Defense
- Power Electronics
- Instrumentation and Measurement

SUPPORTED PROTOCOLS

STM32 microcontrollers support:

- I2C
- SPI
- CAN/CAN-FD
- UART
- LIN
- MODBUS
- RS485
- SDIO
- ecc …



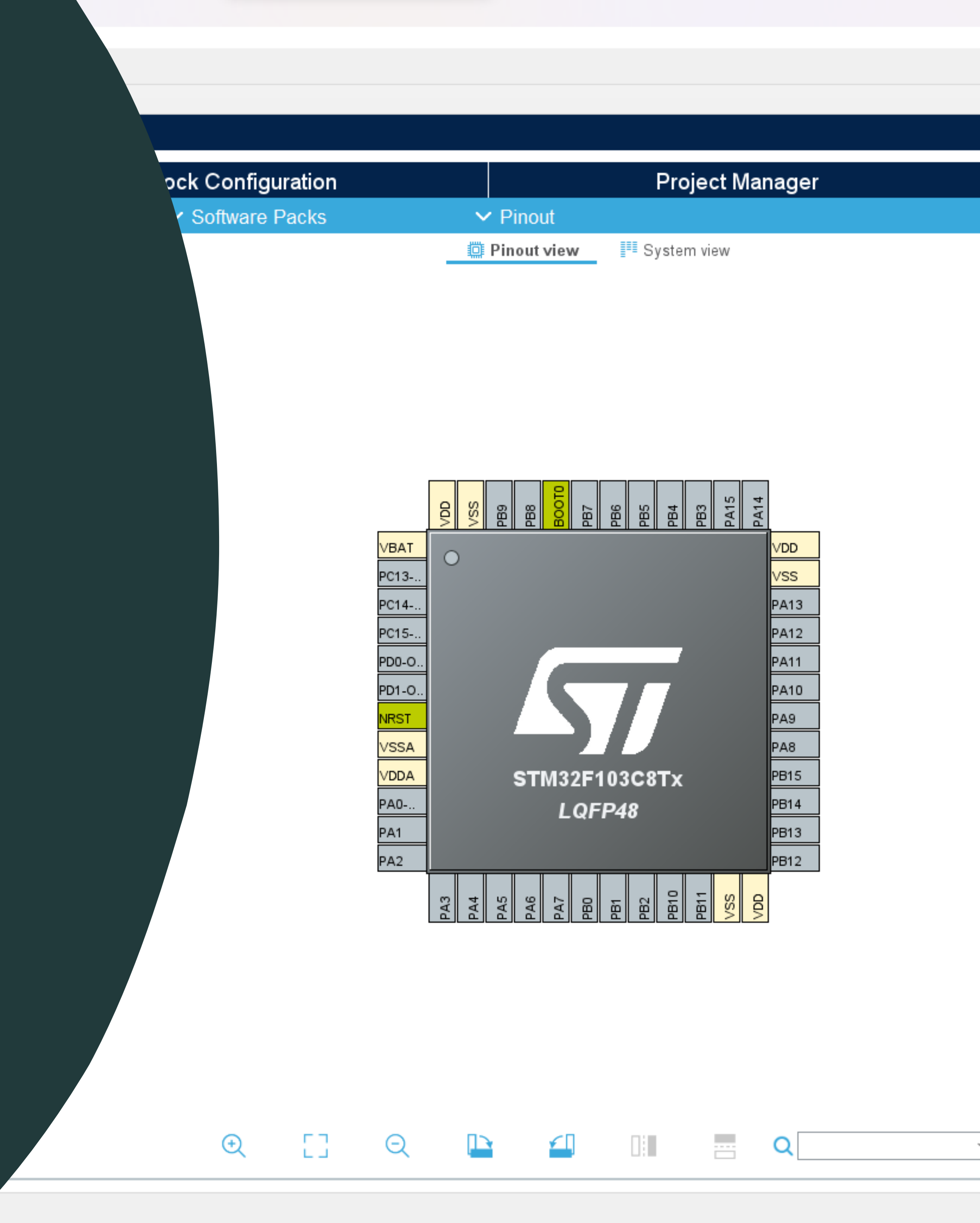
WHY DON'T WE USE STM32 INSTEAD OF ARDUINO?

The development environment is designed to meet the needs of the industry.

Some problems for inexperienced students may be:

- Knowing how to consult the datasheets of a microcontroller
- Defining the layout of the pins to be used
- Working at 3.3V, and not 5V
- Low-level programming of the tools provided by the micro

It is not an easy environment, so Arduino is an excellent starting point for building the experience needed to understand the ST ecosystem.



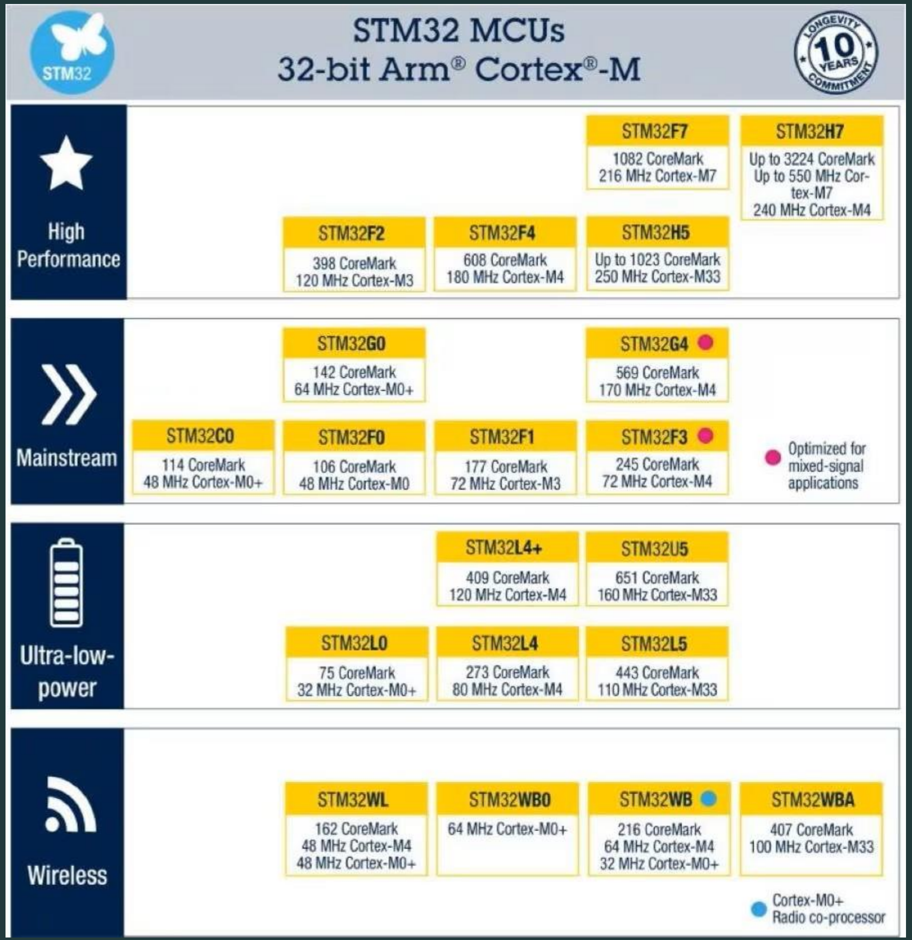
HOW DOES ST MICROELECTRONICS' ECOSYSTEM WORK?

NOMENCLATURE (1)

ST manufactures microcontrollers for a variety of industries.

An example of a microcontroller identifier might be:

"STM32F103C8T6"



Nomenclature (2)

The identification code of the microcontroller gives us so much information regarding what it can offer us

"**ST | M | 32 | F | 103 | C8 | T6**"

ST: indicates the **manufacturer**

M: indicates that the microcontroller is an **ARM Cortex M**

32: indicates that the microcontroller works in **32 bits**

NOMENCLATURE (3)

«**ST | M | 32 | F | 103 | C8 | T6**»

The classes:

- **F**: Full-Featured
- **L**: Low Power
- **H**: High Performance
- **G**: Motor control and power drives
- **W**: Wireless Microcontrollers
- **MP1**: Embedded Linux Applications
- **U**: Ultra-Low Power
- **B**: Security and Encryption
- **X**: Specific Application Microcontrollers (encryption, security, ecc…)
- **C**: Automotive

NOMENCLATURE (4)

«ST | M | 32 | F | 103 | C8 | T6»

The remaining information in the microcontroller code indicates:

- XXX (103): identifier of the microcontroller in that family (F in this case)
- XX (C8): additional identifier to distinguish microcontrollers of the same type but with different specifications (e.g., amount of memory, clock speed, etc...)
- XX (T6): package or enclosure type of the microcontroller (this is useful information for PCB design)

ST's microcontroller selector can be found here.

Development Environment

Different development environments can be used; we will use ST's:

- STM32CUBEIDE: https://www.st.com/en/development-tools/stm32cubeide.html

Others could be:

- Keil µVision: https://www.keil.com/download/
- Atollic TRUESTUDIO: https://www.st.com/en/development-tools/truestudio.html
- IAR Embedded Workbench: https://www.iar.com/ewarm

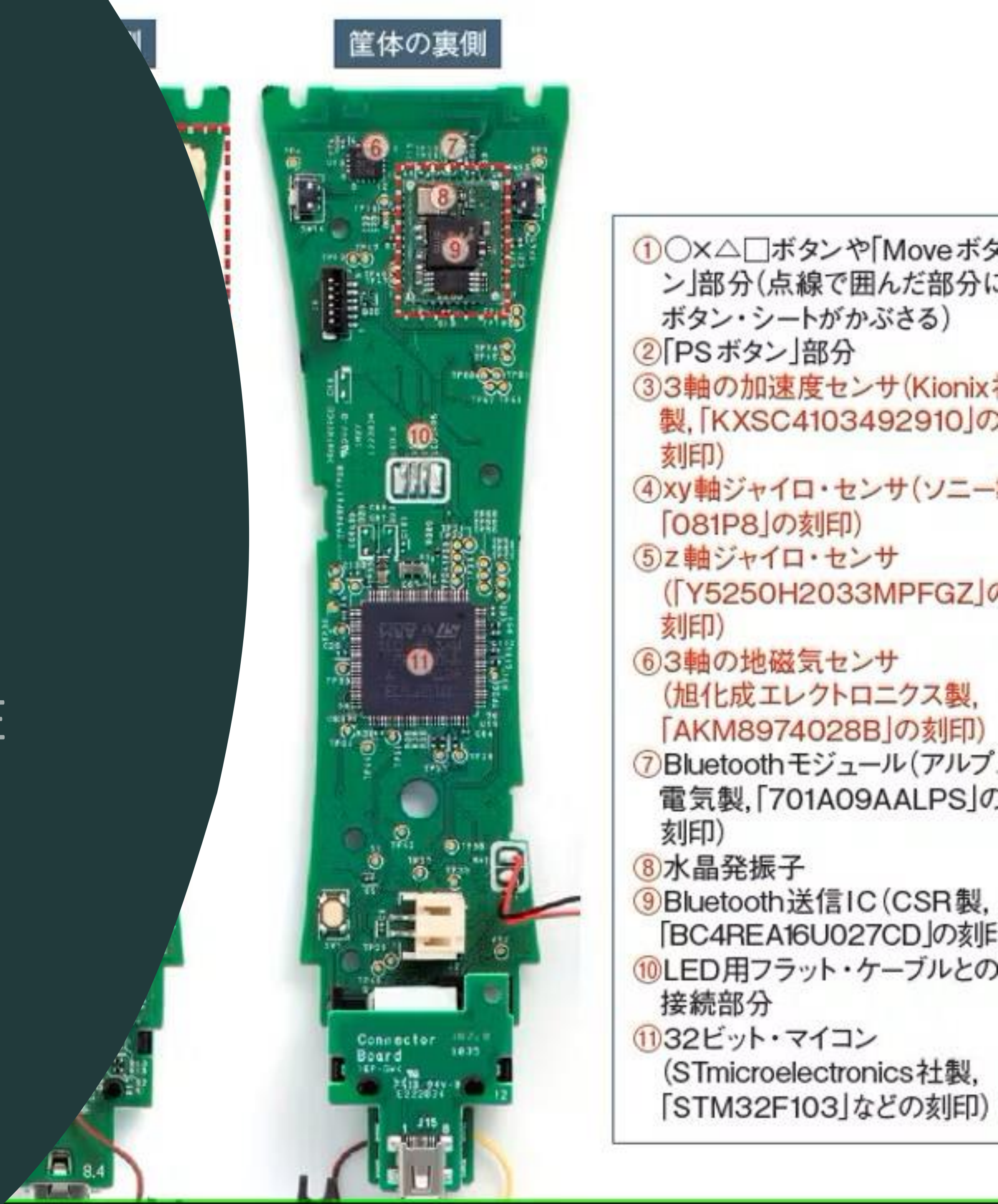
Often with third-party IDEs you also need to install:

- STM32CUBEMX: https://www.st.com/en/development-tools/stm32cubemx.html

Case Example: STM32F103C8T6

Alias “BluePill” used within the “MOVE MOTION” PlayStation 3 controller

Available here with STLink



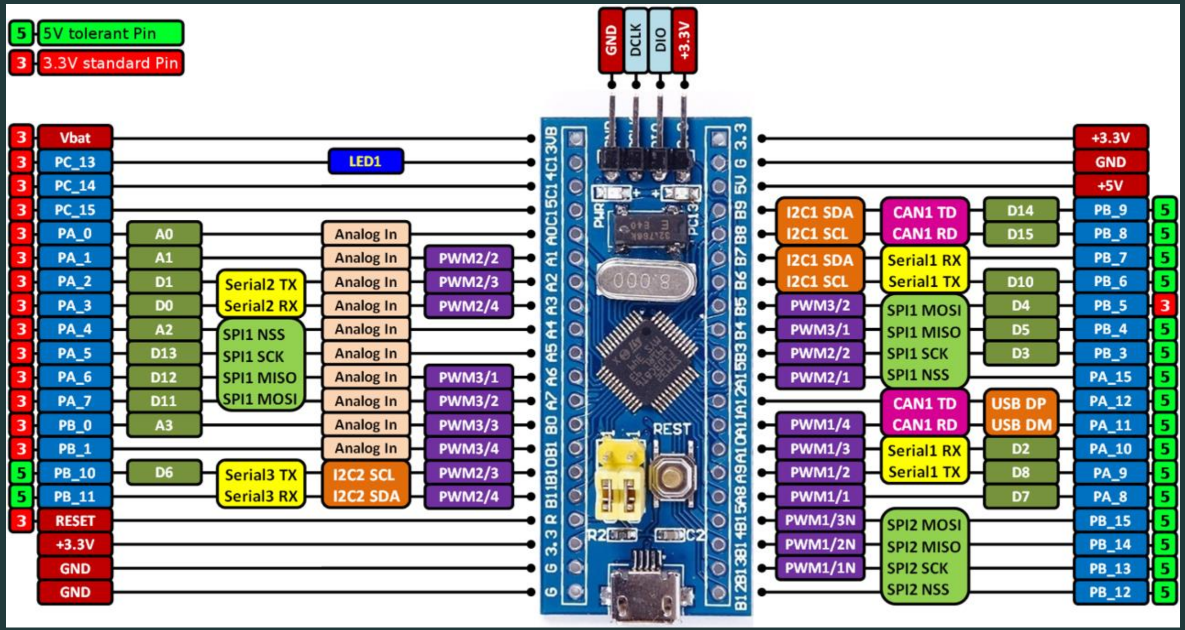
STM32F103C8T6 PINOUT

Each board has its own PinOut, and each peripheral can have outputs on different pins

!Tip: search on google

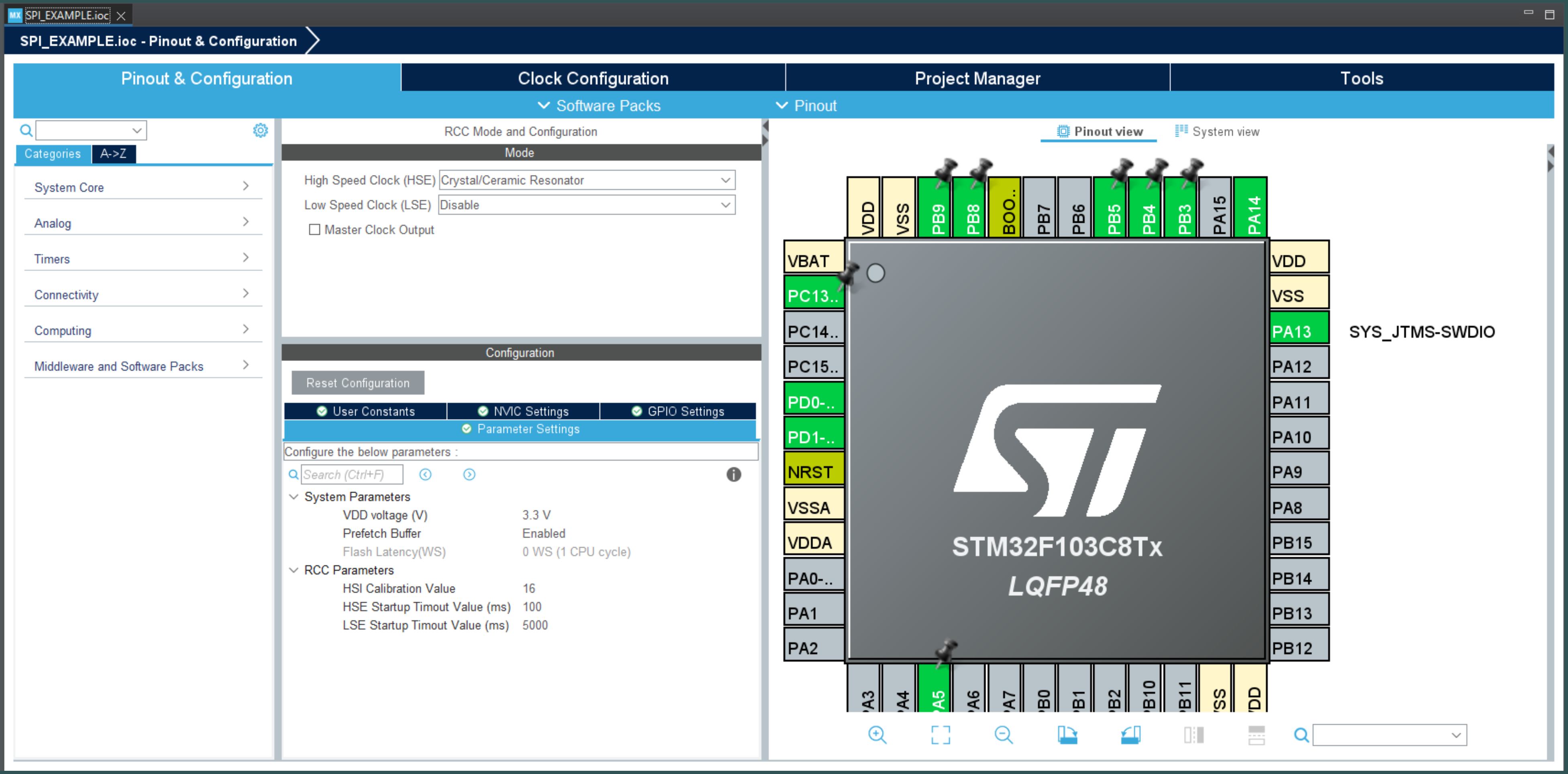
"board_name PinOut mbed"

At MBED website you can find the pinout of different classical STM32 boards (such as STM32F401RE)



STM32 CUBE IDE: IOC

- Here you can configure GPIO, Communication ports, Timers, RCC and so on.
- By saving this configuration (ctrl+S), the code will be generated



STM32 CLOCK CONFIGURATION

- You must tweak manually the clock sources and prescalers
- A simpler way to set the clock is to set the preferred frequency in HCLK and then manually tweak the APBx prescalers if needed

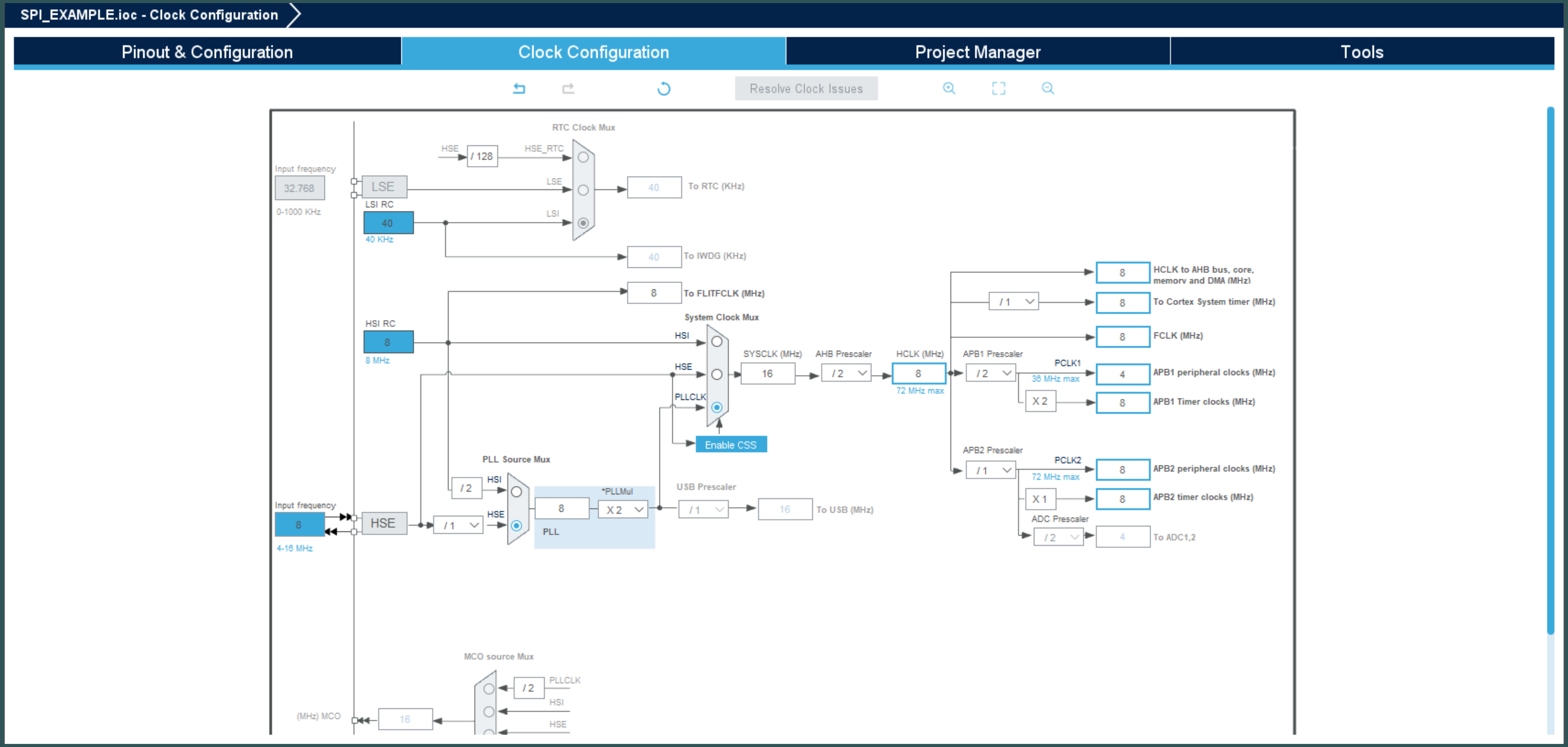
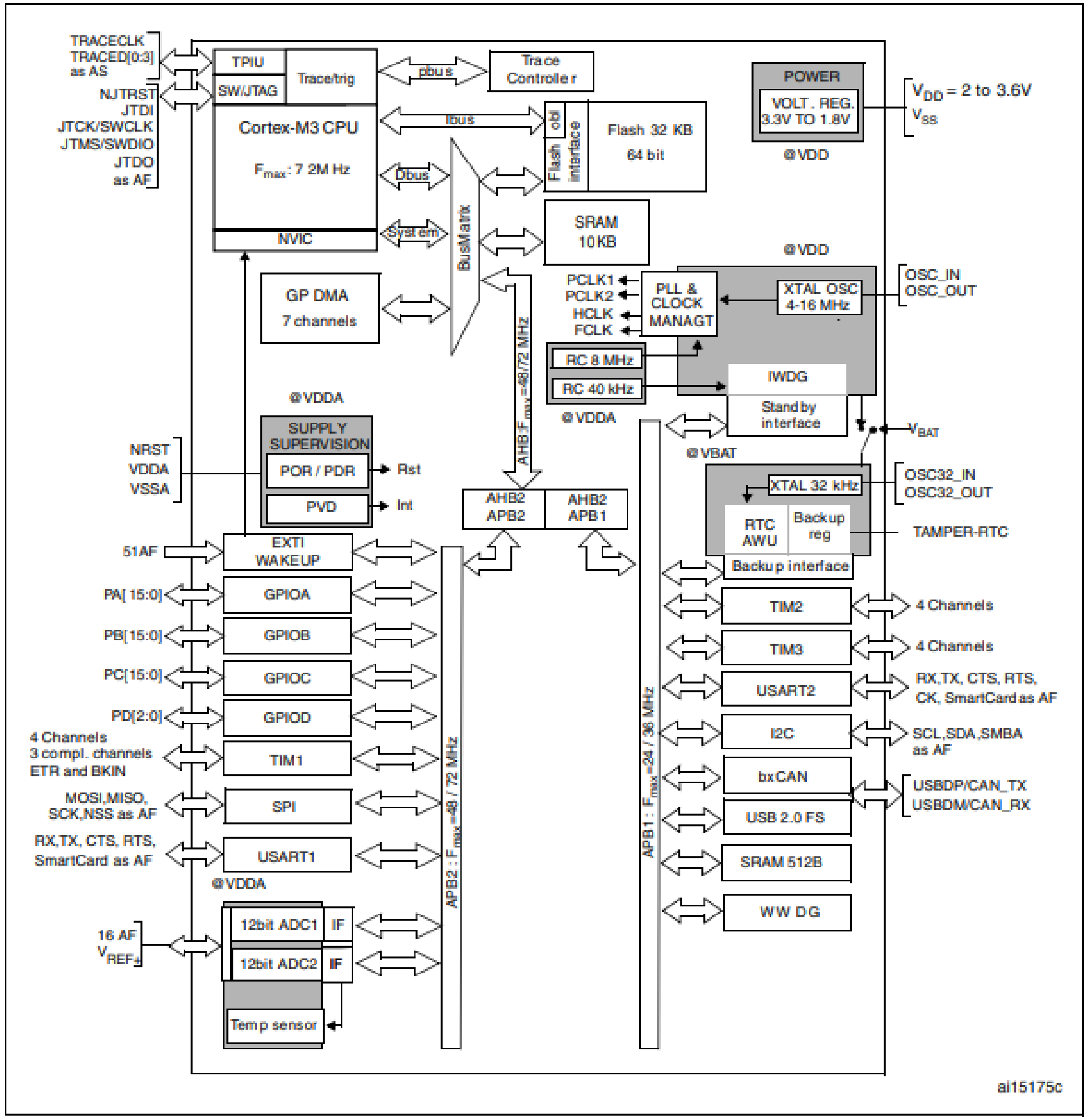


Figure 1. STM32F103xx performance line block diagram

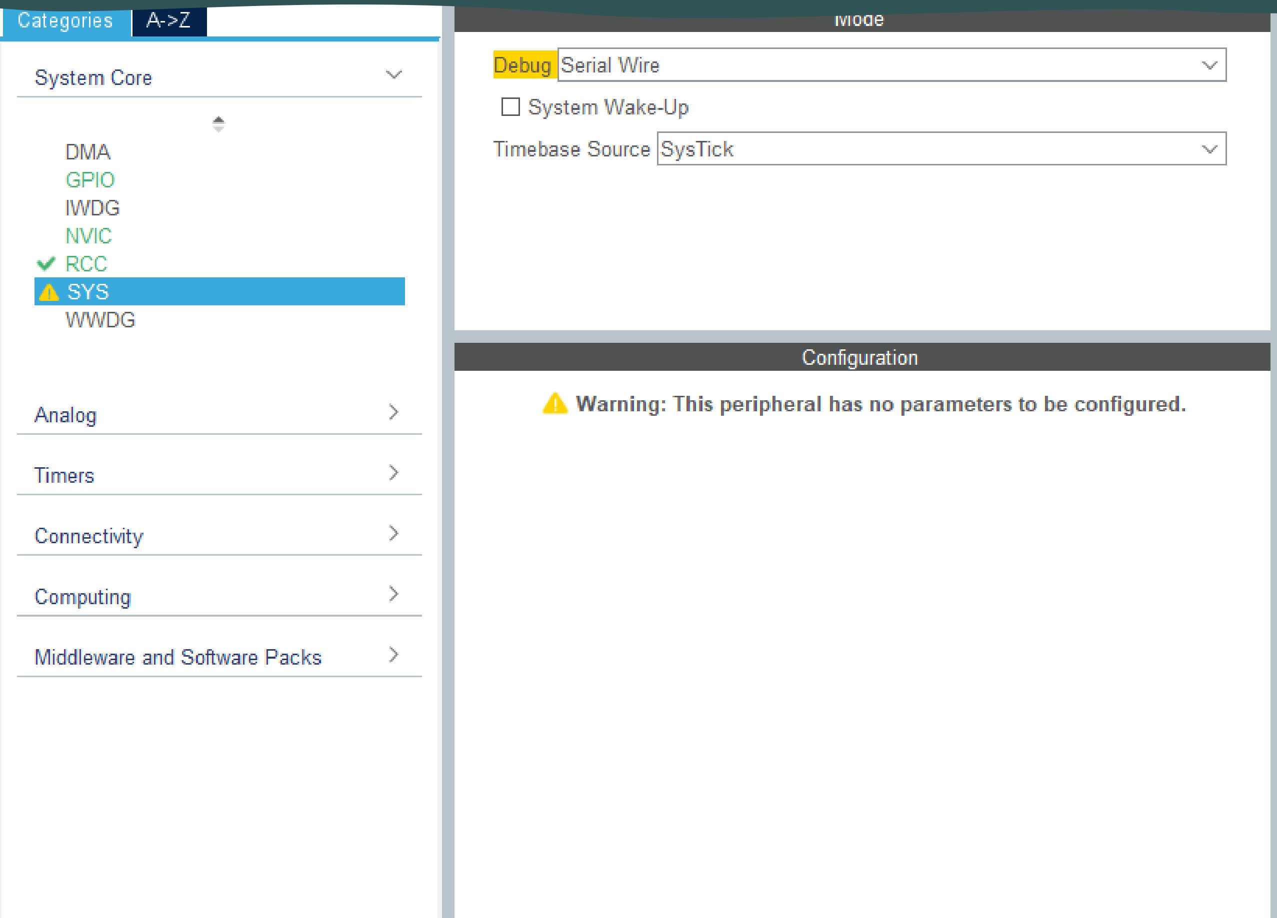


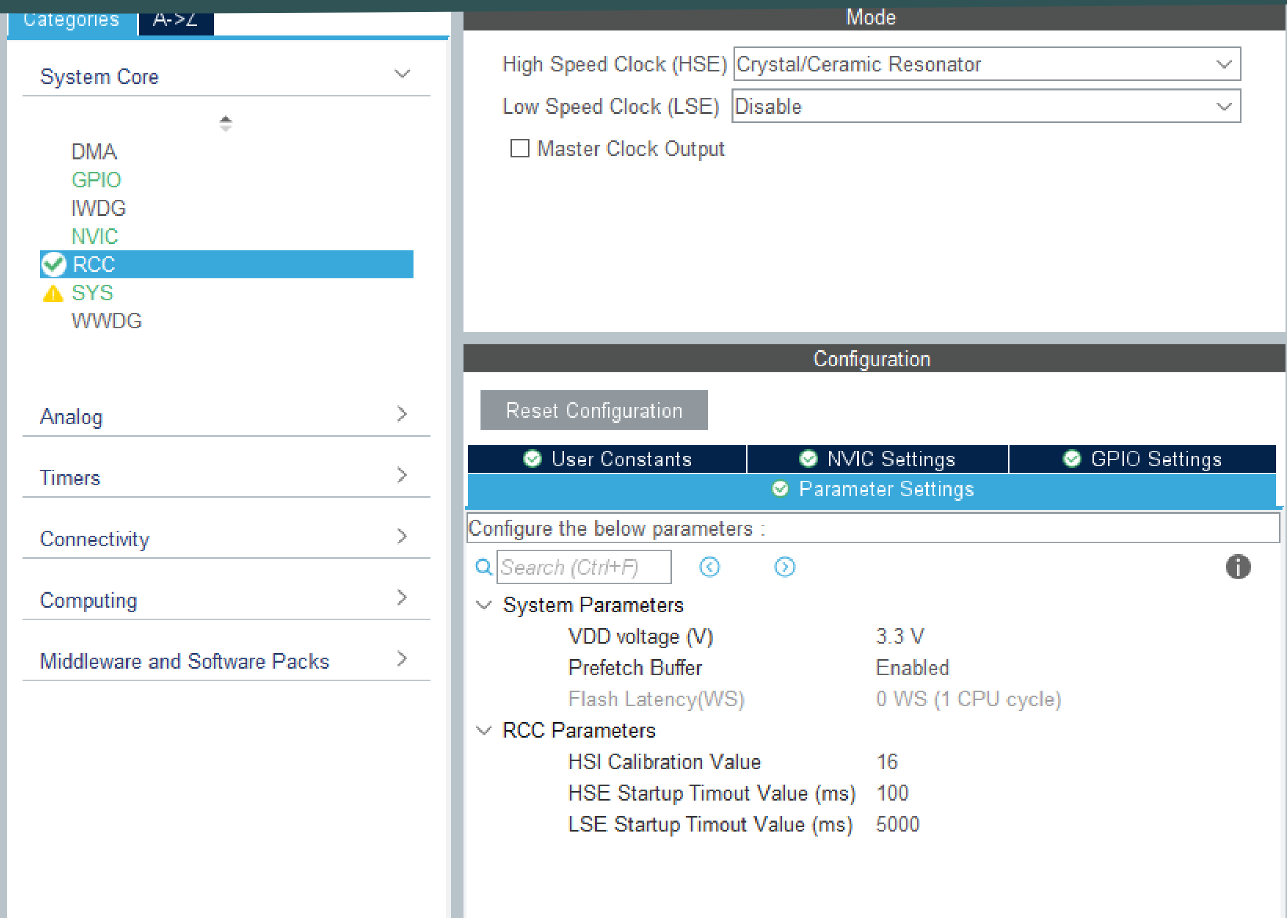
FREQUENCY OF PERIPHERAL DEVICES

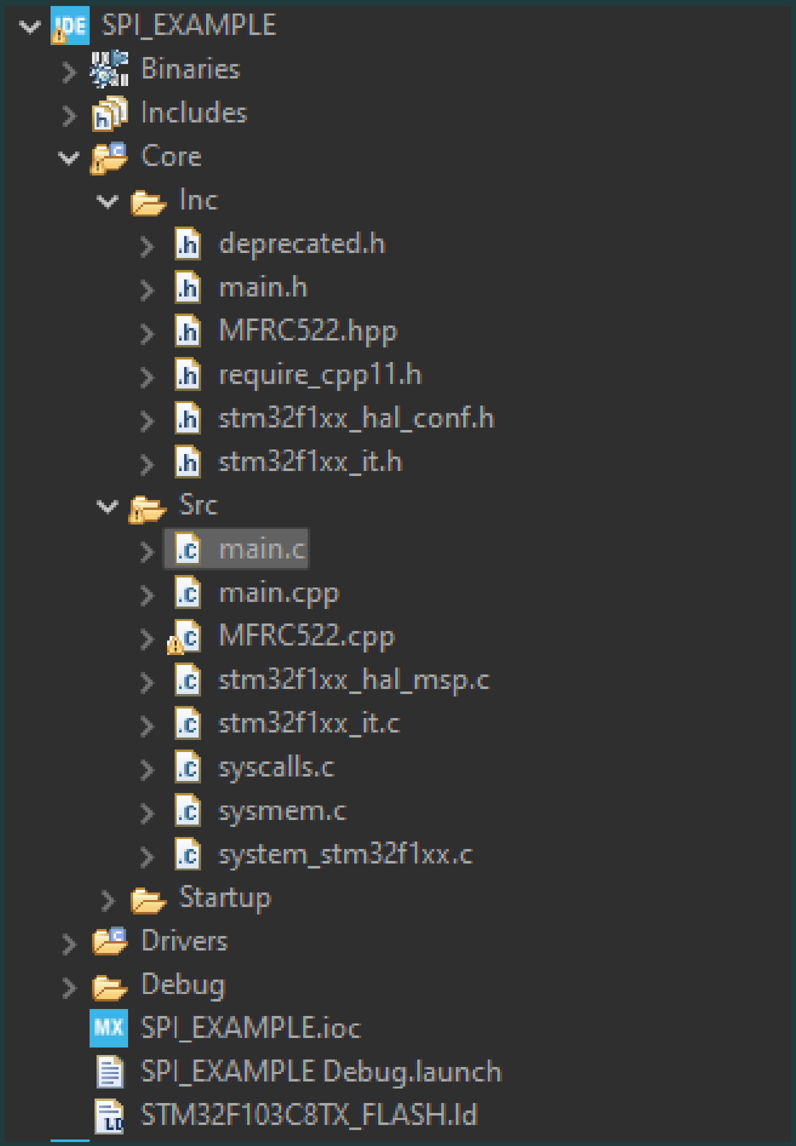
- You can find the bus configuration within the datasheets.
- i.e. if you have to set the frequency of HSPI1 to 4 MHz, and you have set your HCLK to 64MHz, you should use a prescaler of 16.
- If you want to communicate with an external device you have to check the protocol details on its datasheets

MANDATORY SETTINGS

- In RCC you must select a clock source
- In SYS you have to set the communication between the PC and the Micro (tipically through the ST-Link)







STM32 PROJECT

- In Core/Inc you can find header files
- In Core/Src you can find .c files
- You can choose to program in C++ during project creation (beginning). Here you have to change main.c to main.cpp
- Many of the files you see here al specific libraries generated for the STM32f103
- Debug contains the builded files

MAIN

- Programming an STM32 is closer to the classical C programming rather than the Arduino env
- HAL is the main library for STM32, here you can find all directives for controlling your micro
- The void loop actually is a while true
- Never put a return within whe infinite loop! If you have to stop the computation just use another while(1)
- You **MUST** place your code in specific sections (USER CODE BEGIN --- USER CODE END)

```c
int main(void)
{
  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */

  /* MCU Configuration--------------------------------------------------------*/

  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();

  /* USER CODE BEGIN Init */

  /* USER CODE END Init */

  /* Configure the system clock */
  SystemClock_Config();

  /* USER CODE BEGIN SysInit */

  /* USER CODE END SysInit */

  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  MX_SPI1_Init();
  /* USER CODE BEGIN 2 */

  /* USER CODE END 2 */

  /* Infinite loop */
  /* USER CODE BEGIN WHILE */
  while (1)
  {
```

```c
  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();

  /* USER CODE BEGIN Init */

  /* USER CODE END Init */

  /* Configure the system clock */
  SystemClock_Config();

  /* USER CODE BEGIN SysInit */

  /* USER CODE END SysInit */

  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  MX_SPI1_Init();
  /* USER CODE BEGIN 2 */

  /* USER CODE END 2 */

  /* Infinite loop */
  /* USER CODE BEGIN WHILE */
  while (1)
  {

    /* USER CODE END WHILE */

    /* USER CODE BEGIN 3 */
  }
  /* USER CODE END 3 */
```

SPECULAR IOC SETTINGS

- The stuff you set within the IOC is then implemented within the main, at the bottom. So you could also edit your settings here

```c
static void MX_SPI1_Init(void)
{

  /* USER CODE BEGIN SPI1_Init 0 */

  /* USER CODE END SPI1_Init 0 */

  /* USER CODE BEGIN SPI1_Init 1 */

  /* USER CODE END SPI1_Init 1 */
  /* SPI1 parameter configuration*/
  hspi1.Instance = SPI1;
  hspi1.Init.Mode = SPI_MODE_MASTER;
  hspi1.Init.Direction = SPI_DIRECTION_2LINES;
  hspi1.Init.DataSize = SPI_DATASIZE_8BIT;
  hspi1.Init.CLKPolarity = SPI_POLARITY_LOW;
  hspi1.Init.CLKPhase = SPI_PHASE_1EDGE;
  hspi1.Init.NSS = SPI_NSS_SOFT;
  hspi1.Init.BaudRatePrescaler = SPI_BAUDRATEPRESCALER_2;
  hspi1.Init.FirstBit = SPI_FIRSTBIT_MSB;
  hspi1.Init.TIMode = SPI_TIMODE_DISABLE;
  hspi1.Init.CRCCalculation = SPI_CRCCALCULATION_DISABLE;
  hspi1.Init.CRCPolynomial = 10;
  if (HAL_SPI_Init(&hspi1) != HAL_OK)
  {
    Error_Handler();
  }
```

```c
void SystemClock_Config(void)
{
  RCC_OscInitTypeDef RCC_OscInitStruct = {0};
  RCC_ClkInitTypeDef RCC_ClkInitStruct = {0};

  /** Initializes the RCC Oscillators according to the specified parameters
  * in the RCC_OscInitTypeDef structure.
  */
  RCC_OscInitStruct.OscillatorType = RCC_OSCILLATORTYPE_HSE;
  RCC_OscInitStruct.HSEState = RCC_HSE_ON;
  RCC_OscInitStruct.HSEPredivValue = RCC_HSE_PREDIV_DIV1;
  RCC_OscInitStruct.HSIState = RCC_HSI_ON;
  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_ON;
  RCC_OscInitStruct.PLL.PLLSource = RCC_PLLSOURCE_HSE;
  RCC_OscInitStruct.PLL.PLLMUL = RCC_PLL_MUL2;
  if (HAL_RCC_OscConfig(&RCC_OscInitStruct) != HAL_OK)
  {
    Error_Handler();
  }

  /** Initializes the CPU, AHB and APB buses clocks
  */
  RCC_ClkInitStruct.ClockType = RCC_CLOCKTYPE_HCLK|RCC_CLOCKTYPE_SYSCLK
                              |RCC_CLOCKTYPE_PCLK1|RCC_CLOCKTYPE_PCLK2;
  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_PLLCLK;
  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV2;
  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV2;
  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV1;

  if (HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_0) != HAL_OK)
  {
    Error_Handler();
  }
}
```

Some Basic Functions

- HAL_Delay(100); -> set a delay of 100ms (same as delay(100))
- HAL_GPIO_WritePin(GPIO_Port, GPIO_Pin, GPIO_PIN_SET); -> digitalWrite(Pin, HIGH);
  - GPIO_PIN_SET = HIGH (1) – GPIO_PIN_RESET = LOW (0)
  - E.g. Pin=B1 -> GPIO_Port=GPIOB and GPIO_Pin=GPIO_PIN_1 (check main.h)
- GPIO_PinState state = HAL_GPIO_ReadPin(GPIO_Port, GPIO_Pin);

I Want to use SPI to communicate with an MFRC522, but the arduino library does not work. What should I do?

It is hard to find the same arduino library implemented also for an STM32, so you have to port it!

```
/**
 * Writes a uint8_t to the specified register in the MFRC522 chip.
 * The interface is described in the datasheet section 8.1.2.
 */
void MFRC522::PCD_WriteRegister(PCD_Register reg, uint8_t value) {

    HAL_GPIO_WritePin(CS_Port, CS, GPIO_PIN_RESET);
    // MSB == 0 is for writing. LSB is not used in address. Datasheet section 8.1.2.3.
    HAL_SPI_Transmit(hspi, (uint8_t *) &reg, sizeof(reg), HAL_MAX_DELAY);
    HAL_SPI_Transmit(hspi, &value, sizeof(value), HAL_MAX_DELAY);
    HAL_GPIO_WritePin(CS_Port, CS, GPIO_PIN_SET);
} // End PCD_WriteRegister()
```

```
void MFRC522::PCD_WriteRegister(        PCD_Register reg,       ///< The register to write to. One of the
                                                                    byte value                          /
                                                                ) {
        SPI.beginTransaction(SPISettings(MFRC522_SPICLOCK, MSBFIRST, SPI_MODE0));       // Set the settir
        digitalWrite(_chipSelectPin, LOW);              // Select slave
        SPI.transfer(reg);                                      // MSB == 0 is for writing. LSB i
        SPI.transfer(value);
        digitalWrite(_chipSelectPin, HIGH);             // Release slave again
        SPI.endTransaction(); // Stop using the SPI bus
} // End PCD_WriteRegister()
```

SO, WHY USING AN STM32

- Due to specific requirements:
  - ADC 12 bit, ease of peripherical frequency setting, more GPIO, more computational power
  - Code optimization due to low level API access
  - Specific pheripherical ports: CAN, RS485, …
  - Watchdog, interrupts, timers, DMA, …

IOT PROJECT TIPS

Environmental monitoring system: An environmental monitoring system can be used to measure environmental parameters such as temperature, humidity, air quality, or noise level. The collected data can be sent to a server for analysis or visualization. Use AI to predict these parameter for the following day/week

Home automation system: A home automation system can be used to control home devices such as lights, thermostats, and locks. Devices can be controlled manually or automatically based on certain events or conditions.

Security system: A security system can be used to monitor an area or building for intrusions or other unexpected events. The data collected can be sent to a cloud for analysis or triggering alarms.

Tracking system: A tracking system can be used to track the location of people entering and exiting a building. This scenario is very interesting in the industrial context. Estimate with AI the number of people within a building

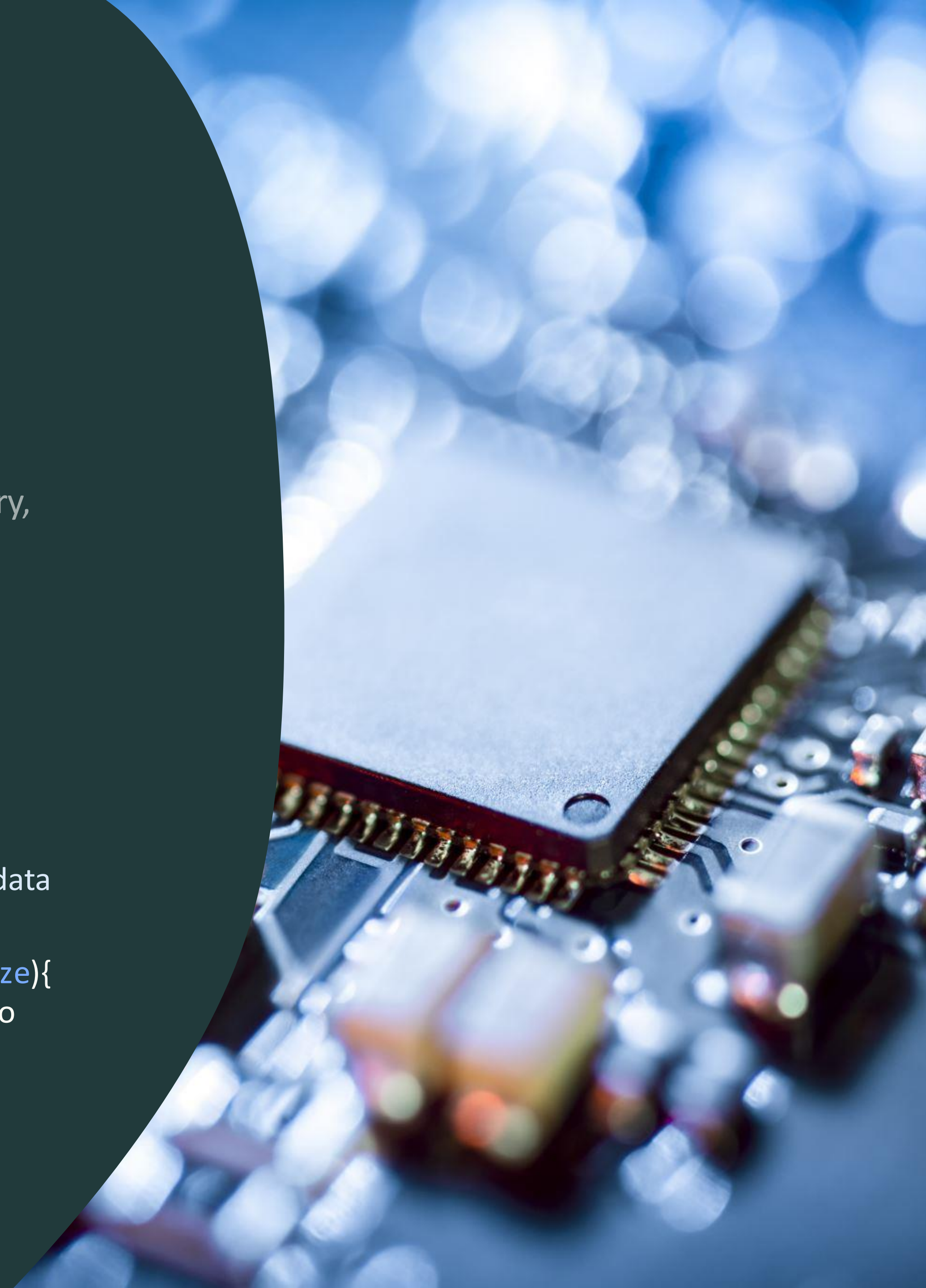
For PRO students: try to embed AI within the microcontroller

Extra: Interrupts

- An interrupt is a signal generated externally from the CPU stream, which warns about the occurrence of an event (e.g. data has arrived on a peripheral, a button has been pressed, and so on ...)
- In the STM32 IDE, interrupts are called NVICs.
- Example:
    - HAL_NVIC_SetPriority(EXTI9_5_IRQn, 0, 0);
    - HAL_NVIC_EnableIRQ(EXTI9_5_IRQn); -> we enable interrupts for pins between 5 and 9
    - EXTI->RTSR1 |= EXTI_RTSR1_RT9; -> we enable trigger on rising edge
    - void EXTI9_5_IRQHandler(void) {
        - if (EXTI->PR & EXTI_PR_PR9) {
            - EXTI->PR = EXTI_PR_PR9; -> After handling the interrupt, resets the PR register bit ... then do something ...

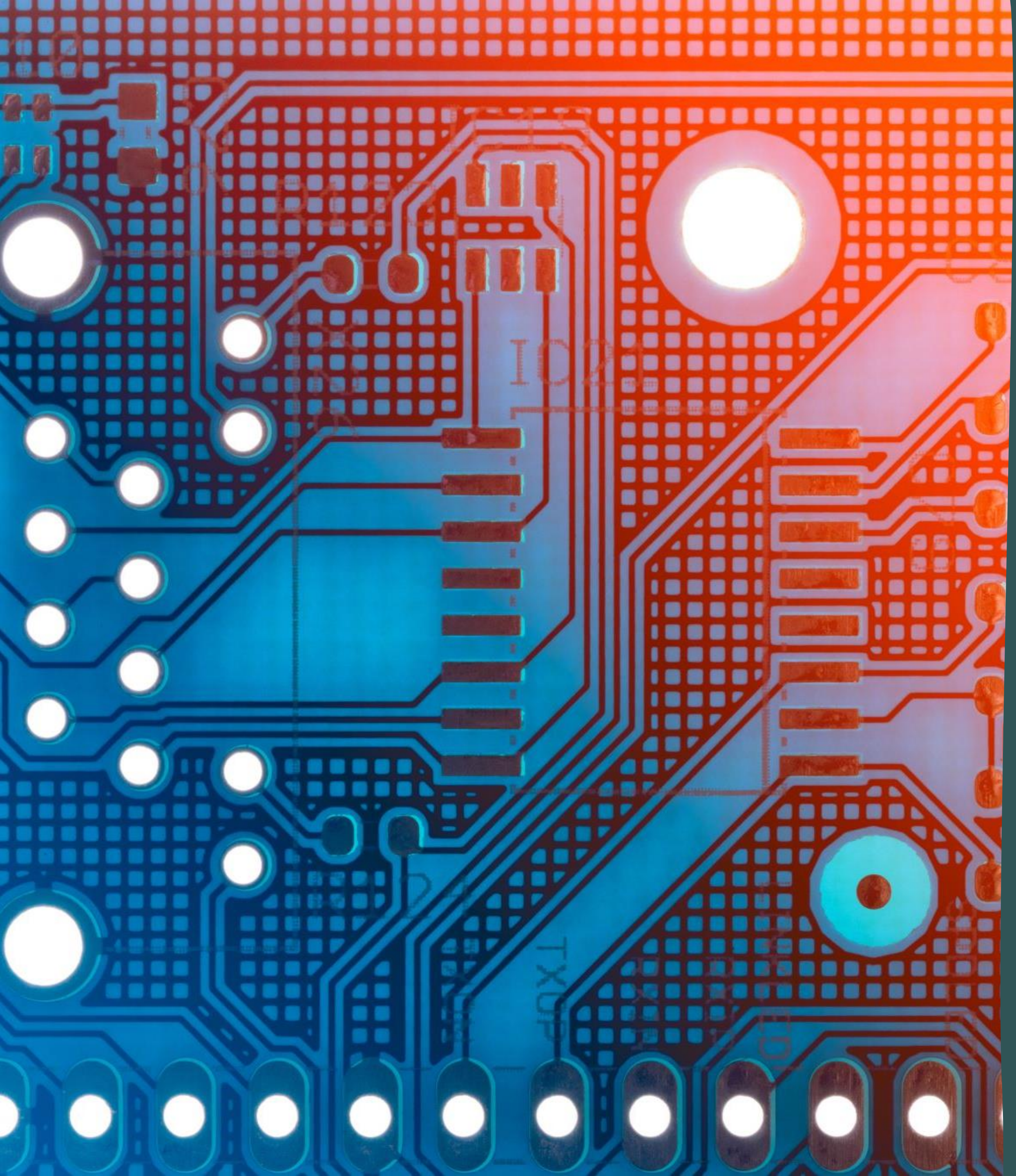
EXTRA: DIRECT MEMORY ACCESS (DMA)

- DMA is a mechanism that allows peripheral devices direct access to memory, without involving the CPU
- Example: we want to read some incoming data from the USART Port:
    - In USART1 -> DMA SETTINGS –> add USART1_RX in normal mode
    - Activate USART1 global interrupt
    - HAL_UARTEx_ReceiveToIdle_DMA(&huart1, (uint8_t*) rxbuffer, MAX_STRING_LENGTH); -> we set the DMA Buffer and its size
    - __HAL_DMA_DISABLE_IT(&hdma_usart1_rx, DMA_IT_HT); -> disable the half data transfer interrupt
    - void HAL_UARTEx_RxEventCallback(UART_HandleTypeDef *huart, uint16_t size){
        - if(huart->Instance == USART1){ … -> we define the DMA interrupt callback to read RX data



AI ON STM32


TensorFlow Lite
Keras
learn
ONNX
MATLAB
PyTorch
STM32
Cube.AI
Processing libraries
Model conversion
Code optimization
Memory optimization



HARDWARE LIMITATIONS

Deploying a Neural Network on a Microcontroller is not Trivial

- Up to a few KiloBytes of RAM
- Usually less than 1 MegaByte of Internal Storage
- Limited computational power
- Tipically, a floating point unit is not available

SOFTWARE LIMITATIONS

- Do I need a specific C/C++ library for running my model on the Microcontroller?
- How do I load the model within the Microcontroller?
- The model does not fit in the Microcontroller's memory, how can I reduce its size?

Open Neural Network Exchange

- It is recommended to watch this video
- ONNX is an open format built to represent machine learning models.
- Neural Network built upon different frameworks (such as PyTorch, Tensorflow, etc.) can be exported to this format
- It is useful when we want to optimize our network for a specific hardware platform

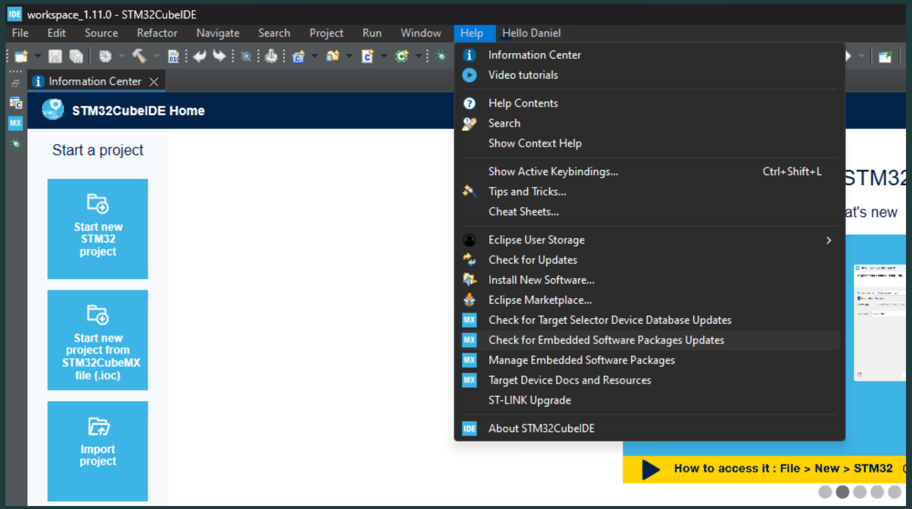
IT IS WORTH TO GIVE IT A LOOK

These are the main ONNX supporters!

ONNX FOR STM32

On an STM32 Microcontroller it is possible to upload the following models:

- Tensorflow light
- Keras
- ONNX

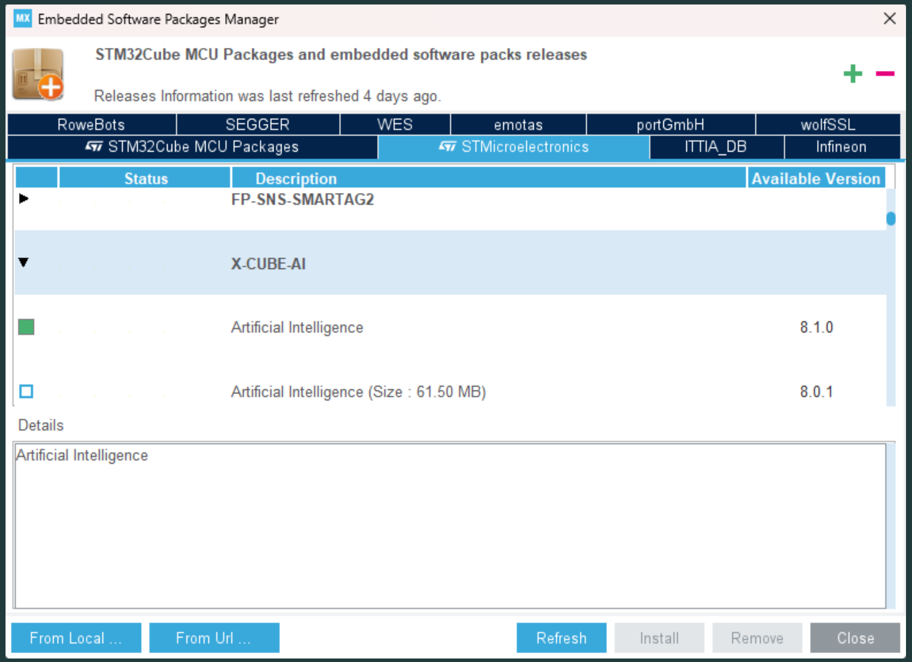


You can proceed by installing STM32CubeAI extension within your IDE

Click on: Help -> Check for Embedded Software Packages Updates

STM32 X-CUBE-AI

- Proceed by installing X-CUBE-AI extension for STM32 CUBE IDE
- This is an ST toolkit useful to load and run AI models within a microcontroller



SinNet: An Application Example for AI on STM32

- Here we have SinNet, a Feed-Forward Neural Network which tries to approximate the Sin function
- **Hidden_size**: number of hidden neurons (256 is enough)
- **Batch Normalization**: helps to converge faster (normalizes the input data before feeding them to the following layer)
- **Dropout**: regularization is necessary to prevent overfitting (small network = small regularization)
- **Tanh activation**: we need to propagate gradient also for negative values (x in [0, 2pi]; Sin(x) in [-1,1])

SinNet.py

```python
import torch
from torch import nn


class SinNet(nn.Module):
    def __init__(self, hidden_size: int= 1024, p_dropout=0.35) -> None:
        super(SinNet, self).__init__()
        self.hidden_size = hidden_size
        self.p_dropout = p_dropout

        self.input_layer = nn.Linear(1, self.hidden_size)
        self.hidden_layer = nn.Linear(self.hidden_size, self.hidden_size)
        self.output_layer = nn.Linear(self.hidden_size, 1)

        self.activation = nn.Tanh()

        self.network = nn.Sequential(
            self.input_layer,
            self.activation,
            nn.Dropout(self.p_dropout),

            nn.BatchNorm1d(self.hidden_size),
            self.hidden_layer,
            self.activation,
            nn.Dropout(self.p_dropout),

            nn.BatchNorm1d(self.hidden_size),
            self.output_layer,
            self.activation,
        )

    def forward(self, x: torch.Tensor) -> torch.Tensor:
        x = self.network(x)
        return x
```

What to do after storing NN weights? (Quantization)

- In order to fit the model on an STM32, we need to reduce its size!
- Quantizations means changing the resolution of the network's weights
  - Tipically, a network works with Float (32 bit) data and variables (let's say we have a 4KB model)
  - One way to reduce the model's size could be using 16/8 bit data and variables (16 bit means 2KB, 8 bit means 1KB)
  - This is a practical example of weights quantization (This is not the only solution)
- Quantization can be done through ONNX

QUANTIZATION

- For this example we will use 8 bit Uint quantization
- Weights and activation functions will be represented with 8 bit
- Remember that it is not true to say that quantization reduces the accuracy!

  Rarely it is possible to obtain a better accuracy since quantization is also a way to reduce overfitting
- On the other hand, it is also not true that quantized models are faster, this depends upon the underlying Hardware

ONNX Model Conversion

- Before applying ONNX quantization, we must convert the model from a PyTorch representation to an ONNX representation

```python
def convert_to_onnx(train_outputs: dict, args: argparse.Namespace) -> None:
    print("\nConverting model to ONNX format")

    model = train_outputs["model"] # pytorch float32 model
    model.train(False)
    model.to("cpu")

    calibration_set = torch.randn(args.batch_size, 1, requires_grad=True).to("cpu")

    onnx_model_path = os.path.join(train_outputs["run_path"], "model.onnx")
    torch.onnx.export(model,                     # model being run
                      calibration_set,           # model input (or a tuple for multiple inputs)
                      onnx_model_path,           # where to save the model (can be a file or file-like object)
                      export_params=True,        # store the trained parameter weights inside the model file
                      opset_version=17,          # the ONNX version to export the model to
                      do_constant_folding=True,  # whether to execute constant folding for optimization
                      input_names = ['input'],   # the model's input names
                      output_names = ['output'], # the model's output names
                      dynamic_axes={'input' : {0 : 'batch_size'},    # variable length axes
                                    'output' : {0 : 'batch_size'}},
                      )


    onnx_model = onnx.load(onnx_model_path)
    onnx.checker.check_model(onnx_model)
    train_outputs["onnx_model"] = onnx_model

    test_onnx_model(model, onnx_model_path, ["CPUExecutionProvider"], train_outputs, args)
    print("Exported model has been tested with ONNXRuntime, and the result looks good!")
    print(f"ONNX model stored at {onnx_model_path}")
```

ONNX QUANTIZATION

- Quantization needs a calibration set in order to better estimate the weights and activations values
- It is possible to set different variable representation and to use different calibration methods
- The quantization results in a model that we can fit into an STM32

- .pth means PyTorch model while .onnx means ONNX model

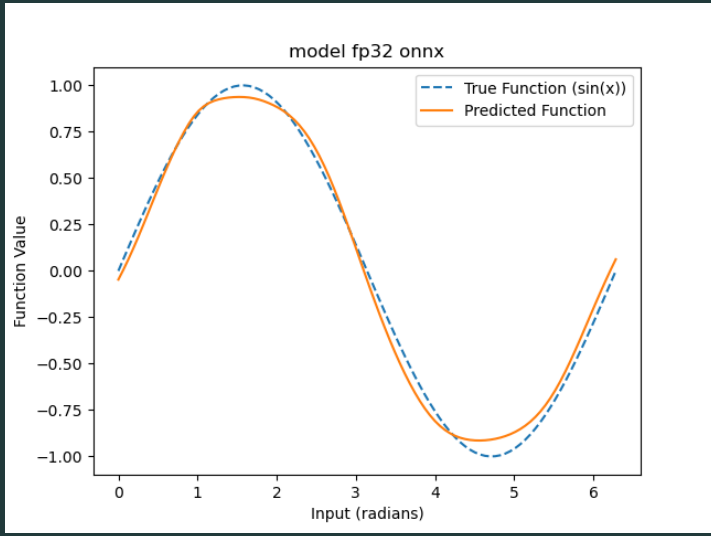
```
calibration_set = torch.rand(10**3).unsqueeze(1) * 2 * torch.pi
ort_session = onnxruntime.InferenceSession(model_fp32_path, providers=['CPUExecutionProvider'])
qdr = QuntizationDataReader(calibration_set,
                            batch_size=1,
                            input_name=ort_session.get_inputs()[0].name
                            )

quantization.shape_inference.quant_pre_process(model_fp32_path, model_prep_path)
q_static_opts = {
    "ActivationSymmetric":True,
    "WeightSymmetric":True
            }

model_int8_path = os.path.join(train_outputs["run_path"], 'model_int8.onnx')
quantized_onnxmodel = quantization.quantize_static(model_input=model_prep_path,
                                        model_output=model_int8_path,
                                        calibration_data_reader=qdr,
                                        extra_options=q_static_opts,
                                        weight_type=QuantType.QUInt8,
                                        activation_type=QuantType.QUInt8,
                                        calibrate_method=CalibrationMethod.MinMax
                                        )

onnx.checker.check_model(model_int8_path)
test_onnx_model(model, model_int8_path, ["CPUExecutionProvider"], train_outputs, args)
train_outputs["onnx_model_int8"] = quantized_onnxmodel

print("Quantization done!")
```

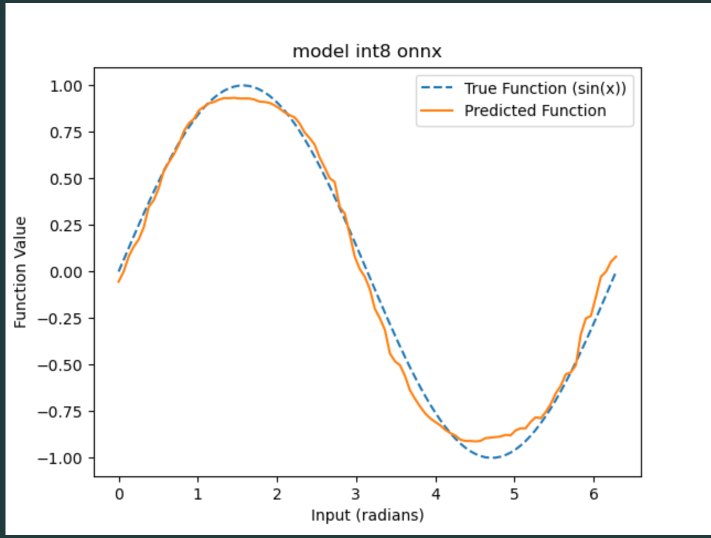
model_int8.onnx	05/12/2023 16:27	File ONNX	83 KB
model_int8.pth	05/12/2023 16:27	File PTH	169 KB
model.onnx	05/12/2023 16:27	File ONNX	270 KB
model_prep.onnx	05/12/2023 16:27	File ONNX	271 KB
model_fp32.pth	05/12/2023 16:26	File PTH	274 KB

Quantization Results

- From these results we can see that the quantized model is still pretty good in approximating the Sin function
- To obtain a better quantized model we could increase the number of neurons (or just spend more time on testing different hyperparameters)

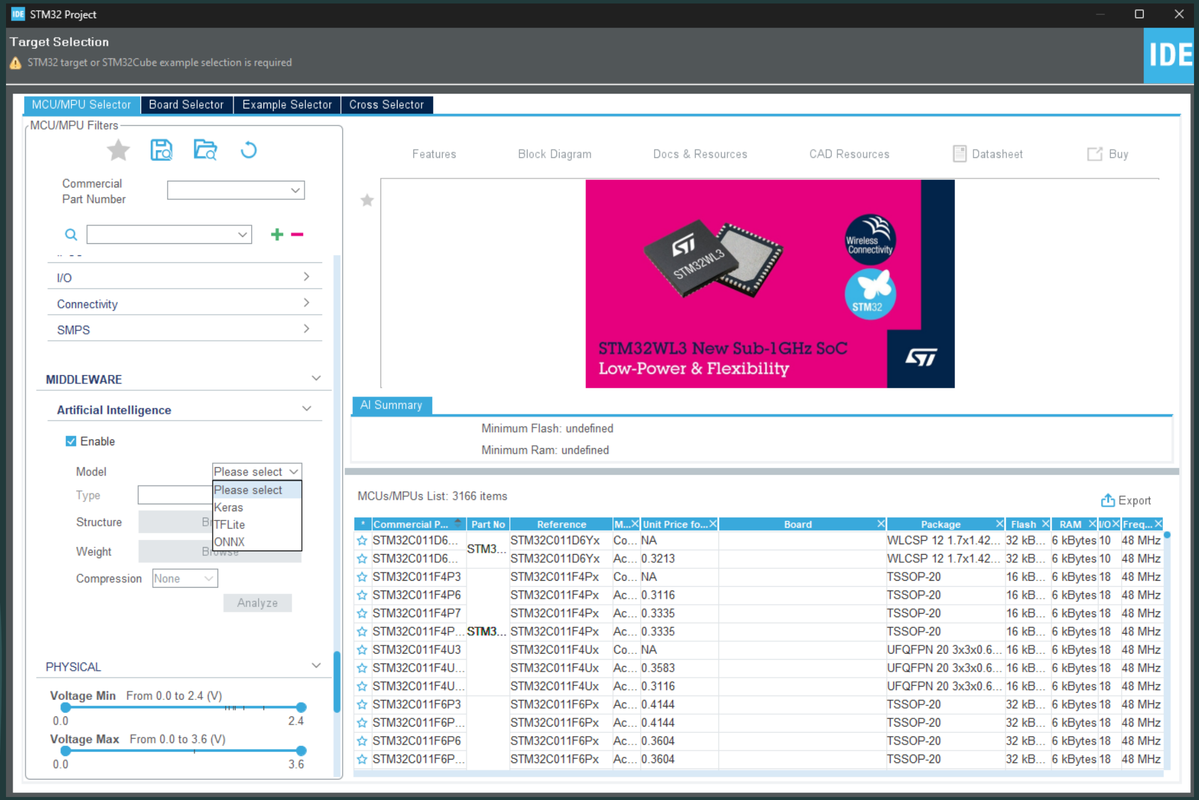
- But, consider that this model fits on a cheap STM32F401RE





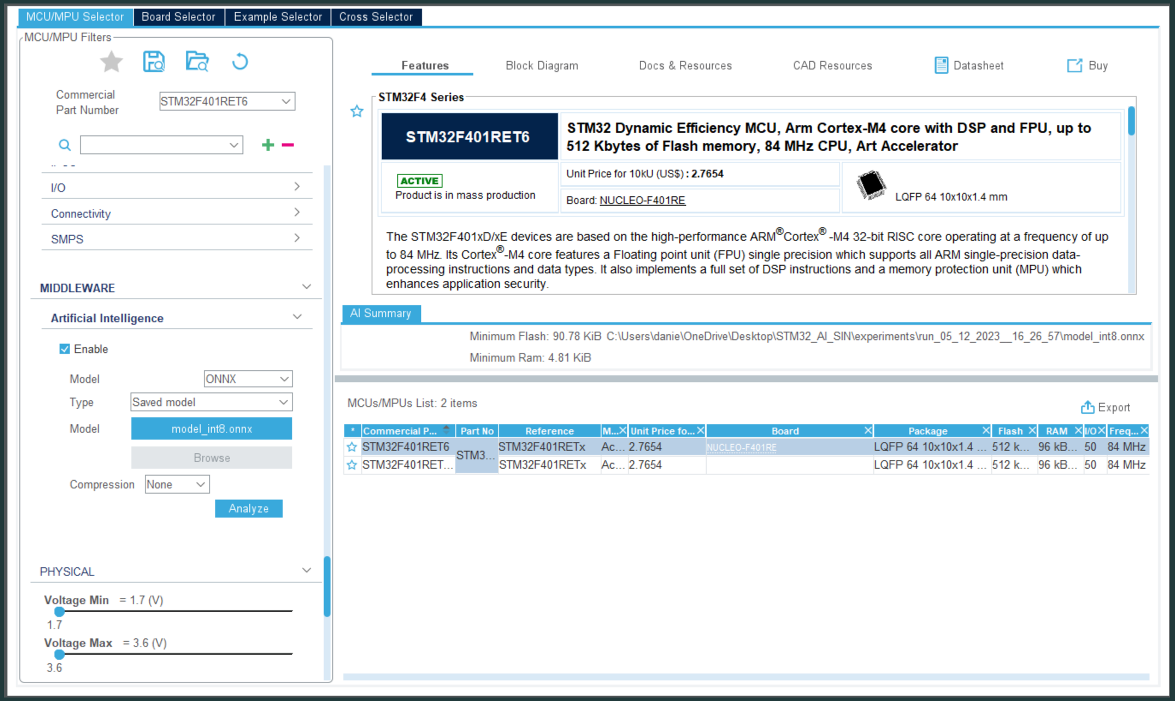
LOADING THE MODEL ON AN STM32

- Create a new project, scroll down to reach "Artificial Intelligence"
- On "model" select ONNX
- Load the model's weights (in this case model_int8.onnx)
- Try not to apply further compression
- Finally, click on "Analyze"



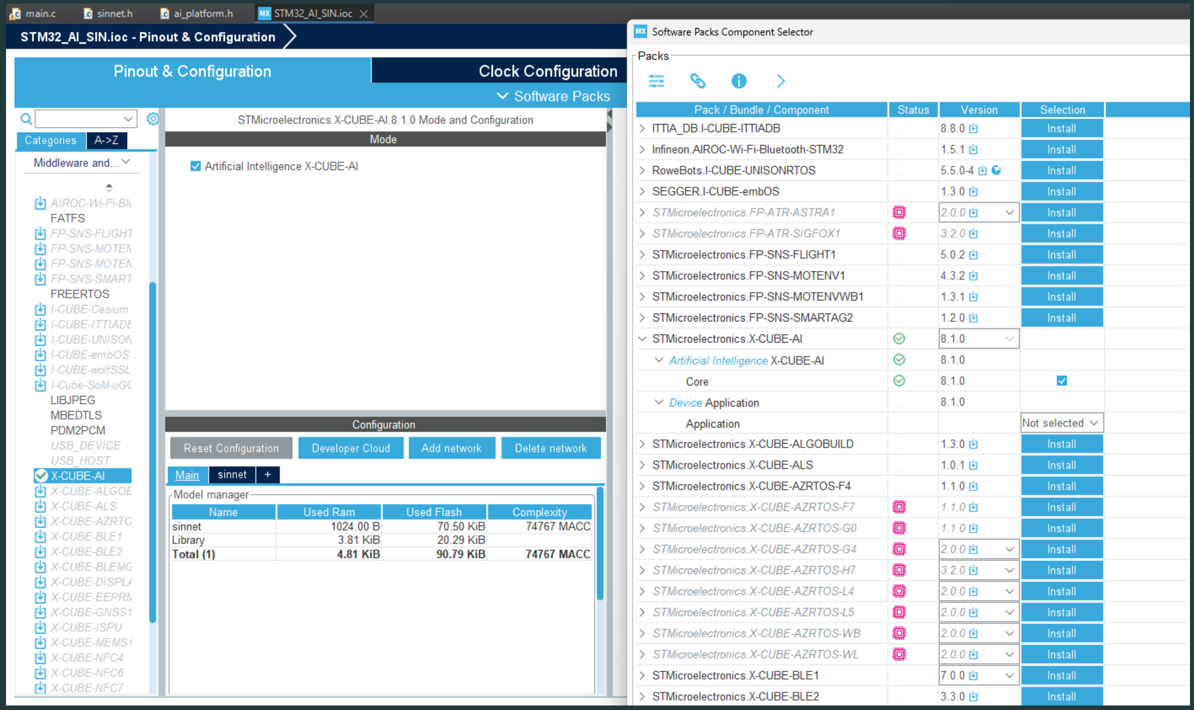
Choose your microcontroller

- Select the board you want to use and check if it supports the model
- If it is not supported:
    - Change microcontroller
    - Try to reduce the model's size



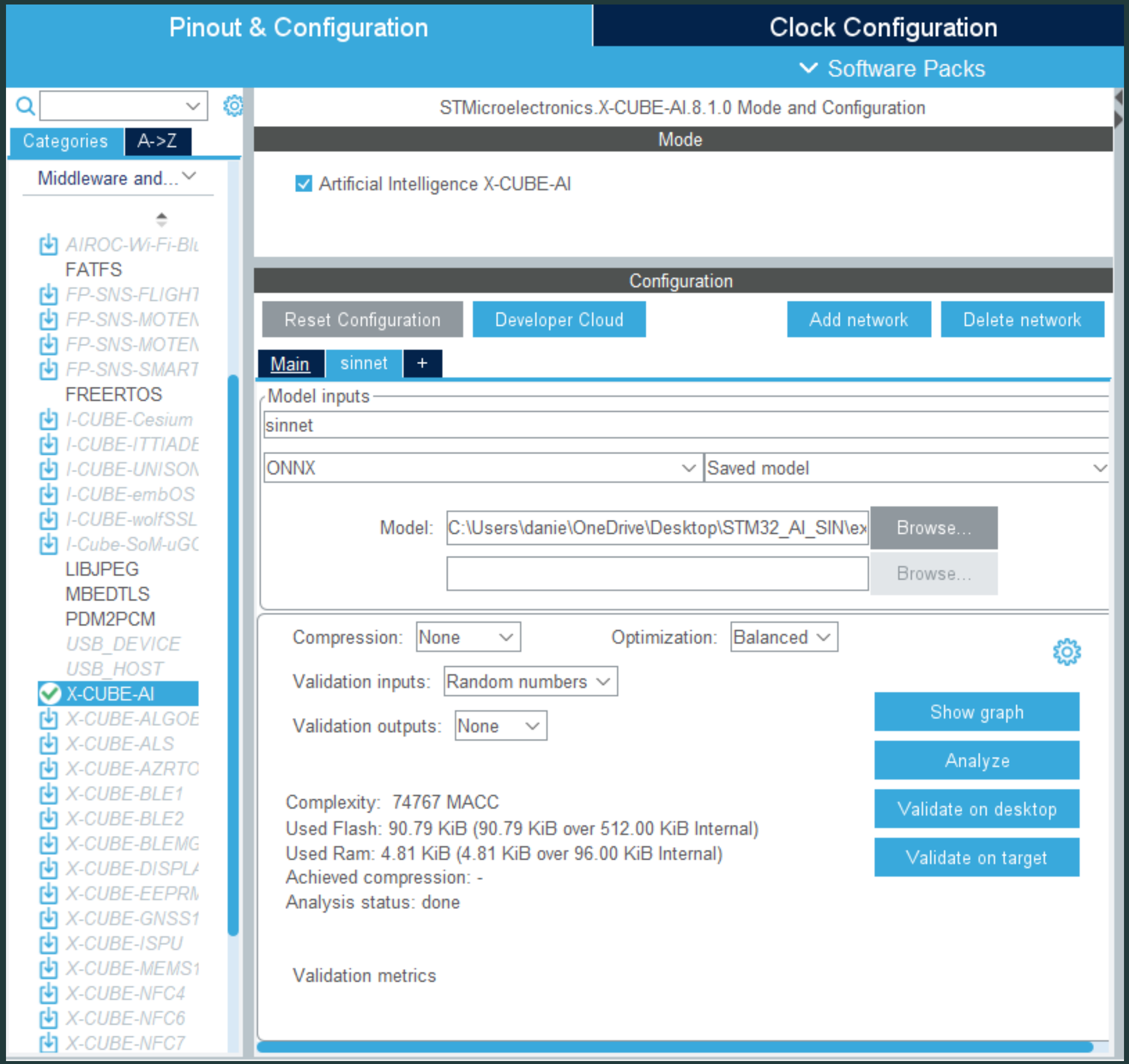
CUBE AI PROJECT SETUP

To import the Neural Network go to “middleware”, look for “X-CUBE AI” and in the meanwhile click on “Software Packs”->”Select Components and enable “Core” flag under STMicroelectronics-X-CUBE-AI



X-CUBE AI MENU

- In this menu you can add, remove neural networks, edit and validate them
- Under "Main" you can check memory and RAM consumption
- If you choose to further compress the network, it is recommended to run "Validate on desktop"



RUNNIGN THE MODEL

- Getting the model to run is not straightforward since there are many expedients to do before
- The neural network files are generated under ''X-CUBE_AI/App''

```
// Chunk of memory used to store the intermediate values of the network
AI_ALIGNED(4) ai_u8 activations[AI_SINNET_DATA_ACTIVATIONS_SIZE];

// Chunk of memory used to store input and output data
AI_ALIGNED(4) ai_i8 input_data[AI_SINNET_IN_1_SIZE_BYTES];
AI_ALIGNED(4) ai_i8 output_data[AI_SINNET_OUT_1_SIZE_BYTES];

// pointer which points at the model
ai_handle model = AI_HANDLE_NULL;

// structs which points to input and output data
ai_buffer model_input[AI_SINNET_IN_NUM];// = AI_SINNET_IN;
ai_buffer model_output[AI_SINNET_OUT_NUM];// = AI_SINNET_OUT;

// get weights and activations of the model
ai_network_params model_params = {
    AI_SINNET_DATA_WEIGHTS(ai_sinnet_data_weights_get()),
    AI_SINNET_DATA_ACTIVATIONS(activations)
};

// let model input and output point towards input_data and output_data memories
model_input[0].size = 1;
model_input[0].data = AI_HANDLE_PTR(input_data);
model_output[0].size = 1; // theoretically number of batches
model_output[0].data = AI_HANDLE_PTR(output_data);
```

USEFUL RESOURCES

- https://www.st.com/resource/en/data_brief/x-cube-ai.pdf
- https://www.st.com/resource/en/user_manual/um2526-getting-started-with-xcubeai-expansion-package-for-artificial-intelligence-ai-stmicroelectronics.pdfa

THE END

- A deeper explaination of STM32, AI for embedded systems and AI on STM32 Microcontrollers would take an entire course
- My personal recommendation si to exploit the mandatory IoT Project for the exam to dive deeper into these topics or even base your master thesis on a research project or possible application in the field of AI for embedded systems

For any kind of support you can contact me here