

Make Learn 2022
#makerfairerome

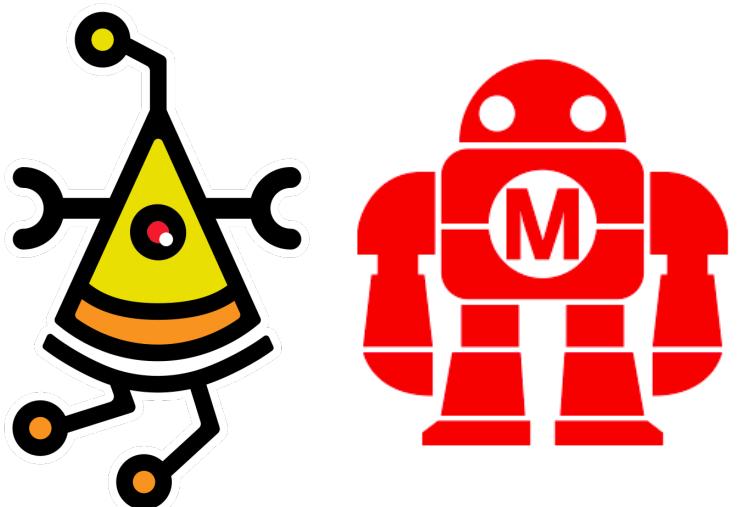


November 16th 2022

TinyML

with Arduino Nano RP2040 Connect

Giovanni di Dio Bruno



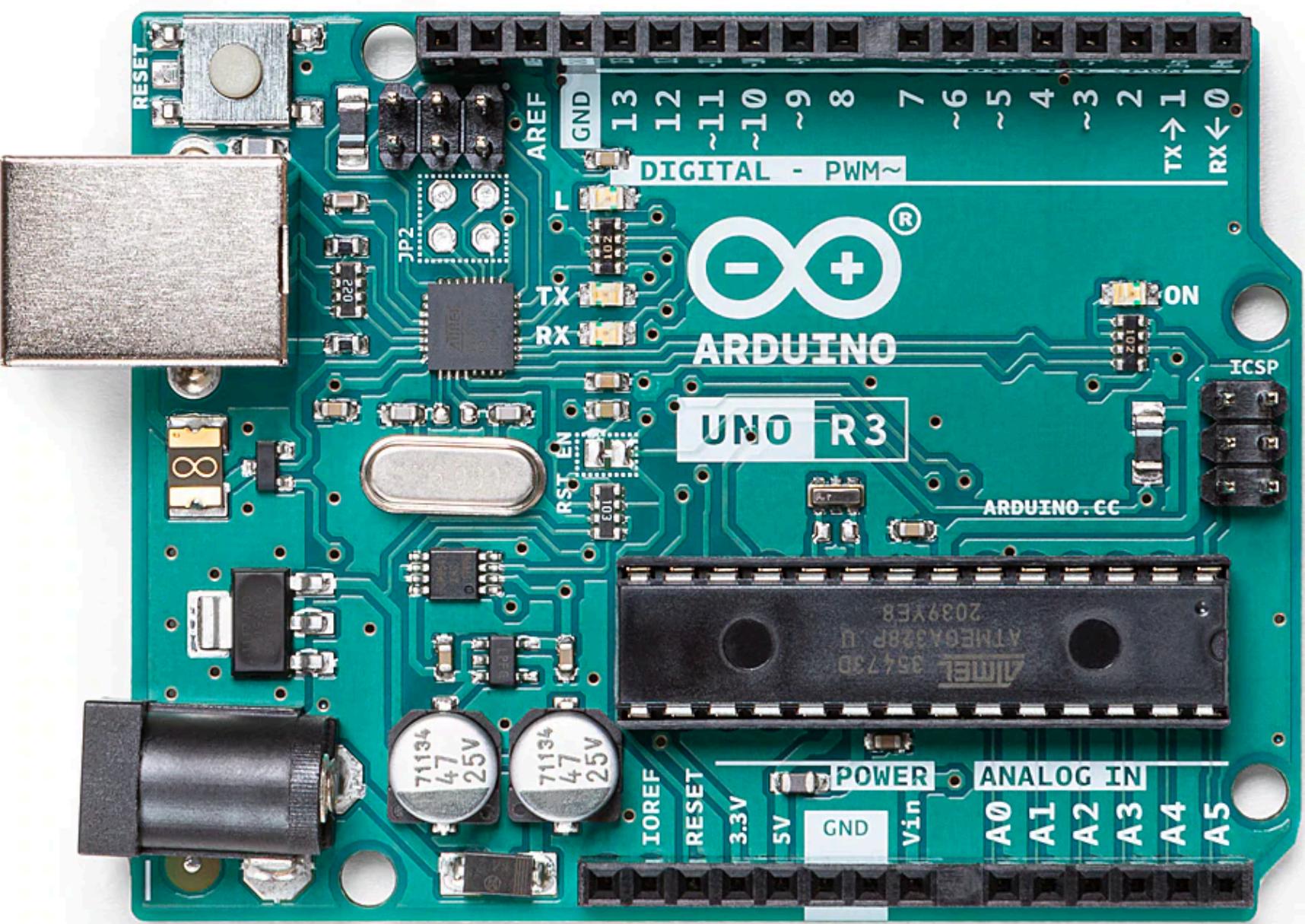
@johnnyrobomeka 
gbr1.github.io 
gbr1 
@br1johnny 

“microcontroller” ?

MCU

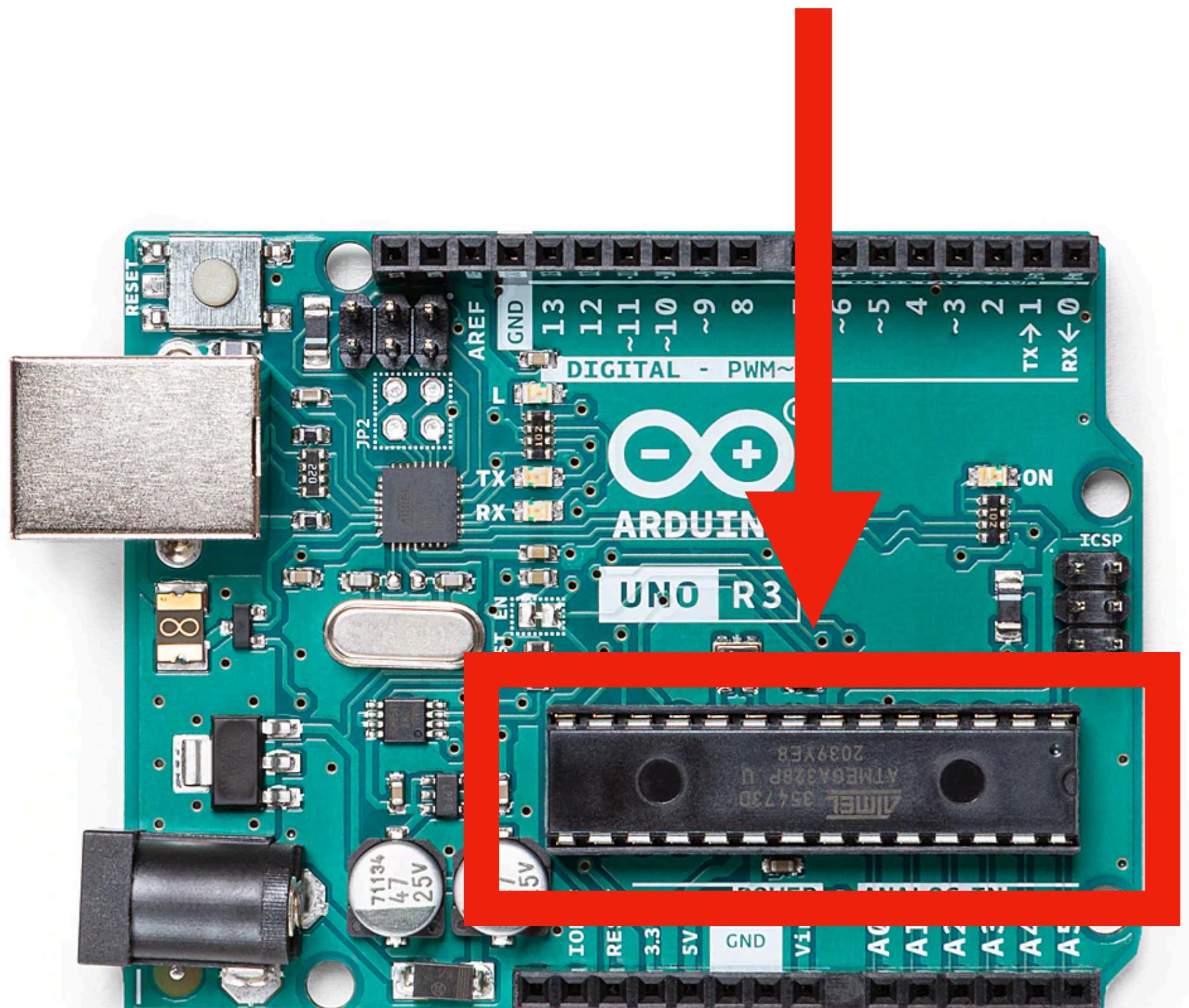
- low computational power
- small RAM
- programmable I/O
- interface for complex peripherals
- few bucks

MCU



Arduino Uno

MCU



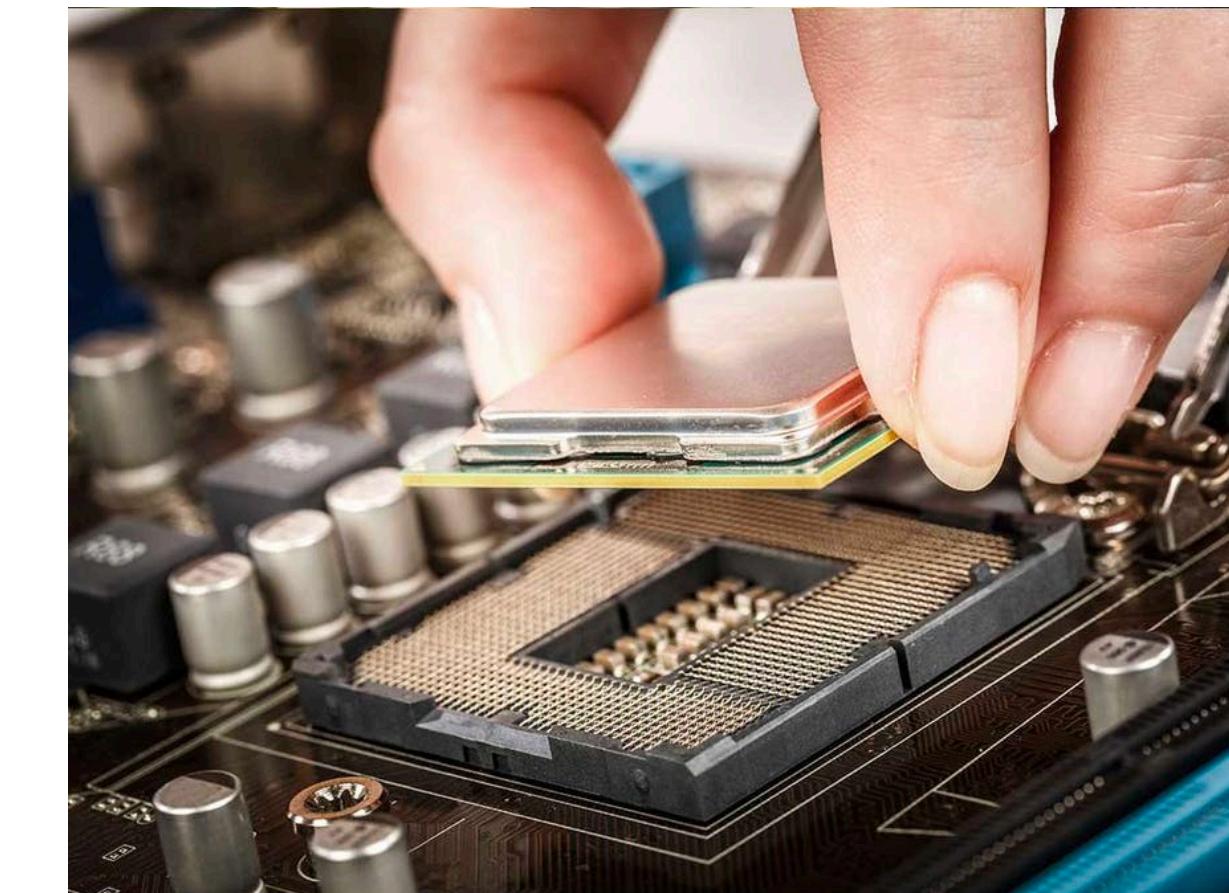
Arduino Uno

MCU vs micropocessor

- high computational power
- high RAM
- integrated GPU
- high price

MCU vs micropocessor

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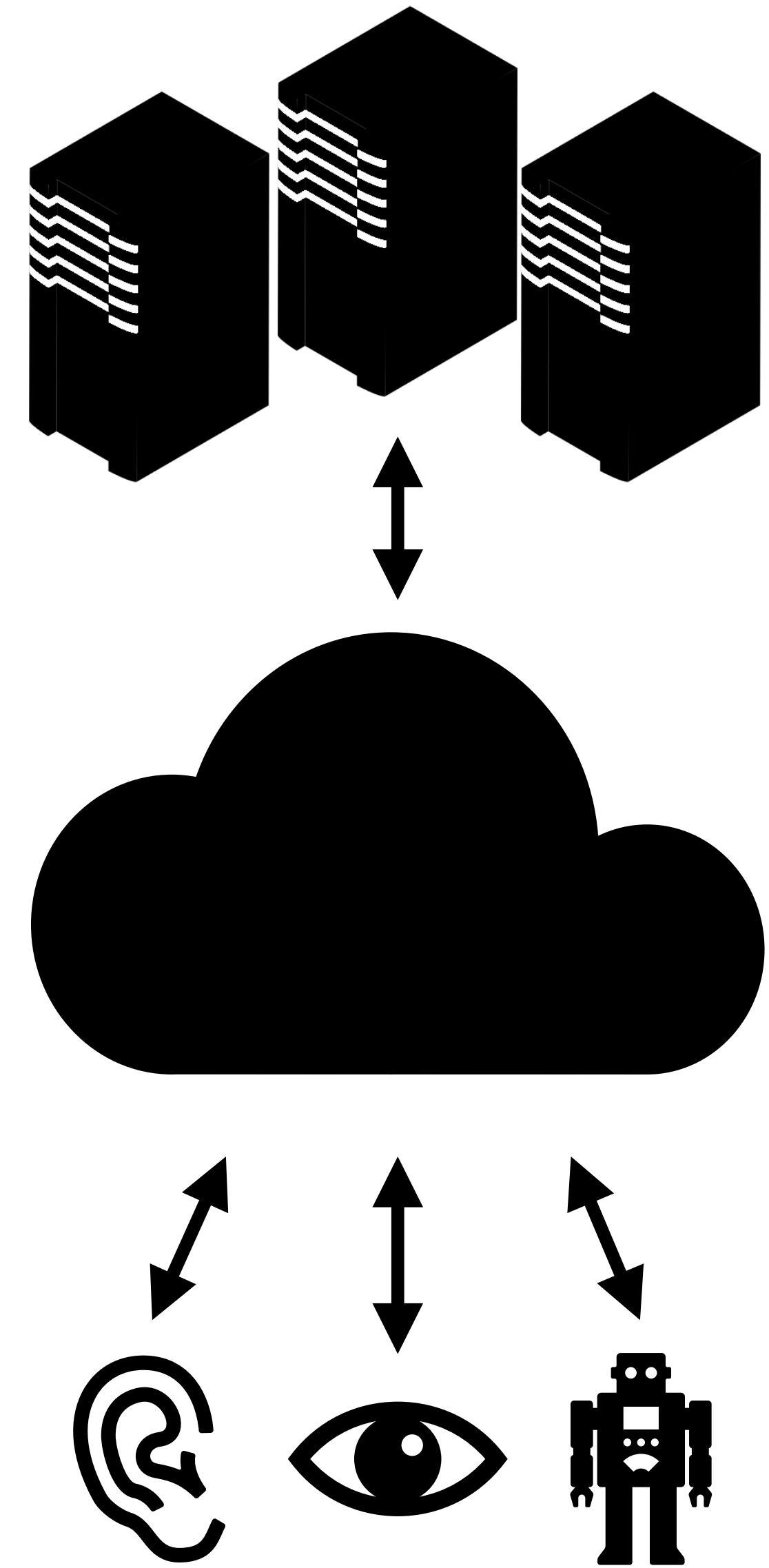


SoC

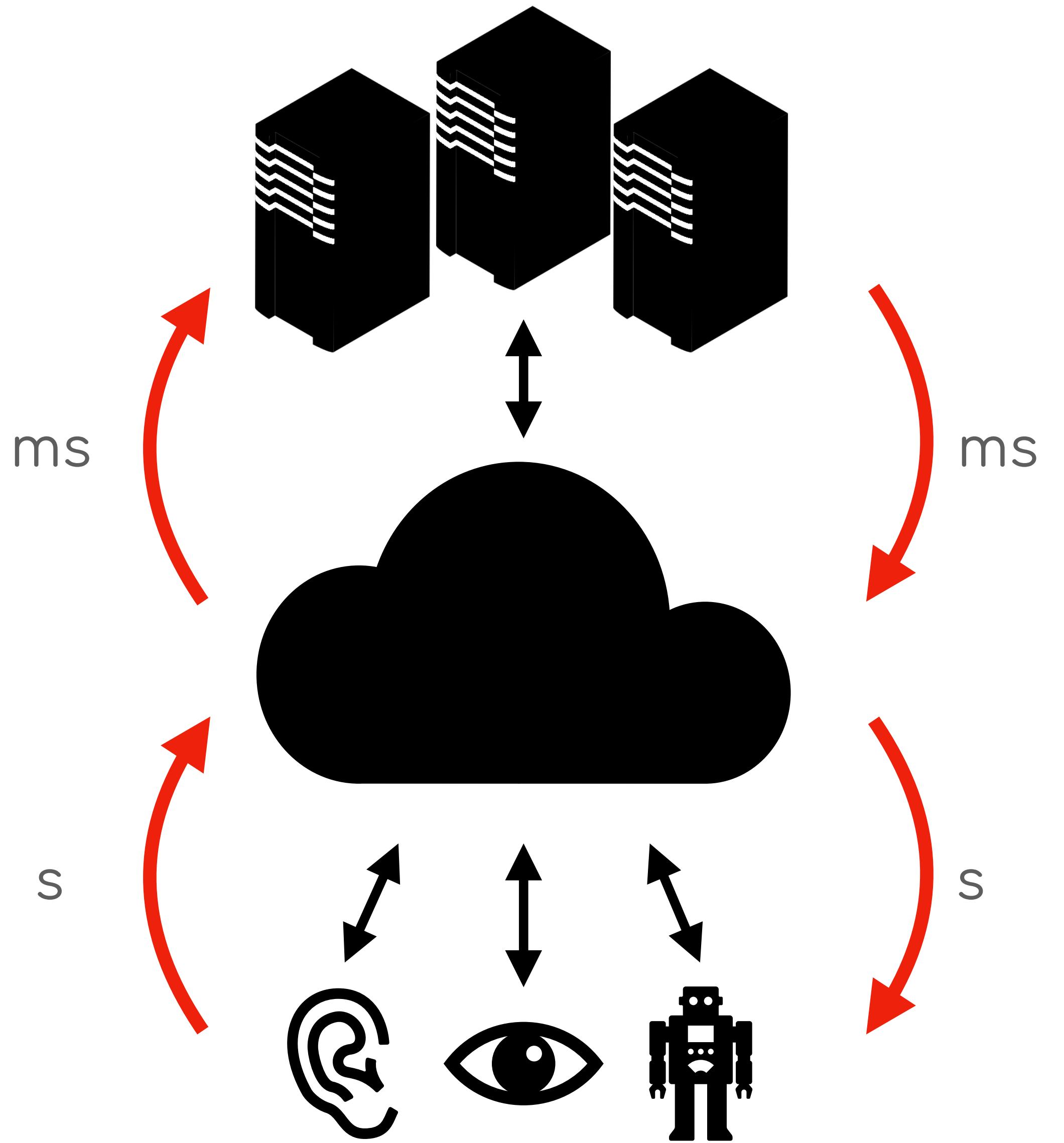
- fusion
- adding peripherals
- embedded

typical cloud IoT ML

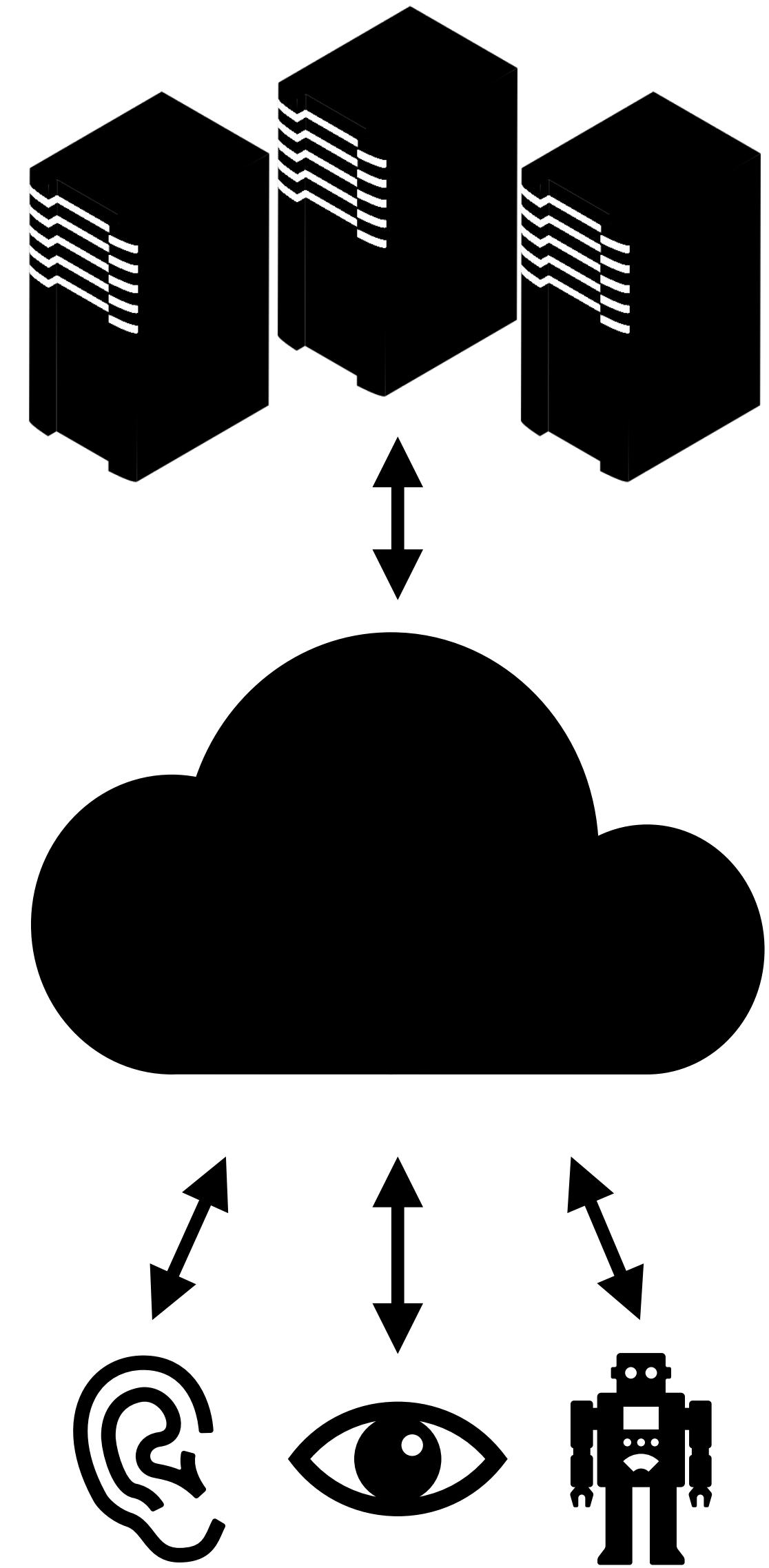
typical cloud IoT ML



typical cloud IoT ML



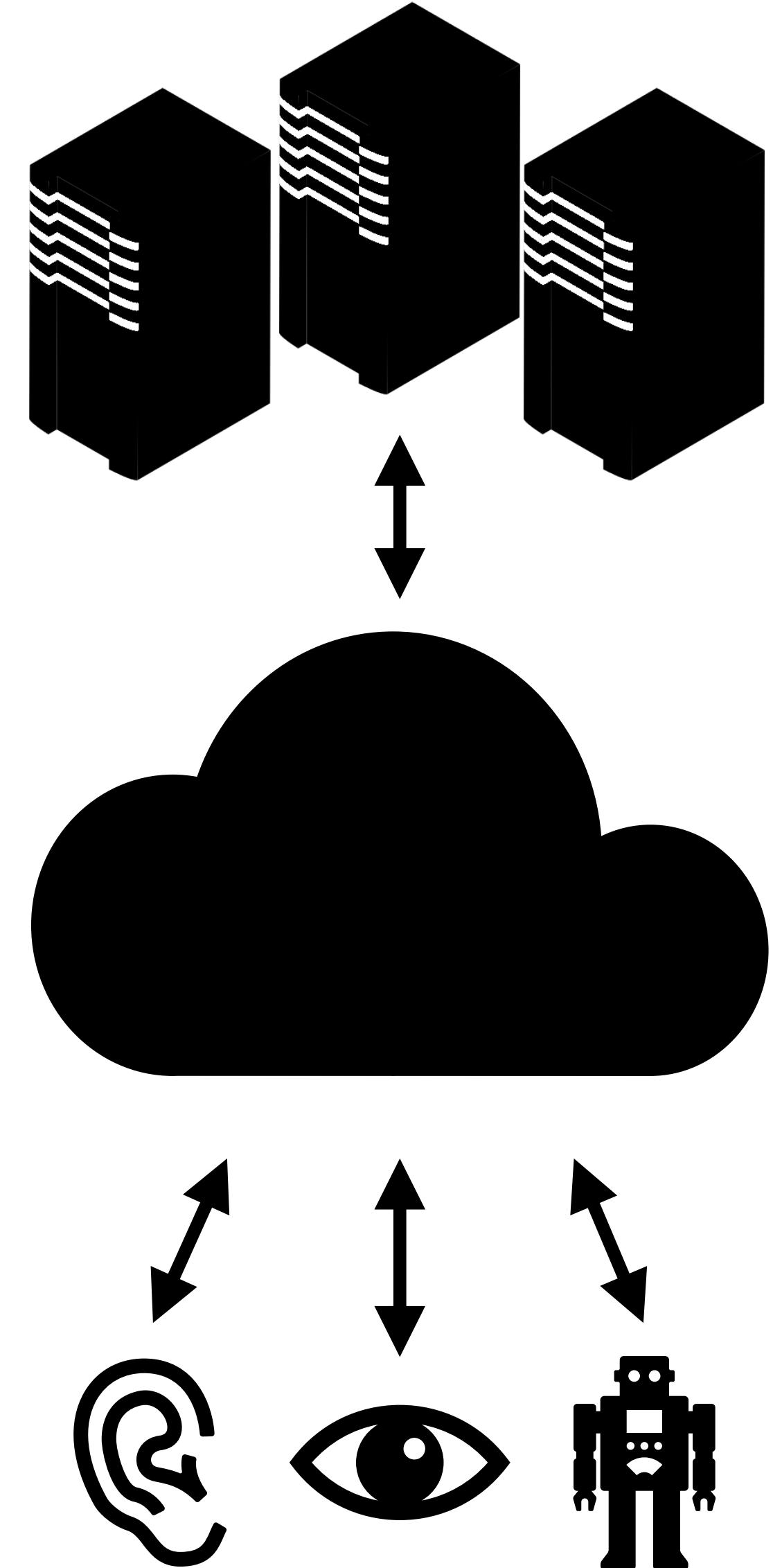
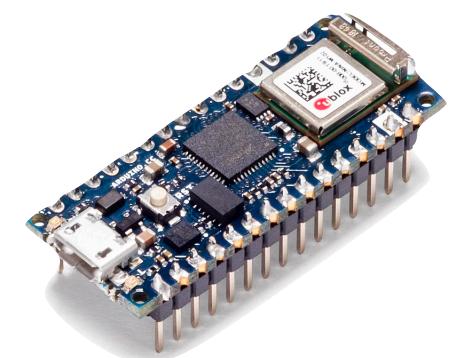
typical cloud IoT ML



typical cloud IoT ML

Arduino Nano 33 IoT
(SAMD21 + Nina)

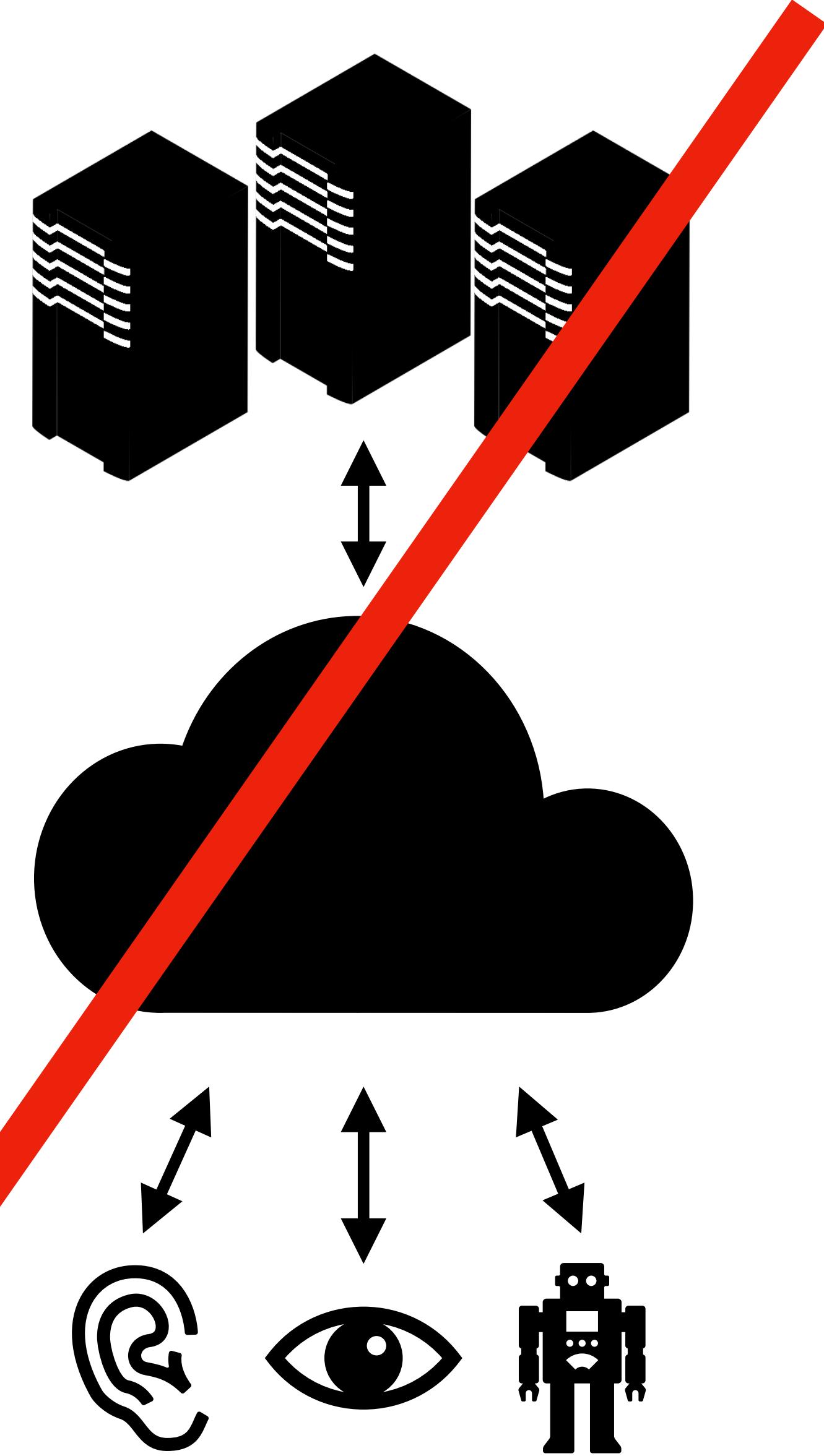
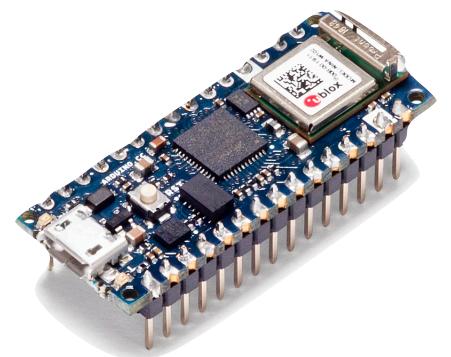
~200mA



offline ML

Arduino Nano 33 IoT
(SAMD21)

~30mA



offline ML

- latency
- power consumption
- privacy

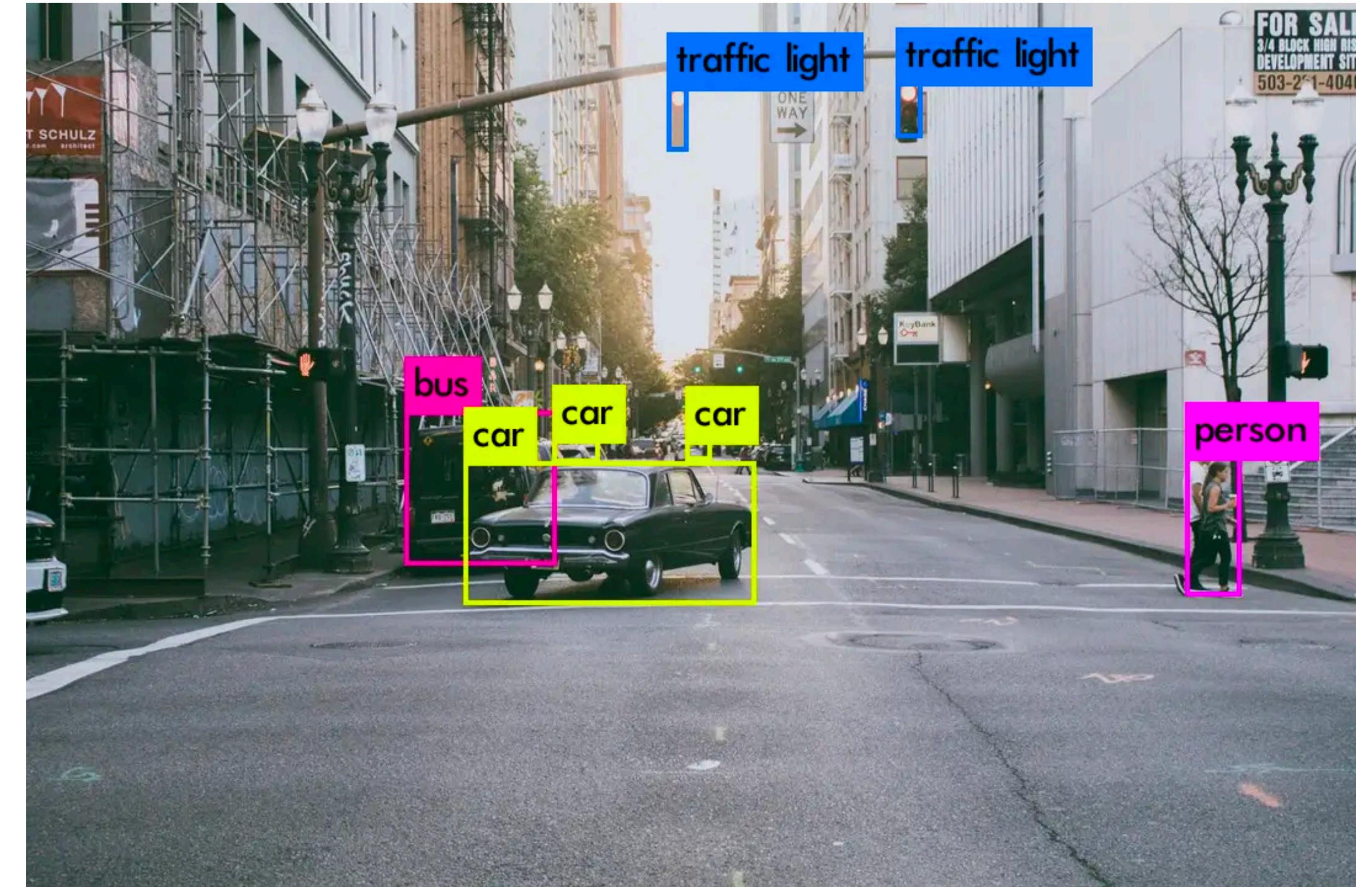
why “Machine Learning” ?

Machine Learning

- part of AI field
- methodologies and algorithms
- builds models by training
- predictions and decisions without programming
- data analysis

Machine Learning

Keyword: learning



Deep learning: YOLO

why “microcontrollers” ?

TinyML

- offline
- low cost
- small devices
- simple applications
- we can teach what to do

Applications of TinyML

Applications of TinyML



activity recognition

Applications of TinyML



activity recognition

Applications of TinyML



keyword spotting

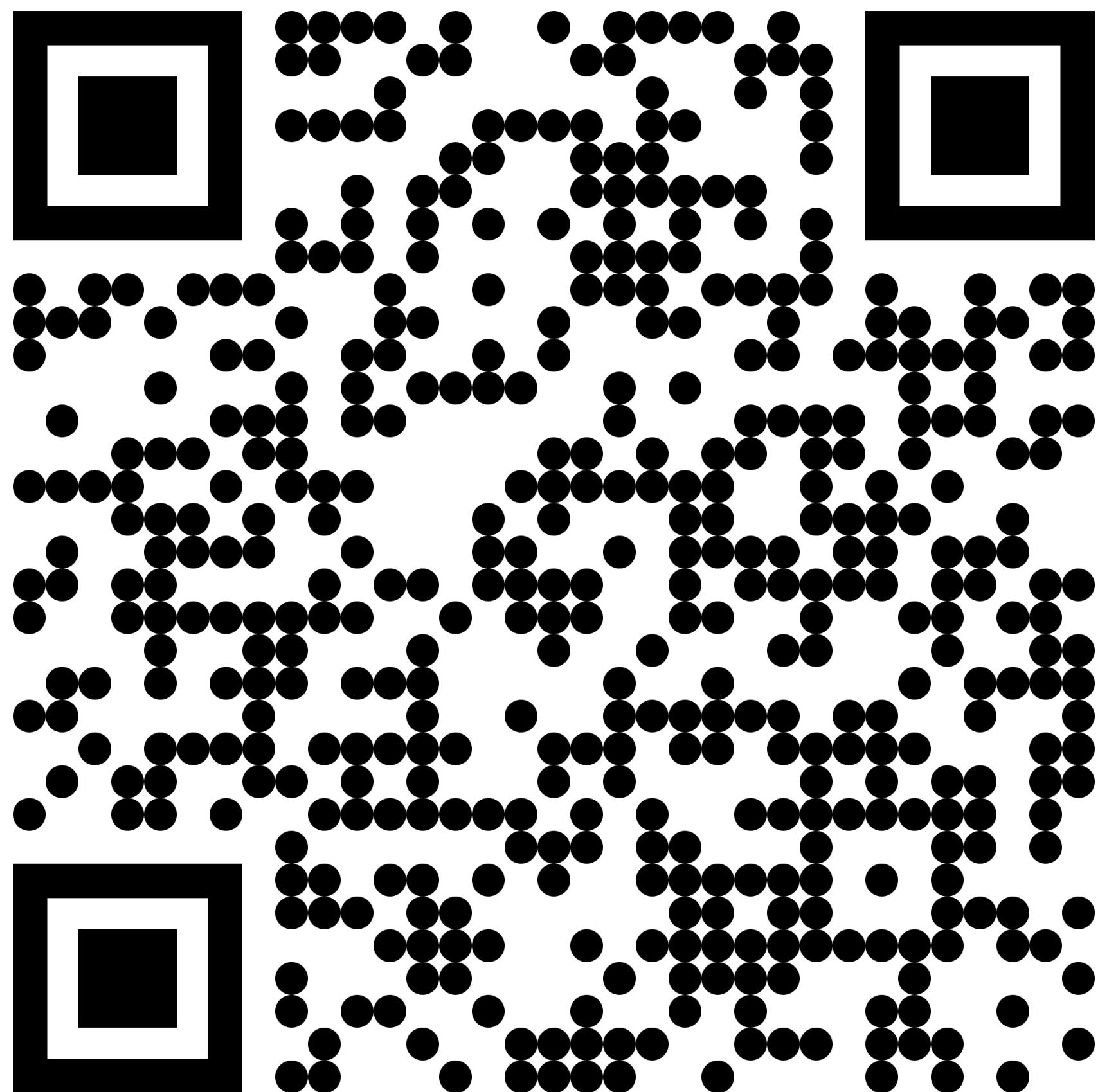
Applications of TinyML



image is only a reference for device typology

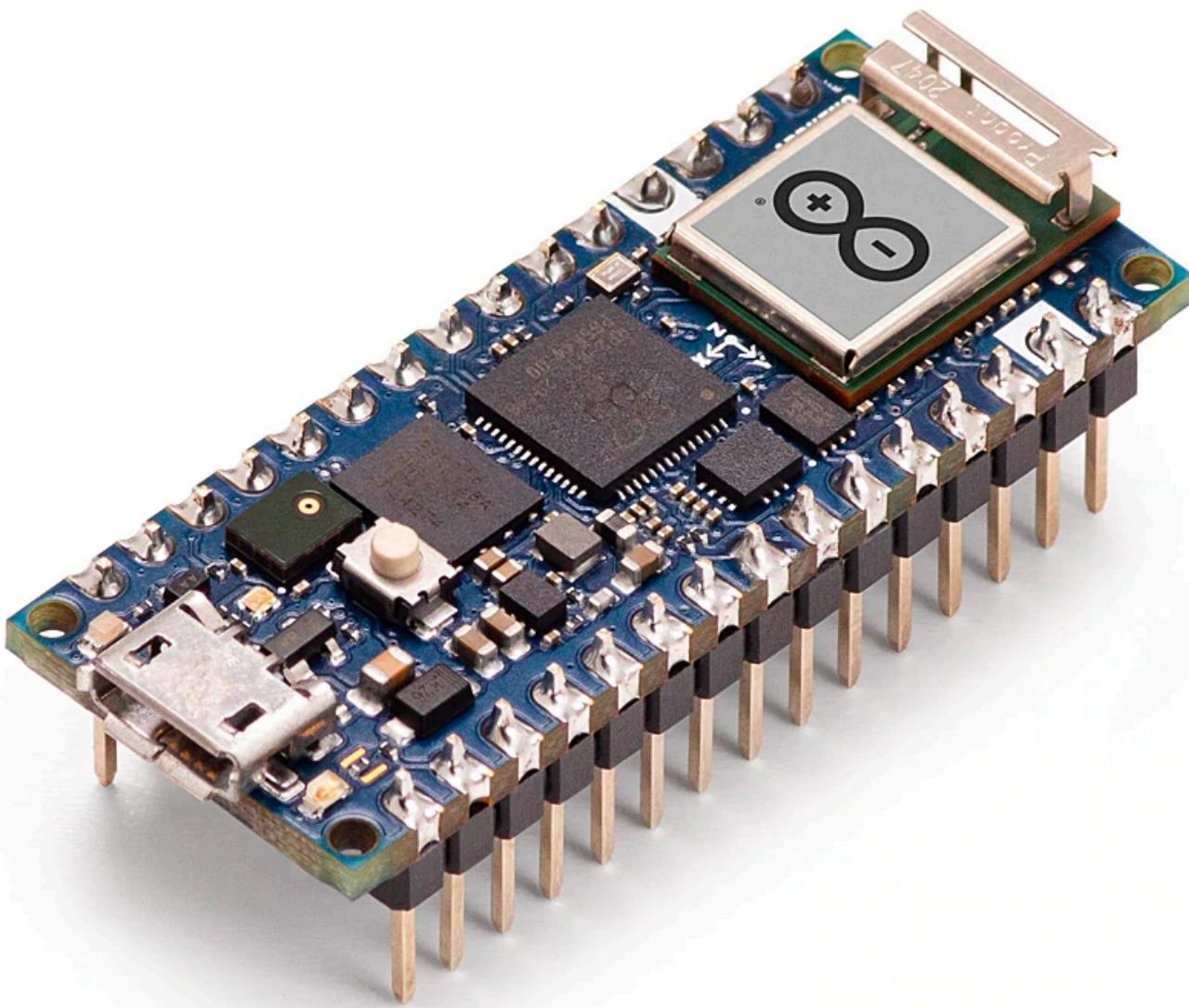
keyword spotting

Applications of TinyML

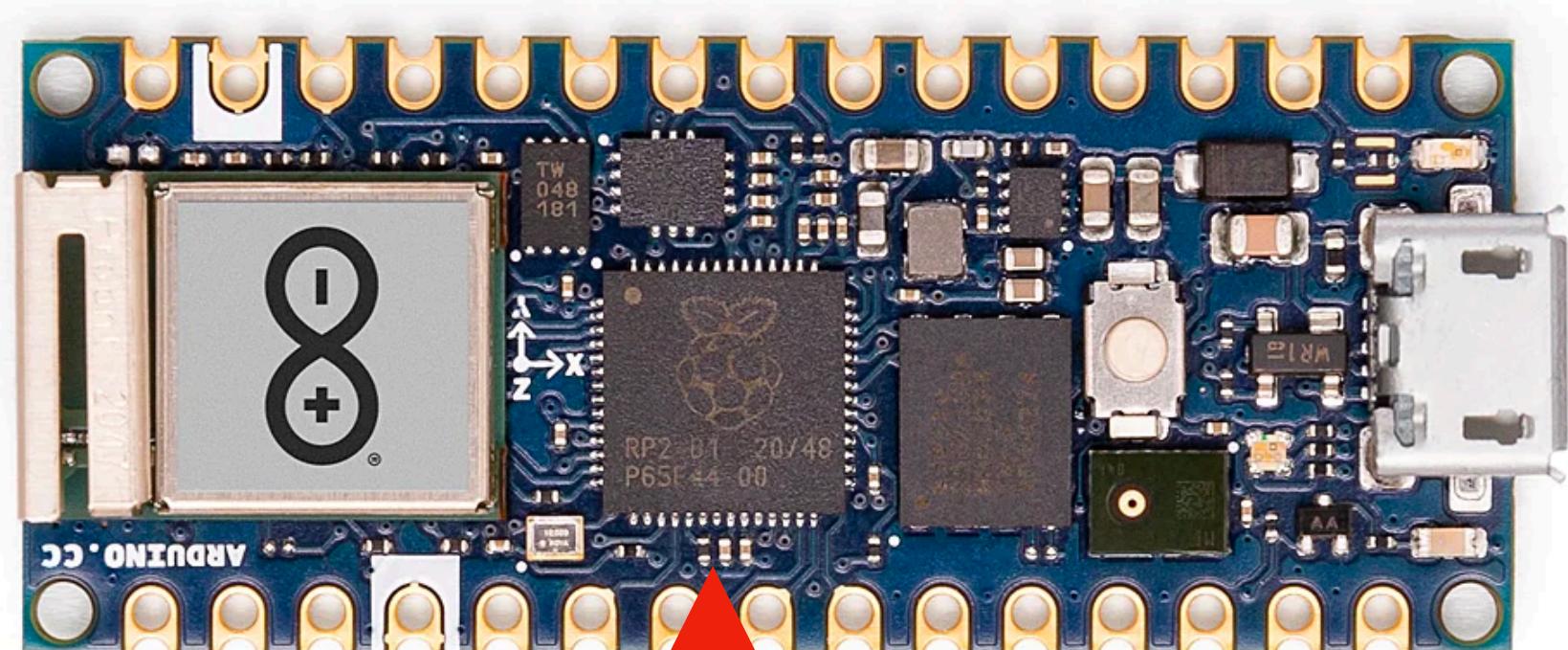


[https://github.com/gigwegbe/
tinyml-papers-and-projects](https://github.com/gigwegbe/tinyml-papers-and-projects)

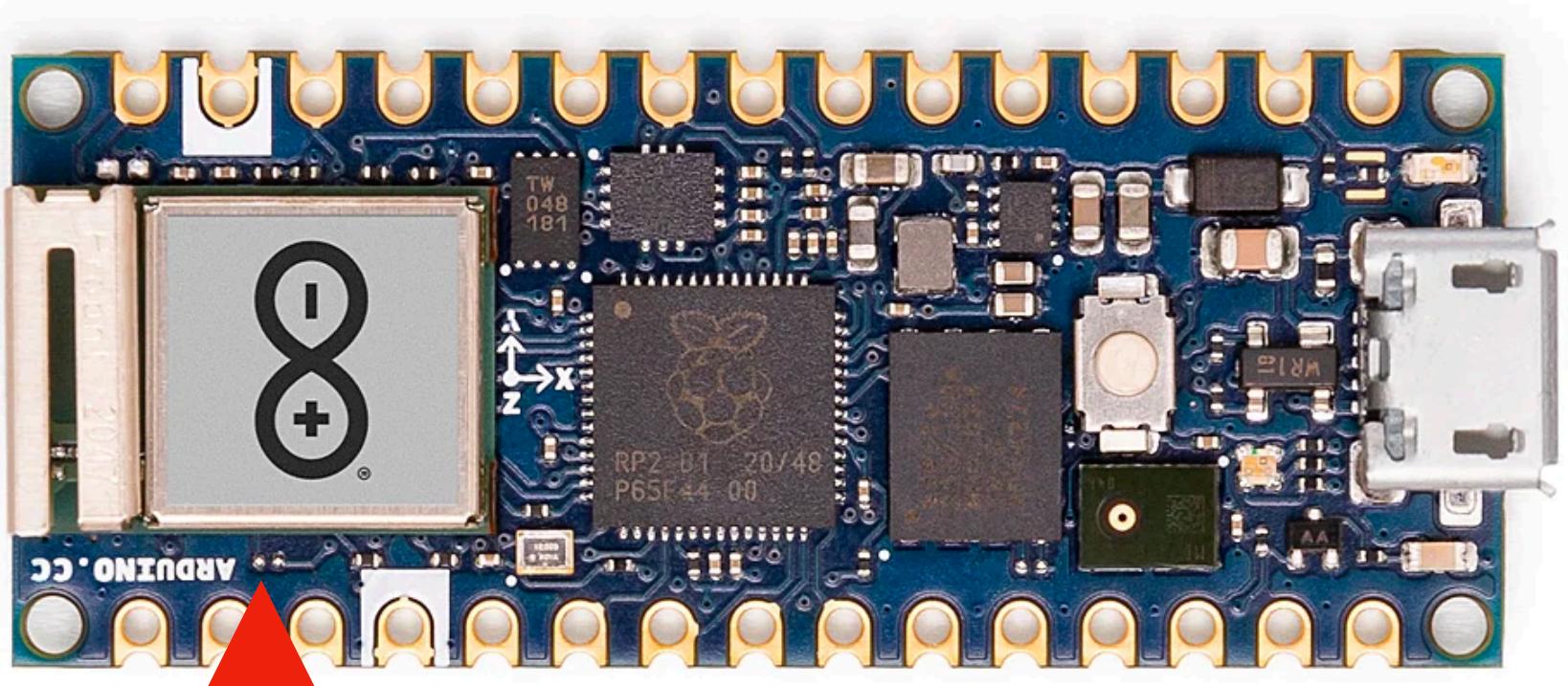
Arduino Nano RP2040 connect



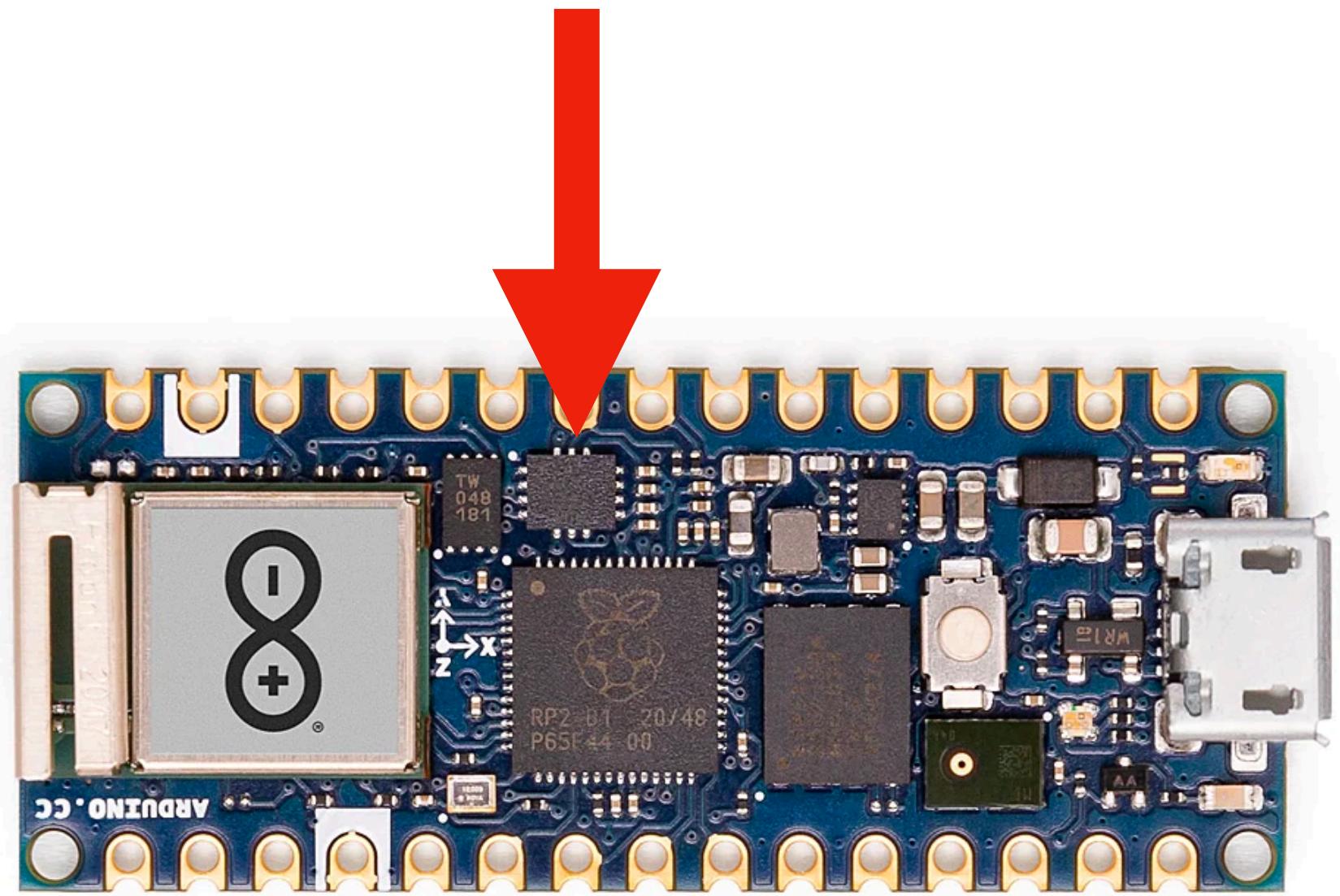
Arduino Nano RP2040 connect



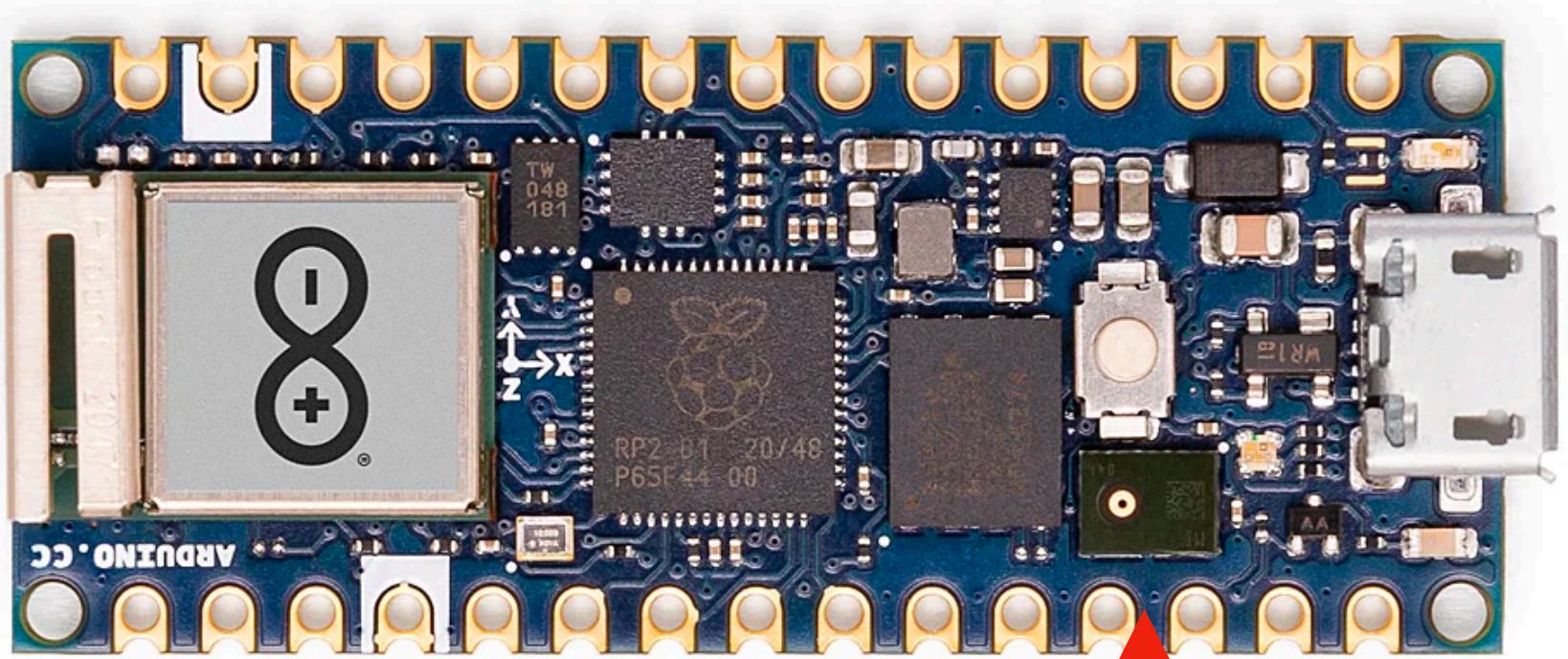
Arduino Nano RP2040 connect



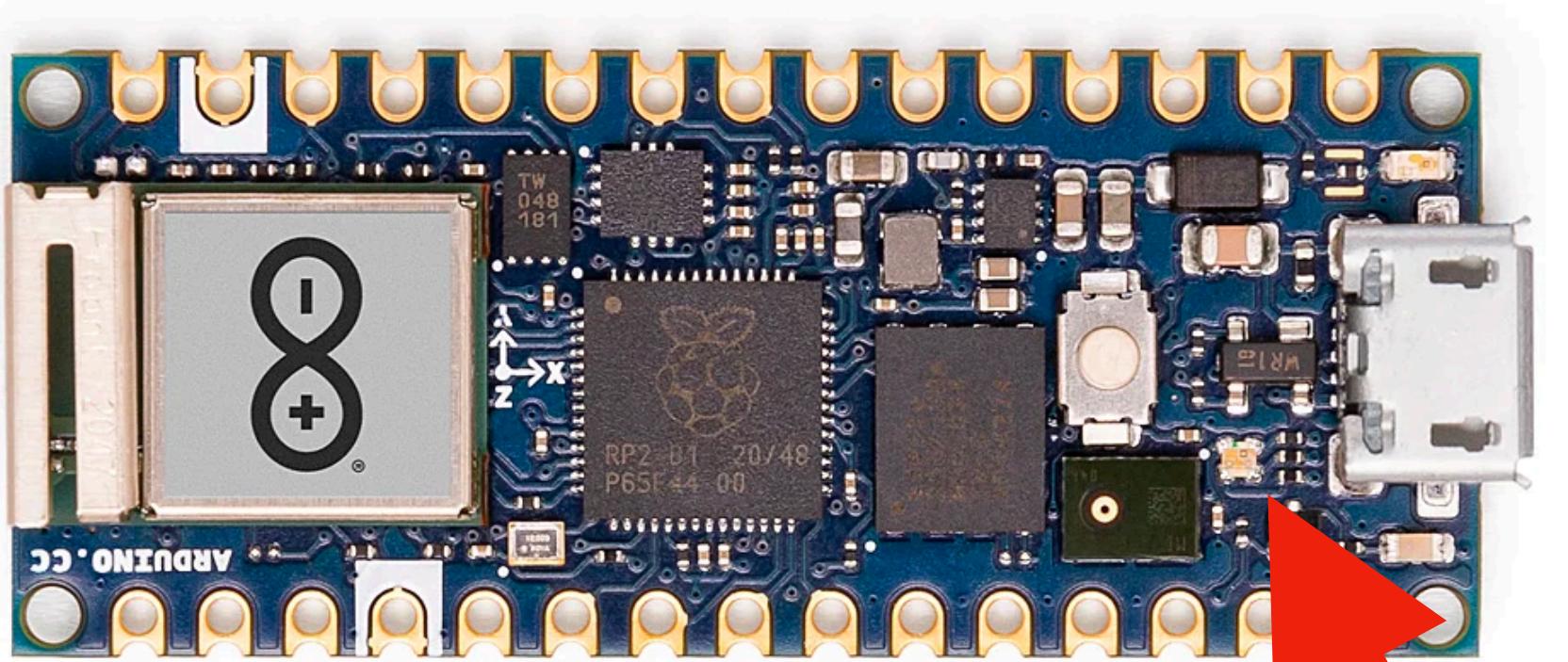
Arduino Nano RP2040 connect



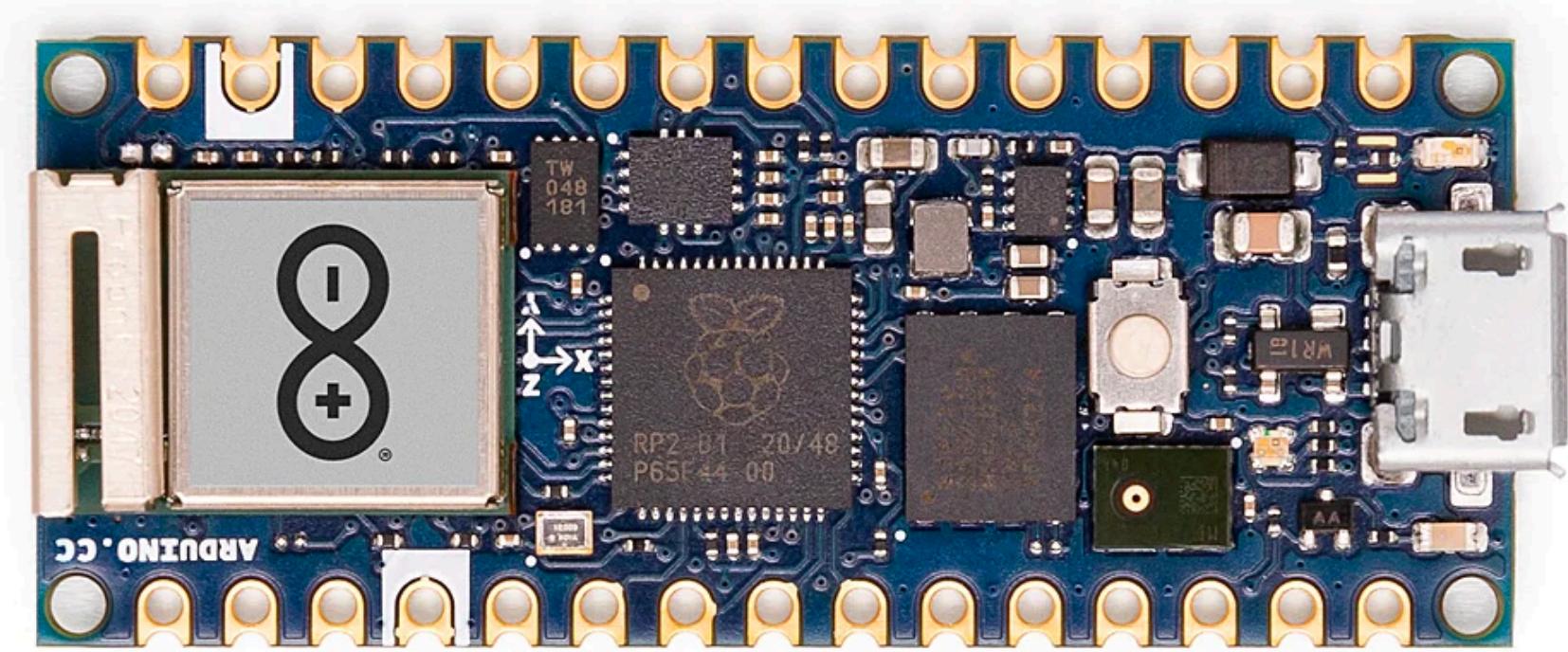
Arduino Nano RP2040 connect



Arduino Nano RP2040 connect



Arduino Nano RP2040 connect



[https://store.arduino.cc/products/
arduino-nano-rp2040-connect](https://store.arduino.cc/products/arduino-nano-rp2040-connect)

Edge Impulse



**EDGE
IMPULSE**

Edge Impulse

- freeware (developer account)
- based on opensource tools
- easy to use
- optimisation tools
- dedicated to TinyML

Example #1

- use IMU
- continuous sensing
- detect shaking or standing

new project: MFR22_motion

add device

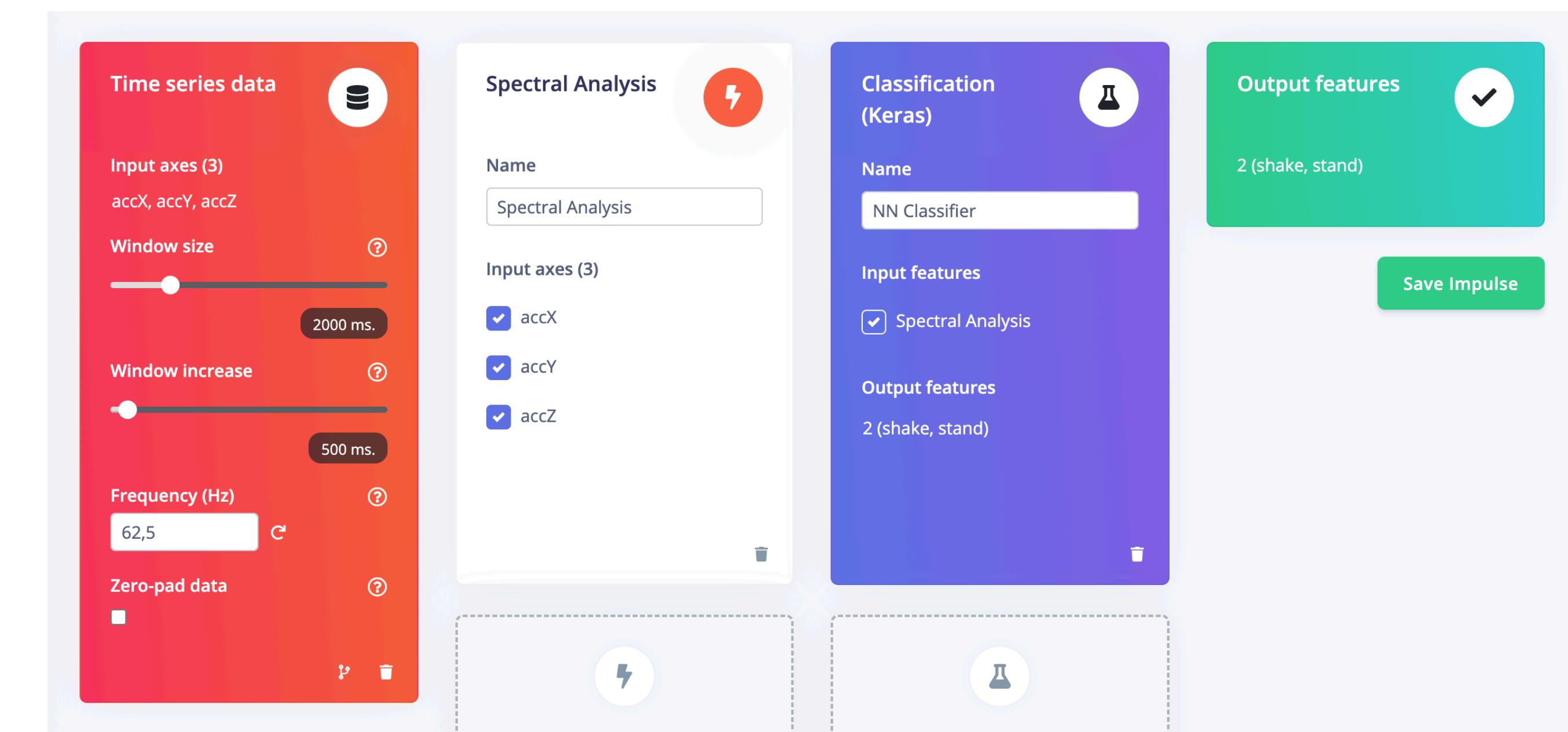
| NAME | ID | TYPE | SENSORS | REMO... | LAST SEEN | ⋮ |
|--|----------------|---------------|----------------------------|---------|-----------------|---|
|  phone_laiw0jla | PHONE_LAIWOJLA | MOBILE_CLIENT | Accelerometer, Micropho... | ● | Today, 01:11:35 | ⋮ |

you can also use “Data Forwarder”

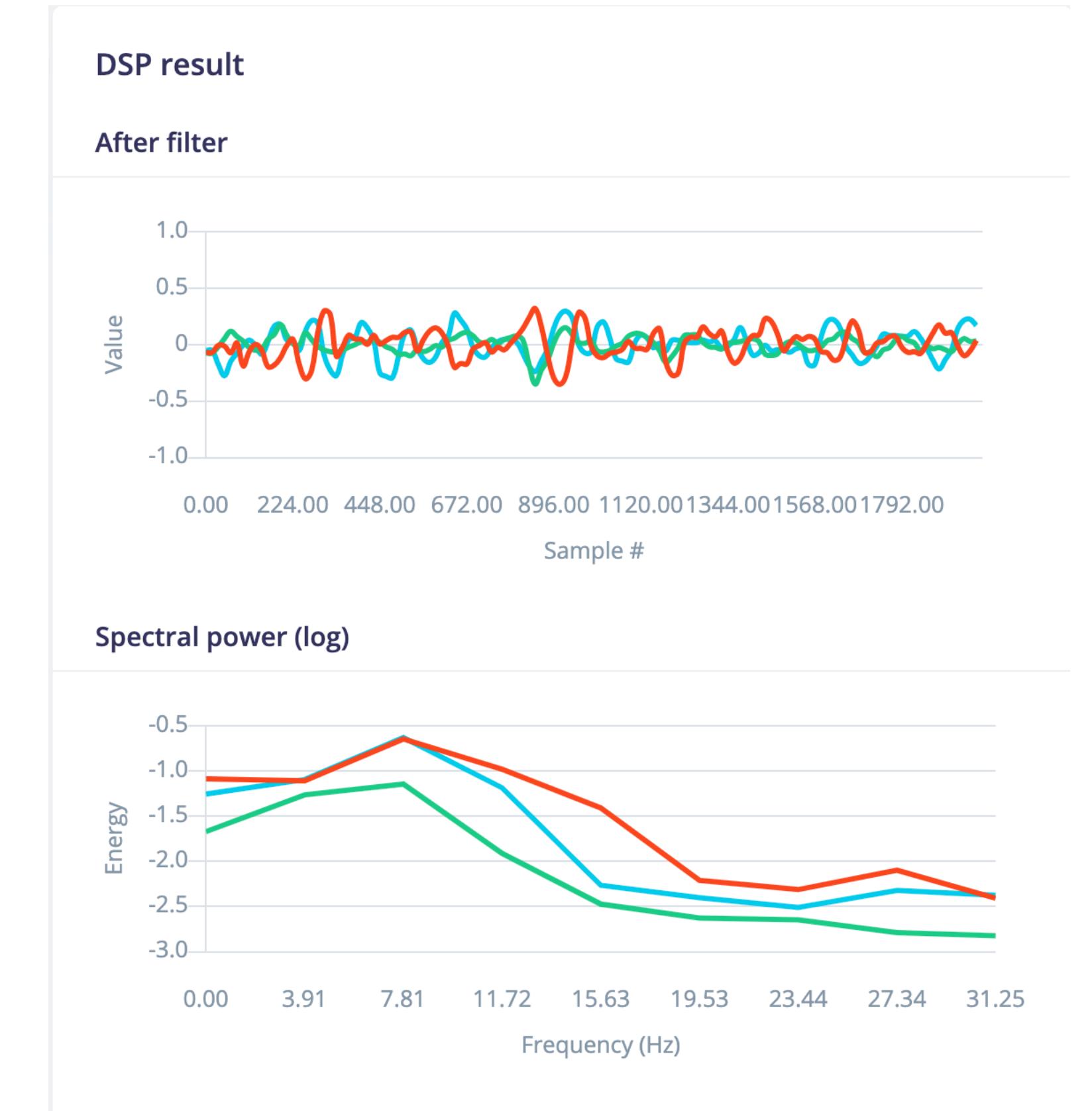
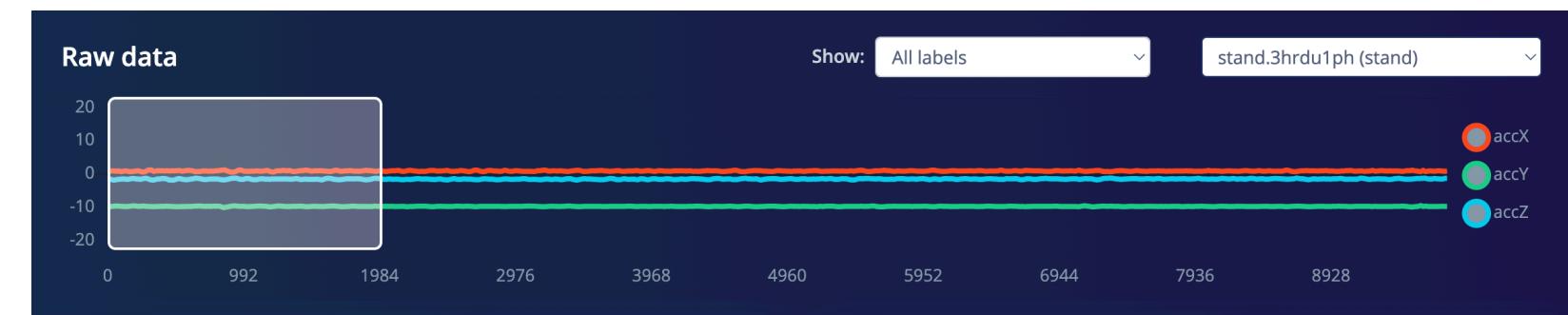
data acquisition



create an Impulse

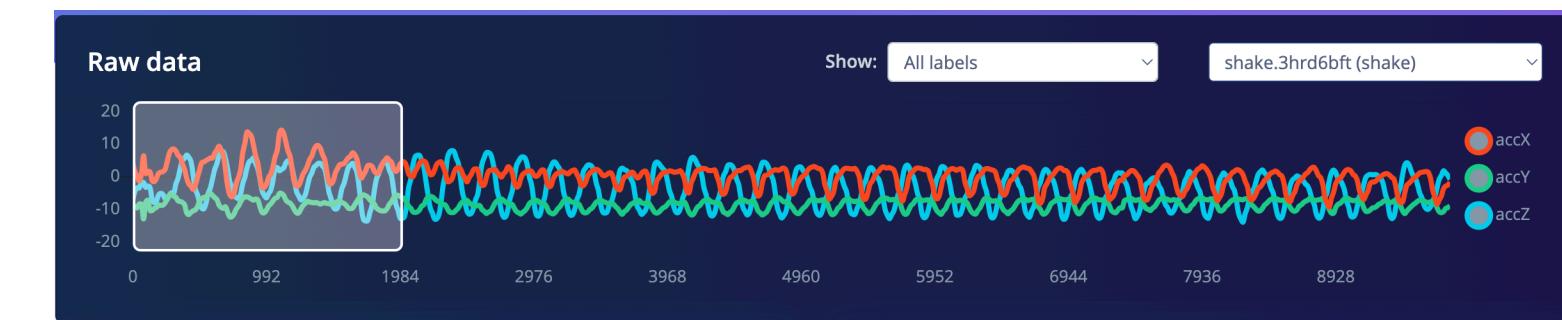


Spectral Analysis



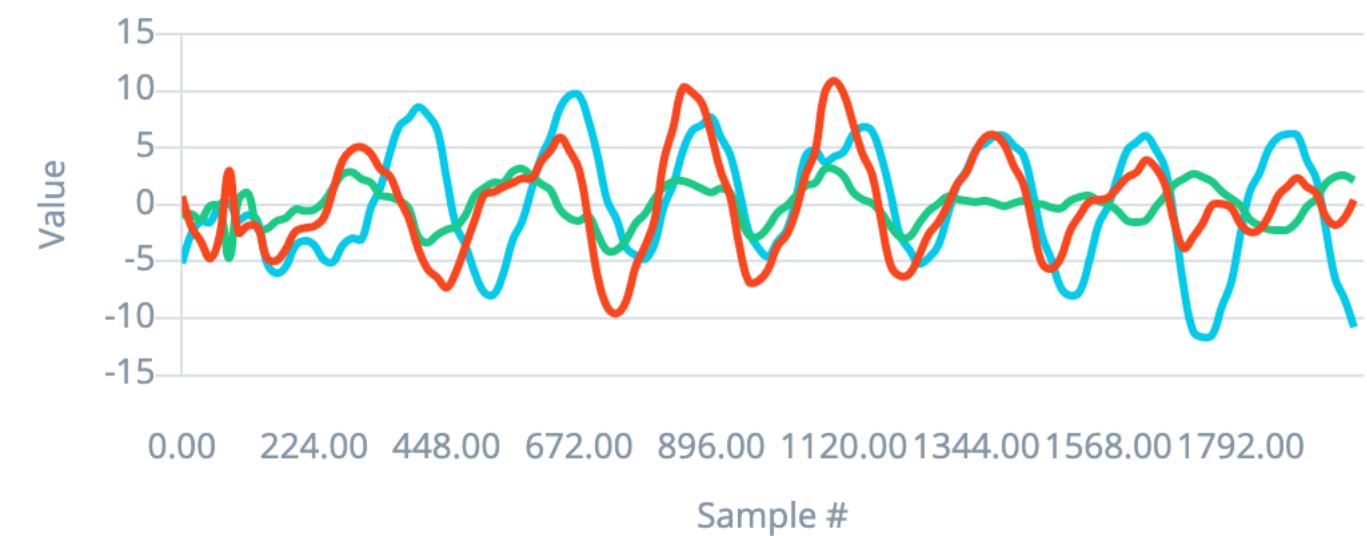
stand

Spectral Analysis

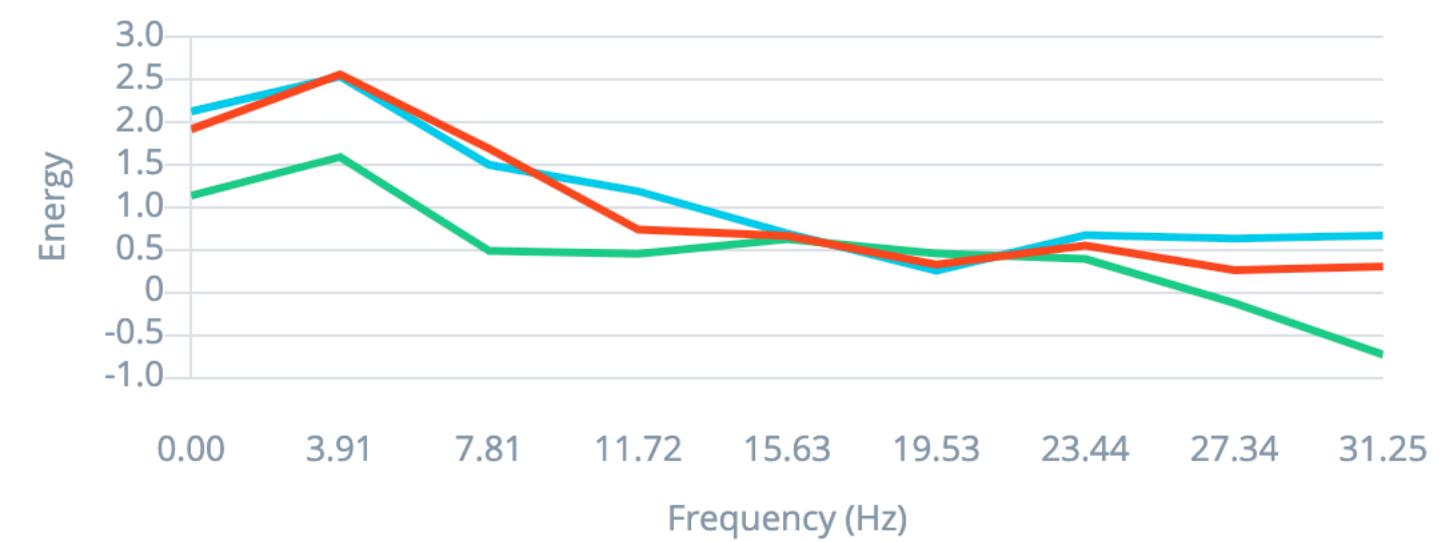


DSP result

After filter



Spectral power (log)



shake

NN Classifier

Number of training cycles

Learning rate

Validation set size %

Auto-balance dataset

Neural network architecture

- Input layer (33 features)
- Dense layer (40 neurons)
- Dense layer (20 neurons)
- Dense layer (10 neurons)
- Dropout (rate 0.25)
- Add an extra layer
- Output layer (2 classes)

Last training performance (validation set)

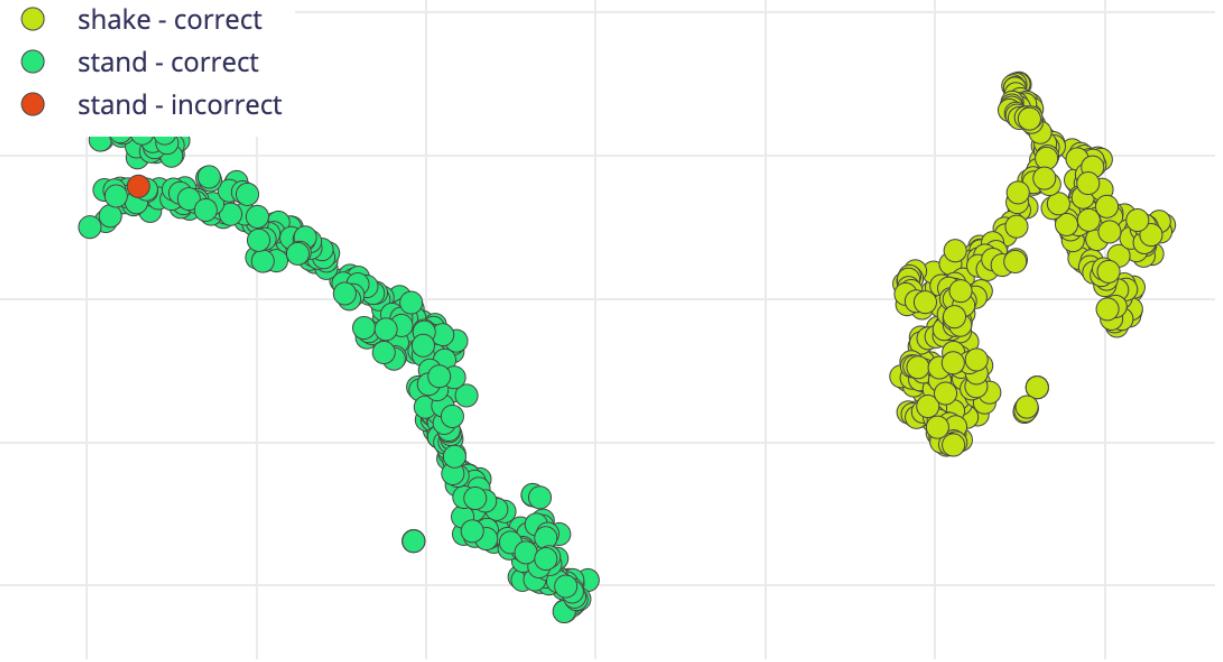
| | |
|---|---------------|
|  ACCURACY | 100.0% |
|  LOSS | 0.00 |

Confusion matrix (validation set)

| | SHAKE | STAND |
|----------|-------|-------|
| SHAKE | 100% | 0% |
| STAND | 0% | 100% |
| F1 SCORE | 1.00 | 1.00 |

Data explorer (full training set) 

- shake - correct (yellow)
- stand - correct (green)
- stand - incorrect (red)



On-device performance 

| | |
|---|-------|
|  INFERENCING ... | 4 ms. |
|  PEAK RAM US... | 2.1K |
|  FLASH USAGE | 18.5K |

Live Classification

- use smartphone
- test using dataset
- test on a real device

Live Classification

Classify new data [Connect using WebUSB](#)

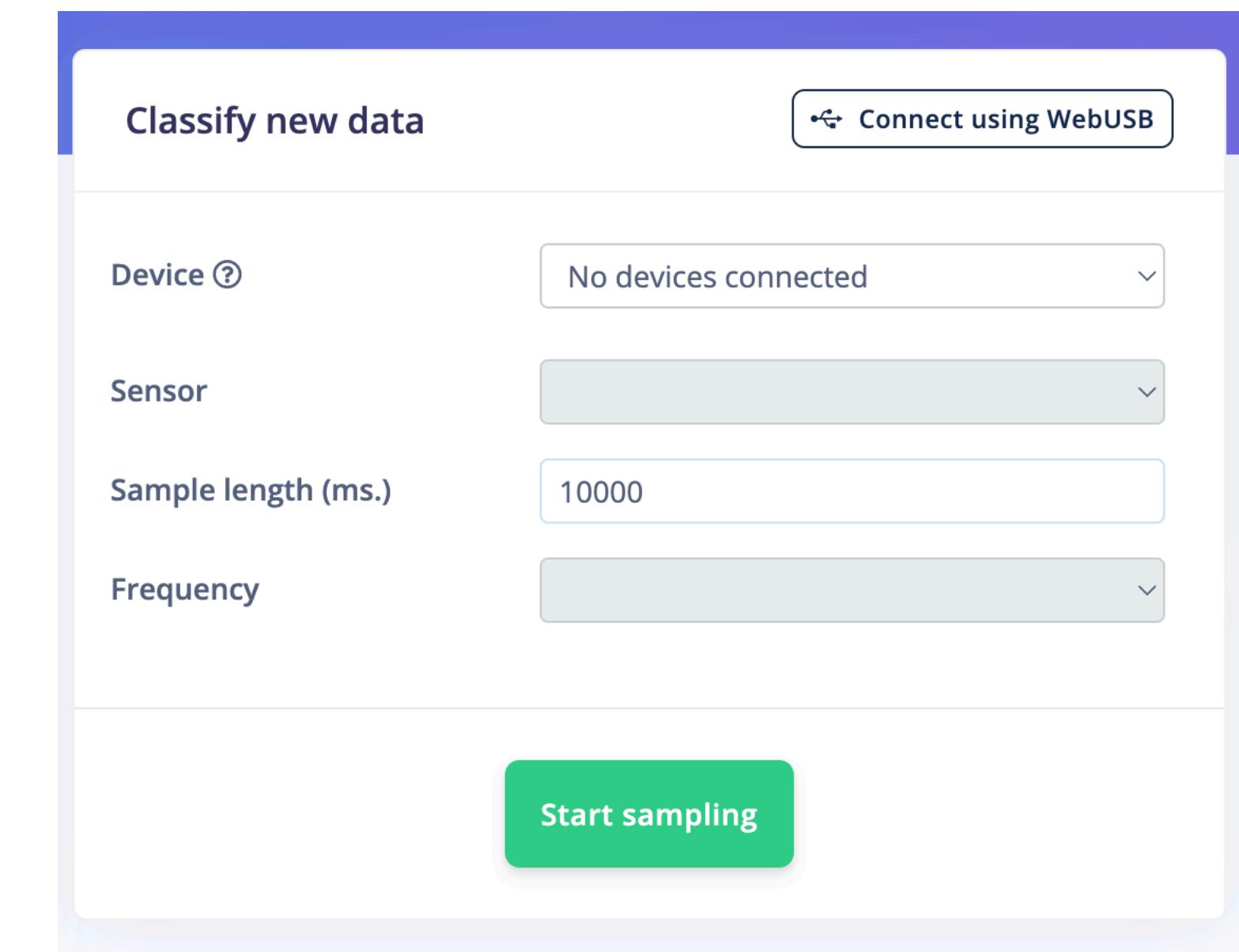
Device ⓘ No devices connected

Sensor

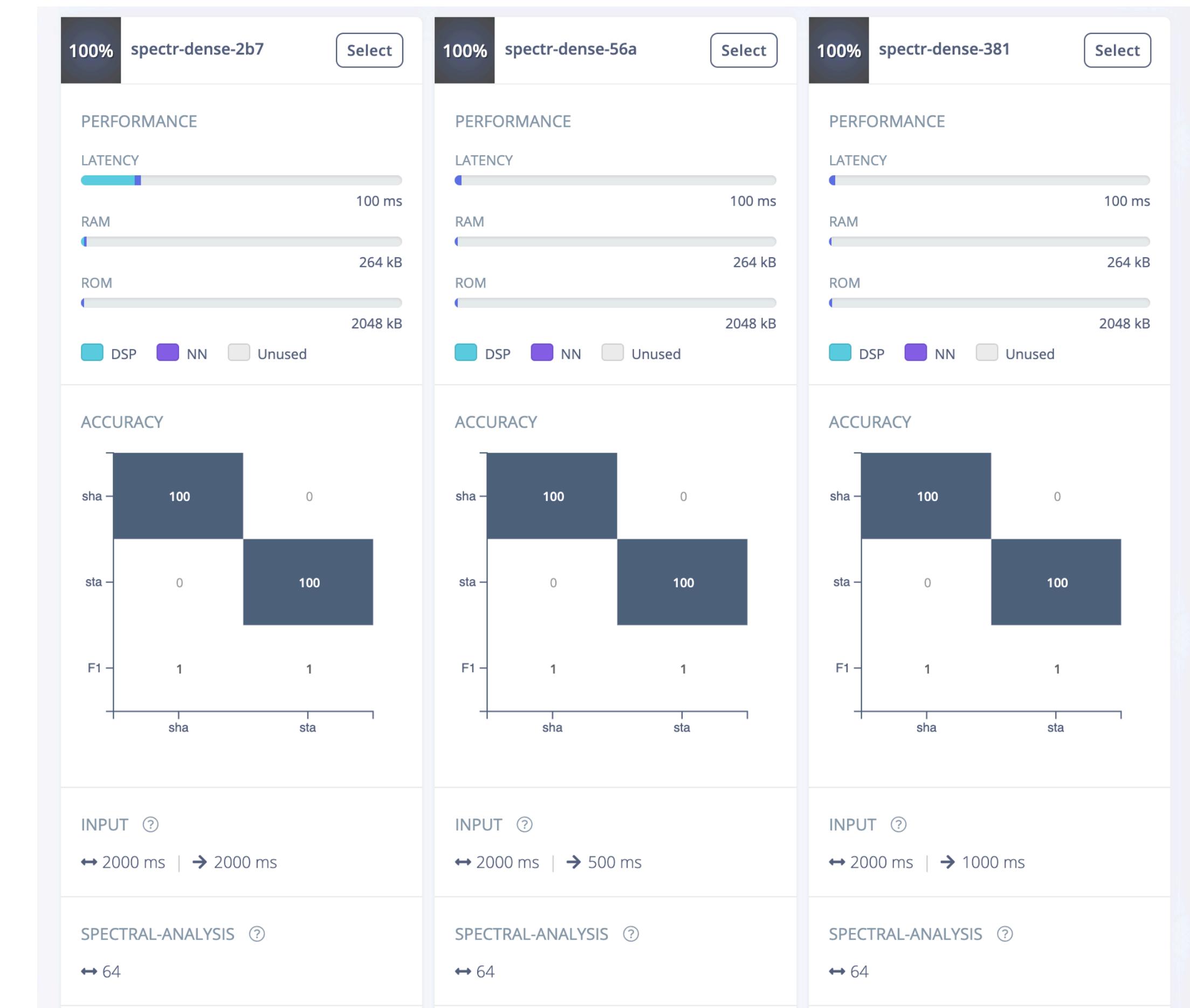
Sample length (ms.) 10000

Frequency

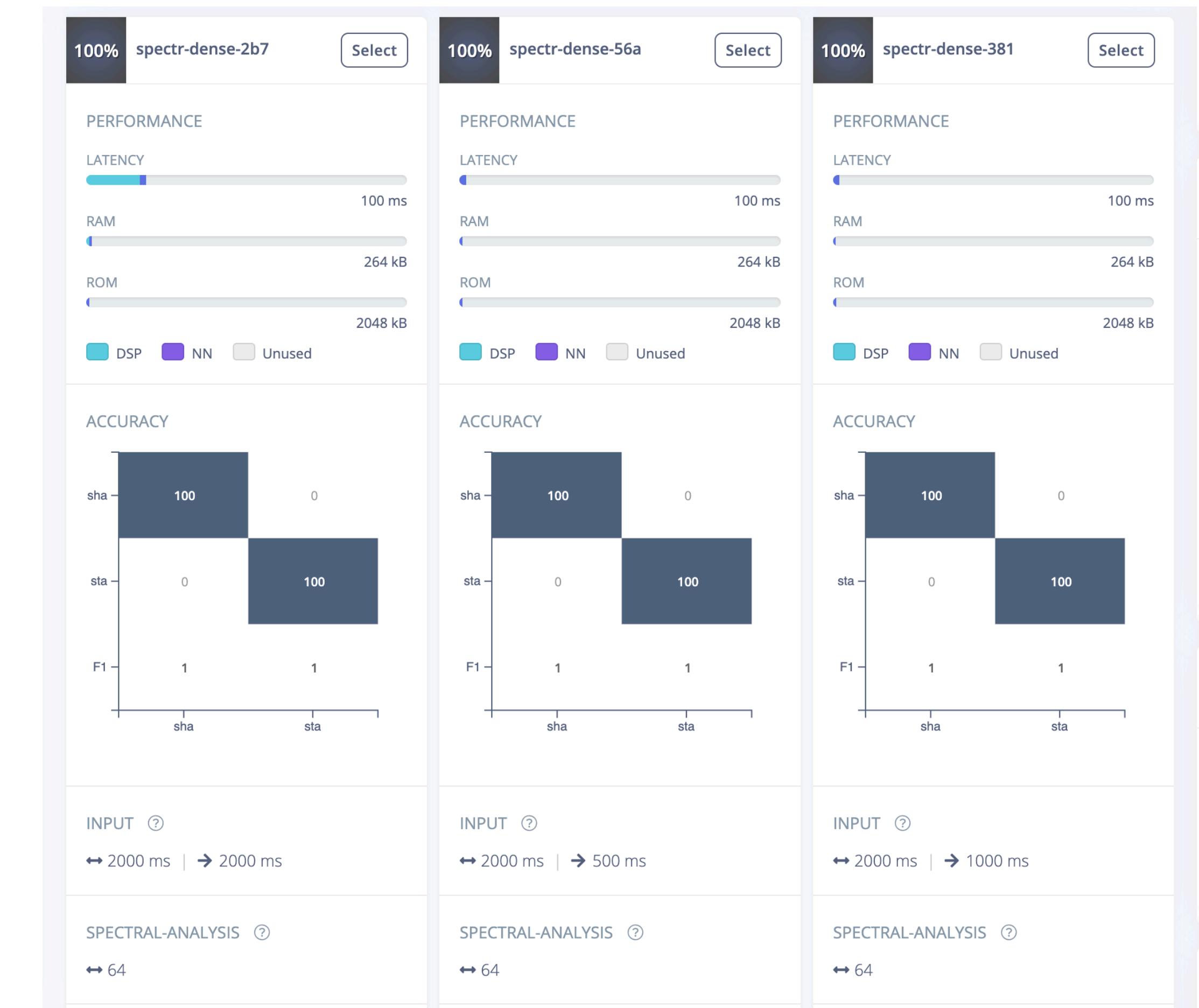
[Start sampling](#)



EON Tuner

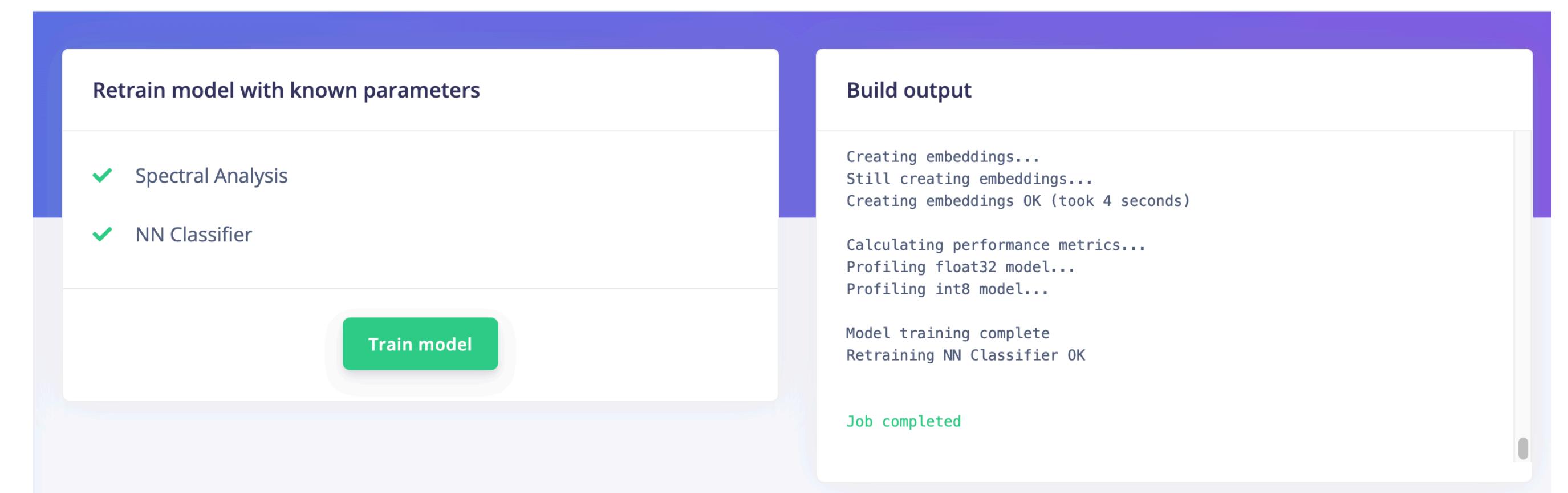


EON Tuner



select “continuous motion” and “RP2040”

Retrain model



Test the model

Deploy!

You can deploy your impulse to any device. This makes the model run without an internet connection, minimizes latency, and runs with minimal power consumption. [Read more.](#)

Create library

Turn your impulse into optimized source code that you can run on any device.

An Arduino library with examples that runs on most Arm-based Arduino development boards.



C++ library



Arduino library



Cube.MX CMSIS-PACK



WebAssembly



TensorRT library



Ethos-U library



Tensai Flow library



Simplicity Studio Component

Build firmware

Get a ready-to-go binary for your development board that includes your impulse.





Go to Arduino IDE 2.0!

Built Arduino library

Add this library through the Arduino IDE via:

[Sketch > Include Library > Add .ZIP Library...](#)

Examples can then be found under:

[File > Examples > MFR22_motion_inferencing](#)

The screenshot shows the Arduino IDE interface. The left sidebar contains icons for file operations like Open, Save, and Find. The main window displays a portion of an Arduino sketch with syntax highlighting for C++ and specific Arduino libraries. A context menu is open over the code, with the 'Examples' option selected. This menu lists various examples categorized into sections: 'Examples for Arduino Nano RP2040 Connect' (including MLC, Nano33BLE_System, PDM, Scheduler, ThreadDebug, USB Mass Storage, and USBHID), 'Examples from Custom Libraries' (including Adafruit BusIO, Adafruit GFX Library, Adafruit LiquidCrystal, Adafruit SSD1306, Adafruit Zero DMA Library, Adafruit Zero I2S Library, ArduinoBLE, ArduinoMotorCarrier, ArduinoOTA, ArduinoSound, Arduino_BHY2, Arduino_Braccio_plusplus, Arduino_LSM6DSOX, Arduino_PortentaBreakout, Ethernet, Firmata, GxEPD2, Keyboard, LiquidCrystal, MFR22_motion_inferencing, PacketSerial, SD, Servo, and WiFi). The 'MFR22_motion_inferencing' example is currently highlighted in the list.

```
/* Constant definitions
#define CONVERT_G
#define MAX_ACCEP

/*
 ** NOTE: If you
 ** This may be defined
 ** Try defining
 ** if it doesn't
 ** `<ARDUINO_COR
 **
 ** See
 ** (https://support.arduino.cc)
 ** to find where
 **
 ** If the problem
 */

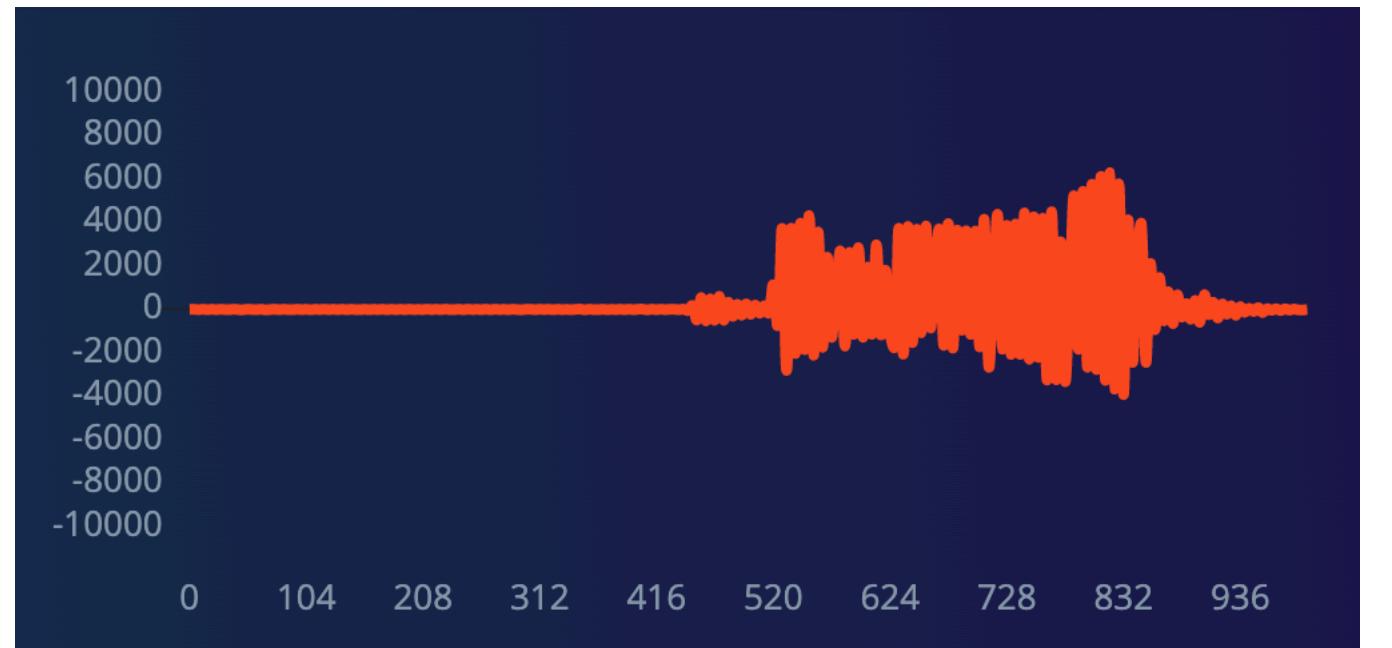
/* Private variables
static bool debug;
static uint32_t r;
static rtos::Thread;
static float buff;
static float info;

/* Forward declarations
void run_inference();

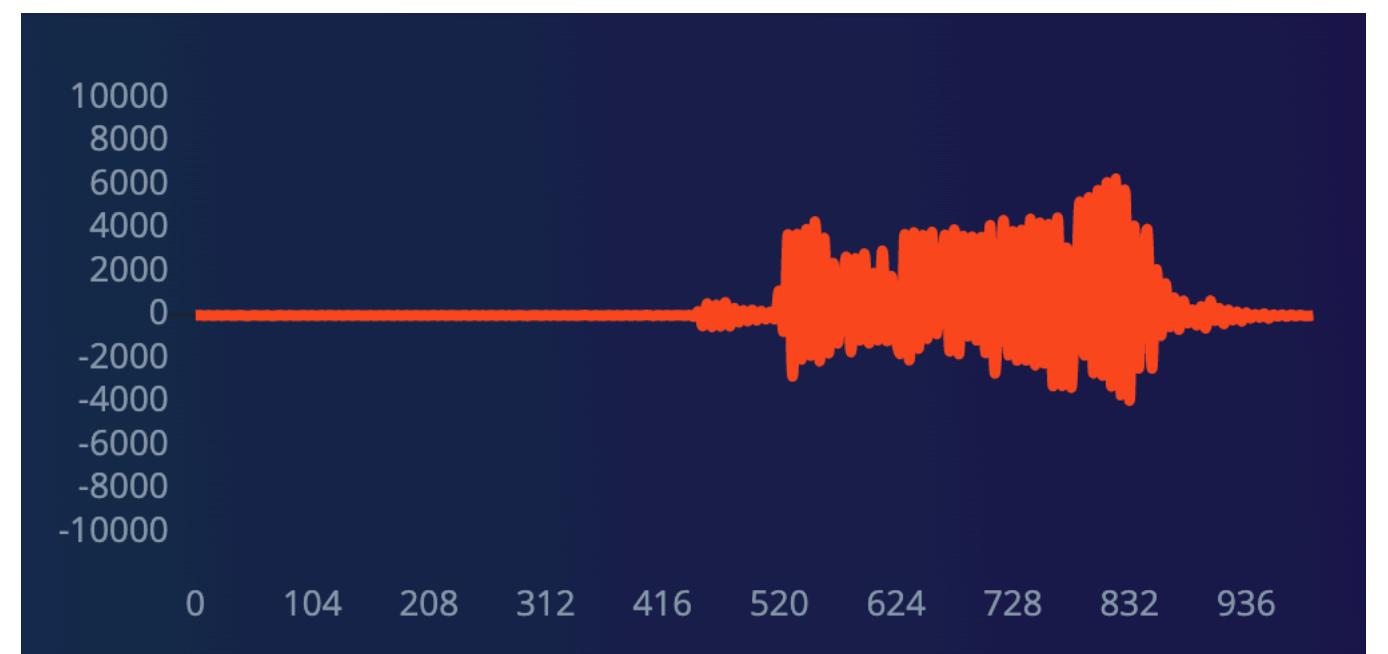
/**
 * @brief      Ard
 */
void setup()
{
    pinMode(LED_B
    digitalWrite(
        // put your s
    Serial.begin(
        // comment ou
        while (!Serial
            delay(100);
}
```

Example #2

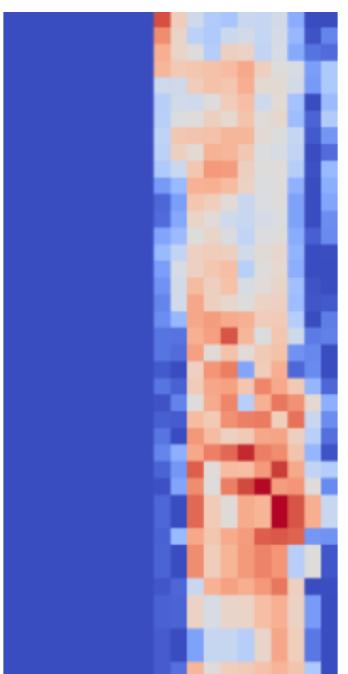
- use microphone
- continuous listening
- detect keywords



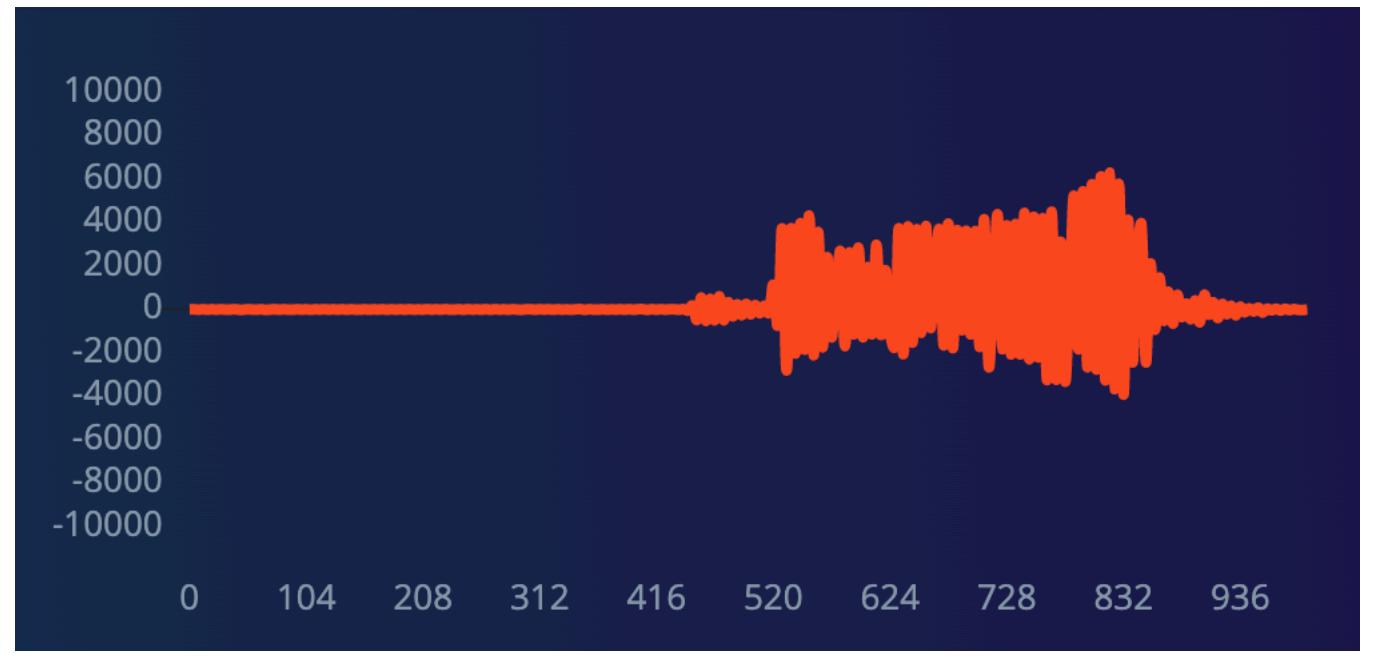
audio
(air pressure)



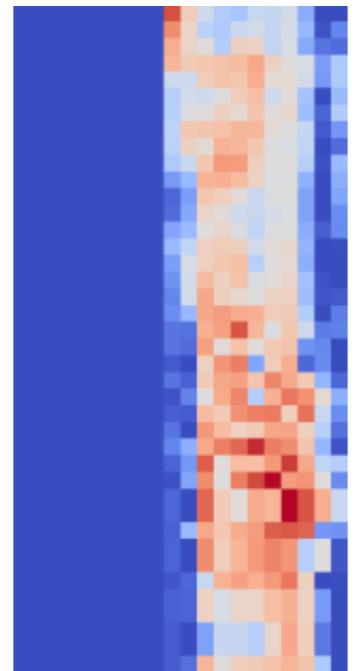
audio
(air pressure)



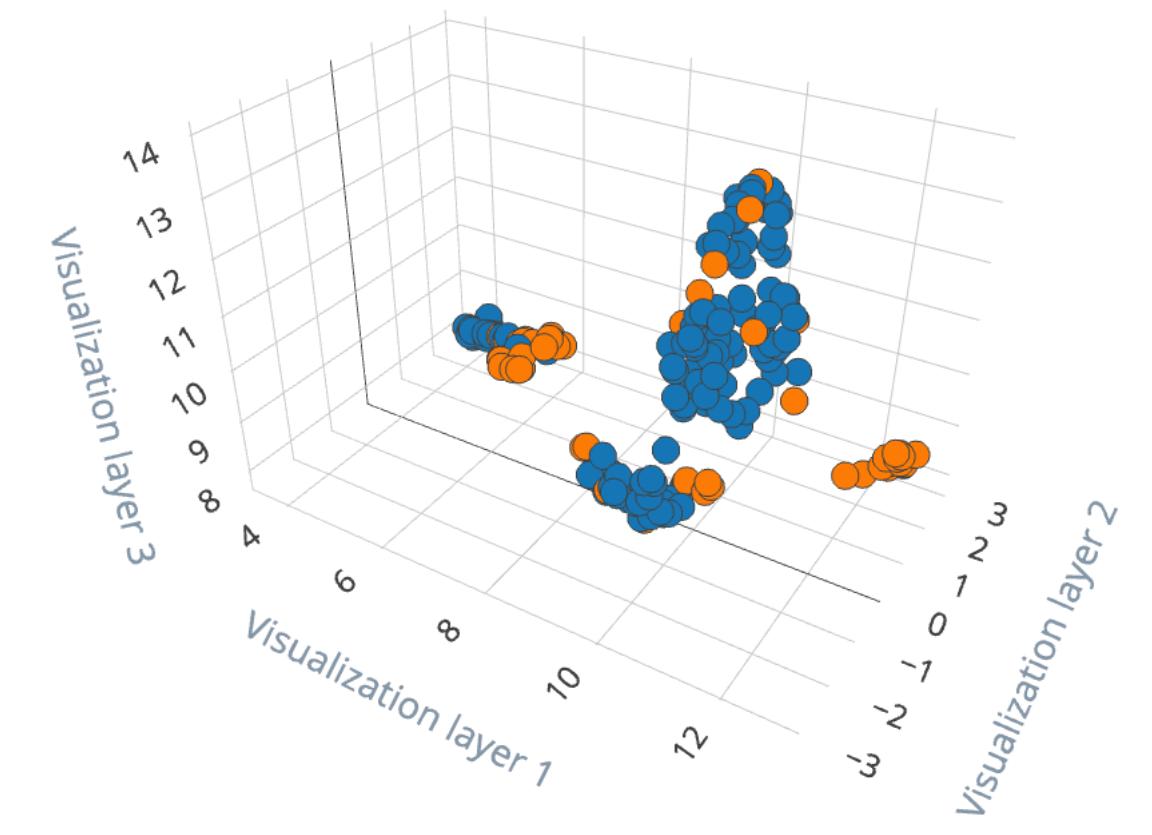
MFE and MFCC
(frequency-energy)



audio
(air pressure)



MFE and MFCC
(frequency-energy)

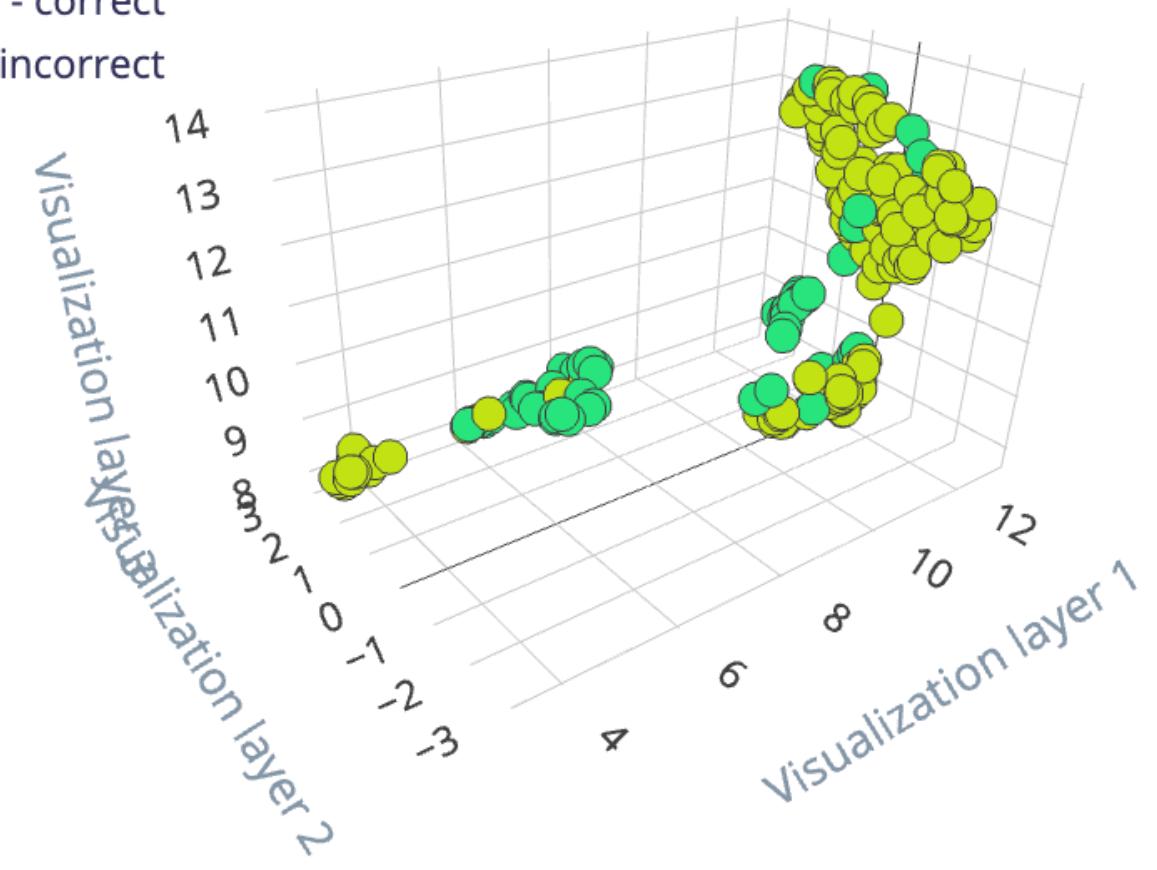


feature extraction

| | 00_CIAO | UNKNOWN |
|----------|---------|---------|
| 00_CIAO | 95.7% | 4.3% |
| UNKNOWN | 0% | 100% |
| F1 SCORE | 0.98 | 0.97 |

Feature explorer (full training set) [?](#)

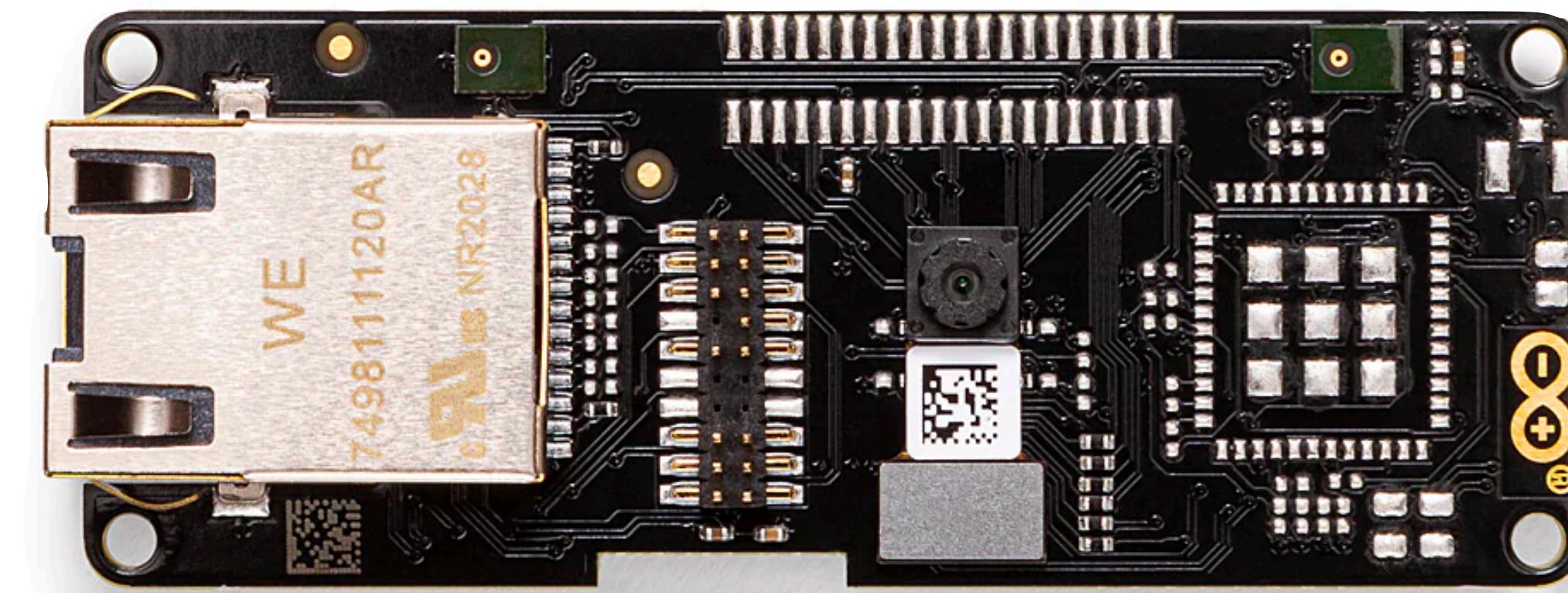
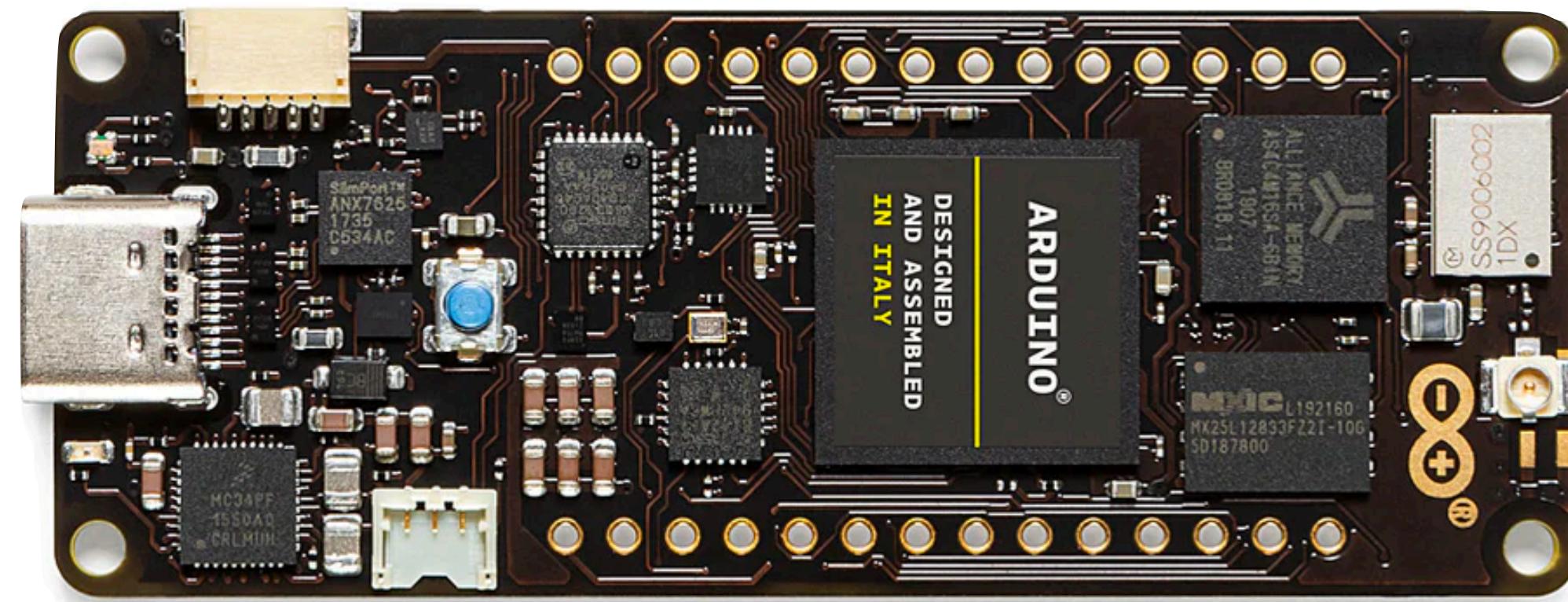
- 00_ciao - correct
- unknown - correct
- 00_ciao - incorrect



keras (CNN)

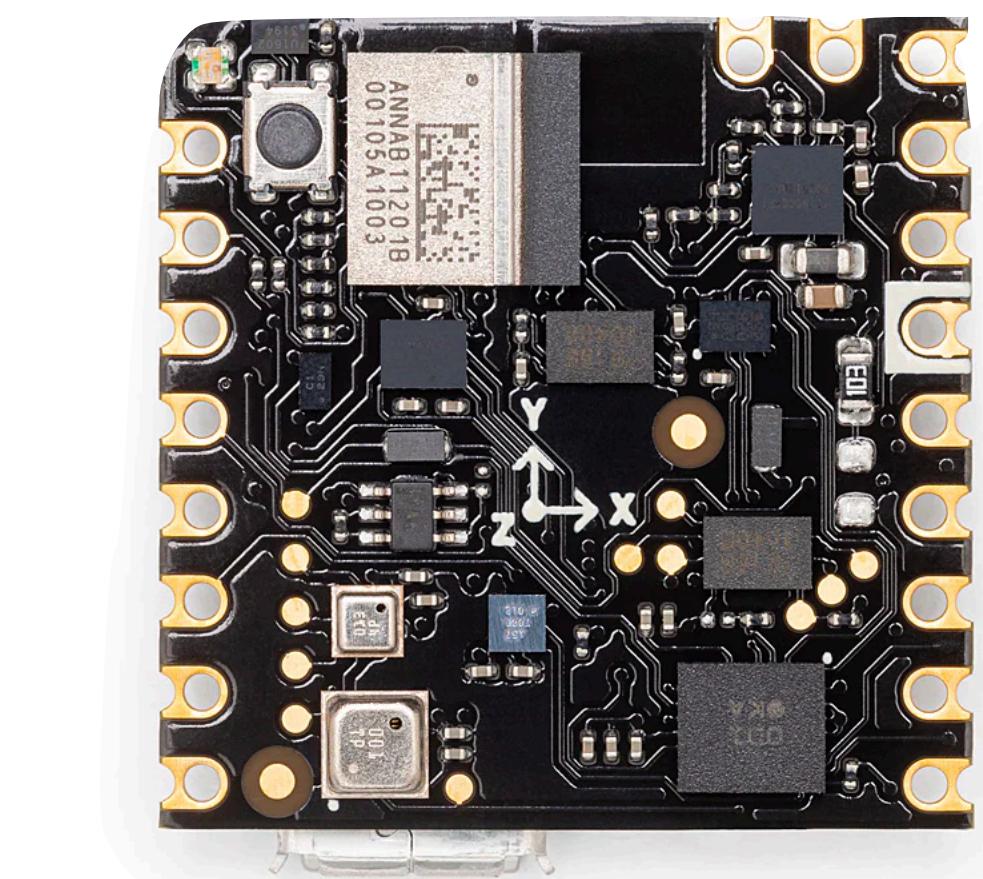
Unleash TinyML power!

Portenta H7

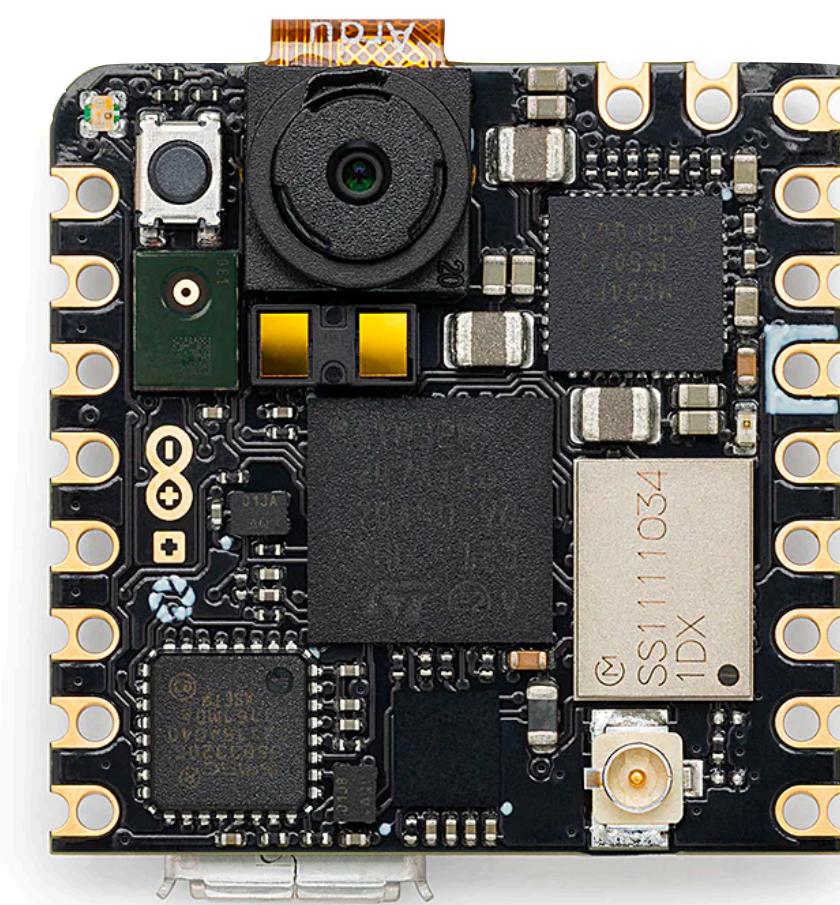


vision shield

Nicla



Sense ME



Vision H7

Challenges

Challenges



<https://blog.arduino.cc/2022/10/10/arduino-and-k-way-with-the-support-of-edge-impulse-team-up-for-a-new-idea-of-smart-clothing/>

Challenges

**Build ML projects,
win big prizes**

Challenge yourself to build innovative ML projects using Edge Impulse. Share your projects to empower other developers and engineers to get started on their ideas.

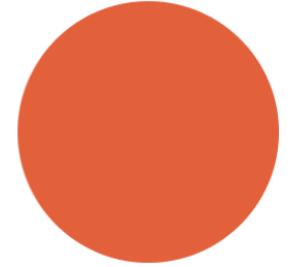
[Submit project](#)



Build



Learn



Showcase



<https://www.edgeimpulse.com/projectofthemonth>

TinyML

Meetup and TALKS webcast



TinyML

License

TinyML License



Useful links

- tinyml.org
- edgeimpulse.com
- tensorflow.org/lite
- arduino.cc

Contact me

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gbr1.github.io 

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@br1johnny 

