Lecture and tutorial:

"IoT modules and its tutorial by using ~~SBC~~ MCU"

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Himeji, JAPAN

Contents

- Introduce myself
- Overview of IoT/MEMS
- Instruction for IoT tutorial

University of Hyogo

Graduate School of Engineering

Hyogo prefecture

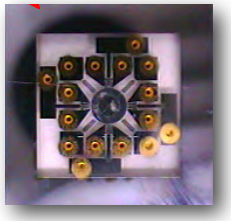
Sapporo
Aomori
Akita
Morioka
Sendai
Niigata
Fukushima
Nagano
Utsunomiya
Tokyo
Nagoya
Chiba
Shizuoka
Tottori
Osaka
Himeji
Kobe
Tsu
Fukuoka
Matsuyama
Kagawa
Saga
Oita
Nagasaki
Kumamoto
Kagoshima
Miyazaki

Himeji castle

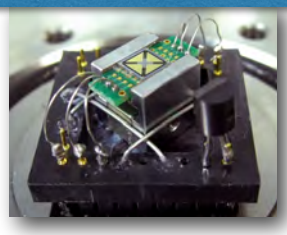
Kobe Beef

My research history

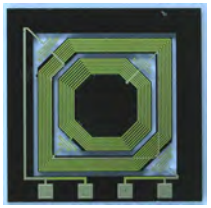
- MEMS physical sensors
  - Gyroscope
  - Accelerometers
- MEMS actuators
  - Mirror device
  - PID control system
- Environmental sensor
  - Multi sensor module for health monitoring



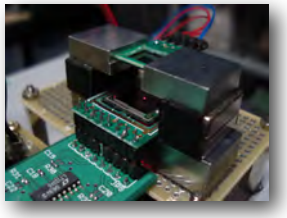
2D gyroscope



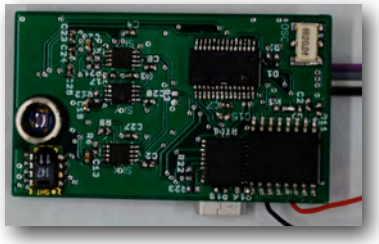
Vibratory beam accelerometer



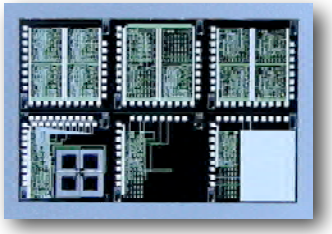
Electromagnetic MEMS mirror



Mirror control system



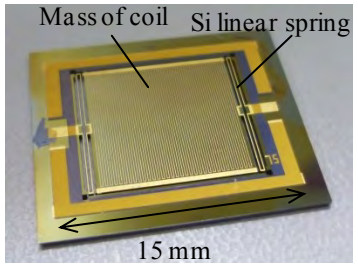
Multi-sensor module

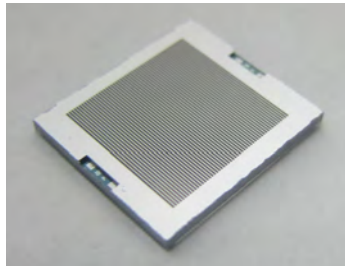


Environmental sensor

Recently, working on

- **Vibration MEMS energy harvester**
- **IoT systems for Medical applications**





Vibration energy harvester

Clean room facilities for MEMS

CleanRoom for MEMS

- Operated & managed by
  - 3 faculties
  - 1 technician
  - ~20 students

- **Full MEMS fabrication process on site**
  - Photomask fabrication, photolithography
  - Deep-RIE, dry etching, wet etching
  - Metallization, Magnetic/PZT film sputtering
  - Electroplating, Polymer-flexible electronics

AMERI, U-Hyogo

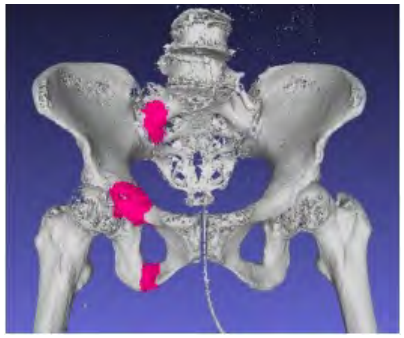
Move to New institute

open Apr. 2022

Advanced **M**edical **E**ngineering
Research **I**nstitute,
University of Hyogo

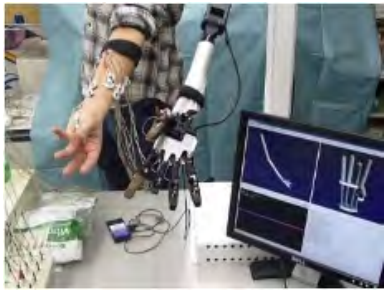
In the 2nd largest prefectural hospital in Hyogo

Research Topics of AMERI

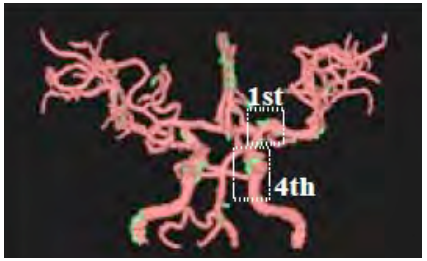


AI-based pelvic fracture location determination

Health observation using adhesive plaster-type MEMS sensors



Finger joint estimation robotic prosthetic hand

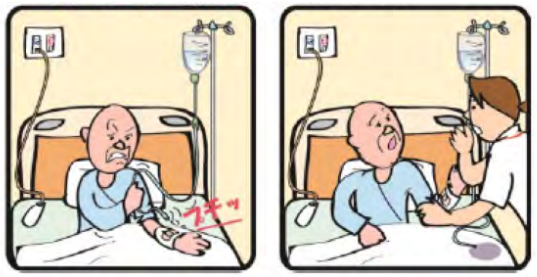


AI-based aneurysm visualization

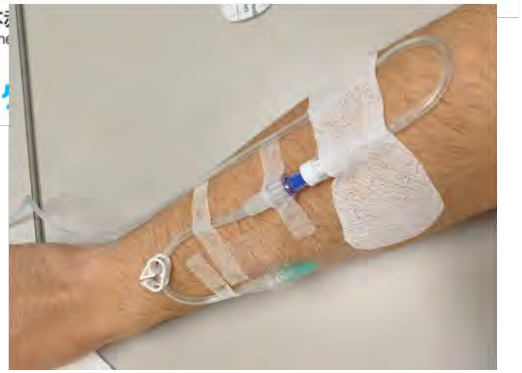
Silicone flexible 3D printed artificial heart valve

Ex.1) Tube self-extraction sensing

Unscheduled removal of tubes is a serious problem



Did you ou pull it out?



Sensor monitors

> Pull out

> Signs of Pulling

Two types of capacitive sensor

Stretchable force sensor
With adhesive touch sensor

+ BLE beacon module
Battery

Medical + IoT

Removal of tube monitoring on Cloud

Realtime visualization by Grafana

LINE alarm on smartphone

Grafana is very powerful visualization tool

We'll have tutorial with Grafana later

Ex.2) Fall down detection around bed

The number of incidence of falls among elderly patients in hospital is high

- **Falls** account for **20.5%** of incidents in Japan.*

  (total falls: 983, total incidents: 4802)

- Half of the falls occur at bed-leaving.

It is difficult to frequently observe patients due to staff shortages

Bed-leaving sensors are being increasingly utilized as preventive measures against falls during bed-leaving behavior.

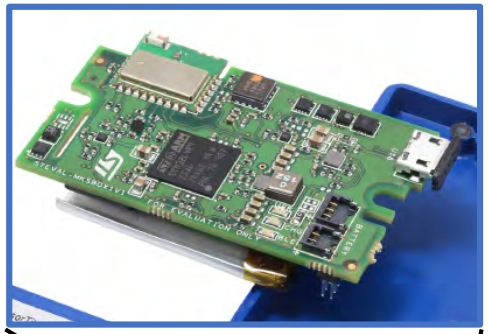
* Japan Council for Quality Health Care, Medical Accident Information Collection and Related Activities, Annual Report 2020

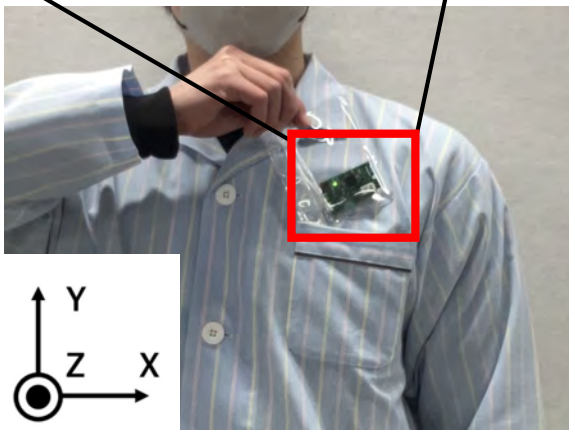
9-DOF Sensor and BLE MCU

STEVAL-MKSBOX1V1TM product summary	
iNEMO 6DoF inertial module	LSM6DSOX
Digital 3-axis magnetometer	LIS2MDL
Digital nano pressure sensor	LPS22HH
Other features	BLE etc.

LSM6DSOX product summary	
Power consumption	0.55mA
full-scale acceleration range	± 2g / ± 4g / ± 8g / ± 16g
full-scale angular rate range	± 125dps / ± 250dps / ± 500dps / ± 1000dps / ± 2000dps
MLC decision tree	Up to 8 trees, 32 features
Other features	Equipped with a MEMS motion sensor that incorporates **MLC** etc.

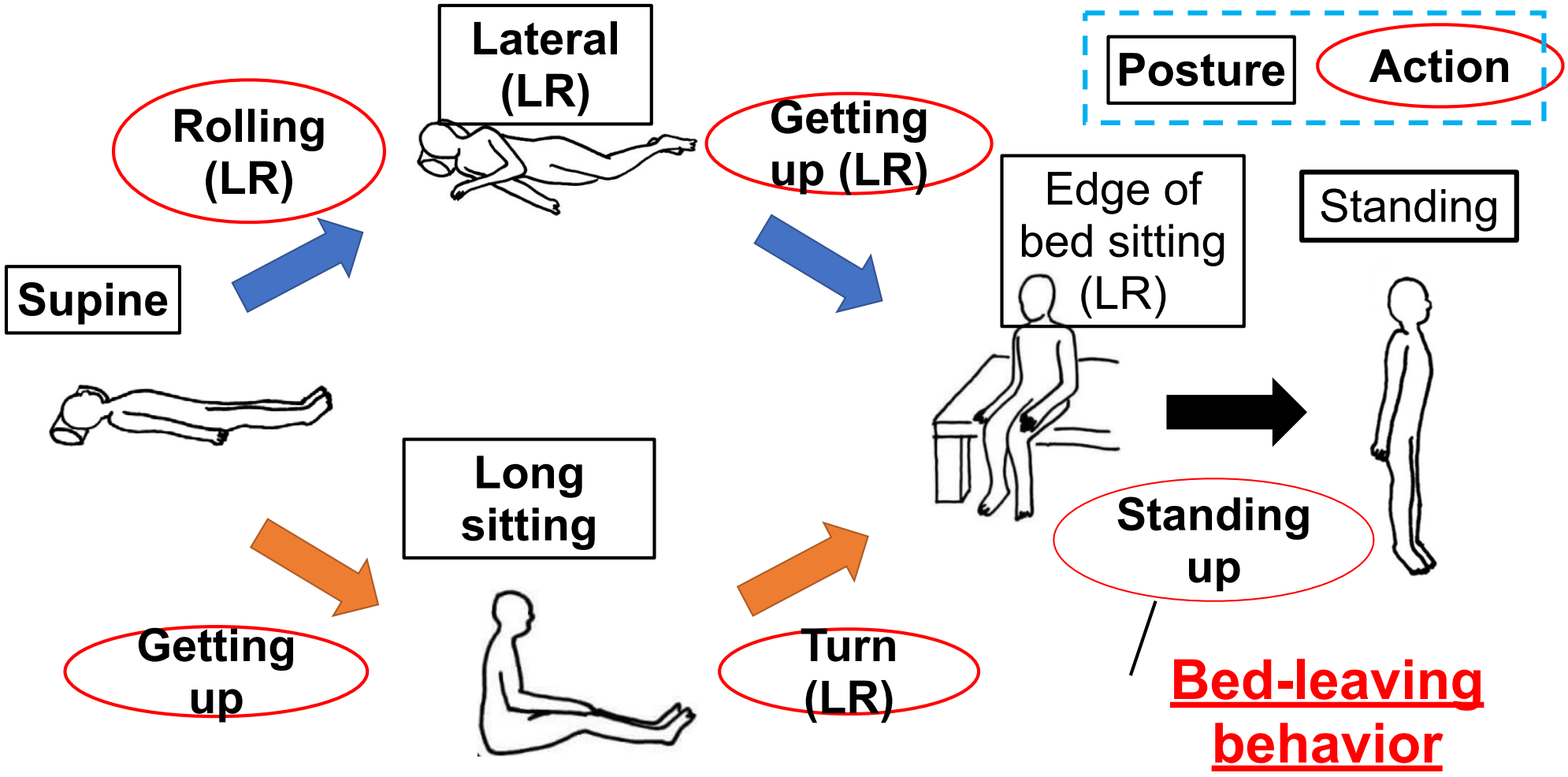
STEVAL-MKSBOX1V1™ (STMicroelectronics)





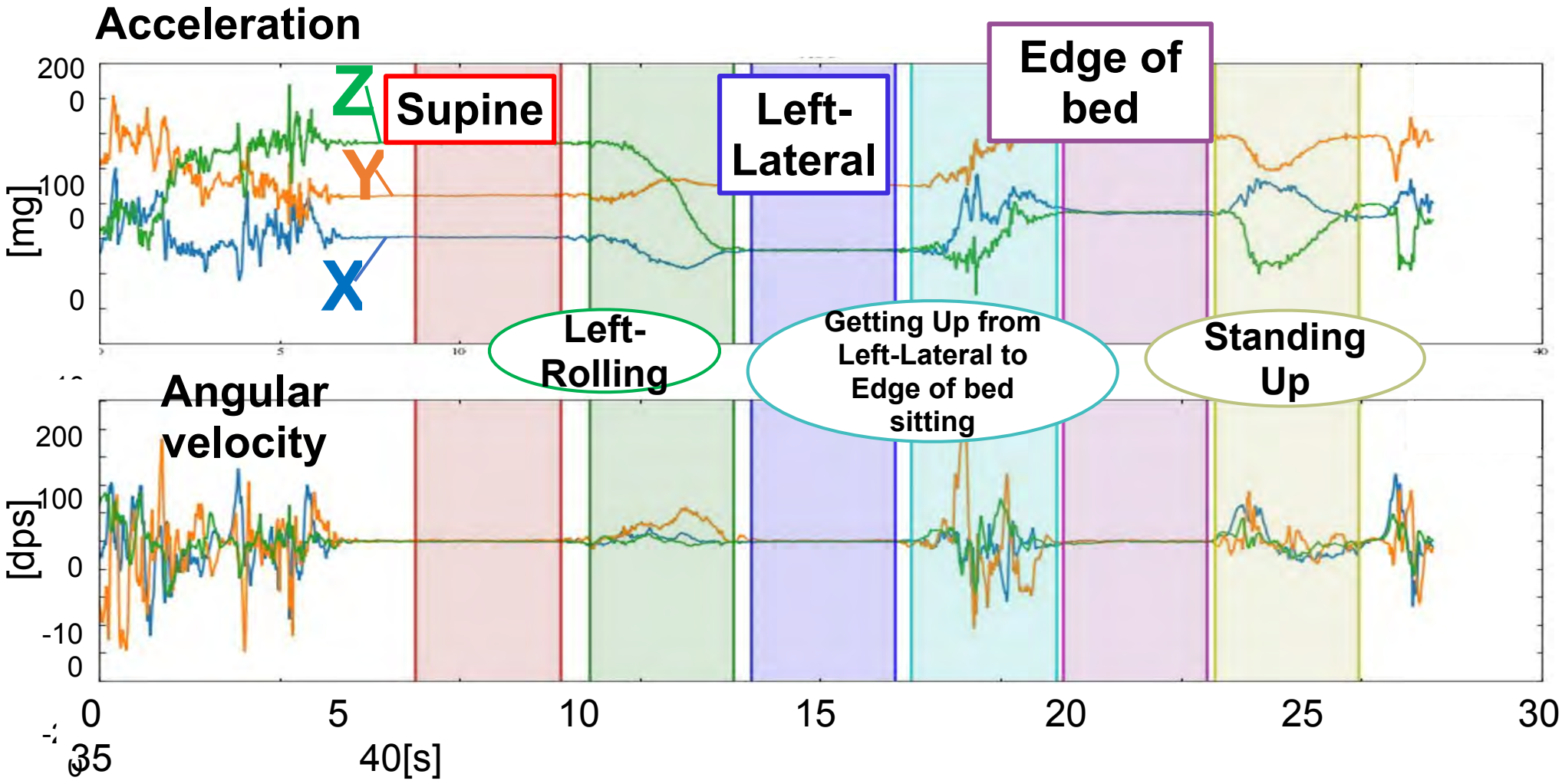
- Insert sensor into the chest pocket of the patient's clothing.

Postures and actions measurements



Training data preparation with predefined protocols

Annotation to Acc.& A.Velo. Data from situations



Real-time detection experiment

Value	Behavior
0	Supine
1	Supine to Left lateral
2	Supine to Right lateral
3	Left lateral
4	Right lateral
5	Supine to Long sitting
6	Long sitting
7	Left lateral to Left edge of bed
8	Right lateral to Right edge of bed
9	Long sitting to Left edge of bed
10	Long sitting to Right edge of bed

Medical + IoT + AI

Contents

- Introduce myself
- **Overview of IoT/MEMS**
- Instruction for IoT tutorial

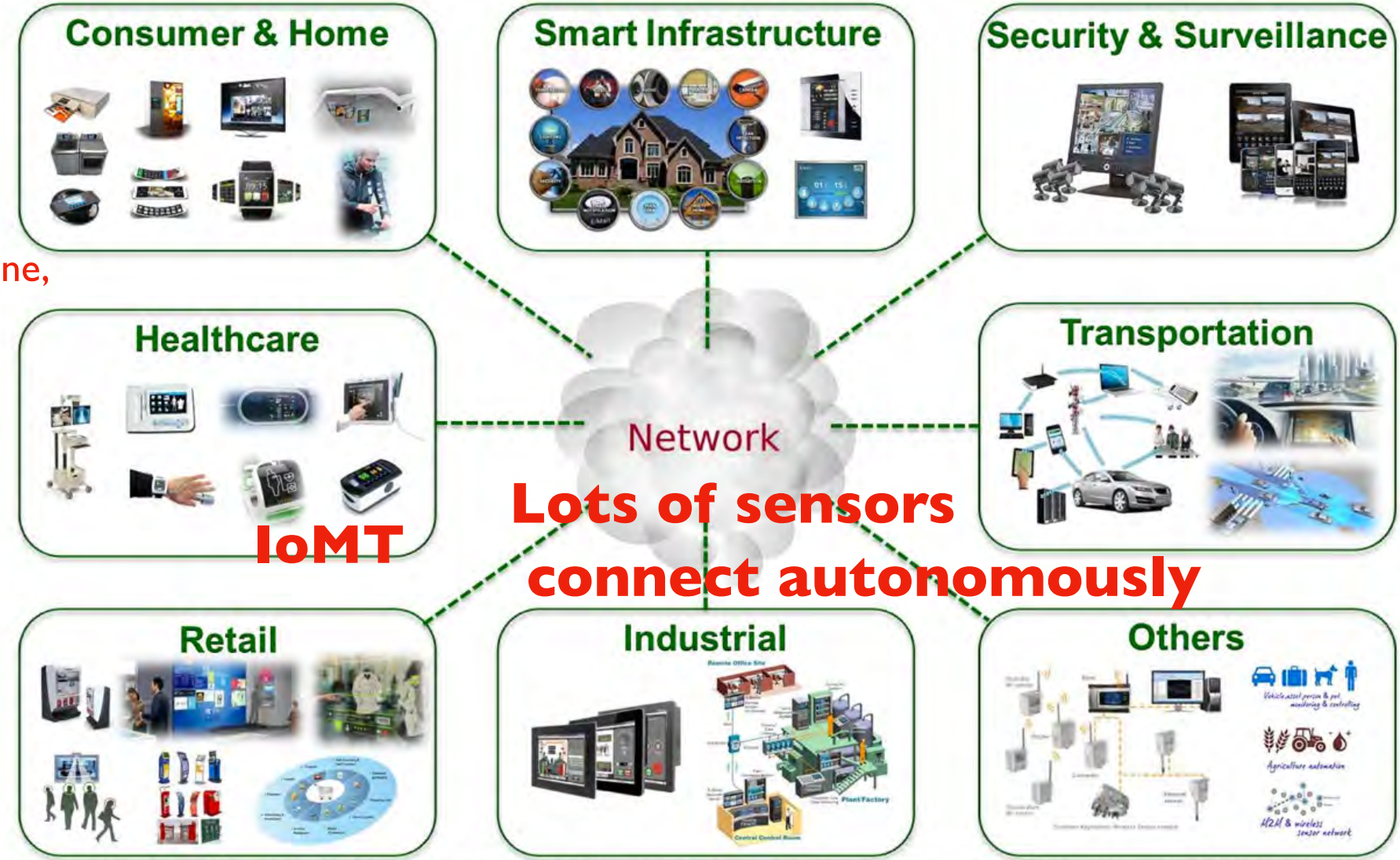
IoT (Internet of Things)

Human uses the Internet

Smartphone, Tablet, PC

IoT

Internet connection for everything not limited to Human operated device

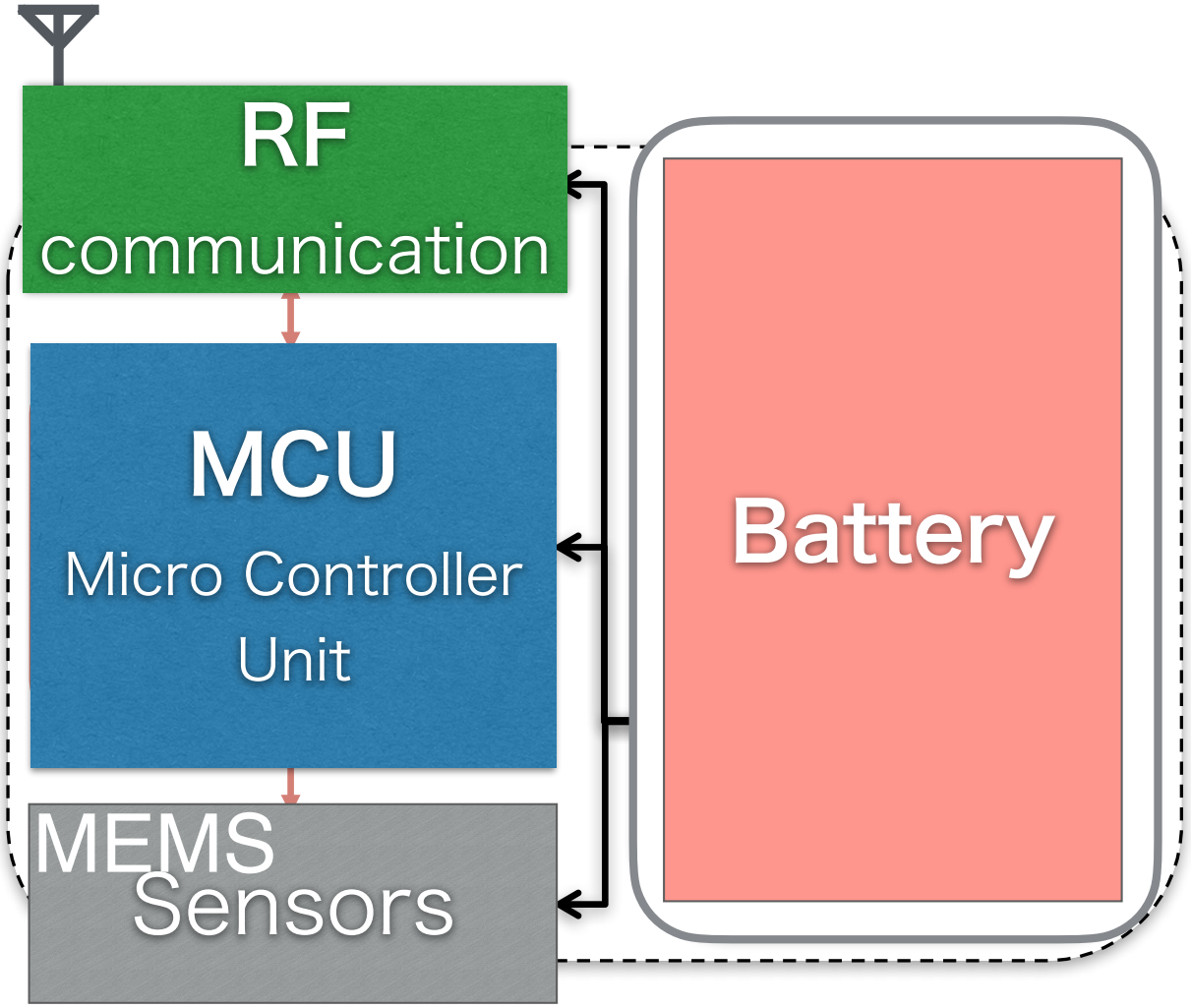


IoMT

Lots of sensors connect autonomously

IoT node architecture

Typical architecture of IoT node



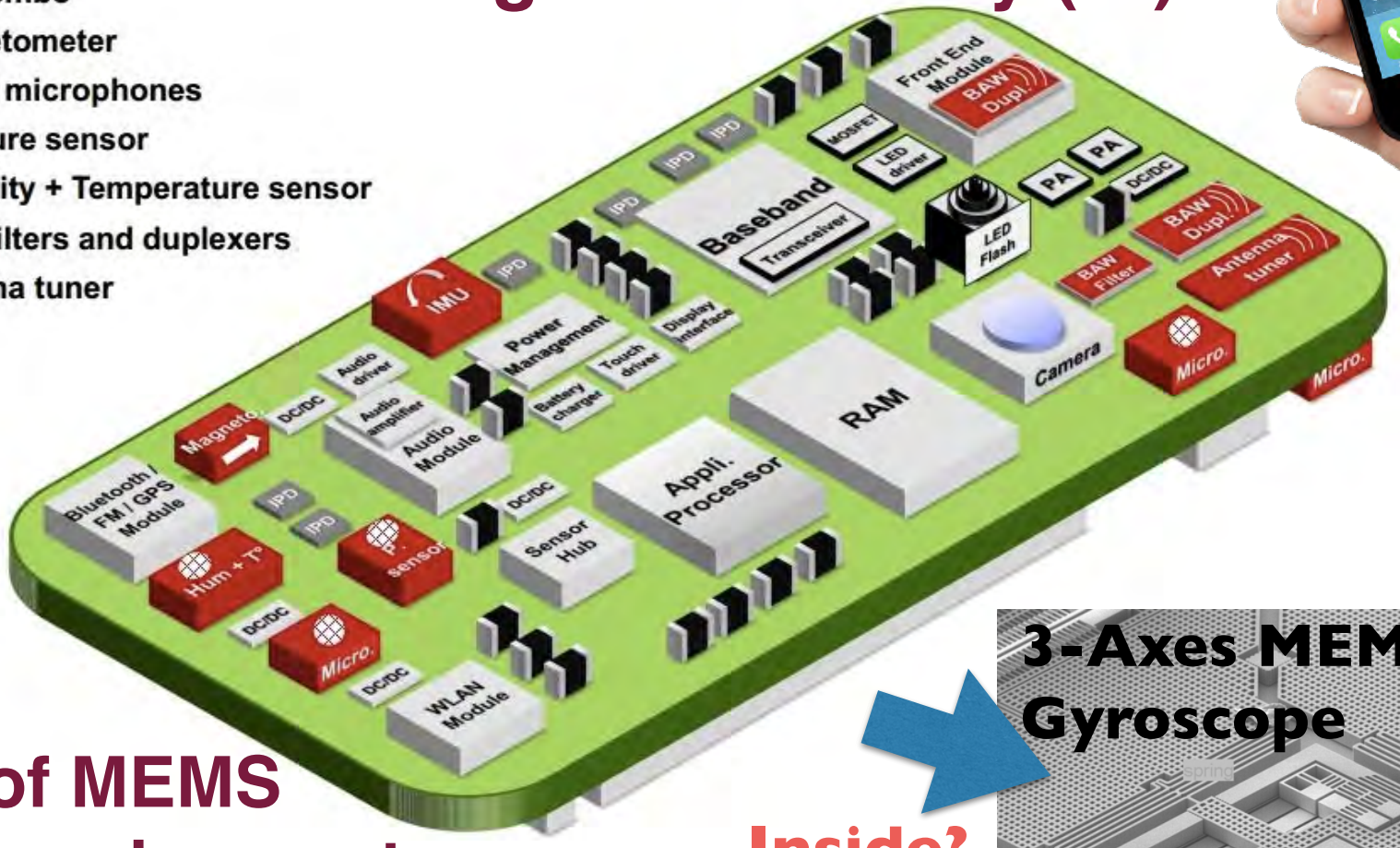
Architecture of a sensor node

IoT has developed dramatically thanks to **MEMS**

MEMS - Micro Electromechanical Systems

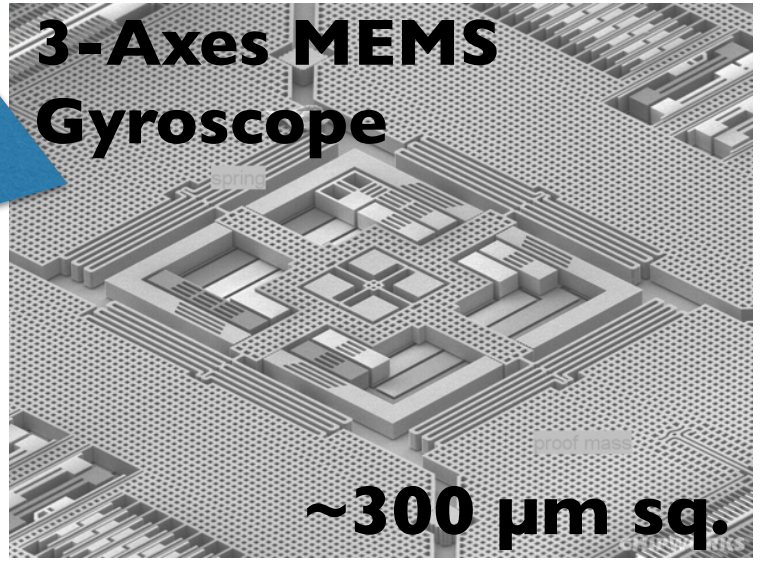
MEMS = Fusion of ultra small machine and Integrated Circuity (IC)

- IMU combo
- Magnetometer
- MEMS microphones
- Pressure sensor
- Humidity + Temperature sensor
- BAW filters and duplexers
- Antenna tuner



Full of MEMS sensors in smart phone

Inside?



at least <u>5 MEMS sensors</u>

History of MEMS application

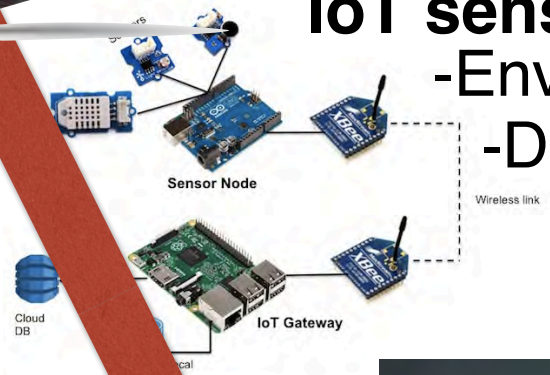
Automotive

-**Airbag** control
-Electronic stability control
-Rollover detection
-Navigation (GPS support)

Mobilephone / Entertainment

-Input device
-Navigation

IoT sensor node



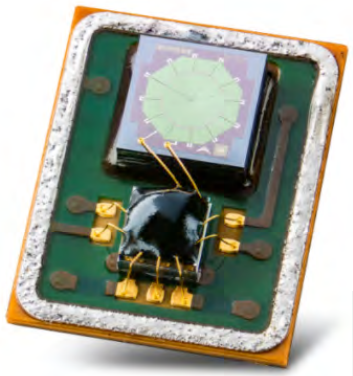
-Environmental sensing
-Drones

Health

-Medical devices

Performance & Number ↑
Size & Cost ↓

MEMS device 1: Microphone



4 x 3 mm

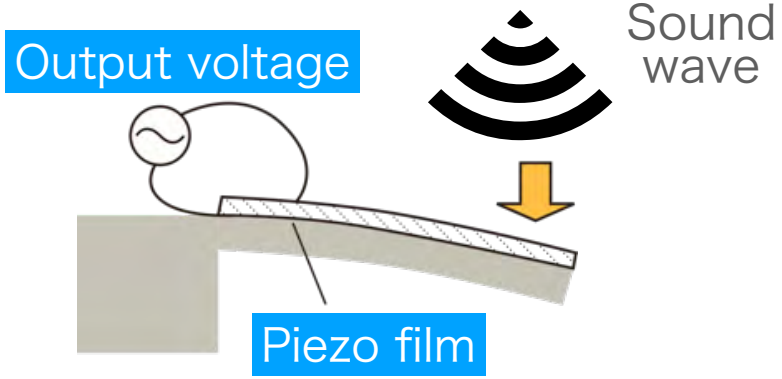
© Vesper

Rice grain size

vesper

MEMS makes compact, high-performance microphones inexpensive

Cantilever with piezoelectric material vibrate by sound



iPhone 11

© Voista Media

iPhone 11 has 4 microphones

3 4 for main mic.

Others are use for noise cancelation

MEMS device 2: Apple watch etc.

Activity tracking for health care

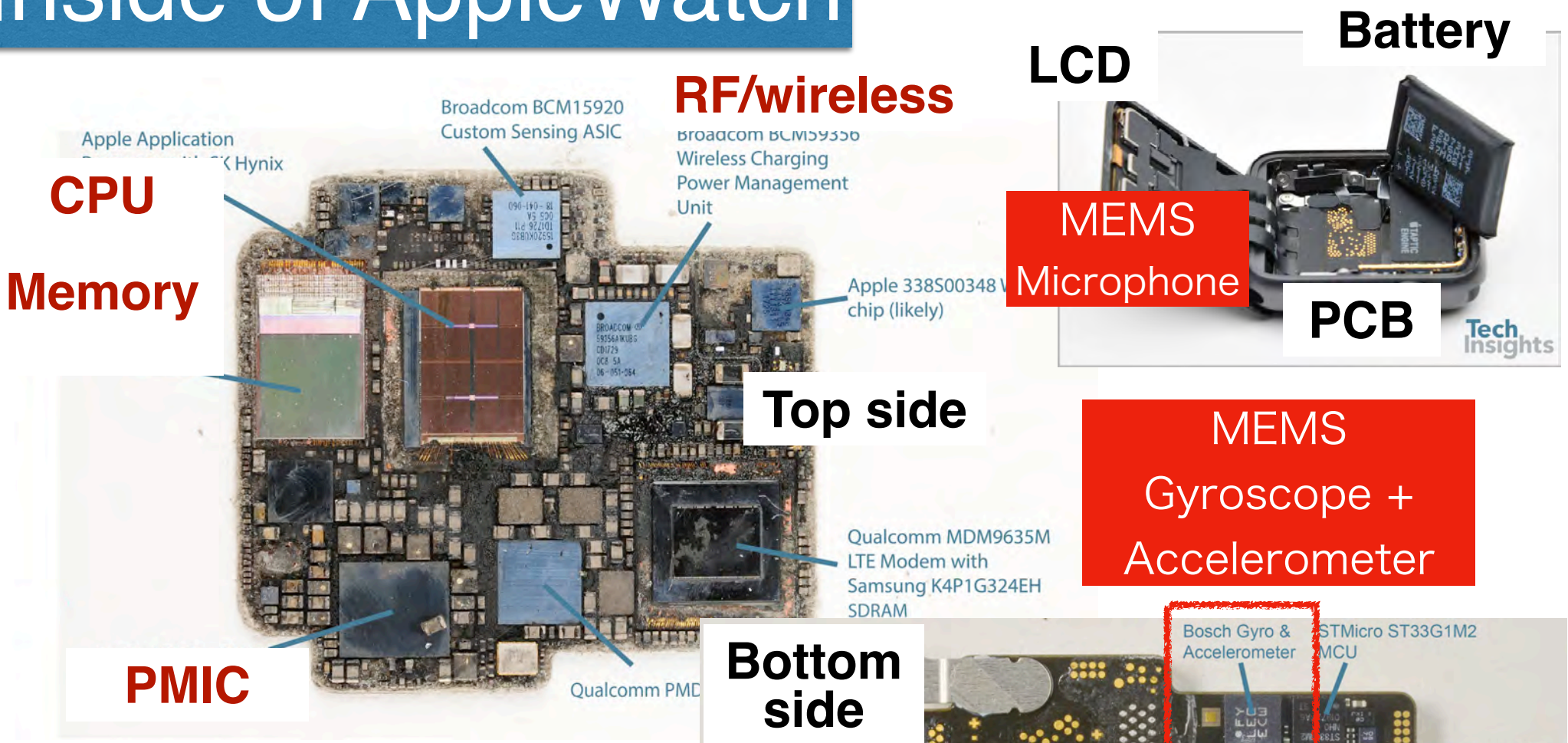
Similar technology

RF, MCU, battery
&
MEMS sensors
Acc. Gyro,

Optical sensor
For SPO_2, heart rate

Various devices of "healthy gadgets"

Inside of AppleWatch



AppleWatch 3rd gen.

IoT on market : IoT Body scale

¥20,000
(USD 150)
worth the price

Withings

Made in France

- **WiFi connection**
- **No switch, Easy to use**
- **Automatically data upload**

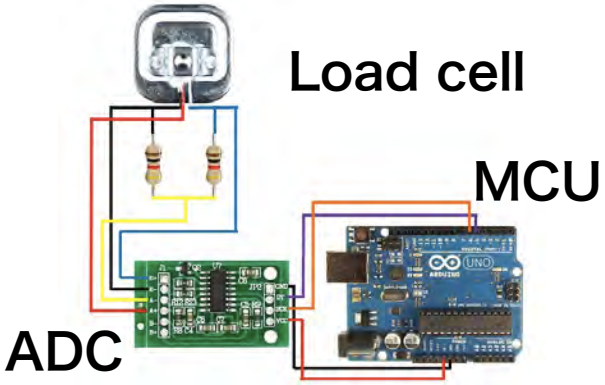
Replaced new one

Data still ongoing

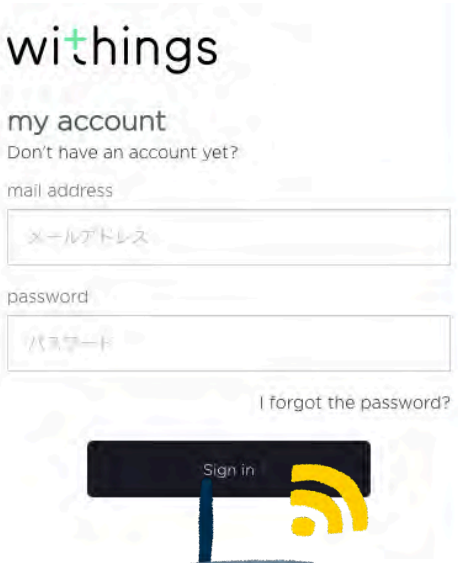
Statistics of my body weight for 13 yrs. are stored on Cloud

Inside of Withings IoT scale

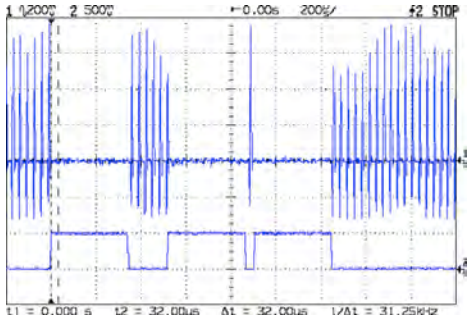
Body weight measured
by load-cell (strain sensor)



Withings server



Body fat % by impedance measurement

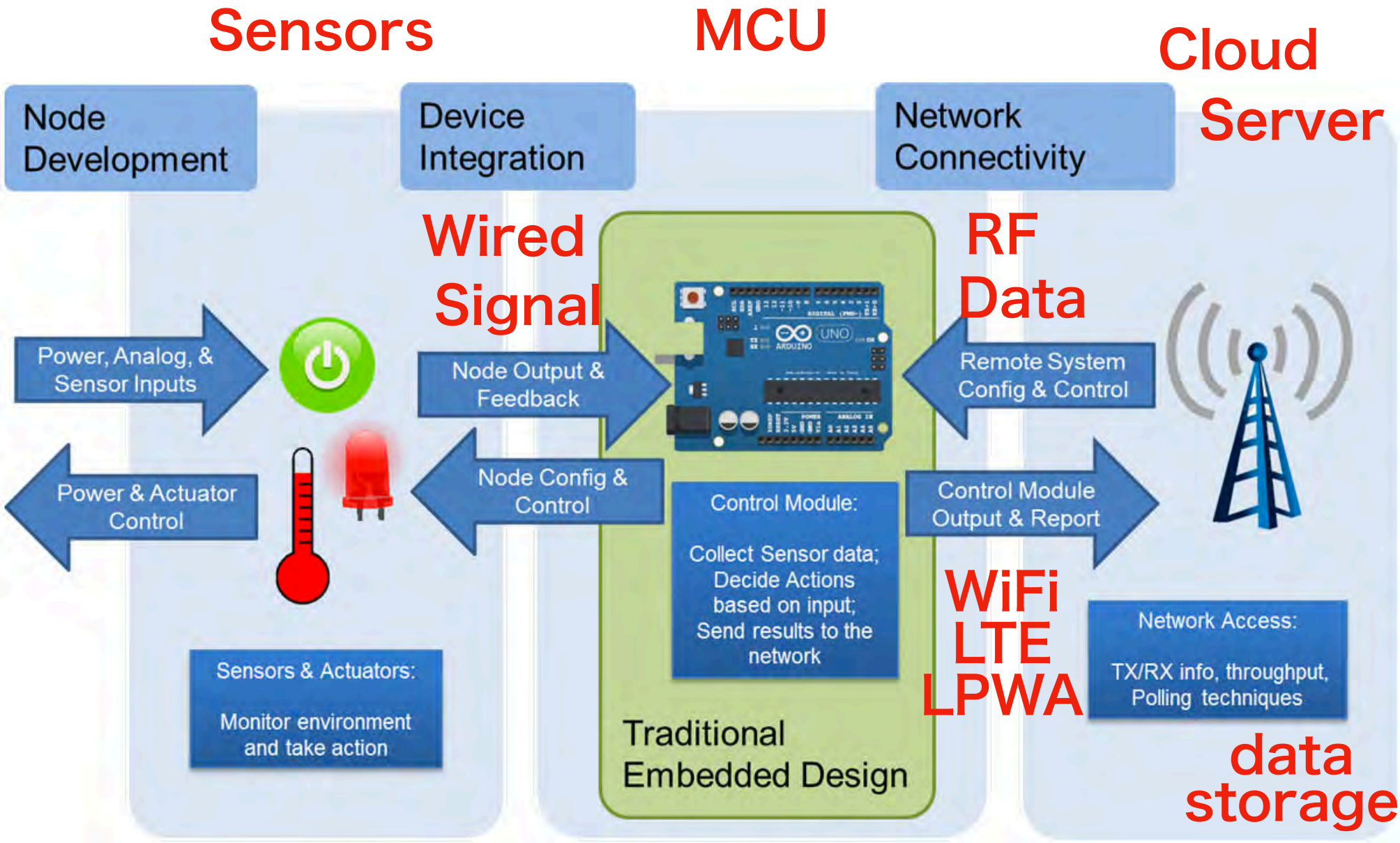


WiFi

Generate graph on cloud

Connect via Wifi (pre-configured SSID / password)
> upload data to Withings cloud server

Typical configuration IoT

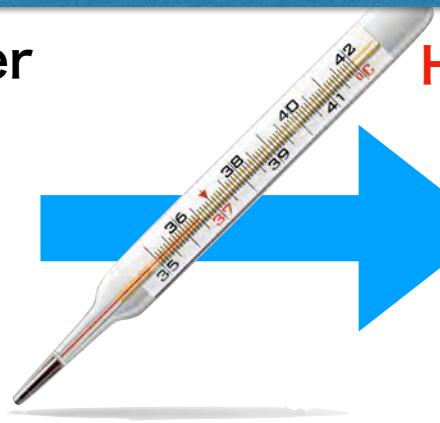


>NEXT **Introduction to the history of measurement, using temperature as an example**

Temperature measurement (primitive method)

ex. Glass tube thermometer

Physical change
> Temperature



Have you ever seen it?

Physical change
> thermal expansion of alcohol

No electricity

Visual check only

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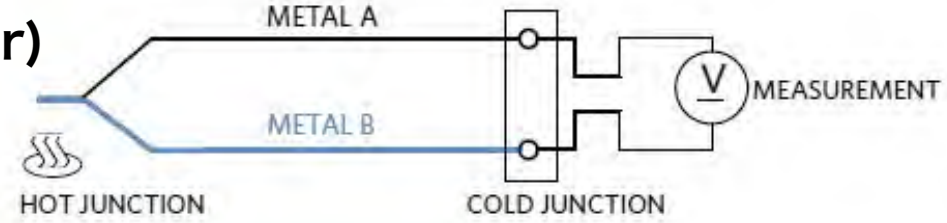
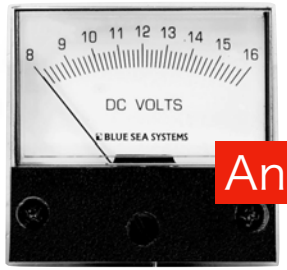
ex. Thermocouple
(temperature sensor)



Analog meter



Analog value

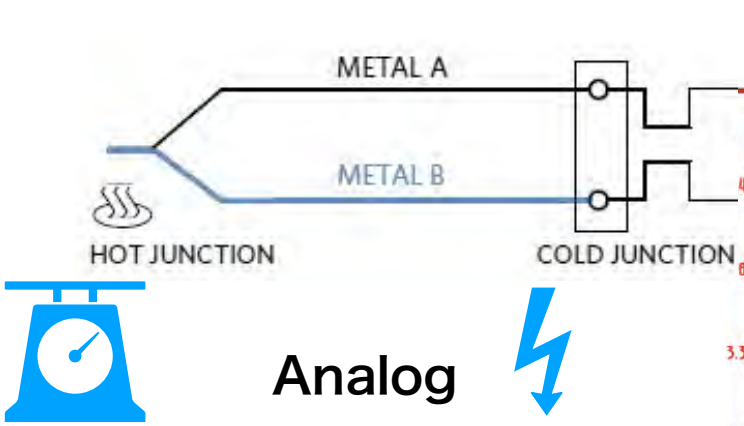
Physical change
> Temperature

Electrical change
> Electromotive force

Physical change
> meter movement

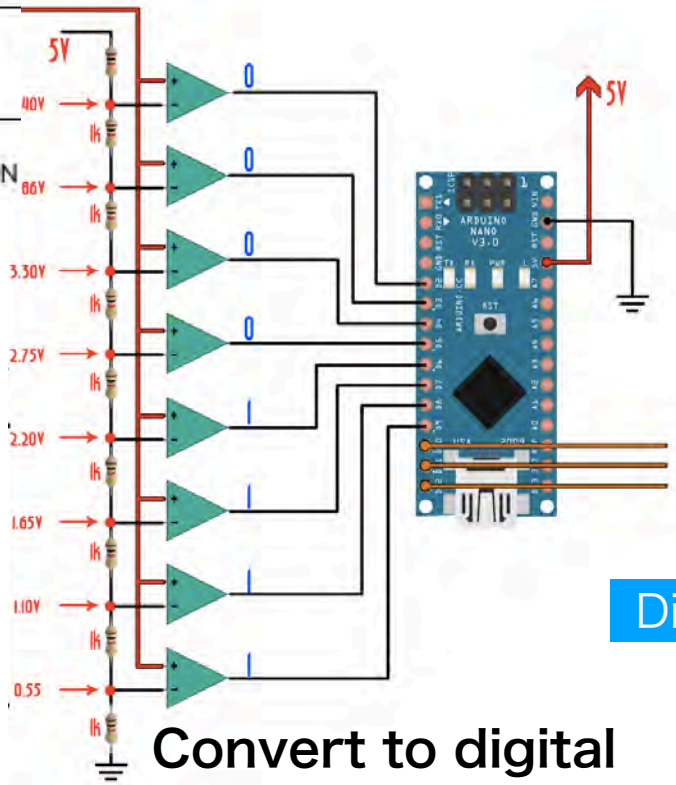
Analog values are difficult to connect MCU or SBC

Temperature measurement (w/ ADC)



Analog

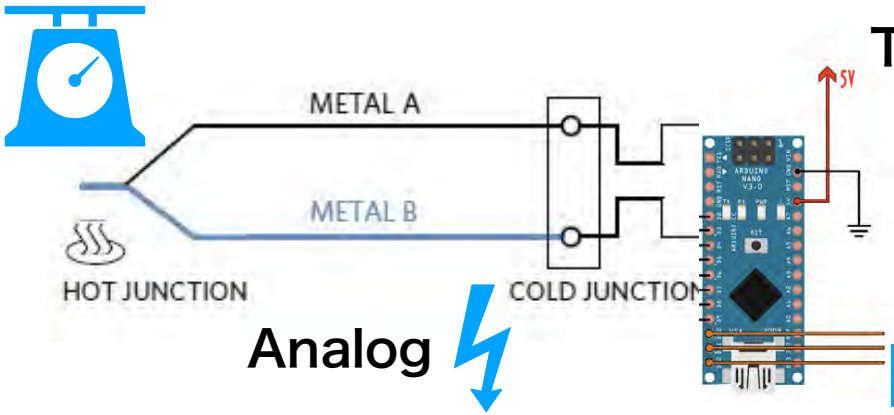
series of comparators



Resolution depends on the number of ladder resistors

Digital digit

Convert to digital (ADC)



Analog

Typical MCU (ESP32) has
Internal ADC
12 bits, 3.3V

Digital digit

Resolution: 0.8 mV

Recent digital output MEMS sensor

BOSCH
Invented for life

BME280
combo sensor

Use this on tutorial

Fully digital output with compensation parameters

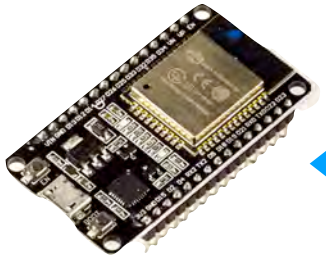
Single chip
-Temperature
-Humidity
-Pressure

Main features

Relative Humidity
Measures relative humidity with a fast response time

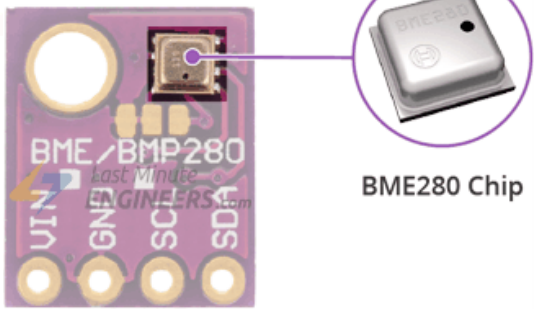
Pressure
Measures barometric pressure and altitude

Temperature
Measures ambient temperature



MCU

Digital



Sensor

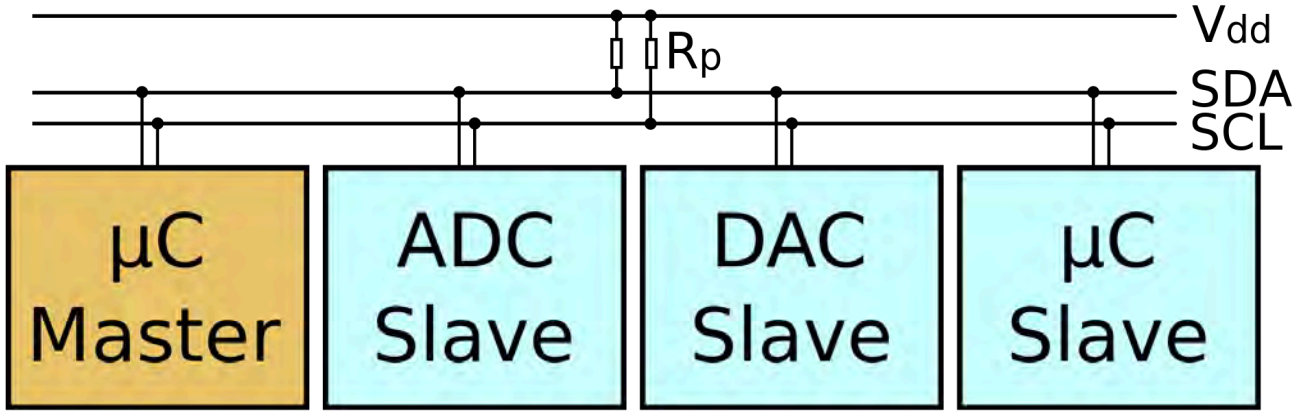
BME280 Chip

Direct connection via I2C/SPI protocol

What is interface protocol?

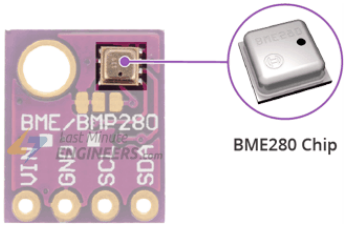
1) Inter-Integrated Circuit (I²C)

I²C (**Inter-Integrated Circuit**), pronounced *I-squared-C*, is a synchronous, multi-master, multi-slave, packet switched, single-ended, serial computer bus. It is widely used for attaching lower-speed peripheral ICs to processors and microcontrollers in short-distance, intra-board communication. Alternatively I²C is spelled **I2C** (pronounced I-two-C) or **IIC** (pronounced I-I-C).



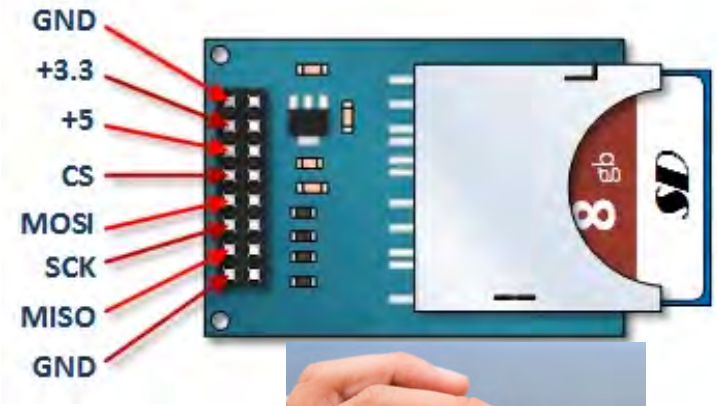
2 digital signal line + 2 power line

Selected by unique-address

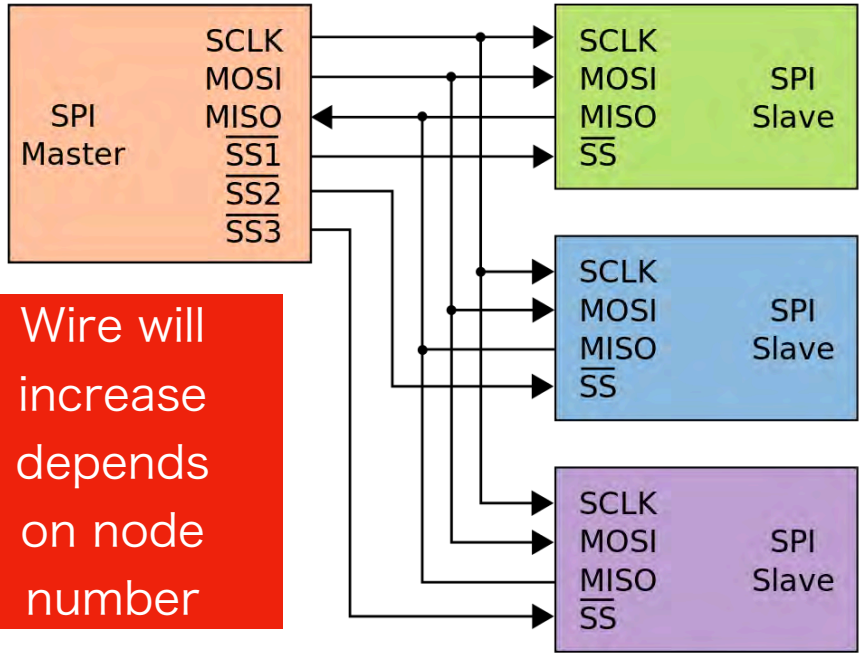


2) Serial Peripheral Interface (SPI)

The **Serial Peripheral Interface** (**SPI**) is a synchronous serial communication interface specification used for short-distance communication, primarily in embedded systems. Typical applications include Secure Digital cards and liquid crystal displays. SPI devices communicate in full duplex mode using a master-slave architecture with a single master. The master device originates the frame for reading and writing. Multiple slave-devices are supported through selection with individual slave select (SS), sometimes called chip select (CS), lines.



High-speed



Wire will increase depends on node number

2 digital signal line + 2 power line

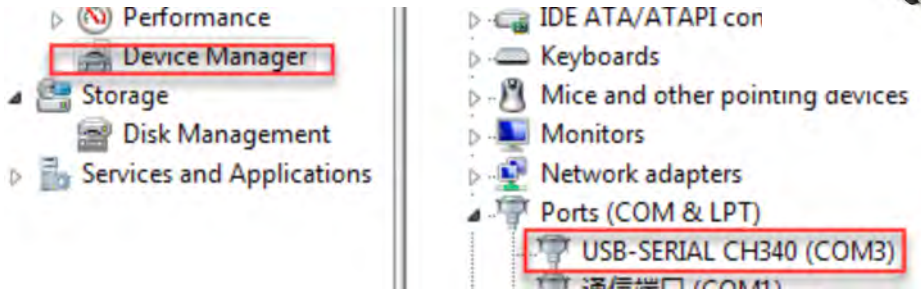
+1 CS line for chip select

3) Universal Asynchronous Receiver/Transmitter (UART)

A universal asynchronous receiver-transmitter (UART) is a computer hardware device for asynchronous serial communication in which the data format and transmission speeds are configurable. The electric signaling levels are handled by a driver circuit external to the UART. Two common signal levels are RS-232, a 12-volt system, and RS-485, a 5-volt system.

Old PC has RS-232C Serial port

USB (Universal Serial Bus) Replaced it



Windows recognize it as COMmunication port

Almost all MCU board includes USB-UART converter chip Ex. CH340

Contents

- Introduce myself
- Overview of IoT/MEMS

- **Instruction for IoT tutorial**

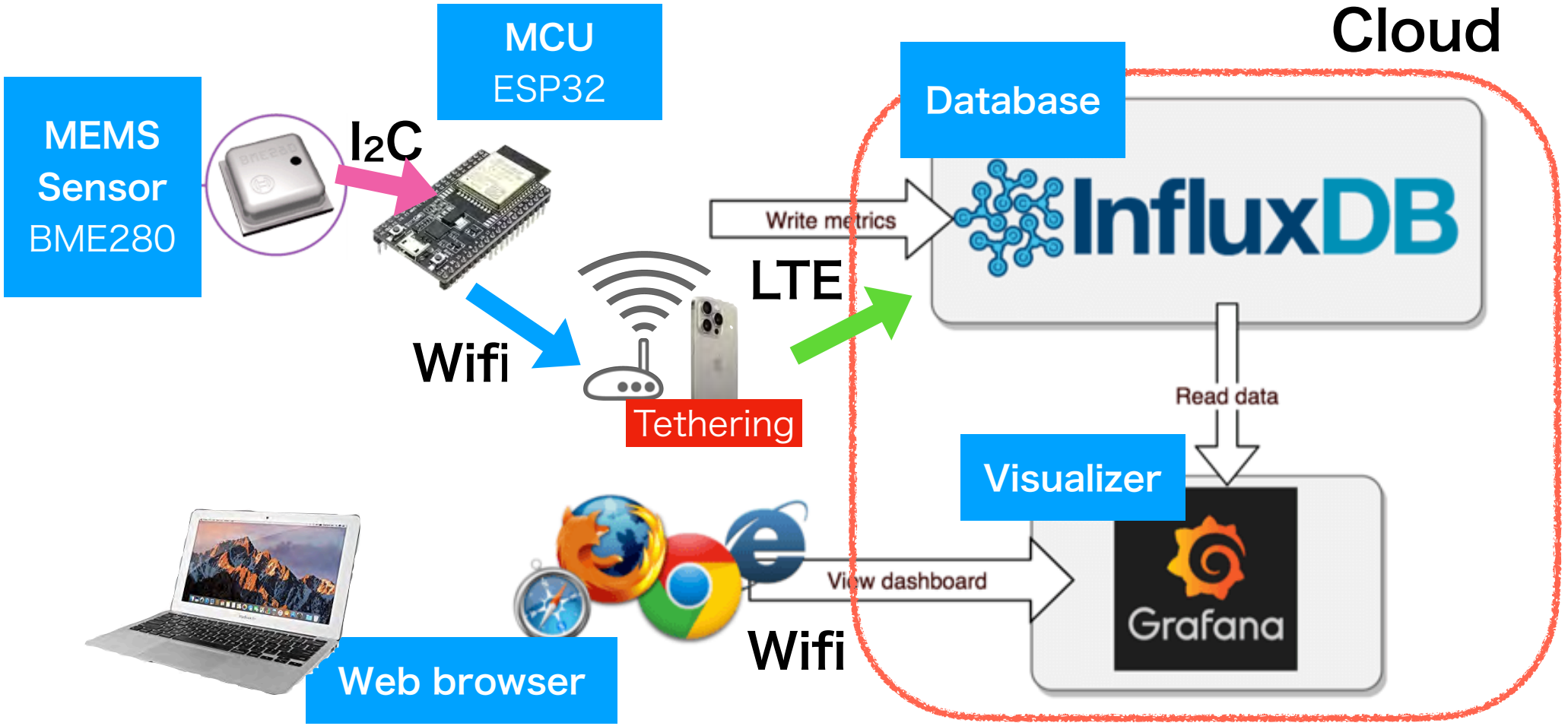
Goal of tutorial

Sensing data from MEMS environmental sensor

> gather & processing data on MCU

> transmit to InfluxDB database on cloud

> visualized by Grafana > display on web browser



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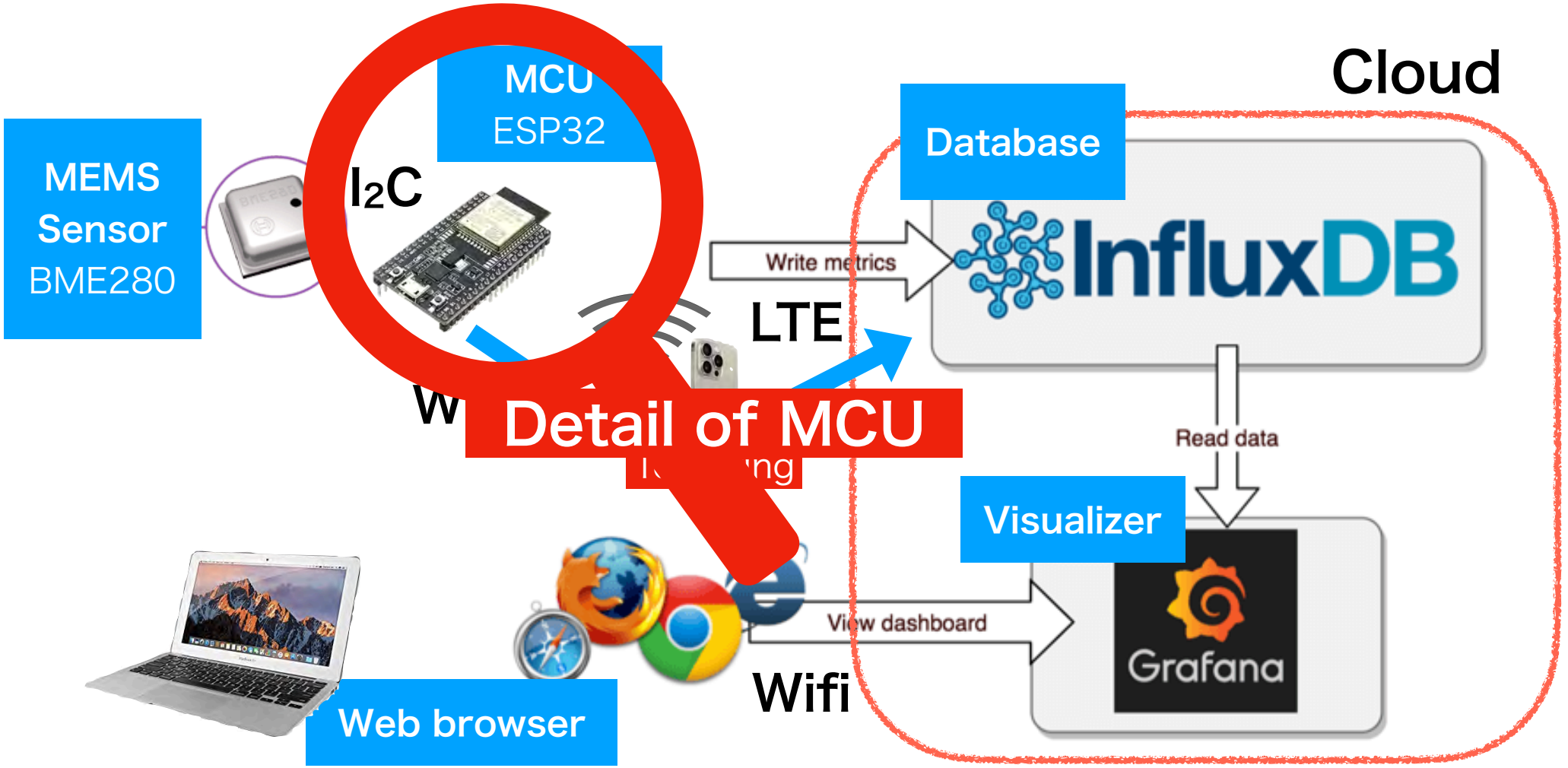


Wide variety of MCU variations

ARM-based MCU is popular these days

Apple silicon also ARM based core

Raspberry Pi Pico

Wi-Fi, BLE

ARM Cortex M0+

ESP32

Use this on tutorial

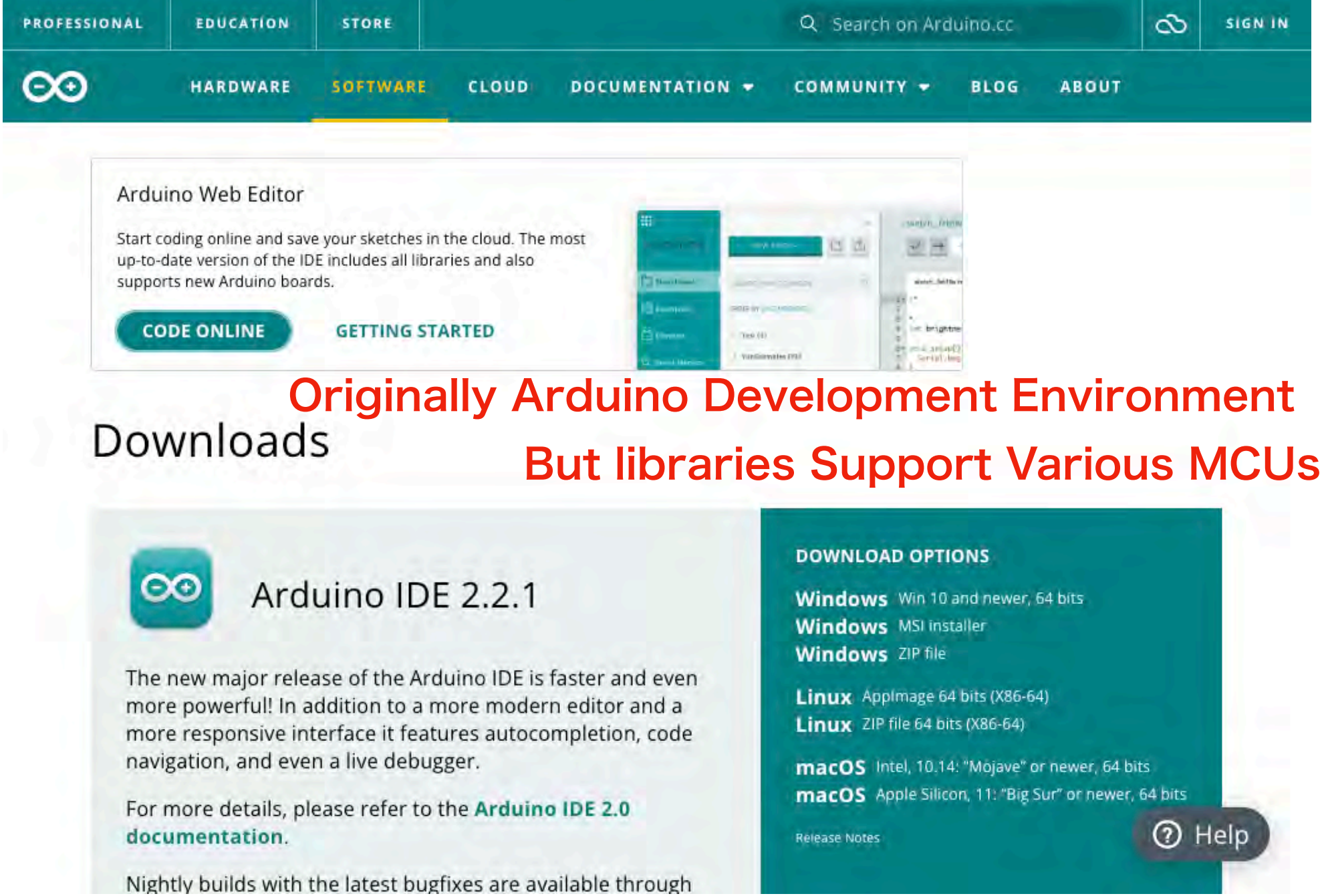
Tensilica Xtensa LX6

nRF52840

ARM Cortex M4

Each company's original IDE (Integrated Development Environment)

Generic development environment is useful in terms of asset utilization


PROFESSIONAL
EDUCATION
STORE
Search on Arduino.cc
SIGN IN
HARDWARE
SOFTWARE
CLOUD
DOCUMENTATION
COMMUNITY
BLOG
ABOUT
Arduino Web Editor
Start coding online and save your sketches in the cloud. The most up-to-date version of the IDE includes all libraries and also supports new Arduino boards.
CODE ONLINE
GETTING STARTED
Originally Arduino Development Environment
Downloads
But libraries Support Various MCUs
Arduino IDE 2.2.1
The new major release of the Arduino IDE is faster and even more powerful! In addition to a more modern editor and a more responsive interface it features autocompletion, code navigation, and even a live debugger.
For more details, please refer to the Arduino IDE 2.0 documentation.
Nightly builds with the latest bugfixes are available through
DOWNLOAD OPTIONS
Windows Win 10 and newer, 64 bits
Windows MSI installer
Windows ZIP file
Linux AppImage 64 bits (X86-64)
Linux ZIP file 64 bits (X86-64)
macOS Intel, 10.14: "Mojave" or newer, 64 bits
macOS Apple Silicon, 11: "Big Sur" or newer, 64 bits
Release Notes
Help
Based on C/C++ language

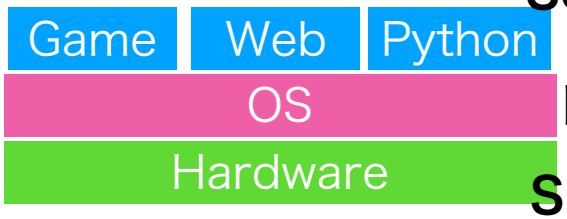
Comparison of SBC and MCU

SBC

Single Board Computer

= Like a small PC

Raspberry Pi5



Very flexible operation

MCU

Micro Contoroller Unit

= CPU + peripheral I/F

ESP32

No OS

Single software= Firmware

e.g. Temp. Cont.

Very robust operation

This tutorial uses Python on the MCU as an alternative solution

MicroPython DOWNLOAD DOCS DISCORD DISCUSSIONS WIKI STORE

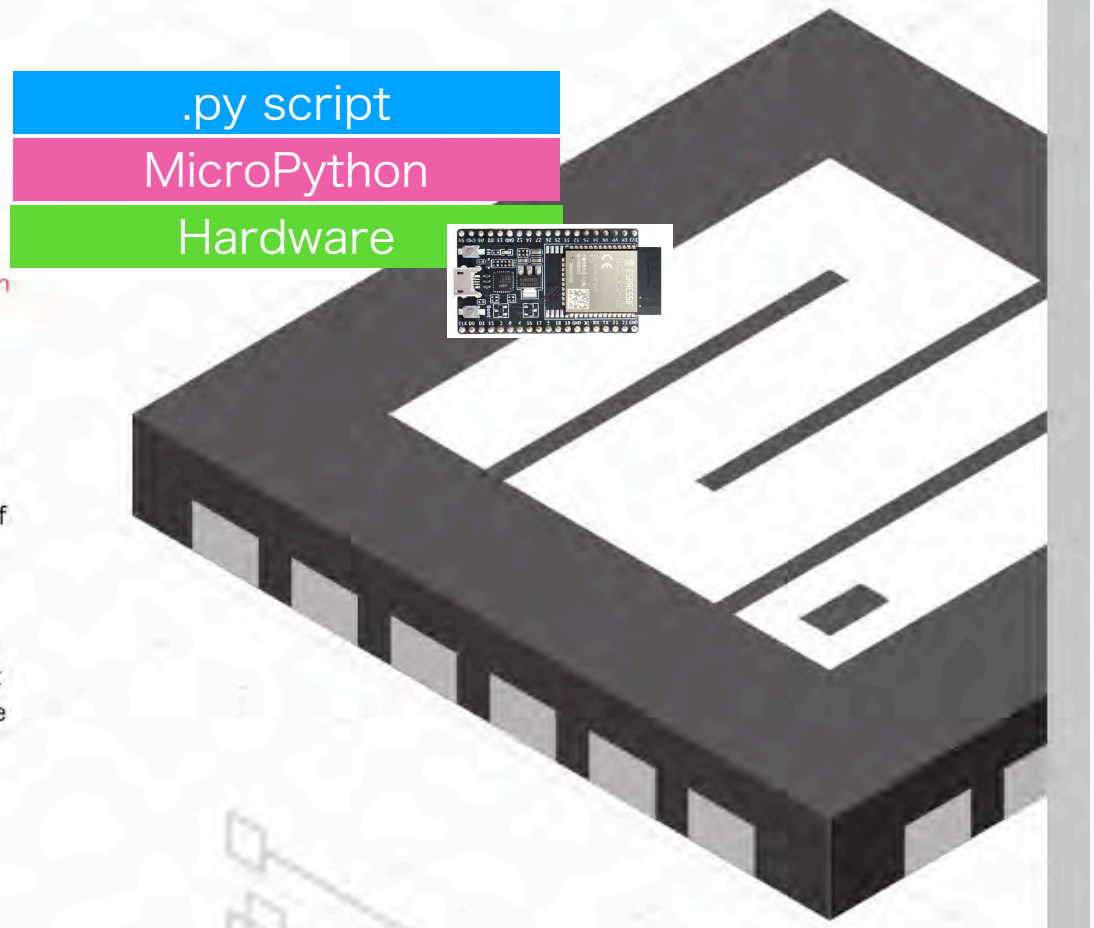
MicroPython

MicroPython is a lean and efficient implementation of the Python 3 programming language that includes a small subset of the Python standard library and is optimised to run on microcontrollers and in constrained environments.

The MicroPython pyboard is a compact electronic circuit board that runs MicroPython on the bare metal, giving you a low-level Python operating system that can be used to control all kinds of electronic projects.

MicroPython is packed full of advanced features such as an interactive prompt, arbitrary precision integers, closures, list comprehension, generators, exception handling and more. Yet it is compact enough to fit and run within just 256k of code space and 16k of RAM.

MicroPython aims to be as compatible with normal Python as possible to allow you to transfer code with ease from the desktop to a microcontroller or embedded system.



Programming language for small resources compatible with Python

Run within just 256k of code space and 16k of RAM.

C++ IDE vs. μPython (development)

C++

On PC

Arduino IDE

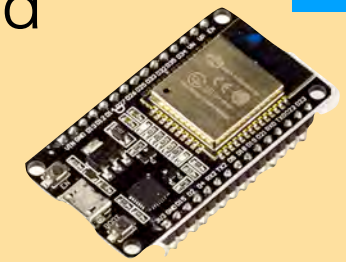
Programing & Compiling

Generate binary

Upload

Retry

On MCU



Reset, Operation check

Little complicated

MicroPython

On PC

Thonny IDE

Once μPython farm is uploaded

On MCU

REPL 【Read-Evaluation-Print Loop】

Operation check

Revise

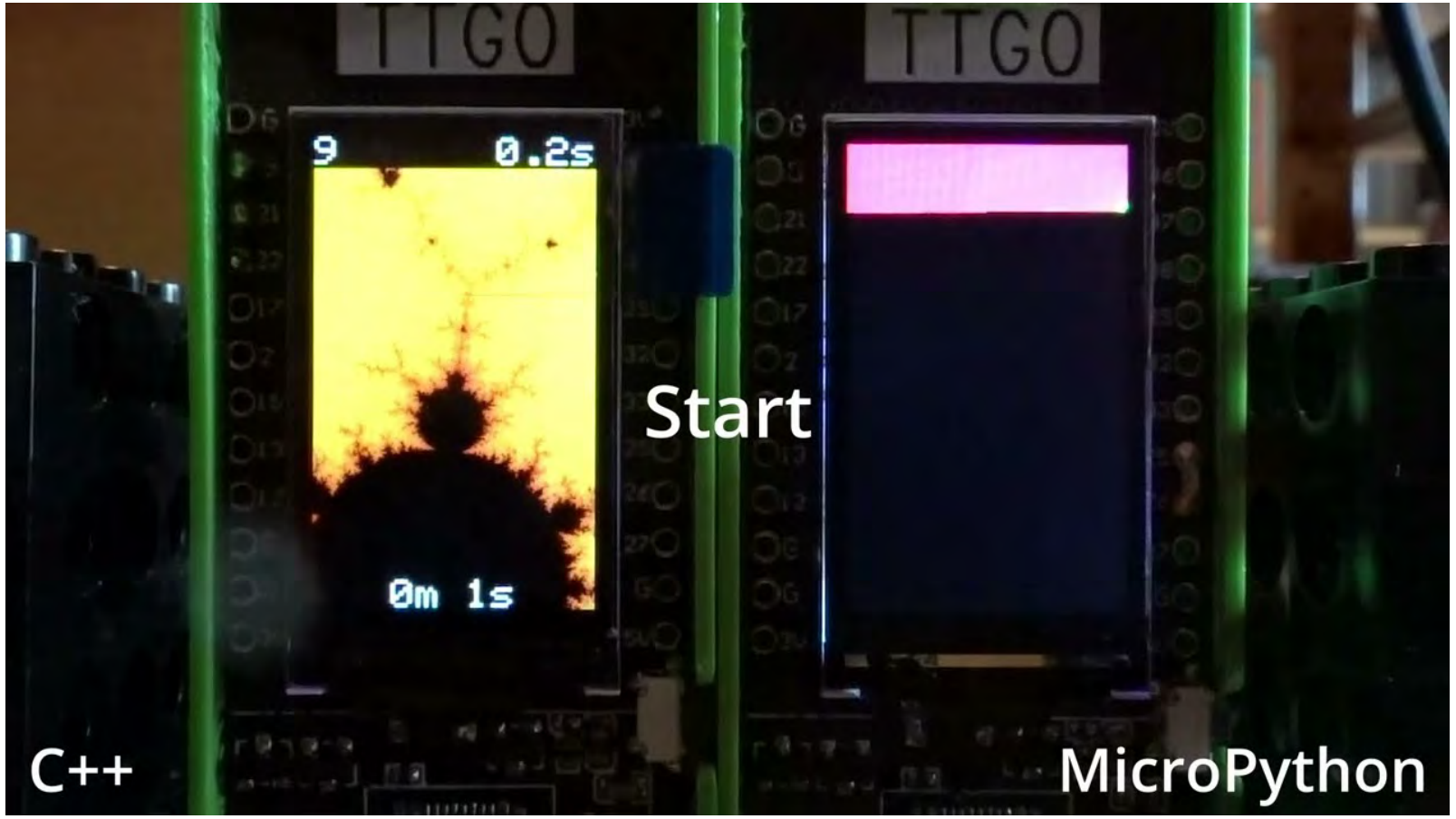
Very easy for prototyping

C++ IDE vs. μPython (performance)

r/esp32 • 2 yr. ago
TomFlatterhand

How fast is Python - MicroPython versus C++

Mandelbrot with ESP32+LED



©YouTube

C++ is 400 times faster than μPython @ ESP32

> μPython is for prototyping

> C++ is for production

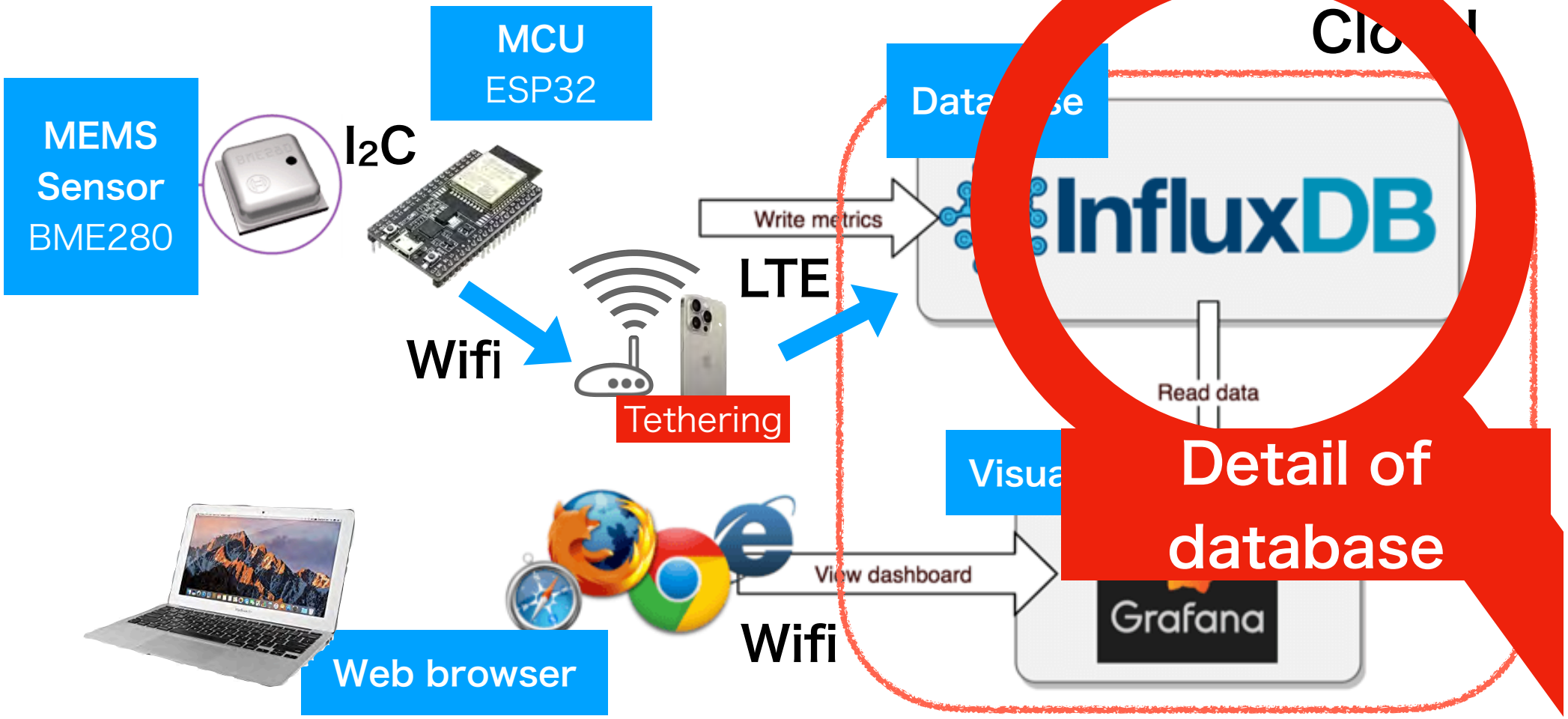
Goal of tutorial

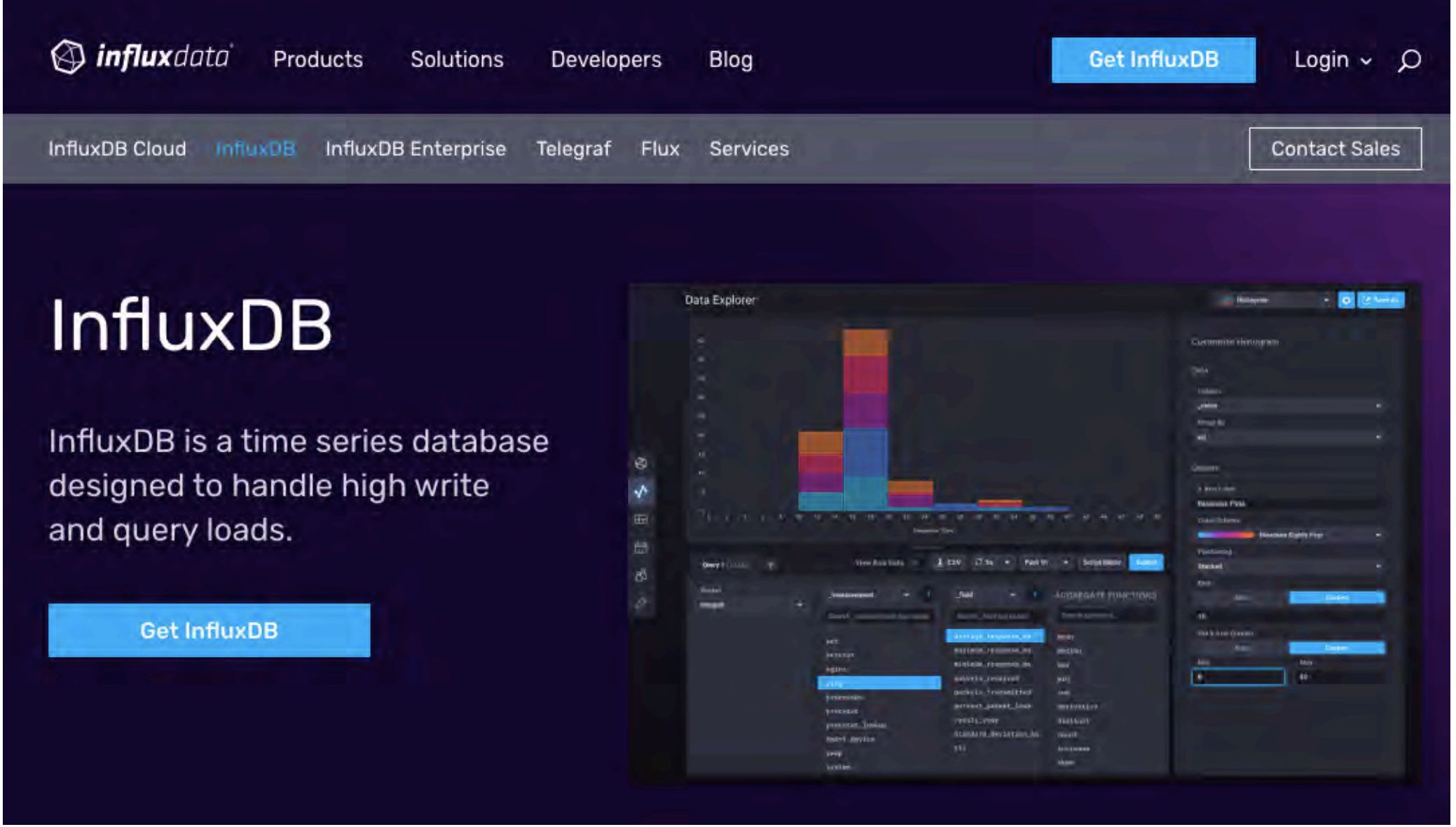
Sensing data from MEMS environmental sensor

> gather & processing data on MCU

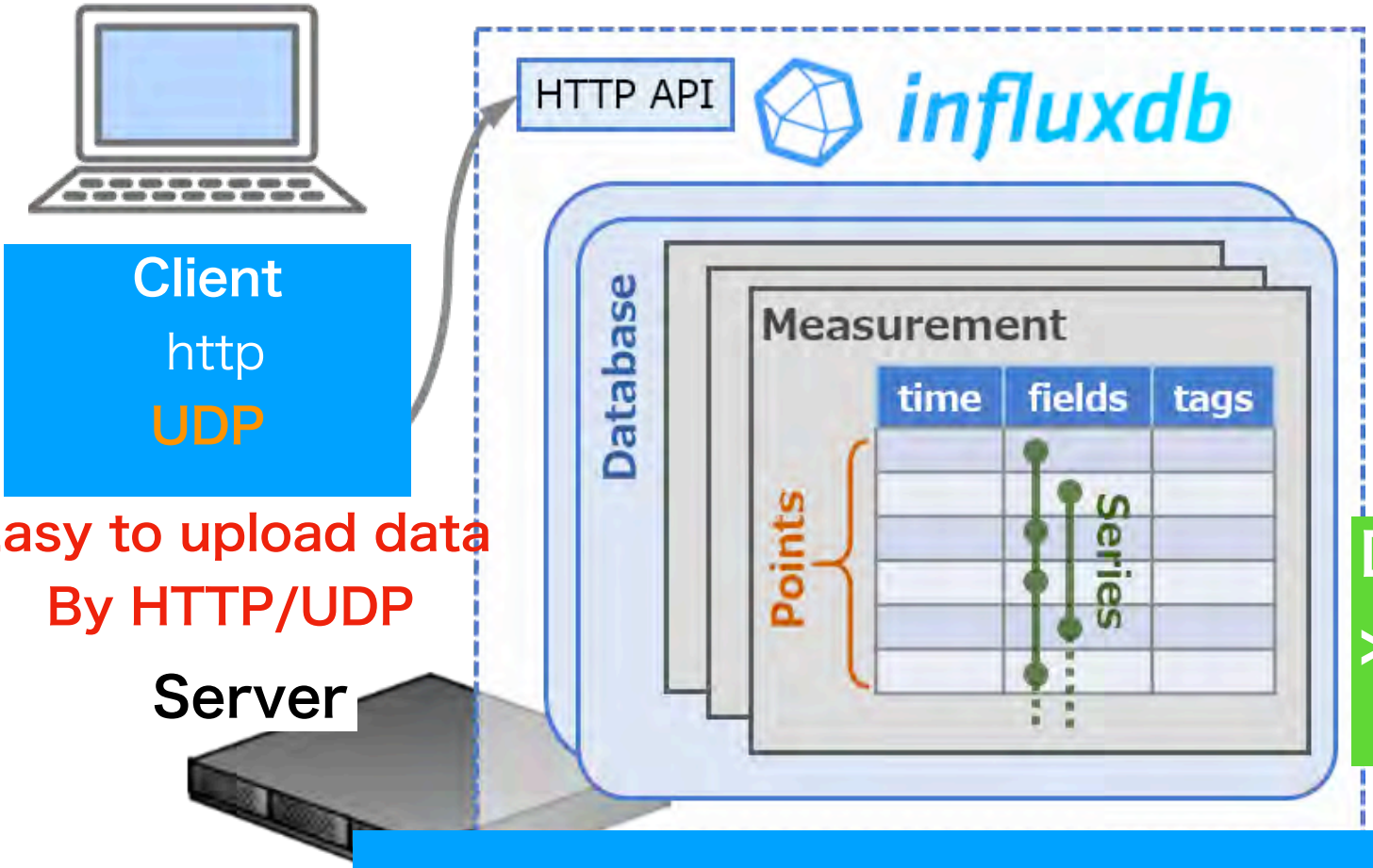
> transmit to InfluxDB database on cloud

> visualized by Grafana > display on web browser





InfluxDB is a high-performance data store written specifically for time series data. It allows for high throughput ingest, compression and real-time querying. InfluxDB is written entirely in Go and compiles into a single binary with no external dependencies. It provides write and query capabilities with a command-line interface, a built-in HTTP API.



Structure of InfluxDB database

Database

Measurement

Values

	Timestamp	Location	Temperature	Humidity	Barometer
Point	1597746439000000000	bedroom	23.4	67.8	1023.4
	1597746499000000000	bedroom	23.5	67.9	1023.6
	1597746559000000000	bedroom	23.5	68.1	1023.7

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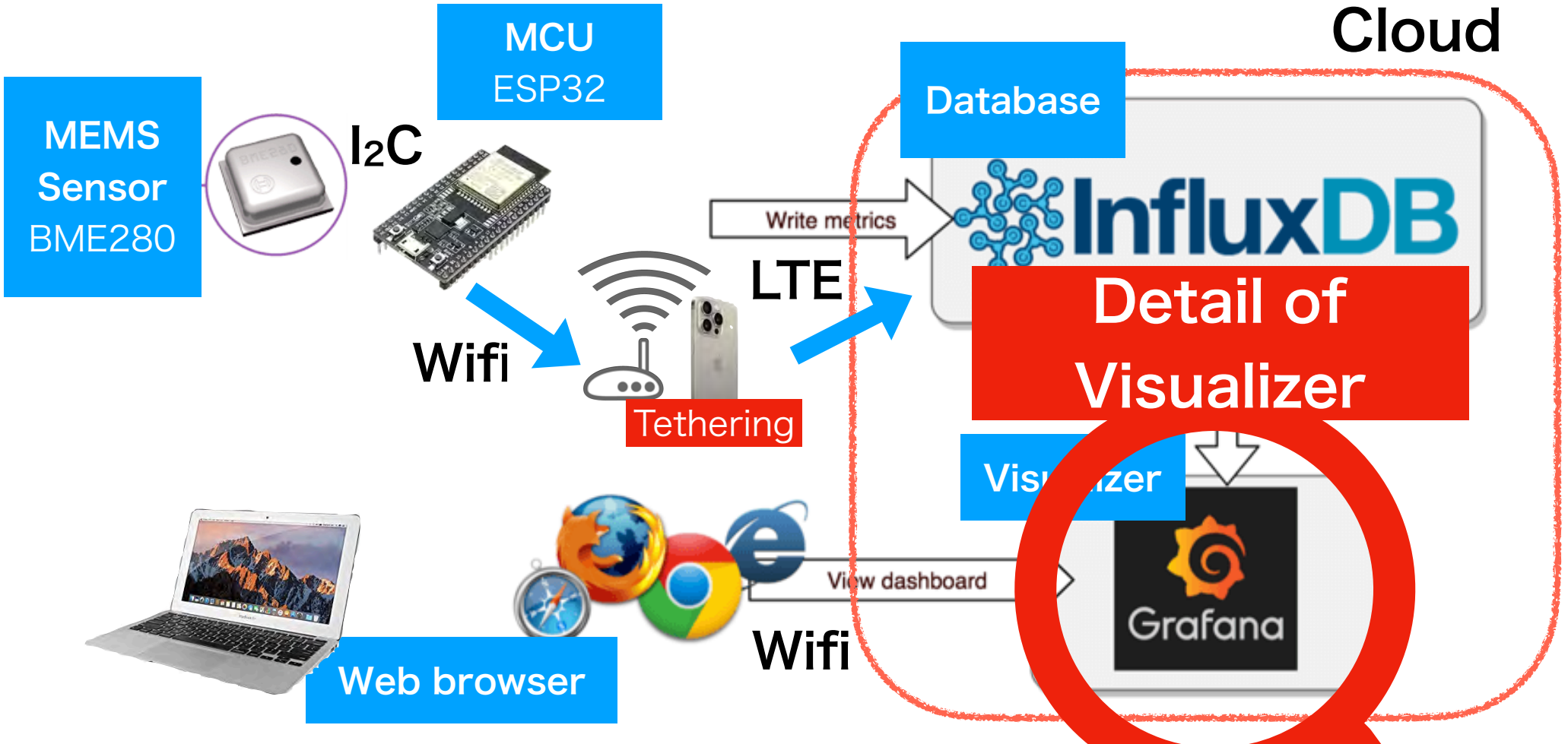
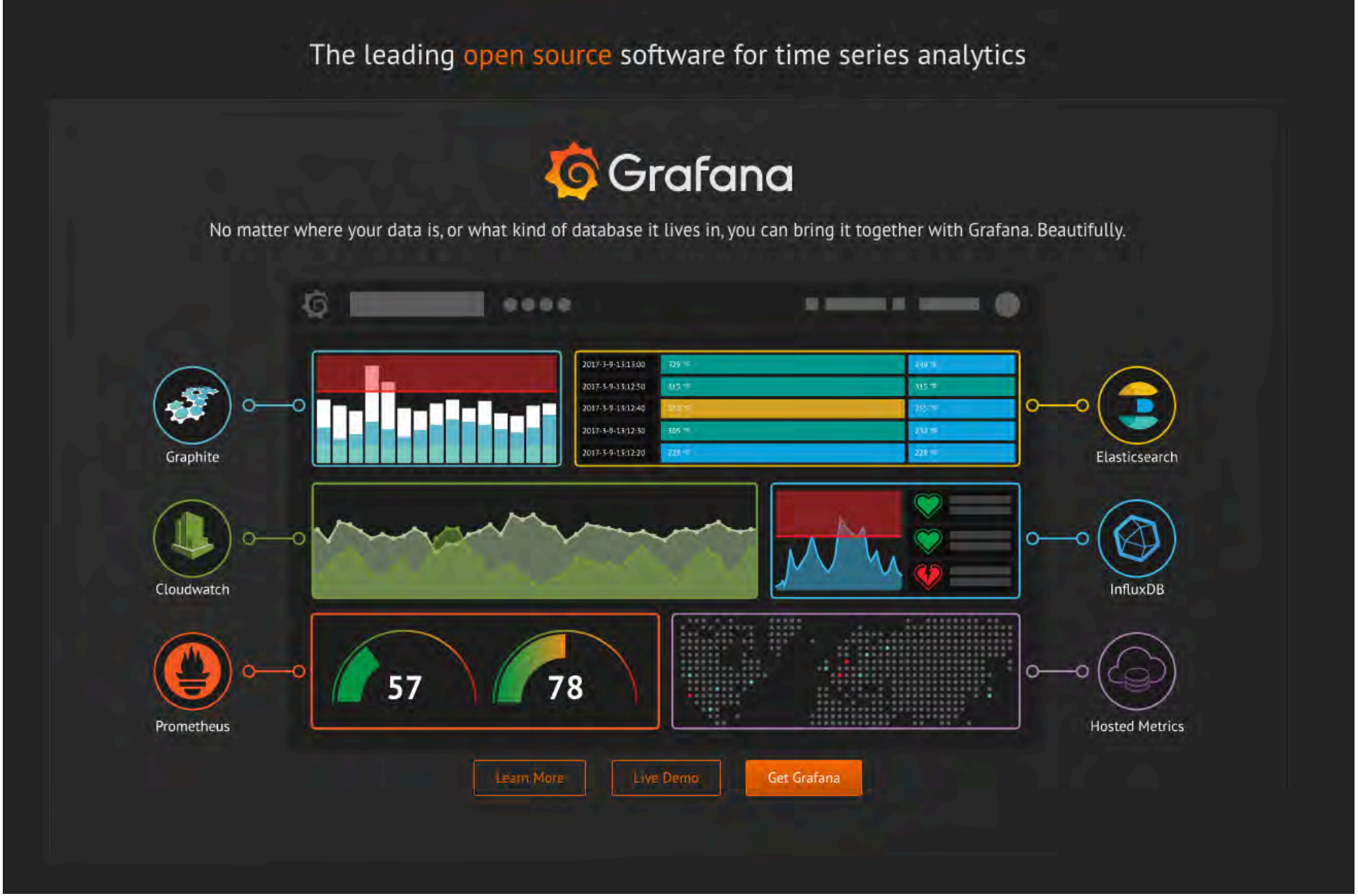




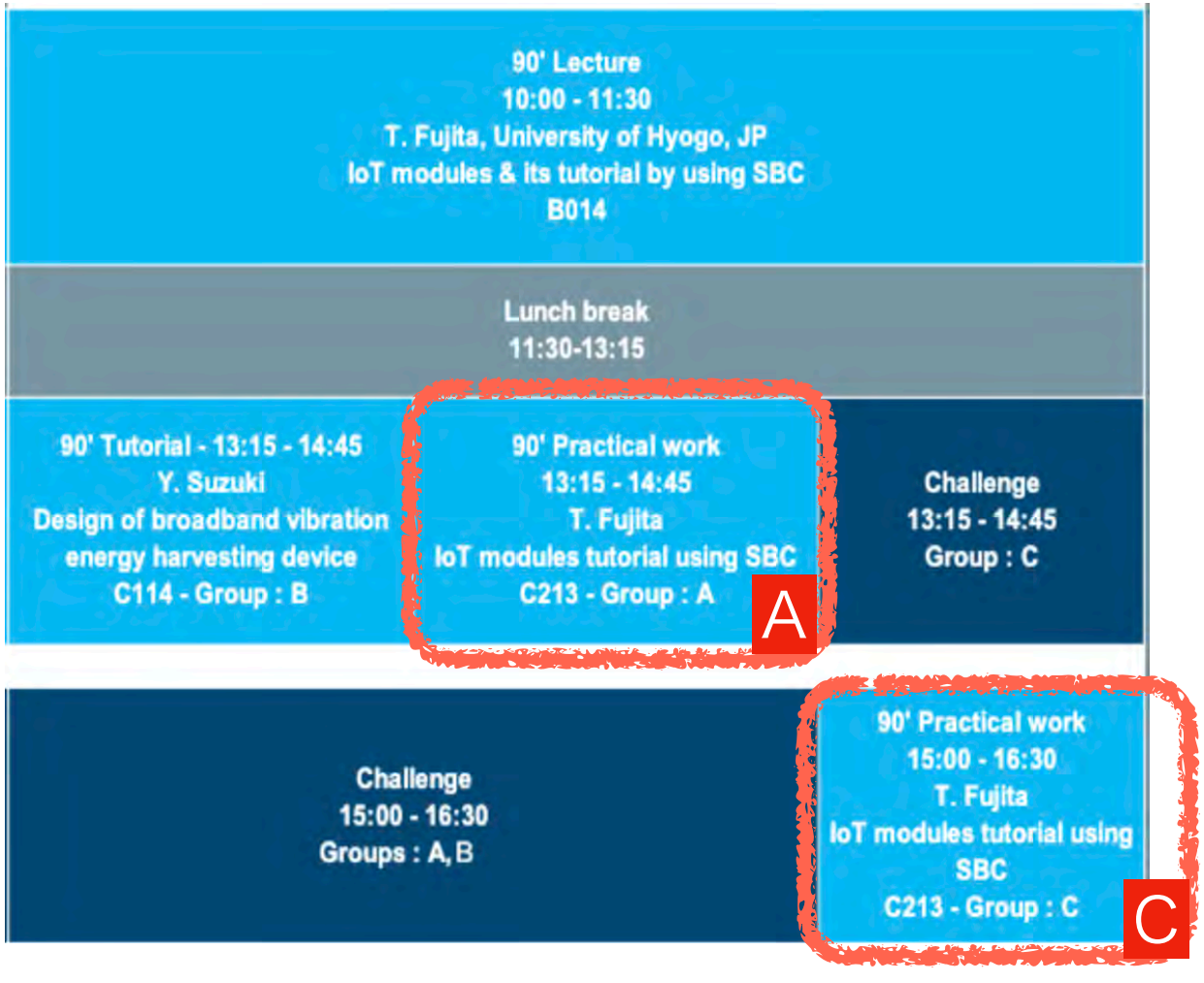
Grafana allows you to query, visualize, alert on and understand your metrics no matter where they are stored. Create, explore, and share dashboards with your team and foster a data driven culture.

Example of Grafana (my home env.) on RPi

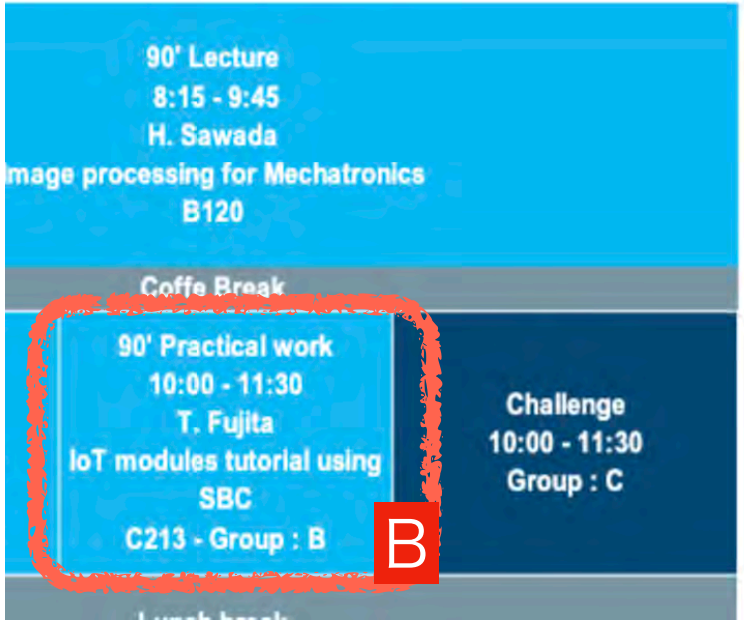
Tutorial IoT installed in my apartment where I'm staying.

Tutorial instruction

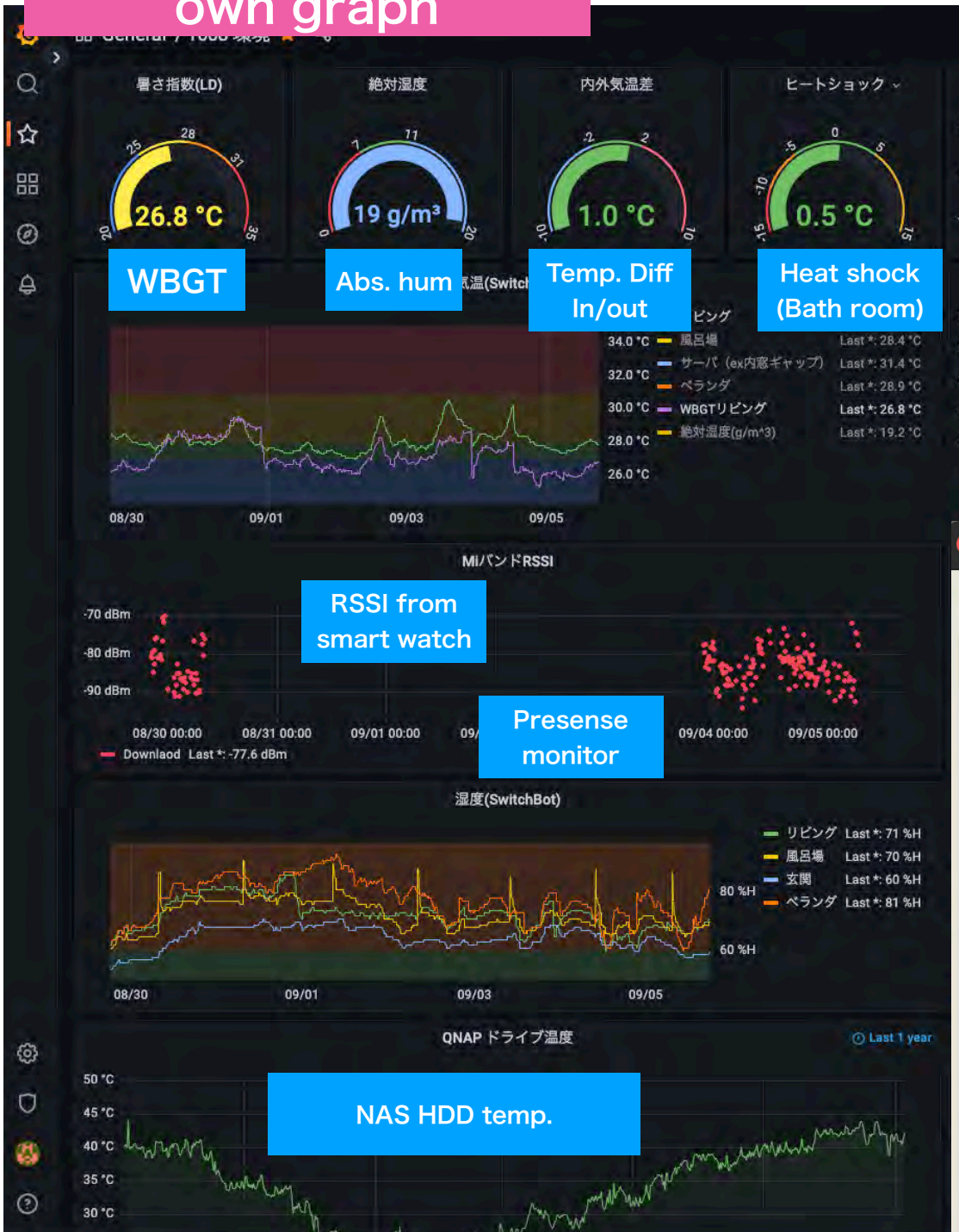
This afternoon



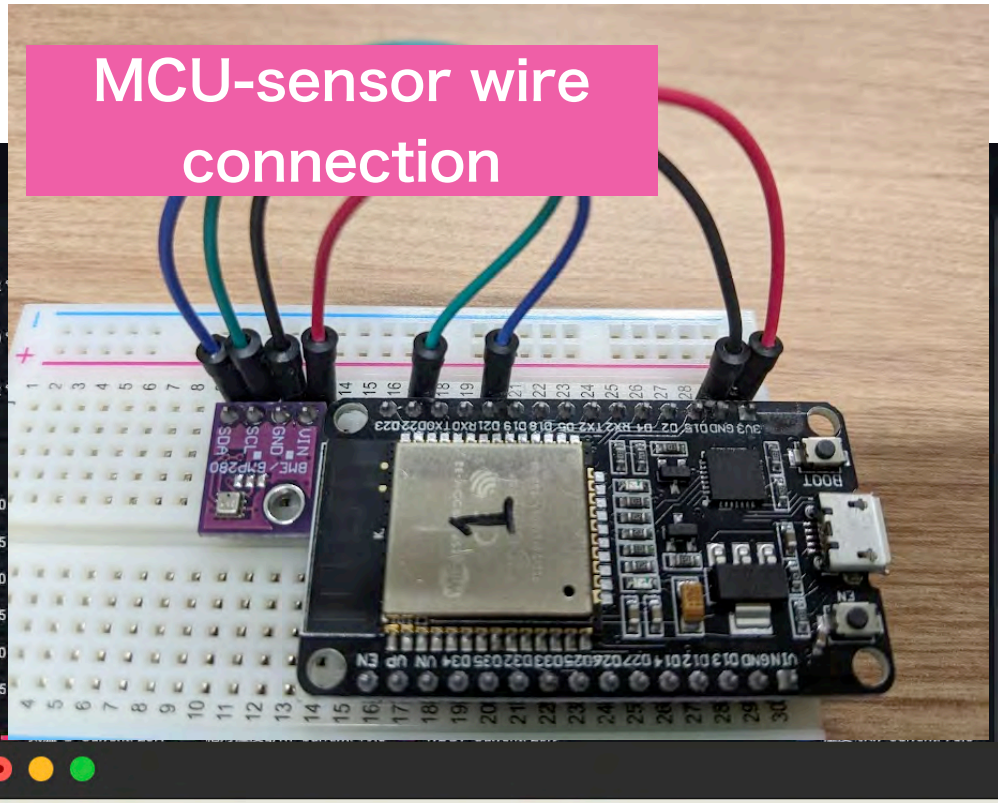
Monday Sept 16

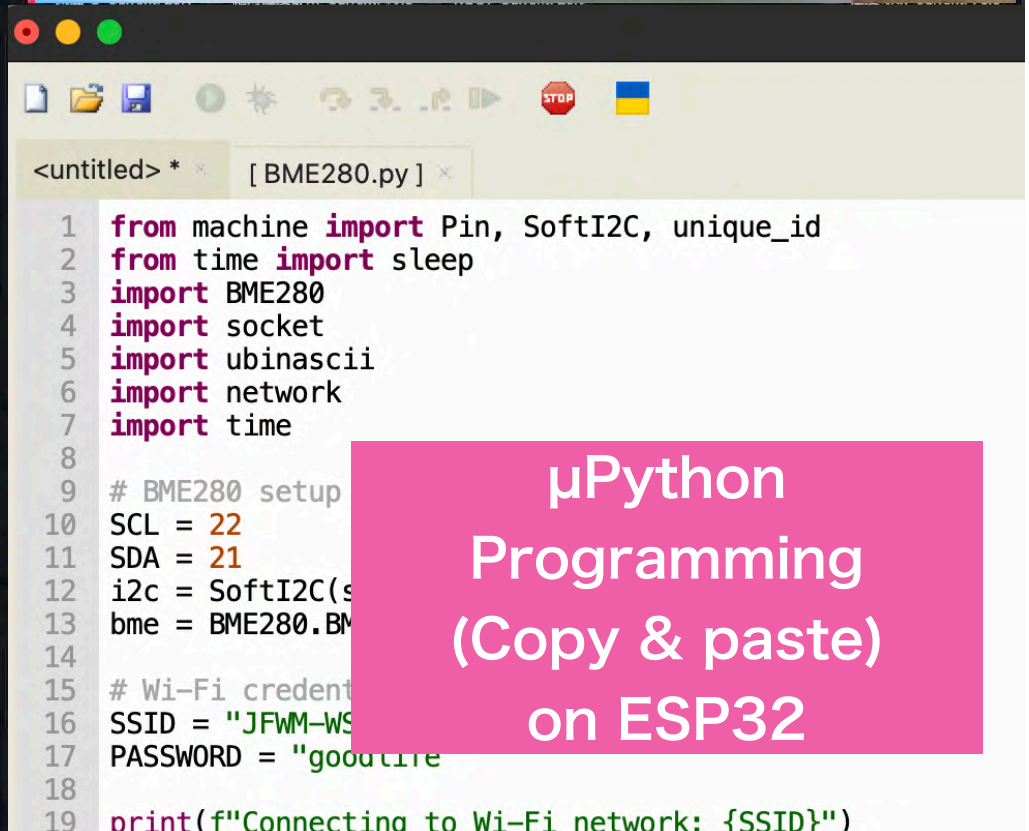


Final goal : Make your own graph



MCU-sensor wire connection





µPython Programming (Copy & paste) on ESP32

Tutorial list

Instruction & sample program

http://161.34.0.113/

Preparation

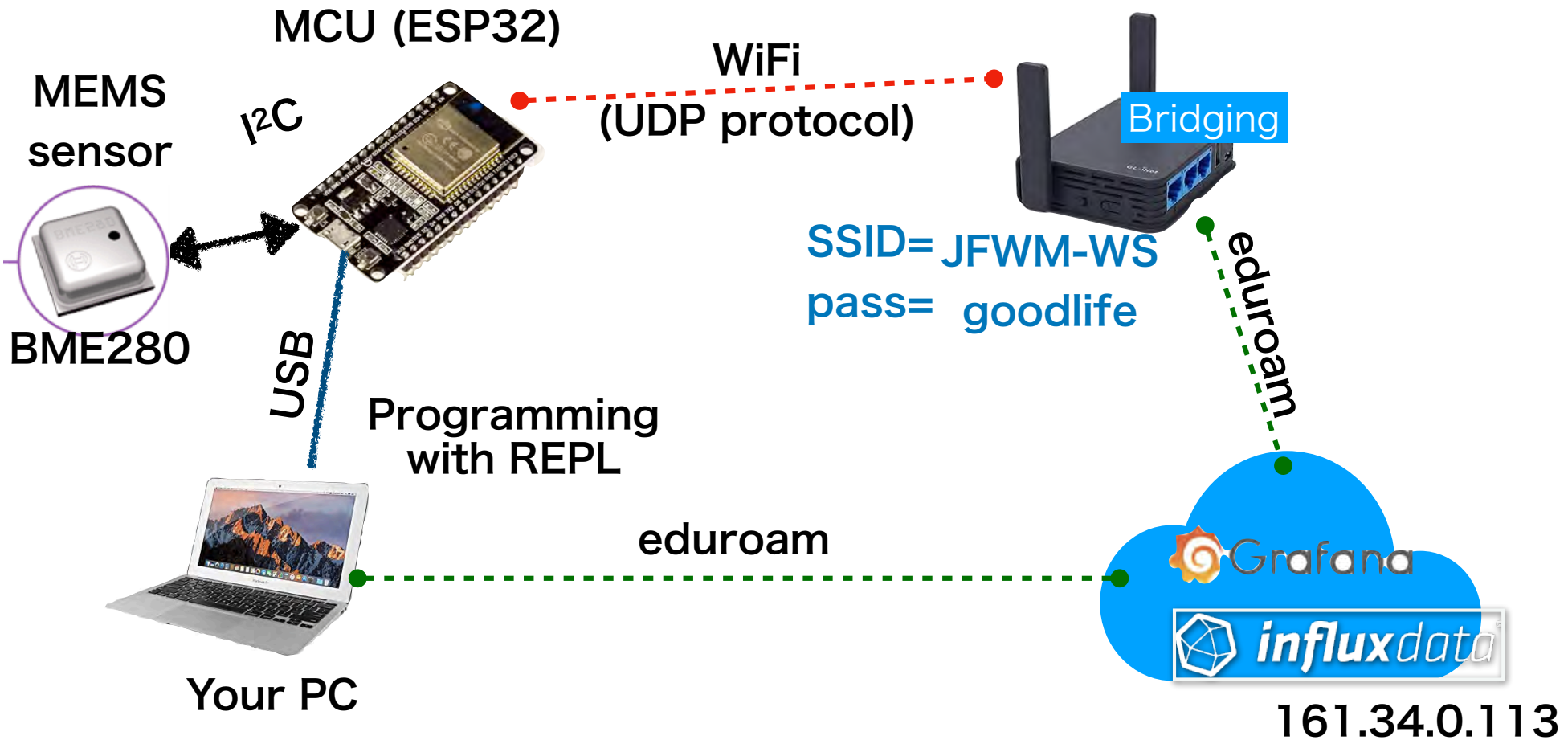
0. MicroPython install on ESP32 by Thonny IDE

Experiments

1. Blink LED on ESP32
2. Checking the WiFi function of ESP32
3. Wire BME280 to get data
   (BME280.py library installation)
4. Upload BME280 data to cloud via UDP
5. Visualization on Grafana

(Extra) BLE Beacon RSSI monitoring on Grafana

Overview of connections



Please try connection on your PC

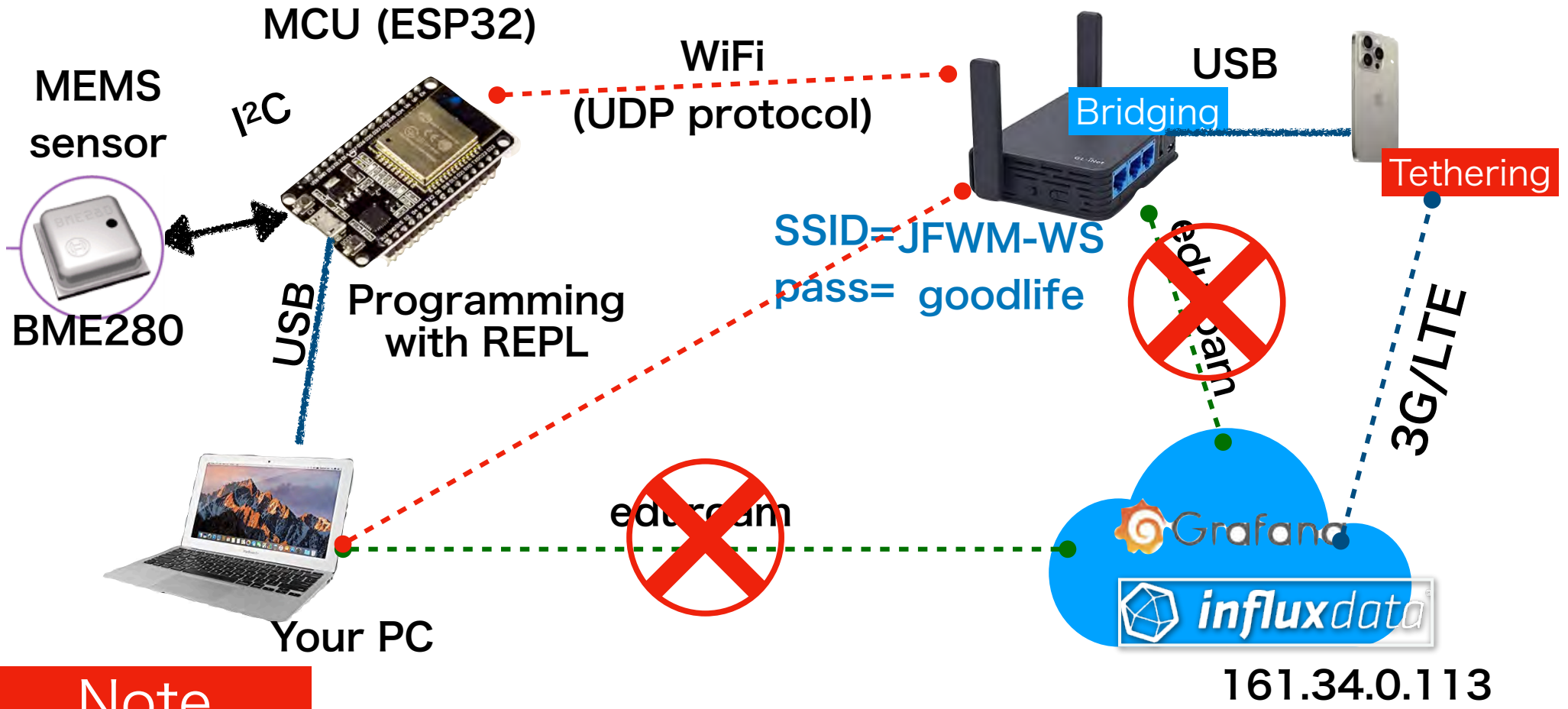
1) Can you to connect http://161.34.0.113 for instructions ?

Yes

2) Can you to connect http://161.34.0.113:3000 for Grafana ?

Might be No

Overview of connections (revised)



Note

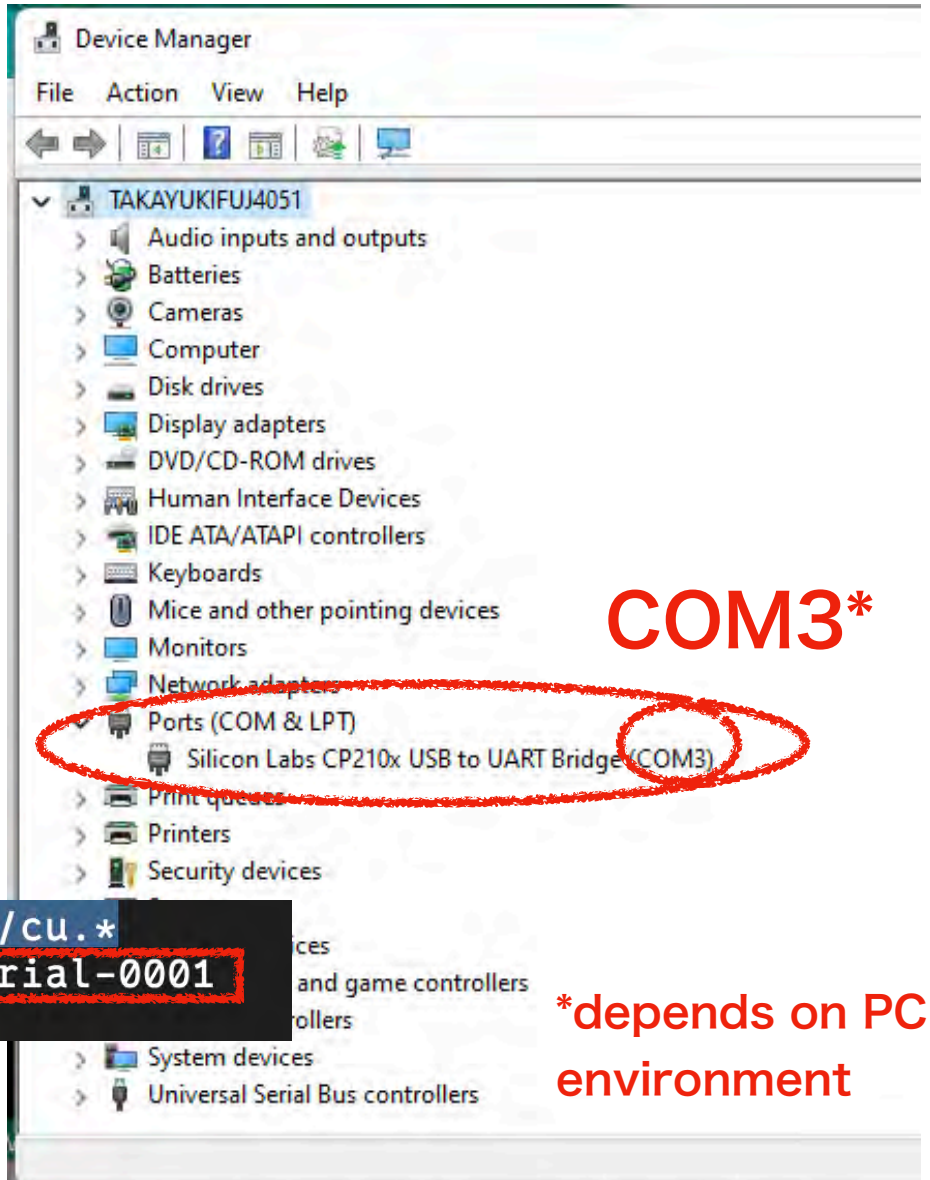
eduroam@USMB's security policy is restricting the Grafana communication

Please connect to 'JFWM-WS' during the tutorial to connect to Grafana. However, the capacity of tethering is limited, so only one PC in the group should be connected, and do not use large capacity communication such as Youtube, Onedrive.

Let’s connect ESP32 to PC

Connect ESP32 board to Windows PC /Mac w/μ-USB cable

Confirm COM port number on Device Manager



COM3*

*depends on PC environment

On MacOS Terminal App. just input

ls /dev/cu.*

```
(base) takayukifujita@MacBook-Air ~ % ls /dev/cu.*
/dev/cu.BNO085-BT                 /dev/cu.usbserial-0001
/dev/cu.Bluetooth-Incoming-Port
```

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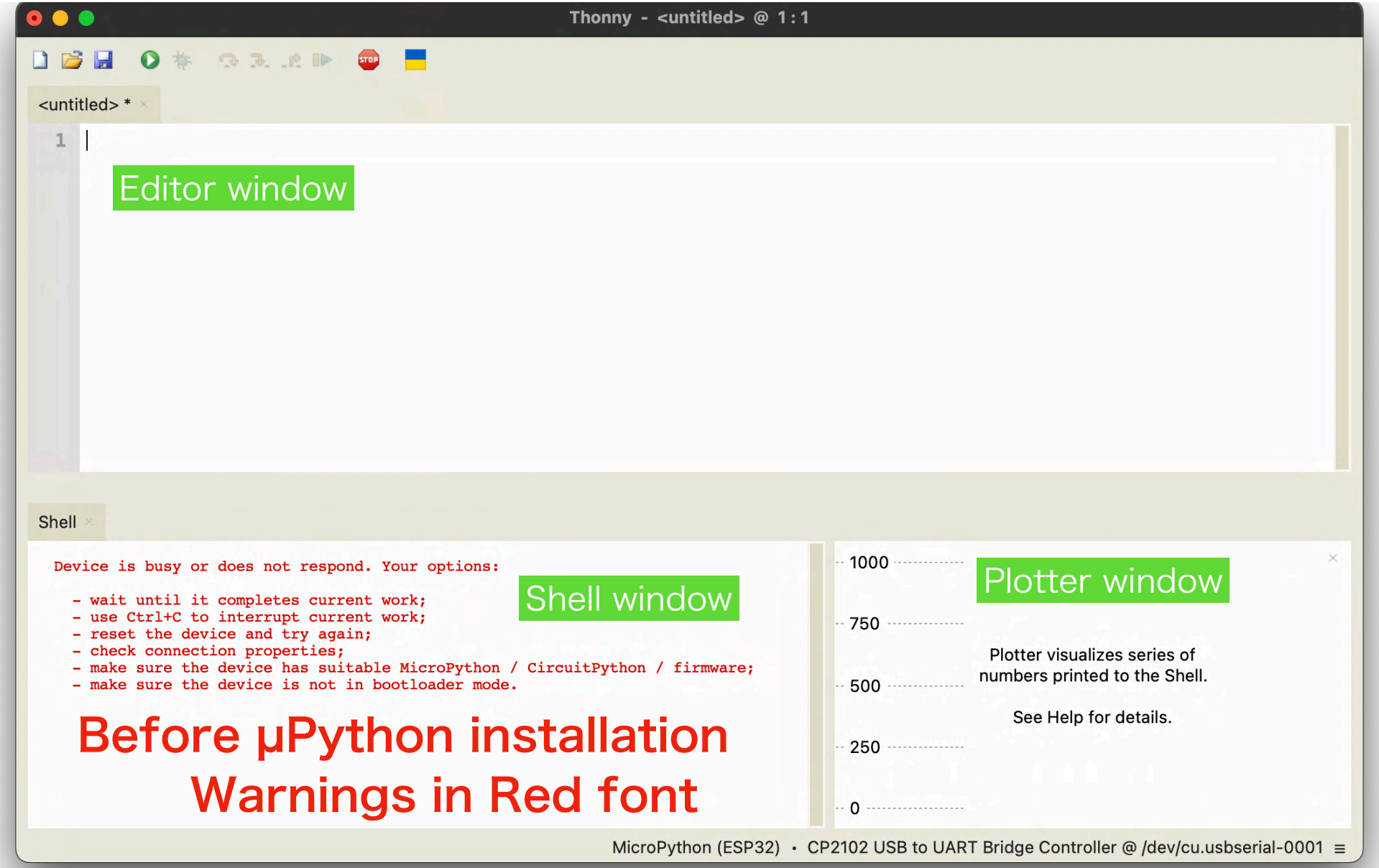
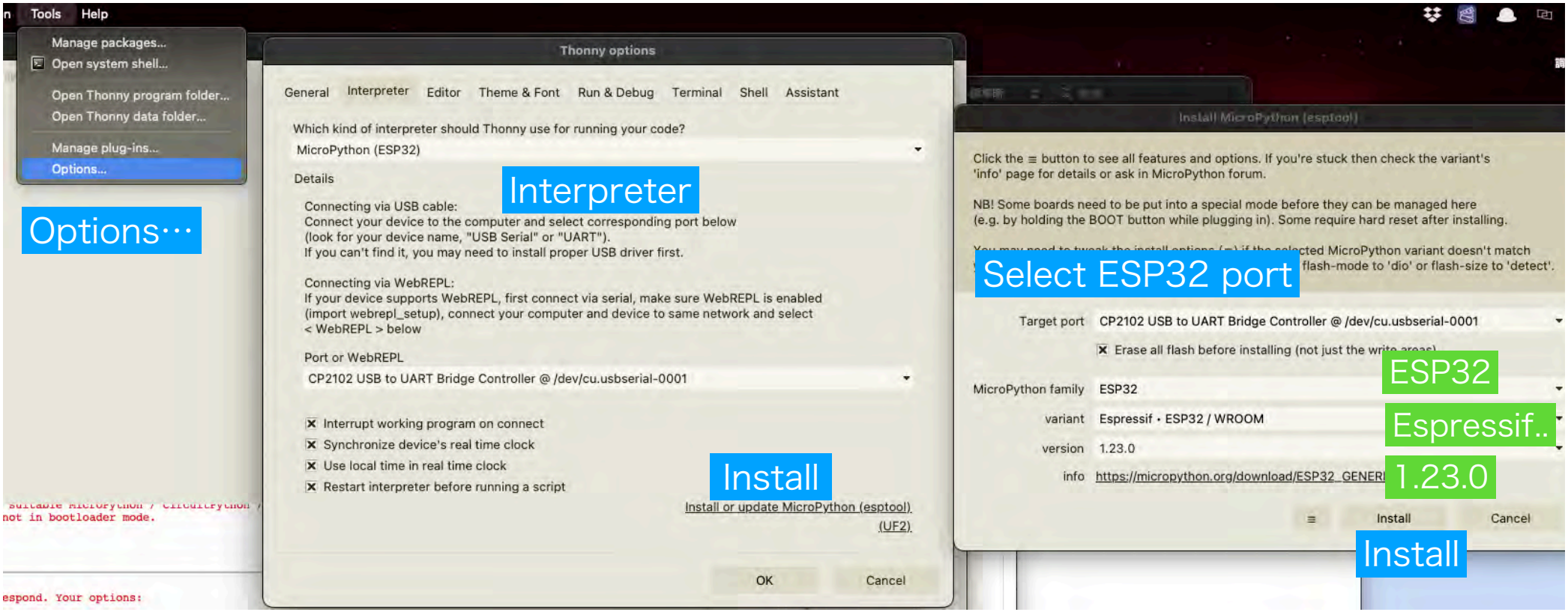
Install μPython via Thonny app

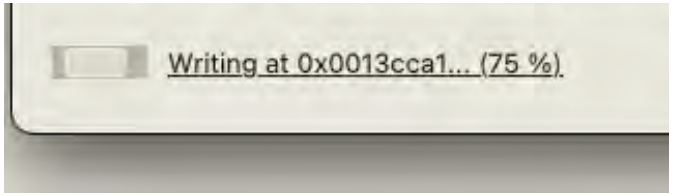
Sample of Thonny's window



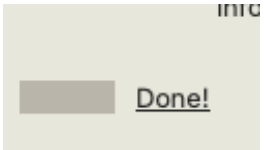
Install μPython via Thonny app

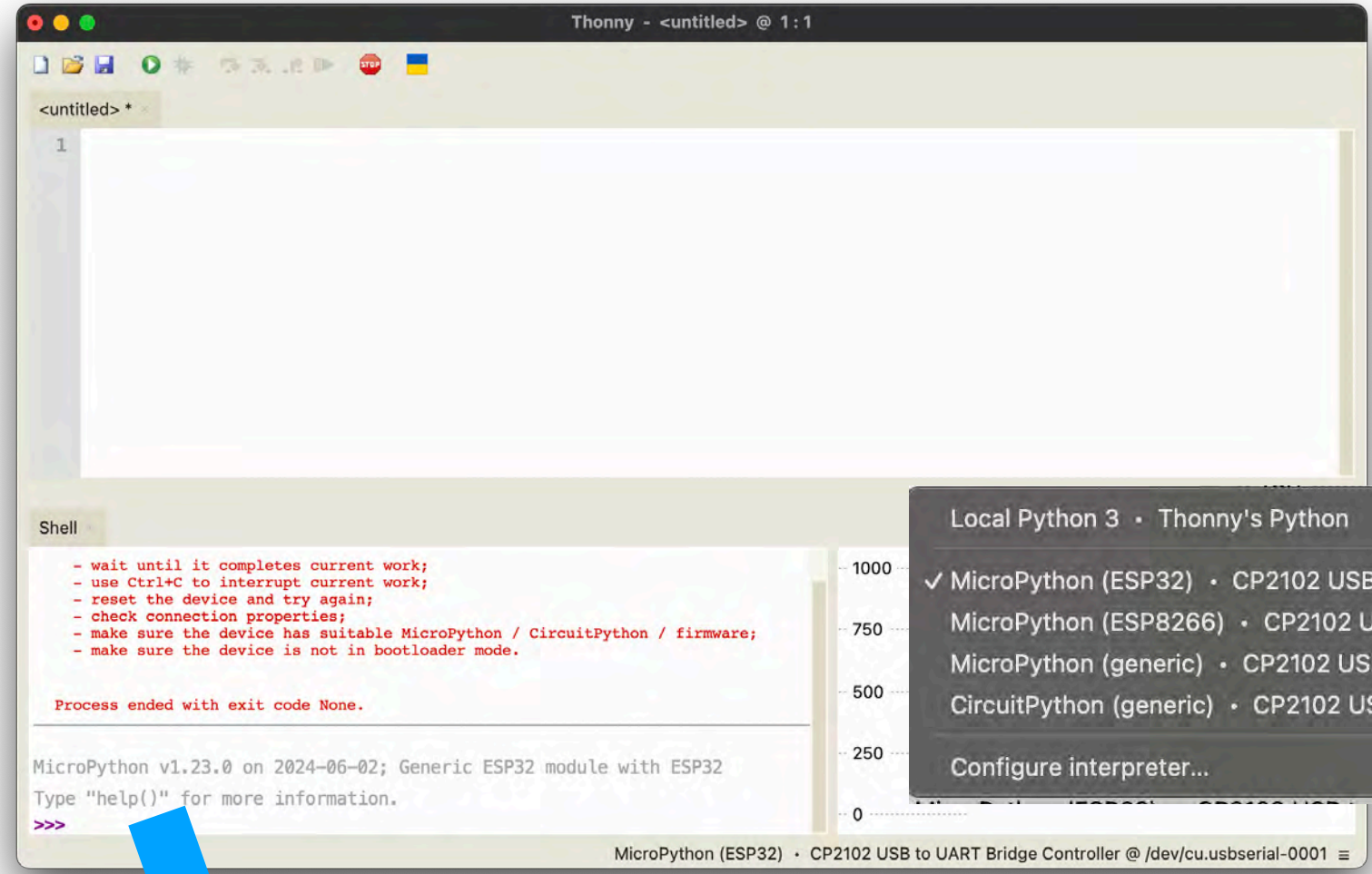
Download Thonny and install, Run

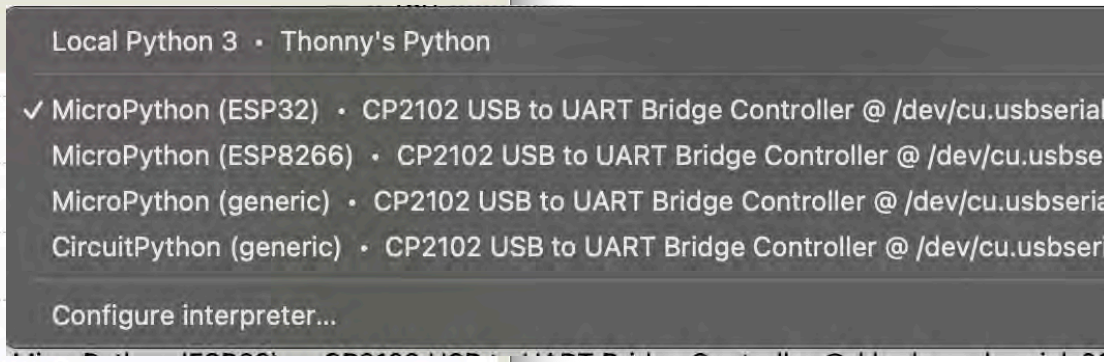




Wait for writing until “Done”







Click the right bottom to choose interpreter (ESP32)

Now you can use µPython on ESP32

```
MicroPython v1.23.0 on 2024-06-02; Generic ESP32 module with ESP32
Type "help()" for more information.
>>>
```

Tutorial list

Instruction & sample program

http://161.34.0.113/

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MicroPython install on ESP32 by Thonny IDE

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(Extra) BLE Beacon RSSI monitoring on Grafana

Ex1) Blink LED

Copy & paste

Python code

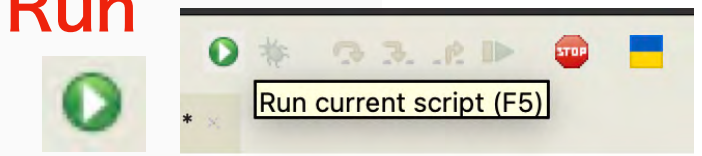
Thonny - <untitled> @ 12 : 39

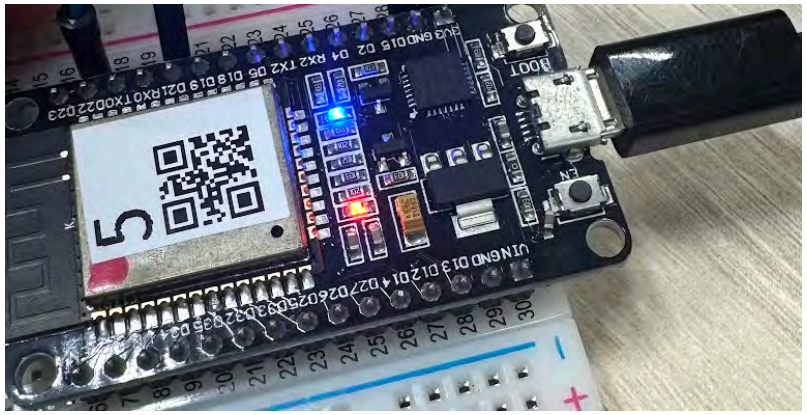
<untitled> *

```
1  from machine import Pin
2  import time
3
4  # Initialize pin 2 for the LED as an output
5  led = Pin(2, Pin.OUT)
6
7  # Main loop
8  while True:
9      led.on()  # Turn the LED on
10     time.sleep(1)  # Wait for 1 second
11     led.off()  # Turn the LED off
12     time.sleep(1)  # Wait for 1 second
```

Then push

Run





Blue LED(pin 2) blinking

Try to change blink intervals

Just change time.sleep and Run

Tutorial list

Instruction & sample program

http://161.34.0.113/

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(Extra) BLE Beacon RSSI monitoring on Grafana

Ex2) Wi-Fi finder nearby

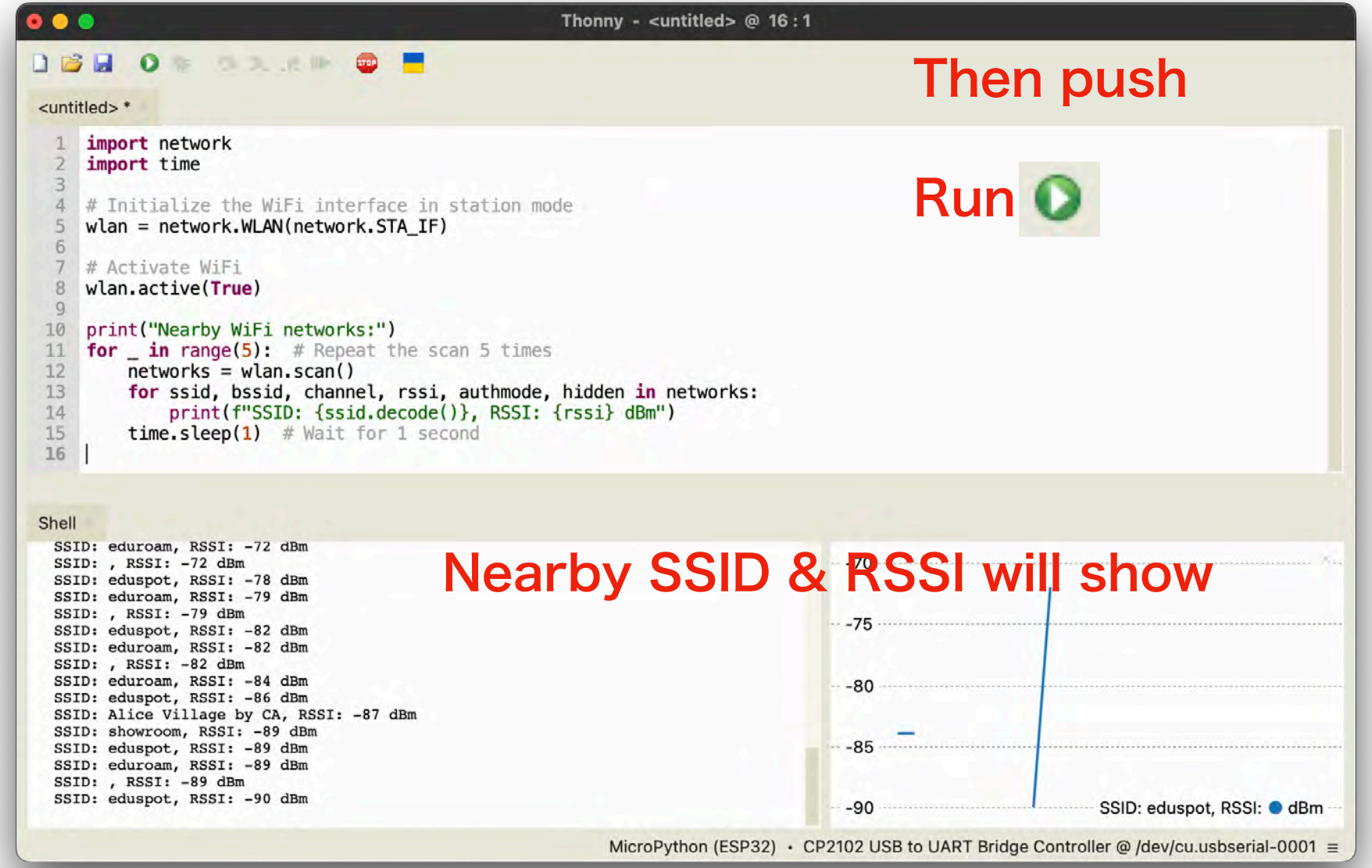
Copy & paste
Python code

Then push

Run

Nearby SSID & RSSI will show

Finding SSID “JFWM-WS”



Tutorial list

Instruction & sample program

http://161.34.0.113/

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MicroPython install on ESP32 by Thonny IDE

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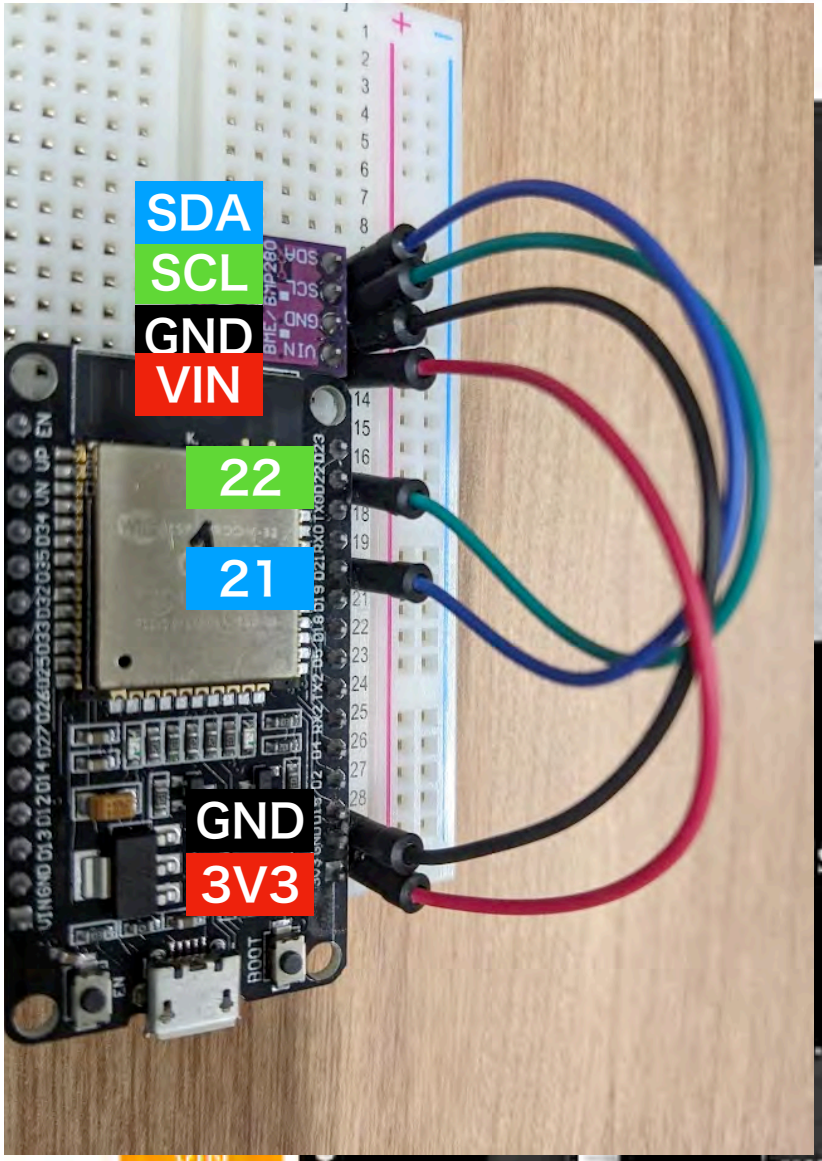
(Extra) BLE Beacon RSSI monitoring on Grafana

Wire connection on bredboard



4 wires for I2C connection

GPIO23	VSPI MOSI			
GPIO22	I2C SCL			Serial clock
GPIO1	UART 0 TX			
GPIO3	UART 0 RX			
GPIO21	I2C SDA			Serial data
GPIO19	VSPI MISO			
GPIO18	VSPI CLK			
GPIO5	VSPI CS0			
GPIO17	UART 2 TX			
GPIO16	UART 2 RX			
GPIO4	ADC2 CH0	TOUCH0	RTC_GPIO10	
GPIO2	ADC2 CH2	TOUCH2	RTC_GPIO12	
GPIO15	ADC2 CH3	TOUCH3	HSPI CS0	RTC_GPIO13
GND				
3V3	VIN			Power line

Ex3) BME280 data get

Copy & paste

Python code

Thonny - <untitled> @ 17 : 13

<untitled> *

```
2  from time import sleep
3  import BME280
4
5  # BME280 setup
6  SCL = 22
7  SDA = 21
8  i2c = SoftI2C(scl=Pin(SCL), sda=Pin(SDA))
9  bme = BME280.BME280(i2c=i2c)
10
11 while True:
12     temp = bme.temperature
13     hum = bme.humidity
14     press = bme.pressure
15     print(f"Temperature: {temp}°C, Humidity: {hum}%, Pressure: {press}hPa")
16
17     sleep(1)
```

Then push

Run 

Shell

```
>>> %Run -c $EDITOR_CONTENT

  MPY: soft reboot
  Traceback (most recent call last):
    File "<stdin>", line 3, in <module>
  ImportError: no module named 'BME280'

>>>
```

You will get error message

no module named ‘BME280’

Need to install ‘BME280.py’ libraly

-70
-75
-80
-85
-90

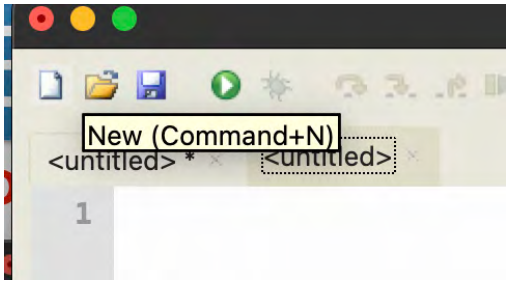
Plotter visualizes series of numbers printed to the Shell.

See Help for details.

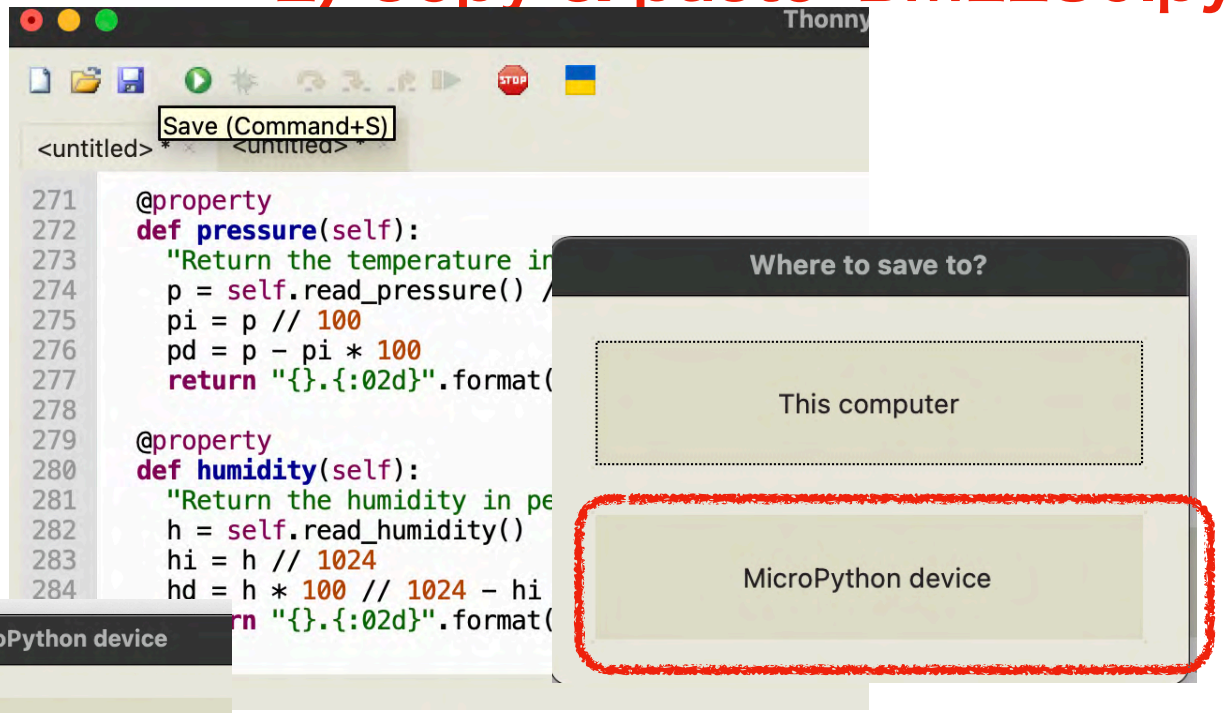
MicroPython (ESP32) • CP2102 USB to UART Bridge Controller @ /dev/cu.usbserial-0001

Ex3) BME280 data get

1) Create new editor window



2) Copy & paste 'BME280.py'



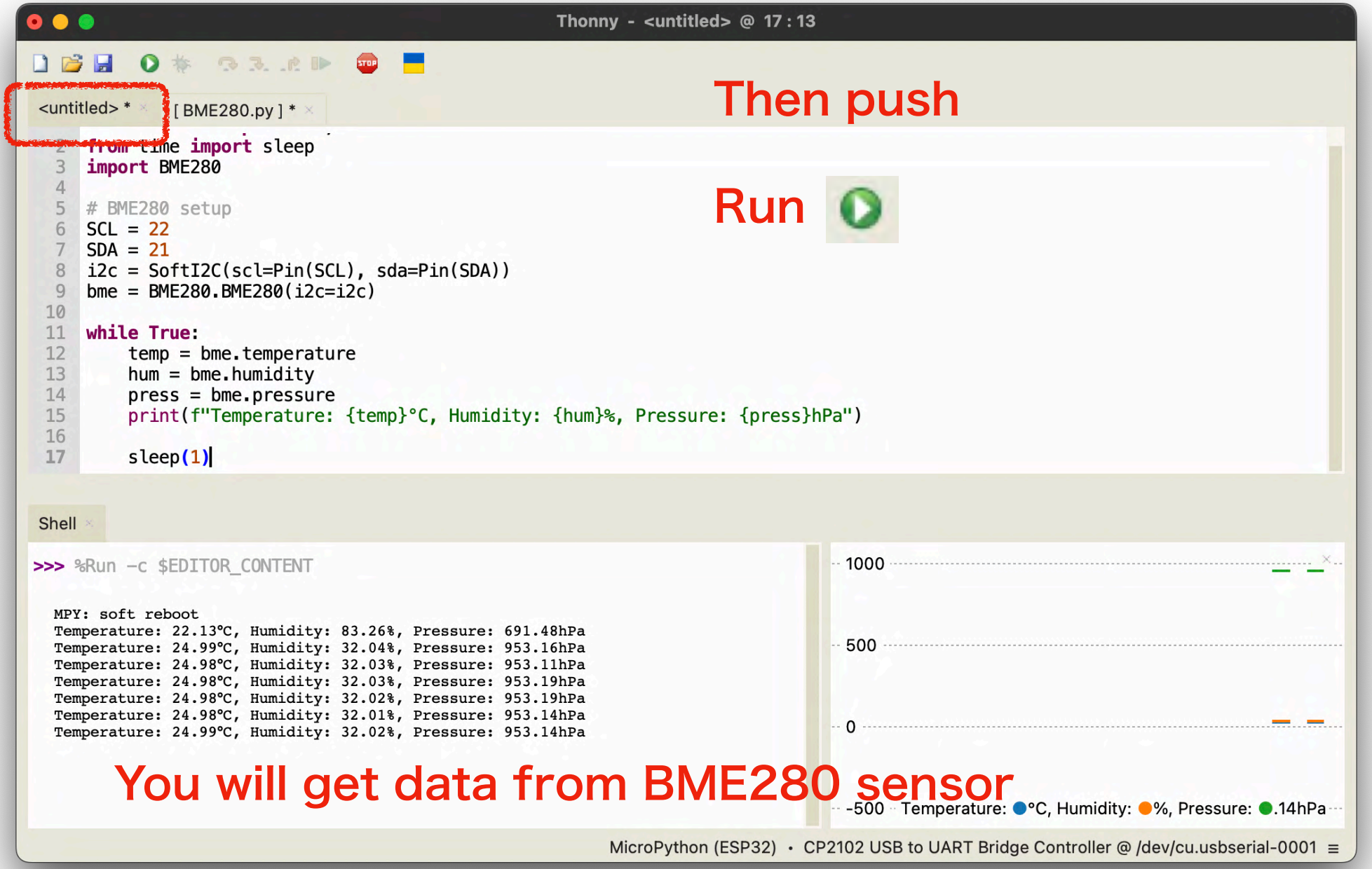
3) Then Save it to ESP32

4) Set file name 'BME280.py'

Save > [OK]

Ex3) BME280 data get

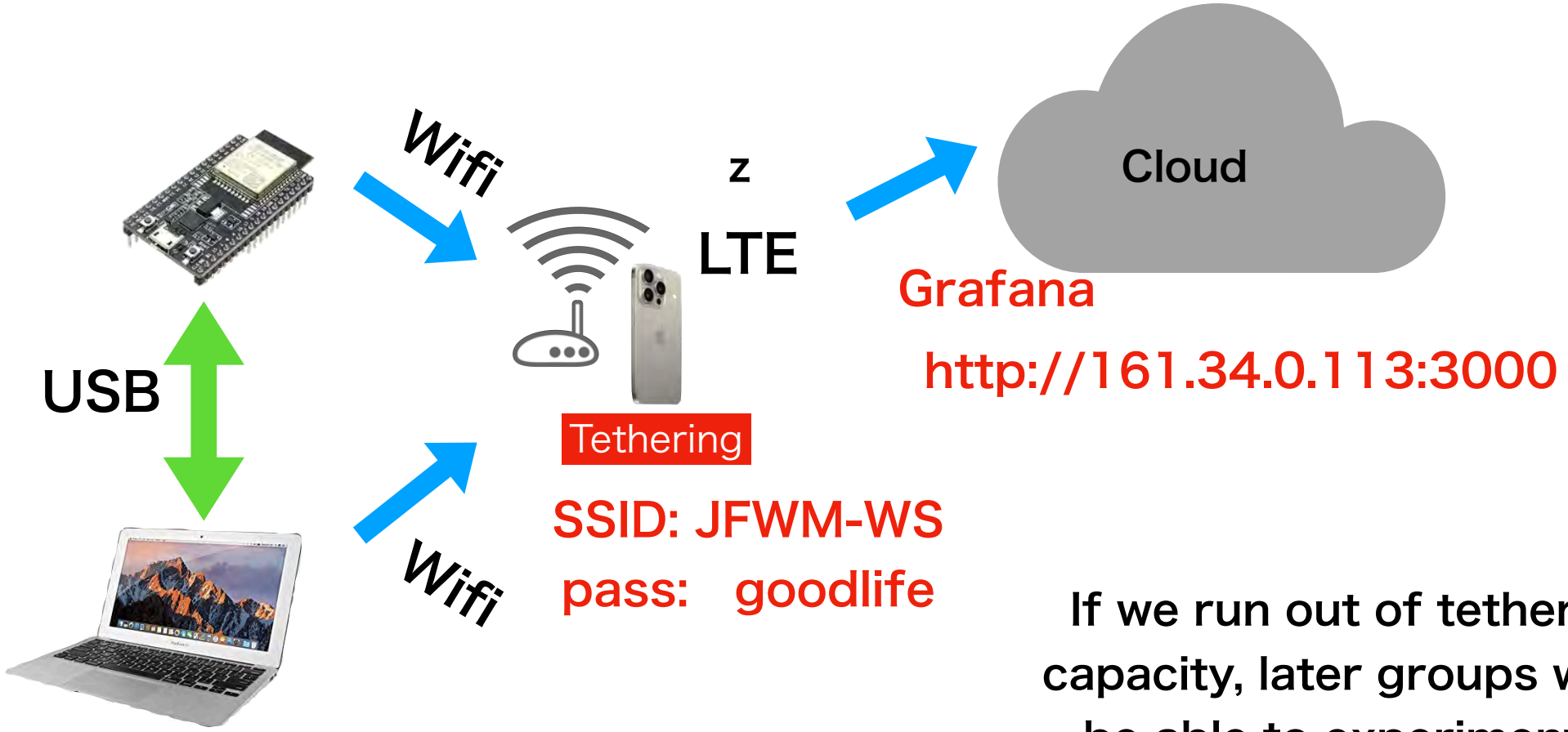
Press initial tab (Untitled..)



CAUTION

Due to the limited capacity of tethering, please connect to the following AP and setup Grafana only during the tutorial

Never use Youtube, cloud storage, or other large traffic services



Grafana

http://161.34.0.113:3000

SSID: JFWM-WS

pass: goodlife

One PC connection for each group

If we run out of tethering capacity, later groups won't be able to experiment & Fujita's trip in France will be disastrous.

Ex4) BME280 data upload to InfluxDB

Copy & paste

Then push

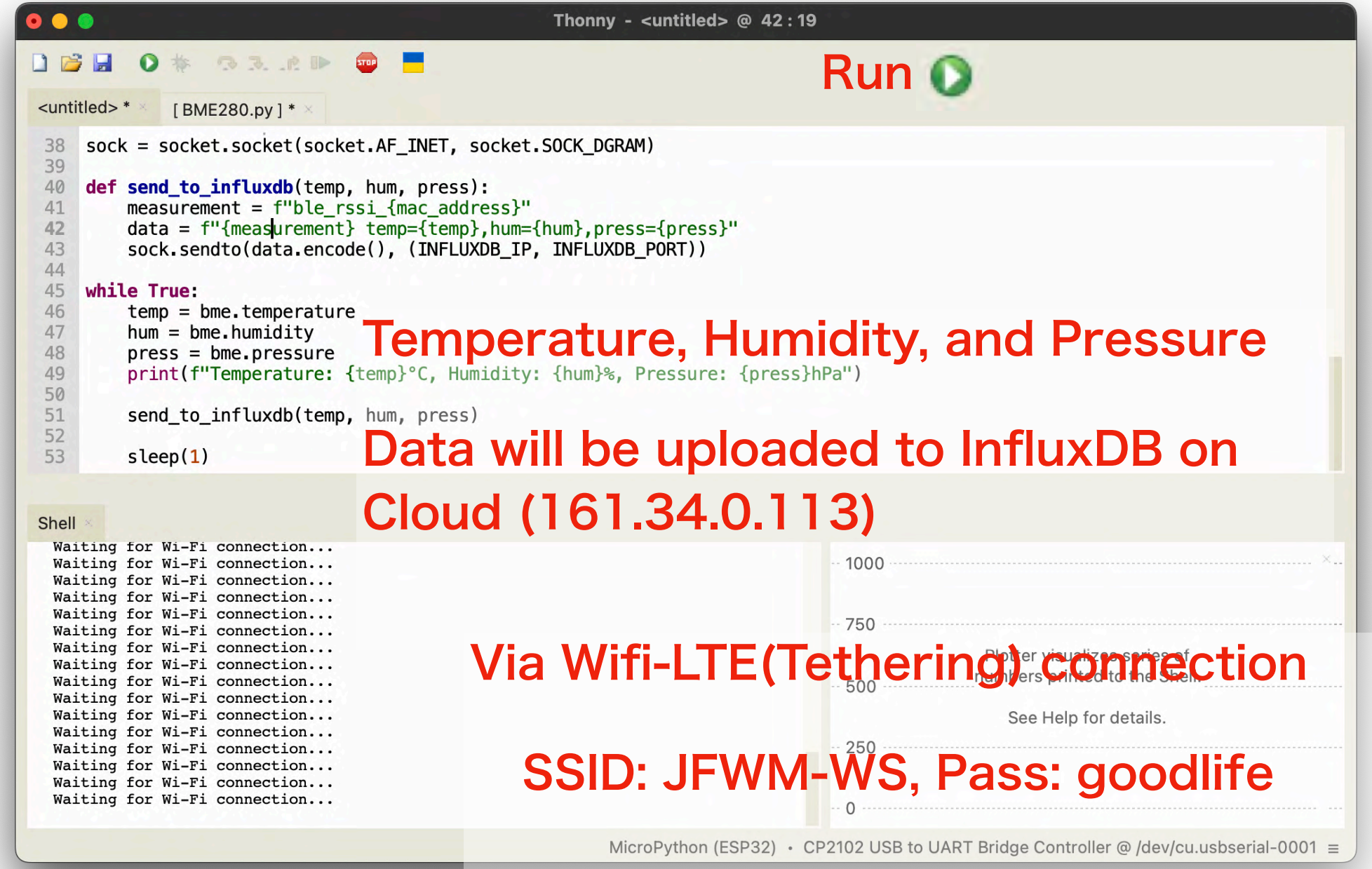
Run

Temperature, Humidity, and Pressure

Data will be uploaded to InfluxDB on Cloud (161.34.0.113)

Via Wifi-LTE(Tethering) connection

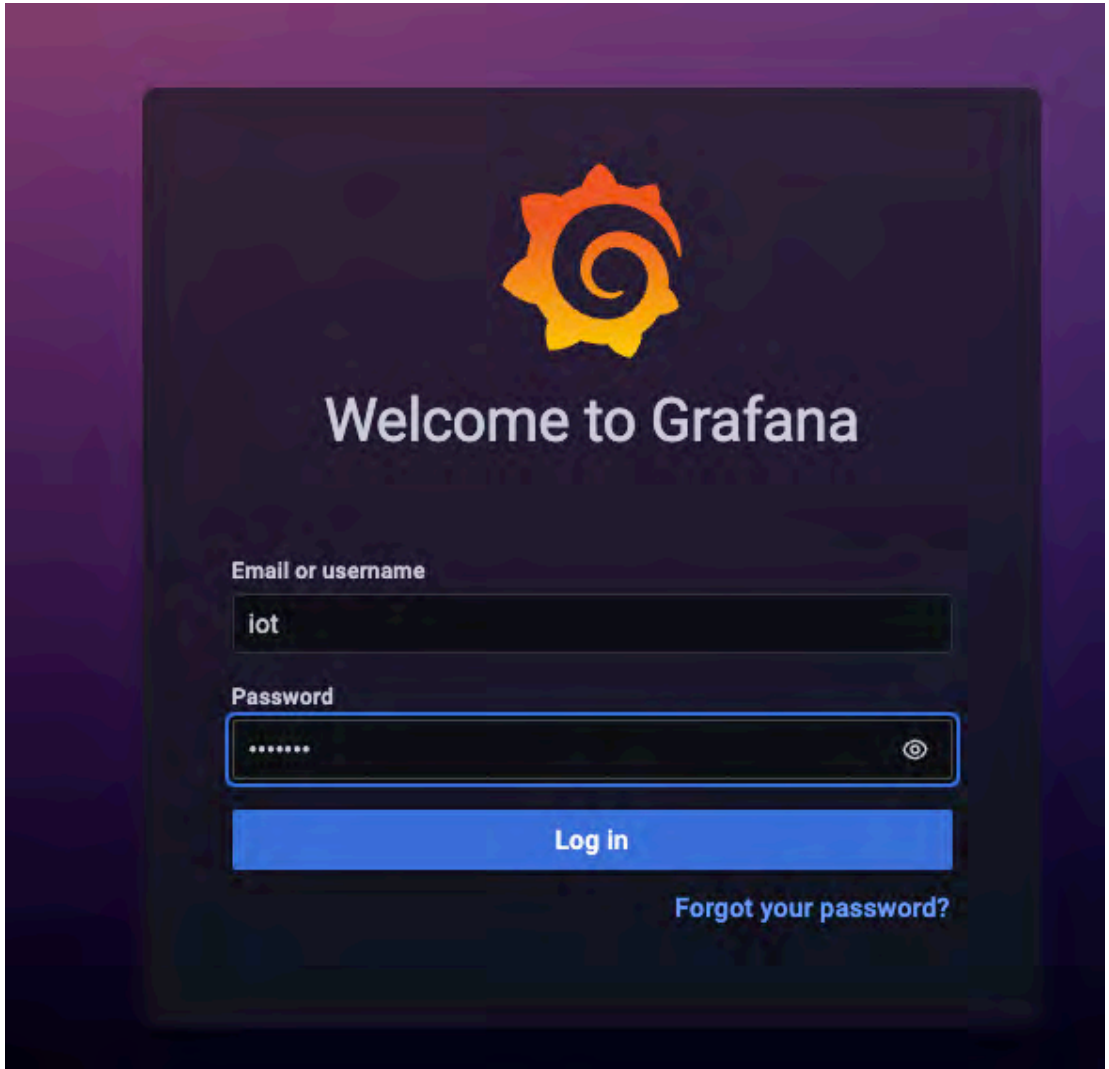
SSID: JFWM-WS, Pass: goodlife



Data visualization on Grafana

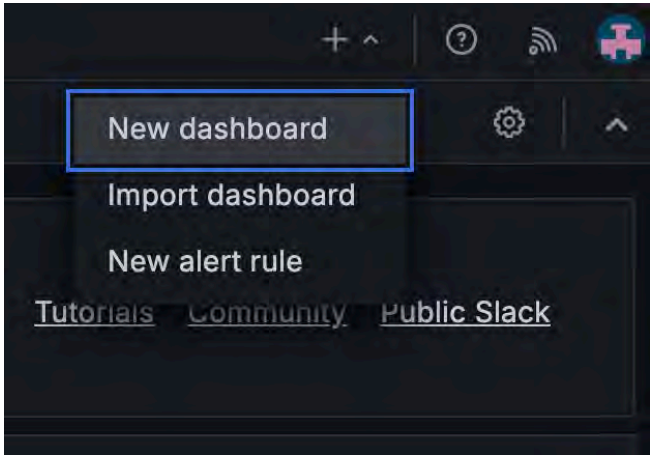
Access grafana server on cloud via AP
(SSID: JFWM-WS, pass: goodlife)

http://161.34.0.113:3000/

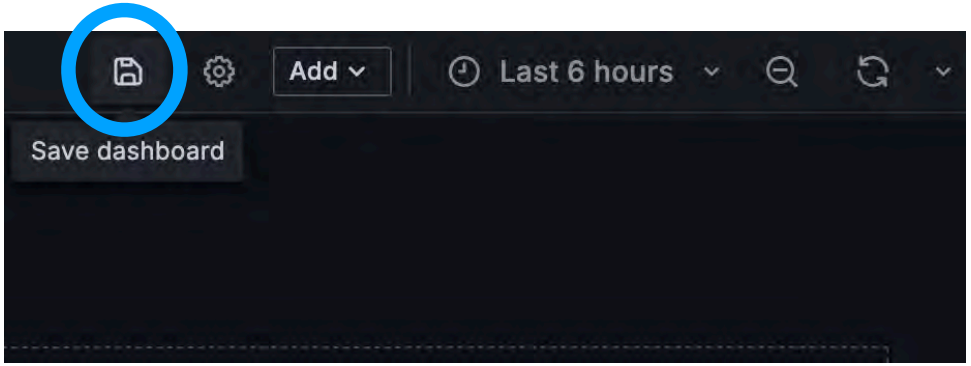


user: iomt
pass: iomt2023

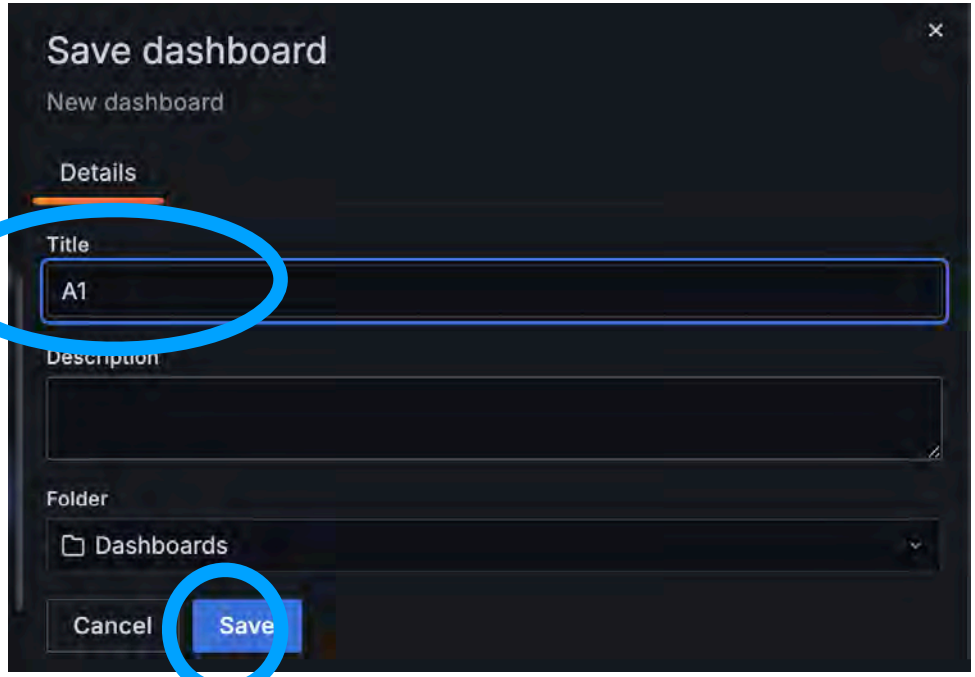
(1) create “Dashboard”



(2) Save…

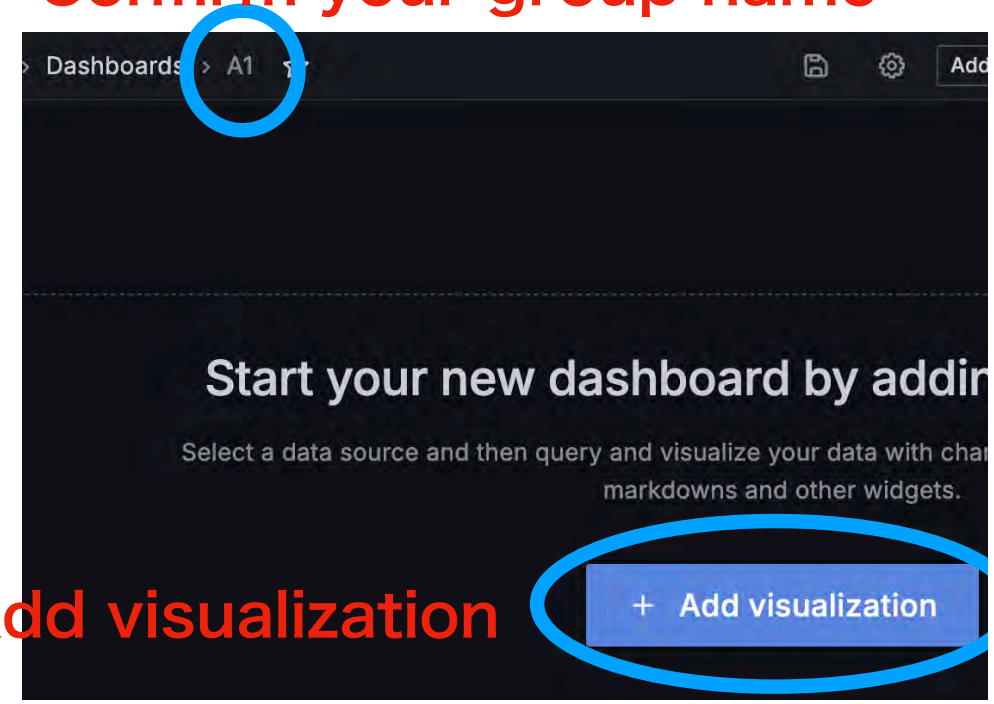


(3) Input title as your group A1…C3



(4) Save

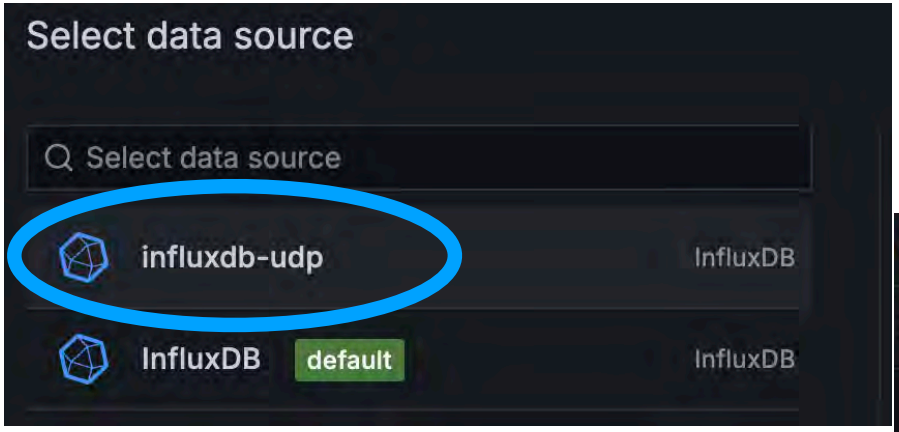
Confirm your group name



(5) Add visualization

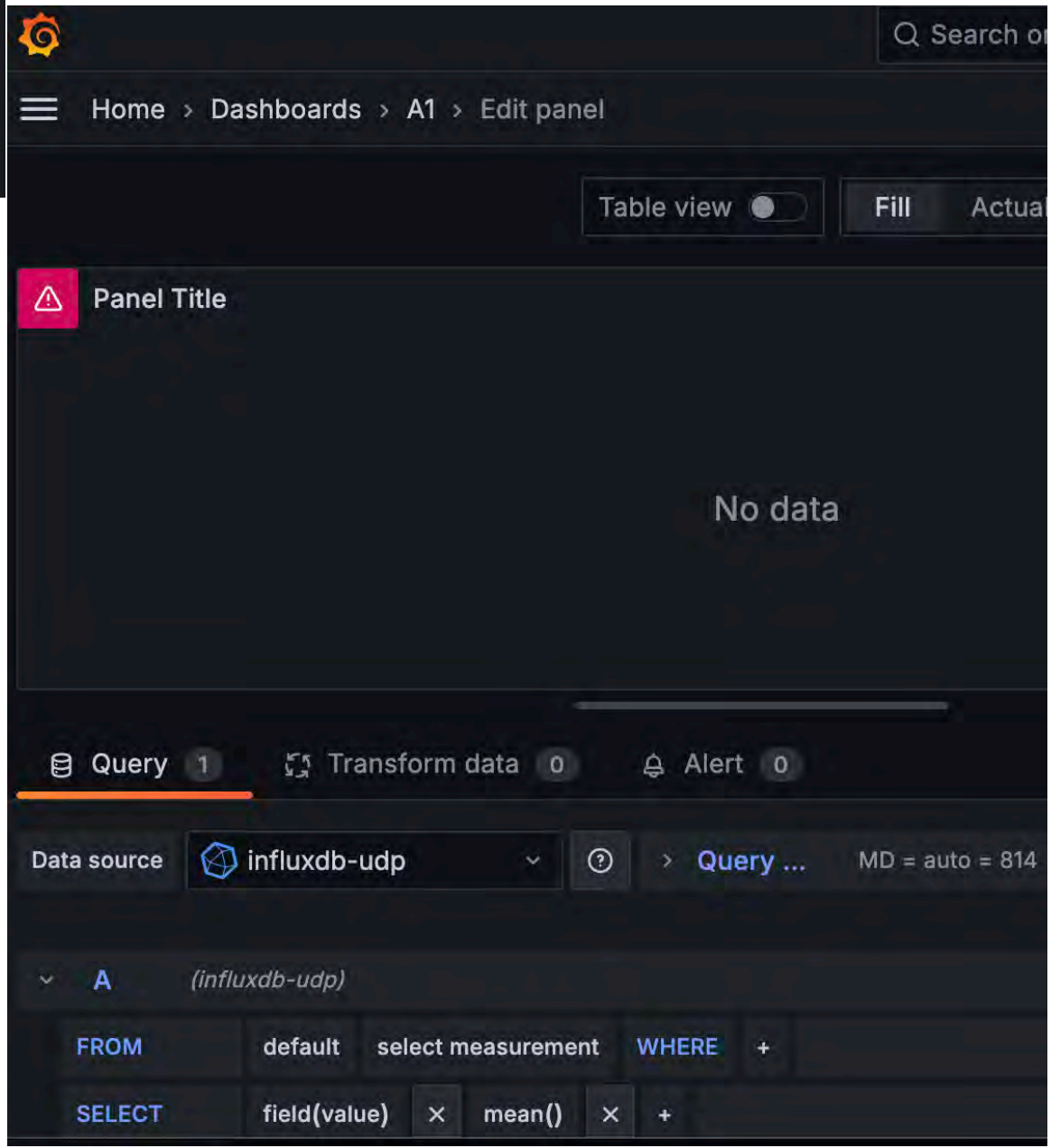
(6) Select data source

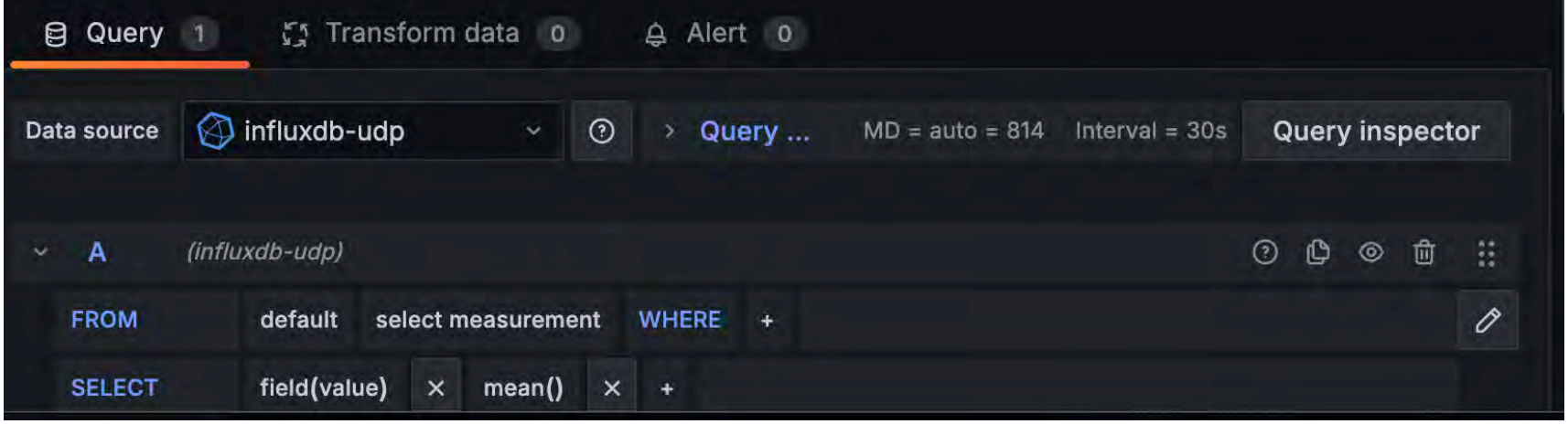
Data from ESP32 is stored in influxdb-udp



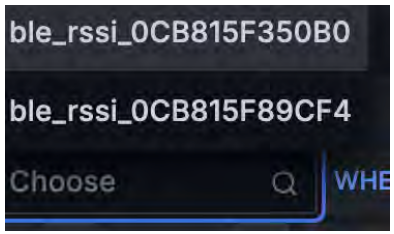
(7) Press 'influxdb-udp'

> Edit panel appears





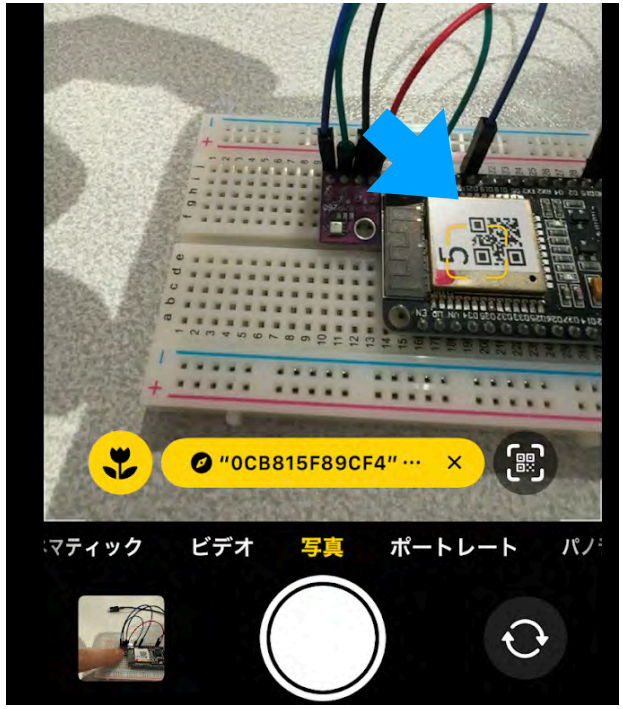
(8) Select measurement



Finding ble_rssi_????????

???????? is MAC address of your ESP32

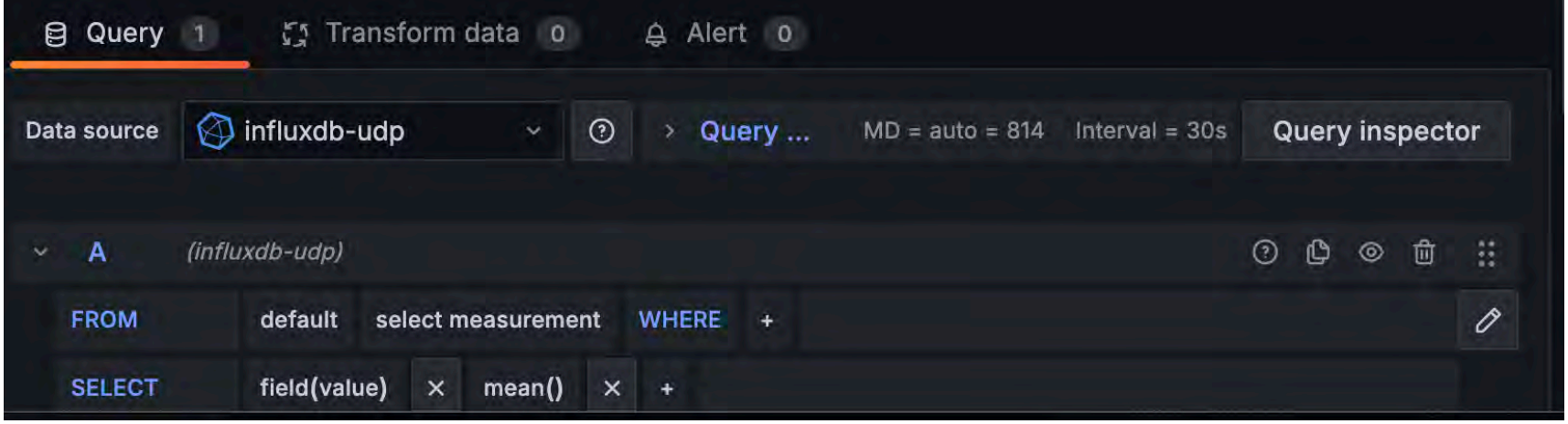
You can get address by QR code reader



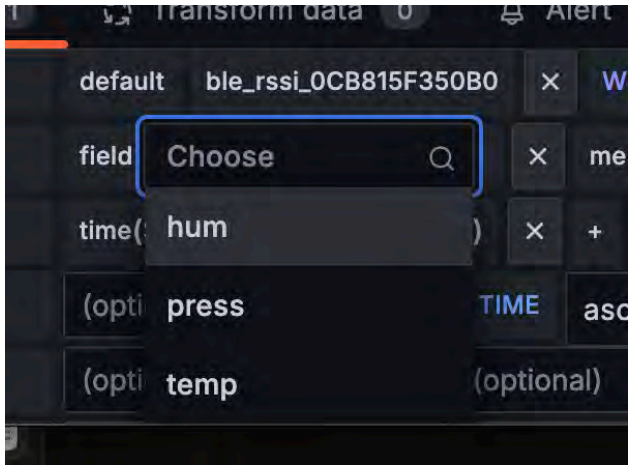
Or labelled number on ESP32 and address

1. 0CB815F89518
2. 0CB815F58564
3. 0CB815F72A38
4. 0CB815F350B0
5. 0CB815F89CF4
6. 0CB815F66E08

Select your group's address one



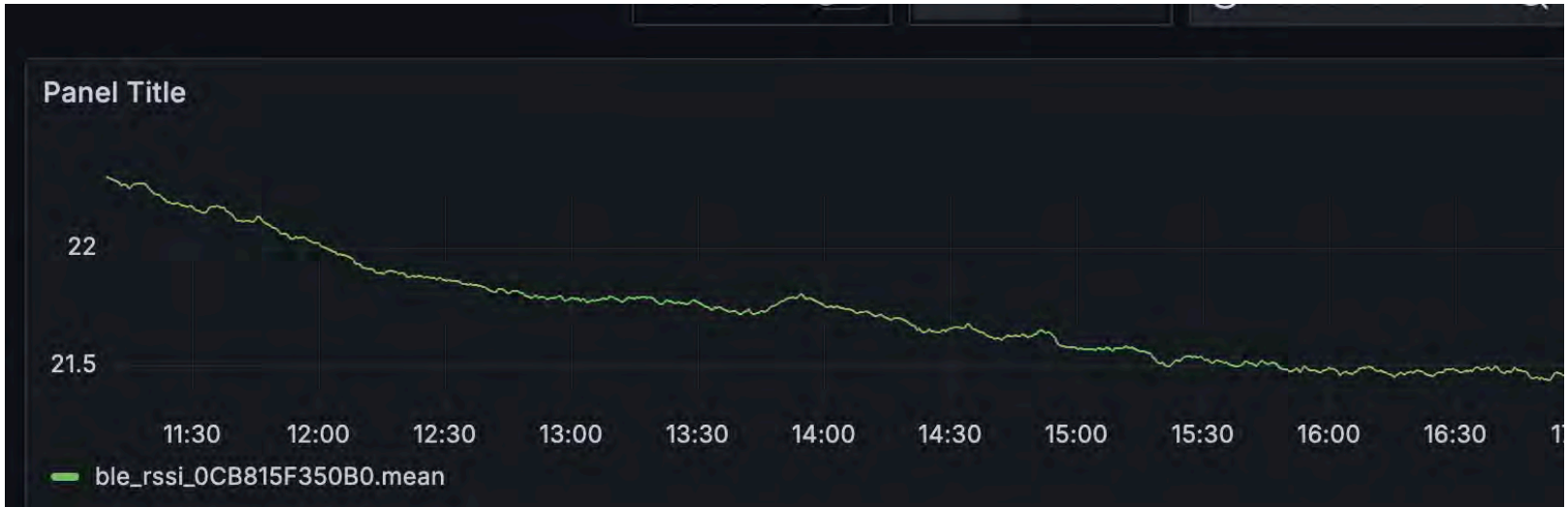
(9) Select field (value)



You can choose
hum: Humidity
press: Pressure
temp: Temperature

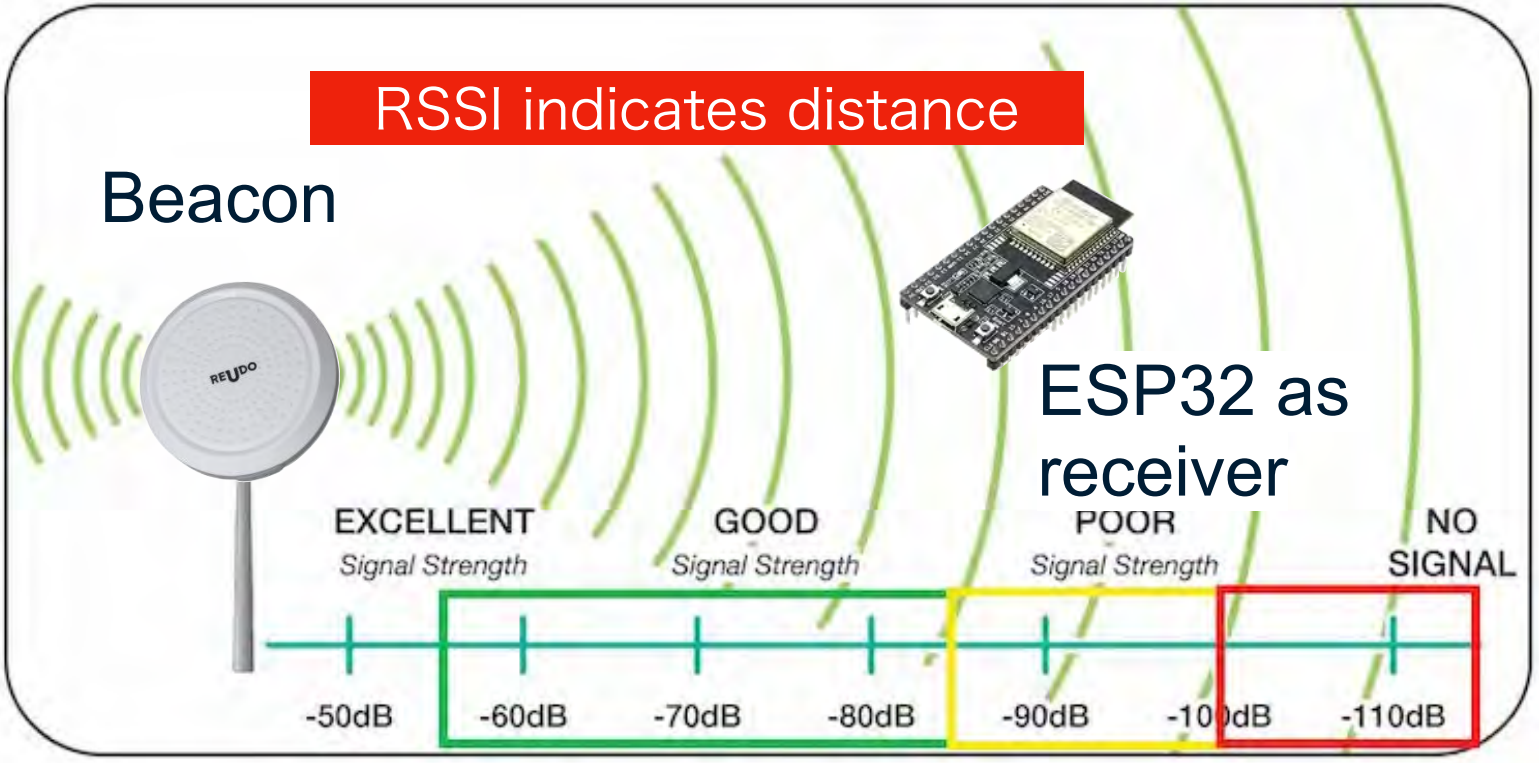
Details will be explained on site

(10)
Finally, get a graph for selection



Opt) Beacon RSSI upload InfluxDB

Bluetooth Low Energy (BLE) beacons are small, battery-powered devices that transmit data using Bluetooth Low Energy.



Before programing

Power on Beacon

Press and hold the button

LED flashes and SW ON

Opt) Beacon RSSI upload InfluxDB

Copy & paste

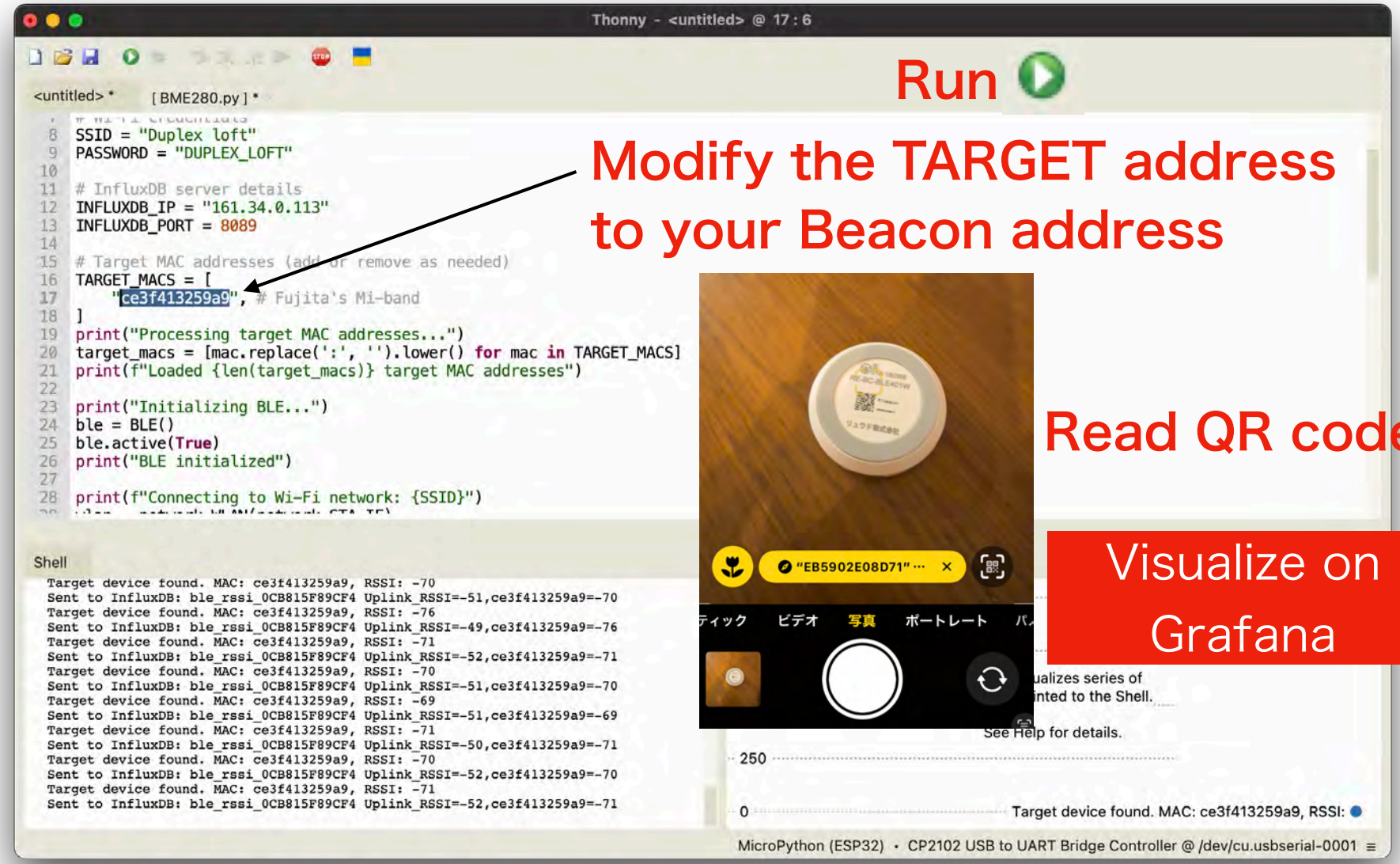
Then push

Run

Modify the TARGET address to your Beacon address

Read QR code

Visualize on Grafana



RSSI values for specific Beacon address

and uplink to AP will be uploaded

If you still have time and energy left over, you can modify a program to upload the WBGT values from BME280 sensor

19th Aug. 2019
Japantimes
news

A temperature indicator measures 31.3 degrees Celsius during a test of heat countermeasures for the Tokyo 2020 Olympic and Paralympic Games in the Japanese capital on July 25. | REUTERS

NATIONAL

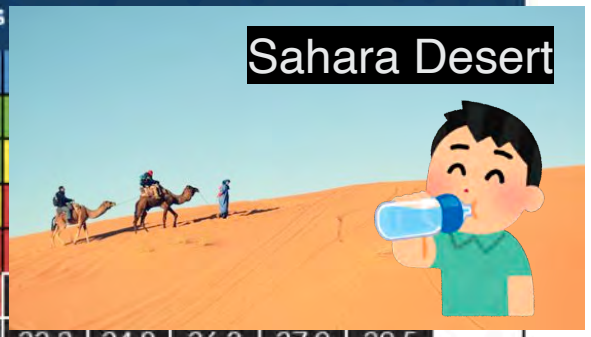
Heatstroke death toll since July exceeds 100 in Tokyo's 23 wards

Wet Bulb Globe Temperature (WBGT) from Temperature and Relative Humidity

Temperature in Degrees Celsius

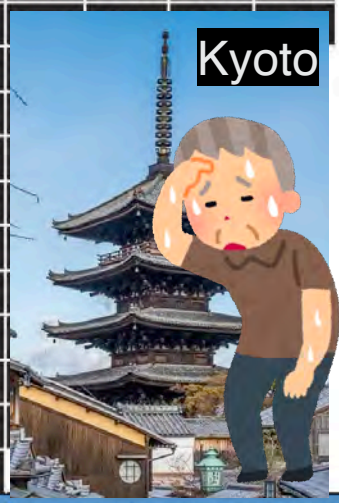
Relative Humidity (%)	20	22	24	26	28	30	32	34	36	38
0	14.8	16.1	18.0	18.6	19.8	21.1	22.3	23.5	24.7	25.8
5	15.3	16.7	18.7	19.4	20.7	22.0	23.3	24.6	25.9	27.2
10	16.0	17.4	19.4	20.2	21.6	23.0	24.3	25.7	27.1	28.4
15	16.5	18.0	20.1	20.9	22.4	23.8	25.2	26.7	28.1	29.5
20	17.1	18.7	20.8	21.6	23.1	24.6	26.2	27.7	29.2	30.8
25	17.6	19.3	21.4	22.3	24.0	25.5	27.0	28.6	30.1	31.7
30	18.2	19.8	22.0	23.0	24.6	26.2	27.8	29.4	31.0	32.7
35	18.7	20.3	22.6	23.6	25.3	26.9	28.6	30.2	31.9	33.5
40	19.3	20.9	23.2	24.3	26.0	27.6	29.4	31.0	32.7	34.4
45	19.7	21.5	23.8	24.9	26.6	28.3	30.1	31.8	33.5	35.2
50	20.2	22.0	24.3	25.5	27.3	29.0	30.8	32.5		
55	20.7	22.4	24.8	26.0	27.8	29.6	31.4	33.3		
60	21.1	22.9	25.4	26.6	28.4	30.2	32.1	34.0		
65	21.6	23.2	25.9	27.1	29.0	30.9	32.7	34.5		
70	22.1	23.9	26.4	27.6	29.4	31.4	33.3	35.1		
75	22.5	24.4	26.9	28.2	30.1	32.0	33.8	35.8		
80	22.9	24.8	27.4	28.7	30.6	32.5	34.4	36.3		
85	23.3	25.2	27.8	29.2	31.1	33.0	35.0	36.9		
90	23.7	25.7	28.3	29.6	31.6	33.5	35.5	37.5		
95	24.2	26.1	28.7	30.1	32.0	34.0	36.0	38.0		
100	24.5	26.5	29.1	30.5	32.5	34.5	36.5	38.5		

NOTE: This chart is calculated using temperature and humidity, assuming a very clear sky (maximal solar load), and atmospheric pressure of 1ATA (760 mmHg). Chart A was developed by Professor Yoram Epstein to be used in Ariel's Checklist for hikers in Israel.



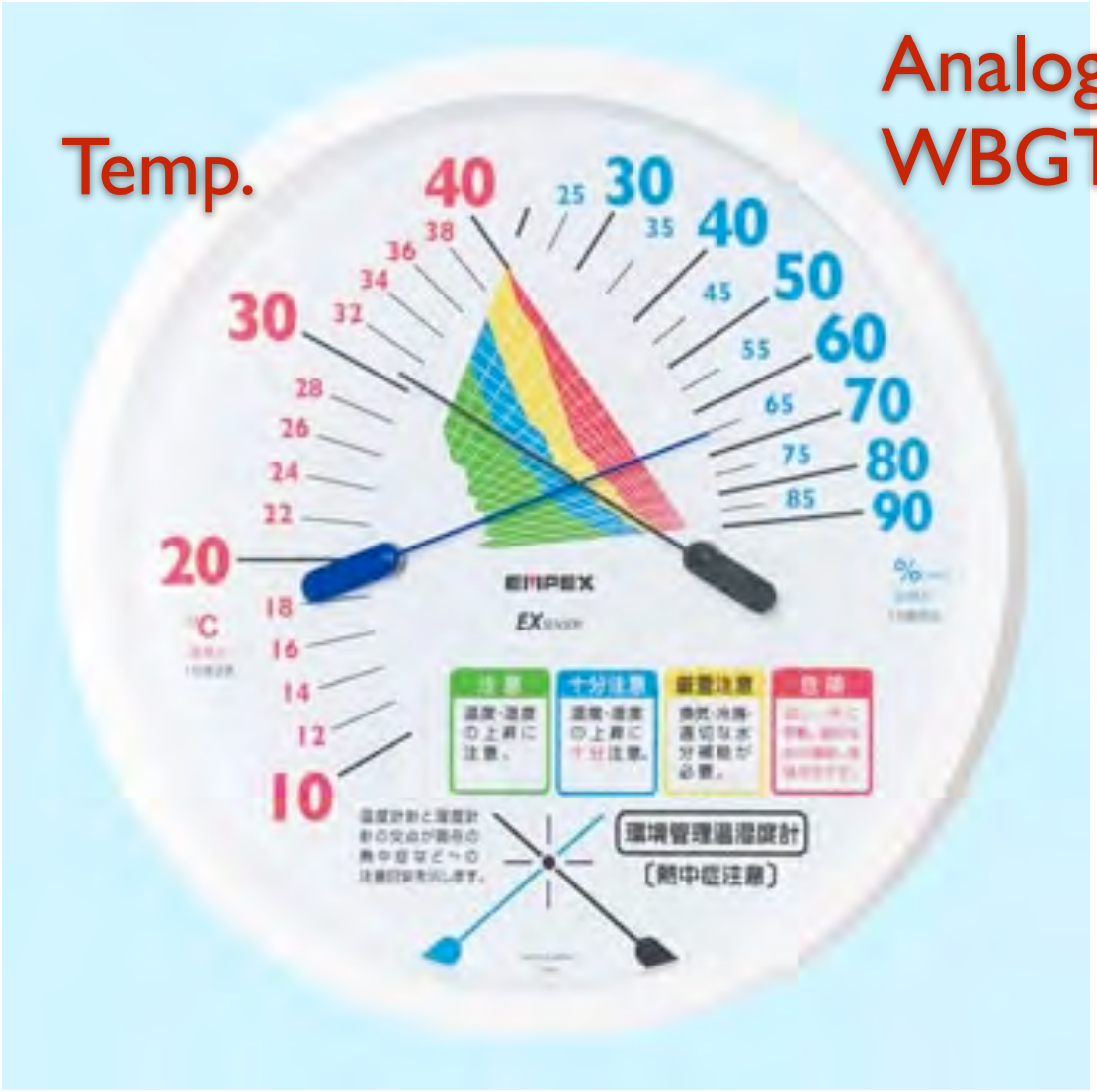
VHigh temp.
Low Hum

Calculate
by temp.
and humidity



High temp.
High Hum

Heatstroke WBGT meter



Cross point
= WBGT
Heatstroke

Requires special equipment

A U.S. Navy technician checking the wet-bulb globe temperature at the Corry Station Naval Technical Training Center, Florida

$$\mathrm{WBGT} = 0.7T_{\mathrm{w}} + 0.2T_{\mathrm{g}} + 0.1T_{\mathrm{d}}$$

where

- T_{w} = Natural wet-bulb temperature (combined with dry-bulb temperature indicates humidity)
- T_{g} = Globe thermometer temperature (measured with a globe thermometer, also known as a black globe thermometer)
- T_{d} = Dry-bulb temperature (actual air temperature)
- Temperatures may be in either Celsius or Fahrenheit

Three sensors Required for outdoor

Indoors, or when solar radiation is negligible, the following formula is often used:

$$\mathrm{WBGT} = 0.7T_{\mathrm{w}} + 0.3T_{\mathrm{g}}$$

Difficult to get Wet-bulb temp.

How to get WBGT from °C + %Rh.

Approximation equation

$$WBGT = (Humidity\text{-}20)\cdot\left((Temperature\text{-}40)^2 \cdot (-0.00025) + 0.185\right) + \frac{11}{15}\cdot(Temperature\text{-}25) + 17.8$$

For program

```
WBGT = (hum -20.0) * (  (-0.00025) *
pow ((temp - 40.0 ),2) + 0.185) + (11 /
15) * (temp - 25.0) + 17.8;
```