MAE 6291
Internet of Things for Engineers

Prof. Kartik Bulusu, MAE Dept.

Week 4 [02/12/2025]	• Setting up the Edge Lab • IoT Architecture and Ecosystem • Layers in IoT systems - 3 level layer model • Sensors • Sensor types and considerations • Discussion on the midterm projects for updates and reporting • Guest lecture: Protocol for point-to-point communication between two devices by Jitish Kolanjery	• dweet.io – Twitter of things • Fetching data from dweet • dweet an LED - Your first IoT program Raspberry Pi messaging with Python scripts • HW 3 assigned

git clone https://github.com/gwu-mae6291-iot/spring2025_codes.git

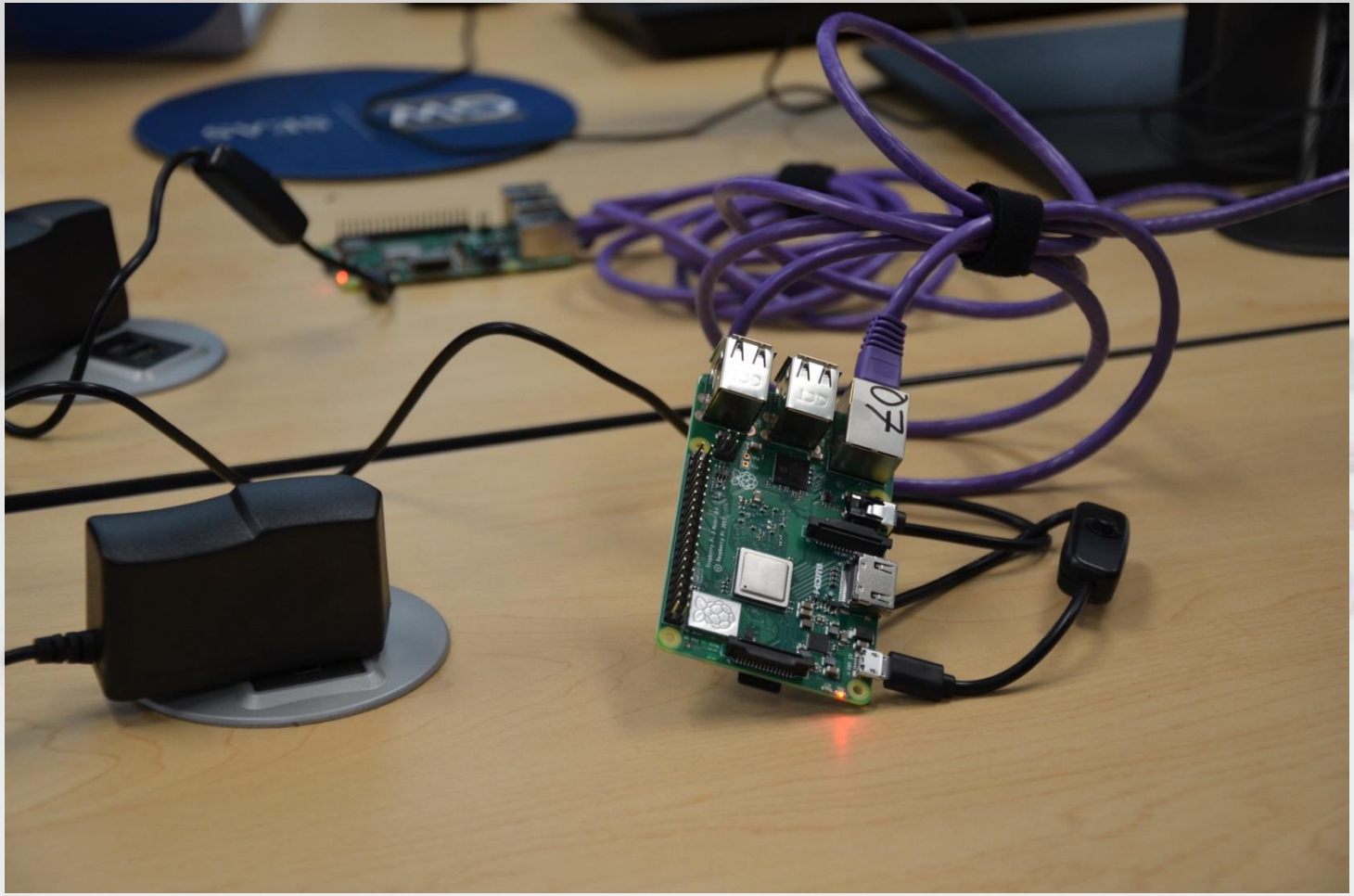
GW School of Engineering & Applied Science
THE GEORGE WASHINGTON UNIVERSITY

Spring 2025

Photo: Kartik Bulusu

Set up lab the Edge-lab

STEP [1]:
Connect the RPis to each desk power outlet as shown



- Make sure there is a microSD card installed in the RPi
- Connect the RPi using the microUSB cable provided
- Connect the purple colored ethernet cables specifically for RPi connections
- LEDs on the RPi will start blinking indicating that it is booting up

STEP [2]:
Access the RPi in the Edge-lab

2.1 Open up remote desktop connection (using the VNC server)

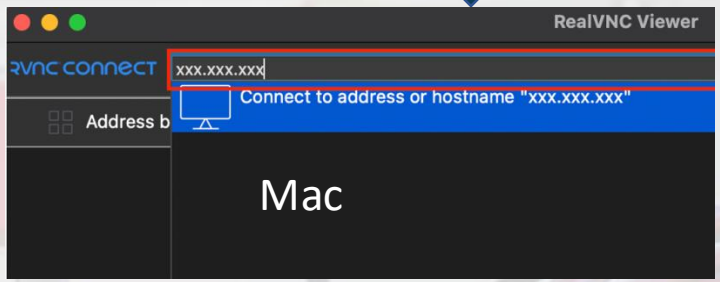
Each RPi has unique alpha-numeric name (e.g., Pi07, Pi152 etc)

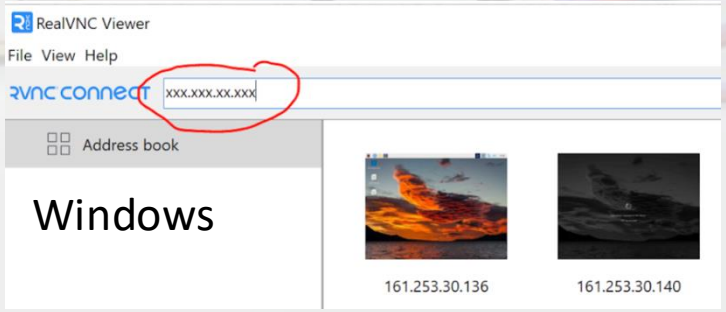
- Locate the Pi-name and the IP address on the <128.164.139.xx>

OR

Each RPi connected using an ethernet cable directly to your laptops

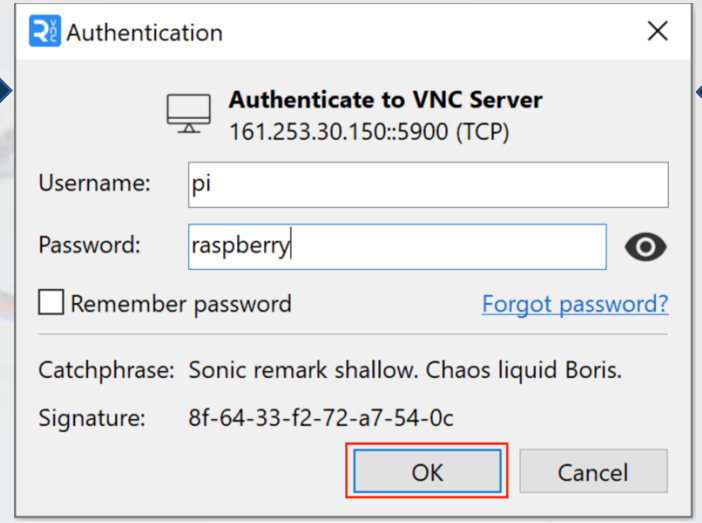
- raspberrypi.local





2.2 Once you are connected you will

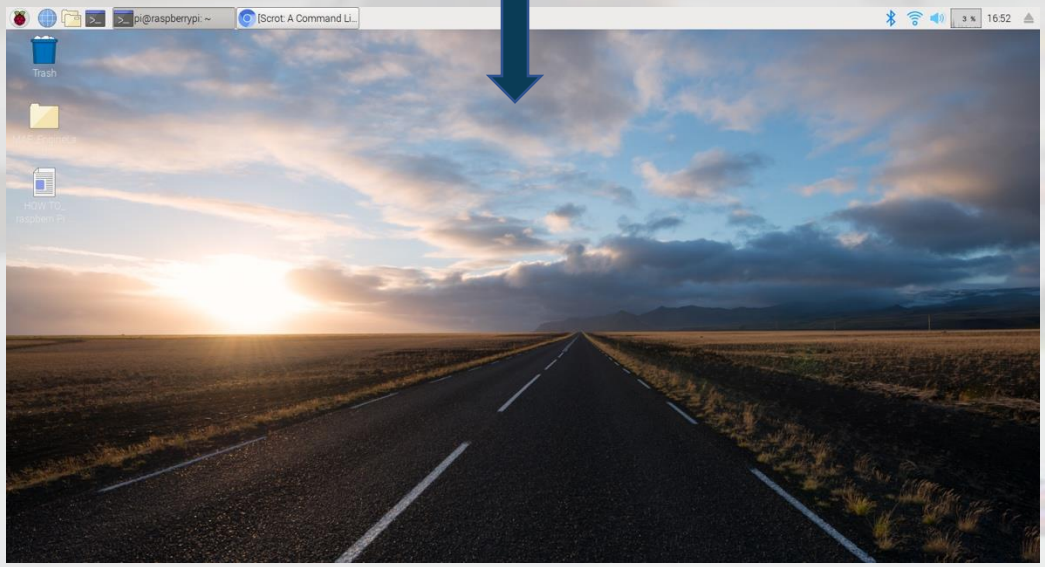
- See Authentication box below
- Type in the Username and Password



STEP [3]:

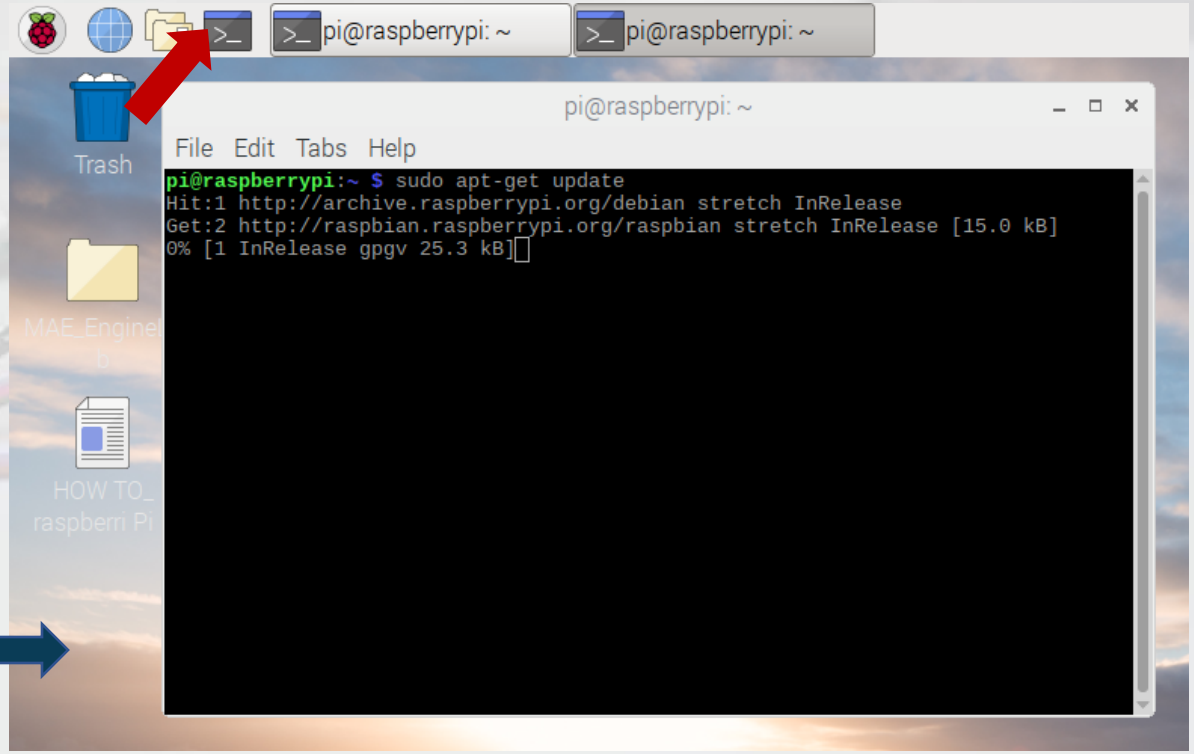
Now that you accessed the RPi…

You will see a screen like the one shown below



3.1 Click on terminal(shown with a red arrow below)

- At the prompt type: sudo apt-get update
- Wait for the updates to complete
- Then type: sudo apt-get upgrade
- If you get the following prompt
  - Do you want to continue [Y/n]
  - Type: y
  - And hit "Enter" on your keyboard and let the upgrades complete



3.2 Testing is complete when you get to this step.

- Students should get the RPis to this step before the laboratory modules begin.

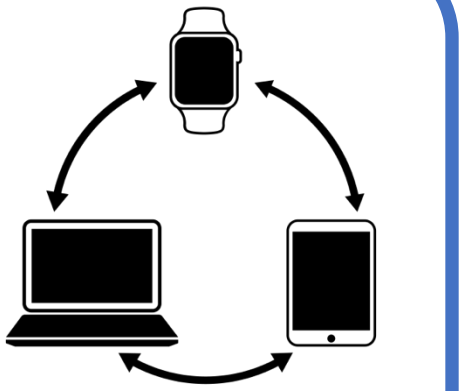
Short walk back
- What's the "thing" in IoT?

Sources:
Calculator by Markus from https://thenounproject.com/browse/icons/term/calculator/
internet of things by Davo Sime from https://thenounproject.com/browse/icons/term/internet-of-things/
L. Bernardi, S. Sarma and K. R. Traub, The Inversion Factor: How to Thrive in the IoT Economy

Paradigm #1

- A **thing** is self-contained and only operates within the confines of its physical shell.
  - **Thing** carries out only those functions that its designer envisioned when it was fabricated.
- The **thing** contains a powerful computer inside but is completely hidden from the user.
- The **thing** has firmware (not called software).

Paradigm #2



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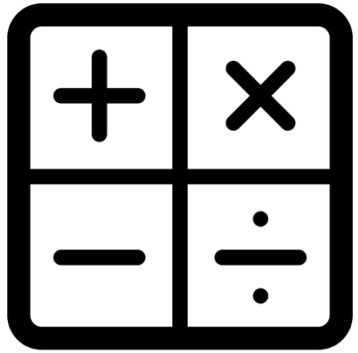


Paradigm #3

Icon source:
https://thenounproject.com/icon/clean-energy-4339399/

Two questions up for discussion

1. How should we start perceiving an IoT system, physically ?

2. How / Where do we place the “thing” in that system ?

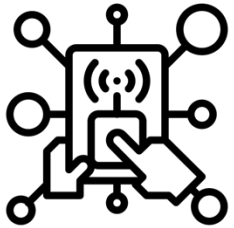
Keywords:
GUI, display, Small, functional, re-envisioning applications, efficient, sensor-driven, smart-sensors, connectivity, autonomy, data-driven, durability, fault tolerance, interoperability

Proximity to data, compute-power, network, distributed-network etc.

Building up the IoT Architecture and Ecosystem

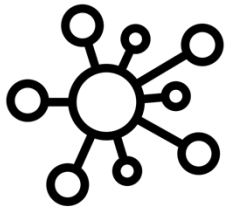
Icon Sources:
sensor by Carolina Cani:, sensor by Pham Duy Phuong Hung, sensor by Tippawan Sookruay, sensor by Lorenzo: https://thenounproject.com/browse/icons/term/sensor
fire sensor by LAFS : https://thenounproject.com/browse/icons/term/fire-sensor/
Ultrasound by Shocho: https://thenounproject.com/browse/icons/term/ultrasound/
Network by Solikin:, Network by Tippawan: https://thenounproject.com/browse/icons/term/network
application by Chaowalit Koetchuea: https://thenounproject.com/browse/icons/term/application/

Information-layer



Data

Communication-layer



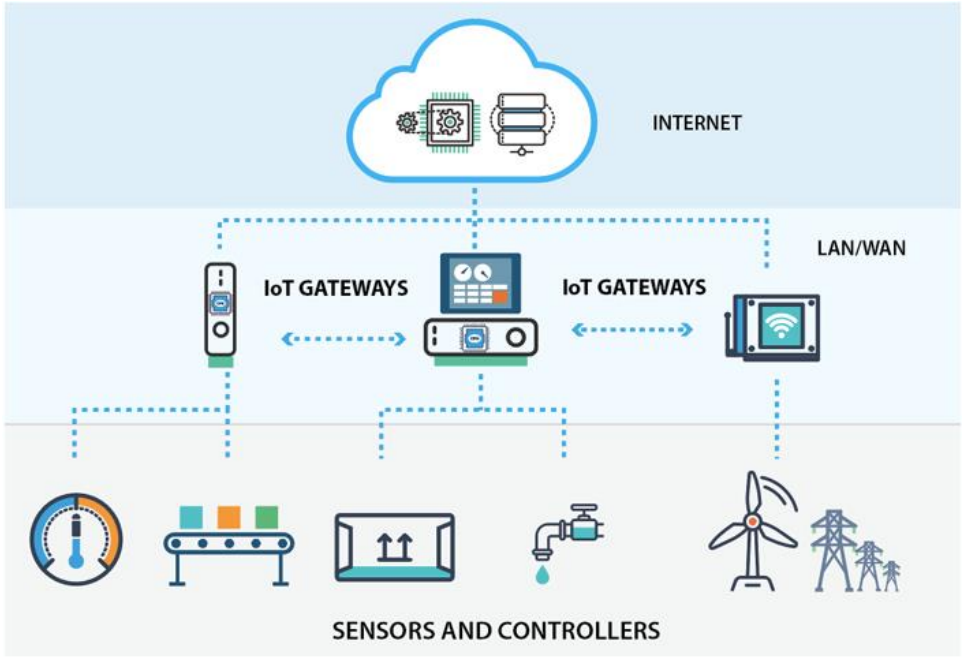
Connectivity

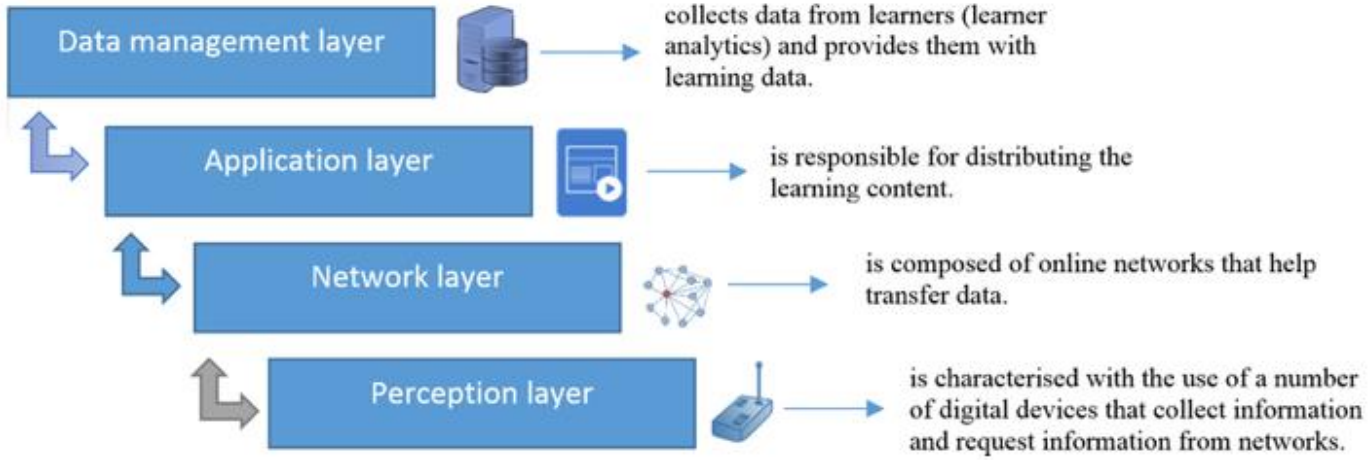
Sensor-layer

Things

Refining and defining the 3-Layer IoT Architecture

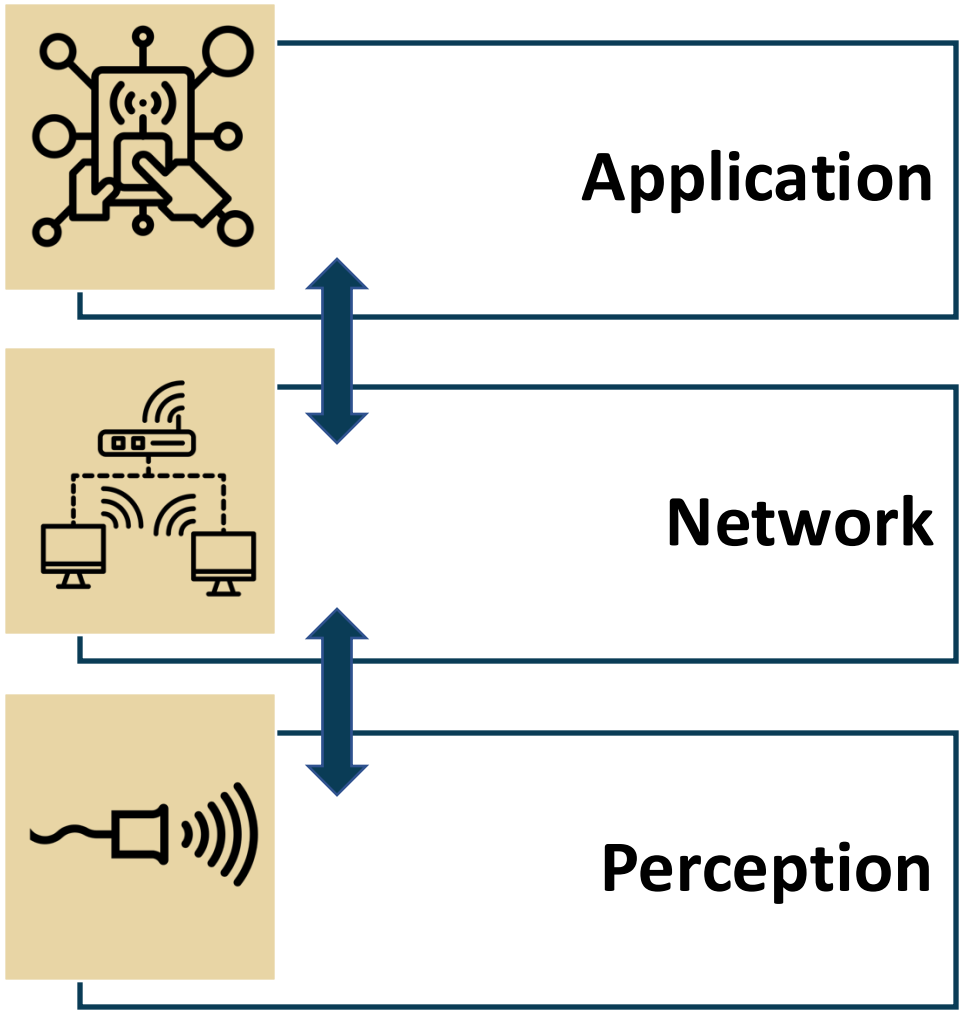
Sources:
Internet of Things, IoT Architecture: https://www.zibtek.com/blog/iot-architecture/





The 3-Layer IoT Architecture

Icon Sources:
sensor by Carolina Cani:, sensor by Pham Duy Phuong Hung, sensor by Tippawan Sookruay, sensor by Lorenzo: https://thenounproject.com/browse/icons/term/sensor
wifi network by Matthias Hartmann:: https://thenounproject.com/browse/icons/term/wifi-network/
application by Chaowalit Koetchuea: https://thenounproject.com/browse/icons/term/application/



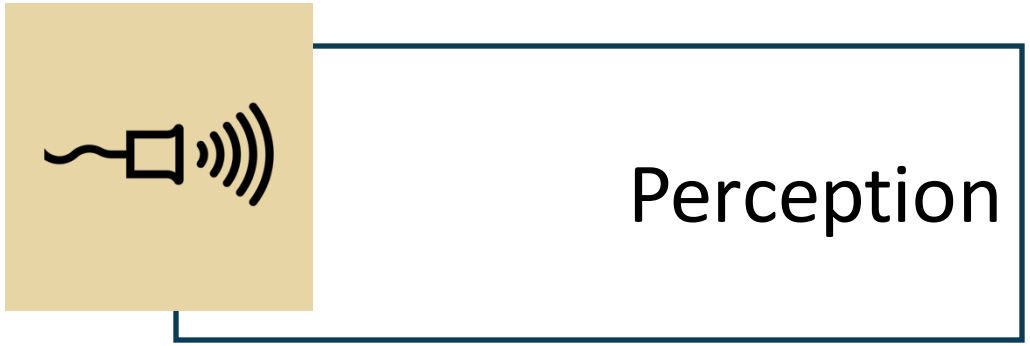
Network layer

Guest lecture

Protocol for point-to-point communication between two devices

by
Jitish Kolanjery
Sr. Software Engineer
Google Inc.

Sensors and the IoT perception layer



Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Opem
Workflow by Nithinan: https://thenounproject.com/browse/icons/term/workflow/

What is a sensor?

A device that receives a stimulus and responds with an electrical signal.

Reference: Fraden, Jacob, Handbook of Modern Sensors, 4th ed. New York: Springer, 2010.

A device that responds to a physical input of interest with a recordable, functionally related output that is usually electrical or optical.

Reference: Jones, Deric P., Biomedical Sensors, 1st ed. New York: Momentum Press, 2010.

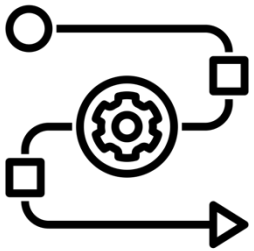
A sensor generally refers to a device that converts a physical measure into a signal that is read by an observer or by an instrument.

Reference: Chen, K. Y., K. F. Janz, W. Zhu, and R. J. Brychta, "Redefining the roles of sensors in objective physical activity monitoring," Medicine and Science in Sports and Exercise, vol. 44, pp. 13–12, 2012.

A device which provides a usable output in response to a specific measurand.

Reference: ANSI, Americian National Standards Institute, "ISA S37.1–1975 (R1982)," ed, 1975.

Key idea



Energy conversion

What is a transducer?

A converter of any one type of energy into another [as opposed to a sensor, which] converts any type of energy into electrical energy.

Reference: Fraden, Jacob, Handbook of Modern Sensors, 4th ed. New York: Springer, 2010.

A sensor differs from a transducer in that a sensor converts the received signal into electrical form only.

A sensor collects information from the real world. A transducer only converts energy from one form to another.

Reference: Khanna, Vinod Kumar, Nanosensors: Physical, Chemical, and Biological. Boca Raton: CRC Press, 2012.

Sources:

McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Opem

https://www.rohm.com/sensor-shield-support/heart-rate-sensor

Adafruit: https://www.adafruit.com/product/1075?gclid=CjwKCAiA85efBhBbEiwAD7oLQBeaVzL3TCUexZkYZQqnzdLQuRU2b_M6Ygk-0GHJRMqjL_GfdS17tRoC9MwQAvD_BwE

Homedics: https://www.homedics.com/infrared-ear-and-forehead-thermometer/

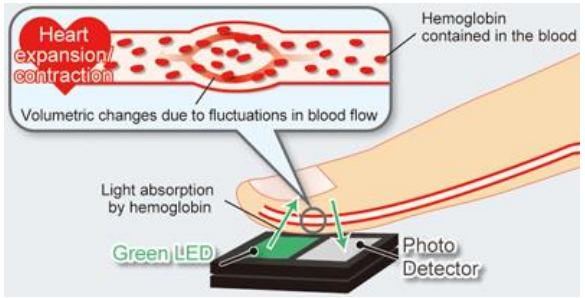
Healthline: https://www.healthline.com/diabetesmine/glucose-test-strips-diabetes-uses-accuracy-costs

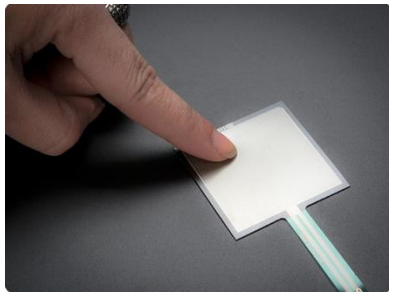
Sensor measurement classification-based on proximity to the measurand

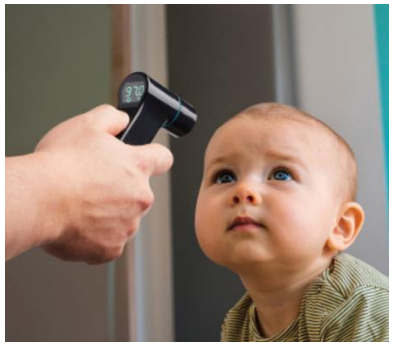
Contact — require physical contact with the quantity of interest.

Non-contact — do not require physical contact with the quantity of interest.

Sample removal — involves an invasive collection of a representative sample by a human or automated sampling system.







Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)
Electronics hub: https://www.electronicshub.org/different-types-sensors/

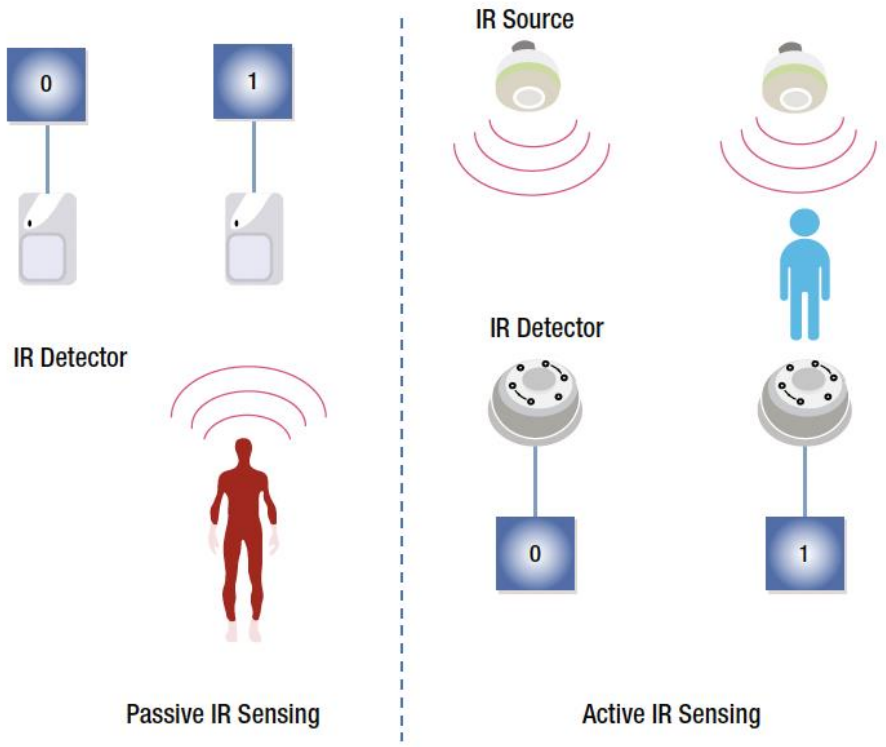
Sensor classification-based on power requirements

Active sensors

- require an external circuitry or mechanism to power them up.

Passive sensors

- do not require external circuitry provide it with power
- directly respond to the external stimuli from its ambient environment and converts it into an output signal.



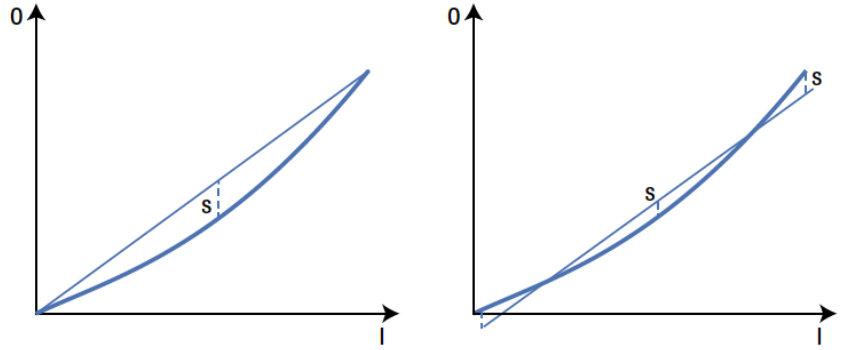
Sensing considerations

Sources:
resolution by Smashicons: https://thenounproject.com/browse/icons/term/resolution/
range by Adrien Coquet: https://thenounproject.com/browse/icons/term/range/
Energy by scarlett mckay: https://thenounproject.com/browse/icons/term/energy/
size by Woof Print Shop: https://thenounproject.com/browse/icons/term/size/
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Opem

Resolution:
Minimum discernable measurement

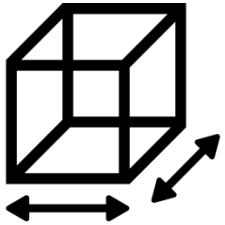
Sensing range:
Maximum and minimum of the possible measurement

Linearity and the transfer function

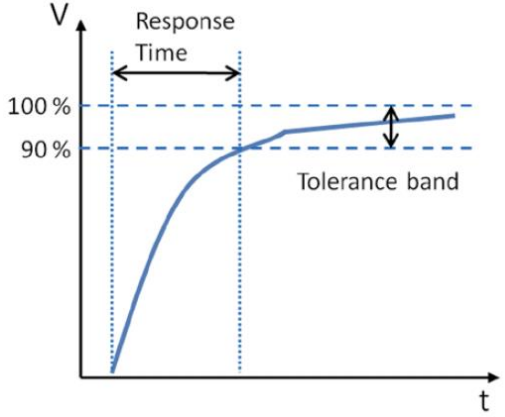


Energy consumption

Device size and form factor



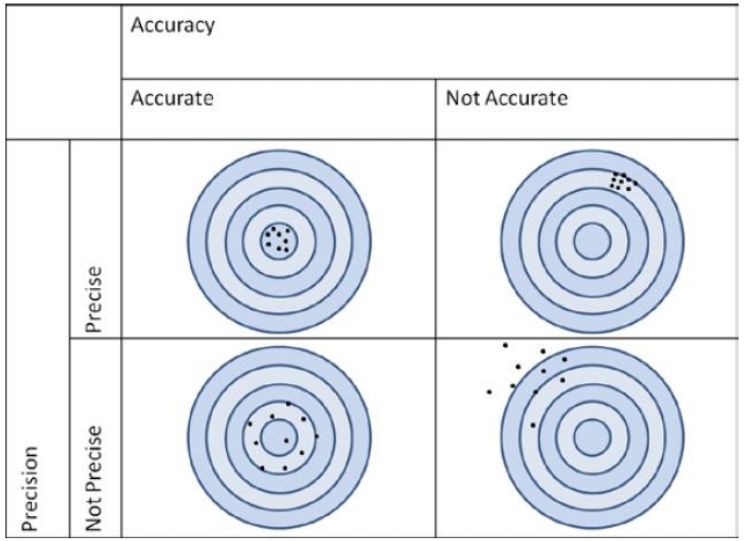
Response time



Sensing errors

Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)

Accuracy and Precision



$$Percentage\ Relative\ Error = \frac{(Measured\ Value - True\ Value)}{(True\ Value)} \times 100$$

$$Percentage\ Standard\ Deviation = \frac{(Standard\ Deviation)}{(Mean)} \times 100$$

Systematic Errors

Systematic errors are reproducible inaccuracies that can be corrected with compensation methods, such as feedback, filtering, and calibration

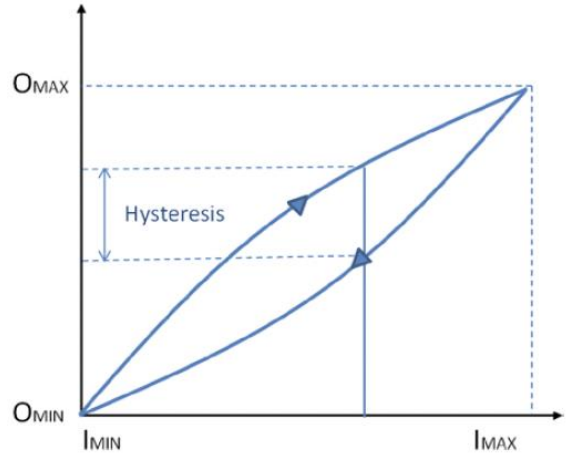
Reference: *Wilson, Jon S., Sensor Technology Handbook. Burlington, MA: Newnes, 2004.*

Random error

Random error (also called noise) is a signal component that carries no information.

The quality of a signal is expressed quantitatively as the signal-to-noise ratio (SNR), which is the ratio of the true signal amplitude to the standard deviation of the noise.

Hysteresis



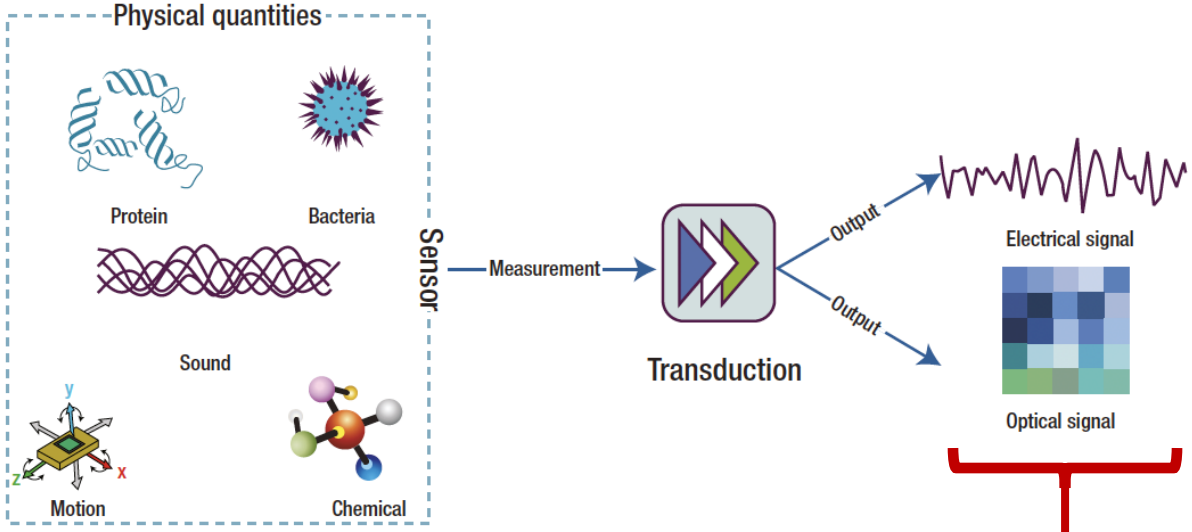
Repeatability

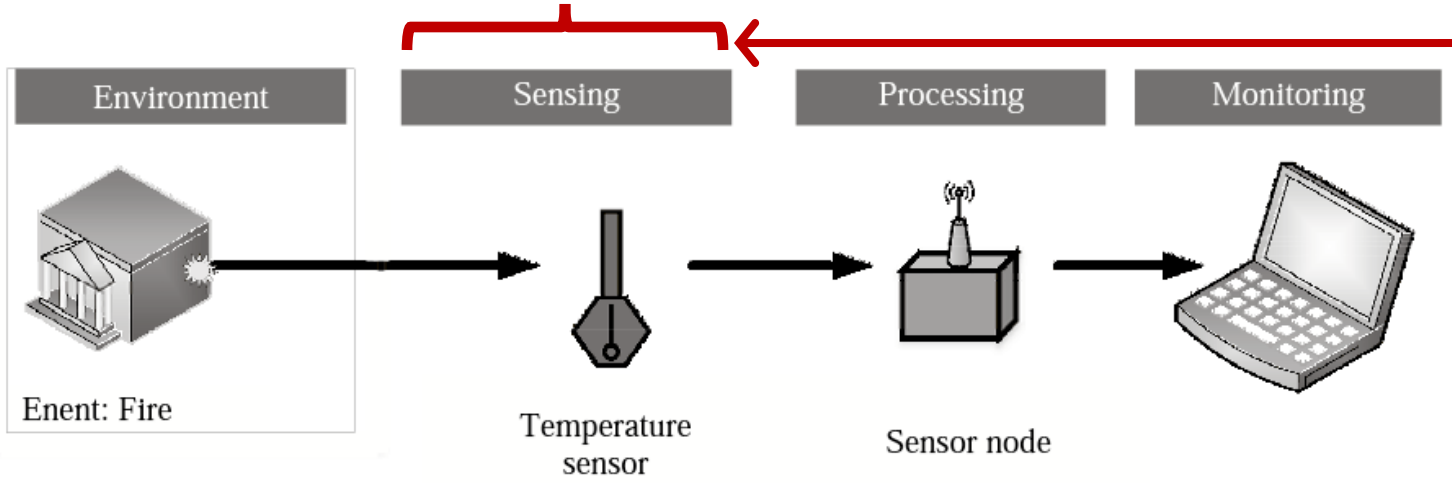
Repeatability is the ability of a sensor to produce the same output when the same input is applied to it.

Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)

Outline of a Sensing Operation

Sensor measurements are converted by a transducer into a signal that represents the quantity of interest to an observer or to the external world.

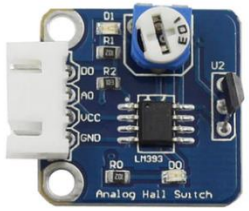




In the IoT-framework, sensor signals and data are communicated to a remote monitor by a processor through a network

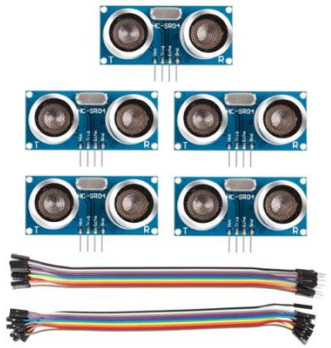
Common types of commercially available sensors (Sunfounder kit)

Source:
Sunfounder:
https://www.sunfounder.com/collections/raspberry-pi-store



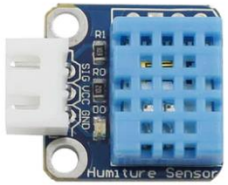
SUNFOUNDER

Analog Hall Sensor Module



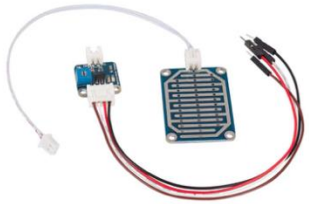
SUNFOUNDER

5pcs HC-SR04 Ultrasonic Module Distance Sensor



SUNFOUNDER

Humiture Sensor Module

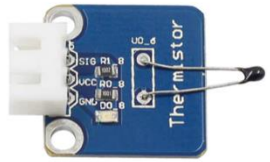


SUNFOUNDER

Raindrop Sensor Module

SUNFOUNDER

Photoresistor Sensor Module



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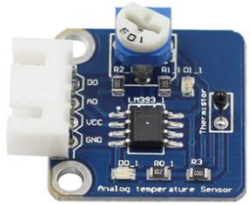
Thermistor Sensor Module



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Analog Temperature Sensor Module

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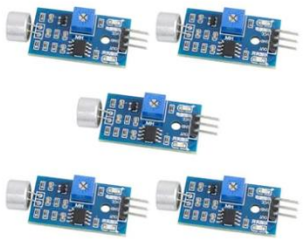
HHC MQ-2 Gas Sensor Module



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Sound Sensor Module (5

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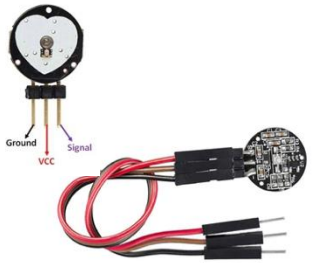
Flame Sensor Module

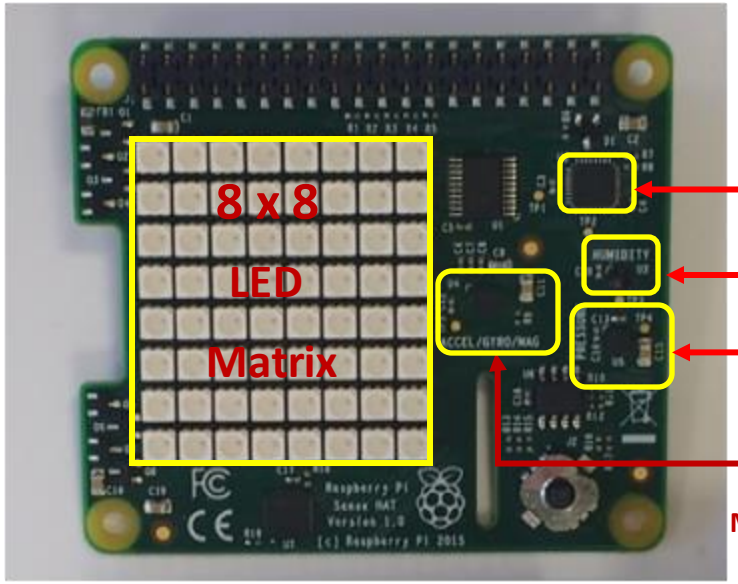


SUNFOUNDER

PulseSensor Heart Rate Monitoring Sensor Module

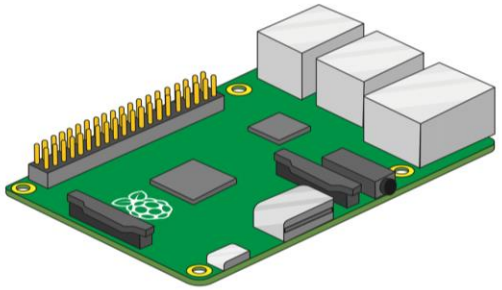
Other types of commercially available sensors and modules

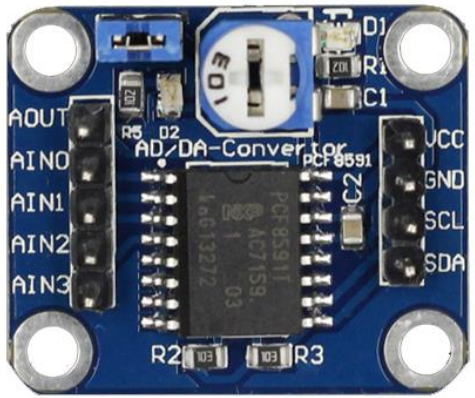
Image and animation source:
https://projects.raspberrypi.org/en/projects/getting-started-with-the-sense-hat/2
http://wiki.sunfounder.cc/index.php?title=Main_Page
https://www.adafruit.com/product/3100#description



- The Sense HAT has a variety of sensors that can be read from:

"Temperature"	reads temperature in degrees Celsius
"Humidity"	reads humidity in % RH
"Pressure"	reads atmospheric pressure in millibars
"Rotation"	reads gyroscopic motion in revolutions per second
"Acceleration"	reads acceleration in terms of standard accelerations due to gravity on Earth's surface
"Orientation"	reads orientation relative to magnetic north in degrees
"Magnetic Field"	reads strength and direction of a magnetic field around the sensor in microteslas





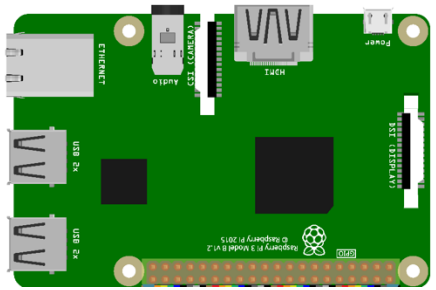
dweet.io

A simple publishing and subscribing tool for IoT devices ..

or anybody's thing

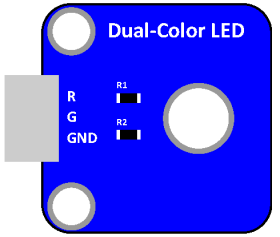
It's like Twitter of things!

Scenario



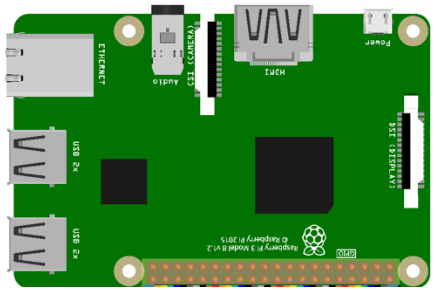
I write some code on a computer and run it

Communicate with a physical entity to do something

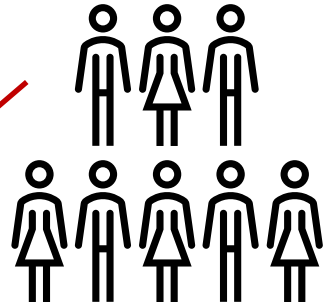


Observe response from that entity

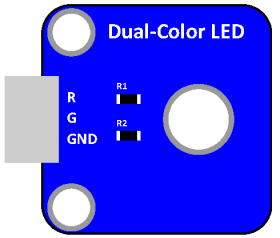
What-if-scenario



I write some code on a computer



I realize people may not really care about it.
But want to use it anyway.

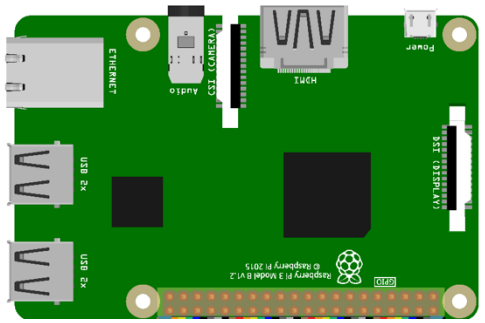


And curiously observe the response from that entity

Created by Candy Design
from Noun Project

Thing

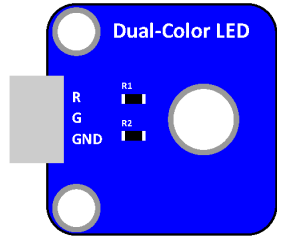
Client



Broker

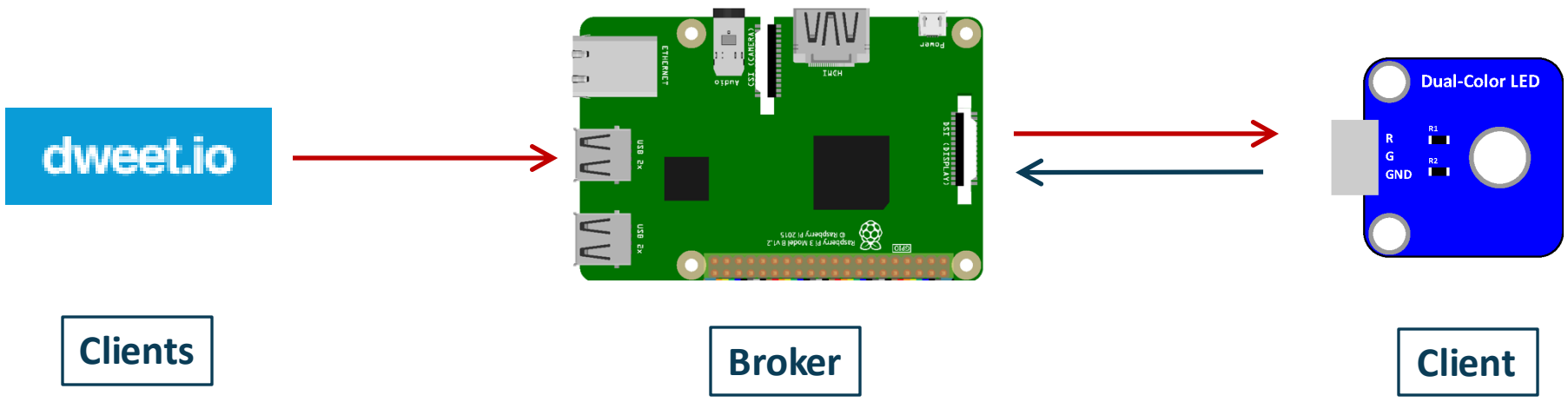
dweet to control
LED

Client



Goal-2:
dweet to control LED

dweet to control LED



Let’s get started

Preliminaries:

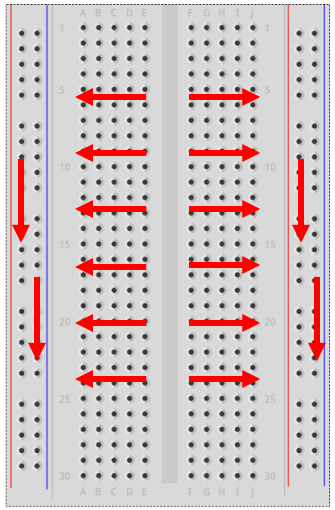
1. **git-clone**

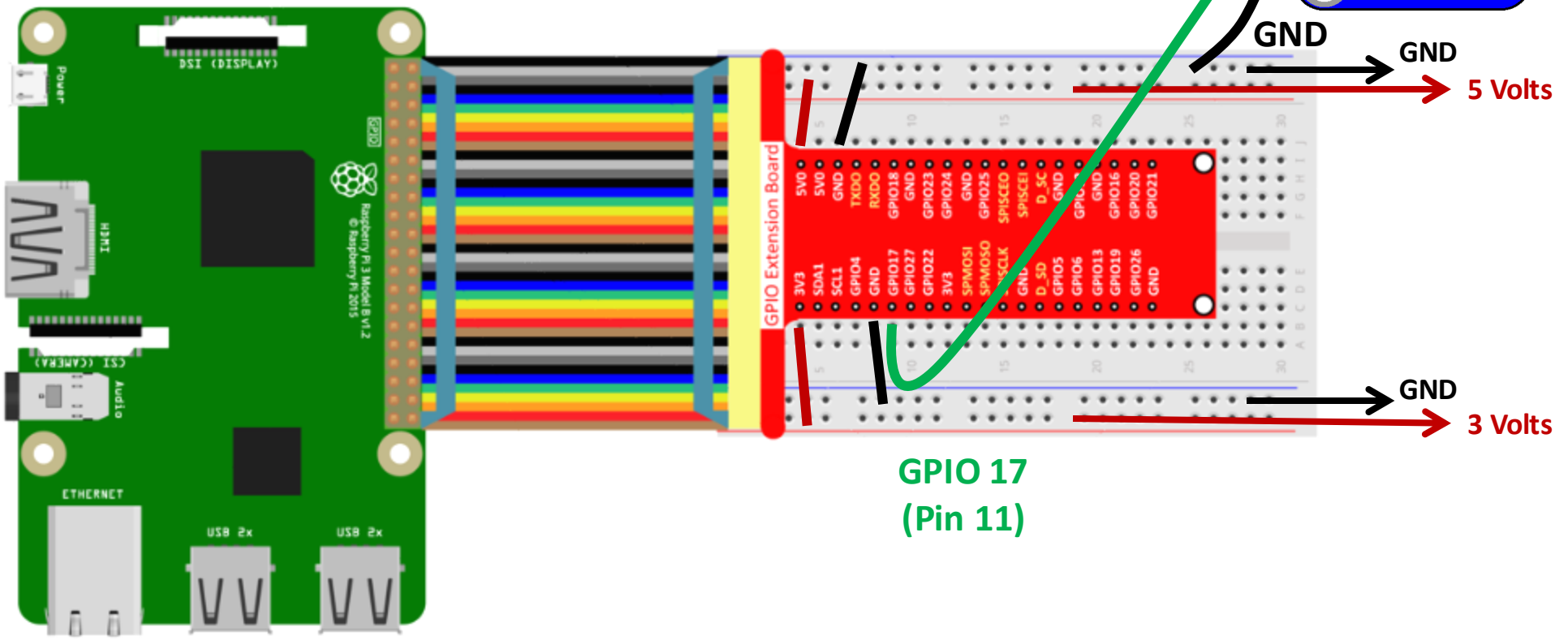
git clone https://github.com/gwu-mae6291-iot/spring2025_codes.git

2. **I have the files on a USB in case there is a slowdown!**

Step-0:

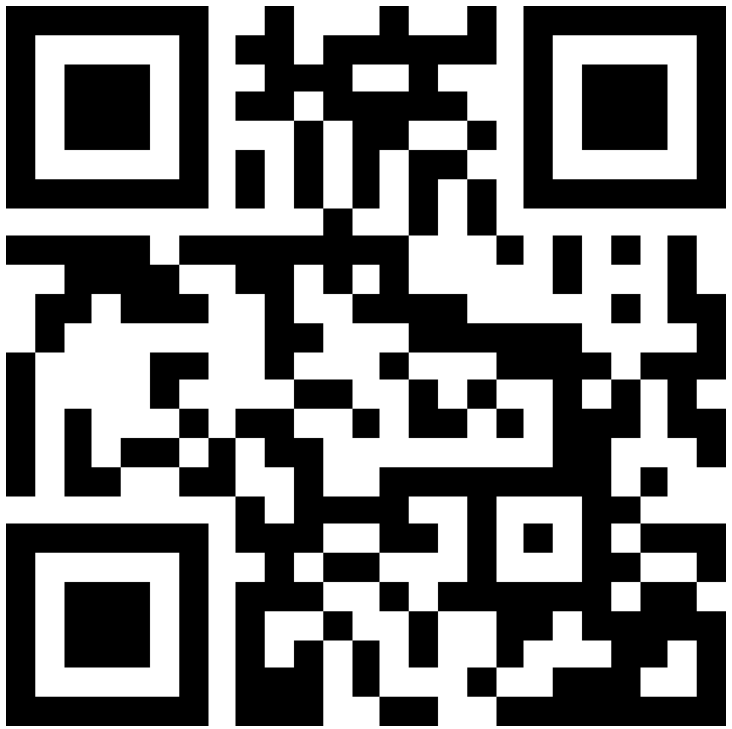
Put together the LED circuit connections on your Raspberry Pi 4B





Run
dweet_LED_Example

Your first IoT program



LED ON

LED OFF

LED Blink

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