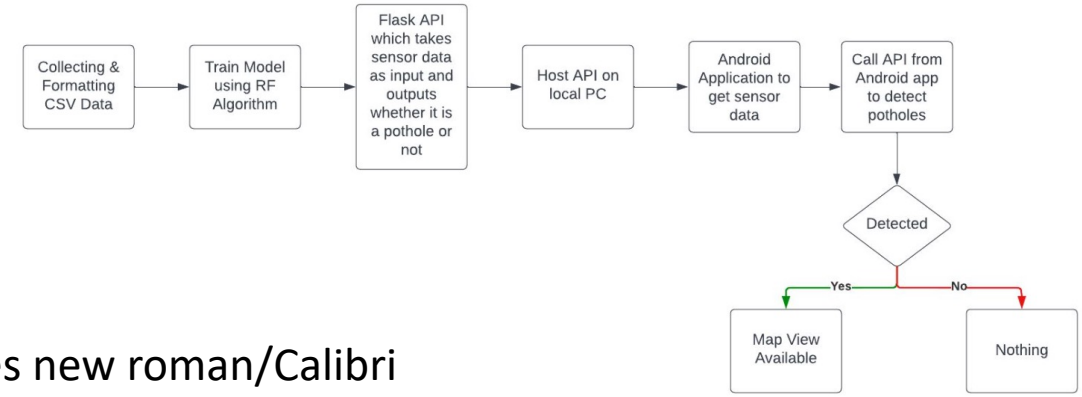
Projects

- Group formation
  - Due Oct 31st Via Google Drive
  - https://docs.google.com/spreadsheets/d/10-RV4V60ajTHDWobIVtrf2Ck6Q3-pEn-E57OE36zuiI/edit?usp=sharing
- Project Discussion Day (zoom discussion)
  - Oct 27th, Schedule via Google Drive
  - https://docs.google.com/spreadsheets/d/1CoKyYJnABQ-wF8aoHeqmxPrj0NR6PbMMY8hlC3w_zfw/edit?usp=sharing
  - Zoom link: https://uml.zoom.us/j/94459888925
- Project Proposal Submission and Proposal Presentation
  - Nov 7th , In Class

Project Proposal Submission



- 1-2 Pages PDF, 10 pt, times new roman/Calibri
- Title
- Names of the students and email addresses
- Introduction: Introduce the problem
- Tentative device requirements
- Tentative Overview
  - Overview diagram/Flow diagram, Must use https://draw.io/
  - Hardware Design Plan
  - Software Design Plan
  - Machine learning analysis Plan
- Tentative Final project outcome and future works

Project Proposal Presentation

- Duration 5 minutes per group/project
- 2 minutes questions/answers/suggestions
- Please incorporate multiple presenters
- Slides
  - Project title, team members (1 slide)
  - Introduction to the problem (1 slide)
  - Devices required/acquired (1 slide)
  - Techniques used/will be used (2-3 slides)
    - Hardware integration
    - Signal processing
    - Machine learning (Must be included)
  - Final demo plan (1 slide)
    - What you are going to show in the final presentation

COMP.5650/4150.201
Internet of Things
Lecture 8: Project Discussions

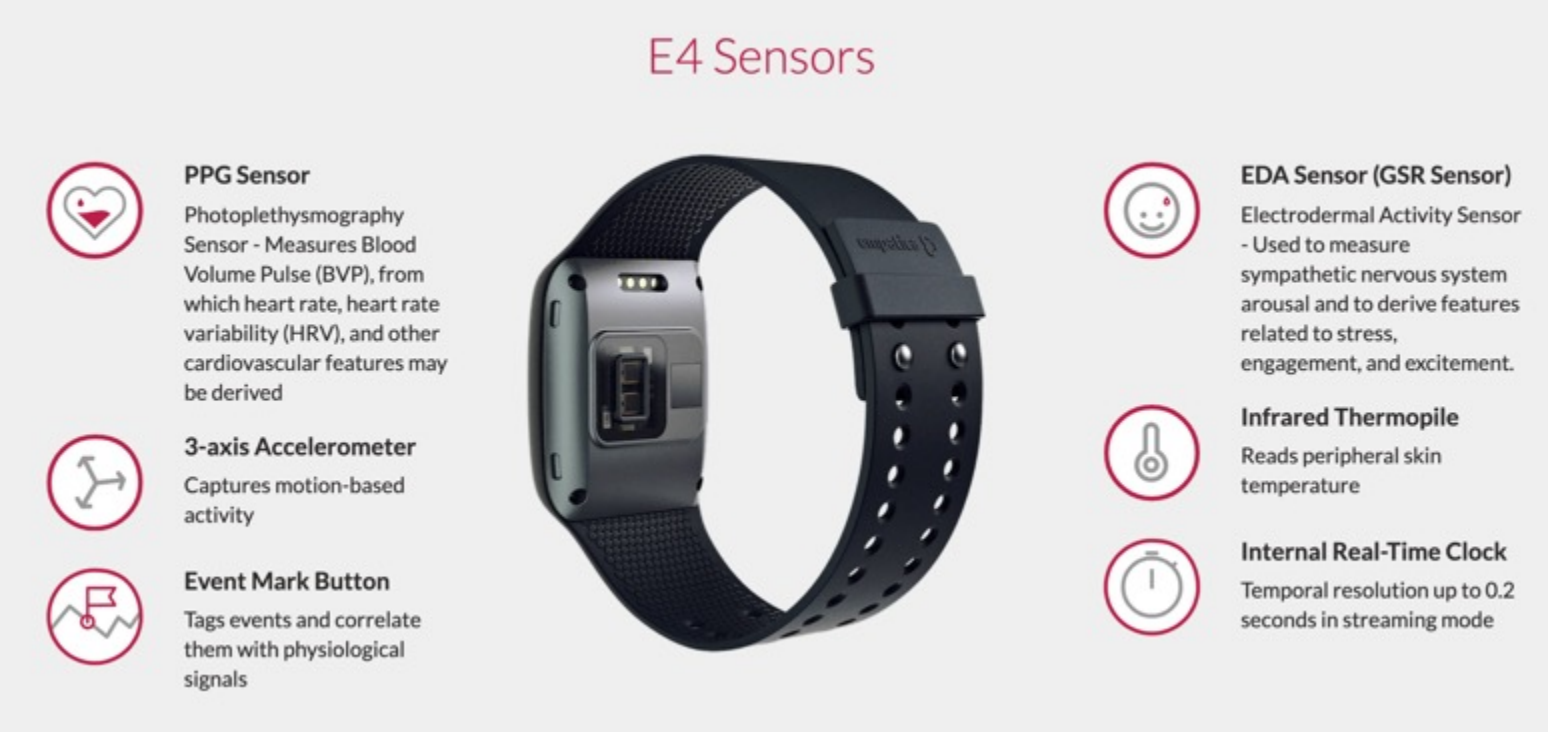
Instructor
Mohammad Arif Ul Alam

List of Instruments

- Google drive view
- https://drive.google.com/file/d/1d2uHHDjPu6Esh-2-qseKpoQU6Or1E-4u/view?usp=sharing

Available Technologies

Empatica E4



Android Connectivity, preliminary data collection, preliminary data analysis, ML implementation codes will be provides

Potential Projects Empatica E4

- Dehydration/Hydration status detection
- Mobile phone addiction detection
  - Short form video addiction
- Driving Stress estimation
- Smoking craving detection
- Sleep quality monitoring
- Over-exercise prediction
- Asthma episode prediction
- Opioid Craving Detection
- Alcohol consumption detection
- Stress/Anxiety detection

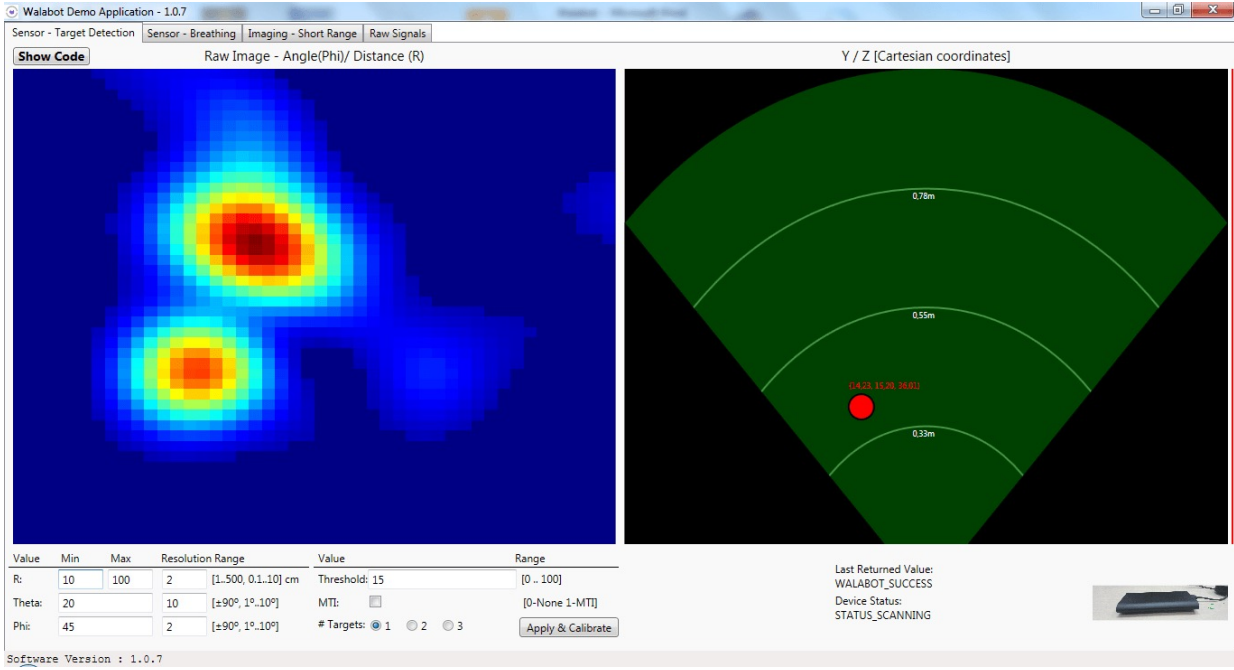
EEG Sensor (brain signal)

- 4 Different Channels
- Implementation code with Raspberry PI, Arduino and Android will be provided

Potential Projects

- Music Recommendation
- Robotic Arm Control using Brain Signal
- Emotion Detection
  - Emotional videos playing and differentiate them
- Video rating
  - Watch a video and automatically rate (like or not like) the video

Radar

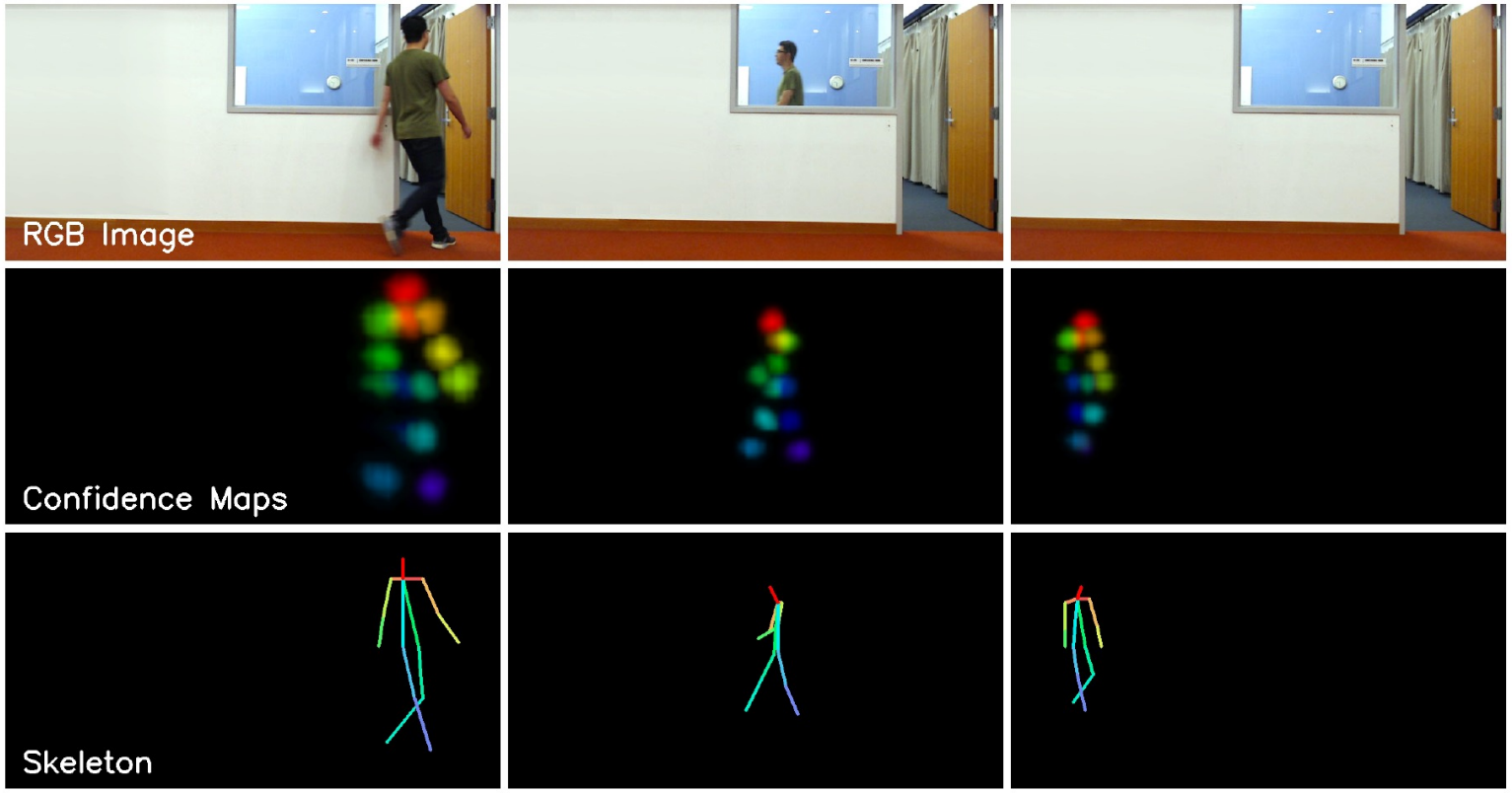


- Raspberry PI implementation codes, basic data collection code and basic ML codes will be provided

Potential Projects

- People count in Hospital Waiting Room/Crowd
- Fall Detection
- Gate detection (distance between your two step/ stride size)
- Activity Recognition (sitting, standing, lying)
- Sleep quality detection

High Definition Radar (One unit)



Potential Projects

- Eavesdropping, detecting activities of your neighbor through wall (privacy violation)
- Listening speech through wall (Privacy violation)

Potentiostat Sensor

- A potentiostat is an electronic instrument that controls the voltage difference between a Working Electrode and a Reference Electrode.
- Both electrodes are contained in an electrochemical cell.
- The potentiostat implements this control by injecting current into the cell through an Auxiliary, or Counter, electrode.

Palmsens Sensit Smart

Water Contaminants Detection

Example Projects

1. Multiple Sensors (Lidar, Radar, RF, Infrared and Camera) fusion for activity recognition (dataset will be created)
2. Eye Tracker and Brain Signal (EEG) signal analytics for human subconscious attention signal processing towards explainable AI (few dataset have already been created)
3. Deep MRI processing for Alzheimer's disease detection (data will be provided)
4. Electronic Health Record analysis towards Disease cause inference (data will be provided)
5. AI Fairness towards older adults' cognitive health assessment (data will be provided)
6. Improving Breast Cancer detection from mammography and ultrasound images (data will be provided)
7. Smart home appliance energy consumption data based health anomaly detection (dataset will be provided)
8. Galvanik Skin Response sensor processing for fear, stress, depression detection (data will be provided, but you can also collect some data, in that case, device will be provided with proper training how to collect data)
9. Sleep assessment using Sleep Pad (Withings Sleeping Pad) that detects heart rate, breathing rate, movements and snoring (data needs to be collected, device will be provided)

Source of Projects

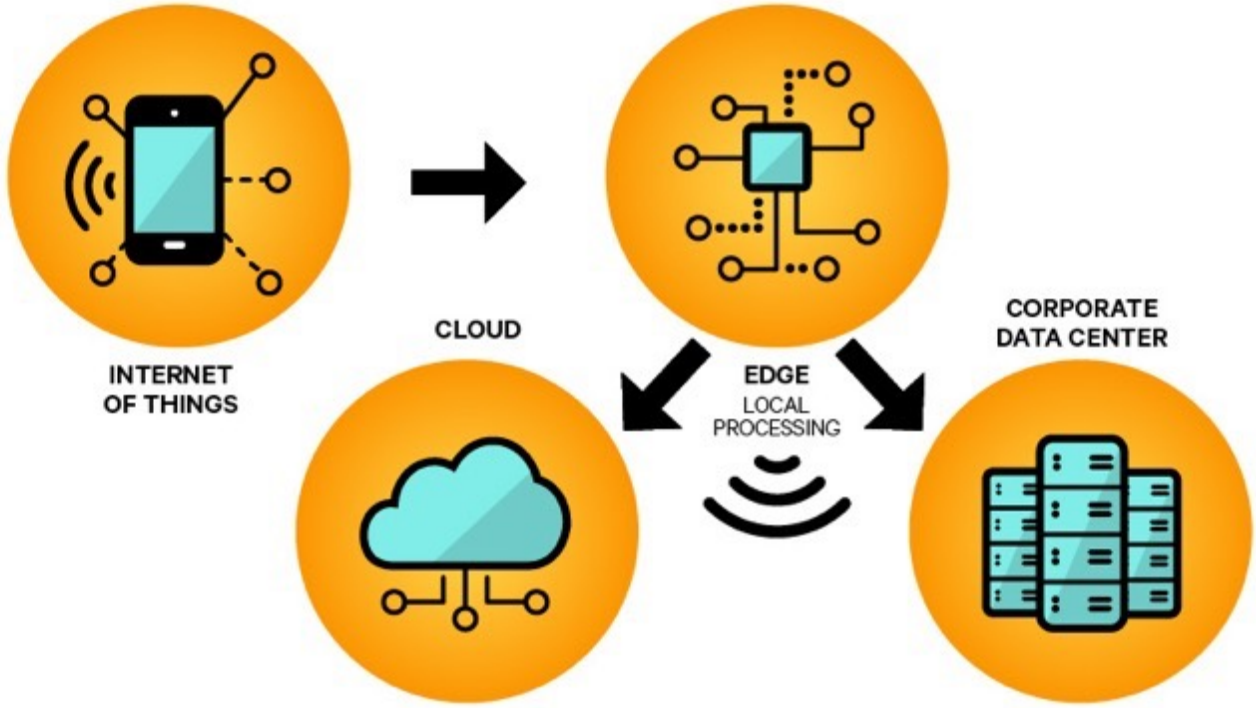
- https://www.hackster.io/

COMP.5650/4150.201
Internet of Things
Lecture 8.1: Edge and Cloud Computing

Instructor
Mohammad Arif Ul Alam

HOW EDGE COMPUTING WORKS

Edge computing allows data from Internet of Things devices to be analyzed at the edge of the network before being sent to a data center or the cloud.



Cloud Computing

['klaud kəm-'pyüt-iŋ]

The delivery of different services through the Internet which includes tools and applications like data storage, servers, databases, networking, and software.

Investopedia

When to Use Edge Computing vs Cloud Computing?

Cloud Computing	Edge Computing
Non-time-sensitive data processing	Real-time data processing
Reliable internet connection	Remote locations with limited or no internet connectivity
Dynamic workloads	Large datasets that are too costly to send to the cloud
Data in cloud storage	Highly sensitive data and strict data laws

EDGE IMPULSE

A world-class team of industry leaders and investors, creating the platform and ecosystem for embedded ML, enabling developers and enterprises from research to production.

Zach Shelby
Founder, CEO

Jan Jongboom
Founder, CTO

fika VENTURES

L2 VENTURES

Acrew

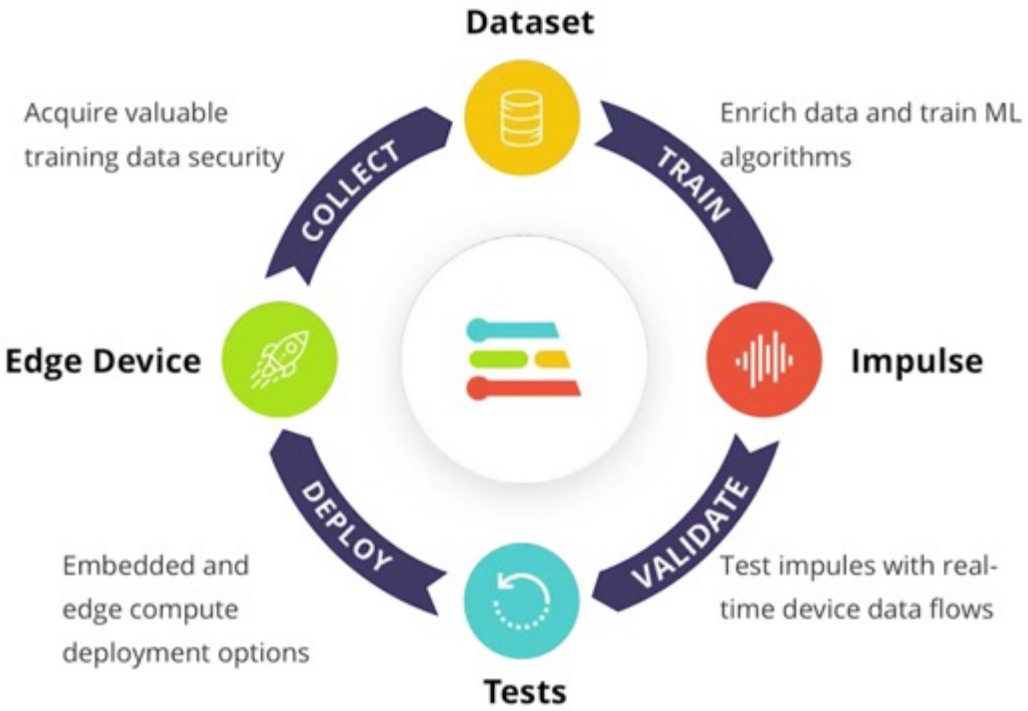
MOMENTA VENTURES

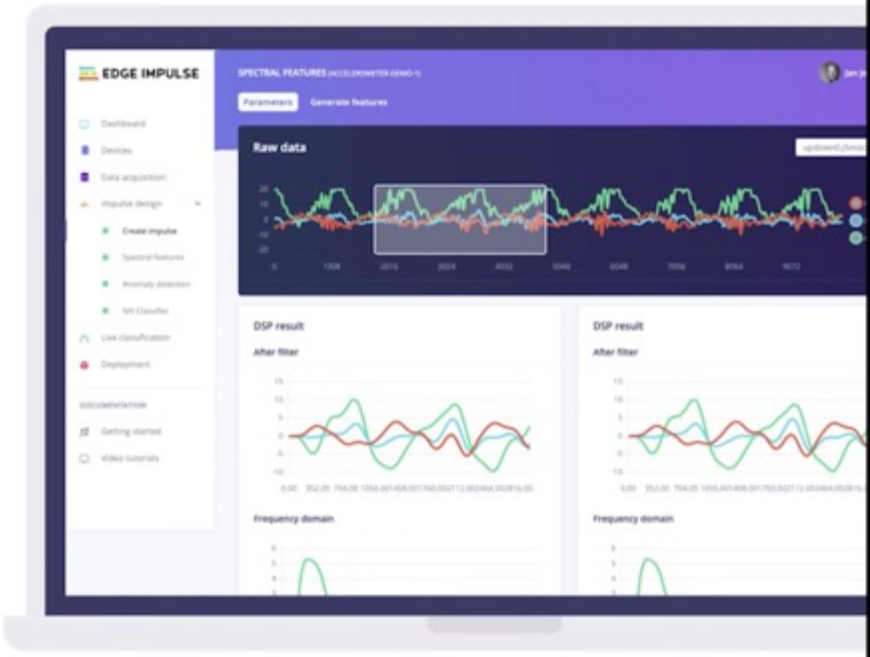
"2.5 billion devices and 3 million developers will use embedded ML by 2030"

ABI Research 2020, SlashData 2019

Edge Impulse

The ML development platform





Learn more at http://edgeimpulse.com

Industrial

- Predictive maintenance
- Process and logistical optimization
- Remote asset management

Enterprise

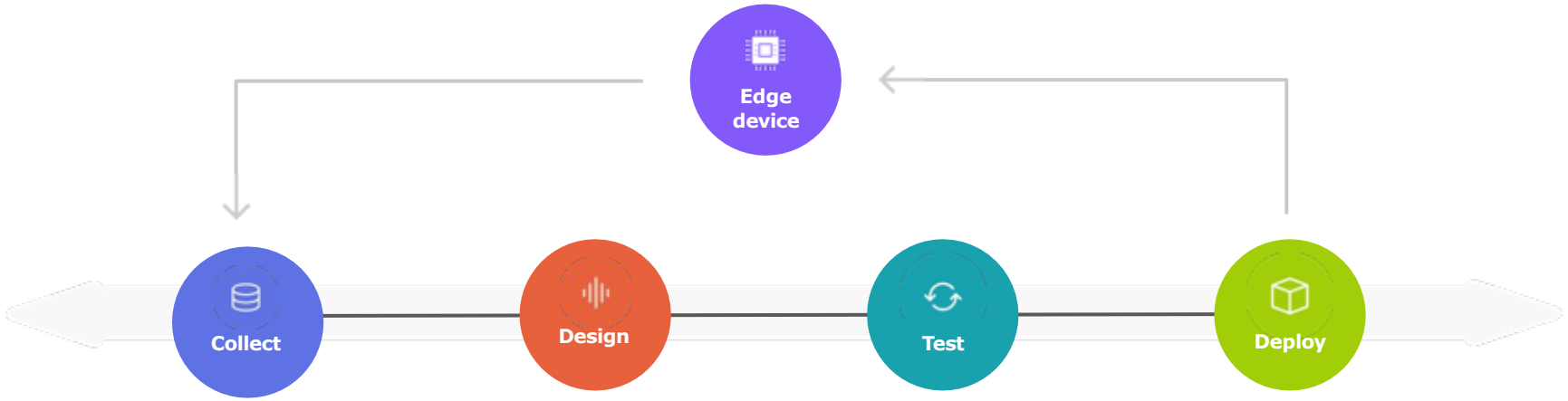
- Asset tracking and utilization analysis
- Facility usage optimization
- Metering and infrastructure monitoring

Wearables

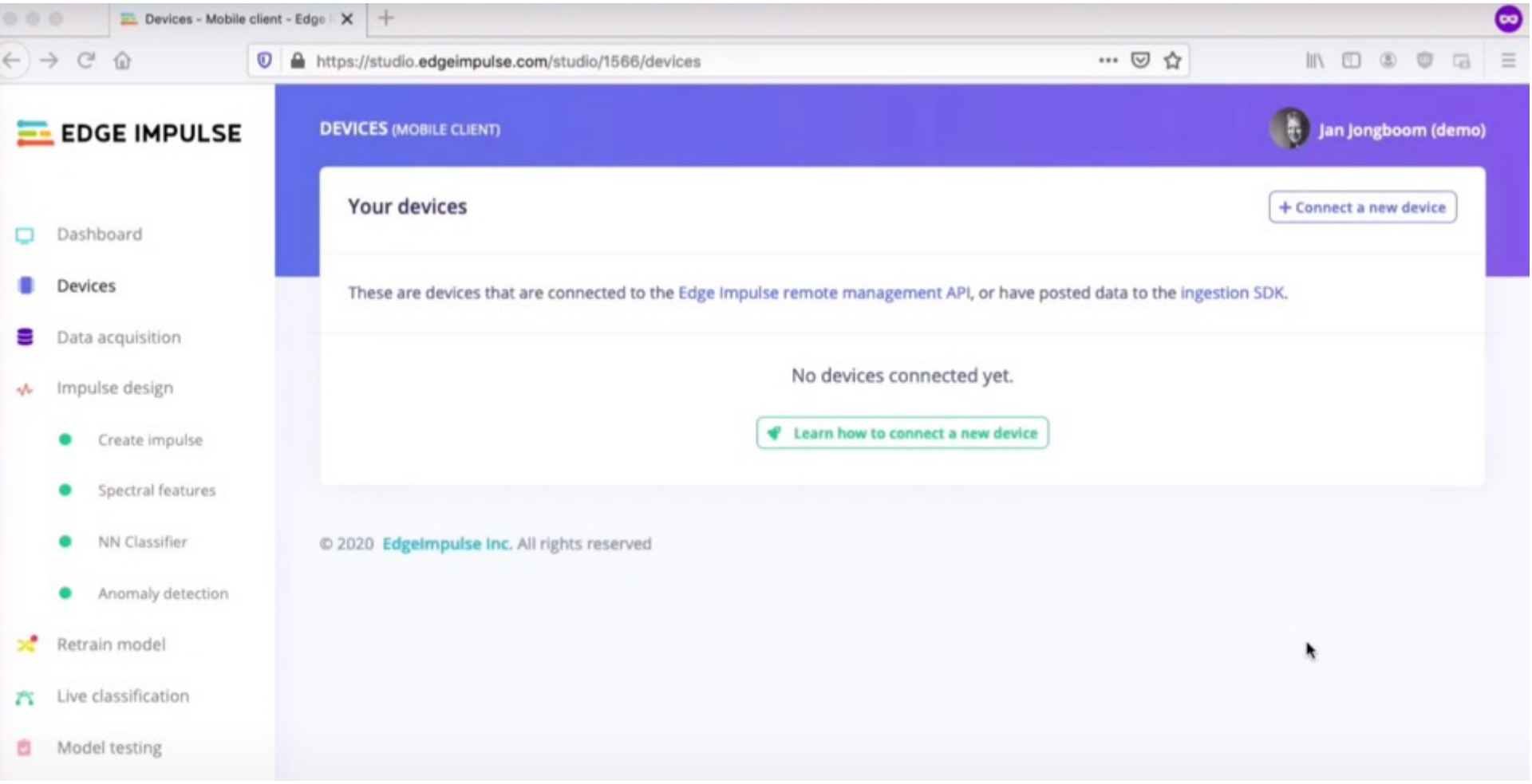
- Health monitoring
- Worker safety monitoring
- Occupancy and foot traffic analytics

Develop edge ML applications with Edge Impulse

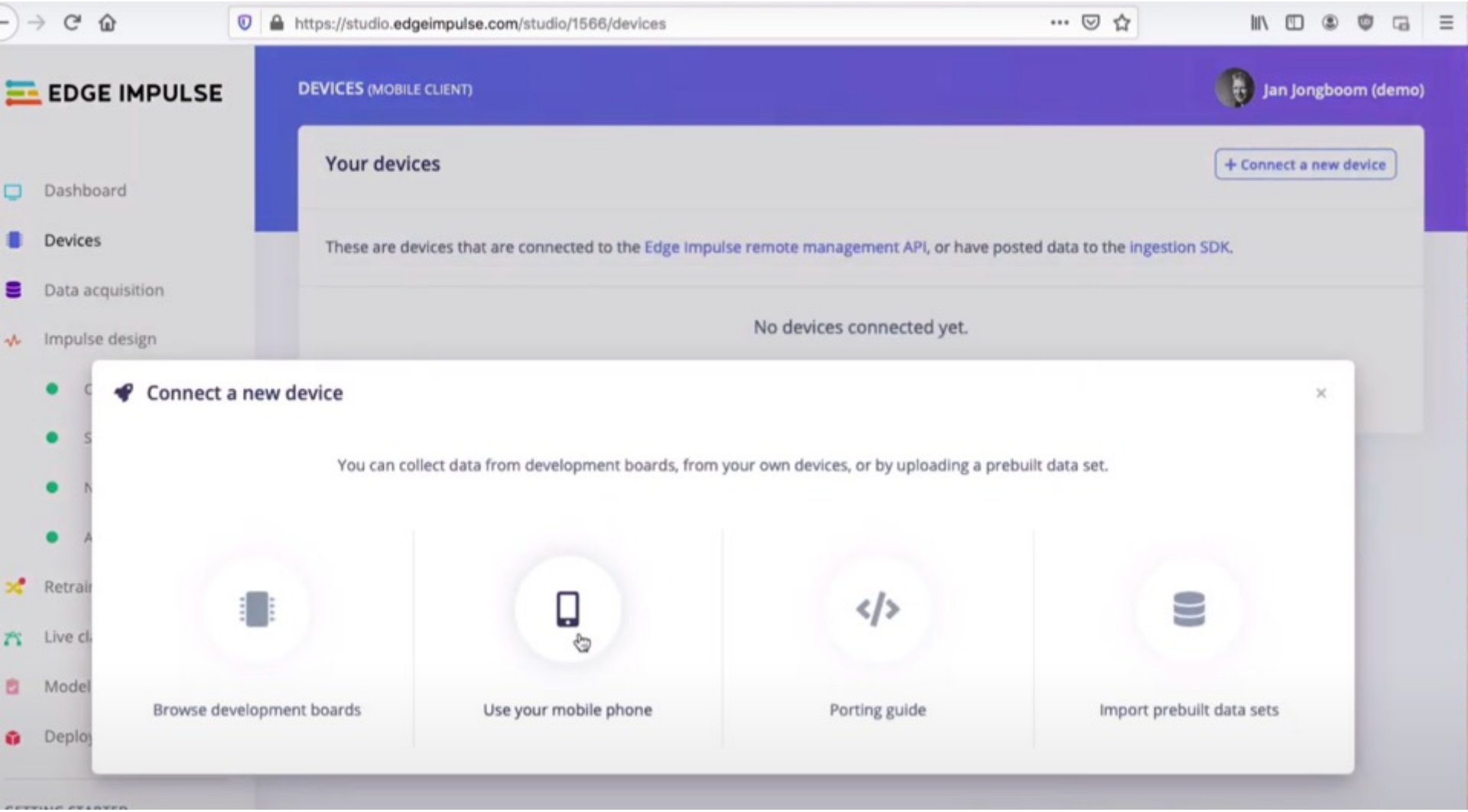
The infrastructure and integrations your data science and ML teams need.



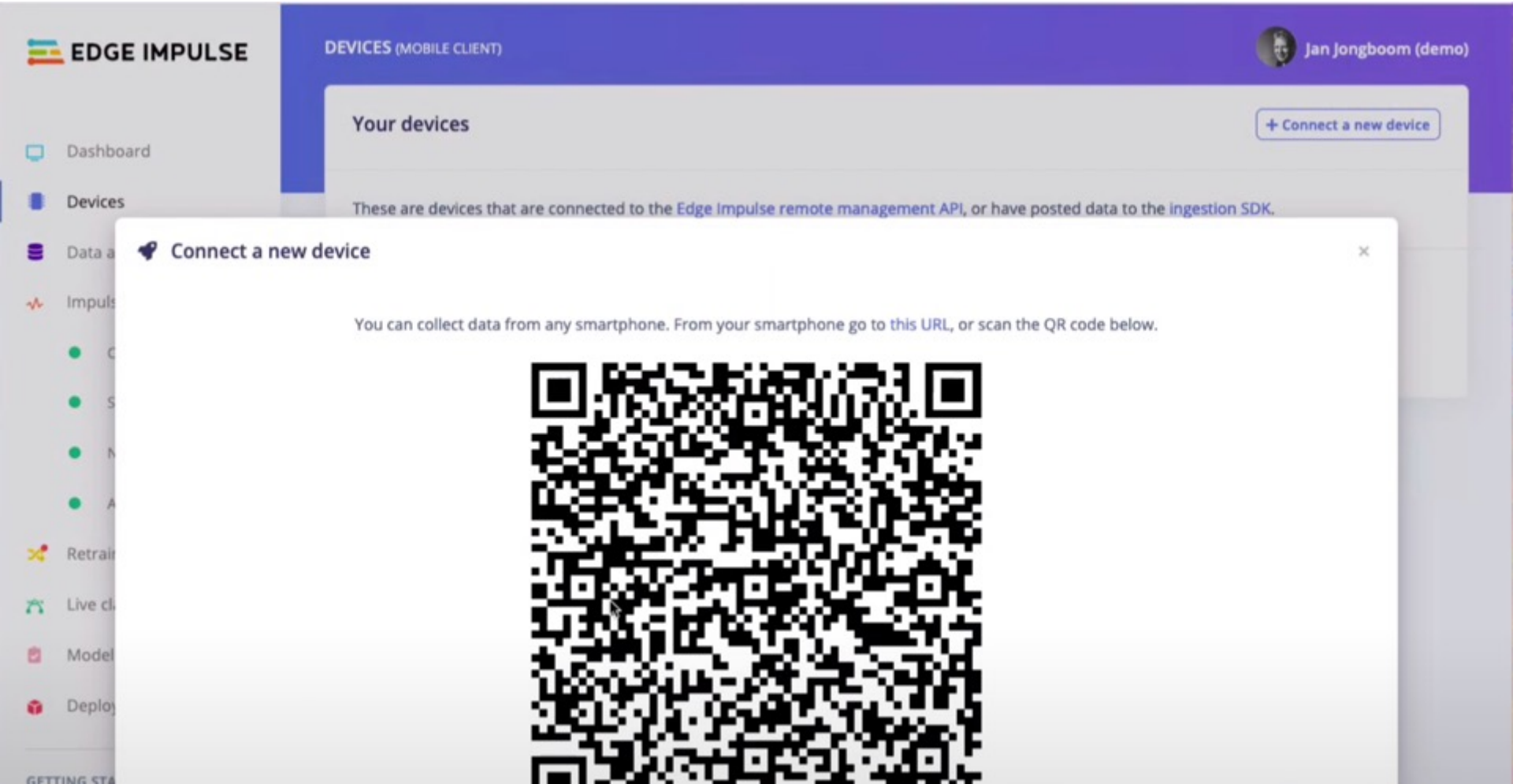
Activity Recognition in Smart Phone



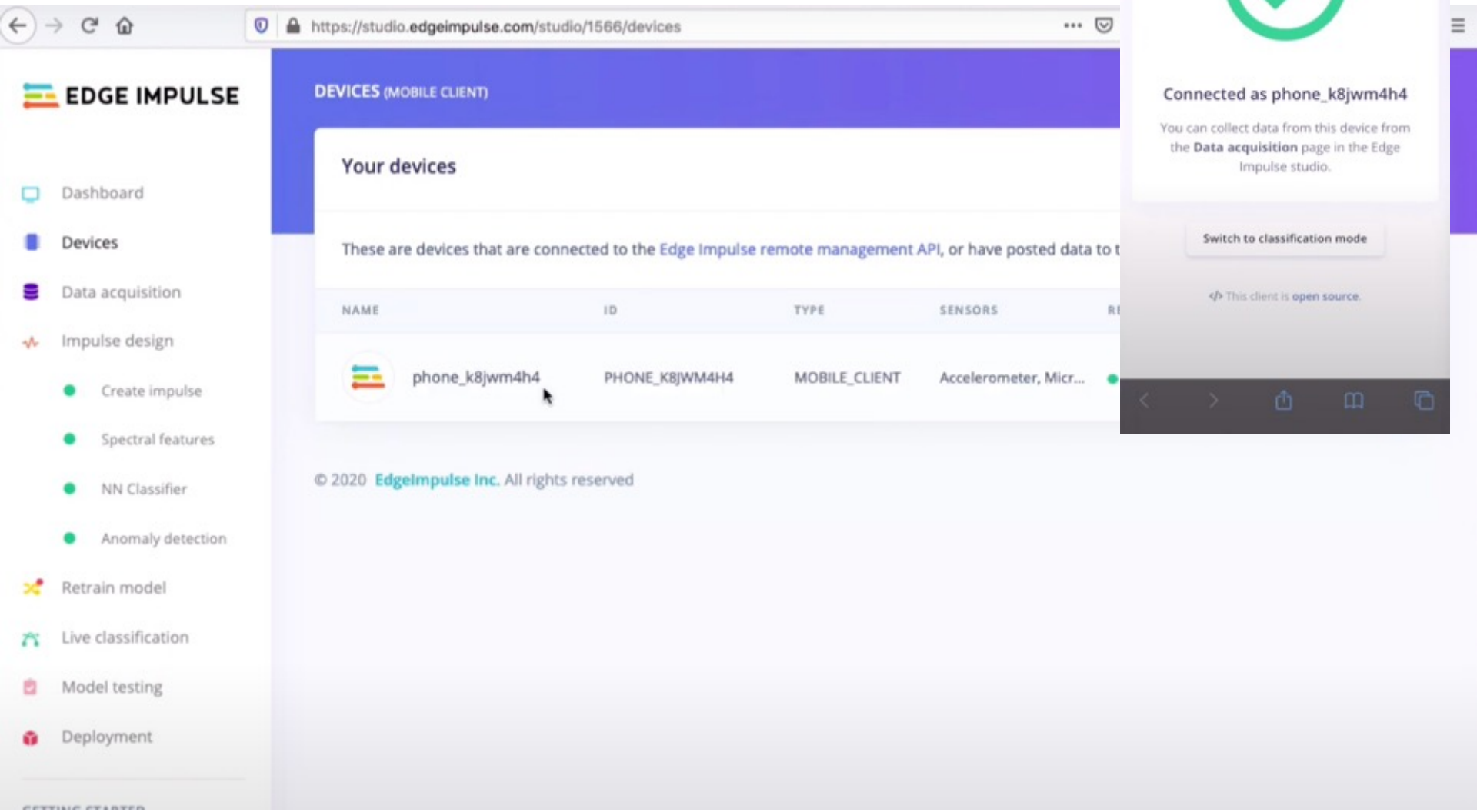
Activity Recognition in Smart Phone



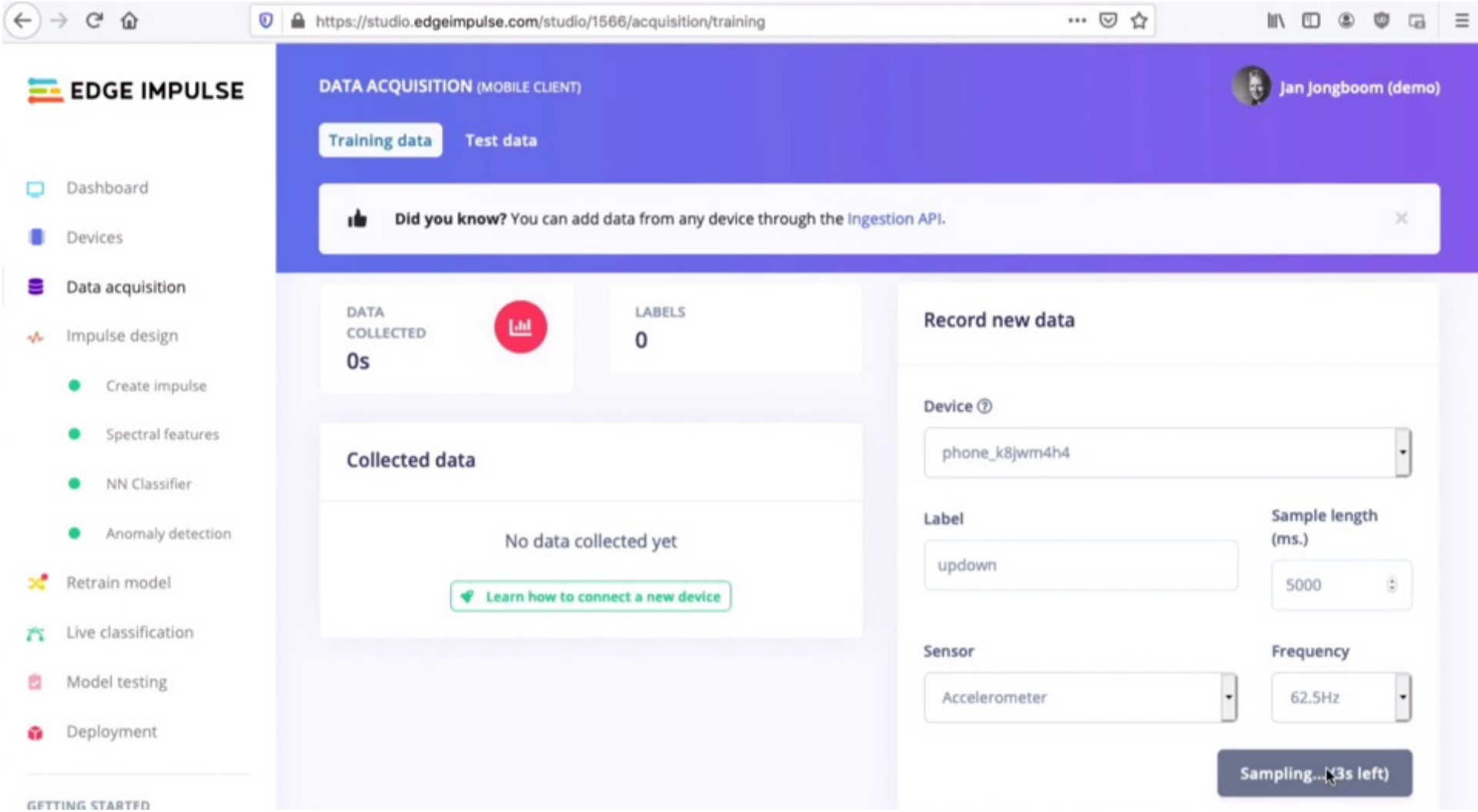
Activity Recognition in Smart Phone



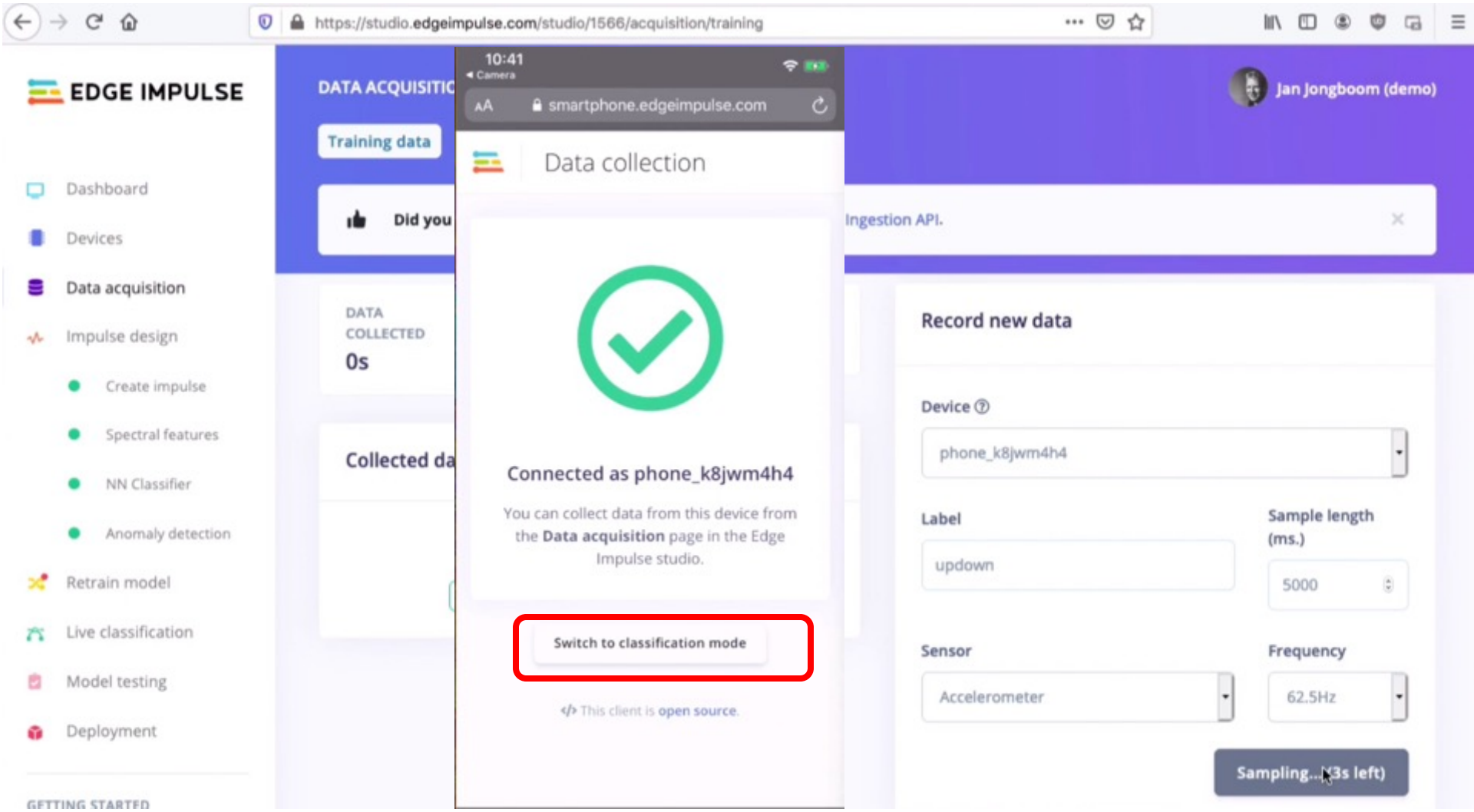
Activity Recognition in Smart Phone



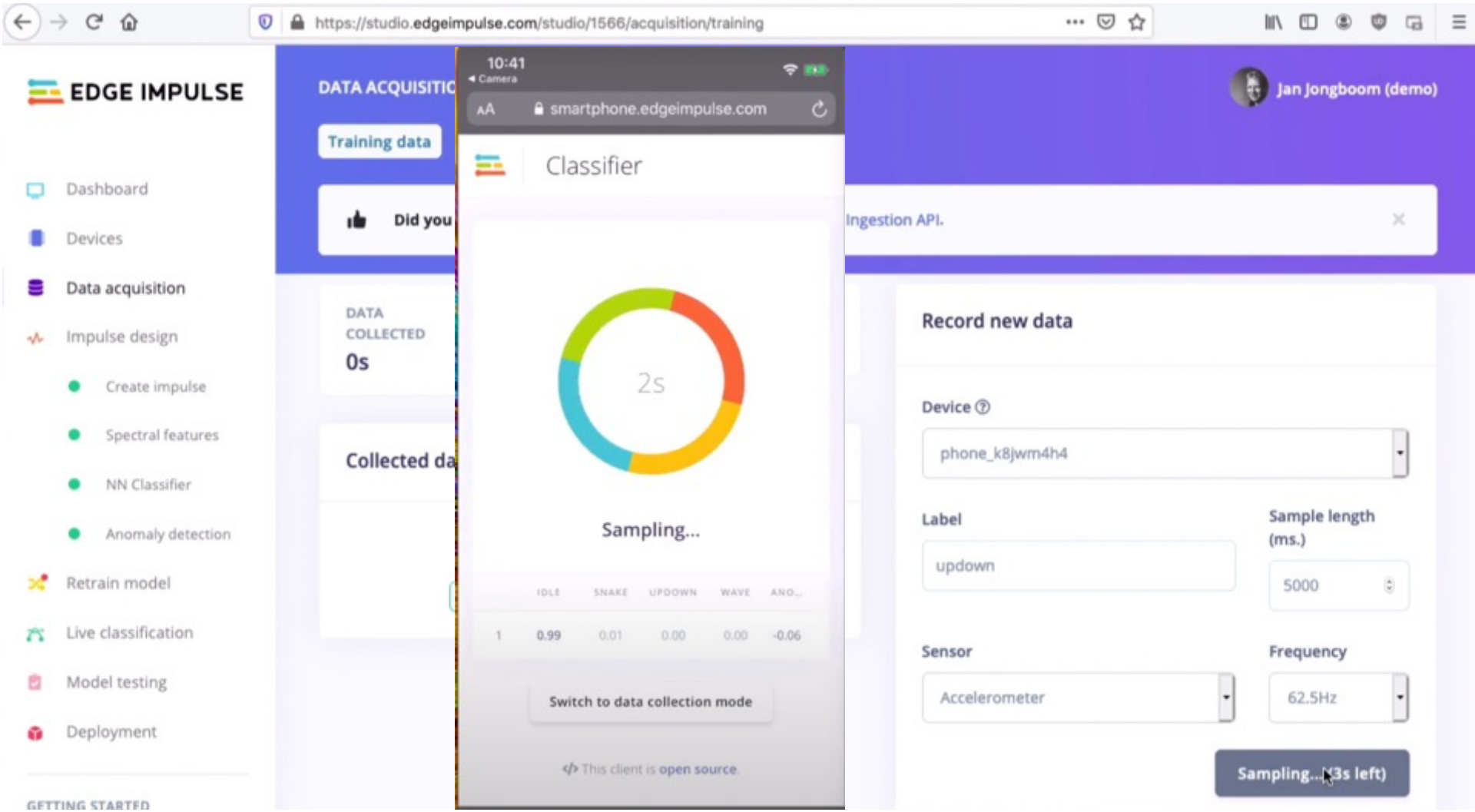
Activity Recognition in Smart Phone



Activity Recognition in Smart Phone



Activity Recognition in Smart Phone



Edge Impulse for Arduino and Raspberry PI

- Arduino
  - https://docs.edgeimpulse.com/docs/development-platforms/officially-supported-mcu-targets/arduino-nano-33-ble-sense
- Raspberry PI
  - https://docs.edgeimpulse.com/docs/development-platforms/officially-supported-cpu-gpu-targets/raspberry-pi-4

- Edge Impulse is for High School Students
- We are computer scientist

EDGE IMPULSE

Cloud Computing

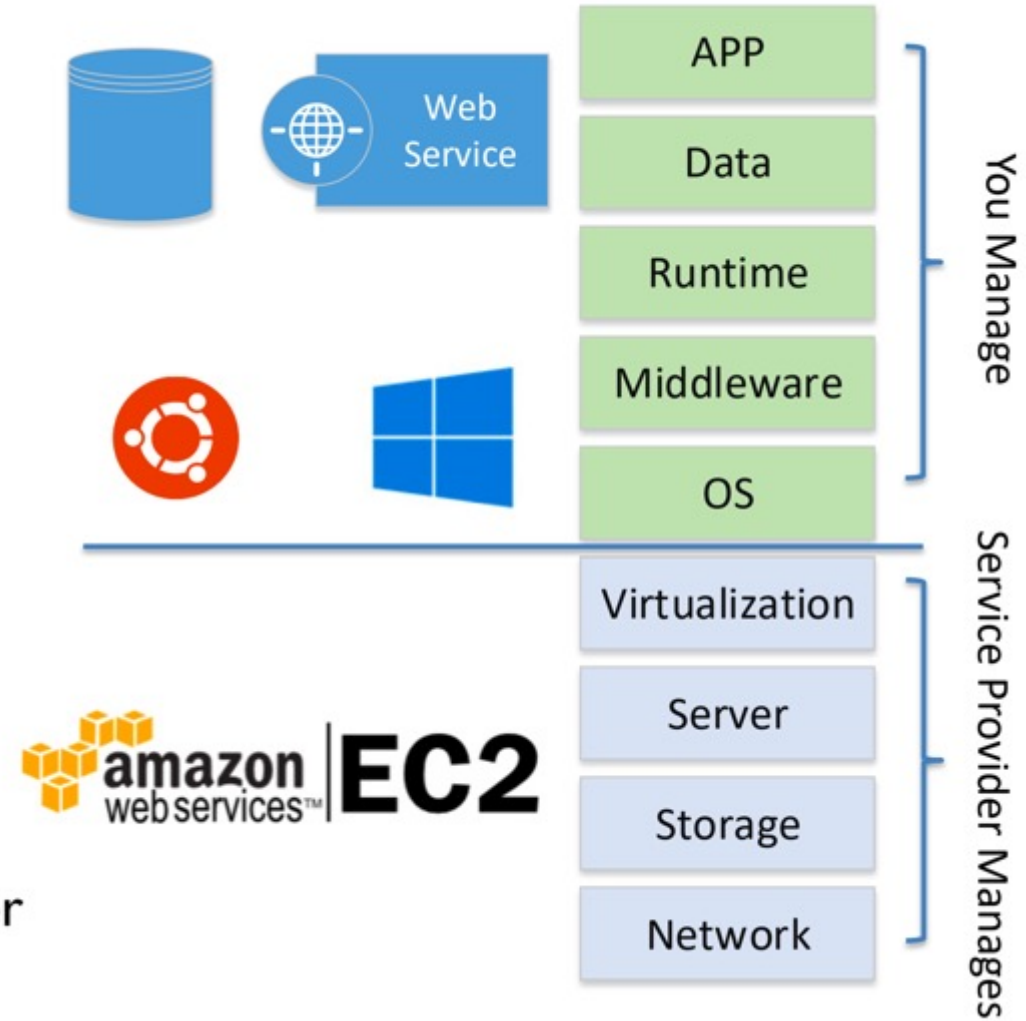
- Cloud computing provides **shared pool of configurable computing resource** to end users **on demand**
- Three service models
  - **IaaS (Infrastructure as a Service):** virtual machines, storage, network …

  - **PaaS (Platform as a Service):** execution runtime, middleware, web server, database, development tool …

  - **SaaS (Software as a Service):** email, virtual desktop, games …

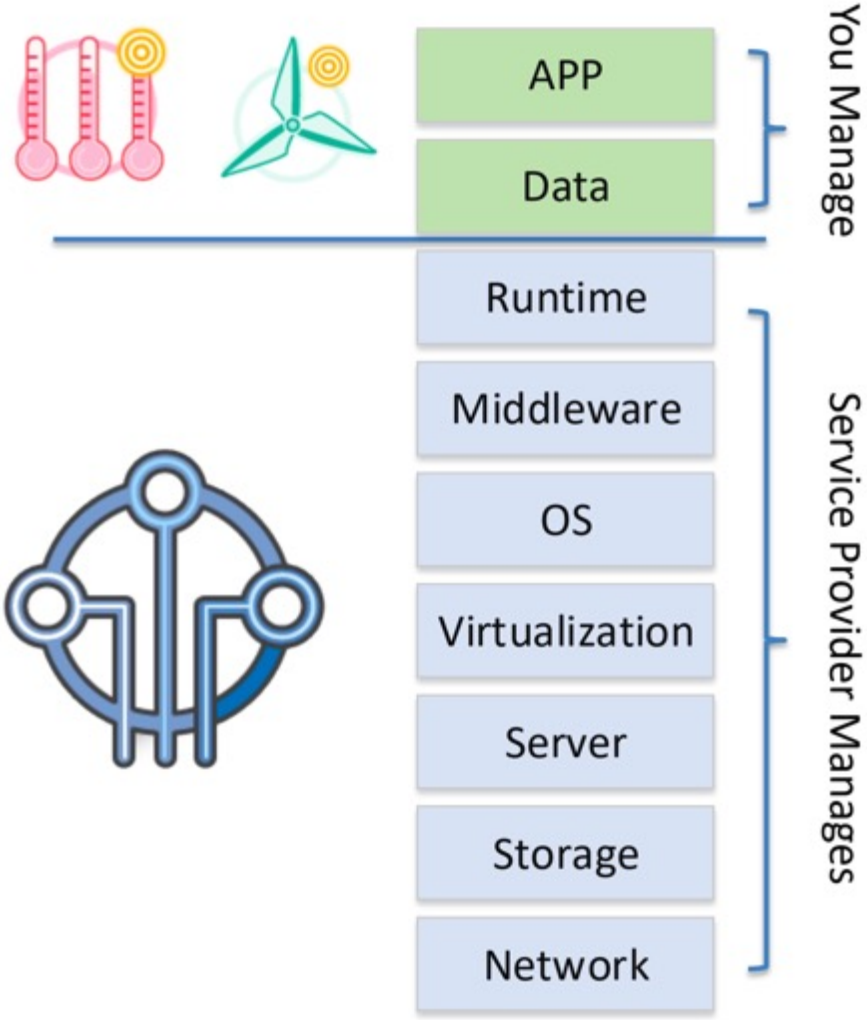
Infrastructure as a Service (IaaS)

- IaaS
  - "physical server box"
  - Virtual Machine
    - Memory
    - Storage
    - CPU
    - Network
- Example
  - AWS EC2
  - AWS EFS
- Use case
  - Build up you VM cluster

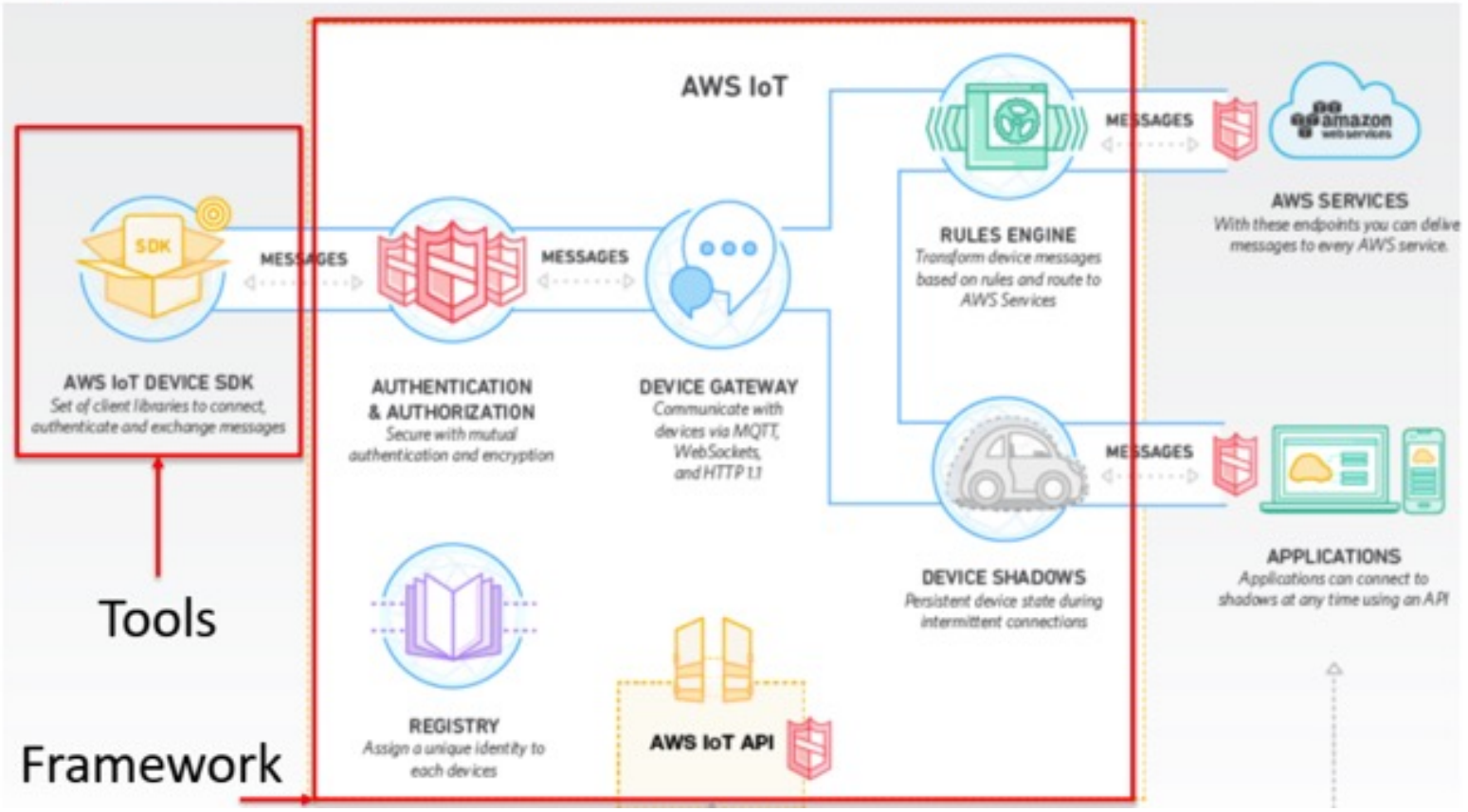


Platform as a Service (PaaS)

- PaaS
  - You get a framework
  - Host Application
  - Tools
- Example
  - AWS IoT
- Use case
  - Build up you're smart A/C controller



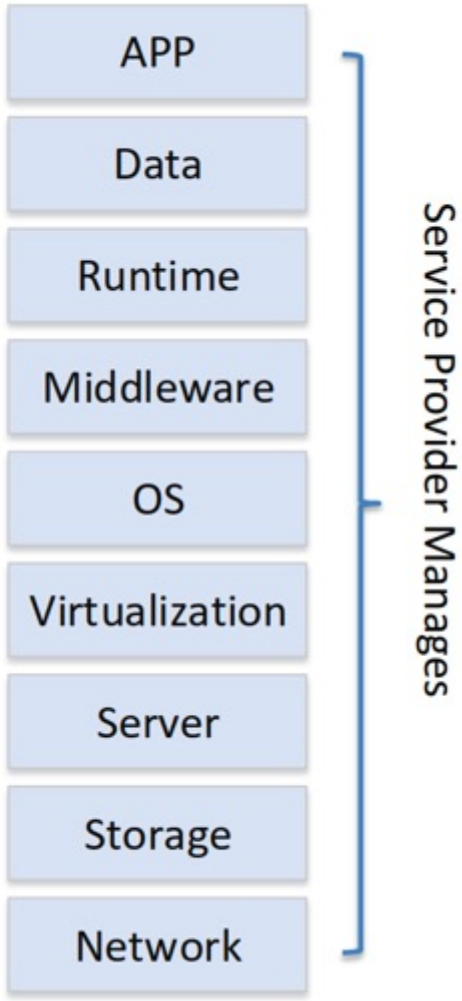
PaaS Example: AWS IoT



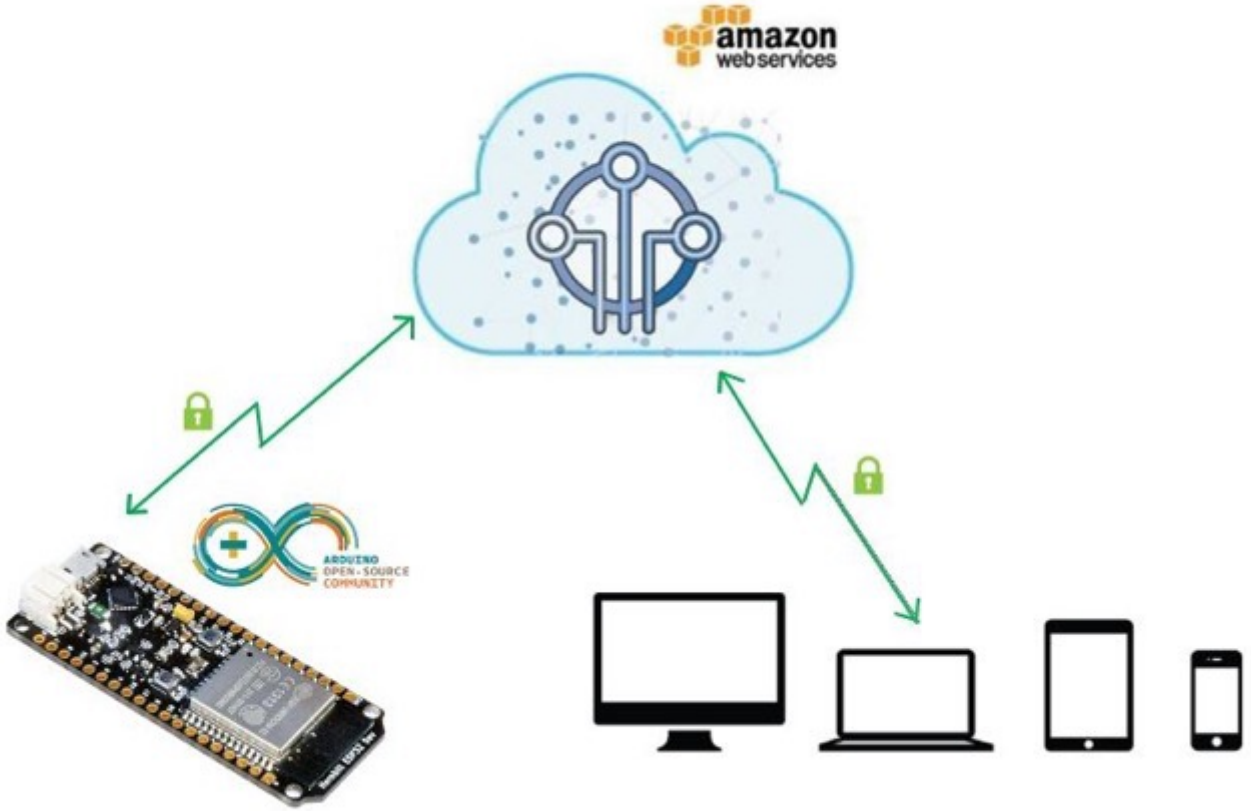
The essence is **MESSAGING MIDDLEWARE**
Send messages between sensors and servers...

Software as a Service (SaaS)

- SaaS
  - You get a whole solution
- Example
  - Gmail
  - Dropbox
  - Office365

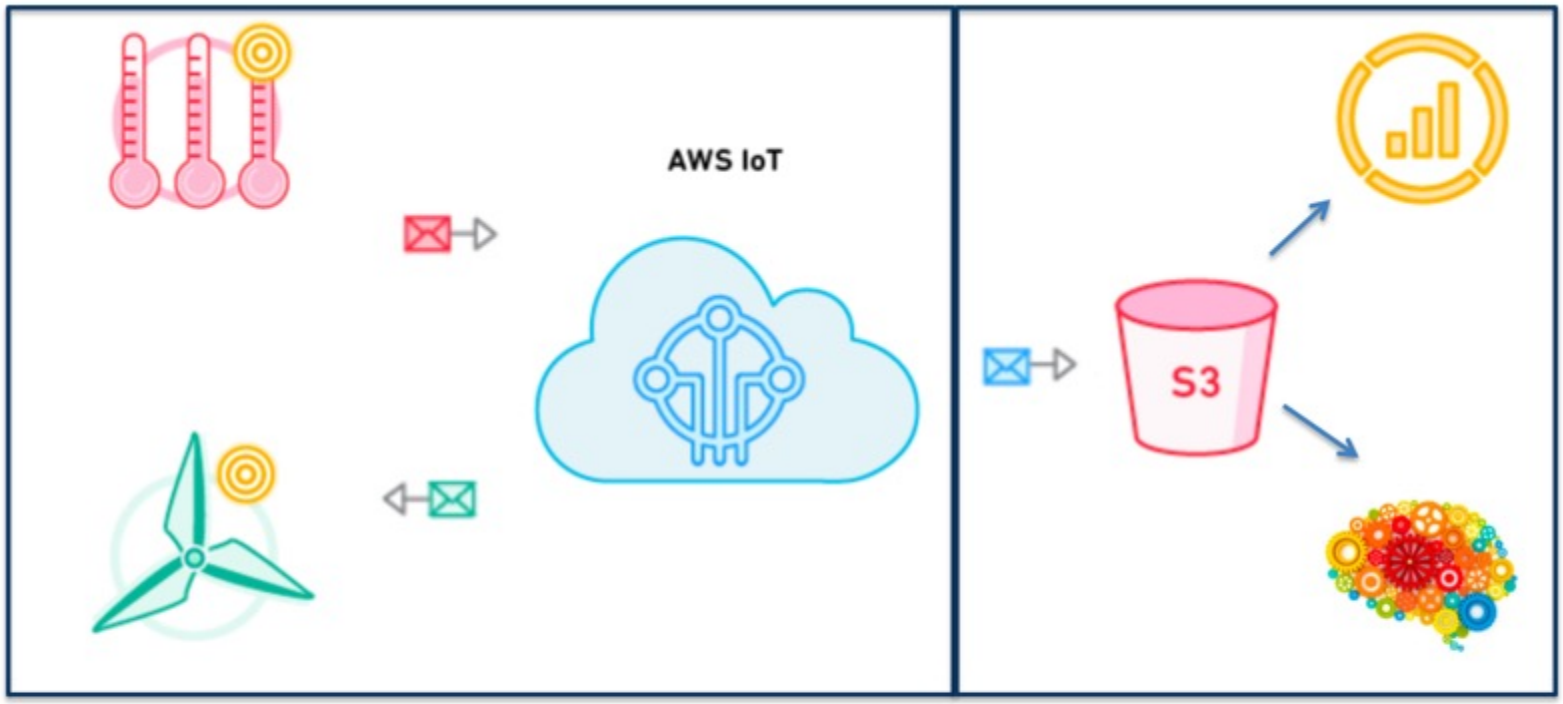


Amazon Web Service (AWS) for IoT Core



https://exploreembedded.com/wiki/Secure_IOT_with_AWS_and_Hornbill_ESP32

AWS IoT



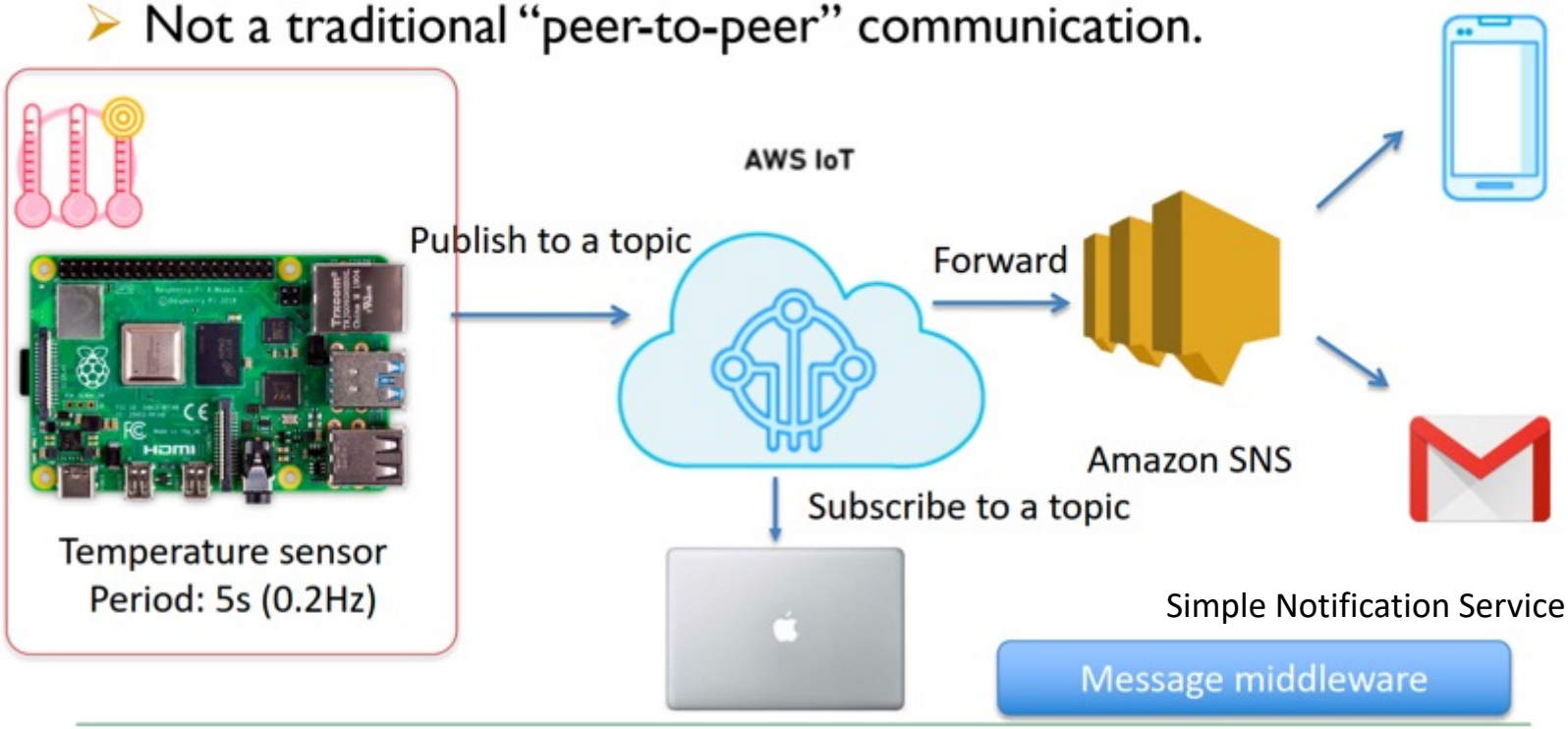
United: Connect + Communication

Stated: “Thing Shadow”

Smart: Other Cloud Service
Data Storage
Machine Learning

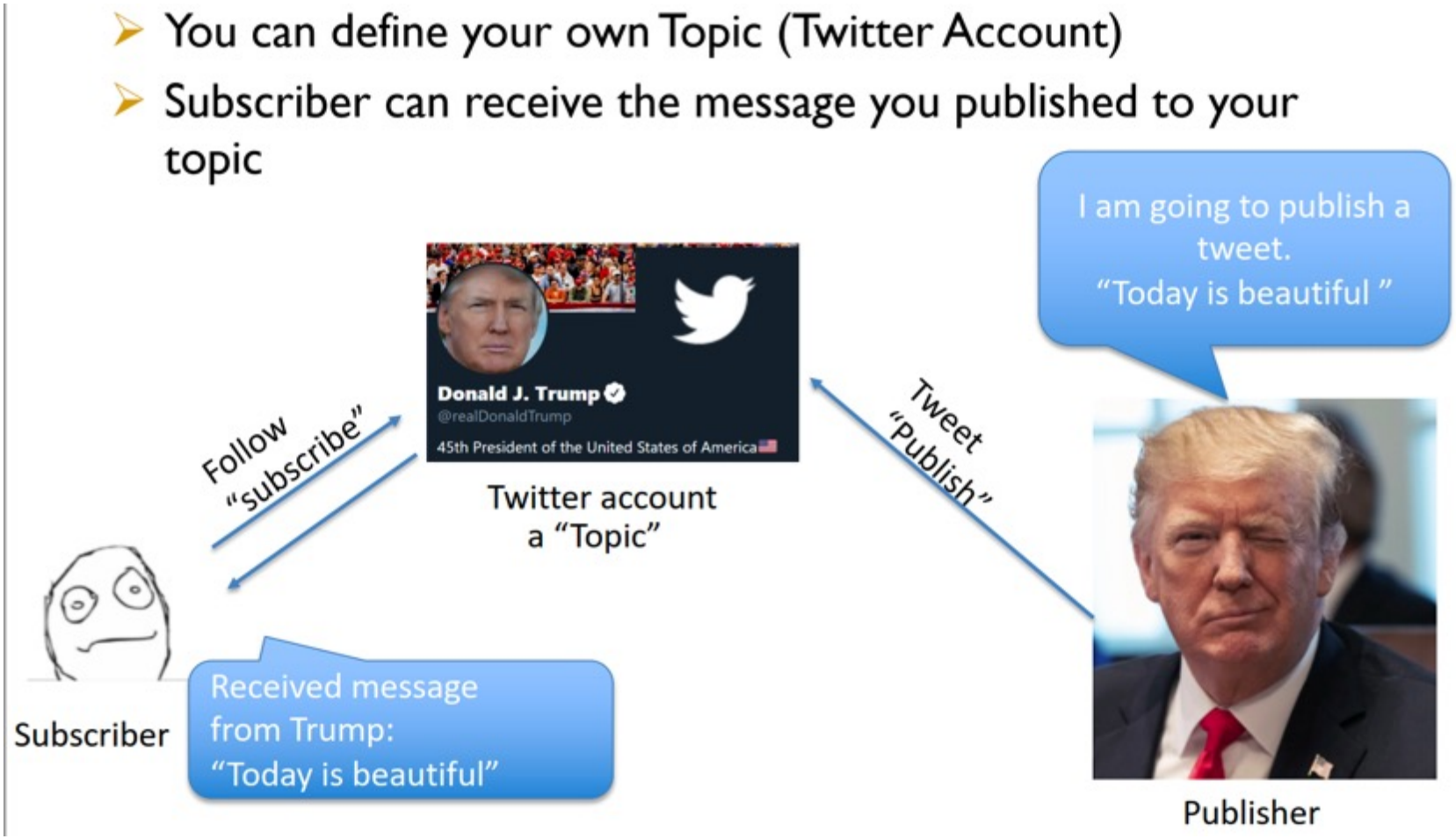
Tutorial: Hello AWS IoT!

- Key concepts:
  - Publisher (e.g. Sensor), Subscriber (e.g. Server), **Topic**
    - **Topic is used to identify the message.**
- Not a traditional "peer-to-peer" communication.

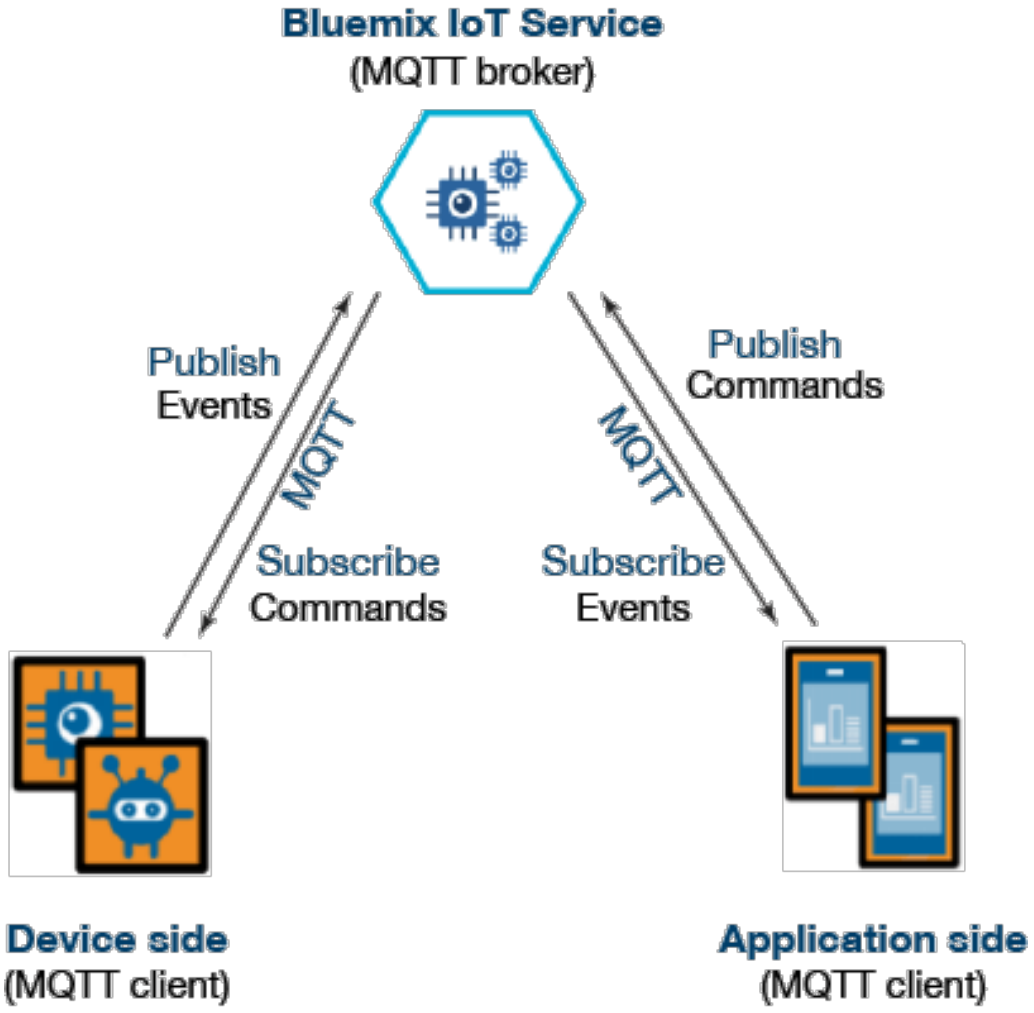


Basic Interact: Subscribe/Publish

- You can define your own Topic (Twitter Account)
- Subscriber can receive the message you published to your topic



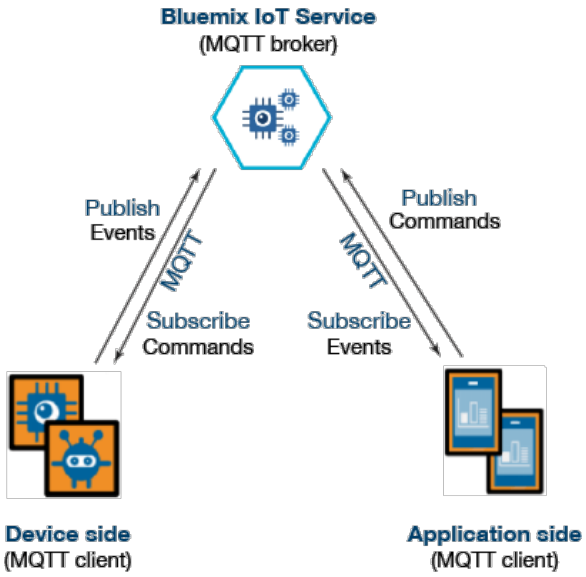
MQTT: Message Queuing Telemetry Transport



MQTT

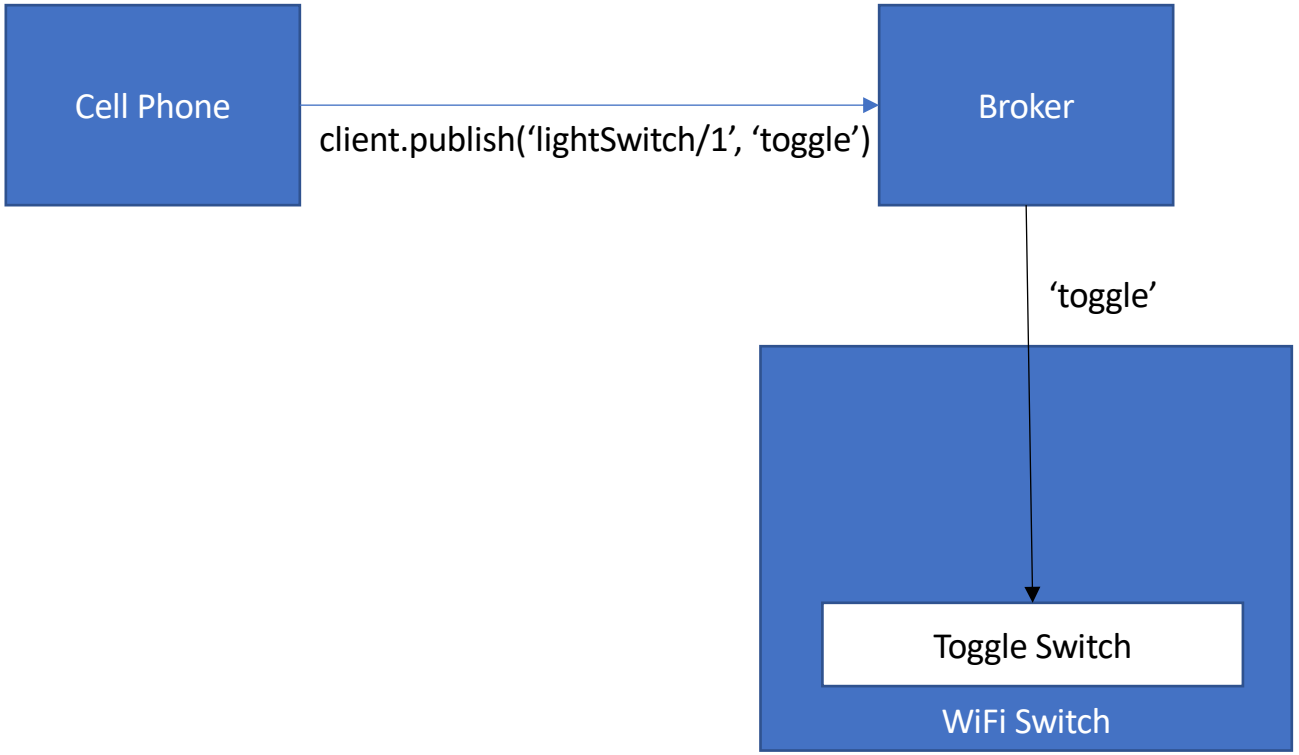
- MQTT was invented by Andy Stanford-Clark (IBM) and Arlen Nipper (Arcom, now Cirrus Link) back in 1999, where their use case was to create a protocol for minimal battery loss and minimal bandwidth connecting oil pipelines over satellite connection. They specified the following goals, which the future protocol should have:
  - Simple to implement
  - Provide a Quality of Service Data Delivery
  - Lightweight and Bandwidth Efficient
  - Data Agnostic
  - Continuous Session Awareness

MQTT: Pub/Sub



- Clients connect to a “Broker”
- Clients subscribe to topics eg,
  - client.subscribe(‘toggleLight/1’)
  - client.subscribe(‘toggleLight/2’)
  - client.subscribe(‘toggleLight/3’)
- Clients can publish messages to topics:
  - client.publish(‘toggleLight/1’, ‘toggle’);
  - client.publish(‘toggleLight/2’, ‘toggle’);
- All clients receive all messages published to topics they subscribe to
- **Messages can be anything**
  - Text
  - Images
  - etc

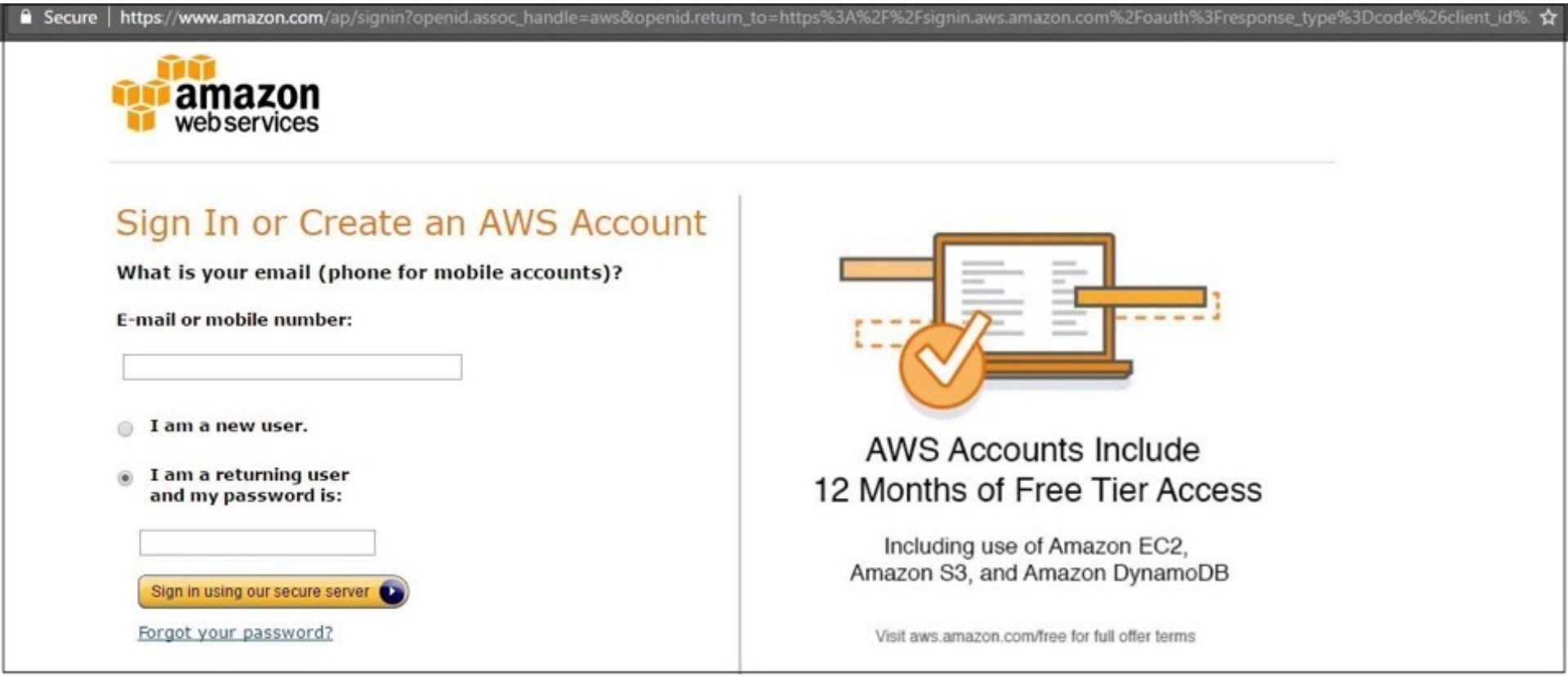
MQTT Hypothetical Light Switch



Apply for $40 credits for Amazon AWS

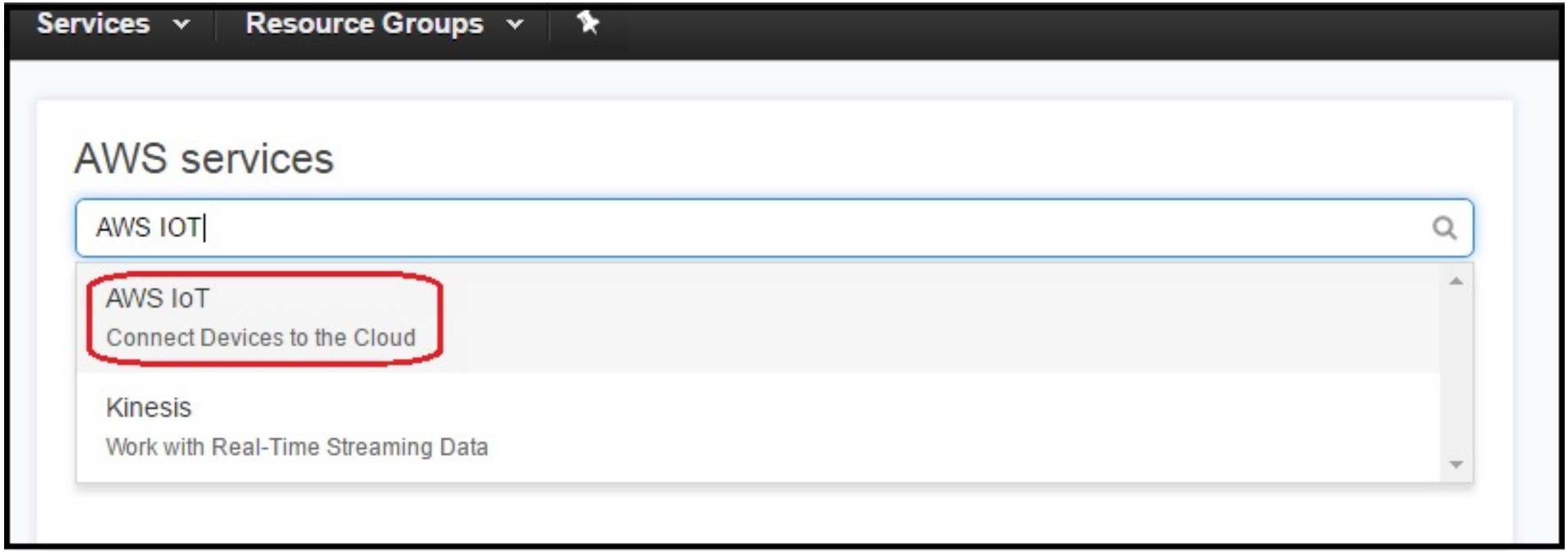
- https://aws.amazon.com/education/awseducate/apply
- https://www.youtube.com/watch?v=idf-gGXvIu4

AWS User Account



Creating a new thing

- After Login, click on **Signin To Console** to go to AWS dash board. Now type AWS IOT and Select the AWS IOT (Connect Devices to Cloud) from drop down as shown below



AWS IoT

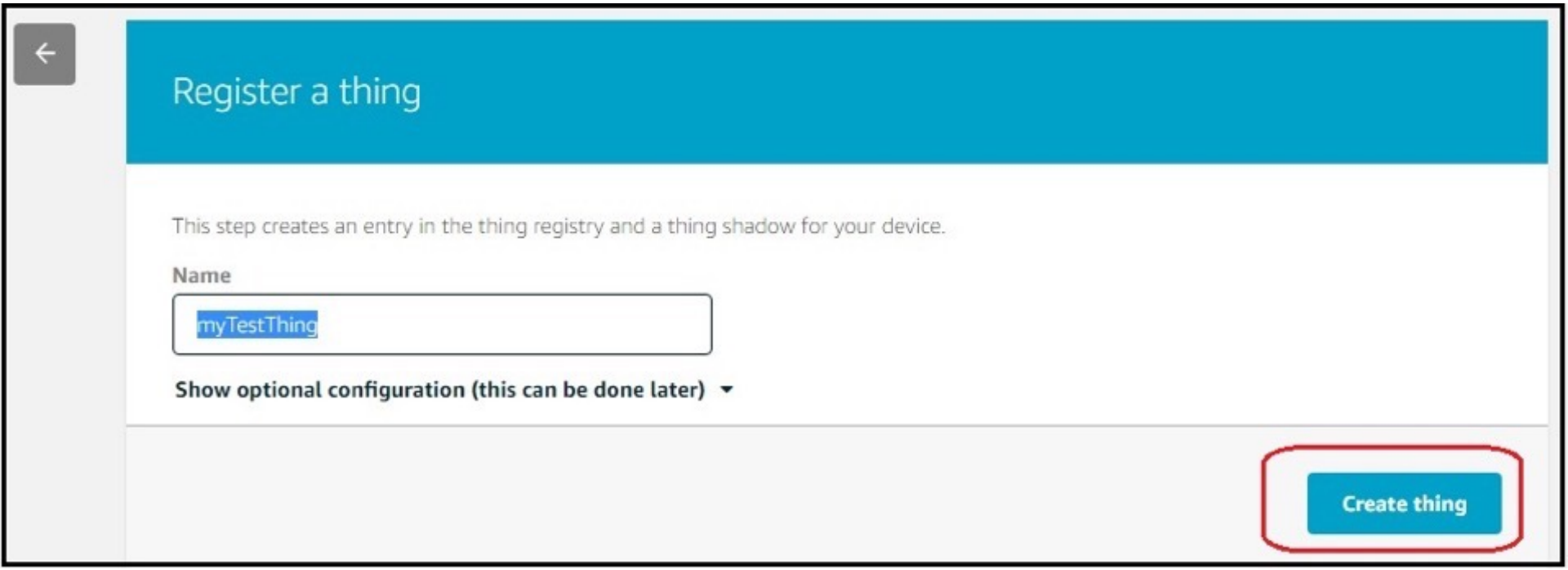
AWS IoT is a managed cloud platform that lets connected devices - cars, light bulbs, sensor grids, and more - easily and securely interact with cloud applications and other devices.

Get started

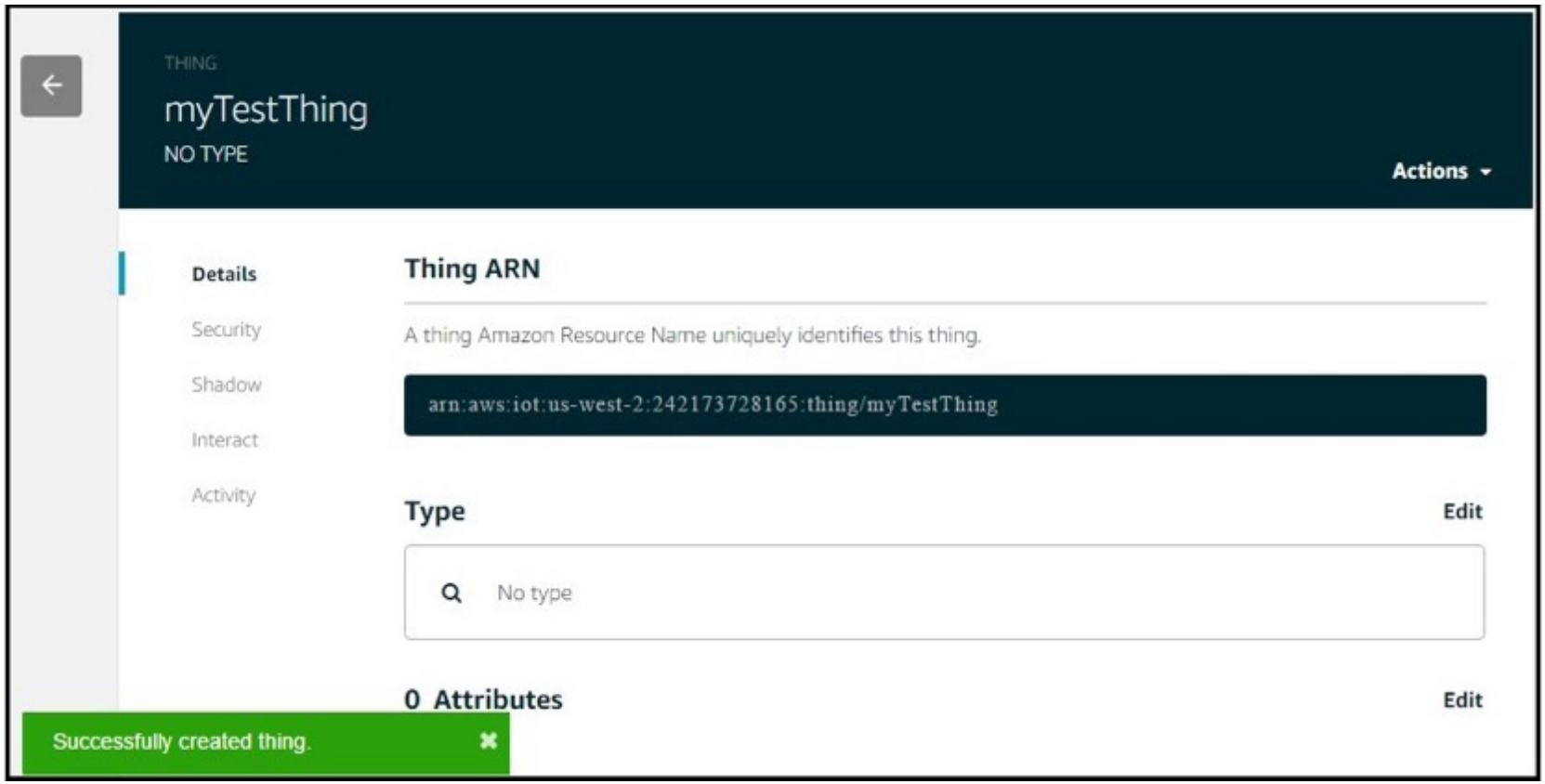
Click on Register-->Things for registering a new **Thing** as shown below.

Click on Create to create a new **Thing.**

Provide a unique **Thing** name and click on Create to proceed.

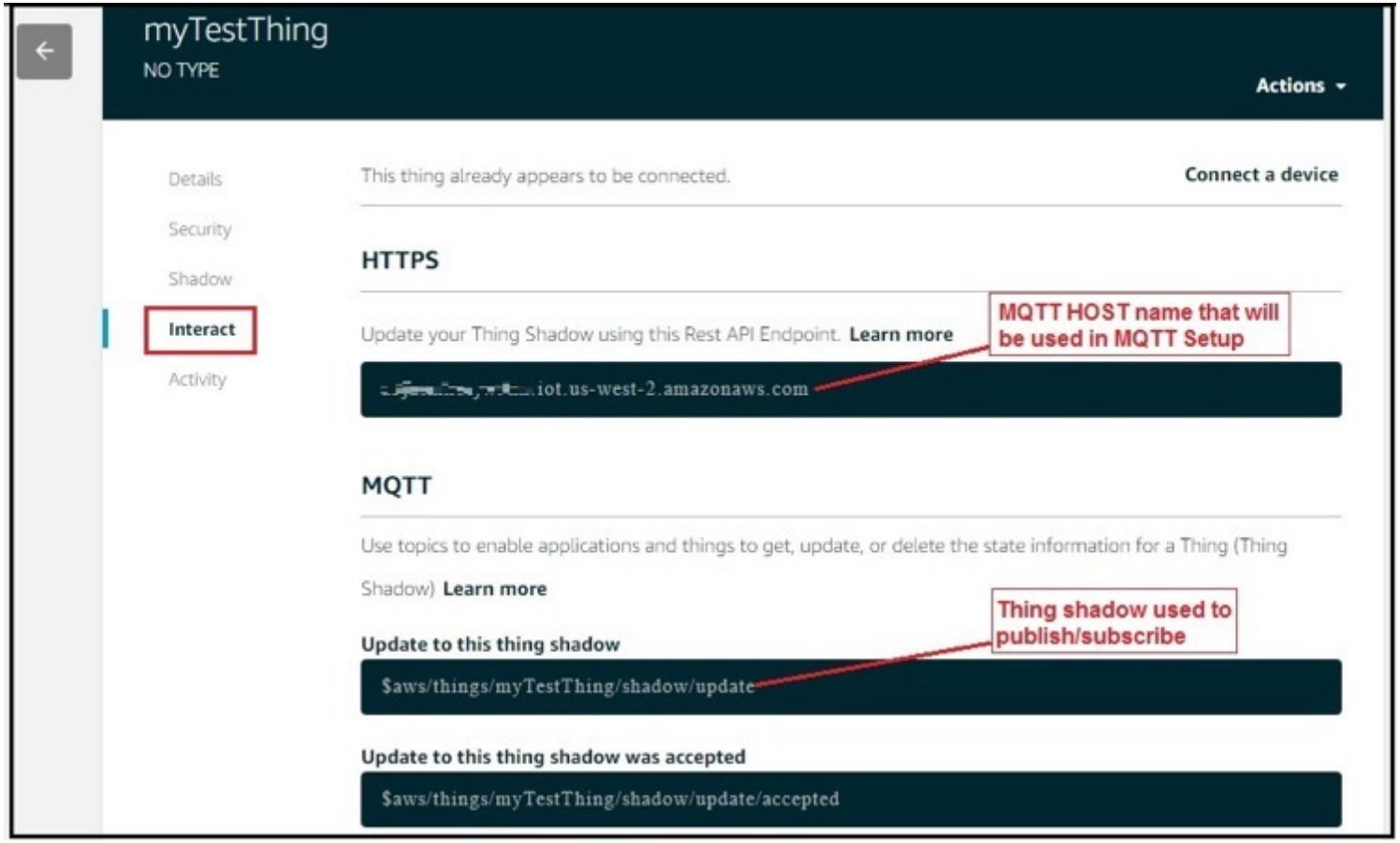


myTestThing is SuccessFul created as shown below.



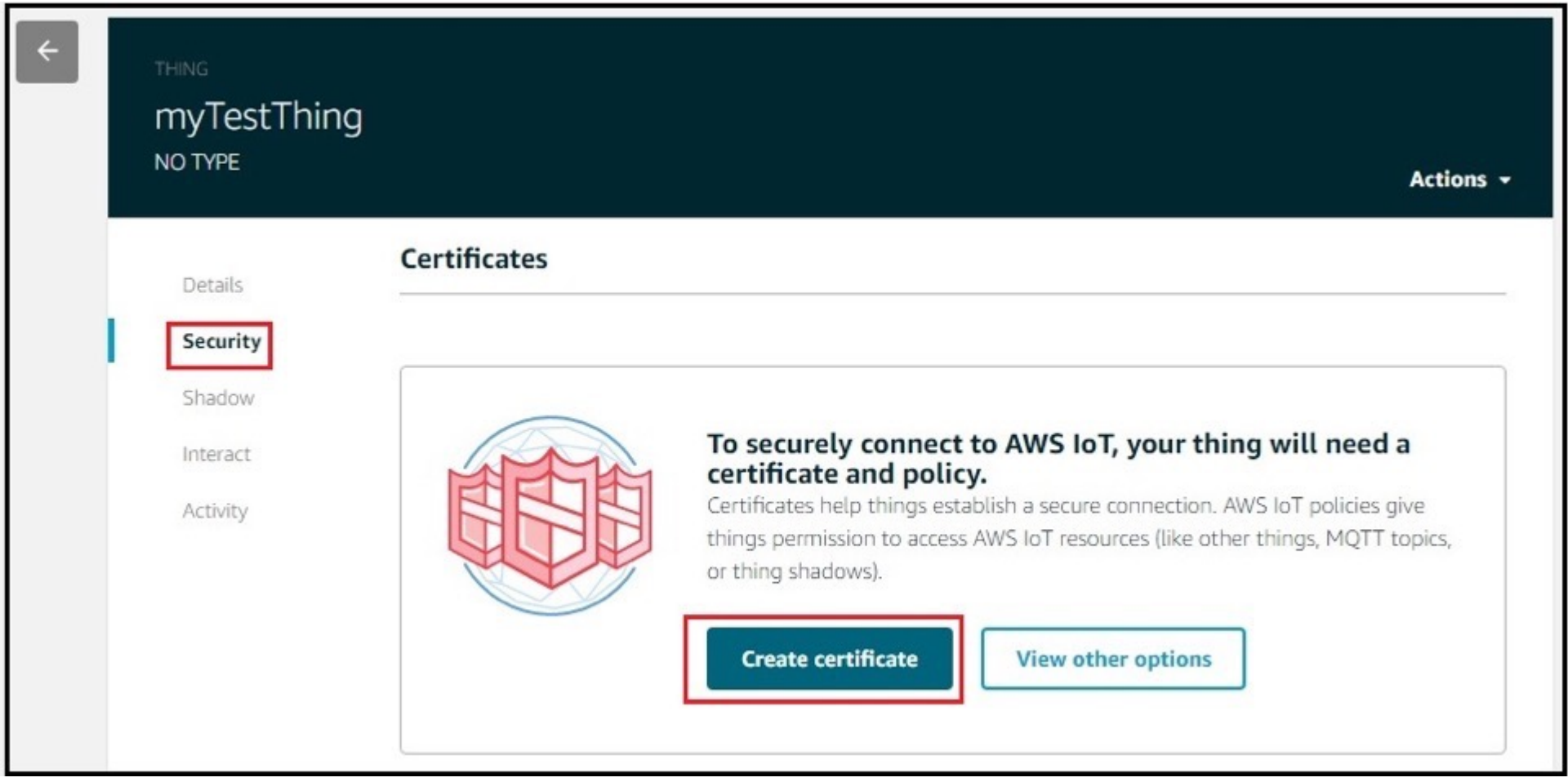
Get the MQTT HOST name and thing name from Interact menu.

- These will be used to connect with AWS MQTT and also to subscribe/publish the topics.

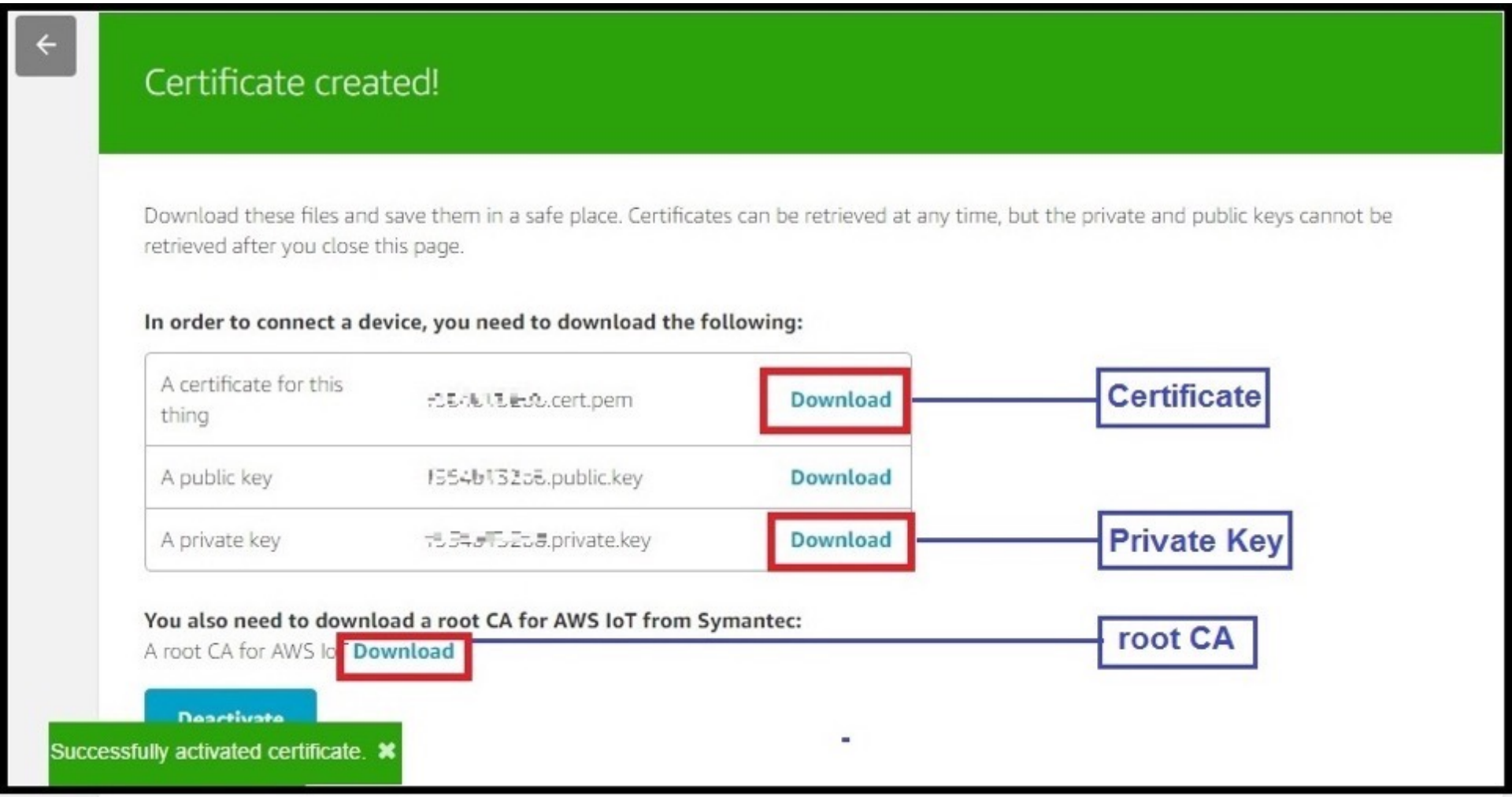


Generate certificates for new thing

- Go to Security menu and click on Create Certificate to register the certificates.

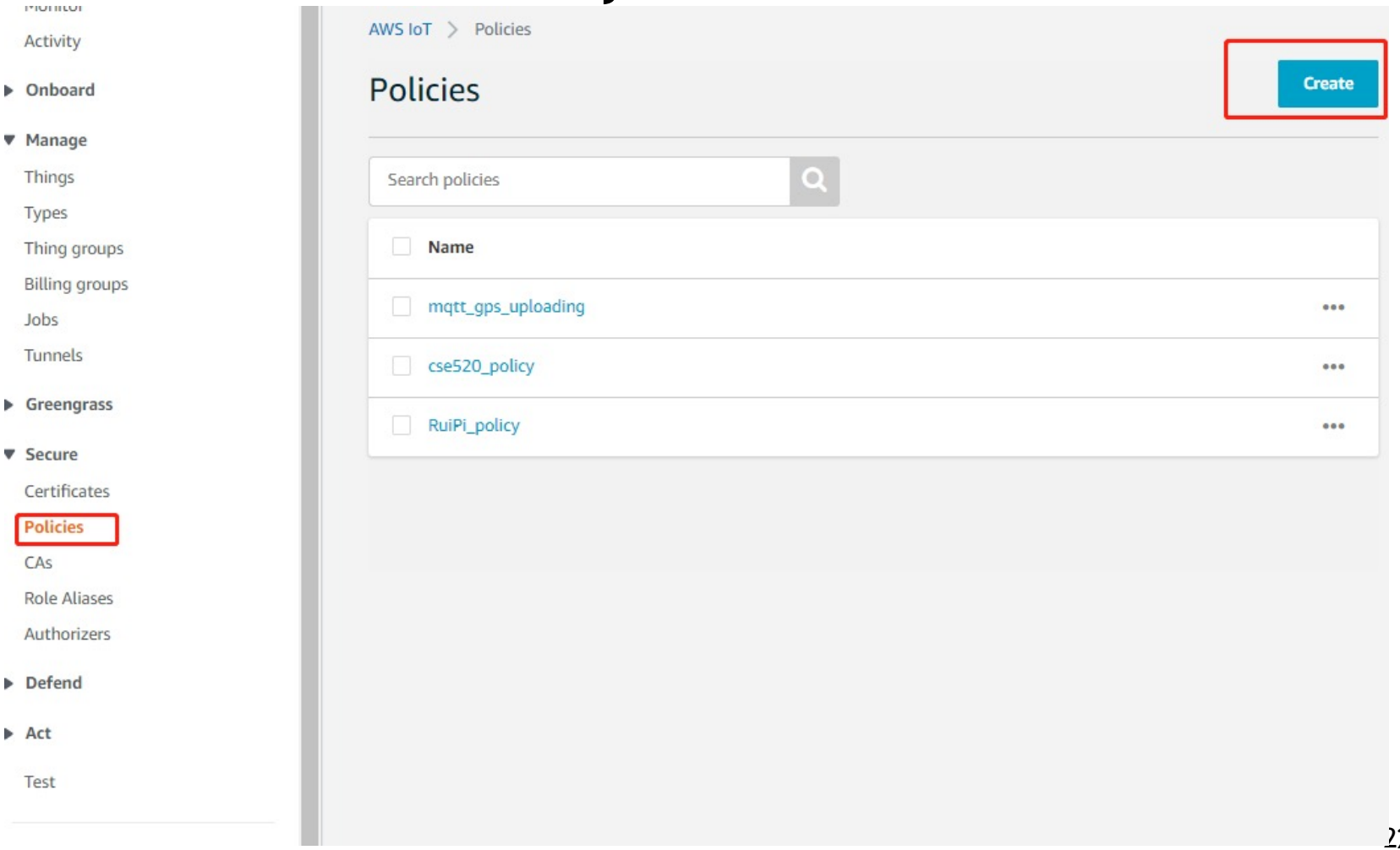


Click on the activate button to activate the certificates



Create Policy

- A policy is attached to a key/cert
  - **It tells what this key/cert can do**



Create a policy

Create a policy to define a set of authorized actions. You can authorize actions on one or more resources (things, topics, topic filters). To learn more about IoT policies go to the AWS IoT Policies documentation page.

Name

cse521_policy

Add statements

Policy statements define the types of actions that can be performed by a resource.

Advanced mode

Action

iot:*

Here, we grant it all permissions for demo!

Resource ARN

*

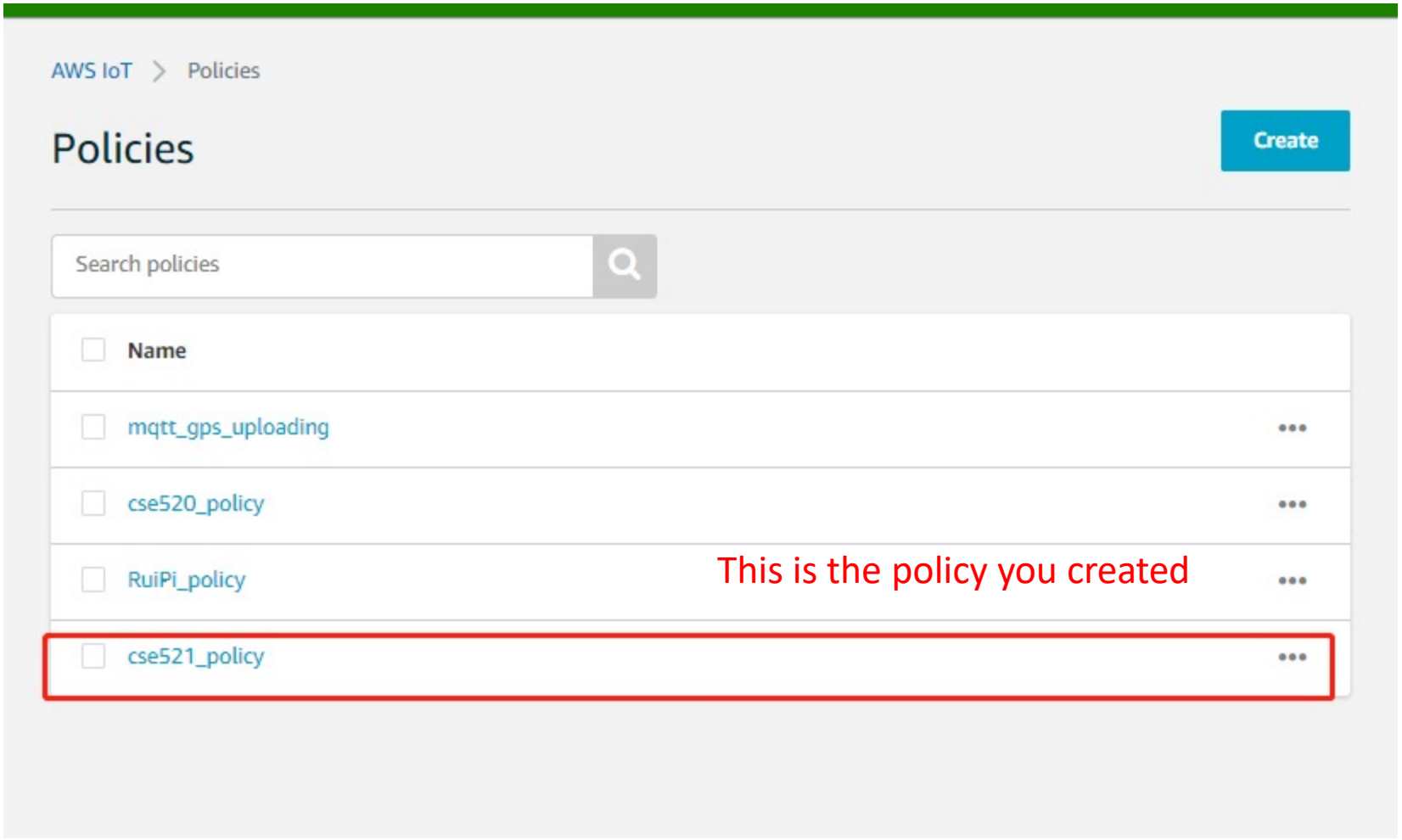
Effect

Allow Deny

Remove

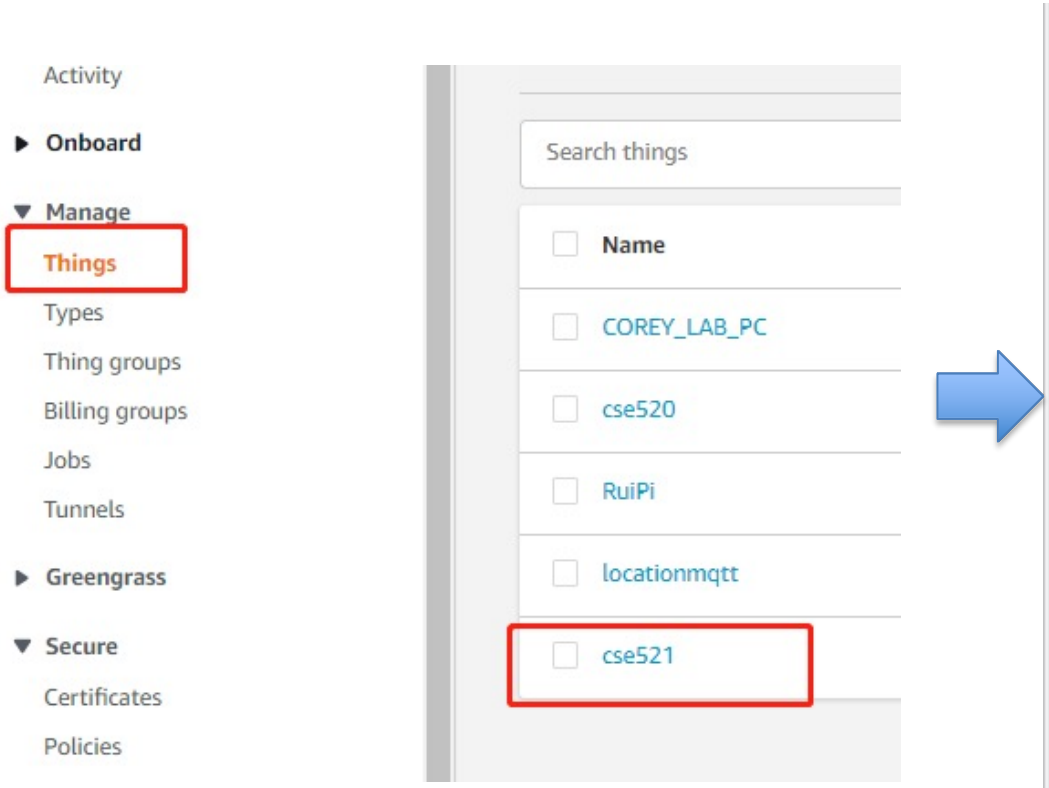
Add statement

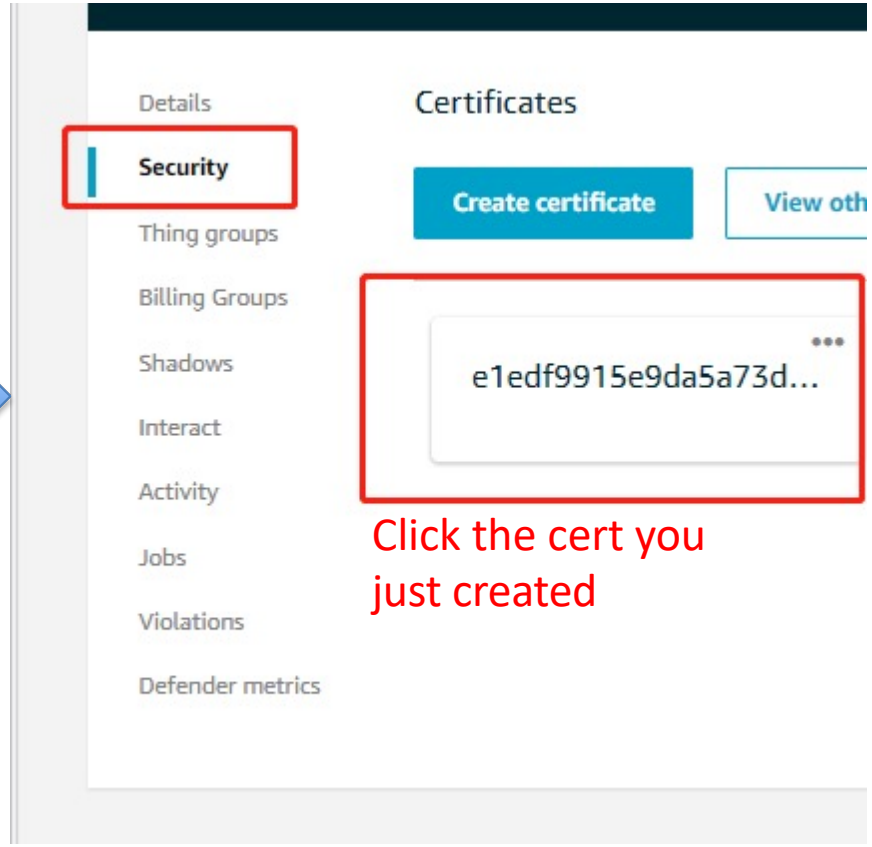
Create

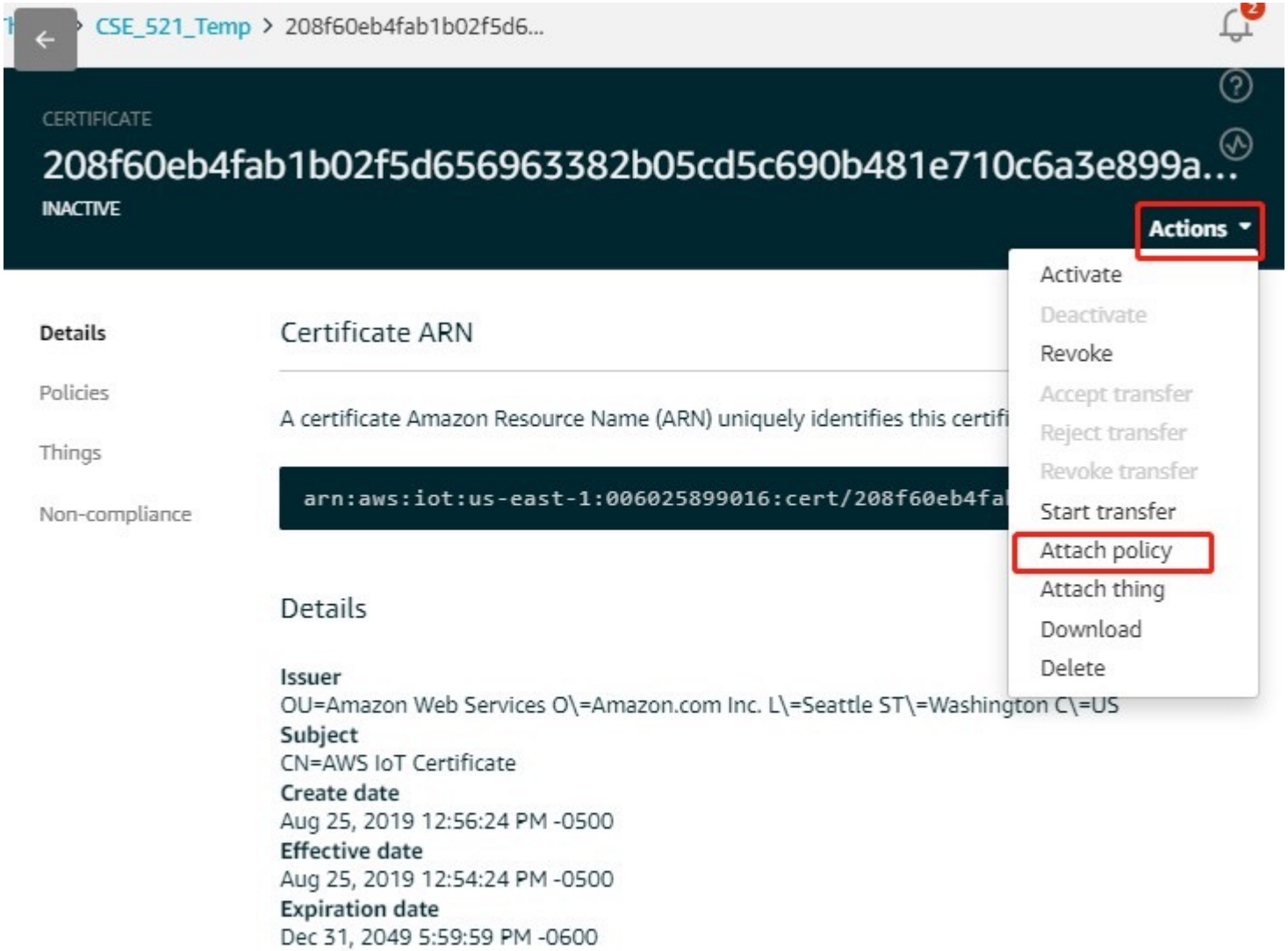

AWS IoT > Policies
Policies
Create
Search policies
Name
mqtt_gps_uploading
cse520_policy
RuiPi_policy
cse521_policy
This is the policy you created

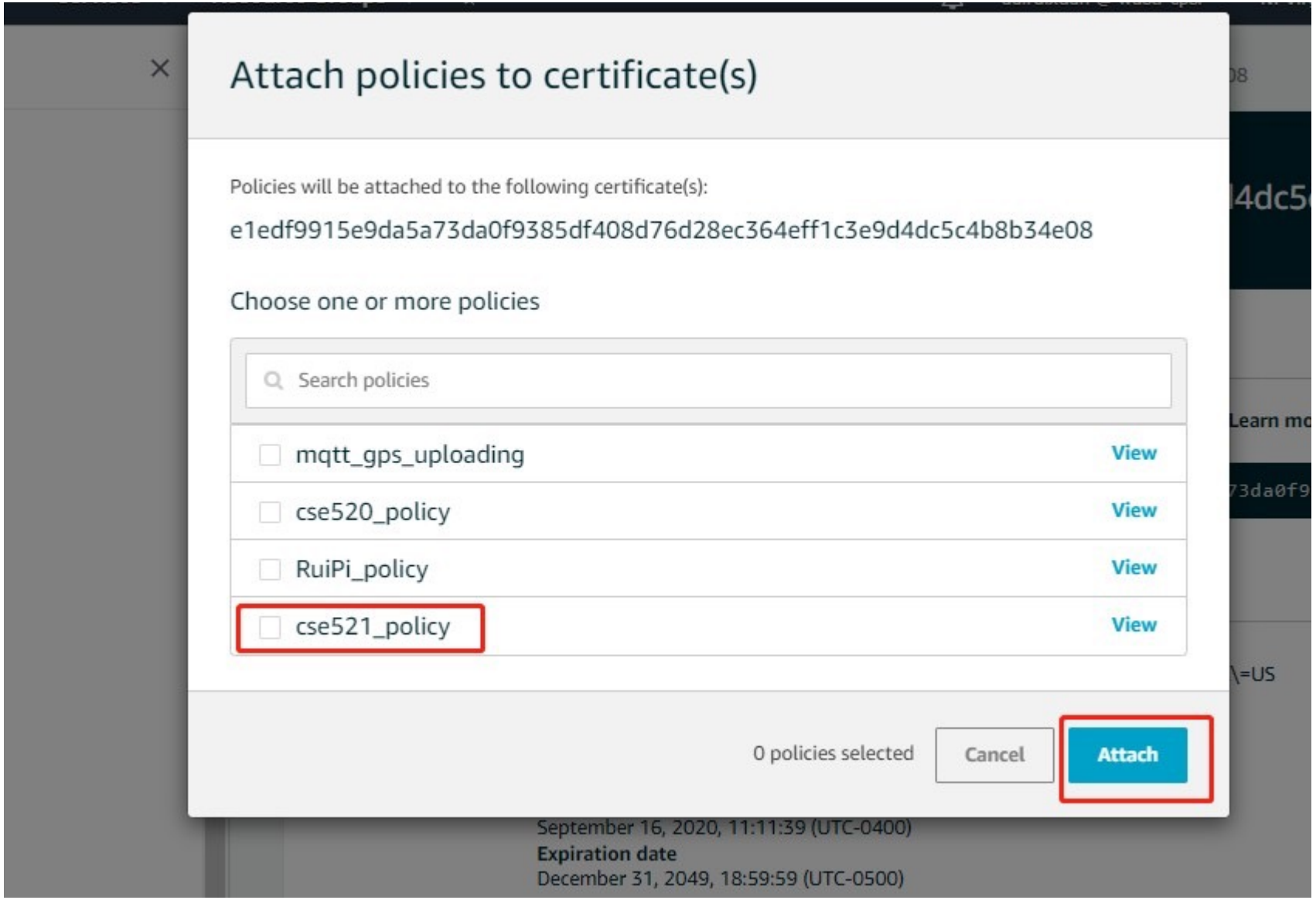
Attach Policy

- Attach Policy to the key/cert
  - A policy tells what this key/cert can do





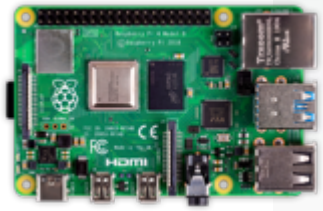

CSE_521_Temp > 208f60eb4fab1b02f5d6...
CERTIFICATE
208f60eb4fab1b02f5d656963382b05cd5c690b481e710c6a3e899a...
INACTIVE
Actions
Activate
Deactivate
Revoke
Accept transfer
Reject transfer
Revoke transfer
Start transfer
Attach policy
Attach thing
Download
Delete
Details
Policies
Things
Non-compliance
Certificate ARN
A certificate Amazon Resource Name (ARN) uniquely identifies this certifi
arn:aws:iot:us-east-1:006025899016:cert/208f60eb4fa
Details
Issuer
OU=Amazon Web Services O\=Amazon.com Inc. L\=Seattle ST\=Washington C\=US
Subject
CN=AWS IoT Certificate
Create date
Aug 25, 2019 12:56:24 PM -0500
Effective date
Aug 25, 2019 12:54:24 PM -0500
Expiration date
Dec 31, 2049 5:59:59 PM -0600

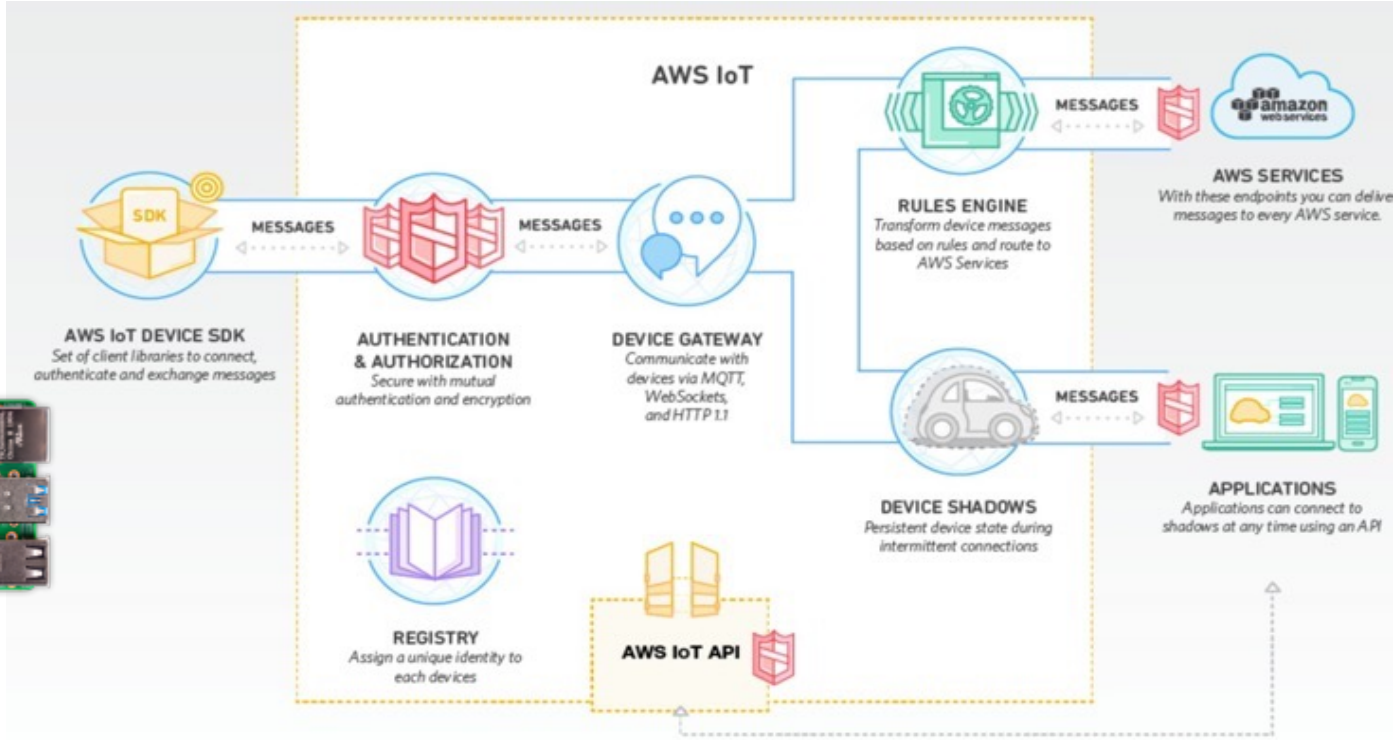

Attach policies to certificate(s)
Policies will be attached to the following certificate(s):
e1edf9915e9da5a73da0f9385df408d76d28ec364eff1c3e9d4dc5c4b8b34e08
Choose one or more policies
Search policies
mqtt_gps_uploading
View
cse520_policy
View
RuiPi_policy
View
cse521_policy
View
0 policies selected
Cancel
Attach
September 16, 2020, 11:11:39 (UTC-0400)
Expiration date
December 31, 2049, 18:59:59 (UTC-0500)

Now, you have a virtual thing on AWS!

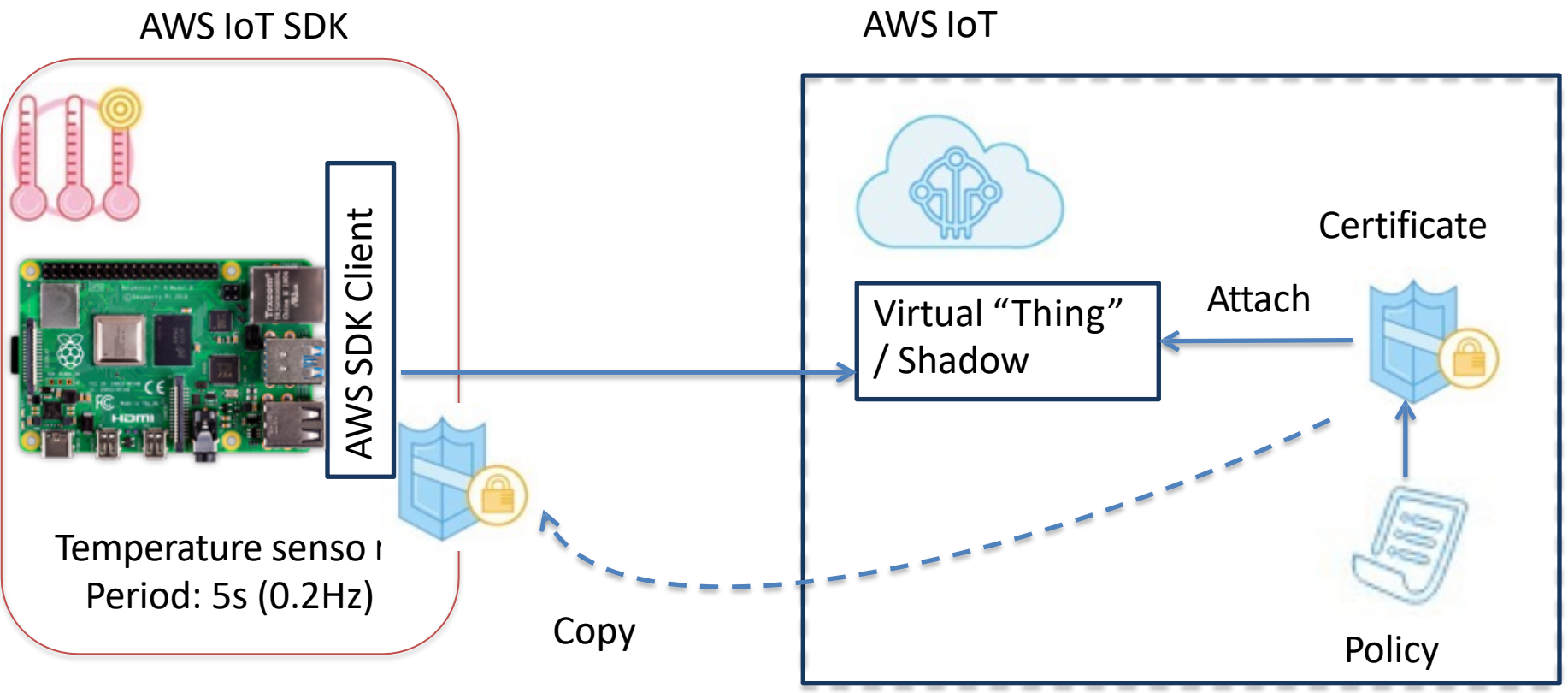
AWS Things Summary

- **Certificate: authenticate the device**
- **Policy: define the roles/permissions of the certificate**
- **Virtual copy of the thing (Shadow): Store/retrieve some information**





Step 2: Connect a “Physical” Device



[Connect AWS IoT with ESP32:
https://exploreembedded.com/wiki/AWS_IOT_with_Arduino_ESP32](https://exploreembedded.com/wiki/AWS_IOT_with_Arduino_ESP32)

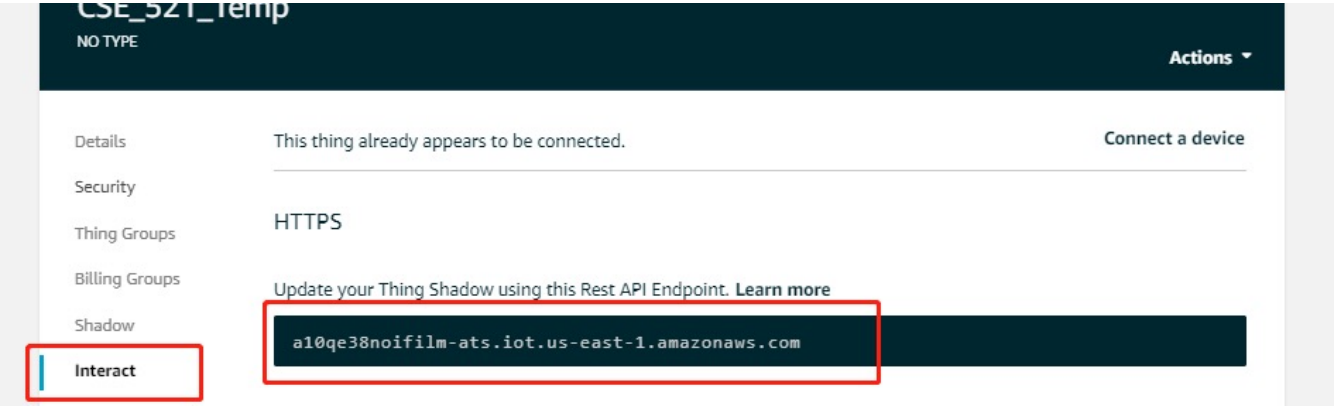
Connect your Device

- Copy certificates to your **physical things**
  - Downloaded before!

- Choose your **AWS SDK** (support MQTT)
  - Node JS
  - Python (pip install AWSIoTPythonSDK)
  - Java
  - ...
- Set up your client with SDK and the certificates

Some Notes

- 1. Copy the certificates/keys to your real thing
- 2. You will need the endpoint and port (8883)



Host(Endpoint)

- 3. Set up your configuration of the code with SDK

```
host = "a10qe38noifilm-ats.iot.us-east-1.amazonaws.com" # Your thing's endpoint. See tutorial slides
rootCAPath = "root-CA.crt"
certificatePath = "e1edf9915e-certificate.pem.crt"
privateKeyPath = "e1edf9915e-private.pem.key"
port = 8883
clientId = "CSE521"
topic = "$aws/things/cse521/shadow/update" # Shadow topic of your Thing
```

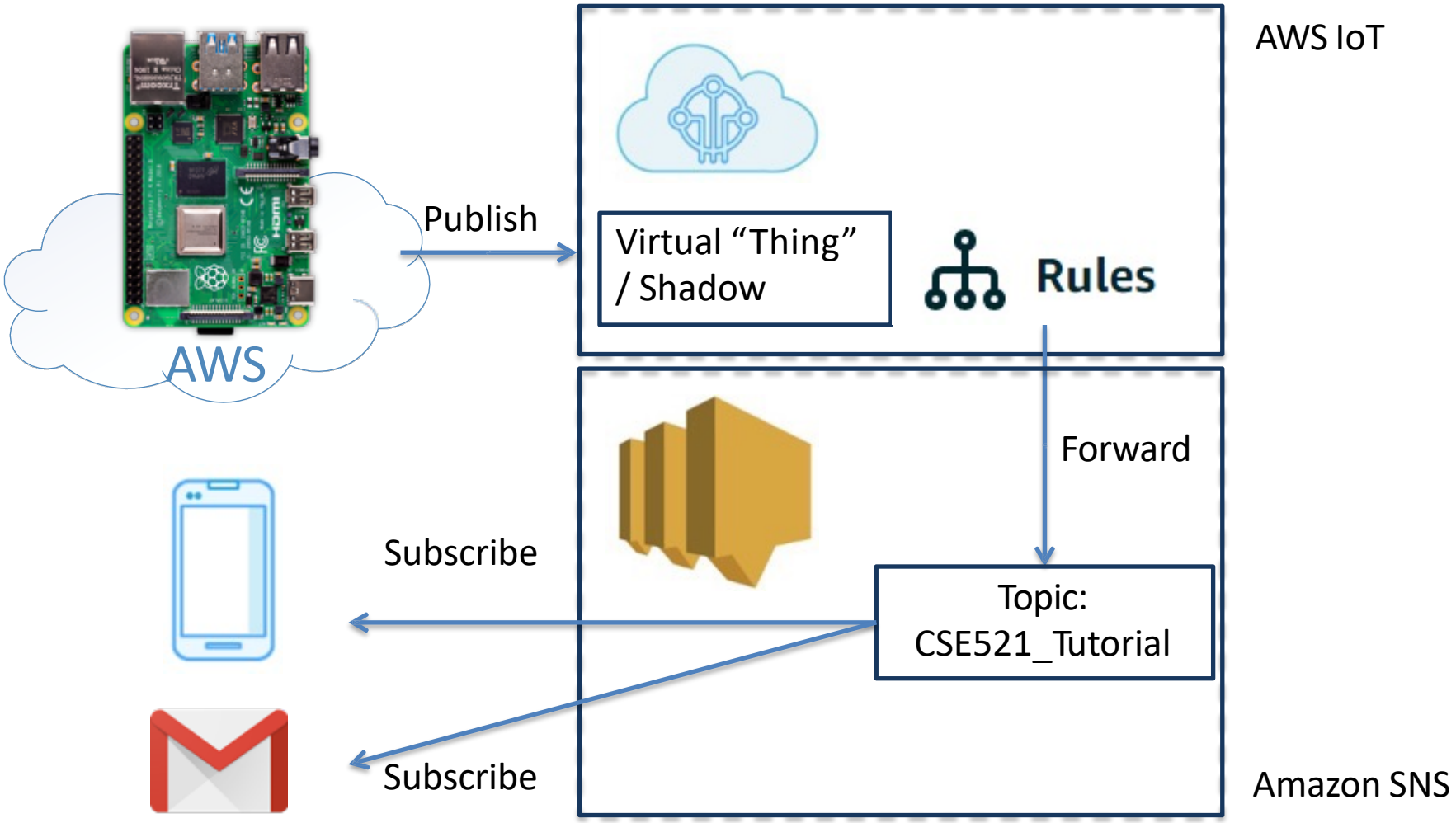
Change your code accordingly!

SDK and Demo Codes

- https://github.com/aws/aws-iot-device-sdk-python
- https://github.com/aws/aws-iot-device-sdk-python/blob/master/samples/basicPubSub/basicPubSub.py

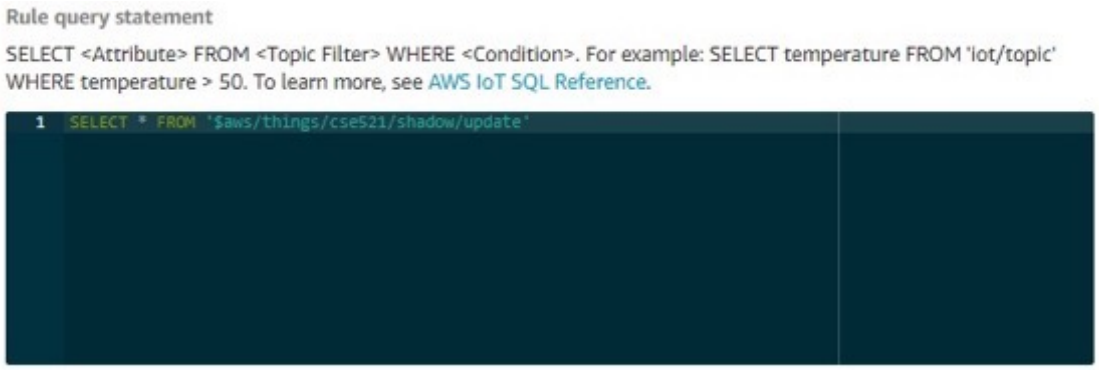
More: Rule Engine, Link with SNS services

- Simple Notification Service

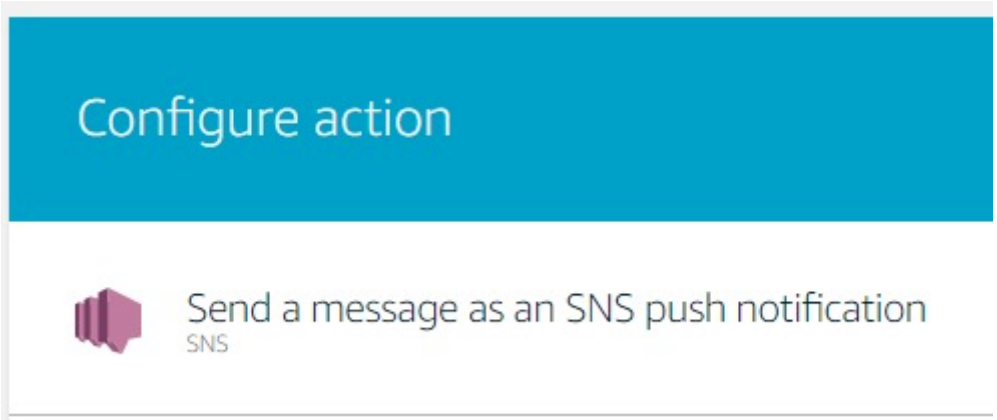


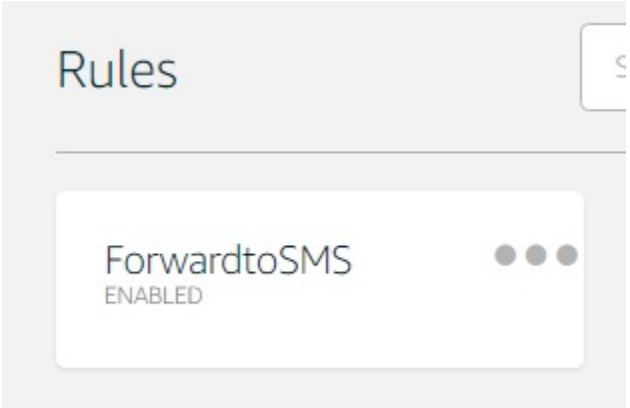
Create a Rule in Amazon IoT

- Add a query to filter your interesting topic (event)

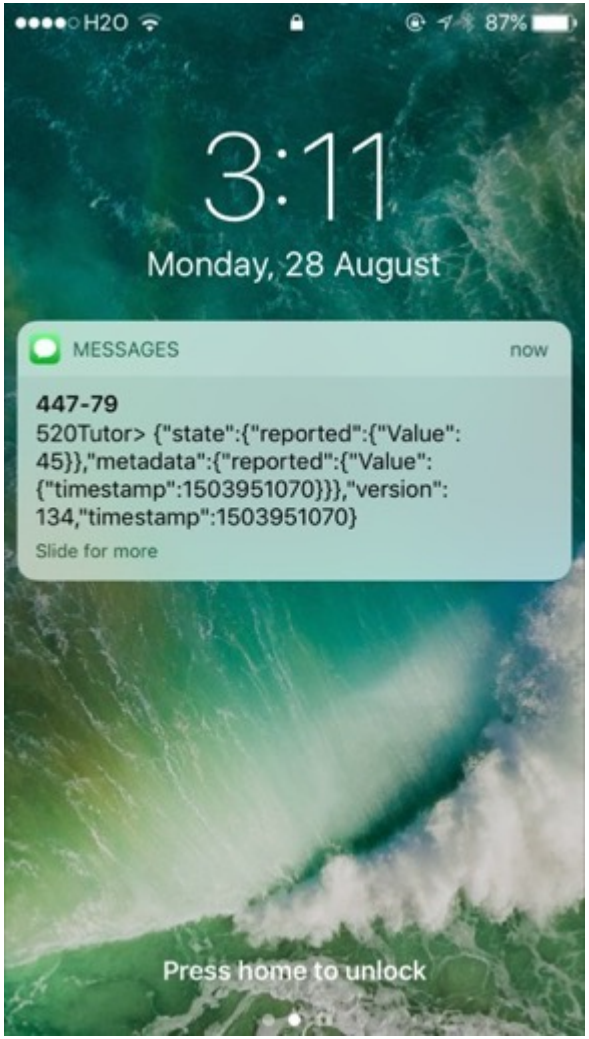


- Add an Action:
  - Forward this message to SNS
  - Specify Dest ARN
  - Enable Rule





Notification on SMS & Email



AWS Notification Message Inbox x

520Tutor no-reply@sns.amazona 3:11 PM (28 minutes ago)

to me

{"state":{"reported":{"Value":45}},"metadata":{"reported":{"Value":{"timestamp":1503951070}}},"version":134,"timestamp":1503951070}

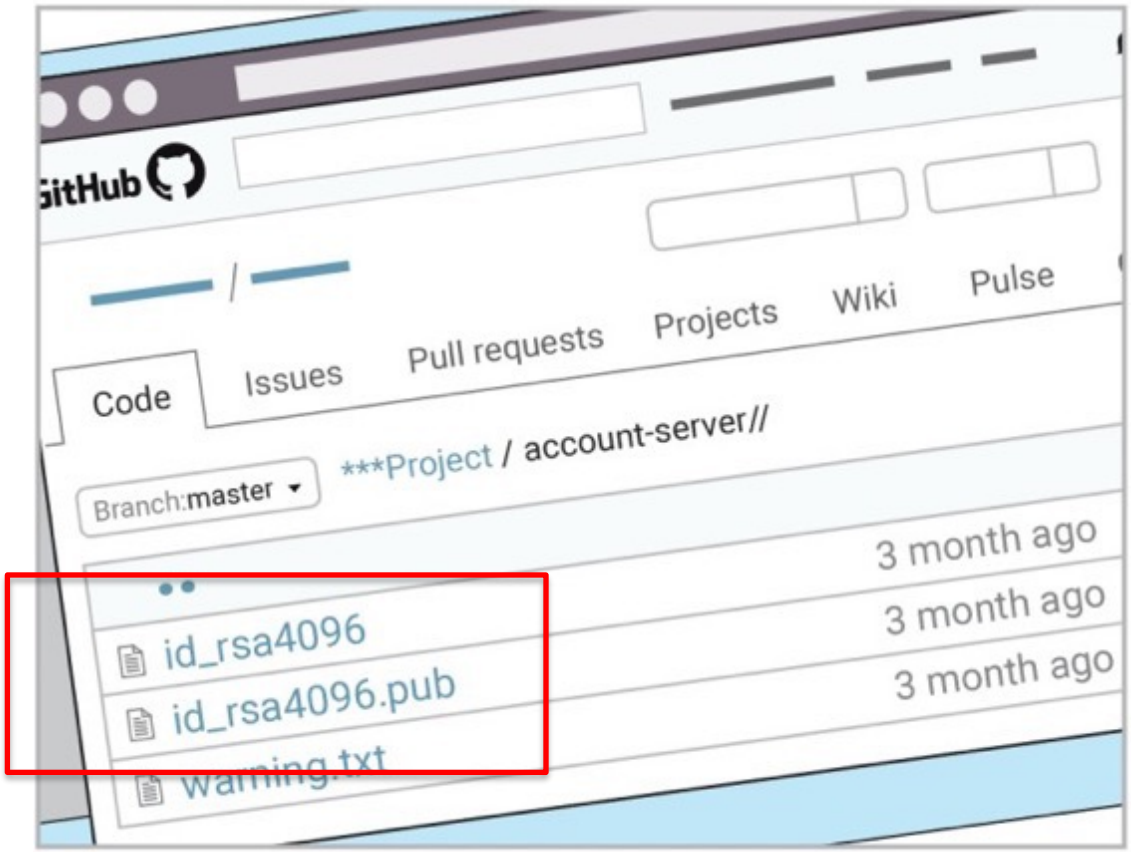
--

If you wish to stop receiving notifications from this topic, please click or visit the link below to unsubscribe:
https://sns.us-west-2.amazonaws.com/unsubscribe.html?SubscriptionArn=arn:aws:sns:us-west-2:401317363811:CSE520S_Tutorial:00c54352-7d1a-4c09-9cc1-15aed3c395e3&Endpoint=naroahlee@gmail.com

Please do not reply directly to this email. If you have any questions or comments regarding this email, please contact us at
https://aws.amazon.com/support

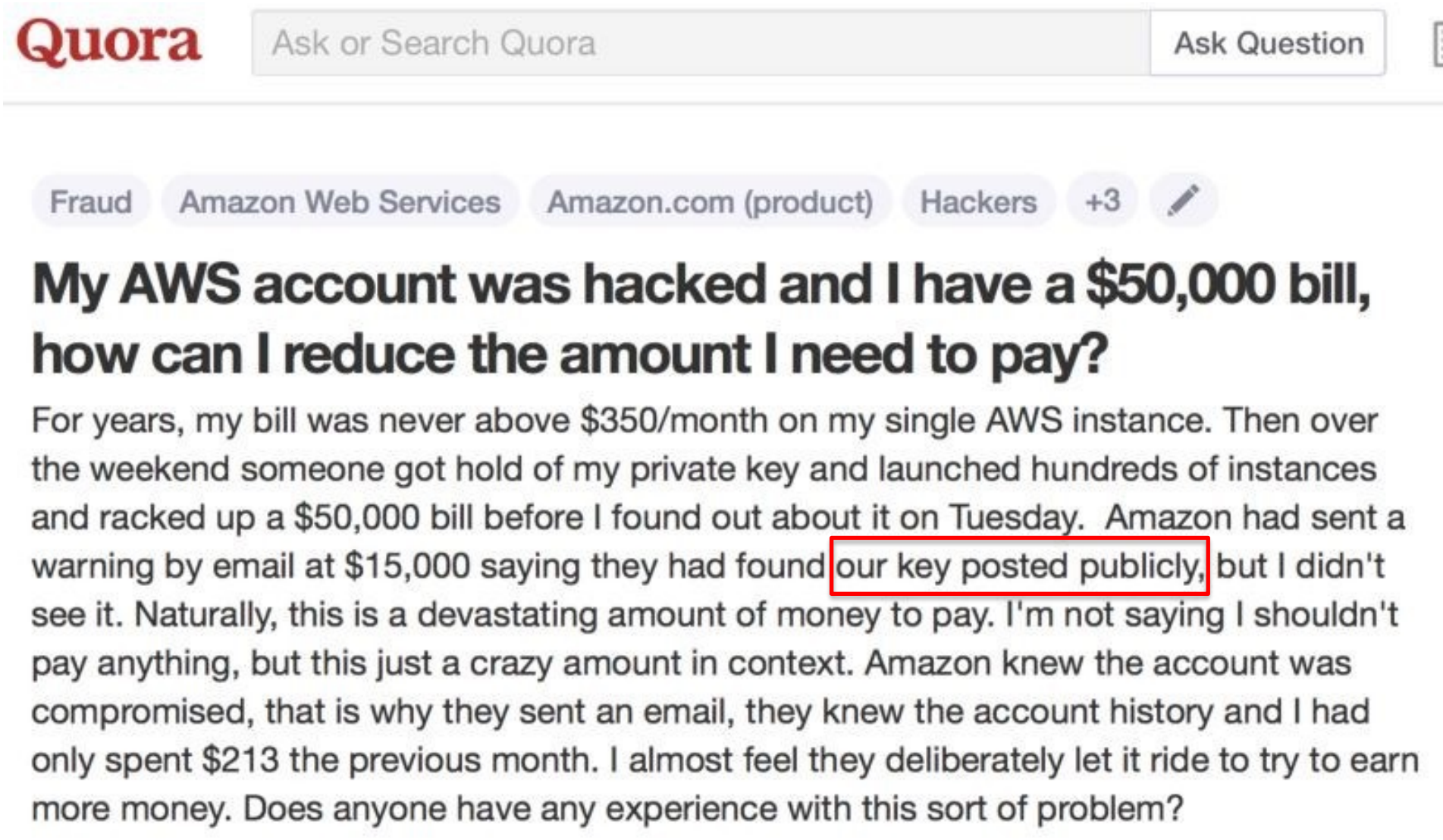
One More Thing: Account Security

- DON'T UPLOAD YOUR KEY PUBLICLY!!!



Source: WeChat Subscriptions: 西乔《神秘的程序员们 39》 Geek Life Chpt 39.

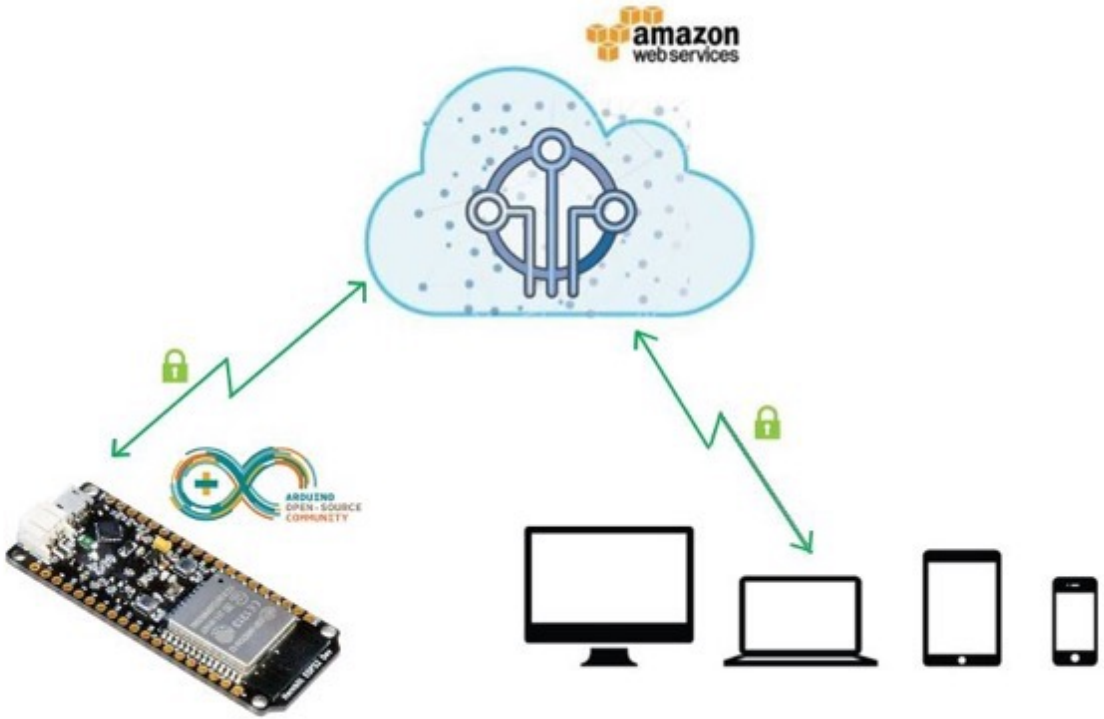
What if… $50,000 AWS Bill!



Source: https://www.quora.com/My-AWS-account-was-hacked-and-I-have-a-50-000-bill-how-can-I-reduce-the-amount-I-need-to-pay

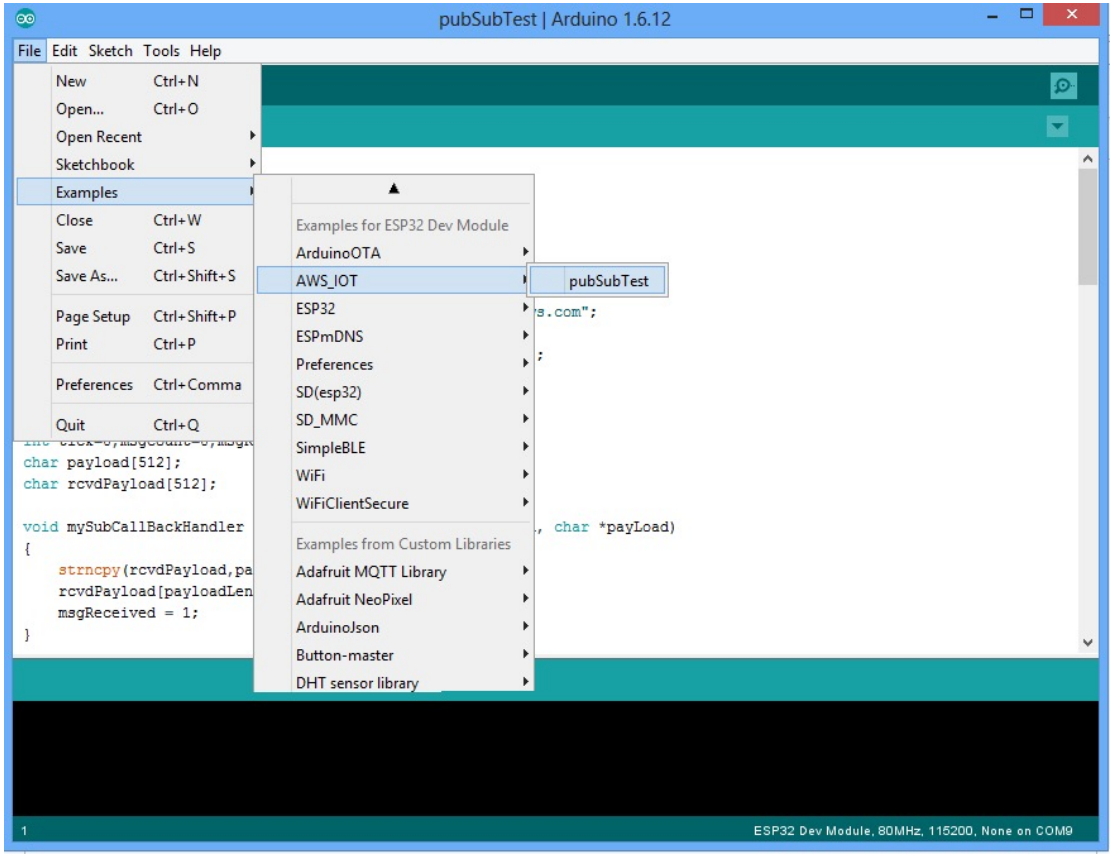
AWS IoT for ESP32

- https://exploreembedded.com/wiki/AWS_IOT_with_Arduino_ESP32



AWS IoT for ESP32

- Download the AWS IOT library for Arduino ESP32 from this link. Now open the first example pubSubTest.ino as shown below.



pubSubTest | Arduino 1.6.12

File Edit Sketch Tools Help

pubSubTest §

```
#include <AWS_IOT.h>
#include <WiFi.h>

AWS_IOT hornbill;

char WIFI_SSID[]="your Wifi SSID";
char WIFI_PASSWORD[]="Wifi Password";
char HOST_ADDRESS[]="AWS host address";
char CLIENT_ID[]= "client id";
char TOPIC_NAME[]= "your thing/topic name";


int status = WL_IDLE_STATUS;
int tick=0,msgCount=0,msgReceived = 0;
char payload[512];
char rcvdPayload[512];

void mySubCallBackHandler (char *topicName, int payloadLen, char *payLoad)
{
    strncpy(rcvdPayload,payLoad,payloadLen);
    rcvdPayload[payloadLen] = 0;
    msgReceived = 1;
}
```


ESP32 Dev Module, 80MHz, 115200, None on COM9

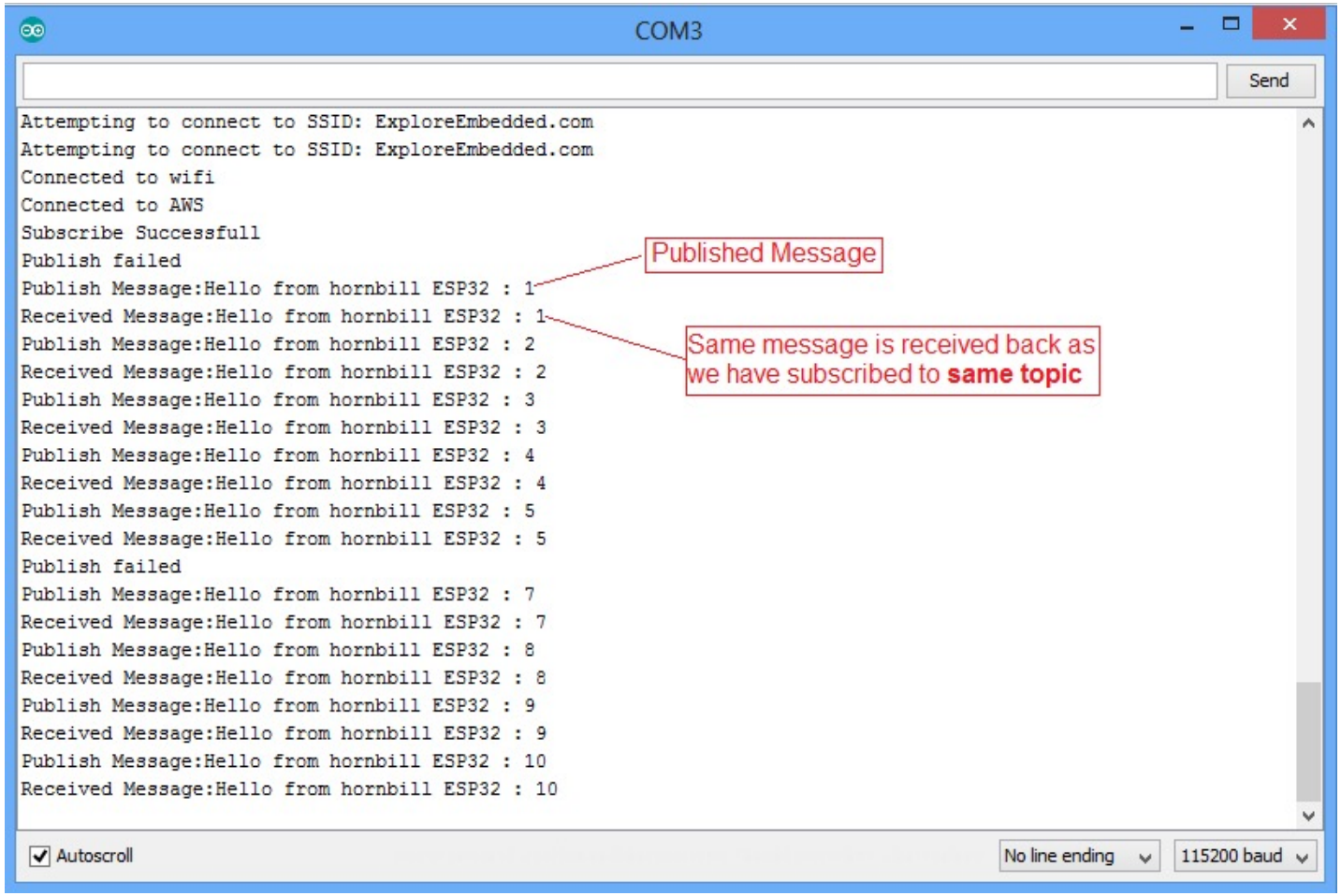
AWS IoT for ESP32

- The below certificate and private key needs to be copied to aws_iot_certificate.c file in the form of array.

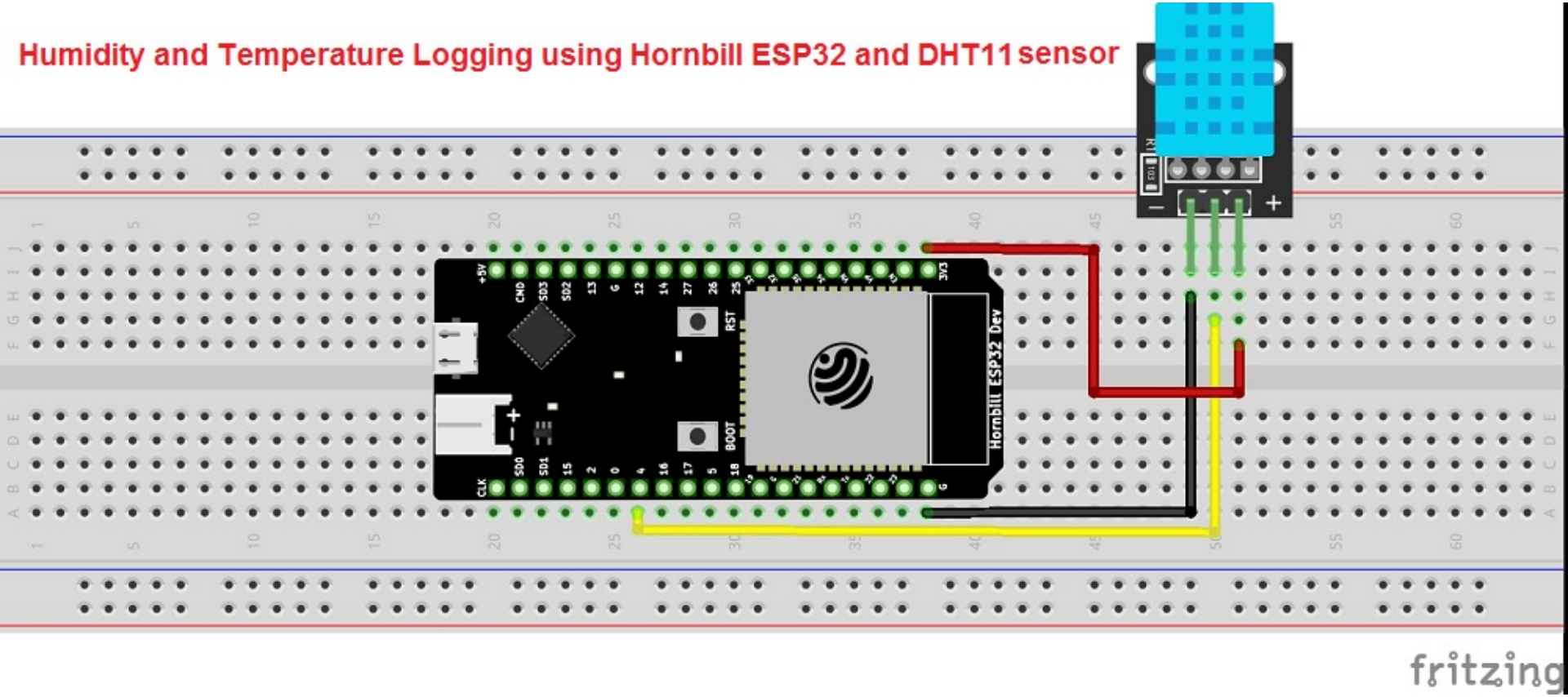
1. aws-root-ca.pem
2. certificate.pem.crt
3. private.pem.key

Upload the sketch and verify the output

- Publish and subscribe(received) messages printed on terminal.



Logging Temperature and Humidity using DHT11 sensor



Logging Temperature and Humidity using DHT11 sensor

```
#include <WiFi.h>

#include "DHT.h"

#define DHTPIN 4 // what digital pin we're connected to

// Uncomment whatever type you're using!
#define DHTTYPE DHT11 // DHT 11
//#define DHTTYPE DHT22 // DHT 22 (AM2302), AM2321
//#define DHTTYPE DHT21 // DHT 21 (AM2301)

DHT dht(DHTPIN, DHTTYPE);

AWS_IOT hornbill; // AWS_IOT instance

char WIFI_SSID[]="your Wifi SSID";
char WIFI_PASSWORD[]="Wifi Password";
char HOST_ADDRESS[]="AWS host address";
char CLIENT_ID[]= "client id";
char TOPIC_NAME[]= "your thing/topic name";


int status = WL_IDLE_STATUS;
int tick=0,msgCount=0,msgReceived = 0;
char payload[512];
char rcvdPayload[512];
```

```

Serial.begin(115200);
delay(2000);

while (status != WL_CONNECTED)
{
Serial.print("Attempting to connect to SSID: ");
Serial.println(WIFI_SSID);
// Connect to WPA/WPA2 network. Change this line if using open or WEP network:
status = WiFi.begin(WIFI_SSID, WIFI_PASSWORD);

// wait 5 seconds for connection:
delay(5000);
}

Serial.println("Connected to wifi");

if(hornbill.connect(HOST_ADDRESS,CLIENT_ID)== 0) // Connect to AWS using Host Address and Cliend ID
{
Serial.println("Connected to AWS");
delay(1000);
}
else
{
Serial.println("AWS connection failed, Check the HOST Address");
while(1);
}

delay(2000);

dht.begin(); //Initialize the DHT11 sensor
}
```

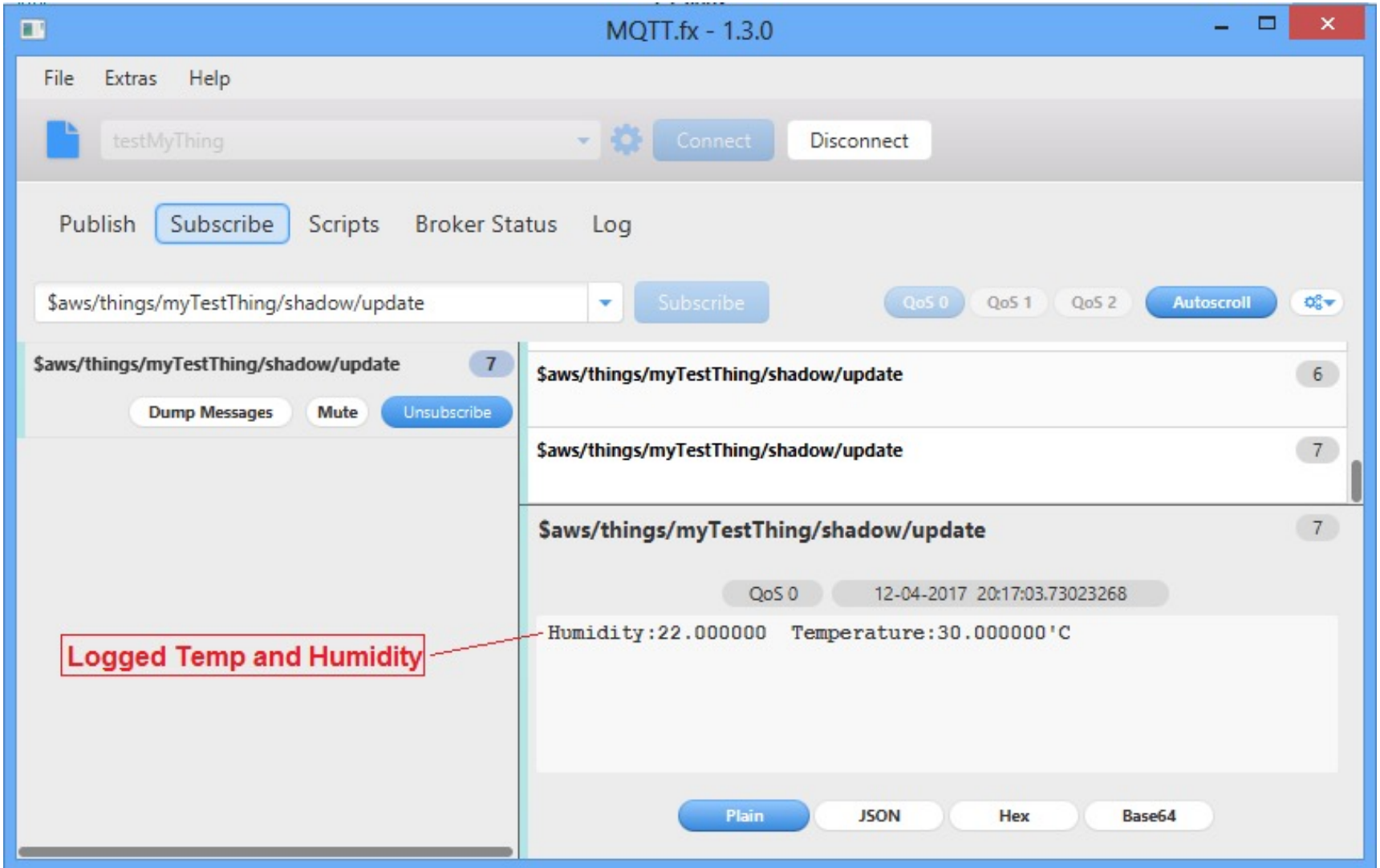
Logging Temperature and Humidity using DHT11 sensor

```
// Reading temperature or humidity takes about 250 milliseconds!
// Sensor readings may also be up to 2 seconds 'old' (its a very slow sensor)
float h = dht.readHumidity();
// Read temperature as Celsius (the default)
float t = dht.readTemperature();
// Read temperature as Fahrenheit (isFahrenheit = true)
float f = dht.readTemperature(true);

// Check if any reads failed and exit early (to try again).
if (isnan(h) || isnan(t) || isnan(f)) {
Serial.println("Failed to read from DHT sensor!");
}
else
{
sprintf(payload,"Humidity:%f Temperature:%f'C",h,t); // Create the payload for publishing

if(hornbill.publish(TOPIC_NAME,payload) == 0) // Publish the message(Temp and humidity)
{
Serial.print("Publish Message:");
Serial.println(payload);
}
else
{
Serial.println("Publish failed");
}
// publish the temp and humidity every 5 seconds.
vTaskDelay(5000 / portTICK_RATE_MS);
}
}
```

Temp and Humidity logged to AWS IOT server.



AWS IoT for Android

https://www.linkedin.com/pulse/android-app-aws-iot-core-guide-felipe-ramos-da-silva/

Next Week, AWS IoT Greengrass ML Inference

COMP.5650/4150.201
Internet of Things
Lecture 8.2: Speech Analysis

Instructor
Mohammad Arif Ul Alam

Voice Based Analytics

- Voice can be analyzed, lots of useful information extracted
  - Who is talking? (Speaker identification): Human Speech Frequency ranges 100 – 3200Hz
  - How many social interactions a person has a day
  - Emotion of person while speaking
  - Anxiety, depression, intoxication, of person, etc.
- For speech recognition, voice analytics used to:
  - Discard useless information (background noise, etc)
  - Extract information useful for identifying linguistic content

Mel Frequency Cepstral Coefficients (MFCCs)

- MFCCs widely used in speech and speaker recognition for representing envelope of power spectrum of voice
- Popular approach in Speech recognition
  - MFCC features + Hidden Markov Model (HMM) classifiers

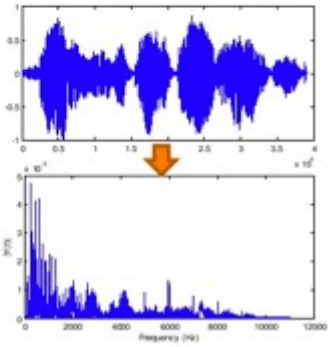
Human Speech

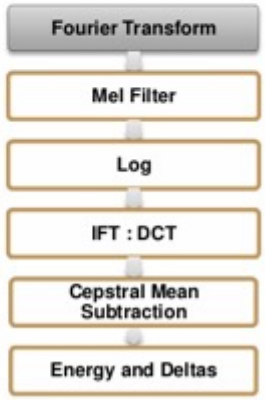
- Human perception of speech is linear until 1000 and logarithmic from there
- cepstrum is
  - Fourier Transform (logarithmic(Fourier Transform (Speech Signal)))

FEATURE EXTRACTION :

FOURIER TRANSFORM

- Gives information about the amount of energy at each frequency band
- FFT used $bin_k = \left| \sum_{n=1}^{N} s_w(n) e^{-i(n-1)k\frac{2\pi}{N}} \right|, \quad k = 0,1,2,\ldots,N-1$





MFCC Steps: Overview

1. Frame the signal into short frames.
2. For each frame calculate the periodogram estimate of the power spectrum.
3. Apply the mel filterbank to the power spectra, sum the energy in each filter.
4. Take the logarithm of all filterbank energies.
5. Take the DCT of the log filterbank energies.
6. Keep DCT coefficients 2-13, discard the rest.

discrete cosine transform (DCT)

Step 1: Windowing

- Audio is continuously changing.
- Break into short segments (20-40 milliseconds)
- Can assume audio does not change in short window

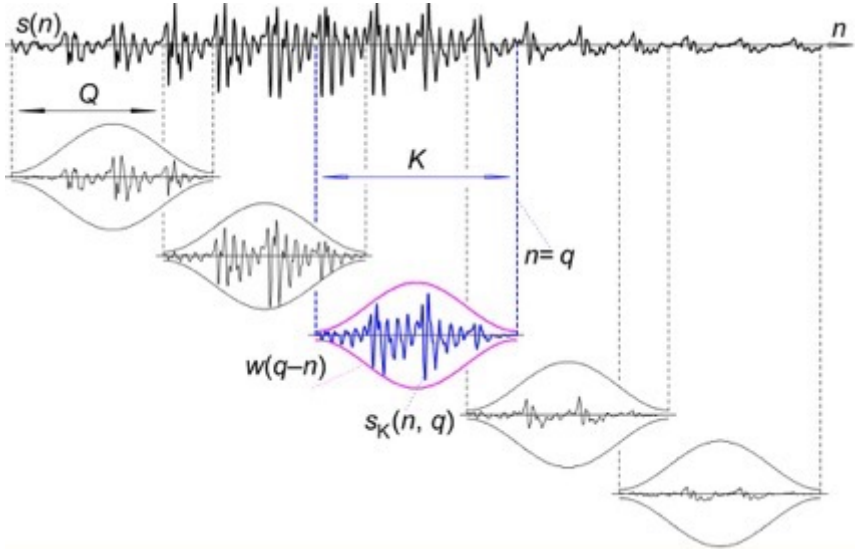
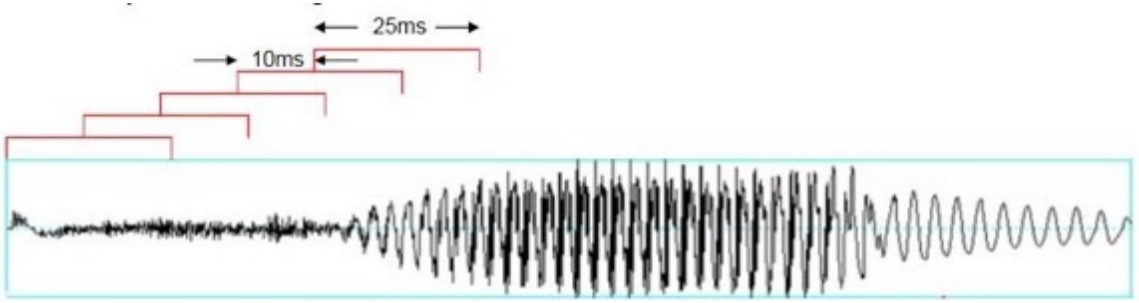


Image credits: http://recognize-speech.com/preprocessing/cepstral-mean-normalization/10-preprocessing

Step 1: Windowing

- Essentially, break into smaller overlapping frames
- Need to select frame length (e.g. 25 ms), shift (e.g. 10 ms)

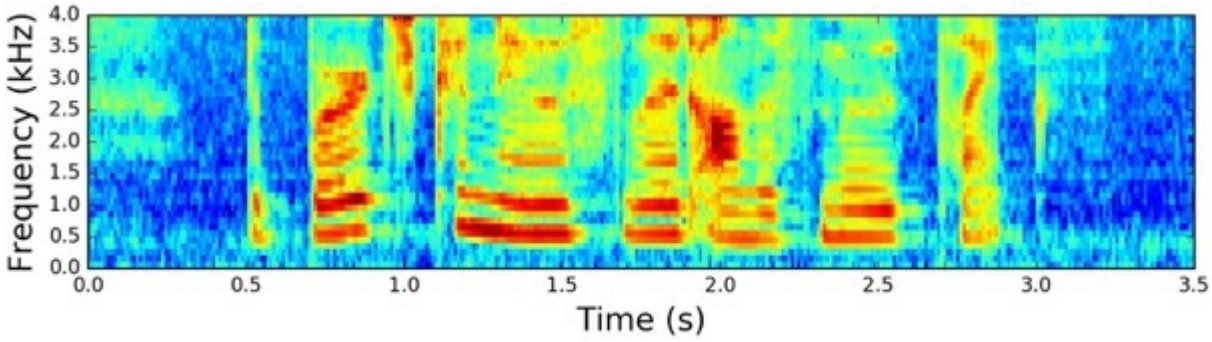


- So what? Can compare frames from reference vs test words (i.e. calculate distances between them)

http://slideplayer.com/slide/7674116/

Step 2: Calculate Power Spectrum of each Frame

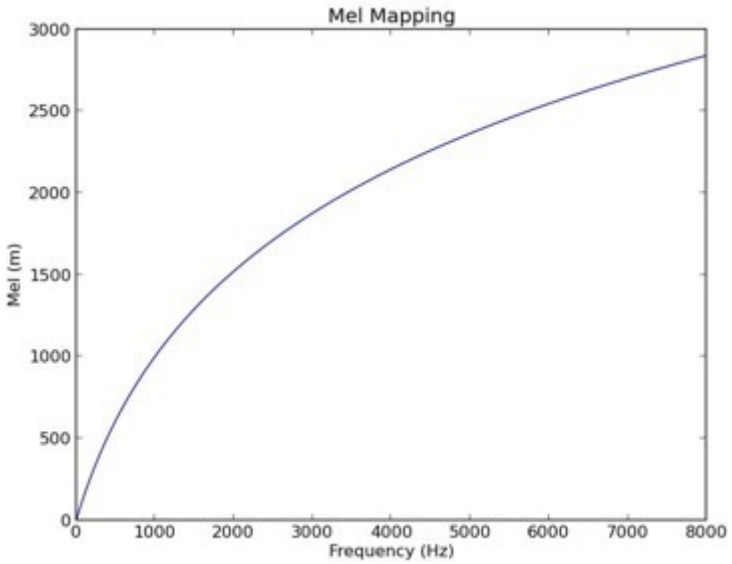
- Cochlea (Part of human ear) vibrates at different parts depending on sound frequency
- Power spectrum Periodogram similarly identifies frequencies present in each frame



Step 3: Apply Mel FilterBank

- Non-linear conversion from frequency to Mel Space

$$M(f) = 1125 \ln(1 + f/700) \qquad (1)$$



Step 4: Apply Logarithm of Mel Filterbank

- Take log of filterbank energies at each frequency
- This step makes output mimic human hearing better
  - We don't hear loudness on a linear scale
  - Changes in loud noises may not sound different

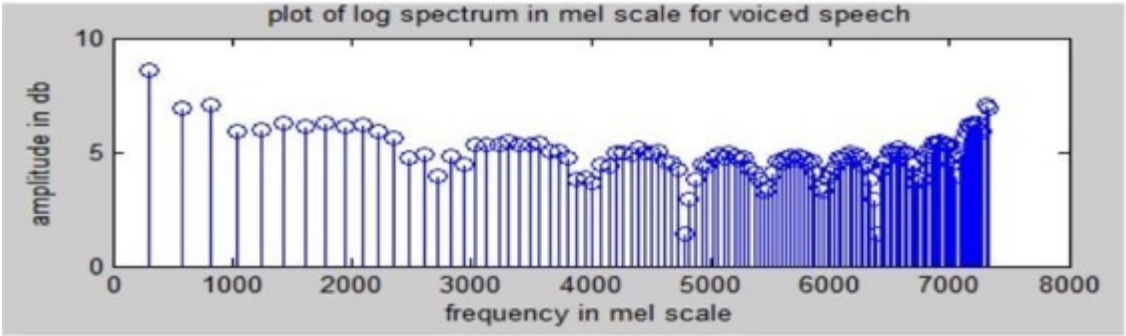


Fig.7. Spectrum of voiced speech

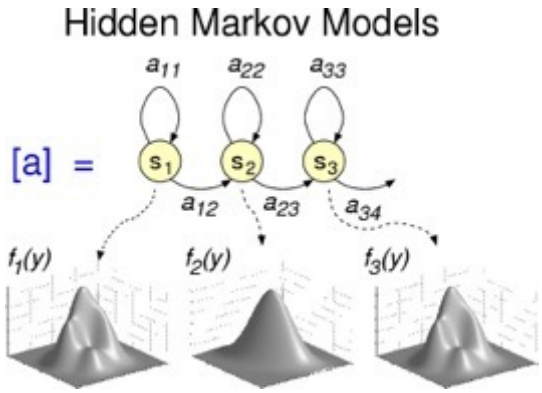
Step 5: **DCT of log filterbank**

- **Step 5: DCT of log filterbank:**
  - There are correlations between signals at different frequencies
  - Discrete Cosine Transform (DCT) extracts most useful and independent features

- Final result: 39 element acoustic vector used in speech processing algorithms

Speech Classification

- Human speech can be broken into phonemes
- Example of phoneme is /k/ in the words (**c**at, s**ch**ool, s**k**ill)
- Speech recognition tries to recognize sequence of phonemes in a word
- Typically uses Hidden Markov Model (HMM)
  - Recognizes letters, then words, then sentences



Speech Classification

- Human speech can be broken into phonemes
- Example of phoneme is /k/ in the words (**c**at, s**ch**ool, s**k**ill)
- Speech recognition tries to recognize sequence of phonemes in a word
- Dynamic Time Warping

Practice 8. 1 Speech Recognition and Print Texts Using Android

- Using SpeechRecognizer service

```
protected Intent intent;
protected SpeechRecognizer recognizer;

@Override
protected void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    setContentView(R.layout.activity_main);

    textViewResults = (TextView)findViewById(R.id.textViewResults);

    intent = new Intent(RecognizerIntent.ACTION_RECOGNIZE_SPEECH);
    intent.putExtra(RecognizerIntent.EXTRA_LANGUAGE_MODEL, "en-US");
    intent.putExtra(RecognizerIntent.EXTRA_WEB_SEARCH_ONLY, "false");
    intent.putExtra(RecognizerIntent.EXTRA_SPEECH_INPUT_MINIMUM_LENGTH_MILLIS, "3000");

    recognizer = SpeechRecognizer.createSpeechRecognizer(this);
    recognizer.setRecognitionListener(this);
    recognizer.startListening(intent);
}
```

Practice 8. 1 Speech Recognition and Print Texts Using Android

- Using SpeechRecognizer service

```
@Override
public void onResults(Bundle results) {
    ArrayList<String> words = results.getStringArrayList(SpeechRecognizer.RESULTS_RECOGNITION);

    String text = "";

    for (String word : words) {
        text += word + " ";
    }

    textViewResults.setText(text);

    //recognizer.stopListening();
    //recognizer.startListening(intent);
}
```

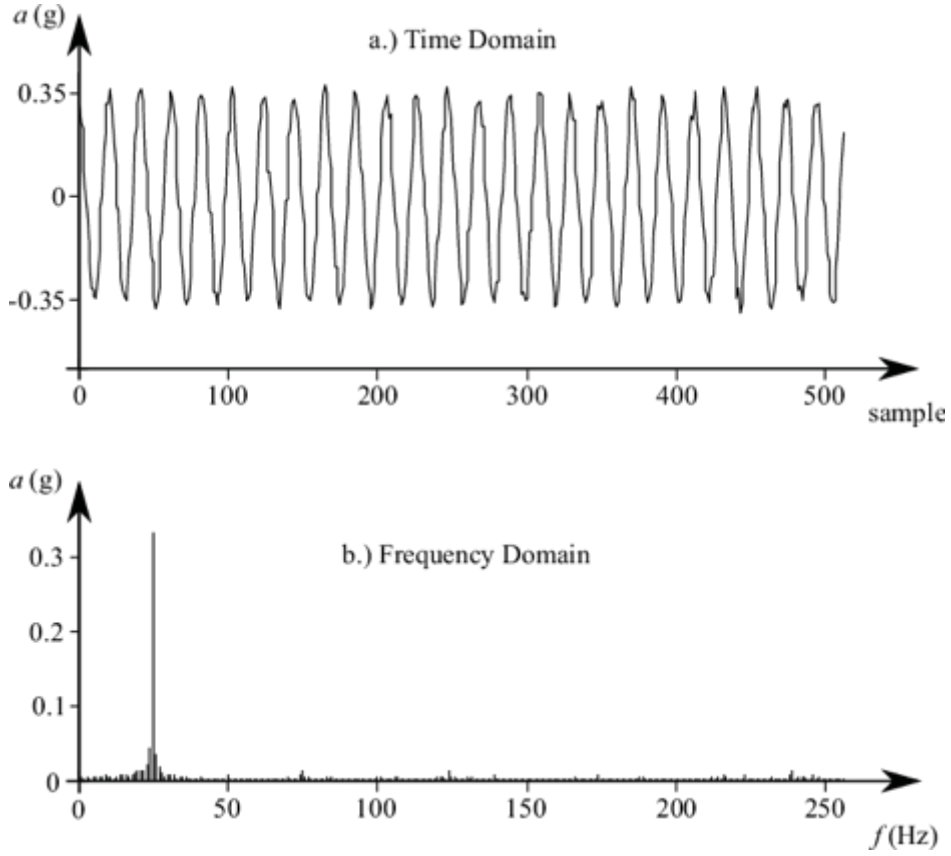
COMP.5650/4150.201
Internet of Things
Lecture 8.3: Sensor Signal Processing

Instructor
Mohammad Arif Ul Alam

Sensor Signals Two Types

- Time Domain
- Frequency Domain

Example: Accelerometer



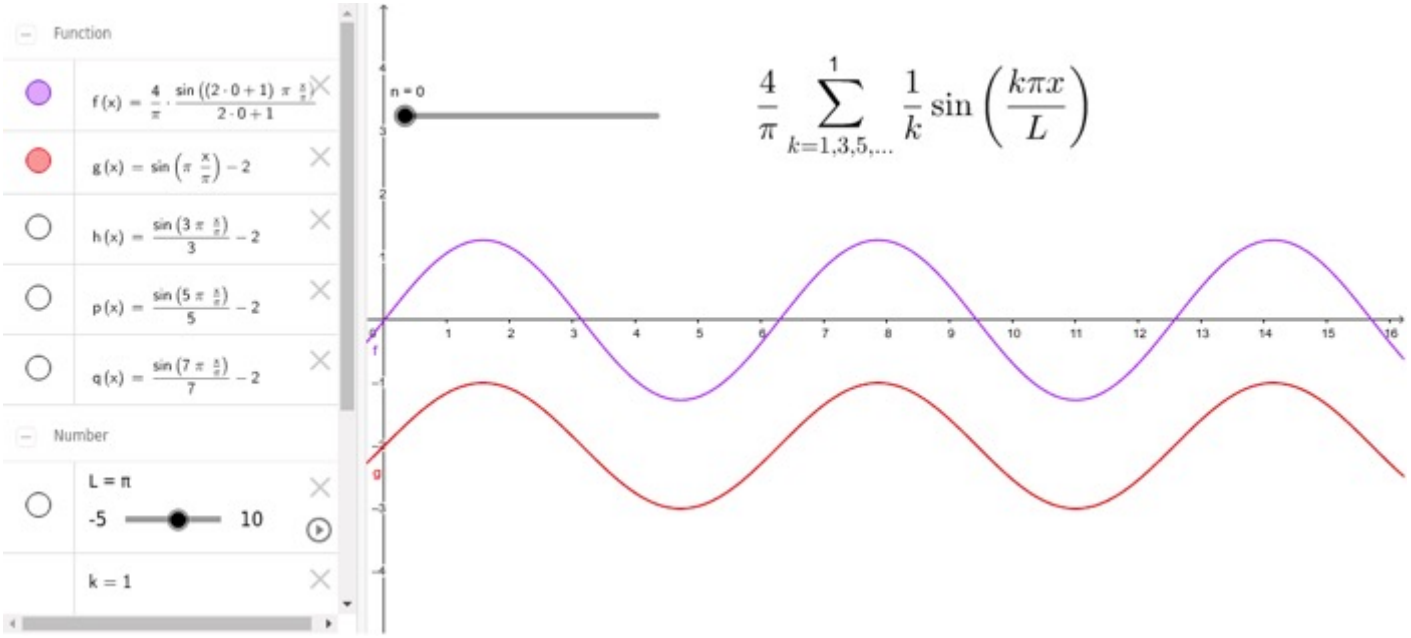
Transform Time Domain to Frequency Domain

- Fourier transform – nonrepetitive signals, transients.
- Laplace transform – electronic circuits and control systems.
- Z transform – discrete-time signals, digital signal processing.
- Wavelet transform — image analysis, data compression.

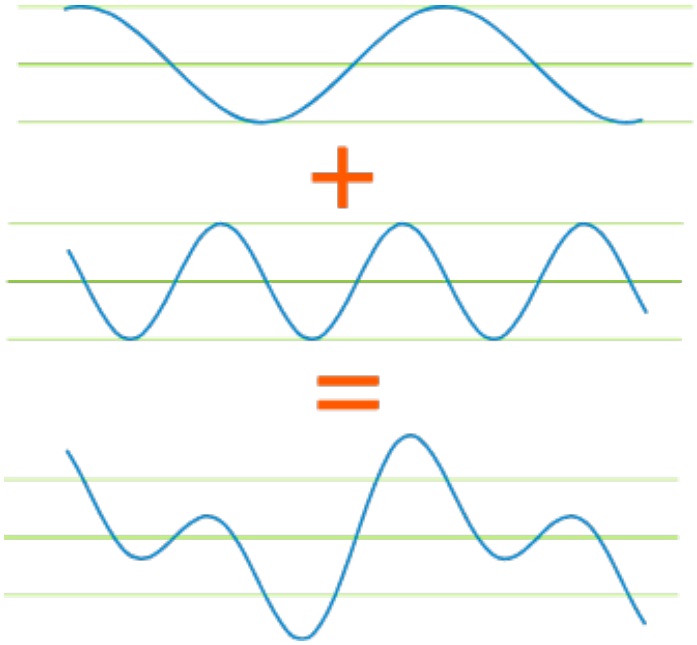
Fourier Series

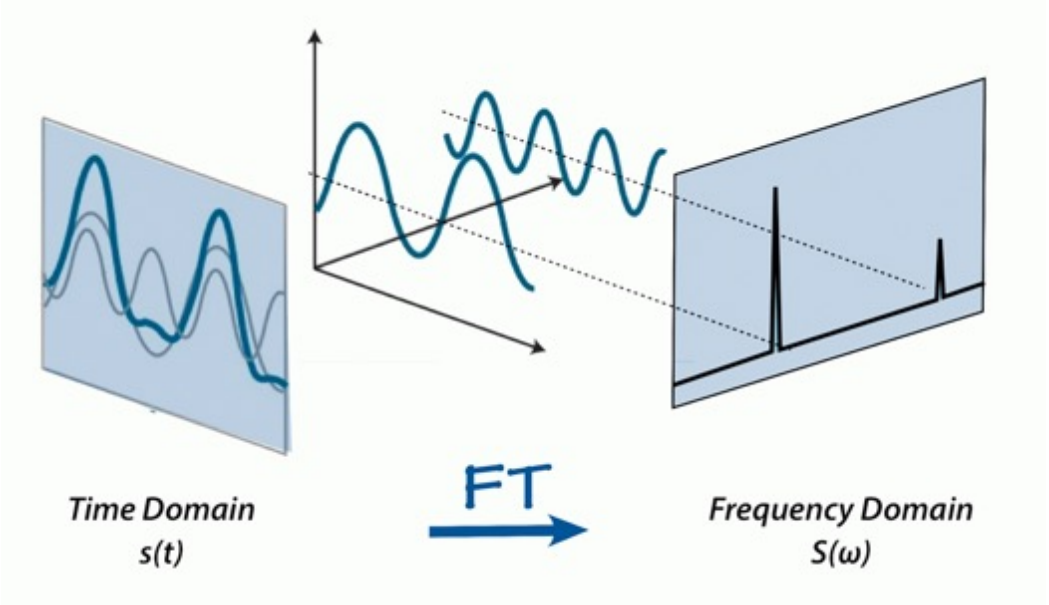
Fourier Series

- A series of sinusoidal signals



Fourier Transform

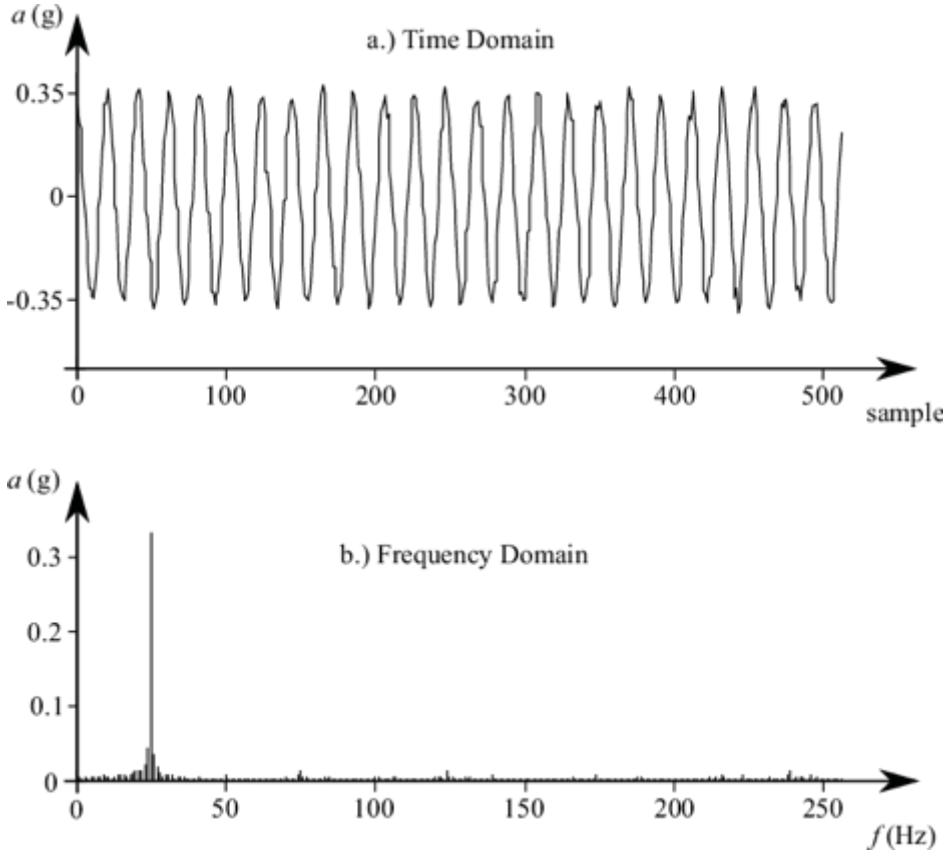




Accelerometer Frequency Domain Transform

- Time Domain
- Frequency Domain

Example: Accelerometer



Pass Filters

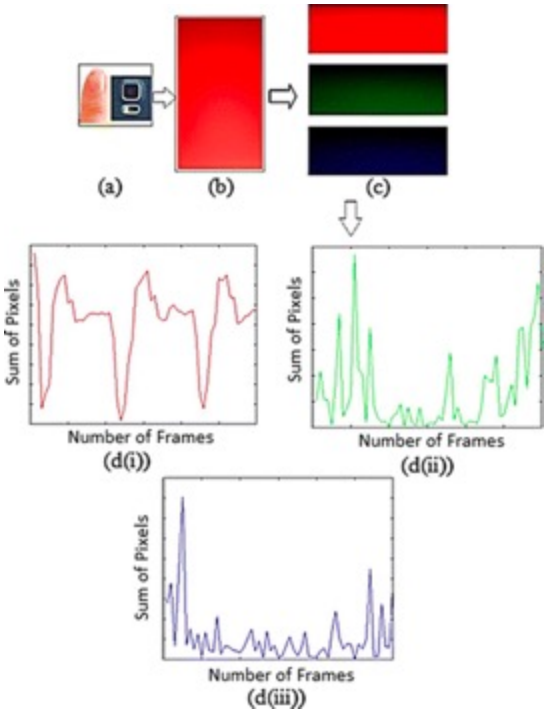
- Low pass filter
  - A low-pass filter (LPF) is a filter that passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency.
- High pass filter
  - A high-pass filter (HPF) is an electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. The amount of attenuation for each frequency depends on the filter design.
- Band Pass filter
  - Band Pass Filters passes signals within a certain "band" or "spread" of frequencies without distorting the input signal or introducing extra noise. This band of frequencies can be any width and is commonly known as the filters Bandwidth.

Usage

- Audio filter
  - Loud sound reduction, enhance small sounds, Audio amplifier
- Music filter
  - Instrument, voice separation
- Motion filter
  - Filter out large motion or small motion
- Noise reduction
  - Noises are unusual amplification or reduction of frequencies (in general)

Demo: Smartphone Camera Based Heart Rate Detection

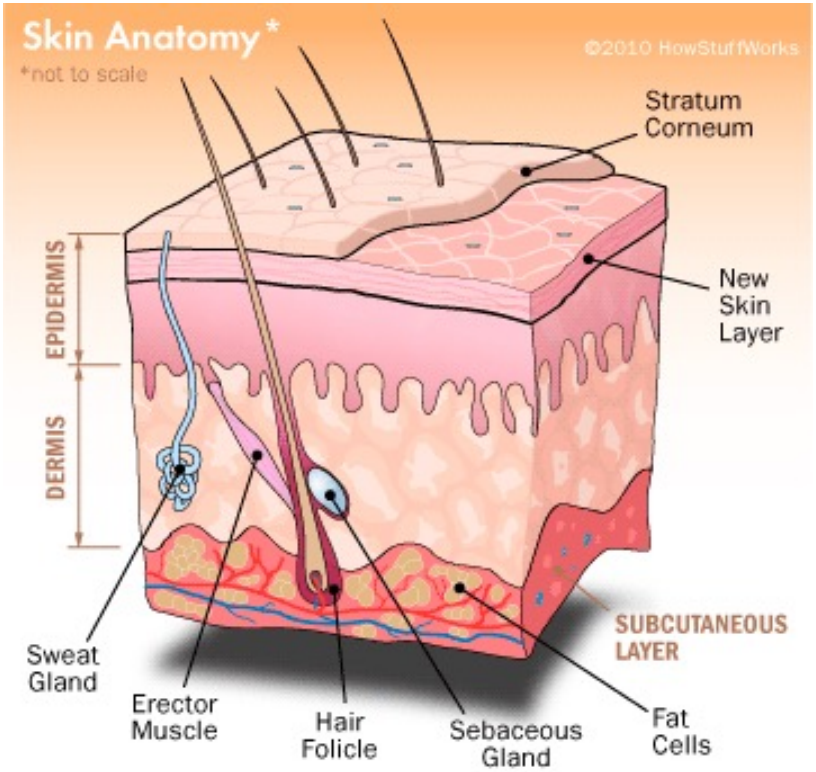
Demo: Smartphone Camera Based Heart Rate Detection



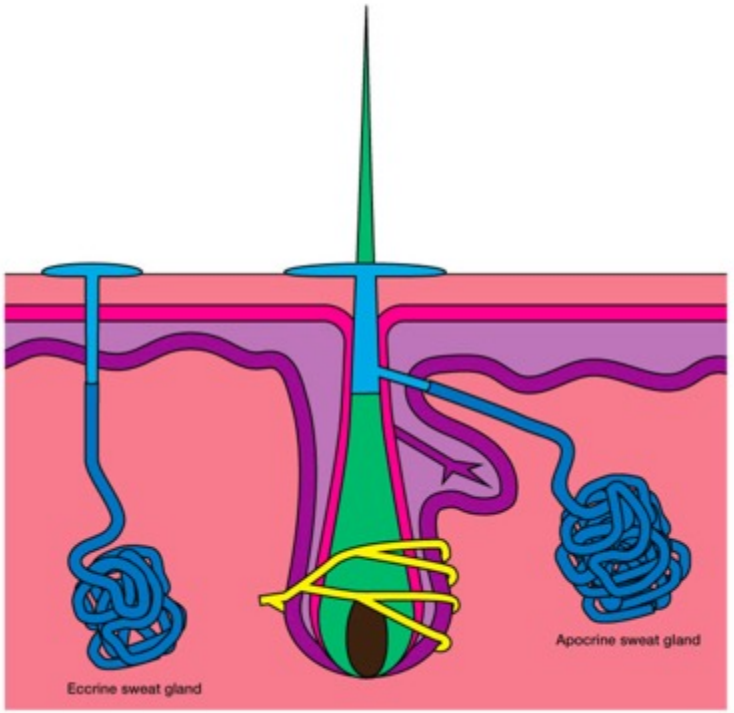
COMP.5650/4150.201
Internet of Things
Lecture 8.4: EDA and PPG

Instructor
Mohammad Arif Ul Alam

Skin Anatomy

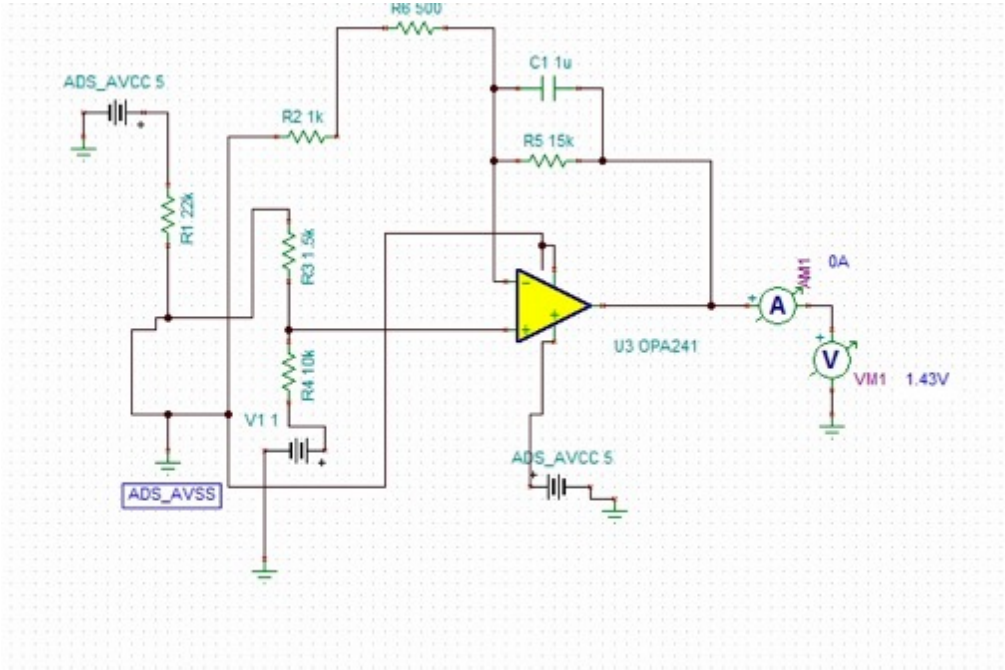


Some brain events (arousal) stress, depression, seizure



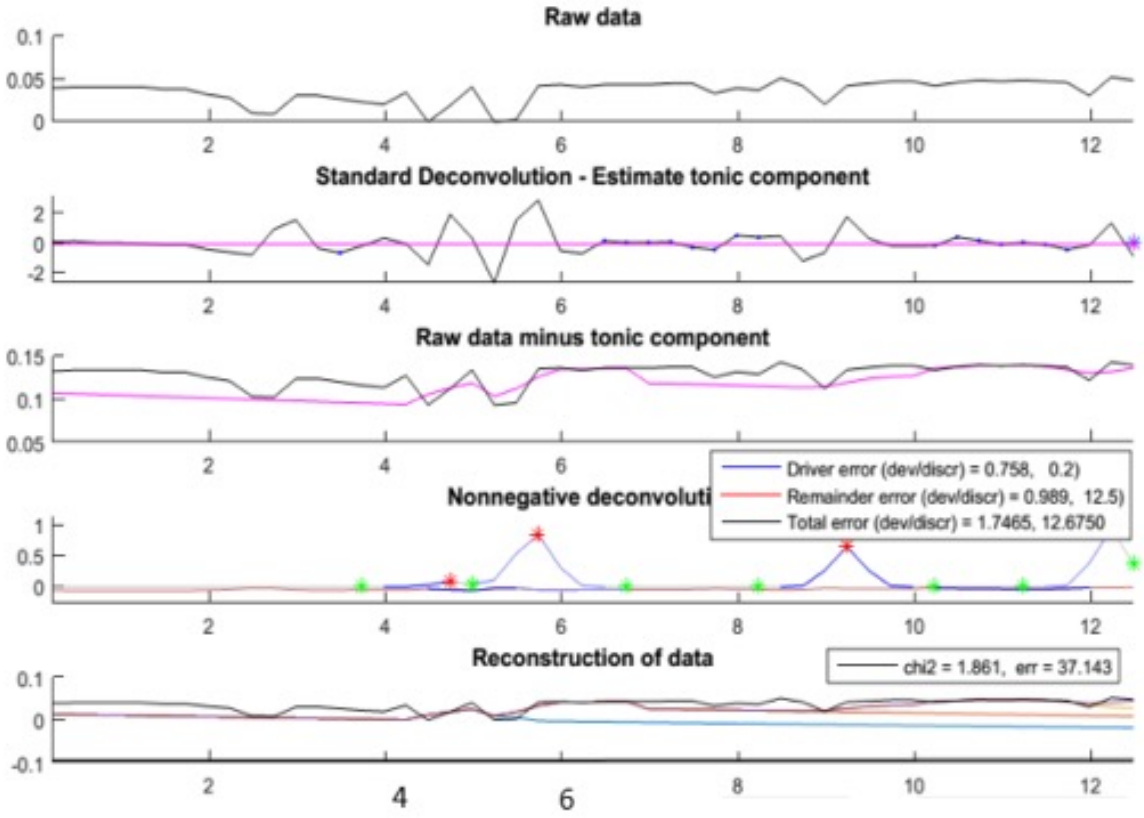
Electrodermal Activity

- Increase water level, increase conductance
- Electrodermal Response
- Voltage and Amplitude
- Quantified as Amplitude
  - Micro Siemense



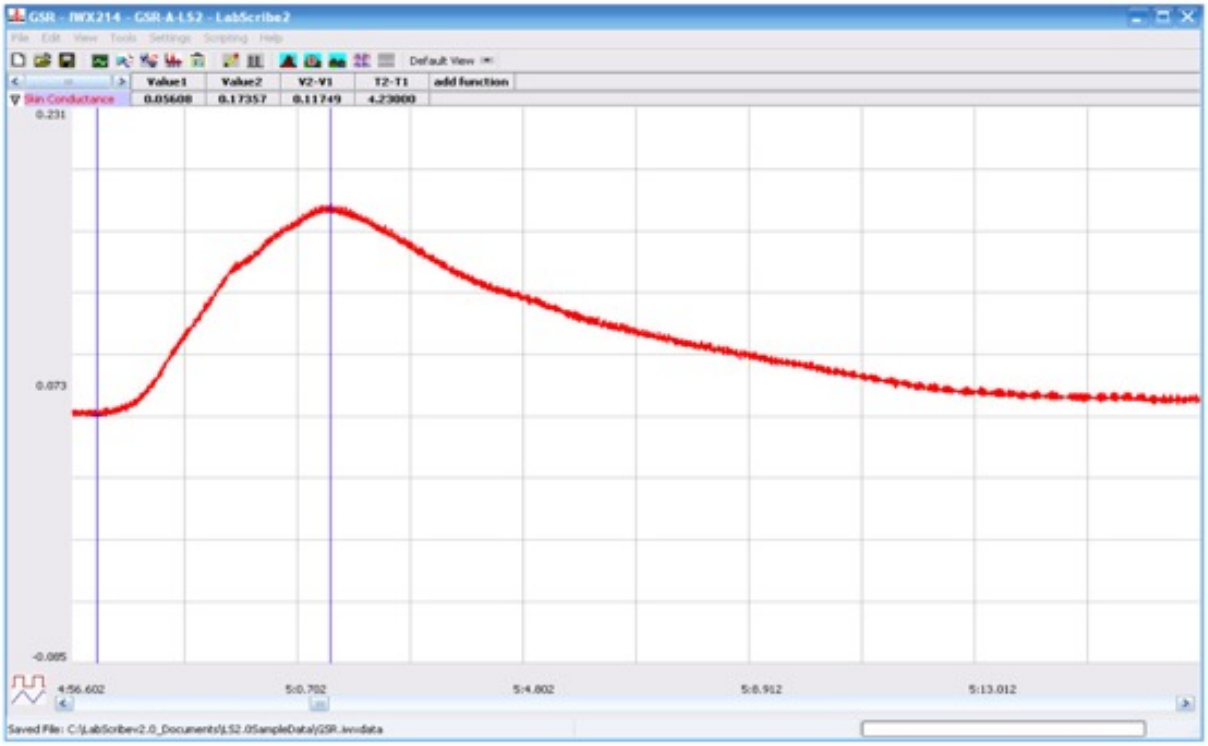
Electrodermal Activity

- Amplitude
  - Difference between tonic and Skin conductance

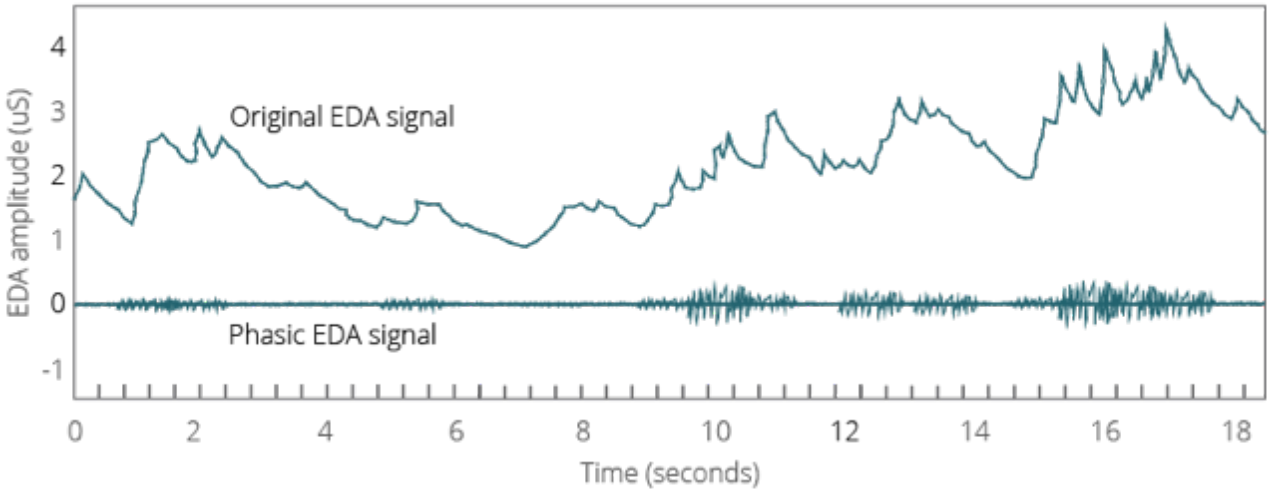


Electrodermal Activity

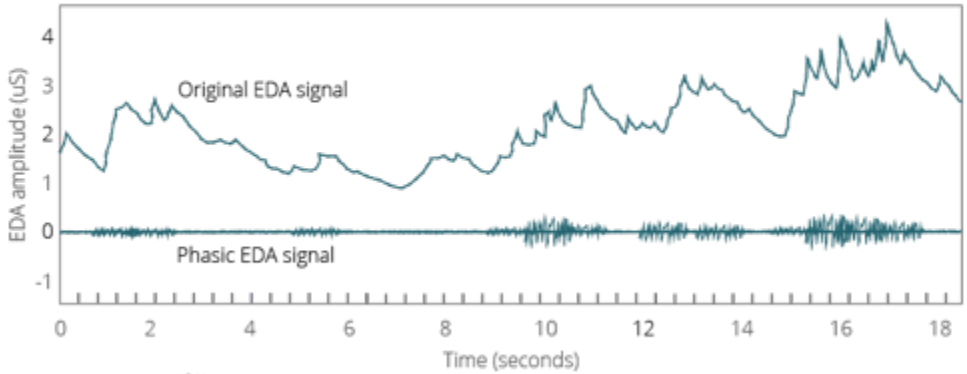
- Amplitude
  - Difference between tonic and Skin conductance
- Tonic 7.5 microS
- Amplitude 2.12 microS
- Arousal
  - Local Maxima

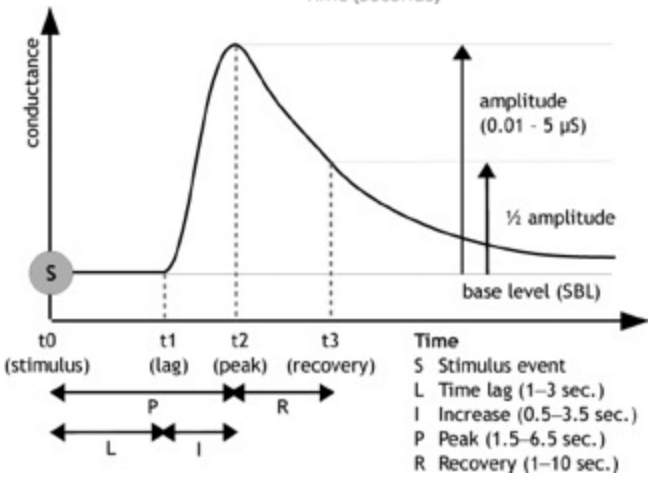


Electrodermal Activity

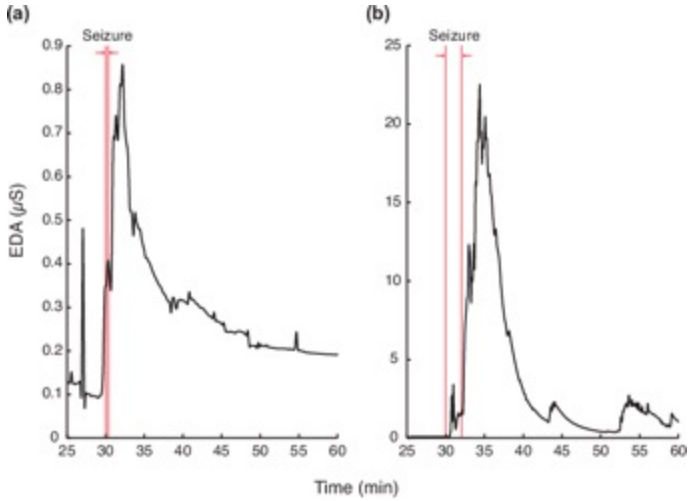


Electrodermal Activity



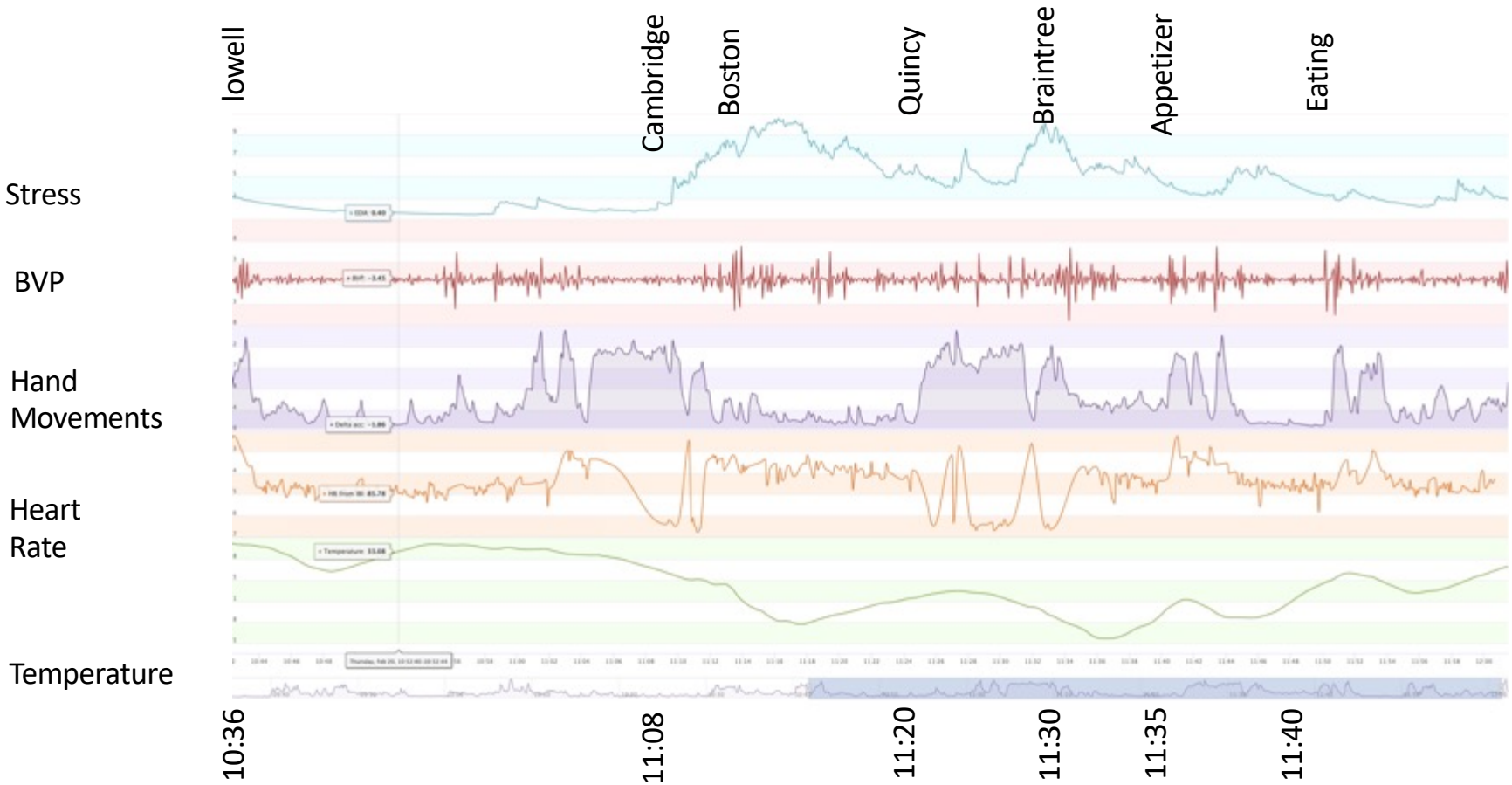


Electrodermal Activity (Usage)

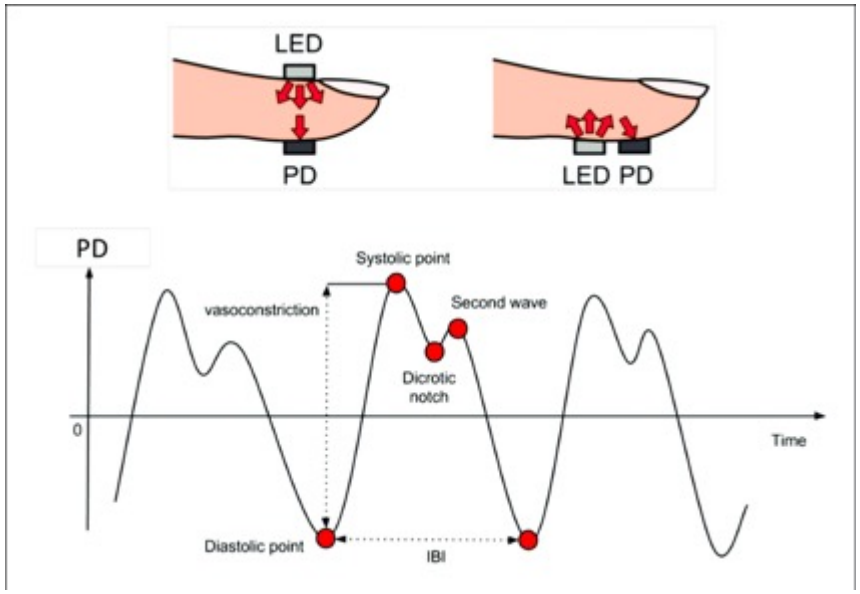


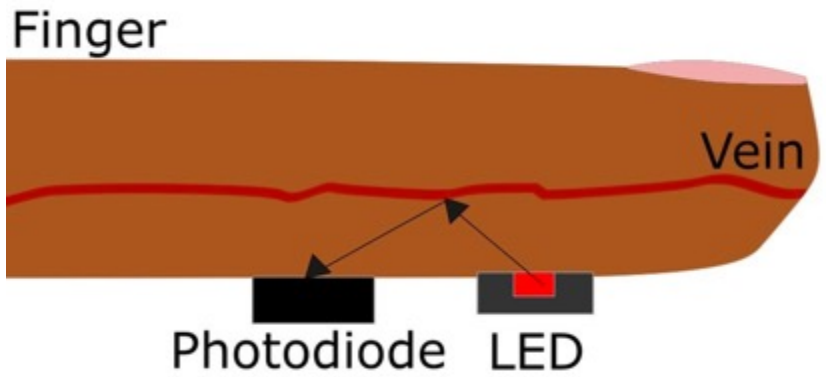
Epileptic Seizure Detection Real-time

My Stress Assessment to join a Party in BrainTree

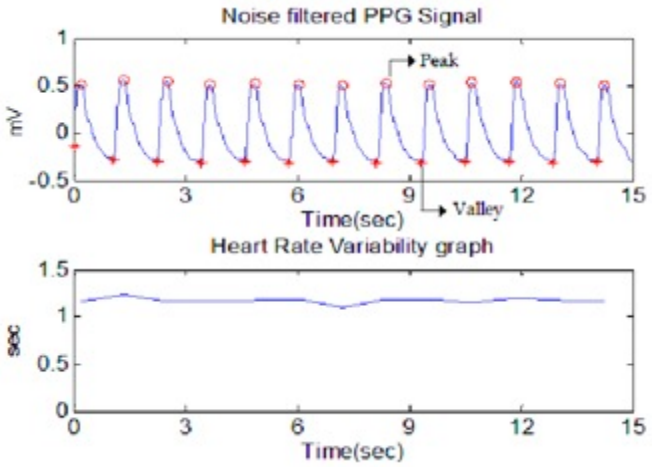


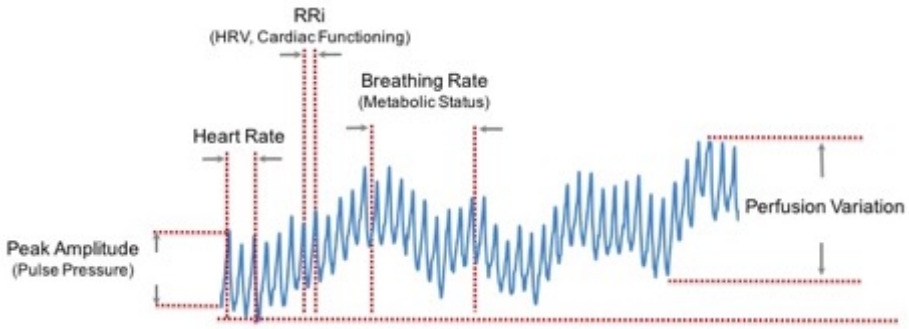
PPG : Photoplethysmography



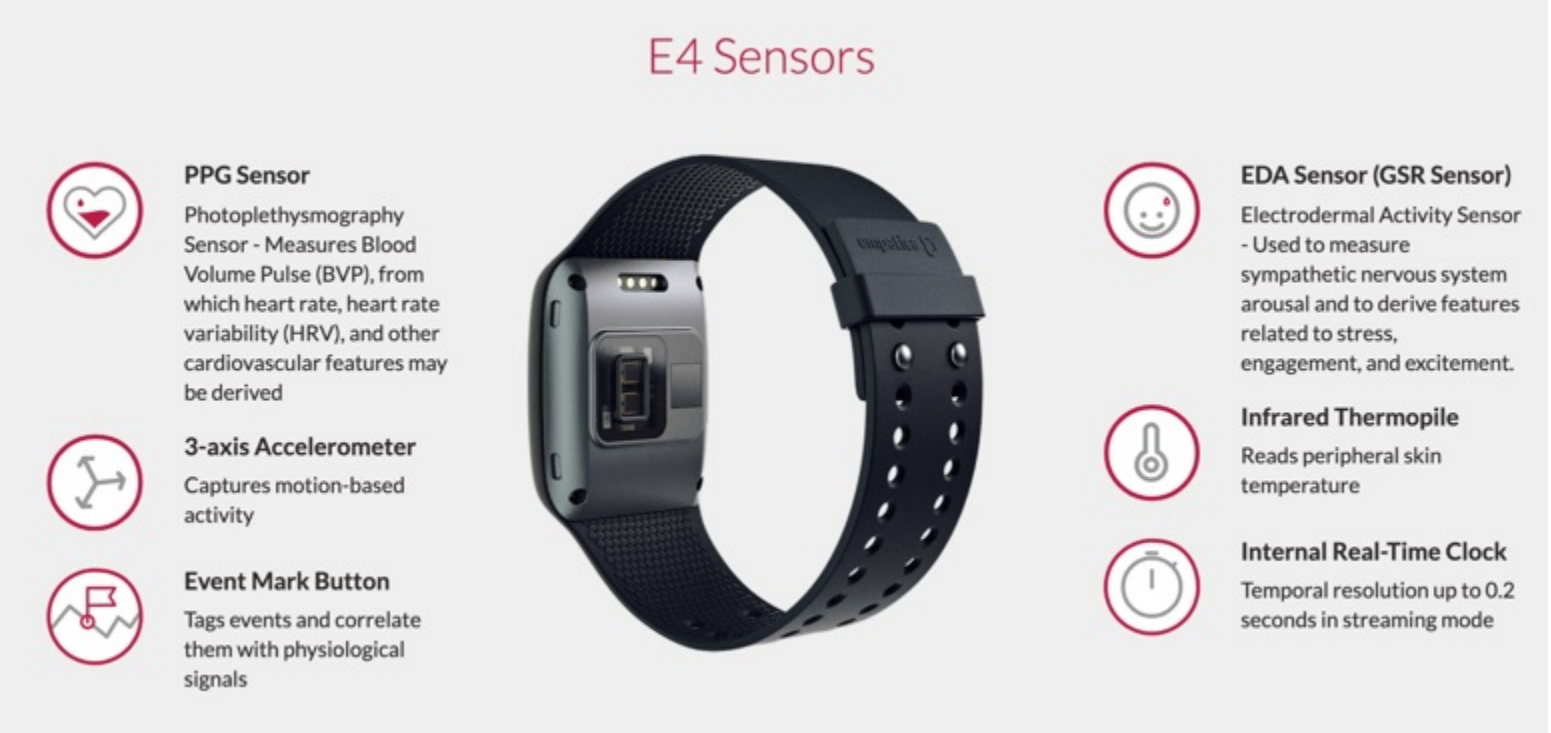


PPG : Photoplethysmography

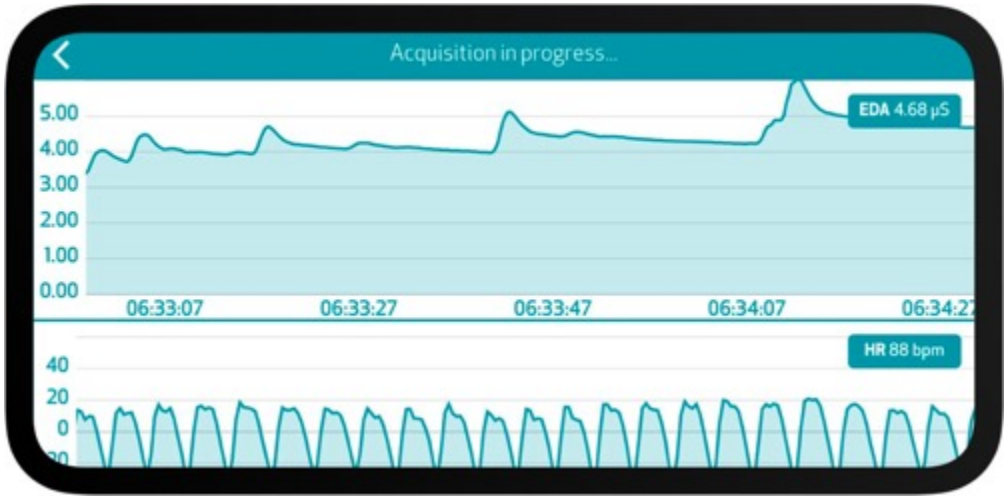


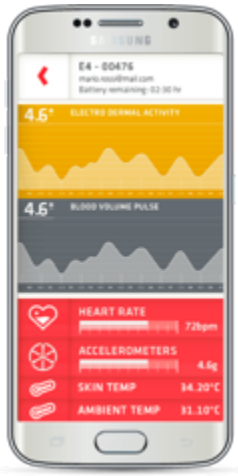


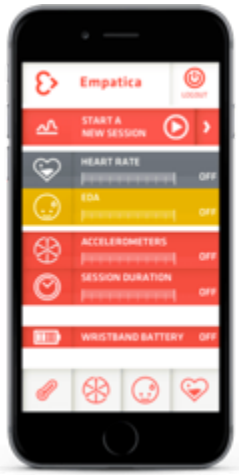
Empatica E4


E4 Sensors
PPG Sensor
Photoplethysmography Sensor - Measures Blood Volume Pulse (BVP), from which heart rate, heart rate variability (HRV), and other cardiovascular features may be derived
3-axis Accelerometer
Captures motion-based activity
Event Mark Button
Tags events and correlate them with physiological signals
EDA Sensor (GSR Sensor)
Electrodermal Activity Sensor - Used to measure sympathetic nervous system arousal and to derive features related to stress, engagement, and excitement.
Infrared Thermopile
Reads peripheral skin temperature
Internal Real-Time Clock
Temporal resolution up to 0.2 seconds in streaming mode

Empatica E4


Acquisition in progress...
EDA 4.68 µS
5.00
4.00
3.00
2.00
1.00
0.00
06:33:07
06:33:27
06:33:47
06:34:07
HR 88 bpm
40
20
0


HEART RATE
ACCELEROMETERS
SKIN TEMP
AMBIENT TEMP


Empatica
START A NEW SESSION
HEART RATE
EDA
ACCELEROMETERS
SESSION DURATION
WRISTBAND BATTERY

Empatica E4 Data

- ACC.csv - Data from 3-axis acceleometer sensor in the range [-2g, 2g]. (sampled at 32 Hz)
- BVP.csv - Data from photoplethysmograph (PPG). (sampled at 64 Hz)
- EDA.csv - Data from the electrodermal activity sensor in µS. (sampled at 4 Hz)
- IBI.csv - Inter beat intervals. (intermittent output with 1/64 second resolution)
- TEMP.csv - Data from temperature sensor expressed degrees on the Celsius (°C) scale (sampled at 4 Hz)
- HR.csv - This file contains the average heart rate values, computed in spans of 10 seconds
  More details here: E4 data - HR.csv explanation
- info.txt - Descriptions of the files

Empatica E4 Usage

- Sleep monitoring
- Stress monitoring
- Emotional arousal
- Stress level of dementia
- Memory loss detection
- Autonomic Dysfunction and Autism
- Epileptic seizure monitoring

COMP.5650/4150.201
Internet of Things
Lecture 8.5:
Electroencephalogram (EEG)

Instructor
Mohammad Arif Ul Alam

Why Measure the EEG ?

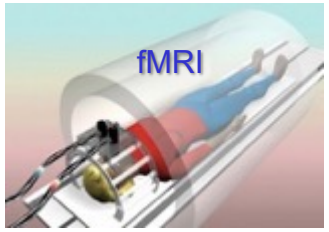
The greatest advantage of EEG is its **temporal resolution**. EEG can determine the relative strengths and positions of electrical activity in different brain regions.

According to R. Bickford (1987) research and clinical applications of the EEG in humans and animals are used to:

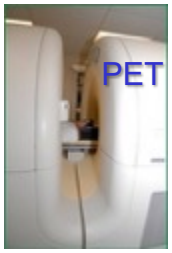
(1)monitor alertness, coma and brain death;
(2)locate areas of damage following head injury, stroke, tumor, etc.;
(3)test afferent pathways (by evoked potentials);
(4)monitor cognitive engagement (alpha rhythm);
(5)produce biofeedback situations, alpha, etc.;
(6)control anesthesia depth ("servo anesthesia");
(7)investigate epilepsy and locate seizure origin;
(8)test epilepsy drug effects;
(9)assist in experimental cortical excision of epileptic focus;
(10)monitor human and animal brain development;
(11)test drugs for convulsive effects;
(12)investigate sleep disorder and physiology.

R.D. Bickford. Electroencephalography. In: Adelman G. ed. *Encyclopedia of Neuroscience*, 371-3, 1987.
M. Teplan, Fundamental of EEG Measurement, In: *Measurement Science Review*, 2, 2002.

Current Neuroimaging Modalities



Functional magnetic resonance imaging

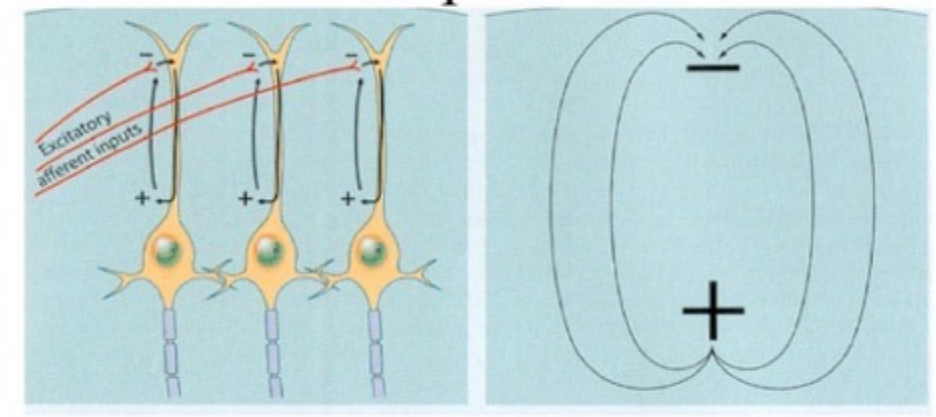


Positron emission tomography

Magnetoencephalography

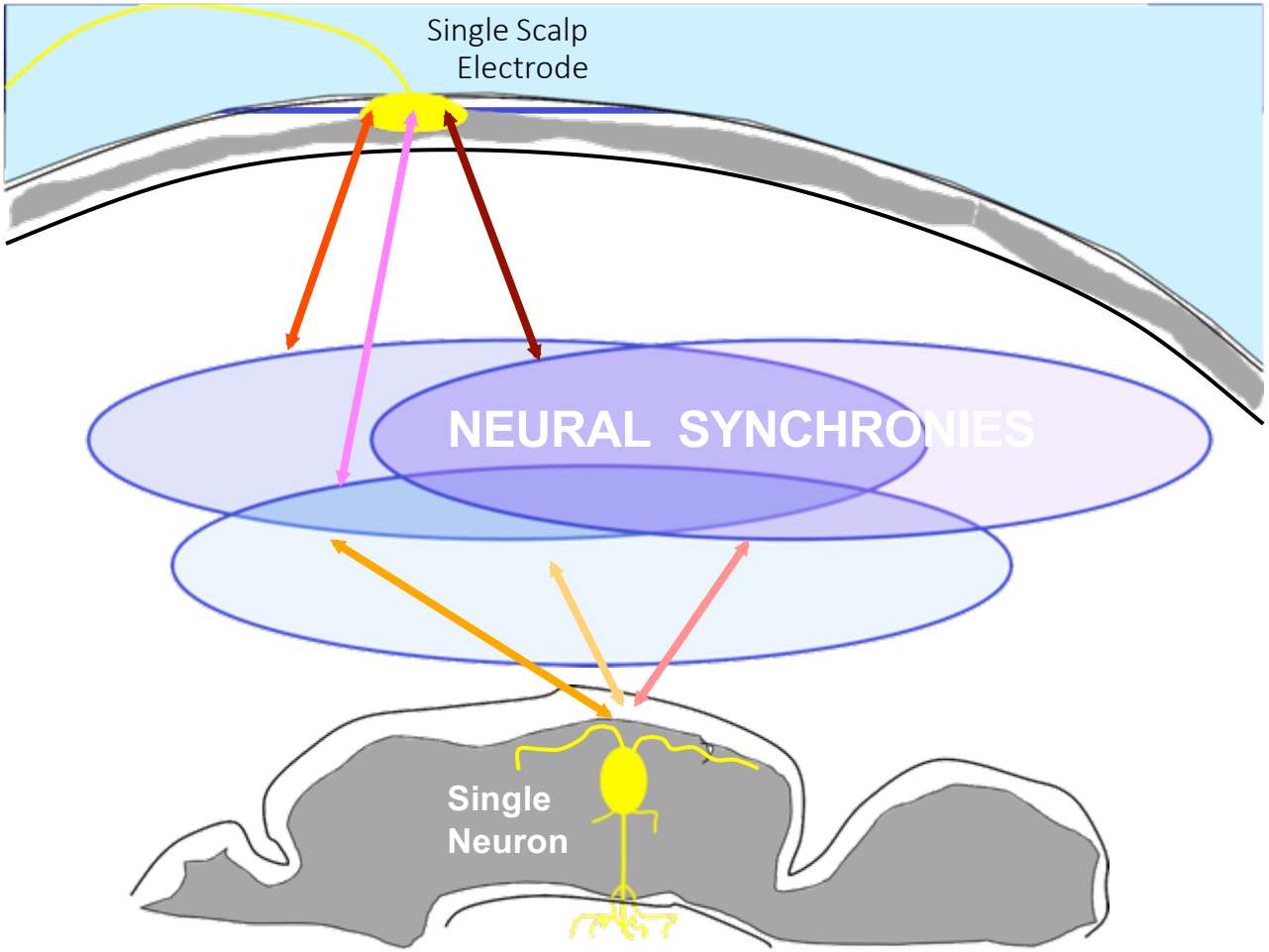
- In all modalities but EEG, the sensors are heavy.
- EEG is the only modality that does not require the head/ body to be fixed.
- EEG might enable the monitoring of the brain functions of unconstrained participants performing normal tasks in the workplace and home.

Dipoles



- When neurons are activated, local currents are produced.
- EEG measures the current that flow during the excitations of the dendrites of many pyramidal neurons in the cerebral cortex.
- Potential differences are caused by summed postsynaptic potentials from pyramidal cells that create diploes between soma and apical dendrites.
- Necessary conditions: Aligned neurons and synchronous activity.

Figure is from Gazzaniga et al., *Cognitive Neuroscience: The biology of the mind Norton and Company*, 2009.


Single Scalp
Electrode
NEURAL SYNCHRONIES
Single
Neuron

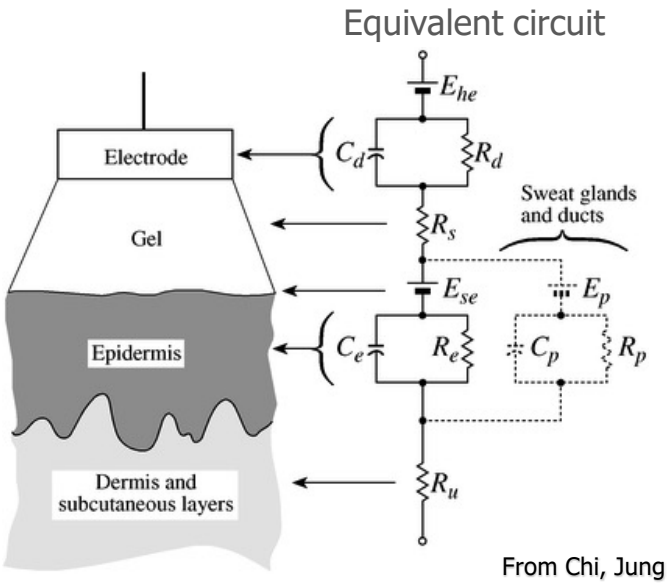
EEG Acquisition

- Electrode caps, conductive jelly, ruler, injection and aid for disinfection.
- EEG amplifier unit, PC/laptop

EEG Electrodes

In common applications, EEG signals are measure by an electrode with electrolyte gel placed directly on the skin.

The coupling between skin and electrode can be described as a layered conductive and capacitive structure, with series combinations of parallel RC elements.

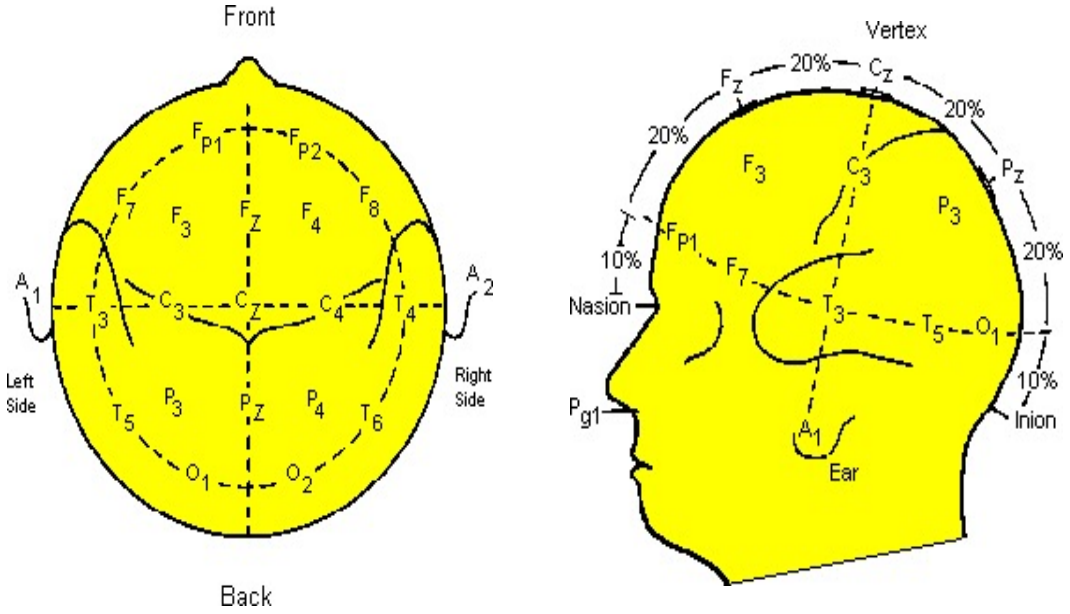


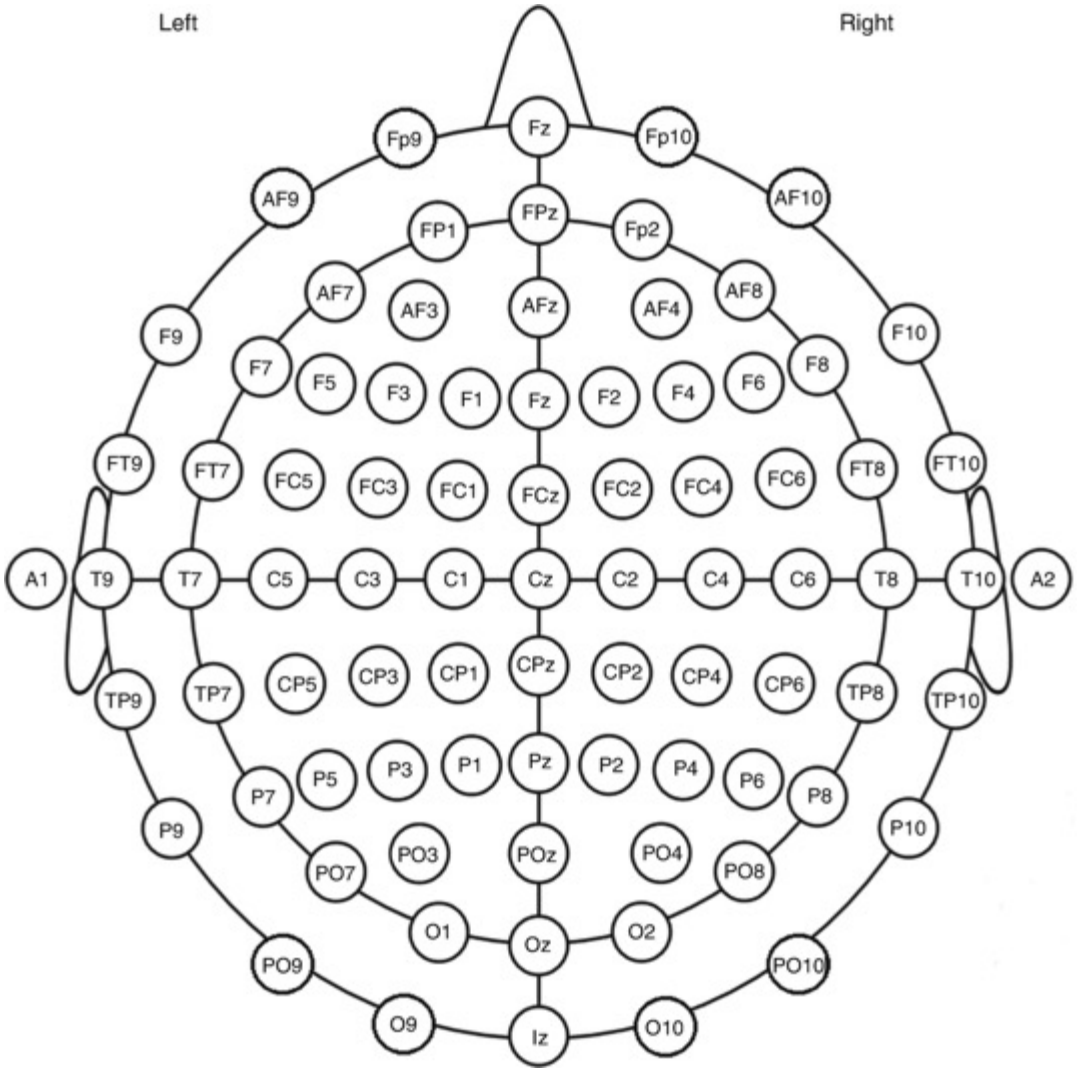
From Chi, Jung & Cauwenberghs, 2010.

Wearable EEG Devices

EEG Montage

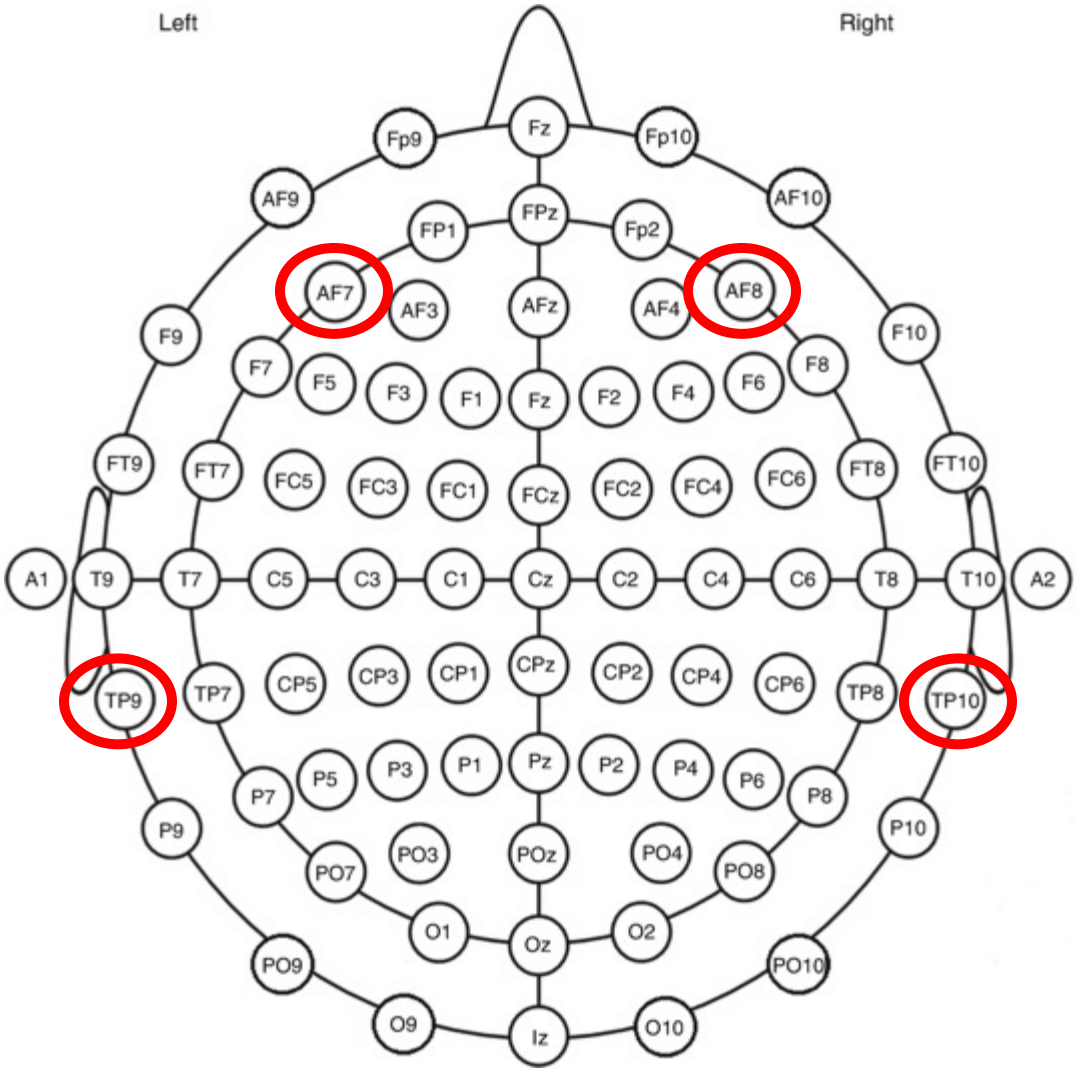
International 10-20 system





MUSE EEG

TP9, AF7, AF8, TP10



MUSE EEG

TP9, AF7, AF8, TP10

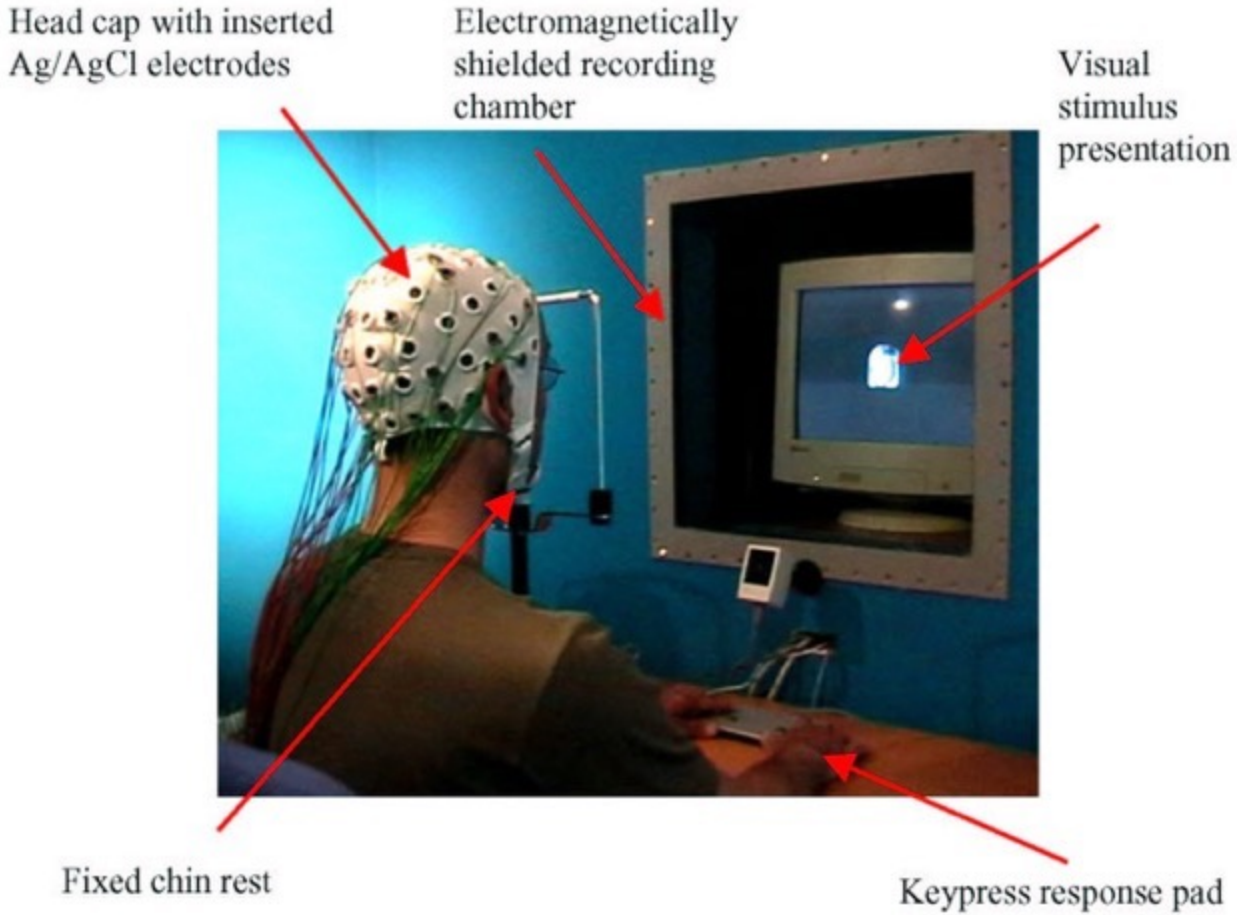
What EEG/ERPs Can and Cannot Tell Us About Brain Functions

CAN

- Precise timing of neural activity
- Sequence of mental operations

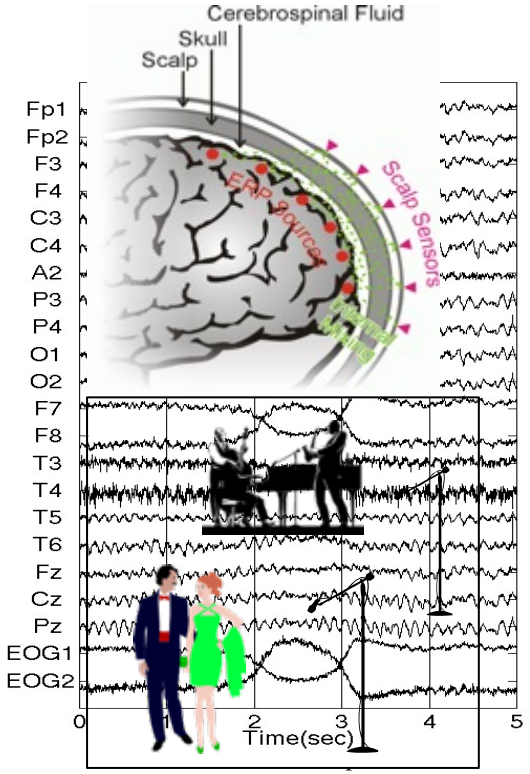
CANNOT

- Precise brain location of neural activity


Head cap with inserted Ag/AgCl electrodes
Electromagnetically shielded recording chamber
Visual stimulus presentation
Fixed chin rest
Keypress response pad

Challenges of EEG Analysis

- Pervasive artifacts
- EEG recordings are mixtures of all brain activities arising from different networks
- Response variability
- Inverse problem
- others



Sensor Values

- Measurement Voltage fluctuations of brain activity

- Frequency of EEG signals range from 0.01 Hz to around 100 Hz
- Four Channels
- Four basic types of fluctuations/frequency bands

Table 1. Basic brain wave with their frequency.

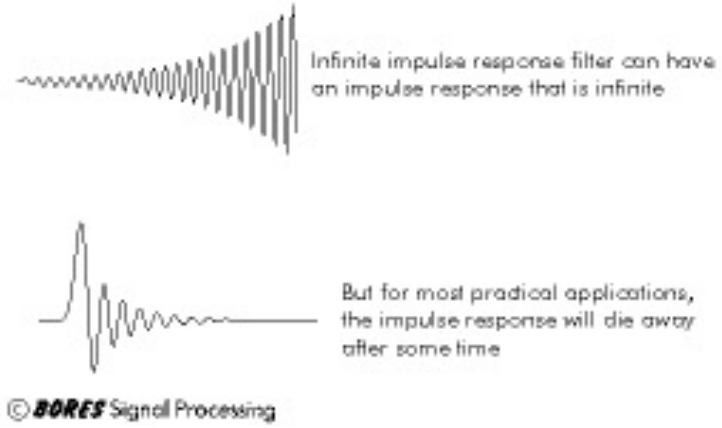
Band Name	Frequency (Hz)	Interpretation
Delta	<4	Deep sleep
Theta	4–8	Relaxed state and meditation
Alpha	8–13	Relaxed state of consciousness
Beta	13–30	active thinking

Artifacts Removal

- Ocular Artifacts
  - Blinking Eyes
- Muscle Artifacts
  - Muscle movements
  - Any muscle of body
- Cardiac Artifacts
  - Electrodes placed near blood vessels
- Extrinsic Artifacts
  - Any external artifacts such as sweating, wet, hair gel etc

Artifacts Removal (Filters)

- Infinite Impulse Response (IIR)
  - Cardiac Artifacts
- Moving Average
  - Smoothen any artifacts
- Band Pass filter
  - High band pass filter
    - Ocular
    - Extrinsic
  - Low band pass filter
    - Muscle movements

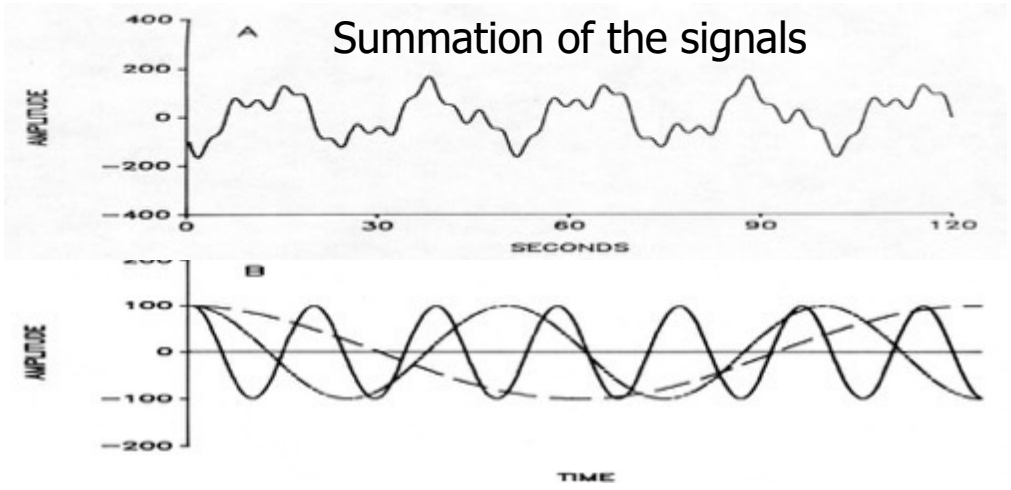


Feature Extraction

- Time Domain and Frequency Domain
- Time domain
  - Average, mean, median, maximum etc.

Frequency-domain Analysis of the EEG

- Joseph Fourier (1768-1830)
- Any complex time series can be broken down into a series of superimposed sinusoids with different frequencies.



Fourier Transform

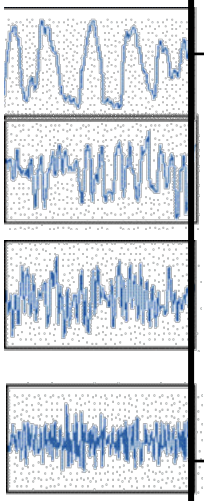
- Advantage:

For many signals, Fourier analysis is extremely useful because the signal's frequency content is of great importance.

- Disadvantage:

Fourier analysis has a serious drawback.
In transforming to the frequency domain, time information is lost.

Frequency-domain Analysis of the EEG



EEG Bands (Hz)	Distribution	Subjective feeling	Associated tasks & behaviors	Physiological correlates
Delta 0.1-3	Distribution: generally broad or diffused	deep, dreamless sleep, non-REM sleep, unconscious	lethargic, not moving, not attentive	not moving, low-level of arousal
Theta 4-8	usually regional, may involve many lobes	intuitive, creative, recall, fantasy, imagery, creative, dreamlike, drowsy	creative, intuitive; distracted, unfocused	healing, integration of mind/body
Alpha 8-12	regional, usually involves entire lobe	relaxed, not agitated, but not drowsy	meditation, no action	relaxed, he

Time-Frequency Analysis of the EEG

- We often apply a 'window' to the data.
- This simply means taking the amount we want from the data stream
- ie

The window is moved along the data; we perform the FFT on this windowed data

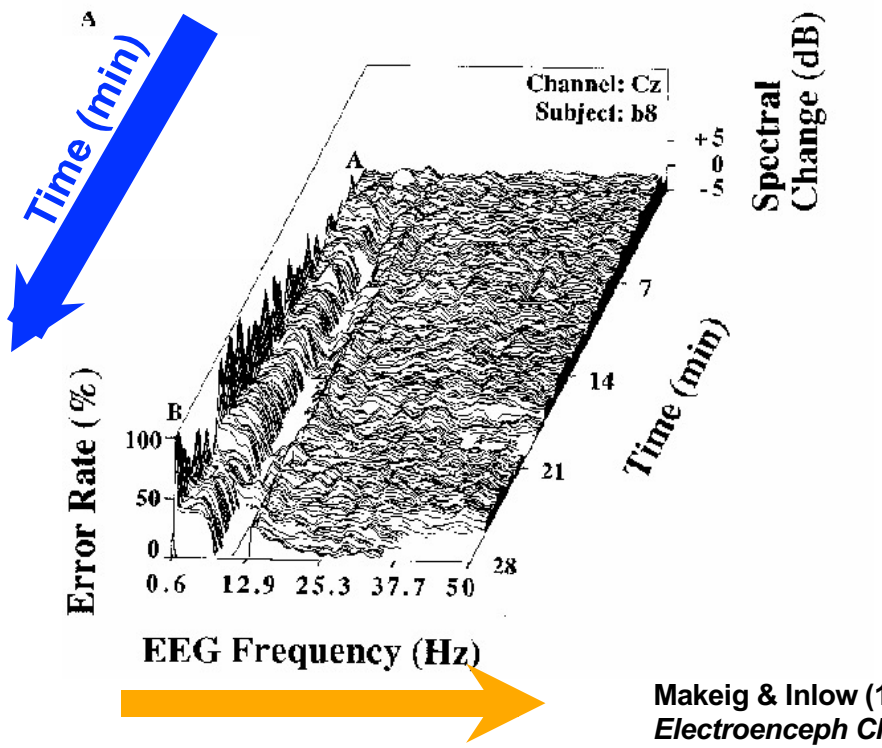
Time-Frequency Analysis of the EEG

- Four channels of EEG signal
  - double[][] rawEEG
  - rawEEG[][0-3]
  - TP9, AF7, AF8, TP10
- Extract Bands
  - Suppose you want to extract 6 bands features for each channel
    - BAND = {1, 4, 8, 12, 18, 30, 45};
  - BandPassFilter(rawEEG, SampleRate, WindowSize, Num_Band)
    - returns 24 (6 x 4) features

    https://github.com/zhijiee/MuseEEGClassifier/blob/master/app/src/main/java/controllers/SVMController/SVM_Helper.java

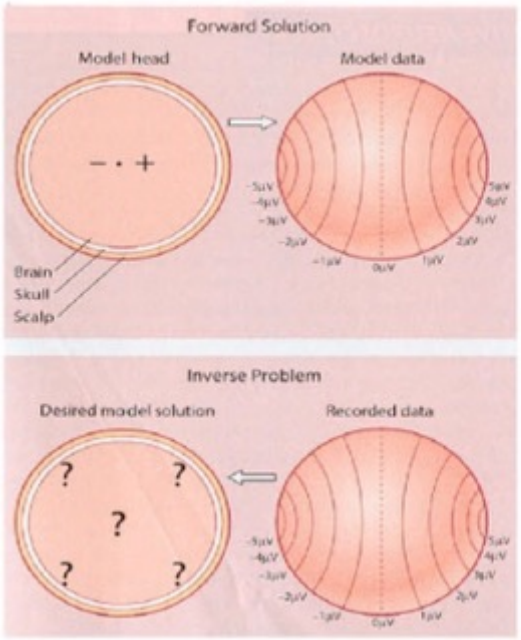
https://imotions.com/blog/eeg/

Time-Frequency Analysis of the ***EEG***



Makeig & Inlow (1993)
Electroenceph Clin Neuro

Forward Solution and Inverse Problem



A single pattern of neural activity will produce a unique scalp map

BUT …A single scalp map could have been produced by an infinite number of patterns of neural activity

Figure is copied from Gazzaniga et al., *Cognitive Neuroscience: The biology of the mind Norton and Company*, 2009.

Thank You