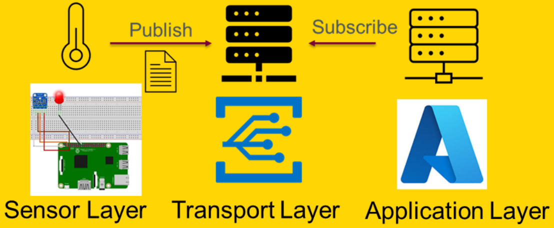
IoT Sensor Data Analytics and Smart Health Systems

Omar Boursalie, Ph.D.



Mock Lecture

Lecture Slides, Code, and Data:
https://github.com/OBoursalie/SMRTTECH_4HM3

Land Acknowledgement

I take this time to recognize that McMaster University is currently on the traditional territory shared between the Haudenosaunee confederacy and the Anishinabe nations, which was acknowledged in the Dish with One Spoon Wampum belt.

That wampum uses the symbolism of a **dish to represent the territory**, and **one spoon to represent that the people** are to **share the resources** of the land and only take what they need.

https://www.torontomu.ca/aec/land-acknowledgment/

https://healthsci.mcmaster.ca/docs/librariesprovider59/resources/mcmaster-university-land-acknowledgment-guide.pdf?sfvrsn=7318d517_2

My Journey

Omar Boursalie, B.Eng, M.A.Sc., Ph.D.

You Are Here

- 1991: Born (at McMaster Hospital!)
- 2009-2014: **Undergraduate** Electrical, Computer, and Biomedical Engineering (McMaster)
  - 2012-2013: 12-Month co-op Instructional Assistant Intern (IAI) for 1C03 (McMaster)
- 2014-2016: M.A.Sc. Biomedical Engineering (McMaster)
- 2016-2021: Ph.D. Biomedical Engineering (McMaster)
  - Artificial intelligence in healthcare
- 2022-2023: Postdoctoral Fellow (Toronto Metropolitan University)
  - Sessional Instructor (Winter 2022): Electrical and Computer Engineering (McMaster)
- 2023-now: Assistant Professor in Mechanical Engineering and the iBioMed Program (McMaster)
- My Goal: Teaching Professor Position

boursao@mcmaster.ca if you want to chat!
Meet with students, staff, and faculty 9:00 AM to 9:30 AM ETB 223

Lessons Learned

(Or what I wished I knew before I started)

- Co-op
  - Longer co-ops are easier to get then four month
  - Start looking early!
- Extracurricular projects
  - Your undergraduate courses are a starting point
  - Pick your favorite courses and use them as a launching board for your own side projects (e.g., Raspberry Pi)
  - Usually what you discuss in interviews
- Writing (especially if you are interested in doing graduate school)
  - Academic writing is an important skill
  - University has lots of free resources you can take advantage on your own
  - Classes may not require it but you can take courses and apply it to your labs on your own
- Mental Health
  - Importance of weekends and breaks

“IoT Sensor Data Analytics and Smart Health Systems”

Lecture Objectives

1. **Motivation**
2. IoT Layer I: Collection
3. IoT Layer II: Transmission
4. IoT Layer III: Processing
   - Signal Processing
   - Machine Learning
5. Where Should Processing Take Place?

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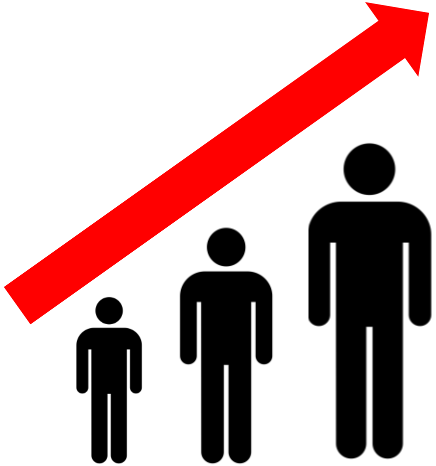
Textbook: m-Health: Fundamentals and Applications

Motivation

Challenges in Healthcare

Growing Population

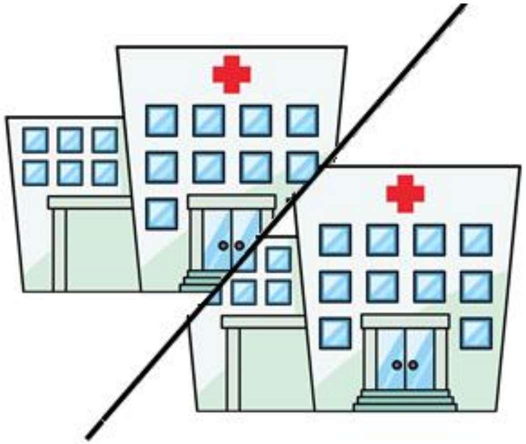


51 million by 2063
(Stats Canada, 2014)

Aging Population

25% of Population by 2036
(Stats Canada, 2016)

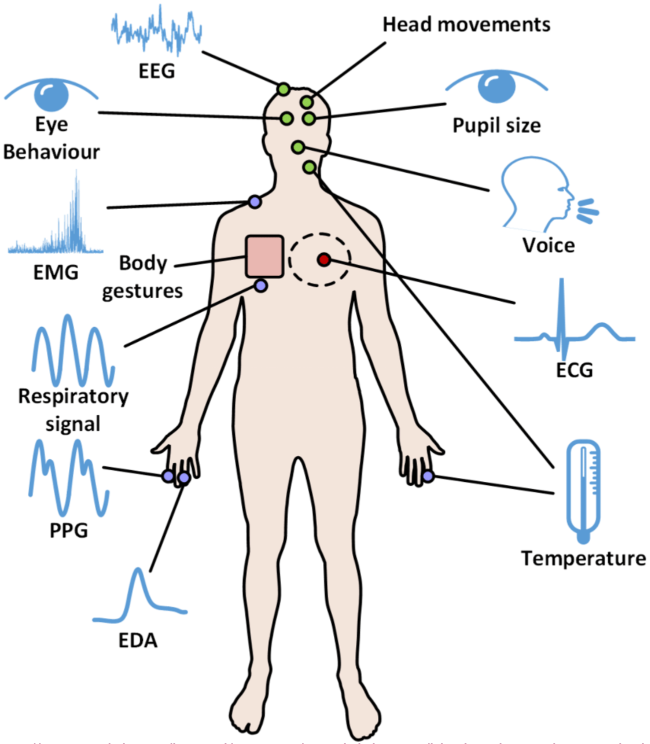
Medical resources not increasing fast enough



Length of stay for admitted patients was up 11% in 2018 (CIHI, 2018)

Motivation

Biomedical signals can be captured (mostly) non-invasively and used as indicators of overall health

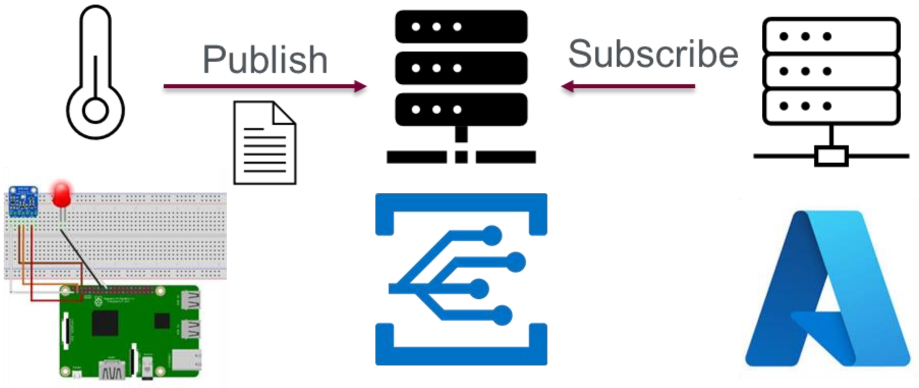


https://www.mdpi.com/journal/sensors/special_issues/biosignal_sensing_analysis

- Electroencephalogram (EEG)
- Electrooculogram (EOG)
- Electrocardiogram (ECG)
- Electromyogram (EMG)
- Photoplethysmogram (PPG)
- Electrodermal activity (EDA)

Internet of Things (IoT)

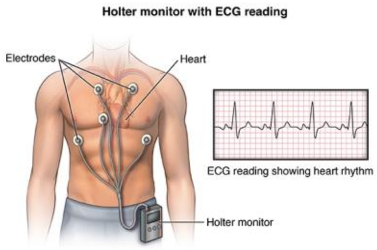
The Internet of Things (IoT) describes the network of physical objects—“things”—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet or other communications networks



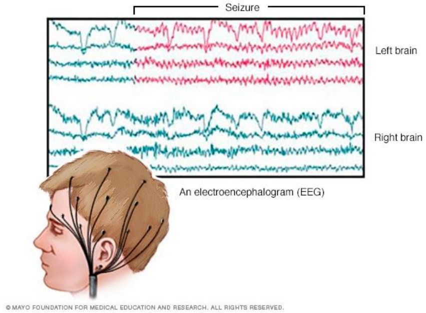
Data Collection Data Transmission Data Processing

IoT Sensor Data Analytics and Smart Health Systems

Screening
(e.g., Depression Voice Analysis)



Diagnosis
(e.g., ECG Holter Monitor)
https://www.hopkinsmedicine.org/health



Treatment
(e.g., EEG Brain Control Interface)
https://www.mayoclinic.org/tests-procedures/eeg/about/pac-20393875

Monitoring
(e.g., Apple Watch)
https://www.apple.com/ca/shop/buy-watch

Disease Management
(e.g., Blood Glucose)
https://www.cbc.ca/news/canada/edmonton/glucose-monitoring

Motivation

IoT Sensor Data Analytics

- Undergraduate Studies
  - PROCTECH 4TR1/3 - Capstone Design Project I/II
  - SMRTTECH 4AI3 – Artificial Intelligence and Machine Learning
  - PROCTECH 4MH3 – Machine Health and Remote Monitoring
  - SMRTTECH 4SC3 – Smart Cities and Communities
  - SMRTTECH 4ID3 – IoT Devices and Networks
  - GENTECH 4EP3 - Entrepreneurial Thinking and Innovation
- Graduate Studies
  - https://www.eng.uwo.ca/electrical/faculty/fang_f/index.html
  - https://www.eng.mcmaster.ca/research-innovation/research-clusters/digital-smart-systems/
  - SEP 769 – Cyber-Physical Systems
- Careers
  - Data Analytics, Network, Security, IoT Architect/ Developer, Cloud Computing
  - Cloud Solutions Architect – Internet of Things (IoT)
  - Connexall - Business and Data Analyst
- Start-ups
  - https://www.incorahealth.com/ (IoT Earrings)

“IoT Sensor Data Analytics and Smart Health Systems”

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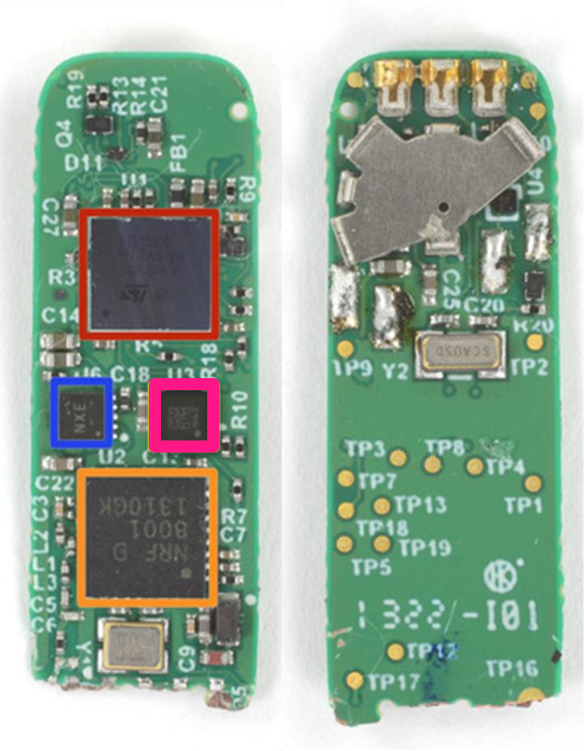
Textbook: m-Health: Fundamentals and Applications

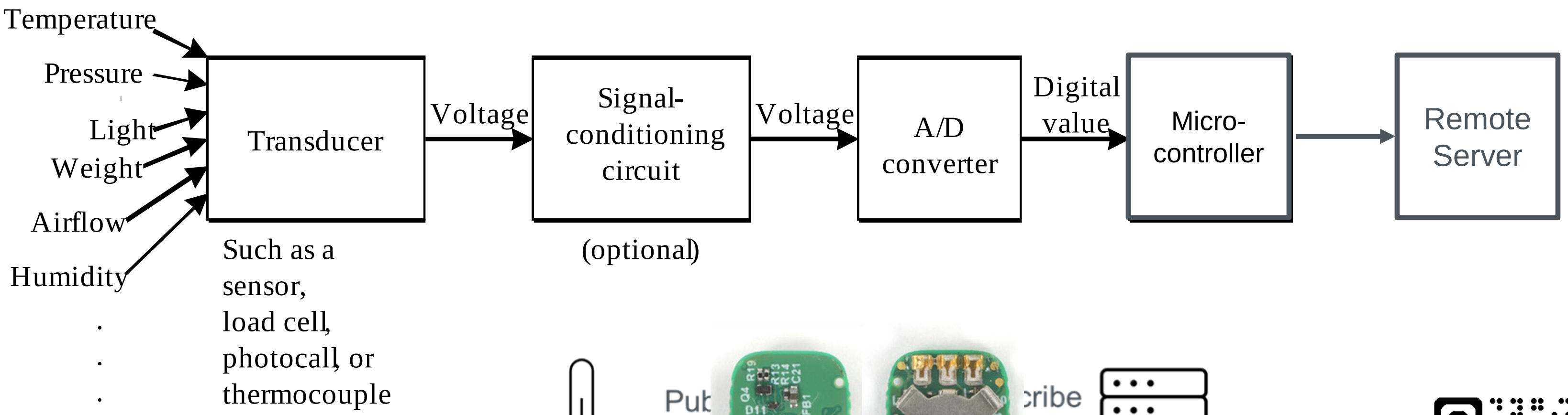
What Makes the Fitbit Tick?

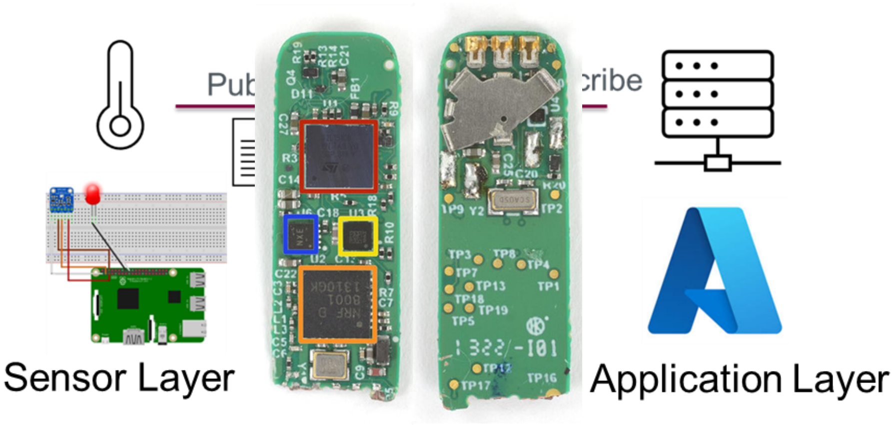


- Accelerometer
- Thermometer
- Microcontroller
- WiFi
- Charger

Acquiring Real-World Data

All IoT devices for data acquisition follow this process

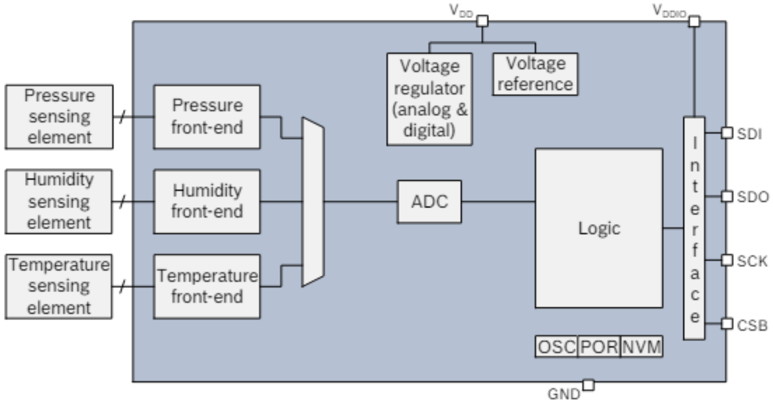




Acquiring Real-World Data

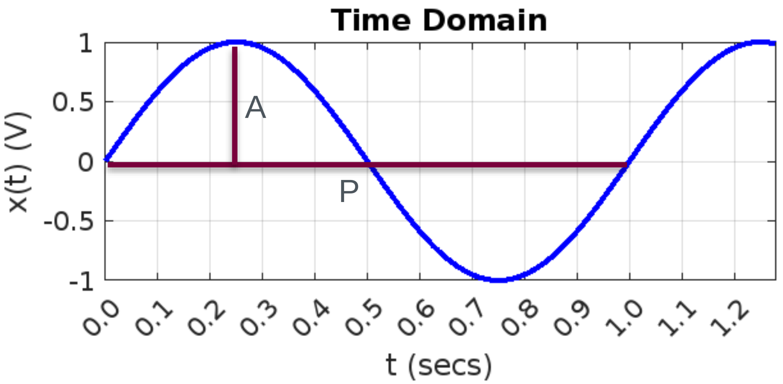
Transducer

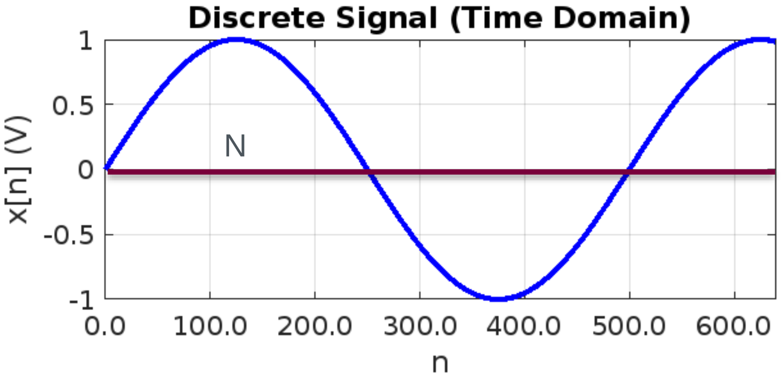
- BME280 is an integrated circuit that contains a thermistor
  - A resistor whose resistance (and voltage) is dependent on temperature
  - Range is -45 to +85 Degrees Celsius
- Datasheet provides more information



Acquiring Real-World Data

Analog-to-Digital (ADC) Conversion





We know our signal is a sine wave

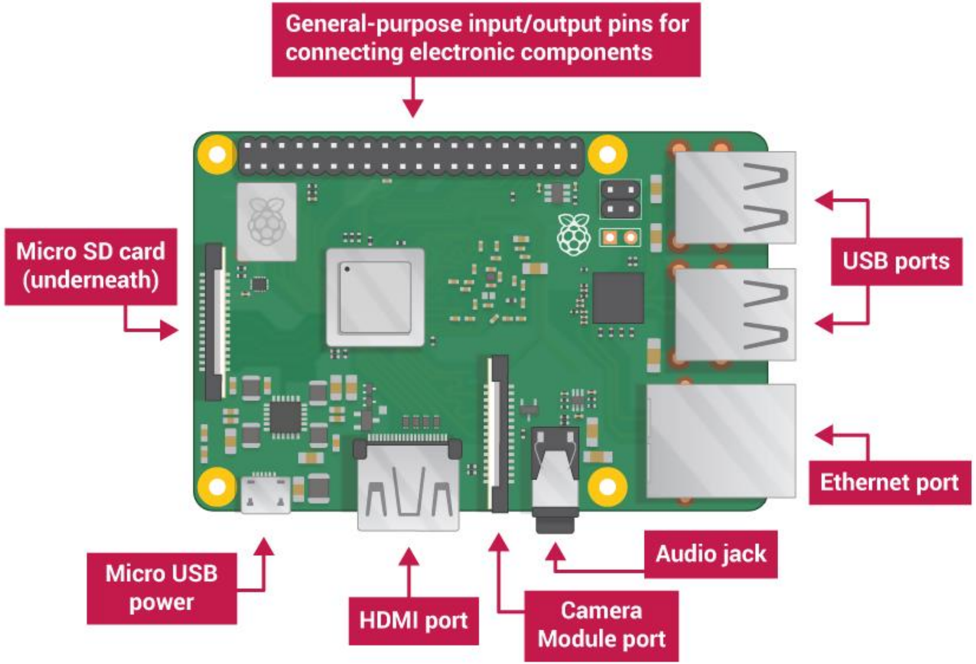
- Continuous-time function $x(t) = A\sin(2\pi ft)$ (Not known usually)
- Amplitude = A = 1 V
- Period = P = 1 second (repeats every 1 second)
- Frequency = f = 1/P = 1 Hz (repeats every 1 second)
- X-axis = time (t) in secs
- Y-axis = x(t)

We sample x(t) at a fixed rate and record a vector of n discrete values x[0], x[1], …, x[N] (blue dots)

- X-axis = sample number n
- Y-axis = x[n]
- Sample Rate = F_s = 500 Hz (500 samples every 1 sec)
- N = Number of Samples = 640

Acquiring Real-World Data

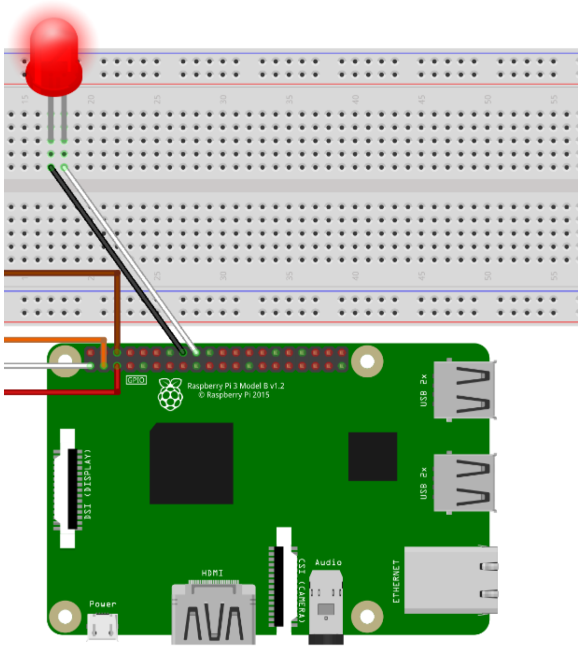
Microcontroller



- Quad Core 1.2GHz Broadcom BCM2837 64bit CPU 1GB RAM
- Communication
  - I2C (Connect to BME280 Temperature Sensor)
  - WiFi (Connect to Internet)
- Python
- Javascript
  - Control GPIO
  - Provide IoT functionality
  - Microsoft Simulator Code

IoT Simulator Example

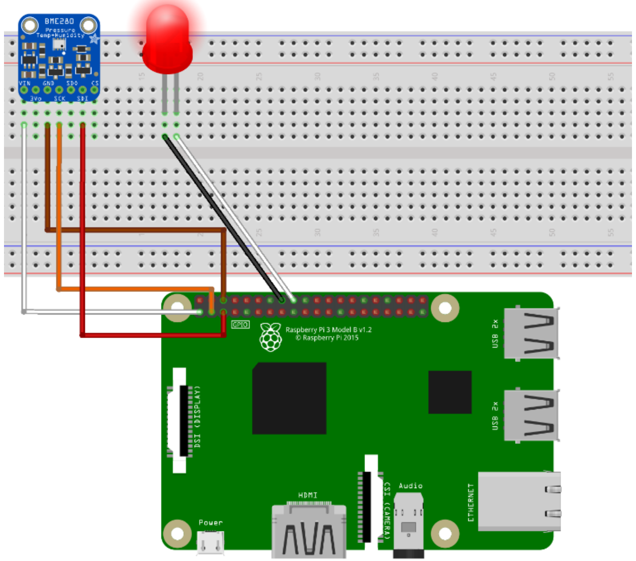
Turn LED On and Off




```javascript
const LEDPin = 4;
const wpi = require('wiring-pi');

// set up wiring
wpi.setup('wpi');
wpi.pinMode(LEDPin, wpi.OUTPUT);

//blinkLED();
//LED Setup
wpi.digitalWrite(LEDPin, 1);

setTimeout(function() {wpi.digitalWrite(LEDPin, 0);}, 500);
```

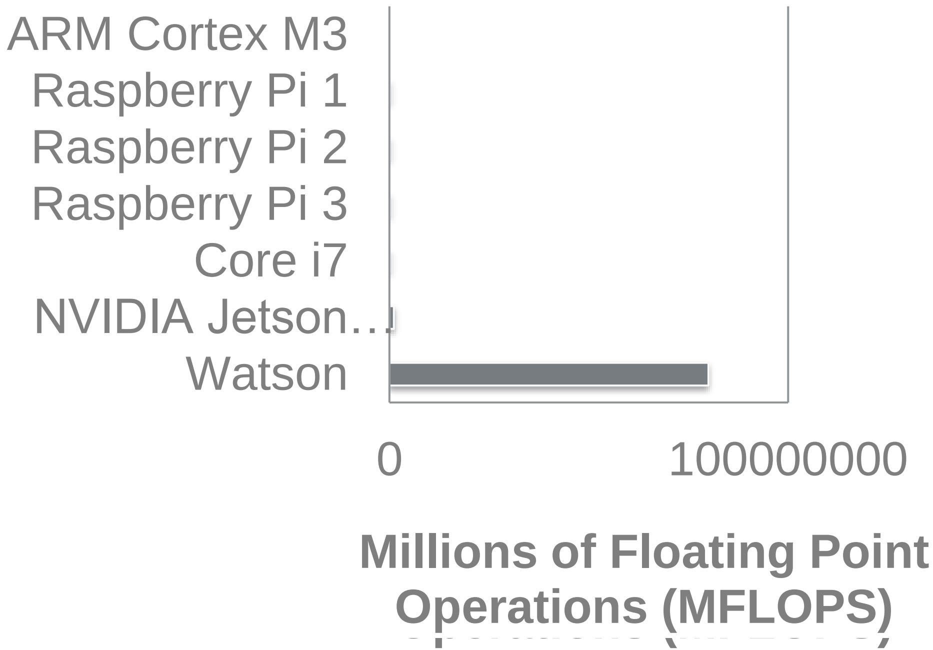
IoT Simulator Example

Get BME280 Temperature Values




```javascript
//Library and Setup
const BME280 = require('bme280-sensor');
const BME280_OPTION = {
  i2cBusNo: 1, // defaults to 1
  i2cAddress: BME280.BME280_DEFAULT_I2C_ADDRESS() // defaults to 0x77
};
sensor = new BME280(BME280_OPTION);
sensor.init().then(function () {
    sendingMessage = true;
  })
  .catch(function (err) {
    console.error(err.message || err);
  });

// Get Sensor Function Setup
function getSensorValue(cb) {
  sensor.readSensorData().then(function (data) {cb(data.temperature_C);});
}
//Get Sensor Value and Print to Console
getSensorValue(function (content) {console.log(content);});
```

Comparison of Processing Power



- When considering the mobile ecosystem, a comparison of computational power is a useful benchmark.
- The processing power of common mobile processors are shown on the left.
- Collect the data locally and transport it to more powerful systems for analysis
  - What are the disadvantages of this?

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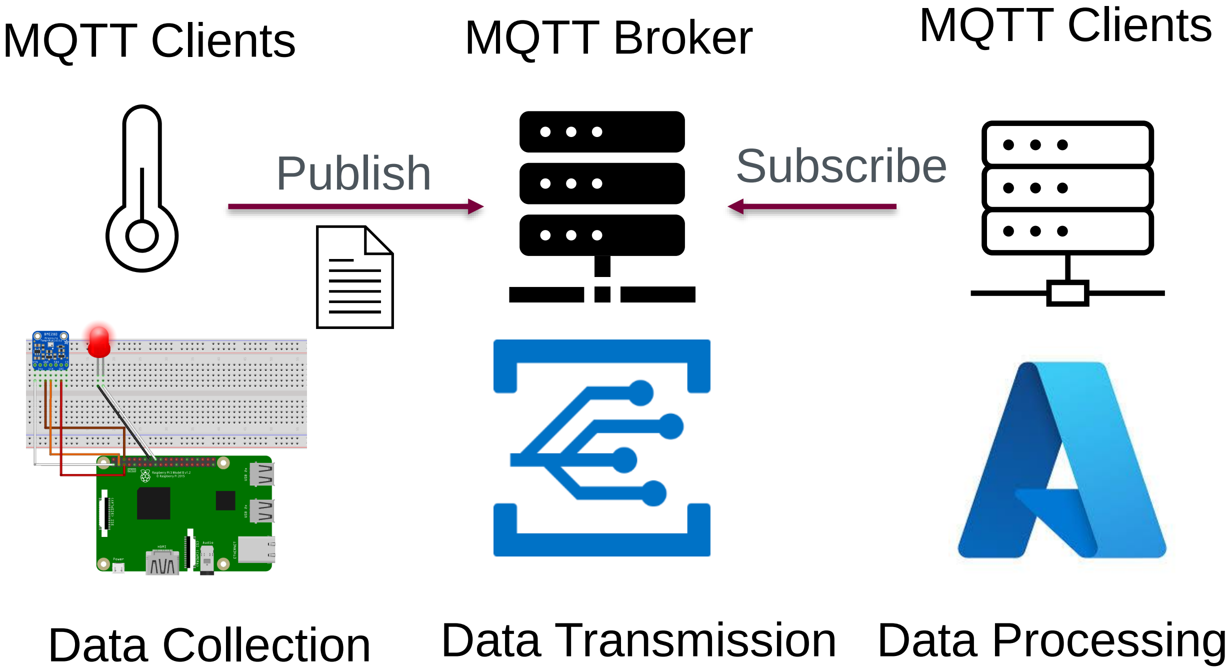
Textbook: m-Health: Fundamentals and Applications

Data Transmission Using MQTT (Publish/Subscribe)

IoT Messaging Protocol

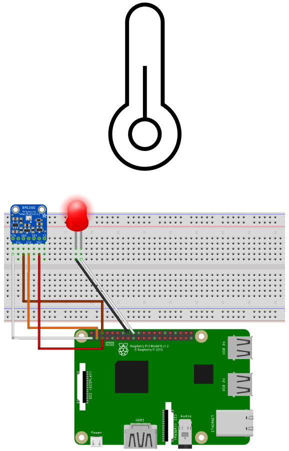


- MQTT client(s) publishes data to the MQTT Broker
- MQTT broker distributes data to subscribed MQTT client(s)
- Advantages
  - Efficient
  - Scalable
  - Bidirectional
  - Decoupled
    - Designed for reliable communication over unreliable channels

Data Transmission Using MQTT

1) Create a Client on the Rasberry Pi

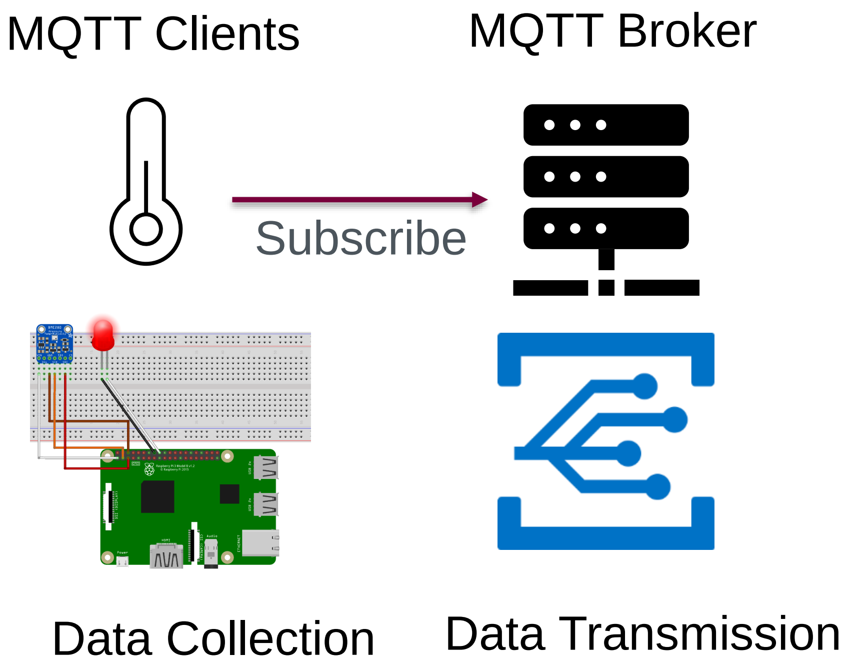
MQTT Clients

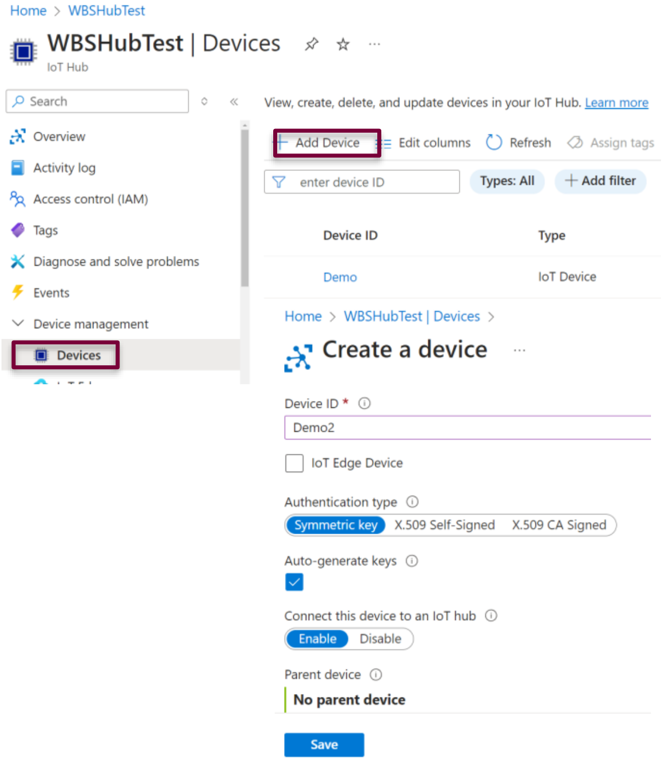


```
//Library and Setup
const Client = require('azure-iot-device').Client;
const Protocol = require('azure-iot-device-mqtt').Mqtt;

const connectionString = '[Your IoT hub device connection string]';

// Create a client
client = Client.fromConnectionString(connectionString, Protocol);
```

Data Transmission Using MQTT

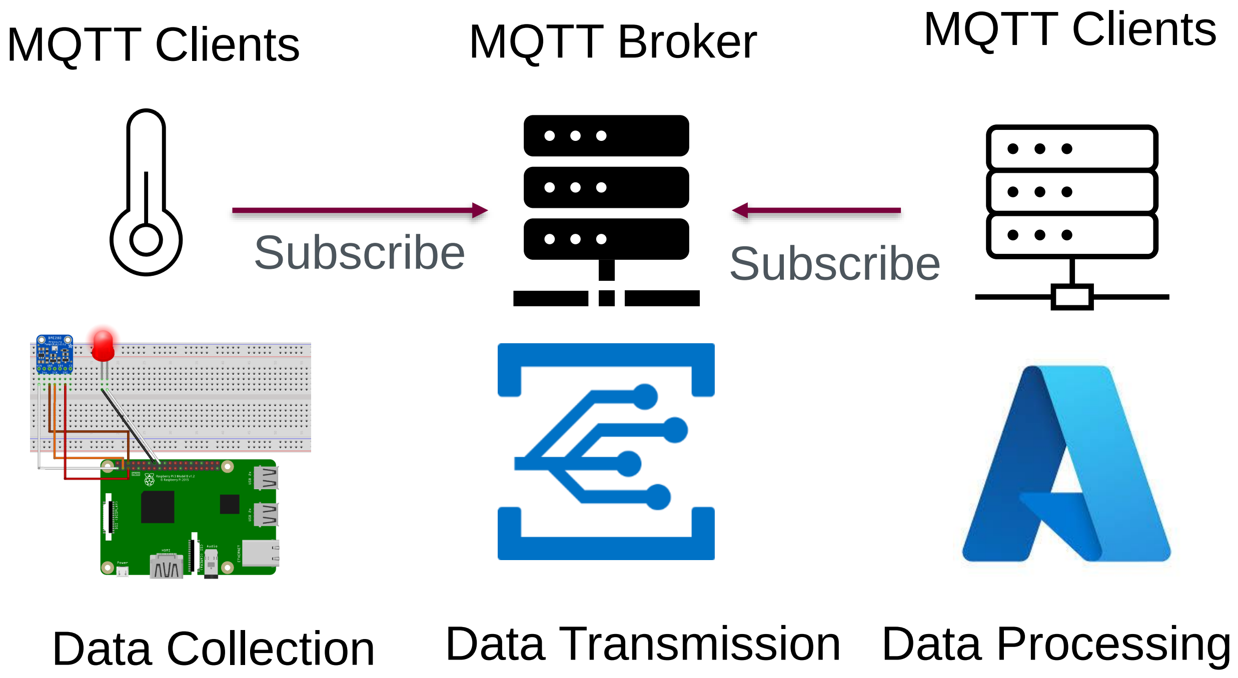
2) Get Connection String by Subscribing Device to MQTT Broker (Azure Event Grid)



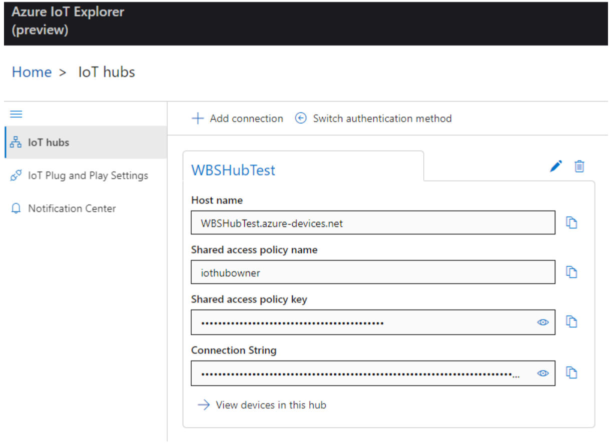


Data Transmission Using MQTT

3) Subscribe Azure IoT Explorer to MQTT Broker (Azure Event Grid)



- Azure IoT Explorer

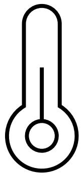


Data Transmission Using MQTT

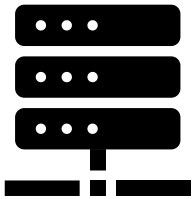
4) Publish Data from Raspberry Pi to MQTT Broker Which Distributes Data to Subscribed Client(s)

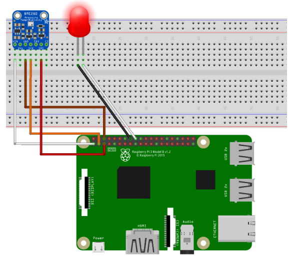
MQTT Clients

MQTT Broker



Publish





```
function sendMessage() {
  if (!sendingMessage) { return; }

  getMessage(function (content, temperatureAlert) {
    var message = new Message(content);
    message.properties.add('temperatureAlert', temperatureAlert.toString());
    console.log('Sending message: ' + content);
    client.sendEvent(message, function (err) {
      if (err) {
        console.error('Failed to send message to Azure IoT Hub');
      } else {
        blinkLED();
        console.log('Message sent to Azure IoT Hub');
      }
    });
  });
}
```

Data Collection

Data Transmission

Demo

IoT Hub Usage

Number of messages used

Device to cloud messages

Tue May 14 2024 11:20:01 GMT-0400 (Eastern Daylight Time):


```
{
  "body": {
    "messageId": 11,
    "deviceId": "Demo",
    "temperature": 28.917938926369718,
    "humidity": 79.1669979800193
  },
  "enqueuedTime": "Tue May 14 2024 11:20:01 GMT-0400 (Eastern Daylight Time)",
  "properties": {
    "temperatureAlert": "false"
  }
}
```


Tue May 14 2024 11:19:59 GMT-0400 (Eastern Daylight Time):


```
{
  "body": {
    "messageId": 10,
    "deviceId": "Demo",
    "temperature": 21.274506294825684,
    "humidity": 68.9571214294603
  },
  "enqueuedTime": "Tue May 14 2024 11:19:59 GMT-0400 (Eastern Daylight Time)",
  "properties": {
    "temperatureAlert": "false"
  }
}
```


Tue May 14 2024 11:19:58 GMT-0400 (Eastern Daylight Time):


```
{
  "body": {
    "messageId": 9,
    "deviceId": "Demo",
    "temperature": 20.511996560971788,
    "humidity": 61.0247687908586
  },
  "enqueuedTime": "Tue May 14 2024 11:19:58 GMT-0400 (Eastern Daylight Time)",
  "properties": {
    "temperatureAlert": "false"
  }
}
```

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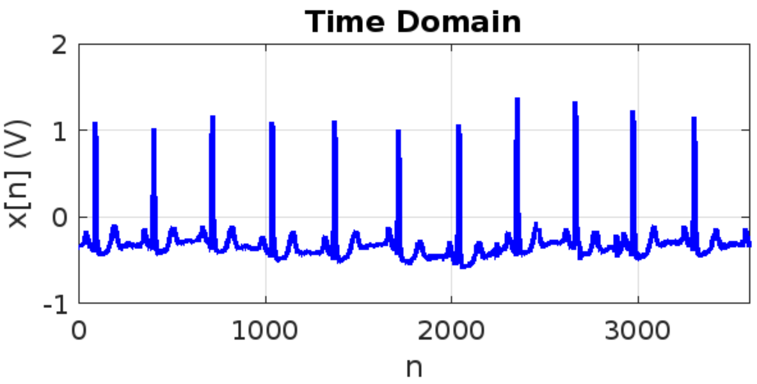
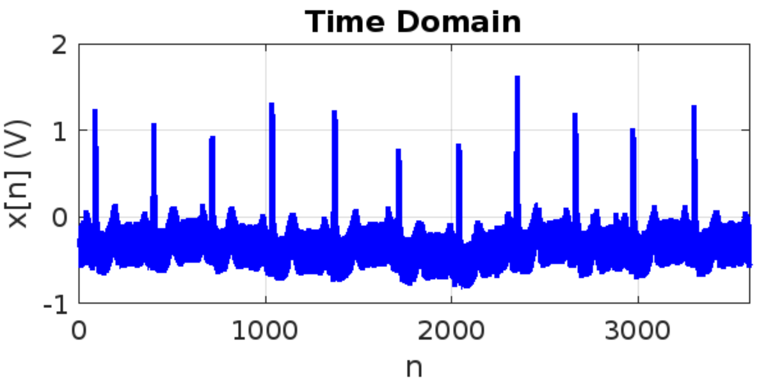
Signal Processing

Biomedical Signals are Noisy

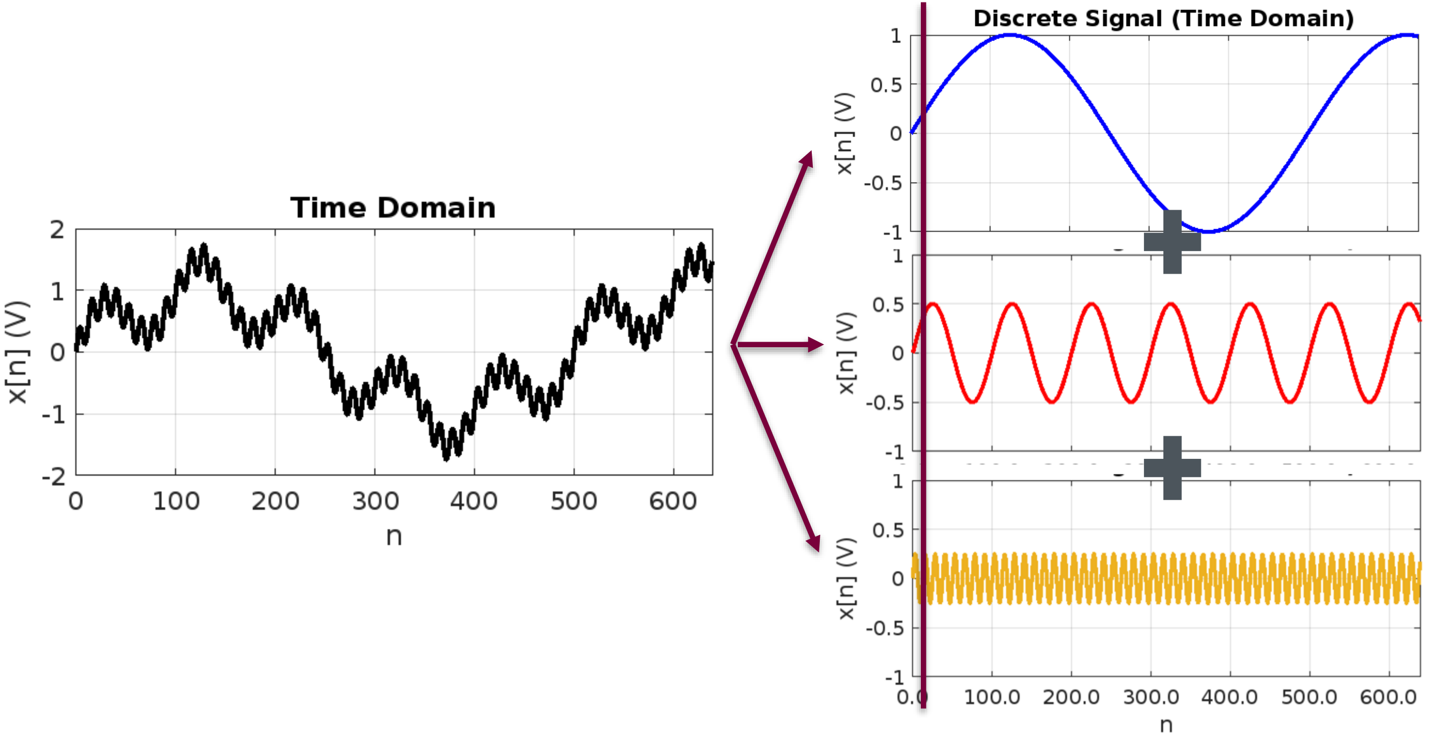




- These are real ECG signals
  - Sample 101 from the MIT-BIH Arrhythmia Database
  - https://archive.physionet.org/physiobank/database/mitdb/
- Biomedical signals contain
  - Noise of different types, e.g., movement, electricity interference)
  - Aggregated information from different concurrent sources (e.g., EOG, EEG, and EMG)
- Signal processing techniques are needed to extract clinically meaningful information from the biomedical signals

Signal Processing

Any signal can be approximated as a sum of sines and cosines of increasing frequencies



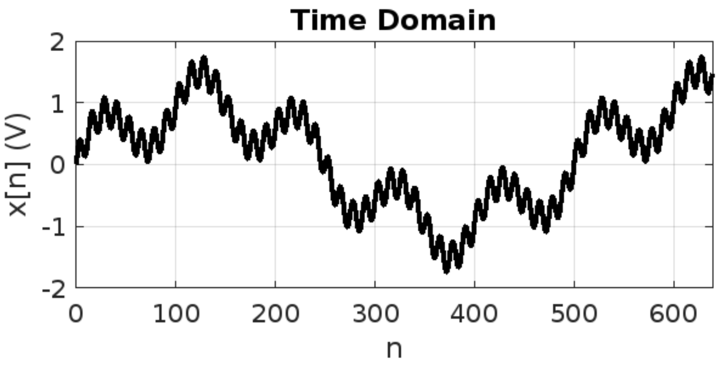
Sine wave
Amplitude = A = 1 V
Frequency = f = 1 Hz
Sample Rate = 500 Hz

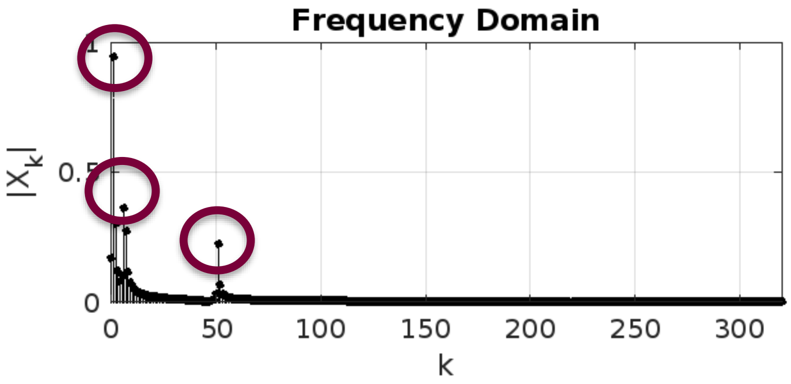
Sine wave
Amplitude = A = 0.5 V
Frequency = f = 5 Hz
Sample Rate = 500 Hz

Sine wave
A = 0.25 V
Frequency = f = 40 Hz
Sample Rate = 500 Hz

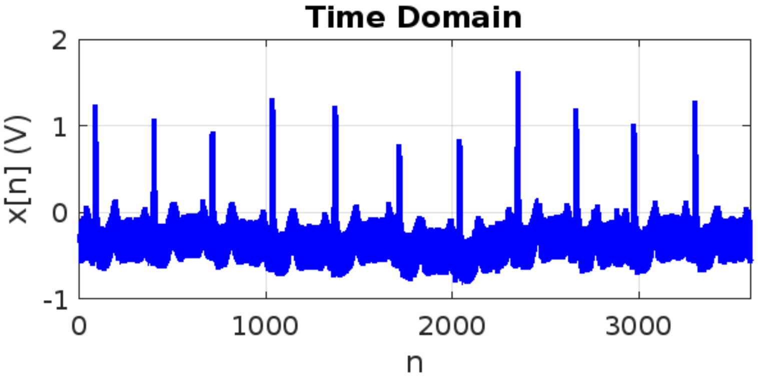
Signal Processing

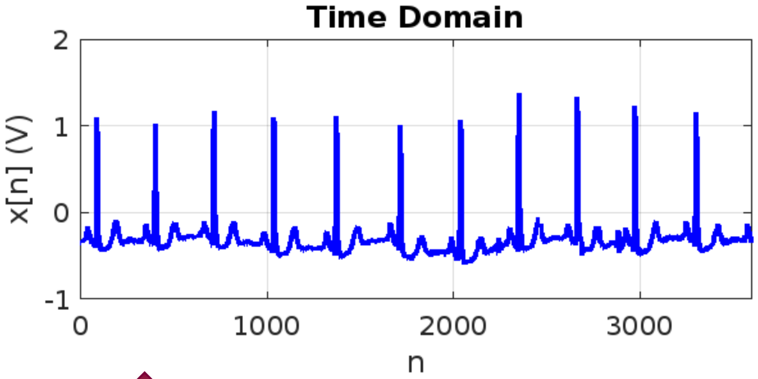
Any signal can be approximated as a sum of sines and cosines of increasing frequencies





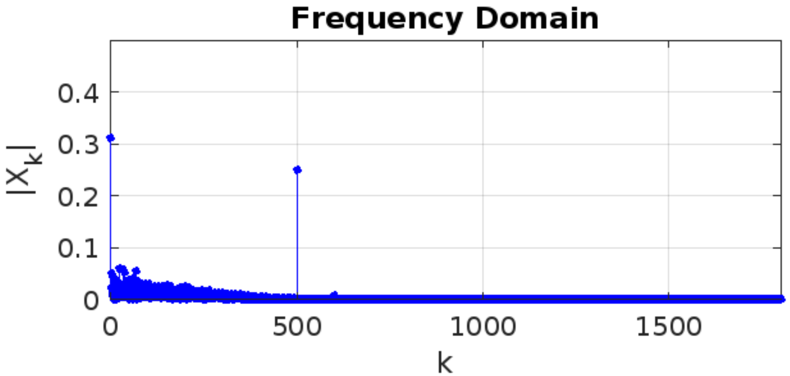
From Time to Frequency Domain and Back Again



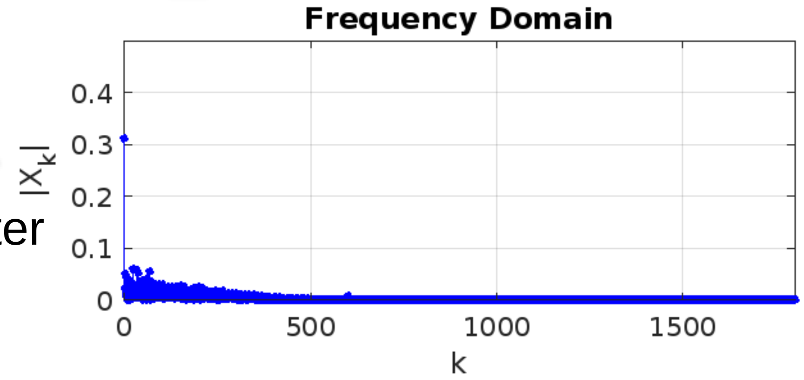


1) Fourier Transform

3) Inverse Fourier Transform



2) Filter



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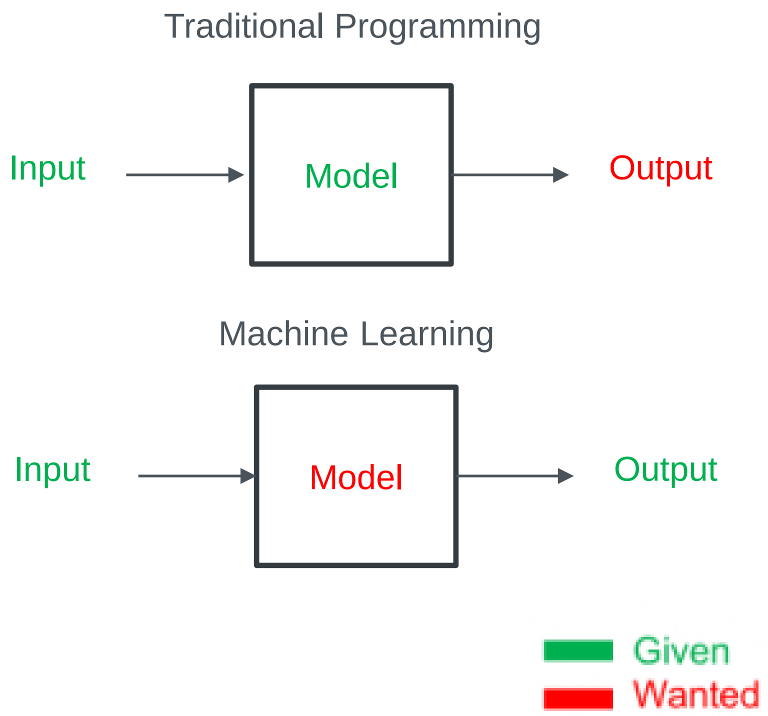
Textbook: m-Health: Fundamentals and Applications

What is an Algorithm? What is Machine Learning?

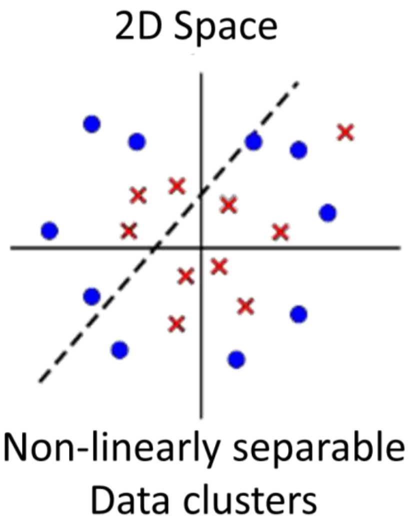


- An algorithm is a sequence of instructions that tells a computer what to do
  - E.g., Algorithm for playing tic-tac-toe
- Normally, humans write the algorithms that turns input into outputs
  - We have to **hand craft our algorithm for every possible outcome**
- With machine learning, **computers write their own algorithms**
  - Machine learning **generates the algorithm that turns inputs into outputs**!

https://www.xceptional.com/2017/07/18/machine-learning-network-automation-find-drunk-driver/

What does Machine Learning Do?

Neural Networks

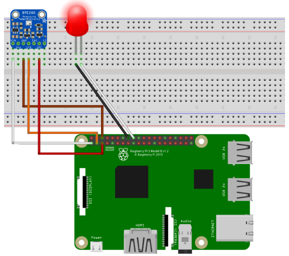


Algorithm attempts to separate data into two classes

Vapnik, V.N., Chervonenkis, A.J. Theory of pattern recognition 1974

How Does A Machine Learn?

Input and preprocessing



Preprocess → Age → x_1

Preprocess → Temp → x_2

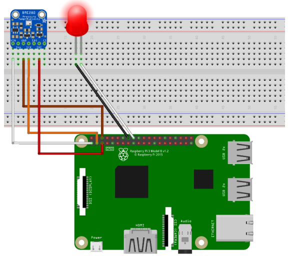
Preprocess → Activity → x_3

$\xrightarrow{i_f}$ Heart Attack Risk
1 = High
0 = Low

Each attribute must be preprocessed

How Does A Machine Learn?

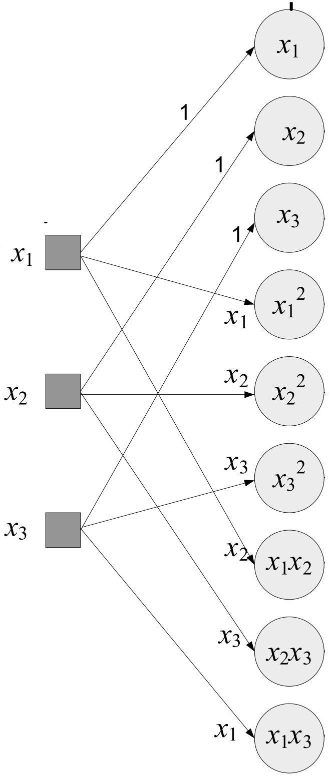
Data Mapping



Preprocess → Age →

Preprocess → Temp →

Preprocess → Activity →



$\xrightarrow{i_f}$ Heart Attack Risk
1 = High
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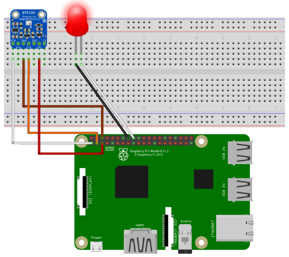
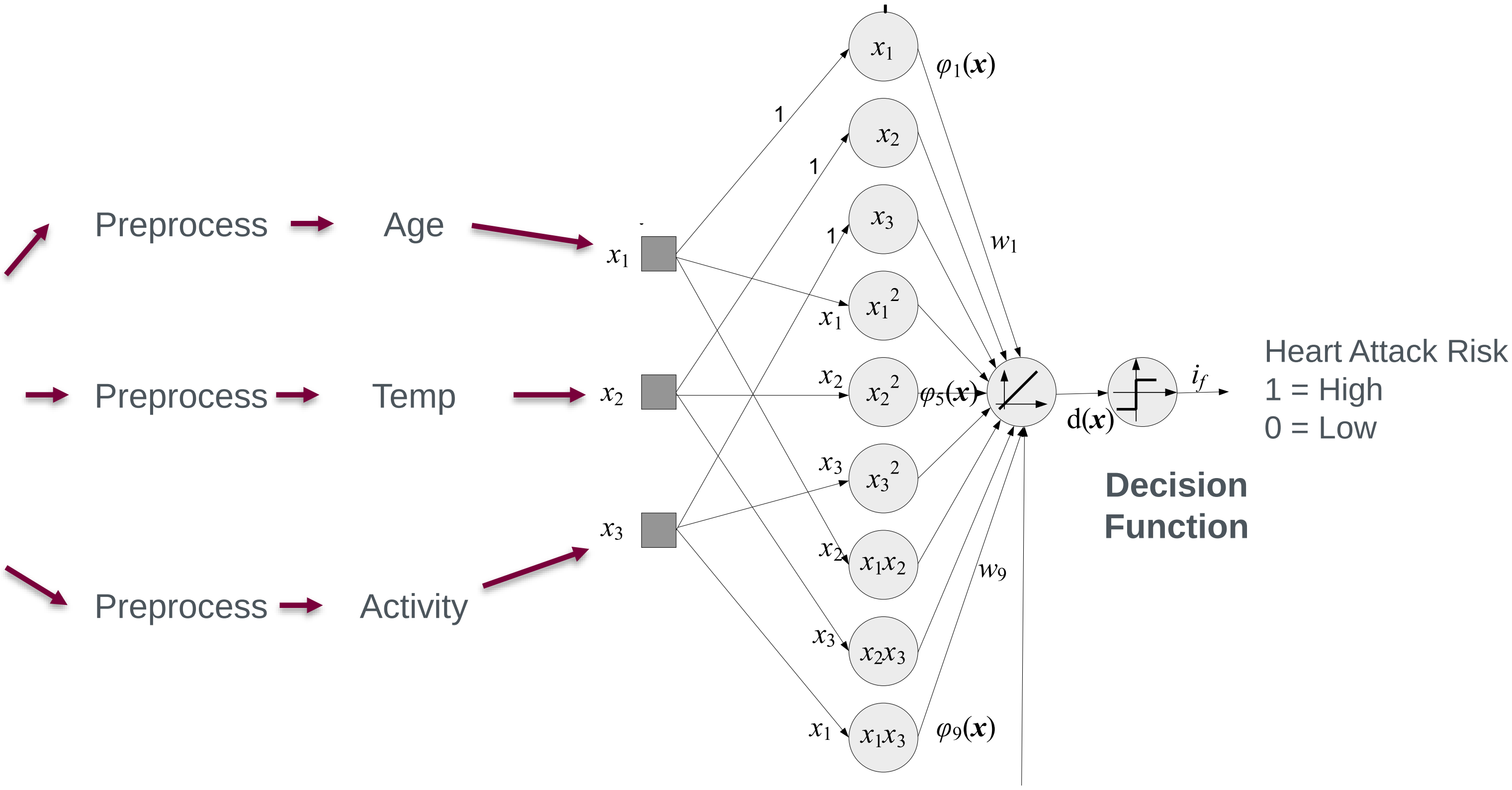
Each attribute must be preprocessed

Data Mapping Applied

How Does A Machine Learn?

Data Mapping



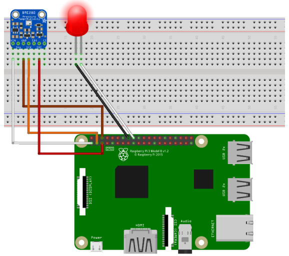


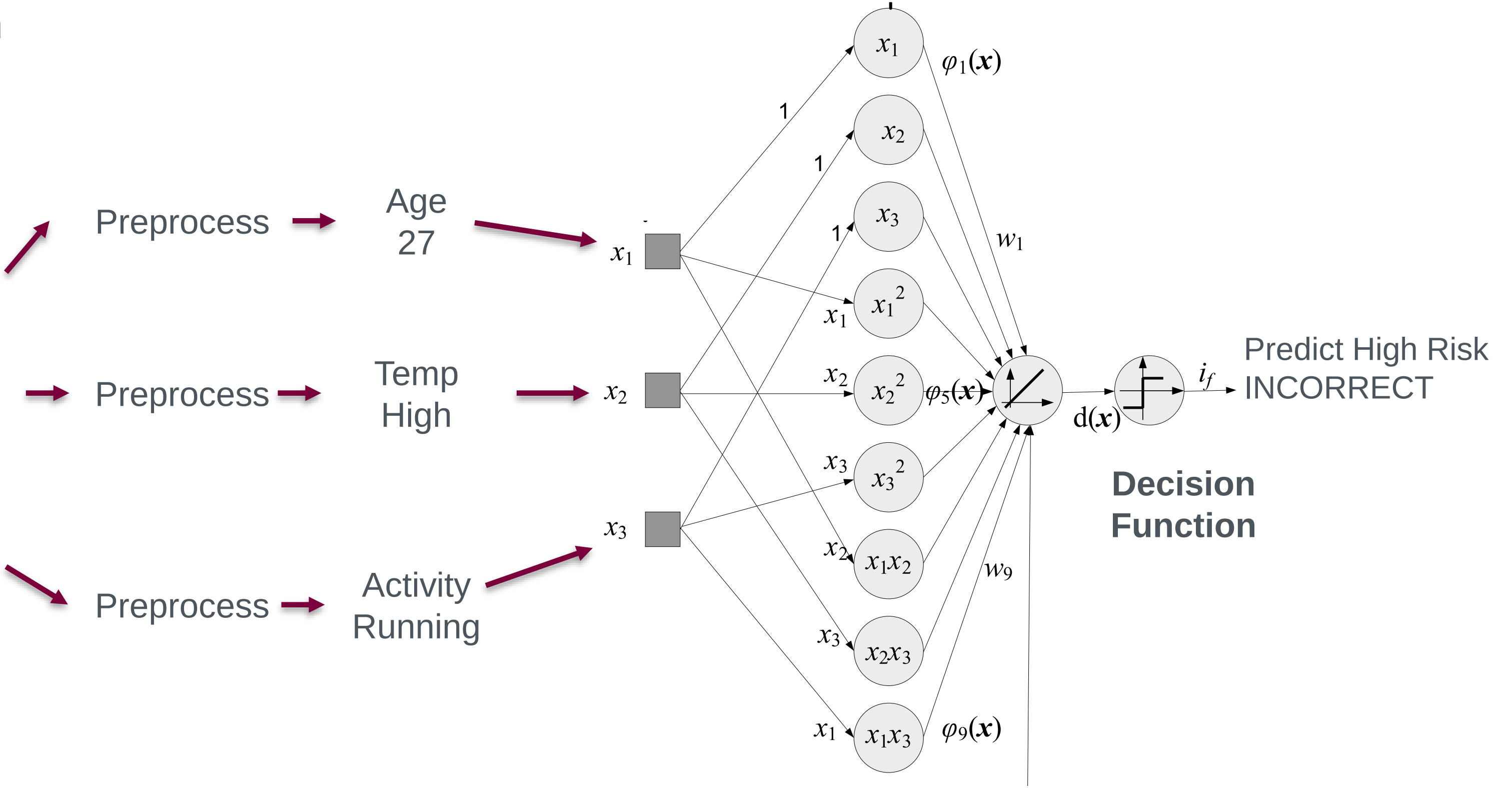
Each attribute must be preprocessed

Data Mapping Applied

How Does A Machine Learn?

Decision Function



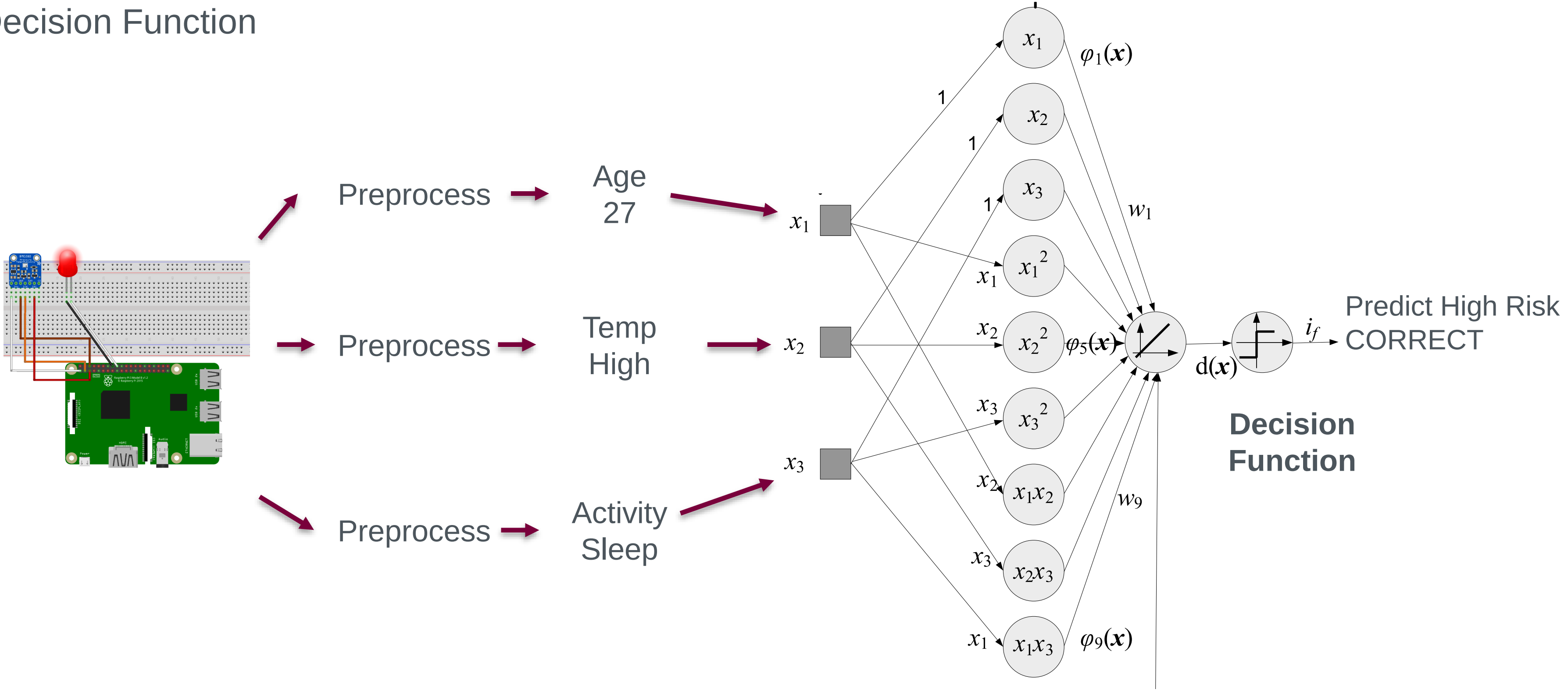


Each attribute must be preprocessed

Data Mapping Applied

How Does A Machine Learn?

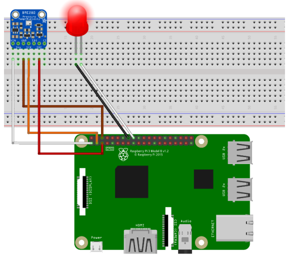
Decision Function

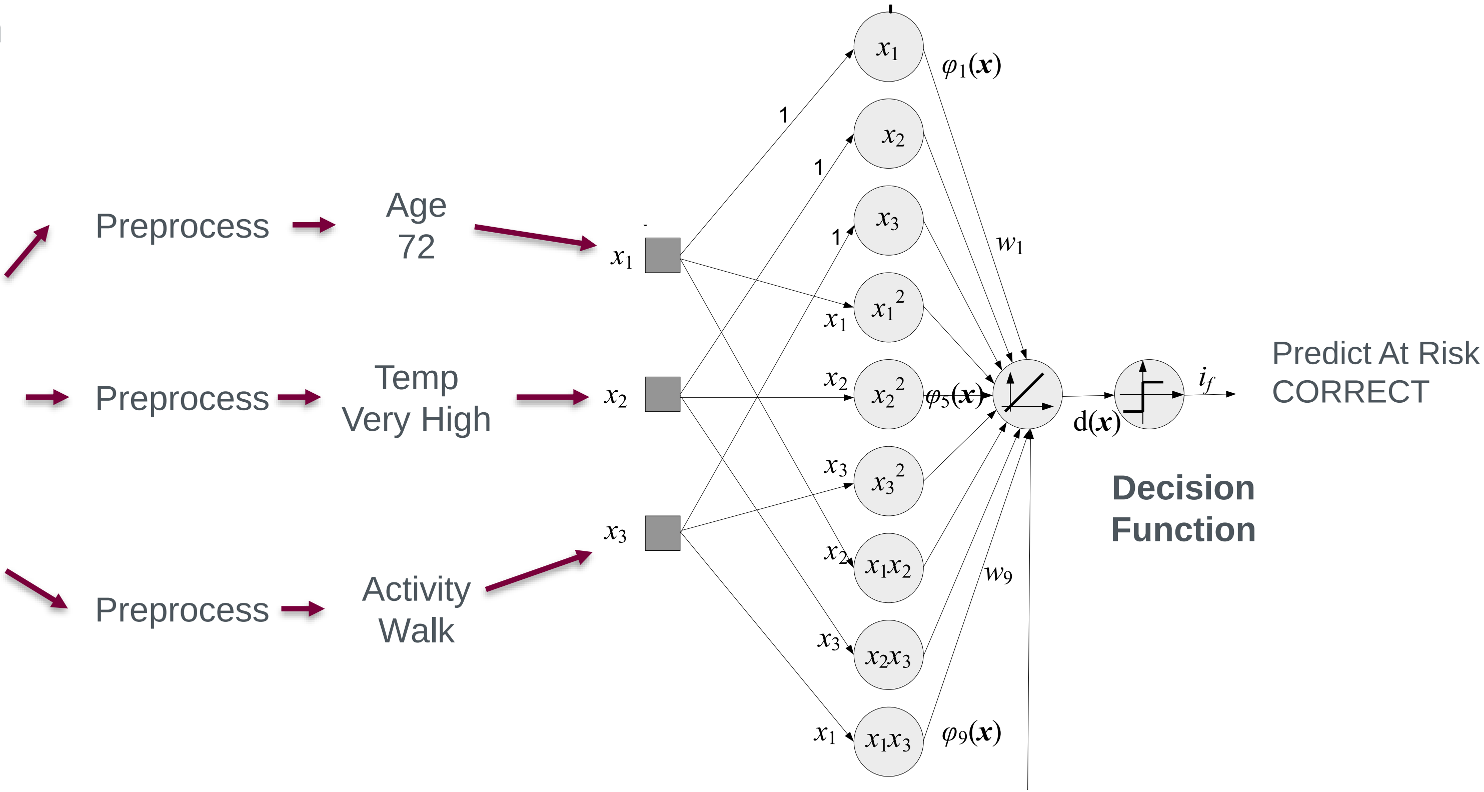


Each attribute must be preprocessed **Data Mapping Applied**

How Does A Machine Learn?

Decision Function





Each attribute must be preprocessed

Data Mapping Applied

Training Machine Learning Algorithm

- **LABEL** — Label data (e.g., healthy and not healthy)
- **SPLIT** — Split data into **training** and **testing set**
- **LEARN** — Algorithm **learns** from **training set**
- **TEST** — Algorithm is **tested** on **test set**
- **DEPLOY** — Deploy to **classify new data**

“IoT Sensor Data Analytics and Smart Health Systems”

Lecture Objectives

1. Motivation
2. IoT Layer I: Collection
3. IoT Layer II: Transmission
4. IoT Layer III: Processing
   - Signal Processing
   - Machine Learning
5. **Where Should Processing Take Place?**

Lecture Slides, Code, and Data:
https://github.com/OBoursalie/SMRTTECH_4HM3

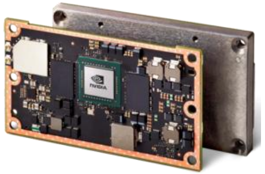
Textbook: m-Health: Fundamentals and Applications

Where Should Data Processing Take Place?

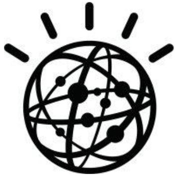
Class 1
- Sensing
- Embedded microcontrollers
- IoT


Class 2
- Smart phone / Tablet
- "Raspberry Pi" type

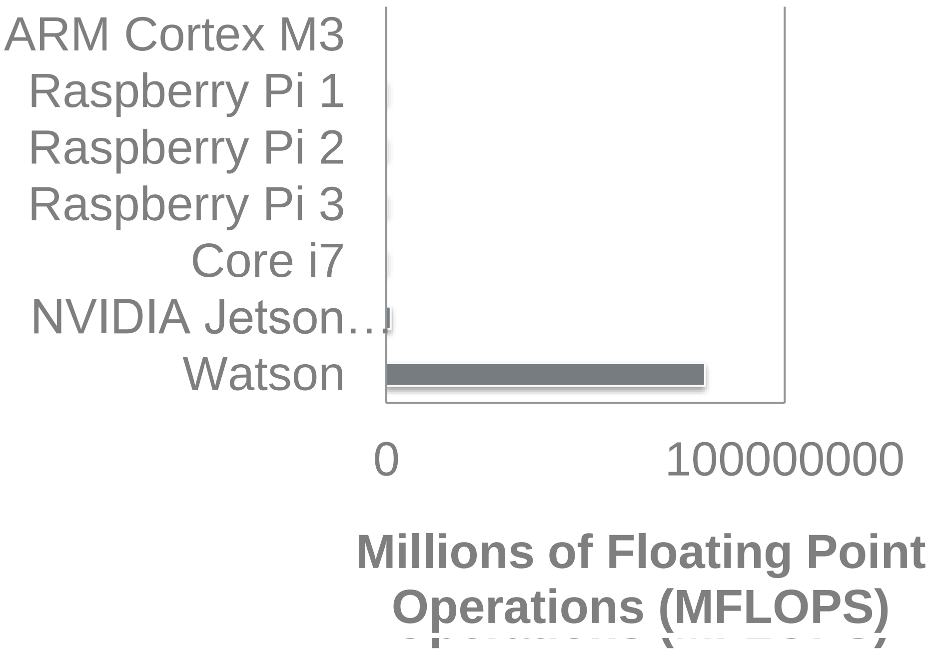
Class 3
- Laptop



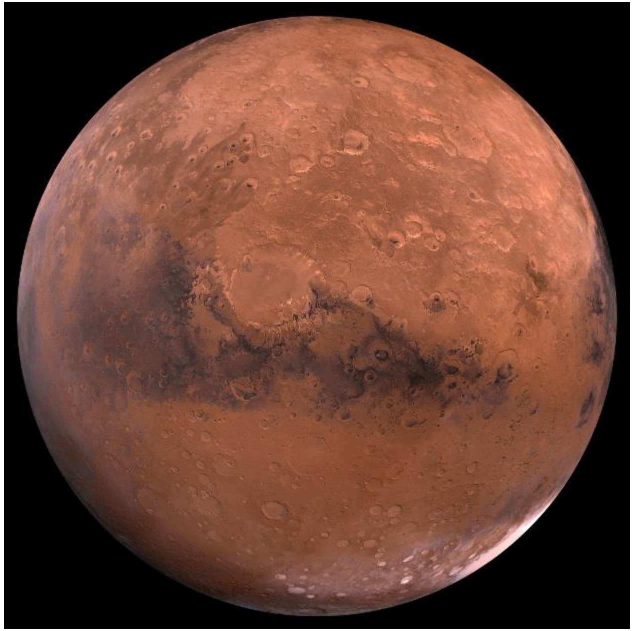
Class 4
- Massively Parallel



Class 5
- Cloud
- HPC



The Challenge



- High bandwidth and constant internet connection is **NOT** always available or is expensive
- Isolated crews (Astronauts)
  - Need **Earth-independent** medical systems where telemedical isn`t available
  - Limited resources
- Rural communities
- Natural disaster
- Extreme weather

Why Send Everything to the Cloud?

- Portable / mobile computing by definition is untethered

- Being untethered requires operation from a limited battery resource

- Where does the power go?
  - Transceiving
  - Transduction
  - Computation
  - Local data access

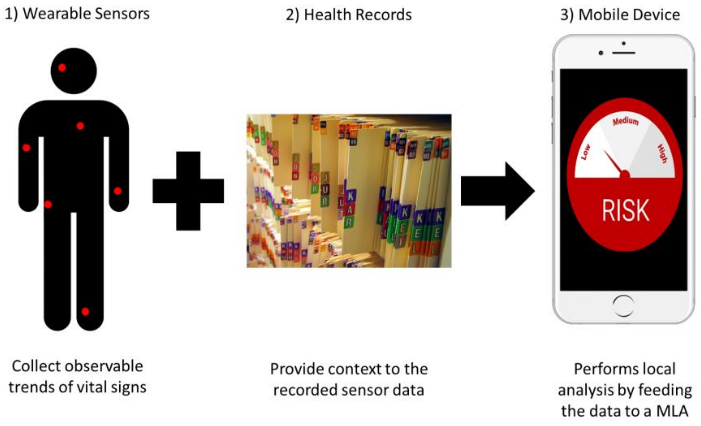
> Power

Thus, continuous data collection and transmission is not desirable

Opportunity to Do More Onboard Processing

M4CVD (Boursalie, 2018): Monitoring Heart Disease on a Mobile Device

Computational Comparison



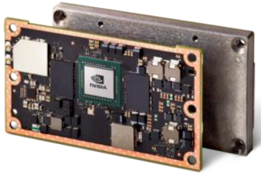
- We deployed M4CVD on a Raspberry Pi 2 in C++
  - 900 MHz processor, 1 GB RAM
- **M4CVD was successful** in analyzing a dataset of hybrid data from wearable sensors and health records on a loca device
- Training **is computationally very expensive**, thus not well suited to mobile devices.
- However, once trained the prediction / classification **is computationally inexpensive**
  - MLA complexity **is not a barrier** to deployment on a low-resource device
- Signal Acquisition and Data Processing **is more computationally expensive**
- Designers need to consider **both accuracy and computational complexity** when designing algorithms for mobile devices

Mobile AI: Moving Processing to Low Resource devices

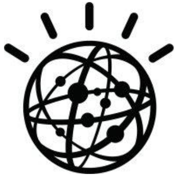
Class 1
- Sensing
- Embedded microcontrollers
- IoT

Class 2
- Smart phone / Tablet
- "Raspberry Pi" type

Class 3
- Laptop



Class 4
- Massively Parallel



Class 5
- Cloud
- HPC

Summary

- Internet of Things (IoT) is a network of embedded sensors that can connect and exchange data over communications networks
  - IoT architecture contains sensor, transport, and Data Processings

- Working with IoT requires knowledge of electronics, programming, networking, security, signal processing, and data analysis (such as machine learning)

- Growing interest in moving data processing to lower-resource devices

THANK YOU

Omar Boursalie

boursao@mcmaster.ca

Meet with students, staff, and faculty 9:00 to 9:30 AM ETB 223

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SOSCIP SMART COMPUTING FOR INNOVATION

Toronto Metropolitan University

IDEaS INNOVATION FOR DEFENCE EXCELLENCE AND SECURITY

References

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