

CSCI 3907

Introduction to IoT and Edge Computing Applications

Prof. Kartik Bulusu, CS Dept.

	Topic(s) and readings	μ-LABs and Assignment(s) due
Week 1 [01/20/2023]	<ul style="list-style-type: none">• IoT and Edge Computing [The big pictures]• Introduction to Raspberry Pi and Python programming• Course overview, policies and deliverables	<ul style="list-style-type: none">• Getting familiar with the Raspberry Pi 3B+• Python programming using Thonny• Week 1 (no deliverables)



School of Engineering
& Applied Science

Spring 2023

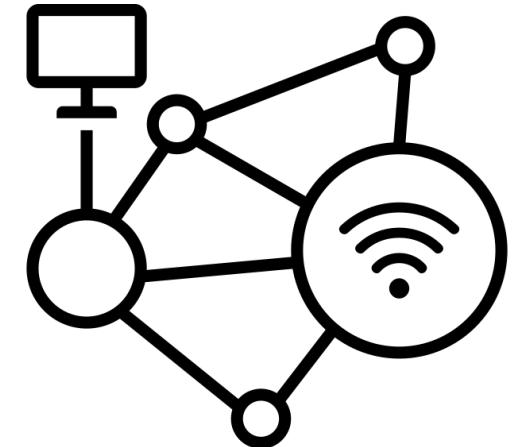
THE GEORGE WASHINGTON UNIVERSITY

Photo: Kartik Bulusu

How do we begin ...

- **1st industrial revolution:** 1760 to 1840 -> Railroads
- **2nd industrial revolution:** Late 19th century to 20th century -> Mass production and electricity
- **3rd industrial revolution:** 1960s -> Digital and revolution
- **4th industrial revolution:** NOW -> Ubiquitous and mobile communication

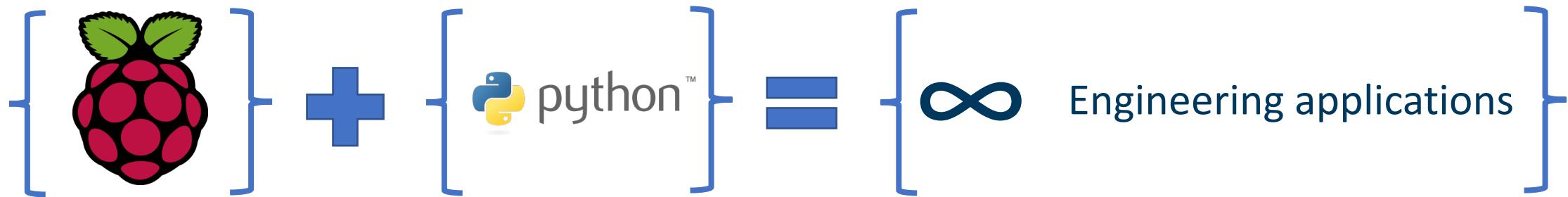
Sources:
K. Schwab. The Fourth Industrial Revolution



Icon Source: IoT by Alla Zaleuska from [Noun Project](#)

IoT with edge computing capability is going to be the backbone of the Industry 4.0.

- We will explore the **IoT** framework
- Expand it with **edge computing** ideology
- Gain practical and hands-on exposure in “**μ-Labs**”

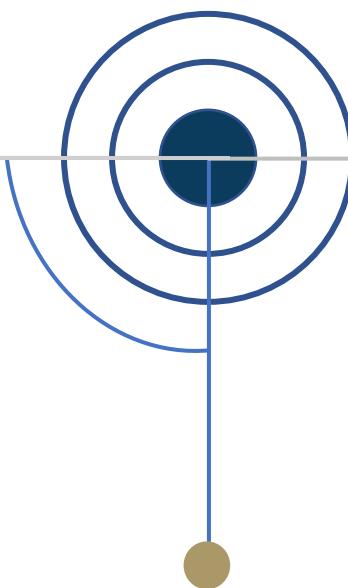


Communication hasn't been the same!

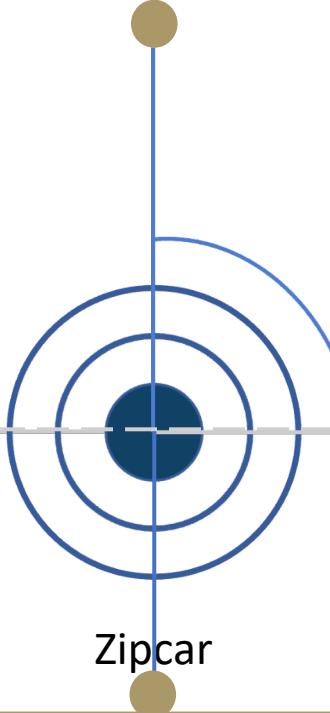
Antje Danielson and Robin Chase
Cambridge, circa 2000

Telephone

Boston
March 10, 1876



Tim Berners-Lee
CERN
www-browser and
HTTP server
August 23, 1991



Internet was through dial up and ethernet cables
AOL Time Warner (2001–2003)
Amazon had yet to turn a profit
Microsoft was selling office productivity suites

Mark Zuckerberg et al.,
Facebook
January 4, 2004

Apple
First-generation iPhone
January 9, 2007

“Things” haven’t been the same!

Zipcar discussion in an IoT course ?

Adam Richardson, 2011, The Four Technologies You Need to Be Working With, <https://hbr.org/2011/09/the-four-technologies-you-need>
 Zipcar: https://en.wikipedia.org/wiki/Zipcar#Embedded_technologies
 L. Bernardi, S. Sarma and K. R. Traub, The Inversion Factor: How to Thrive in the IoT Economy

- Zipcar is an American car-sharing company and a subsidiary of Avis Budget Group.
- Zipcar was founded in 2000 by Antje Danielson and Robin Chase.



RFID cards

- Located on the windshield to lock and unlock

Smartphone app

- “Kill” function
 - sound the vehicle's horn and flash the lights
 - unlock or lock the vehicle
- **Global Positioning System**
 - To locate the vehicle in a parking lot
 - GPS location



Zipcar == IoT in Vehicular Applications



Zipcar

- Pioneer of IoT technology; cornerstone of its business

Fundamental questions Zipcar asked or not

- ✗ “What new technology can we build and sell to people to transport people?”
- ✓ “How can we reinvent how people get where they need to go, using technology?”



On March 14, 2013, Avis Budget Group acquired Zipcar for approximately US\$500 million.

Think (or thing) outside the box

IoT in Fishing and Aquaculture



Reimagining fisheries industry

- How can Artificial Intelligence (AI) and Machine Learning (ML) transform the IoT technologies ?

Fundamental questions

- Can over-fishing be controlled in a sustainable manner ?
- Fish feeding optimization
- Can IoT + AI/ML optimize fishing location, sorting and monitor health of fish farms?

IoT in Smart cities...

Icon sources:

transponder by Stanislav Levin from <https://thenounproject.com/browse/icons/term/transponder/>

Key by Lars Meiertoberens from <https://thenounproject.com/browse/icons/term/key/>

Internet Connection by Jackvisual from <https://thenounproject.com/browse/icons/term/internet-connection/>



Reimagining the landscape

- Connected sensors, lights, and meters to collect and analyze data
- **Improve infrastructure, public utilities and services, and more.**

Fundamental challenges

- Infrastructure
- Security and Hackers
- Privacy concerns
- Community education and engagement
- Being social inclusive

(Re)defining “things”



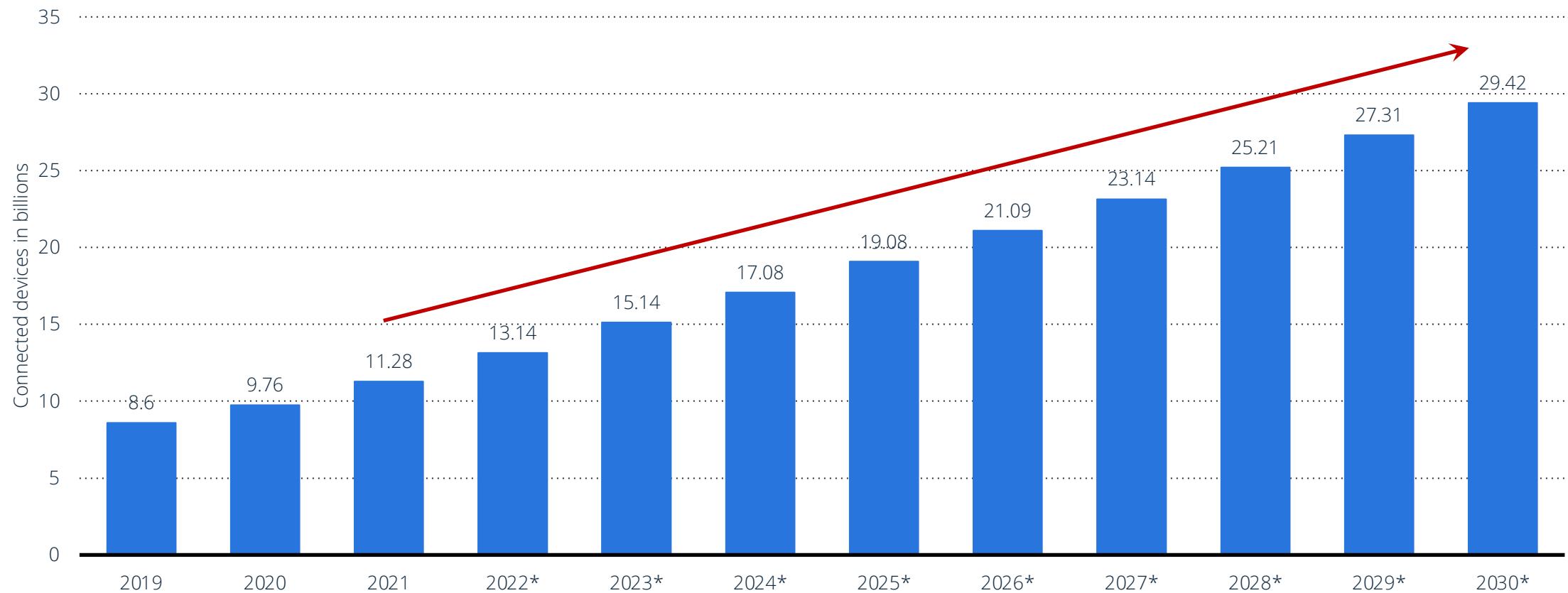
Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2021, with forecasts from 2022 to 2030 (in billions) [Graph], Transforma Insights, July 1, 2022. [Online]. Available: <https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/>

TELECOMMUNICATIONS

Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2021, with forecasts from 2022 to 2030 (in billions)

Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2021, with forecasts from 2022 to 2030 (in billions)

Number of IoT connected devices worldwide 2019-2021, with forecasts to 2030



Note(s): Worldwide; 2019 to 2022

Further information regarding this statistic can be found on [page 8](#).

Source(s): Transforma Insights; ID 1183457



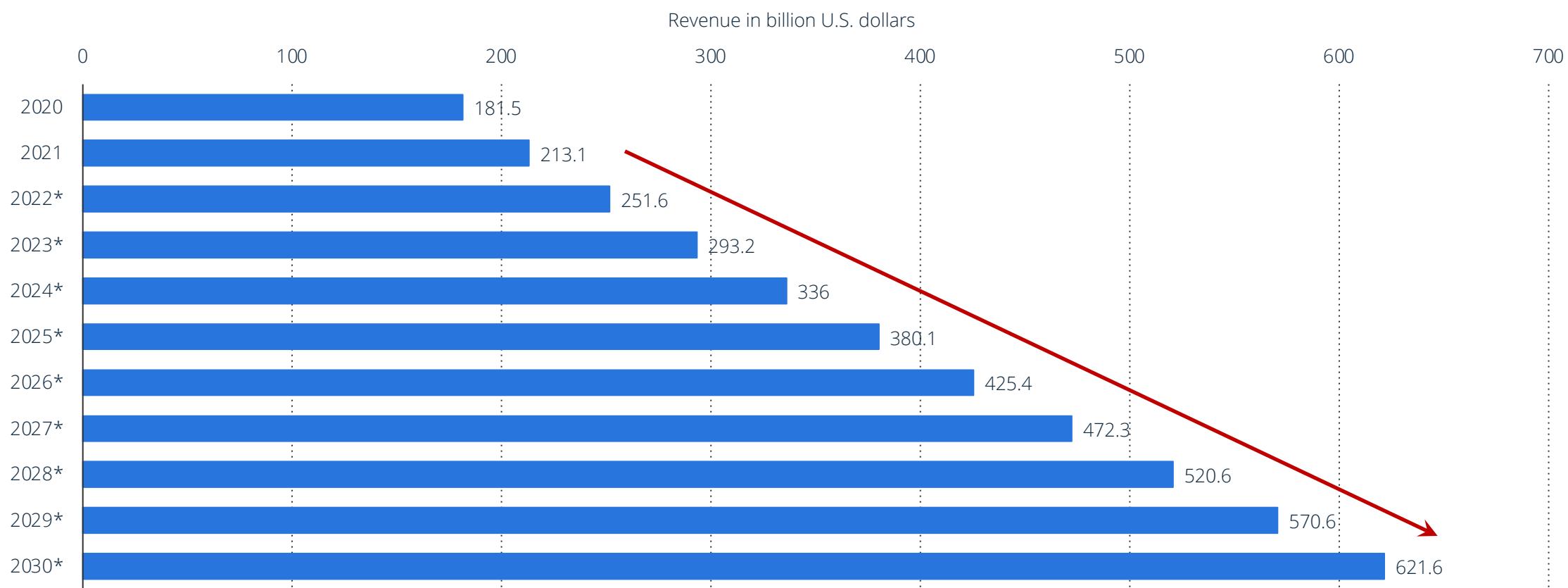
Internet of Things (IoT) total annual revenue worldwide from 2020 to 2030 (in billion U.S. dollars) [Graph], Transforma Insights, July 1, 2022. [Online]. Available: <https://www.statista.com/statistics/1194709/iot-revenue-worldwide/>

TELECOMMUNICATIONS

Internet of Things (IoT) total annual revenue worldwide from 2020 to 2030 (in billion U.S. dollars)

Internet of Things (IoT) total annual revenue worldwide from 2020 to 2030 (in billion U.S. dollars)

IoT global annual revenue 2020-2030



Note(s): Worldwide; 2020 to 2022

Further information regarding this statistic can be found on [page 8](#).

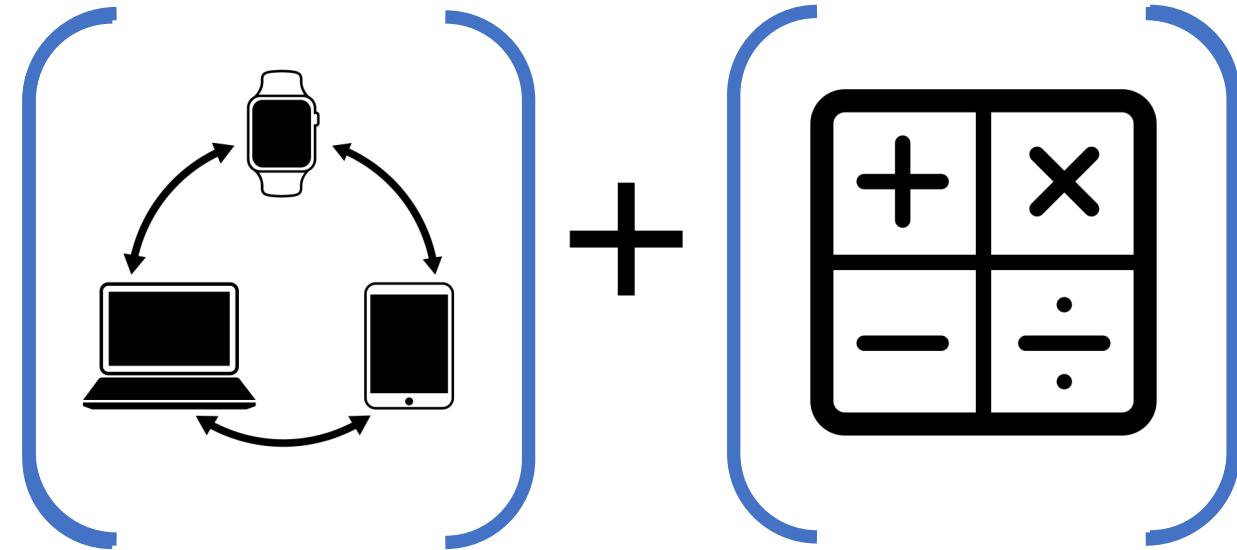
Source(s): Transforma Insights; ID 1194709

What's the “thing”?

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



Paradigm #3

Bluetooth by J703 from <https://thenounproject.com/browse/icons/term/Bluetooth>

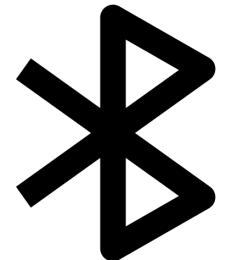
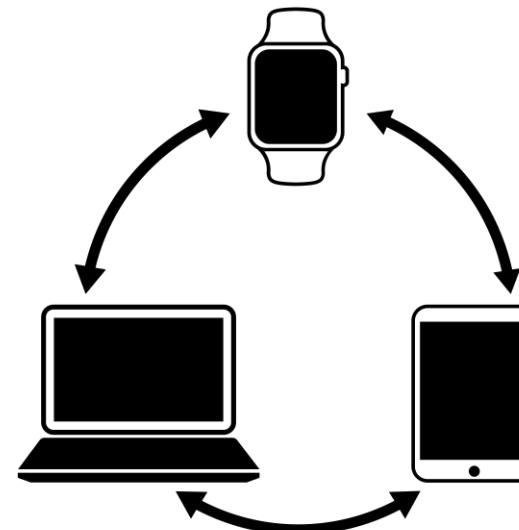
wifi by Cetha Studio from <https://thenounproject.com/browse/icons/term/wifi/>

By Connectivity Standards Alliance - <https://zigbeealliance.org/solutions/>, Public Domain: <https://commons.wikimedia.org/w/index.php?curid=106668572>

By Connectivity Standards Alliance - buildwithmatter.com, Public Domain, <https://commons.wikimedia.org/w/index.php?curid=114216376>

internet of things by Davo Sime from <https://thenounproject.com/browse/icons/term/internet-of-things/>

Connected “things”



5G



The Evolution of Things

IoT

Internet of Things

- Devices connected to internet
- Breaking the boundaries of form

IoT

Intelligence of Things

- Devices that host software applications
- Breaking the boundaries of function

IoT

Innovation of Things

- Devices that become experiences

MIT MANAGEMENT
EXECUTIVE EDUCATION

WHAT IS THE INTERNET OF THINGS AND WHY SHOULD YOU CARE?

with Prof. Sanjay Sarma



“things” with compute

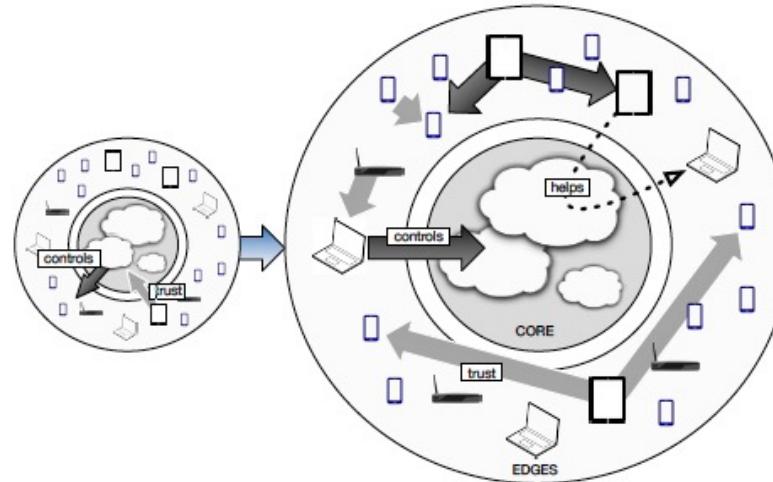
“things” with compute == edge compute

Edge computing is a distributed computing framework that brings enterprise applications closer to data sources such as IoT devices or local edge servers.

This **proximity to data** at its source can deliver strong business benefits, including faster insights, improved response times and better bandwidth availability.



"Edge Computing" was coined around 2002



Content Delivery Networks:

It was mainly associated with the deployment of applications over CDNs, when some large companies announced deals to distribute software through CDN edge servers.

P2P computing:

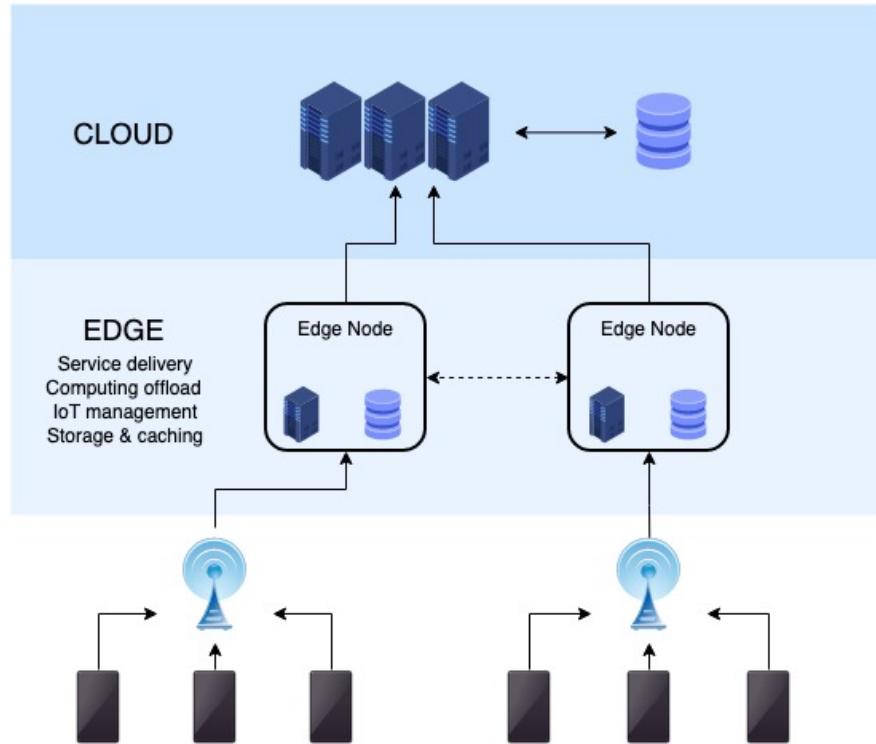
This is another field closely related to edge computing, it is also its main precursor. The term P2P was first introduced around 2000 with the appearance of popular file-sharing systems such as Napster and Kazaa.

Fog computing:

Fog Computing is a recent research field that has substantial overlap with Edge-centric Computing. Proximity to end-users, dense geographical distribution, and support for mobility are the main distinguishing characteristics of Fog Computing.



Edge computing is a form of distributed computing



Classical Paradigm

- **Distributed computing**

- Covers a broad range of technologies
- Earliest success stories could be considered
 - local area networks and
 - the first internet, ARPANET (1960s).

New Paradigm

- **Decentralized, distributed computing**

- **Proximity to data:** Moving the computer workload closer to the data source
 - reduces latency
 - bandwidth and
 - overhead for the centralized data center

Autonomous Car by Tippawan Sookruay from <https://thenounproject.com/browse/icons/term/autonomous-car/>
 clean energy by Juicy Fish from <https://thenounproject.com/browse/icons/term/clean-energy/>
 Health Care by mynamepong from <https://thenounproject.com/browse/icons/term/health-care/>
 Smart City by dDara from <https://thenounproject.com/browse/icons/term/smart-city/>

Four (near future) Edge computing examples



Autonomous Cars

- [Chevrolet](#) collected 4,220 terabytes of data from customer's cars.

McKinsey forecasts that this could grow into a \$450 to 750 billion market by 2030.

Source: <https://www.autoblog.com/2017/02/21/race-for-autonomous-cars-is-over-mcelroy-autoline-opinion/>

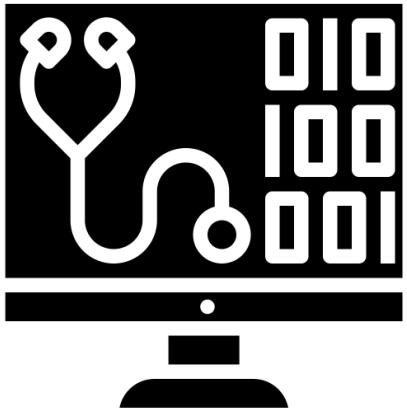


Clean energy technology

- Data centers use an estimated [200 terawatt hours](#) (TWh) of electricity annually
- ~ 50% of all electricity currently used for all global transport.

Edge computing can significantly reduce the amount of time and power, data centers need to use to process data.

Source:
<https://www.forbes.com/sites/forbestechcouncil/2022/03/18/how-machine-learning-and-edge-computing-powers/sustainability/?sh=483ebd025fab>

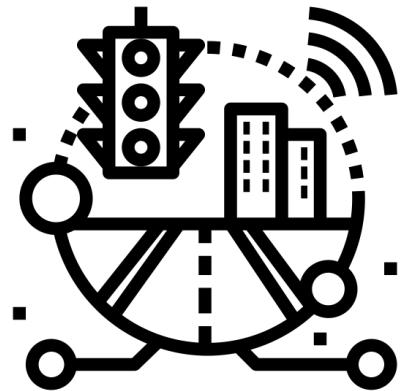


Transforming health care at the edge

- 10 to 15 connected device per US hospital bed
- 3 million data points generated by the average clinical trial
- 30% of all global stored data is from health care

75% of data will be generated at the edge by 2025

Source:
<https://www.technologyreview.com/2021/06/10/1026038/transforming-health-care-at-the-edge/>



Edge AI: Tackling Traffic Management

- A pilot system deployed at Pittsburgh, Pennsylvania, has reportedly
 - reduced travel time by 26%
 - idling time by 41%, and
 - emissions by 21 %.

The INRIX Global Traffic Scorecard: World's 20 most congested cities lost between 164 and 210 hours in congestion per capita through 2018.

Source:
<https://www.iotforall.com/busting-traffic-woes-with-5g-and-edge-ai>



Benefits of Edge computing

- **Reduced latency of communication** between IoT devices and the central IT networks.
- **Faster response times** and increased operational efficiency.
- **Improved network bandwidth.**
- **Continued systems operation offline** when a network connection is lost.
- **Local data processing**, aggregation, and rapid decision making via analytics algorithms and machine learning.

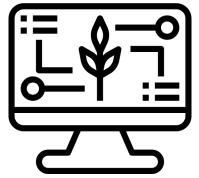
There are concerns!

- **User Privacy** between IoT devices and the central IT networks.
- **Optimization metrics:** There are several layers with various computation abilities in edge computing for choosing an optimal workload allocation.
- **Task-offloading:** Utilizing edge nodes for computation offloading is a concern due to the problem of adequately segmenting computational tasks.
- **Public accessibility of edge nodes:** When an edge device (e.g., a base station, switch, and router) is intended to be used for public access.

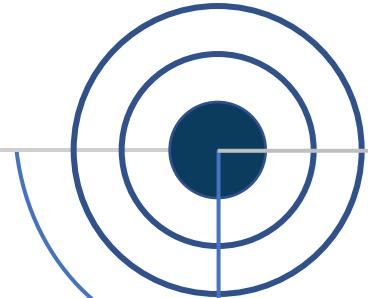
How to we move forward?

I like to democratizing science and this course too

Course Objectives

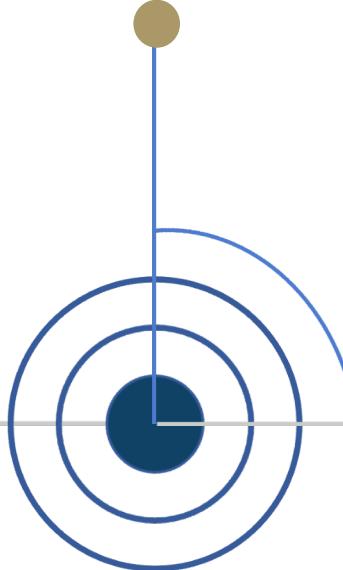


Understand

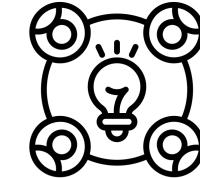
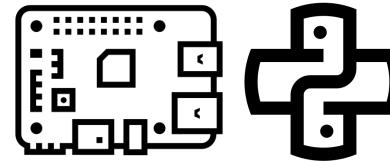


Hardware and
Procedural programming Language

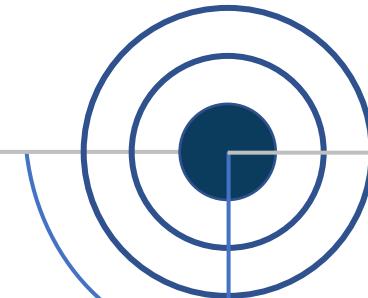
Key concepts and constructs



Familiarize



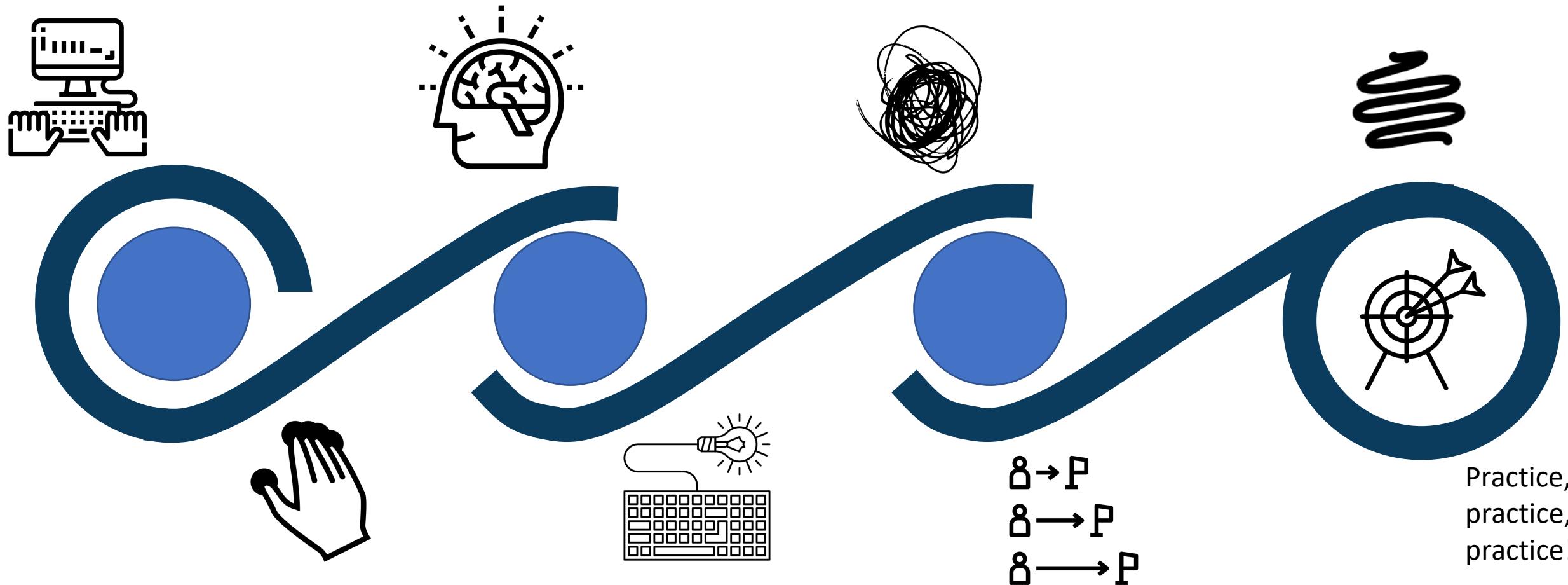
Practice



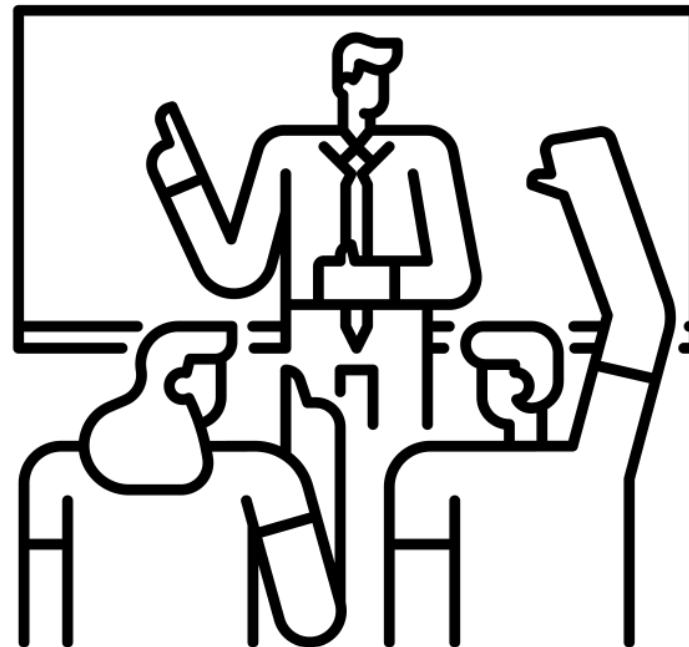
Solve problems at the beginner-level

typing by monkik from <https://thenounproject.com/icon/typing-3382155/>
practice by Kamin Ginkaew from <https://thenounproject.com/icon/practice-4829034/>
touch by Julie Muckensturm from <https://thenounproject.com/icon/touch-26836/>
messy scribble by ochre7 from <https://thenounproject.com/icon/messy-scribble-228748/>
Scribble by Goodfather from <https://thenounproject.com/icon/scribble-363760/>
practice by ProSymbols from <https://thenounproject.com/icon/practice-1876457/>
code idea by Danil Polshin from <https://thenounproject.com/icon/code-idea-597303/>

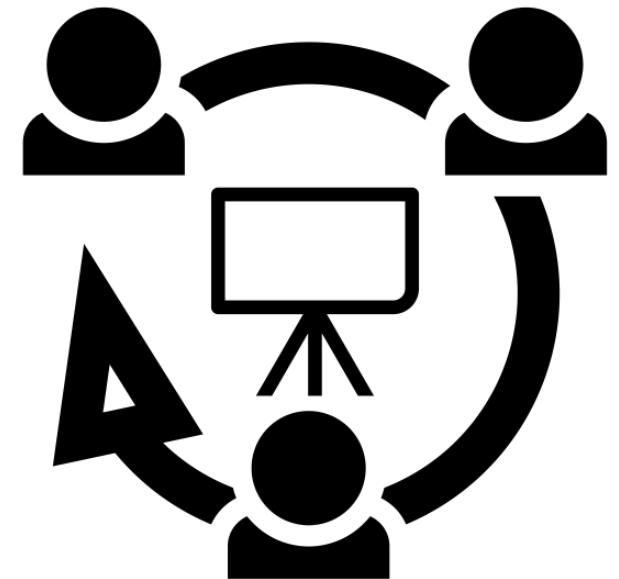
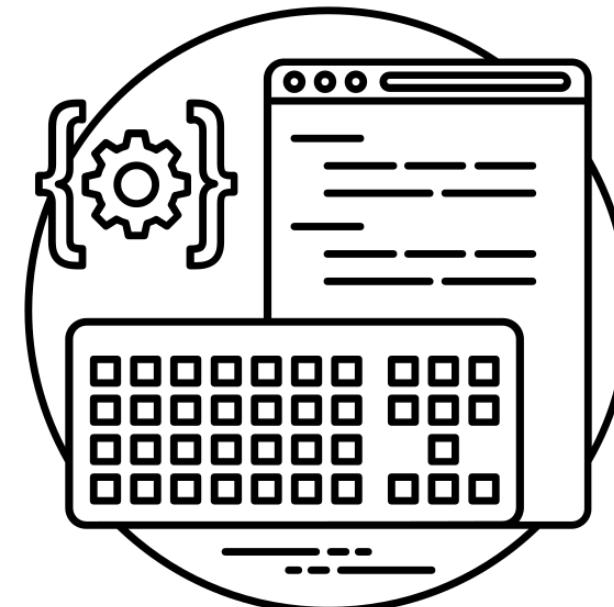
Teaching and learning environment



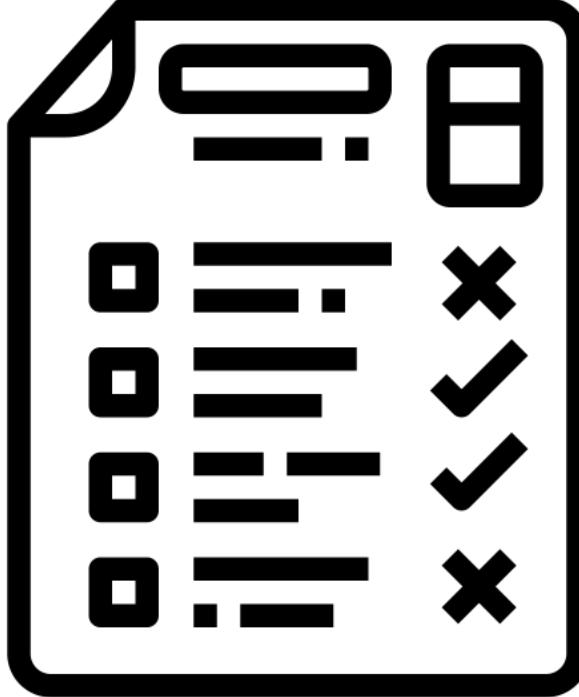
Reading group, discussion and presentations



Coding and hardware demos



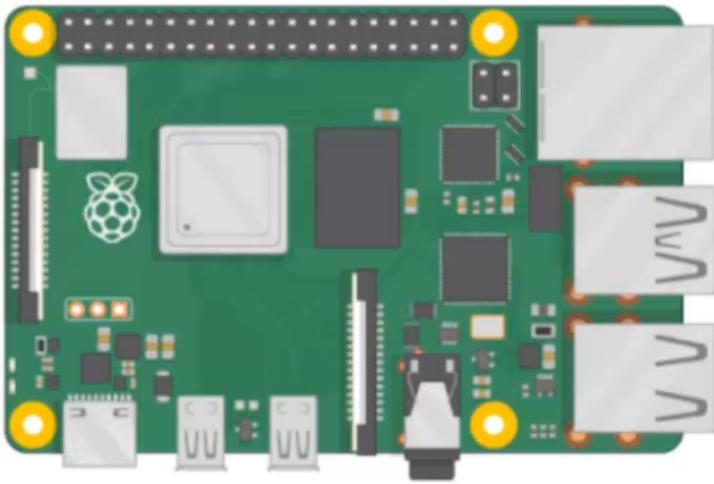
Democratizing the grading and other course policies



- Attendance and/or peer-to-peer and instructor interactions 10%
- In-class work and/or Weekly Quizzes 10%
- Project reports, paper reviews and in-class presentations 10%
- Python programming and other Homework 20%
- Projects (including code, demo, written report and presentation) 50%
 - 20% midterm project; 30% final project

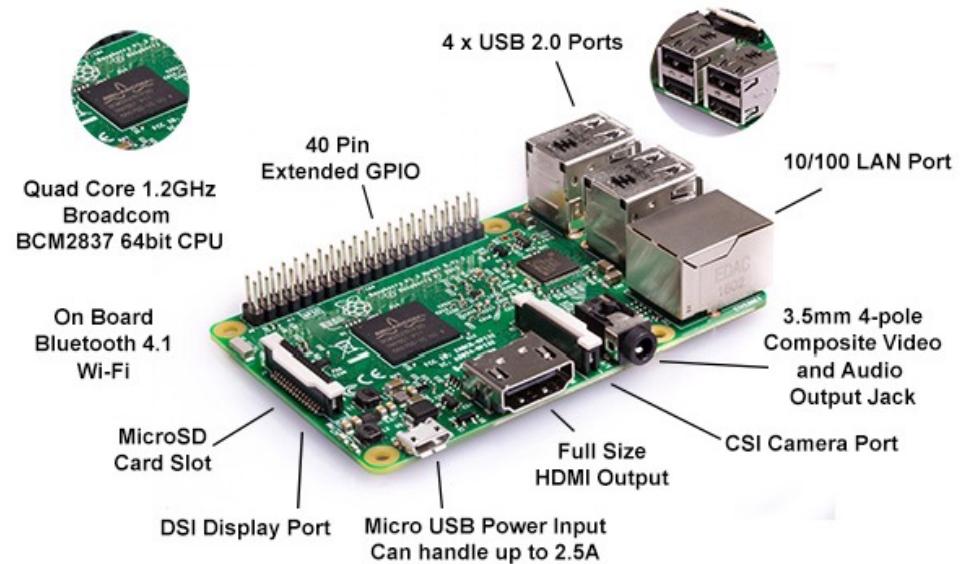
Get to know your hardware and set up lab

Raspberry Pi Hardware and Connections

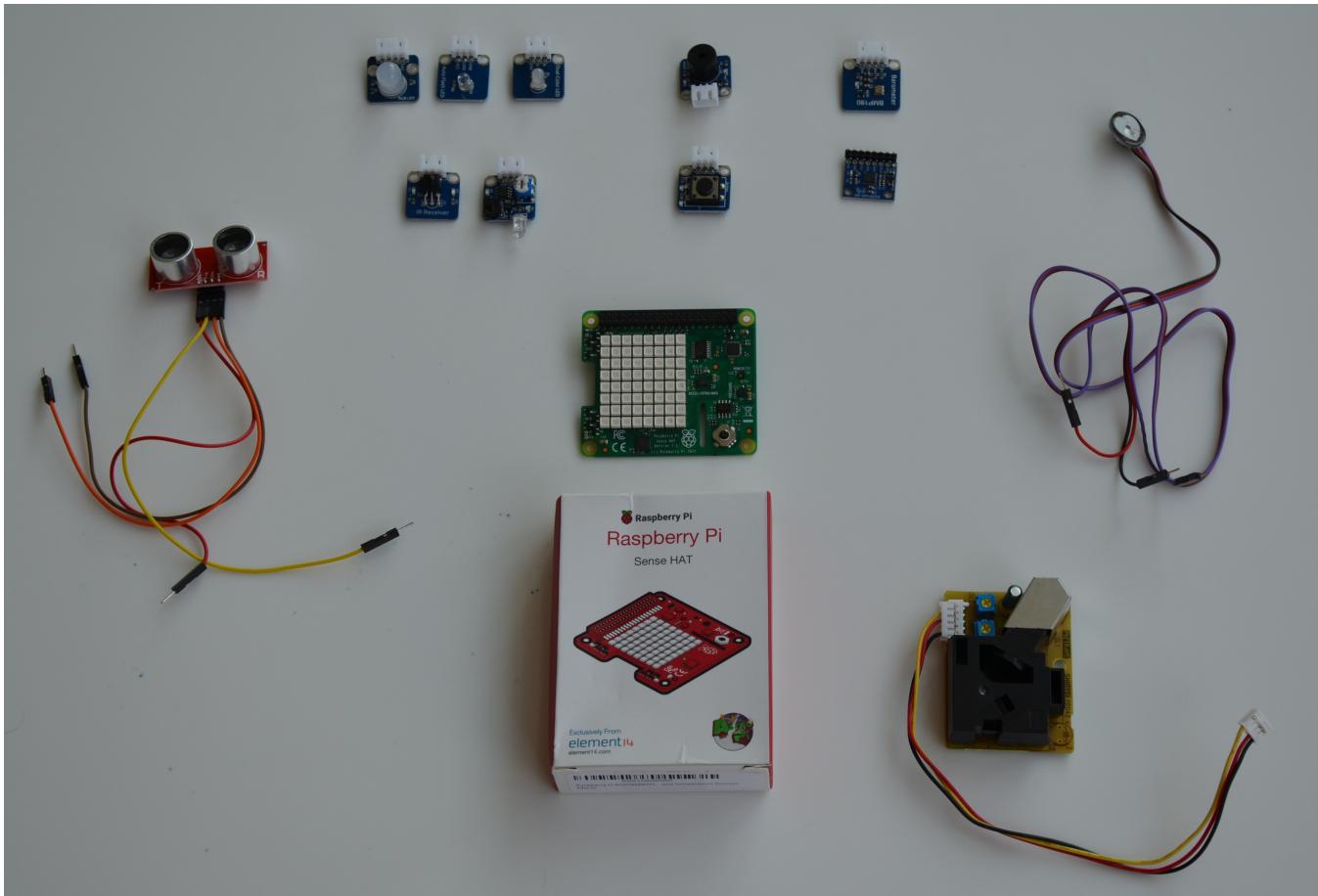
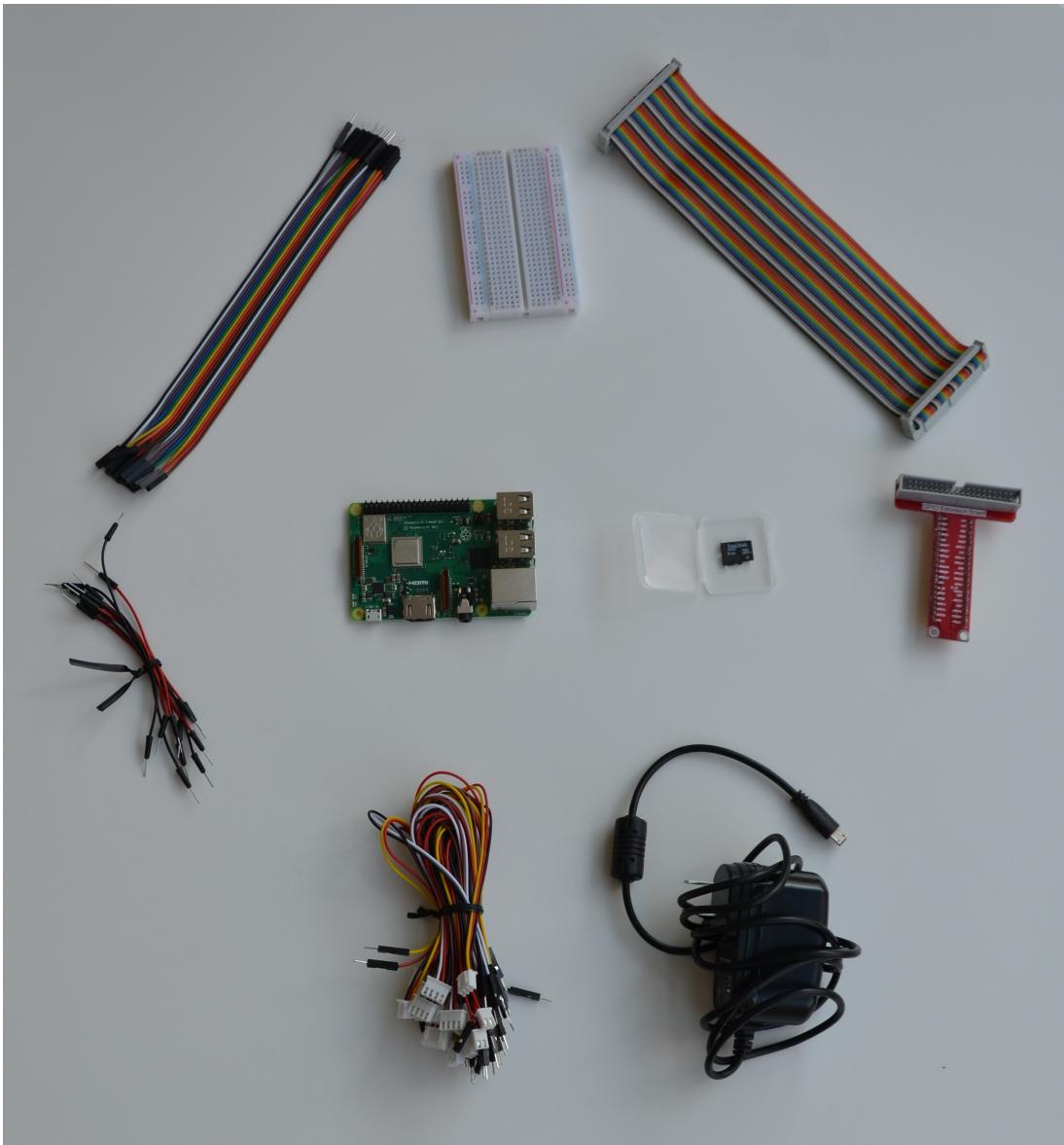


Source: <https://www.raspberrypi.org/help/>

GET STARTED WITH RASPBERRY PI



Source: <https://opensensorhub.org/2019/05/19/kinect-support-on-raspberrypi-3b/>

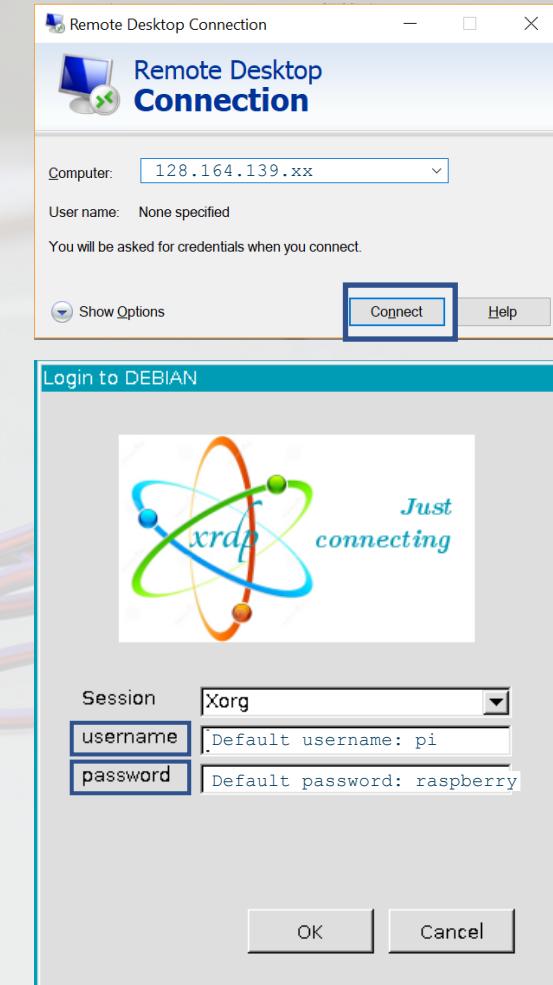


Components and sensors in your kits

Connect the Raspberry Pi Model 3 B+ (RPi) to a bread board



Access to the RPi in the laboratory



Each RPi is assigned a unique

- IP address <128.164.139.xx>
- username & password

Source: https://upload.wikimedia.org/wikipedia/commons/f/f1/XRDP_Screenshot.png