Chapter 1/1

Introduction

What you'll learn in this page

- **Understand** what the Internet of Things (IoT) is and why it is important
- **Understand** characteristics of IoT as a research topic.
- **Contrast** IoT with other computing paradigms.

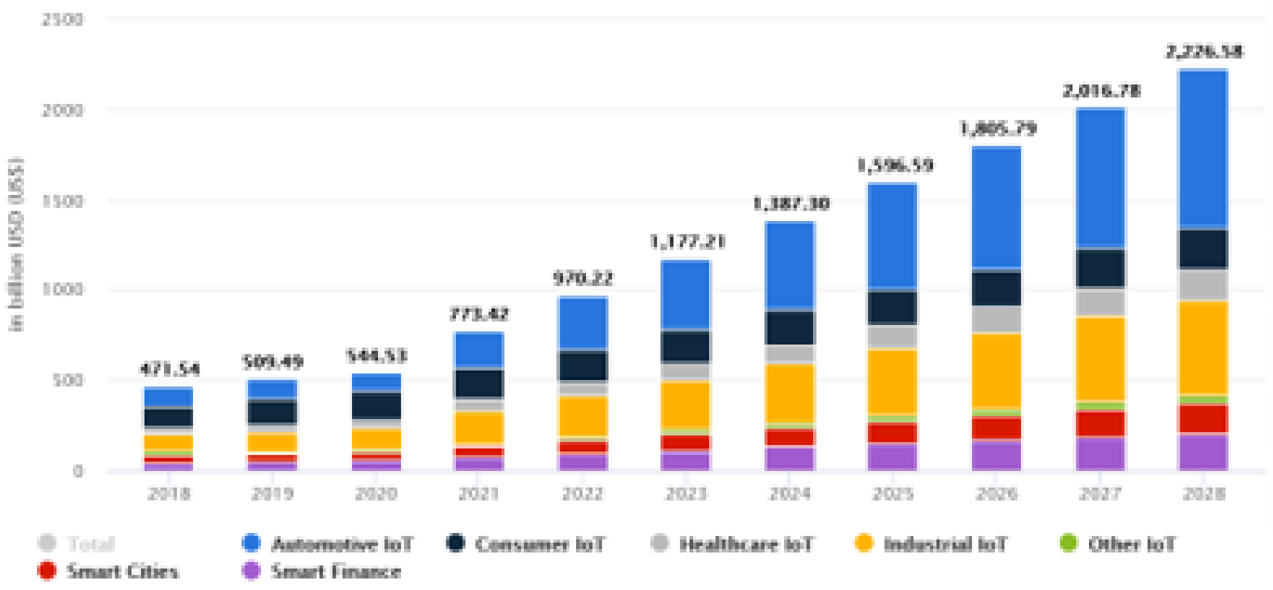
Devices that connect to the Internet or to other devices are everywhere. Most people have a smartphone, and people increasingly have tablets, smartwatches, or wearable devices (e.g., rings, earbuds, and health or fitness monitoring devices such as heart rate monitors). Homes and offices are populated by connected appliances ranging from TVs to washing machines, buildings use wireless energy monitoring devices to gather electricity consumption data, and other kinds of devices ranging from drones to fully automated cars are slowly becoming commonplace. Collectively these devices form a broader computing ecosystem which is known as **the Internet of Things** or **IoT**.

This MOOC provides a thorough overview and reference of key elements in the modern Internet of Things. The main learning objective is to provide the necessary skills and knowledge to be able to **design and evaluate Internet of Things devices, applications, and services**. The course is split into six chapters. The first chapter provides a high-level overview of IoT and IoT devices whereas successive chapters provide a detailed overview of the key sub-components of IoT devices, applications, and services.

Before going into details about what the Internet of Things is and what aspects there are to IoT, let us briefly discuss reasons for why IoT is an important domain in the modern computing landscape.

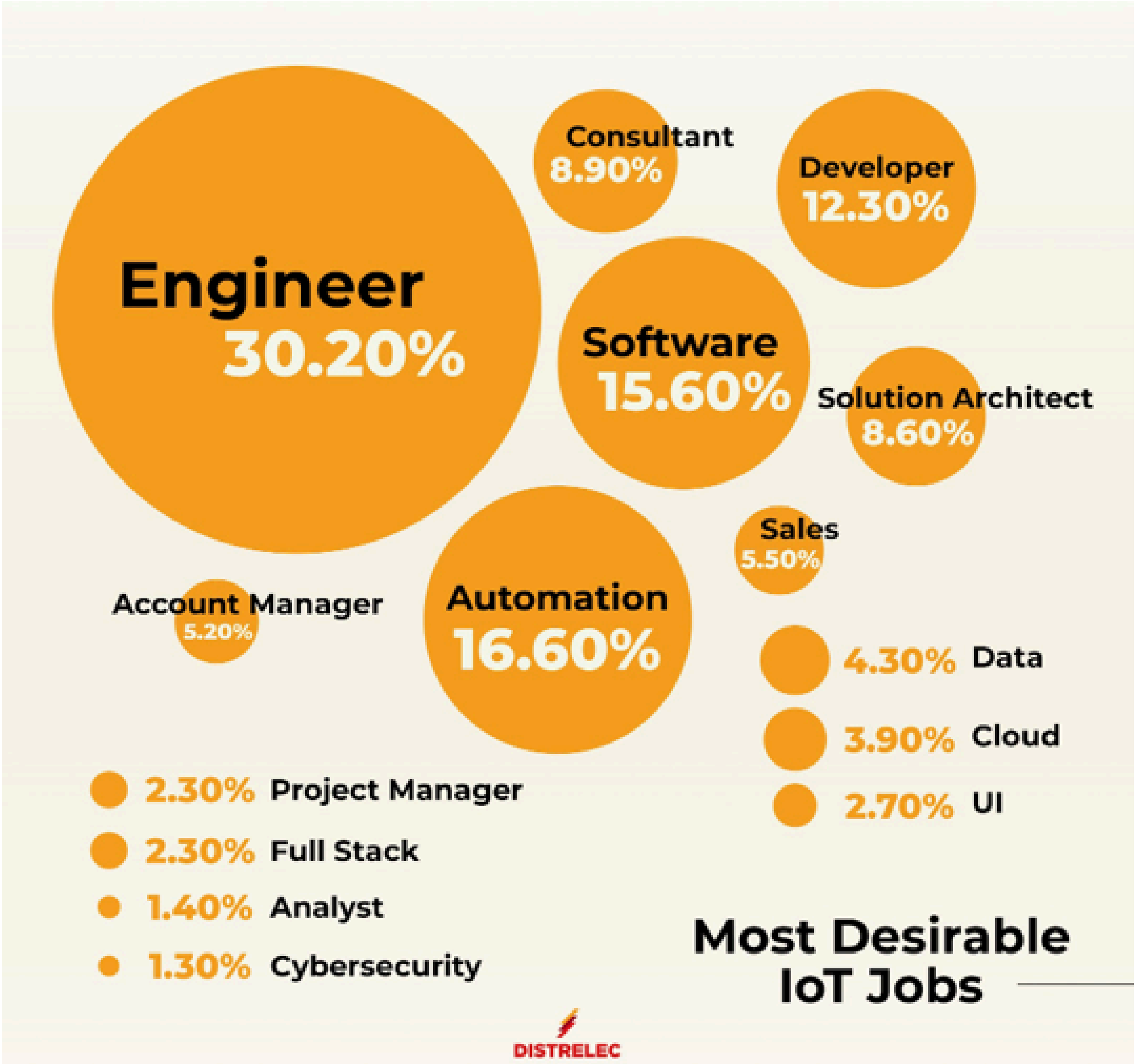
Why should you care about IoT?

The Internet of Things is built around **connected devices** which refer to any computing equipment that is connected to the Internet or that can connect with other devices in their vicinity. Over the past decade, the number of connected devices has witnessed significant growth with an estimated 17 billion devices already connecting to the Internet. Traditional computing devices, such as laptops, tablets, and smartphones typically account for half of this number. Indeed, in many countries people already own more than one connected device on average. While the growth in personal device ownership has started to slow down, the overall number of connected devices continues to grow thanks to increased availability of IoT devices. It should be noted that nowadays traditional computing devices are seen as part of the Internet of Things as these devices increasingly serve a role within IoT applications and services. The estimated increase of computing devices (IoT and traditional or non-IoT) is highlighted in the figure below.



Source: https://www.statista.com/outlook/tmo/internet-of-things/worldwide#revenue

The Internet of Things is not only the dominant source of computing devices for our everyday interactions, but it has also long served as one of the fastest growing ICT sectors. In 2018 the total market was estimated to be already worth more than $150 billion and estimates at that time suggested that the market would reach $1500 billion by 2025. Despite economic growth slowing down since then, the importance of IoT has remained stable. Indeed, IoT is seen as one of the key technological enablers for future economic growth as it can foster improved productivity. Another reason to study IoT is that IoT devices are increasingly used as sources of data, and companies are offering data scientists (and related) positions that build on data collected from IoT devices. Examples of jobs linked to IoT are shown in the figure below.



Source: https://knowhow.distrelec.com/internet-of-things/rise-of-the-internet-of-things-jobs/

As we mentioned above, the number of connected devices has grown rapidly over the years and the number of devices connected to the Internet surpassed the number of people already in 2008. However, this is not the only important development as the devices that are connected have also evolved over the years. Indeed, modern connected devices integrate **sensing, computing, interaction, and other capabilities**, offering opportunities to harness the devices and their capabilities to generate new types of applications and services. This development means that IoT can be used to bring benefits to everything from science to services and businesses. The availability of sensor-enabled connected devices also is a critical enabler for increased automation, control, and resource use optimization. For example, indoor environments can rely on IoT solutions to reduce excess energy use and agriculture IoT solutions can be used to control pesticide and watering schedules. Overall, IoT not so much enables these areas rather than **serves as technology integrator and framework** for integrating diverse capabilities. Similarly, the true value of IoT is not in the devices it enables but, **in the data, and capabilities that connected devices provide**.

A brief history of IoT

Things (-> 1970s)

While the popularity of the Internet of Things has only expanded significantly within the last two decades, the roots of the field stretch to the 1950s when Norman Joseph Woodland and Bernard Silver built and patented the first barcode reader (1952). The initial design comprised of a bullseye design shown in the figure below. The barcodes were read using a light emitter that illuminated the label contained in the code and a photomultiplier that read the light reflected by the code label. This design never received widespread acceptance due to the size of the required equipment and poor reliability of reading the codes. Nevertheless, this development is seen as the first step for the emergence of IoT as it offered the first known way to **address, identify** and **track everyday objects**.

Initial design of barcode (source: https://drexel.edu/news/archive/2012/october/barcode-60th-anniversary)

Almost 20 years later (1971), George Laurer at IBM created a new version of the barcode that relied on the emergence of laser optics and compact reading technologies. This technology is known as the Universal Product Code (UPC), and it offered the first large-scale technology for tracking and addressing products. The barcode designs were designed to be robust to distortions since most of them were generated using ink printers that were vulnerable to smudge errors from ink bleeding. UPC barcodes are still used today in practically every shop as the codes are affordable to produce and the reading technology is cheap and easily available. The figure below shows an example of an UPC barcode and its overall structure.

Barcode structure

Connected Things (1970s -> 1990s)

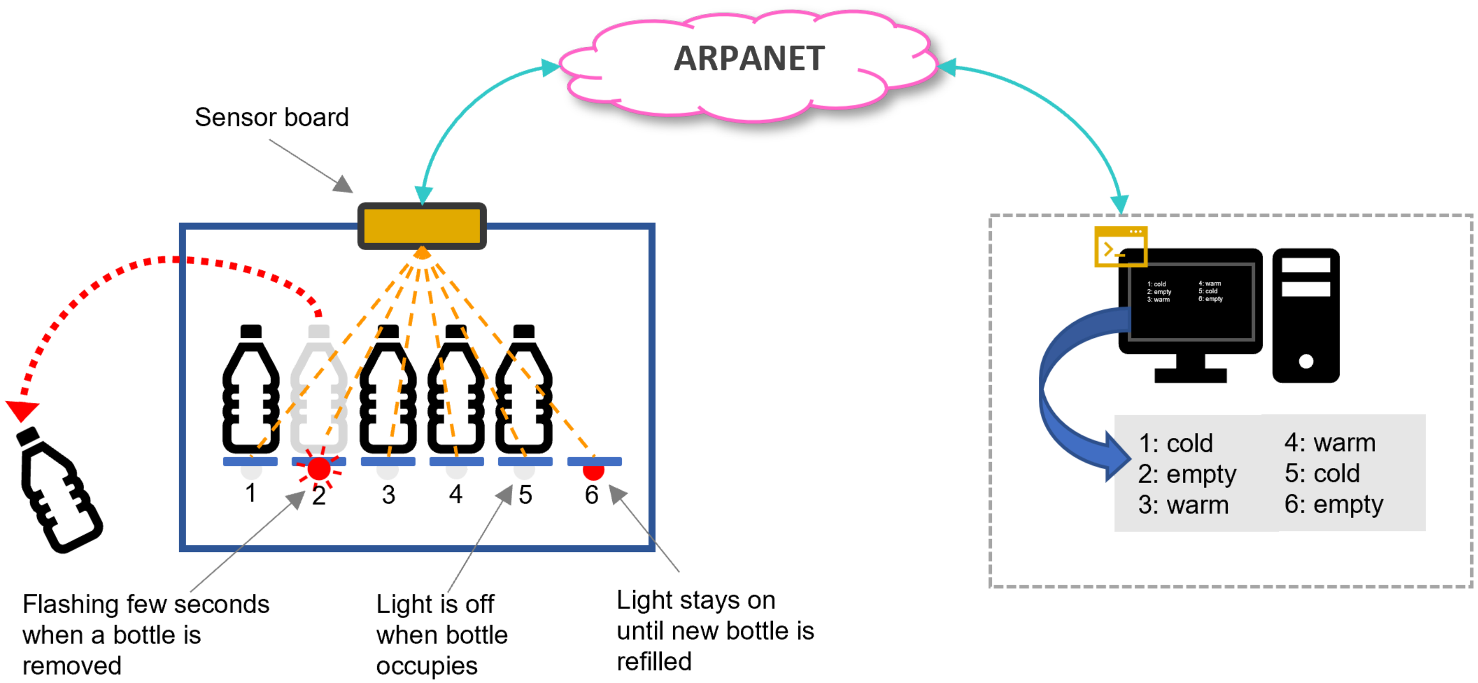
Barcodes - including later developments such as QR codes and other 2D codes - solved the issue of how to address, identify, and track objects. This enabled converting everyday objects into "things" that can be integrated into computing systems. This alone, however, is not sufficient for enabling IoT as the "Internet" part of the IoT refers to connectivity among the devices.

The roots of IoT connectivity align with the roots of modern telecommunications. The first major step was the development of **Arpanet**, the first packet-switching network, which was developed in the early 1970s. Arpanet resulted from the need to easily connect geographically spread research computers, and its development contributed to the development of network protocols (e.g., TCP/IP). The core principles underlying Arpanet were later integrated into the **Internet** as we know today which was officially launched in 1989.

The first "things" that harnessed the emergence of large-scale networking emerged in the 1980s and the mid-90s. These were initially focused on everyday objects that were connected to the network. One of the first such examples is the Carnegie Mellon University vending machine, which is often referred to as one of the first IoT devices. The machine provided a remote interface for monitoring product availability through the Arpanet and included the following main components:

- Sensors for detecting which shelves have bottles. This was based on a web camera that monitored LED lights placed on top of bottle racks. The light was green whenever the shelf had a bottle, and red otherwise.
- Simple algorithms to track the temperature of bottles (warm or cold). When the status of a shelf switched from empty to filled (i.e., the LED changed from red to green), the system marked the bottle as warm and started a 30-minute counter. Once this counter elapsed, the status of the bottle was changed to cold.
- Communication protocols to allow remote access to check the status of the machine.

An illustration of the internal workings of the vending machine and its functionality are shown in the figure below.



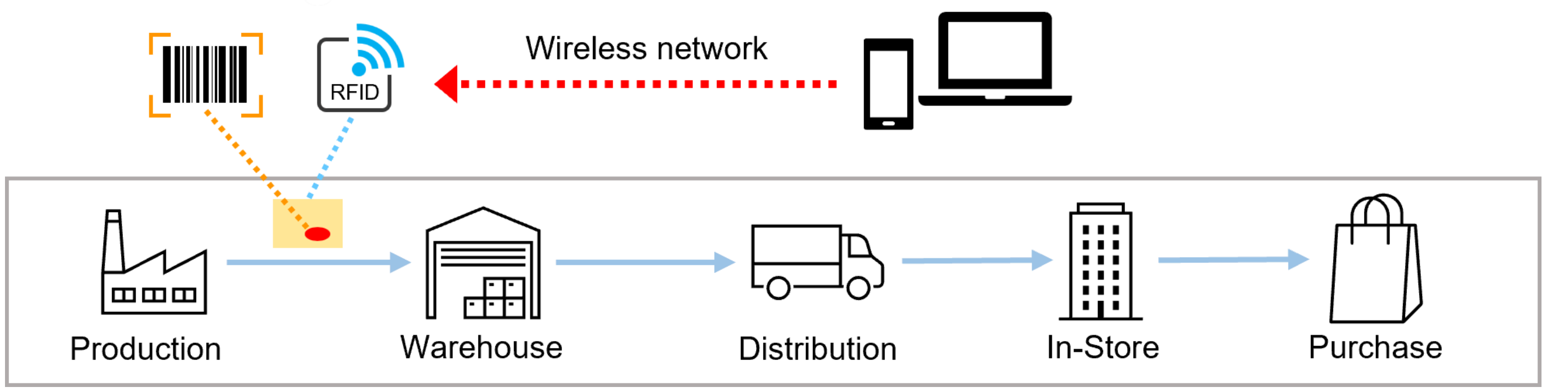
Monitoring product availability and product status

Towards Internet of Things (1990s - 2000s)

> *"The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so."*

Kevin Ashton

The first use of the term Internet of Things is attributed to Kevin Ashton and a presentation given at Procter & Gamble in 1999. The definition stems from the so-called "lipstick problem," which attempts to answer why one colour of lipstick is always sold out from a particular store. Answering this question was not possible with existing technologies but required a way to track objects through service chains. While barcodes (UPC) were already being used at cashiers, they were not widely adopted as part of the other parts of the service chain. Also, tracking every product individually at every step was not efficient and thus alternatives were needed. This resulted in significant research activity around the development of RFID technology, which made it possible to track containers instead of individual objects. An example of how the development of RFID together with UPC codes and networking allowed to solve the lipstick problem is shown in the figure below.



End-to-end product tracking using UPC codes, RFID, and wireless networks.

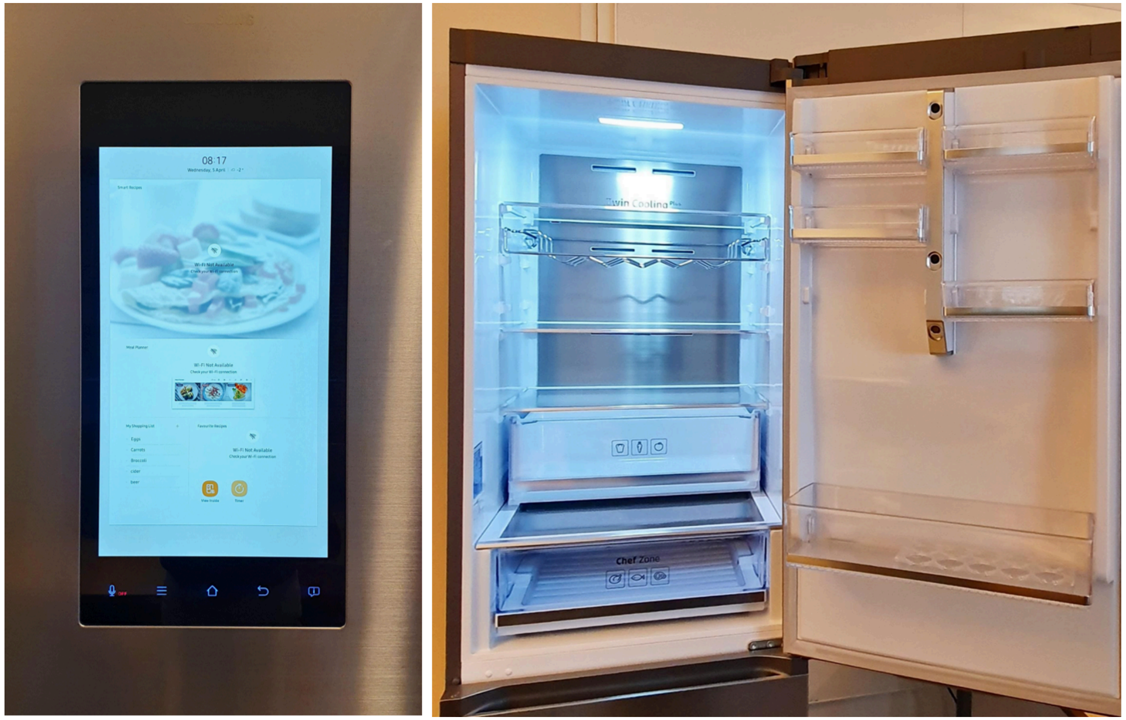
Modern Networking and the Mobile Internet (2000s ->)

A key phase for the large-scale uptake of IoT was the adoption of IPv6 in 1999. The initial version of the Internet was built around IPv4 which supported only approximately 4.3 billion network addresses, meaning that this was the upper limit of devices that could be connected. With IPv6 the number of addresses increased to 340 trillion trillion trillion addresses. This was due to a move from 32-bit address field to a 128-bit address field. IPv6 also brought other improvements, including better support for network security (including end-to-end encryption and secure name resolution) and improved connectivity and support for uniquely and directly addressing IoT devices.

Another important development in networking was the adoption of mobile Internet as it offered the first wireless communication solution that was widely available. Mobile Internet was launched in 2000 when the International Telecommunication Union (ITU) created a global standard for wireless data networks. This standard is called International Mobile Telecommunications-2000 (IMT-2000) and is more commonly known as the Third-Generation mobile network (3G). The first commercial 3G services were launched by NTT DoCoMo in Japan in 2001. The 3G standard offered fast wireless data transmission rates (about 5-8 Mbps) and low latency (100 - 500 ms) which enabled mobile access to Internet services. Until then, practically all IoT devices required wired connectivity. Modern networking solutions, such as 4G and 5G, have further optimized the networks but the basic premise has remained the same.

Commercial Connected Things (2000s ->)

The first commercial Internet-connected devices started to appear between 2000 and 2005. As an example, we consider the LG Internet Digital DIOS (R-S73CT) which was the first smart fridge to appear on the commercial market. The fridge was launched In June 2000, after 3 years of research and an investment of about $50 million. Besides the functions of a common fridge, the R-S73CT included new components. These included an LCD screen that provided information of the inside temperature and the level of freshness of products inside the fridge and that allowed to manage and reproduce diverse content (e.g., music, video messages, recipes, schedules). The figure below shows a modern connected smart fridge which integrates a separate screen, camera, temperature sensors, and allows services. Since then, other home appliances and other devices have been developed as IoT enabled devices. Examples of these devices will be discussed in later sections of this course.



Camera

Temperature sensor

Touch screen

View recipes

Travel pictures

Morning brief

. . .

A camera, temperature sensor, and a touch screen are integrated in a smart fridge, enabling multi-tasking during meal preparation.

The Internet of Things: Definition

During this course we use the following definition for the Internet of Things:

> the Internet of Things is a paradigm where **physical and virtual things are interconnected through**
> **communication technologies** with the goal of providing a **global platform for advanced services of the information society.**

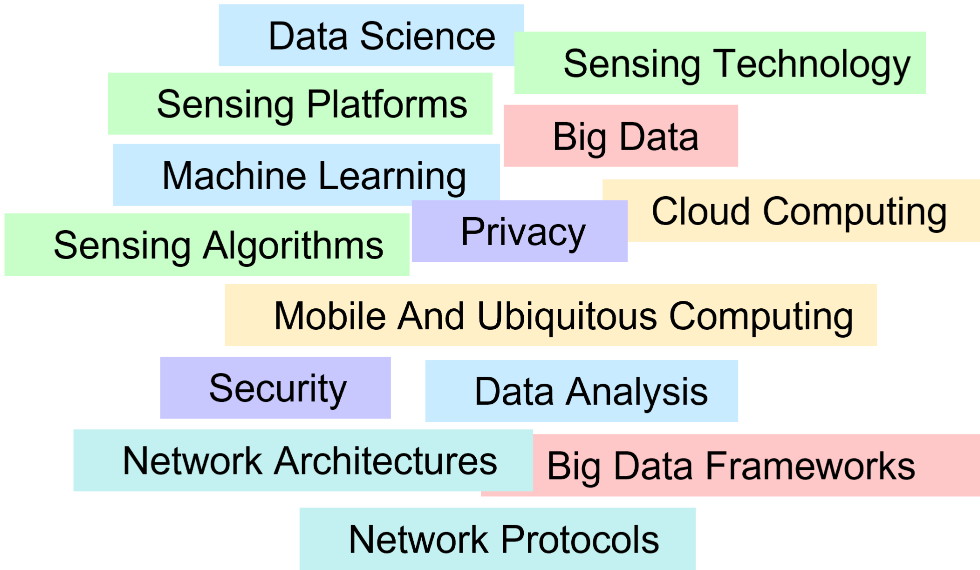
> ITU-T Y.2060 recommendation of the Internet of Things standards initiative http://www.itu.int/en/ITU-T/gsi/iot/

This definition highlights that IoT is not simply about connectivity but about offering a **platform** on top of which services can be built, and that this platform integrates **things** that are **networked**. This definition of IoT is broader than what was originally used in the field and reflects the evolution of the field as well as the overall computing landscape. For example, as indicated during the historical overview, first IoT devices were everyday objects that were connected to the Internet and potentially also accessible from the Internet (e.g., household appliances, personal items, cars, bicycles). Since then, the definition has become broader, and it reflects technological developments. For example, devices are assumed to be interconnected but they do not necessarily need to be connected to / over the Internet. Hence, direct connectivity to other devices is often sufficient. At the same time, the services and the devices are often considered to be more powerful, e.g., most IoT devices are nowadays "smart" in the sense that they can be programmed, they integrate sensors to produce and collect data, and they can operate AI / intelligence to react to their environment.

IoT as Research Topic

Research in a particular domain usually reflects the maturity of the field. The early phase of any technology tends to focus on exploring the potential of the technology, and IoT is no exception with the first research explorations focusing on developing new kinds of IoT applications and services. As the field has matured and as the definition of IoT has evolved, also the nature of IoT as a research topic has evolved from the early days.

Nowadays IoT is not necessarily a separate research domain, rather a confluence of research topics that address challenges in designing, implementing and operating IoT systems. These challenges relate to the distinct parts of IoT systems which are covered during the course. Key research directions within IoT are highlighted in the word cloud below.



Examples of research topics within IoT.

To understand the focus of IoT research, it is important to understand how it relates and differs from related computing paradigms. In the case of Internet of Things, there are two closely related research paradigms that provide reference points for understanding IoT. These two paradigms are mobile computing and ubiquitous computing.

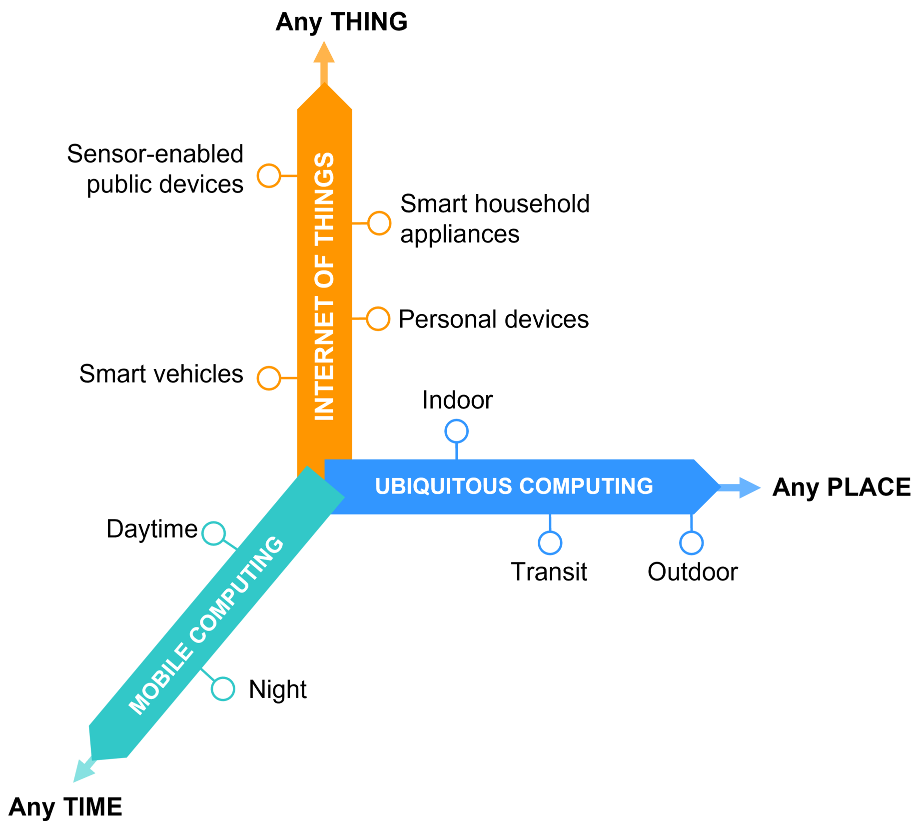
Mobile computing refers to computing that is characterized by **portability** as the computing device can be carried with all the time. When these devices offer connectivity, it offers the chance to access people, data, computing, or other resources, regardless of whether the people carrying the devices are stationary or on the move. Thus, the focus of mobile computing is to offer computing **at any time**.

Ubiquitous computing, in contrast, is a computing paradigm that builds around the availability of devices in our surroundings. The following quote from Mark Weiser (early 1990s) summarizes the basic premise of ubiquitous computing:

> The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.
>
> Mark Weiser

Thus, ubiquitous computing offers the possibility to access computing in **any place**.

Internet of Things encapsulates both mobile computing and ubiquitous computing but extends them to computing with **any thing**. These relationships between the different research paradigms are illustrated in the figure below.



Relationships between research paradigms

Summary

- Internet of Things defined as a paradigm where physical and virtual things are interconnected through communication technologies with the goal of providing a global platform for advanced services of the information society.
- Objects that are **addressable** and **identifiable** are things. Things that are **interconnected** are part of the Internet of Things, provided they can be used to develop applications / services.

- IoT serves as a technology enabler for integrating diverse technologies and modern computing positions are increasingly linked with IoT in one form or another.
- IoT as a research paradigm focuses on any thing, place, and time computing.

Exercises

Exercise:

1.1. Understanding the Internet of Things

TRIES 1 POINTS 2.33/3

Instructions

Choose the correct answer(s) about the following concepts related with the Internet of Things.

Which of the following apply for IoT?

Devices interconnected but not necessarily over the Internet.

Everyday objects being connected to/over the Internet.

Physical and virtual things interconnected through communication technologies.

Your answer was partially correct. Which conditions does the ITU definition require?

A plastic bottle with a barcode

is addressable and identifiable.

is part of IoT.

can be used to implement services /applications.

Your answer was correct.

Compared with other paradigms, IoT involves computing for:

Any time, any place, and any thing.

Any time and any place.

Any thing and any place.

Your answer was correct.

Try again

Exercise:

1.1. Internet of Things Use Cases

TRIES 0 POINTS 3/3

Instructions

Your task is to determine whether the following applications belong to the IoT or not. Please pick either the option "IoT" or "Not IoT" depending which of them you feel is most appropriate for the given choice.

Video doorbell with a camera, microphone and remote door opening feature that allows communication and operation from the owner's smartphone.

IoT CORRECT

Not IoT INCORRECT

Your answer was correct. The video camera is addressable and identifiable (e.g., using MAC address), it is connected, and the overall solution is a service. Hence the example satisfies all criteria for IoT.

The Trojan Room coffee pot. An Internet connected web camera monitoring the level of remaining coffee in a pot.

IoT CORRECT

Not IoT INCORRECT

Your answer was correct. The camera is connected and hence part of IoT. The Trojan Room coffee pot is a service that has been built using the connected thing. So there are some elements of IoT and thus the example is at least somewhat part of IoT.

The Trojan Room coffee pot without the coffee pot, i.e., an Internet connected web camera monitoring the level of remaining coffee in a pot when the pot is taken away.

IoT INCORRECT

Not IoT CORRECT

Your answer was correct. The camera is connected and hence part of IoT. Once the coffee pot is removed, the installation no longer acts as a service, and hence it cannot be anymore seen as part of IoT.

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Things and IoT Application Domains