Internet of Things

Lecture 1

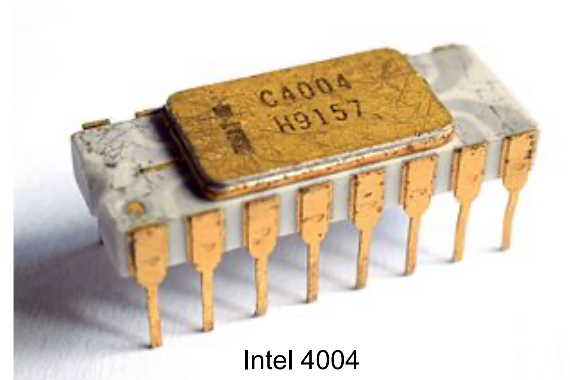
Introduction to and History of the Internet of Things

Michael Engel

From embedded systems to the IoT

Microcontroller history – 4004, 8051, AVR

- Intel 4004: 4 bit, November 1971
    - 0.5-0.7 MHz
    - first commercially produced microprocessor, used in calculators
- Intel 8051: 8 bit, 1980
    - 12 MHz, 128 bytes RAM, 4 kB ROM
    - still shipping billions of units every year!
- Atmel/Microchip AVR: 8 bit, since 1996
    - many different models up to 24 MHz
    - 64 bytes–16 kB RAM
    - popular as basis of Arduino boards
    - Developed as master thesis of two students at NTNU (Alf-Egil Bogen and Vegard Wollan)



Intel 4004

Intel 8051

32 bit are the norm today

8-bit microcontrollers are too limited for modern applications, e.g.

- Wireless communication (Wifi/802.11, Bluetooth, 2/3/4/5G, …)
- Image and audio processing

- ARM-based 32-bit microprocessors (Cortex-A also 64 bit today)
    - Original ARM CPU ("Acorn RISC Machine") introduced 1986
- Three families provided by ARM today as basis for different SoCs
    - Cortex-M: microcontrollers
    - Cortex-R: real-time controllers
    - Cortex-A: application processors (mobile phones, tablets)
- Example: Nordic Semiconductor nRF52840 (2016)
    - Cortex-M4, 64 MHz, floating point, 1 MB flash, 256 kB RAM
    - Many wireless protocols: Bluetooth Low Energy, Bluetooth mesh, NFC, Thread and Zigbee

The consequences of Moore's Law

Moore's Law (1965): *observation that **the number of transistors in a dense integrated circuit (IC) doubles about every two years***

Empirical relationship linked to gains from experience in production (not a law of physics!) observed by Gordon Moore

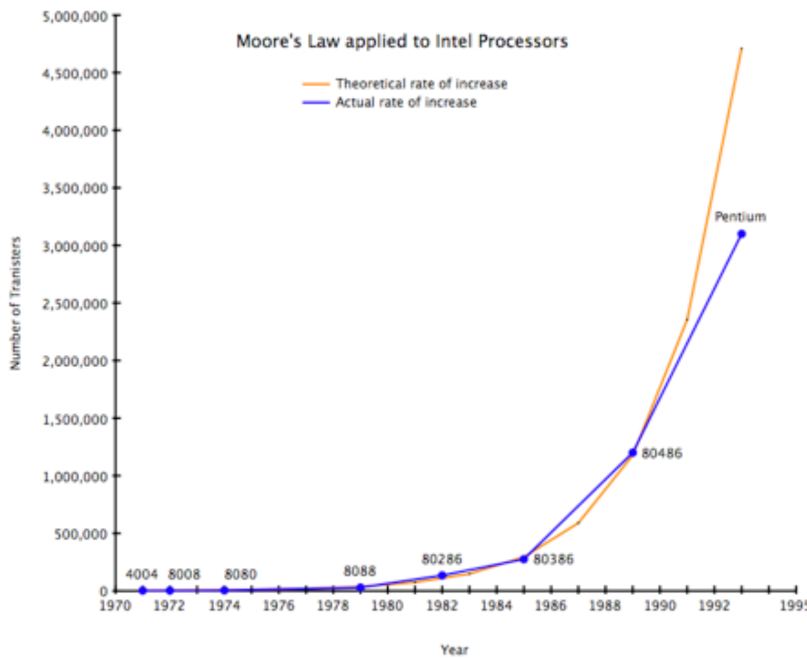
Reason: shrinking structure sizes

- Intel 4004 (1971): 10 μm
- nRF52840 (2016): 55 nm
- Apple M1 (2020): 5 nm

Smaller structure sizes

➛ more transistors per silicon area

➛ lower cost of semiconductors



Scaling and the end of Moore's Law

Dennard scaling – another important observation especially for battery-operated devices:

"As transistors get smaller, their power density stays constant, so that the power use stays in proportion with area."

This implies that both voltage and current scale (downward) with the semiconductor structure length.

Both Moore's Law and Dennard scaling hit physical limits today
⇒ New approaches to scaling and energy efficiency must be found

(Tiny) computers are everywhere

Moore's Law enabled increasing functionality and speed and lower prices; in addition, Dennard Scaling predicted improvements in energy efficiency.

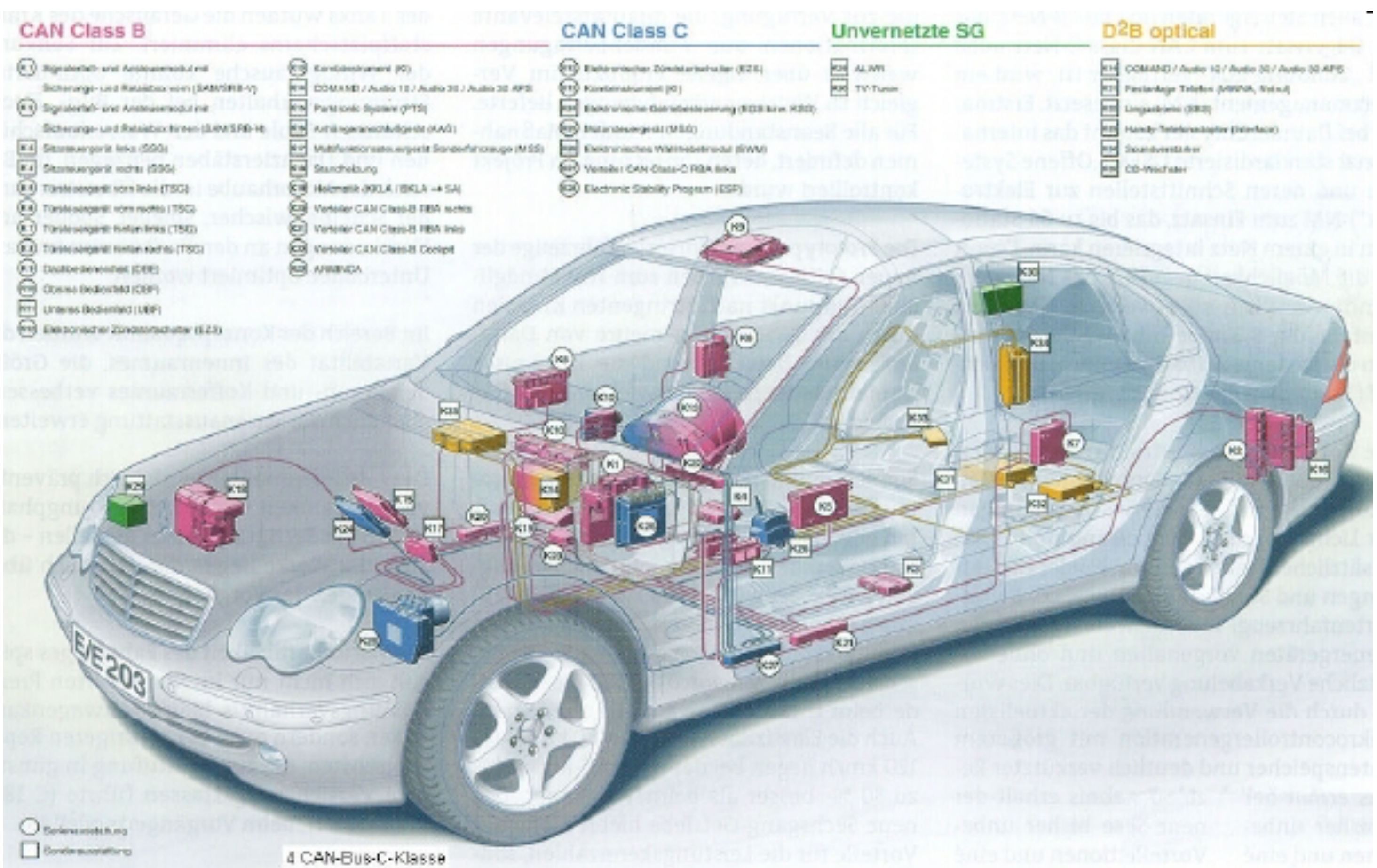
Consequence: Microprocessors and microcontrollers could be integrated into almost any device ⇒ e***mbedded systems***

> *"Embedded systems are information processing systems embedded into enclosing products"* [5]

Networking (especially wireless) proliferated starting in the late 1990s with IEEE802.11 (Wifi) and Bluetooth due to the availability of highly integrated semiconductors to handle communication.

(Tiny) computers are everywhere – example

A modern car uses more than 100 embedded devices (called ECUs – embedded control units) which are networked using different standards.



Mark Weiser’s groundbreaking ideas

Early work at **Xerox’ PARC research labs**, which also invented

- Graphical user interfaces and the mouse (Douglas Engelbart)
- Ethernet networks (Robert Metcalfe et al.)
- The laser printer, the personal computer, electronic paper, …

In 1991, **Mark Weiser** worked at PARC and formulated his vision in "The Computer for the 21st Century" [1]:

Mark Weiser (1952–1999), photo by Xerox, fair use

"Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ***ubiquitous*** *that no one will notice their presence."*

This is a direct consequence of the progress of Moore’s Law.

Ubiquitous computing principles

Some of Weiser’s principles (nr. 1 and 3) were focused on human interaction with computers. The large invisible part of the IoT infrastructure is captured in nrs. 2 and 4.

The set of ubiquitous computing principles in Weiser’s paper [1]:

1. The purpose of a computer is to help you do something else
2. The best computer is a quiet, invisible servant
3. The more you can do by intuition the smarter you are; the computer should extend your unconscious
4. Technology should create calm

In *Designing Calm Technology* [6] Weiser and John Seely Brown describe calm technology as "that which informs but doesn't demand our focus or attention."

The "post PC" era

Three generations of computing

1. **Mainframe** Computing:

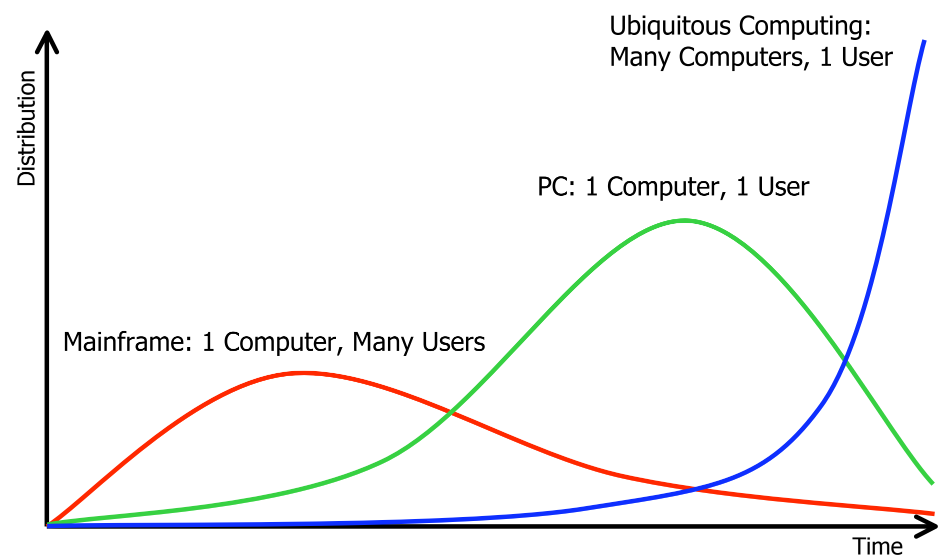
   One computer, many users

2. **Desktop** Computing:

   One computer per user

3. **Ubiquitous** Computing:

   Many computers per user



(According to Mark Weiser)

Early ubiquitous devices

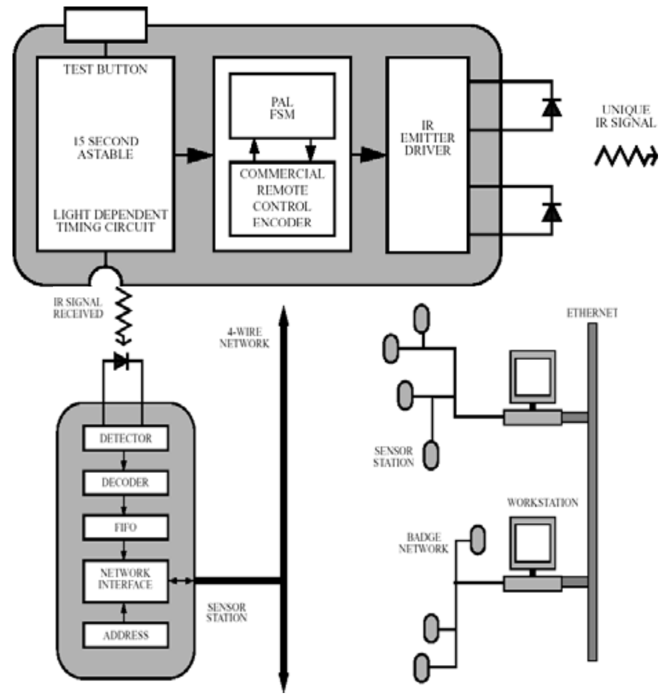
Olivetti/AT&T's **Active Badges** (1992) [2]

Badges emit infrared (IR remote) signals every 15s. Buttons can trigger events, sensors distributed in the building

Functionality

- Teleport
    - Redirect screen output from "home" computer to nearby computer
- Phone forwarding
    - Automatically forward phone calls to nearest phone

Different Active Badge devices



Active Badge technology

Pictures by Olivetti

Early ubiquitous devices

Xerox **ParcTab** (1993) [3]

- Mobile tab-sized devices
- Motorola 683xx processor, 4MB RAM
- Unistroke input via pen

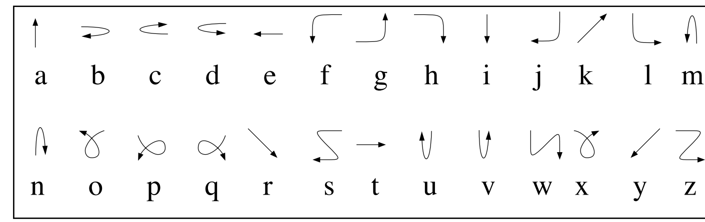
Infrared **wireless base station**

- Base stations in the ceiling
- Low bandwidth, modulated carrier
- Transmission radius ~7m

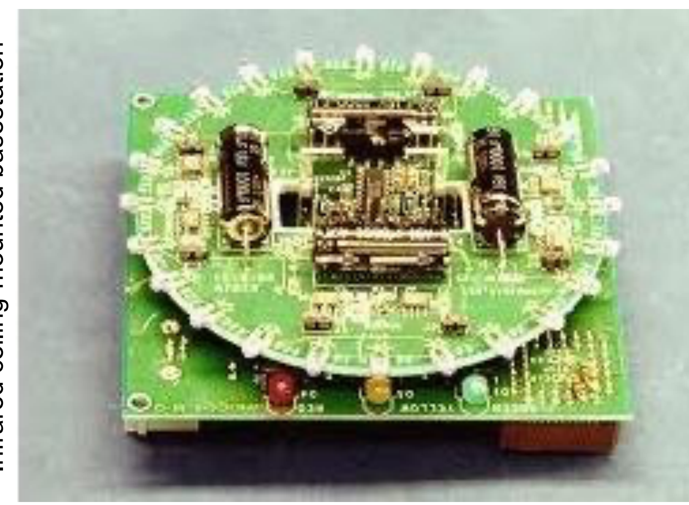
Context-aware applications

- Information access
- Communication and collaboration

Xerox ParcTab handheld device



Unistroke character input system



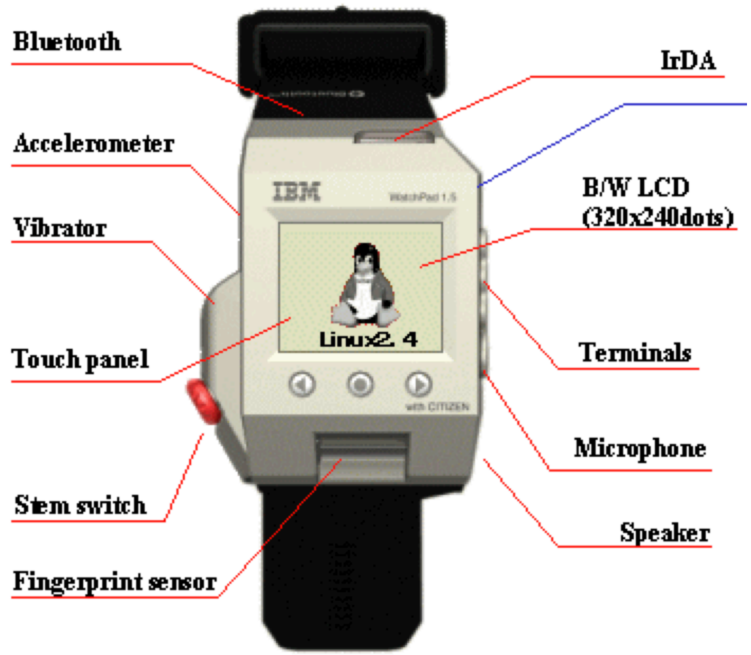
Infrared ceiling-mounted basestation

Pictures by Xerox

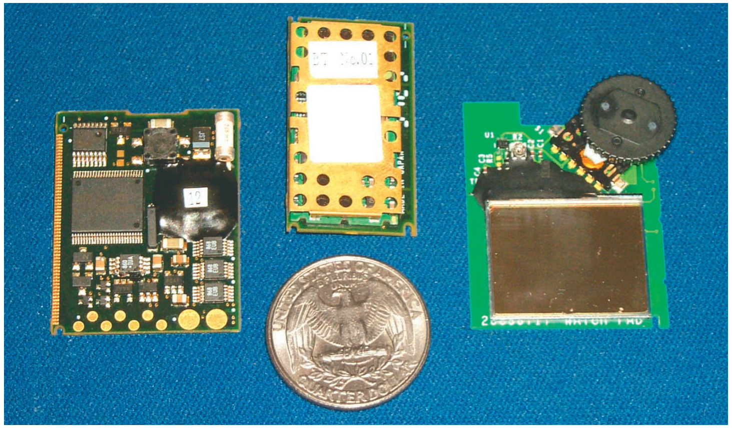
IBM Linux watch

IBM **WatchPad** (1999) [4]

- Size: 65mm x 46mm x 16mm
- Weight: 43g (w/o band)
- CPU: ARM7 (18–74MHz)
- Input Devices
  - Touch Panel
  - Stem Switch (crown)
  - 3 Buttons
- Display: 320x240 monochrome LCD (later model: 640x480 OLED)
- Memory: 8MB DRAM, 16MB Flash
- **Communication**
  - Bluetooth, IrDA, Serial (Cradle)
- Other Devices – Speaker, Mic, Vibrator, Fingerprint sensor, Two-axis Accelerometer



Watchpad prototype



Watchpad PCBs

Pictures by IBM

WatchPad applications

Many different applications were prototyped
(see also https://researcher.watson.ibm.com/researcher/view_group_subpage.php?id=8146)

- Personal Information Management
- Gesture recognition, Handwriting input
- Controller for other devices
- Mobile Web Services
- Limited function WML browser
- Symbiosis with other devices (Everywhere Display)
- Lynx browser
- SIP User-agent
- Viewer for a GPS in backpack
- Mobile Payments
- Password Vault

Pictures by IBM

Ubiquitous networking

Prototypes and early devices used infrared light communication (1990s)

- IrDA (Infrared Data Association) standard: 850-900 nm light
- Line-of-sight required, in practice speeds up to 4 MBit/s
- Different application layer protocols, IrOBEX (object exchange), IrCOMM (serial interface emulation)

Proliferation of wireless network technology (since late 1990s)

Enabled by availability of ISM radio frequency band (2.4 GHz)

- First generation wireless networks (**WiFi**): IEEE 802.11 standard (introduced 1997)
    - originally 2 MBit/s, now up to 700 MBit/s (802.11ac)
    - use of 5 GHz frequency band in later standards to avoid overloaded 2.4 GHz ISM band
    - commonly used as replacement for cabled ethernet infrastructures
- **Bluetooth** (since 1998)
    - exchange data between fixed and mobile devices and build personal area networks
    - short range: up to 10m in the most commonly used mode
- **Low power** wireless networking
    - IEEE 802.15.4 – basis for protocols such as Zigbee, 6LoWPAN and Thread
    - Bluetooth Low Energy (BLE) – independent of classic Bluetooth (since 2006)
- **Mobile** network infrastructures
    - 2G (first digital standard) in Finland: GSM in 1991 up to 40 kBit/s, today 5G (up to 4 GBit/s)
- **Wide range** low throughput (LoRaWAN)
    - proprietary technology for long-range transmissions with low power consumption (up to 27 kBit/s)

Wireless sensor networks

"*Networks of spatially dispersed and dedicated sensors that monitor and record the physical conditions of the environment and forward the collected data to a central location*" [7] – **a predecessor and important part of IoT technology today**.

Active research area since the late 1990s with many applications

- Area monitoring
- Health care monitoring
- Habitat Monitoring
- Environmental/Earth sensing
    - air/water quality, forest fires, landslide monitoring
- Industrial monitoring
    - machine health, data logging, structural health

Common characteristics

- Power consumption constraints, nodes use batteries or energy harvesting
- Resilience – network is capable of handing node failures
- Node mobility, heterogeneous node infrastructures, scalability of networks

Cyber-physical systems

Cyber-physical systems (CPS) are "*engineered systems that are built from and depend upon the synergy of computational and physical components*" [5]

The physical environment is important here, CPS interact with it by using different sensors and actuators.

Example systems include
- smart grid
- autonomous automobile systems
- medical monitoring
- industrial control systems
- robotics systems
- automatic pilot avionics

Merging it all: the IoT

"*The internet of things, or IoT, is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer **data** over a network without requiring human-to-human or human-to-computer interaction.*" [8]

The IoT builds on previously discussed technologies embedded/cyber-physical systems, ubiquitous computing, wireless networking and sensor networks.

"*A thing in the internet of things can be a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low or any other natural or man-made object that can be assigned an Internet Protocol (IP) address and is able to transfer data over a network.*" [8]

However, IoT applications comprise more than these fundamental technologies

- What about ***data*** in the IoT?

It’s all about data?

IoT systems are complex, networked, heterogeneous distributed systems [9].
How is application data handled in IoT systems?

Protocols for the IoT can be broadly classified into

- Network protocols for IoT (Datalink / Physical layers)
- IoT data protocols (Presentation / Application layers)

IoT data protocols are used to connect low-power IoT devices.

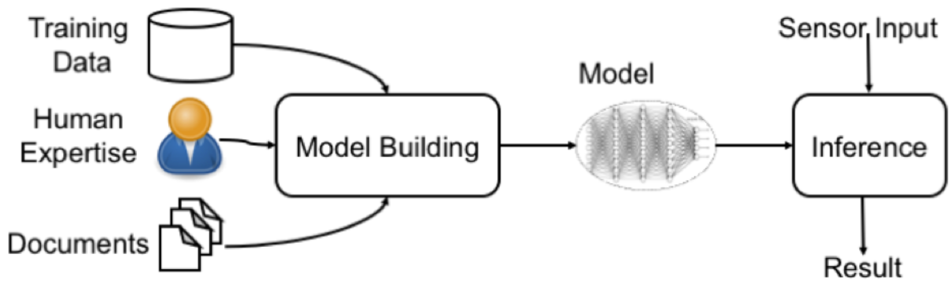
- Provide communication with hardware on the user side

Examples

- MQTT (Message Queuing Telemetry Transport)
  - publisher-subscriber messaging model, simple data flow between different devices
- CoAP (Constrained Application Protocol)
  - application layer protocol to address the needs of HTTP-based IoT systems
- AMQP (Advanced Message Queuing Protocol)
  - application layer protocol used for transactional messages between servers

It's all about AI?

Artificial intelligence (AI) is discussed as a technology to complement and extend IoT applications' capabilities [10]

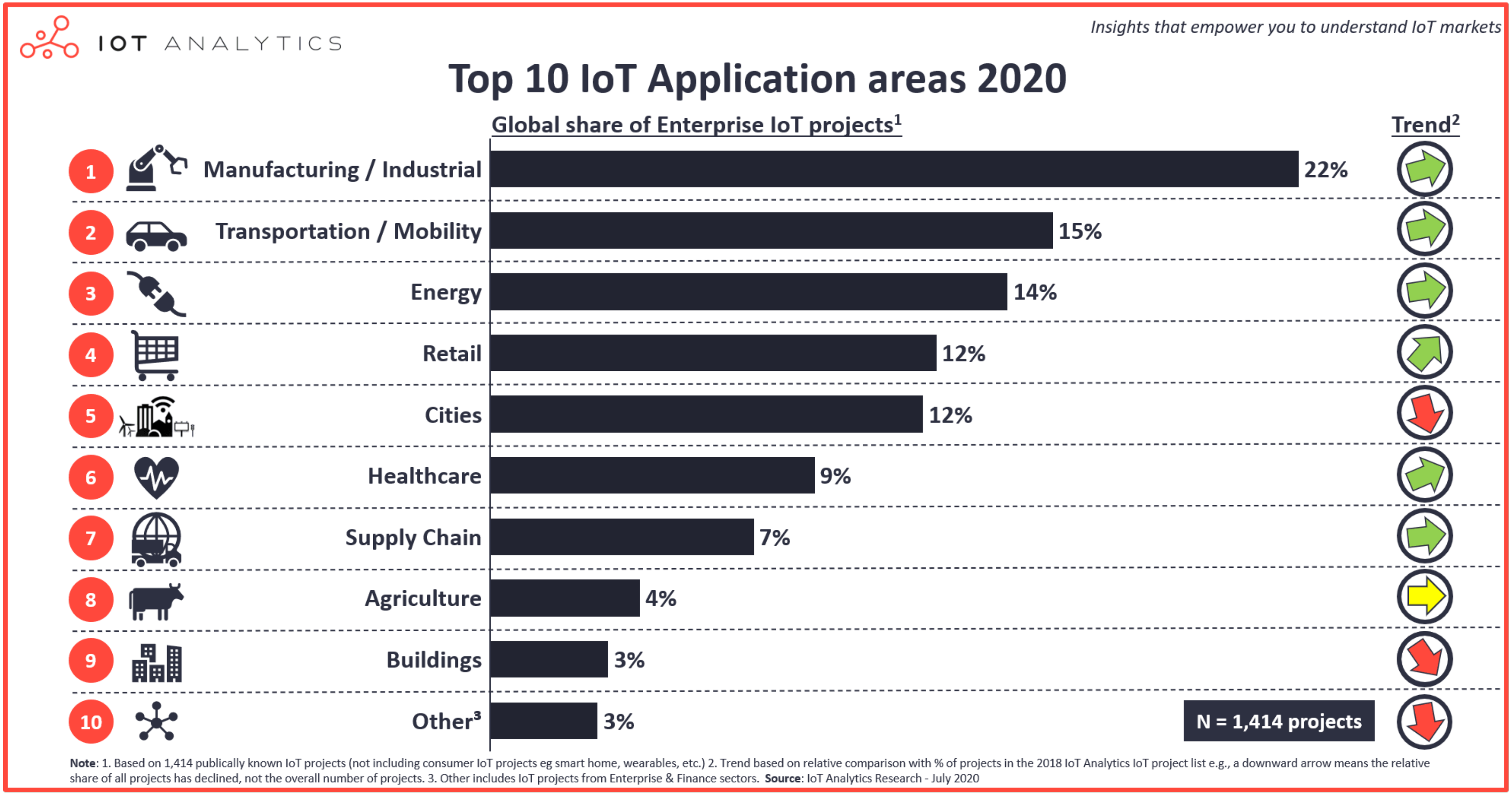


Abstracted AI approach from [10]

Here, AI often refers to machine learning technologies

- Renaissance through ***deep learning*** neural networks in the last decade
- Support complex tasks such as machine vision, speech recognition
- Usually require significant compute power
    - In the network infrastructure (**Cloud**), e.g. amazon's Alexa
    - On the end device (**Edge computing**), e.g. autonomous cars

IoT application areas



Most relevant IoT application areas 2020
(by https://iot-analytics.com)

IoT challenges

What are some of the major challenges developing IoT systems?

- Interoperability
    - many different protocols on all layers
- Energy efficiency
    - building low-power devices and applications
- Security and privacy
    - …the "S" in "IoT" stands for security 😀
- Support and longevity
    - planned obsolescence of devices and e-waste
    - electronic and software vs. device lifetime (e.g. in cars)
- Internet-protocol based IoT: IPv4-based address shortage
    - The adoption of IPv6 is still slow

Modelling the IoT

Levels

7 **Collaboration & Processes**
(Involving People & Business Processes)

6 **Application**
(Reporting, Analytics, Control)

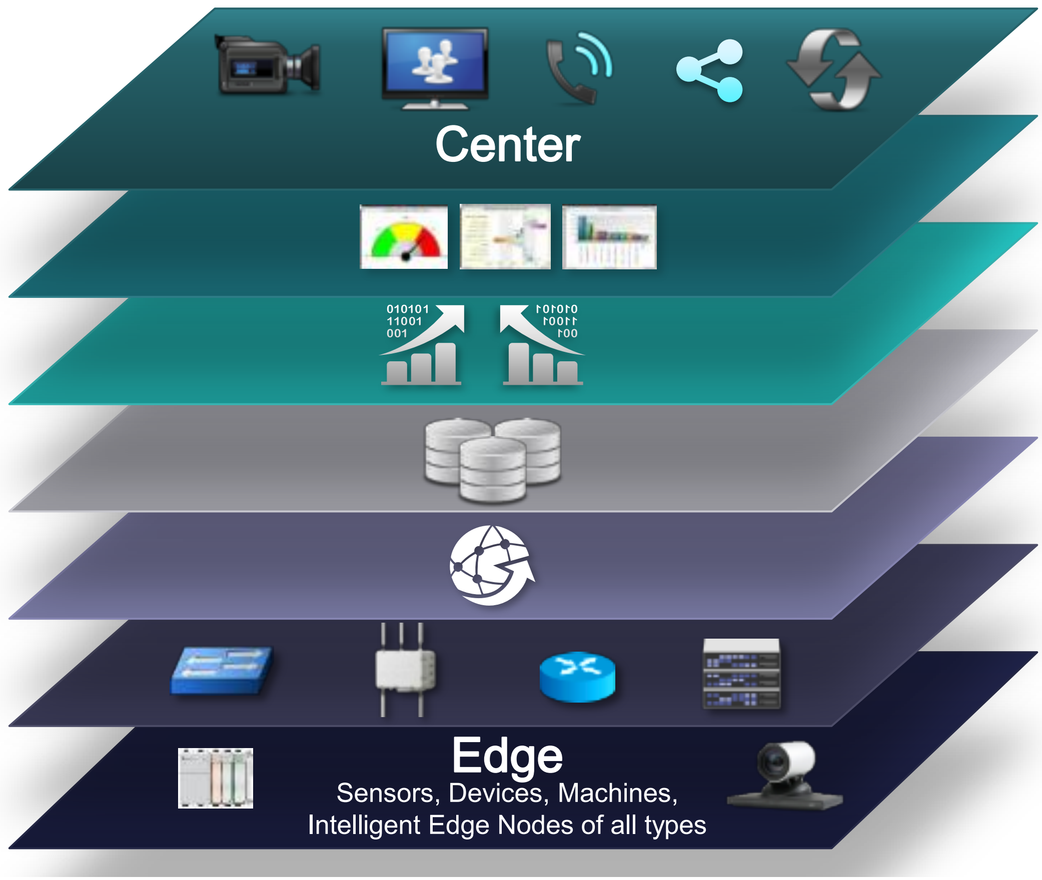
5 **Data Abstraction**
(Aggregation & Access)

4 **Data Accumulation**
(Storage)

3 **Edge Computing**
(Data Element Analysis & Transformation)

2 **Connectivity**
(Communication & Processing Units)

1 **Physical Devices & Controllers**
(The "Things" in IoT)



IoT World forum reference model

Defining the IoT

Perhaps the most difficult question: ***what is the IoT?***

Everyone has
- a different idea
- different expectations and constraints
- different applications and use cases

This course…
- gives an insight of the most relevant areas of IoT technology
    - applications, infrastructure, data management, privacy and security, and energy efficiency
- provides real-world examples and use cases through case studies and interviews
- provides hands-on experience with IoT applications through a practical project (DVAD70 only)

Course overview (all included in DVAD70)

1. **Areas of application** (DVAD71)

   Health, smart homes, smart cities, industry 4.0, …

2. **Infrastructures** (DVAD72)

   Online sensors, gateway connections, mesh networks.
   Technologies such as NB-IoT, ZigBee, 433MHz, Z-Wave, LoRa, WiFi, Bluetooth, CoAP, MQTT

3. **Data management** (DVAD73)

   collection, storage, processing, analysis, automation, presentation)

4. **Privacy and security** (DVAD74)

   surveillance, behavioral patterns, encryption, firmware updates, attack vectors

5. **Energy optimisation** (DVAD75)

   10 years of battery life – how can we achieve this?
   What can influence energy consumption?
   How can we minimize energy consumption?

References

[1] Mark Weiser, *The Computer for the 21st Century*, Scientific American, September 1991

[2] Roy Want, Andy Hopper, Veronica Falcão, and Jonathan Gibbons. 1992. *The active badge location system*. ACM Trans. Inf. Syst. 10, 1 (Jan. 1992), 91–102. doi: 10.1145/128756.128759

[3] R. Want et al., *An overview of the PARCTAB ubiquitous computing experiment*, in IEEE Personal Communications, vol. 2, no. 6, pp. 28-43, Dec. 1995, doi: 10.1109/98.475986

[4] C. Narayanaswami, *IBM's Linux Watch: The Challenge of Miniaturization*, IEEE Computer January 2002, pp. 33-41, vol. 35, doi: 10.1109/2.976917

[5] Peter Marwedel, *Embedded System Design – Embedded Systems Foundations of Cyber-Physical Systems, and the Internet of Things*, Springer 2021, ISBN: 978-3-030-60909-2

Open access at https://link.springer.com/book/10.1007/978-3-030-60910-8

[6] Mark Weiser and John Seely Brown, *Designing Calm Technology*, Xerox PARC 1995

[7] Ullo, Silvia Liberata; Sinha, G. R. (2020-05-31), *Advances in Smart Environment Monitoring Systems Using IoT and Sensors*, Sensors (Basel). 20 (11): 3113

[8] Alexander Gillis, *What is internet of things (IoT)?,* IOT Agenda https://internetofthingsagenda.techtarget.com/definition/Internet-of-Things-IoT

[9] Friedemann Mattern and Christian Floerkemeier, *From the Internet of Computers to the Internet of Things*, Informatik-Spektrum 33(2):107–121 (2010)

[10] Seraphin B. Calo et al. *Edge computing architecture for applying AI to IoT*, 2017 IEEE International Conference on Big Data (Big Data). IEEE, 2017.