Lecture 1 - Introduction to Cyber-Physical Systems & Internet of Things

Lecture Information

Master's Degree	Digital Automation Engineering (D.M.270/04)
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Lecture Title	Cyber-Physical Systems & Internet of Things
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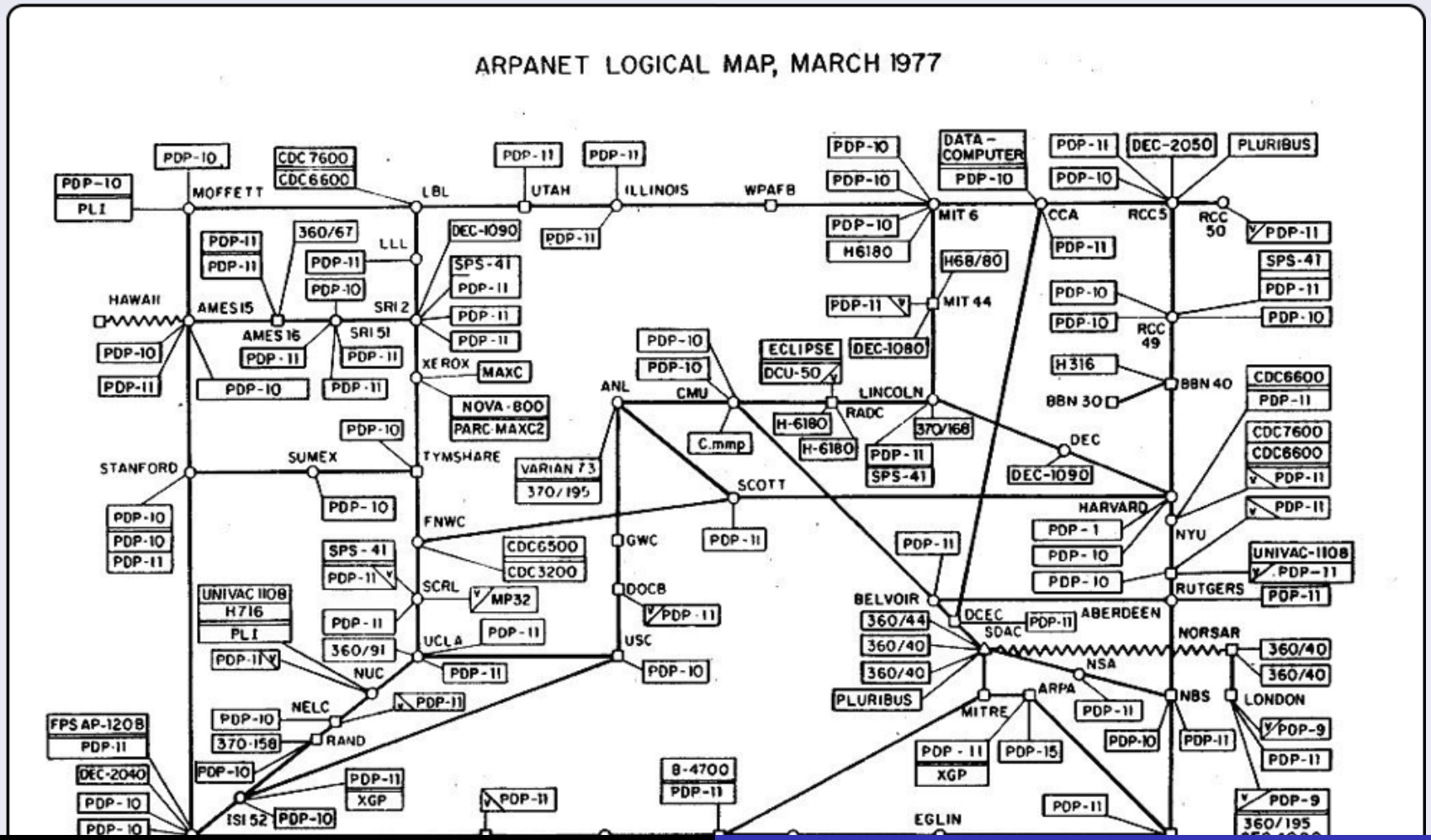
Outline

- Cyber-Physical Systems
- Cyber-Physical Application Scenarios
- Internet of Things (IoT) Definition & Vision
- From WSN and M2M to IoT
- IoT Characteristics
- IoT Protocol Stack
- IoT Connectivity
- IoT Software

Internet & Connected Devices

Where do we started ?

Since from the beginning of the Internet, there was the desire to connect more "things" to it. Source: ARPANET Completion Report: January 4, 1978.



Where are we today ?

Today, the Internet and the Web have evolved far beyond their original purpose of connecting a handful of computers. They now interconnect billions of devices worldwide—including smartphones, tablets, sensors, vehicles, appliances, and industrial machines—across every continent. This massive global network enables seamless communication, collaboration, and data exchange at unprecedented scale.

The exponential growth in connected devices has led to an explosion in the volume of data generated, transmitted, and processed every second. Modern Internet infrastructure supports vast amounts of real-time information, multimedia content, and interactive services. Cloud computing, edge computing, and advanced networking technologies have made it possible to deliver rich digital experiences, from social media and streaming platforms to e-commerce, smart cities, and industrial automation.

As a result, the Internet has become the backbone for countless services and applications, powering innovation and transforming how we live, work, and interact. The availability of massive data

The First "Connected Devices" - The Cold Drink Machine

The students of Carnegie Mellon University invent the ARPANET-connected coke machine. Four students from the School of Computer Science department installed the switches in the coke machine. They counted how many coke bottles had remained in each row and for how long. If the loaded bottle spends a long time in the machine, it is labeled "cold". All this data was then remotely available to customers via a finger interface. This experiment had inspired a lot of inventors all over the world to create their own connected appliances.

The First "Connected Devices" - The XCoffee

The XCoffee is created at the Computer Laboratory of the University of Cambridge. Two academics who worked at the Trojan Room in the laboratory had a video-frame grabber attached to one of the computers. They decided to connect a camera controlled by a server application that was observing the coffee pot and taking pictures of it several times a minute. Then the pictures were sent to the client application, to keep the user updated on the information about whether the pot was filled.

The Mobile Centric World

The mobile revolution is changing the way we live, work, and interact. Mobile devices have become an integral part of our daily lives, enabling us to stay connected, access information, and perform various tasks on the go. The proliferation of smartphones, tablets, and wearable devices has transformed communication, entertainment, and productivity, making it easier than ever to stay connected to the world around us.

In the picture below, you can see how the mobile revolution has transformed St. Peter's Square in Vatican City. The left image from 2005 shows a traditional gathering of people, while the right image from 2013 captures a sea of mobile devices held up by attendees, highlighting the significant impact of mobile technology on social interactions and events.

What a difference 8 years makes: St. Peter's Square in 2005 and yesterday (2013)" (Facebook NBC News)

Another interesting aspect of the mobile revolution is the rise of wearable computing devices, such as smartwatches, fitness trackers, and augmented reality glasses. These devices are designed to be worn on the body and provide users with real-time access to information, notifications, and health monitoring features.

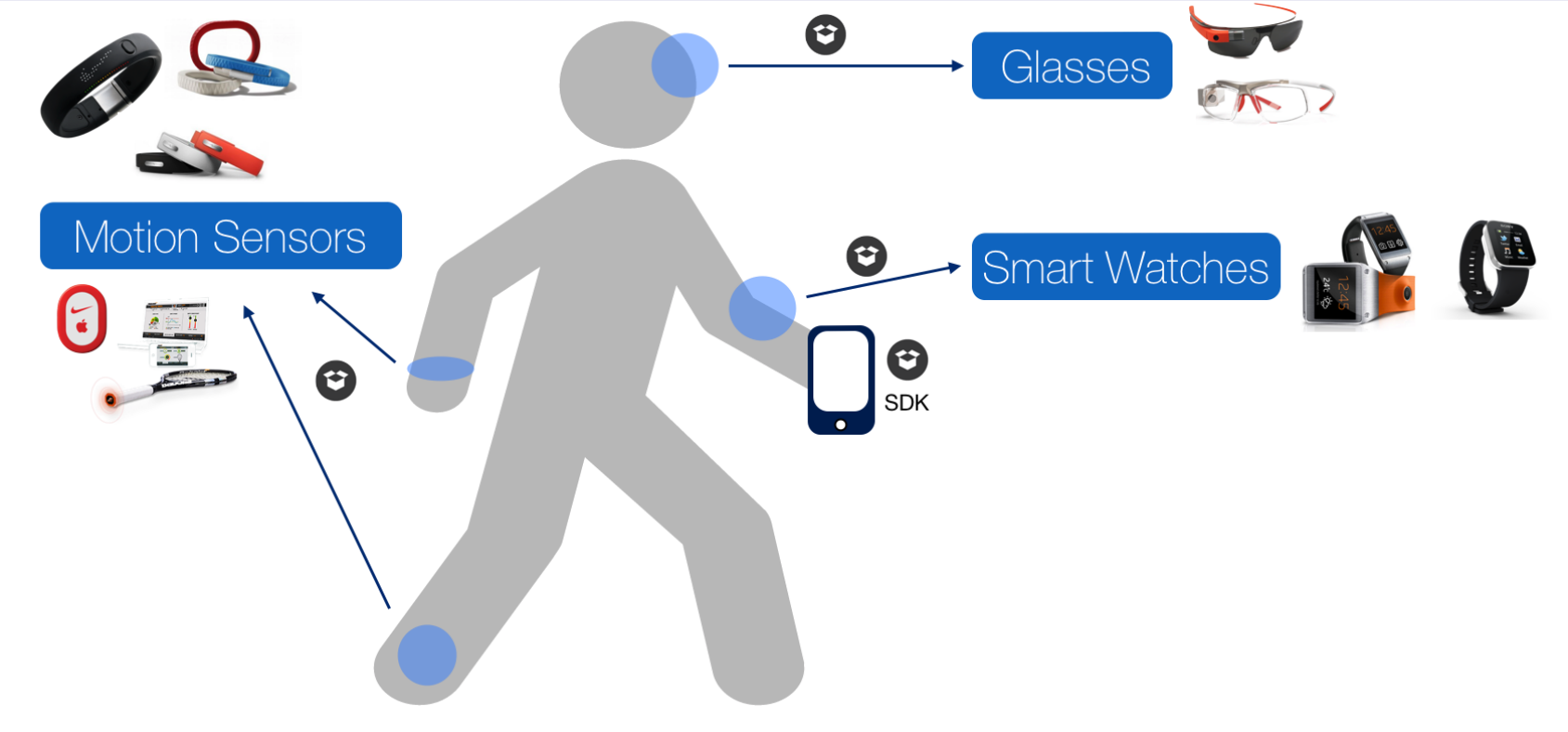


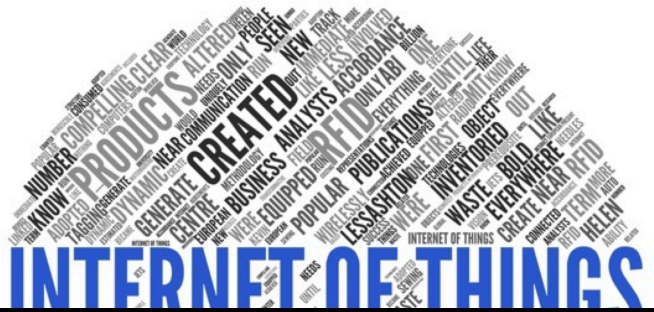
Figure 1.7: Wearable Computing Devices

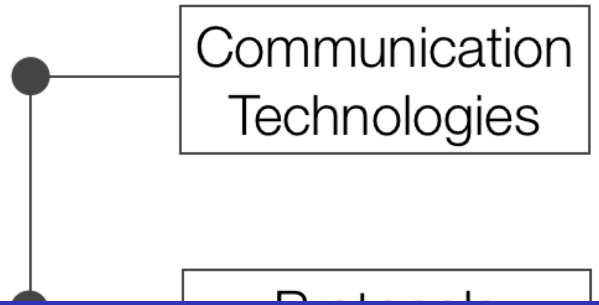
Nowadays, we are not just associated to one or two mobile devices,

The Internet of Things (IoT) Evolution & Revolution

In the context of the mobile revolution, the Internet of Things (IoT) has emerged as a transformative concept that envisions a world where everyday objects are connected to the internet, enabling them to collect and exchange data. The IoT represents a significant evolution in the way we interact with technology, as it extends connectivity beyond traditional computing devices to encompass a wide range of physical objects and environments.

> *The **Internet of Things (IoT)** refers to the idea of a network of networks with billions of uniquely identified physical devices denoted also as **Smart Objects** organized in an **Internet-like structure**. Smart Objects are items such as sensors, consumer devices, and enterprise assets that are **connected to both the Internet and each other**.*

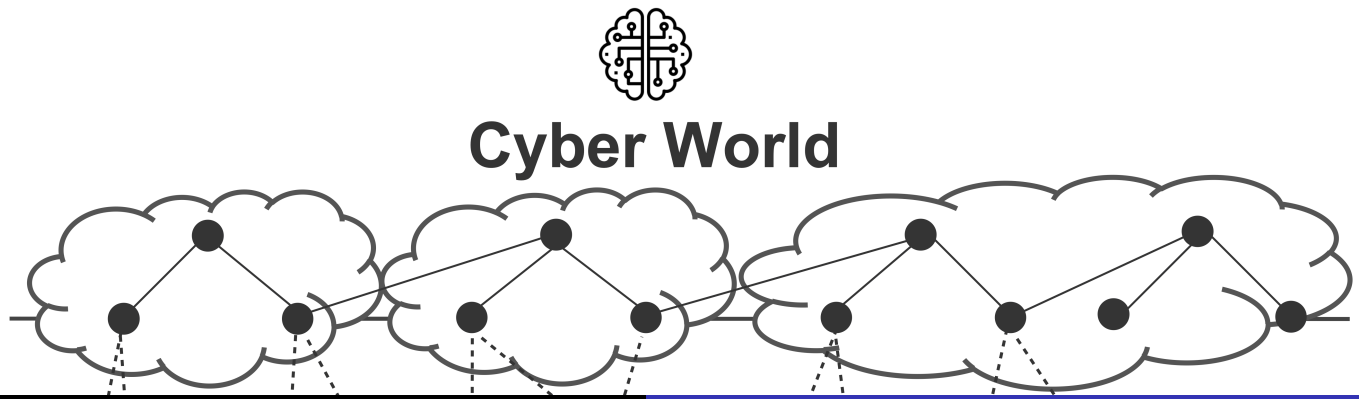




Cyber–Physical Systems

In this context, **Cyber-Physical Systems (CPS)** play a crucial role in bridging the gap between the physical and digital worlds. CPS are systems that integrate computation, networking, and physical processes to enable real-time monitoring, control, and interaction with the physical environment.

> *A **Cyber-Physical System (CPS)** refers to integrated systems that combine computational elements with physical components, enabling the interaction and collaboration between the digital and physical worlds. CPS typically involve a network of **sensors**, **actuators**, and **computational devices** that **collect data** from the physical environment, **process** it, and **control** physical processes or objects.*



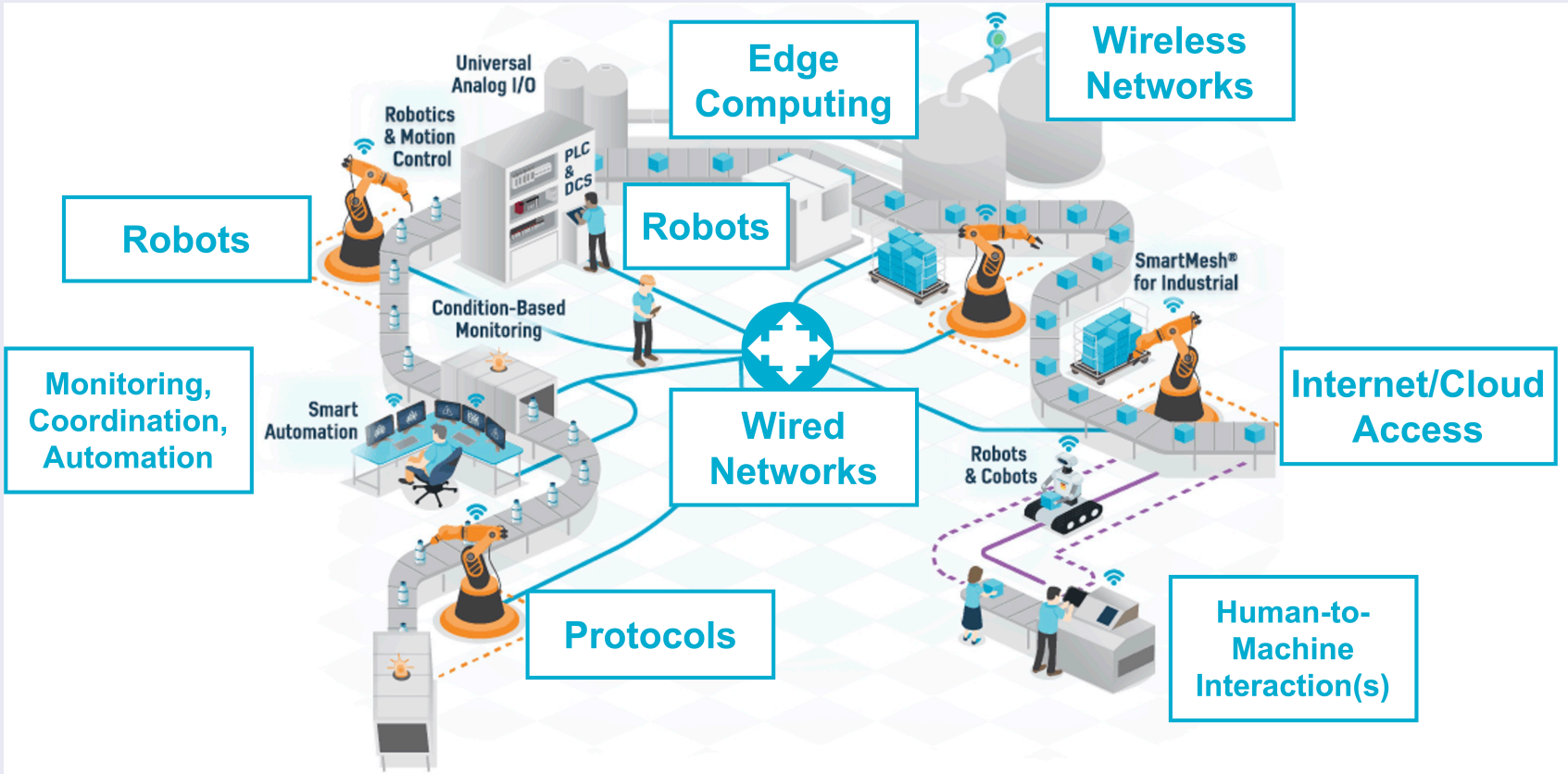
A Multi-Disciplinary Approach

The field of cyber-physical systems is cross-disciplinary in nature — building upon complex technology systems that promote advancement in countless fields Cyber-physical systems are engineered systems where functionalities and salient properties emerge from the networked interaction of cyber/digital and physical components CPS technology seeks to develop and deploy technologies needed for the seamless integration of cyber and physical systems including:

- Processes
- Software
- Networking
- Artificial Intelligence
- Coordination/Orchestration Algorithms
- Systems on Chip (SoC)
- Embedded Systems
- Robotics
- and counting ...

Cyber-physical systems are also a way to encompass the large

An Industrial "Example" of CPS Technologies



Sources: Link1, Link2

The previous figure shows some of the main technologies that are used in CPS and Industry 4.0 applications that traditionally are complex systems that integrate physical processes with computational resources and networking capabilities to enable real-time monitoring, control, and optimization of industrial

From Technologies to Services

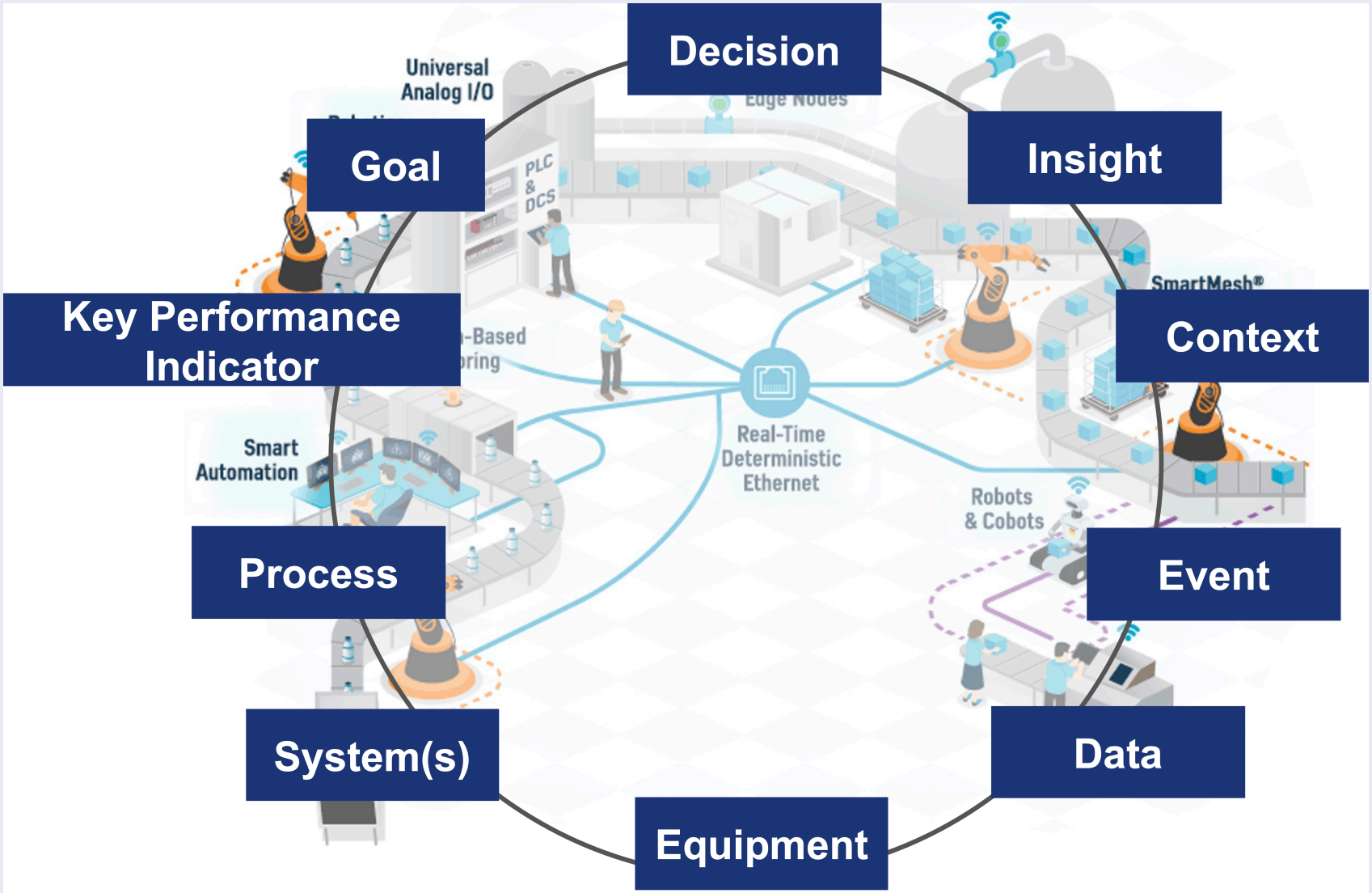


Figure 3: CPS Industrial Technologies

One important aspect of CPS is that technologies are meant to

CPS Software as Distributed Software

One of the main characteristics of CPS is that each component is characterized by its own software module that is responsible for the management of the component itself. When multiple components are integrated into a CPS, the software modules of each component need to interact and communicate with each other to enable the overall functionality of the system and we start talking about **Distributed Systems** and **Distributed Software**.

From CPS to CPSoS (Cyber-Physical System of Systems)

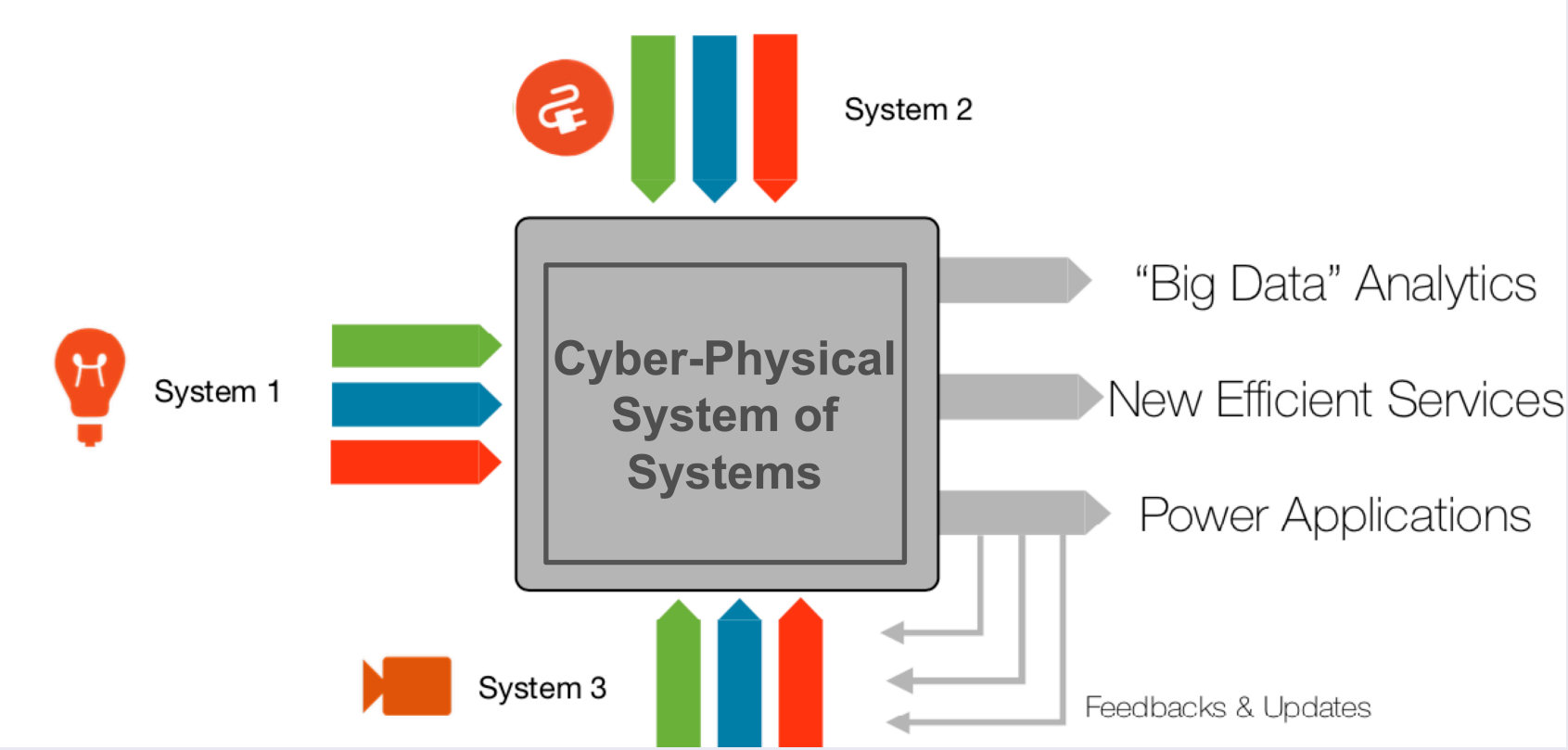


Figure 5: Cyber-Physical System of Systems

The concept of **Cyber-Physical System of Systems (CPSoS)** refers to the **integration** and **collaboration** of multiple, interconnected **Cyber-Physical Systems (CPSs)** to form a more complex and sophisticated system. In a CPSoS, each individual CPS maintains its **autonomy** and **functionality**, yet participates in