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Cyber Physical System (CPS) and Data Security

Module II: Digital Factory Modeling: How to formulate a virtual world

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Curriculum Development
of Master's Degree Program in
Industrial Engineering for Thailand Sustainable Smart Industry

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- **Learning Outcome**

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Learning Outcome

Formulate a data model representing data streamlining in a production line of an existing traditional factory using a data flow diagram

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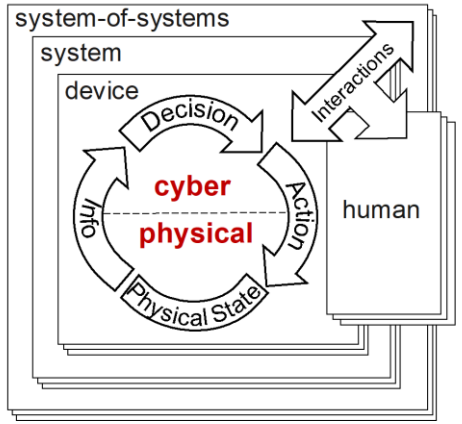
Definition

Digital Factory

A cyber physical system (CPS) is a complex system that integrates computation, communication, and physical processes. **Digital manufacturing** is a method of using computers and related technologies to control an entire production process. **Industry 4.0** can make manufacturing more efficient, flexible, and sustainable through communication and intelligence; therefore, it can increase the competitiveness. Key technologies such as the Internet of Things, cloud computing, machine-to-machine (M2M) communications, 3D printing, and Big Data have great impacts on Industry 4.0. Therefore, **CPS** is the way to **streamlining process** in a production line of an existing traditional factory using a data flow diagram for Digital factory is important.

- *Cyber-physical systems are physical, biological, and engineered systems whose operations are integrated, monitored, and/or controlled by a computational core. Components are networked at every scale.*



The Framework for Cyber-Physical Systems was released by the NIST CPSPWG on May 26, 2016

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Definition

What are Cyber Physical Systems?

https://www.youtube.com/watch?v=FxRJFLWbyjM

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Definition

What are Cyber Physical Systems?

https://www.youtube.com/watch?v=C53GIimgLCA

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Definition

What are Cyber Physical Systems?

- Cyber – computation, communication, and control that are discrete, logical, and switched
- Physical – natural and human-made systems governed by the laws of physics and operating in continuous time
- Cyber-Physical Systems – systems in which the cyber and physical systems are tightly integrated at all scales and levels Change from cyber merely appliquéd on physical
- Change from physical with off-the-shelf commodity “computing as parts” mindset
- Change from ad hoc to grounded, assured development

https://www.sciencedirect.com/science/article/pii/S2095809918306120X

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Definition

Why Cyber Physical Systems?

- **Embedded computers allow us to add capabilities to physical systems.**

  eg: Computer - controlled automotive engines are fuel-efficient and low-emission.

- **By merging computing and communication with physical processes, CPS brings many benefits:**

  Safer and more efficient systems

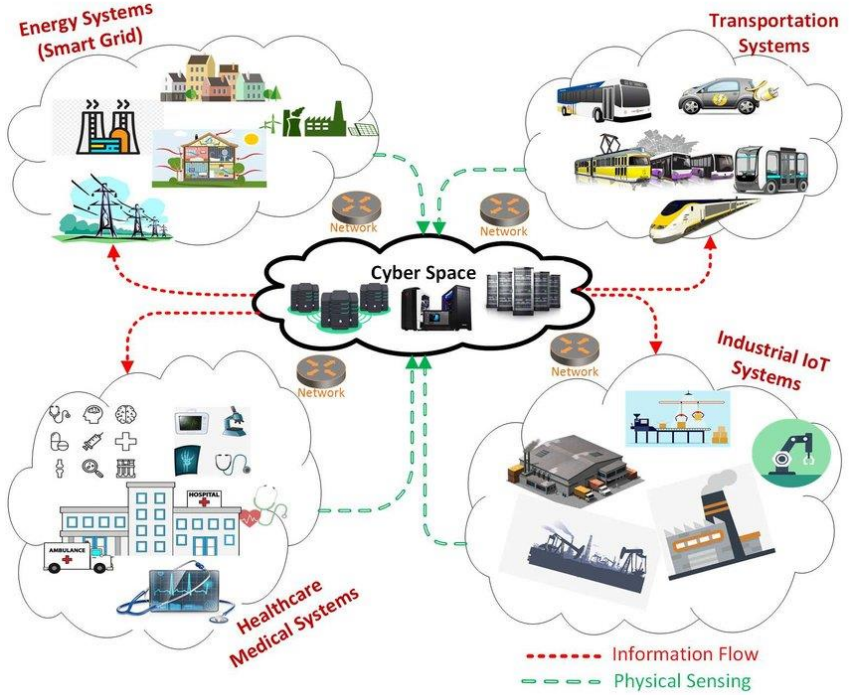
  Reduce the cost of building and operating systems

  Could form complex systems that provide new capabilities

- **Technological and Economic Drivers**

  The decreasing cost of computation, networking, and sensing provides the economic motivation.

  Environmental pressures make new technologies appear to improve energy efficiency and reduce pollution.



https://www.researchgate.net/figure/Application-Scenarios-of-cyber-physical-systems-describing-the-information-flow-and_fig2_329466954

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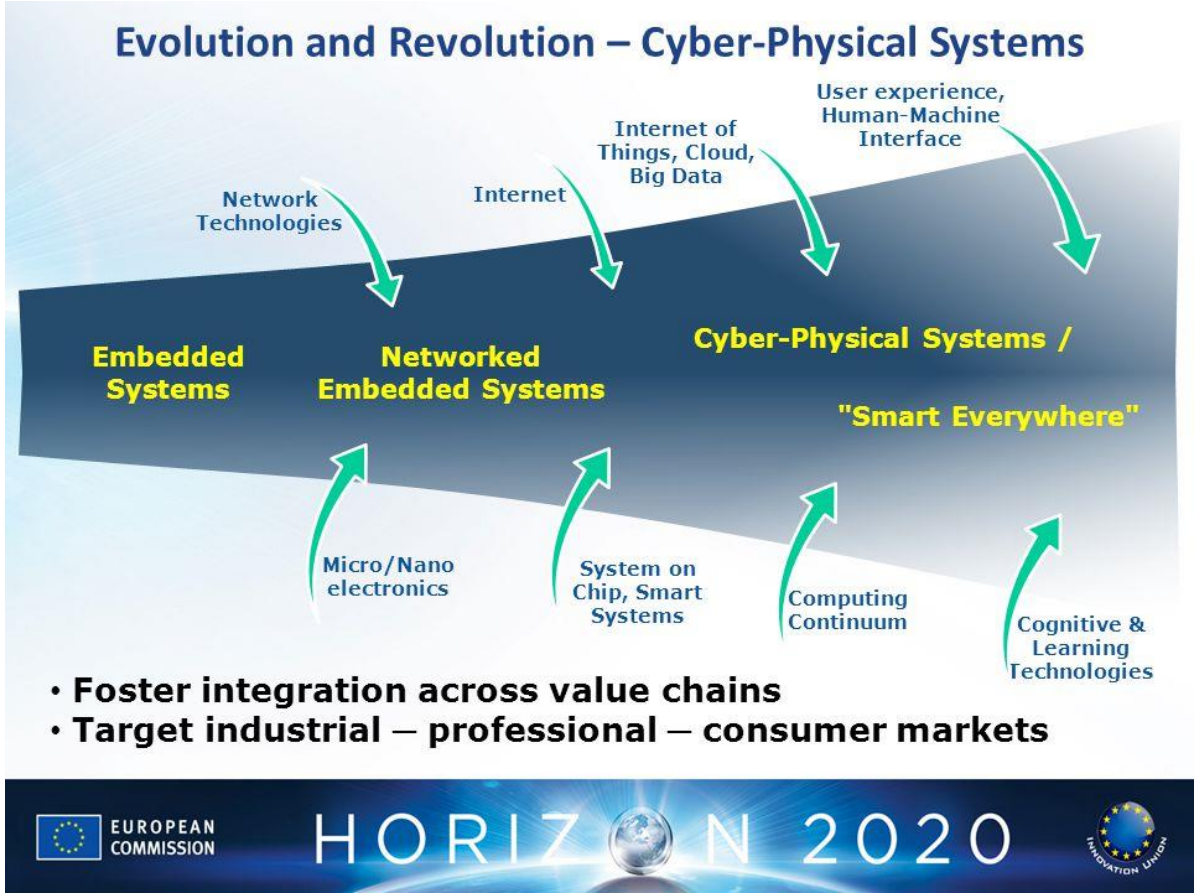
EVOLUTION OF CPS

Digital Factory

- **Two types of computing systems**
  - Desktops, servers, PCs, and notebooks
  - Embedded
- **The next frontier**
  - Mainframe computing (60’s-70’s)
    - Large computers to execute big data processing applications
  - Desktop computing & Internet (80’s-90’s)
    - One computer at every desk to do business/personal activities
  - **Embedded computing (21st Century)**
    - **“Invisible” part of the environment**
    - **Transformation of industry**



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https://www.slideserve.com/emily-jenkins/ict-1-smart-cyber-physical-s-ystems-in-h2020

EVOLUTION OF CPS

Digital Factory

- Cyber-Physical systems, a key infrastructure to support smart manufacturing, are integration of physical, networking, and computation processes.
- In a physical systems, embedded sensors and other monitoring devices collect DATA to be fed into computation processes in a cyber system. In this system, there is infrastructure constructed digitally to map with the physical one (Digital Twin).
- After arrive at an optimal solution, the cyber system will feed information back to control the physical system through actuators.
- Networking technology allows the elements in both systems to be connected interactively with each other.

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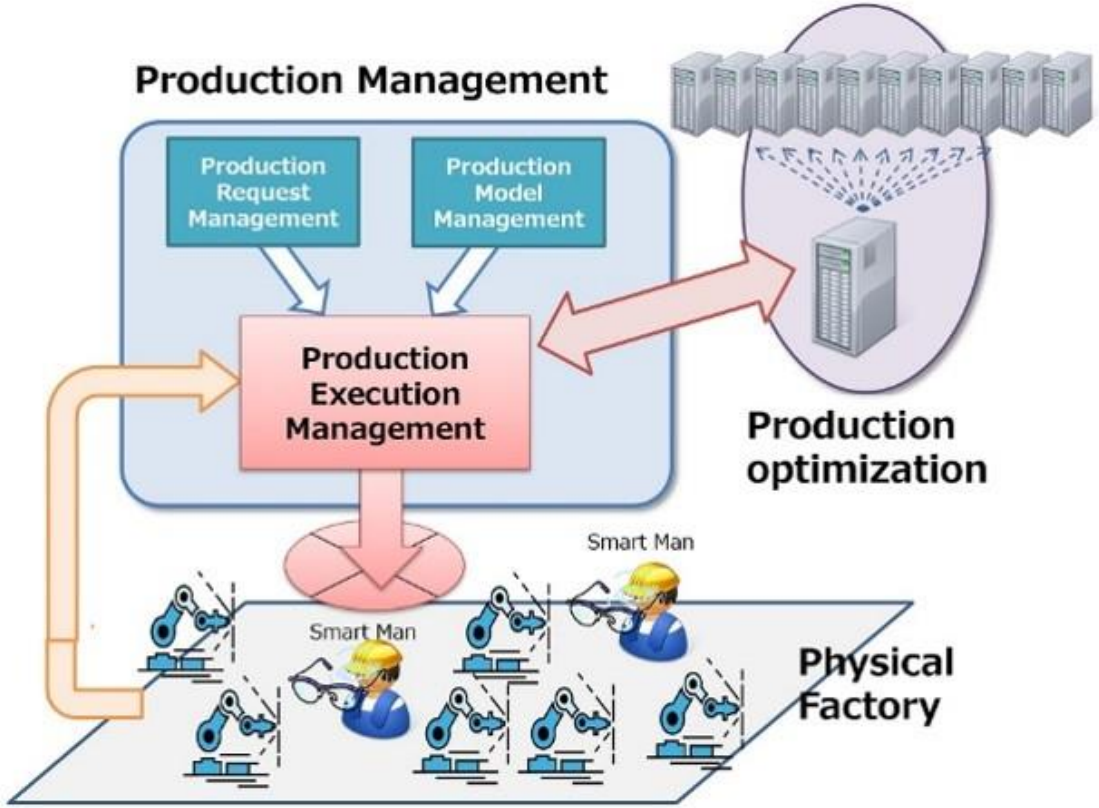
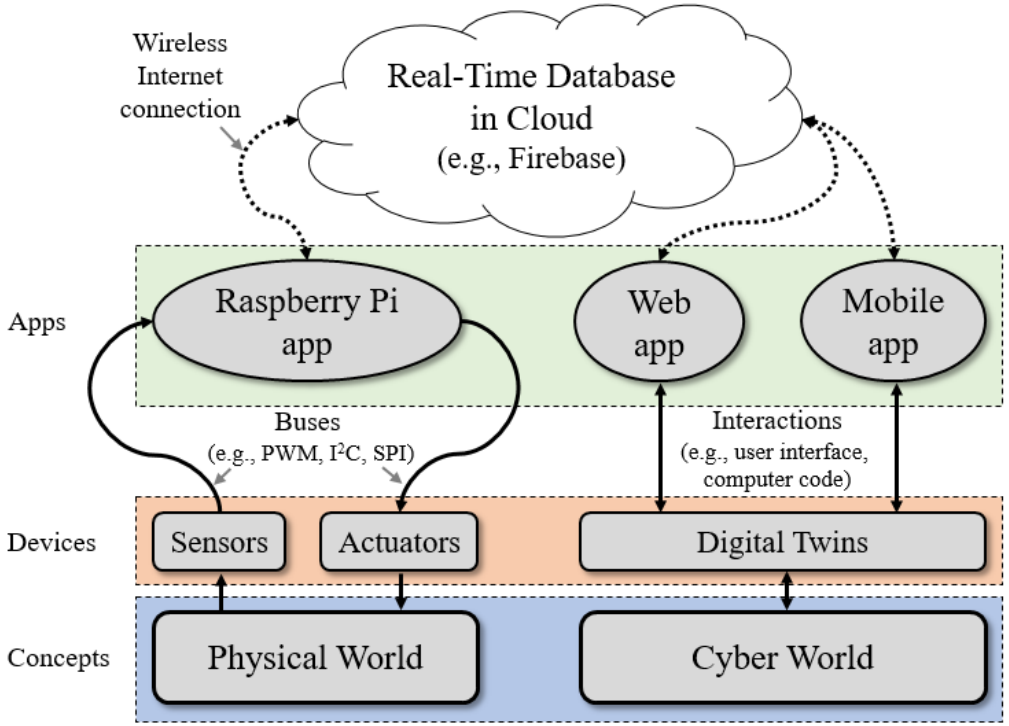
EVOLUTION OF CPS

Digital Factory

- **Relationship between the physical and cyber systems**



http://www.lexer.co.jp/en/product/iot



A Cyber-Physical System for Programming and Controlling IoT Systems

https://medium.com/@charlesxie/building-a-cyber-physical-system-to-simplify-iot-app-development-f3579b7916dc

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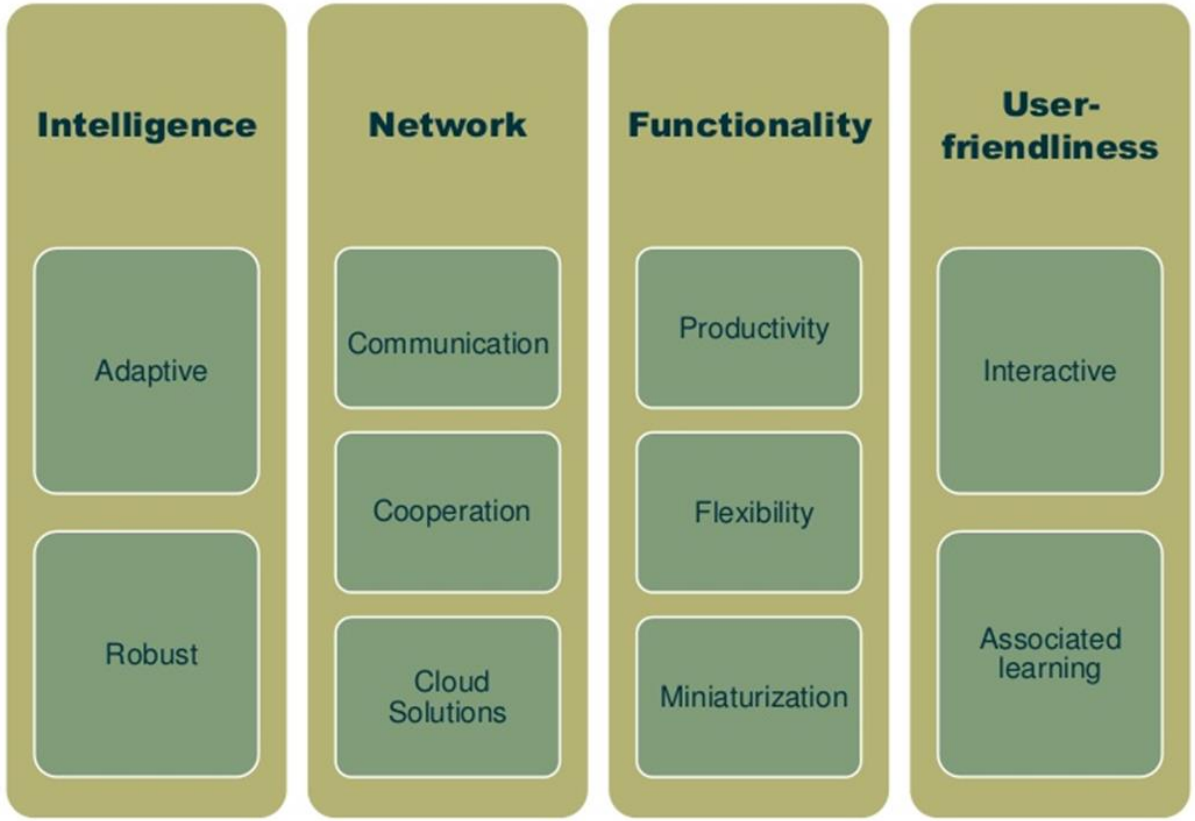
EVOLUTION OF CPS

- **Characteristics of CPSs**



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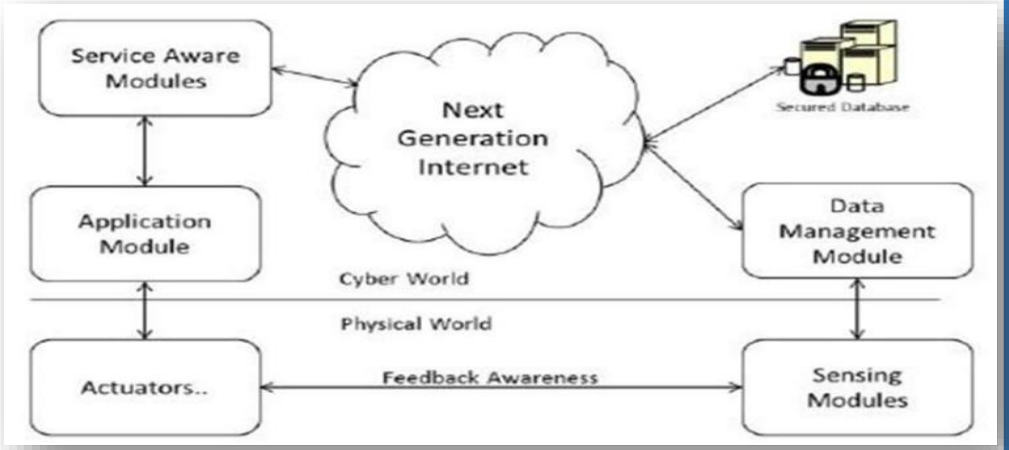
EVOLUTION OF CPS

- **MODULES IN CPS**
  - **Sensing Module**
    - Data collection from physical world through sensors
  - **Data Management Module(DMM)**
    - Consists of the computational devices and storage media
  - **Next Generation Internet**
    - Enabling applications to select the path, or paths that their packets take between the source and destination
  - **Service Aware Modules (SAM)**
    - Sensed data is being recognized and sent to the services available
  - **Application Module (AM)**
    - Service are deployed and interact with NGI
    - Info is saved on database for QoS support.(NoSQL)
  - **Sensors and Actuators**
    - Actuator receives the commands from the Application Module, and executes



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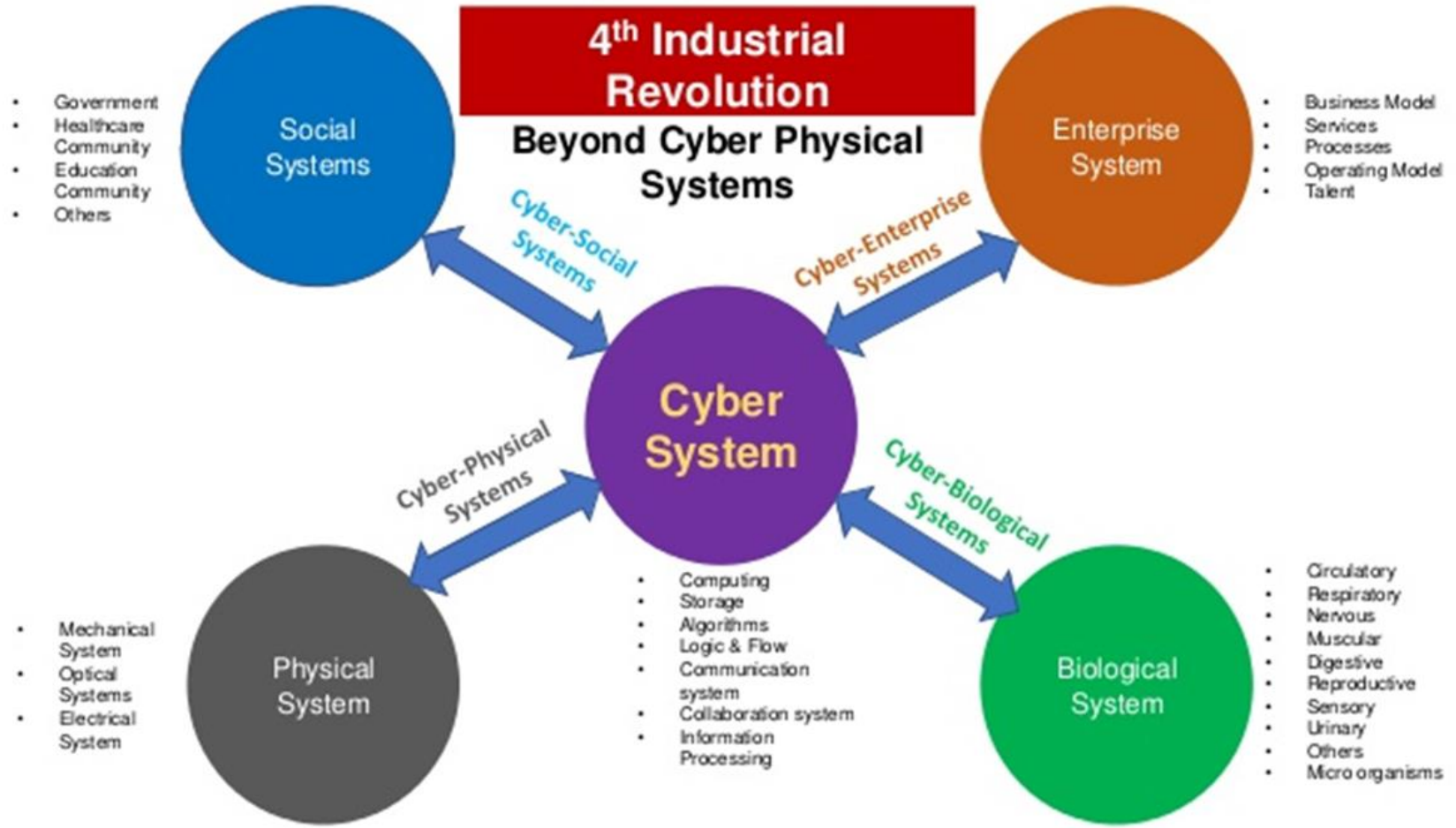
EVOLUTION OF CPS

Digital Factory



https://pt.slideshare.net/vsr0001/4th-industrial-revolution-is-beyond-cyber-physical-systems

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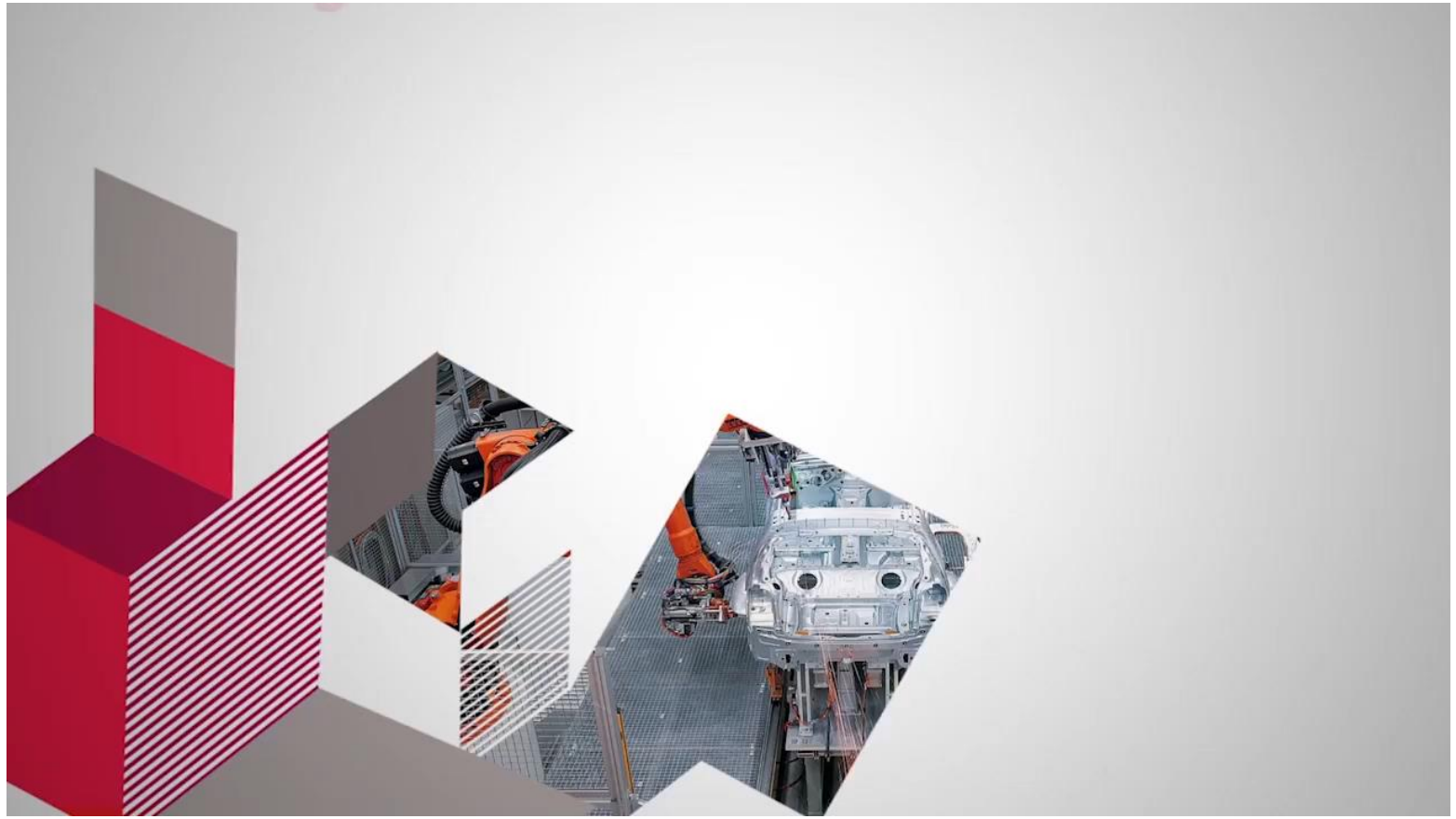
EVOLUTION OF CPS

Digital Factory

- **Industry 4.0 based on CPS**



https://www.youtube.com/watch?v=04GnNgWhv5c&t=12s

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CPS Difference from software and embedded systems

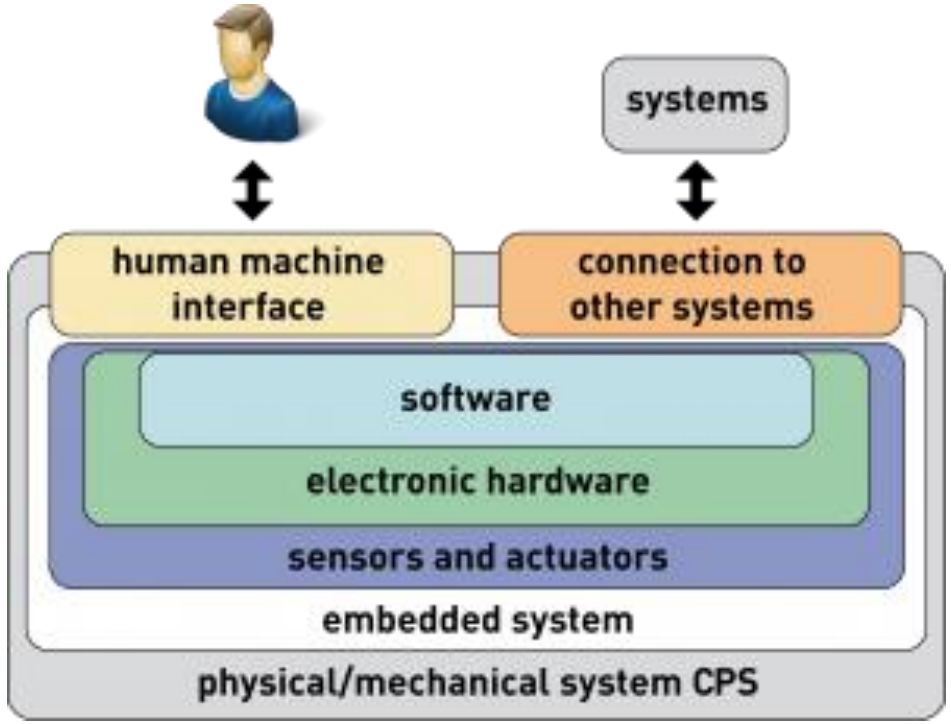
- **Where CPS Differs from General-Purpose Software Systems?**

Software Systems Problem:

- Software systems are sets of interacting sequences of state transformations with the end objective of transforming data

The CPS problem:

- CPS has the end objective of orchestrating physical processes. Timeliness, safety, reliability, security, privacy, and adaptability all take on a different character



http://addi-data.com/cps-cyber-physical-systems/

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CPS Difference from software and embedded systems

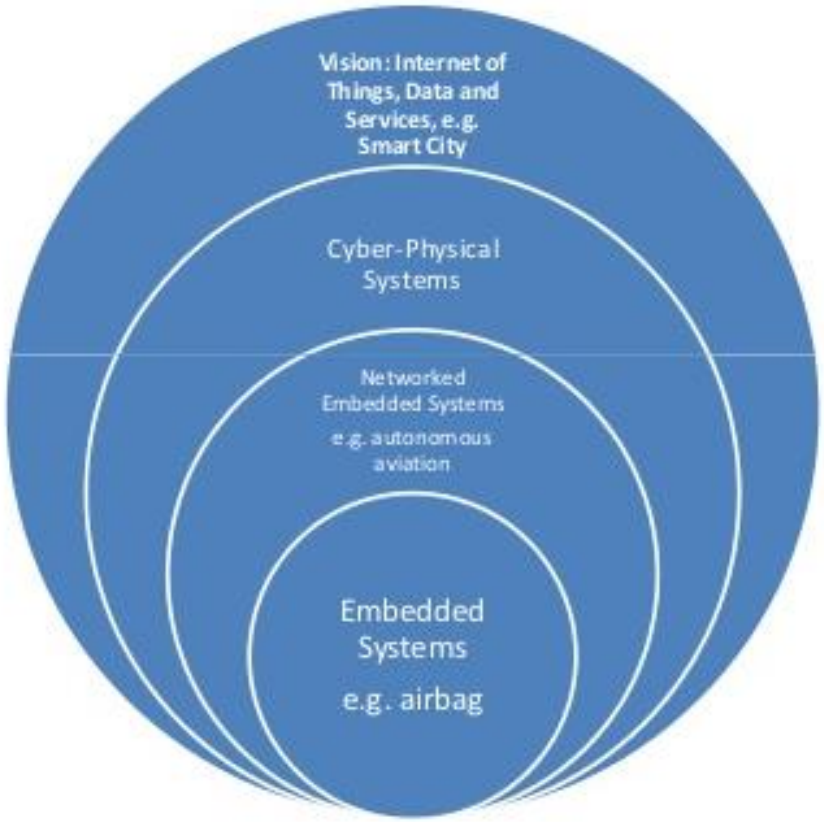
- **Where CPS Differs from Embedded Systems**

The embedded systems problem:

- Embedded software is software on small computers. The technical problem is one of optimization (coping with limited resources)

The CPS problem:

- Computation and networking integrated with physical processes. The technical problem is managing time and concurrency in networked computational systems



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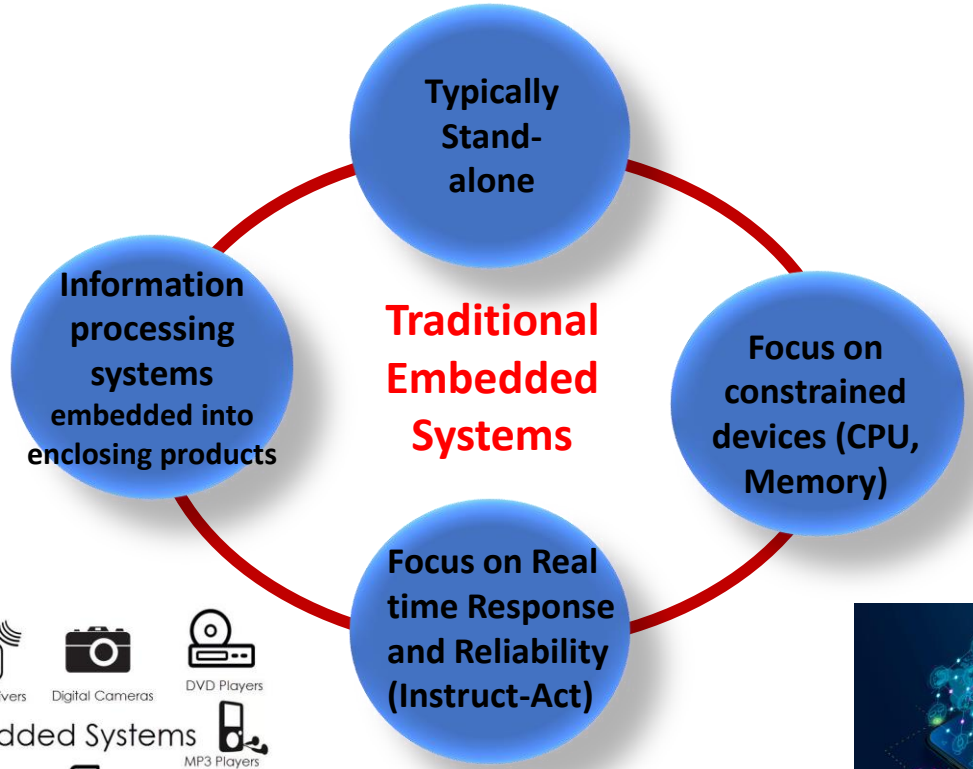
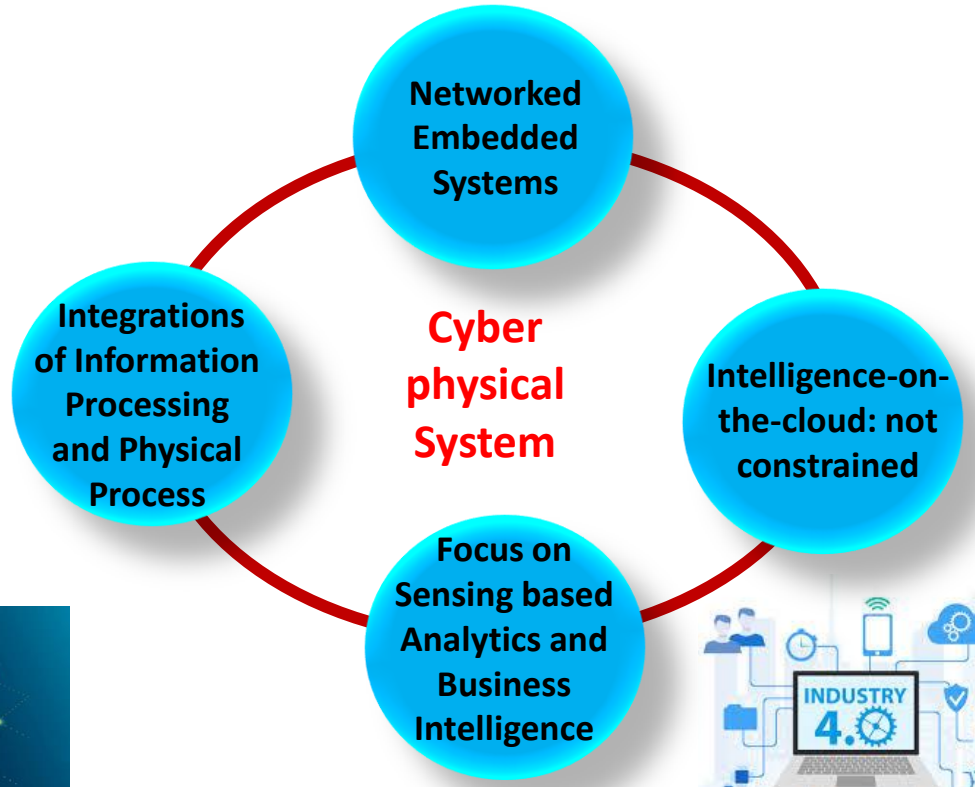
CPS Difference from software and embedded systems

- **Traditional Embedded Systems vs. Cyber physical System**





From Embedded ..... Towards CPS

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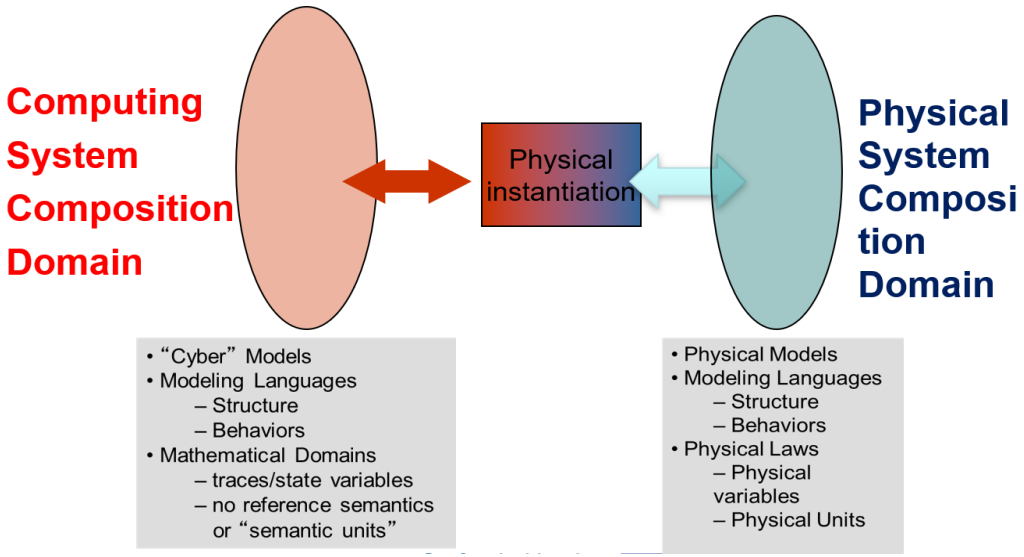
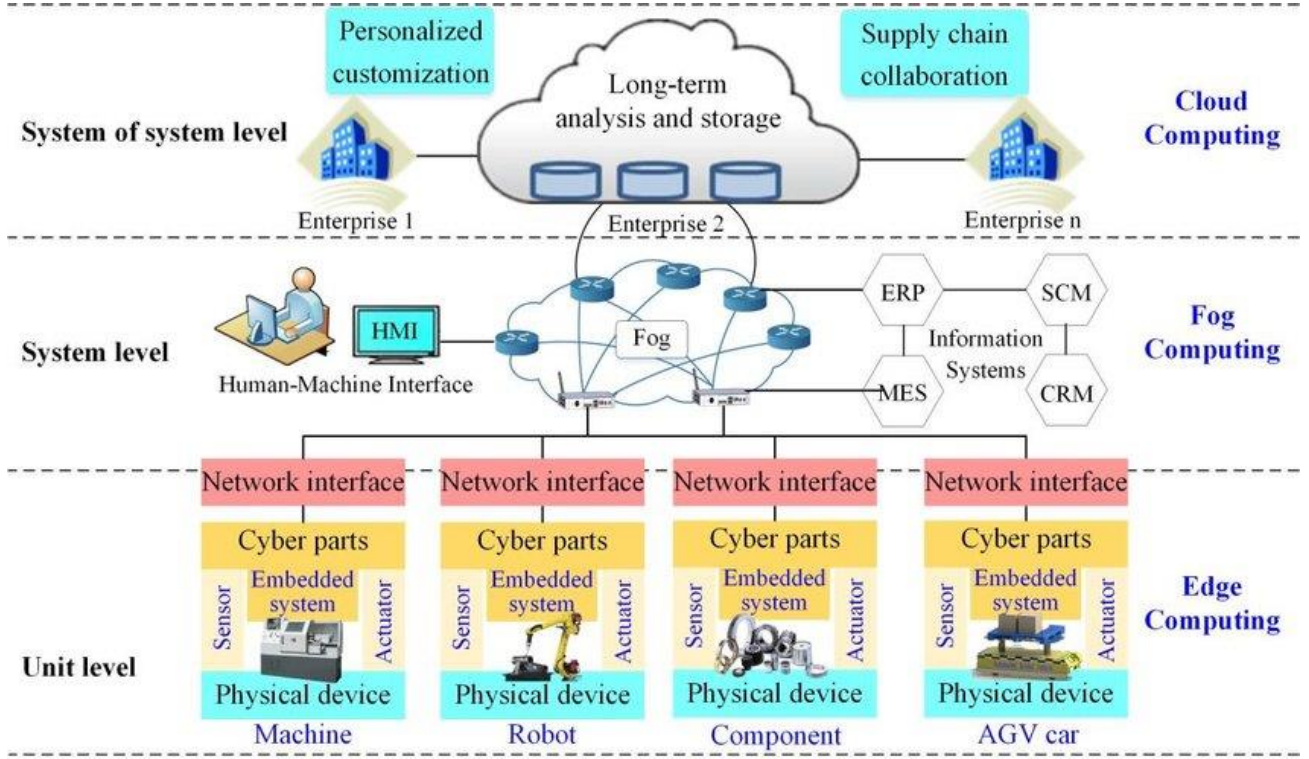
Heterogeneity and Modeling

Digital Factory





https://www.researchgate.net/figure/Modeling-of-various-levels-CPS-and-DT-in-manufacturing-based-on-edge-computing-fog_fig1_327856531

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Long-Term Goal OF CPS

- **Transform how we interact with the physical world just like the internet transformed how we interact with one another.**
  - *Convergence of embedded systems, control theory, hybrid systems, microcontrollers, sensor, actuators, wireless networks, wide area networks, distributed systems, operating systems, advances in structures*

- Building CPSs that integrate computational and physical objects requires **new systems science foundations.**
  - *Fusion of physical and computational sciences*

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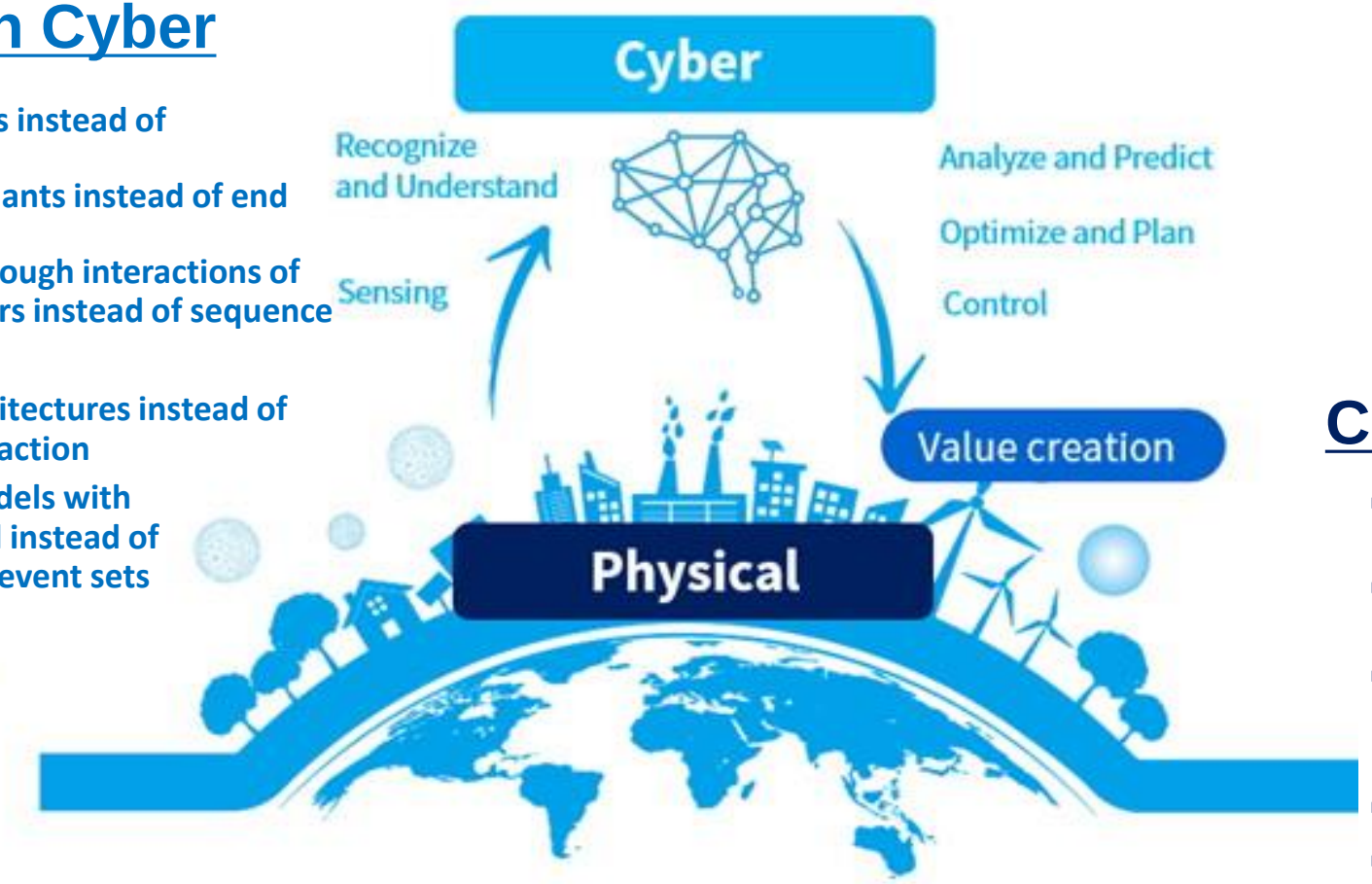
Upgradation Interaction & Coordination

Digital Factory

Changes in Cyber

- Rich time models instead of sequencing
- Behavioral invariants instead of end results
- Functionality through interactions of ongoing behaviors instead of sequence of actions
- Component architectures instead of procedural abstraction
- Concurrency models with partially ordered instead of linearly ordered event sets



Changes in Physical

- Precise interaction and coordination protocols
- Hugely increased system size with controllable, stable behavior
- Dynamic system architectures (nature and extent of interaction can be modified)
- Adaptive, autonomic behavior
- **Self-descriptive, self monitoring system architecture for safety guarantees.**

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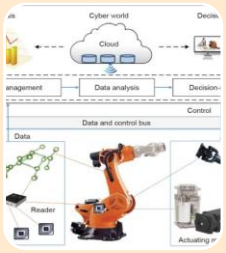
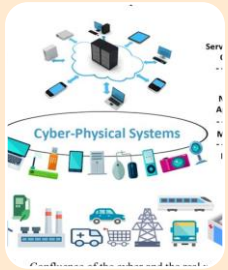
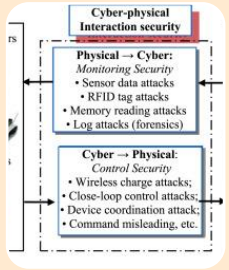
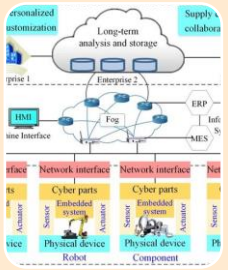
Scientific and technical challenges

Digital Factory









Integrating complex, heterogeneous large-scale systems

Interaction between humans and systems

Dealing with uncertainty

Measuring and verifying system performance

System design

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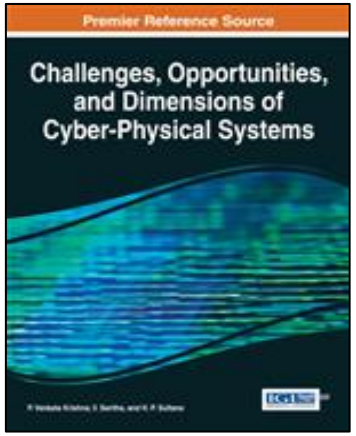
Design process of CPS

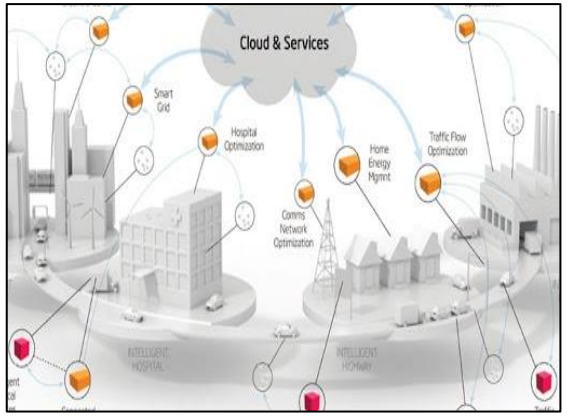
Digital Factory

Phase 1
- Application knowledge

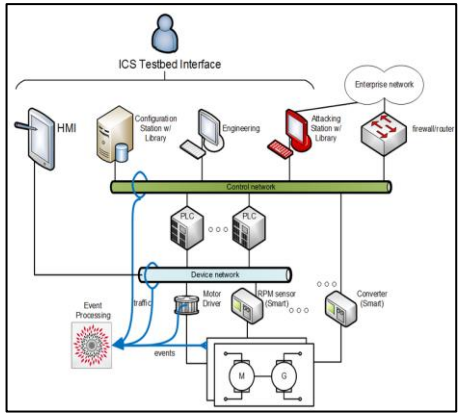


Phase 2
- Specification
- Hardware/Software components

Phase 3
- Design repository
- Application mapping



Phase 4
- Design
- Test



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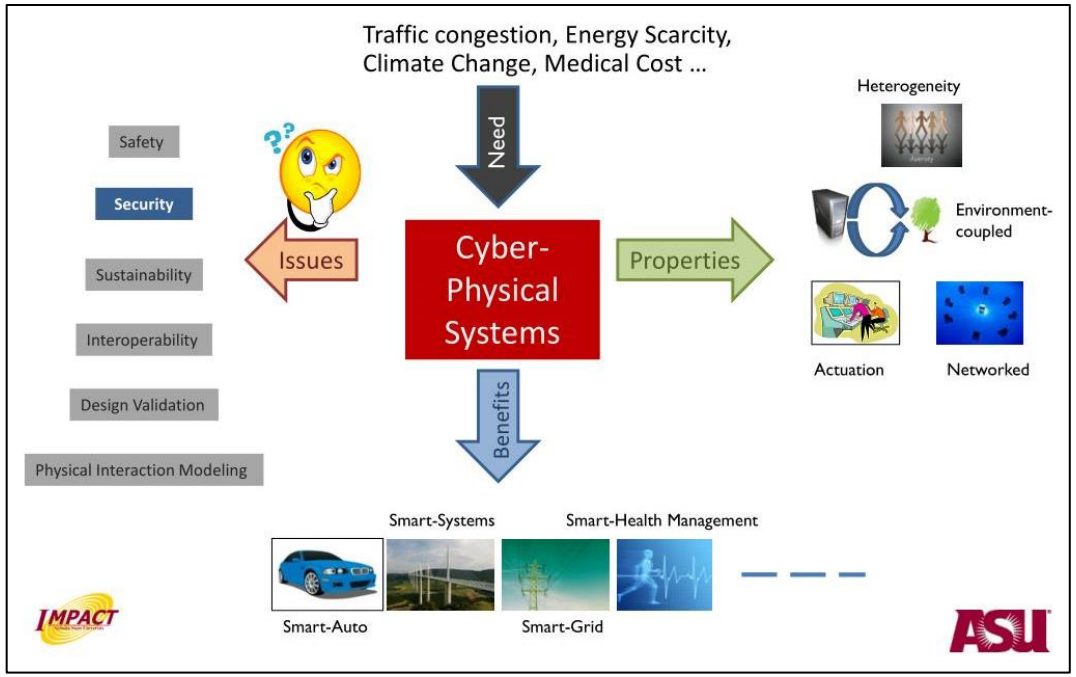
Scientific and technical challenges

Digital Factory

- **Compositionality: system-level properties can be computed from local properties of components**
- **Composability: component properties are not changing as a result of interactions with other components.**
- **Heterogeneity CPS are heterogeneous in components and design requirements.**
- **CPS products make design flows product specific which is bad for design automation.**
- **COST: The cost of certification of complex systems is high.**
- **Security: issues. One side can be attacked through the other side.**



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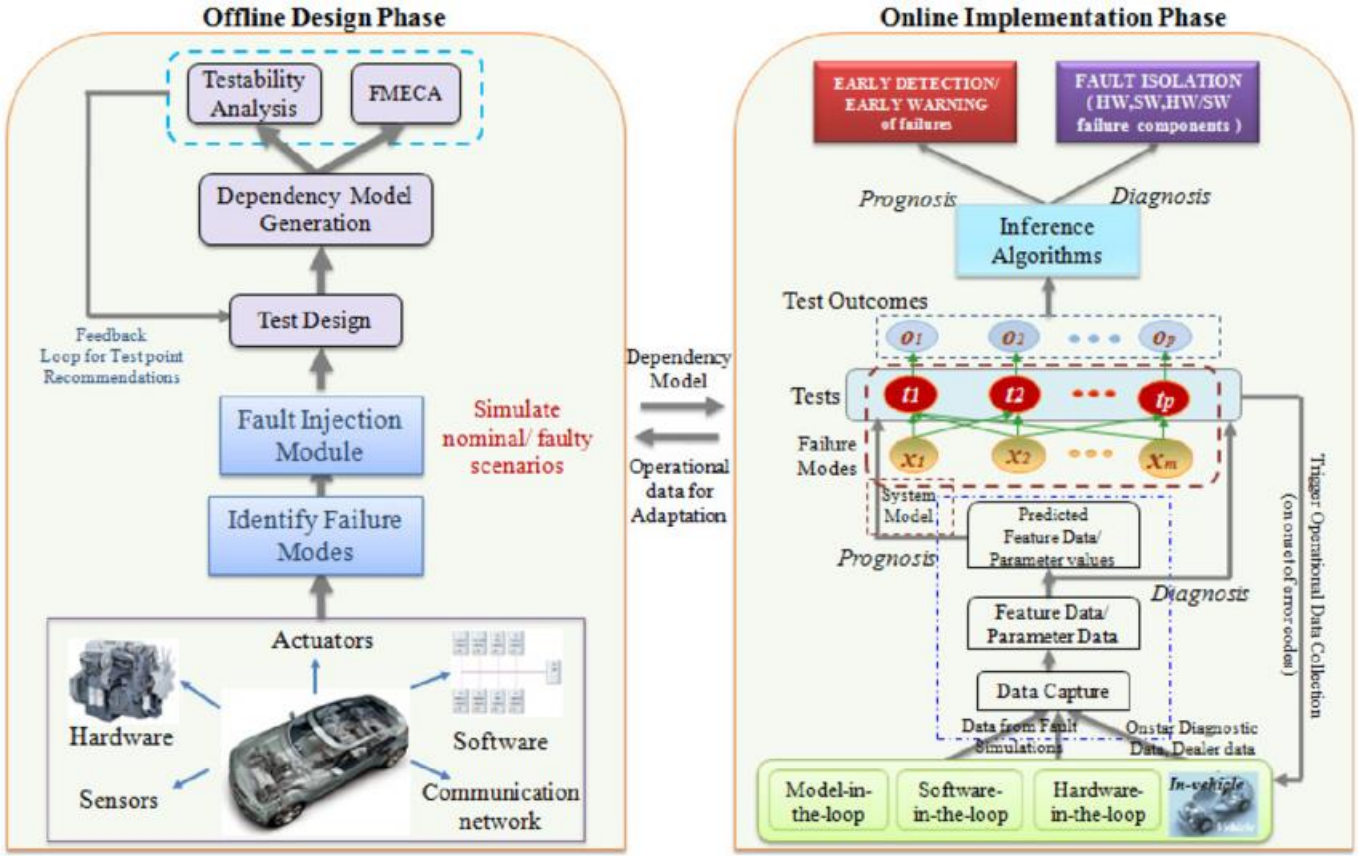
Challenges for CPS software design

Digital Factory

- Dynamic environments
- Capture the required behavior
- Validate specifications
- Efficient translation of specifications into implementations
- How can we check that we meet real-time constraints?
- How do we validate embedded real-time software? – large volumes of data – testing may be safety-critical



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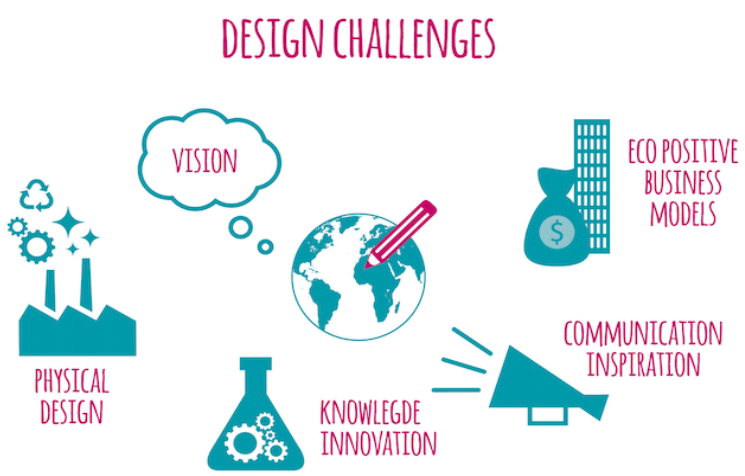
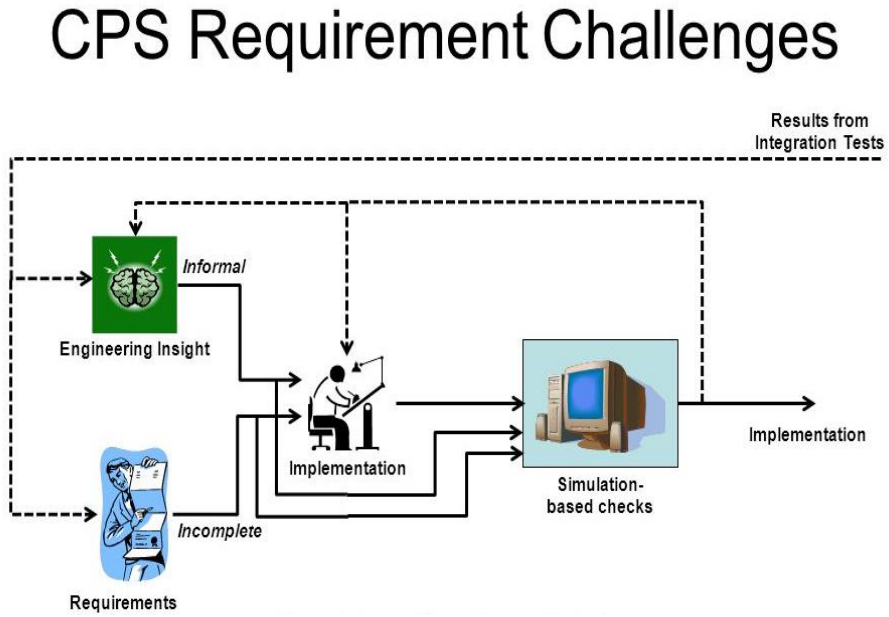
Expectations and design challenges of CPS

- Dependability
- Efficiency
- Meeting real-time requirements
- Hardware properties, physical environment





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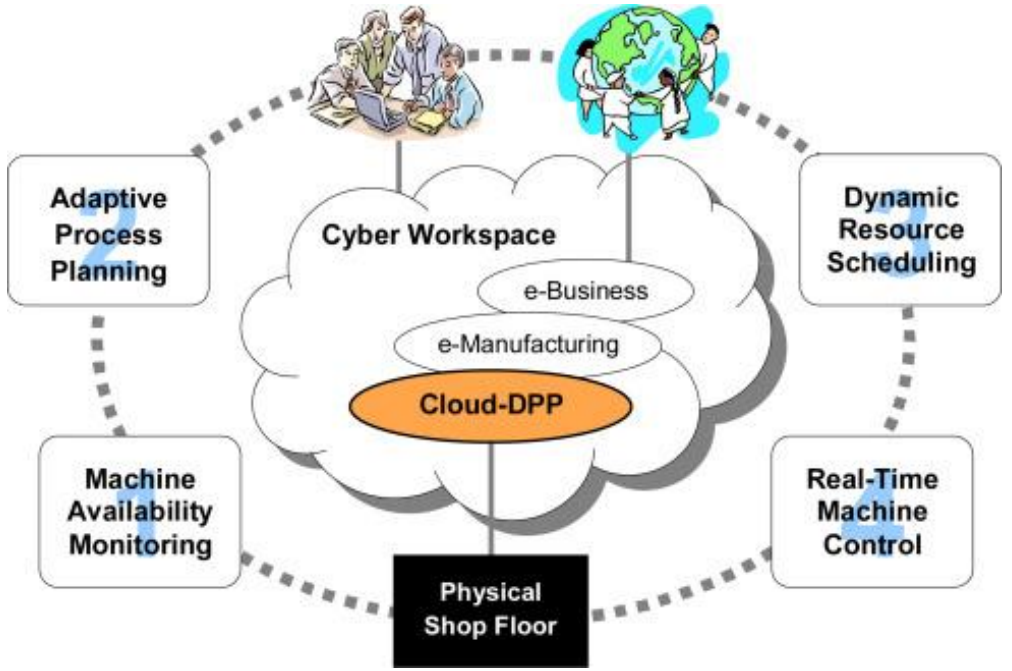
Institutional, societal, and other challenges

- ❑ Trust, security, and privacy
- ❑ Effective models of governance
- ❑ Creation of CPS business models
- ❑ Understanding the value of CPS



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The Challenge of Physical World

Digital Factory

- **Physical world & Industry 4.0**

https://www.youtube.com/watch?v=ktcRXyE8SaY

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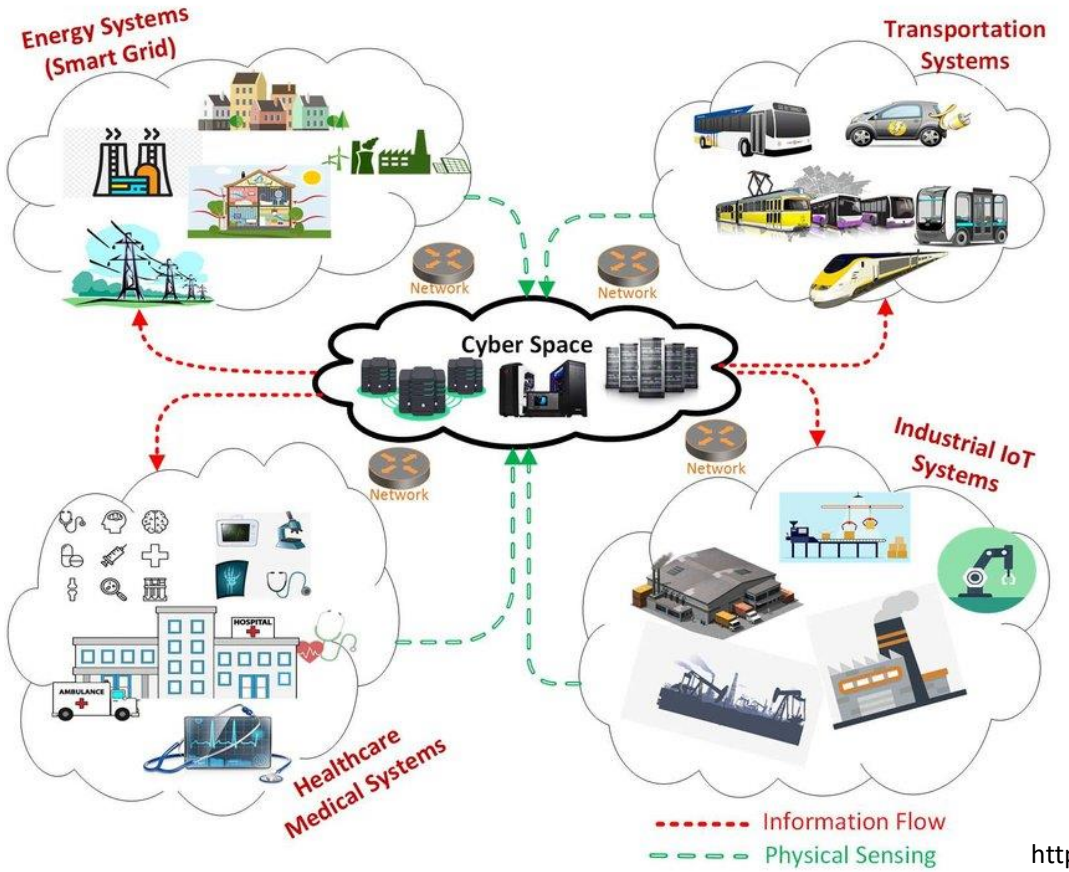
Application

Digital Factory

- **Applications of CPS**



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Application

Digital Factory

- **Applications of CPS**

https://www.youtube.com/watch?v=wro3uoHR-ZY&t=13s

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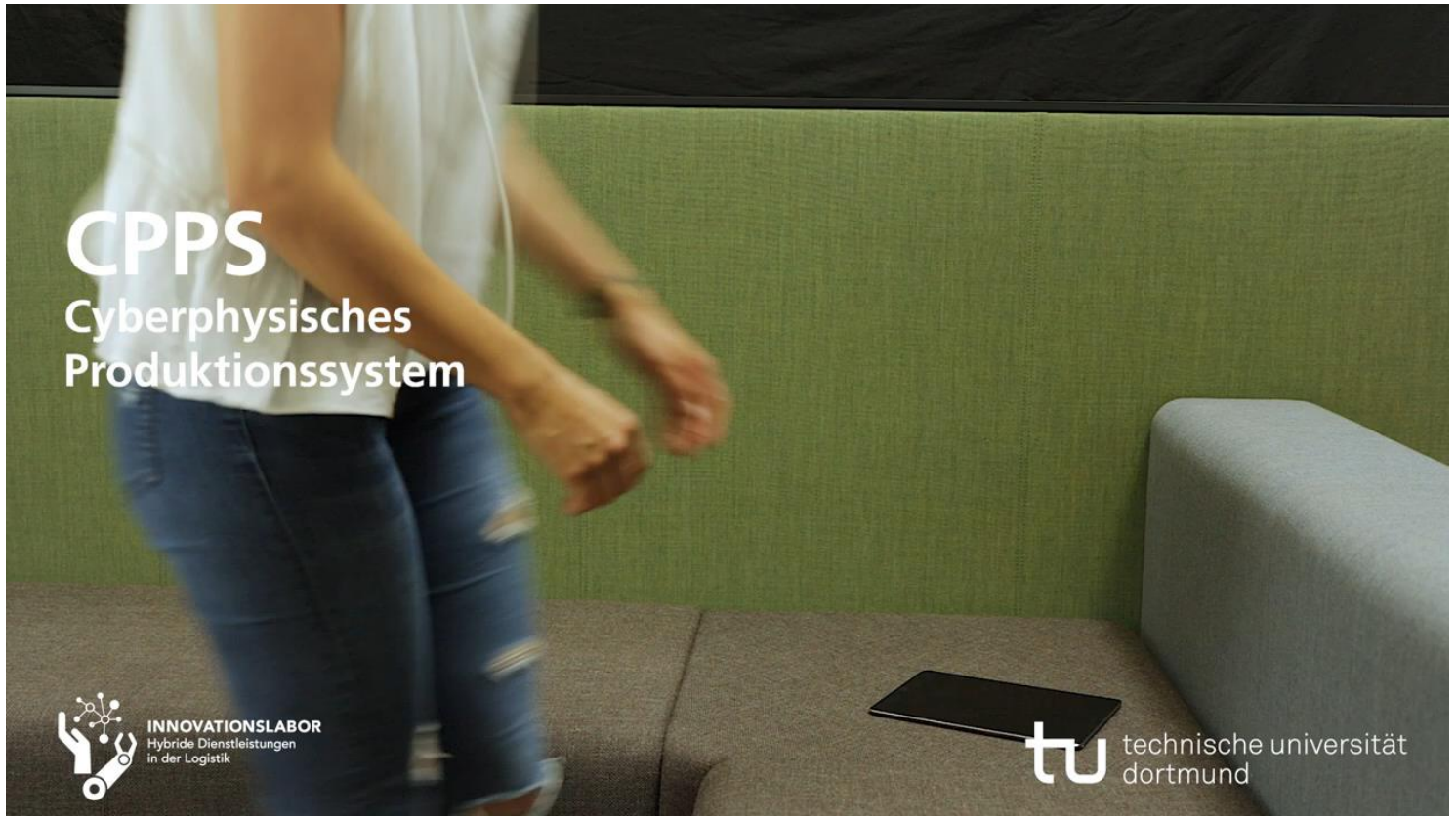
Application

Digital Factory

- **Applications of CPS on production line**



https://www.youtube.com/watch?v=RNCgnZ4Z44I&t=36s

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Application

Digital Factory

- **Applications of CPS : Cyber Physical System based Proactive Collaborative Maintenance**

https://www.youtube.com/watch?v=sHiVEi1BZ0o

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Application

Digital Factory

- **Applications of CPS for Industry 4.0**

https://www.youtube.com/watch?v=hjKC-XhwU1E

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Application

- **Applications of CPS**

https://www.youtube.com/watch?v=raZIpxnjmJs

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Application

Digital Factory

- **CPS on Smart factory**

https://www.youtube.com/watch?v=Ropu4FwMEHo

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Application

- **Applications of CPS : The Internet of Things**

https://www.youtube.com/watch?v=5OQQZ9eWF-4&t=84s

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Application

Digital Factory

- **Applications of CPS**

Health Care and Medicine

Hospital : Real time monitoring and control can be achieved by Data Management Module and Service awareness module which also plays an important role in order to provide QoS monitoring. While designing a system for hospital, sensitive applications are queued on the top priority.

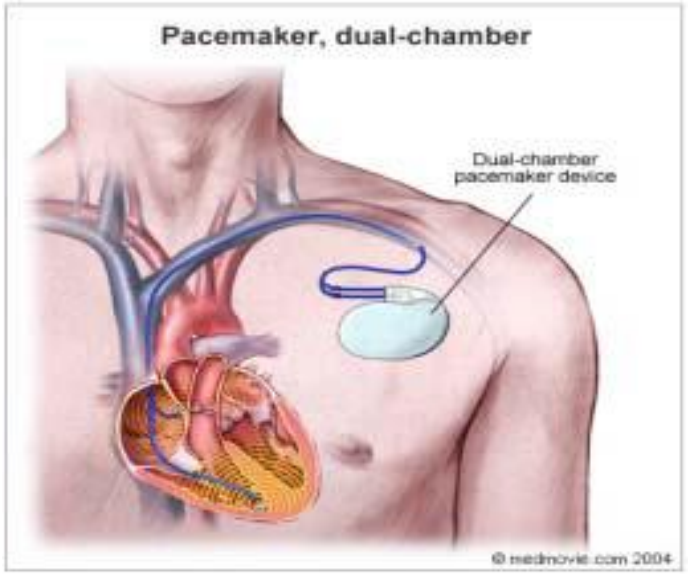
- **Home care: monitoring and control**

  Blood glucose monitors, infusion pumps, accelerometers

- **Operating Room of the Future**

  Robotic Microsurgery

- **Progress in bioinformatics: gene, protein expression, systems biology, disease dynamics, control mechanisms**



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Application

- **Applications of CPS**

Electric Power Grid

- ***Current picture:***

  Equipment protection devices trip locally, reactively

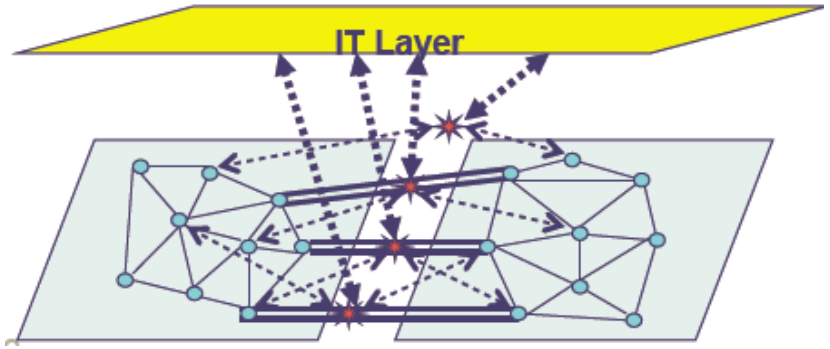
  Cascading failure

- ***Better future?***

  Real-time cooperative control of protection devices

  Self-healing, aggregate islands of stable bulk power

  Coordinate distributed and dynamically interacting participants



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Security and Privacy Issues in Cyber-Physical Systems

- **Differences between corporate IT security and CPS security**

  - ❑ **Software patching and frequent updates, are not well suited for control systems**
  - ❑ **While availability is a well studied problem in information security, real-time availability provides a stricter operational environment than most traditional IT systems**
  - ❑ **Large industrial control systems also have a large amount of legacy systems** (most of the efforts done for legacy systems should be considered as short-term solutions; underlying technology must satisfy some minimum performance)
  - ❑ **Network dynamic**

https://www.youtube.com/watch?v=_6IZ5yCYwx8

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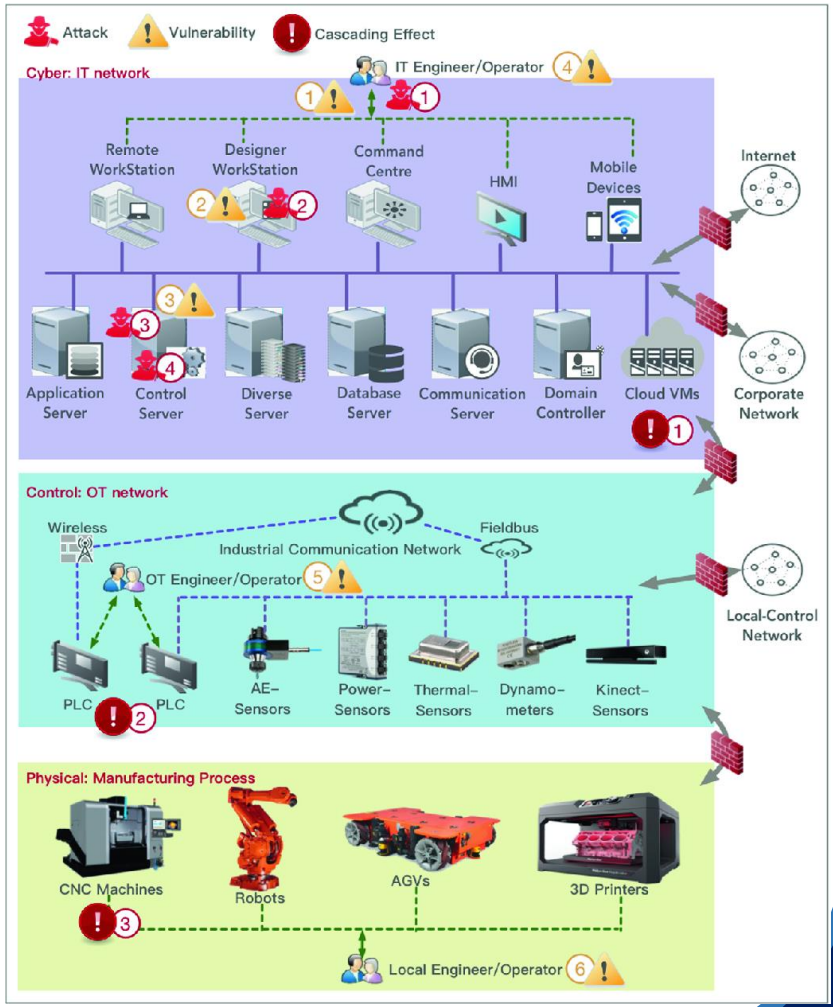
Security and Privacy Issues in Cyber-Physical Systems

Digital Factory

- **New security problem in CPS/Control systems**
  - ❑ **Authentication, access control, message integrity, separation of privilege, etc. can all help**
    - Traditionally focused on information (security)
  - ❑ **How attacks affect the estimation and control algorithms?**
    - Ultimately, how attacks affect the physical world
  - ❑ **Intrusion Detection Systems (IDSs) have not considered algorithms for detecting deception attacks launched by compromised sensor nodes against estimation and control algorithms**
    - Dynamics of physical systems bring more challenges and set of problems
  - ❑ **Information awareness to operators of control systems**



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Security and Privacy Issues in Cyber-Physical Systems

- **Cyberspace and Cybersecurity**

https://www.youtube.com/watch?v=3Wq4S2pXD3c&t=133s

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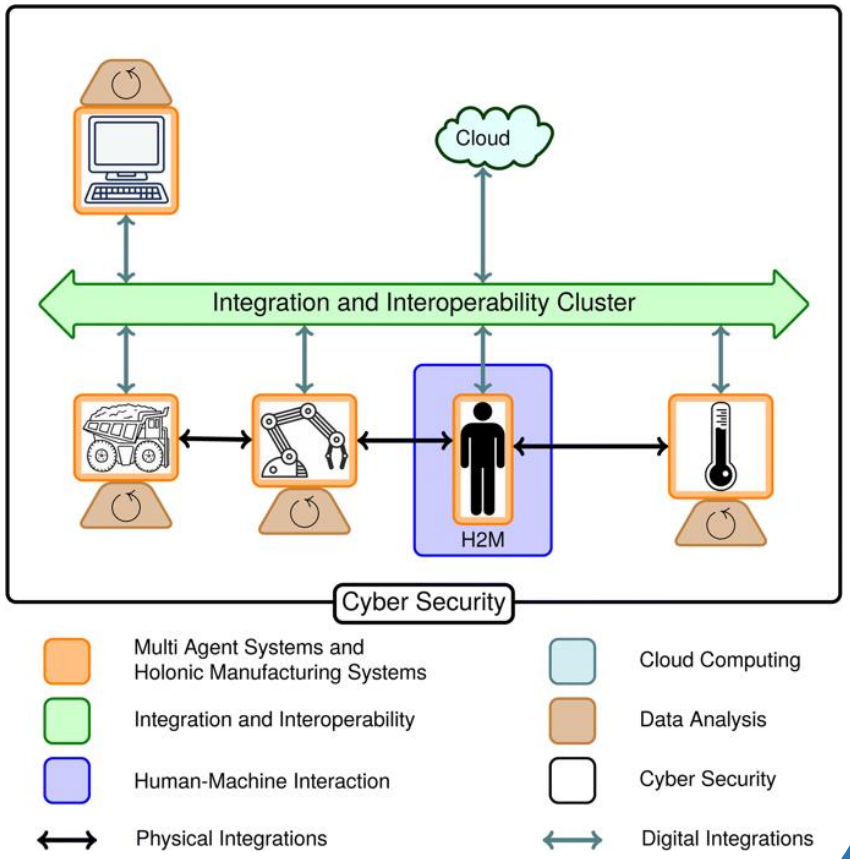
Security and Privacy Issues in Cyber-Physical Systems

- **Countermeasures**

  - **Most of the effort for protecting control systems has focused on reliability (the protection of the system against random faults)**
    - urgent growing concern for protecting control

  - **systems against malicious cyber attacks**
    - Dimensions
    - Prevention
    - Detection and recovery
    - Resilience
    - Deterrence



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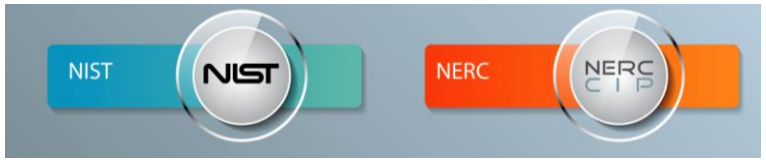
Security and Privacy Issues in Cyber-Physical Systems

- **Prevention**
  - ❖ **cybersecurity standards**
    - ❑ **North American Electric Corporation (NERC) cybersecurity standards for electric systems.**
      - ***NERC*** *is authorized to enforce compliance to these standards, and it is expected that all electric utilities are fully compliant with these standards*
    - ❑ **NIST**
      - **SP 800-53*** the guideline for security best practices which federal agencies should meet
      - **Guide to Industrial Control System (ICS) Security**
    - ❑ **ISA (International Society of Automation)**
      - **ISA SP 99**: a security standard to be used in manufacturing and general industrial controls
    - ❑ **ETSI**
  - ❖ **SCADA - Supervisory Control And Data Acquisition**

    Standardization efforts with respect to access control and key management in wireless sensor networks



ISA 99 / IEC 62443 standard

ISA IEC

ICS/SCADA Security

ETSI

* **NIST** Special Publication 800-53, *"Security and Privacy Controls for Federal Information Systems and Organizations,"*

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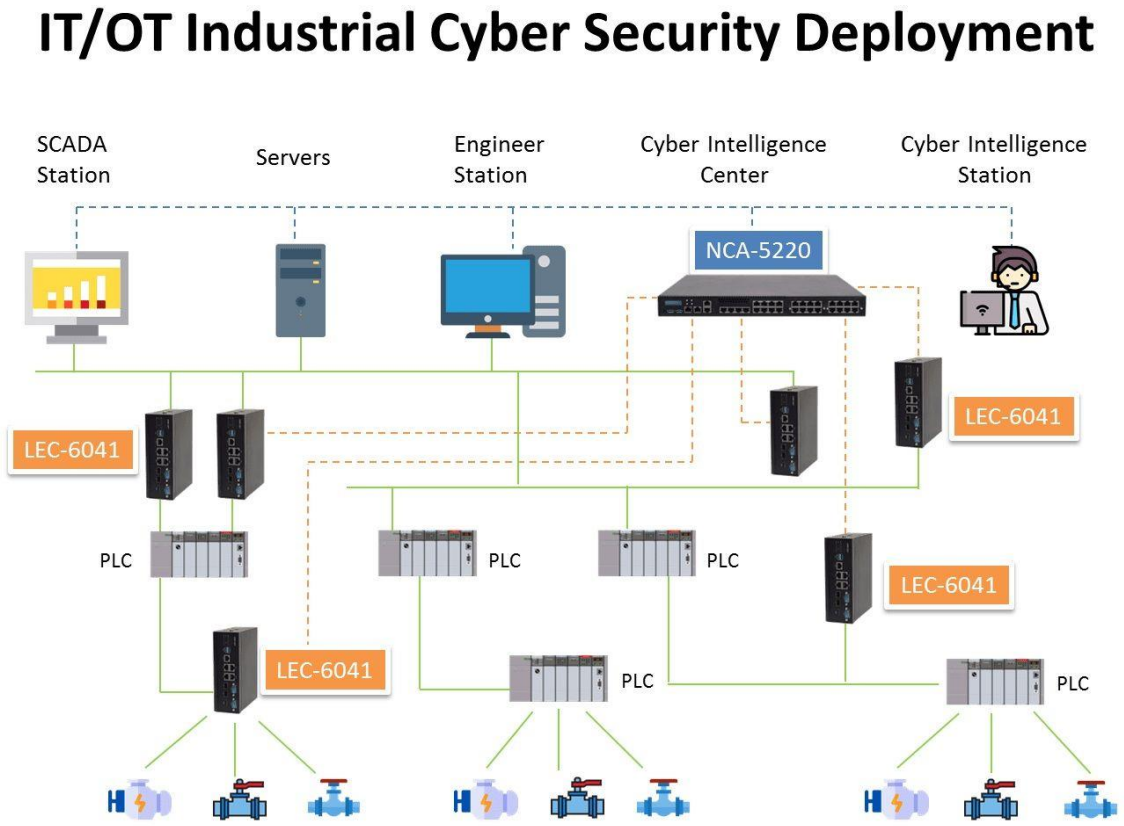
Security and Privacy Issues in Cyber-Physical Systems

- **Example of Prevention with SCADA**



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Security and Privacy Issues in Cyber-Physical Systems

- **Detection and recovery**
  - **Utilizing our knowledge of the physical systems, control systems** can provide a paradigm shift for intrusion detection e.g. by monitoring the physical system for anomalies we may be able to detect attacks that are undetectable from the IT side, e.g. against resonance attack
  - **Identify deception attacks launched by compromised** controllers and/or sensors
  - **Implement a model-based detection scheme,** e.g. as game between the detector and the attacker
  - **Utilizing ideas from control theory** such as reconfiguration or fault-detection and isolation, to design autonomous and real-time detection and response algorithms for safety-critical applications that require real-time responses

https://www.slideshare.net/exigent/how-to-implement-nist-cybersecurity-standards-in-my-organization-125956627

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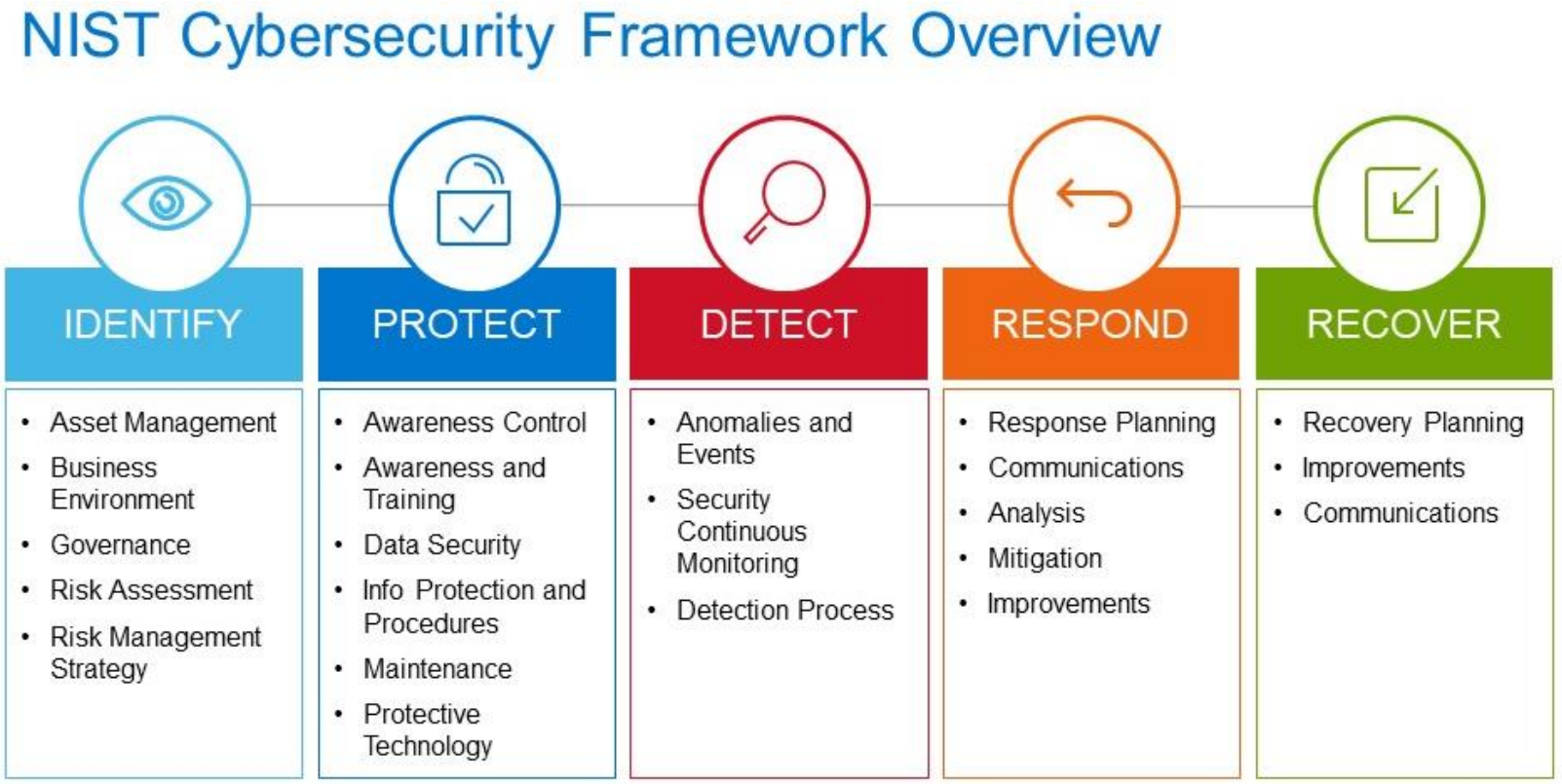
Security and Privacy Issues in Cyber-Physical Systems

- **Example of NIST Standard**



https://infocus.delltechnologies.com/michael_dulavitz/strengthen-security-of-your-data-center-with-the-nist-cybersecurity-framework/

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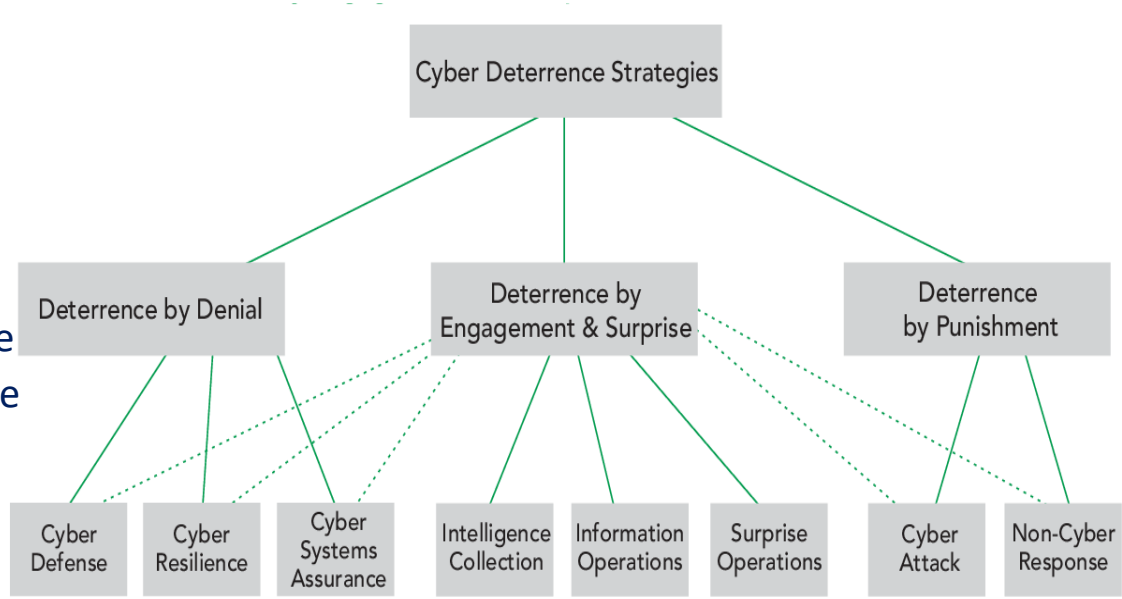
Security and Privacy Issues in Cyber-Physical Systems

- **Resilience and deterrence**
  - **Useful principles**
    - Redundancy as a way to prevent a single-point of failure
    - Diversity as a way to prevent that a single attack vector can compromise all the replicas (the added redundancy)
    - Principle of least-privilege, and the separation of privilege (also known as separation of duty) principle
  - **In CPS**, **physical and analytical redundancies** should be combined with security principles (e.g., diversity and separation of duty) to adapt or reschedule its operation during attacks
  - **Design novel robust control and estimation algorithms** that consider more realistic attack models from a security point-of-view, e.g. Game Theory
  - **Deterrence**



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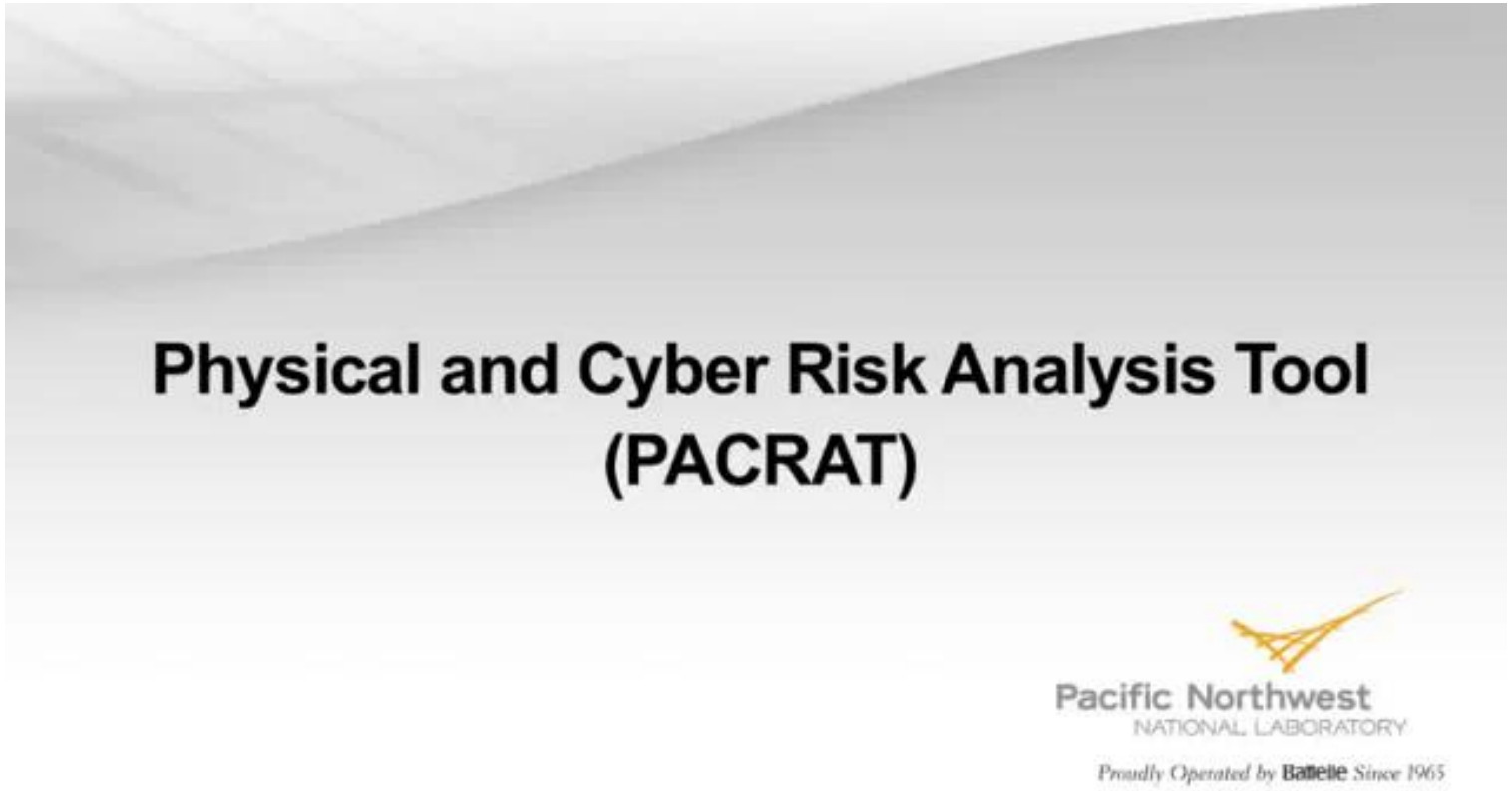
Security and Privacy Issues in Cyber-Physical Systems

Digital Factory

- **Physical Protection & Cyber Security**



https://www.youtube.com/watch?v=Hh5NEpJZGZw&t=22s

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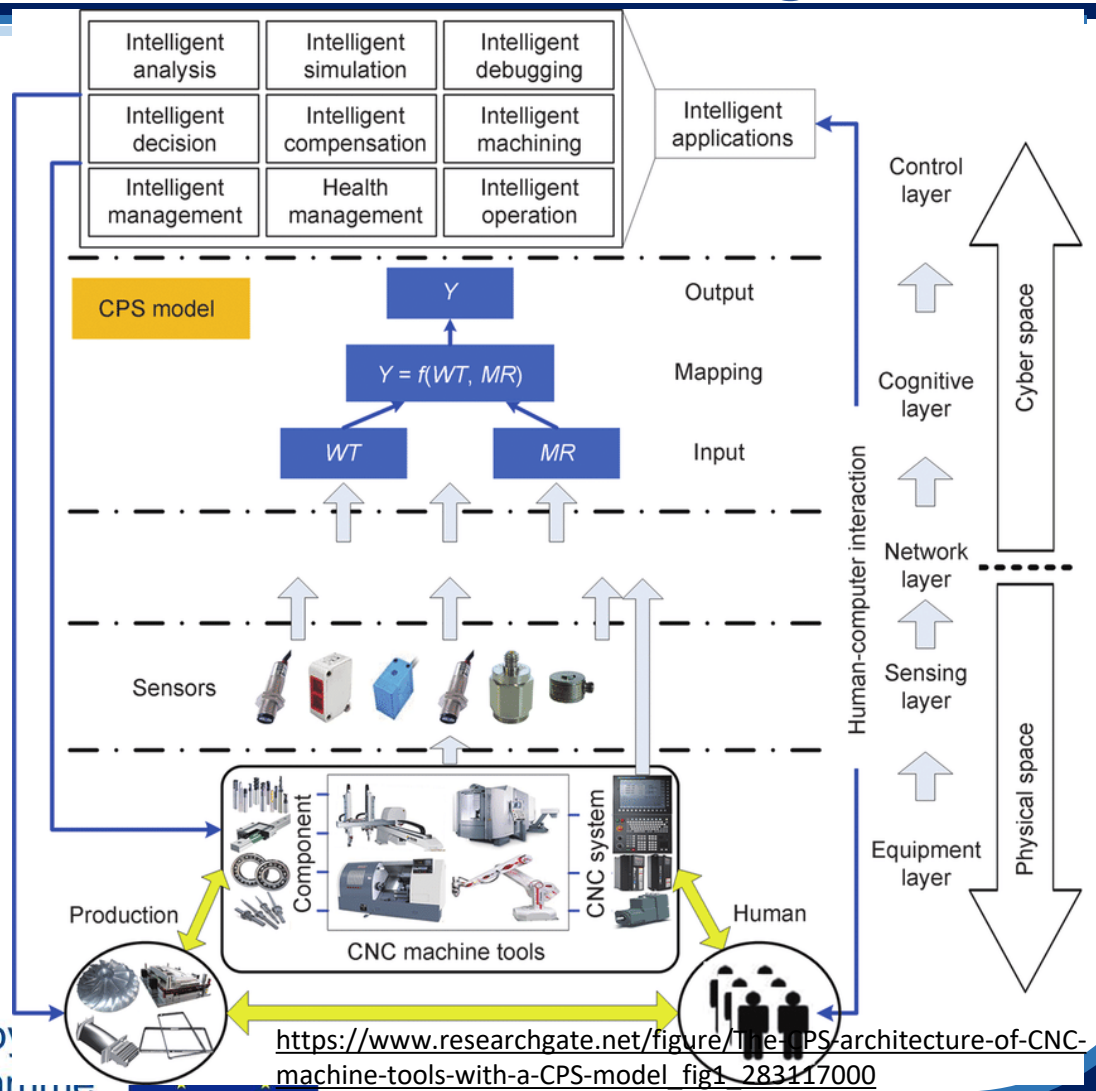
Activities (Example)

Digital Factory

- **The-CPS-architecture-of-CNC-machine-tools-with-a-CPS-model**

https://www.researchgate.net/figure/CPS-enabled-Smart-Machine-Tools-After-the-smart-design-CPS-enabled-smart-machine-tools_fig3_322673524



https://www.researchgate.net/figure/The-CPS-architecture-of-CNC-machine-tools-with-a-CPS-model_fig1_283117000

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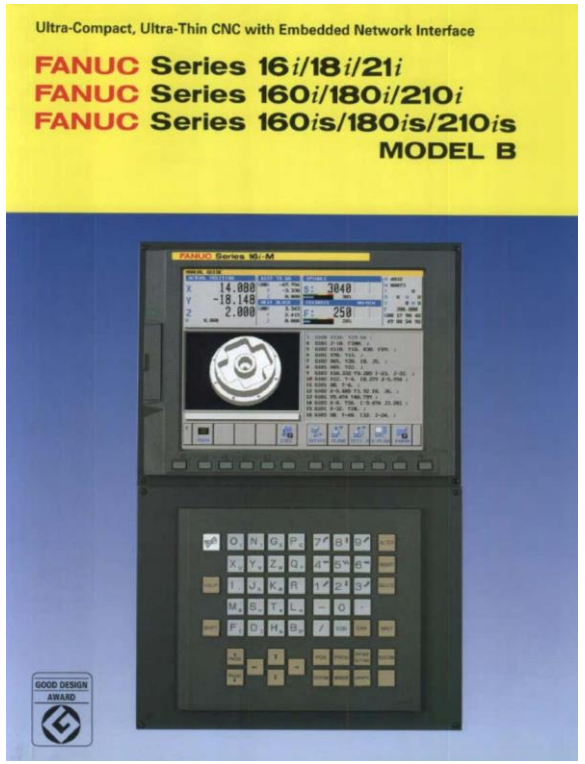
Activities (Lab sheet)

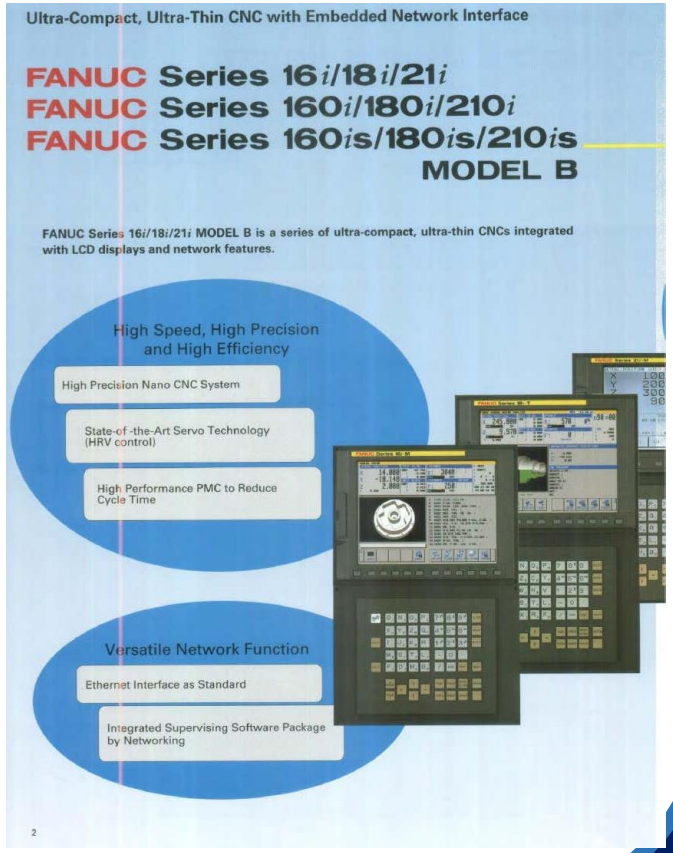
Digital Factory

- Design and development of a system for CNC turning to be in the form of Cyber-Physical Production Systems by writing architecture, data flow diagram and some available services. Streamlining process in the production line of CNC turning. Use data below:

CNC (Fanuc 18i)

- CNC/PMC
- FOCAS 1 Driver
- Sockets
(164.41.17.20:8193)





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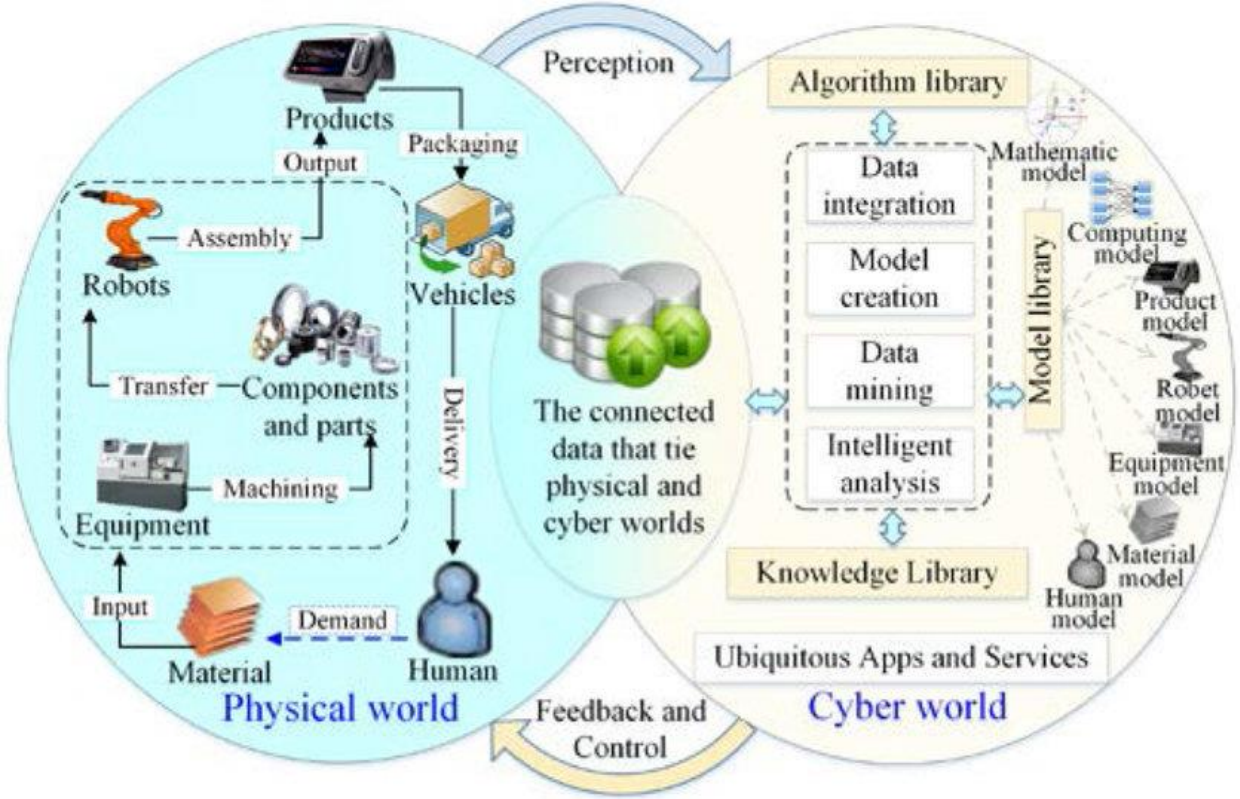
Summary

Digital Factory

- **Cyber-physical systems** are everywhere, from semi-autonomous vehicles to wearable devices. These types of systems blend human and compute power, and integrating mechanical systems with human physical interaction giving both a form of **"super powers"**. Opportunities to specialize in cyber-physical systems are growing as quickly as the technology itself, from large corporations to individual makers ...
- CPS is the way to **streamlining process** in a production line of an existing traditional factory using a data flow diagram.



https://www.researchgate.net/figure/Manufacturing-cyber-physical-integration-and-fusion-supported-by-CPS-in-SoSM_fig6_318694164

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Learning Outcome

Digital Factory

Formulate a data model representing data streamlining in a production line of an existing traditional factory using a data flow diagram

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Thank you