Focus on Cyber-Physical Systems Full of Contradictory Requirements

It's not just information technology anymore:

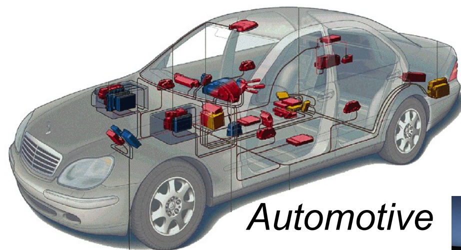
- Cyber + Physical
- Computation + Dynamics
- Security + Safety

Contradictions:

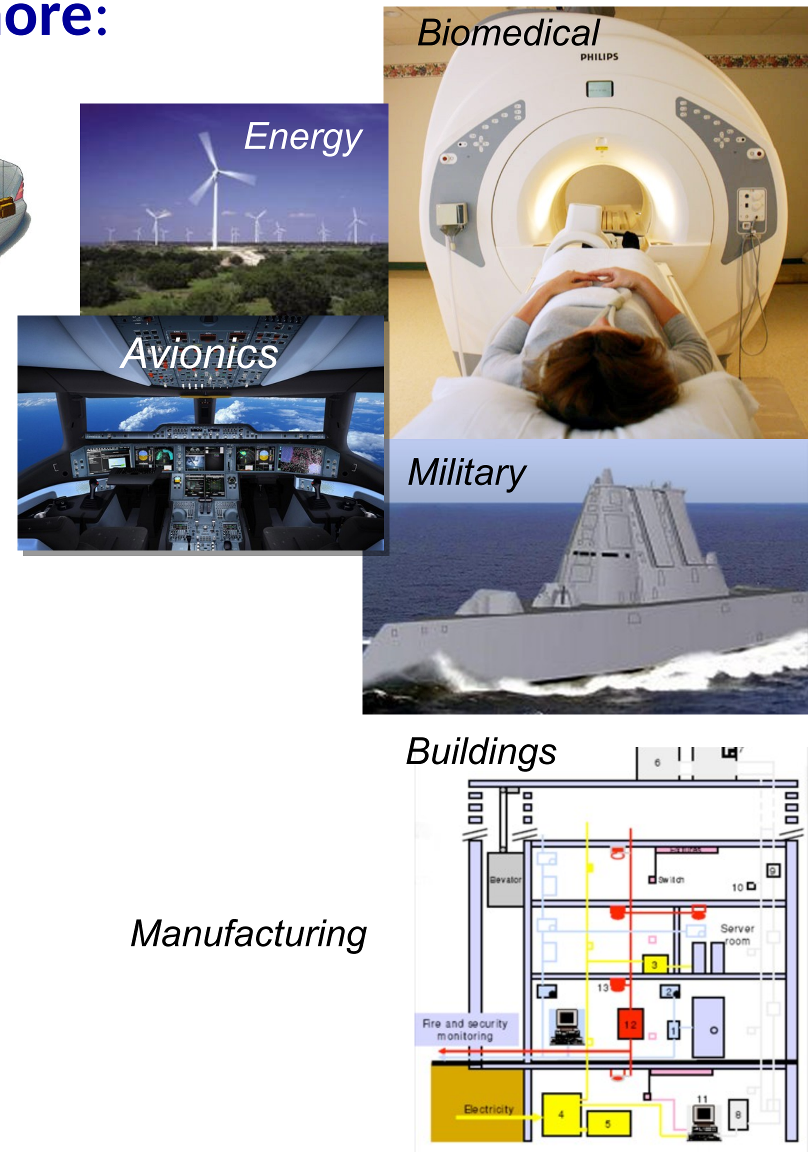
- Adaptability vs. Repeatability
- High connectivity vs. Security and Privacy
- High performance vs. Low Energy
- Asynchrony vs. Coordination/Cooperation
- Scalability vs. Reliability and Predictability
- Laws and Regulations vs. Technical Possibilities
- Economies of scale (cloud) vs. Locality (fog)
- Open vs. Proprietary
- Algorithms vs. Dynamics

Innovation:

Cyber-physical systems require new engineering methods and models to address these contradictions.



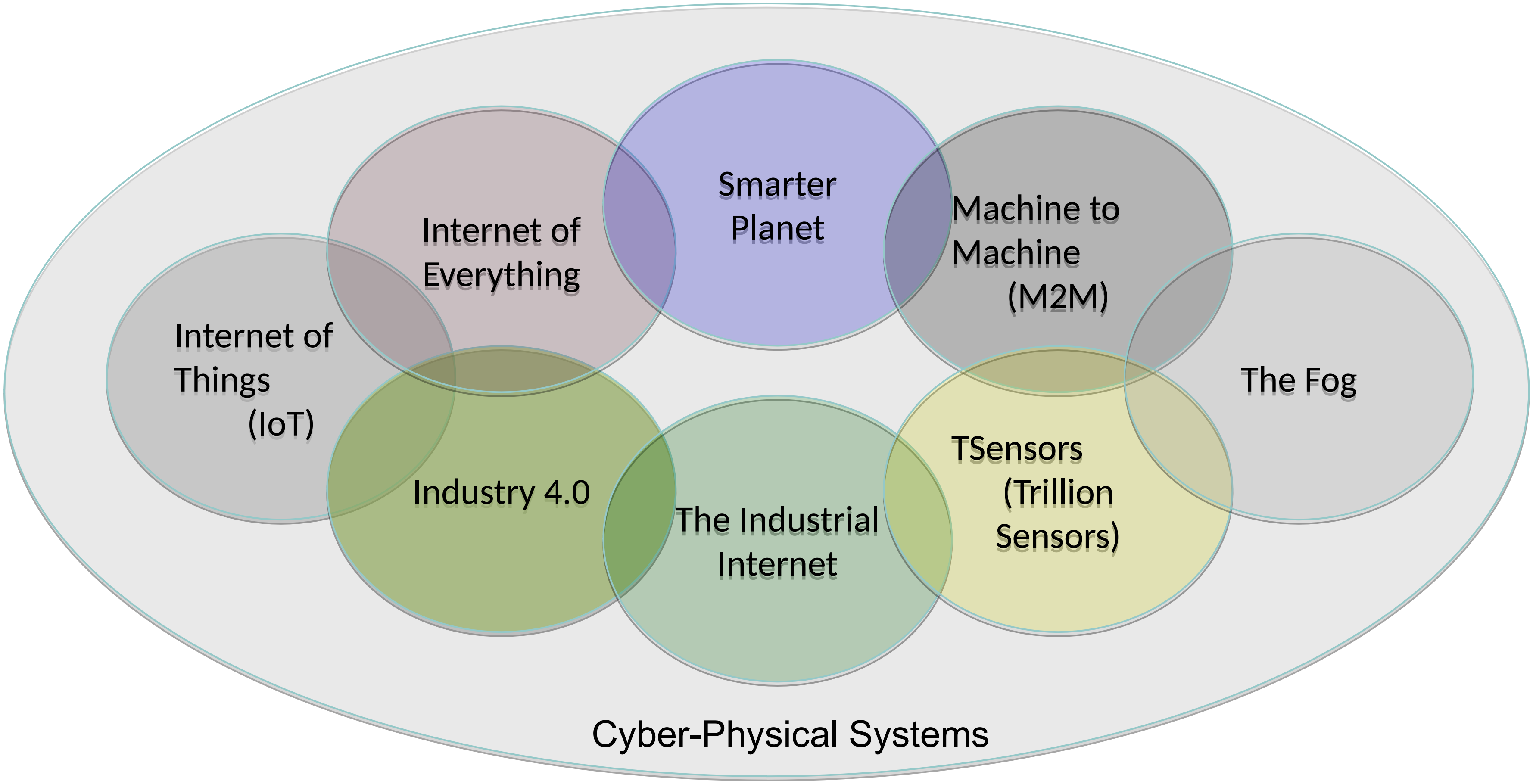
Automotive



Manufacturing

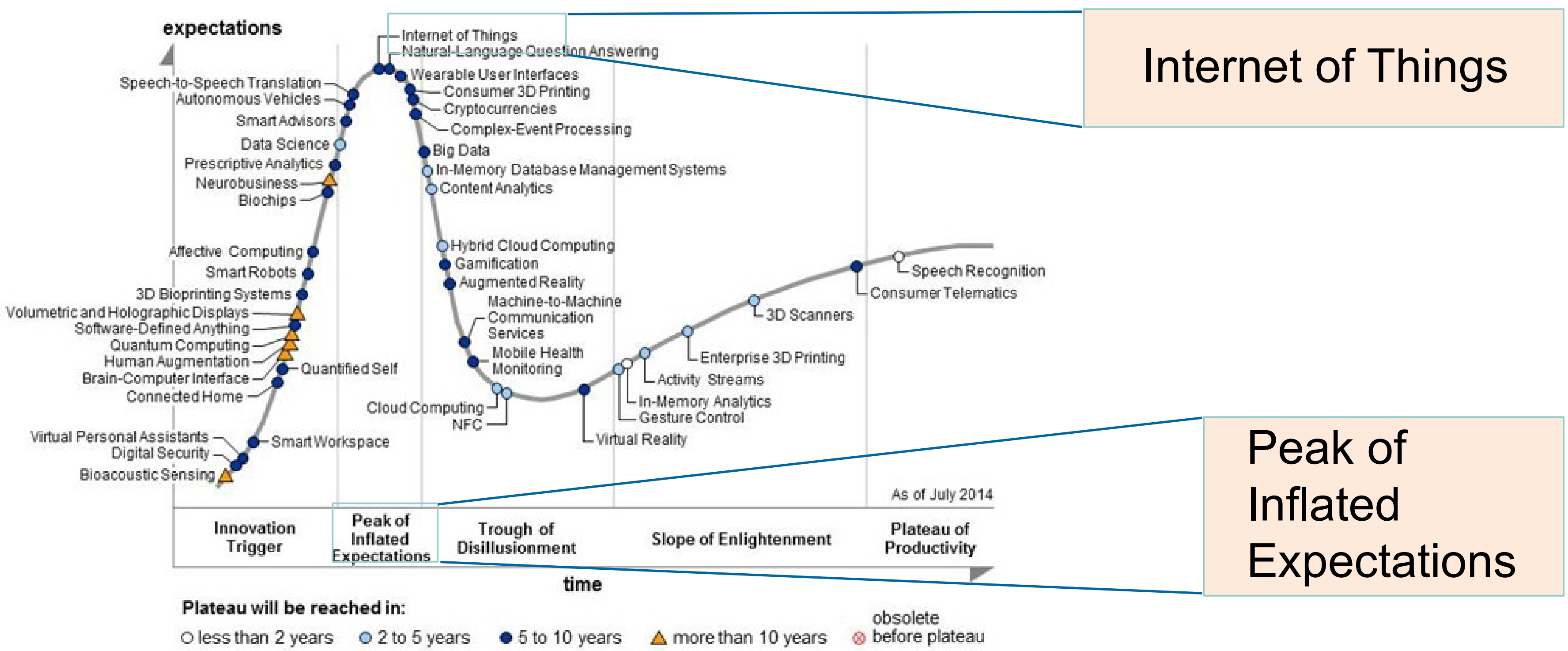
Lee, Berkeley

E Pluribus Unum: Out of Many, One



The Hype Around
The Internet of Things

Using Internet technology to connect physical devices (“things”).



http://www.gartner.com/technology/research/hype-cycles/

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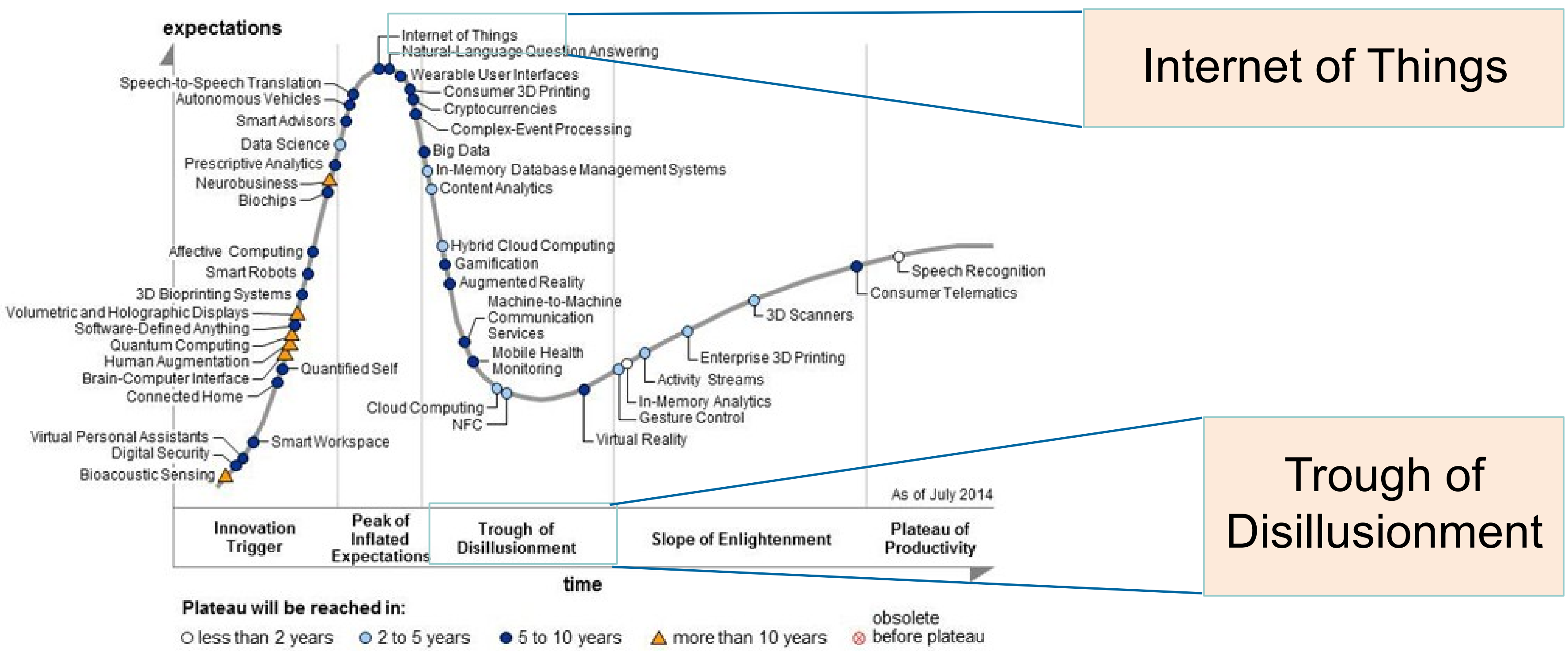

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IoT is the use of Internet technology for Cyber-Physical Systems

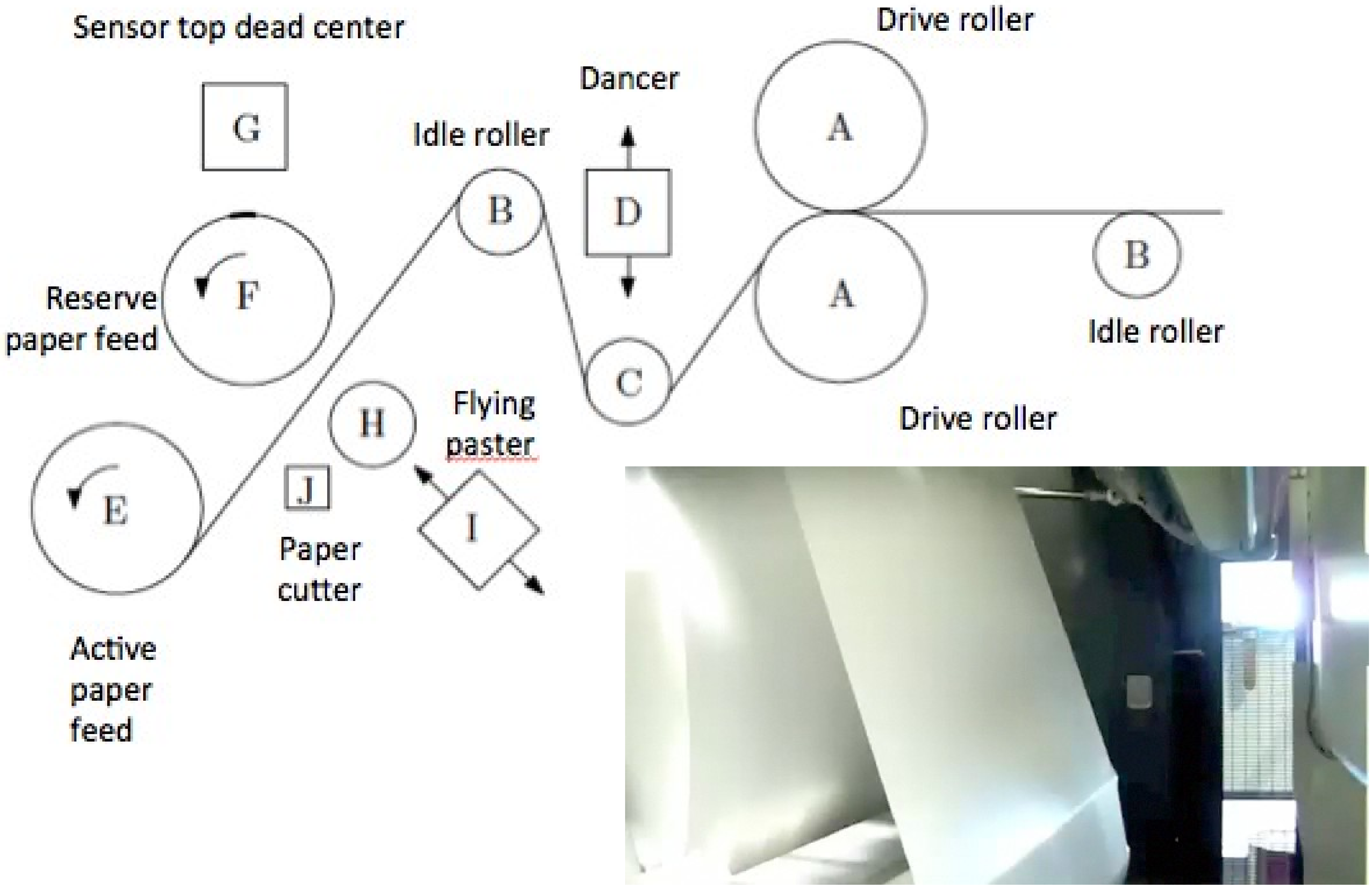
Industrial automation example from 2008: Bosch-Rexroth printing press.

The term “IoT” includes the technical solution “Internet technology” in the problem statement “connect things”.

The term CPS does not.

This Bosch Rexroth printing press is a cyber-physical factory using Ethernet and TCP/IP with high-precision clock synchronization (IEEE 1588) on an isolated LAN.

Example – Flying Paster



Source: http://offsetpressman.blogspot.com/2011/03/how-flying-paster-works.html

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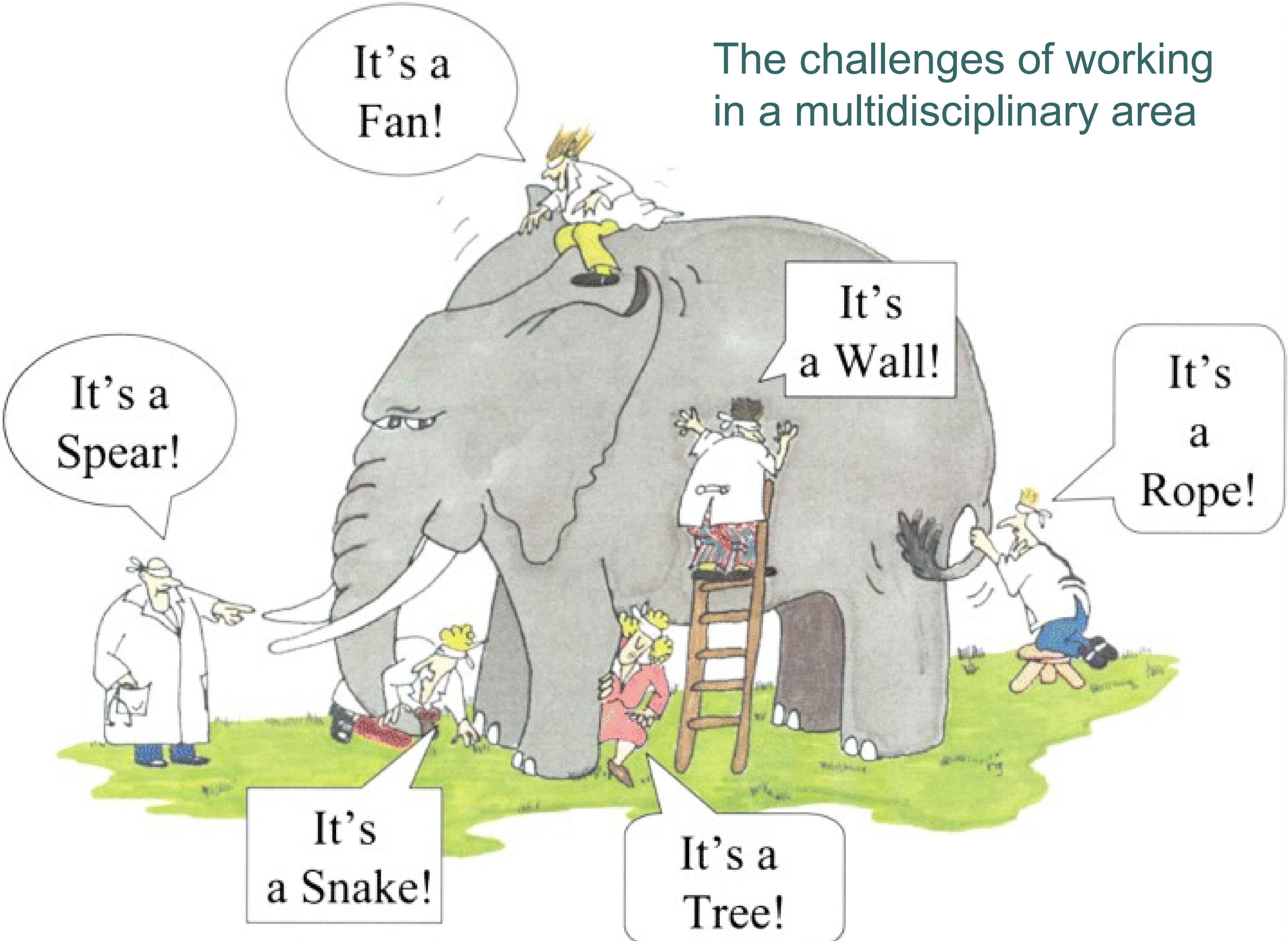
Flying Paster

CPS Challenge Problem: Prevent This

The challenges of working in a multidisciplinary area



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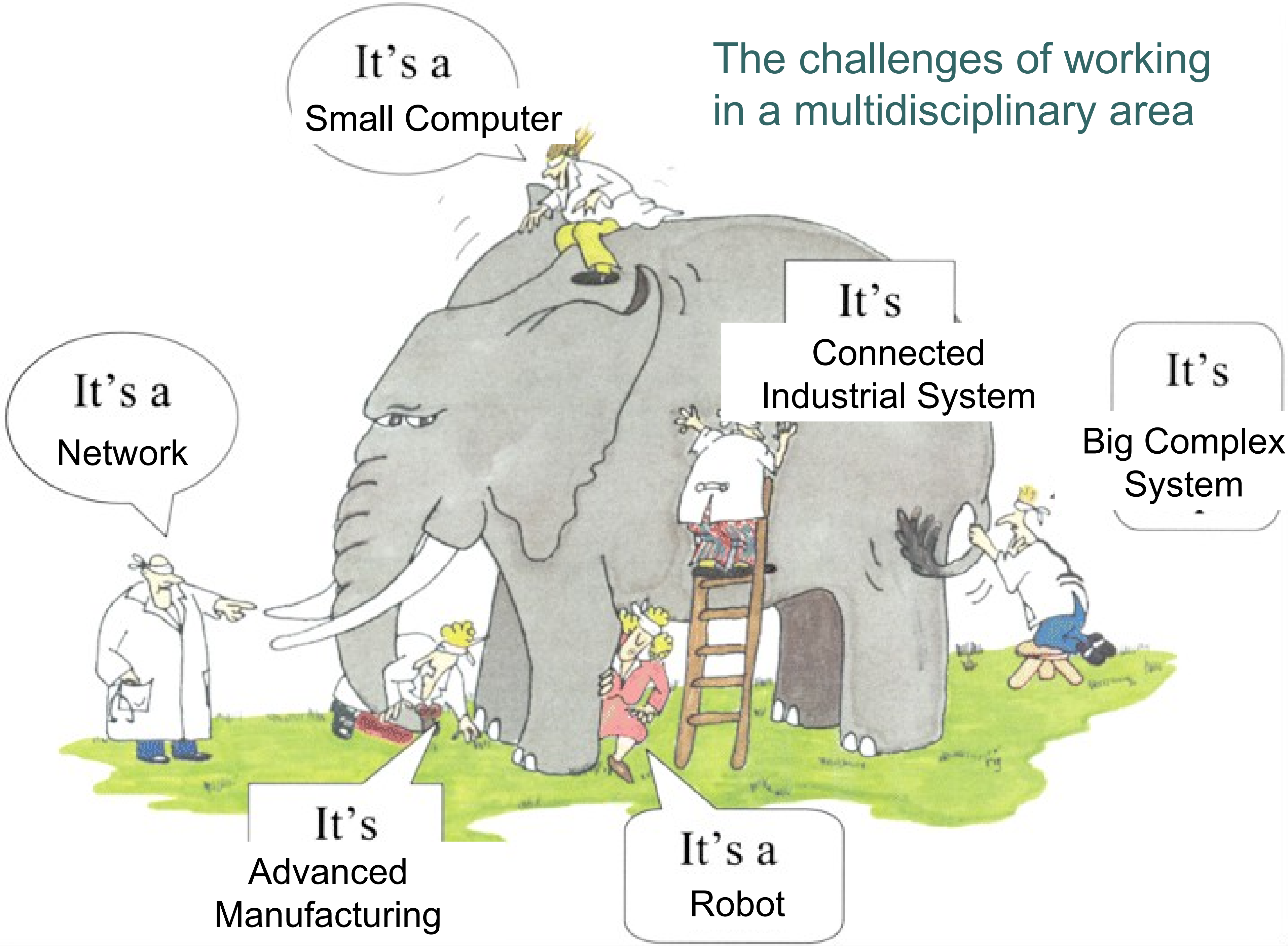
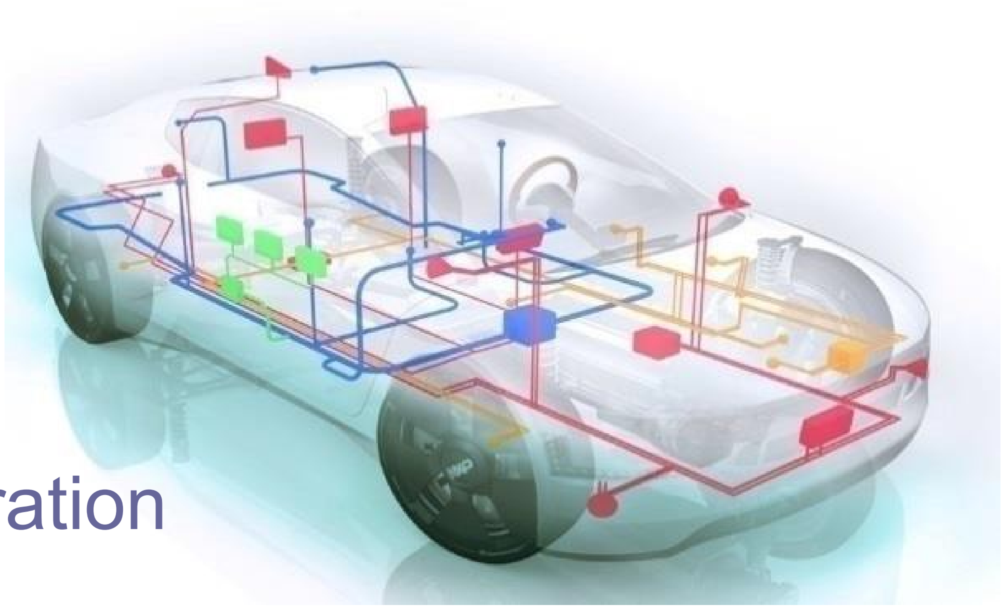
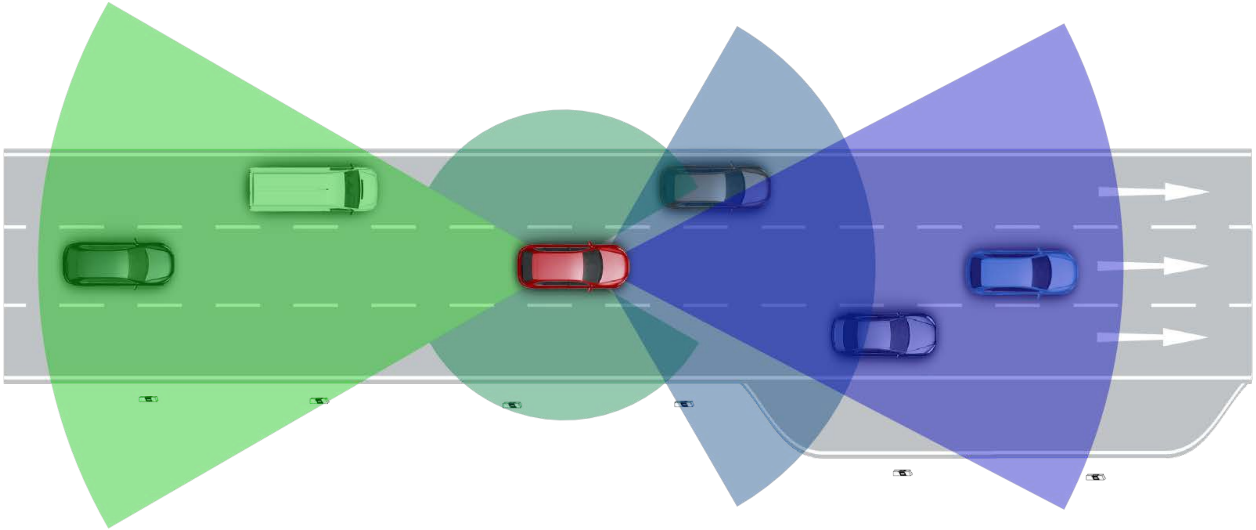


Automotive CPS and Societal Challenges

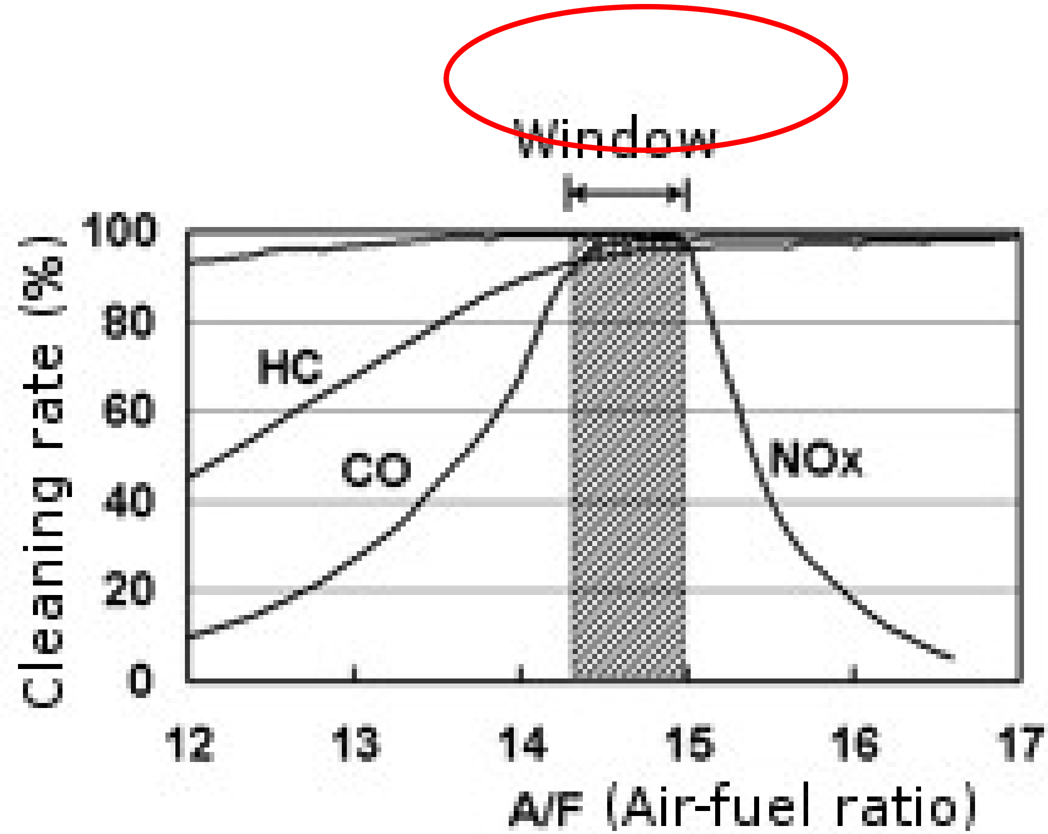
- Safer Transportation
- Reduced Emissions
- Smart Transportation
- Energy Efficiency
- Climate Change
- Human-Robot Collaboration





Example: Air-Fuel ratio control to reduce emissions

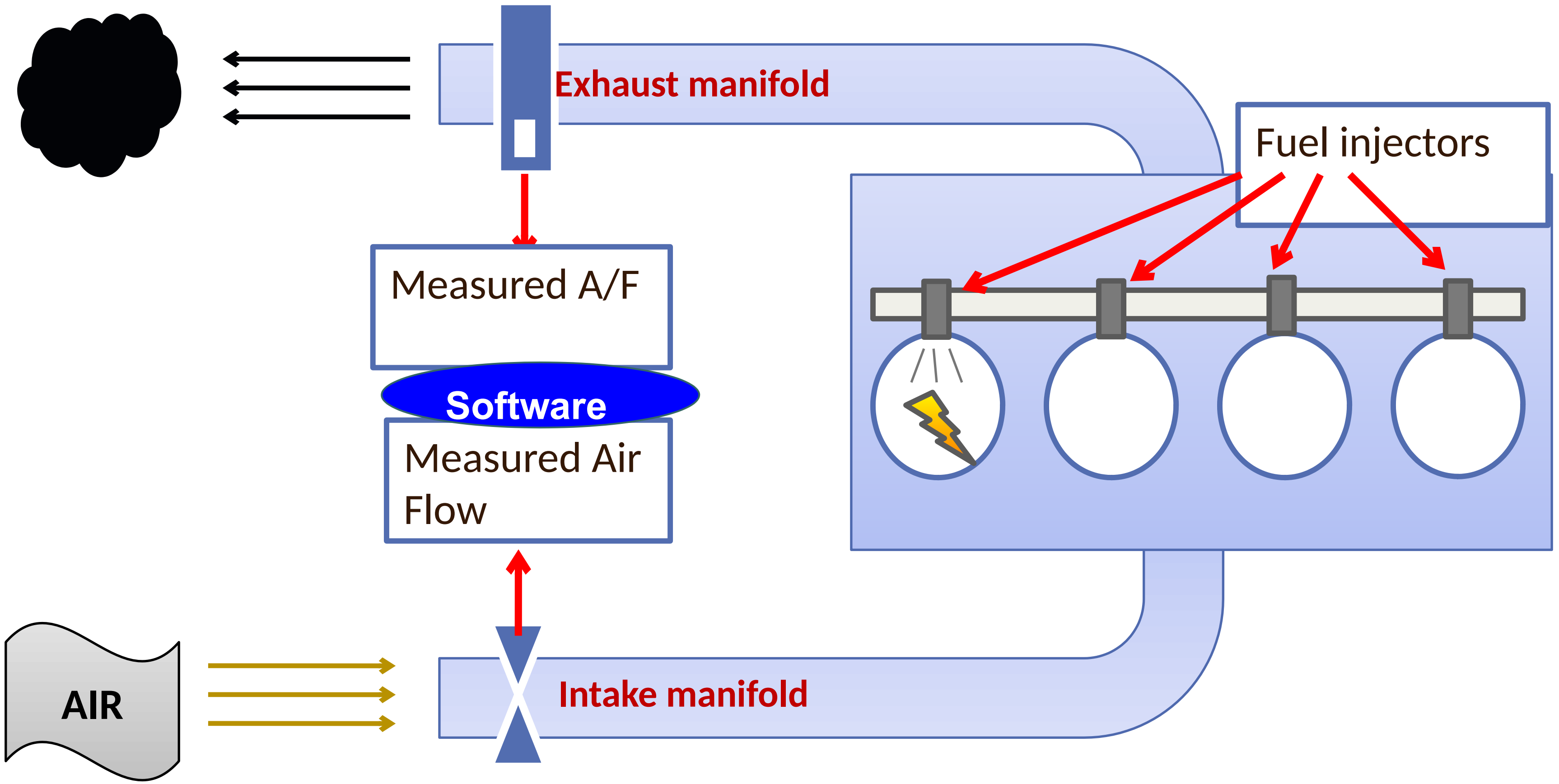
- Catalytic converters reduce CH_4, CO_2, and NO_x emissions
- Conversion efficiency optimal at stoichiometric value
- 7 minutes in video Electronic Control Unit ECU Training



See:
Jin. Kapinski. Deshmukh,
Ueda, Butts,
"Powertrain Control Verification
Benchmark,"
HSCC 2014

[Slide due to J. Deshmukh, Toyota]

Air-Fuel ratio control: Gasoline Engine setting



[Slide due to J. Deshmukh, Toyota]

Report: McKinsey Global Institute

Disruptive technologies:

Advances that will transform life, business, and the global economy

May 2013

… with major CPS components

Twelve potentially economically disruptive technologies

Mobile Internet	Increasingly inexpensive and capable mobile computing devices and Internet connectivity
Automation of knowledge work	Intelligent software systems that can perform knowledge work tasks involving unstructured commands and subtle judgments
The Internet of Things	Networks of low-cost sensors and actuators for data collection, monitoring, decision making, and process optimization
Cloud technology	Use of computer hardware and software resources delivered over a network or the Internet, often as a service
Advanced robotics	Increasingly capable robots with enhanced senses, dexterity, and intelligence used to automate tasks or augment humans
Autonomous and near-autonomous vehicles	Vehicles that can navigate and operate with reduced or no human intervention
Next-generation genomics	Fast, low-cost gene sequencing, advanced big data analytics, and synthetic biology ("writing" DNA)
Energy storage	Devices or systems that store energy for later use, including batteries
3D printing	Additive manufacturing techniques to create objects by printing layers of material based on digital models
Advanced materials	Materials designed to have superior characteristics (e.g., strength, weight, conductivity) or functionality
Advanced oil and gas exploration and recovery	Exploration and recovery techniques that make extraction of unconventional oil and gas economical
Renewable energy	Generation of electricity from renewable sources with reduced harmful climate impact

Economic Potential

The Internet of Things	**300%** Increase in connected machine-to-machine devices over past 5 years **80–90%** Price decline in MEMS (microelectromechanical systems) sensors in past 5 years	**1 trillion** Things that could be connected to the Internet across industries such as manufacturing, health care, and mining **100 million** Global machine to machine (M2M) device connections across sectors like transportation, security, health care, and utilities	**$36 trillion** Operating costs of key affected industries (manufacturing, health care, and mining)
Cloud technology	**18 months** Time to double server performance per dollar **3x** Monthly cost of owning a server vs. renting in the cloud	**2 billion** Global users of cloud-based email services like Gmail, Yahoo, and Hotmail **80%** North American institutions hosting or planning to host critical applications on the cloud	**$1.7 trillion** GDP related to the Internet **$3 trillion** Enterprise IT spend
Advanced robotics	**75–85%** Lower price for Baxter[3] than a typical industrial robot **170%** Growth in sales of industrial robots, 2009–11	**320 million** Manufacturing workers, 12% of global workforce **250 million** Annual major surgeries	**$6 trillion** Manufacturing worker employment costs, 19% of global employment costs **$2–3 trillion** Cost of major surgeries
Autonomous and near-autonomous vehicles	**7** Miles driven by top-performing driverless car in 2004 DARPA Grand Challenge along a 150-mile route **1,540** Miles cumulatively driven by cars competing in 2005 Grand Challenge **300,000+** Miles driven by Google's autonomous cars with only 1 accident (which was human-caused)	**1 billion** Cars and trucks globally **450,000** Civilian, military, and general aviation aircraft in the world	**$4 trillion** Automobile industry revenue **$155 billion** Revenue from sales of civilian, military, and general aviation aircraft

Google Strategy

CNET › Internet › Google closes $3.2 billion purchase of Nest

Google closes $3.2 billion purchase of Nest

The acquisition brings with it the Learning Thermostat and the Protect smoke and CO detector as Google looks to make its mark in the smart home.

by Lance Whitney @lancewhit / February 12, 2014 5:00 AM PST / Updated: February 12, 2014 5:19 AM PST

theguardian | TheObserver

Search

Google's drive into robotics should concern us all

The company's expansion into robotics was developed in tandem with the US military. Where will its power play stop?

John Naughton
The Observer, Sunday 29 December 2013

Google's robotic cars have about $150,000 in equipment including a $70,000 LIDAR (laser radar) system. The range finder mounted on the top is a Velodyne 64-beam laser. This laser allows the vehicle to generate a detailed 3D map of its environment. The car then takes these generated maps and combines them with high-resolution maps of the world, producing different types of data models that allow it to drive itself.

Google and Facebook

Artist's rendering of Titan's Solara 50, which in theory at least, can stay aloft for years.

Wall Street Journal:

By Alistair Barr and Reed Albergotti
April 14, 2014

Google Inc. on Monday acquired a maker of solar-powered drones—a startup that Facebook Inc. had also considered acquiring—as the technology giants battle to extend their influence and find new users in the far corners of the earth.

Tesla Gigafactory

Artists conception of battery factory under construction in Nevada.
From: https://www.tesla.com/gigafactory

Apple iCar?

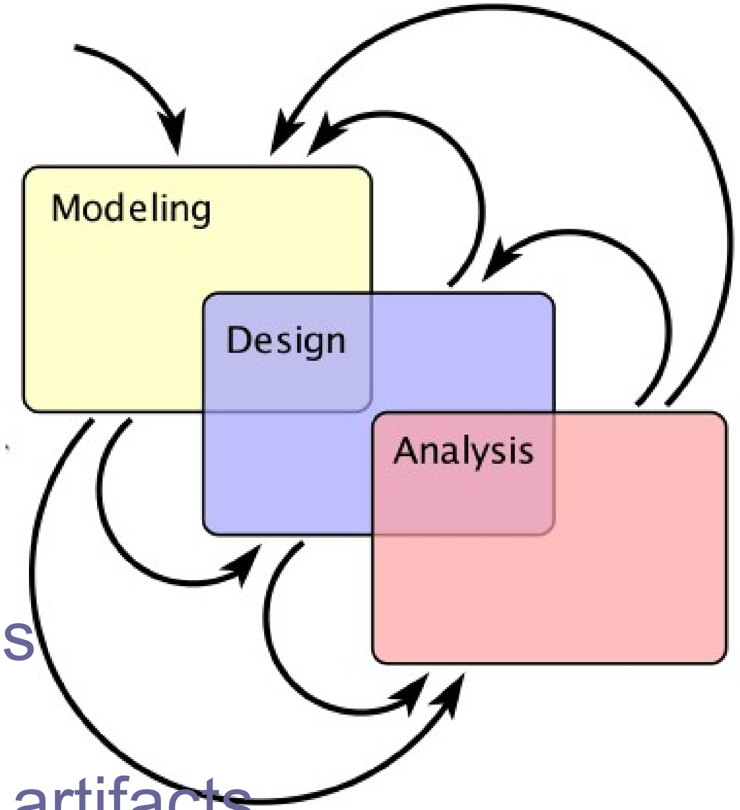
Macworld, Aug. 10, 2016:

Reports suggest that Apple is developing an electric iCar to rival Tesla. With reports that Apple is negotiating with BMW, and poaching Samsung employees (especially battery specialists) and reassigning large numbers of staff for its Project Titan, is Apple manufacturing an iCar, and when will the iCar be launched?

The Emerging IT Scene

Courtesy: J. Rabaey

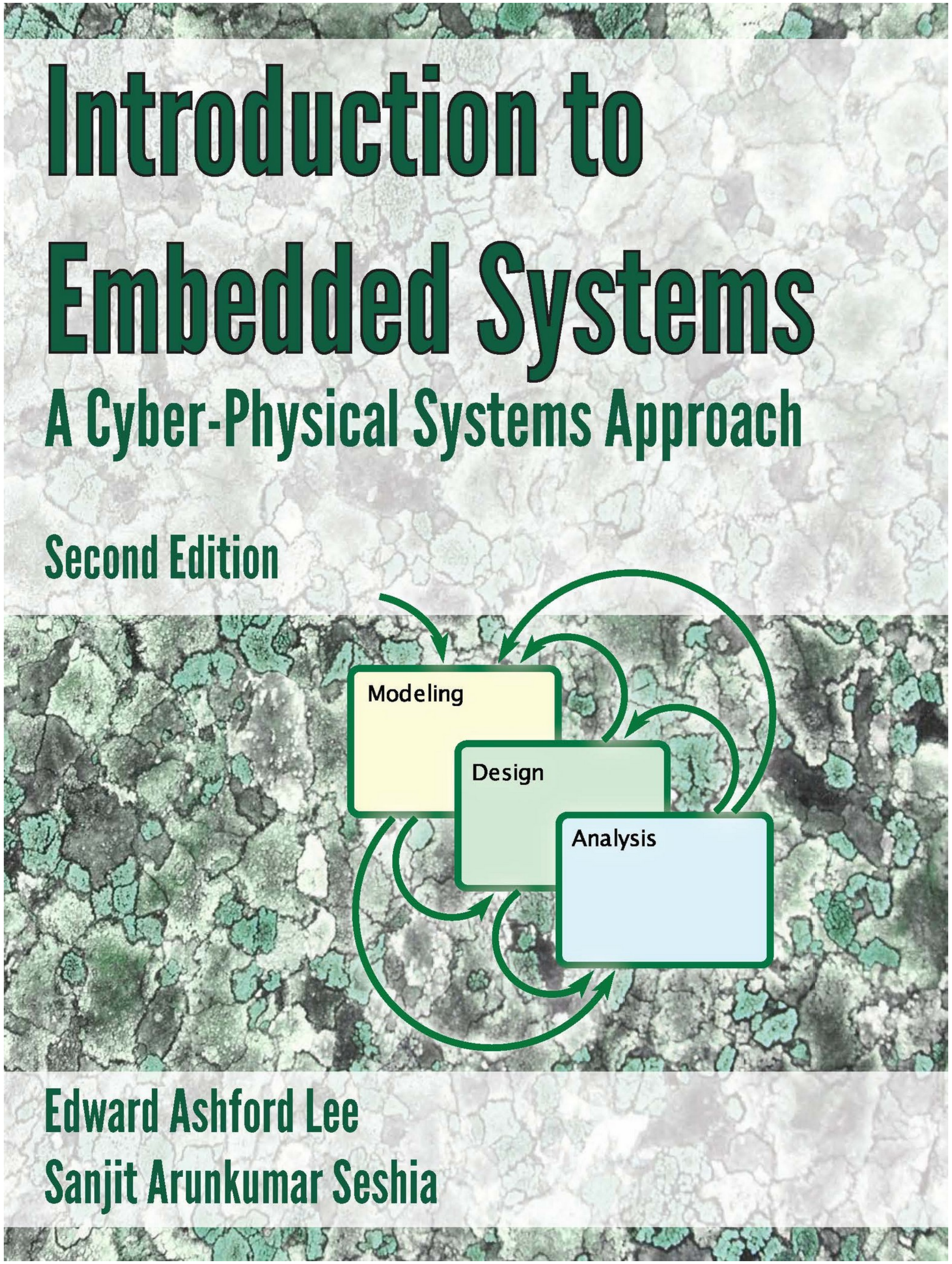
Modeling, Design, Analysis



Modeling is the process of gaining a deeper understanding of a system through imitation. Models express **what** a system does or should do.

Design is the structured creation of artifacts. It specifies **how** a system does what it does.

Analysis is the process of gaining a deeper understanding of a system through dissection. It specifies **why** a system does what it does (or fails to do what a model says it should do).



The emphasis is on modeling, design, and analysis of cyber-physical systems, which integrate computing, networking, and physical processes.

http://LeeSeshia.org

Motivating Example of a Cyber-Physical System
(see Chapter 1 in book)

STARMAC quadrotor aircraft (Tomlin, et al.)

- Introductory Video: http://www.youtube.com/watch?v=rJ9r2orcaYo
- Back-Flip Manuever: http://www.youtube.com/watch?v=iD3QgGpzzIM

Modeling:
- Flight dynamics (ch2)
- Modes of operation (ch3)
- Transitions between modes (ch4)
- Composition of behaviors (ch5)
- Multi-vehicle interaction (ch6)

Design:
- Sensors and Actuators (ch7)
- Processors (ch8)
- Memory system (ch9)
- Sensor interfacing (ch10)
- Concurrent software (ch11)
- Real-time scheduling (ch12)

Analysis
- Specifying safe behavior (ch13)
- Achieving safe behavior (ch14)
- Verifying safe behavior (ch15)
- Guaranteeing timeliness (ch16)
- Security and privacy (ch17)

STARMAC Design Block Diagram