Lecture 1: Introduction

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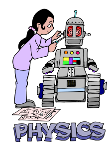
Some slides from Edward Lee, Peter Marwedel, and Philip Koopman

The First Questions

- What is an *Embedded System*?
  - Why is it important?
- What makes a system *Real-Time*?
- What is a *Cyber-Physical System*?
  - How is it related to IoT, Industry 4.0, M2M, etc.
- How to develop them?

Motivation for the Course

- According to forecasts, future of IT characterized by terms such as
  - Disappearing computer,
  - Ubiquitous computing,
  - Pervasive computing,
  - Ambient intelligence,
  - Post-PC era,
  - Cyber-physical systems.
- Basic technologies:
  - *Embedded System technologies*
  - Communication technologies



Embedded Systems & Cyber-Physical Systems

- "Dortmund" Definition: [Peter Marwedel]
  - Embedded systems are information processing systems embedded into a larger product
- Berkeley: [Edward A. Lee]*:*
  - Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems.
  - Cyber-Physical (cy-phy) Systems (CPS) are integrations of computation with physical processes [Edward Lee, 2006].
- *Cyber-physical system* (CPS) = *Embedded System* (ES) + *physical environment*

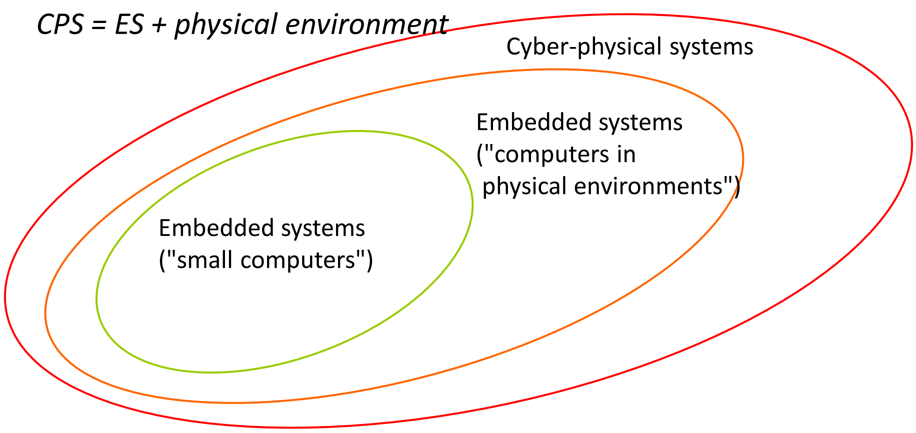
Embedded Systems & Cyber-Physical Systems

- Definition by Helen Gill

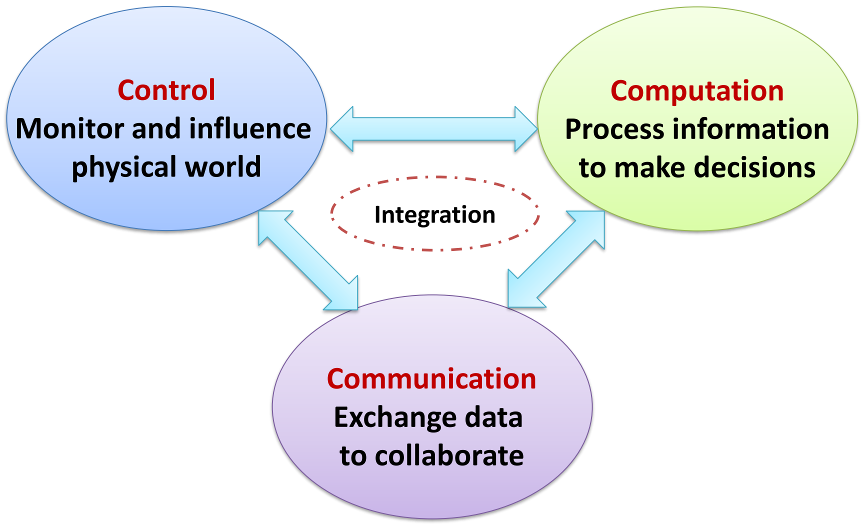
Cyber-physical systems are physical, biological, and engineered systems whose operations are integrated, monitored, and/or controlled by a *computational core*. Components are *networked at every scale*. Computing is "*deeply embedded*" into every physical component, possibly even into materials. The computational core is an *embedded system*, usually demands *real-time* response, and is most often *distributed*. The behavior of a cyber-physical system is a fully-integrated hybridization of computational (logical) and physical action.

Embedded Systems & Cyber-Physical Systems

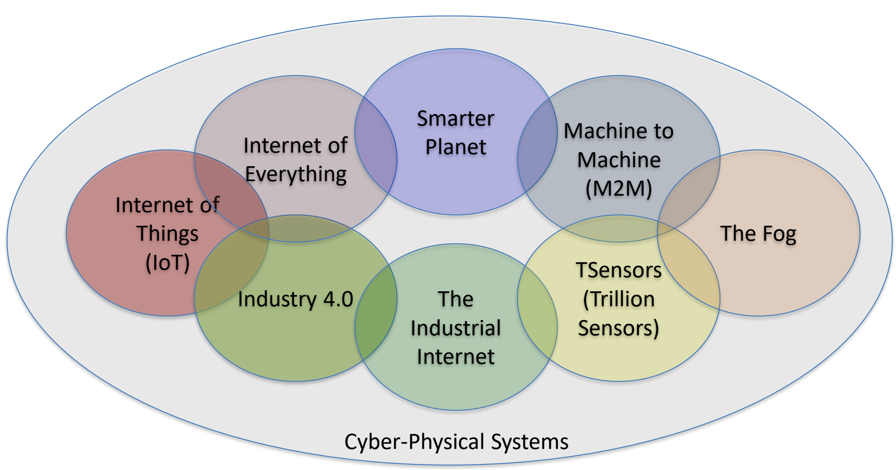
CPS = ES + physical environment



Cyber-Physical Systems: C^3



Related Technologies

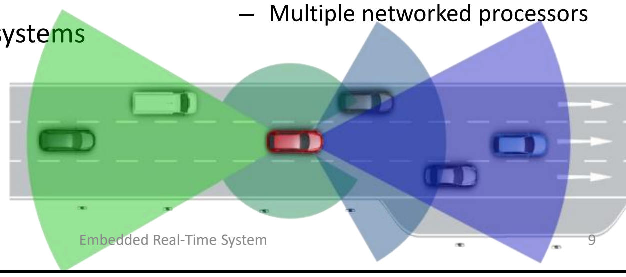


Application Area: Automotive Electronics Clearly Cyber-Physical

Functions by embedded processing:

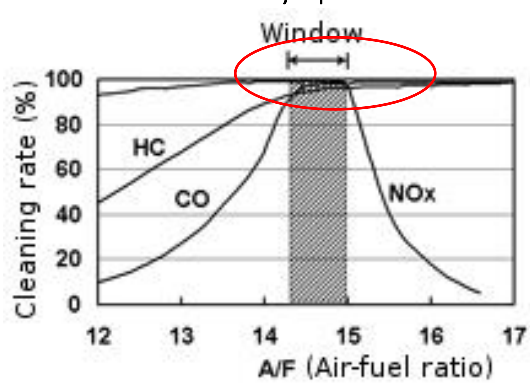
- ABS: Anti-lock braking systems
- ESP: Electronic stability control
- Airbags
- Efficient automatic gearboxes
- Theft prevention with smart keys
- Blind-angle alert systems
- ... etc ...

- Multiple networks
- Multiple networked processors



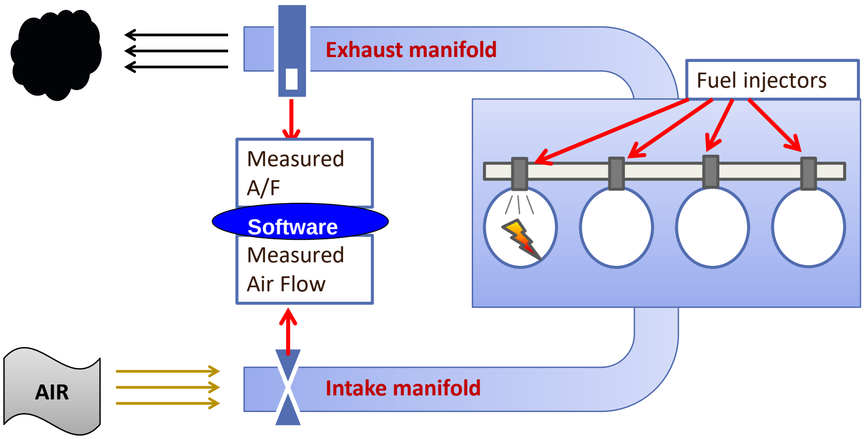
Example: Air-Fuel ratio control to reduce emissions

- Catalytic converters reduce CH_4, CO_2, and NO_x emissions
- Conversion efficiency optimal at stoichiometric value



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

Air-Fuel ratio control: Gasoline Engine setting



Application Area: Avionics Also Cyber-Physical

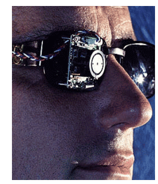
- Flight control systems,
- anti-collision systems,
- pilot information systems,
- power supply system,
- flap control system,
- entertainment system,
- …

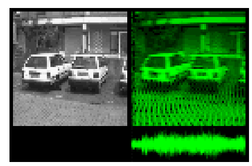
Dependability is of outmost importance.

Medical Systems: Cyber-Physical

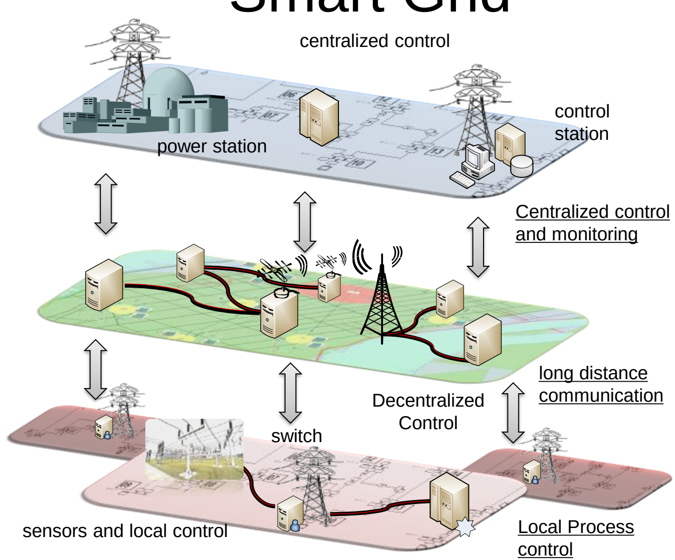
For example:

- Artificial eye: several approaches, e.g.:
  - Camera attached to glasses; computer worn at belt; output directly connected to the brain, "pioneering work by William Dobelle". Previously at [www.dobelle.com]
  - Translation into sound; claiming much better resolution. [http://www.seeingwithsound.com/etumble.htm]





Smart Grid



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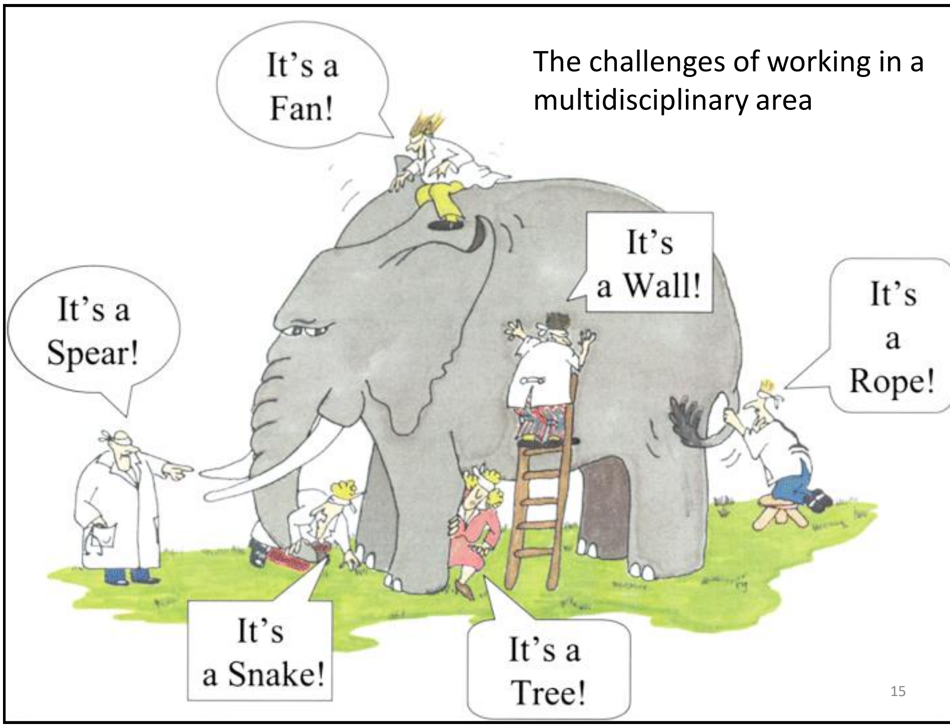
The challenges of working in a multidisciplinary area



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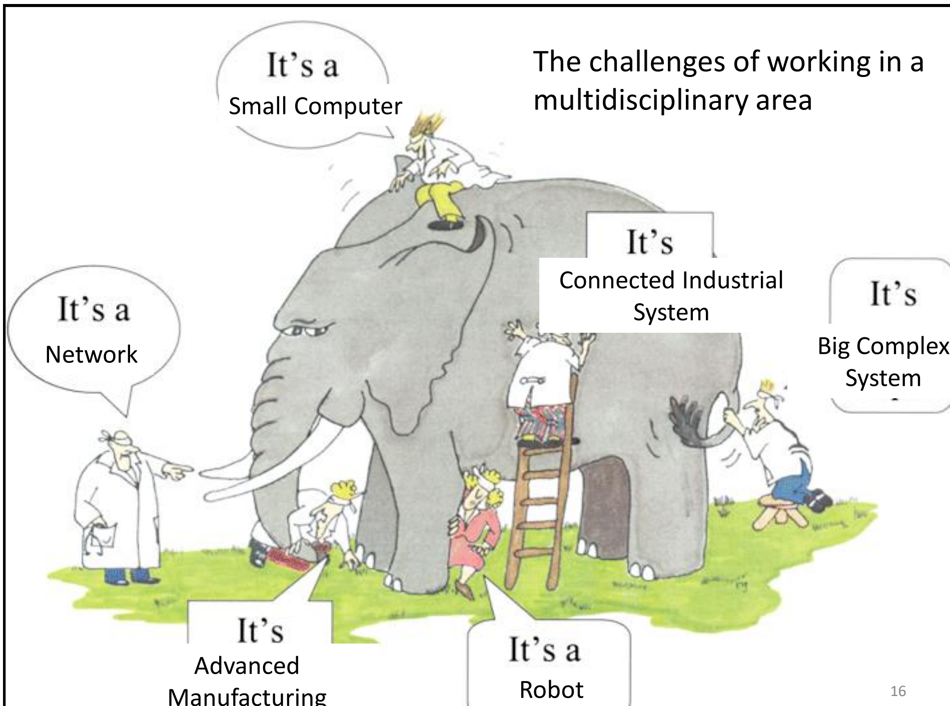

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Focus on Cyber-Physical Systems Full of Contradictory Requirements

It's not just information technology anymore:

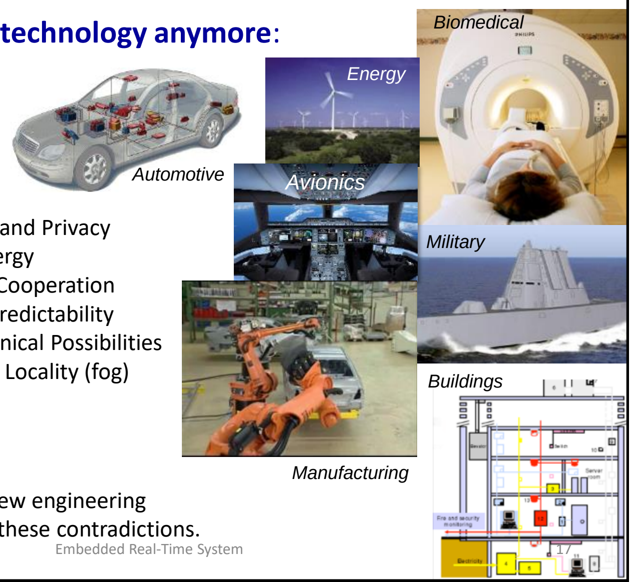
- Cyber + Physical
- Computation + Dynamics
- Security + Safety

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.



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

The Emerging IT Scene

Courtesy: J. Rabaey

Embedded Software Is Important & Challenging

Airbus confirms software configuration error caused plane crash

Airbus A400M flight recorder data confirms "quality issue" in setup caused failure.

thermostat bug plunges customers into cold

By James Billington https://goo.gl/RPv9V6

January 14, 2016 14:27 GMT

Smart thermostat has been leaving customers cold after suffering from a software bug that drained its battery.

CNN Money Chrysler recalls 1.4 million hackable cars

Chrysler is recalling 1.4 million vehicles that can be remotely hacked over the Internet. https://goo.gl/97fY8H

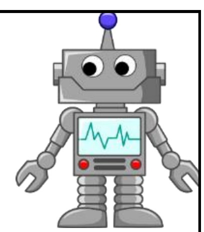
Toyota's killer firmware: Bad design and its consequences https://goo.gl/pX3qgb

Michael Dunn -October 28, 2013

On Thursday October 24, 2013, an Oklahoma court ruled against Toyota in a case of unintended acceleration that lead to the death of one the occupants. Central to the trial was the Engine Control Module's (ECM) firmware.

- Toyota's electronic throttle control system (ETCS) source code is of unreasonable quality.
- Toyota's source code is defective and contains bugs, including bugs that can cause unintended acceleration (UA).
- Code-quality metrics predict presence of additional bugs.
- Toyota's fail safes are defective and inadequate (referring to them as a *"house of cards" safety architecture*).
- Misbehaviors of Toyota's ETCS are a cause of UA.

Embedded Software Quality, Safety & Security



- Software is crucial for providing value
  - But, even a single line of bad code can kill a product/company
  - Writing software is a high-stakes profession.
- Good software requires process + technology + people
  - Embedded software requires *unique technical approaches*
  - **You can't test quality, safety, or security into software**
- Good process enables good software
  - Whether "V" or agile, need to actually follow a good process
- Safety and security are essential
  - Most embedded software is safety critical or mission critical
  - Security is required in essentially all embedded software

What this course is about

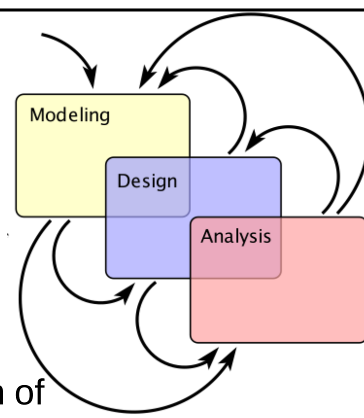
A principled, scientific approach to designing and implementing embedded/cy-phy systems

Not just hacking!!

Hacking can be fun, but it can also be very painful when things go wrong…

Focus on *model-based system design*, and on *embedded software*

Modeling, Design, Analysis

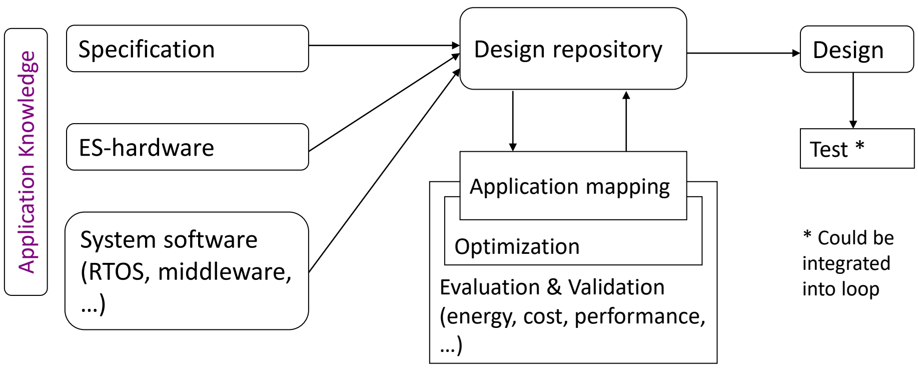


Modeling is the process of gaining a deeper understanding of a system through imitation. Models express **what** a system does or should do.

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

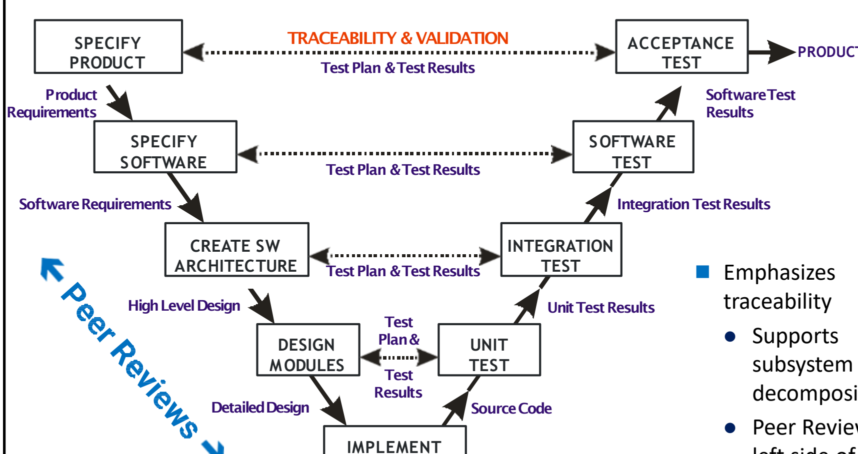
Analysis is the process of gaining a deeper understanding of a system through dissection. It specifies **why** a system does what it does (or fails to do what a model says it should do).

Marwedel's Hypothetical Design Flow



Generic loop: tool chains differ in the number and type of iterations

V (or "Vee") Development Cycle



- Emphasizes traceability
  - Supports subsystem decomposition
  - Peer Reviews on left side of V

Next Lecture

- Embedded and cy-phy systems characteristics
  - Functional requirements
  - Non-functional requirements
    - Temporal requirements
    - Energy efficiency
    - Dependability
  - Classification of real-time systems

SPARE SLIDES

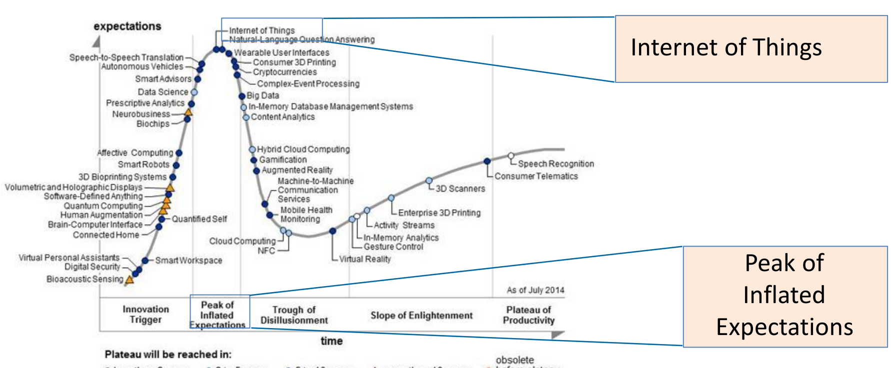
Definition According to National Science Foundation (US)

- Cyber-physical systems (CPS) are engineered systems that are built from and depend upon the **synergy of computational and physical components.**
- Emerging CPS will be **coordinated, distributed**, and **connected**, and must be **robust** and **responsive**.
- The CPS of tomorrow will need to far exceed the systems of today in capability, adaptability, resiliency, safety, security, and usability.
- Examples of the many CPS application areas include the **smart electric grid, smart transportation, smart buildings, smart medical technologies, next-generation air traffic management, and advanced manufacturing**.

cps-vo.org

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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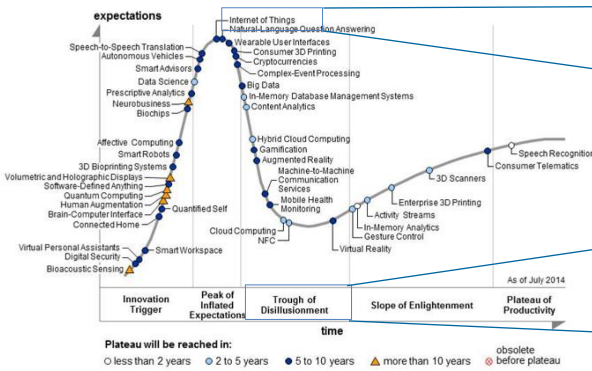

Internet of Things

Trough of Disillusionment

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