CYBER-PHYSICAL SYSTEMS:
THE DREAM OF DR. FRANKENSTEIN

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Cadence Design Systems
Cyber-Physical Systems (CPS): Orchestrating networked computational resources with physical systems

- Power generation and distribution
- Factory automation
- Telecommunications
- Building Systems
- Automotive
- Instrumentation
- Transportation (Air traffic control at SFO)
- Military systems: E-Corner, Siemens
- Telecommunications
- Factory automation

Courtesy of Kuka Robotics Corp.

Courtesy of Doug Schmidt

Courtesy of General Electric

Transportation (Air traffic control at SFO)
Cyber-Physical Systems (CPS) are integrations of computation and physical processes.

Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa.

These systems are multi-scale and heterogeneous, mixing wide ranges of technologies.

Edward Lee and ASV, Proc. Of the IEEE, Spec. Issue on CPS
Where CPS Differs from the Traditional Embedded System Problem

- **The traditional embedded system problem:**
  Software, controllers, sensors and actuators. 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 dynamics, time, and concurrency in networked computational + physical systems.

- **Components:**
generators, loads, buses, contactors, transformers, rectifiers, ECUs, sensors...

- **Design architecture and control** under safety, reliability and real-time performance requirements
CPS Architecture: a Definition

An interconnection of components.
- Not only physical, not only abstract
- Intrinsically heterogeneous
Cyber Physical Systems: A Tale of Integration

Cyber-Physical Systems (CPS): Orchestrating networked computational resources with multi-physics (e.g., mechanical, chemical, electrical) systems. Co-design of physical system and controller. Computation and networking integrated with physical processes. The technical problem is managing dynamics, time, and concurrency in networked, distributed computational + physical systems.
Even a relatively small system is an.....elephant!!

It’s an electromechanical system

It’s a mechanical system

It’s an electrical system

It’s a control system

It’s a software system

It’s a human-computer interface

\[ \dot{x} = f(x, u, \theta) \]
\[ F(x) = 0 \]
Compositionality: Plug and Play?

Plug and Pray!
The Gaps and Opportunities

Issues:

- Faulty designs
- Long re-design cycles
- Missed customer expectations
- Supply chain management
- Testing
- A multitude of domains (e.g., electrical, mechanical, computing, control, communication)
- Computing platforms increasingly heterogeneous
- Severe integration difficulties
- Engineering skills

Introduce Formality and Rigor:

- Unifying design methodology
- Formal Requirement capture and analysis
- Heterogeneous (multi-physics and computing platform) modeling and analysis
- Layers of abstraction
- (Formal) Verification
- Synthesis and Optimization
- Development of proof-of-concept methodology, models and tools based on research for industrial strength CPS test cases
CyberBiological Systems (BioCyber)
Linking the Cyber and Biological Worlds

Examples: Telesurgery, Body-area networks, health diagnostics, drug delivery, brain-machine interfaces, ...
Towards integrated wireless implanted interfaces

Moving the state-of-the-art in wireless sensing

Power budget: mWs to 1 mW
Educational Challenge
Educational Challenge