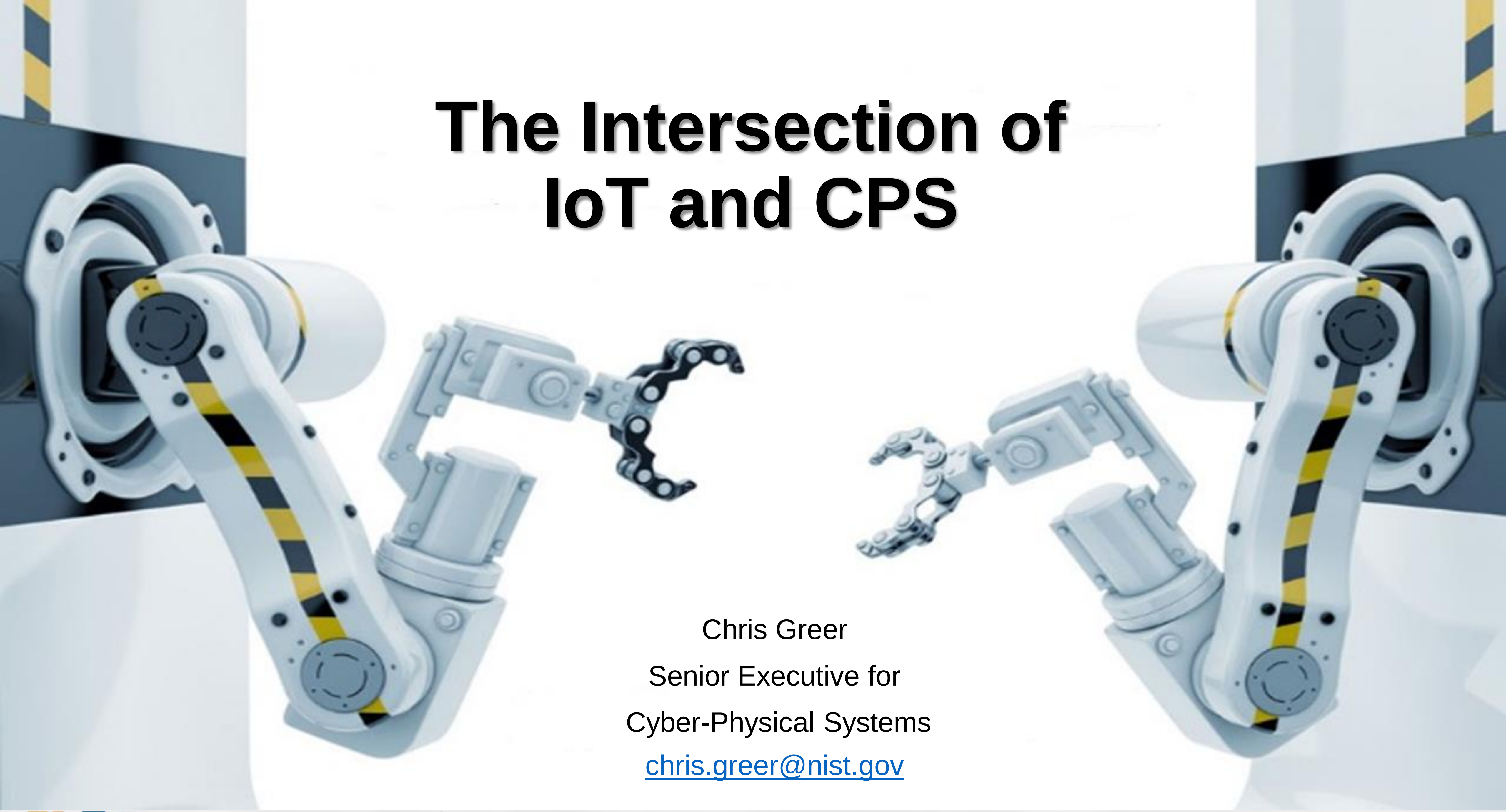

The Intersection of IoT and CPS

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Credit

- Edward Griffor – Framework, Mathematical models
- Marty Burns – Framework, Pivotal Points of Interoperability
- David Wollman – Framework, Physical and Logical Interactions

Outline

- Definitions
- Illustrative Scenarios
- Mathematical Models
- Framework

CPS: Examples of Current Definitions

Cyber-physical systems (CPS) are engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components.

US National Science Foundation

Cyber-physical systems integrate sensing, computation, control and networking into physical objects and infrastructure, connecting them to the Internet and to each other.

CPS Virtual Organization

Cyber-physical systems (CPS) are smart systems that include engineered interacting networks of physical and computational components.

CPS Public Working Group (NIST)

In such technical systems, which are often called cyber-physical systems (CPS), real-time computing elements and physical systems interact tightly. …The merging of IoT and CPS into closed-loop, real-time IoT-enabled cyber-physical systems is seen as an important future challenge.

PICASSO Project Opportunity Report

IoT: Examples of Current Definitions

An infrastructure of interconnected objects, people, systems and information resources together with intelligent services to allow them to process information of the physical and the virtual world and react.

ISO/IEC JTC1, 2015

The Internet of Things (IoT) has been defined in Recommendation ITU-T Y.2060 as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

ITU-TY.400/Y.2060

IoT refers to any systems of interconnected people, physical objects, and IT platforms, as well as any technology to better build, operate, and manage the physical world via pervasive data collection, smart networking, predictive analytics, and deep optimization.

IEEE-SA IoT Ecosystem Study 2015

Relationship Between CPS and IoT: Examples

In most academic and project activities, the difference between “Internet of Things” and “Cyber-Physical Systems (CPS)” is not made clear and it is difficult to find a source that draws a clear-cut distinction … Yet, identified objects in an IoT system can still be networked together so as to control a certain scenario in a coordinated way, in which case an IoT system can be considered to grow to the level of a CPS.

IEEE (2015) Towards a Definition of the Internet of Things

According to the PICASSO definition, the IoT is seen as an enabling technology for CPS or CPSoS (System of Systems) … The merging of IoT and CPS into closed-loop, real-time IoT-enabled cyber-physical systems is seen as an important future challenge.

PICASSO Project Opportunity Report

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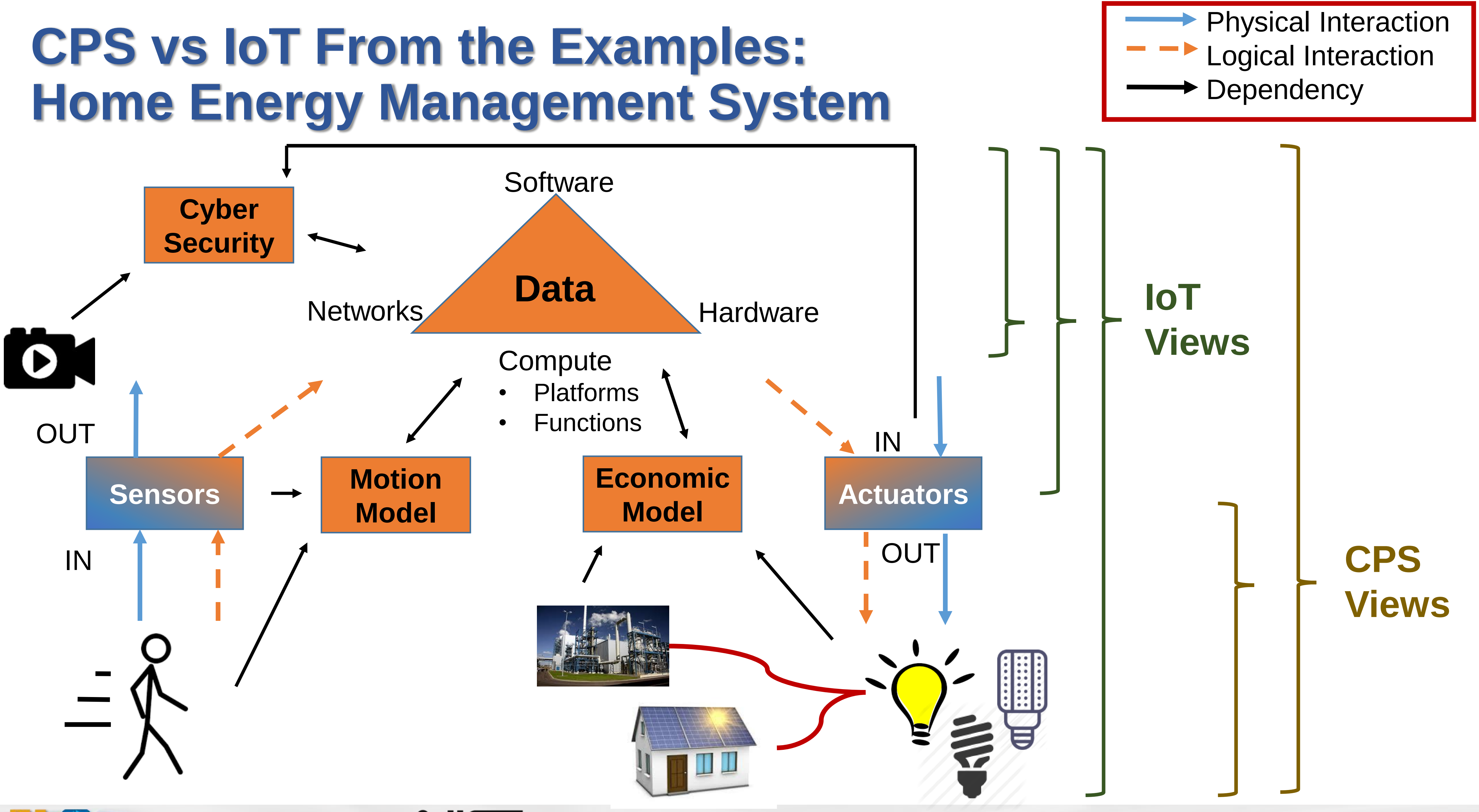
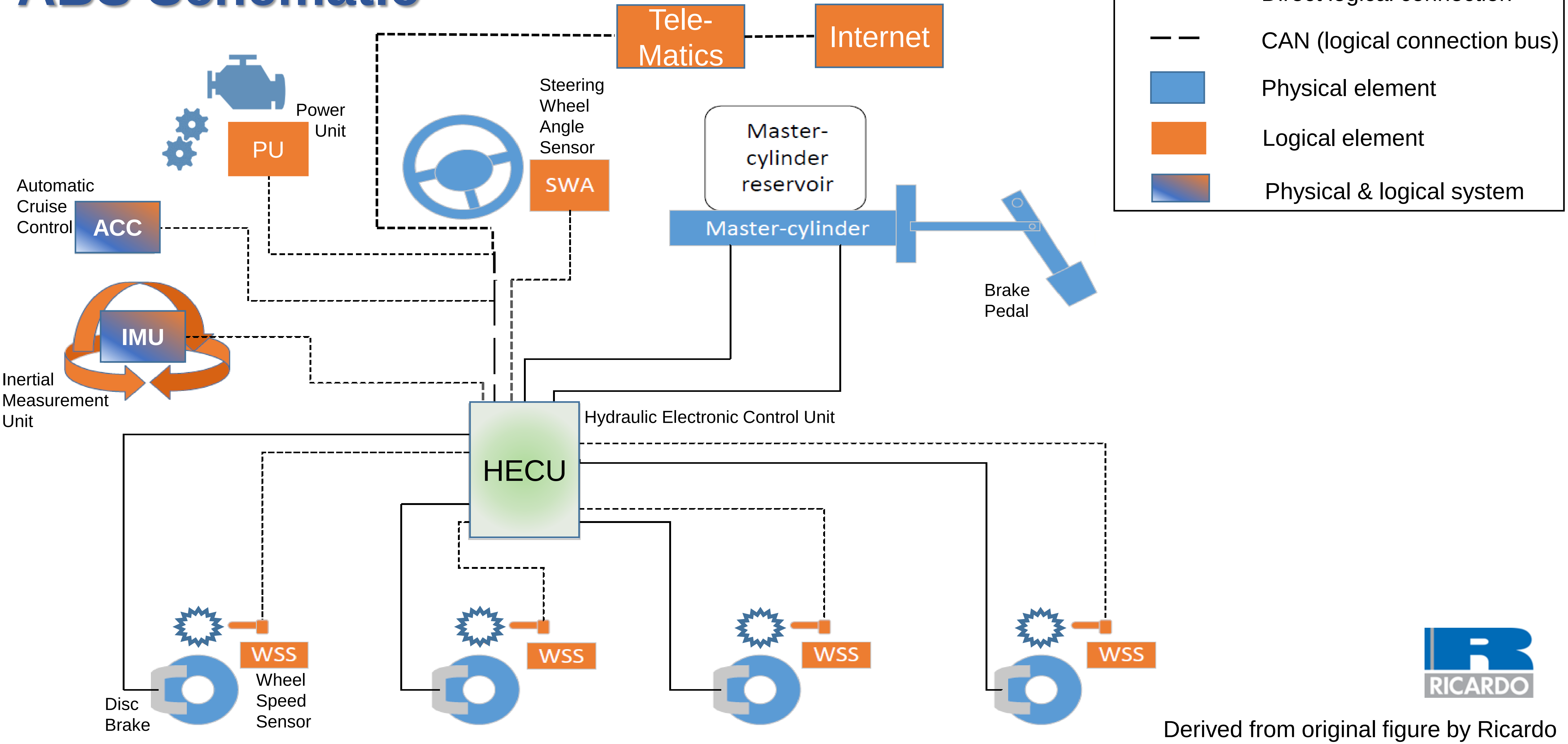
CPS vs IoT From the Examples: Home Energy Management System



ABS Schematic



Derived from original figure by Ricardo
www.ricardo.com

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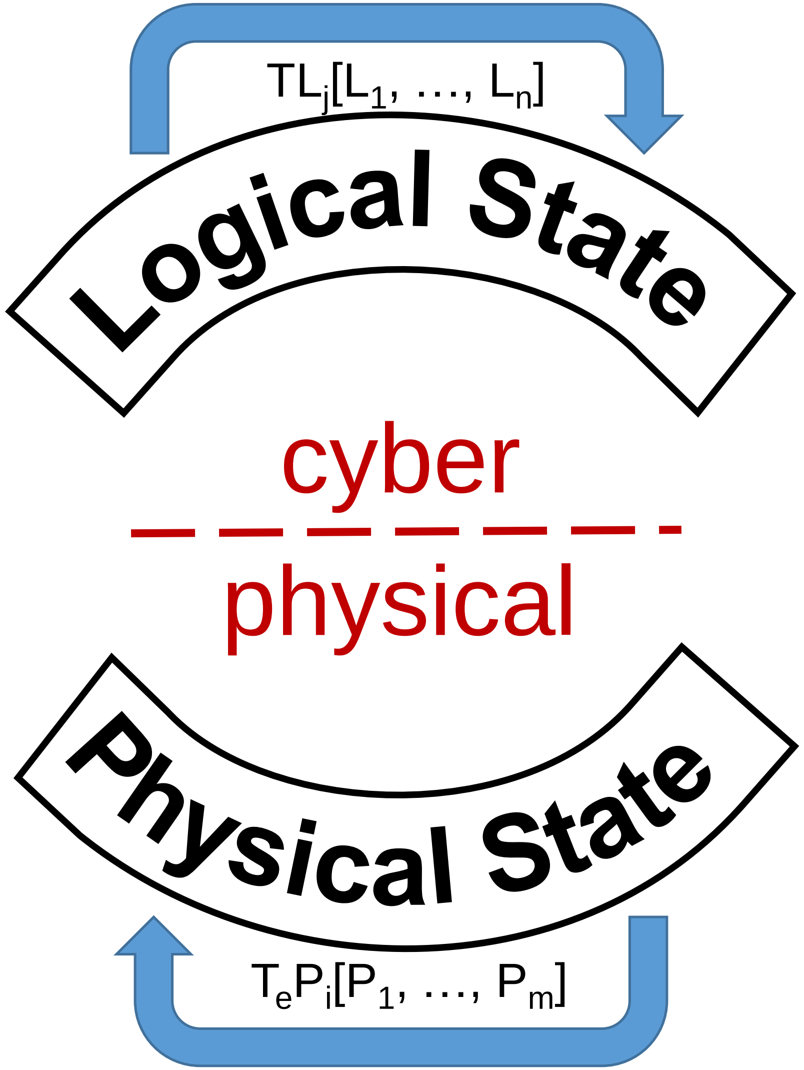
Unified CPS Mathematical Model



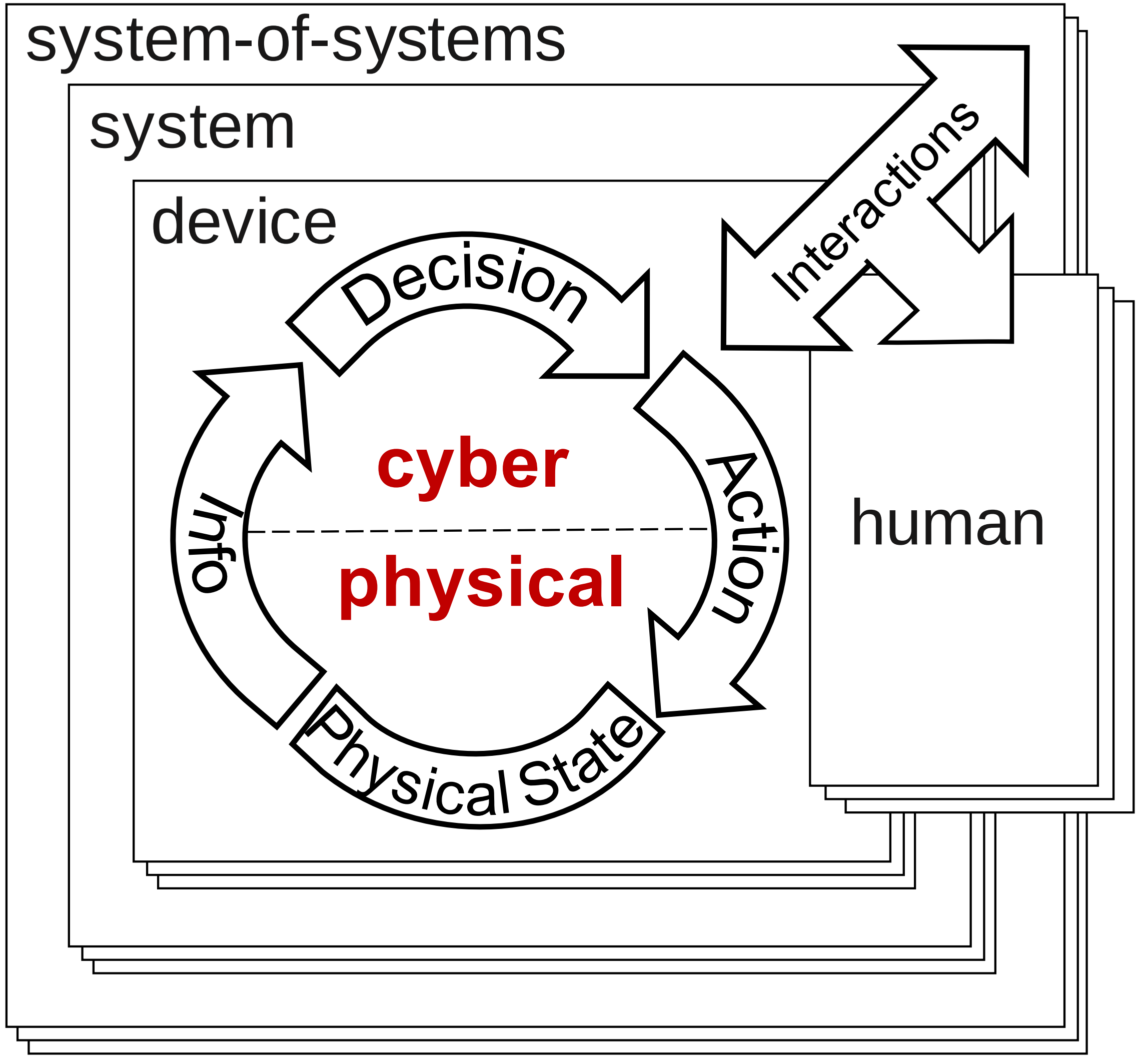
- *Logical State of a CPS* is a vector of *logical state parameters* $<L_1, \ldots, L_n>$
- The Logical State is acted upon by algorithms $TL_1, \ldots, TL_k$ (each can be viewed as an operator on $<L_1, \ldots, L_n>$, resulting in $<L'_1, \ldots, L'_n>$;
- *Physical state of a CPS* is a vector of *physical state parameters* $<P_1, \ldots, P_m>$;
- a physical state vector is a solution to an algebraic system of differential equations (each equation describing a *waveform* for a choice of free variables)
- The Physical State is acted upon by energy exchange processes, represented by algebraic systems of ODEs, $T_{e1}, \ldots, T_{ek}$

Representing CPS: Symmetric Monoidal Categories

- For purposes here **systems will be viewed as processes and interactions between them** (*process algebra* in the sense of Milnor for example)
- We distinguish two sorts of interactions between processes:
  - **Logical interactions** (exchanges of information)
  - **Physical interactions** (exchanges of energy)
- Math model of physical interactions is **algebraic systems of ODEs**
- Math model of logical interactions are **formalizations of agent-based models** such as *complex adaptive systems* (J. Holland)
- We choose symmetric monoidal categories (SMC) as an example of a **model of systems in category theory**

Relation between CPS and IoT

Cyber-Physical Systems (CPS) comprise interacting digital, analog, physical, and human components engineered for function through integrated physics and logic.

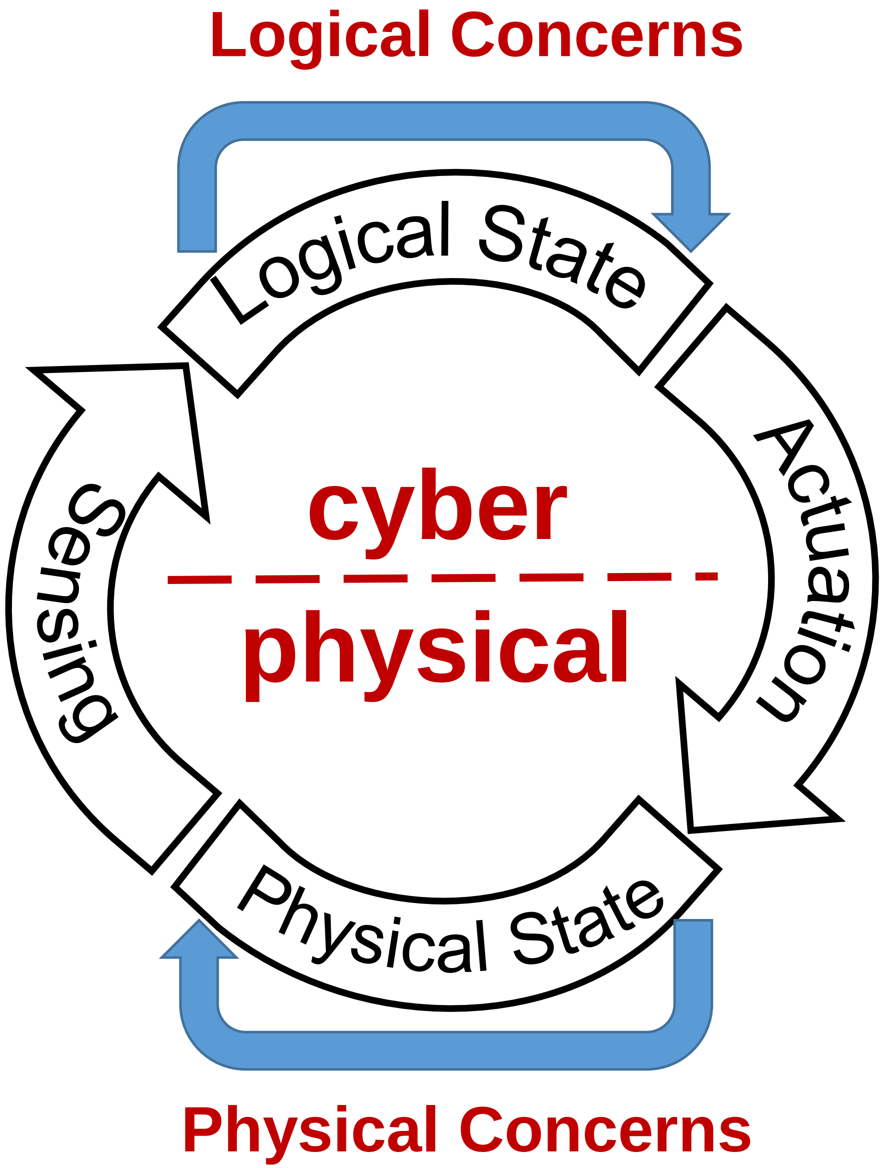


- Examples include a smart gird, a self-driving car, a smart manufacturing plant, an intelligent transportation system, a smart city, and Internet of Things (IoT) instances connecting new devices for new data streams and new applications.
- Common notions of IoT have emphasized networked sensors providing data streams to applications.
- CPS concepts complete these IoT notions, providing the means for conceptualizing, realizing and assuring all aspects of the composed systems of which sensors and data streams are components.

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

CPS Mathematical Models

- Connecting logical and physical forms of concerns using interactions between the logical and physical states of a CPS
- Math of these interactions can provide a unified cyber-physical science.
- Sensing and Actuation ‘connect’ properties of the logical and physical elements of the CPS design



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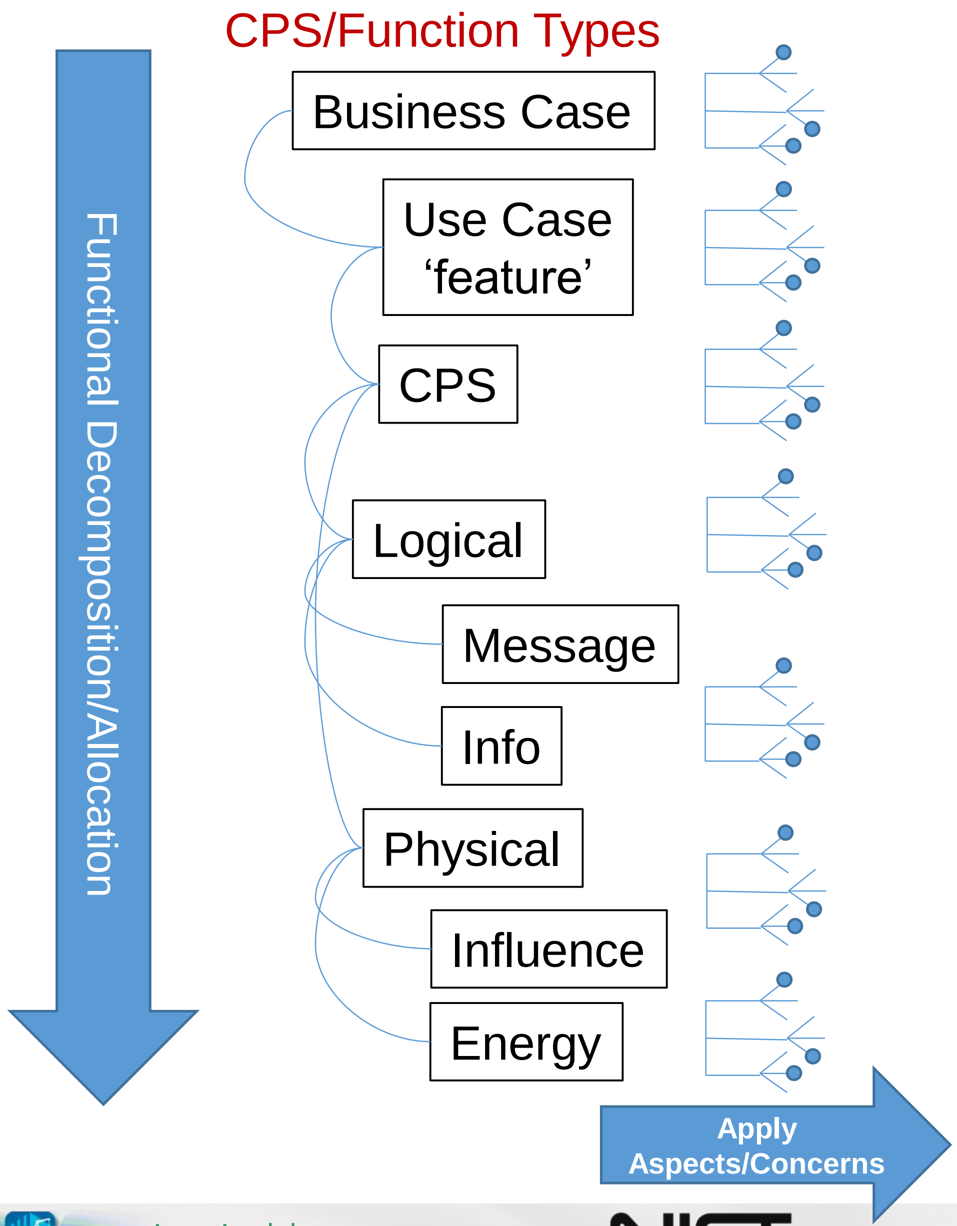
Analyzing and Developing CPS: Decomposition



Safety "Properties" of a decomposed Function: AEB

AEB – vehicle provides automated collision safety function

AEB – vehicle provides/maintains safe stopping

AEB –braking function reacts as required

AEB – messaging function receives distance to obstacles and speed from propulsion function

AEB – distance and speed info is understood by braking function

AEB – stopping algorithm provided safe stopping

AEB – friction function provides appropriate friction

Generate System Properties

CPS Framework

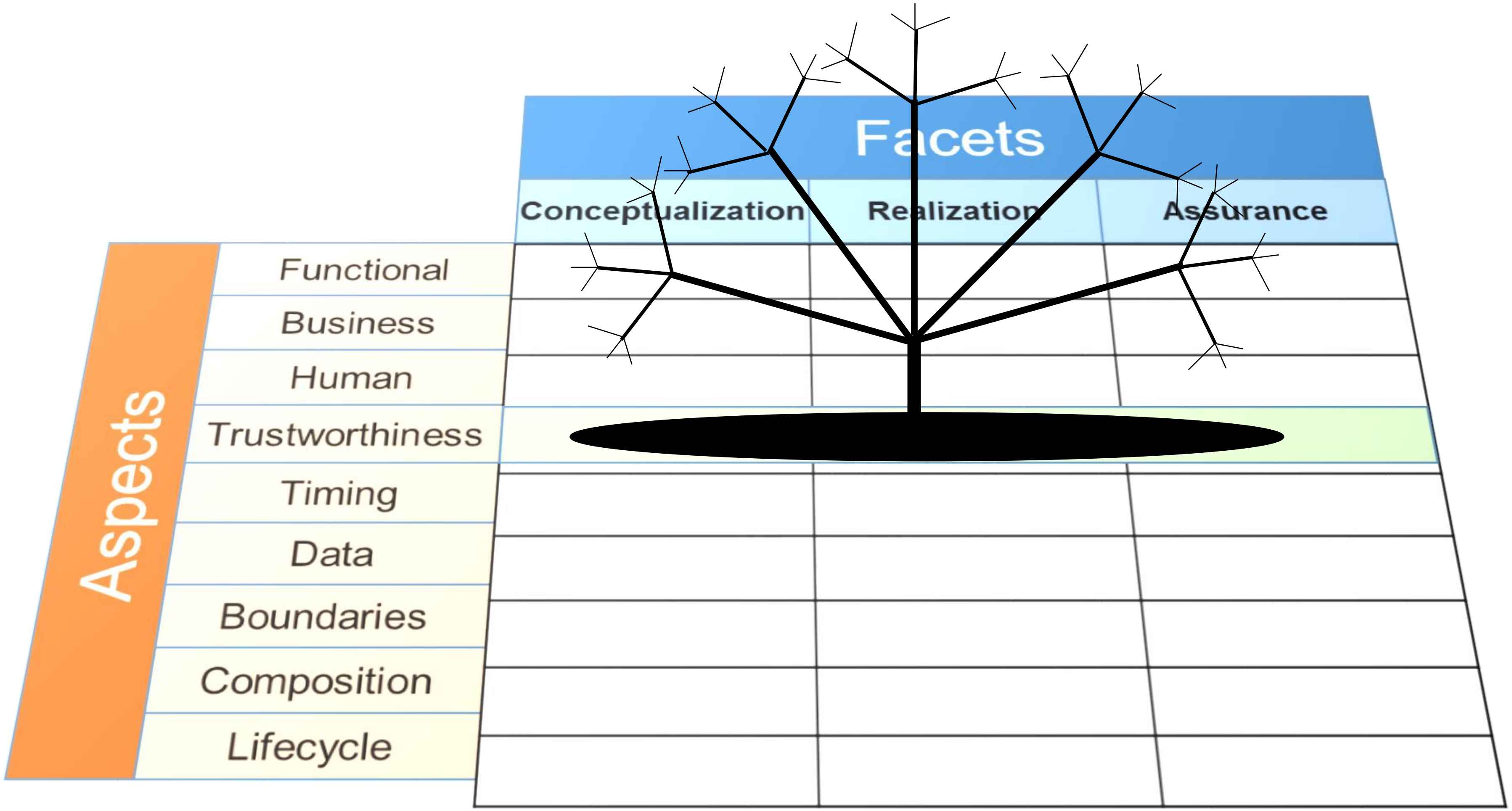
Domains

- **Manufacturing**
- **Transportation**
- **Energy**
- **Healthcare**
- **. . . Domain**

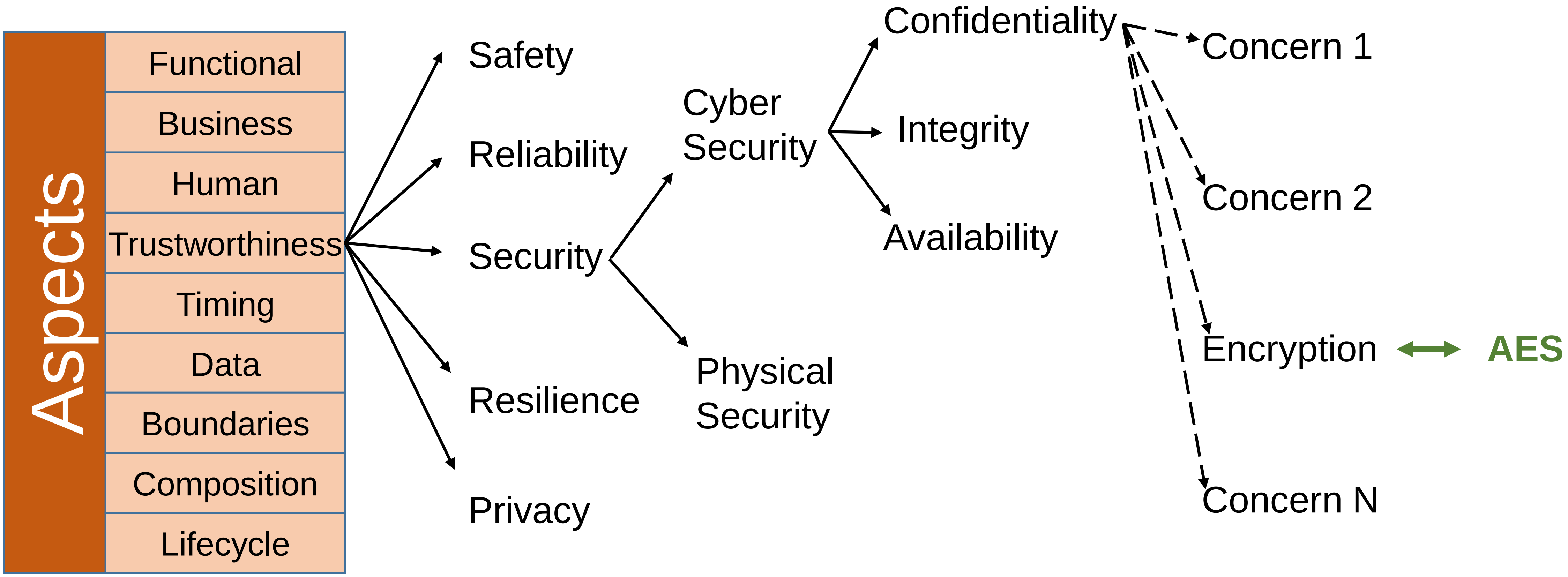
		Facets		
		Conceptualization	**Realization**	**Assurance**
Aspects	Functional			
	Business			
	Human			
	Trustworthiness			
	Timing			
	Data			
	Boundaries			
	Composition			
	Lifecycle			

The Framework for Cyber-Physical Systems was released by the NIST CPSPWG on May 26, 2016, see pages.nist.gov/cpspwg

CPS Concern Tree



CPS Concern Tree



A privacy protected message exchange might consist of the set of properties:
{Trustworthiness.Security.Cybersecurity.Confidentiality.Encryption.AES,
Trustworthiness.Privacy.Predictability.Controls.Authorization.OAuth}

Concern-Driven Analysis of a Standard

Common Concern: Trustworthiness.Security.Cybersecurity.confidentiality

Clause in document: TS-0002 clause 6.4

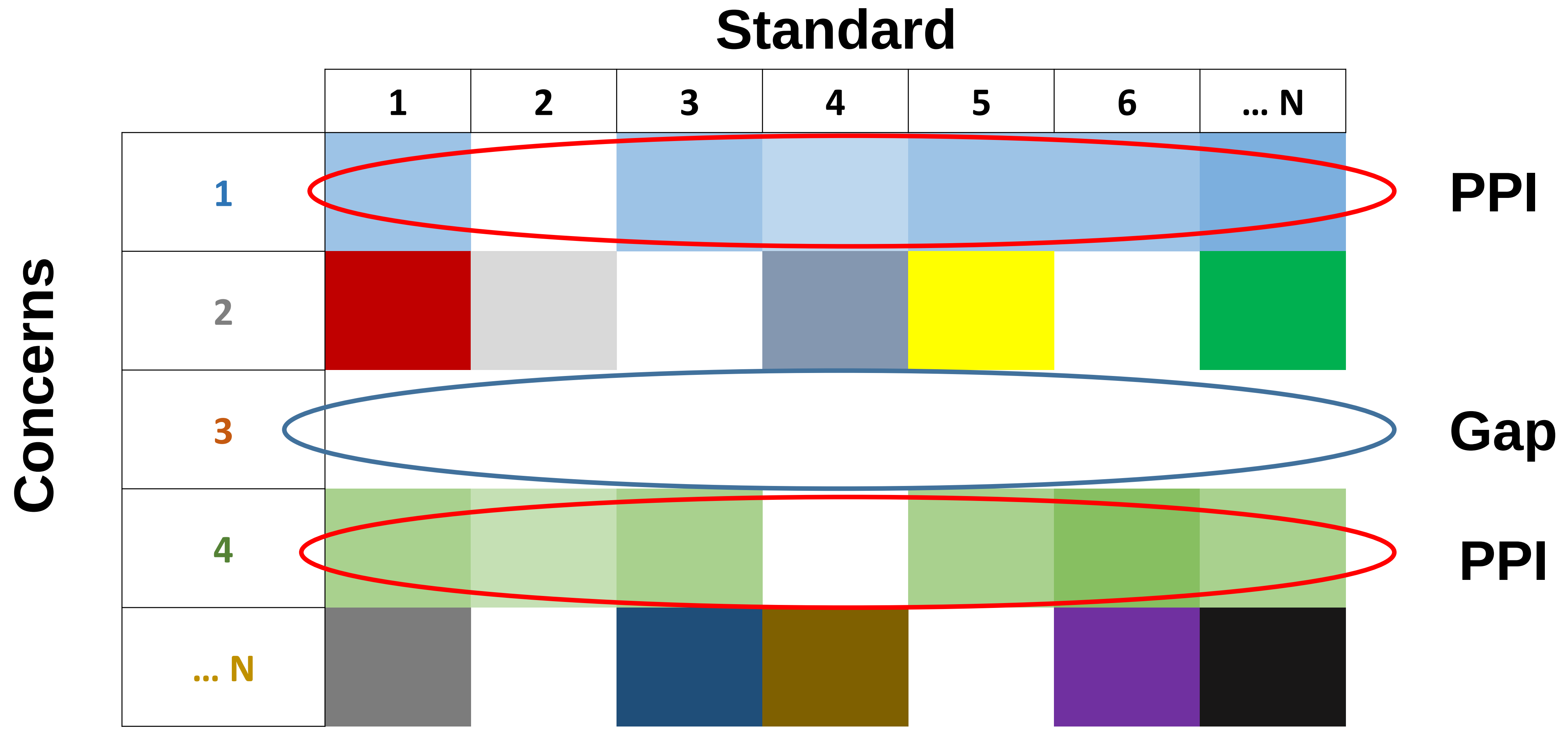
Solution: Access Control and Authorization, TS-0003 clause 7

Technology level (Device, System, System of Systems)
Technology scope description (text)

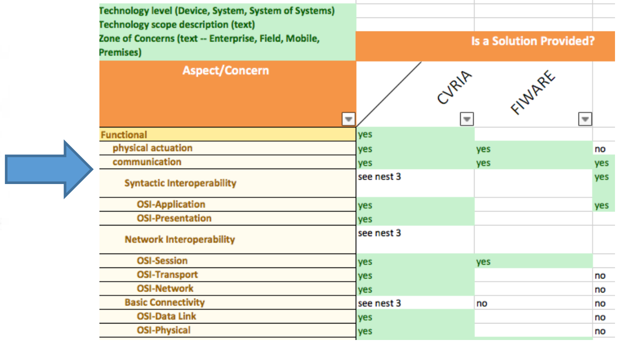
Concern	Aspect/Concern	Discussion of Concern	Discussion Reference(s)	Solution	Solution Reference(s)
Functional	Functional	in general	n/a		
Trustworthiness	Trustworthiness				
privacy	privacy	authorization, privacy and all the security requirements are defined	TS-0002 clause 6.4	Use proper access control settings under control of the data subject (individual whose privacy is exposed by the data)	TS-0003 Clause 7
reliability	reliability	in terms of message delivery, yes	tbd	CMDH(connection management and delivery handling) CSF and its resource types	TS-0001 clause 6.2.2
resilience	resilience	in terms of message delivery, yes	tbd	CMDH(connection management and delivery handling) CSF and its resource types	TS-0001 clause 6.2.2
safety	safety	Every deployment requires a risk and vulnerability assessment	TR-0008	Perform proper risk and vulnerability assessment and mitigate unacceptable risks	Any Risk assessment methodology. See TR-0008
security	security	all the security requirements are defined	TS-0002 clause 6.4, TR-0008	Definition of 4 protection levels suitable for different exposures. Definitrion of security frameworks to protect assets	TS-0003
cybersecurity	cybersecurity	all the security requirements are defined	TS-0002 clause 6.4	CPS security implies cybersecurity with additional challenges. Sdolutions exist to mitigate risks down to acceptable levels!	TR-0008; TS-0003
confidentiality	confidentiality	all the security requirements are defined	TS-0002 clause 6.4	Access Control and Authorization	TS-0003 clause 7
integrity	integrity	all the security requirements are defined	TS-0002 clause 6.4	implement proper protection level	TR-0008; TS-0003
availability	availability	Risks related to Denial of Service must be mitigated	TR-0008	Some mitigatoion mechanisms exist	TR-0008, TS-0003

Concern **Description** **Solution** **Reference**

Foundation for Cooperation

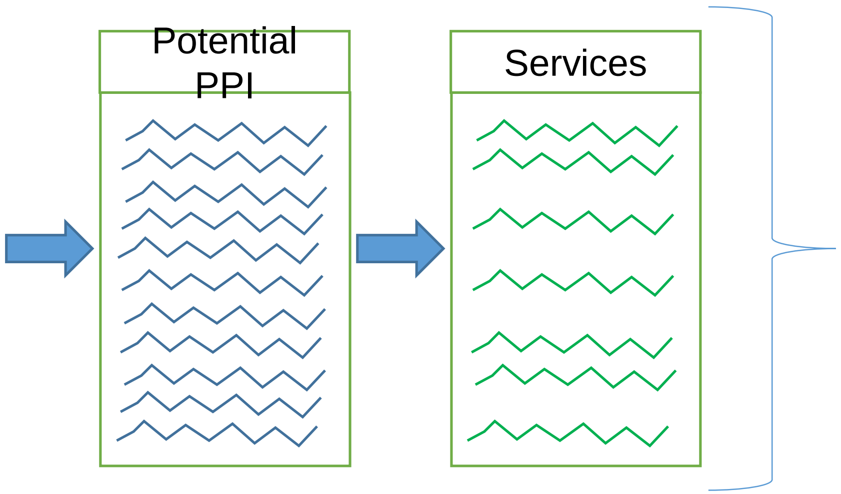


Specs to Pivotal Points of Interoperability



Technology level (Device, System, System of Systems)
Technology scope description (text)
Zone of Concerns (text -- Enterprise, Field, Mobile, Premises)

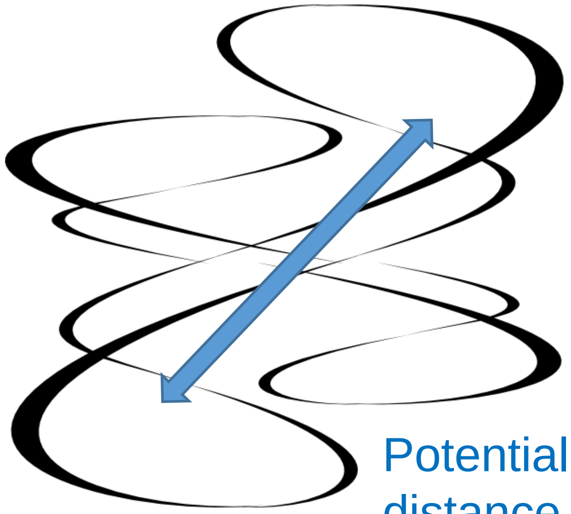
Aspect/Concern	Is a Solution Provided? CVRIA	FIWARE	
Functional	yes		
physical actuation	yes	yes	no
communication	yes	yes	yes
Syntactic Interoperability	see nest 3		yes
OSI-Application	yes		yes
OSI-Presentation	yes		
Network Interoperability	see nest 3		
OSI-Session	yes	yes	
OSI-Transport	yes		no
OSI-Network	yes		no
Basic Connectivity	see nest 3	no	no
OSI-Data Link	yes		no
OSI-Physical	yes		no



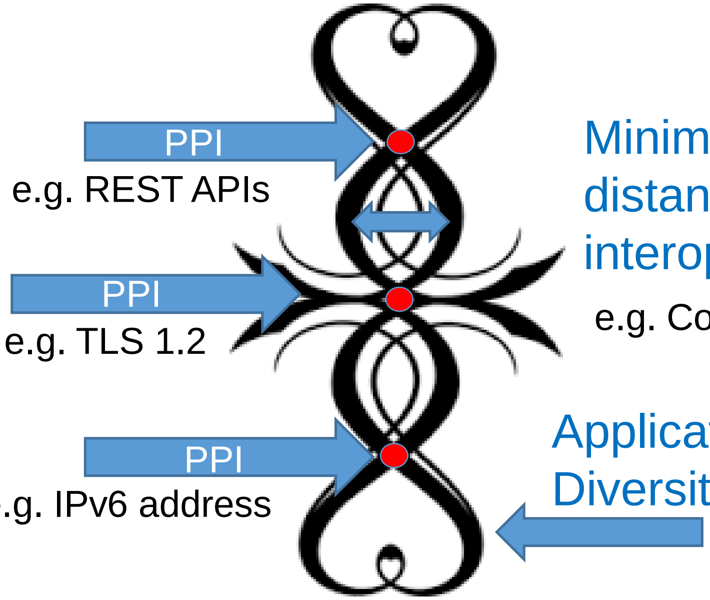
Zone of Concerns = bundles of services that address a "vector" of concerns

Pivotal Points of Interoperability (PPI)

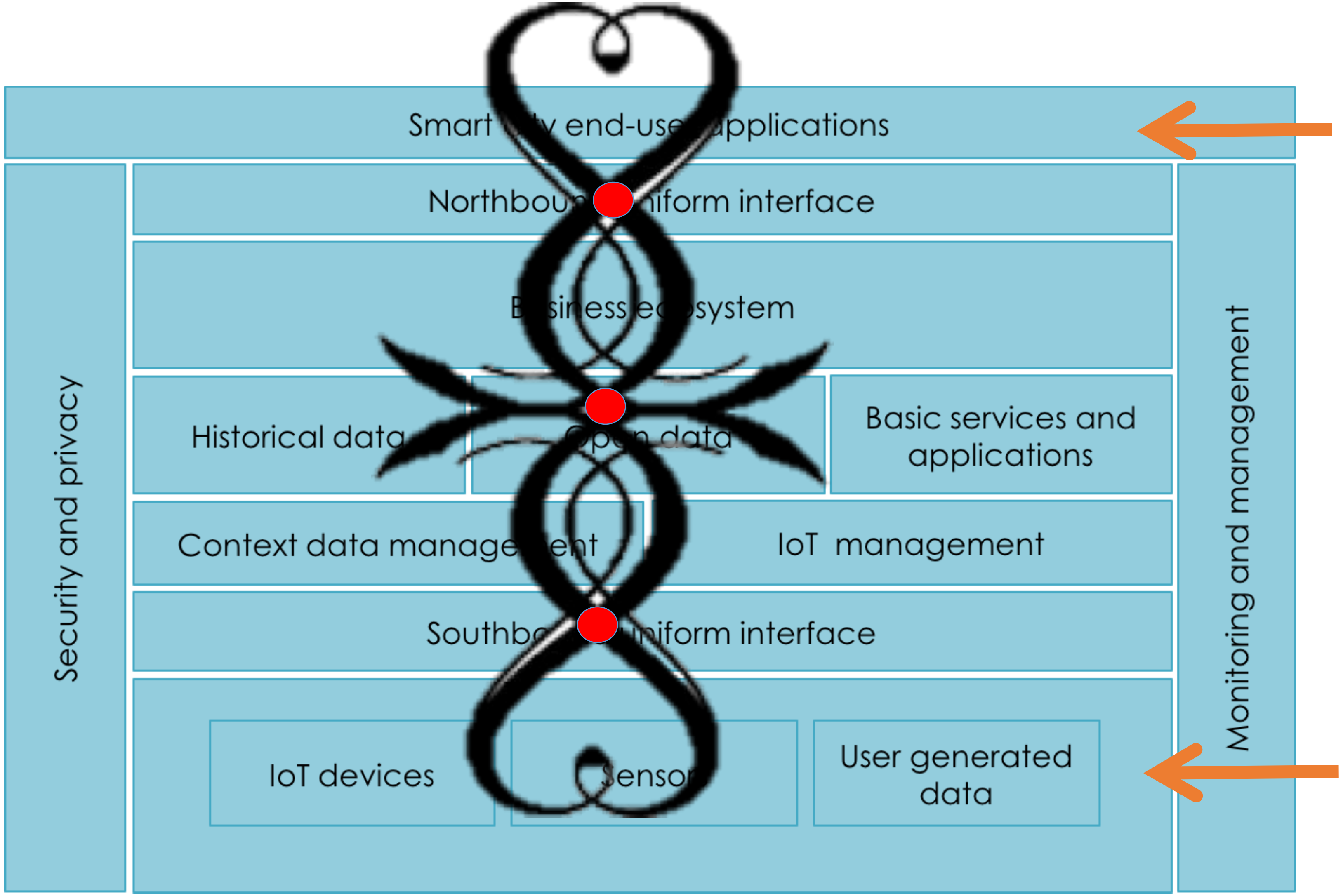
Independent technology deployments

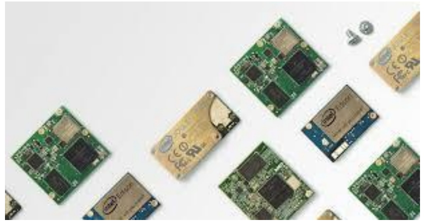


With Pivotal Points of Interoperability

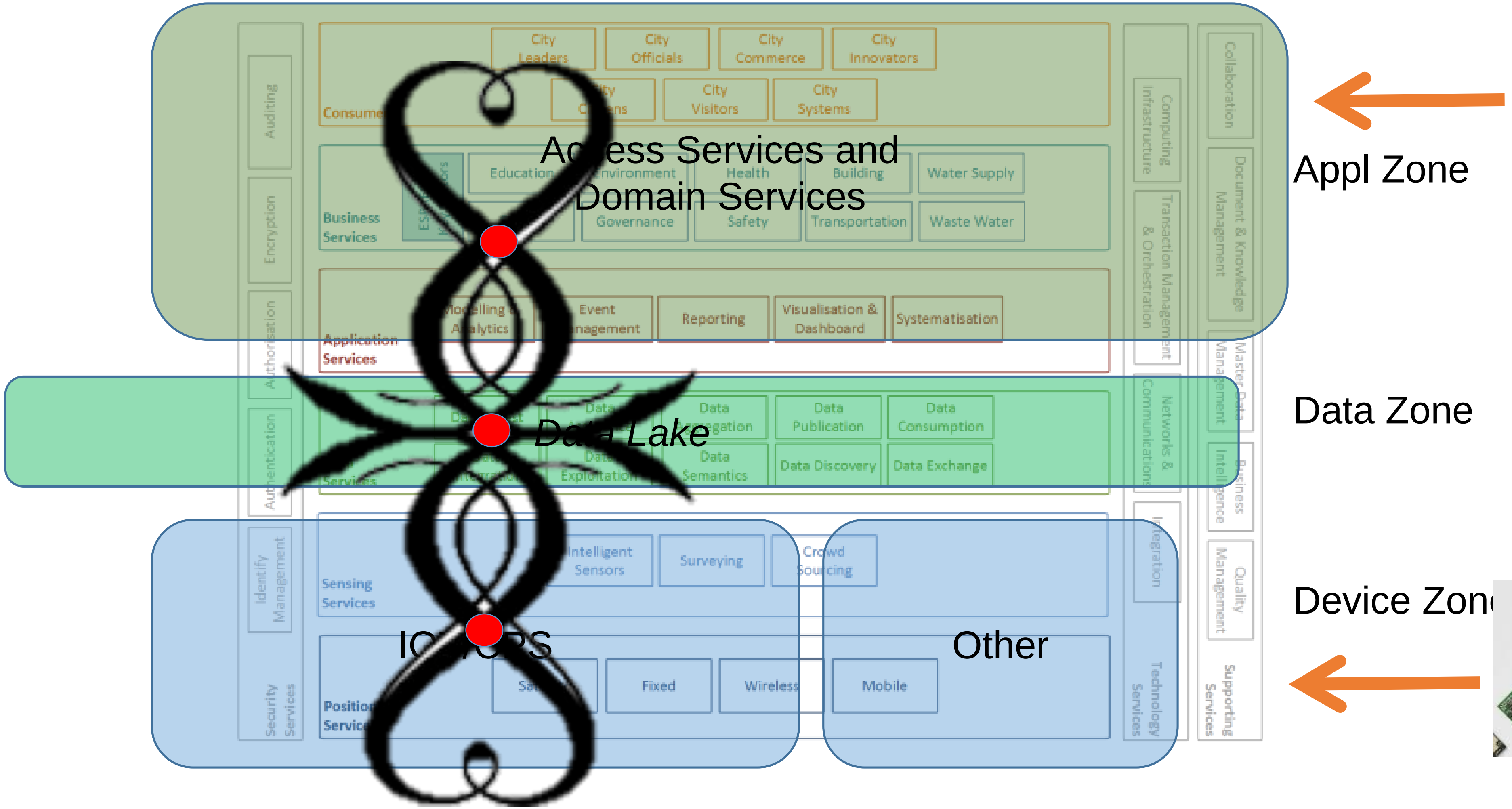


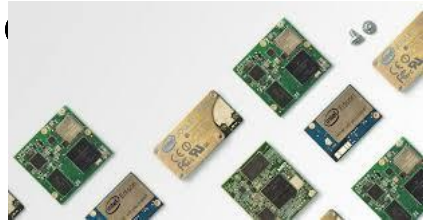
SynchroniCity Zones of Concern





ESPRESSO Zones of Concern

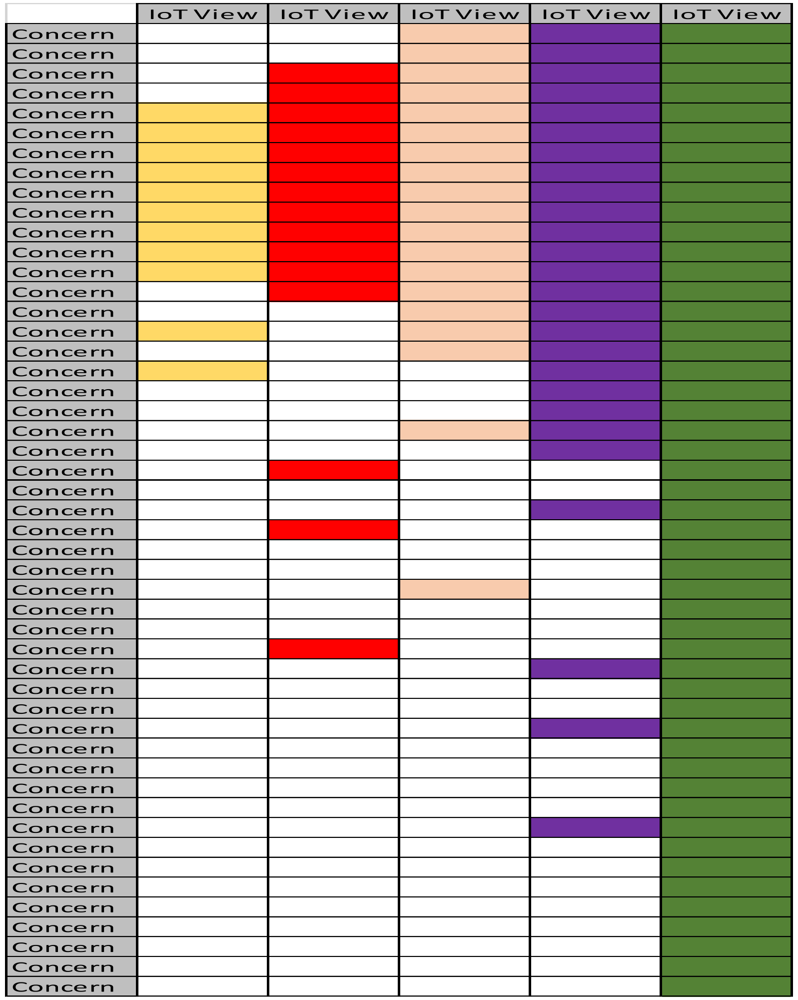




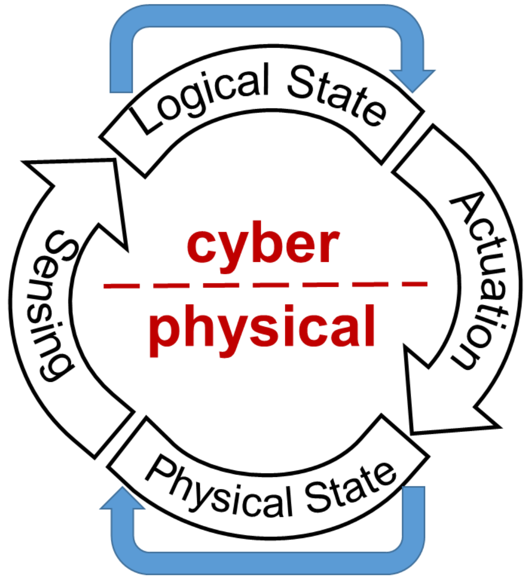
Summary

IoT Views

Concerns



Reconcile IoT Views



Aspects	
	Functional
	Business
	Human
	Trustworthiness
	Timing
	Data
	Boundaries
	Composition
	Lifecycle

For additional information

- Program Web Site:
  www.nist.gov/cps
- CPS Public Working Group
  pages.nist.gov/cpspwg
- Smart City Framework
  pages.nist.gov/smartcitiesarchitecture
- Contact:
  chris.greer@nist.gov