Introduction on Cyber Physical Systems

Francesca Palumbo
Università degli Studi di Sassari

CPS Summer School – From concepts to implementation
Alghero (IT)
17-21 September 2018

Let’s go straight to the point!

https://www.youtube.com/watch?v=U7y1wiYqHDc

Francesca Palumbo, UNISS

Numbers: opportunity or issue?

=

> 7 billion

20 MWh/year = 1,800 kg oil

Numbers: opportunity or issue?

> 7 billion

=

20 MWh/year 1,800 kg oil

> 1 billion smartphones

Numbers: opportunity or issue?

> 7 billion

20 MWh/year =

1,800 kg oil

Designed by Freepik

> 1 billion smartphones

8.4 billion connected things in 2017

(+31% wrt 2016)

20.4 billion by 2020

http://www.gartner.com/newsroom/id/3598917

Computing Evolution

Computing Evolution

UBIQUITUOUS COMPUTING & INFORMATION

DISAPPEARING COMPUTERS PERVASIVE COMPUTING

EMBEDDED EVERYWHERE

SMART EVERYTHING EVERYWHERE

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POST PC ERA

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SMART EVERYTHING EVERYWHERE

POST PC ERA

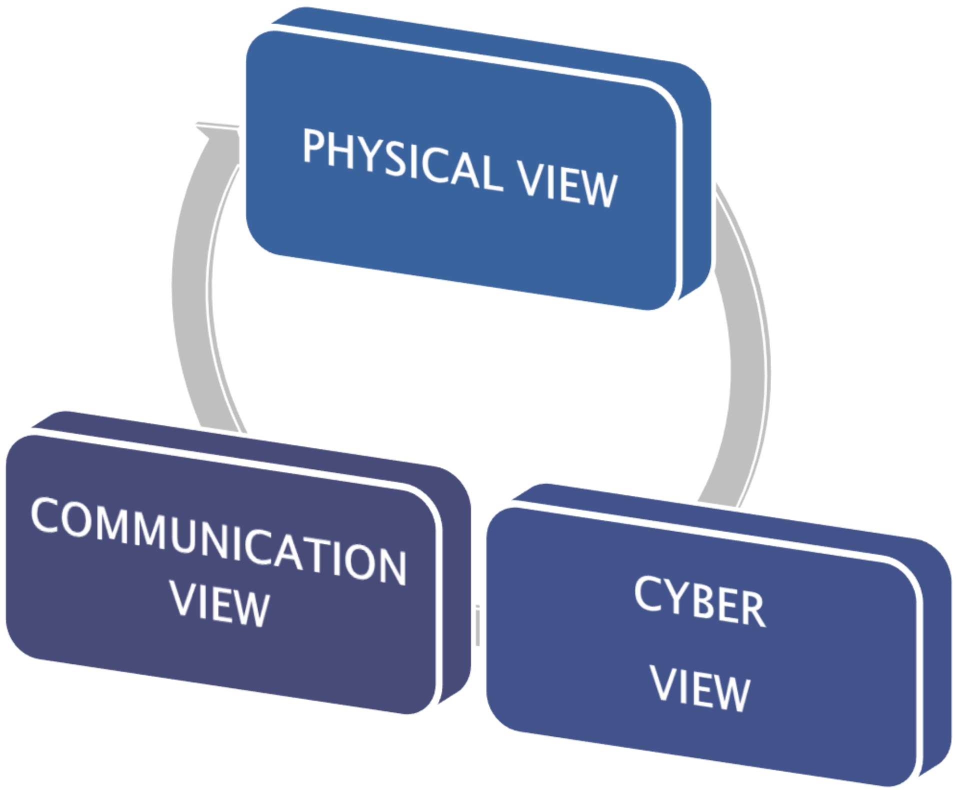
+

PHYSICAL ENTANGLEMENT

CPS ERA

Formal Definitions

CPS are ***smart systems*** that include ***engineered interacting networks of physical and computational components***. National Institute of Standard and Technology (NIST), US. CPS Public Working Group



Formal Definitions

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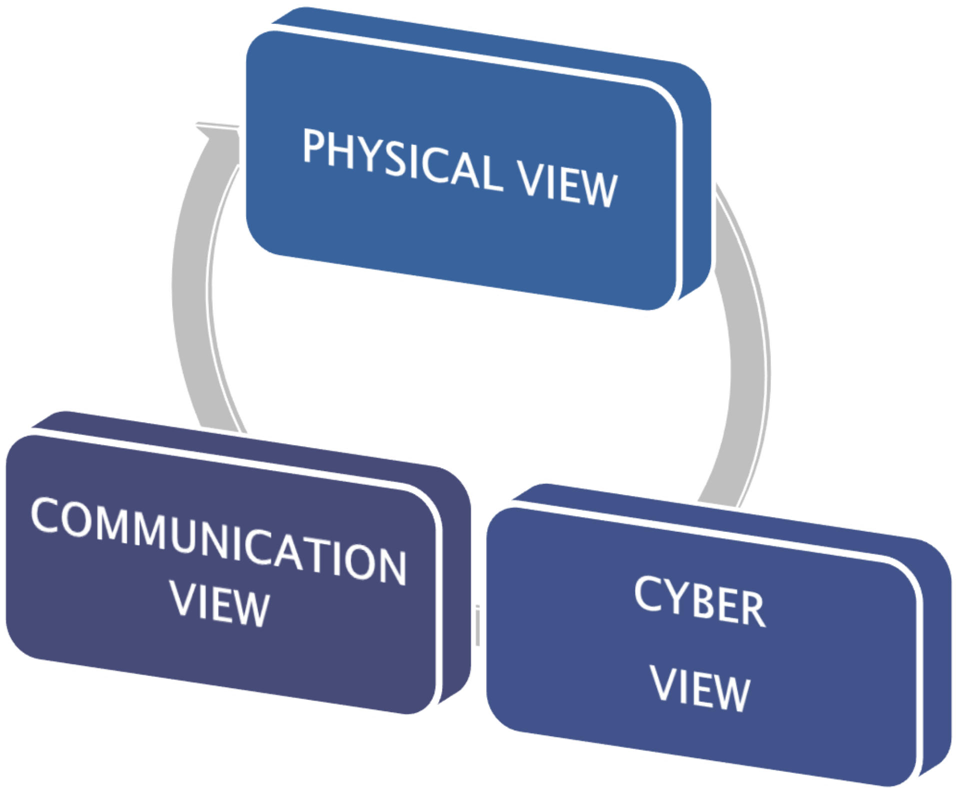
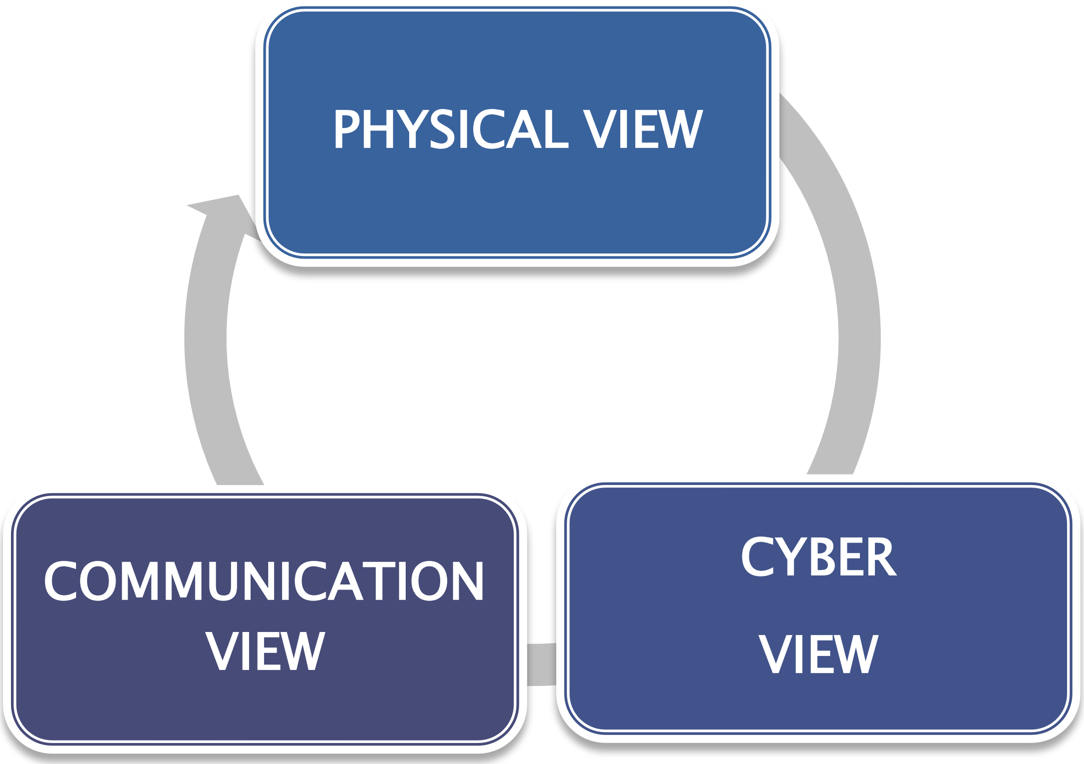
A cyber-physical system (CPS) is an ***orchestration of computers and physical systems***. Embedded computers monitor and control physical processes, usually with feedback loops, where ***physical processes affect computations and vice versa***.
Edward A. Lee
University of Berkeley

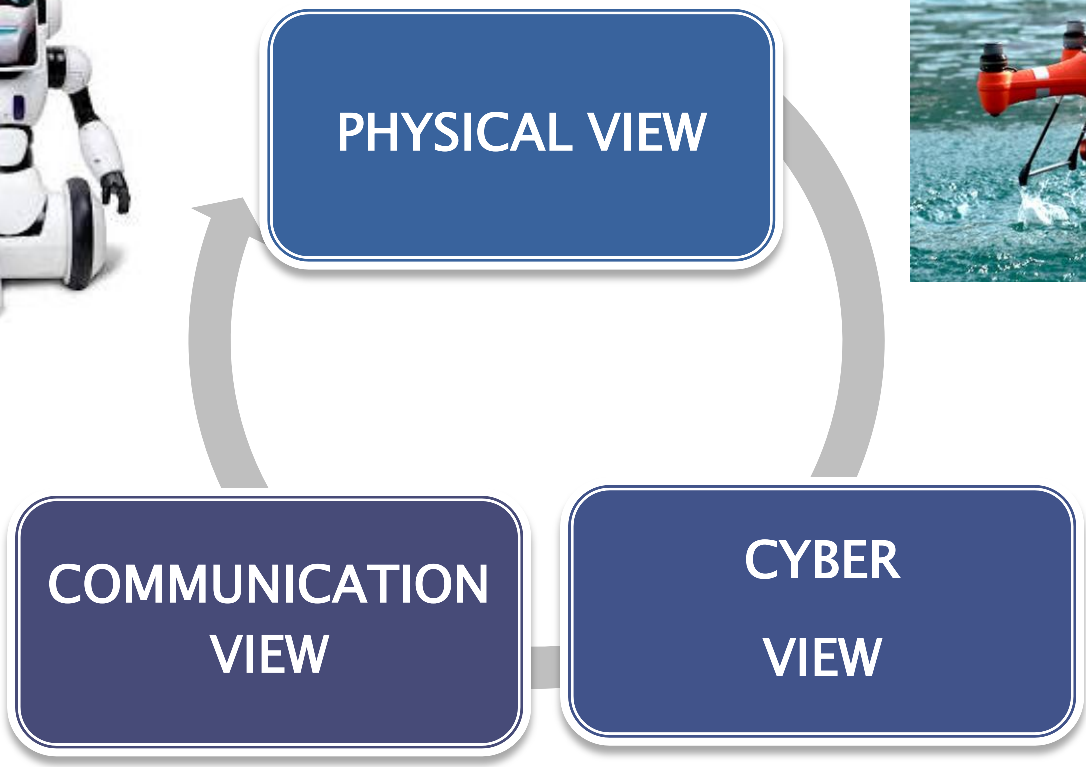


Key Ingredients



Key Ingredients

physical plant/process, users



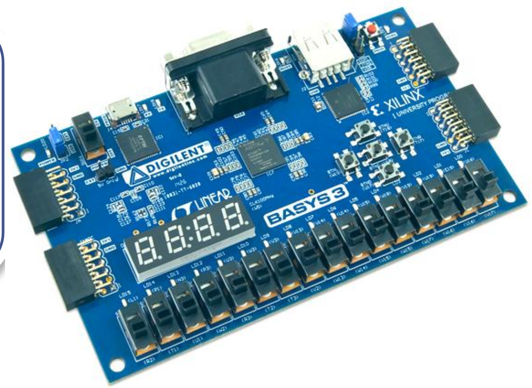
Key Ingredients

physical plant/process, users

PHYSICAL VIEW

COMMUNICATION VIEW

CYBER VIEW



software, algorithm, computation

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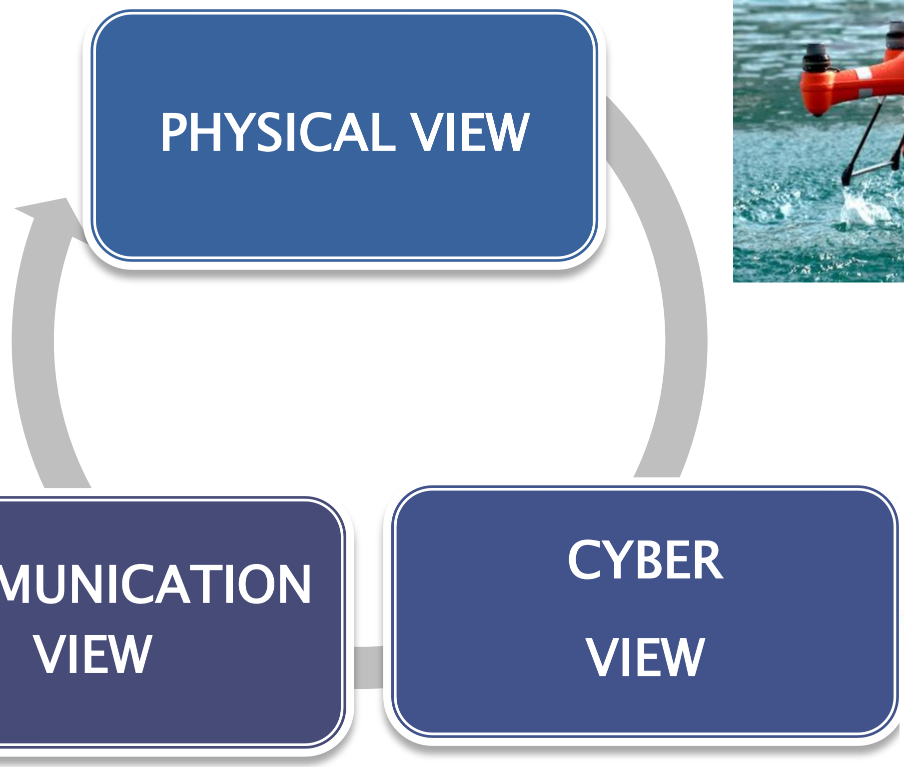

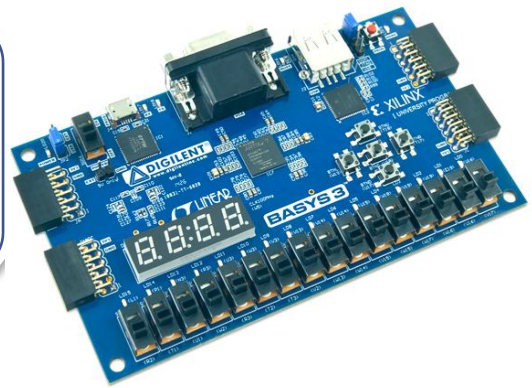

component to component/human/ environment

software, algorithm, computation

Key Ingredients

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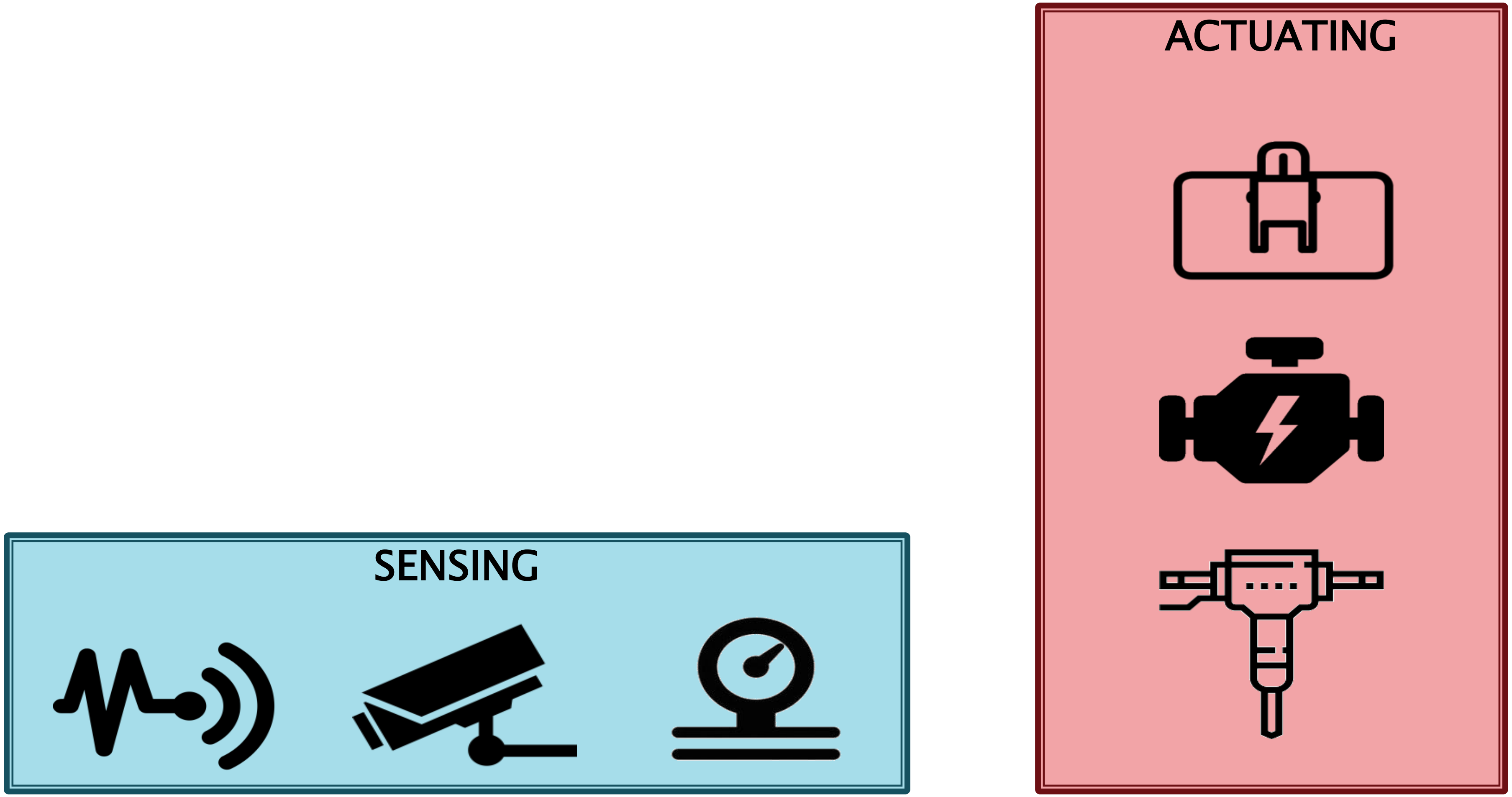

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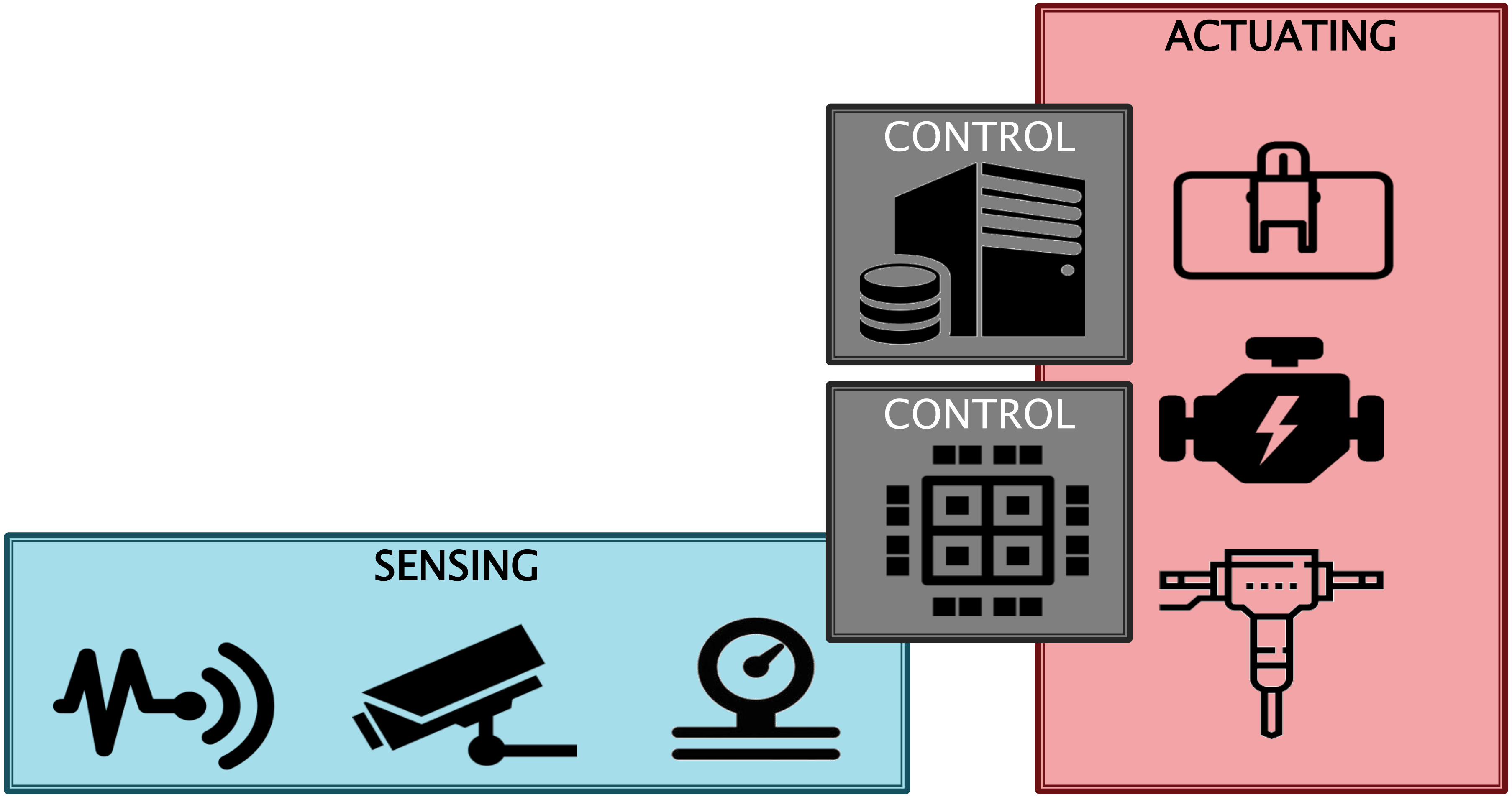

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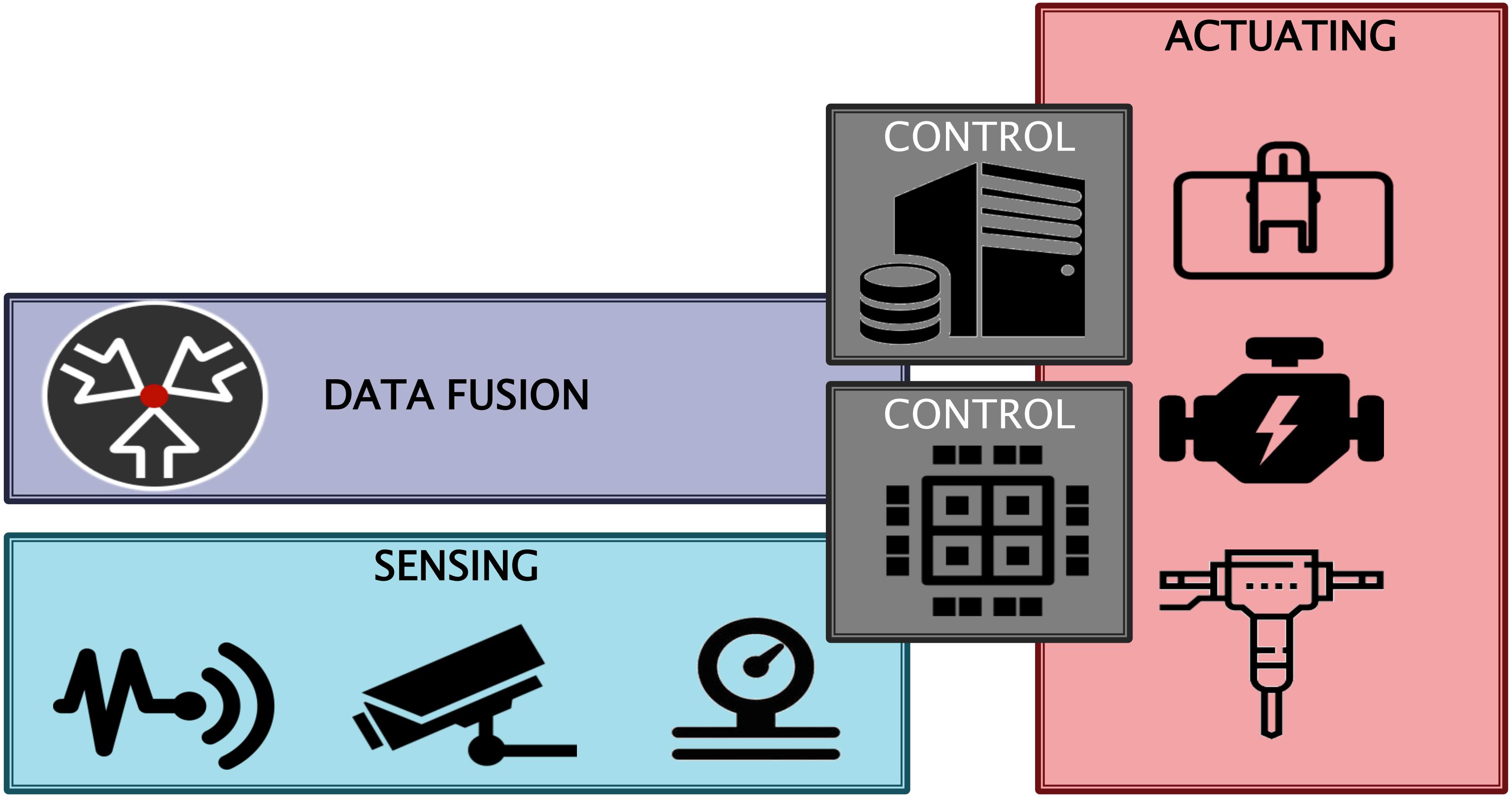

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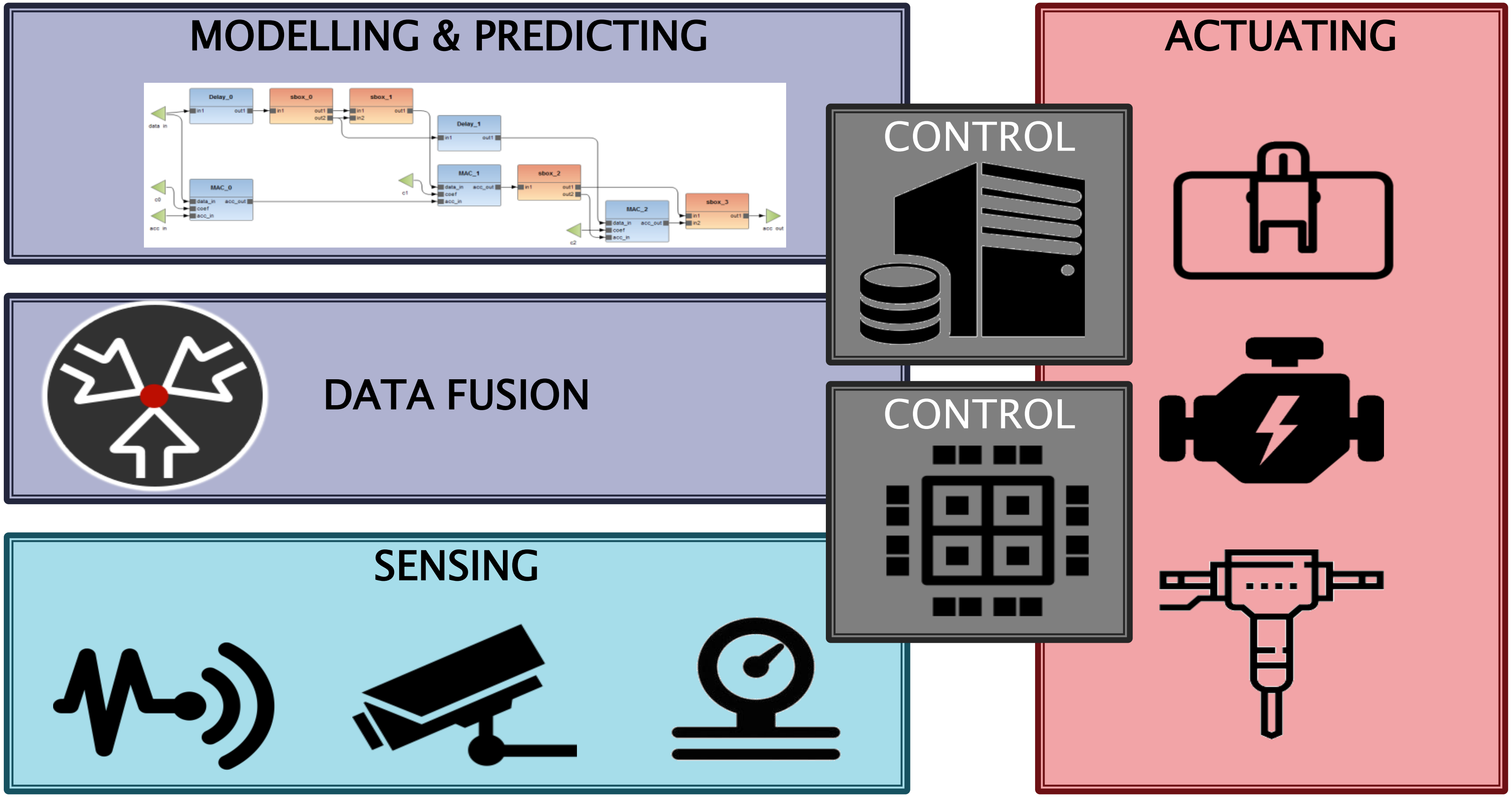
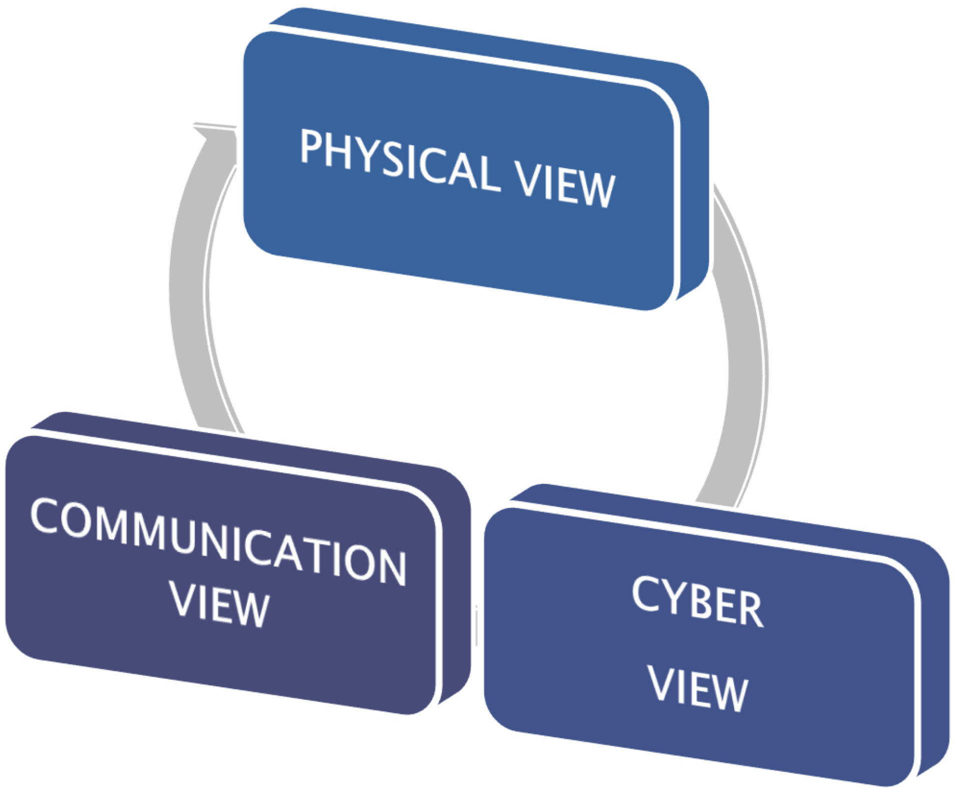


Yet Another Definition

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

Advances in CPS will enable *capability, adaptability, scalability, resiliency …* that will far exceed the simple embedded systems of today.

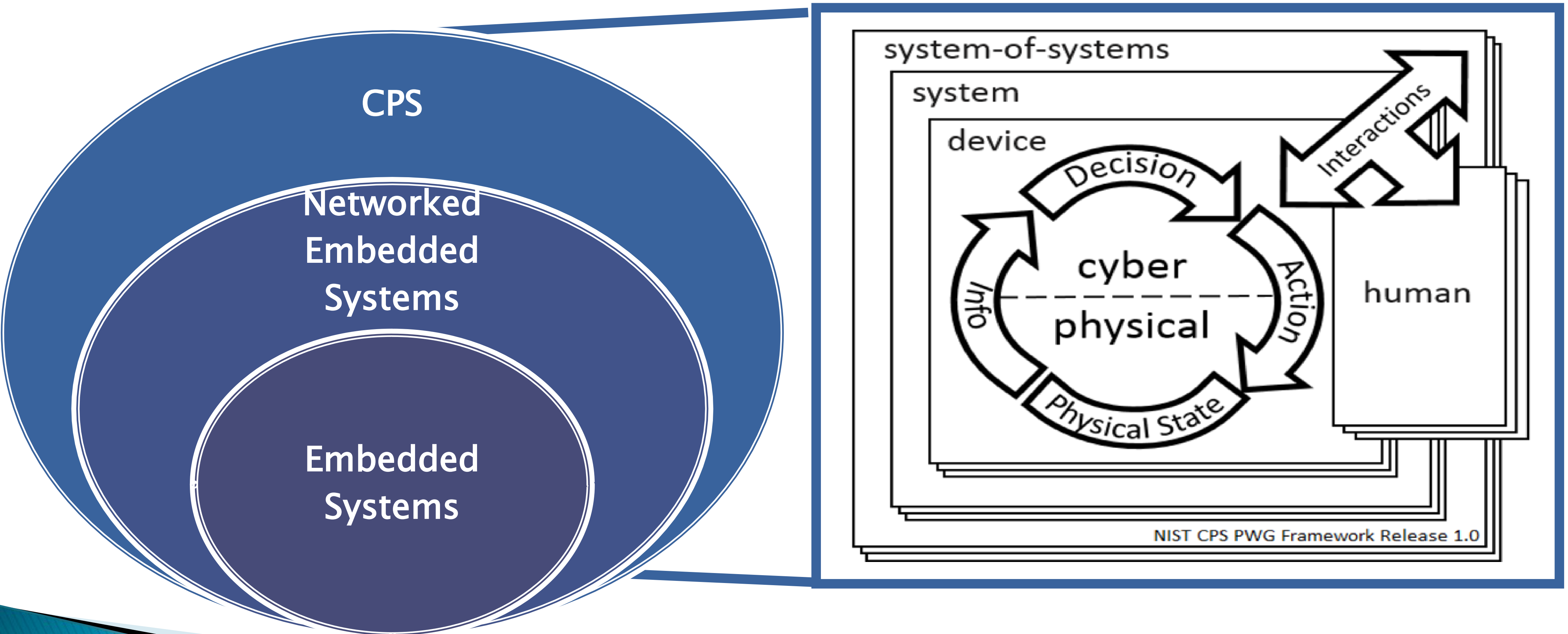
CPS technology will *transform the way people interact with engineered systems* -- just as the Internet has transformed the way people interact with information.



National Science Foundation (NSF), Cyber-Physical Systems Group

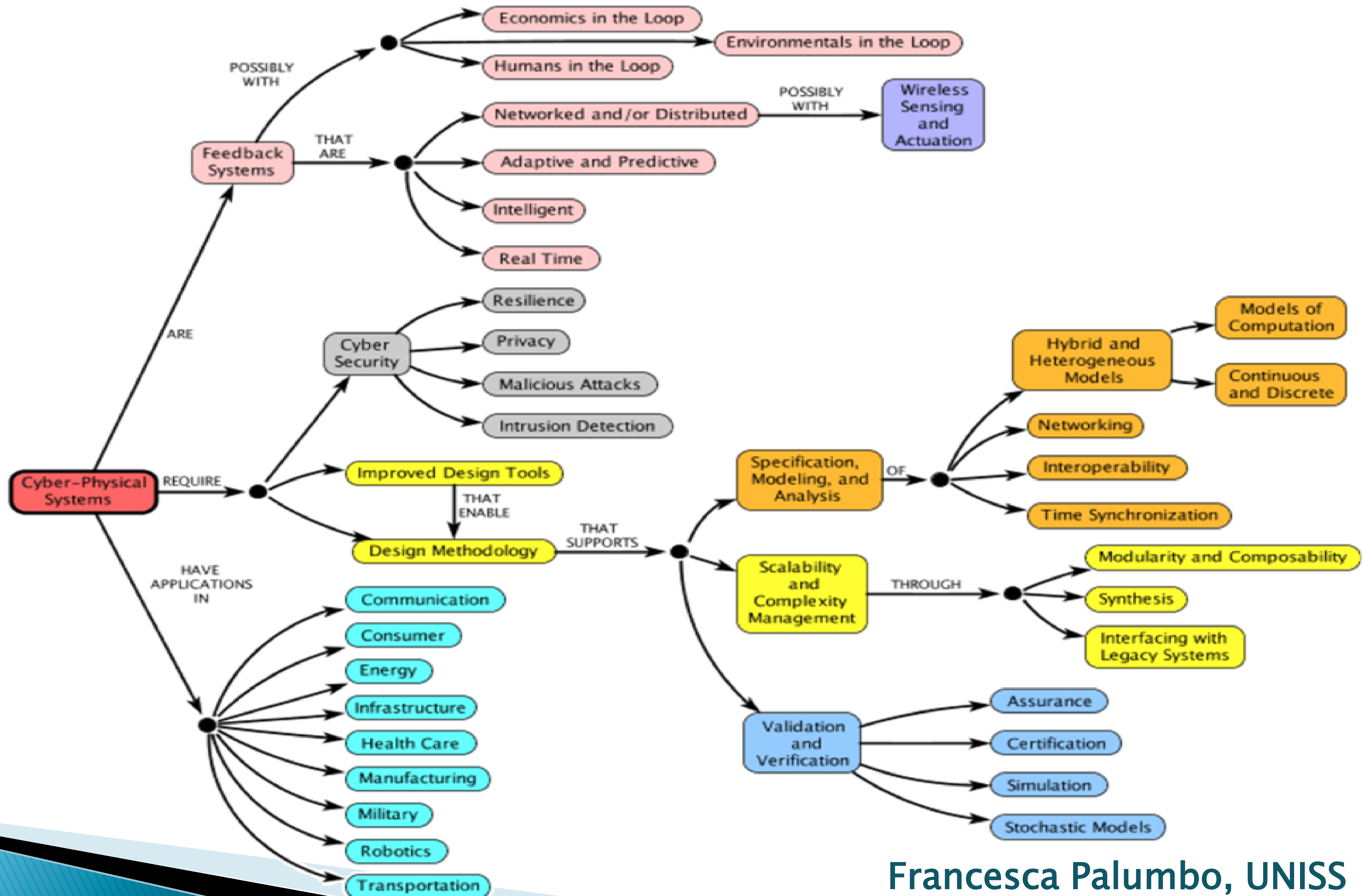
Embedded Systems and CPS

Embedded Systems: dedicated computing elements, everyday more complex, that brought the integration of information into products.



CPS Concept Map

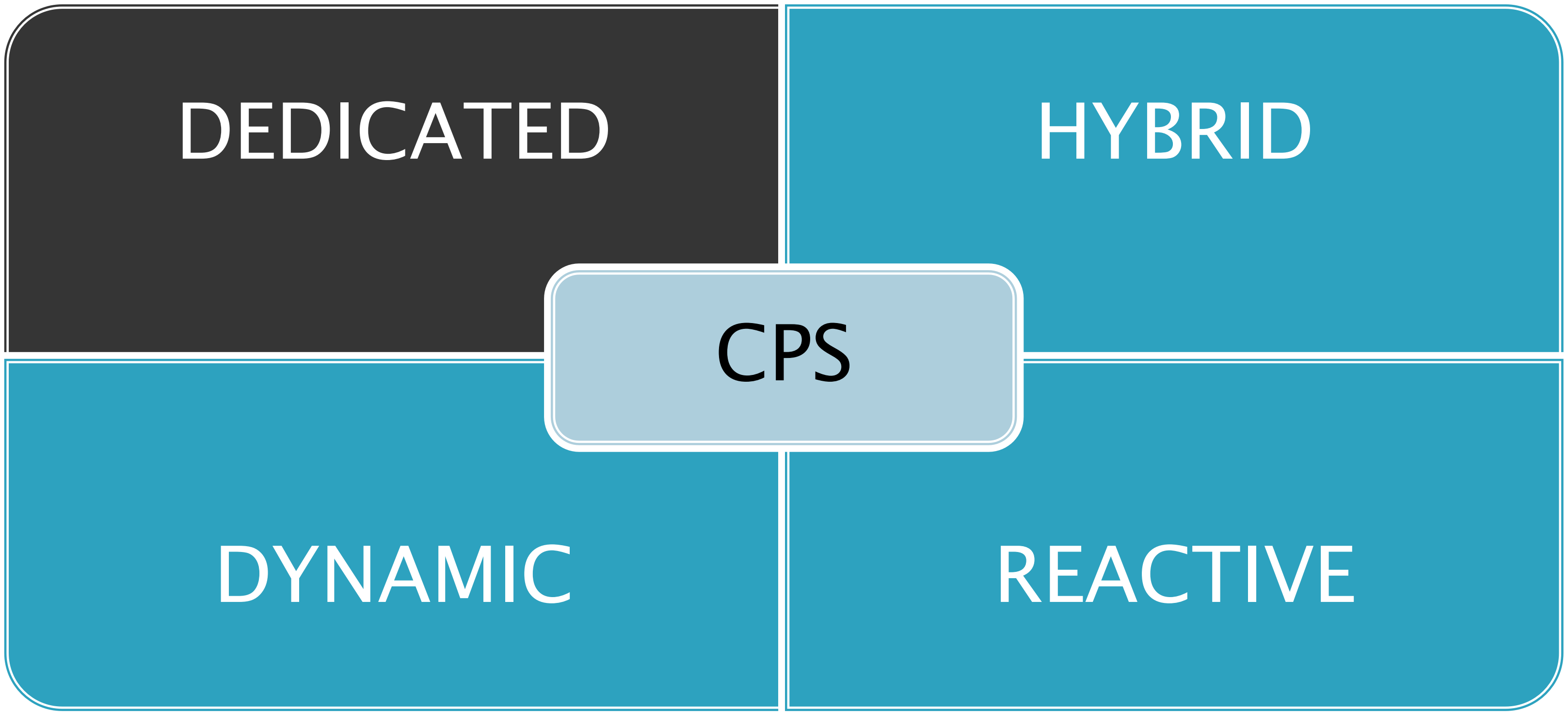
https://ptolemy.berkeley.edu/projects/cps/



Characterists of CPS

DEDICATED: towards a certain application. Knowledge of behaviours may

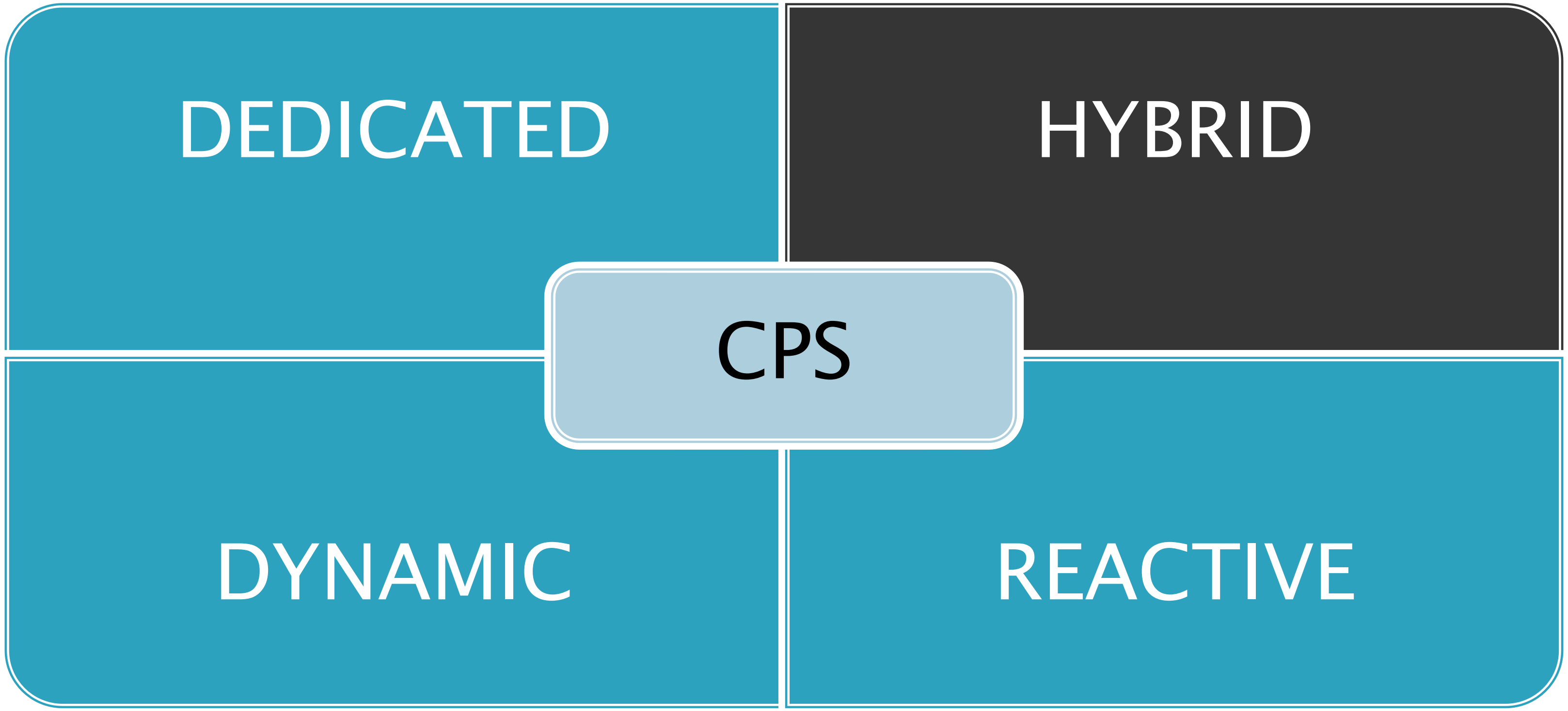
- improve resource minimization and robustness
- require optimized user interfaces



Characterists of CPS

HYBRID: composed of different

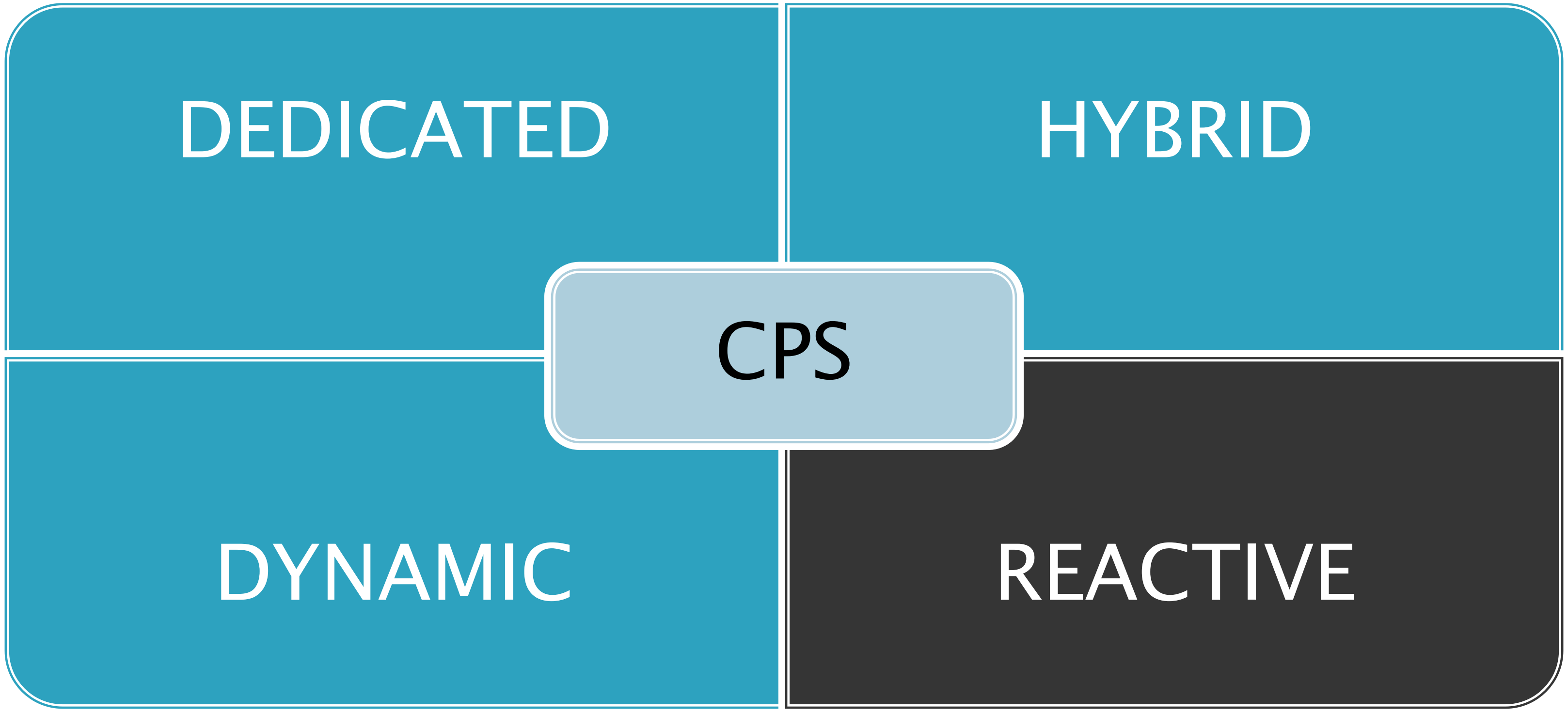
- views (cyber, physical and communication),
- components (hardware and software, analog/digital devices),
- interfaces (e.g. humans, networks).



Characterists of CPS

REACTIVE:

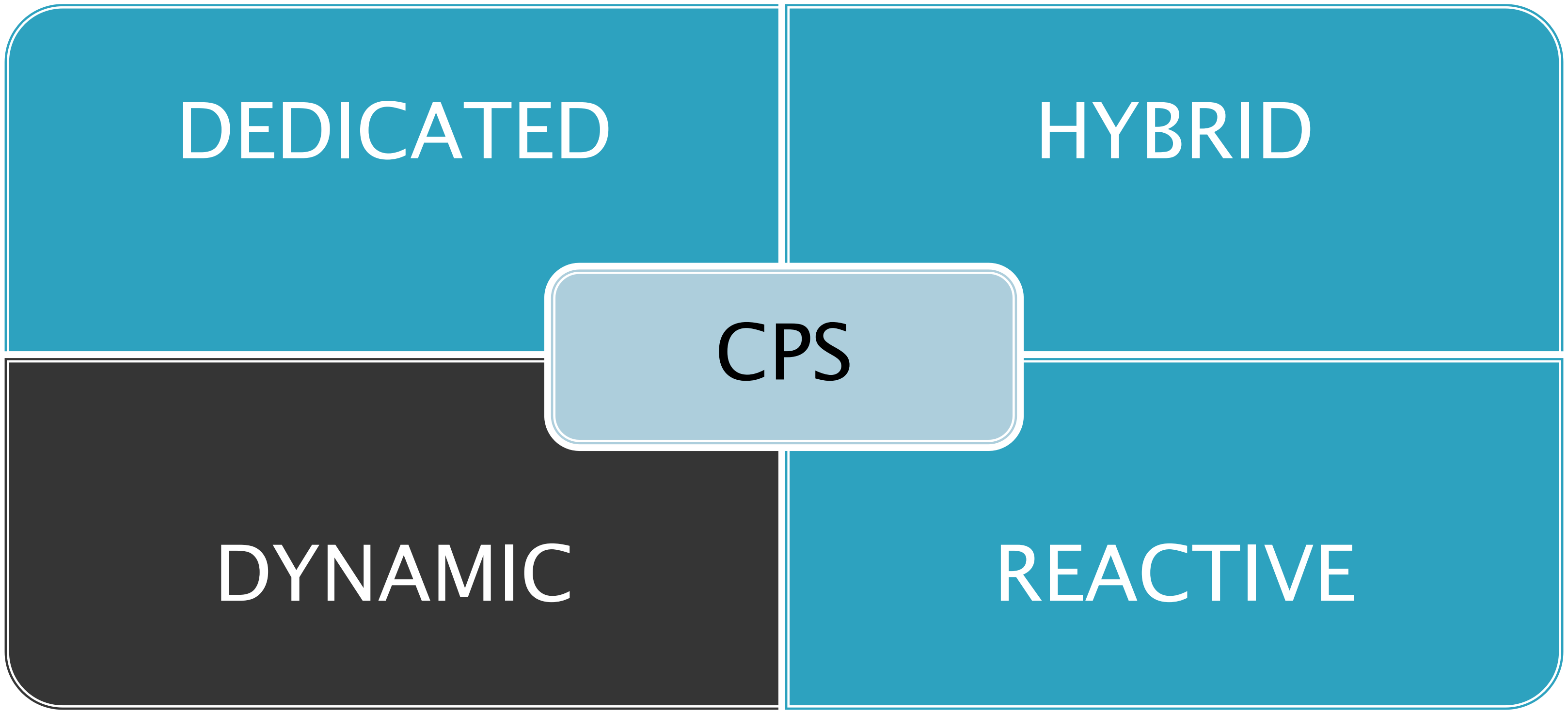
by definition reactive systems are characterized by continuous interactions with the environment where they operate, and execute at a pace that may be determined by the environment.



Characterists of CPS

DYNAMIC: CPS are supposed to adapt to

- changes in the environment;
- runtime variation of the requirements;
- fluctuations in the amount of exchanged and sensed data.



Fields of Application

Real-time situation awareness, dynamic and reactive behaviours have application in...

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Smart-Health: distributed healthcare assistance to improve quality of life and active and healthy ageing.

Smart-Society: increased building efficiency and comfort (i.e. lightning/air quality management).

Smart-Transportation: autonomous vehicle, improved driver assistance and care.

Fields of Application

	Safety	Security	Certif.	Distrib.	HMI	Seamles	MPSoC	Energy
Automotive	x	x	x	x	x	x	x	
Aerospace	x	x	x	x	x		x	x
Healthcare	x	x	x	x	x	x	x	x
Consumer					X	x	x	

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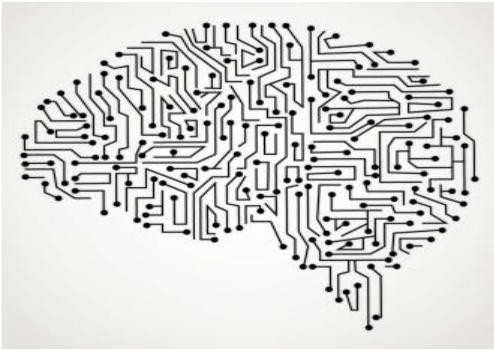

Fields of Application

[17/09]
CPS Market Trends, Dr. Paolo Azzoni [EUROTECH]

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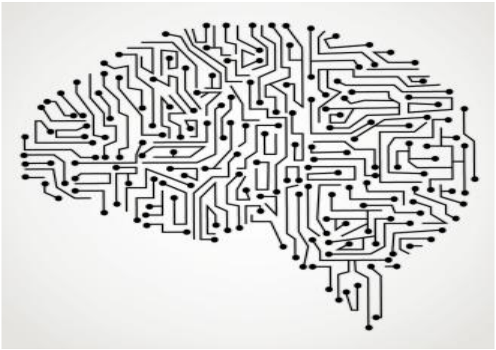
Automotive	x	x	x	x	x	x	x	
Aerospace	x	x	x	x	x		x	x
Healthcare	x	x	x	x	x	x	x	x
Consumer					X	x	x	



Fields of Application

[17/09]

CPS Market Trends, Dr. Paolo Azzoni [EUROTECH]

[18/09]

Legal Issues behind Smart Devices, Dr. Giovanni Pruneddu [Università degli Studi di Sassari]

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Automotive	x	x	x	x	x	x	x	
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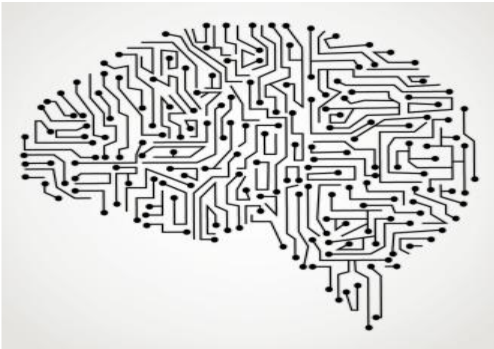


ISSUE # 1
Modelling CPS

Separation of concerns, normally adopted to simplify complexity and heterogeneity, leads to miss important cross-domain interactions.

We need to find proper way of modelling CPS.

The Kopetz Principle

Prof. Dr. Hermann Kopetz

Many (predictive) properties that we assert about systems (determinism, timeliness, reliability, safety) are in fact not properties of an *implemented* system, but rather properties of a *model* of the system.

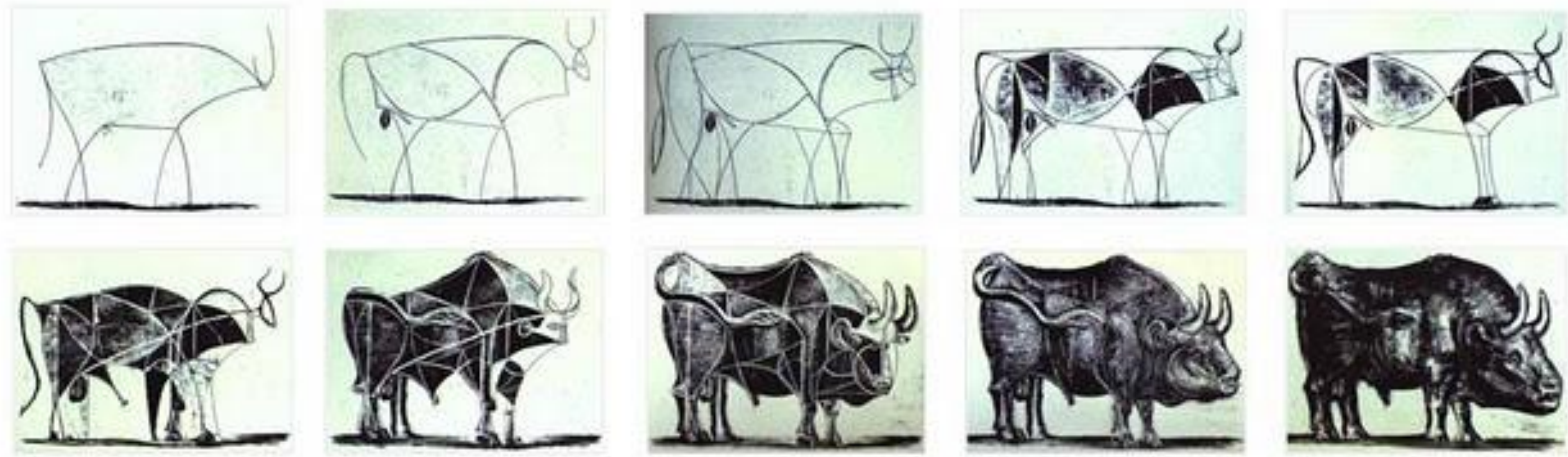
We can make definitive statements about *models*, from which we can *infer* properties of system realizations. The validity of this inference depends on *model fidelity*, which is always approximate.

Edward Lee,
"Cyber-Physical Systems A Rehash or A New Intellectual Challenge?", DAC 2013

Model Fidelity

Francesca Palumbo, UNISS

Model Fidelity



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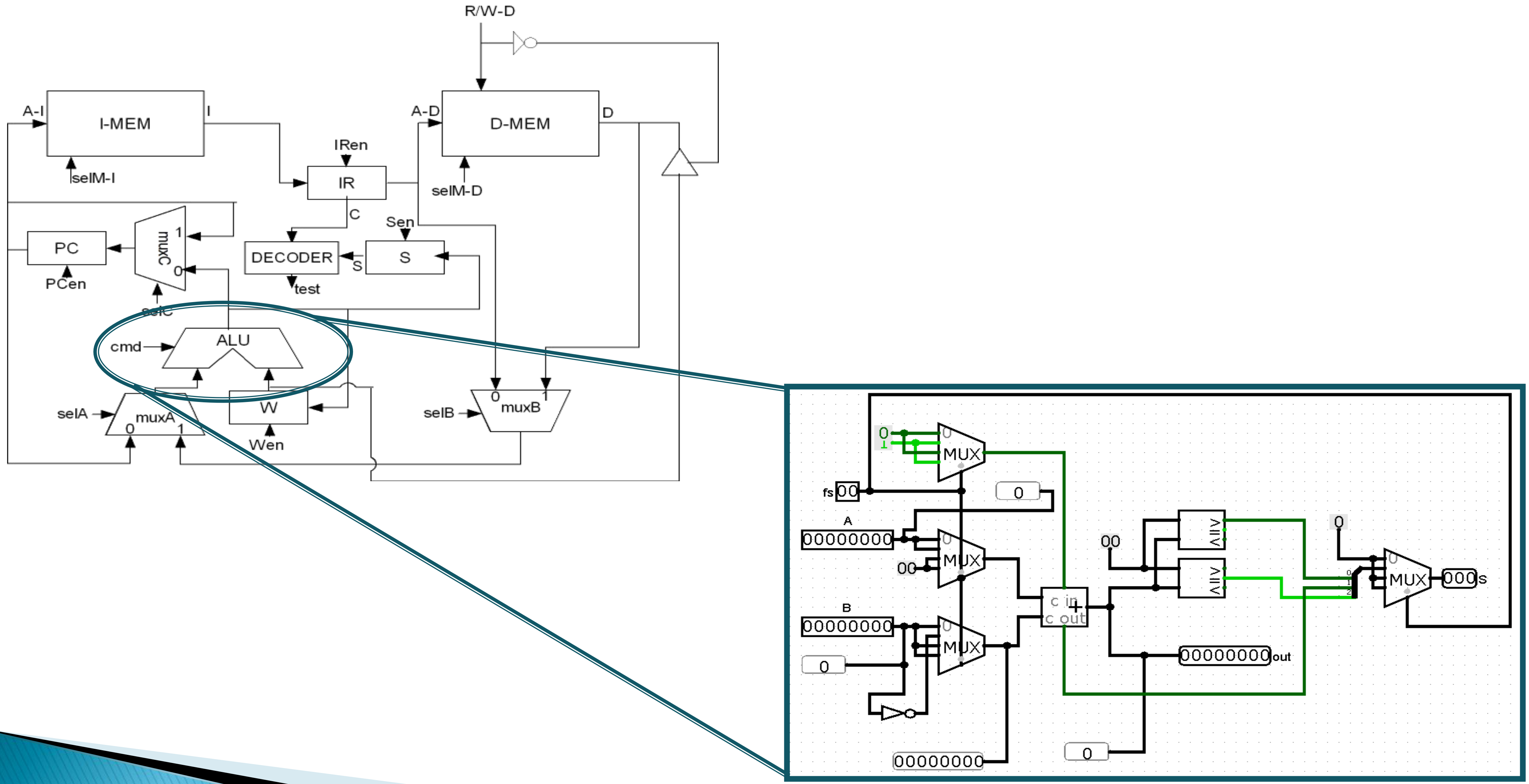
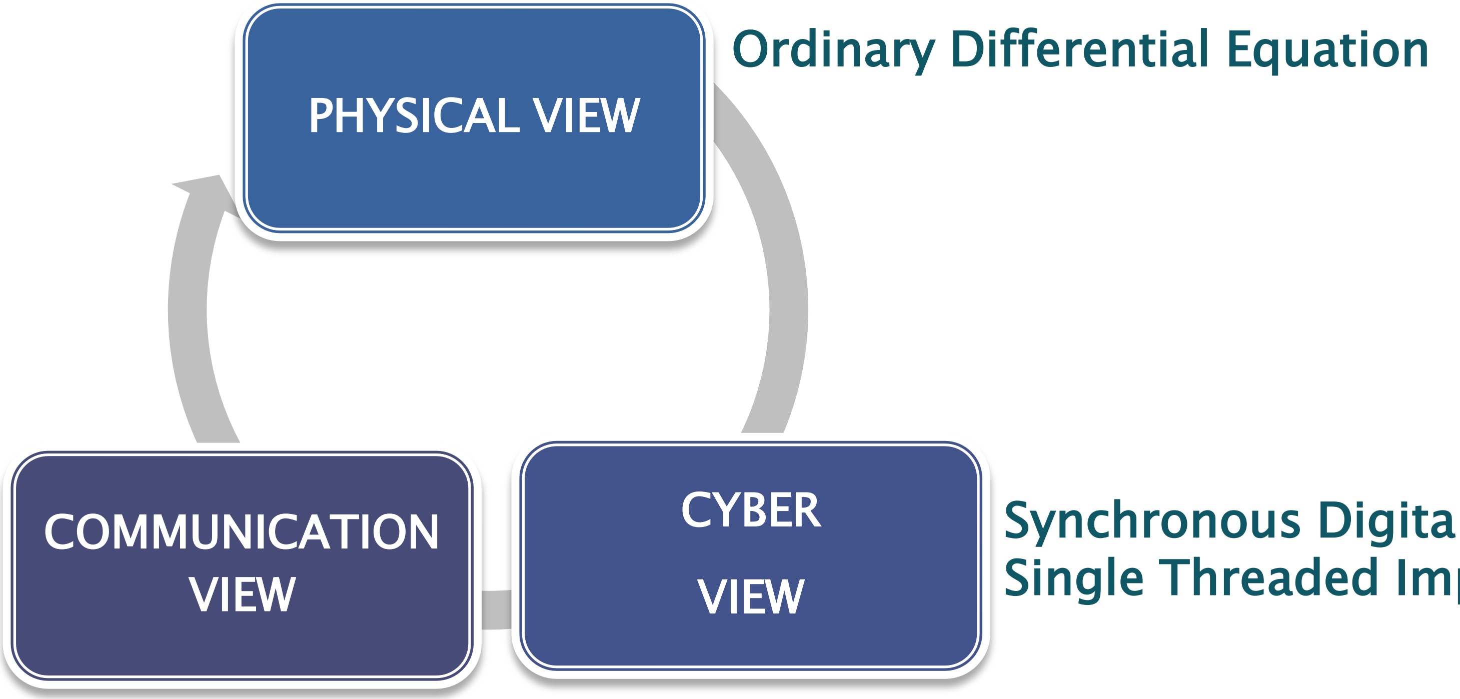
The Synchronous Digital Logic Example



Francesca Palumbo, UNISS

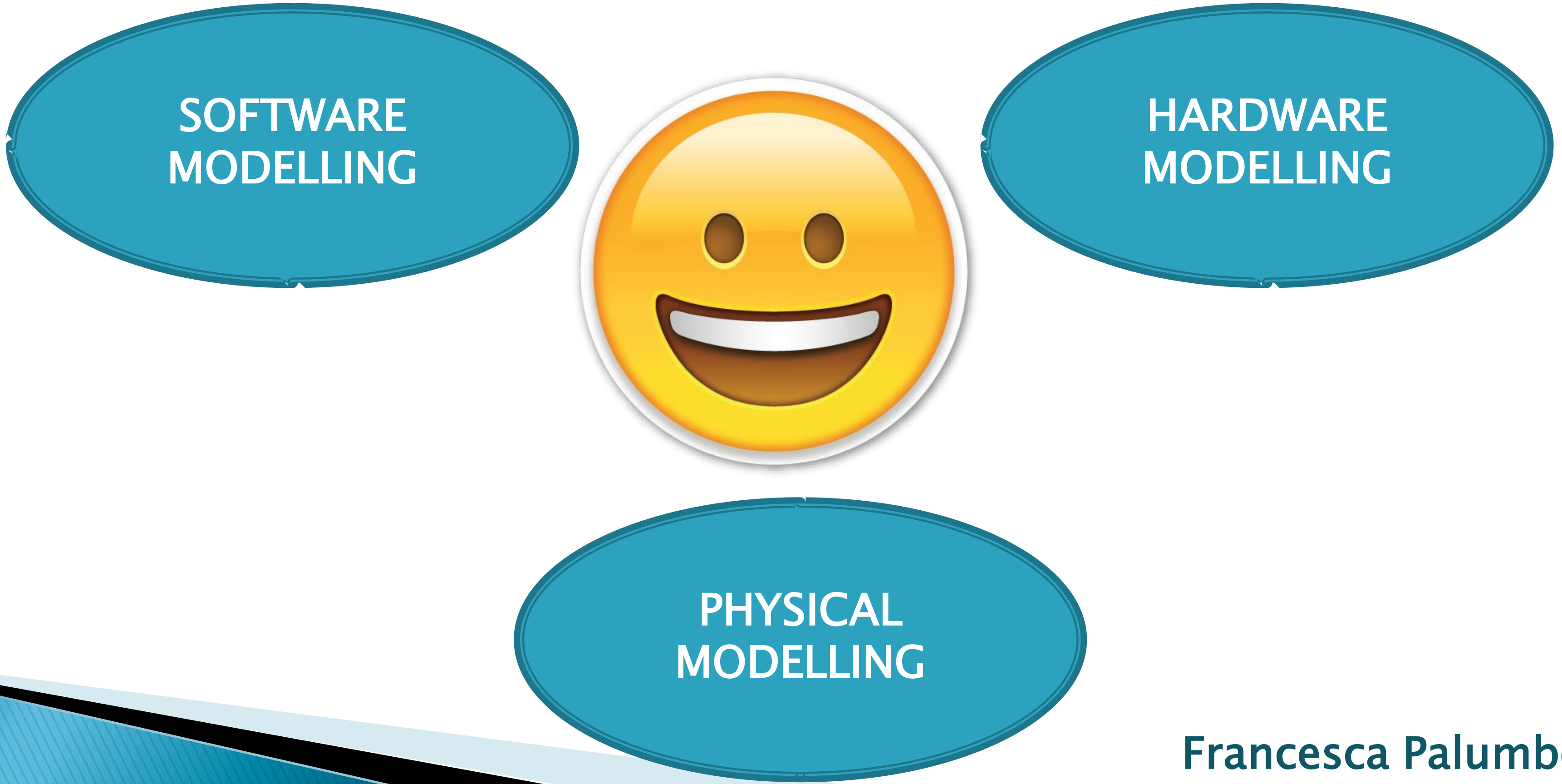
Determinism Issue

- The model has exactly one behavior.
- Unambiguously definition of the "correct" behavior of the thing being modeled.



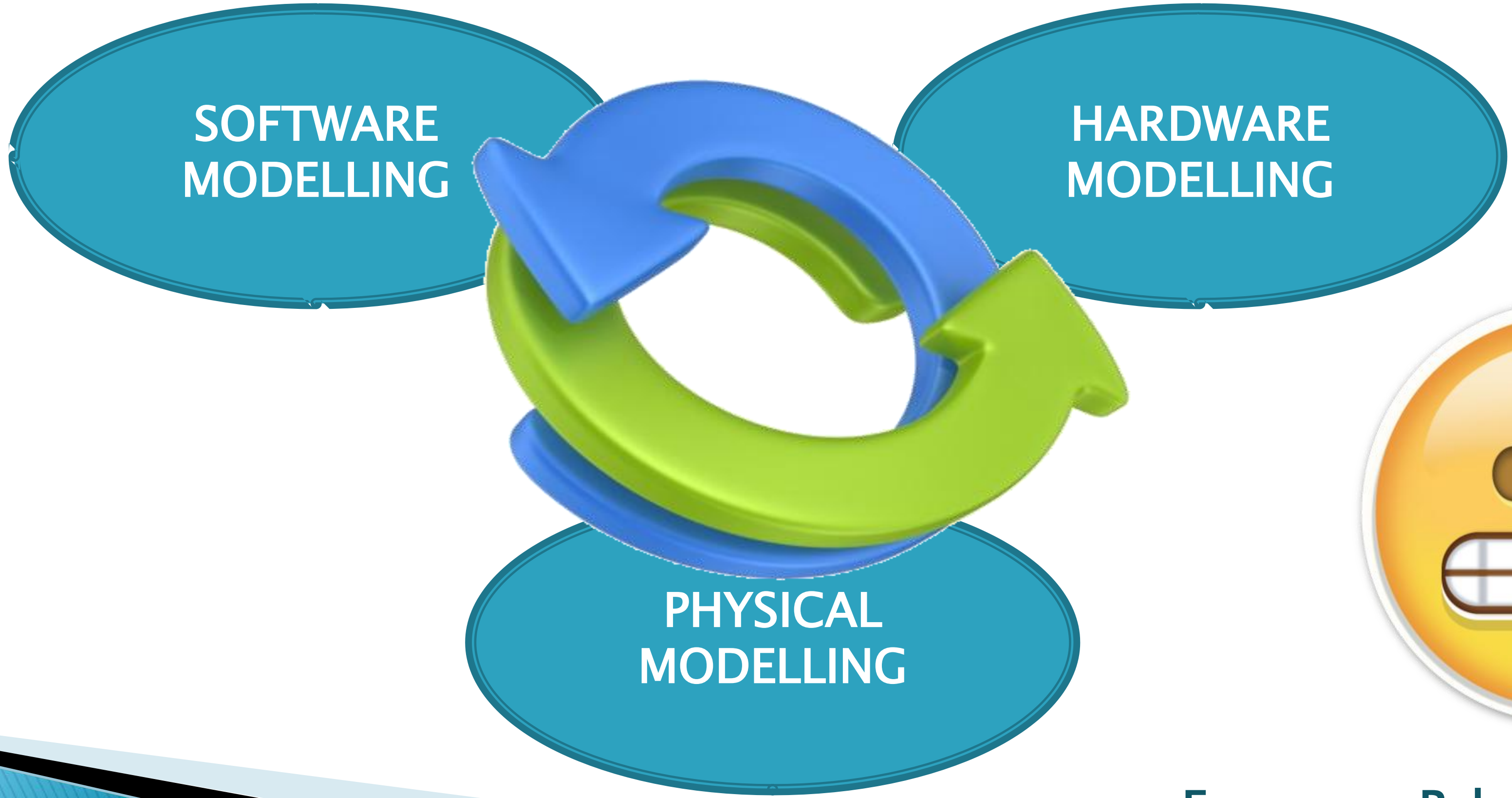
Determinism Issue

- Models are EXTREMELY POWERFUL engineering abstractions
- The real problem is that NON DETERMINISM arises as soon as you cross the border.



Determinism Issue

- Why does NON-DETERMINISM arise?
  - Lack of temporal semantics;
  - The real world is full of uncertainties.



Francesca Palumbo, UNISS

Determinism Issue

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if x>100 {
//this code execute
if (x==0) {
        // should NOT execute
        printf("ERROR!")
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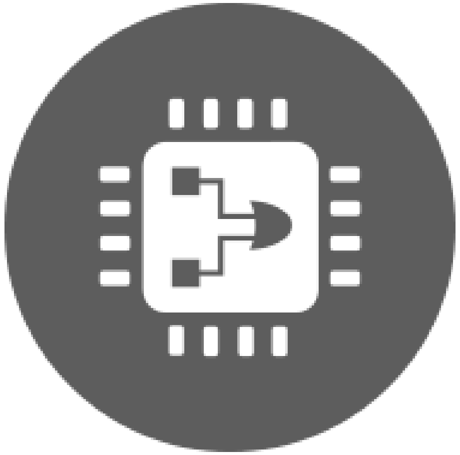
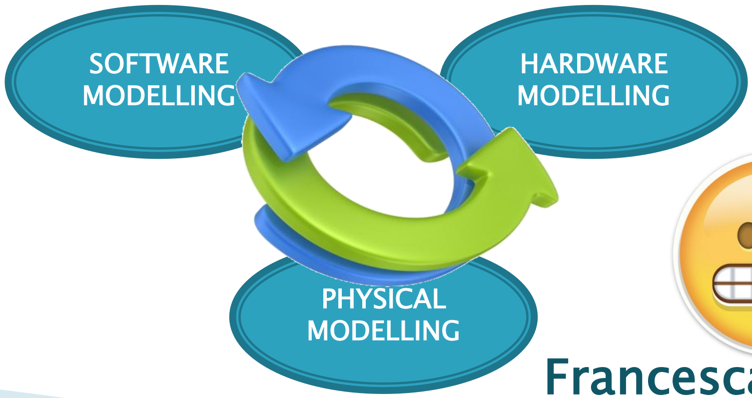
```





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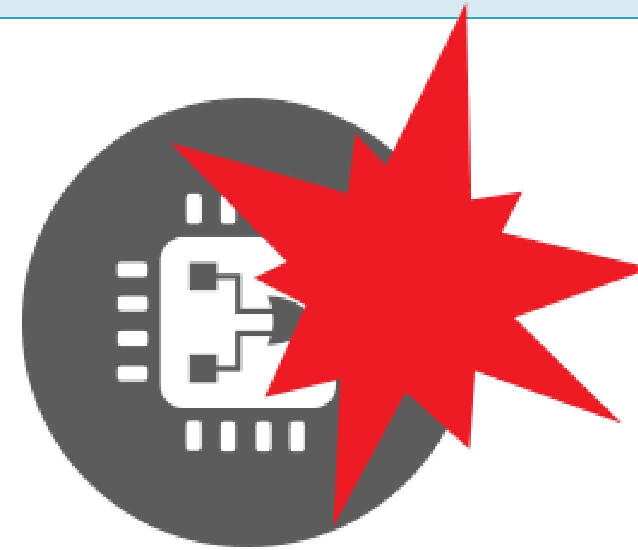

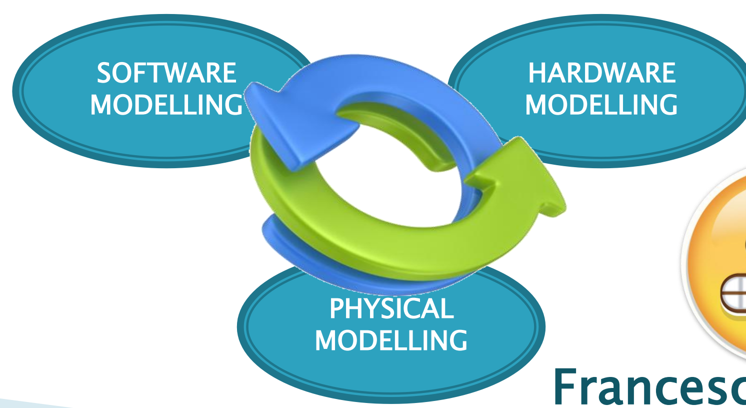

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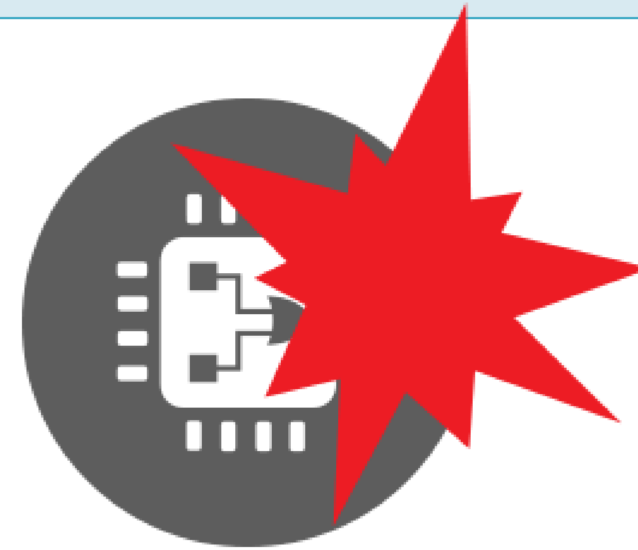
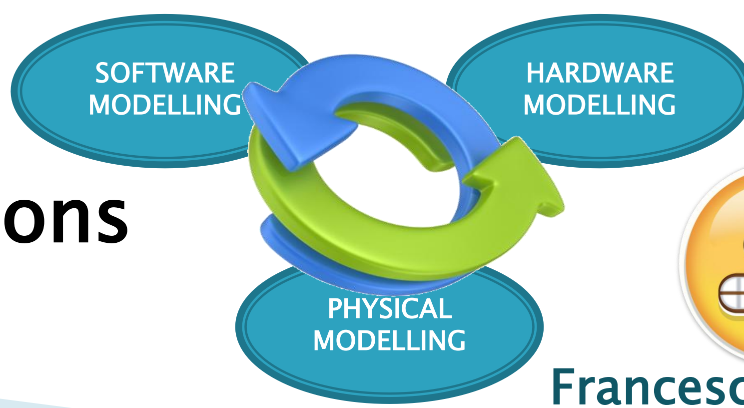


- The REAL BEHAVIOUR comes out when you put together the model with the physical realization of the system.

Interactions
Timing



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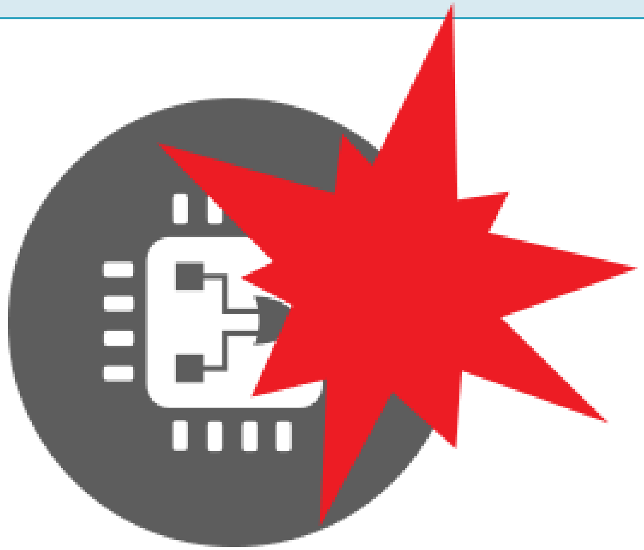
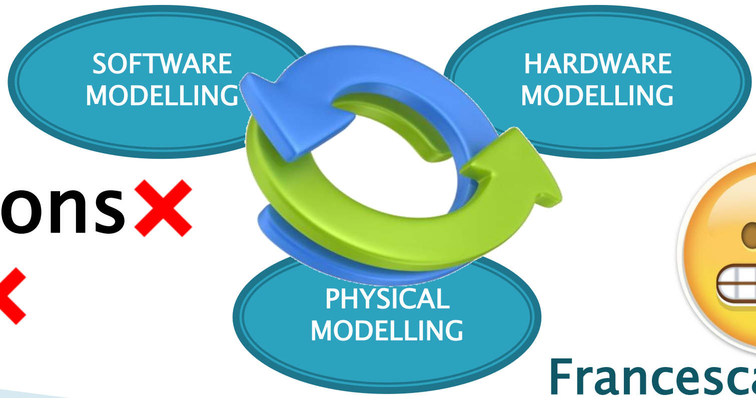


- The REAL BEHAVIOUR comes out when you put together the model with the physical realization of the system.
- You need to guarantee ROBUSTNESS!



Interactions ✗
Timing ✗

CPS Modelling Nightmare

- Modelling the dynamics and the interaction among the heterogeneous and divers views of a CPS is certainly an OPEN ISSUE.
- Dynamic and reactive behaviours have to be guaranteed.

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[18/09] **TALKING ABOUT PROPERTIES AND VERIFICATION**

SMT-based verification of CPSs, Dr. Alessandro Cimatti [Fondazione Bruno Kessler]

Safety & Reliability, Prof. Armando Tacchella [Università degli Studi di Genova]

Low Energy, Prof. Gianluca Palermo [Politecnico di Milano]

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[20/09] **TALKING ABOUT MODELLING**

A Contract-Based Design Methodology for Cyber Physical Systems, Prof. Alberto Sangiovanni-Vincentelli [UC Berkeley]

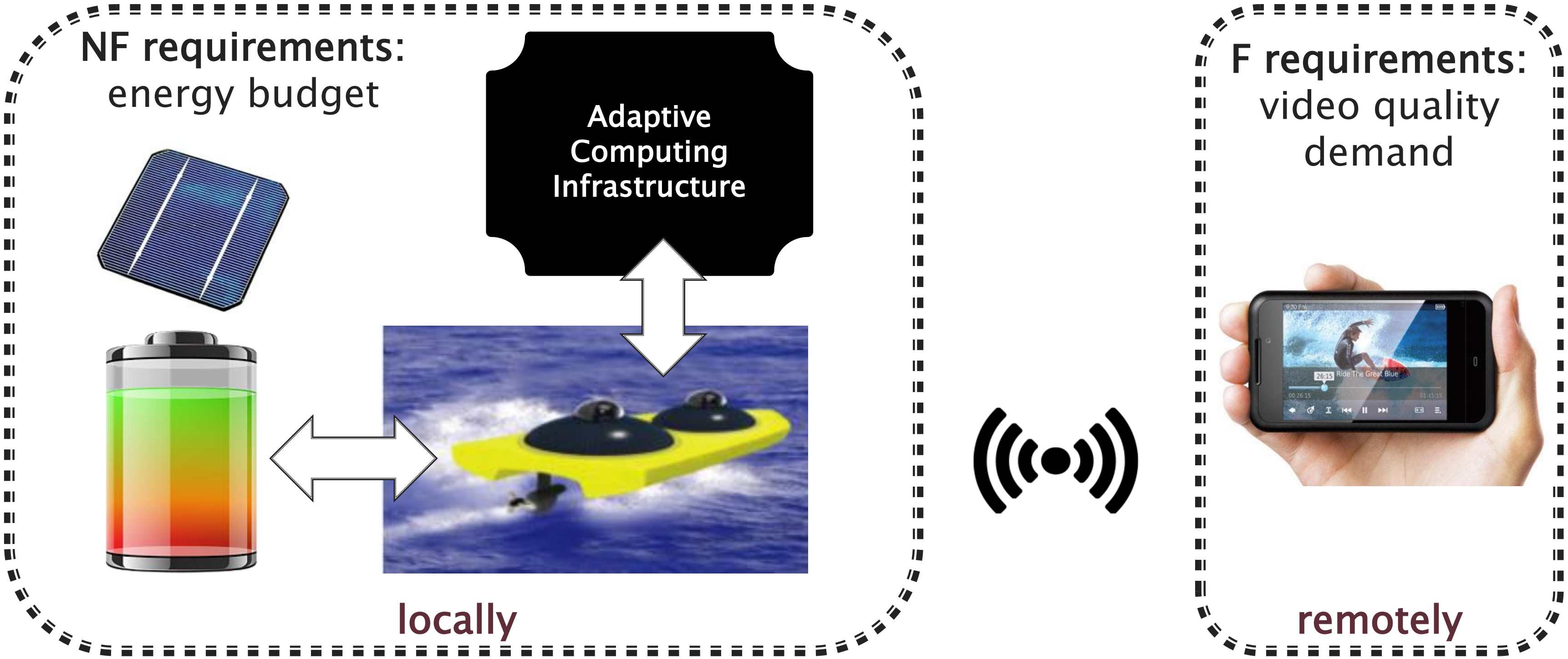
ISSUE # 2
Heterogeneity and Flexibility in CPS

CPS are requested to be *reactive* and *dynamic* to adapt, prospectively autonomously,

- to rapid changes in the environment and in the system itself;
- to satisfy multiple concurring and, potentially, competing requirements.

Adaptivity Issue

- The intrinsic dynamic and reactive nature of CPS requires flexibility.



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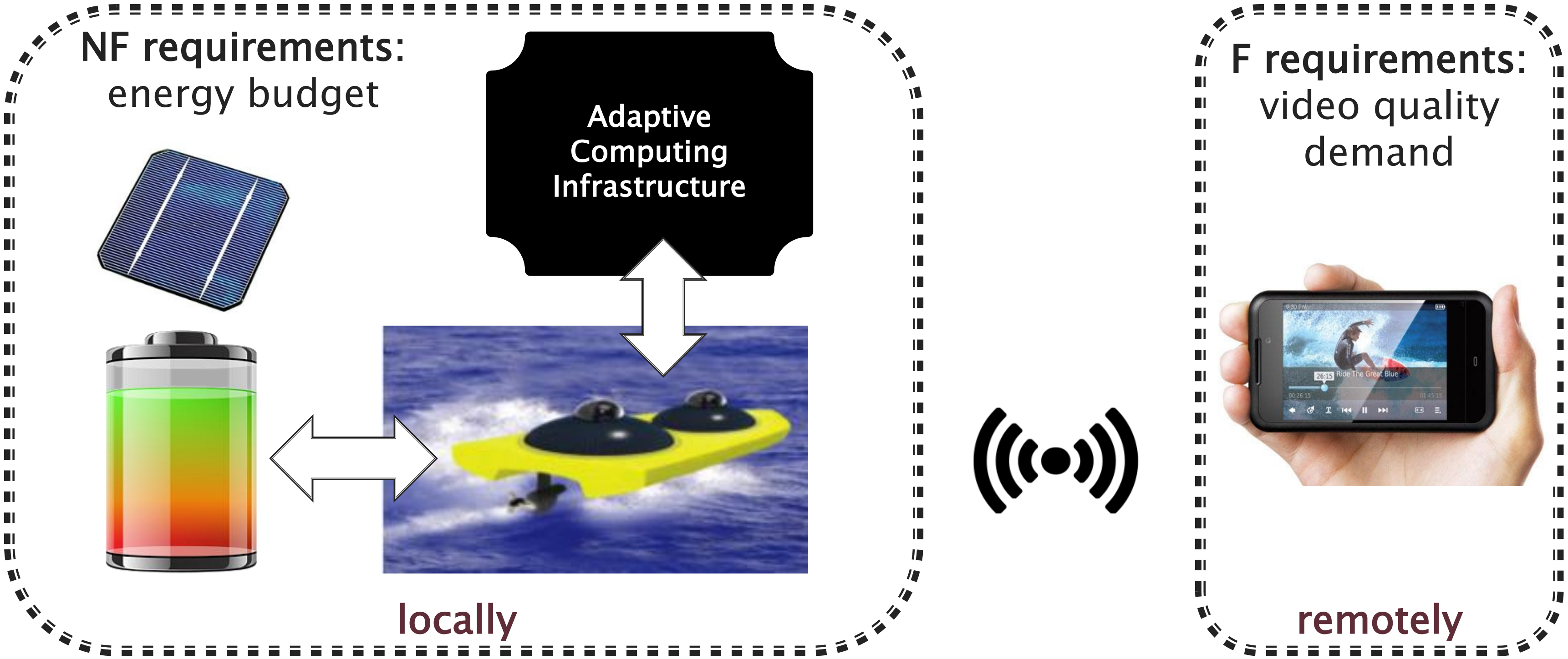

GOAL: multi-layer self-adaptation engine, mastering computing infrastructure reconfigurability.

Francesca Palumbo, UNISS

Adaptivity Issue

Self-adaptation: *runtime actions* changing *structure, functionality and/or parameters* of a system, according to environment, user or self-sensing info.

[F.D. Macías-Escrivá, et al. "*Self-adaptive systems: A survey of current approaches, research challenges and applications*" In Expert Systems with Applications, 2013]

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- Self-reconfiguration and adaptation have been acknowledged as key features for CPS operators:
  - in mixed-critical environments;
  - to handle faults.

Adaptivity Issue

Adaptivity Issue

Adaptivity Issue

EFFICIENT SCHEDULING

Adaptivity Issue

EFFICIENT SCHEDULING

TASK MIGRATION

Adaptivity Issue

EFFICIENT SCHEDULING

TASK MIGRATION
ADAPTIVE PROCESSING

Adaptivity Issue

EFFICIENT SCHEDULING

TASK MIGRATION

ADAPTIVE PROCESSING

COARSE-GRAINED RECONFIGURATION

FINE-GRAINED RECONFIGURATION

Adaptivity Issue

SW ⟷ HW

EFFICIENT SCHEDULING

TASK MIGRATION

ADAPTIVE PROCESSING

COARSE-GRAINED RECONFIGURATION

FINE-GRAINED RECONFIGURATION

[19/09] TALKING ABOUT HETEROGENEITY AND ADAPTIVITY

Artificial Intelligent Sensors at the core of Cyber-Physical-Systems, Dr. Danilo Pau and Dr. Valeria Tomaselli [ST-Microelectronics]

Adaptivity Issue

SW HW

EFFICIENT SCHEDULING

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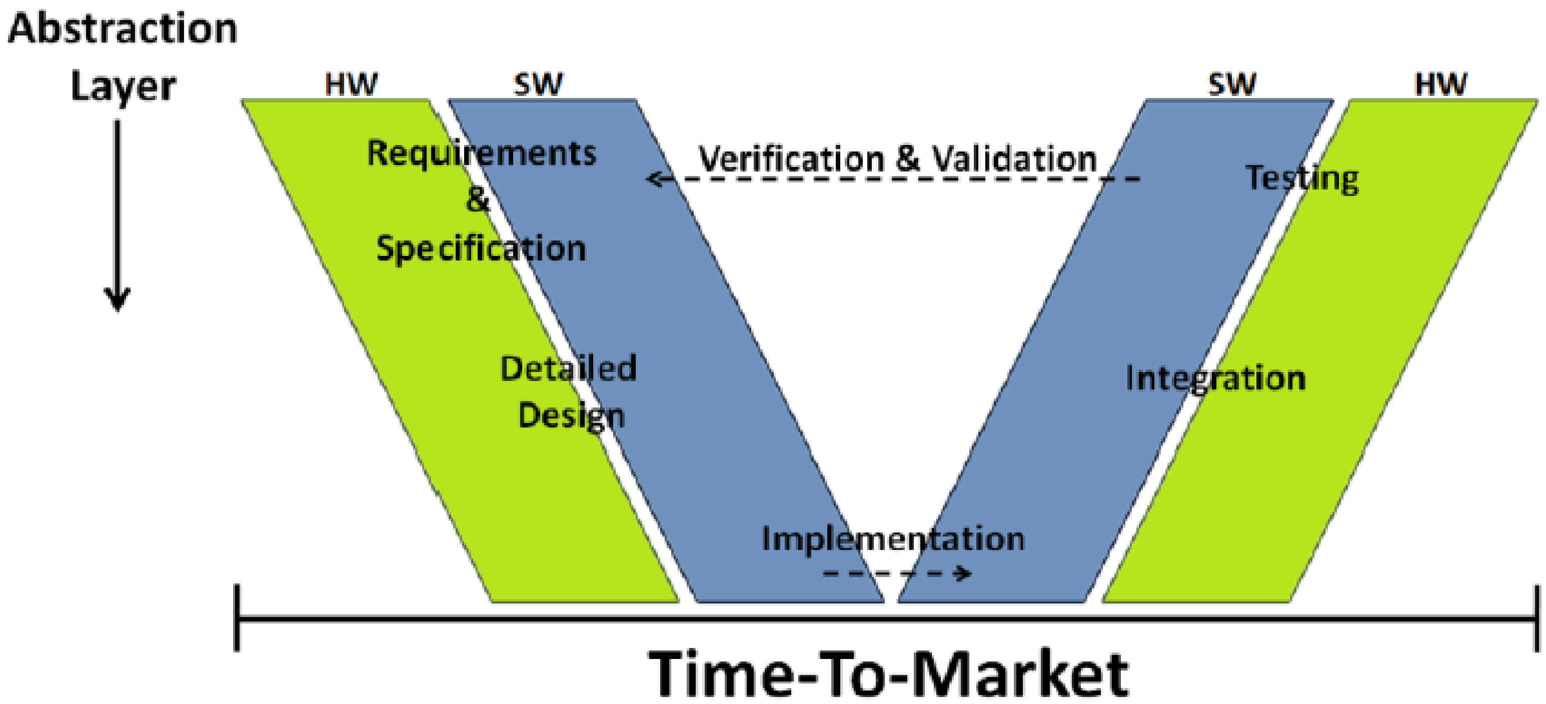
Self-Adaptivity in heterogeneous CPS platforms, Francesca Palumbo [Università degli Studi di Sassari] and Eduardo de la Torre [Universidad Politecnica de Madrid]

ISSUE # 3
Model-based Engineering and Design Tools

Despite their big promise, model-based frameworks are not as popular as it could be expected.

Modeling, maintenance, and interoperability overhead are not addressed in a satisfactory way.

Classical V-model



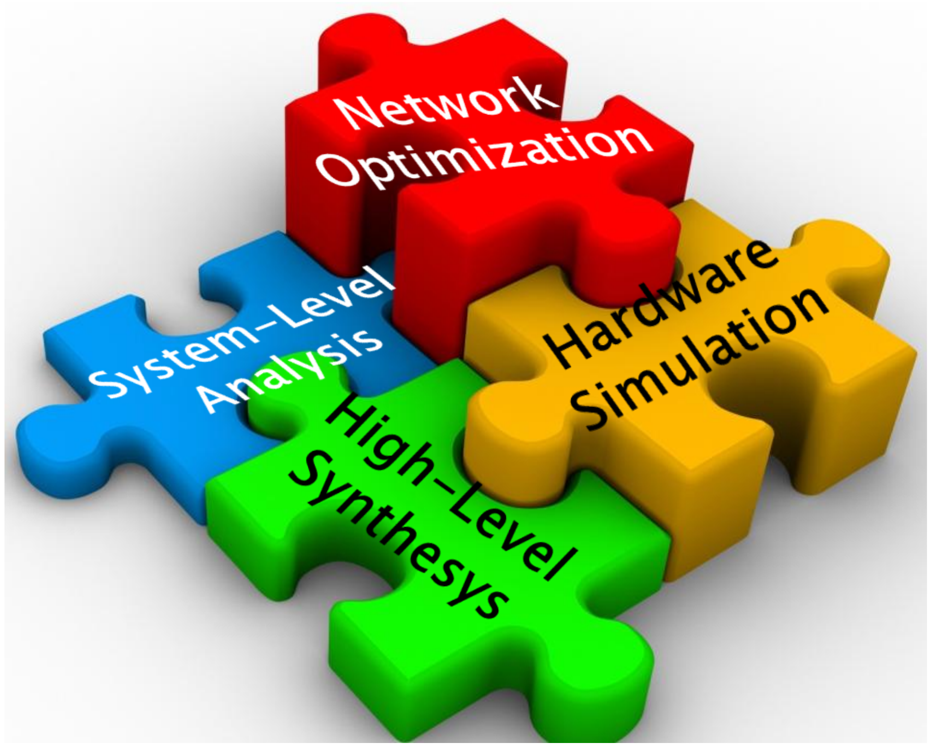
- Separate design, implementation and validation phases
  - long time to market
  - complex HW/SW tuning phase
- Collection of partially integrated toolchains

State-of-the-Art Tools

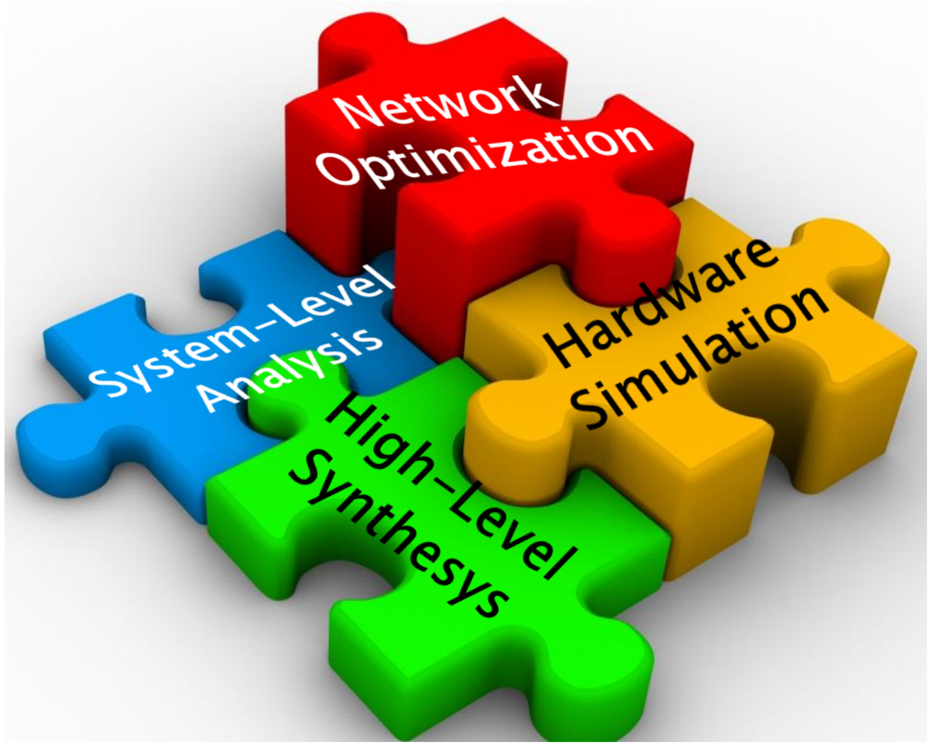
	M	O	D	G	S
Simulink/Stateflow (www.mathworks.nl/products/simulink)	x		x	x	x
Modelica/Dymola (www.3ds.com)	x		x		x
SysML (www.sysml.org)	x		x		
MARTE (www.omgmarte.org)	x		x		
SCADE (www.esterel-technologies.com/products/scade-suite/)	x		x	x	x
gPROMS (www.psenterprise.com/gproms.html)	x	x			x

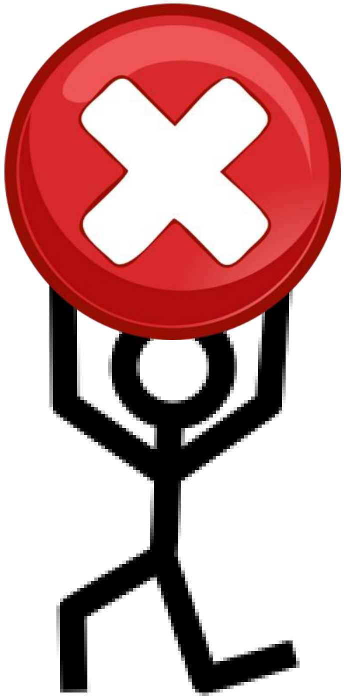
M=Modelling, O=Optimization, D=Design, G= code Generation, S=Simulation

The Tool Integration Nightmare



The Tool Integration Nightmare





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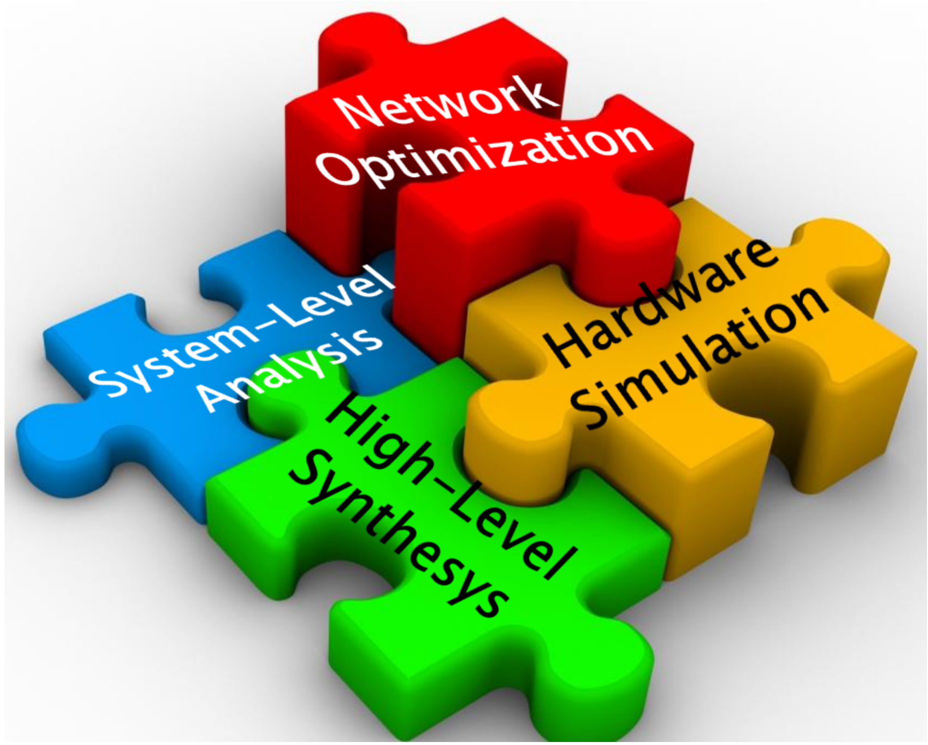

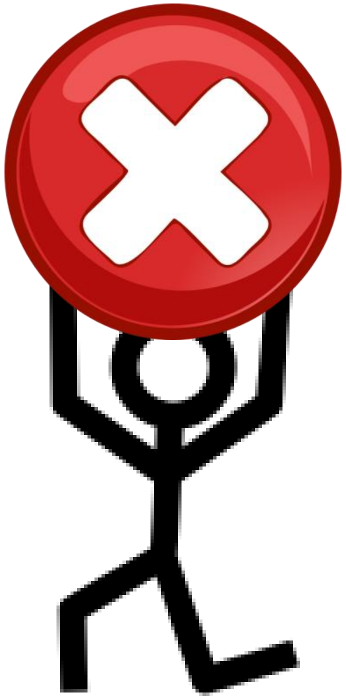

Go for semantic integration rather than for tools combination!

Semantic-oriented Tool Integration

- Do not put tools toghether! Combine the modelling paradigms.

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+

ALL the afternoon tutorials

Requirements Verification, Prof. Luca Pulina [Università degli Studi di Sassari], Prof. Armando Tacchella [Università degli Studi di Genova], Simone Vuotto [Università degli Studi di Sassari/Genova]

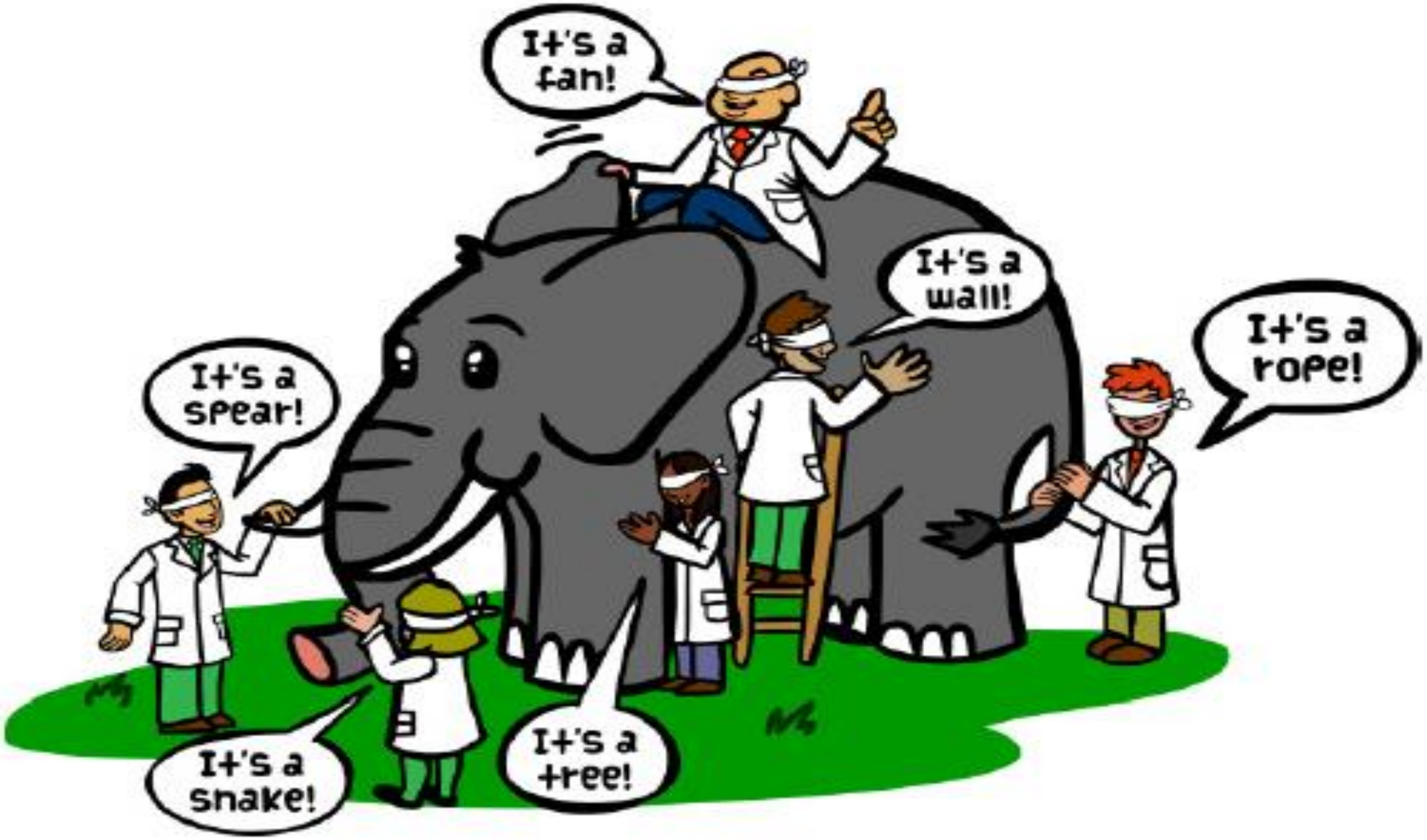
CPS Modeling and Exploration in The CERBERO Project, Dr. Michael Masin [IBM Research], Dr. Julio de Oliveira Filho [TNO]

Reconfigurable CPS Accelerators, Alfonso Rodríguez (Universidad Politecnica de Madrid) and Tiziana Fanni (Università degli Studi di Cagliari)

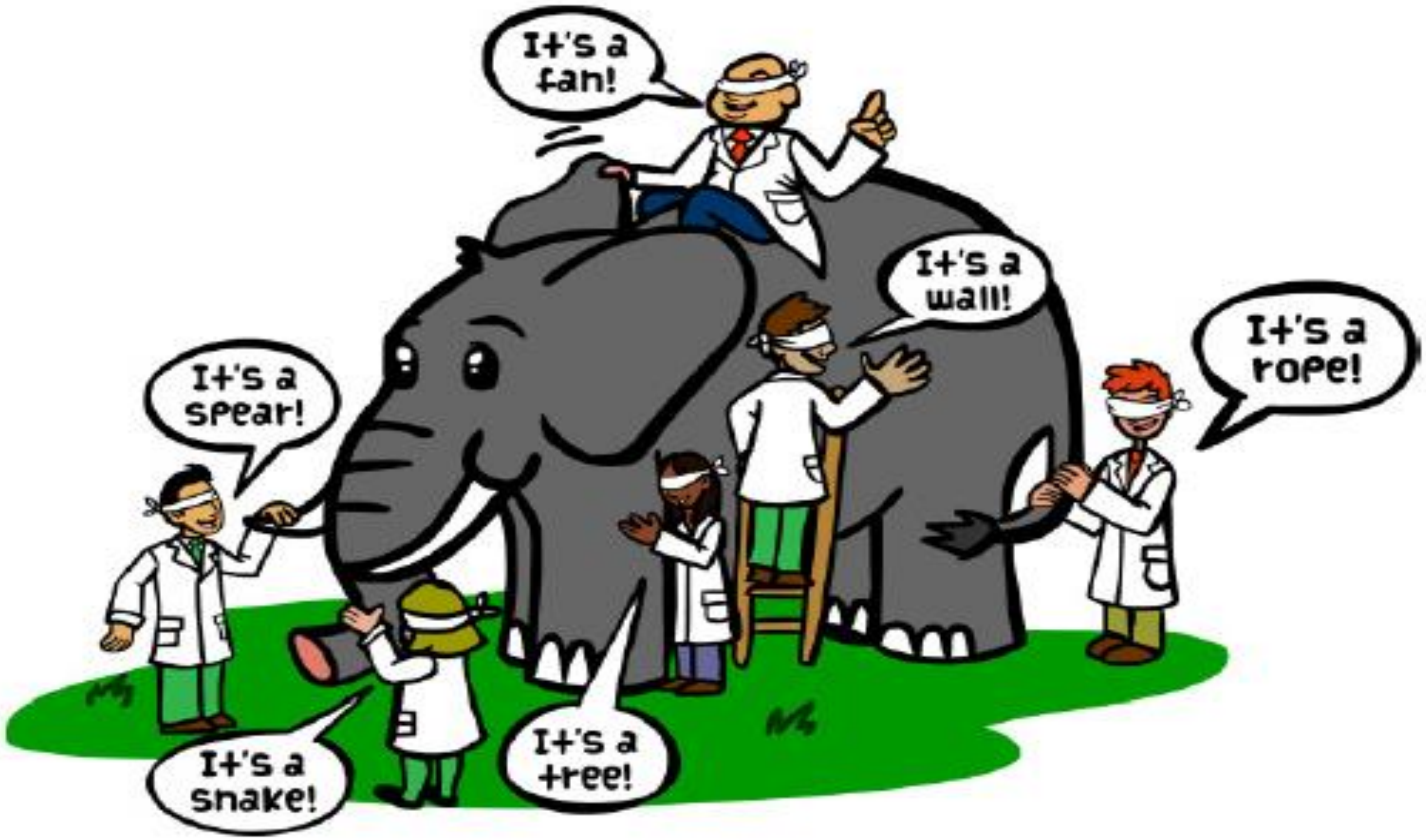
THE RECEPY OF SUCCESS
… be open minded!

Francesca Palumbo, UNISS

Blind Man and the Elephant Problem



Blind Man and the Elephant Problem



Humans tens to project their partial experiences as the whole truth, ignoring other people's partial experiences.

Francesca Palumbo, UNISS

Integral Approach ...Science!

- Huge mistake in CPS design
  - heterogeneity;
  - multi-vendor, multi-physics and multi-modelling;
  - wide variety of requirements and constraints.

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- Huge mistake in CPS design
  - heterogeneity;
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  - wide variety of requirements and constraints.

- You need to be willing
  - to change your point of view;
  - to play with new tools and experimentations;
  - to combine several different components and domains together.

USEFUL READS

Something for you to read …

- The Past, Present and Future of Cyber-Physical Systems: A Focus on Models,
  E. A. Lee – https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4435108/
- Framework for cyber-physical systems, release 1.0
  NIST 2016 – https://pages.nist.gov/cpspwg/
- Metronomy: A function-architecture co-simulation framework for timing verification of cyber-physical systems,
  L. Guo, Q. Zhu, P. Nuzzo, R. Passerone, A. L. Sangiovanni-Vincentelli and E. A. Lee
  CODES+ISSS 2014
- Design tool chain for cyber-physical systems: lessons learned,
  J. Sztipanovits, T. Bapty, S. Neema, X. D. Koutsoukos, and E. K. Jackson
  DAC, 2015