Introduction on Cyber Physical Systems

Francesca Palumbo
University of Sassari

CPS Summer School – From concepts to implementation
Porto Conte Ricerche, Alghero (IT)
25-29 September 2017

Let’s go straight to the point!

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

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

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Computing Evolution

UBIQUITUOUS COMPUTING & INFORMATION

PERVASIVE COMPUTING DISAPPEARING COMPUTERS

EMBEDDED EVERYWHERE

POST PC ERA

+

PHYSICAL ENTANGLEMENT

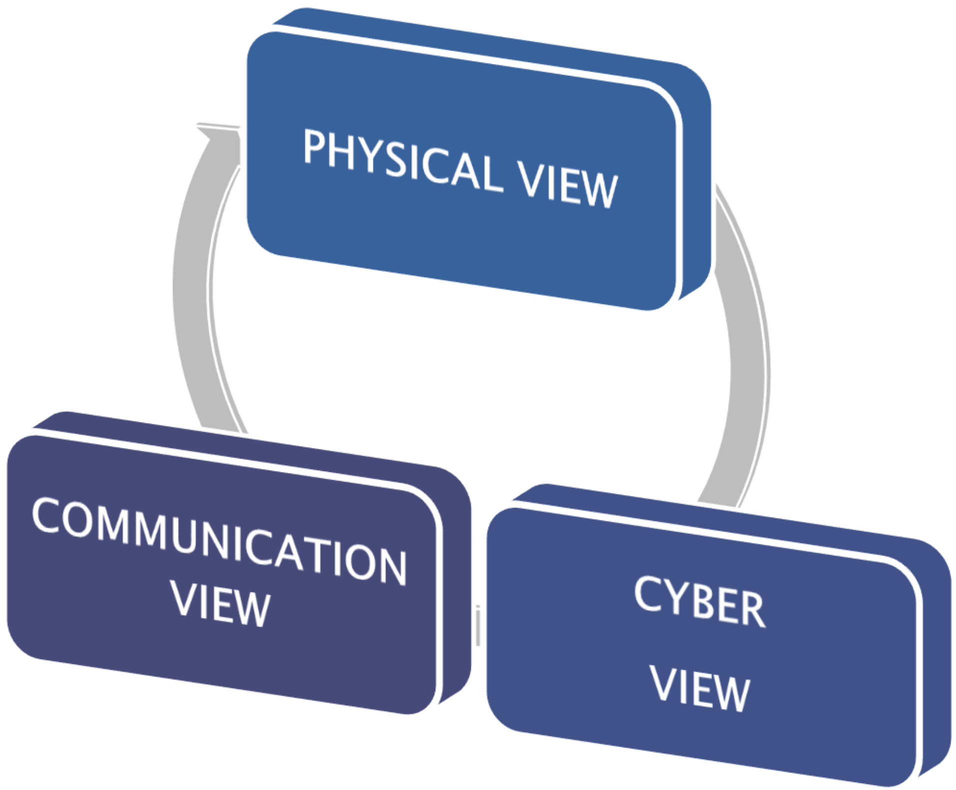
CPS ERA

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**

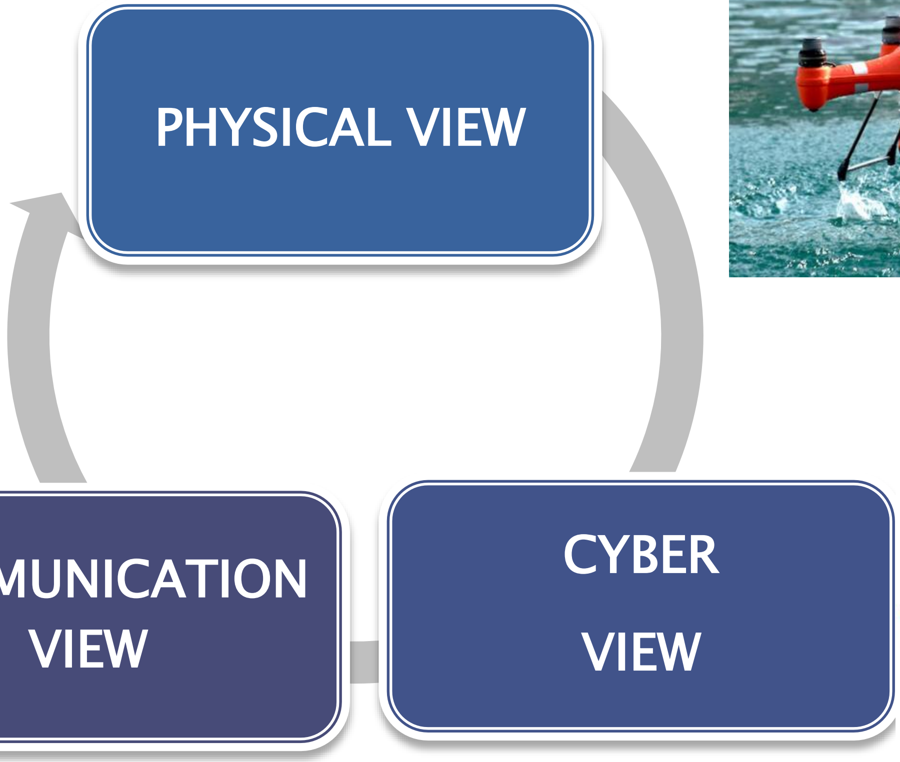
A cyber-physical system (CPS) is an ***orchestration of computers and physical systems***. Embedded computers monitor and control physical processes, usually with feedback loops, where ***physical processes affect computations and vice versa***.

Edward A. Lee
University of Berkeley



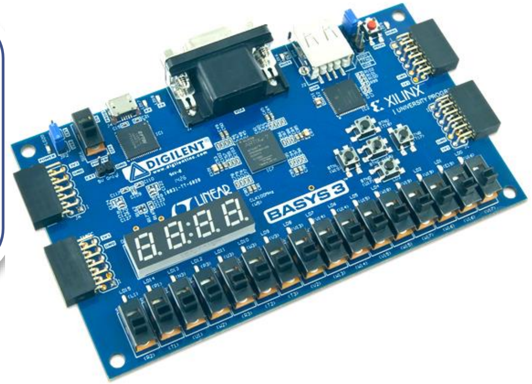
Key Ingredients

physical plant/process, users

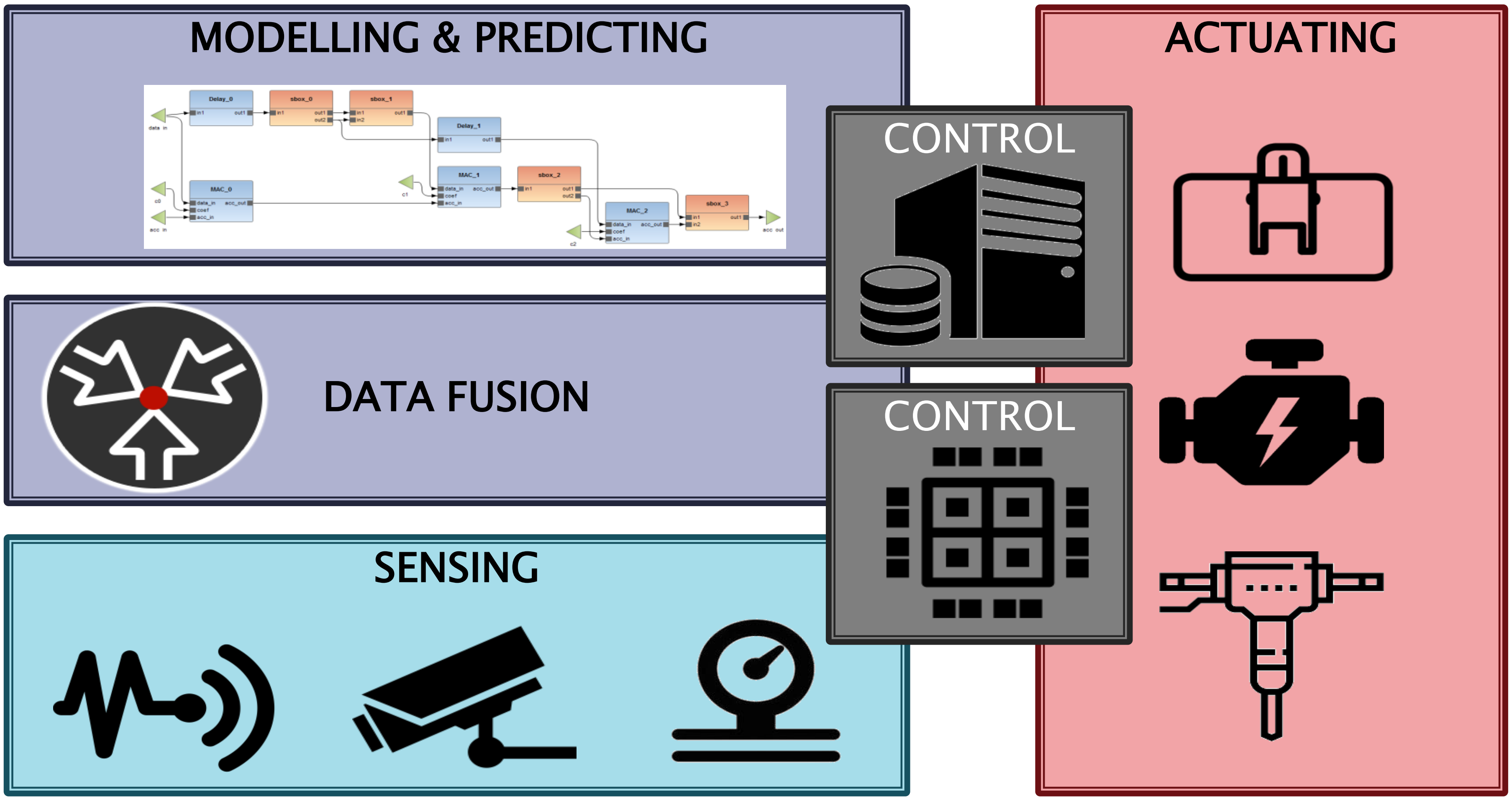


component to component/human/ environment

software, algorithm, computation



Key Ingredients

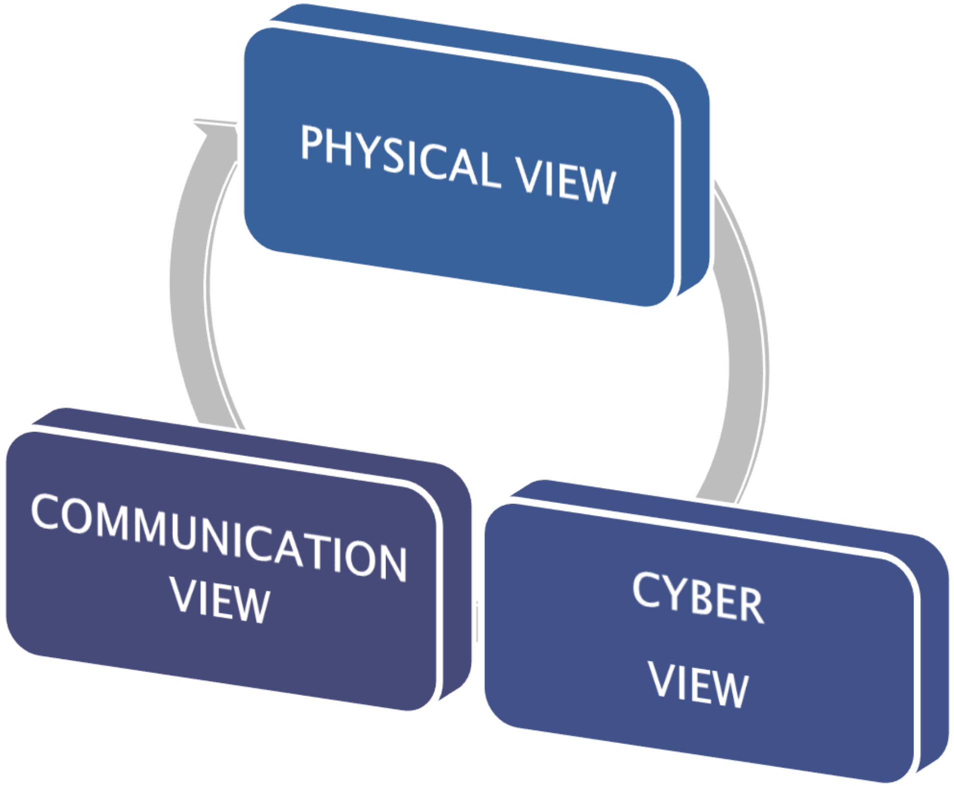


Yet Another Definition

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.

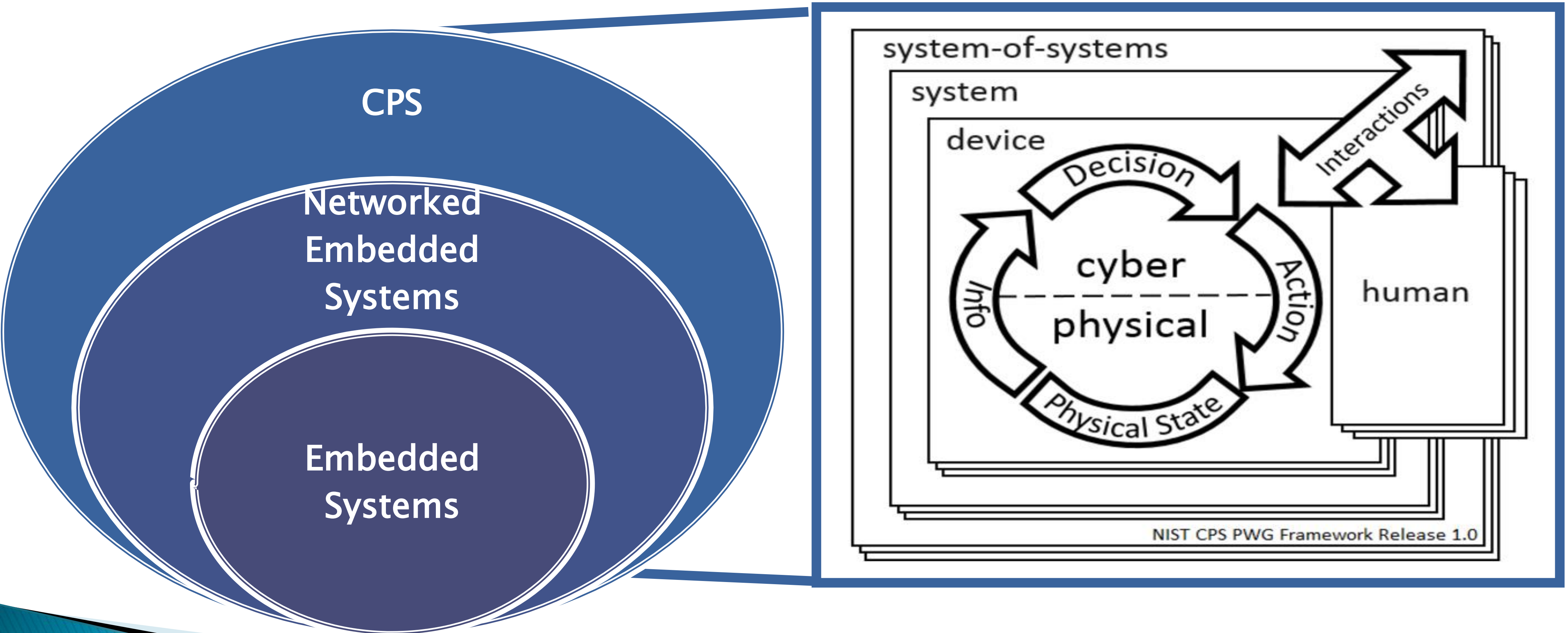
CPS technology will ***transform the way people interact with engineered systems*** -- just as the Internet has transformed the way people interact with information.



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

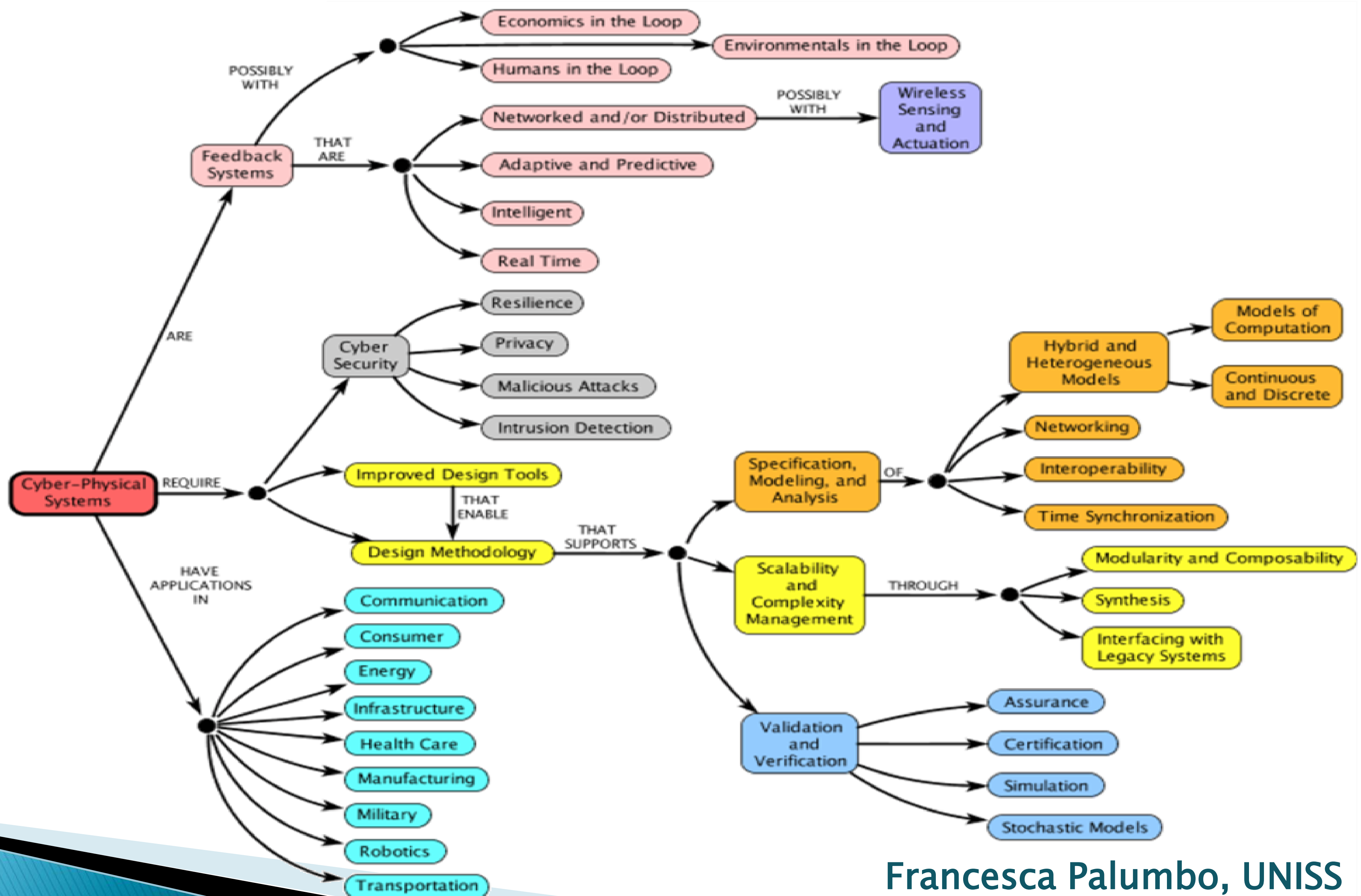
Embedded Systems and CPS

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



CPS Concept Map

http://cyberphysicalsystems.org/



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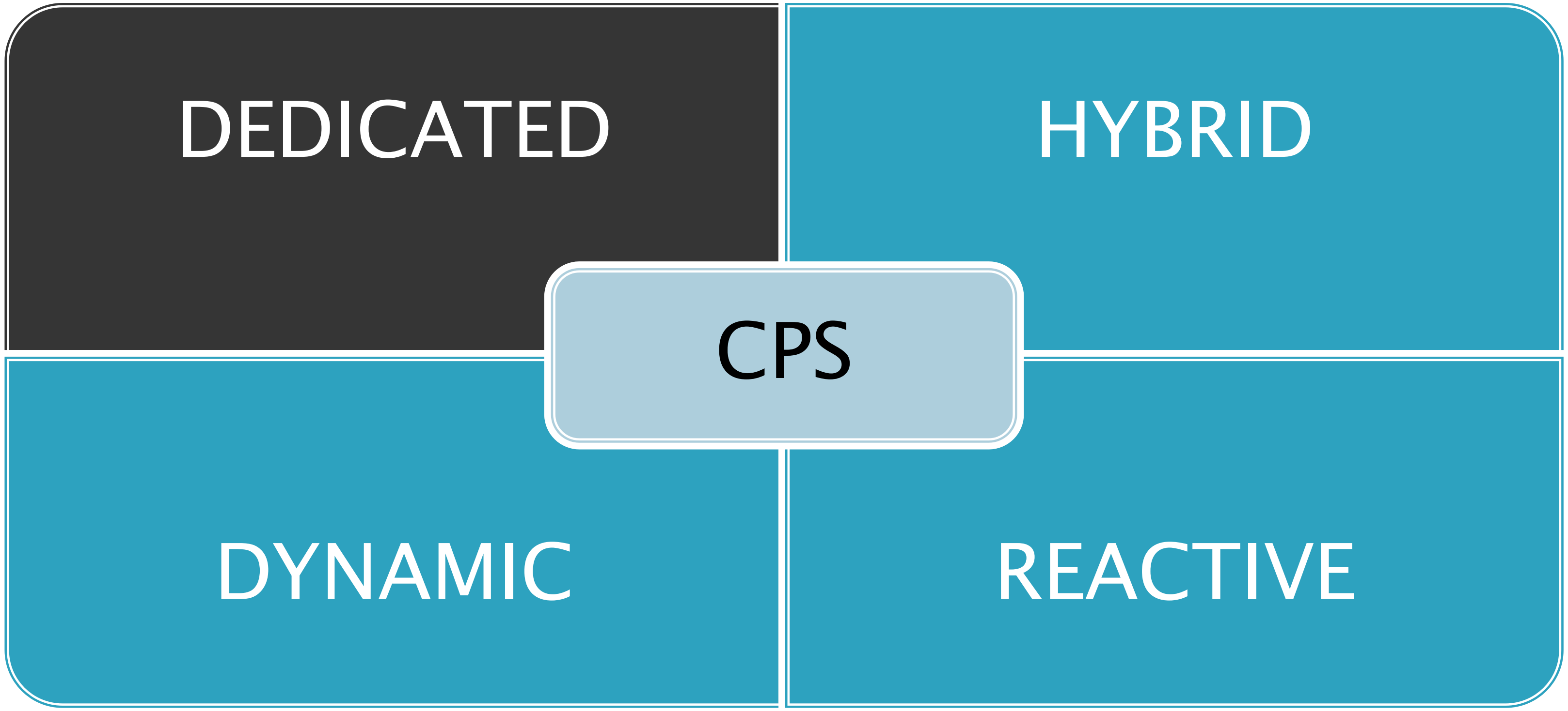
Characterists of CPS

DEDICATED: towards a certain application. Knowledge of behaviours may

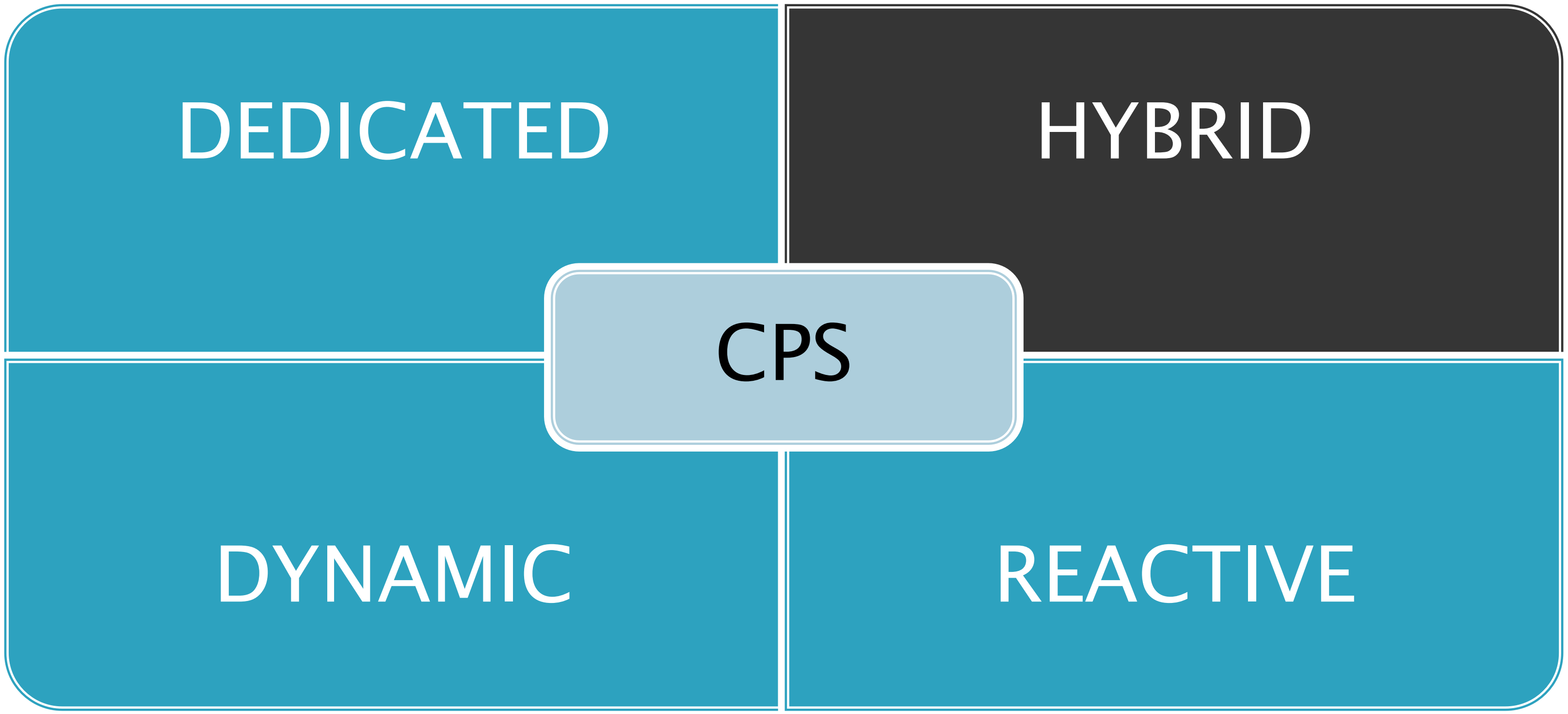
- improve resource minimization and robustness
- require optimized user interfaces



Characterists of CPS

HYBRID: composed of different

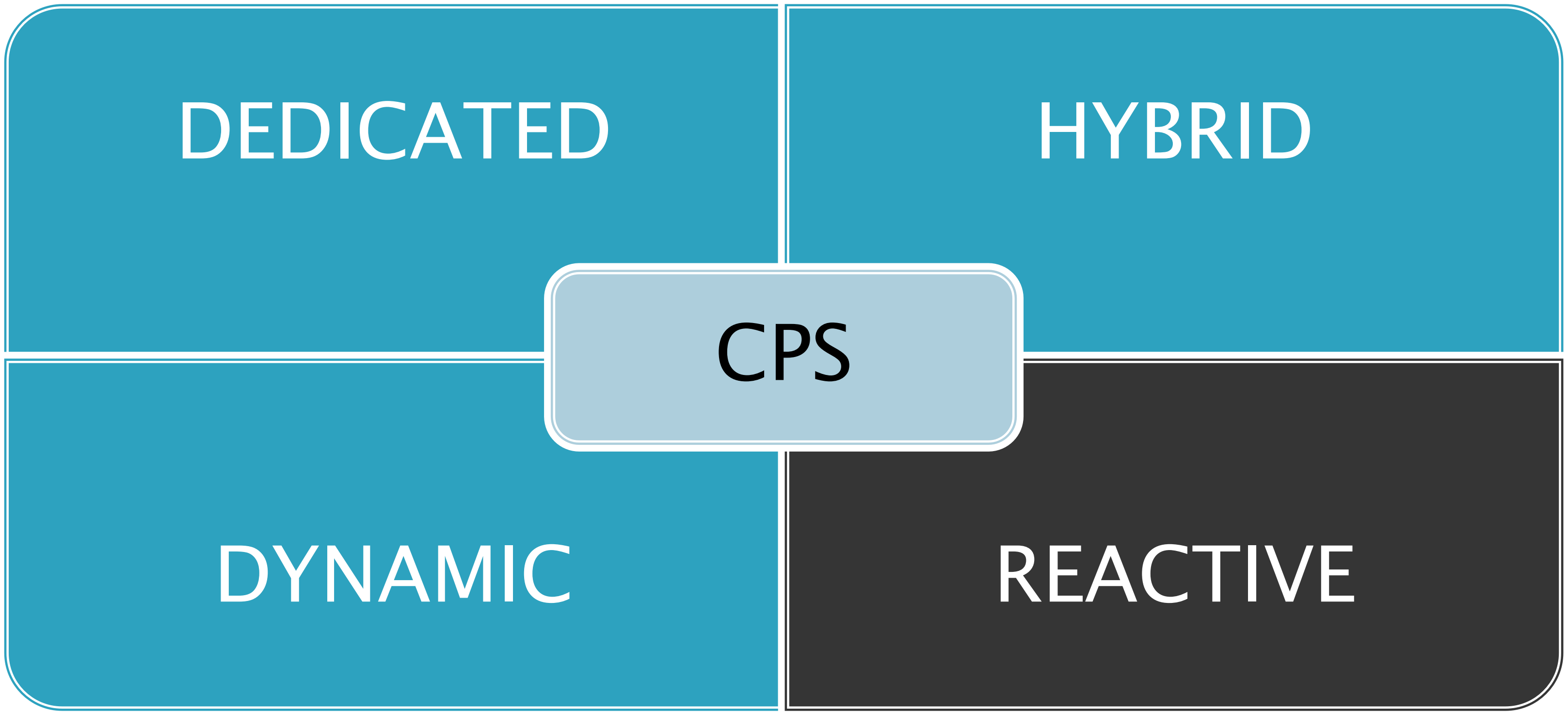
- views (cyber, physical and communication),
- components (hardware and software, analog/digital devices),
- interfaces (e.g. humans, networks).



Characterists of CPS

REACTIVE:

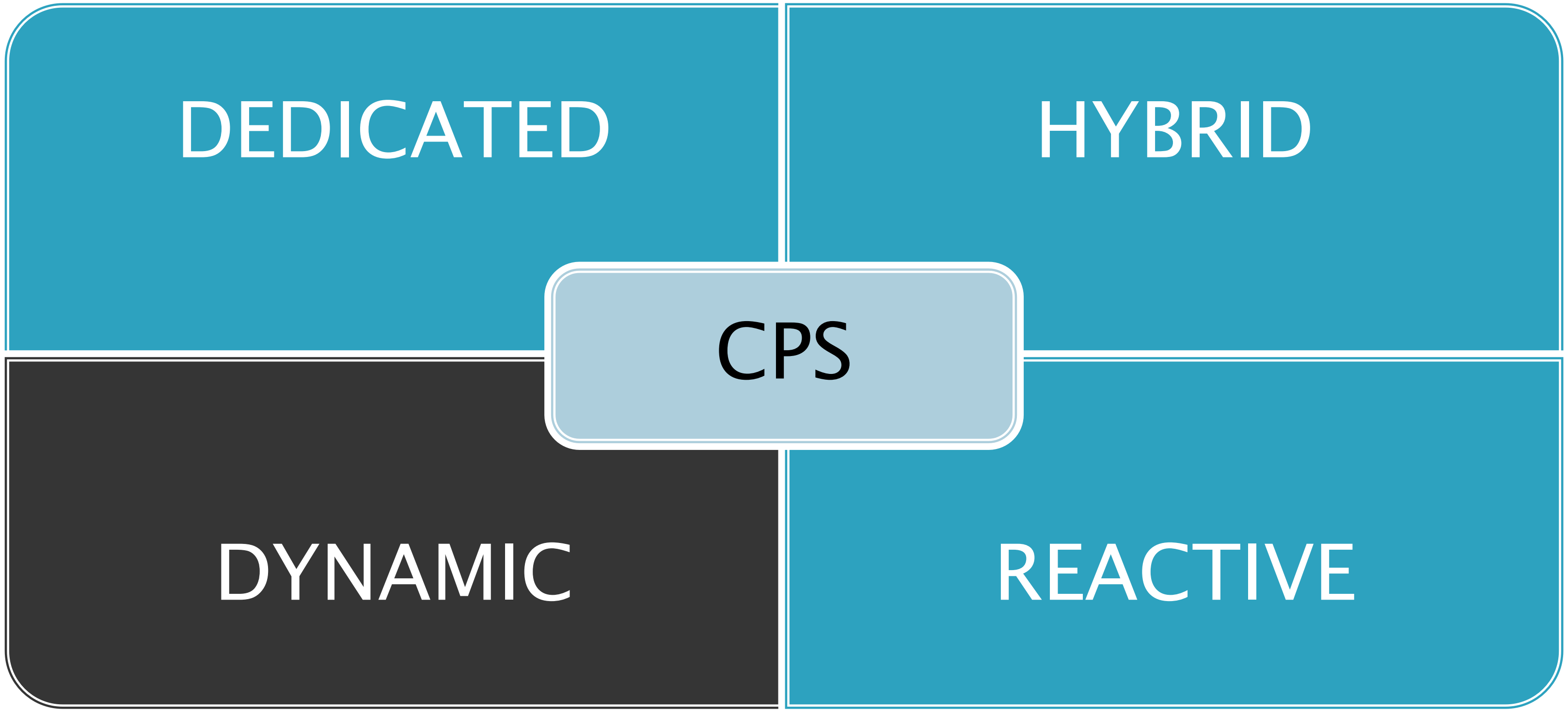
by definition reactive systems are characterized by continuous interactions with the environment where they operate, and execute at a pace that may be determined by the environment.



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...

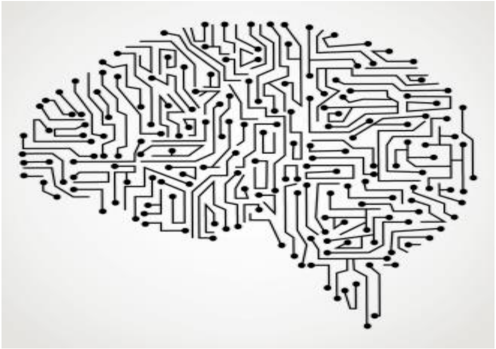
Smart-Health: distributed healthcare assistance to improve quality of life and active and healthy ageing.

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	Seamless	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

Cognitive CPS **TALKING ABOUT TRENDS and APPLICATIONS**

Michael Masin (IBM, IL) and Paolo Meloni (University of Cagliari, IT)

The (Smart) Cyber-Physical Revolution: From Theory to Practice

Danilo Pau (ST Microelectronics, IT)

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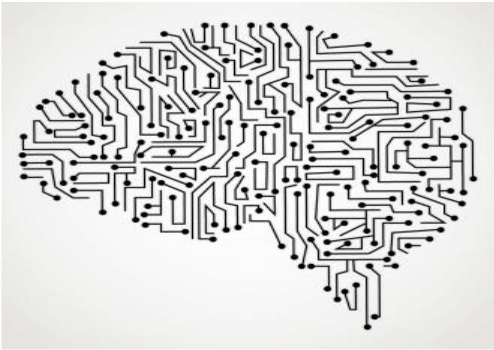
Aerospace	x	x	x	x	x		x	x
Healthcare	x	x	x	x	x	x	x	x
Consumer					x	x	x	



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Fields of Application

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How CPS applications in biomedicine came to reality

Ugo della Croce (University of Sassari, IT)

~~**CPS Industrial applications in the CPSwarm Project**~~

~~Alessandra Bagnato (Softeam, FR)~~

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CPS on Smart-Travelling: the CERBERO use-case

Joost Andriaanse (TNO, NL)

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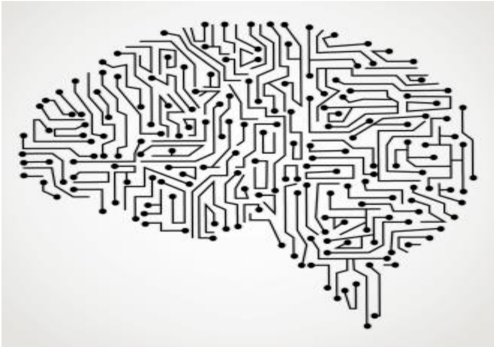


ISSUE # 1

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

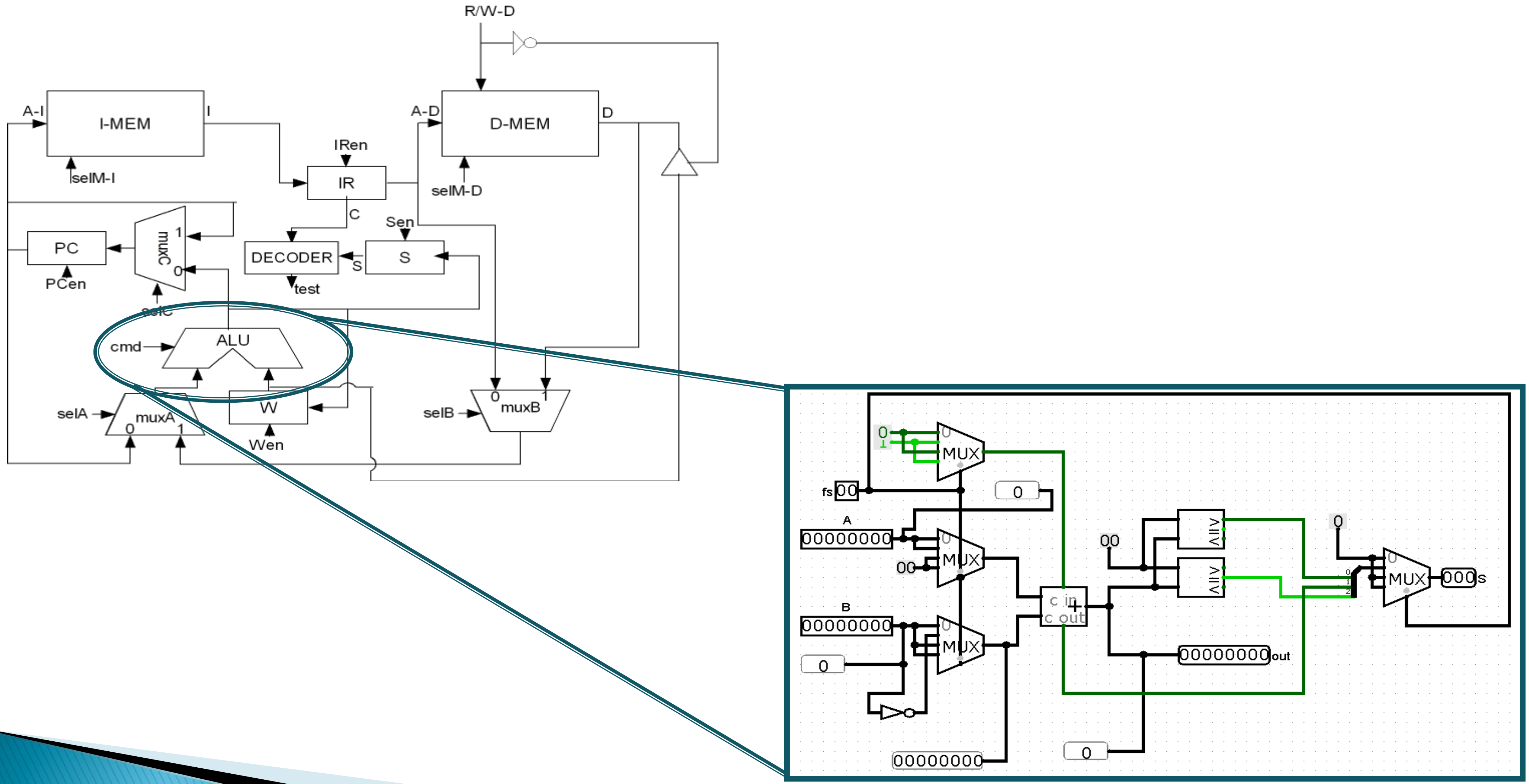
Prof. Dr. Hermann Kopetz

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

The Synchronous Digital Logic Example



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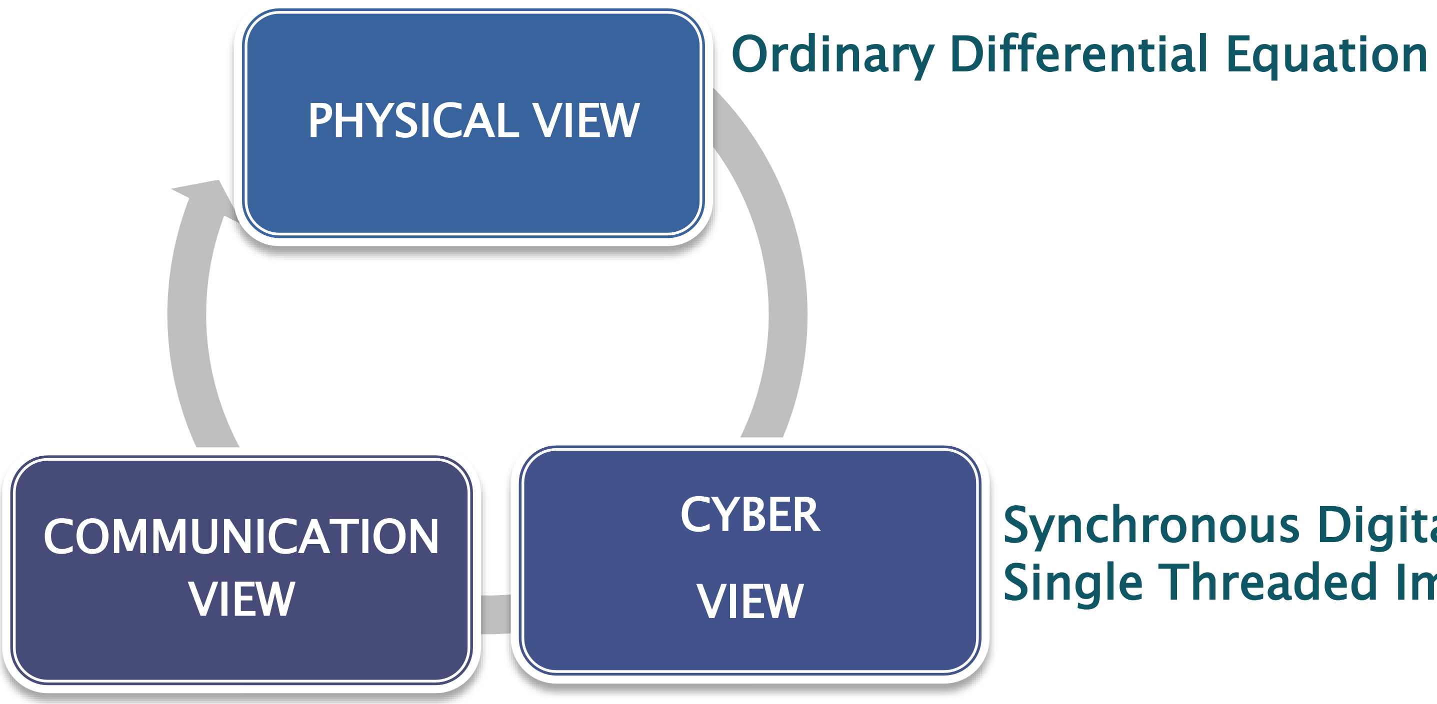
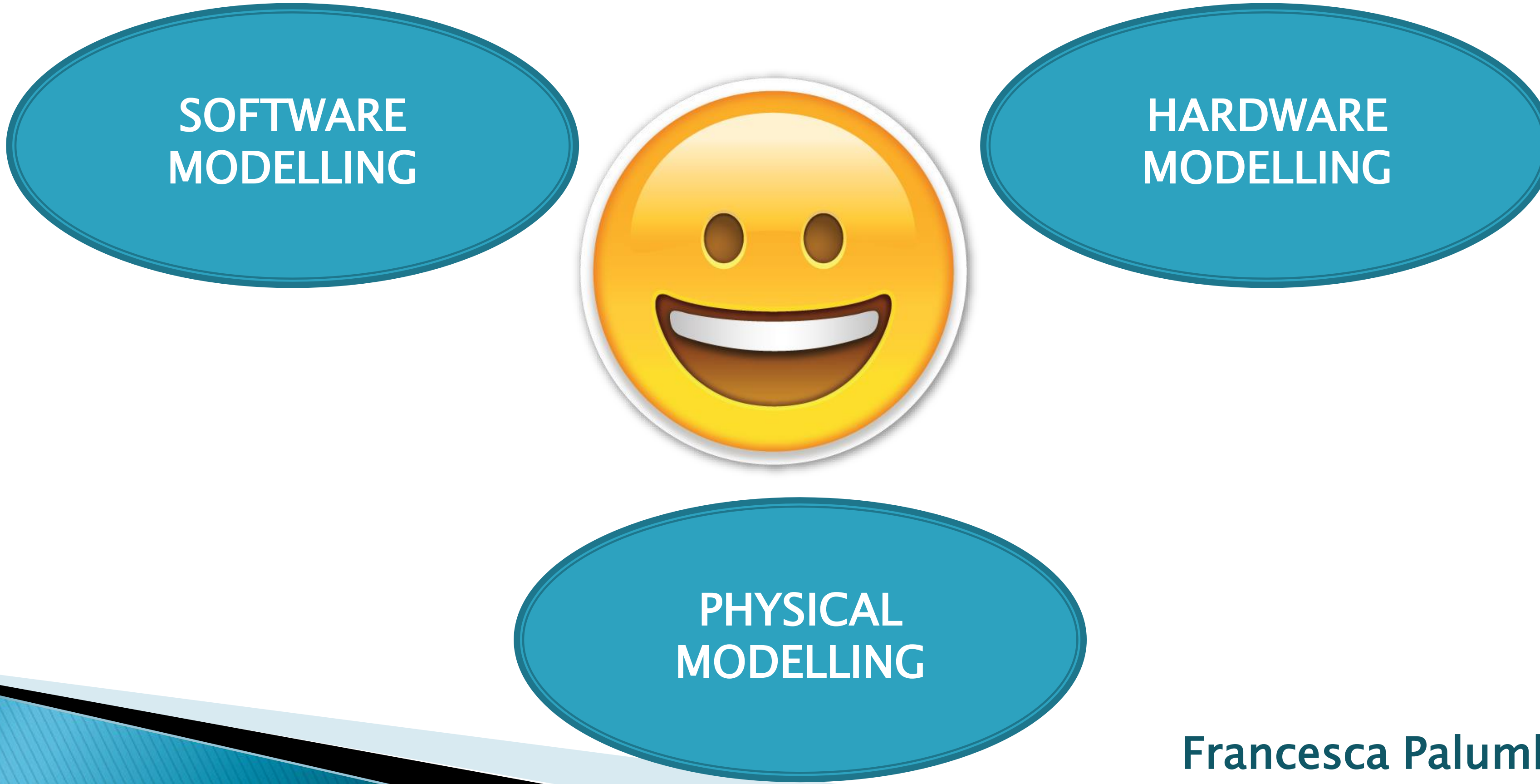
Determinism Issue

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



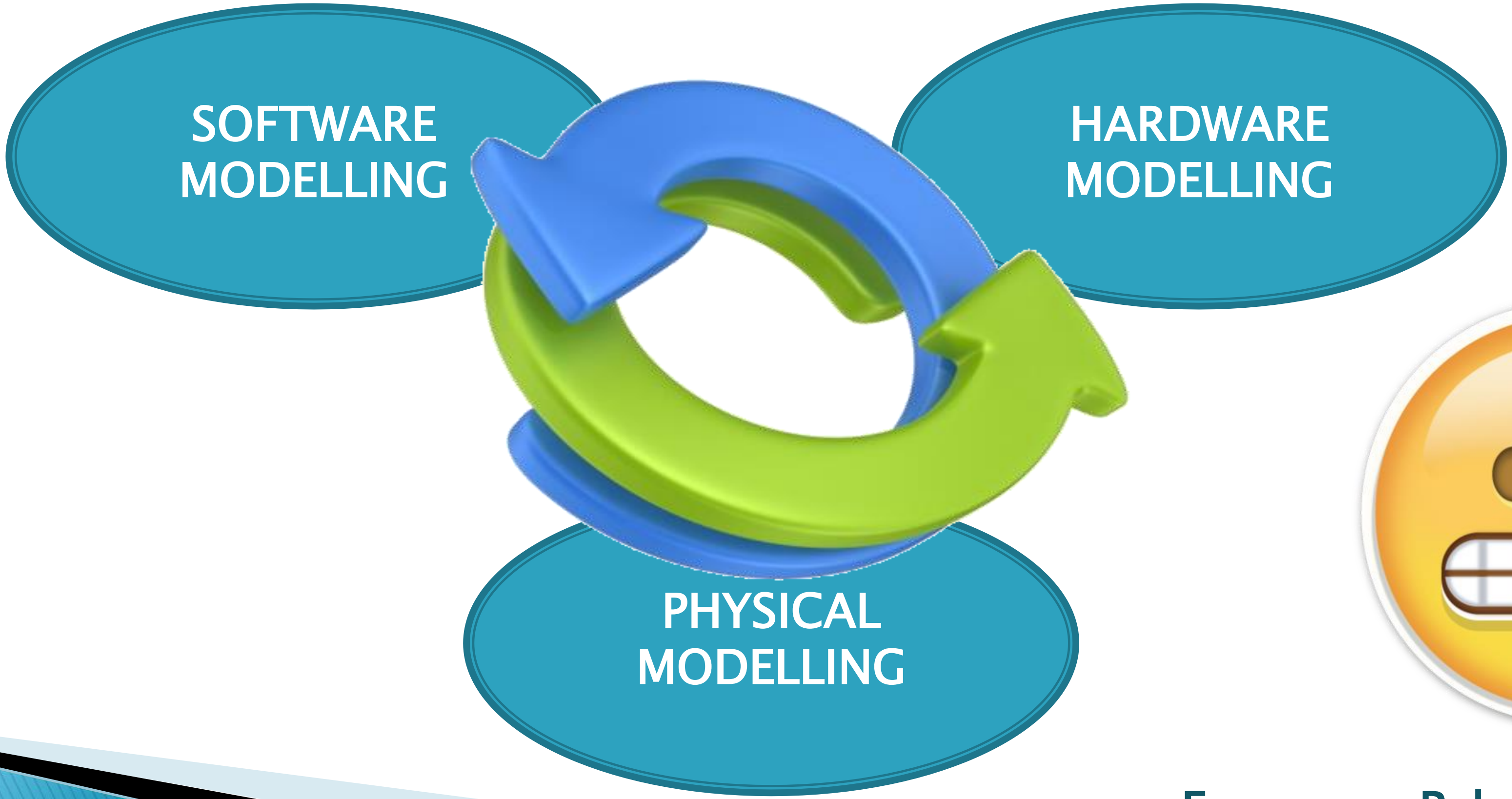
Determinism Issue

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



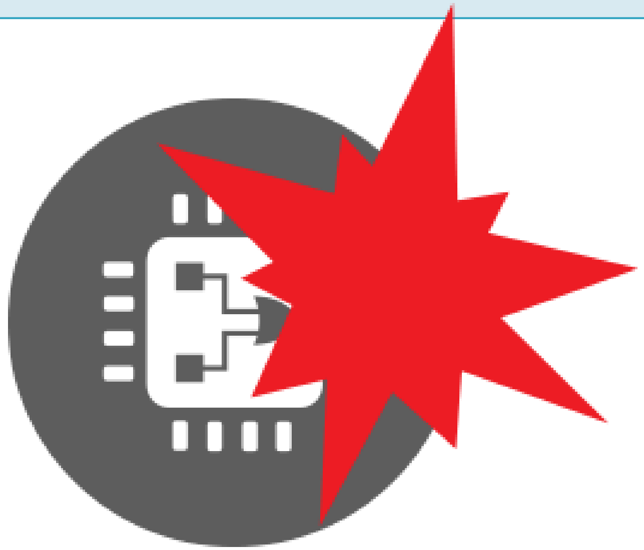
Determinism Issue

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

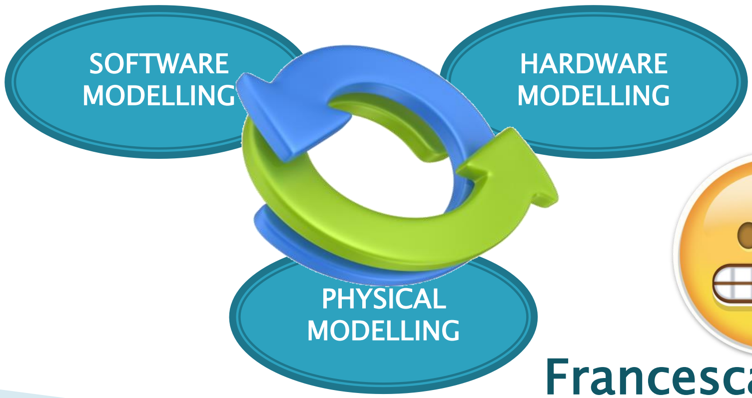


Determinism Issue

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



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



CPS Modelling Nightmare

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

TALKING ABOUT MODELLING AND PROPERTIES

Let's get Physical: Adding Physical Dimensions to Cyber Systems
Alberto Sangiovanni-Vincentelli (University of Berkeley, US)

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Functional & NF Requirements Analysis
Armando Tacchella (University of Genoa, IT)

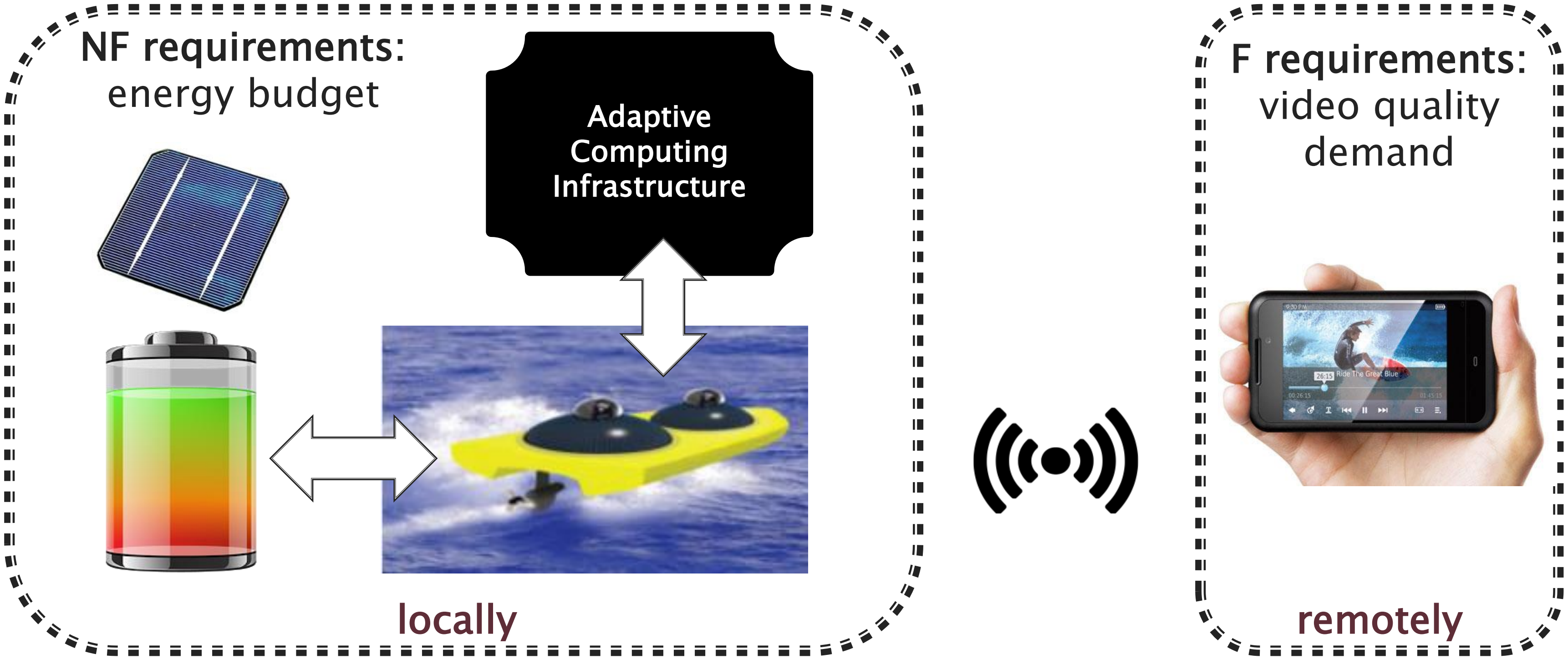
ISSUE # 2
Heterogeneity and Flexibility in CPS

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.



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

Adaptivity Issue

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

EFFICIENT SCHEDULING

TASK MIGRATION

ADAPTIVE PROCESSING

COARSE-GRAINED RECONFIGURATION

FINE-GRAINED RECONFIGURATION

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Adaptivity Issue

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TALKING ABOUT HETEROGENEITY AND ADAPTIVITY

Robust Heterogeneous Computing for CPS
Muhammad Shafique (TU Wien, AU)

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Software and Hardware for High Performance and Low Power Homogeneous and Heterogeneous Multicore Systems
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Securing CPSs, new challenge or solved problem?
Francesco Regazzoni (ALaRI, CH)

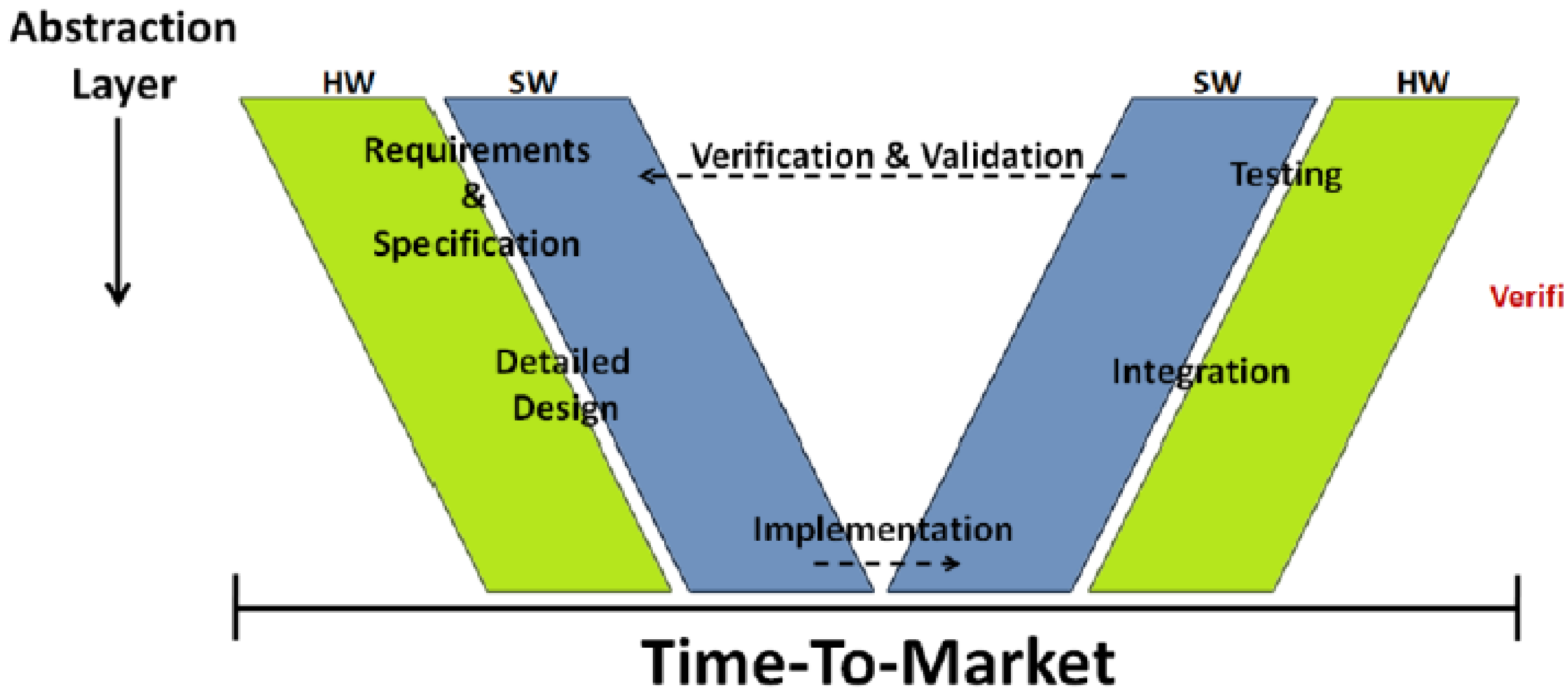
ISSUE # 3

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



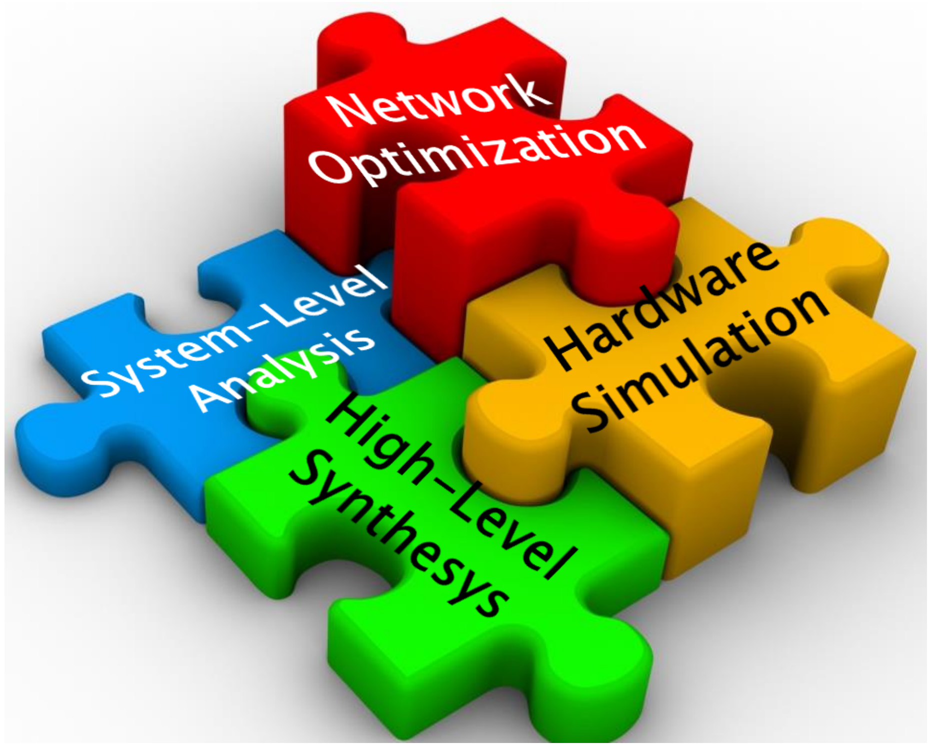
- Separate design, implementation and validation phases
  - long time to market
  - complex HW/SW tuning phase
- Collection of partially integrated toolchains

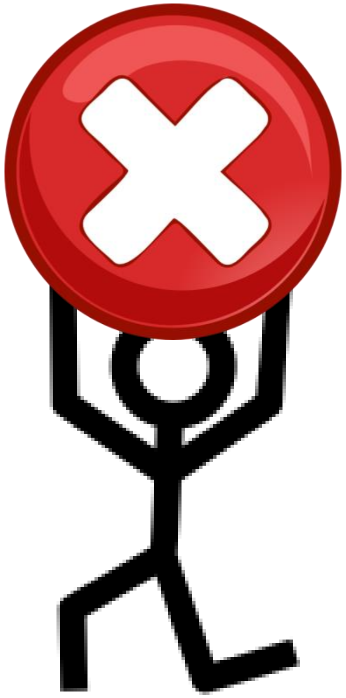
State-of-the-Art Tools

	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





Go for semantic integration rather than for tools combination!

Semantic-oriented Tool Integration

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

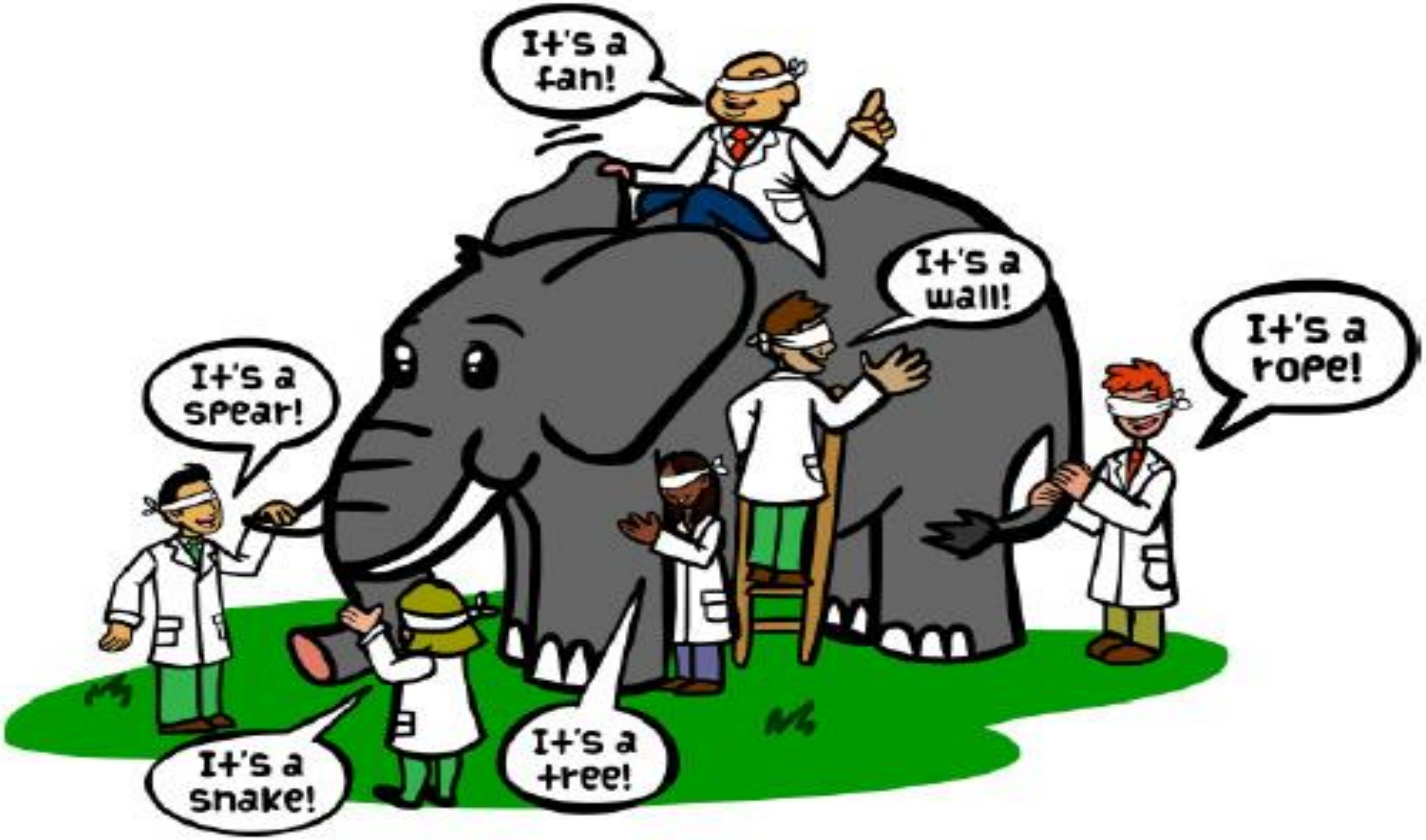
TALKING ABOUT TOOLS

A Contract-Based Design Methodology for Cyber Physical Systems
Alberto Sangiovanni-Vincentelli (University of Berkley, US)
HW/SW Cyber-System modelling tools
Karol Desnos (INSA-Rennes, FR) and Julio De Oliveira Filho (TNO, NL)
High Level Synthesis methods
Jocelyn Serot (Institut Pascal, FR)
From high-level specification down to hardware
Francesca Palumbo (University of Sassari, IT) and Christian Pilato (ALaRI, CH)

HANDS ON DAY
The CERBERO Project tools

THE RECEPY OF SUCCESS
… be open minded!

Blind Man and the Elephant Problem



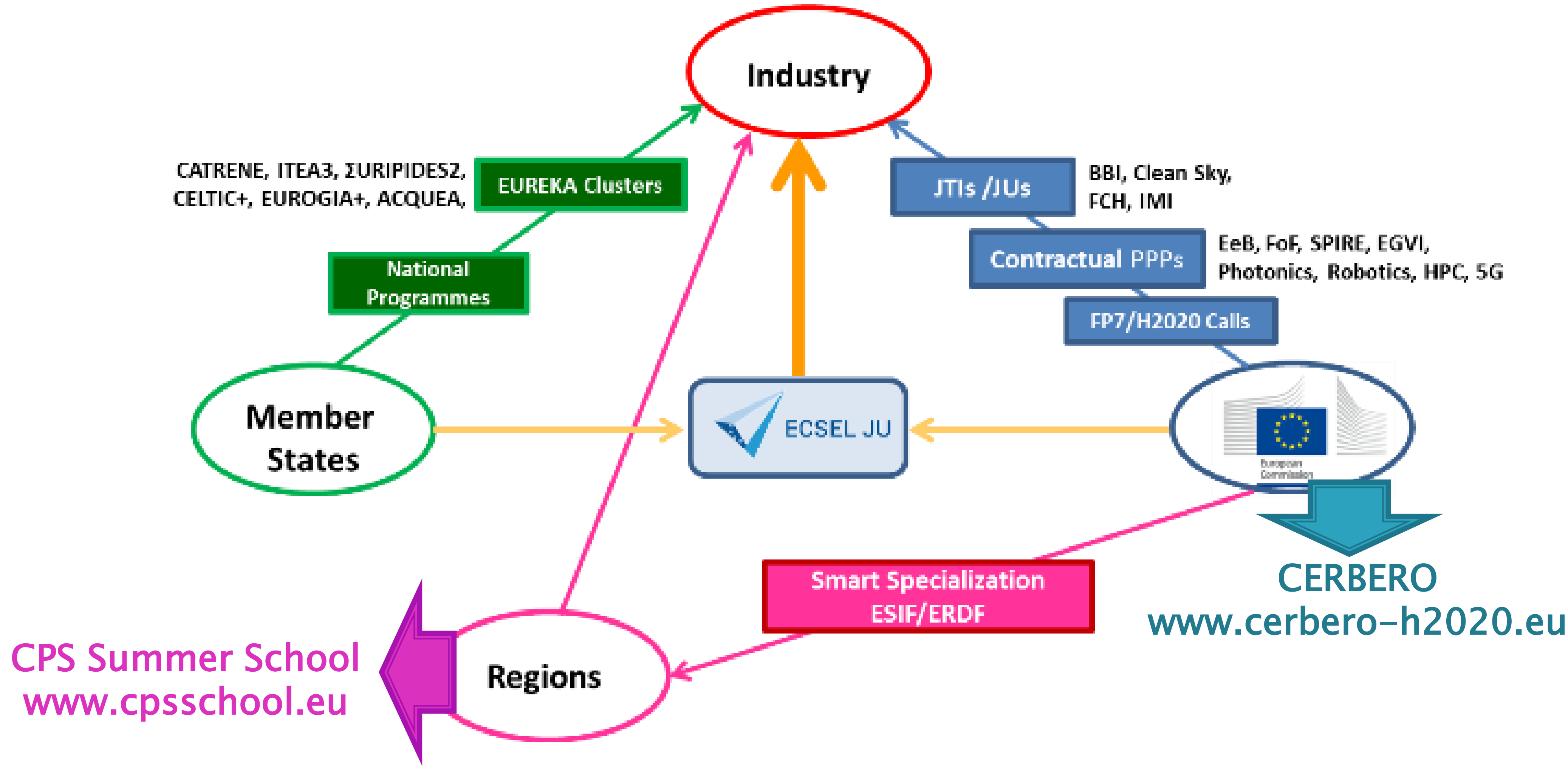
Humans tens to project their partial experiences as the whole truth, ignoring other people's partial experiences.

Integral Approach ...Science!

- Huge mistake in CPS design
  - heterogeneity;
  - multi-vendor, multi-physics and multi-modelling;
  - 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.

Integral Approach ...Funding Programmes!



Francesca Palumbo, UNISS

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
- Modeling Cyber-Physical Systems,
  P. Derler, E. A. Lee, and A. L. Sangiovanni-Vincentelli
  Proceedings of the IEEE, 2011
- Is a Unified Methodology for System-Level Design Possible?,
  A. L. Sangiovanni-Vincentelli
  IEEE Design & Test of Computers, 2008