

# Cyber-Physical Systems

## a short introduction

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CUSO Winter School in Computer Science

Modelling of knowledge and the cyber-physical systems

5 – 9 February 2018  
Champéry, Switzerland



# Working Definition of Cyber-Physical Systems



CPS are engineered systems where functionality and salient characteristics emerge from the networked interaction of computational and physical components



Janos Sztipanovits  
(Model Integration Languages)

Term coined around 2006 and tended by “instigators”: Gill, Kumar, Lee, Midkiff, Mok, Rajkumar, Sastry, Sha, Shin, Stankovic, Sztipanovits.

# CPS consist of

- software components
- physical components
- network components

## often interacting with

- a highly-uncertain environment
- including human actors

Based on the recognition that convergence in engineered systems in -

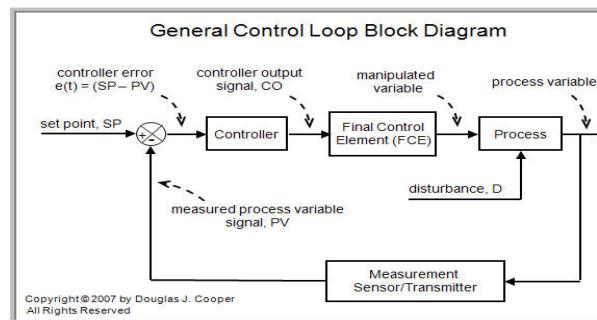
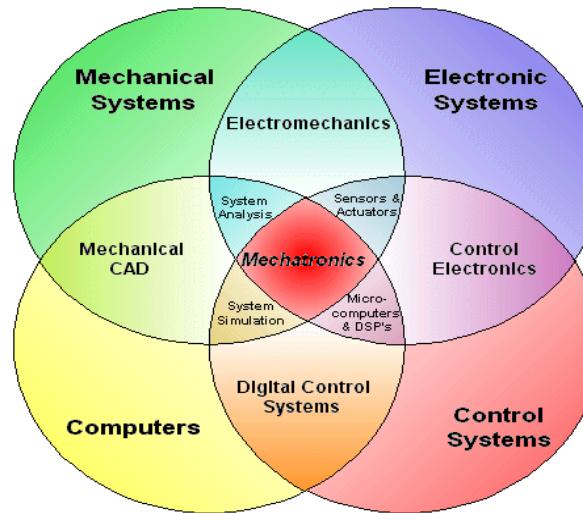
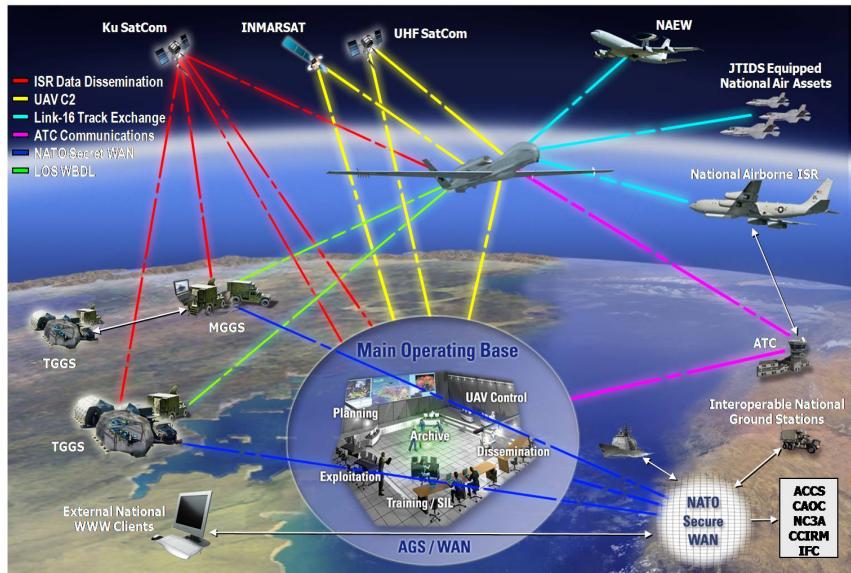
Network	Software	Control	Systems
<p>Model-based Design</p>			

is deeper than an interdisciplinary approach would enable



# CPS is engineering (but foundations of), not science: medicine, biology, physics, ...

Beyond:  
embedded systems  
mechatronics  
control theory  
networks  
systems of systems



**potential:**  
- deal with complexity  
- radically new designs (DSE)

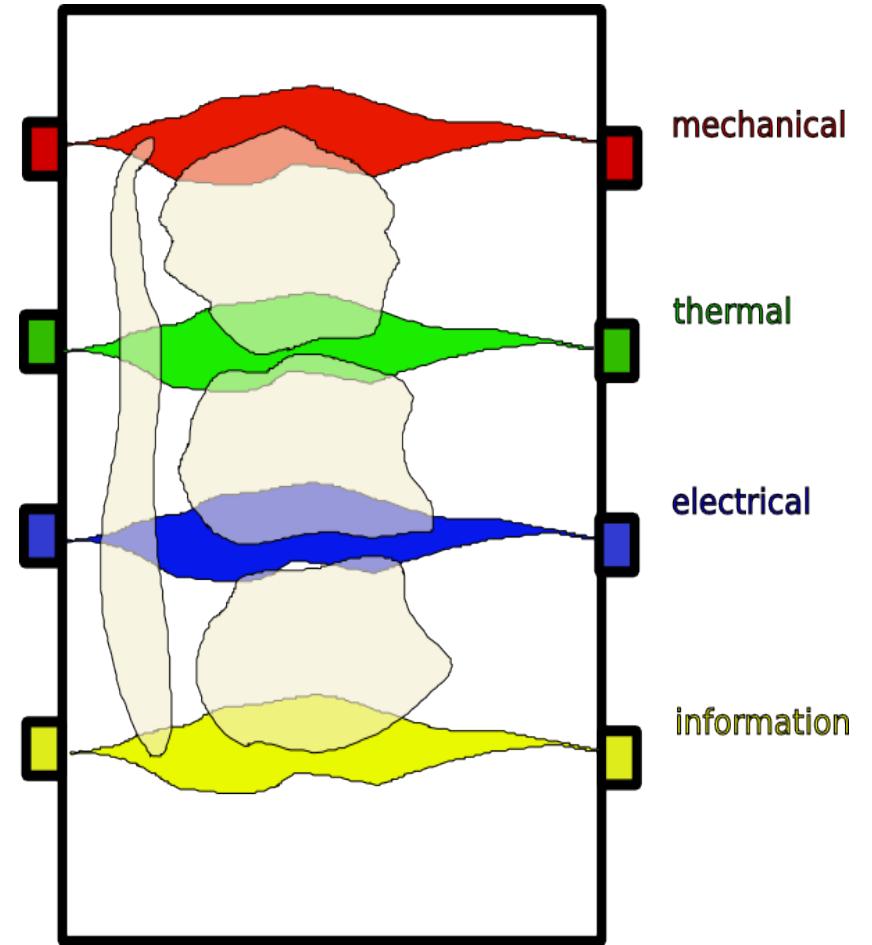
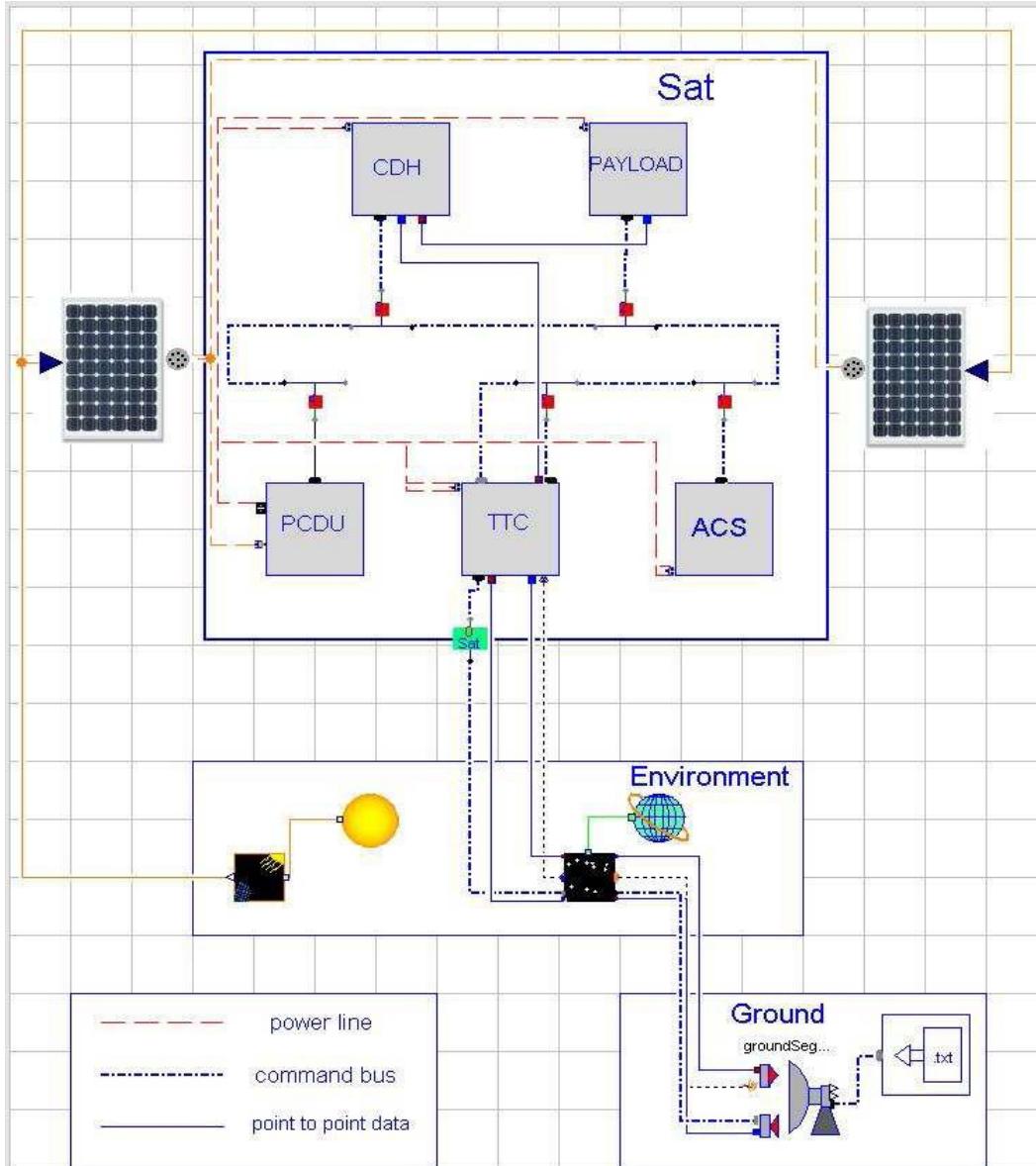
# Typical CPS: networked car



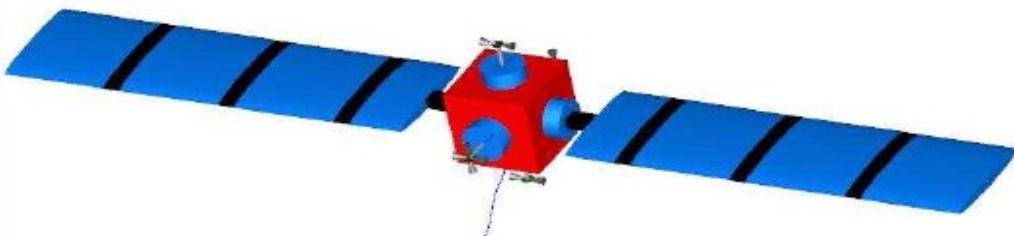
# Typical CPS: smart city (incl. building automation)



# Typical CPS: satellite systems

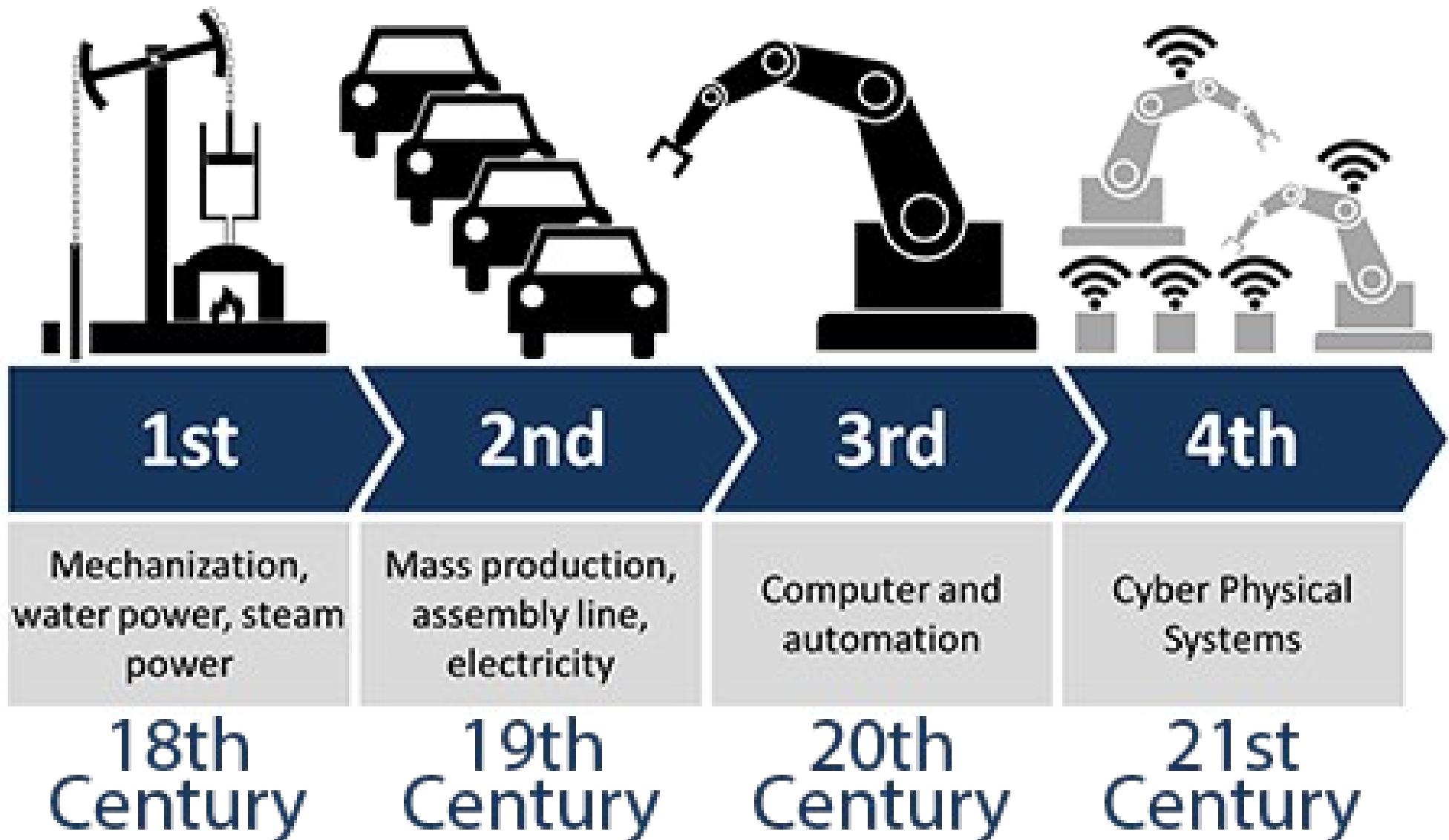


- Encapsulate interactions
- Evolution



the European (German) answer to US initiatives:

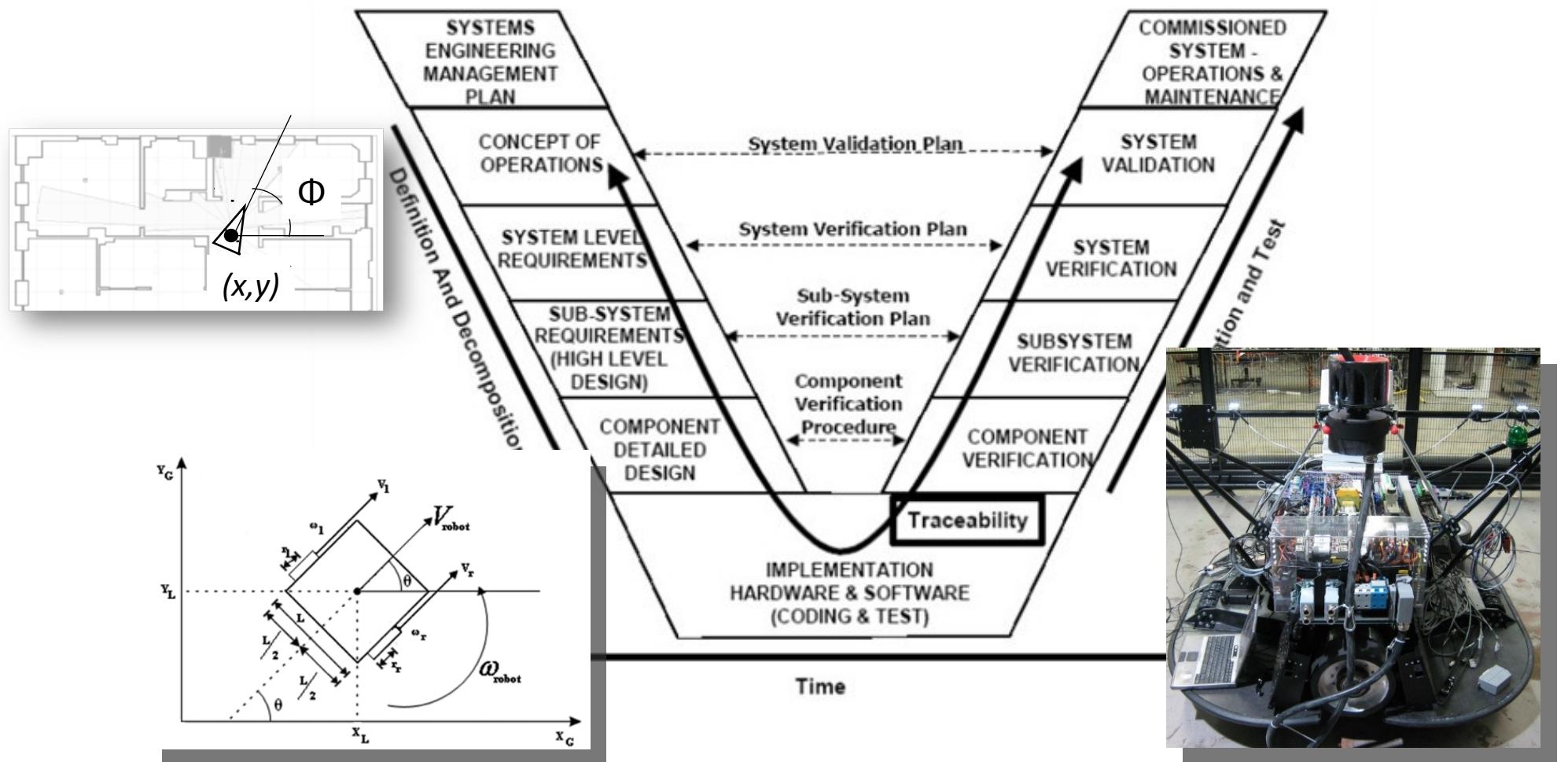
## Industry 4.0



# The Industry 4.0 Vision

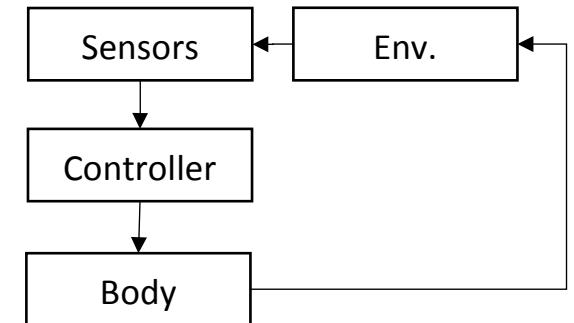
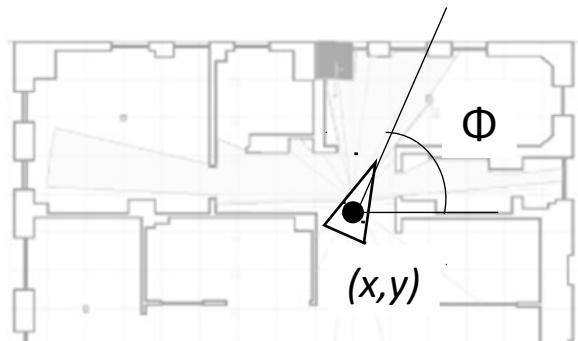
Virtual Design, Build, Operation, and Maintenance  
(possibly in a high-autonomy setting)

# Virtual Design/Implement/Test/...

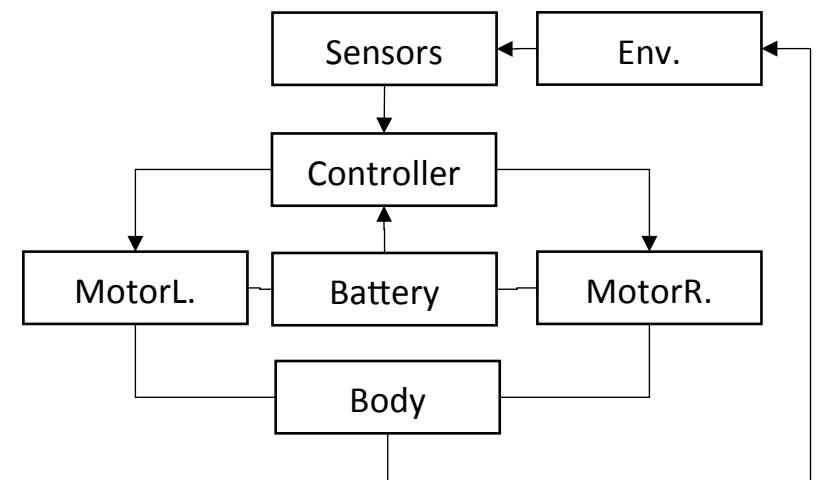
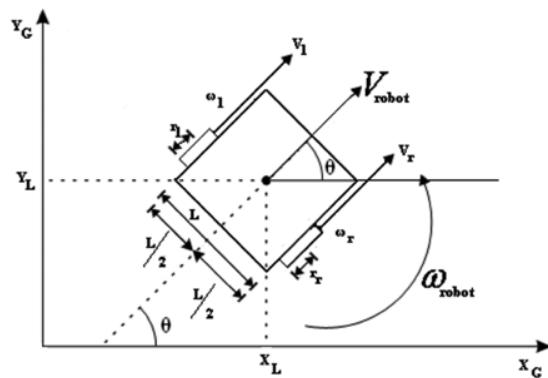


# Virtual Design

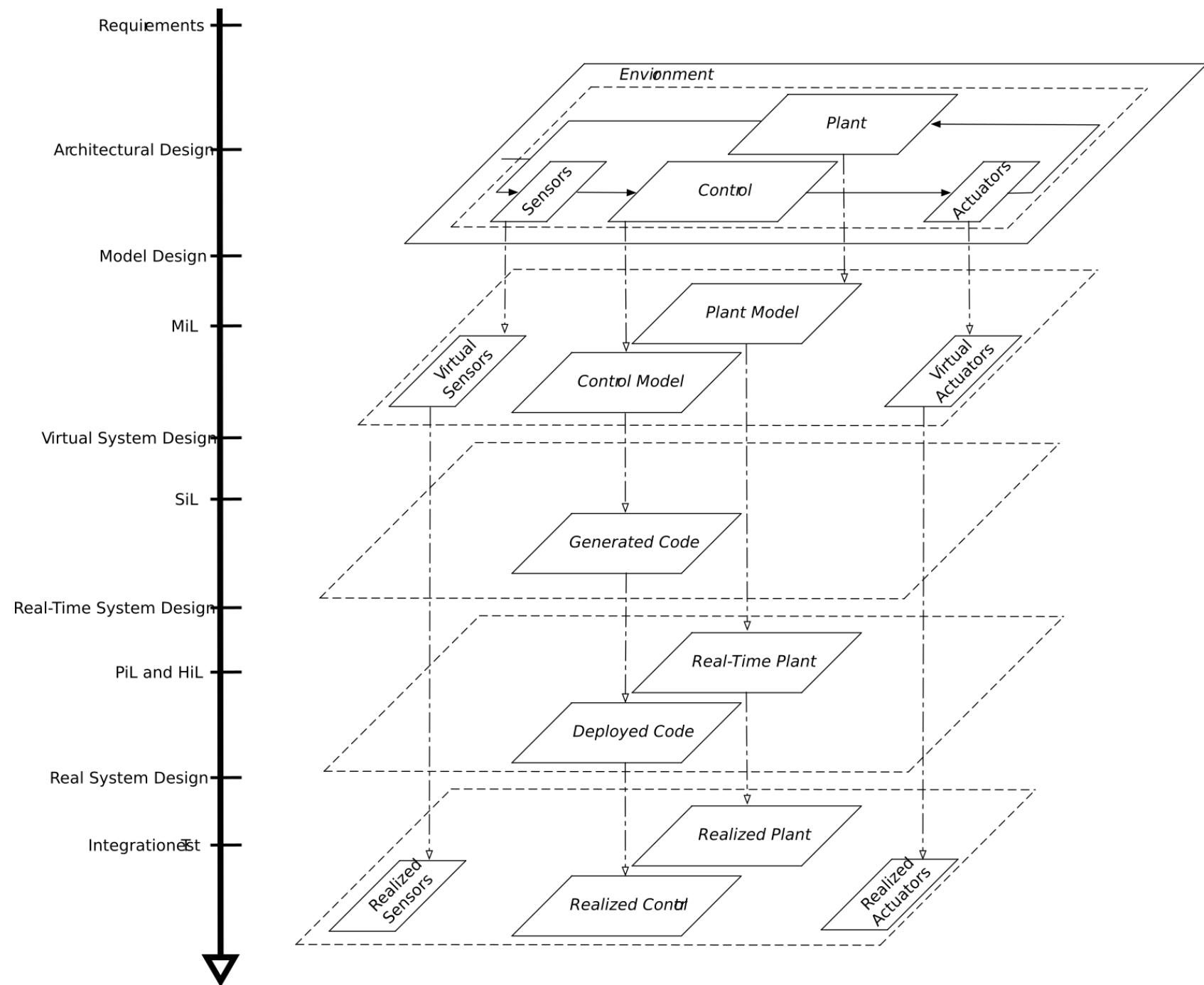
frequent full system evaluation

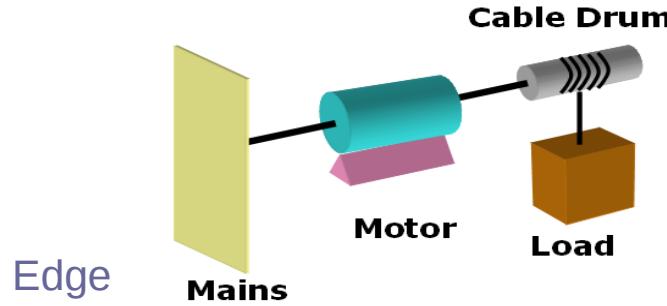


...at multiple levels of refinement

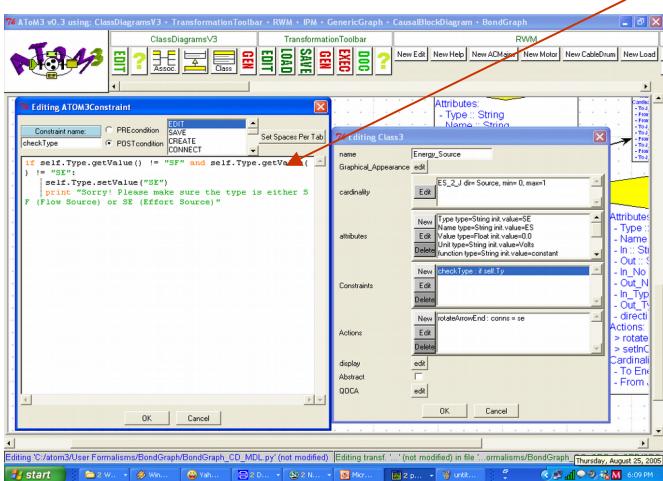
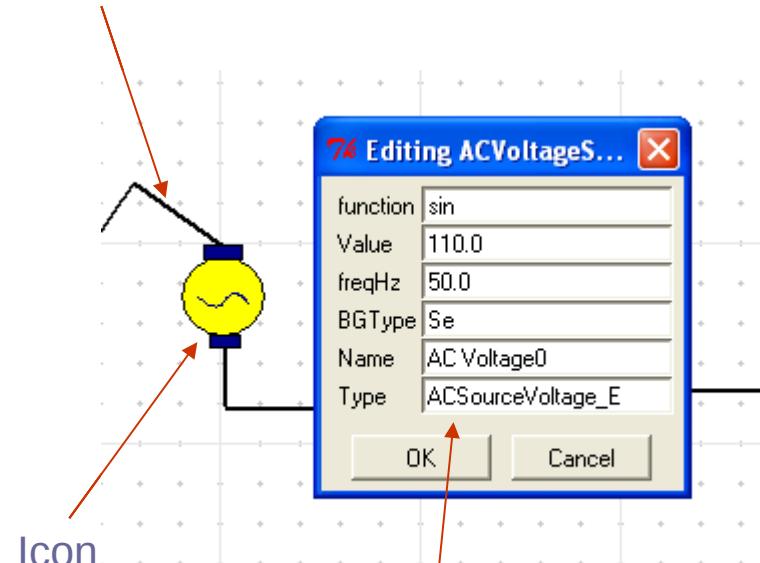


# XiL: X = Model, Software, Processor, Hardware



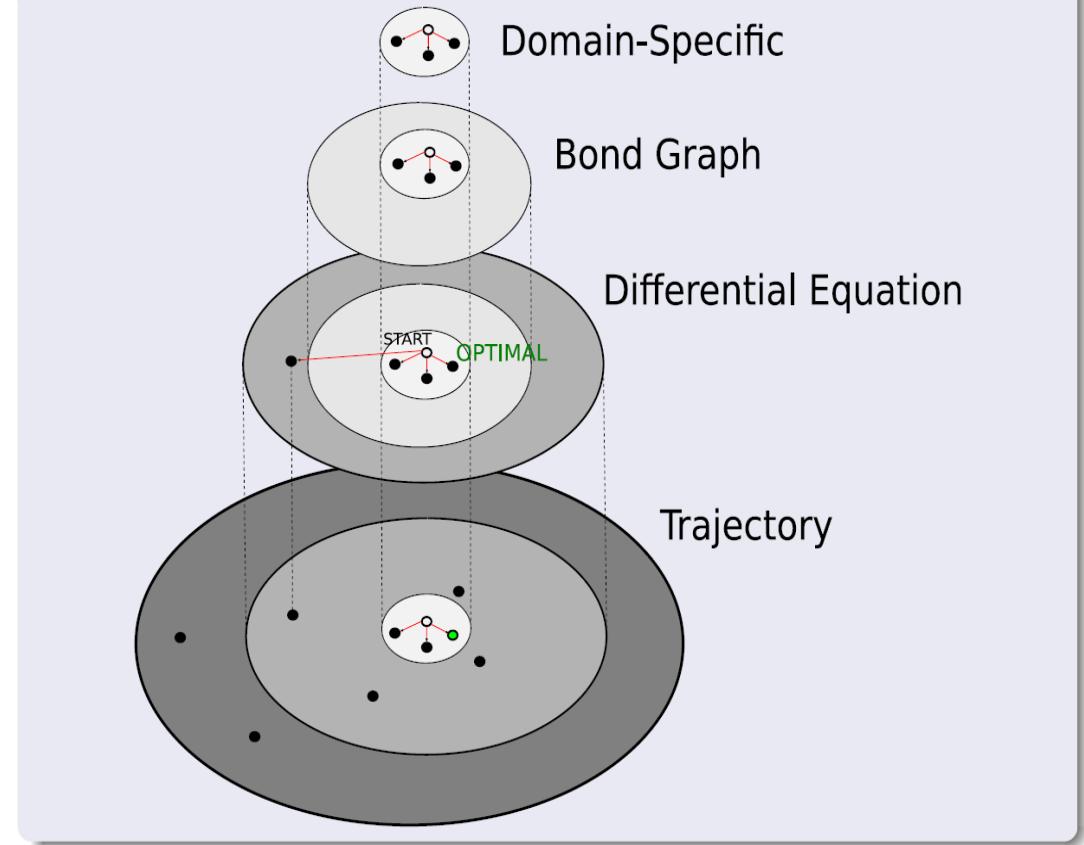


Edge



- modelling of **physical systems**
- domain-specific **design-space exploration** based on evolutionary algorithms

## Design-Space Exploration



Sagar Sen and Hans Vangheluwe. Multi-domain physical system modeling and control based on meta-modeling and graph rewriting. In Computer Aided Control Systems Design (CACSD) , pages 69 - 75, Munich, Germany, 2006. IEEE.

Joachim Denil, Maris Jukss, Clark Verbrugge, and Hans Vangheluwe. Search-Based Model Optimization using Model Transformations. In System Analysis and Modeling: Models and Reusability (SAM), Valencia, Spain , volume 8769 of LNCS, pages 80-95. Springer, 2014.

# Virtual Build

[1] <http://www.partsim.com/>

Online Circuit Simulator X

www.partsim.com/simulator/#78462

Fre Antwerp Login Fin Utils Articles ToRead Repos PhdPositions Jobs Esquilha EstagiosEsquilha PhdVenues Flights Altitude atompm

PartSim DEMO Differential Amplifier (work will not be saved)

Subcircuit Report Transient Analysis BOM

Project Save Save As New Open Spice Run Models Output Export Netlist Share Print Edit Cut Copy Paste Delete History Undo Redo Insert Textbox

Components Probes

Search Parts

Fairchild Semiconduc... 50  
IXYS 17  
Infineon Technologies 107  
N-Channel MOSFETs 107  
Maxim IC 1,082  
Microchip 53  
Nichicon 48  
On Semiconductor 20  
Vishay 74

AUTOMATION AND INDUSTRIAL CONTROL

COMPUTER AND OFFICE PRODUCTS

ELECTRICAL AND ELECTRONIC COMPONENTS

ELECTROMECHANICAL

107 Results

IPP60R160P6XKSA1 MOSFET N-CH 600V TO2...

Category Infineon Technologies  
Subcategory N-Channel MOSFETs  
Section VENDOR PARTS  
Description MOSFET N-CH 600V TO220-3  
Name IPP60R160P6XKSA1  
Manu Infineon

SINE ( 0 -100m 40Hz )

SINE ( 0 100m 500Hz )

15V

V1

TR1

2N2222

R1 1K

Vout

TR2

2N2222

V2

R2 1K

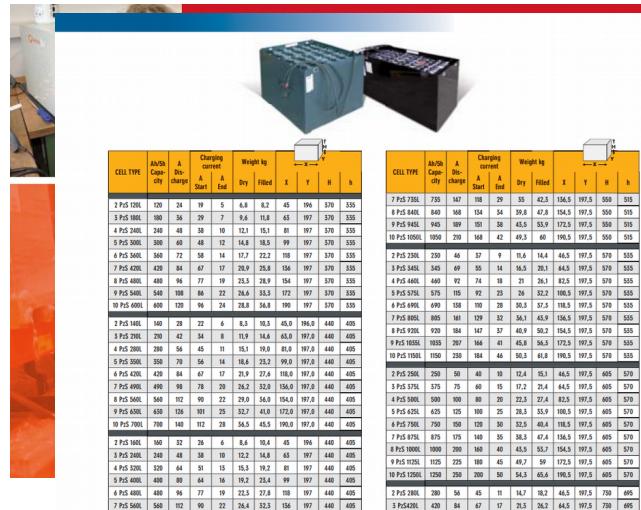
Re

R3 1K

R4 1K

# Virtual Build

Frequent full system evaluation  
...at any level of refinement



...using multiple suppliers

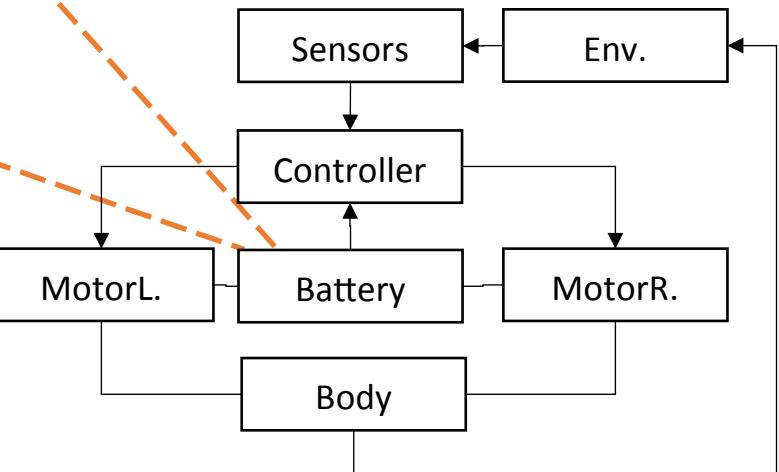
1IG6, 1GH6, 1Hs  
Size 225

**BALDOR**  
A MEMBER OF THE ABB GROUP

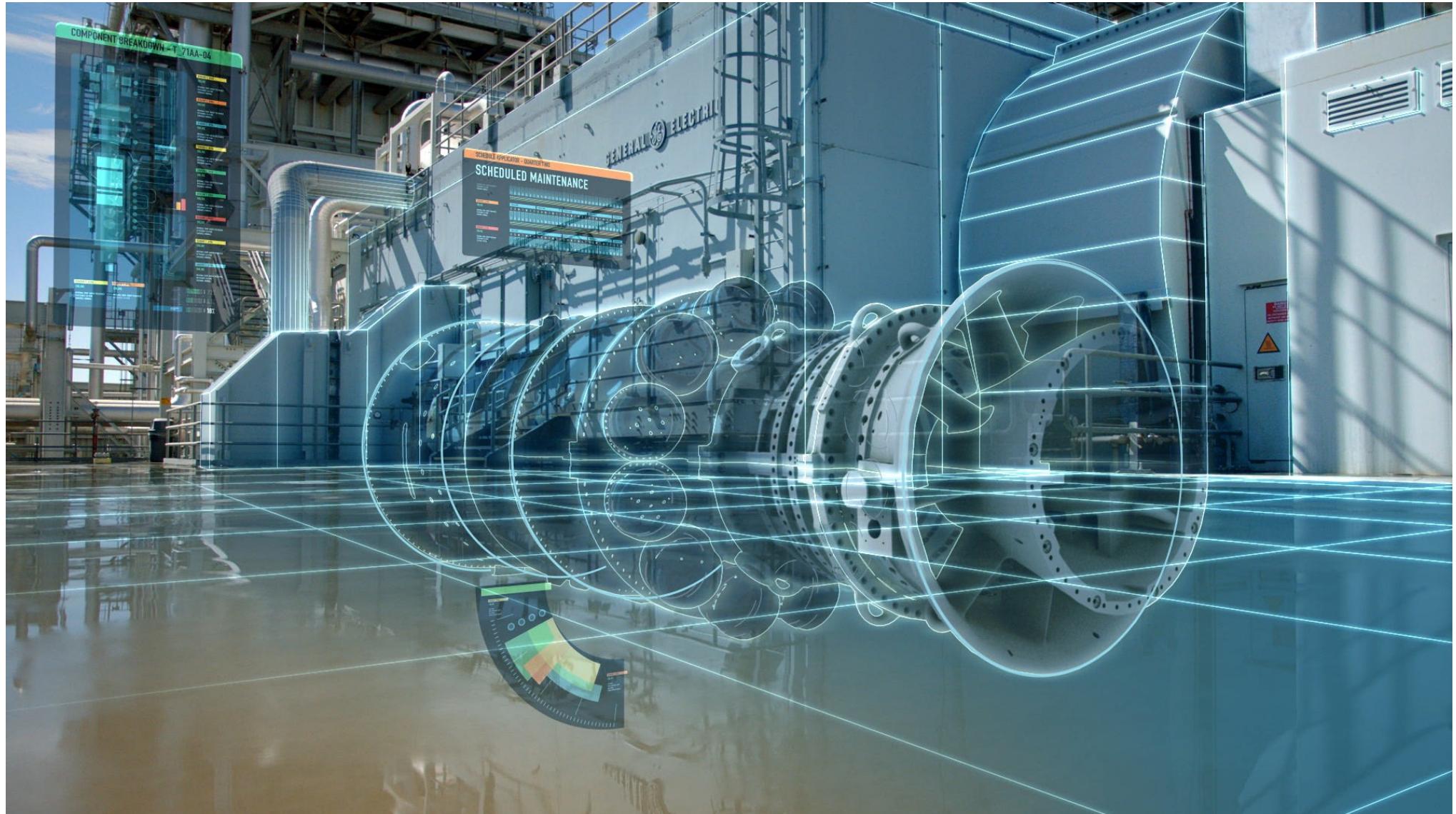
**Performance Data**

**TENV & TEFC PMDC Motors\***

HP	RPM	NEMA Frame	Enclosure	Arm Volts	Full Load Amps	Rated Torq-Amps
1/4	1750	56C	TENV	CDP3110	90	2.5
1/4	1750	56C	TENV	CDP3200	190	1.3
1/4	1750	56C	TEFC	CDP3203	190	1.2
1/3	1750	56C	TENV	CDP3216	180	1.6
1/2	1750	56C	TENV	CDP3330	90	4.8
1/2	1750	56C	TENV	CDP3201	190	2.5
1/2	2500	56C	TENV	CDP3203	190	2.0
3/4	1750	56C	TEFC	CDP3440	90	7.6
3/4	1750	56C	TEFC	CDP3436	180	3.7
3/4	2500	56C	TEFC	CDP3440	90	7.5
1	1750	56C	TEFC	CDP3445	90	10.0
1	1750	56C	TEFC	CDP3455	180	5.0
1	2500	56C	TEFC	CDP3450	90	9.7
1	2500	56C	TEFC	CDP3460	180	4.9
1-1/2	1750	145TC	TEFC	CDP3575	180	7.7
1-1/2	2500	145TC	TEFC	CDP3590	180	7.0
2	1750	145TC	TEFC	CDP3685	180	9.6
2	2500	145TC	TEFC	CDP3600	180	10.0
3	1750	145TC	TEFC	CDP3693	180	11.0
3	1750	180C	TEFC	CDP3904	180	14.0
3	1750	180C	TEFC	CDP3905	180	9.0
6	1750	180IGTC	TEFC	CDP3655	180	21.6
6	1750	180IGTC	TEFC	CDP3675	180	15.0
Explosion Proof PMDC Motors						
1/4	1750	56C	TEFC	CDP3410	90	2.7
1/4	1750	56C	TEFC	CDP3406	180	1.3
1/3	1750	56C	TEFC	CDP3420	90	3.6
1/3	1750	56C	TEFC	CDP3411	190	1.7
1/2	1750	56C	TEFC	CDP3420	190	2.2
1/2	1750	56C	TEFC	CDP3426	180	2.5
3/4	1750	56C	TEFC	CDP3440	90	7.0
3/4	1750	56C	TEFC	CDP3445	180	3.5
1	1750	56C	TEFC	CDP3455	90	10.0
1	1750	56C	TEFC	CDP3465	180	4.9
1	1750	145TC	TEFC	CDP3575	180	7.1
1-1/2	1750	145TC	TEFC	CDP3640	180	1.1
18-25	1750	D71D	TENV	VP7424D	180	1.3
25-33	1750	D71D	TENV	VP3311D	180	1.3
37-5	1750	D71D	TENV	VP3316D	180	1.6
37-5	1750	D71D	TENV	VP3320D	180	2.5
IEC Standard Frame PMDC Motors						



# Virtual Operation the “digital twin”



[1] <http://www.power-technology.com/features/featuredigital-twin-the-living-breathing-and-failing-virtual-power-plant-5742648/>

# Virtual Operation

valuation  
refinement  
suppliers



[1] Dávid, I., Meyers, B., Vanherpen, K., Van Tendeloo, Y., Berx, K., & Vangheluwe, H. (2017). Modeling and Enactment Support for Early Detection of Inconsistencies in Engineering Processes. In *2nd International Workshop on Collaborative Modelling in MDE* (p. to appear). Austin, Texas.

[2] Case Study by Kristof Berx , Davy Maes, and Klaas Gadeyne, from Flanders Make

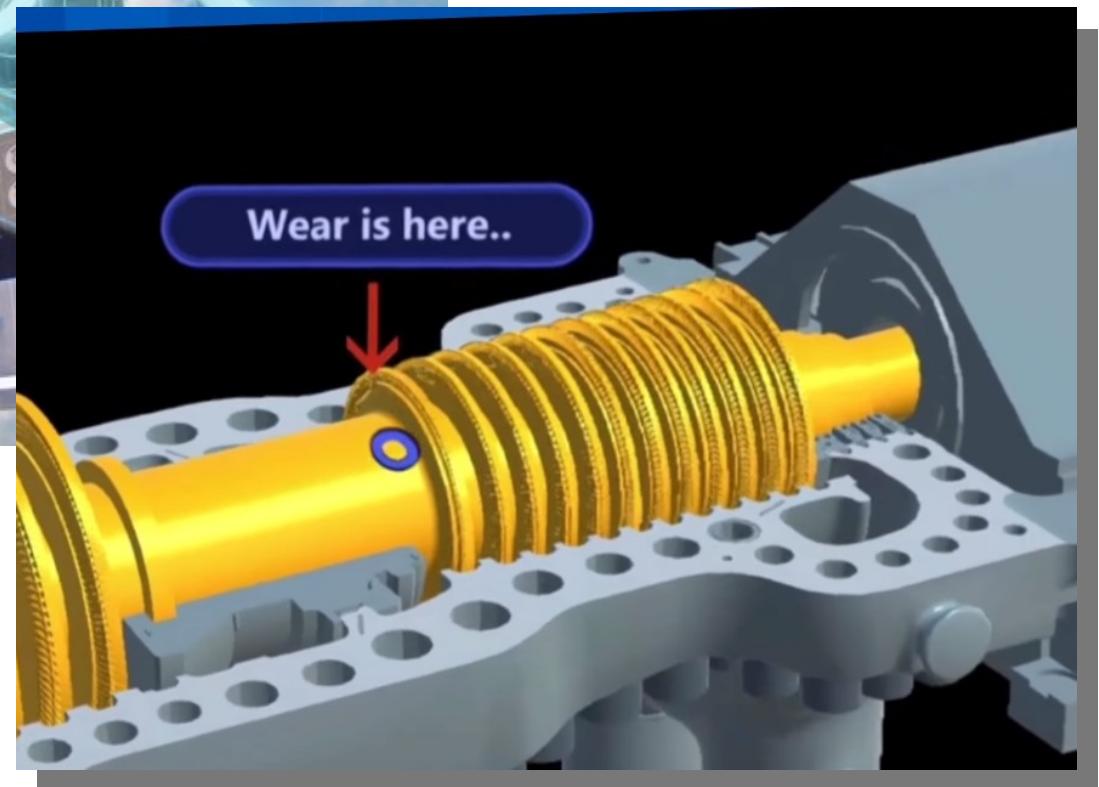
[3] <https://www.virtualis.com/blogs/2013/09/06/germany-s-dlr-turns-to-virtualis-for-cockpit-simulator-upgrade-4/>

[4] Palmieri, M., Bernardeschi, C., & Masci, P. (2017). Co-simulation of semi-autonomous systems: the Line Follower Robot case study. In *1st Workshop on Formal Co-Simulation*. Trento, Italy.

# Virtual Maintenance



[1]



[1] <https://www.fool.com/investing/2016/09/18/what-is-the-industrial-internet.aspx>

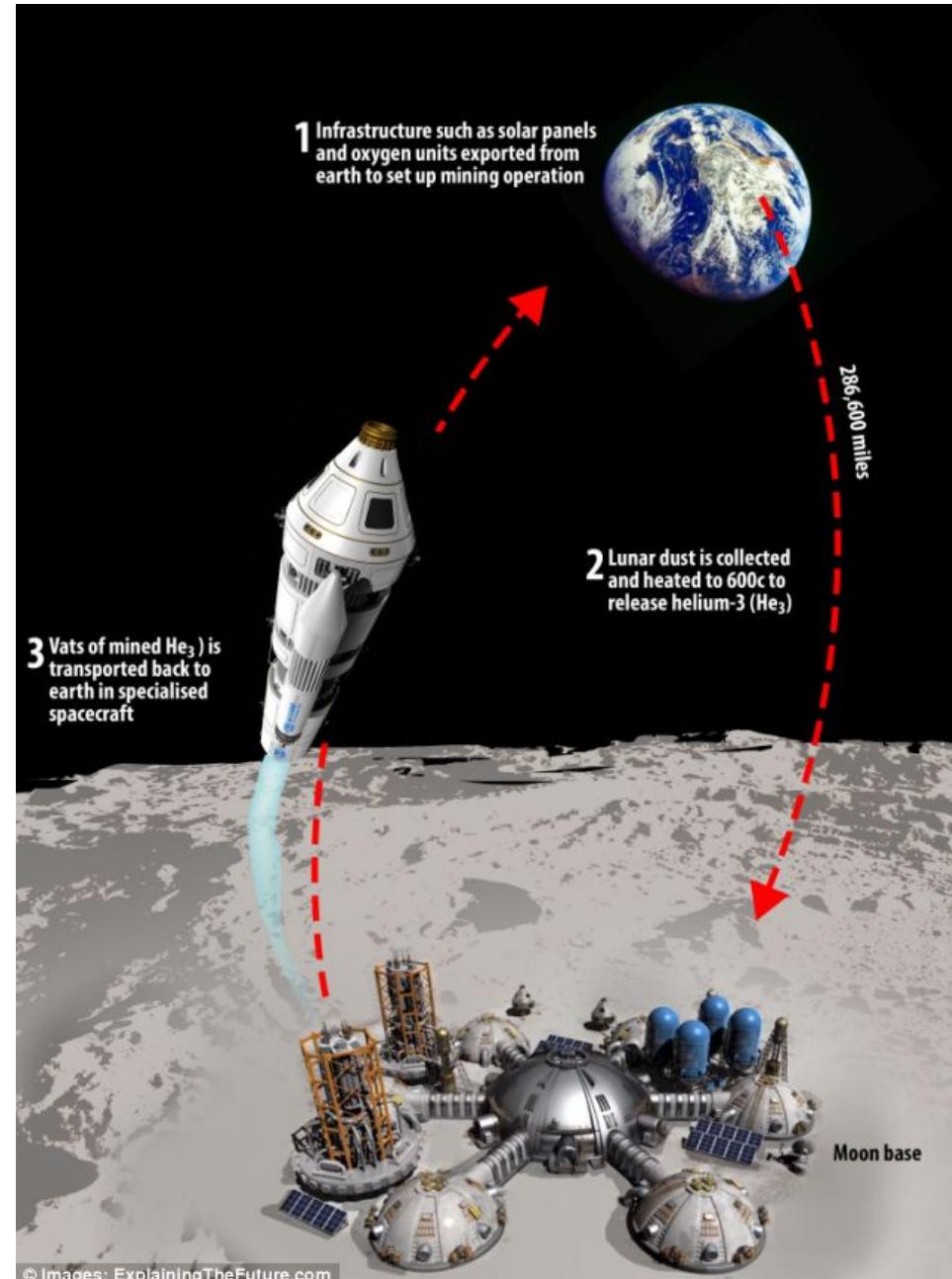
[2] <https://www.youtube.com/watch?v=2dCz3oL2rTw>

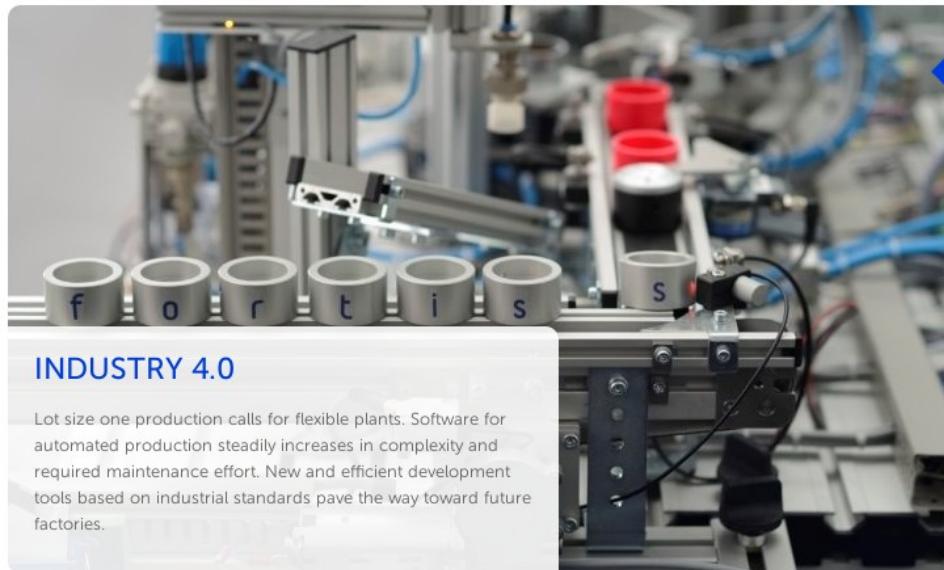
# High Autonomy CPS

→ need “virtual experimentation”

**autonomously**

- construct (often by connecting existing) models for diagnosis, design, ...
- experiment with models





## INDUSTRY 4.0

Lot size one production calls for flexible plants. Software for automated production steadily increases in complexity and required maintenance effort. New and efficient development tools based on industrial standards pave the way toward future factories.

INDUSTRY 4.0

E-MOBILITY

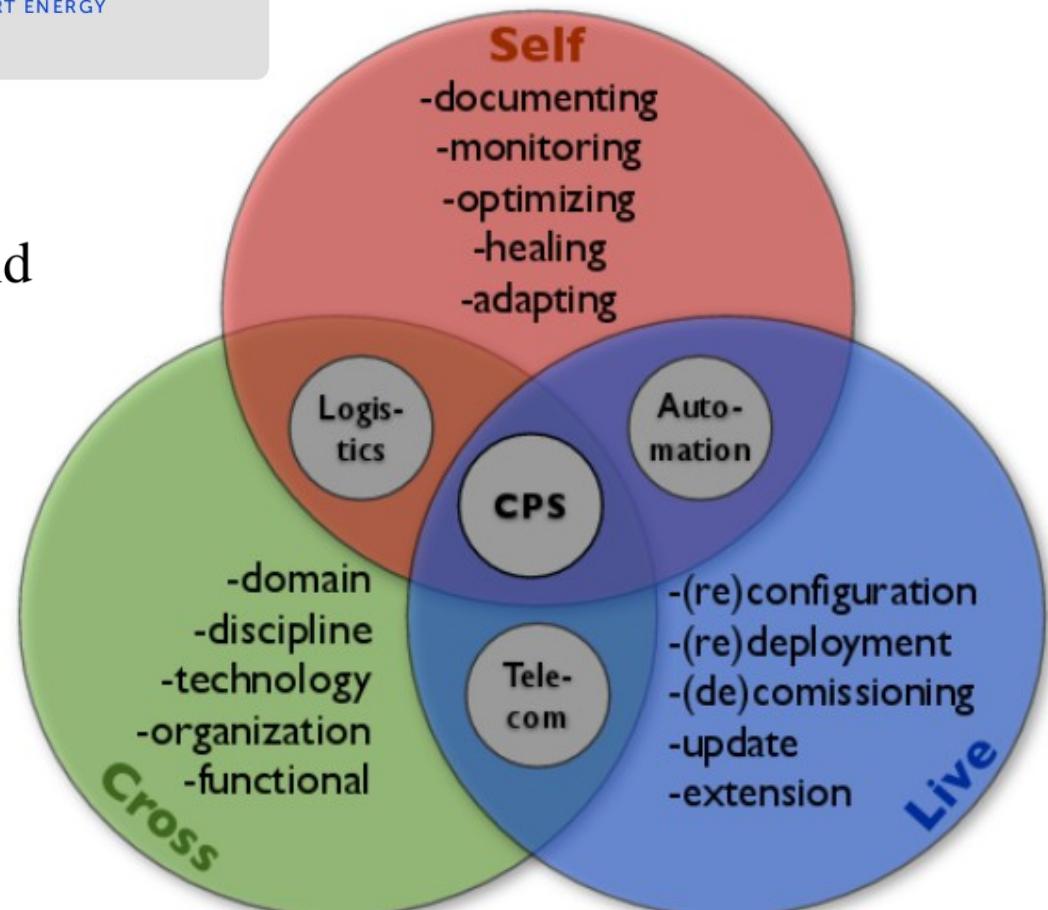
ELECTRONIC CIVIL SERVICES

ROBOTICS

SMART ENERGY

# The Role of Models in Engineering of Cyber-Physical Systems – Challenges and Possibilities

Bernhard Schätz, fortiss GmbH  
schaetz@fortiss.org



## Virtual Product



# MODEL EVERYTHING!

## Multi-Paradigm Modelling (MPM)

at the most appropriate **level(s) of abstraction**  
using the most appropriate **formalism(s)**  
**explicitly modelling processes**

Enabler: (domain-specific) modelling language engineering,  
including model transformation



**Simulation in Europe**



ESPRIT Basic Research Working Group 8467  
Simulation for the Future: New Concepts, Tools and Applications

Keywords:

simulation technologies, multi-paradigm modelling, solvers, standards, interoperability, industrial deployment, demonstrators, user-simulator interfaces

Pieter J. Mosterman and Hans Vangheluwe.  
Computer Automated Multi-Paradigm Modeling:  
An Introduction. *Simulation: Transactions of the Society for Modeling and Simulation International*, 80(9):433- 450, September 2004.  
Special Issue: Grand Challenges for Modeling and Simulation.



