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.

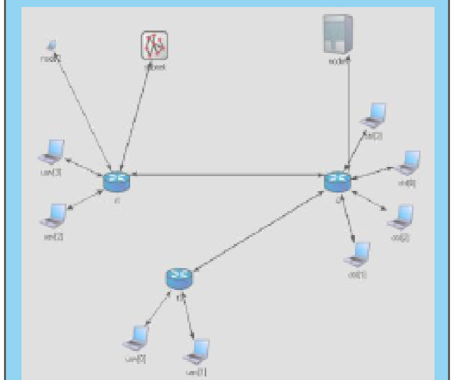
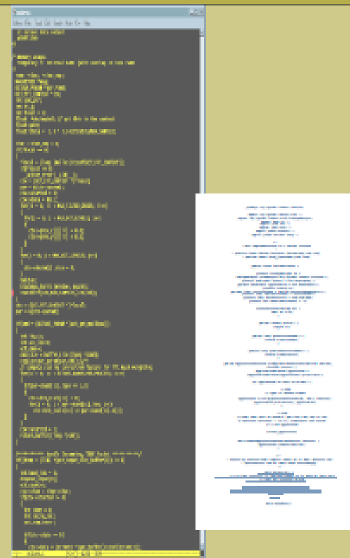
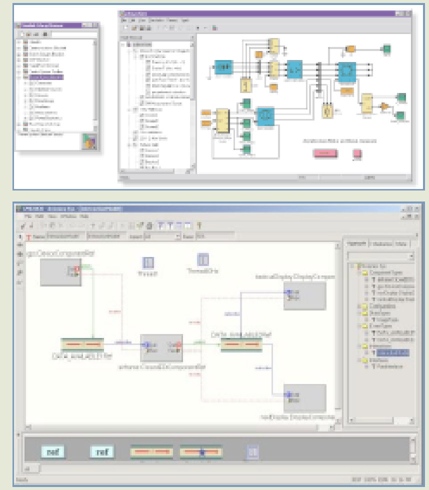
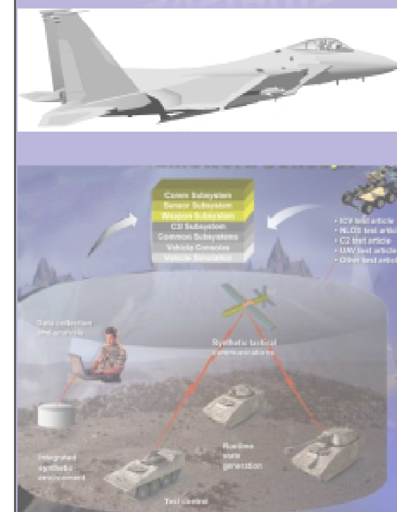
CPS consist of

- 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 -

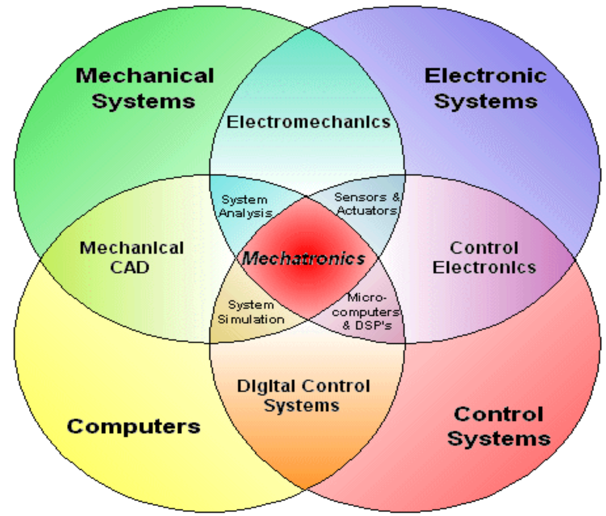
Network	Software	Control	Systems
			

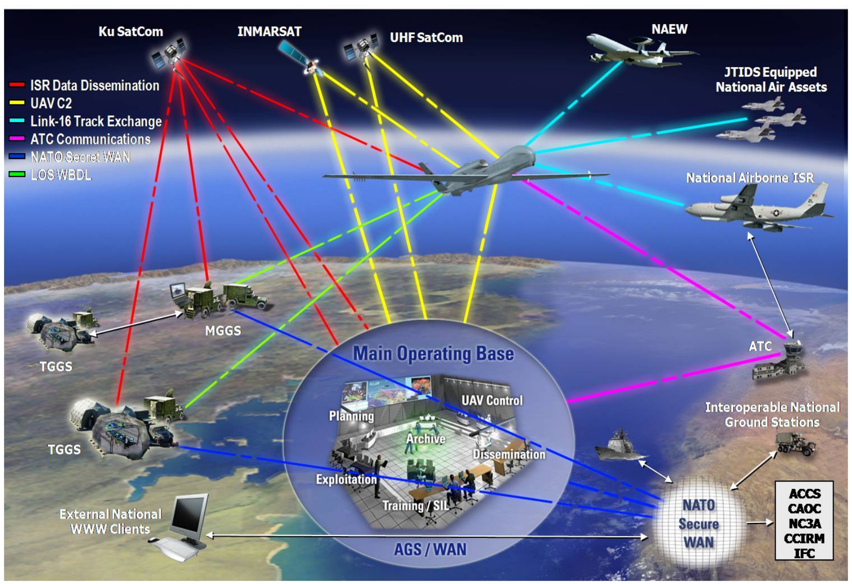
Model-based Design

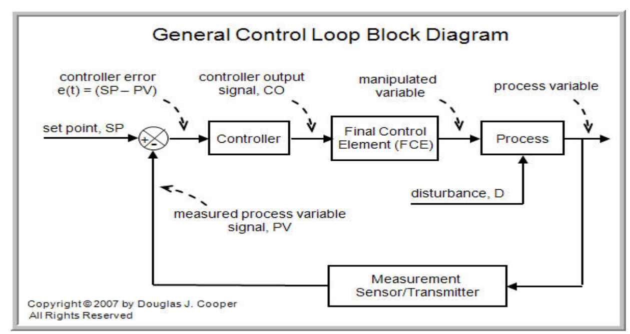
is deeper than an interdisciplinary approach would enable

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

Beyond:
- embedded systems
- mechatronics
- control theory
- networks
- systems of systems





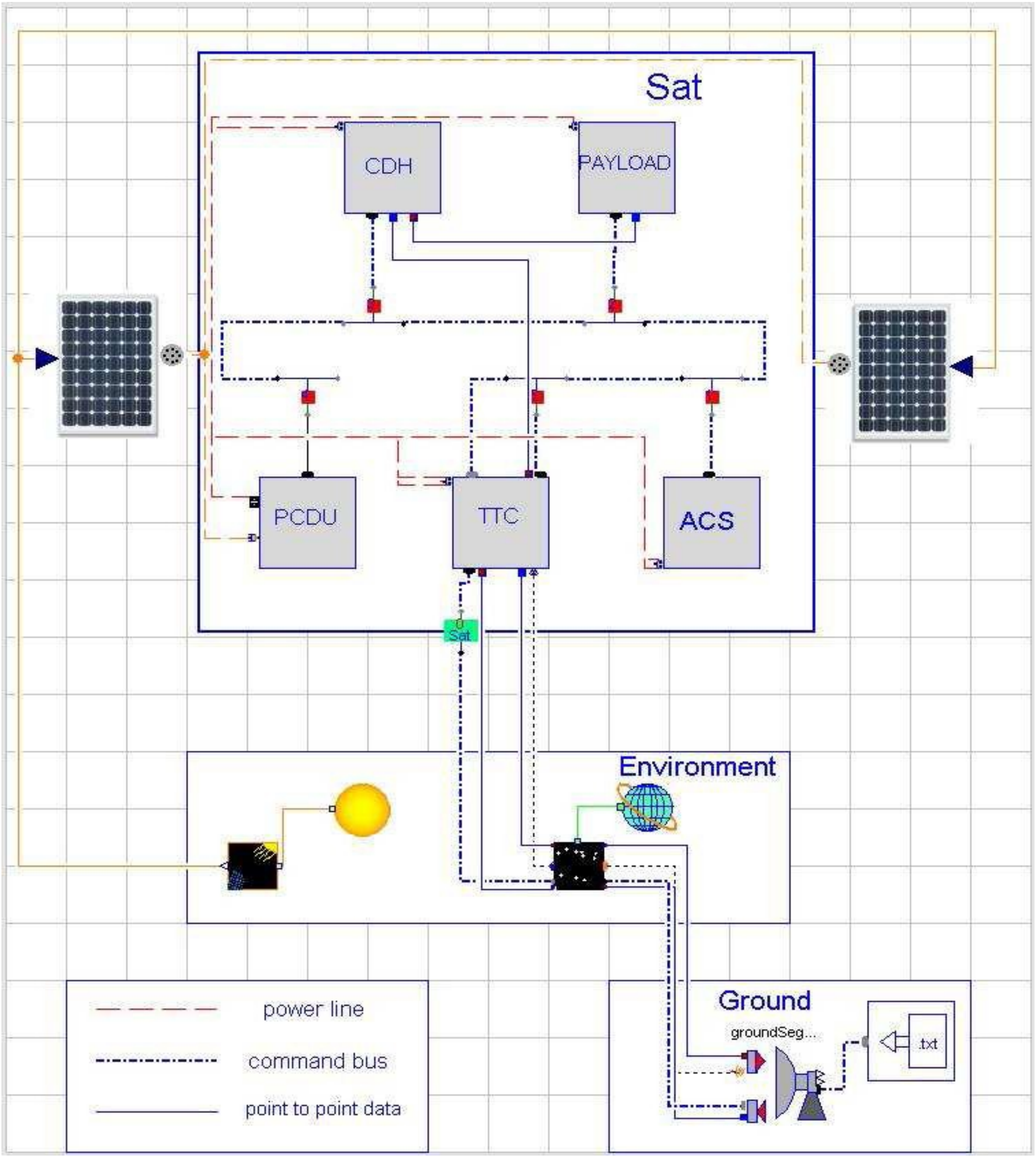


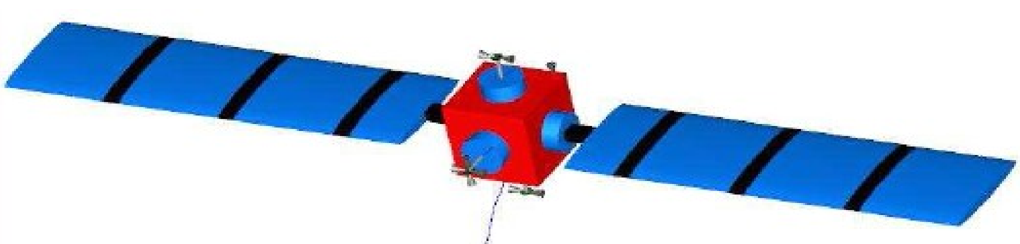
potential:
- deal with complexity
- radically new designs (DSE)

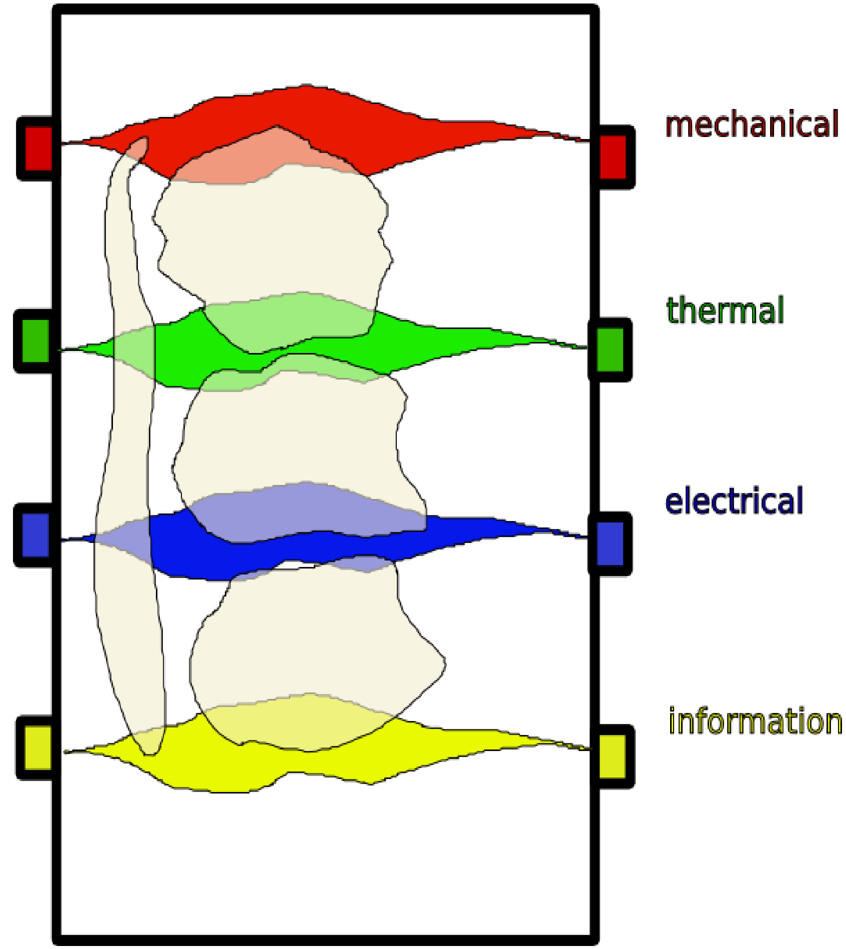
Typical CPS: networked car

Typical CPS: smart city (incl. building automation)

Typical CPS: satellite systems



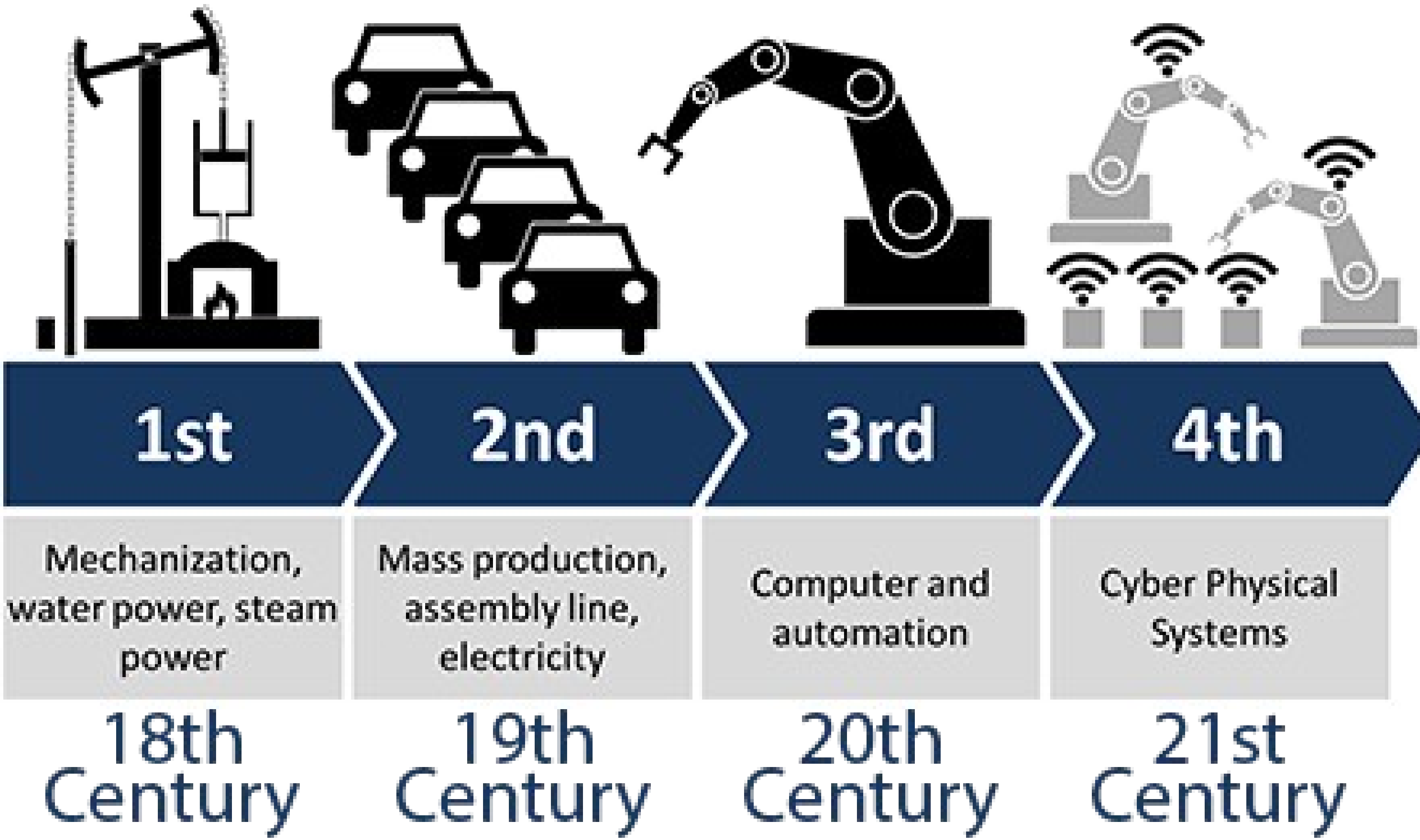




- Encapsulate interactions
- Evolution

the European (German) answer to US initiatives:

Industry 4.0

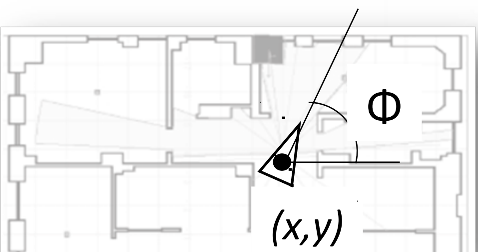


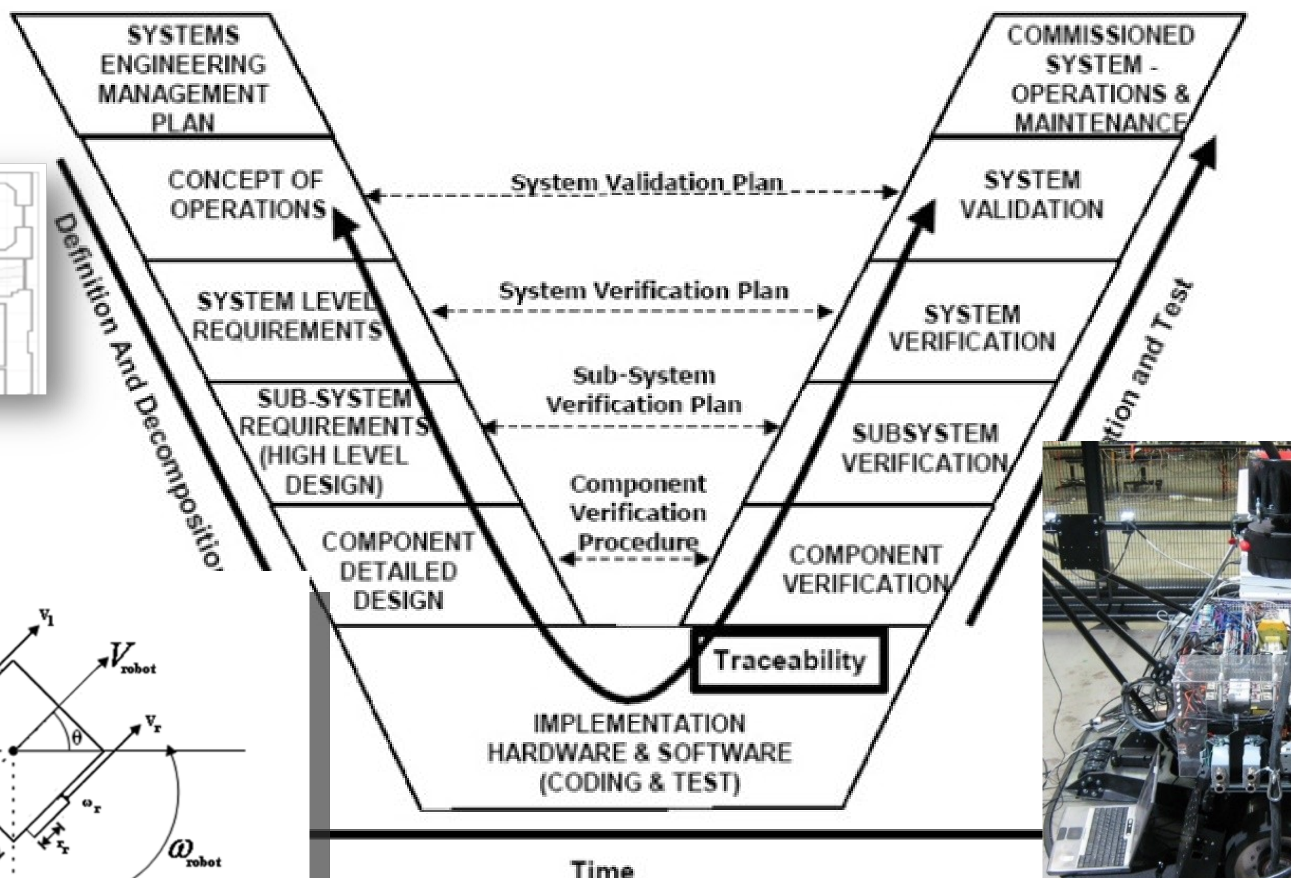
The Industry 4.0 Vision

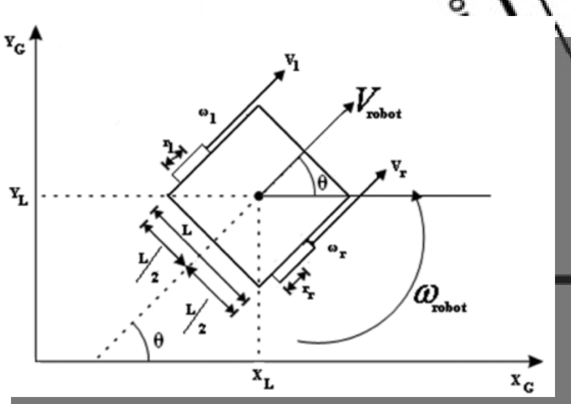
Virtual Design, Build, Operation, and Maintenance

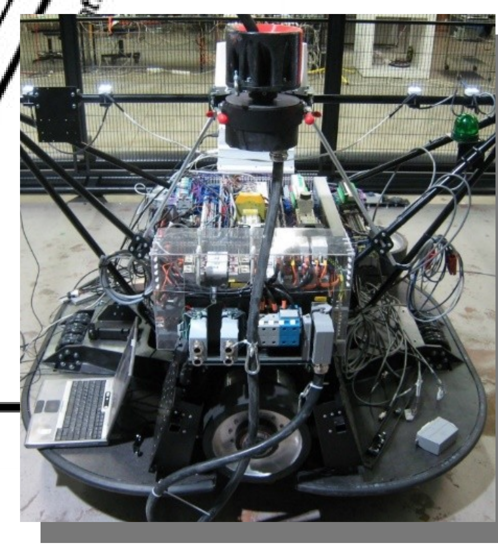
(possibly in a high-autonomy setting)

Virtual Design/Implement/Test/...

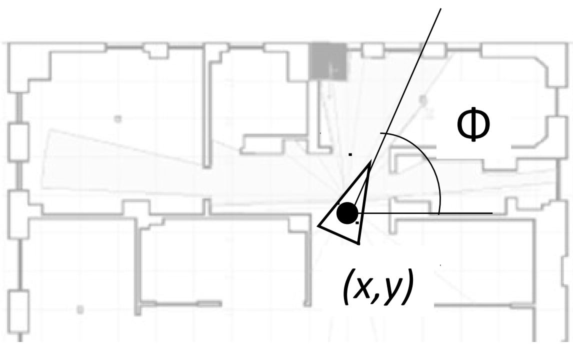




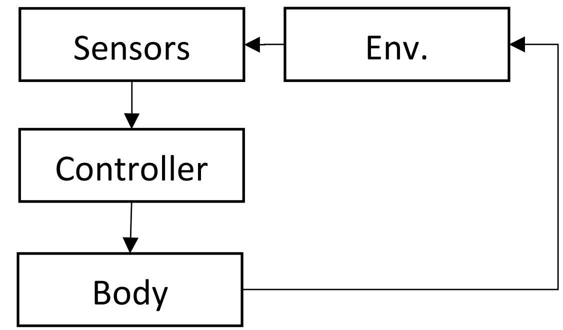


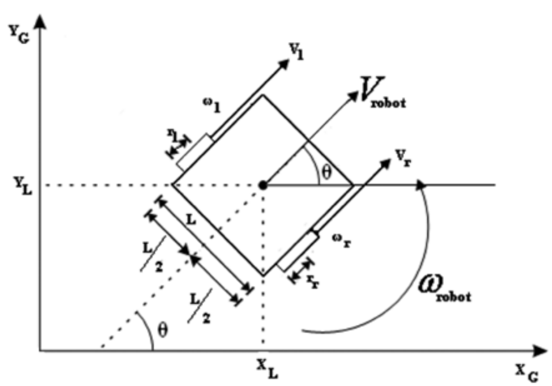


Virtual Design

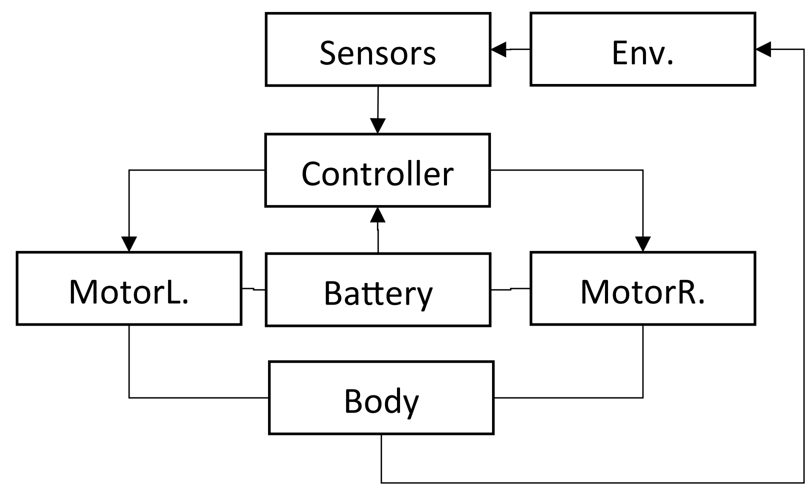


frequent full system evaluation

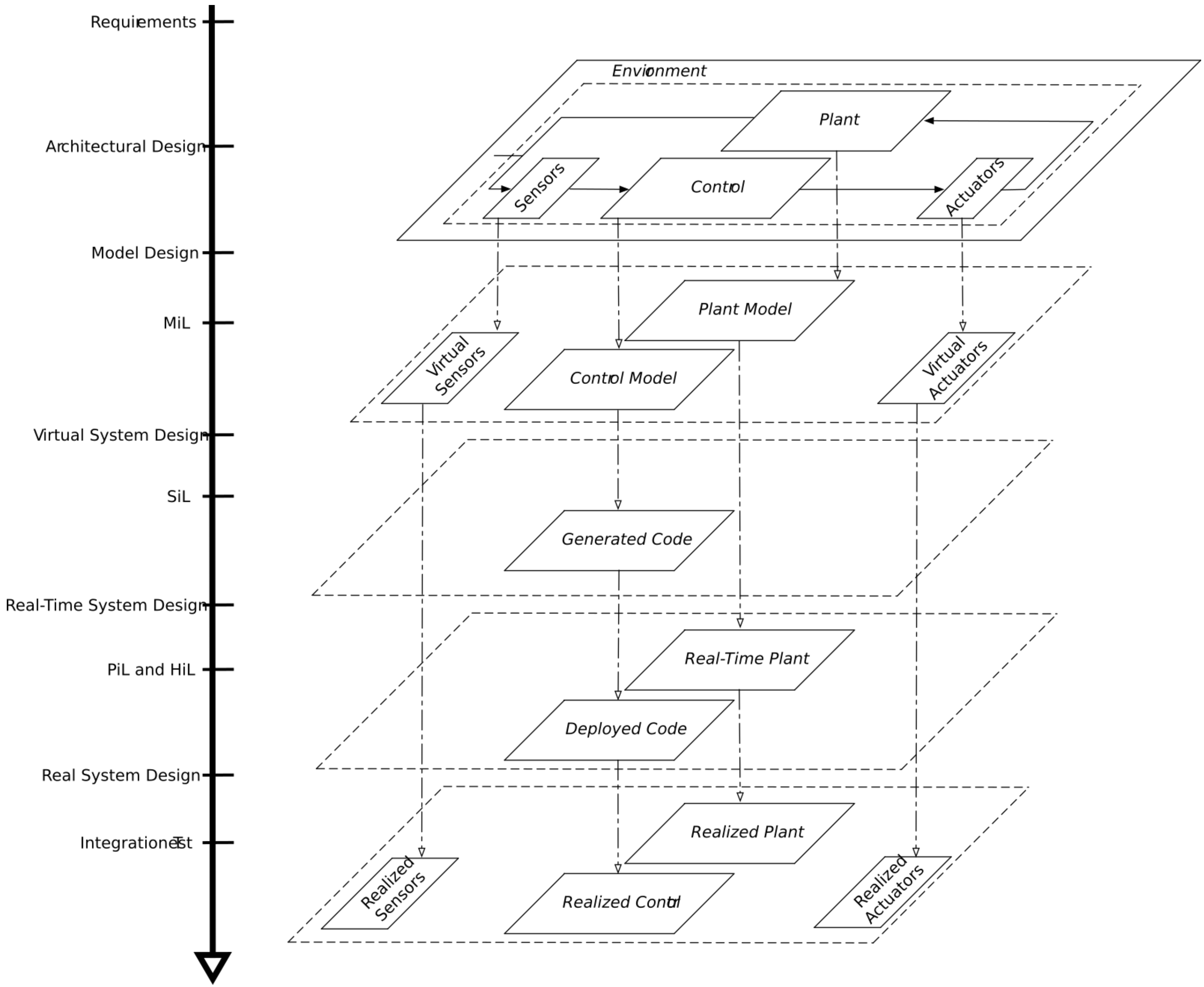


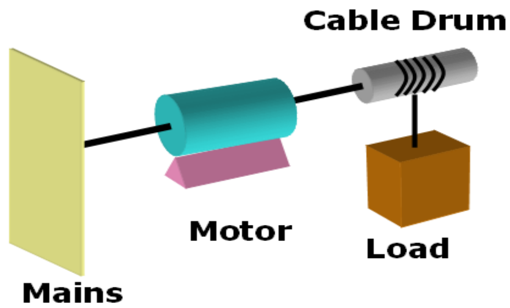


...at multiple levels of refinement

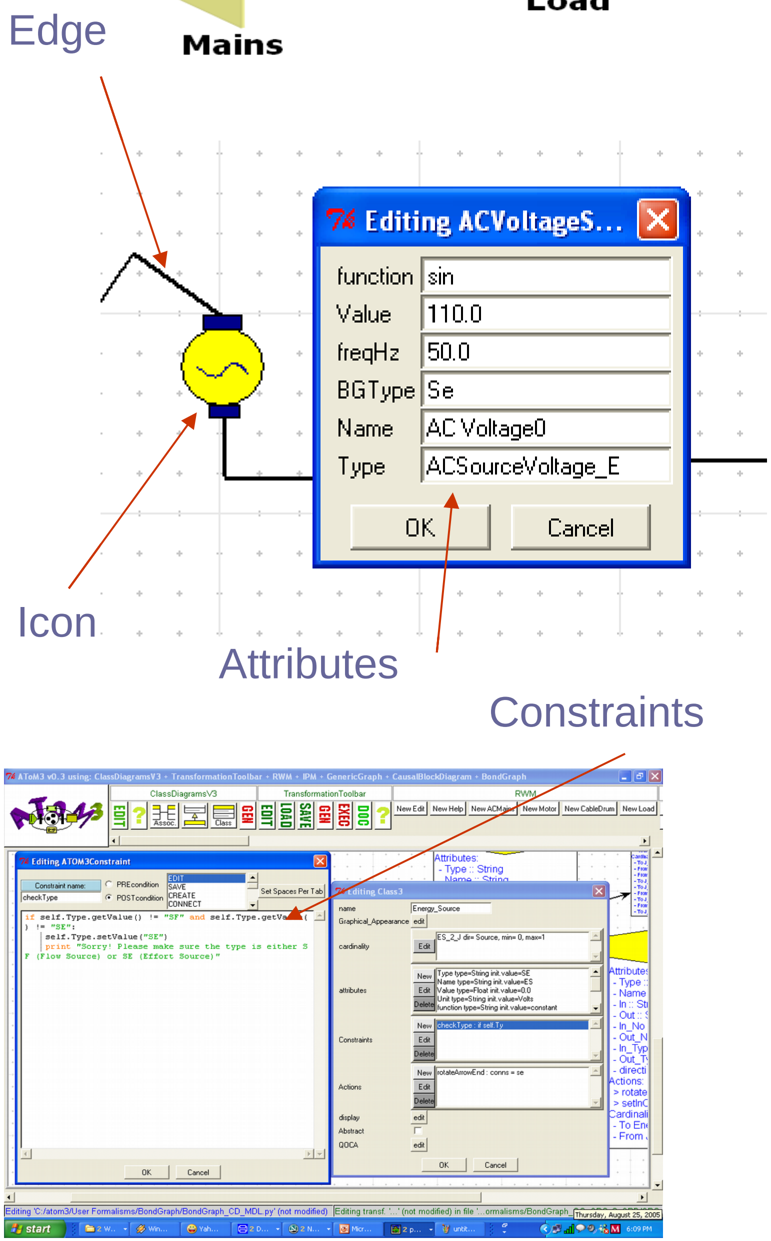


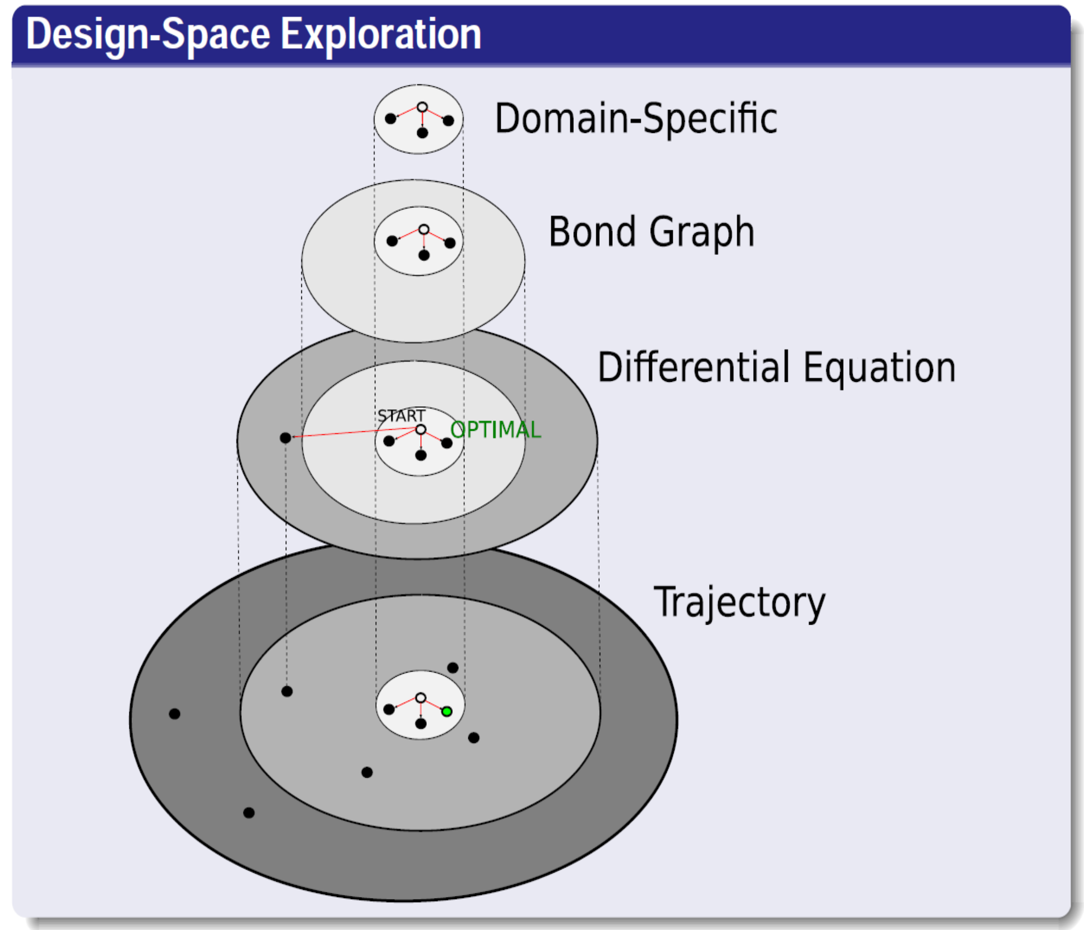
XiL: X = Model, Software, Processor, Hardware





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



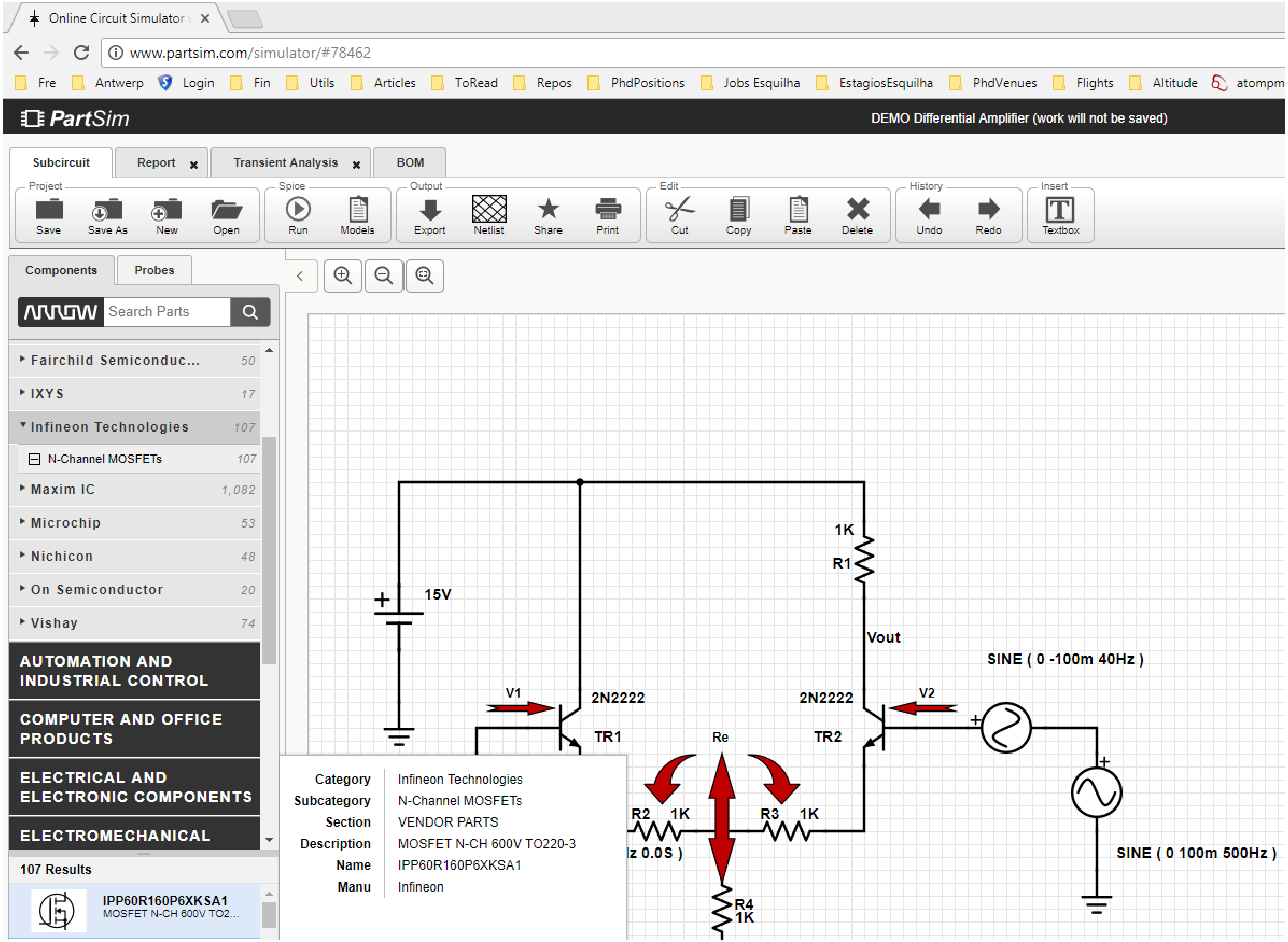


Sagar Sen and Hans Vangheluwe. Multi-domain physical system modeling and control based on meta-modeling and graph rewriting. In Computer Aided Control Systems Design (CACSD) , pages 69 - 75, Munich, Germany, 2006. IEEE.

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/

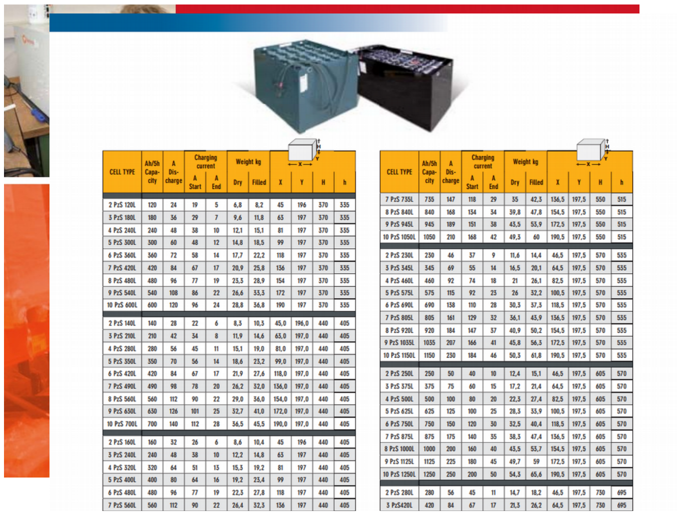


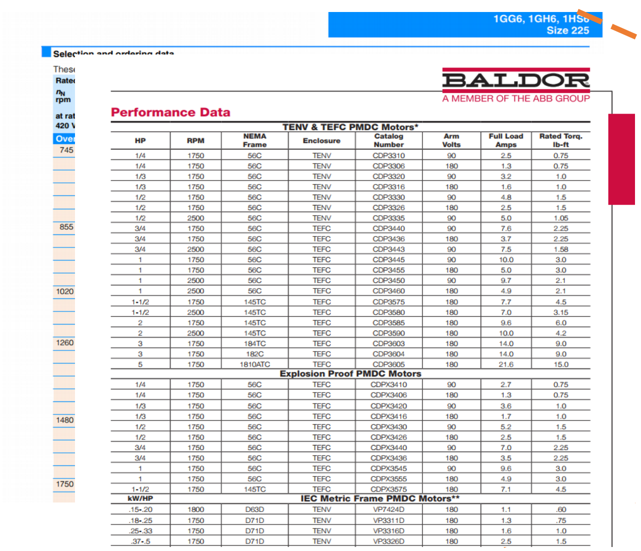
Virtual Build

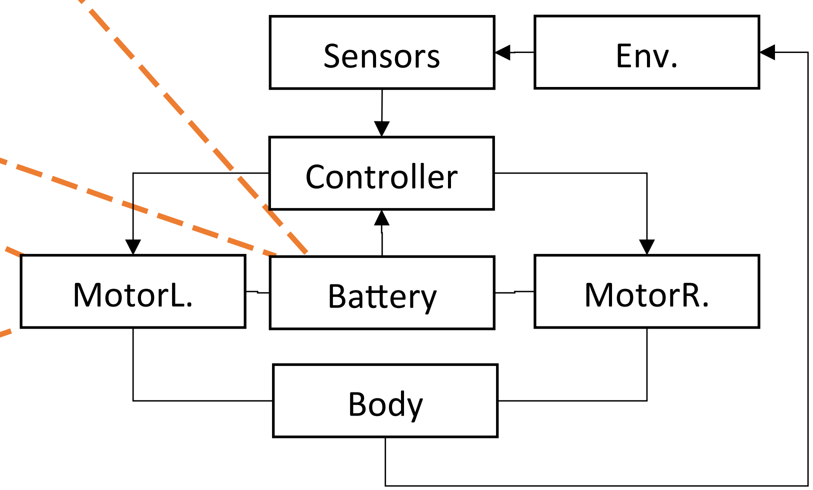
Frequent full system evaluation

...at any level of refinement

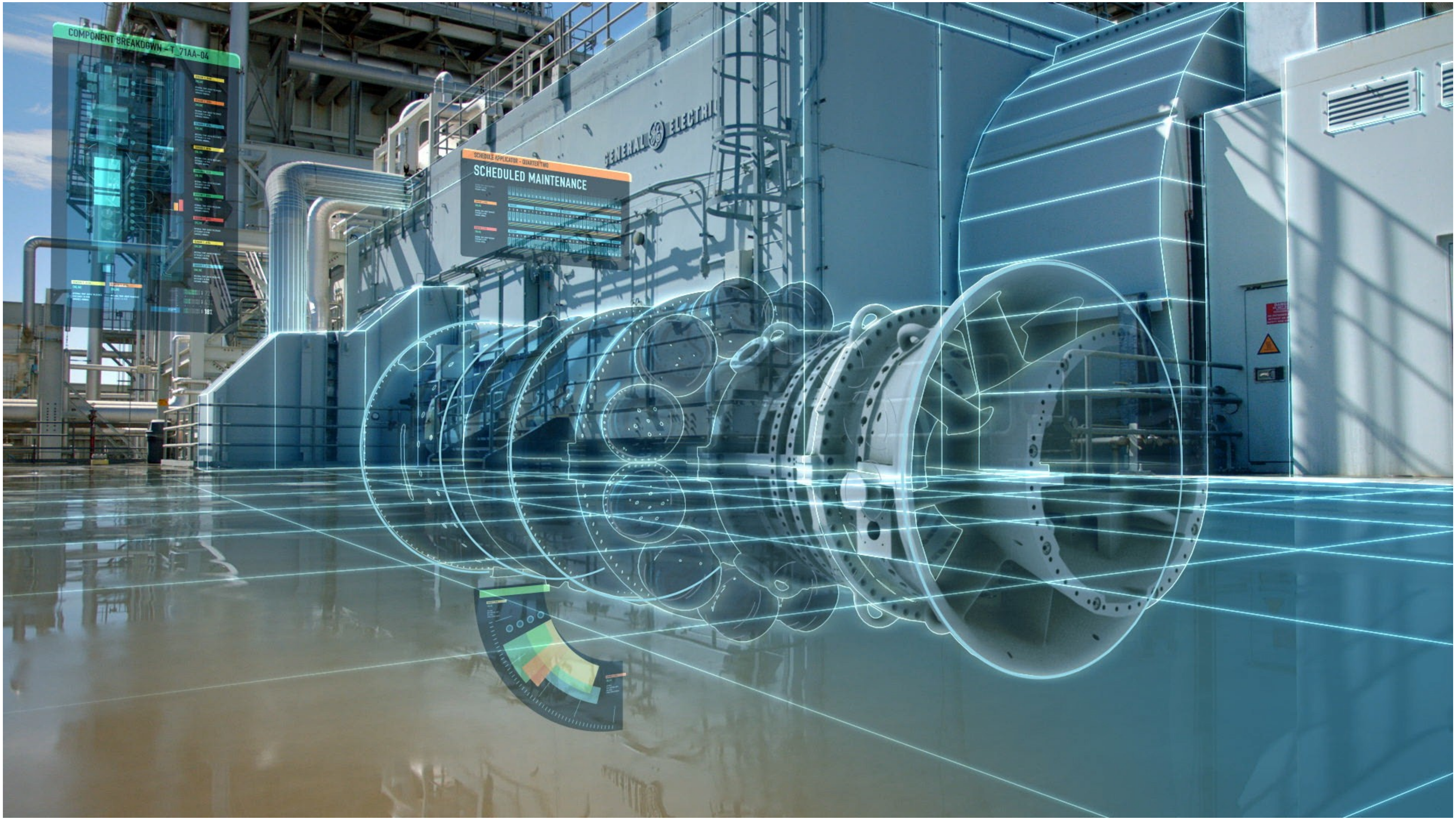
...using multiple suppliers







Virtual Operation
the "digital twin"

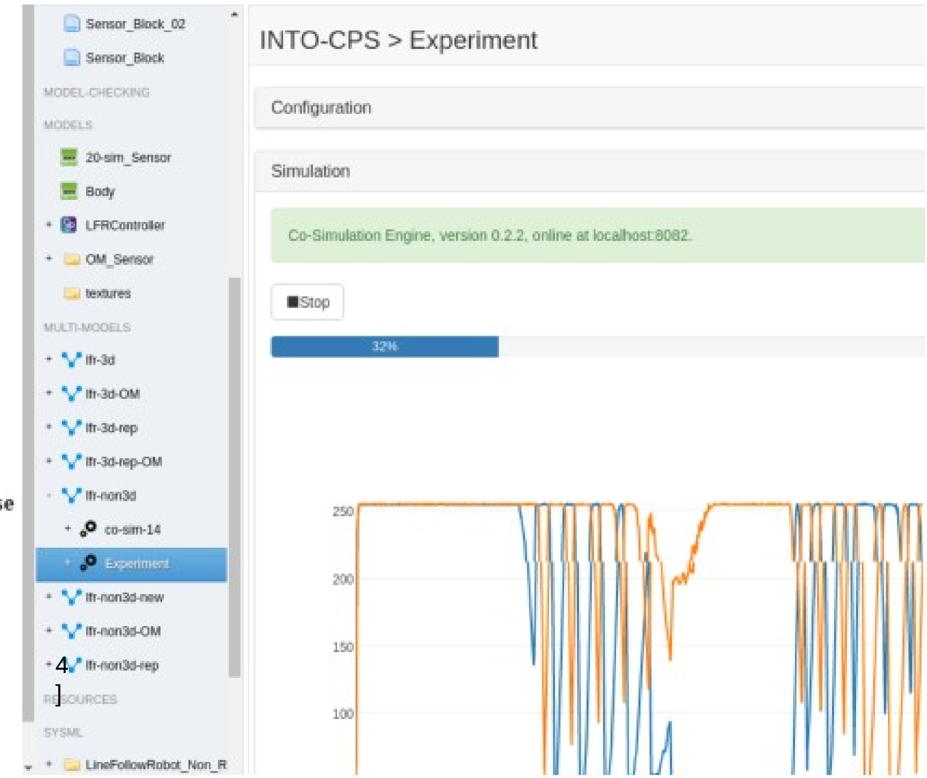


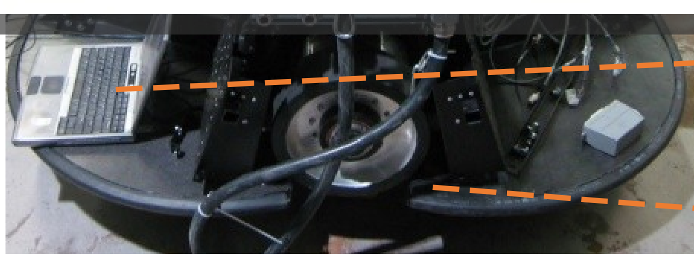
[1] http://www.power-technology.com/features/featuredigital-twin-the-living-breathing-and-failing-virtual-power-plant-5742648/

Virtual Operation

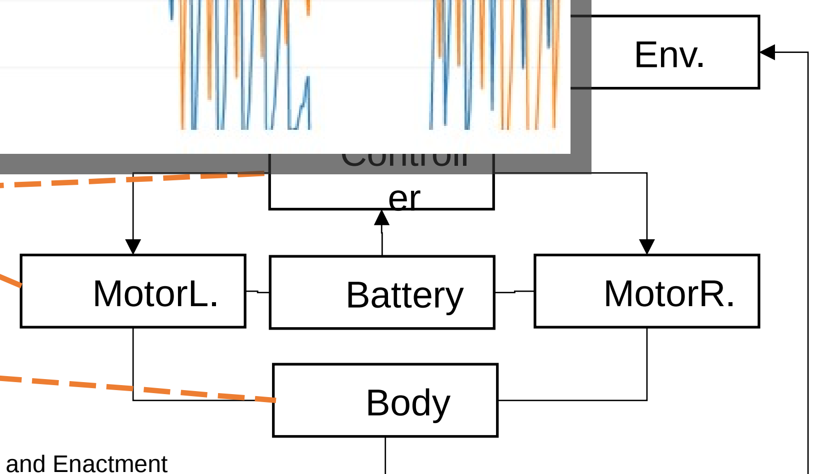
...valuation
...efinement
suppliers
...-the-loop

[4]





[1,2]



[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.virtalis.com/blogs/2013/09/06/germanys-dlr-turns-to-virtalis-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]

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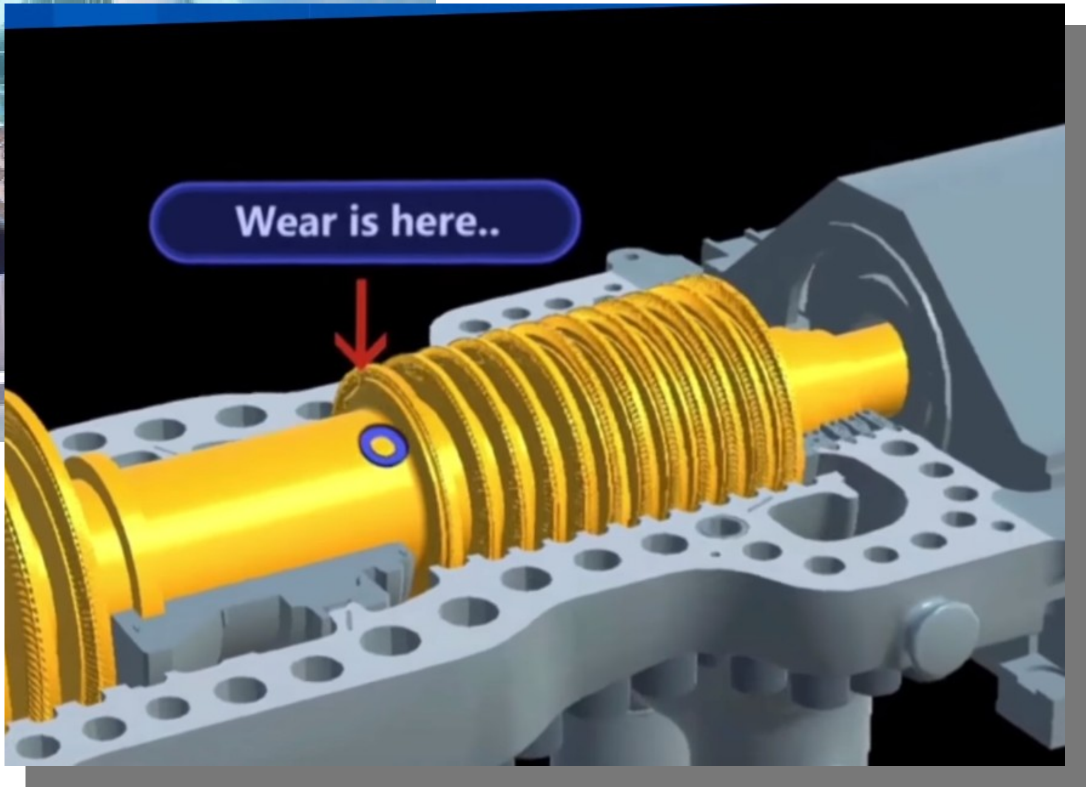


[1] https://www.fool.com/investing/2016/09/18/what-is-the-industrial-internet.aspx

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

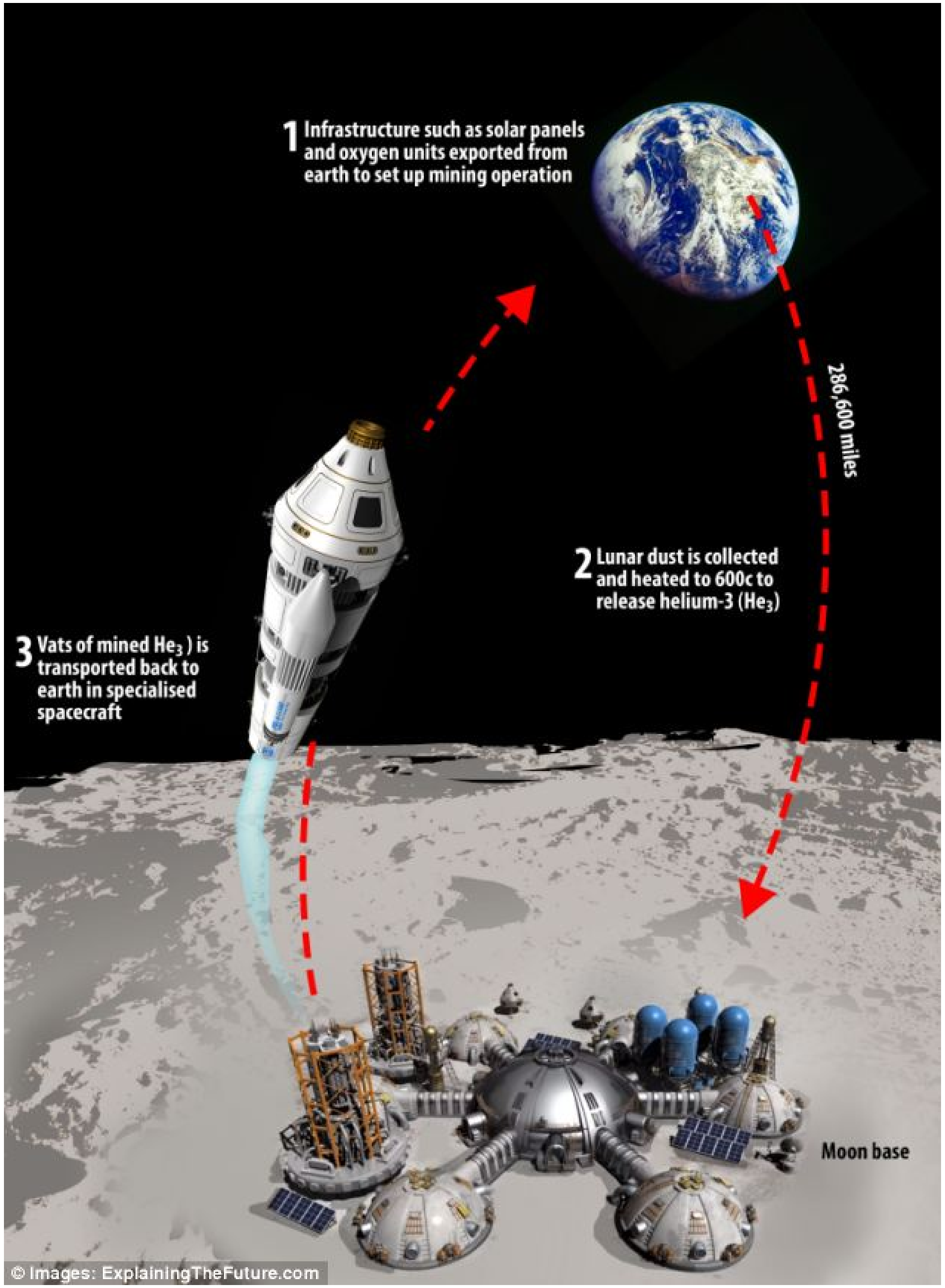
High Autonomy CPS

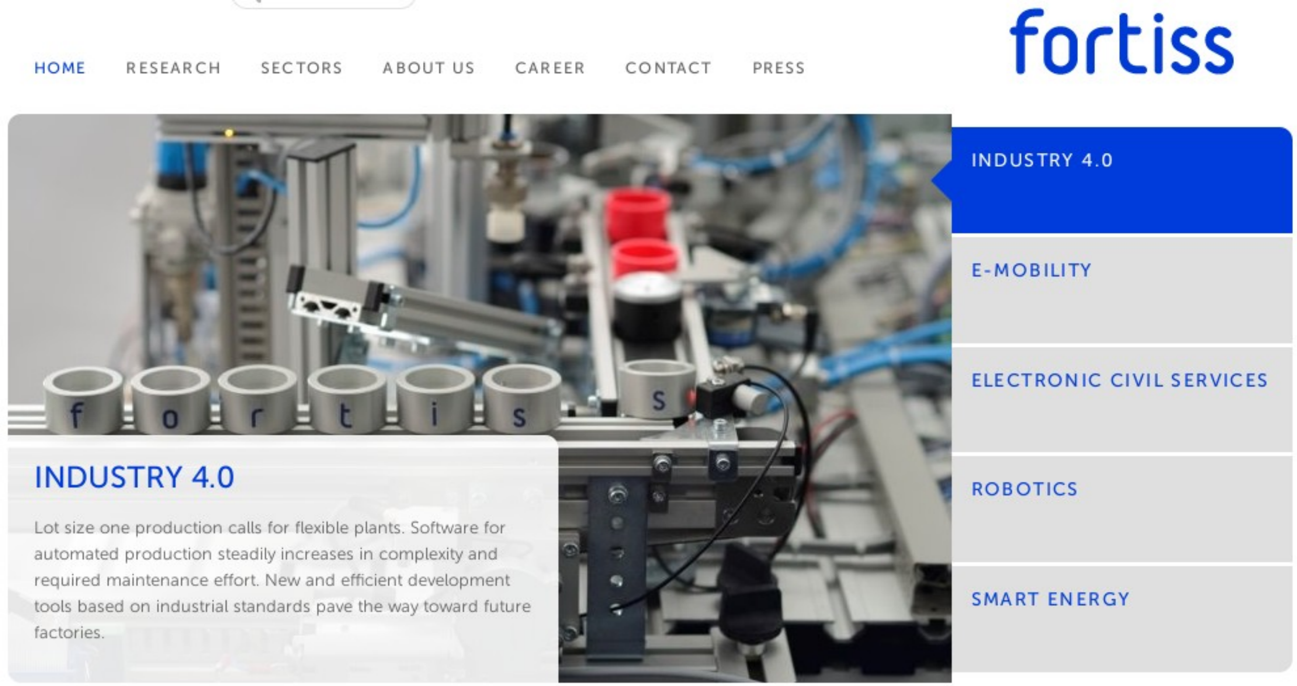
→ need “virtual experimentation”

autonomously

- construct (often by connecting existing) models for diagnosis, design, …

- experiment with models





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

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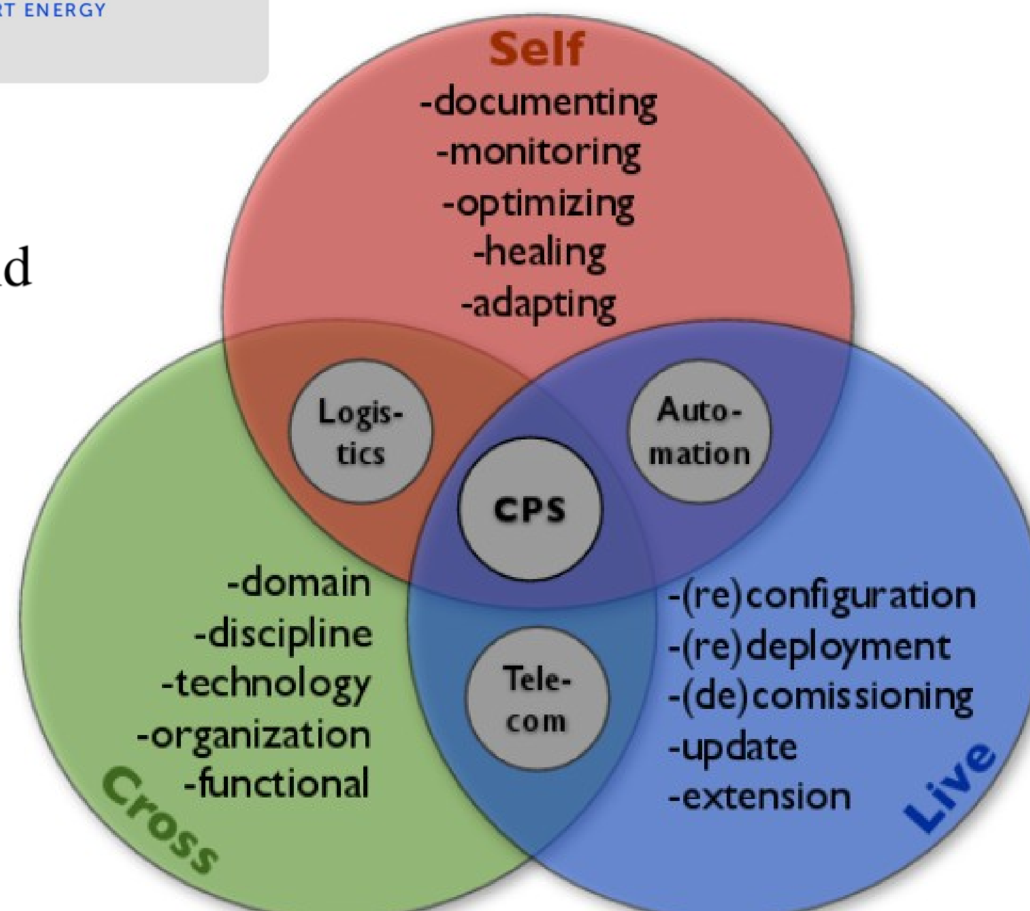

Multi-Paradigm Modelling (MPM)

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

SiE

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.

MPM4CPS

cost
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