CPS Week 2018
Tutorial on Design of Adaptive and Secure CPS
April 10-13, 2018

CERBERO

Hw/Sw Cyber-System Co-design and Modelling

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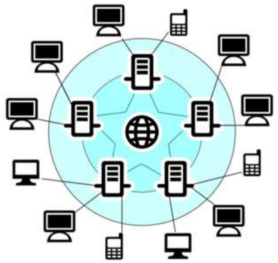
Horizon 2020
European Union funding
for Research & Innovation

Introduction

Text-book definitions for Cyber-Physical Systems :

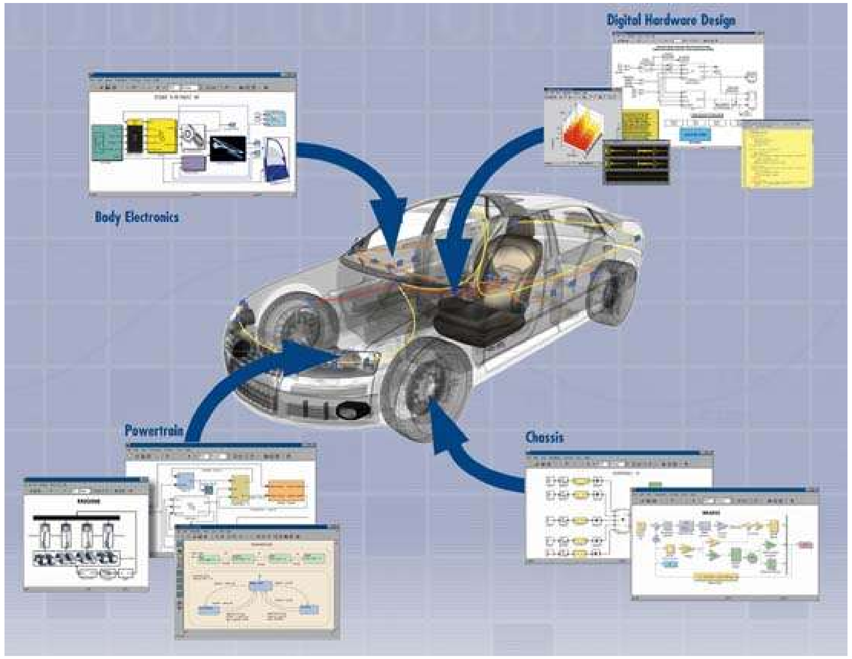
- CPS are complex systems integrating:
  - Computation processes
  - Network of communication
  - Physical entities *(actuators and sensors, time, mechanics, temperature, …, and you!)*

 +  + 

- CPS is an engineering discipline, focused on technology, with a strong foundation in mathematical abstractions.

source: Berkeley CPS website, http://cyberphysicalsystems.org/

In this lecture



Source: Mathworks, INC

1. **An eagle's view on modelling Cyber-physical Systems**

   Challenges on modelling CPS

   Modelling at different abstraction levels and with different views

   A look behind the tools – model automation

Who are we?

Julio Oliveira (Dr. Rer. Nat. , Brazilian)

Crazy about inventing new ways to describe, model, and analyze multi-domain, complex, large scale cyber-physical systems.

Innovation researcher at TNO – The Netherlands

Karol Desnos (Dr. Associate Prof. , France)

Dataflow programming expert and freak designer of MPSoCs.

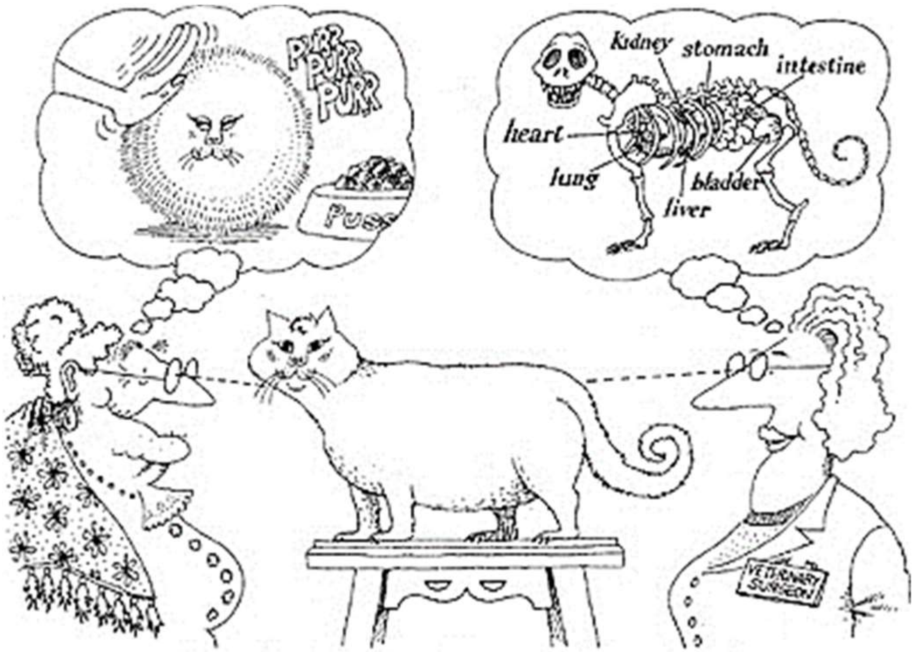
Associate Professor at INSA and researcher at IETR – France

First things first…

What are models ? And why !?!

Models

Modeling as an engineering activity



Abstraction (Simplification)

Description (Specification)

Operational (Executable)

Abstraction

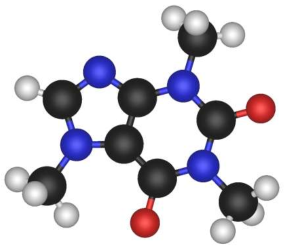
Tradeoff between level of details and complexity.

Description

Models for similar systems may take many forms.

- To capture different characteristics.
- To be more suitable for a different system size.

Molecules



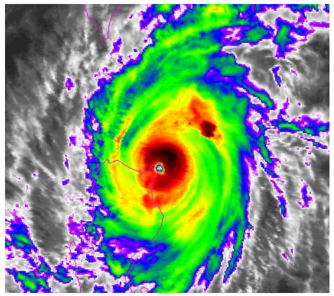
Ideal Gas Law

pressure *moles* *temp.*

$$pV = nRT$$

volume *gas constant**

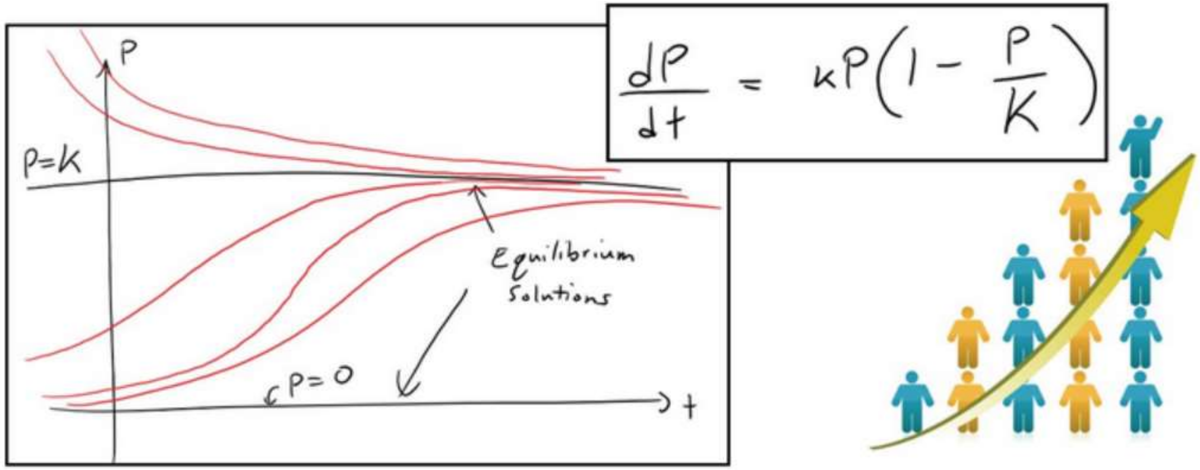
Meteorology



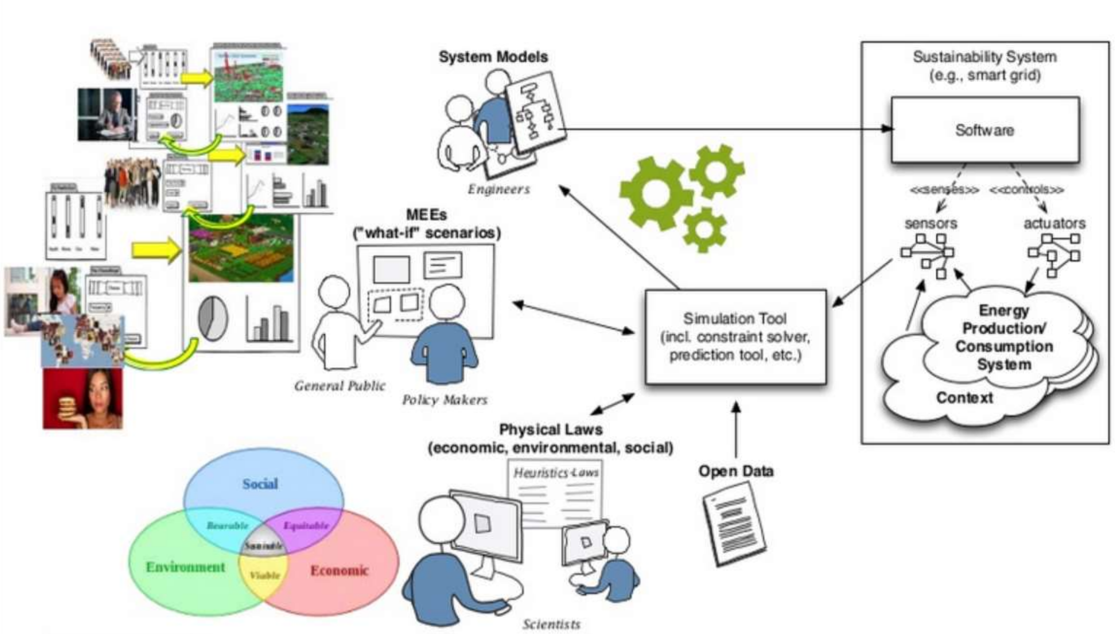
*: Physicist way of saying magic number

Operational

Useful for drawing conclusions



Why models ?



Communication

Analysis

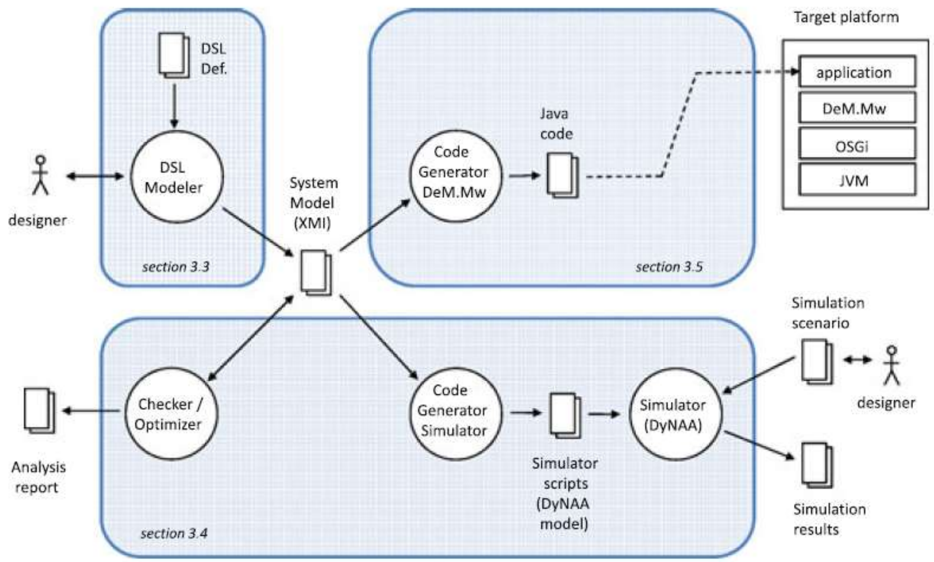
Design

Validation

Source: INRIA

Why Models ?

Automation !



Source: EU DEMANES project

Challenges

Challenges on modelling CPS

Why modeling CPS (SoS) is challenging?

Which abstraction?

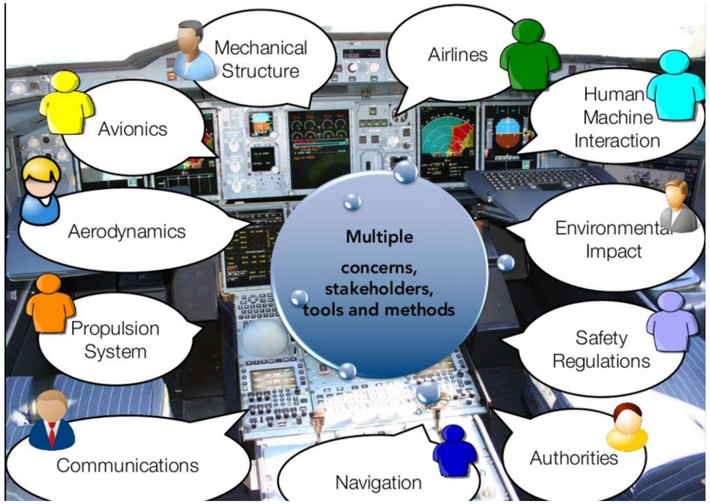
How to describe?

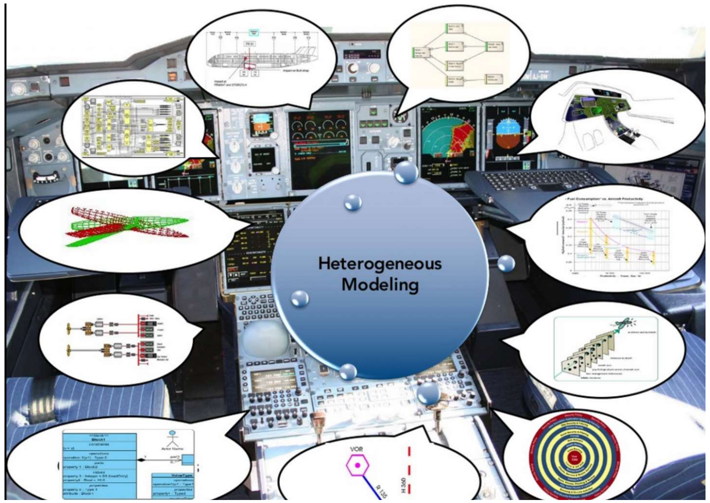
Operational?

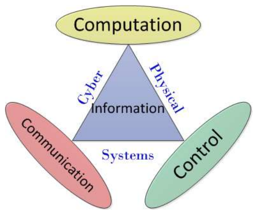
Complexity!

What we mean by complexity?

What we mean by <u>complexity</u>?

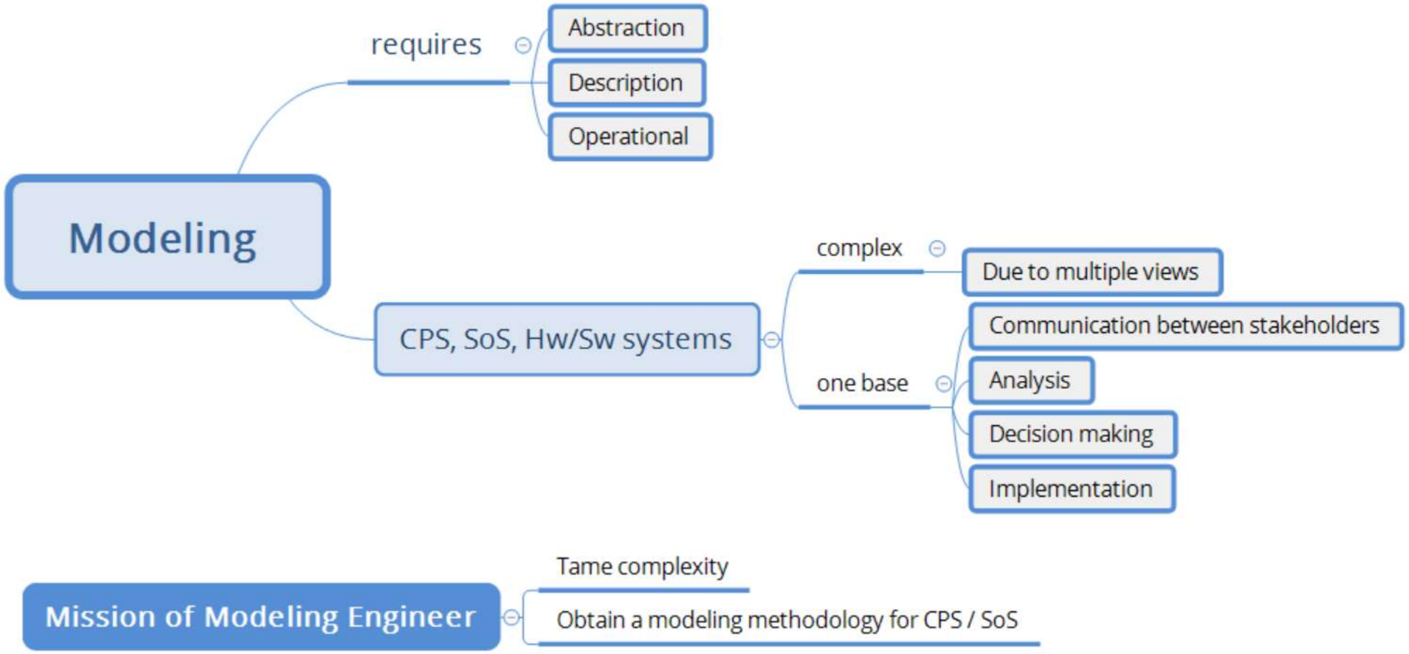






Source: INRIA

All so far, in a nutshell



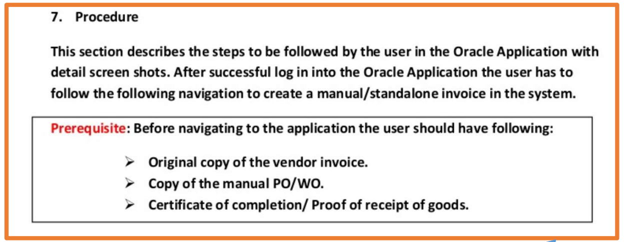
Facing the challenges I

Some ideas on taming modelling complexity

CERBERO

<u>Integrative Multi-view modelling</u>

Approach 1: Model for the task in hand

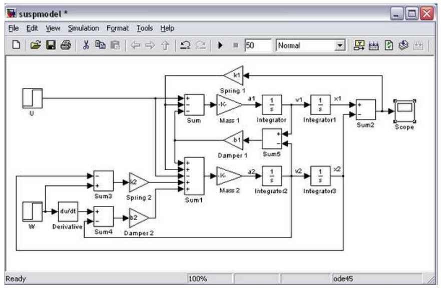


7. **Procedure**

This section describes the steps to be followed by the user in the Oracle Application with detail screen shots. After successful log in into the Oracle Application the user has to follow the following navigation to create a manual/standalone invoice in the system.

Prerequisite: Before navigating to the application the user should have following:

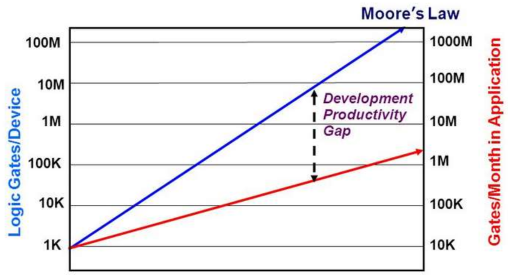
- Original copy of the vendor invoice.
- Copy of the manual PO/WO.
- Certificate of completion/ Proof of receipt of goods.




```
<?php

namespace SampleApp\Common;

class ServiceLocator implements RegistrableInterface
{
    protected $_resources = array();

    /**
     * Set the specified resource
     */
    public function set($key, AbstractResource $resource)
    {
        if (!isset($this->_resources[$key])) {
            $this->_resources[$key] = $resource;
```

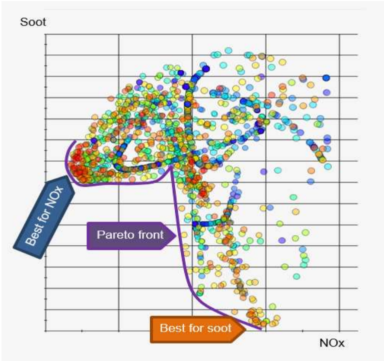
- User Requirements Engineering ⇢ Acceptance Testing
  - System Requirements Engineering ⇢ System Testing
    - Architecture Engineering ⇢ System Integration Testing
      - Design ⇢ Subsystem Integration Testing
        - Coding (SW) Fabrication (HW) ⇢ Unit Testing

Model for the task in hand fails



Major problem for the development productivity

Introduction of errors :
Human failure or mis-interpretation

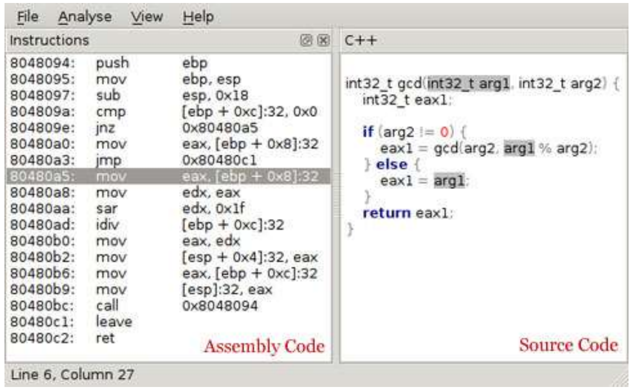


Almost impossible to optimize at system level

Approach 2: Model transformation

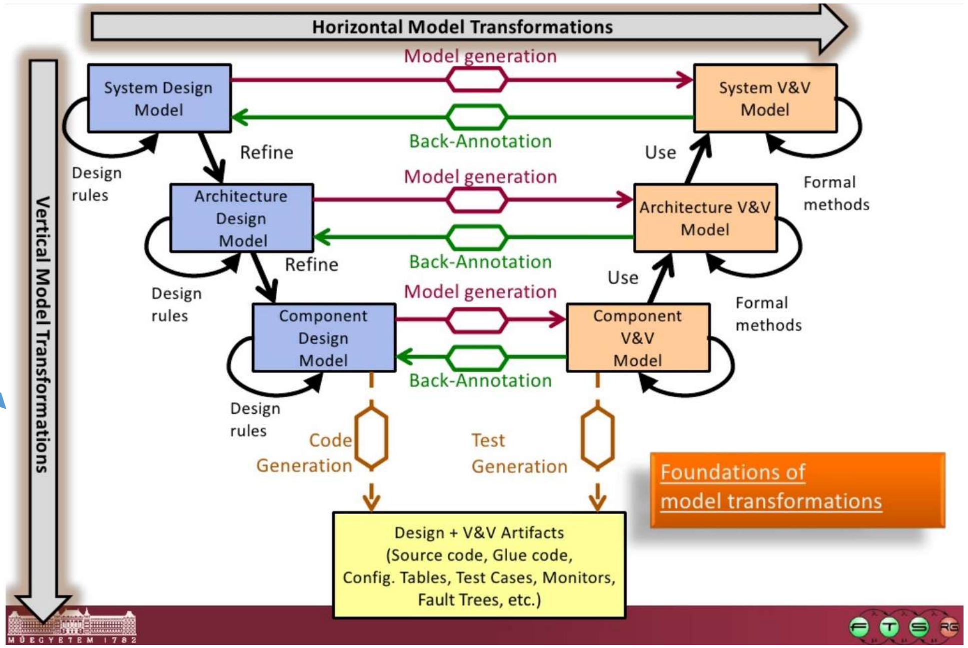
A **model transformation** is an automated way of modifying and creating models.

(Best) Example: Compilers



Model transformation and the design process

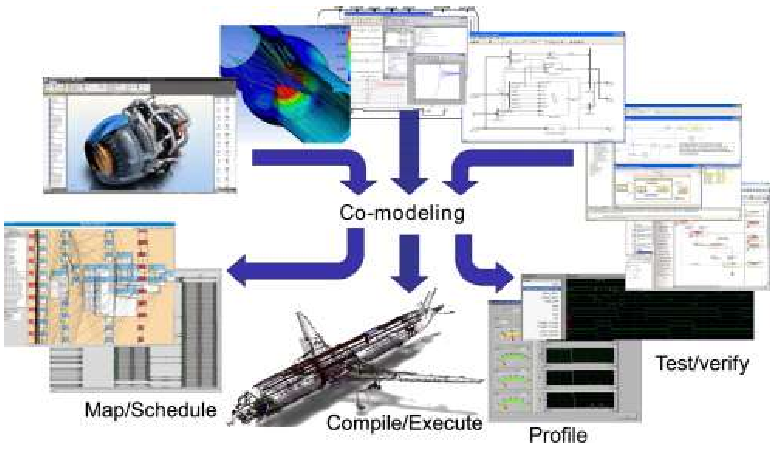
Main challenge



Source: Daniel Varro, CSMR2012

Approach 3: Multi-aspect modeling

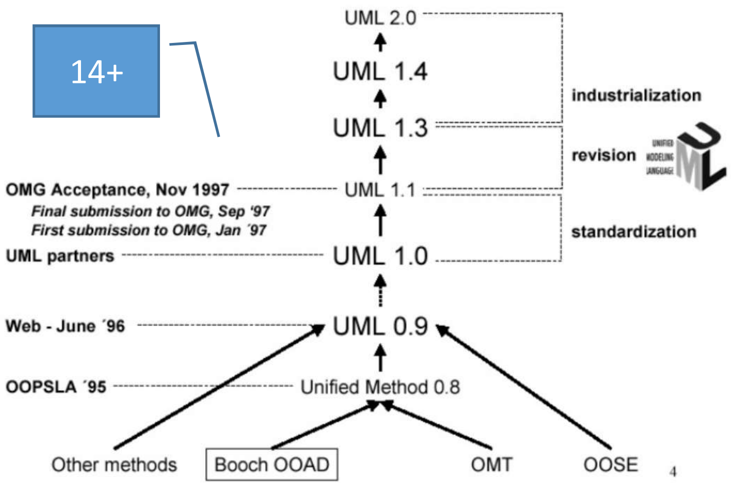
A *system aspect*, or *system view*, is a way to look at or describe a system as a whole. Each system aspect has its own associated semantic domain and can provide an exhaustive description of the system, but only from that particular point of view.



Multi-aspect examples

Examples

14+



Methods war!

Source: Emertxe Ltd

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AADL

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ISO IEC ITU RM-ODP

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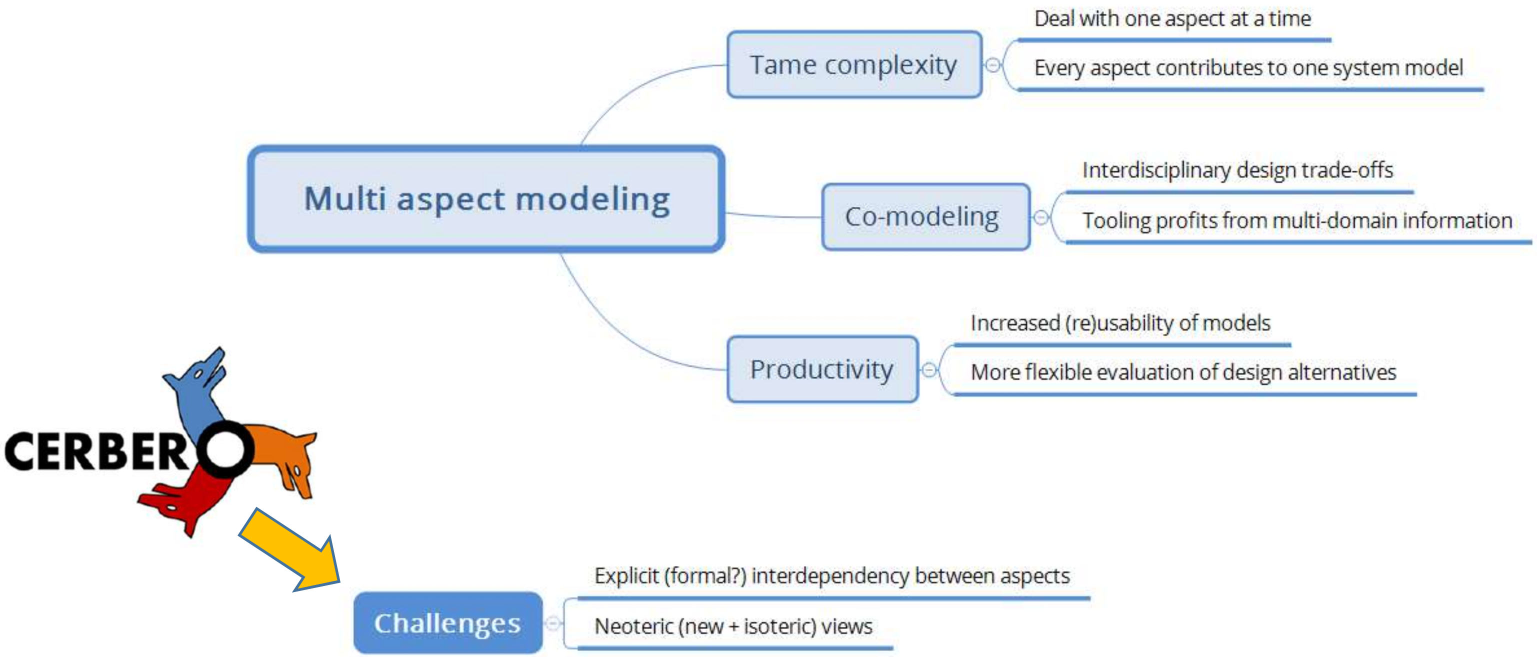
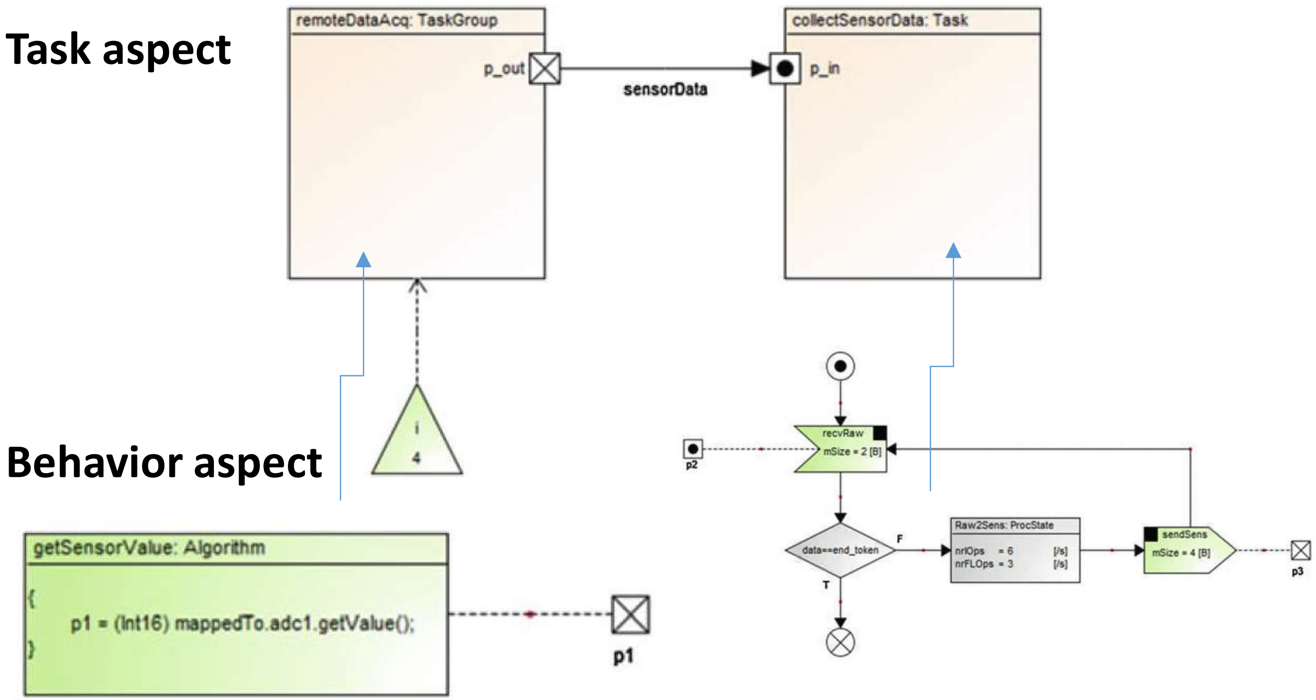
OMG SYSTEMS MODELING LANGUAGE SysML

UML MARTE

Advantages of multi-aspect modeling

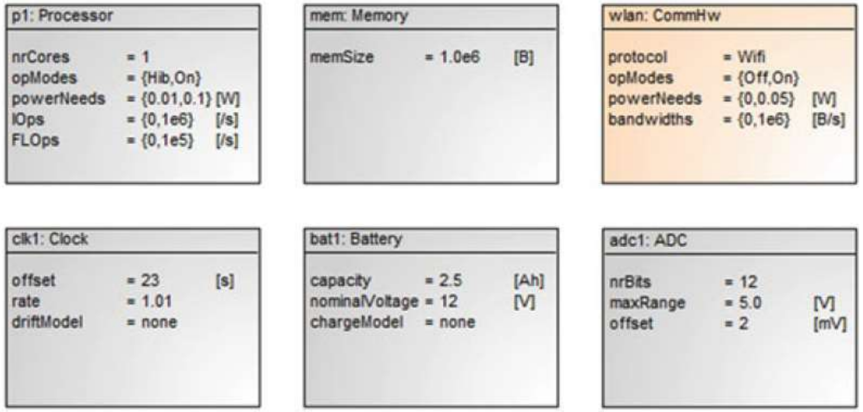


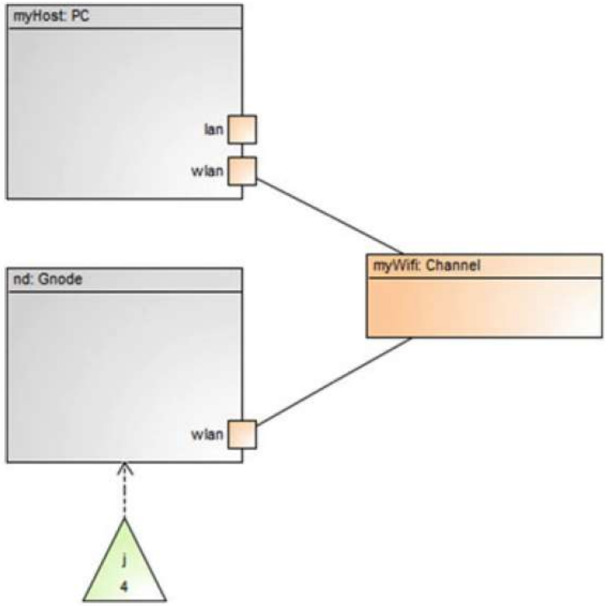
An example from CERBERO 1/3



An example from CERBERO 2/3

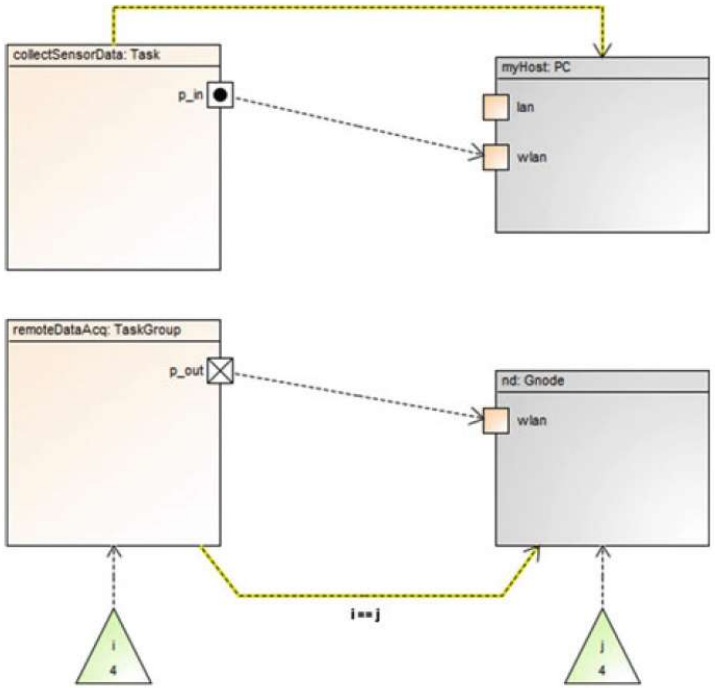
Physical aspect





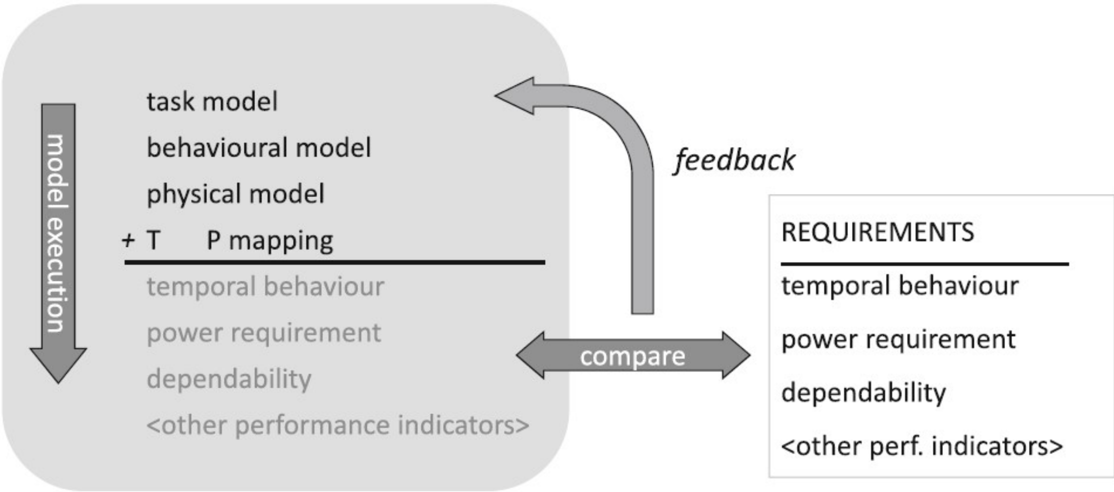
An example from CERBERO 3/3

Mapping view



Putting it all together

Using the models together to assess KPIs



Facing the challenges II

Some ideas on taming modelling complexity

<u>Choosing an adequate Model of Computation</u>

Models of Computation

Model of Computation (MoC)

a.k.a. programming paradigm

⚠ A MoC is not a language ⚠

Definition:

- A set of operational elements that can be composed to describe the behavior of an application.
  → **Semantics of the computation**

Objective:

- Specify implementation-independent system behavior.
- Ease specification, implementation, verification of system properties.

How:

- MoCs act as the interface between computer science & mathematical domain.

Differences to a programming language

Language

Definition:

- A set of textual/graphical symbols that can be assembled respecting a well defined grammar to specify the behavior of a program
  → **Syntax of a the language**

Objective:

- Ease system description and maximize developer productivity.
- Be developer-friendly: readability, reusability, modularity, …

How:

- Languages are the interface between the programmer & the Machine (through the compiler).

A Language implements one or several MoCs

Examples of models of computation I

A few MoCs

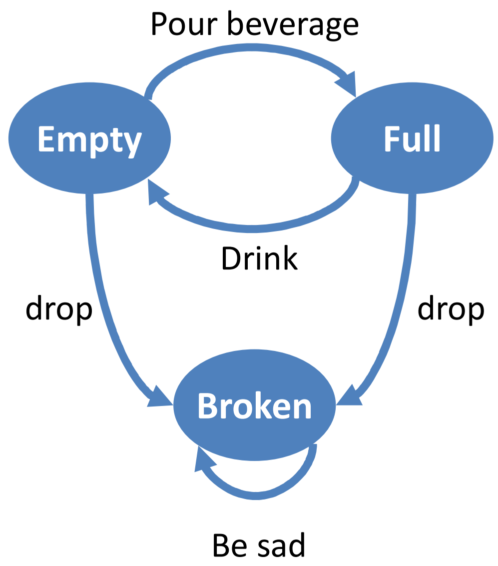
Finite State Machine MoCs

Semantics
- States
- Transitions (possibly conditional)

Used for
- Sequential logic
- System-level behavior
- Communication protocols
- …

Property
- Non-deterministic, sequential

FSM for drinking beer



Examples of Models of Computation II

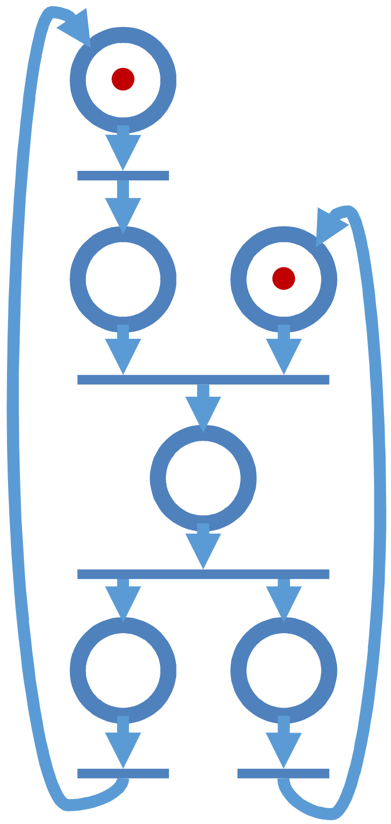
A few MoCs

Petri Nets

Semantics
- Places
- Transitions & Arcs

Used for
- Synchronization protocols
- Parallel computations
- …

Property
- Parallelism
- Liveness, Boundedness, Reachability



Examples of Models of Computation III

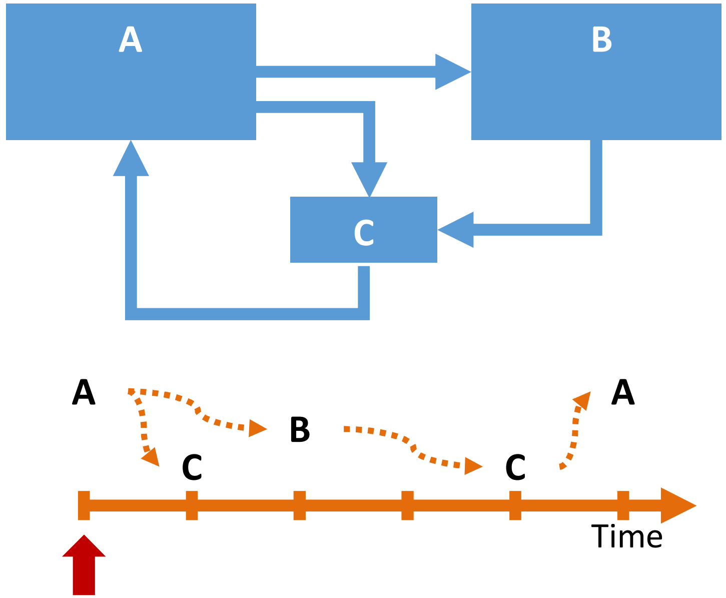
A few MoCs

Discrete Event MoCs

Semantics
- Modules
- Signals
- Timed events
- Global clock

Used for
- Hardware Description
- “System” Simulation

Properties
- Timed, Non-deterministic *(if badly used)*



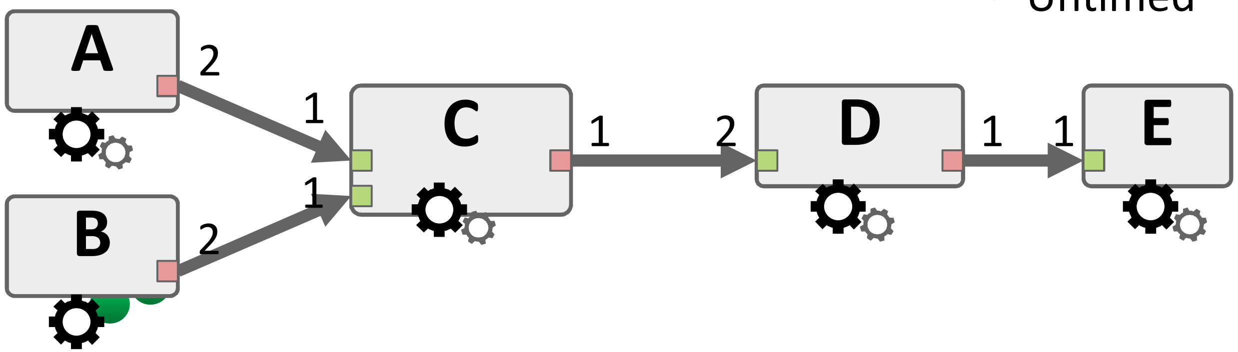
A few MoCs

Synchronous Dataflow

Semantics
- Actors & ports
- FIFO queues

Used for
- Parallel computations
- Stream processing

Properties
- Liveness
- Boundedness
- Deterministic
- Untimed



Source: E. Lee and D. Messerschmitt, “Synchronous data flow”, Proceedings of the IEEE, 1987.

Component level > MoCs

MoC properties are important.

You need to know them to select the MoC suiting your needs

Feature	SDF	ADF	IBSDF	DSSF	PSDF	PiSDF	SADF	SPDF	DPN	KPN
Expressivity	Low				Med.		Turing			
Hierarchical			X	X	X	X				
Compositional			X	X		X				
Reconfigurable					X	X	X	X	X	X
Statically schedulable	X	X	X	X						
Decidable	X	X	X	X	(X)	(X)	X	(X)		
Variable rates		X			X	X	X	X	X	X
Non-determinism							X	X	X	

SDF: Synchronous Dataflow
ADF: Affine Dataflow
IBSDF: Interface-Based Dataflow
DSSF: Deterministic SDF with Shared Fifos
PSDF: Parameterized SDF

PiSDF Parameterized and Interfaced SDF
SADF: Scenario-Aware Dataflow
SPDF: Schedulable Parametric Dataflow
DPN: Dataflow Process Network
KPN: Kahn Process Network

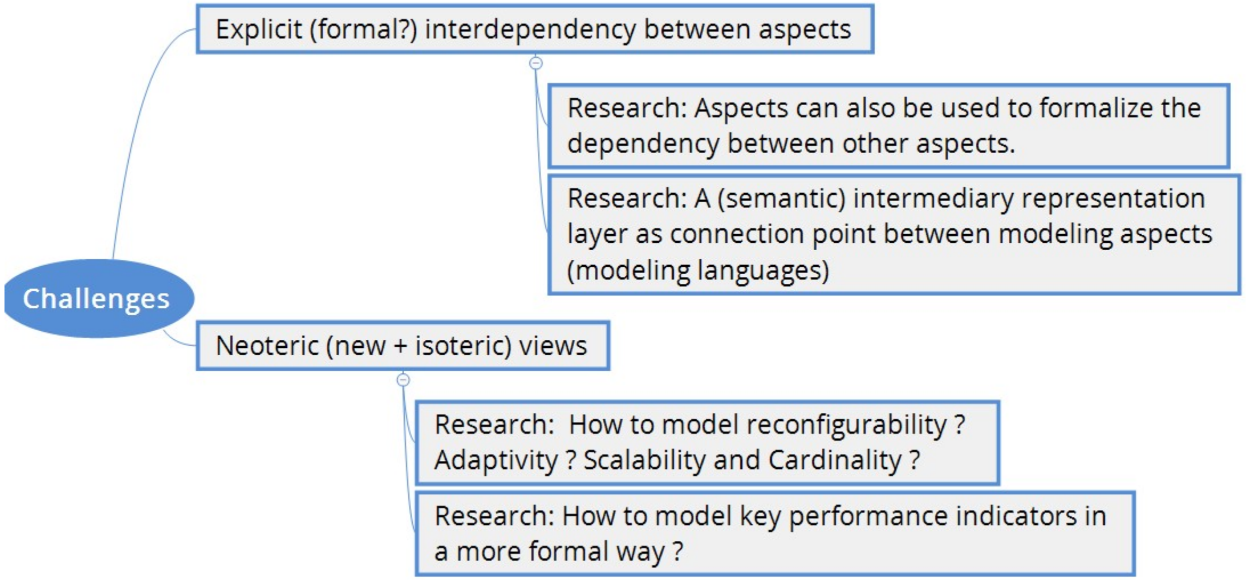
Closing words

- Modelling CPS is a fascinating and challenging area of research
- Complexity is the main challenge
- CERBERO contributes on new techniques for modelling complex systems.

Thank you

Backup Slides

Some CERBERO contributions (on going work)



Outline

- …
  - ..