COST Action IC1404: Multi-Paradigm Modelling for Cyber-Physical Systems

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Proceedings of the 5th Workshop of the MPM4CPS COST Action

November 24-25, 2016 • Malaga, Spain

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Preface

In virtually any area of human activity, Cyber-Physical Systems (CPS) are emerging. CPS are truly complex, designed systems that integrate physical, software and network aspects. To date, no unifying theory and no systematic design methods, techniques and tools exist for such systems. Individual mechanical, electrical, network or software engineering disciplines only offer partial solutions. Multi-paradigm Modelling (MPM) proposes to model every part and aspect of a system explicitly, at the most appropriate level(s) of abstraction, using the most appropriate modelling formalism(s). Modelling language engineering, including model transformations, and the study of their semantics, are used to realize MPM. MPM is seen as an effective answer to the challenges of designing CPS.

The COST Action IC1404: Multi-Paradigm Modelling for Cyber-Physical Systems (MPM4CPS) aims to promote foundations, techniques and tools for multi-paradigm modelling for cyber-physical systems, and to provide educational resources to both academia and industry. This will be achieved by bringing together and disseminating knowledge and experiments on CPS problems and MPM solutions.

The fifth MPM4CPS workshop took place on November 24-25, 2016 in Malaga, Spain. The program comprised presentations of MPM4CPS COST Action members discussing their work on foundations, techniques, application domains, and education in MPM4CPS, as well as joint work meetings. These proceedings collect the presentations given at the workshop. They cover many different aspects of multi-paradigm modelling for cyber-physical systems including, but not limited to

- foundations of MPM4CPS including
  - language engineering,
  - model transformations,
  - verification paradigms,
  - traceability;
- techniques in MPM4CPS including
  - co-simulation,
  - uncertainty modelling,
  - model-driven testing,
  - predictive analysis;
- application domains of MPM4CPS in the
  - automotive industry,
  - aviation industry,
  - smart grids,
  - robotics;
- education in MPM4CPS.

We would like to thank the presenters contributing their work to the MPM4CPS COST Action. Furthermore, we would like to thank Antonio Vallecillo, Loli Burgueño and Tanja Mayerhofer for organizing the workshop.

December 2016

IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems

MPM4CPS

Malaga, Spain, 24-25 November, 2016

Modeling Mobility using Dynamic Topology Models

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Portugal

Introduction

- The representation of spatially moving entities is commonly achieved using publish/subscribe communication (PSC)
- PSC can become complex and inefficient
  - requires the definition of regions of interest
  - generates false positive messages
- Conventional, **static**, peer-to-peer communication (P2PC), though usually more efficient, does not have the required flexibility to represent mobile entities

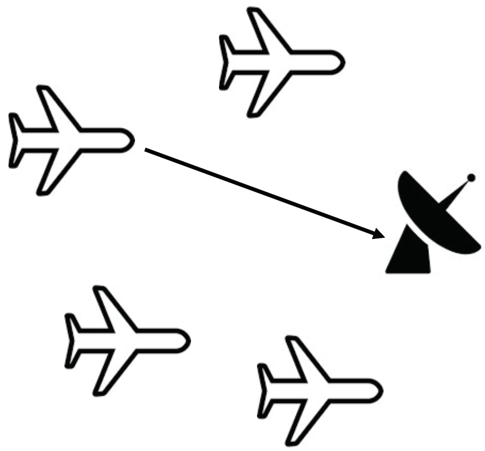
Introduction

- We have developed the integration of PSC and P2PC styles under the hierarchical and modular dynamic topology paradigm
- The unification is achieved using runtime topology adaptation
  It involves the dynamic creation/deletion of links to capture the current interactions between entities
- The architecture combines the advantages of PSC and P2PC, enabling a flexible simulation architecture

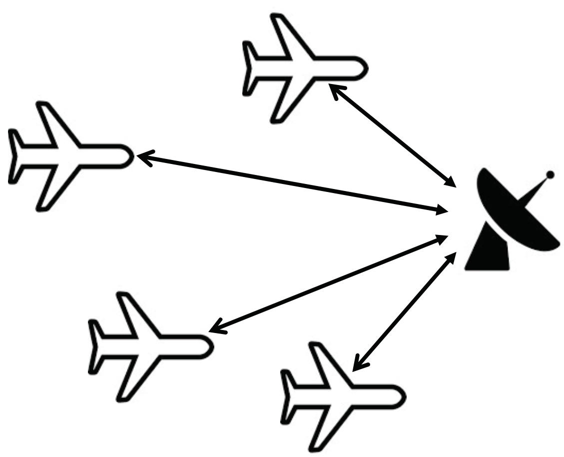
Introduction

- The architecture supports two types of PSC styles:
  - the traditional push style → events
  - the novel pull style → sampling
    abstracts information request and information sending
    enables, ex., a radar to sample at its own rate
- Benefits are demonstrated through the modeling of an air-defense scenario described in the HyFlow modeling and simulation framework

Push Communication



Pull Communication



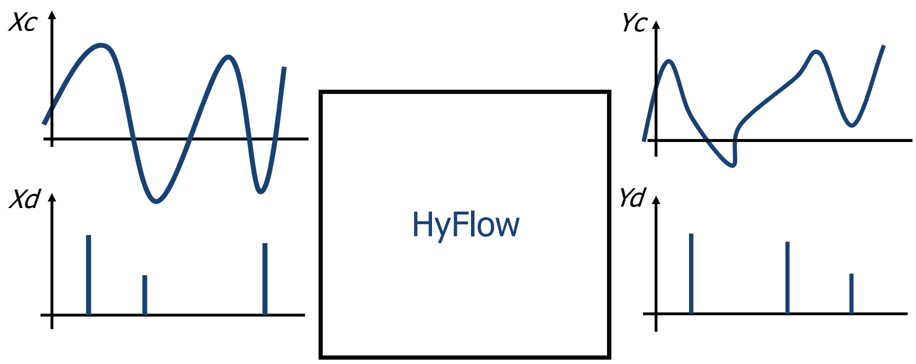
HyFlow Formalism

- The Hybrid Flow System Specification (HyFlow) is a formalism aimed to describe heterogeneous systems
- HyFlow combines traditional event-based systems and the novel concept of generalized sampling
- HyFlow can describe dense trajectories through the concept of continuous flow
- Trajectories can be sampled enabling the description of numerical methods for ODE (ordinary differential equation) integration and event-detection (zero-crossing detector)

HyFlow/JUse M&S Environment

- HyFlow has two types of models: basic and network
- A basic model can read and produce continuous and discrete flows (events) and it provides the basic operators for state representation and dynamic behavior
- A network model is a composition of basic models and/or other network models providing an abstraction for representing hierarchical systems

HyFlow Basic Model



HyFlow Basic Model

$M_B = (X, Y, P, \rho, \omega, s_0, \delta, \bar{\Lambda}, \ddot{\Lambda})$

$X = \bar{X} \times \ddot{X}$ is the set of input flow values

> $\bar{X}$ is the set of continuous input flow values
> $\ddot{X}$ is the set of discrete input flow values

$Y = \bar{Y} \times \ddot{Y}$ is the set of output flow values

> $\bar{Y}$ is the set of continuous output flow values
> $\ddot{Y}$ is the set of discrete output flow values

P is the set of partial states (p-states)

$\rho : P \longrightarrow \mathbb{H}_0^+$ is the time-to-input function

$\omega : P \longrightarrow \mathbb{H}_0^+$ is the time-to-output function

HyFlow Basic Model

$M_B = (X, Y, P, \rho, \omega, s_0, \delta, \bar{\Lambda}, \ddot{\Lambda})$

$S = \{(p, e) | p \in P, 0 \leq e \leq \nu(p)\}$ is the state set

with $\nu(p) = \min\{\rho(p), \omega(p)\}$, the time-to-transition function

$s_0 \in S$ is the initial state

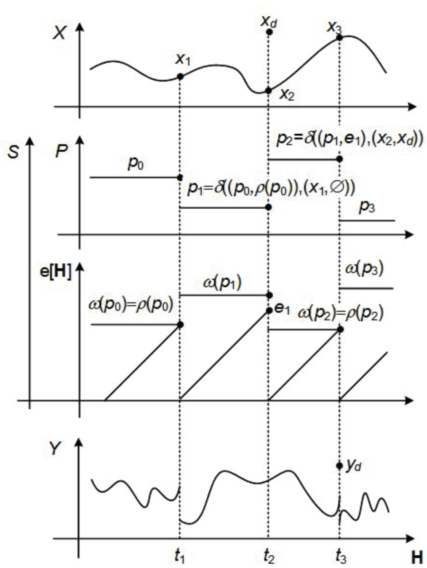
$\delta : S \times X^{\phi} \longrightarrow P$ is the transition function

where $X^{\phi} = \bar{X} \times (\ddot{X} \cup \{\phi\})$
and ϕ is the null value (absence of value)

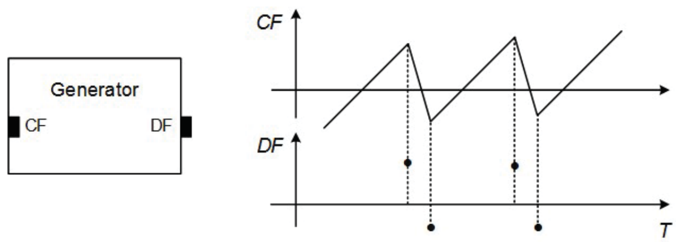
$\bar{\Lambda} : S \longrightarrow \bar{Y}$ is the continuous output function

$\ddot{\Lambda} : S \longrightarrow \ddot{Y}$ is the discrete output function

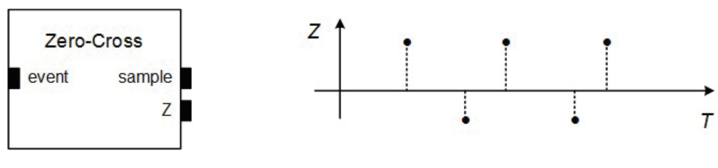
HyFlow Basic Model



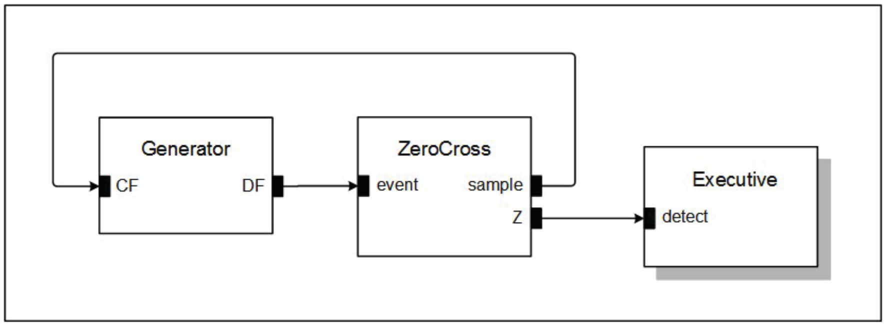
Generator (Basic) Model



Zero-Cross (Basic) Model



HyFlow Network Model



HyFlow/JUse M&S Environment

```
class GeneratorZeroCross extends Executive {
	public void topology() {
		super.topology();
		addComponent(Generator, "Generator");
		addComponent(ZeroCross, "ZeroCross");
		link("Generator", "DF", "ZeroCross", "event");
		link("ZeroCross", "sample", "Generator", "CF");
		link("ZeroCross", "Z", "Executive", "detect");
	}
	public void detect(double clock, double value) {
		println "$clock\t$value";
	}
}
```

HyFlow/JUse M&S Environment

- The topology (composition and linking) of HyFlow networks is dynamic, enabling to adjust the model according to, for example, the distance between moving entities
- It becomes possible to link mobile entities that are within sensor range, and to remove these communication links when entities become far apart

HyFlow/JUse M&S Environment

- Network topology is managed by the HyFlow executive component
- This element is a HyFlow basic model increased with topology management operations
- This design enables the direct communication of the executive with the other network components
- Components can make requests to modify the topology and also to retrieve information about the current network topology

HLA Overview

- The High Level Architecture (HLA) is a standard for M&S
- HLA is based on publish-subscribe communication (PSC)
- HLA enables the interoperability of simulators to create complex scenarios
- HLA supports federates, and federations (a combination of federates)

HLA Overview

- HLA-objects can be used to achieve the communication through shared memory
- HLA-objects are passive entities depending on federates to be modified
- The federates involved in HLA-object management and information retrieval have their reuse severely limited

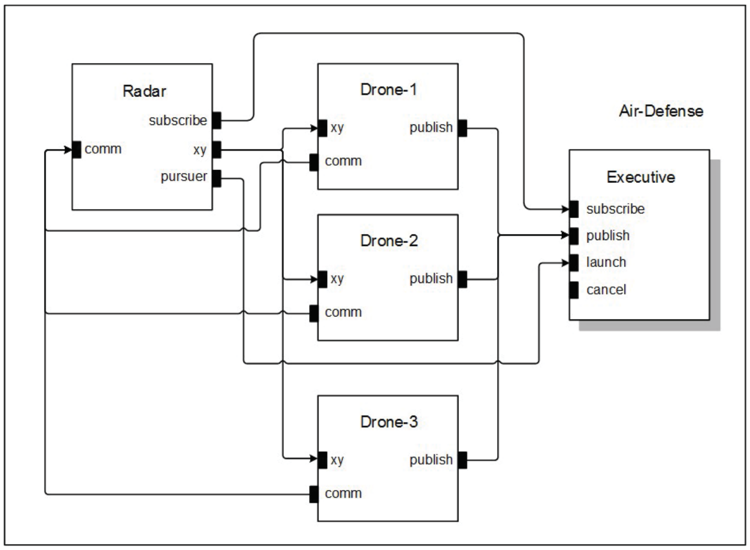
HLA Limitations

- HLA RTI cannot be modified
  - no support for P2PC
- HLA supports only flat models
  - complex models benefit form a hierarchical representation
- HLA imposes PSC
  - P2PC can provide a better representation
- HLA is based on the discrete-event paradigm
  - how to represent continuous models?
    - moving entities?

Combining P2P with PSC

- Publish/subscribe operations provide an abstraction for describing dynamic topologies
- New components can be added/removed dynamically to/from a network without affecting the existing components
- P2P communication is more efficient for representing known links
  - no false positive messages
  - requires no filters
- Our solution
  - Use dynamic P2PC to represent PSC

Combining P2P with PSC



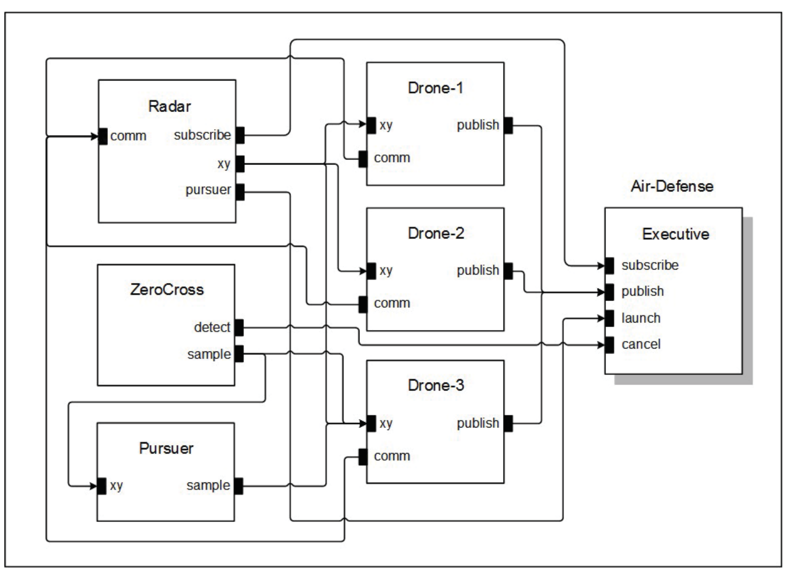
Combining P2P with PSC

- Topology can be described in a compact manner by bulk commands
- Drone-1, ..., Drone-3
  - publish(CF, xy)
  - publish(DF, comm)
- Radar
  - subscribe(CF, xy)
  - subscribe(DF, comm)
- Bulk commands can be mapped into P2PC links in JUse-HyFlow
  - Provides the unification of PSC and P2PC

Combining P2P with PSC

- In many models we want to link entities that are known to interact:
  - Pursuer-drone
    - A purser is only connected to one target, why using PSC?
  - Radar-drone
    - Accurate detection requires adaptive sampling depending on beam-drone distance!
- HyFlow executive can create dynamic links to support P2PC communication

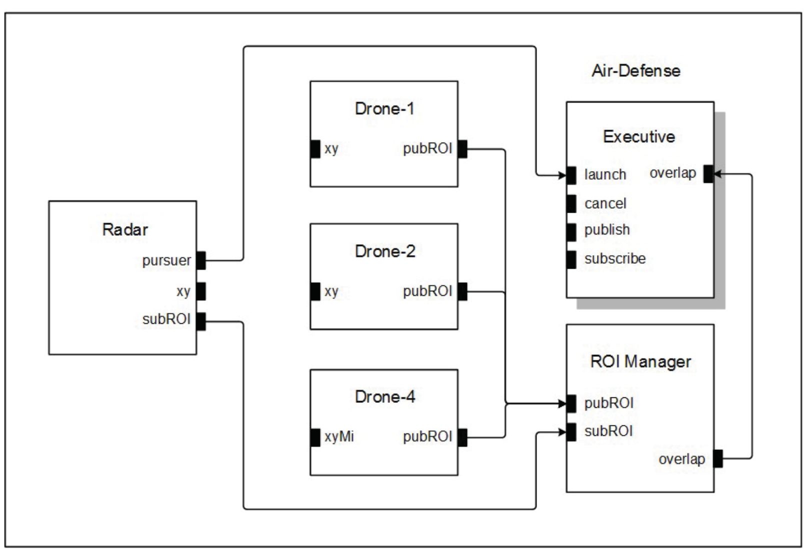
Combining P2P with PSC



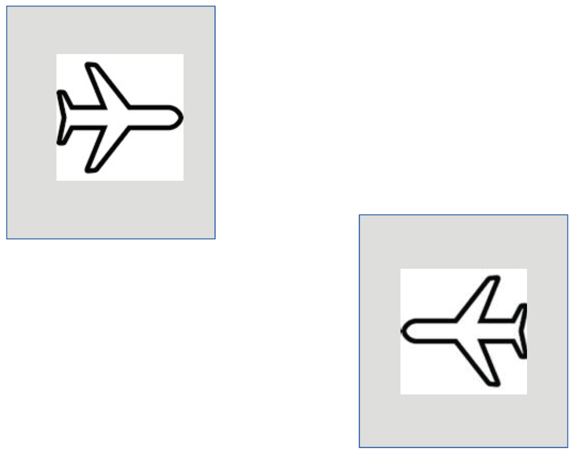
Air-Defense

- Spatial partitioning can be integrated with P2PC in order to achieve an efficient description of mobile entities
- We consider a region of interest (ROI) manager component with the ability to keep track of publish/subscribe
- Entities can declare ROIs to the manager
  - when these regions overlap, this component sends a signal to the executive that can adapt the topology

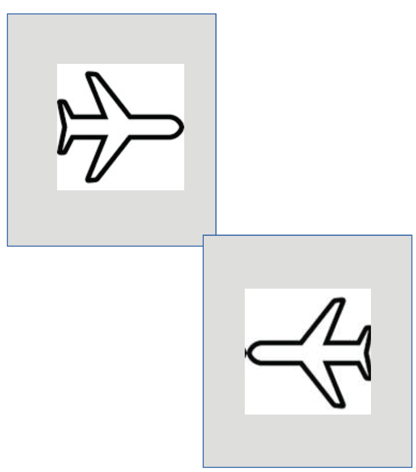
Air-Defense



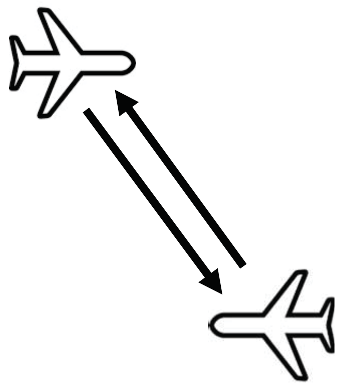
ROIs



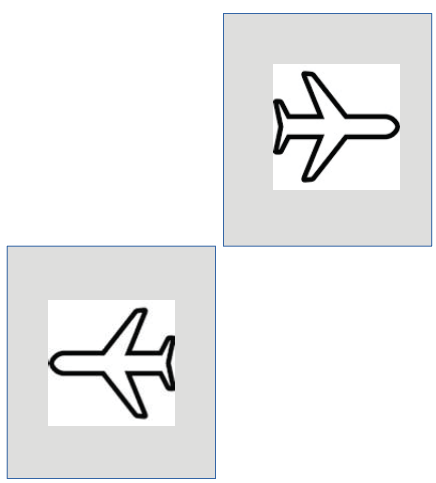
ROIs



Peer-to-Peer Communication



ROIs



Air-Defense

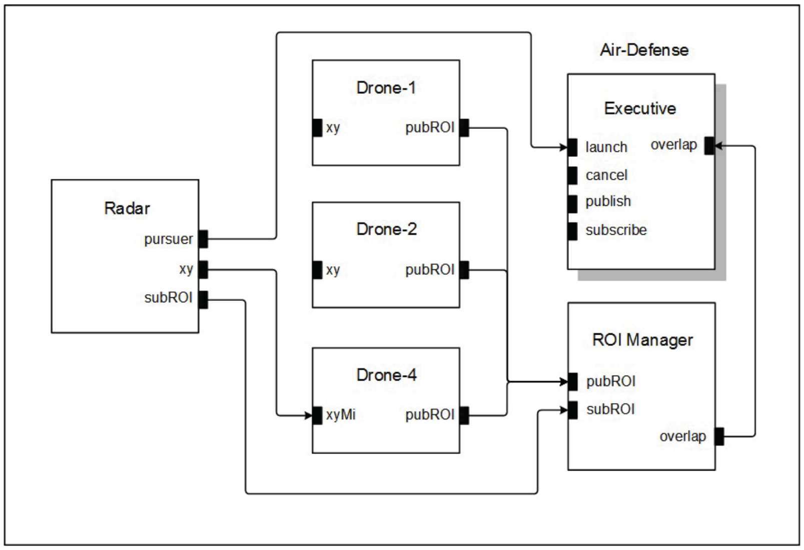
- As entities move, their regions of interest will eventually overlap
- The manager upon overlap detection sends a request to the executive that will create a link between the radar and the drone so it can be tracked
- Drone-4 cannot be used in conventional publish-subscribe communication since its interface does not match radar sampling port xy
- Drone port xyMi conveys the position in miles, while the radar requires this information in km

Air-Defense

- The communication between the radar and Drone-4 is established by the JUse-HyFlow command:

```
link("Radar","xy","Drone-4", "xyMi",
  x->x, mi->[1.61*mi[0],1.61*mi[1]])
```

Air-Defense



Air-Defense

- HyFlow dynamic peer-to-peer communication is able to represent publish-subscribe communication
- It can also represent the space partitioning algorithms required to obtain an efficient representation of moving entities
- Additionally, peer-to-peer links can be established using JUse-HyFlow adapter capabilities

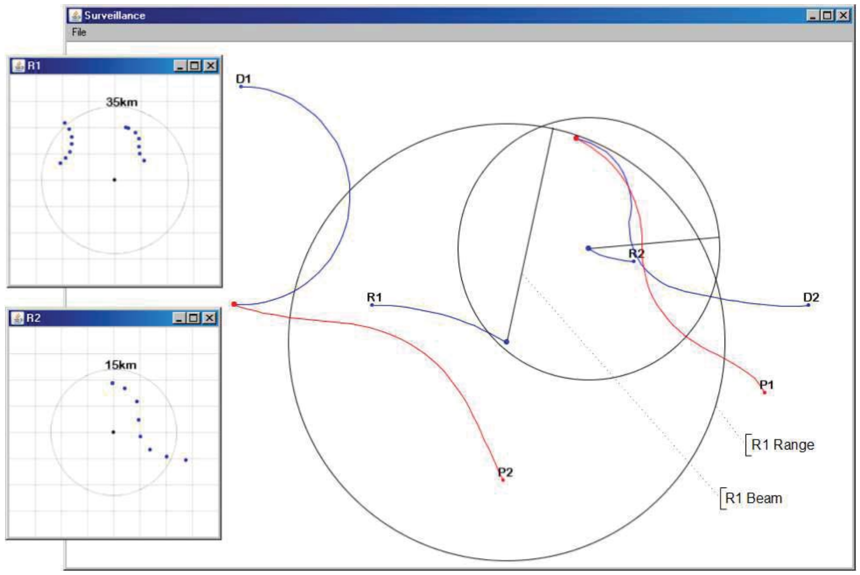
Air-Defense

- Scenario with two airborne radars, R1 and R2, moving at constant velocities with fixed radius trajectories
- Two drones, D1 and D2, moving at a constant velocity but with a piecewise constant radius that changes at random times
- The radars are modeled by their rotating beams that have a fixed period
- A radar echo is produced when a radar beam detects a drone

Air-Defense

- These interactions requires the creation of a new detector for each drone
  - it benefits from P2PC to enable the detector to sample the position information from both the radar beam and from a specific drone
- Upon detection, radars can launch a pursuer to disable the drone
- Pursuers have a digital controller that uses a proportional law for guidance

Air-Defense



Conclusion

- Publish-subscribe interaction can be mapped into a peer-to-peer communication network with a dynamic topology
- This mapping enables both communication styles to be used in combination to describe different aspects of the same model
- The integration of styles enables modelers to use the best representation for a given system

Future Work

- We plan to extend JUSE-HYFLOW model library in order to represent more complex and detailed scenarios
- We consider also that future versions of the HLA supporting the modeling constructs discussed here, like the open RTI, sampling, and peer-to-peer connections, can improve its expressiveness simplifying the description of complex systems

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- http://dx.doi.org/10.1016/j.simpat.2016.06.001

MPM4CPS

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

COST Action IC1404 “MPM4CPS” workshop
Malaga, Spain 24 November 2016

Engineering Hybrid Modelling Languages

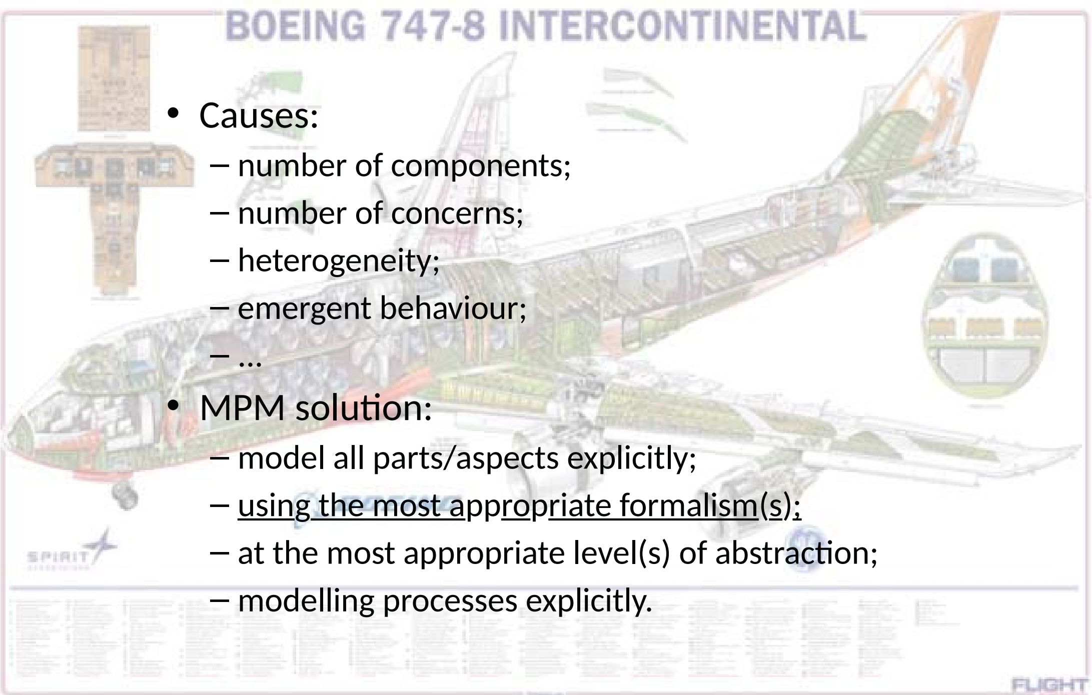
Sadaf Mustafiz Cláudio Gomes Bruno Barroca Hans Vangheluwe

Sadaf Mustaz, Claudio Gomes, Bruno Barroca, and Hans Vangheluwe. Modular design of hybrid languages by explicit modeling of semantic adaptation. In Proceedings of the 2016 Symposium on Theory of Modeling and Simulation - DEVS , TMS/DEVS '16, part of the Spring Simulation Multi-Conference, pages 591 - 598. Society for Computer Simulation International, April 2016.

Sadaf Mustaz, Bruno Barroca, Claudio Gomes, and Hans Vangheluwe. Towards modular language design using language fragments: The hybrid systems case study. In Proceedings of the 13th International Conference on Information Technology: New Generations (ITNG 2016) , pages 785 - 797. Springer, April 2016.

McGill necsis FLANDERS MAKE MANUFACTURING INNOVATION NETWORK Universiteit Antwerpen

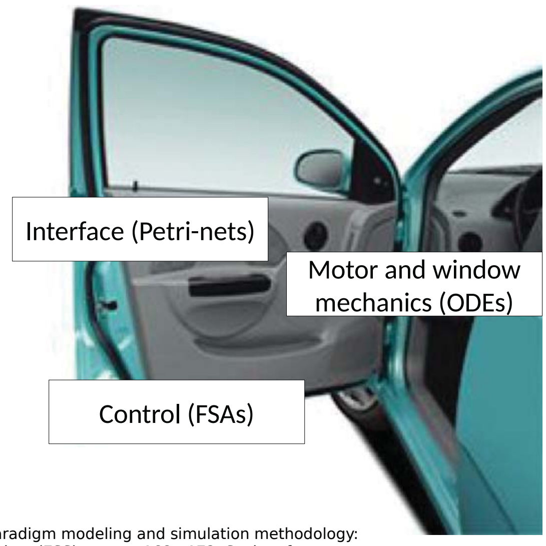
Dealing with Complexity



- Causes:
  - number of components;
  - number of concerns;
  - heterogeneity;
  - emergent behaviour;
  - ...
- MPM solution:
  - model all parts/aspects explicitly;
  - using the most appropriate formalism(s);
  - at the most appropriate level(s) of abstraction;
  - modelling processes explicitly.

Most Appropriate Formalism(s)

- Multiple components/views require multiple formalisms
- Interactions/Relations between formalisms require **Hybrid Formalisms**
  (when mapping onto a single common formalism is impossible)



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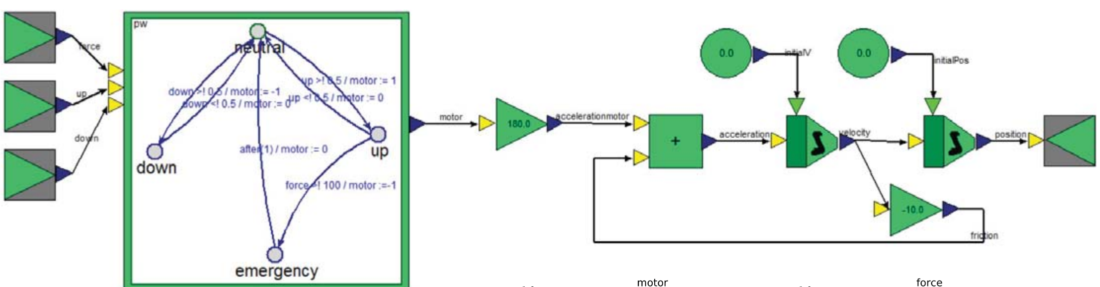
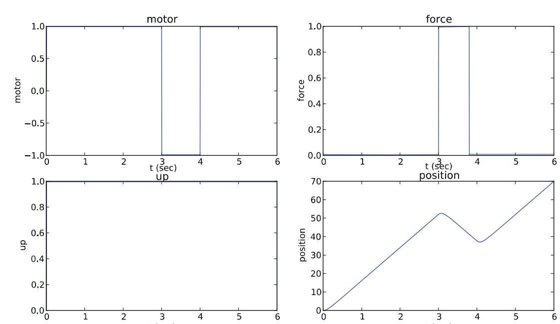
Example 1: CBD (host) + TFSA (embedded)

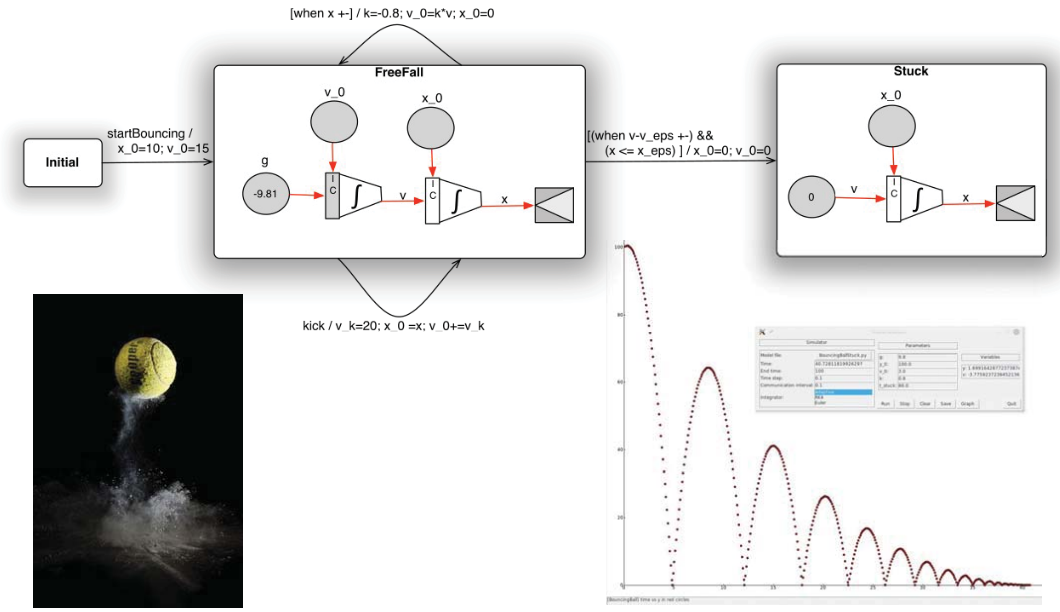




Bart Meyers, Joachim Denil, Frederic Boulanger, Cecile Hardebolle, Christophe Jacquet, Hans Vangheluwe. A DSL for Explicit Semantic Adaptation. MPM@MoDELS 2013:47-56.

Joachim Denil, Bart Meyers, Paul De Meulenaere, and Hans Vangheluwe. Explicit semantic adaptation of hybrid formalisms for FMI co-simulation. In Proceedings of the 2015 Spring Simulation Multi-Conference, pages 852 - 859. SCS, April 2015.

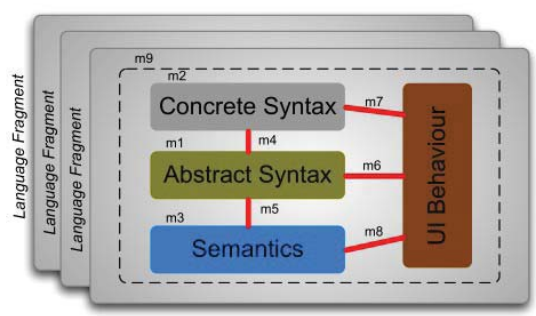
Example 2: TFSA (host) +CBD (embedded)



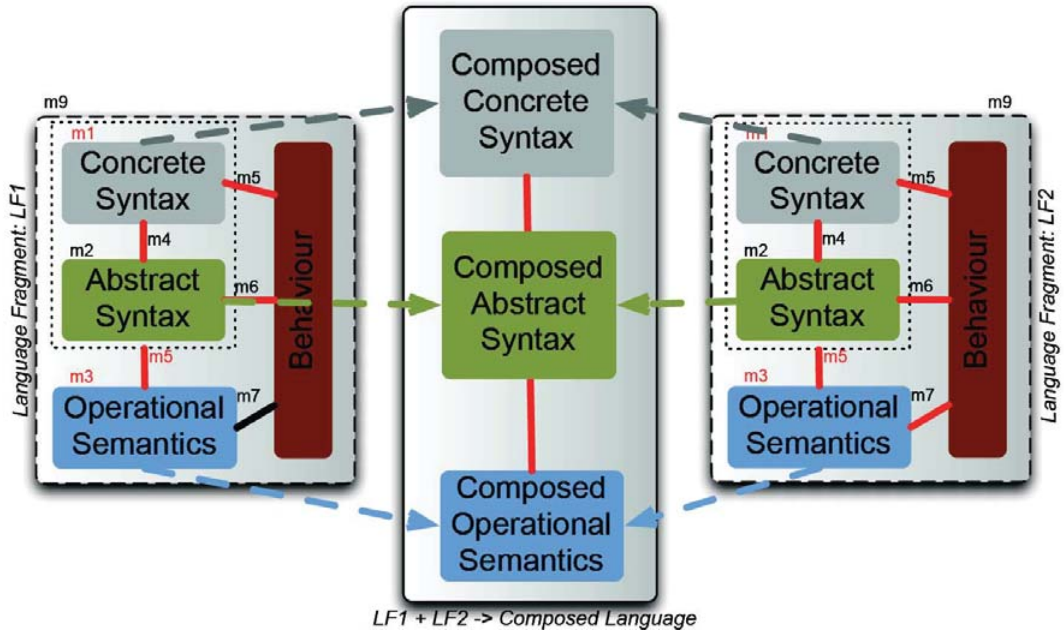
Simon Lacoste-Julien, Hans Vangheluwe, Juan de Lara, and Pieter J. Mosterman. Meta-modelling hybrid formalisms. In Pieter J. Mosterman and Jin-Shyan Lee, editors, IEEE International Symposium on Computer-Aided Control System Design , pages 65 - 70. IEEE Computer Society Press, September 2004. Taipei, Taiwan.

Modular Language Engineering: Language Specification Fragments (LSF)

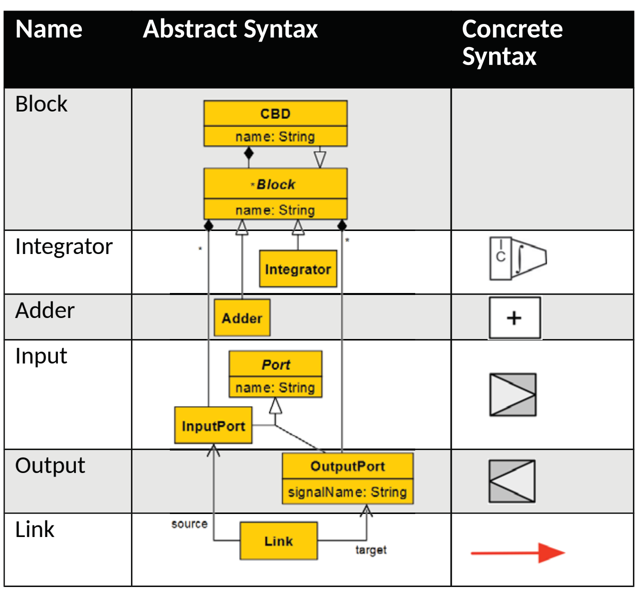
- Reusable components of a language specification
  - Syntax (Concrete/Abstract)
  - Operational semantics
  - UI-Behavior
- Combine fragments to create hybrid languages

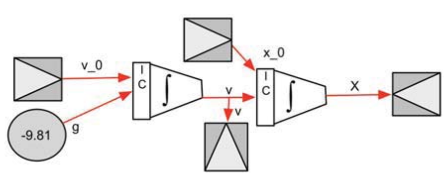


Composition of Language Specification Fragments



Background: CBD* Syntax

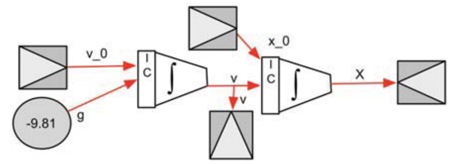


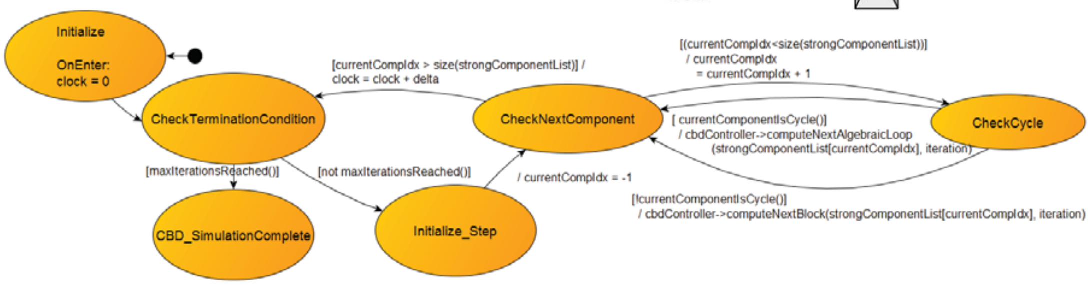


*Causal Block Diagram (such as Simulink®)

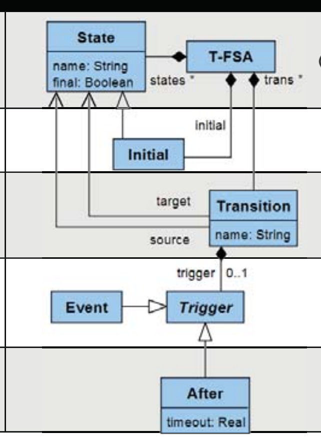
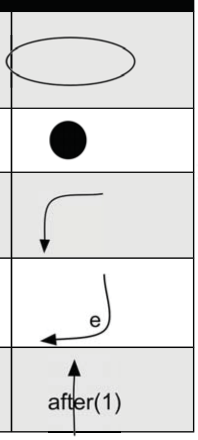
Background: CBD Semantics

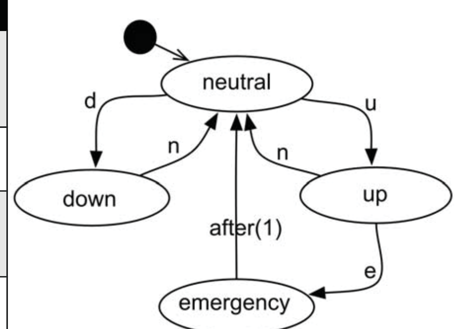
```
logicalTime ← 0
while not end_condition do
    schedule ← LOOPDETECT(DEPGRAPH(cbd))
    for gblock in schedule do
        COMPUTE(gblock)
    end for
    logicalTime ← logicalTime + Δt
end while
```





Background: TFSA* Syntax

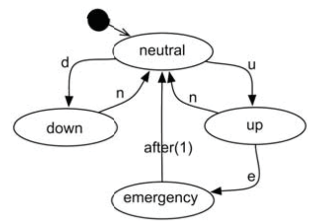
Name	Abstract Syntax	Concrete Syntax
State		
Initial State		
Transition		
Event		
Timeout		

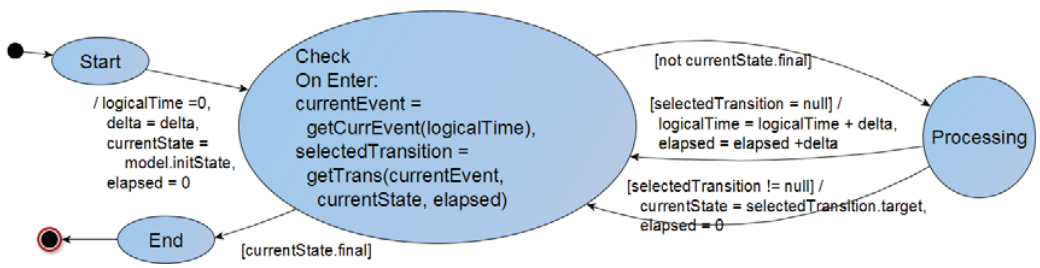


*Timed Finite State Automata

Background: TFSA Semantics

logicalTime, elapsedTime ← 0 ; currentState ← initialState
while currentState is not final **do**
    E ← getInputEventAt(logicalTime)
    if out-transition T from currentState has trigger E **then**
        currentState ← T.destination ; elapsedTime ← 0
        removeInputEventFromInputList(E)
    end if
    if out-transition T from currentState has after(time) & time $\leq$ elapsedTime **then**
        currentState ← T.destination ; elapsedTime ← 0
    end if
    logicalTime ← logicalTime $+\Delta t$; elapsedTime ← elapsedTime + Δt
end while

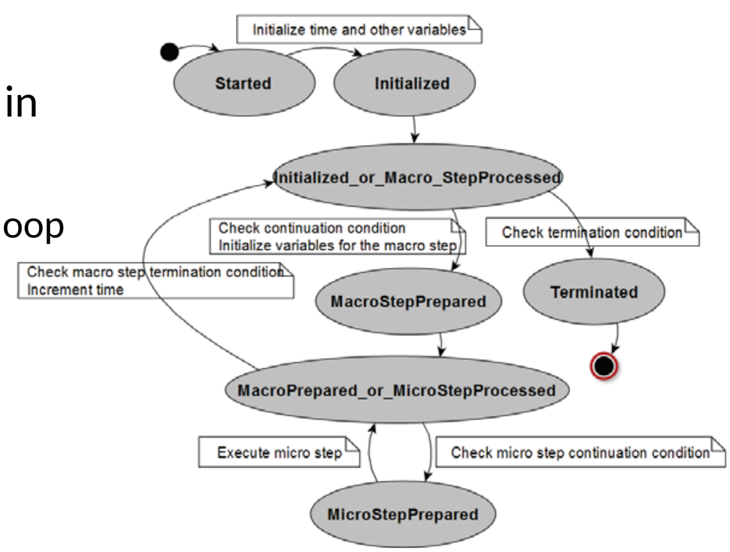




Canonical Operational Semantics

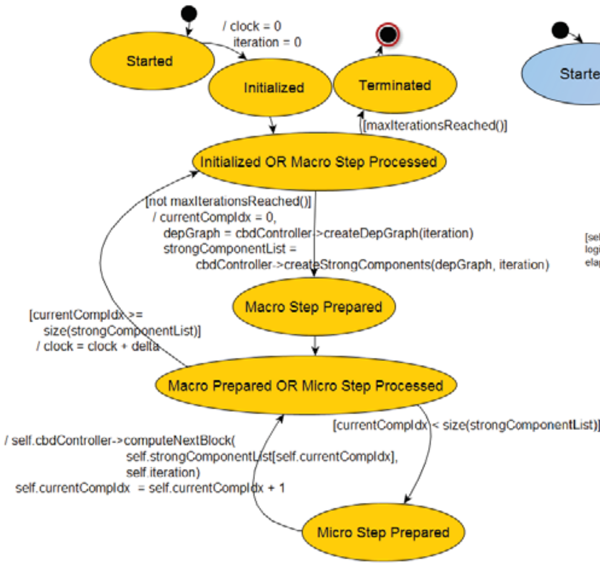
Common pattern in simulators

- Main simulation loop
- Macro-steps
- Micro-steps

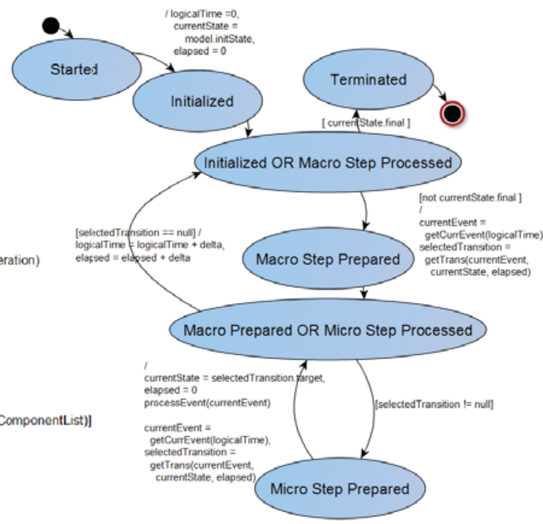


Canonical Operational Semantics of the formalisms to be combined

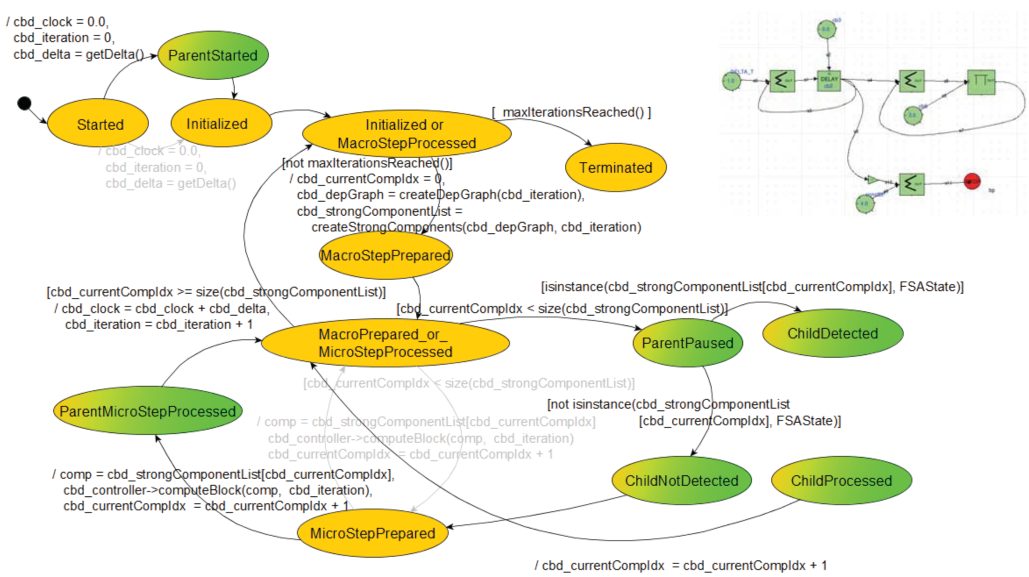
CBD



TFSA

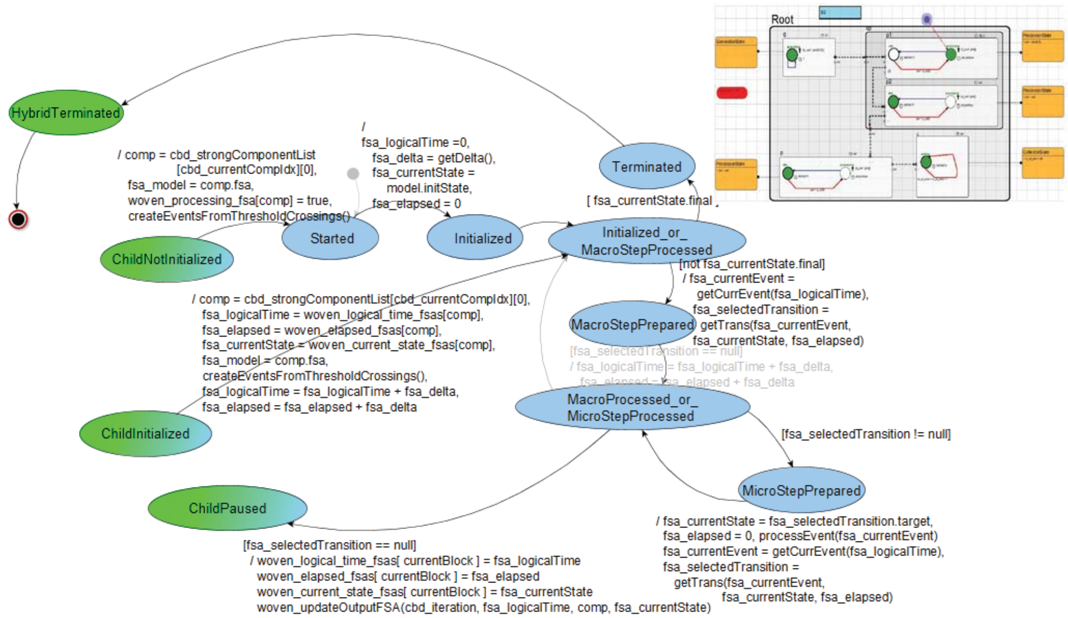


Side-effect of Explicitly Modeled Operational Semantics: Interrupts/Breakpoints Instrumentation (CBD)



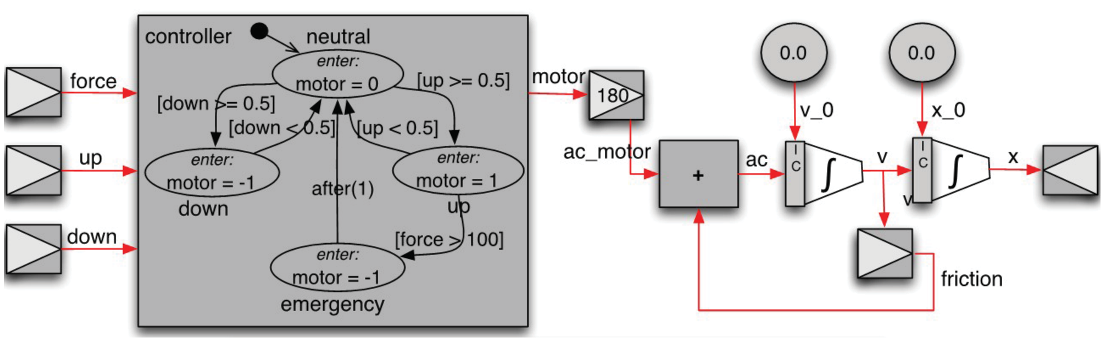
Hans Vangheluwe, Daniel Riegelhaupt, Sadaf Mustaz, Joachim Denil, and Simon Van Mierlo.
Explicit Modelling of a CBD Experimentation Environment. TMS/DEVS '14, pages 379 – 386. April 2014.

Side-effect of Explicitly Modeled Operational Semantics: Interrupts/Breakpoints Instrumentation (TFSA)



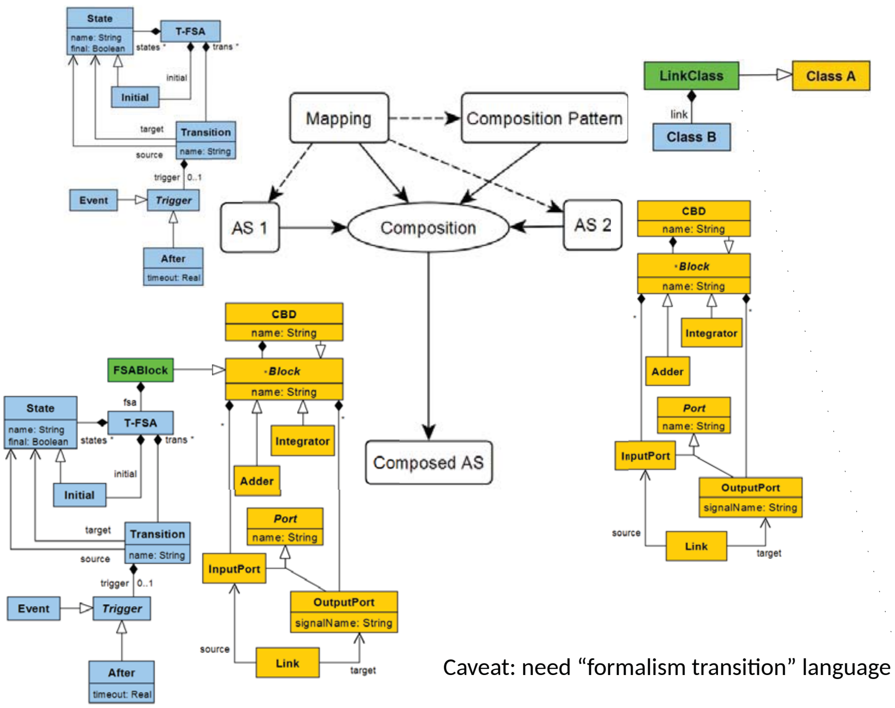
Simon Van Mierlo, Yentl Van Tendeloo, Sadaf Mustaz, Bruno Barroca, and Hans Vangheluwe.
Explicit modelling of a Parallel DEVS experimentation environment. TMS/DEVS '15, pages 860 - 867. April 2015.

Example 1:
Hybrid CBD (host: CBD; embedded: TFSA)



Power-window model

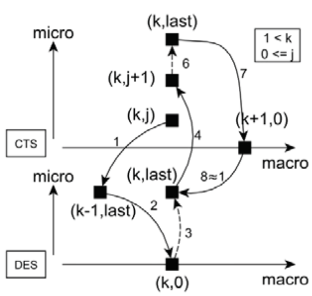
Workflow: Combine AS



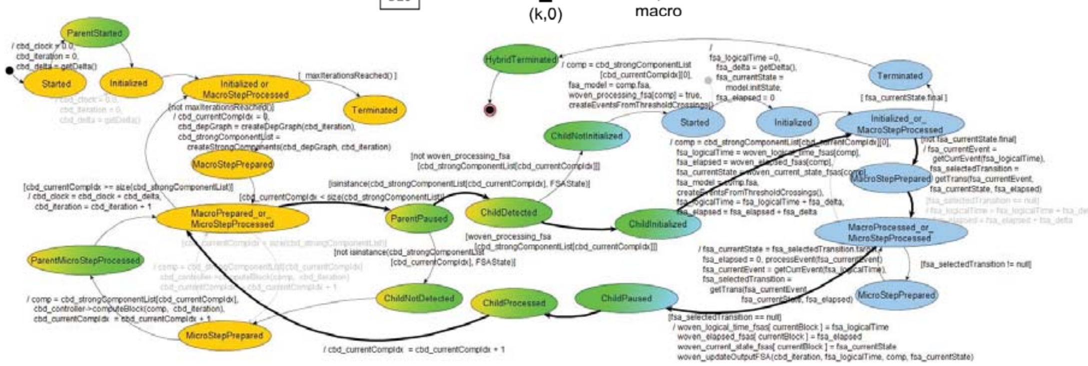
Caveat: need “formalism transition” language too!

Hybrid CBD (host) operational semantics

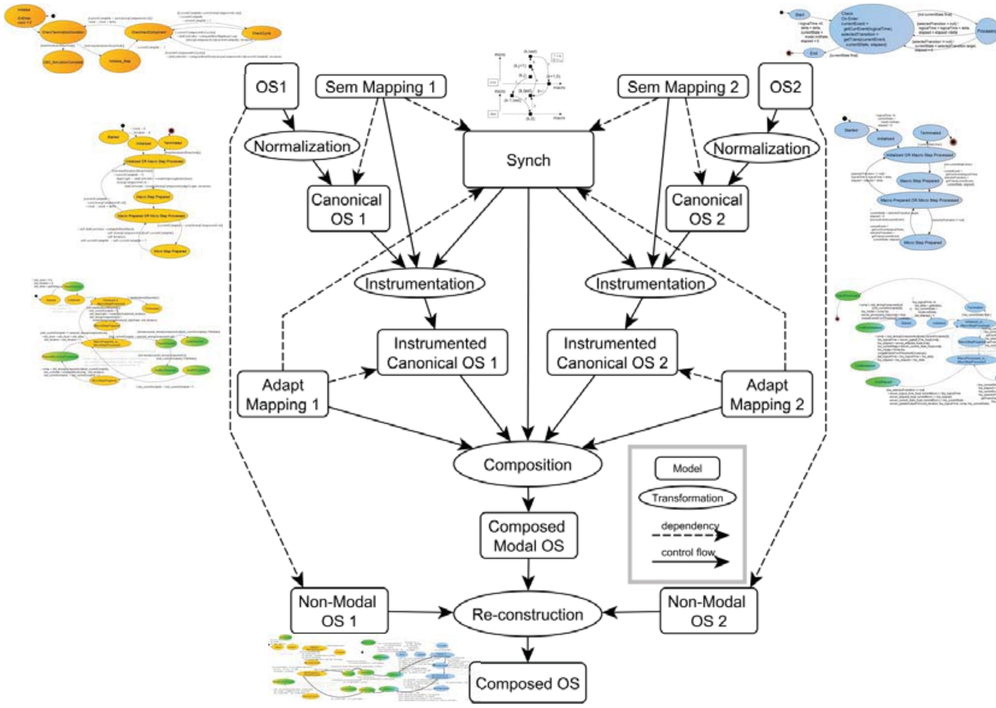
need “orchestration” language
(to specify how to interleave OS)



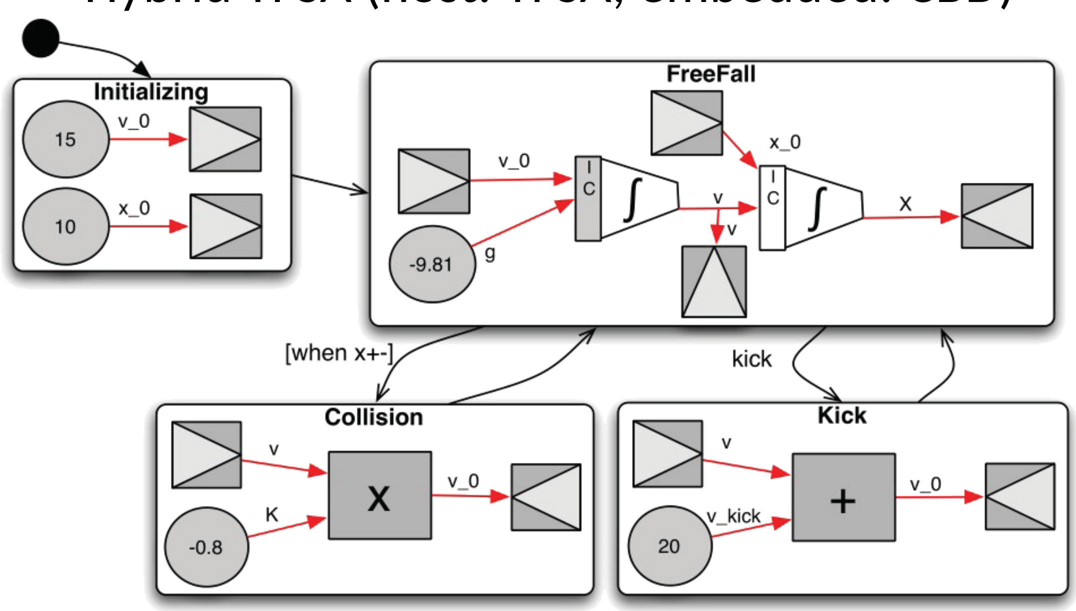
Gheorghe, L., Bouchhima, F., Nicolescu, G., and Boucheneb, H. Semantics for Model-based Validation of Continuous/Discrete Systems. In DATE ’08, pages 498–503.



Workflow: Combine OS

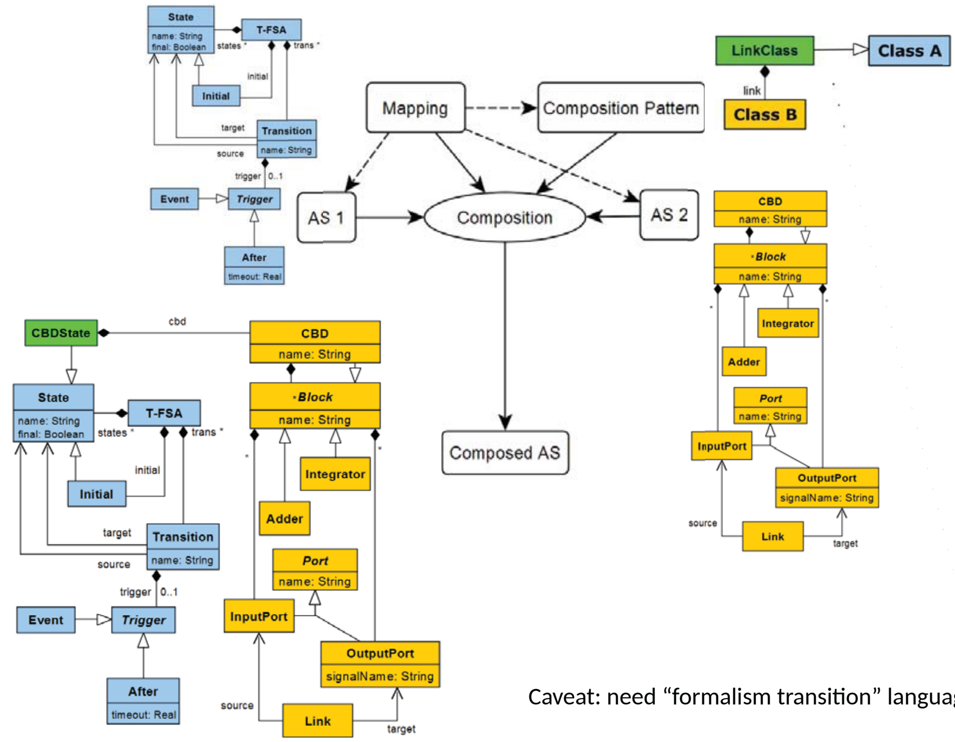


Example 2:
Hybrid TFSA (host: TFSA; embedded: CBD)



Bouncing ball model

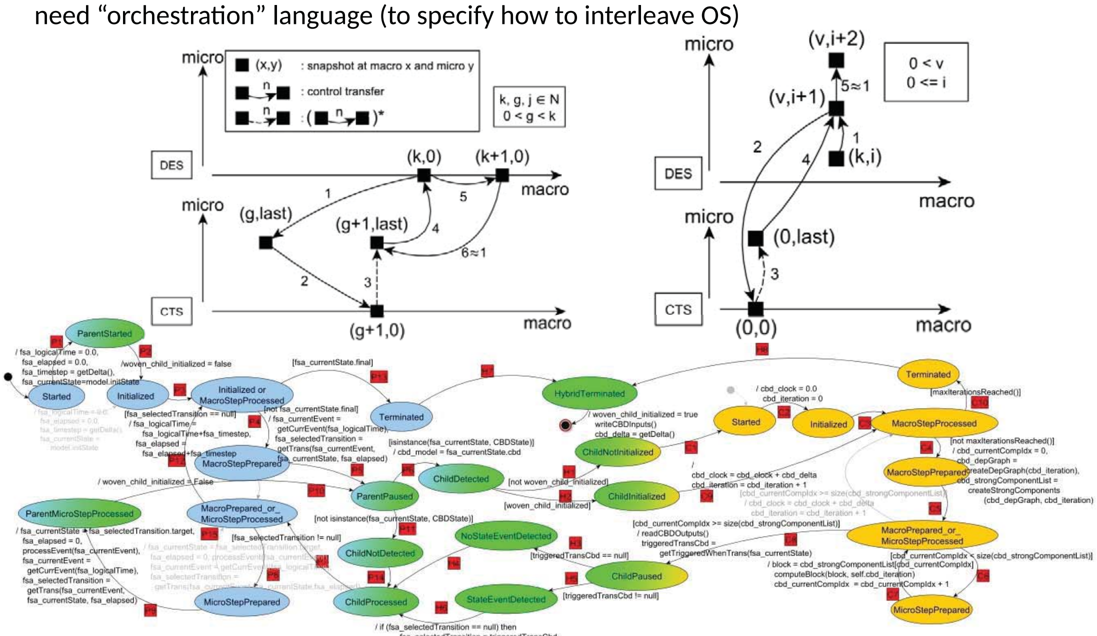
Workflow: Combine AS



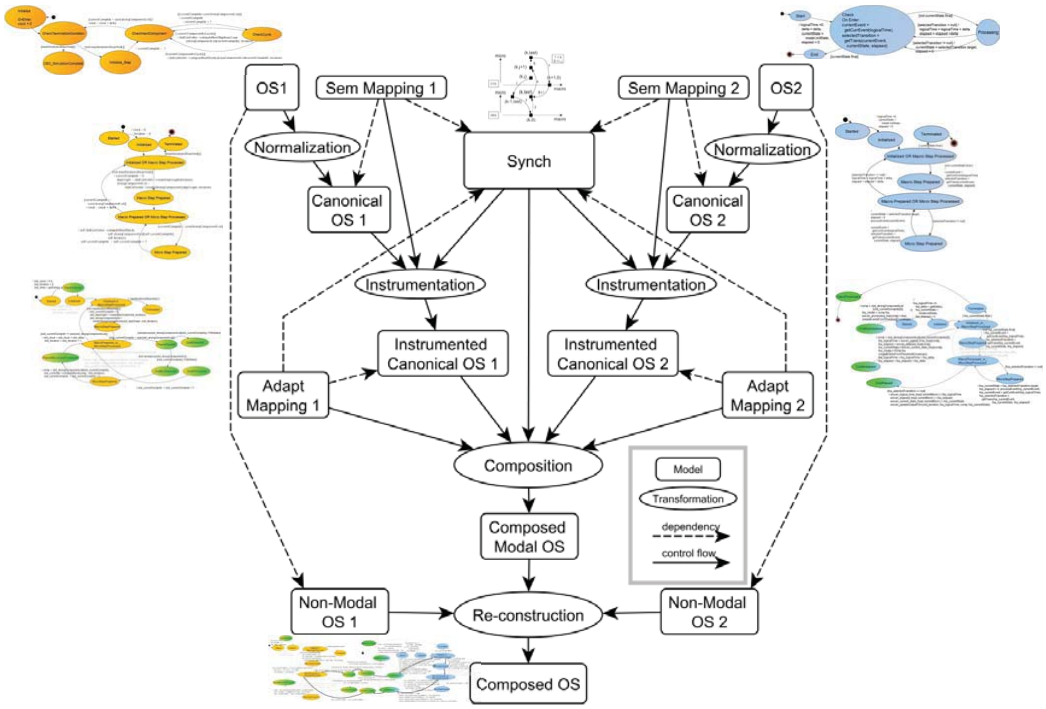
Caveat: need “formalism transition” language too!

Hybrid TFSA (host) operational semantics

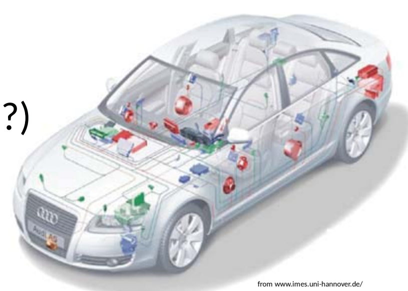
need “orchestration” language (to specify how to interleave OS)



Workflow: Combine OS



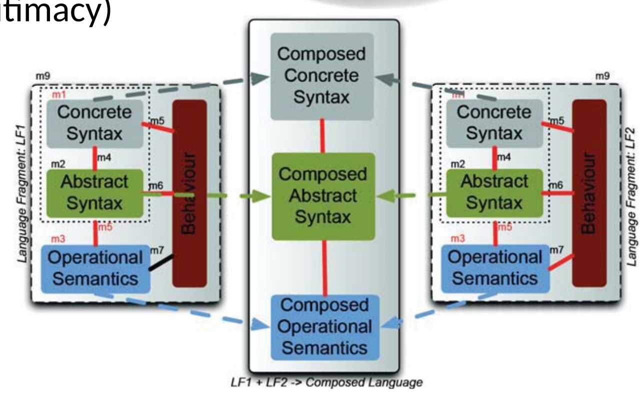
“Optimal” (Hybrid) Formalism?



from www.imes.uni-hannover.de/

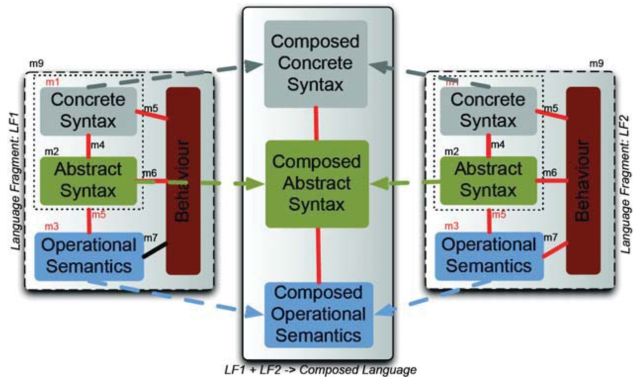
Correct semantic composition (verification possible when modelled?)

- Language continuity
- Completeness of semantics
- Determinism
- Step progression (legitimacy)
- Synchronization
- Fairness
- …



Future Work

- Develop “language transition”, “orchestration” languages
- Hybrid languages are LSFs too
  - Combined to form other Hybrid languages.
  - Support for debugging of simulations
- LSFs for
  - TFSA
  - CBD
  - Dynamic Structure
  - Spatial Distribution
  - Concurrency
  - …



Real-Time MDE: An Overview

Moussa AMRANI, Pierre-Yves SCHOBBENS

MPM4CPS

Cost Action IC1404
MPM4CPS Workshop
Málaga, Spain – Thursday 24-25 November 2016

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On a New Project...

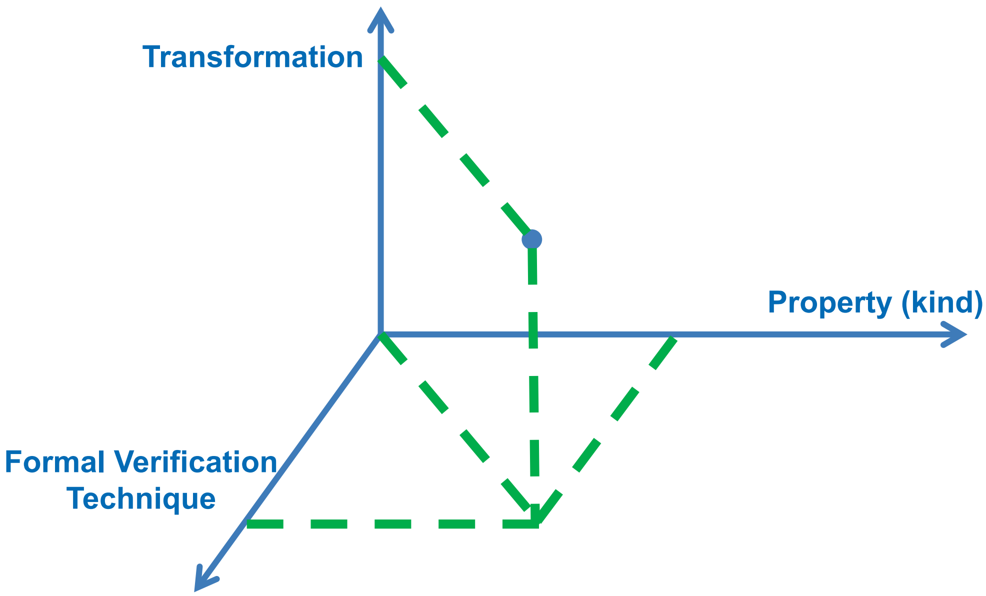
Wallonie

SCADE

C Language

MATLAB SIMULINK

MDE 3D Classification



Amrani, M. and Combemale, B. and Lucio, L. and Selim, G. and Dingel, J. and Le Traon, Y. and Vangheluwe, H. and Cordy, J. ***Formal Verification Techniques for Model Transformations: A Tridimensional Classification***. Journal of Technology (2014)

Barriers for RT Formal Verif.

- ❑ Undecidability
  - Both from the timed and non-timed parts, which are often intrically mixed into functionalities
  - Abstractions required in each part for performing formal verification
- ❑ Tool Maturity
  - Most tools work on very low-level representations (automata + various logics)
  - How to relate results back to model level?

UPPAAL

KRONOS

Maude

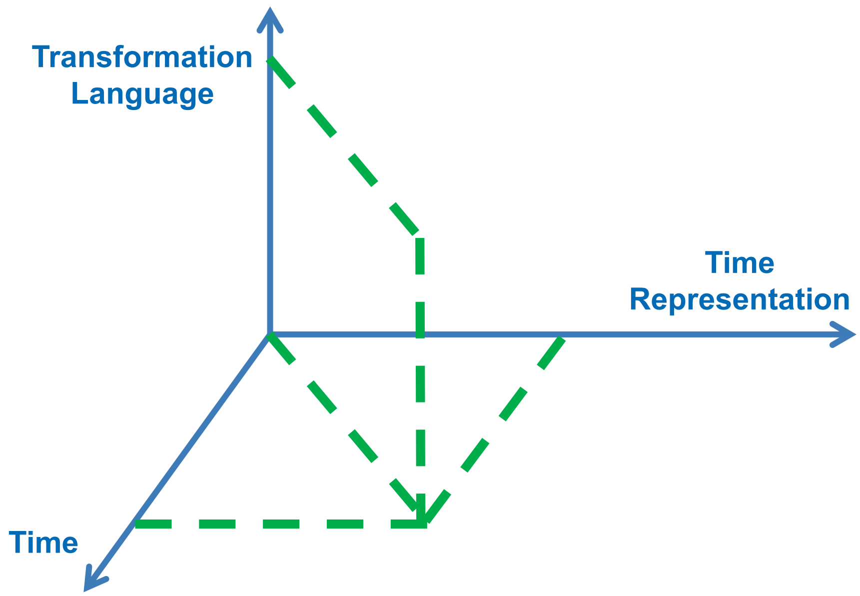
- ❑ Theoretical Foundations in MDE
  - What is a « good » notion of time?
  - Is there a « universal » notion of time?

Agenda

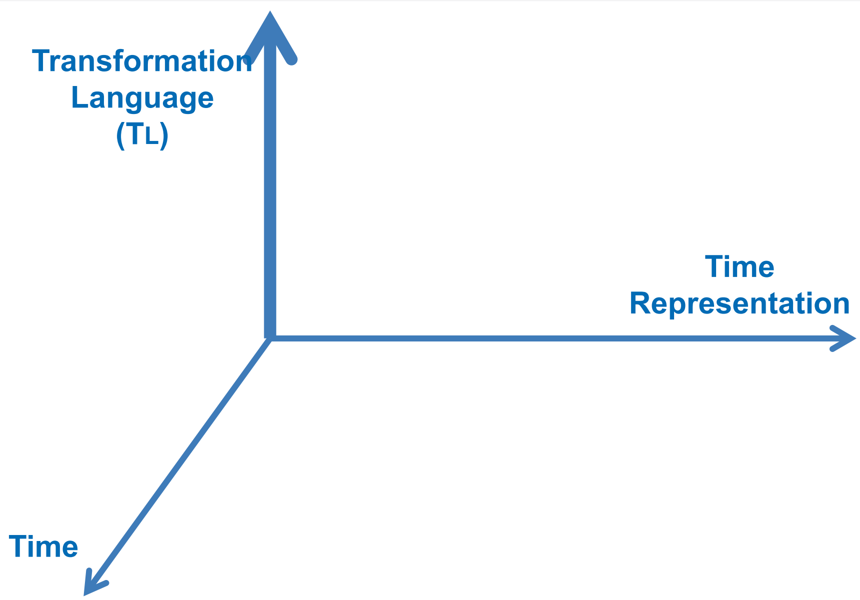
1. Classification
2. Contributions Overview
3. Conclusions

CLASSIFICATION

RT-MDE Classification



Transformation Languages



Graph-Based TLs (GBTLs)

❑ Formal Background: Category Theory [1]

- Tgg,
- Some MDE features (e.g., inheritance & containment) addressed recently [2]

❑ Usually, visual (or hybrid) concrete syntax

- Customisable with metamodel concepts [3,4]
- Also with pure textual syntax (e.g., ATL)

❑ Common formal background with Petri Nets (PNs) [6]

- Reuse of existing tools and existing Fv techniques

[1] ROZENBERG, G. (Ed.) (1997). ***Handbook of Graph Grammars and Computing by Graph Transformation (Vol. I)***. World Scientific Publishing.
[2] JURACK S. and TAENTZER, G. (2010). A Component Concept for Typed Graphs With Inheritance and Containment Structures. In *ICGT*, pp. 187–202.
[3] TAENTZER, G. (2000). AGG: A Tool Environment for Algebraic Graph Transformation. In AGTIVE, LNCS 1779, pp. 333–341.
[4] DE LARA, J. and VANGHELUWE, H. (2002). Using ATOM3as a Meta-CASE Tool. In ICEIS, pp. 642–649.
[6] MAXIMOVA, M. and EHRIG, H. and ERMEL, C. (2010). Formal Relationship Between Petri Net and Graph Transformation Systems Based on Functors between M-Adhesive Categories. In PN-GT, vol. 40, pp. 23–40.

Meta-Programmed Languages (MPLs)

❑ « Action » Languages [1]

- Specifically designed for manipulating model features;
- Operational in nature;
- Usually using a textual syntax close to code

❑ Formal backgrounds

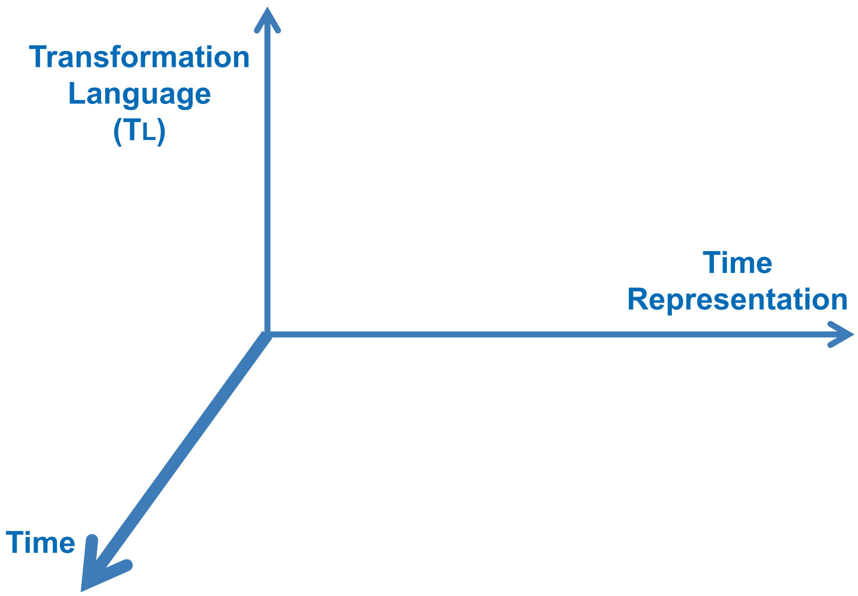
- Semantics foundations from imperative / Object-Oriented Languages [2].

❑ Possible reuse of existing technology

- With a high price for adapting it;
- Not necessarily at the adequate abstraction level

[1] COMBEMALE, B. and CRÉGUT, X. and GAROCHE, P.-L. and THIRIOUX, X (2009). Essay On Semantics Definition in MDE – An Instrumented Approach for Model Verification. *Journal of Software*, **4**(9), pp. 943–958.
[2] G. WINSKEL (1993). ***The Formal Semantics of Programming Languages: An Introduction***. MIT Press.

Time



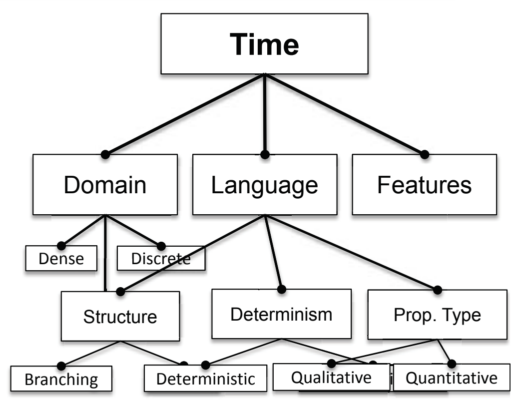
Time Features

❑ Domain

- Discrete (with integers) or Dense (with rationals or reals)
- If bounded, simplifies the Fv

❑ Language

- ❑ ***Structure***, describing how internal states are organised:
  - Linear, in the form of *sequences*
  - Branching, in the form of *trees*
- ❑ ***Determinism***, describing how precisely the system is known:
  - Abstraction from implementation details;
  - Possible unprescribed choices ;
  - Unknown environment
- ❑ ***Property Type***, indicating which language's type of properties are expressible



[1] Furia, C. and Mandrioli, D. and Morzenti, A. and M. Rossi. (2012). ***Modeling Time In Computing***. Springer-Verlag

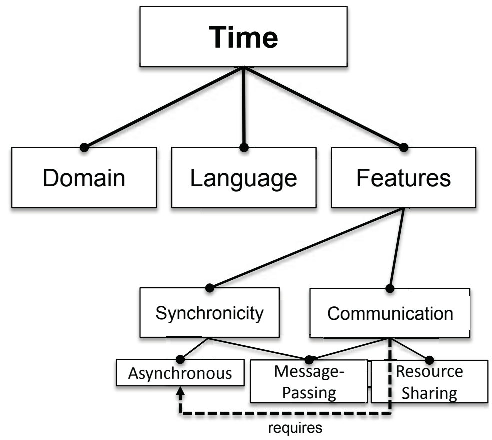
Time Features

❑ Features

Mechanisms within the language to express communication and synchronicity

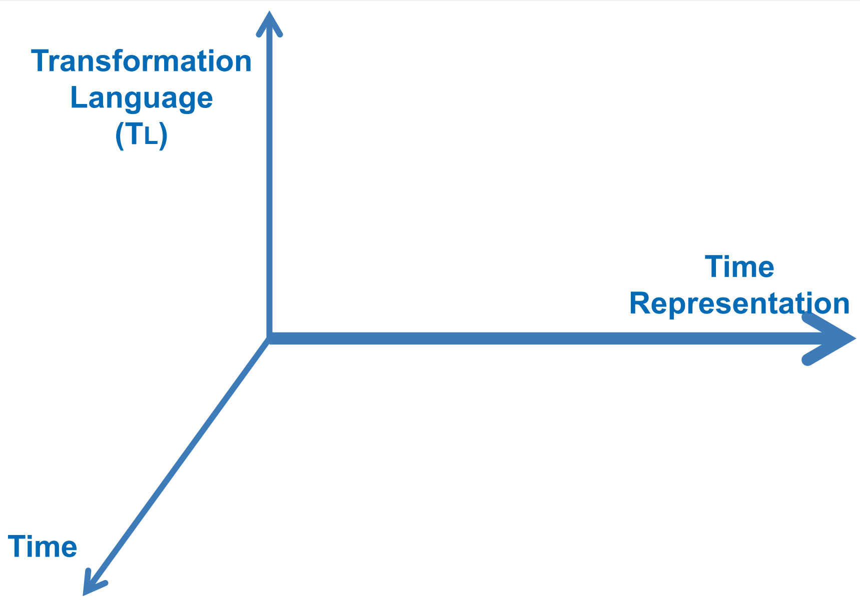
- ❑ ***Synchronicity***, describing at which pace changes occur within the system
  - Synchronous, at the same time;
  - Asynchronous, at different/indpt paces

- ❑ ***Communication***, describing how asynch. systems communicate
  - Through shared resources; or
  - Through message passing;
  - Or both!



[1] Furia, C. and Mandrioli, D. and Morzenti, A. and M. Rossi. (2012). ***Modeling Time In Computing***. Springer-Verlag

Time Representation



Time Representation [1]

- **[TaD]**: Time as Data
  - Time information represented within the model
  - Example: clock counters, timers as MM attributes
- **[TaC]**: Time as Control
  - Time information integrated at transformation level
  - Example: time manipulation constructs available in the TL
- **[TaE]**: Time as Embedding
  - Time not explicitly available
  - Implicit in a third-party language, when translated
  - Requires both model and transformation(s) to become translatable

! **Not mutually exclusive: all three can be mixed!**

[1] J. De Lara, E. Guerra, A. Boronat, R. Heckel, and P. Torrini. Domain-Specific Discrete Event Modelling and Simulation Using Graph Transformation. *Journal of Software and Systems Modelling*, **13**(1):209–238.

CONTRIBUTIONS OVERVIEW

Overview & Choices

Contributions number

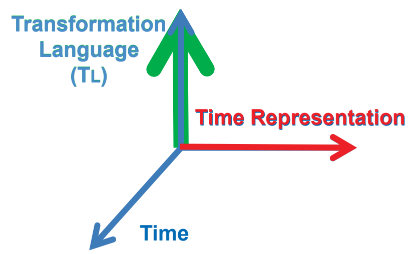
- 5 supporting references (classification, etc.)
- 40 overviewed contributions

Space constraints

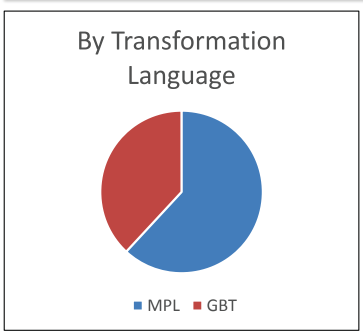
- Some are cited by website (one ref for 10 pubs)
- Others have several references for slightly different usage

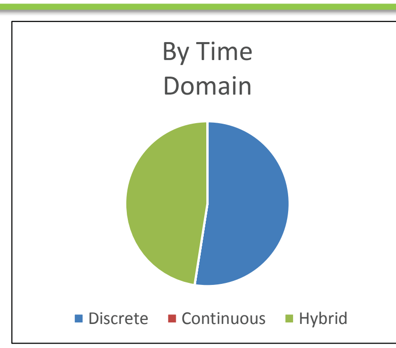
Presentation Choice

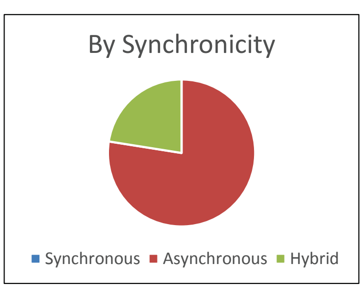
- Also related to space constraints
- First try: by time representation, but does not fit
- Finally: by TL

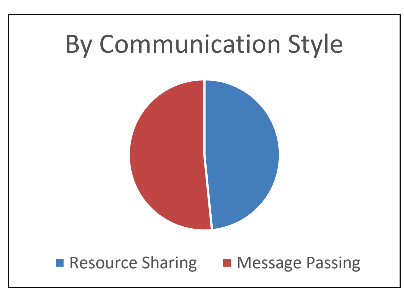


Statistics



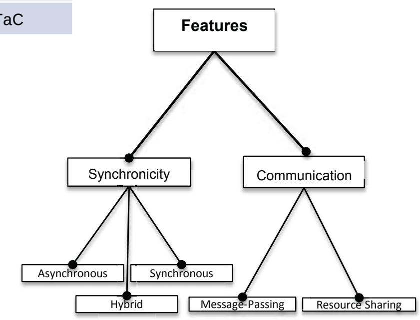






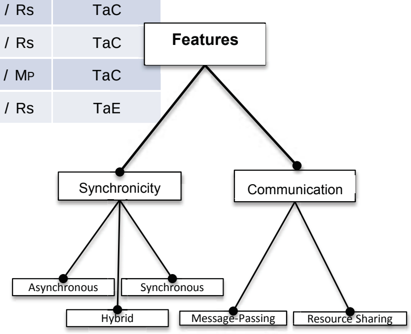
Summary Tables: MPLs

Contribution	Domain	Language	Features	Time Rep.
StateCharts	Discrete	Branching / Non-Determ.	Asynch. / MP	TaC
Activity Diags fUML	Discrete	Branching / Non-Determ.	Asynch. / MP	TaC
MARTE / CCSL	Hybrid	Branching / Non-Determ.	Hybrid / ??	TaD + TaC
HybridUML	Hybrid	Branching / Non-Determ.	Asynch. / RS	TaD + TaC
ForSyDe	Hybrid	Branching / Non-Determ.	Asynch. / RS	TaC
ModHel'X	Hybrid	Branching / Non-Determ.	Hybdrid / MP	TaC
GeMoC	Hybrid	Branching / Non-Determ.	Hybrid / ??	TaC



Summary Tables: GBTLs

Contribution	Domain	Language	Features	Time Rep.
Petri Nets	Discrete	Branching / Non-Determ.	Asynch. / RS	TaC
Stochastic	Hybrid	Branching / Non-Determ.	Asynch. / MP	TaC
De Lara & Vangheluwe	Discrete	Branching / Non-Determ.	Asynch. / RS	TaC
De Lara, Guerra *et al.*	Hybrid	Branching / Non-Determ.	Asynch. / MP	TaD + TaE
Strobl *et al.*	Discrete	Branching / Non-Determ.	Asynch. / RS	TaD
Gapay *et al.*	Discrete	Branching / Non-Determ.	Asynch. / RS	TaD
Moment 2	Discrete	Branching / Non-Determ.	Asynch. / RS	TaC
E-Motions	Discrete	Branching / Non-Determ.	Asynch. / RS	TaC
MechatronicUML	Hybrid	Branching / Non-Determ.	Asynch. / MP	TaC
AToMPM	Discrete	Branching / Non-Determ.	Asynch. / RS	TaE



CONCLUSIONS

Paper Summary

1. **A Classification for studying Real-Time MDE contributions**
   - Which Transformation Language is used?
   - Which characteristics of time are important for V&V?
   - How time is represented in MDE Frameworks?

2. **A partial validation on selected contributions**
   - 43 papers so far

3. **An approach that should be refined, precised and extended**
   - Dimension 3 (Time Representation) should be more precise
   - Is there more contribution in the « pure » MDE scope?
   - How these compare with classical GPL approaches for time? (Ptolemy, DEVS, RT-Maude, but also Java, C, Ada, etc.)

Future Work

1. **How to gather more papers?**
   - Perform a Systematic Litterature Review?
   - Proceed by experience?
     (contact specialised researchers + my own)
   - Extend the study's scope?

2. **Consider all possible V&V techniques for Real-Time**
   - **Integrated Testing** (i.e. with Hw) is common for embedded systems
   - **Simulation** for continuous systems is also a huge domain
   - **Formal Verification** is limited to very specific part in the whole system

Novel verification paradigms for nonlinear hybrid automata

Several application domains

Eva M. Navarro López

School of Computer Science, Manchester, UK

COST Action IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems (MPM4CPS)
Málaga Workshop, WG1 Foundations

Málaga, 24th November, 2016

Summary

1. The hybrid system salad
2. DYVERSE: a modelling, verification and control framework
3. Branches of DYVERSE

The hybrid system salad: A new fresh perspective

Different labels for the same idea

Combination of continuous dynamics and discrete phenomena

Continuous		Discrete		Hybrid
	+		=	
$\mathcal{X} = R^n$		$Q = \{q_1, q_2, \ldots, q_N\}$		$\mathcal{X} \times Q$

Research that challenges orthodoxy

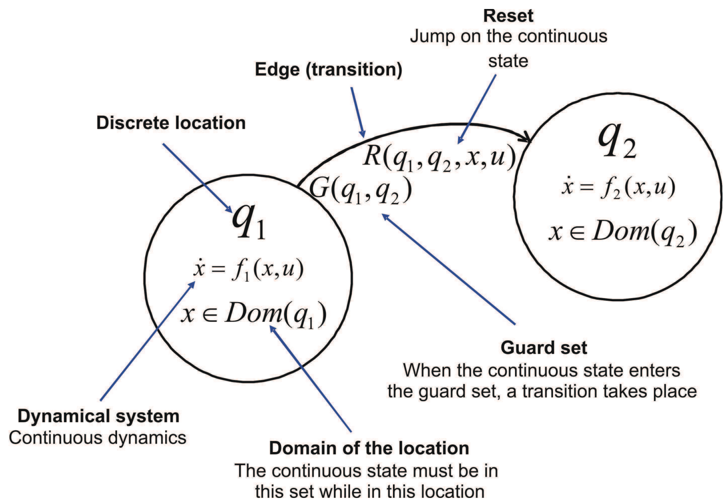
Mixing theory and practice, breaking boundaries of different disciplines

DYnamical-driven **VER**ification of **S**ystems with **E**nergy considerations

The first-funded project in the UK on the verification and control of nonlinear hybrid systems

- **L1** Control theory and engineering
- **L2** Formal verification and formal methods
- **L3** Dynamical systems analysis
- **L4** Engineering systems and systems biology
- **L5** Network science (complex networks)

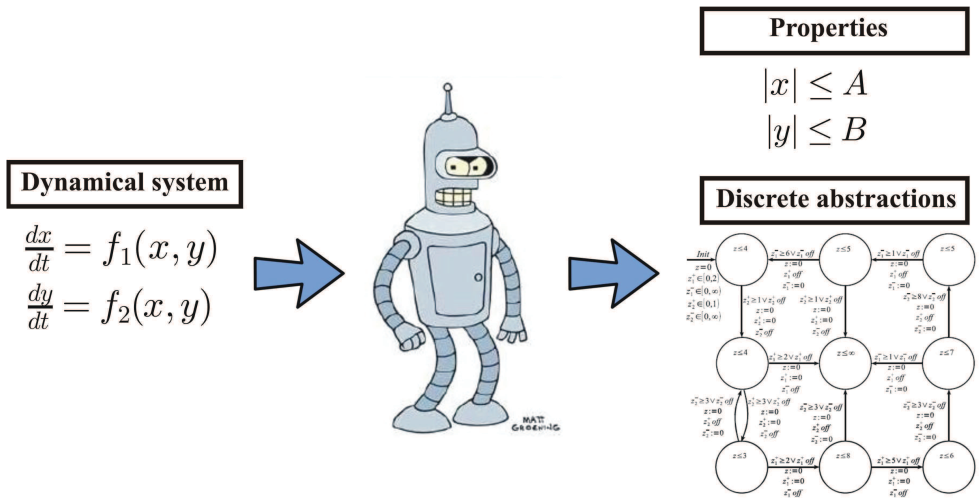
Hybrid automaton framework: basic elements



A collage of ideas

- **Dynamically-aware abstractions and formal verification**: exploiting dynamical properties of systems
- **Application-oriented** approach: results for real-world systems and **automatic generation** of hybrid automata from a dynamical specification
- Verification of **stability-related** and **liveness** properties
- **Complex systems** applications

Automated verification as a dynamical analysis tool



From (Carter and Navarro-López, 2012)

DyverseRBT: Dyverse Rigid Body Toolbox

What?

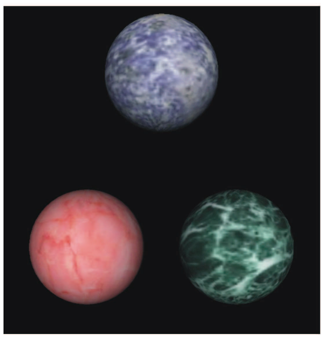
To generate automatically a general-purpose transition system for the description of mechanical systems with multiple impacts and friction

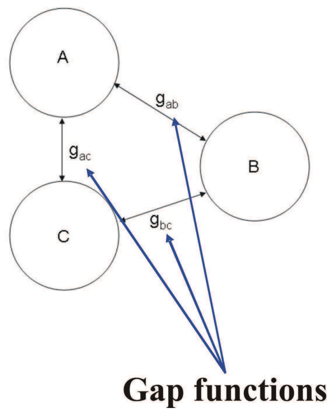
Why?

- **Simulation:** To create event-driven simulations of multi-rigid-body mechanical systems
- **Formal verification:** Hybrid systems automated verification tools to check that properties of mechanical systems are satisfied
- **Control:** To include formal verification results in the control loop to modify system response. Avoid ‘something bad will never happen’ (safety), ensure ‘something good will happen’ (liveness)

Limitations in multi-contact rigid-body systems

Beyond the bouncing ball
A simple example that cannot be expressed using the classical hybrid automaton framework





The hybrid system salad
DYVERSE: a modelling, verification and control framework
Branches of DYVERSE
DyverseRBT: automated generation of hybrid automata
DyverseBMC: falsification of safety properties
Verification of liveness properties

The multi-rigid-body (MRB) hybrid automaton

Typical hybrid automaton elements

- Dynamical discrete locations
- Continuous states
- Initial states
- Continuous dynamics
- Domains of discrete locations
- Edges (discrete transitions)
- Guards
- Reset maps

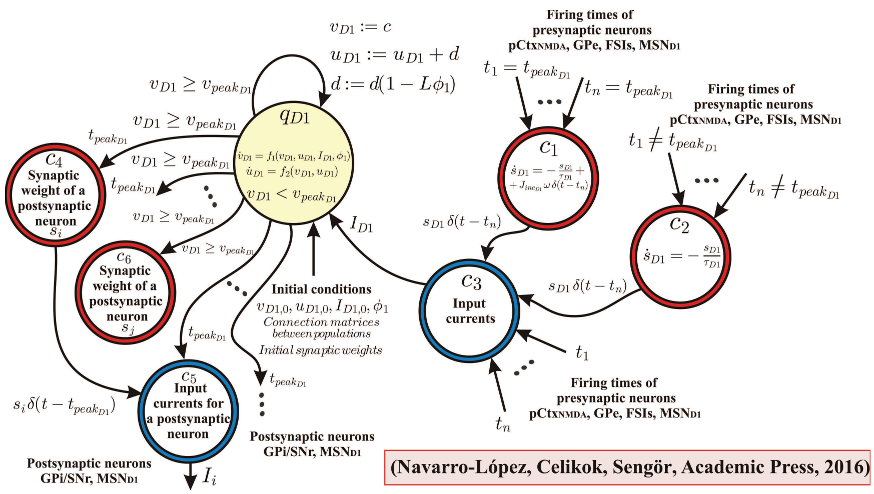
New elements integrating computation of contact forces

- Computation nodes
- Non-dynamical discrete locations

Eva Navarro López DYVERSE

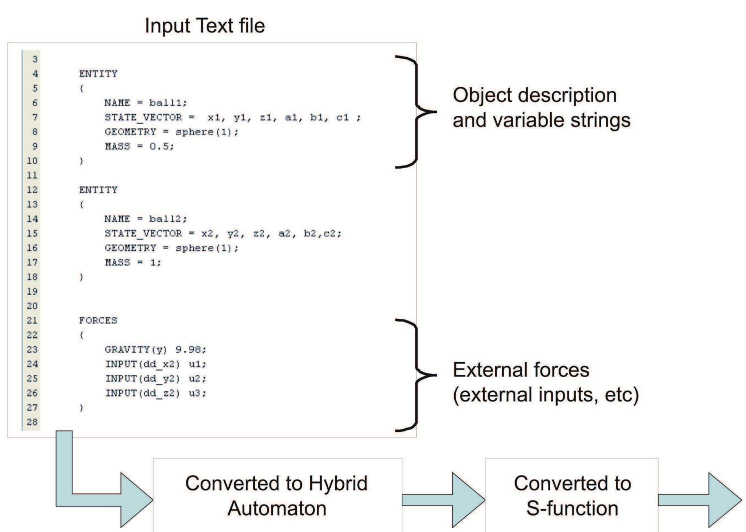
Hybrid automaton with computation nodes for a single neuron

A medium spiny neuron with D_1-type receptors in the striatum

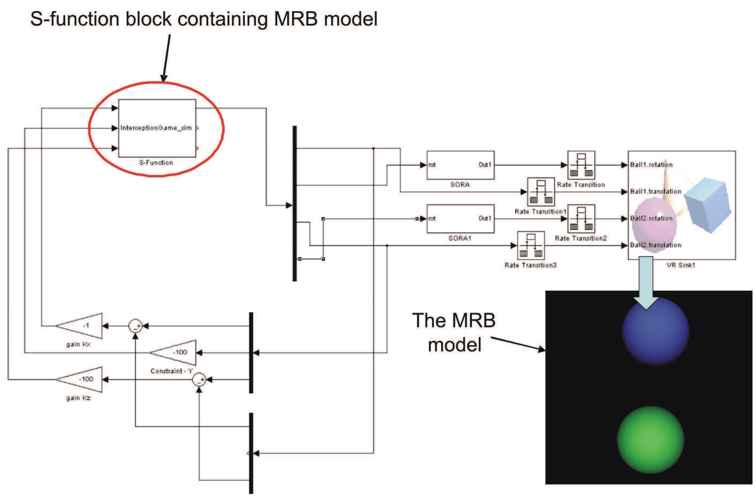


(Navarro-López, Celikok, Sengör, Academic Press, 2016)

Automatic generation of hybrid automata

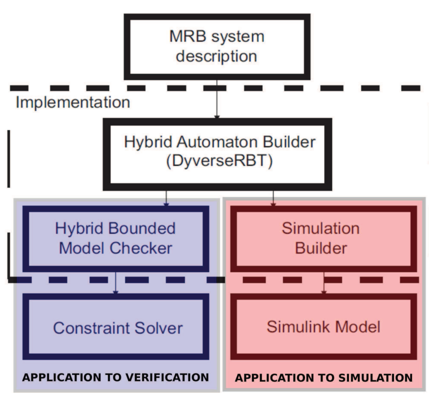


Implementation



Dyverse Bounded Model Checker (DyverseBMC)

Overview of the modelling, simulation and verification framework



Mike O'Toole and Eva Navarro-López

http://staff.cs.manchester.ac.uk/˜navarroe/papers/otoole_navarro2016.pdf

Dynamically-aware verification: liveness and deadness

- **DeadRegions.** Generation of a dead region on a hybrid automaton for a given inevitability property of reaching some desired live region
- **proveByTA.** Abstraction of a linear continuous system of the form $\dot{x} = Ax + b$ to a timed automaton for proving inevitability (reaching a specified live zone). It then uses the stand-alone prover of TA prover UPPAAL to prove the property
- **PWproveByTA.** Abstraction of a piecewise-linear system of a class of the form $\dot{x} = Ax$ to a timed automaton for proving inevitability. It then uses the stand-alone prover of TA prover UPPAAL to prove the property

Eva Navarro-López and Rebekah Carter, TCS 2016

http://staff.cs.manchester.ac.uk/˜navarroe/research/dyverse/liveness/

The hybrid system salad
DYVERSE: a modelling, verification and control framework
Branches of DYVERSE
DyverseRBT: automated generation of hybrid automata
DyverseBMC: falsification of safety properties
Verification of liveness properties

DYVERSE team for the verification branches presented

Rebekah Carter

Mike O'Toole

Studies of:

Liveness

Deadness

Mythical modes

EPSRC **'DYVERSE: A New Kind of Control of Hybrid Systems'**

http://www.cs.man.ac.uk/~navarroe/research/dyverse/

Some references

- E.M. Navarro-López, R. Carter. "Deadness and how to disprove liveness in hybrid dynamical systems". *Theoretical Computer Science*, **642** (2016), 1–23.
- M. O'Toole, E.M. Navarro-López. "Falsification of safety properties in multi-rigid-body mechanical systems with hybrid automata and constraint satisfaction". Available at `http://staff.cs.manchester.ac.uk/~navarroe/papers/otoole_navarro2016.pdf`.
- E.M. Navarro-López, U. Çelikok, N.S. Şengör. "Hybrid systems neuroscience". In the book *Closed-Loop Neuroscience*, pp. 113–129. Academic Press, September 2016.
- E.M. Navarro-López. "DYVERSE: From formal verification to biologically-inspired real-time self-organising systems". In the book *Computation for Humanity – Information Technology to Advance Society*, pp. 305–350. CRC Press/Taylor & Francis, October 2013.
- E.M. Navarro-López, D.S. Laila. "Group and total dissipativity and stability of multi-equilibria hybrid automata". *IEEE Transactions on Automatic Control*, **58**(12) (2013), 3196–3202.
- R. Carter, E.M. Navarro-López. "Dynamically-driven timed automaton abstractions for proving liveness of continuous systems". In *Proceedings of the 10th International Conference on Formal Modelling and Analysis of Timed Systems*, FORMATS 2012, LNCS, vol. 7595 (M. Jurdziński and D. Ničković, Eds), pp. 59–74, Springer-Verlag, 2012.
- E.M. Navarro-López, R. Carter. "Hybrid automata: An insight into the discrete abstraction of discontinuous systems". *International Journal of Systems Science. Special Issue on Variable Structure Systems Methods for Control and Observation of Hybrid Systems*, **42**(11) (2011), 1883–1898.

MPM4CPS

IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems

Usability driven development with Usability Software Engineering Modeling Environment (USE-ME)

Ankica Barišić

supervisors: Vasco Amaral, Miguel Goulão

Domain-Specific Language

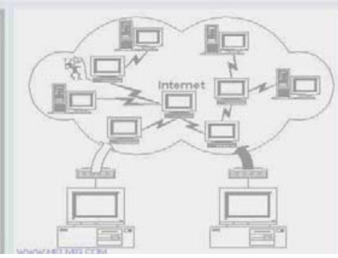
- Meant to close gap between PROBLEM DOMAIN and SOLUTION DOMAIN
- Reduce the use of computation concepts
- Focus on the domain concepts

- Increasingly popular
  - **Raise the abstraction level (closer to the domain)**
  - **Narrow the design space**
- Several benefits claimed, in well-defined domains
  - **Productivity gains**
  - **Better time to market**
  - **Avoid error-prone mappings between domain and software development concepts**
  - **Leverage the expertise of domain experts**

Language

- A language is a means of communication

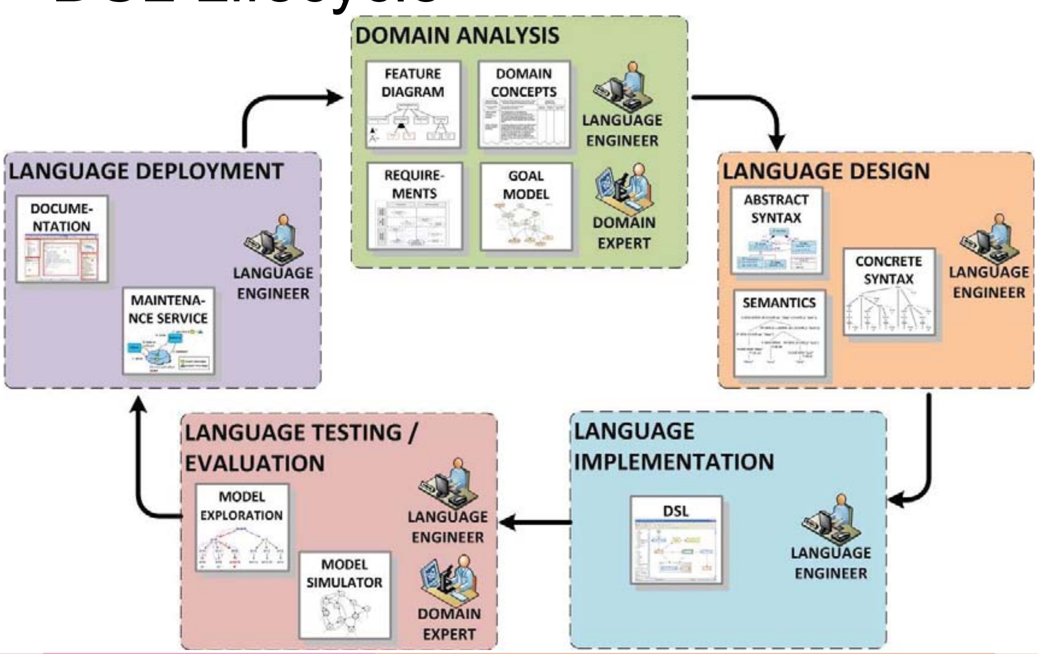
human2human	machine2machine	human2machine
Natural language	Protocol	User interface

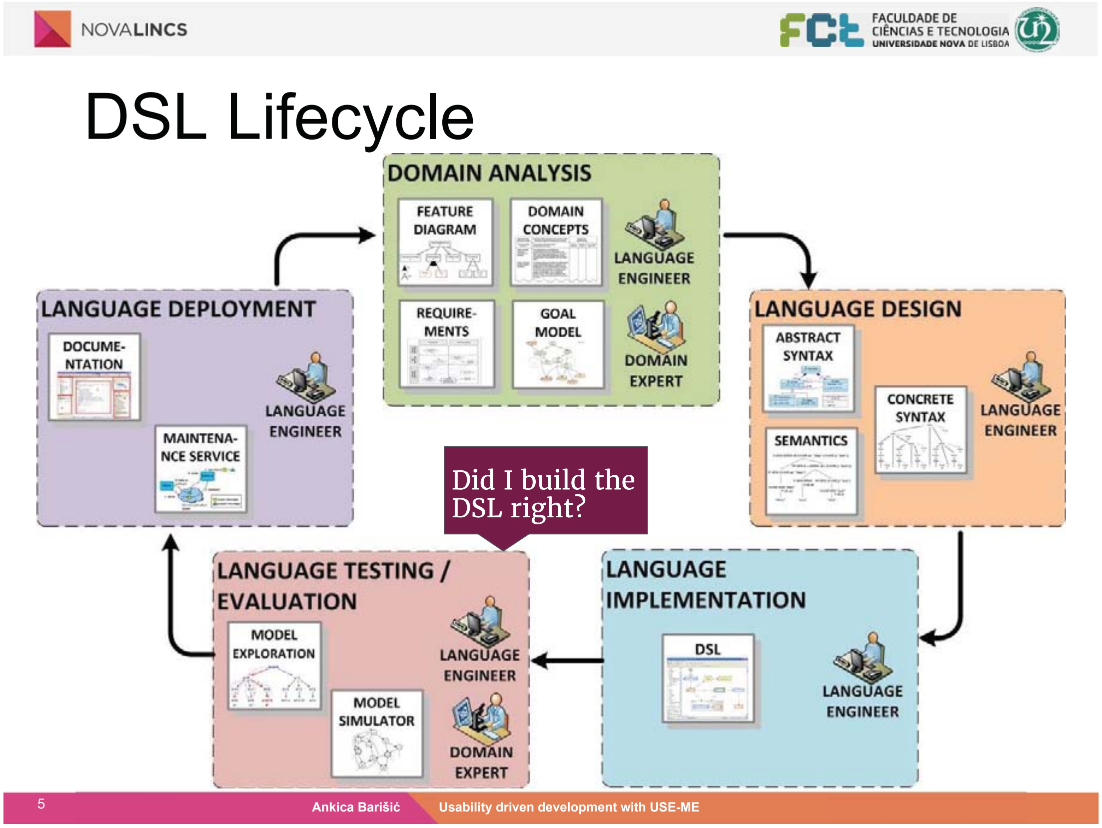


  - The user interface is a realization of a language

- A language is a model that describes the allowed terms and how to compose them into valid sentences

DSL Lifecycle

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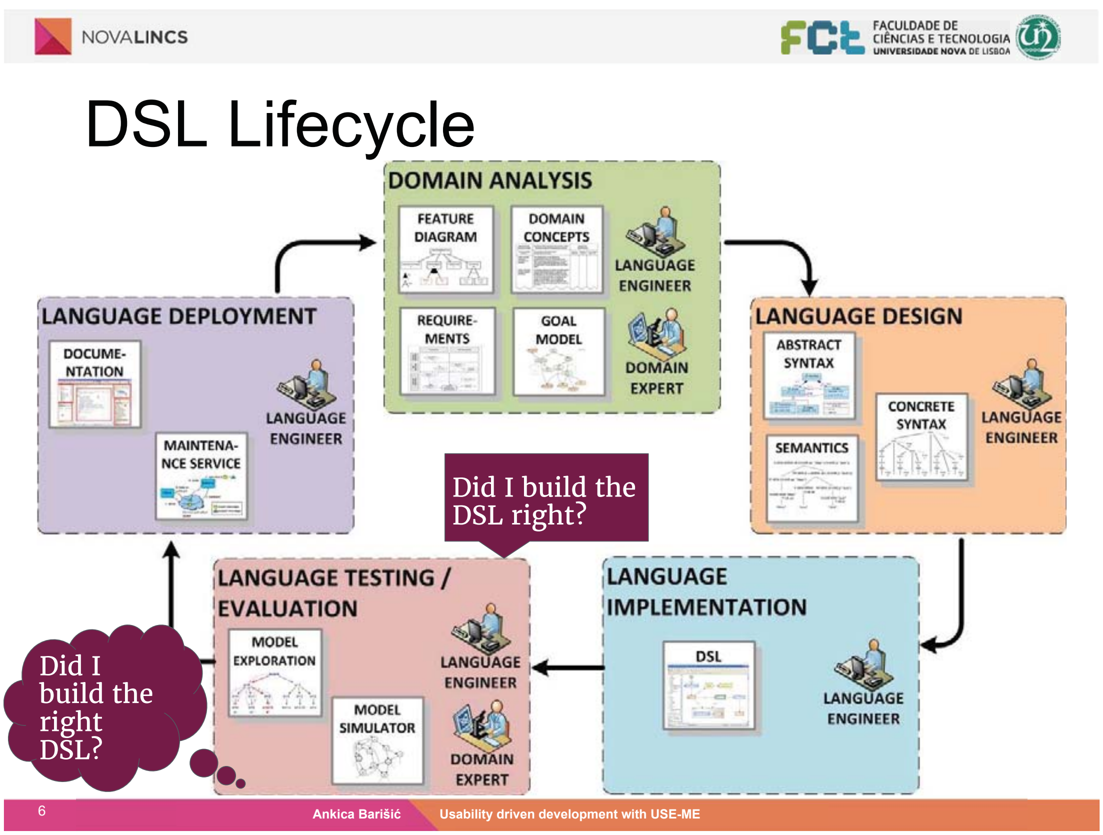
DSL Lifecycle
DOMAIN ANALYSIS
FEATURE DIAGRAM
DOMAIN CONCEPTS
LANGUAGE ENGINEER
REQUIRE-MENTS
GOAL MODEL
DOMAIN EXPERT
LANGUAGE DESIGN
ABSTRACT SYNTAX
CONCRETE SYNTAX
SEMANTICS
LANGUAGE ENGINEER
LANGUAGE DEPLOYMENT
DOCUME-NTATION
MAINTENA-NCE SERVICE
LANGUAGE ENGINEER
Did I build the DSL right?
LANGUAGE TESTING / EVALUATION
MODEL EXPLORATION
MODEL SIMULATOR
LANGUAGE ENGINEER
DOMAIN EXPERT
LANGUAGE IMPLEMENTATION
DSL
LANGUAGE ENGINEER
5
Ankica Barišić
Usability driven development with USE-ME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DSL Lifecycle
DOMAIN ANALYSIS
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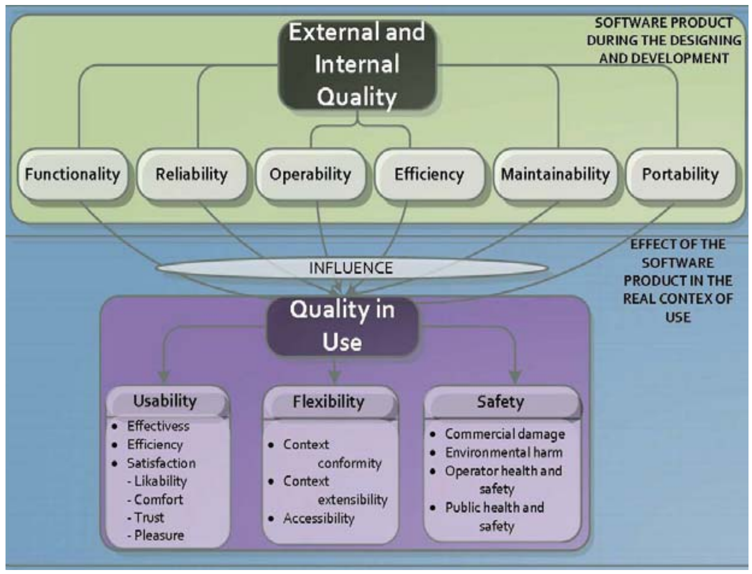
DSL
LANGUAGE ENGINEER
Did I build the right DSL?
6
Ankica Barišić
Usability driven development with USE-ME

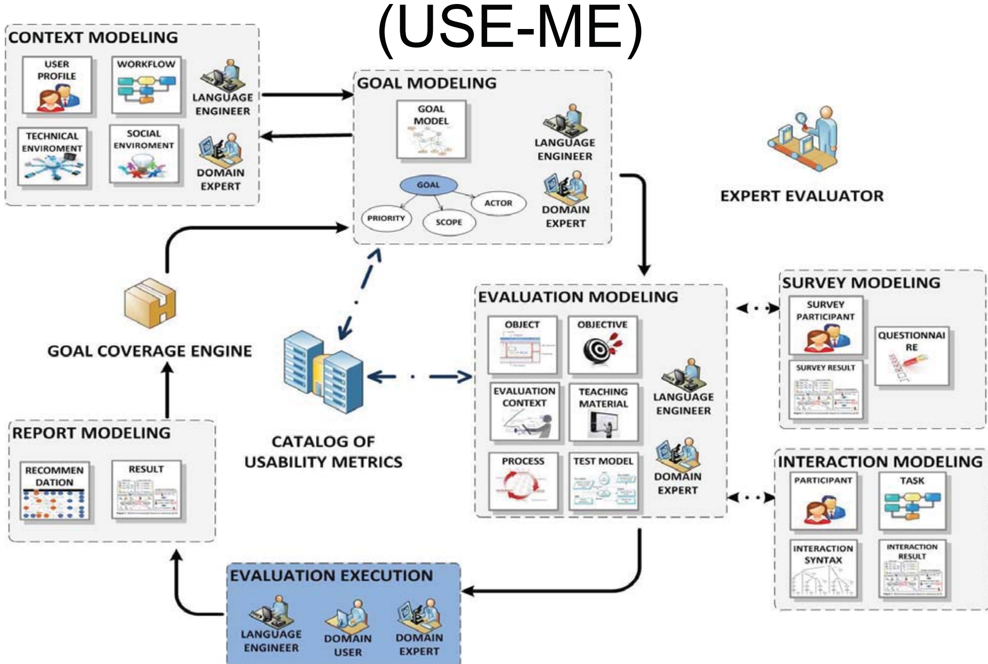
Quality in Use i.e. Usability

'The **capability** of a software product to enable specified users to achieve specified goals with: *effectiveness*, *productivity*, *safety* and *satisfaction*
in specified contexts of use.'

- Different languages likely have different *contexts of use*
- Their users are likely to have different *knowledge sets*
- A minimum set of ontological concepts is required to **use** the language



Usability Software Engineering - Modeling Environment (USE-ME)



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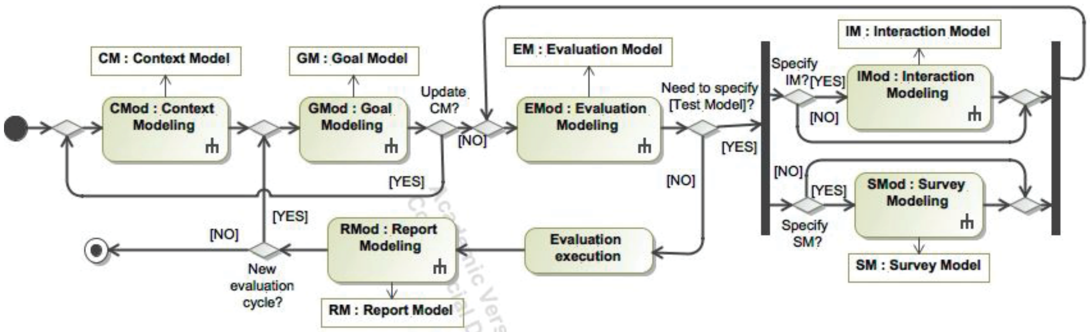
Usability Software Engineering - Modeling Environment (USE-ME)



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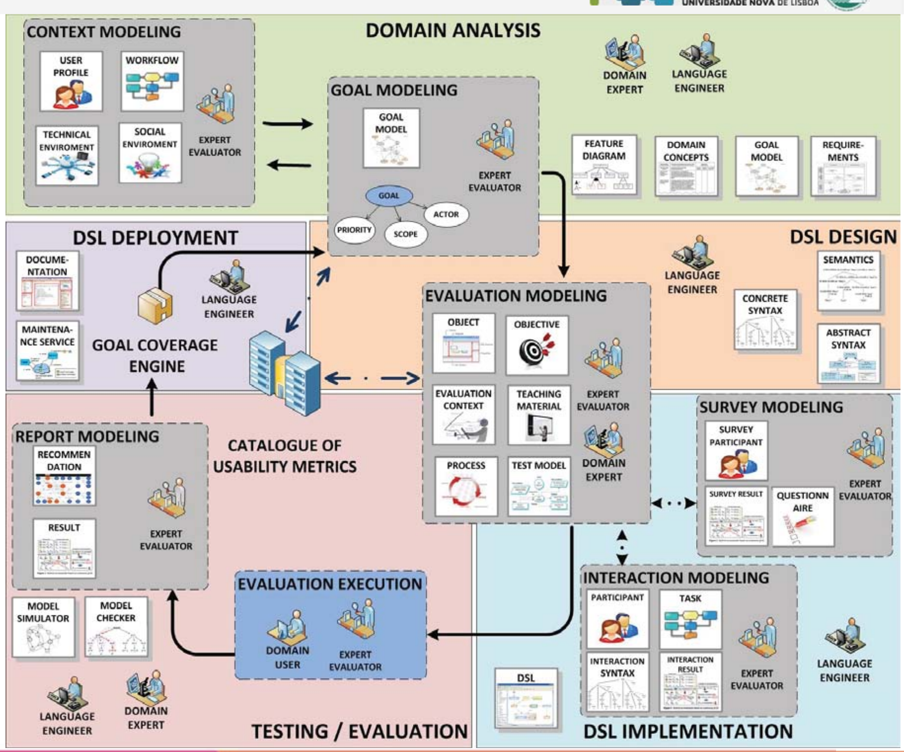
USE-ME in DSL lifecycle



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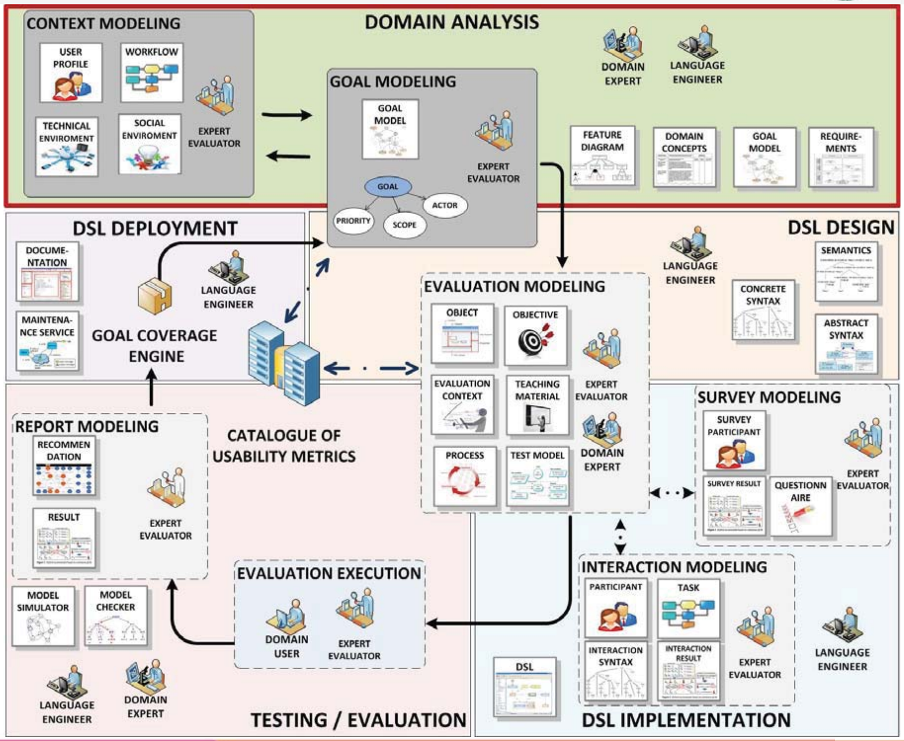
USE-ME in DSL lifecycle



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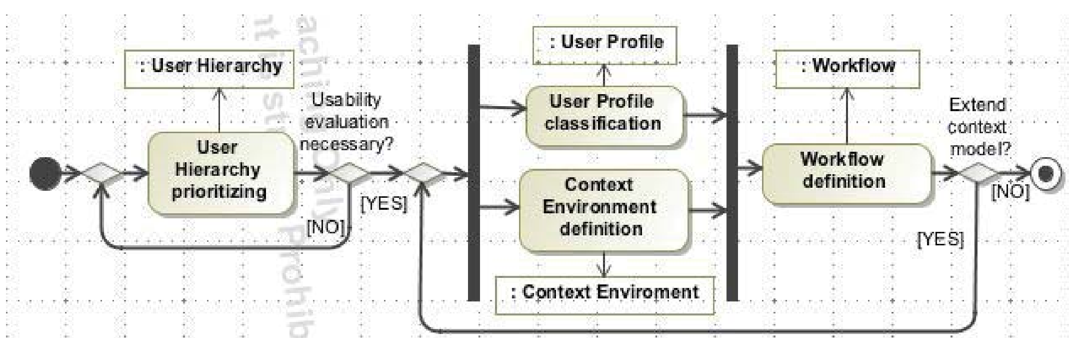
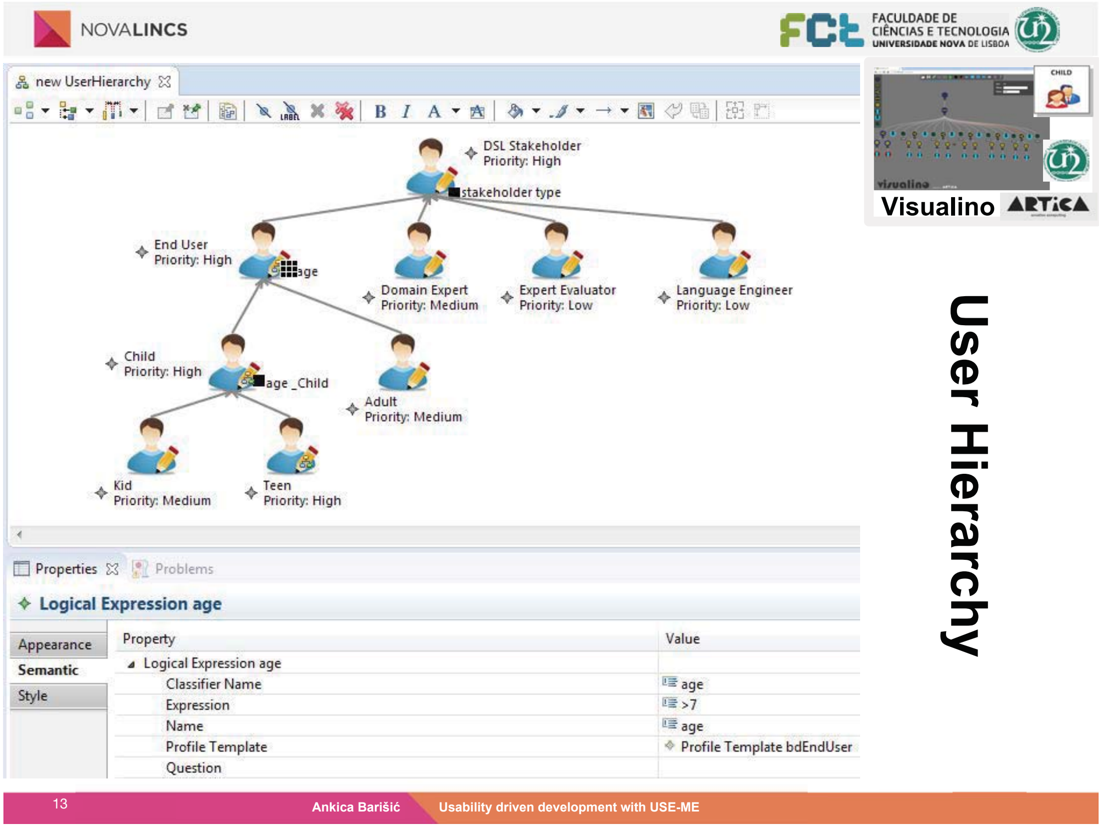
Context Modeling (USE-ME)

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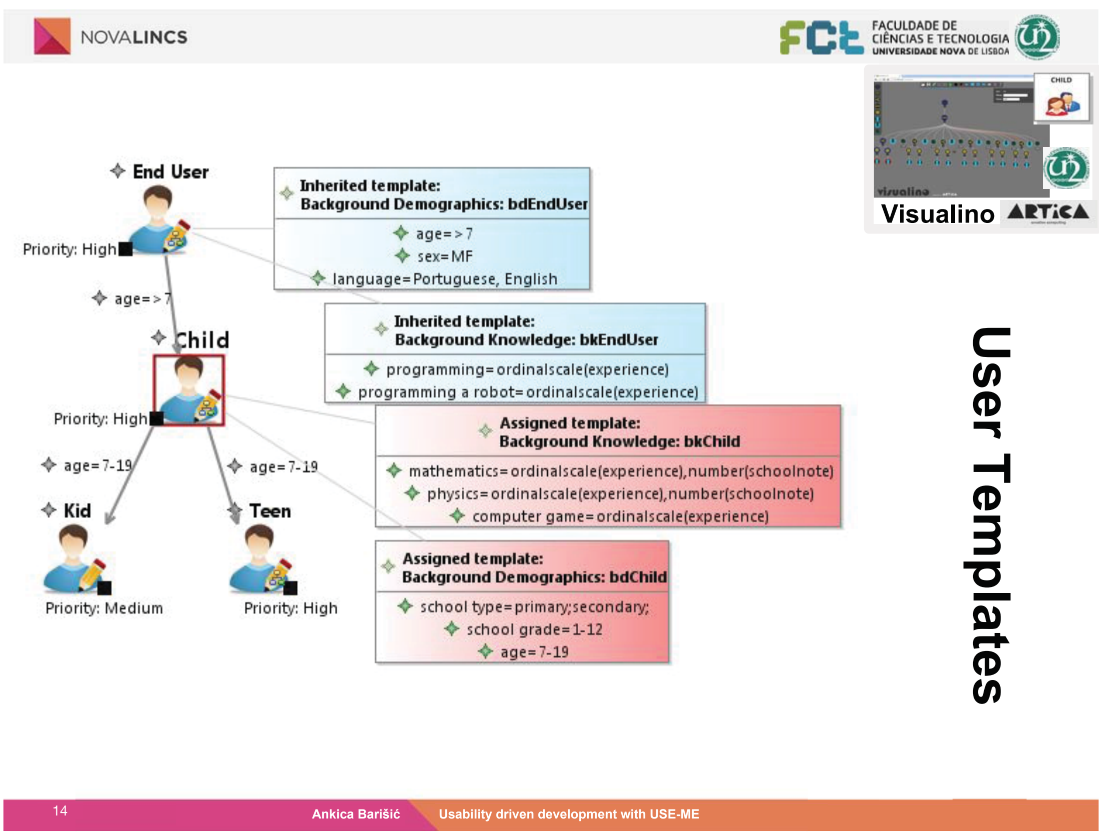
new UserHierarchy
DSL Stakeholder
Priority: High
stakeholder type
End User
Priority: High
age
Domain Expert
Priority: Medium
Expert Evaluator
Priority: Low
Language Engineer
Priority: Low
Child
Priority: High
age _Child
Adult
Priority: Medium
Kid
Priority: Medium
Teen
Priority: High
Properties
Problems
Logical Expression age
Appearance
Semantic
Style
Property
Value
Logical Expression age
Classifier Name
age
Expression
>7
Name
age
Profile Template
Profile Template bdEndUser
Question
Visualino
ARTiCA
User Hierarchy
13
Ankica Barišić
Usability driven development with USE-ME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End User
Priority: High
age=>7
Child
Priority: High
age=7-19
age=7-19
Kid
Teen
Priority: Medium
Priority: High
Inherited template:
Background Demographics: bdEndUser
age=>7
sex=MF
language=Portuguese, English
Inherited template:
Background Knowledge: bkEndUser
programming=ordinalscale(experience)
programming a robot=ordinalscale(experience)
Assigned template:
Background Knowledge: bkChild
mathematics=ordinalscale(experience),number(schoolnote)
physics=ordinalscale(experience),number(schoolnote)
computer game=ordinalscale(experience)
Assigned template:
Background Demographics: bdChild
school type=primary;secondary;
school grade=1-12
age=7-19
Visualino
ARTiCA
User Templates
14
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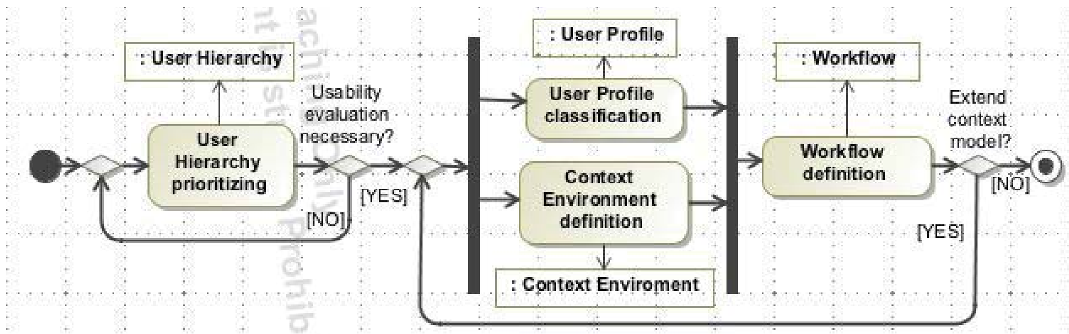
Usability driven development with USE-ME

Context Modeling (USE-ME)



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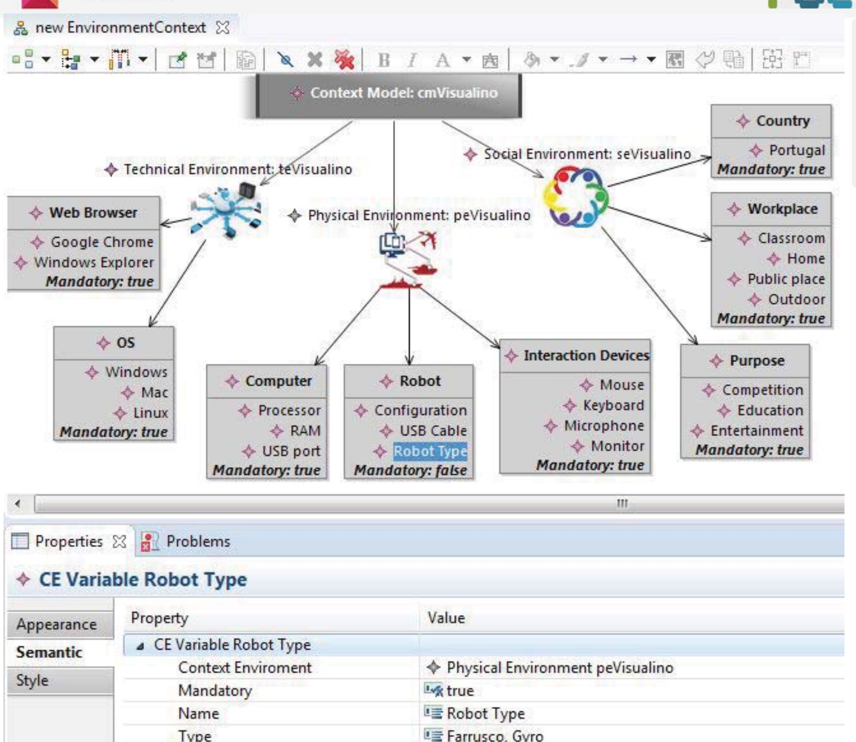
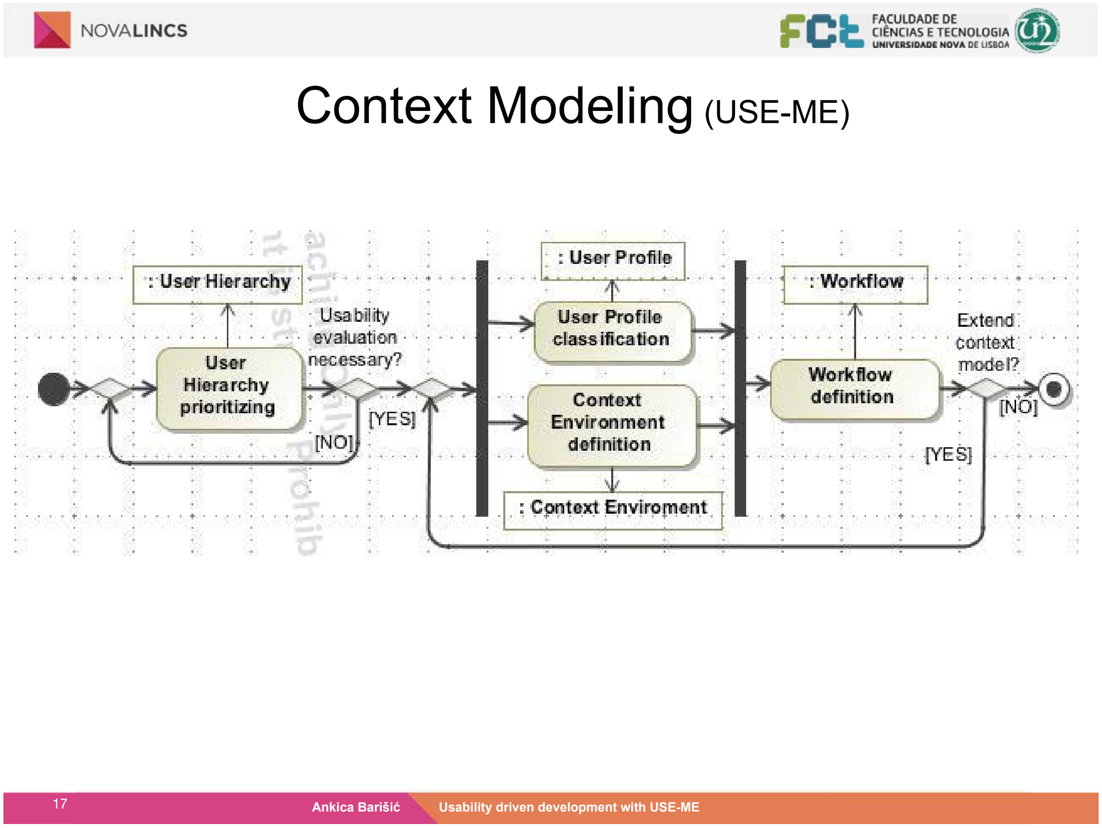


Context Environment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Context Modeling (USE-ME)
: User Hierarchy
User Hierarchy prioritizing
Usability evaluation necessary?
[YES]
[NO]
: User Profile
User Profile classification
Context Environment definition
: Context Enviroment
: Workflow
Workflow definition
Extend context model?
[NO]
[YES]
17
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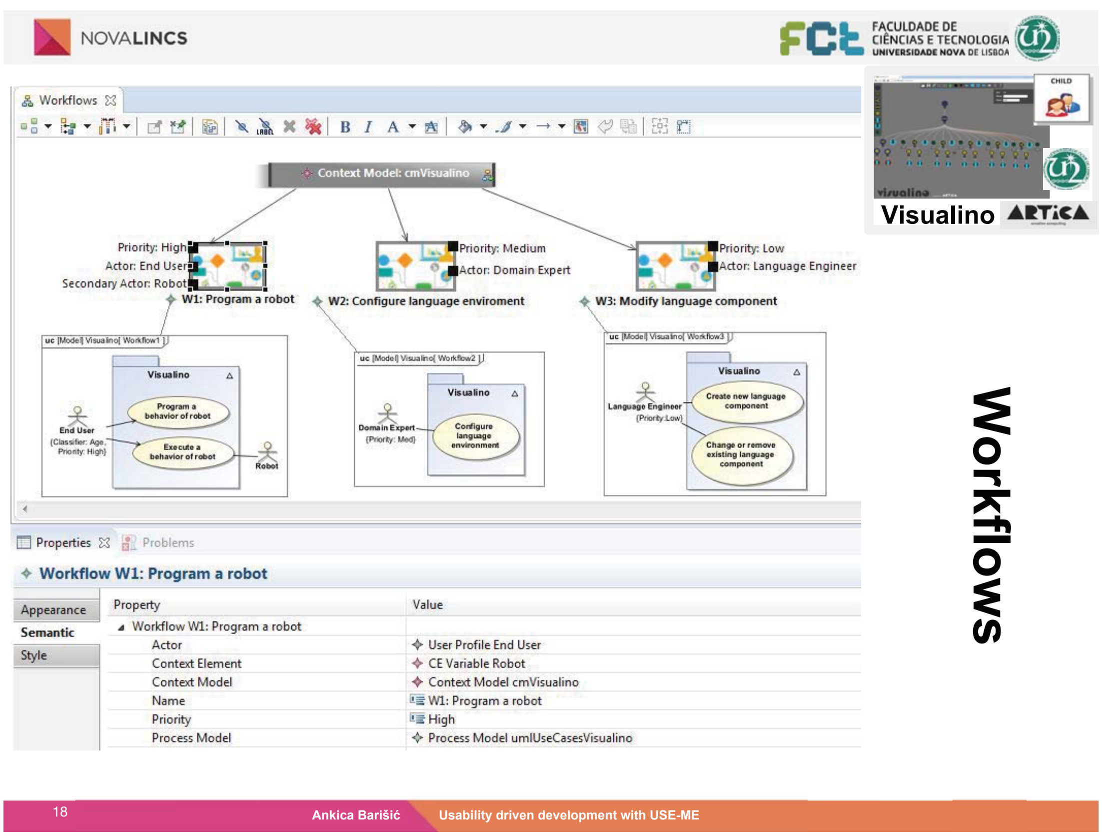
Usability driven development with USE-ME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Workflows
Context Model: cmVisualino
Priority: High
Actor: End User
Secondary Actor: Robot
W1: Program a robot
Priority: Medium
Actor: Domain Expert
W2: Configure language enviroment
Priority: Low
Actor: Language Engineer
W3: Modify language component
Visualino
Program a behavior of robot
Execute a behavior of robot
End User
Robot
Domain Expert
Configure language environment
Language Engineer
Create new language component
Change or remove existing language component
Properties
Problems
Workflow W1: Program a robot
Appearance
Semantic
Style
Property
Value
Workflow W1: Program a robot
Actor
User Profile End User
Context Element
CE Variable Robot
Context Model
Context Model cmVisualino
Name
W1: Program a robot
Priority
High
Process Model
Process Model umlUseCasesVisualino
Visualino
Workflows
18
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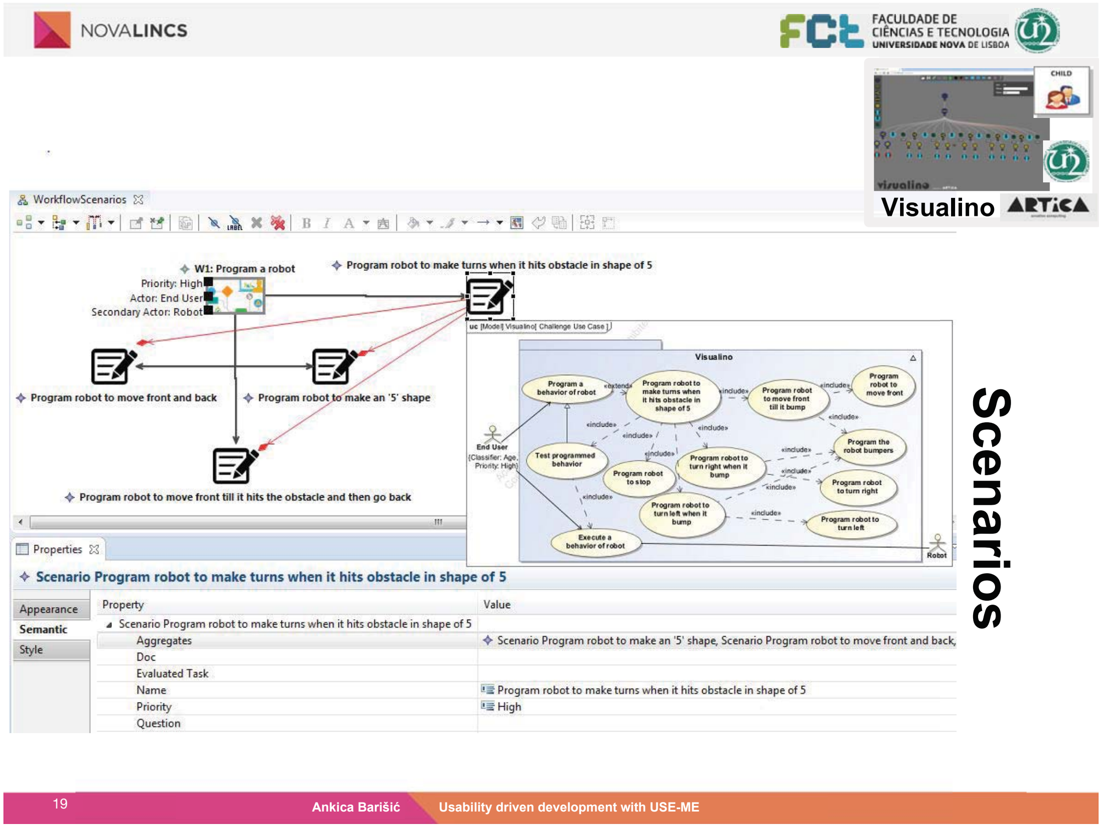
Usability driven development with USE-ME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Visualino
Scenarios
WorkflowScenarios
W1: Program a robot
Priority: High
Actor: End User
Secondary Actor: Robot
Program robot to make turns when it hits obstacle in shape of 5
Program robot to move front and back
Program robot to make an '5' shape
Program robot to move front till it hits the obstacle and then go back
Properties
Scenario Program robot to make turns when it hits obstacle in shape of 5
Appearance
Semantic
Style
Property
Value
Scenario Program robot to make turns when it hits obstacle in shape of 5
Aggregates
Scenario Program robot to make an '5' shape, Scenario Program robot to move front and back,
Doc
Evaluated Task
Name
Program robot to make turns when it hits obstacle in shape of 5
Priority
High
Question
19
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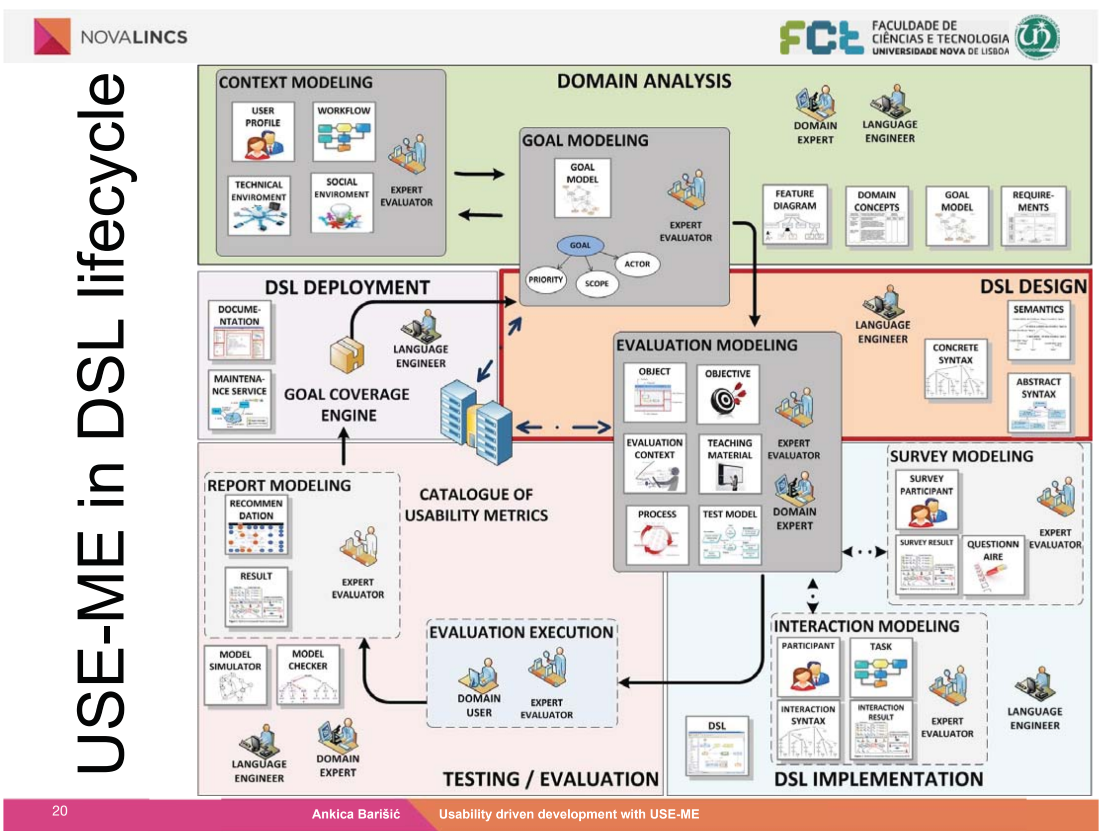
Usability driven development with USE-ME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USE-ME in DSL lifecycle
CONTEXT MODELING
USER PROFILE
WORKFLOW
TECHNICAL ENVIROMENT
SOCIAL ENVIROMENT
EXPERT EVALUATOR
DOMAIN ANALYSIS
DOMAIN EXPERT
LANGUAGE ENGINEER
GOAL MODELING
GOAL MODEL
GOAL
ACTOR
PRIORITY
SCOPE
FEATURE DIAGRAM
DOMAIN CONCEPTS
REQUIRE-MENTS
DSL DEPLOYMENT
DOCUME-NTATION
MAINTENA-NCE SERVICE
GOAL COVERAGE ENGINE
DSL DESIGN
SEMANTICS
CONCRETE SYNTAX
ABSTRACT SYNTAX
EVALUATION MODELING
OBJECT
OBJECTIVE
EVALUATION CONTEXT
TEACHING MATERIAL
PROCESS
TEST MODEL
SURVEY MODELING
SURVEY PARTICIPANT
SURVEY RESULT
QUESTIONN AIRE
REPORT MODELING
RECOMMEN DATION
RESULT
CATALOGUE OF USABILITY METRICS
MODEL SIMULATOR
MODEL CHECKER
EVALUATION EXECUTION
DOMAIN USER
INTERACTION MODELING
PARTICIPANT
TASK
INTERACTION SYNTAX
INTERACTION RESULT
DSL
TESTING / EVALUATION
DSL IMPLEMENTATION
20
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Usability driven development with USE-ME

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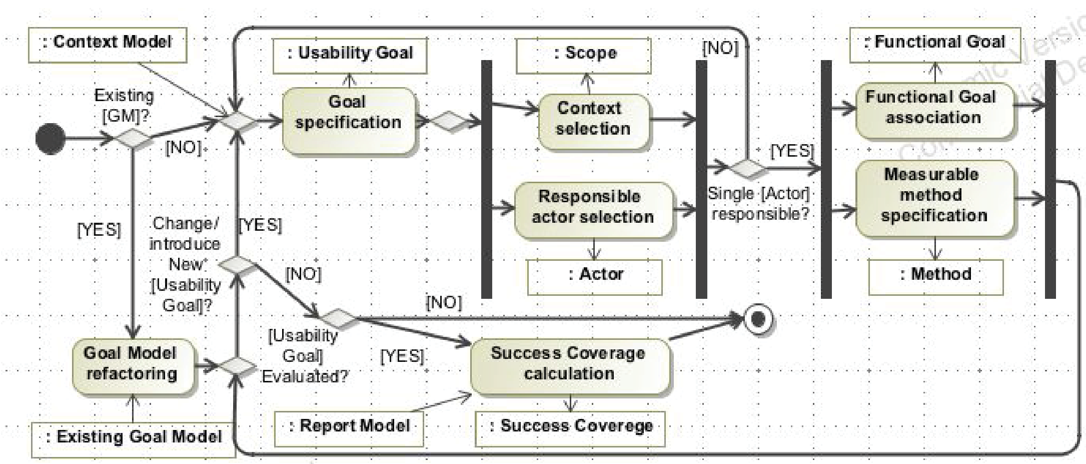
Goal Modeling (USE-ME)



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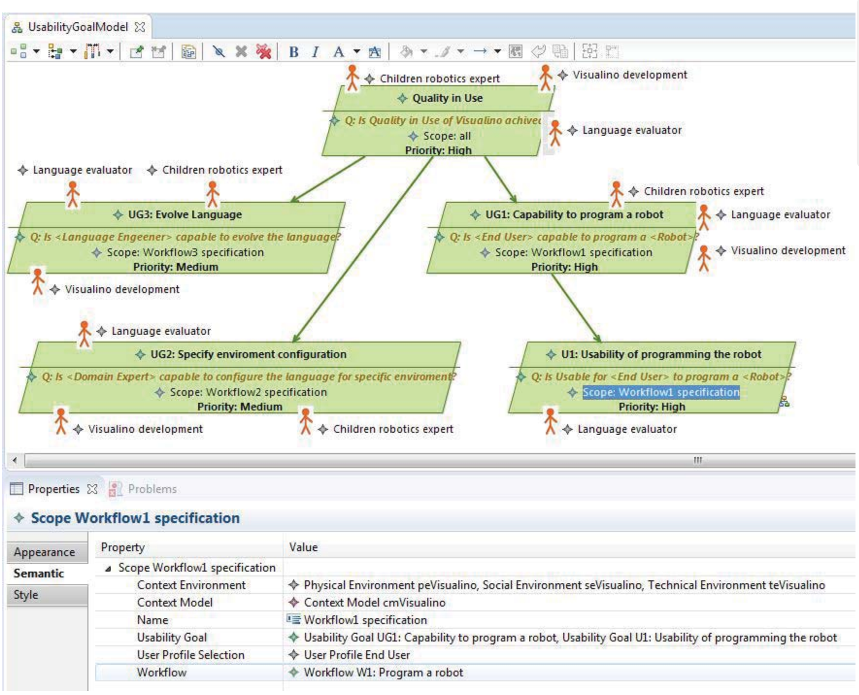

Usability Goal Model

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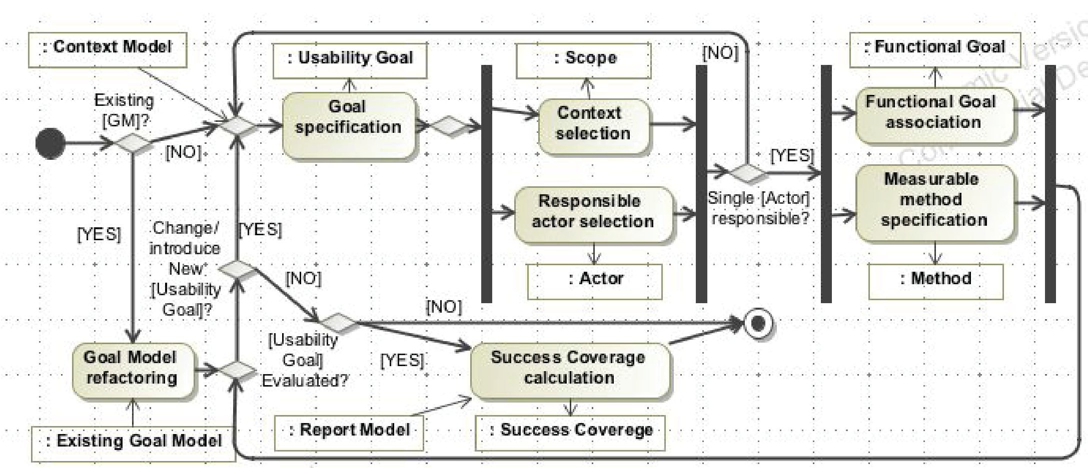
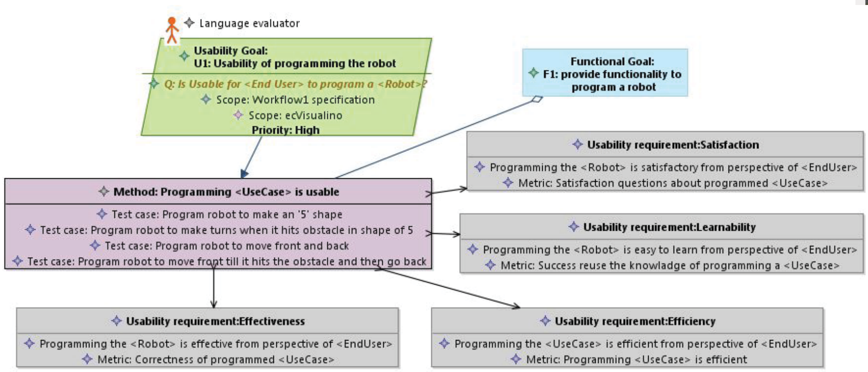
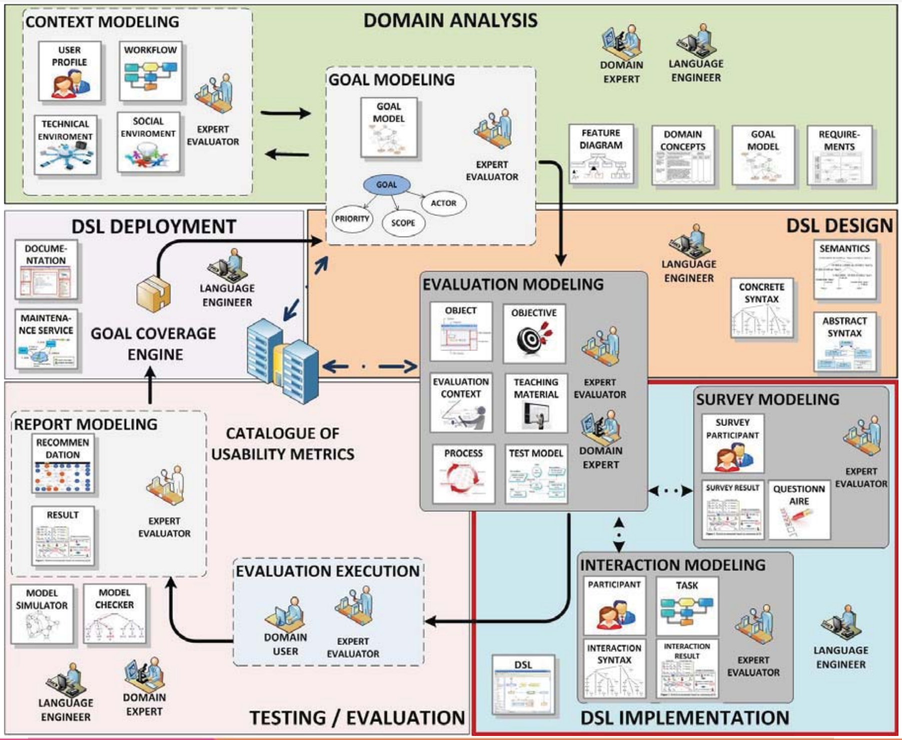
Goal Modeling (USE-ME)



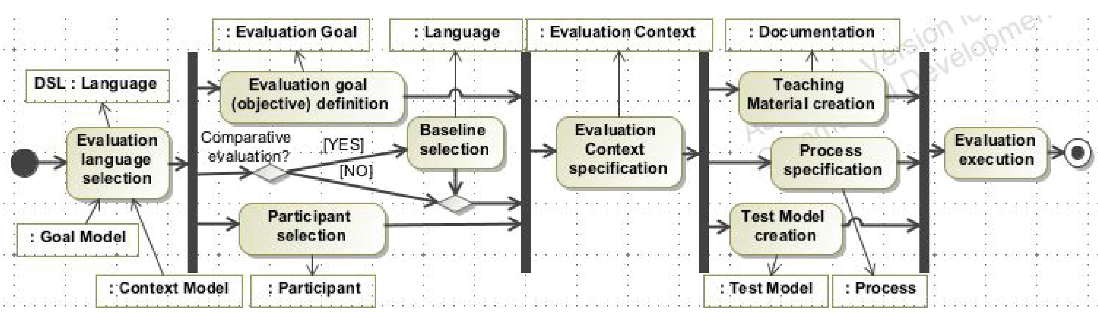
Usability Method and Requirements

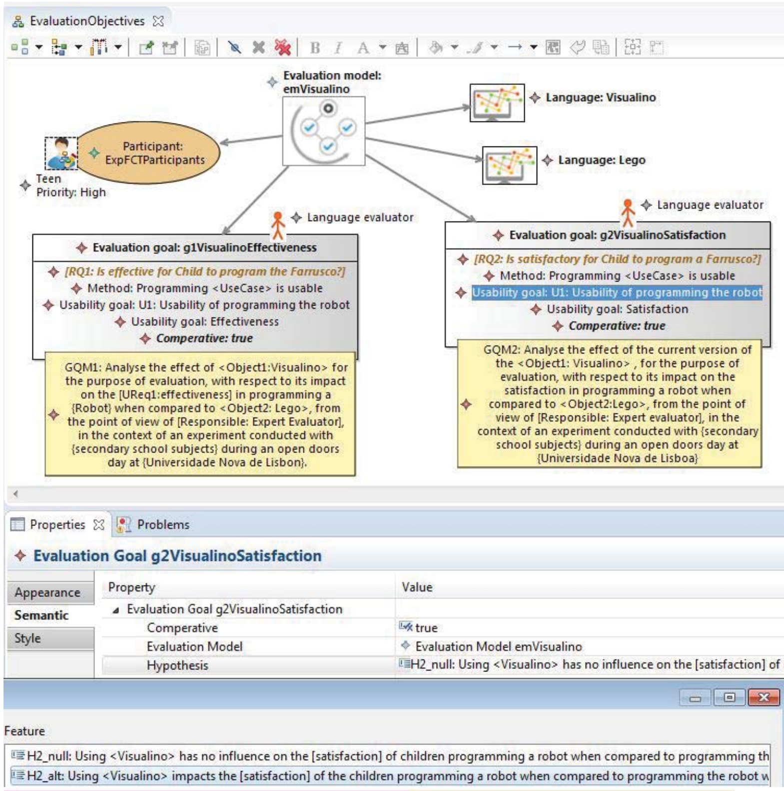


USE-ME in DSL lifecycle



Evaluation Modeling (USE-ME)





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Evaluation Objectives

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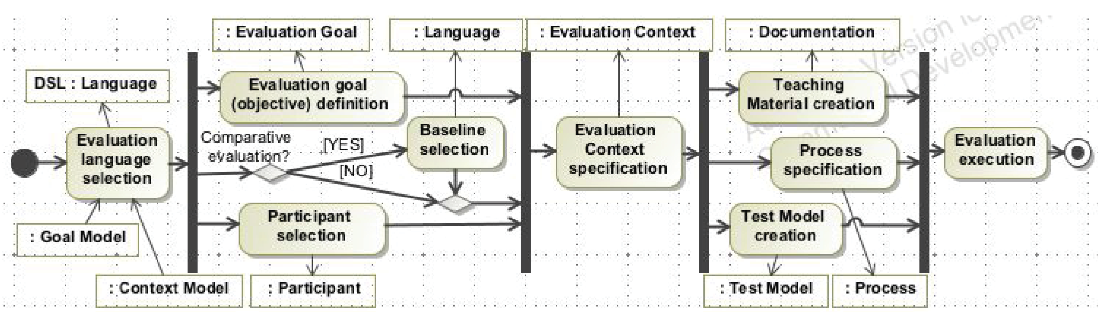
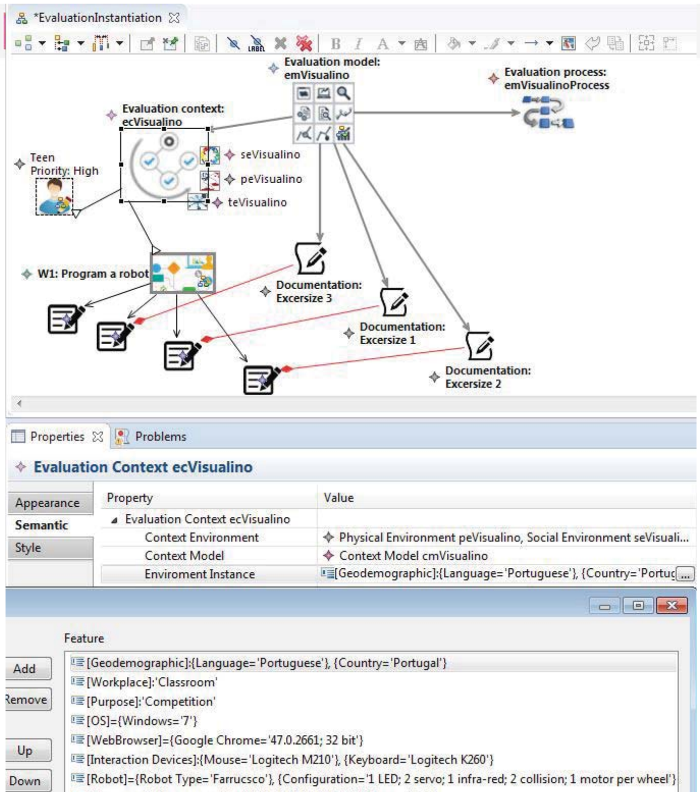
Evaluation Modeling (USE-ME)





Evaluation Instantiation

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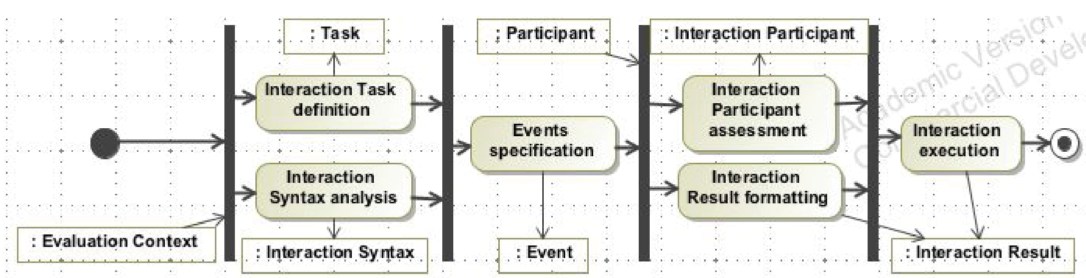
Interaction Modeling (USE-ME)



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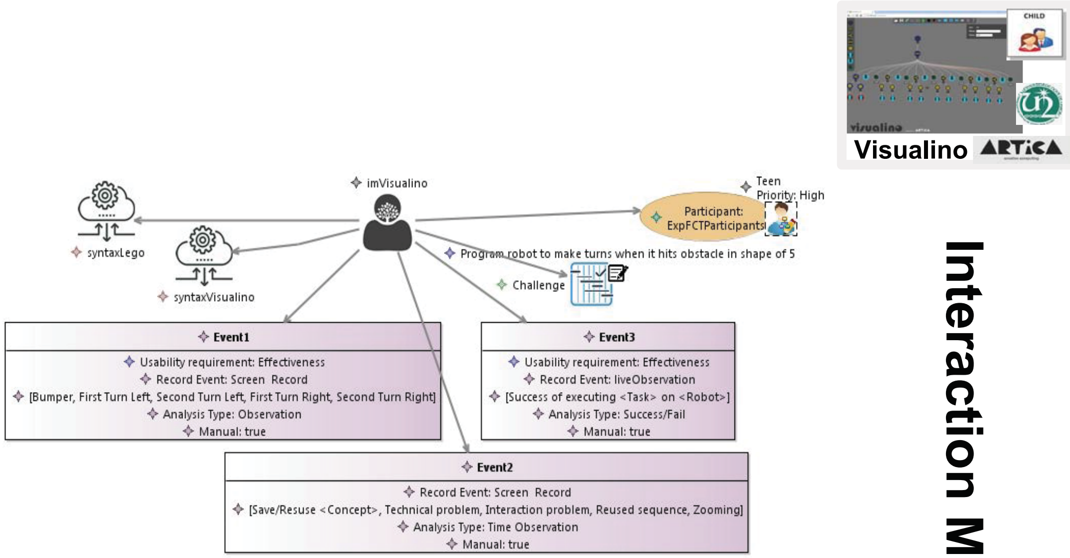

Interaction Model

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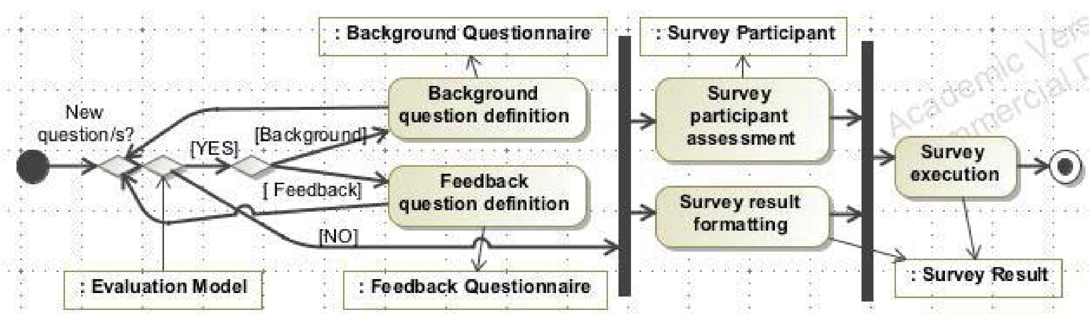
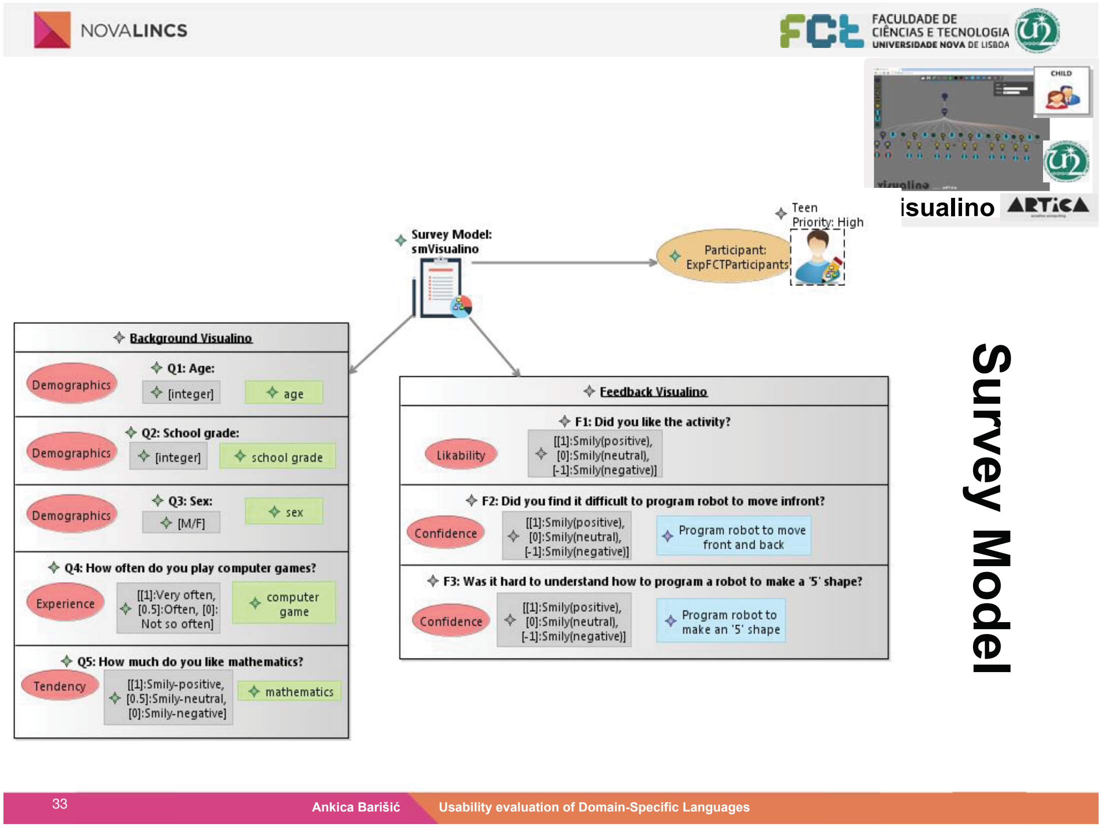
Survey Modeling (USE-ME)





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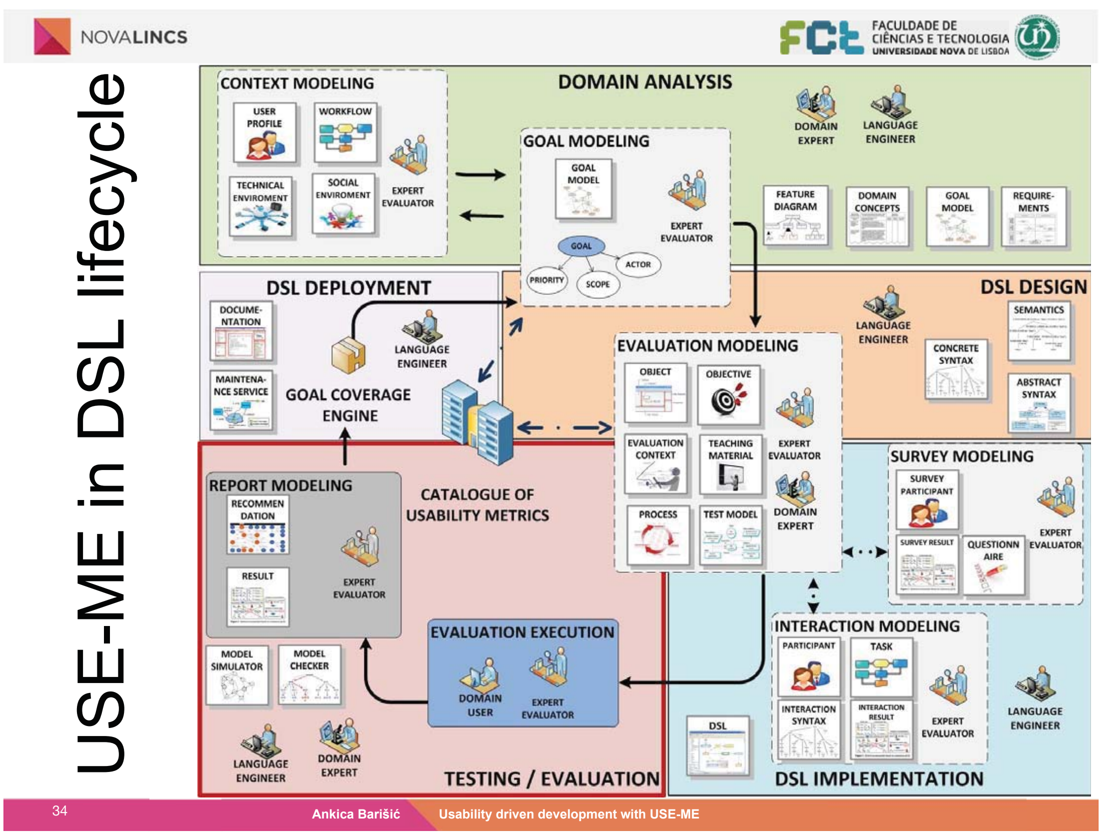
Survey Model
Survey Model: smVisualino
Participant: ExpFCTParticipants
Teen
Priority: High
Background Visualino
Q1: Age:
Demographics
[integer]
age
Q2: School grade:
Demographics
[integer]
school grade
Q3: Sex:
Demographics
[M/F]
sex
Q4: How often do you play computer games?
Experience
[[1]:Very often, [0.5]:Often, [0]: Not so often]
computer game
Q5: How much do you like mathematics?
Tendency
[[1]:Smily-positive, [0.5]:Smily-neutral, [0]:Smily-negative]
mathematics
Feedback Visualino
F1: Did you like the activity?
Likability
[[1]:Smily(positive), [0]:Smily(neutral), [-1]:Smily(negative)]
F2: Did you find it difficult to program robot to move infront?
Confidence
[[1]:Smily(positive), [0]:Smily(neutral), [-1]:Smily(negative)]
Program robot to move front and back
F3: Was it hard to understand how to program a robot to make a '5' shape?
Confidence
[[1]:Smily(positive), [0]:Smily(neutral), [-1]:Smily(negative)]
Program robot to make an '5' shape
isualino
ARTICA
33
Ankica Barišić
Usability evaluation of Domain-Specific Languages



NOVALINCS
FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA
USE-ME in DSL lifecycle
CONTEXT MODELING
USER PROFILE
WORKFLOW
TECHNICAL ENVIROMENT
SOCIAL ENVIROMENT
EXPERT EVALUATOR
DOMAIN ANALYSIS
DOMAIN EXPERT
LANGUAGE ENGINEER
GOAL MODELING
GOAL MODEL
EXPERT EVALUATOR
GOAL
ACTOR
PRIORITY
SCOPE
FEATURE DIAGRAM
DOMAIN CONCEPTS
GOAL MODEL
REQUIRE-MENTS
DSL DEPLOYMENT
DOCUME-NTATION
MAINTENA-NCE SERVICE
LANGUAGE ENGINEER
GOAL COVERAGE ENGINE
DSL DESIGN
LANGUAGE ENGINEER
SEMANTICS
CONCRETE SYNTAX
ABSTRACT SYNTAX
EVALUATION MODELING
OBJECT
OBJECTIVE
EXPERT EVALUATOR
EVALUATION CONTEXT
TEACHING MATERIAL
PROCESS
TEST MODEL
DOMAIN EXPERT
SURVEY MODELING
SURVEY PARTICIPANT
EXPERT EVALUATOR
SURVEY RESULT
QUESTIONNAIRE
REPORT MODELING
RECOMMENDATION
RESULT
EXPERT EVALUATOR
CATALOGUE OF USABILITY METRICS
MODEL SIMULATOR
MODEL CHECKER
EVALUATION EXECUTION
DOMAIN USER
EXPERT EVALUATOR
LANGUAGE ENGINEER
DOMAIN EXPERT
TESTING / EVALUATION
INTERACTION MODELING
PARTICIPANT
TASK
INTERACTION SYNTAX
INTERACTION RESULT
EXPERT EVALUATOR
LANGUAGE ENGINEER
DSL
DSL IMPLEMENTATION
34
Ankica Barišić
Usability driven development with USE-ME

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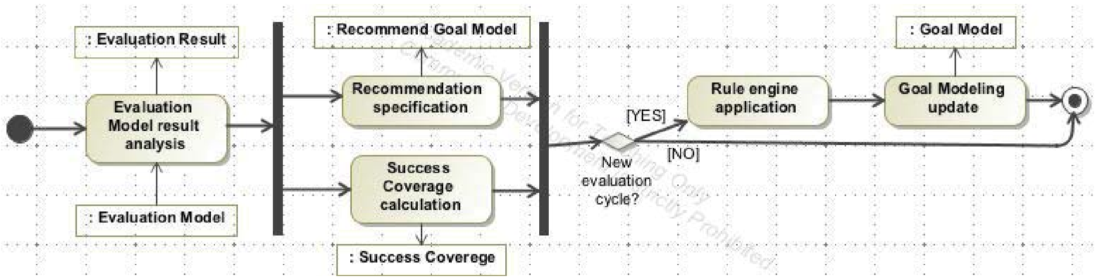
Report Modeling (USE-ME)



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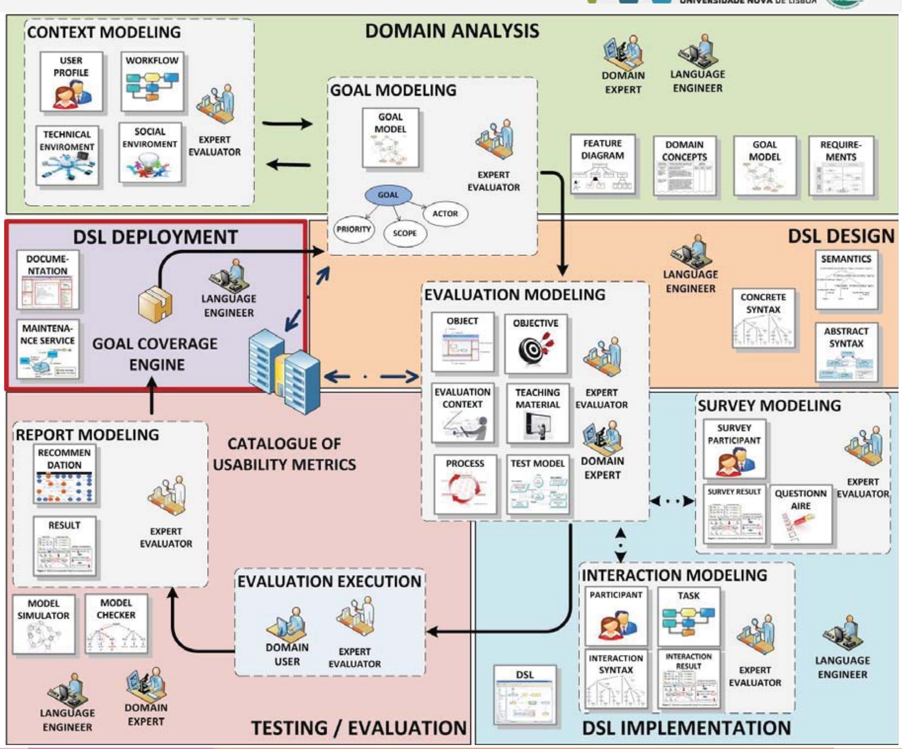
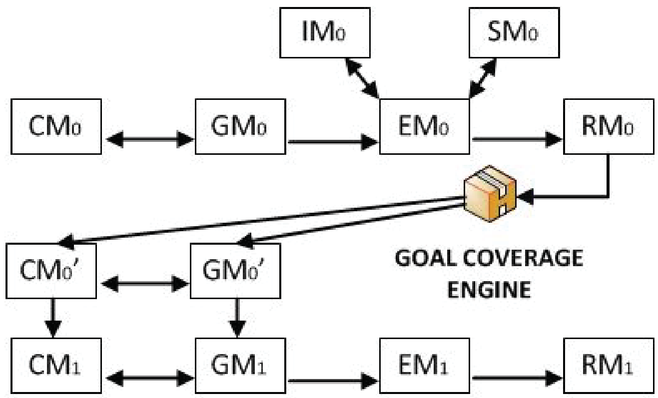
USE-ME in DSL lifecycle



Coverage Engine (USE-ME)



CM – Context Model
GM – Goal Model
EM – Experiment Model
RM – Result Model
IM – Interaction Model
SM – Survey Model

Publications

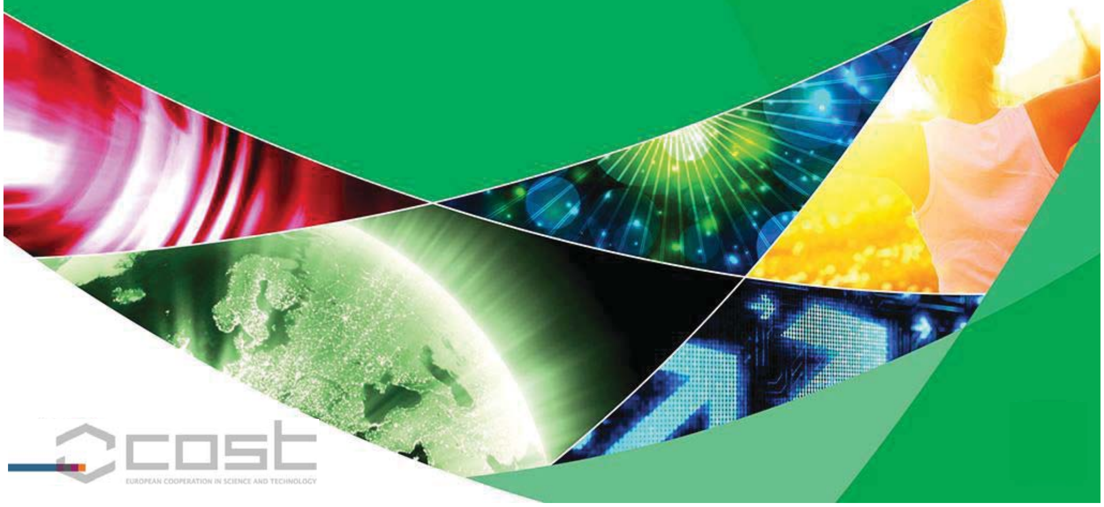
1. Ankica Barišić, Vasco Amaral, Miguel Goulão and Ademar Aguiar: ***"Introducing usability concerns early in the DSL development cycle: FlowSL experience report"***, InProceedings of the 1st International Workshop on Model-Driven Development Processes and Practices at the 17th International MoDELS Conference, Valencia, Spain, October, 2014
2. Ankica Barišić: ***"Evaluating the Quality in Use of Domain-Specific Languages in an Agile Way"***, InProceedings of the Doctoral Symposium at the 16th International Conference on Model Driven Engineering Languages and Systems (MoDELS), Miami, Florida, USA, CEUR, October, 2013
3. Ankica Barišić: **"Iterative evaluation of Domain-Specific Languages"**, InProceedings of the ACM Student Research Competition at the 16th International Conference on Model Driven Engineering Languages and Systems (MoDELS), Miami, Florida, ACM, October, 2013
4. Ankica Barišić, Pedro Monteiro, Vasco Amaral, Miguel Goulão, Miguel Monteiro: ***"Patterns for Evaluating Usability of Domain-Specific Languages"***, InProceedings of the 19th Conference on pattern languages of programs (PLoP), SPLASH 2012 Tucson, Arizona, USA, October 2012
5. Bruno Barroca, Eduardo Marques, Valter Balegas, Vasco Amaral and Ankica Barišić: ***"The RPG DSL: a case study of language engineering using MDD for Generating RPG Games for Mobile Phones"*** InProceedings of the 12th Workshop on Domain-Specific Modeling at SPLASH 2012, Tucson, Arizona, ACM, October 2012
6. Ankica Barišić, Vasco Amaral and Miguel Goulão: ***"Usability Evaluation of Domain-Specific Languages"***, InProceedings of the SEDES Doctoral Symposium at the 8th International Conference on the Quality of Information and Communications Technology (QUATIC), Lisbon, Portugal, IEEE, September 2012,
7. Ankica Barišić, Vasco Amaral, Miguel Goulão and Bruno Barroca: ***"Evaluating the Usability of Domain-Specific Language"***, InBook: Formal and Practical Aspects of Domain-Specific Languages: Recent Developments, edited by Marjan Mernik, IGI Global, September 2012, pages: 386-407
8. Ankica Barišić, Vasco Amaral, Miguel Goulão and Bruno Barroca: ***"Quality in Use of Domain-Specific Language: a Case Study"***, InProceedings of the Workshop on Evaluation and Usability of Programming Languages and Tools (PLATEAU 2011) at SPLASH 2011, Portland, Oregon, USA, ACM, October 2011
9. Ankica Barišić, Vasco Amaral, Miguel Goulão and Bruno Barroca: ***"Quality in Use of DSLs: Current Evaluation Methods"***, InProceedings of the INFORUM'2011, Coimbra, Portugal, September, 2011
10. Ankica Barišić, Vasco Amaral, Miguel Goulão and Bruno Barroca: ***"How to reach a usable DSL? Moving toward a Systematic Evaluation"***, InProceedings of the 5th International Workshop on Multi-Paradigm Modeling (MPM'2011) at Models 2011, Wellington, New Zealand, EASST Journal, October,2011


NOVALINCS
LABORATORY FOR COMPUTER
SCIENCE AND INFORMATICS

Automated Analysis of Traceability in Cyber-Physical Systems

Ferhat Erata, Bedir Tekinerdogan

IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems



Challenges of Traceability in Industry

Semantically meaningful traceability

- traceability relations should have a rich semantic meaning instead of being simple bi-directional referential relation

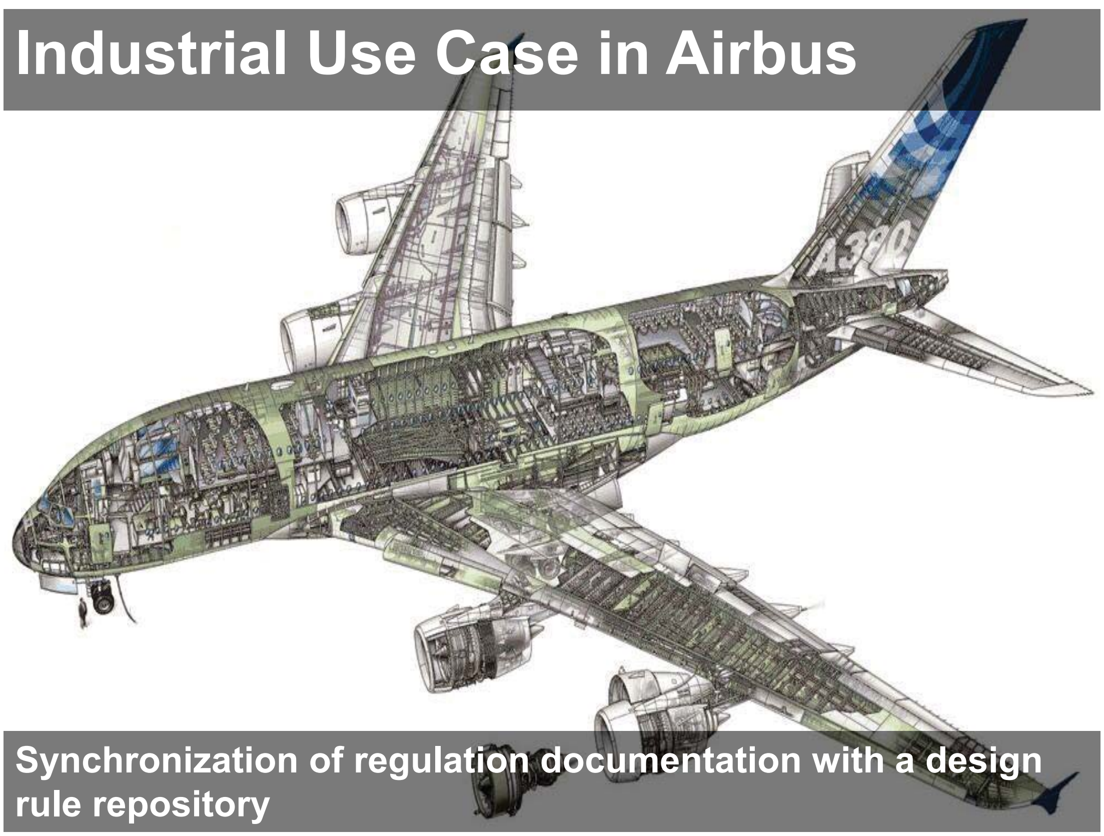
Configurability of traceability (possibly dynamically)

- the semantics of traceability is often statically defined
- the semantics cannot be easily adapted for the needs of different projects.
- different traceable elements and the types of relations exist in industrial settings.

Several industries demands formal proofs of traceability

Consistency checking and repairing broken trace links

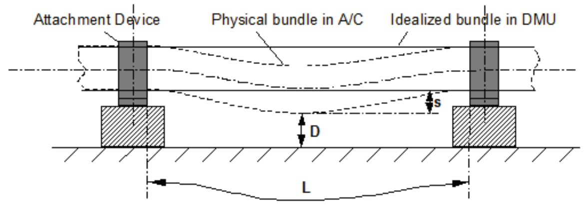

What is the problem?


Industrial Use Case in Airbus
A380
Synchronization of regulation documentation with a design rule repository

SIDP: System Installation Design Principles

SIDP92A001V-A-784

For installation of optical and electrical harnesses additional clearance for sagging (s) shall be provided as detailed below:



s...Sagging of bundle (real behavior of physical bundle in A/C due to gravity, ageing, etc.)
D...Required Distance
L...Actual length of a bundle segment between two Attachment Points (as designed in DMU)

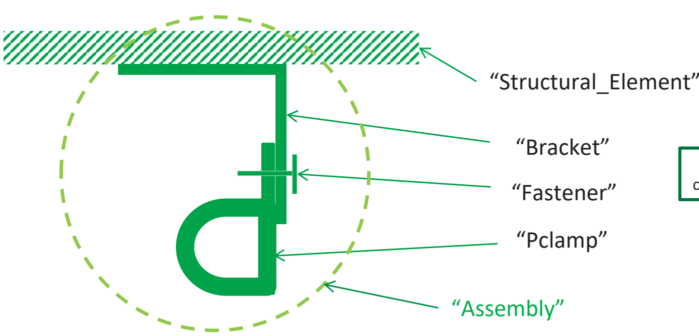
Figure 6: Sagging of bundles between attachment points

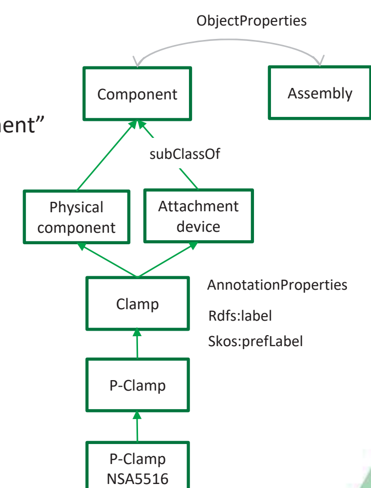
Note: Unless the bundle has a straight routing, L is bigger than the pitch between the Attachment Points.

Component Ontology and Rules

Objectives:

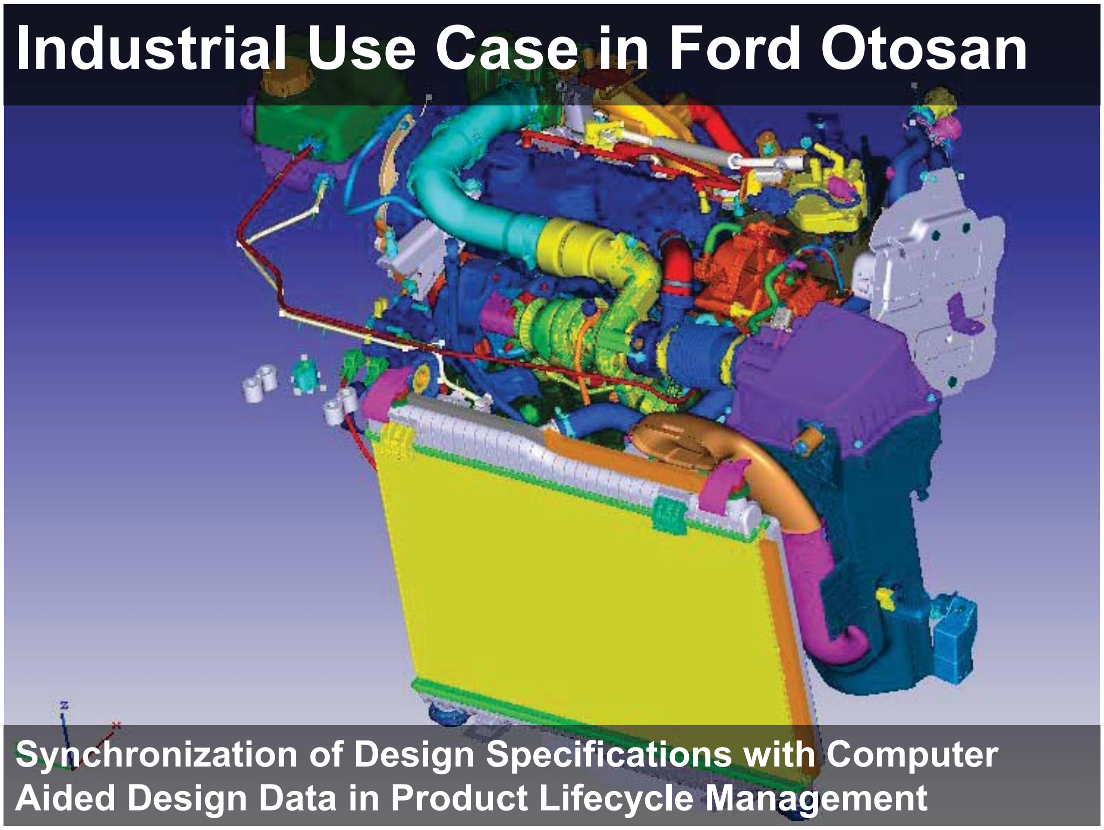
- Manage rules/design principles and improve traceability
- Automate identification of design conflicts against rules

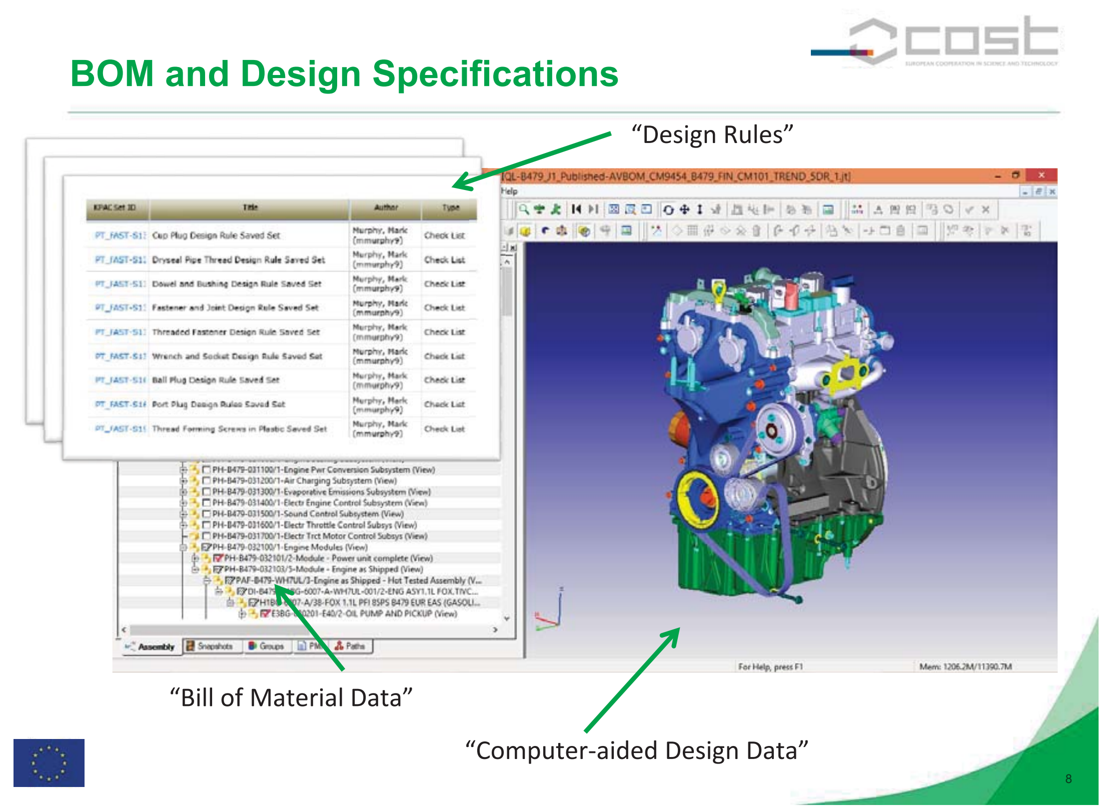




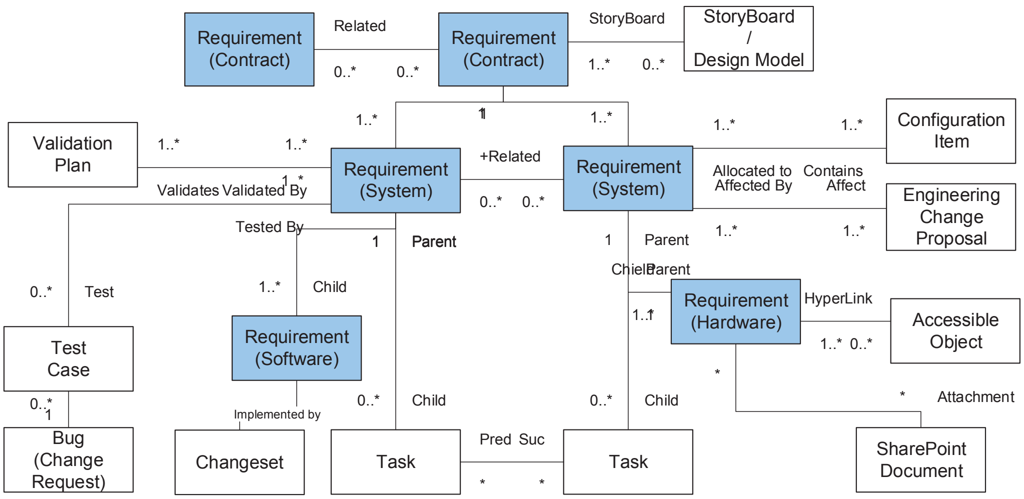
"P-clamp NSA5516 can be fixed on X with Y"

"Physical component" "Standard reference"


Industrial Use Case in Ford Otosan
Synchronization of Design Specifications with Computer Aided Design Data in Product Lifecycle Management


BOM and Design Specifications
cost
"Design Rules"
"Bill of Material Data"
"Computer-aided Design Data"
8

Industrial Use Case in Havelsan

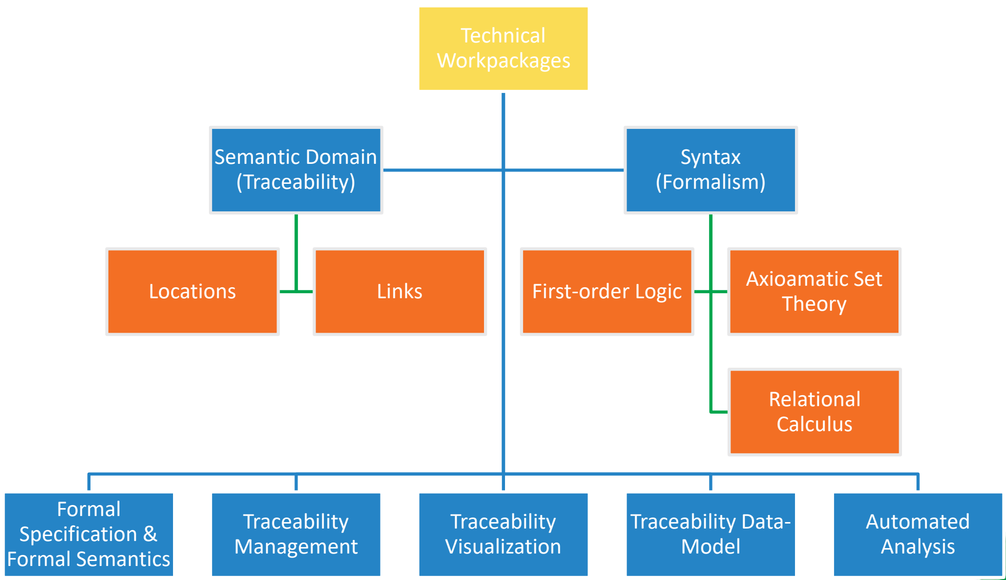


Integration with Application Lifecycle Management to ensure reliability and consistency in the system under development.

Tarski: A Platform for Automated Analysis of Dynamically Configurable Traceability Semantics

The Paper is accepted by "The 32nd ACM Symposium on Applied Computing (SAC'2017), Programming Languages Track".

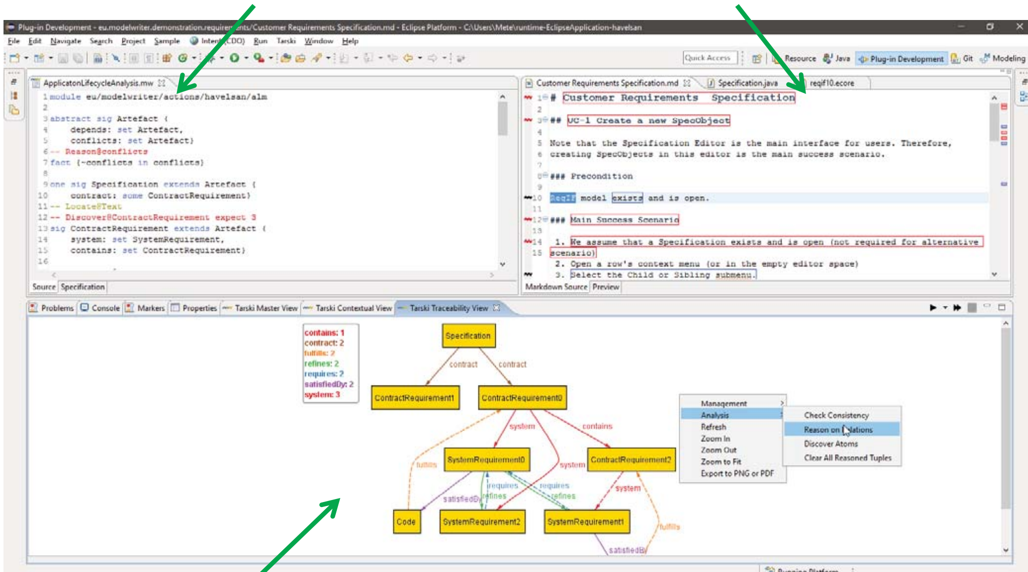
Overview of Technical Contributions @Tarski



Automated Analysis of Dynamically Configured Traceability Semantics

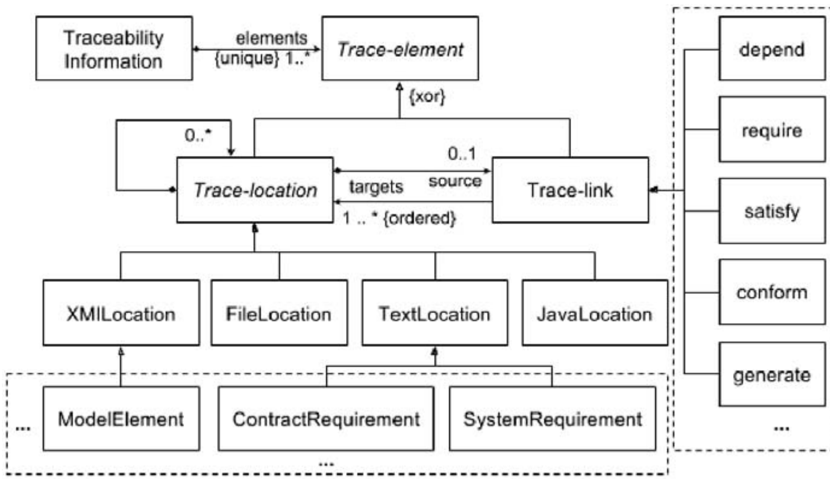
"Traceability Rules to define traceability semantics"

Artefacts or part of artefacts



"Various Traceability Analysis might be performed"

Technical Contributions @Tarski
Conceptual Model for Traceability



IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems

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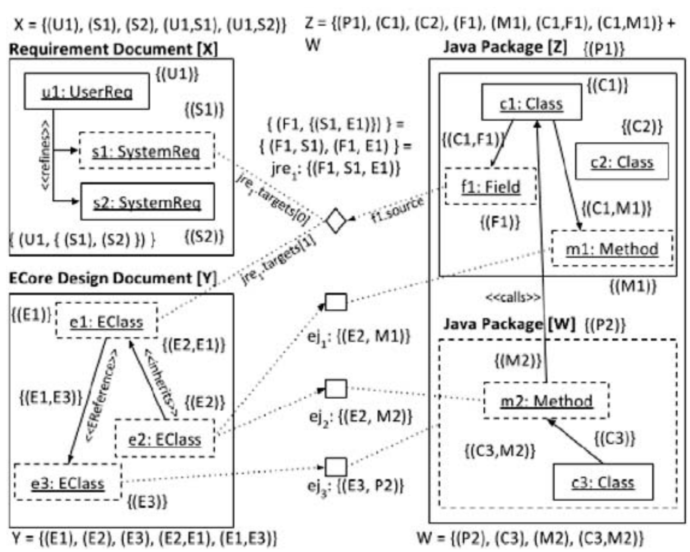
Technical Contributions @Tarski
Formalization of Traceability Semantics



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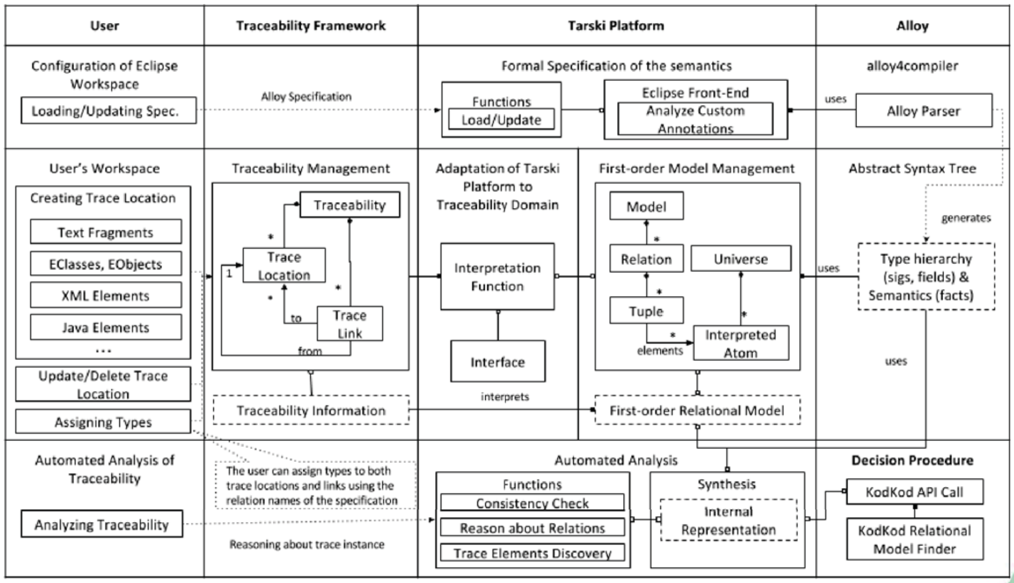
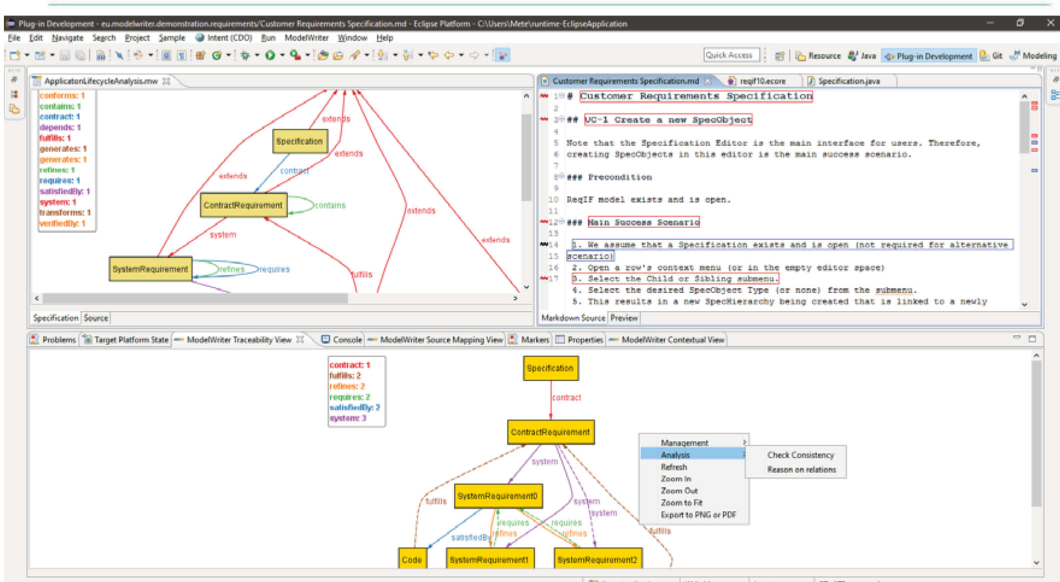
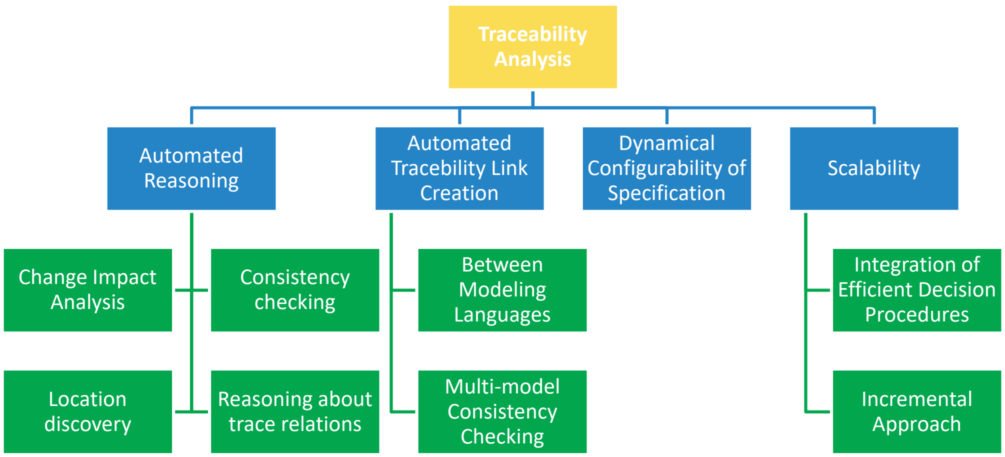
Tarski
Approach



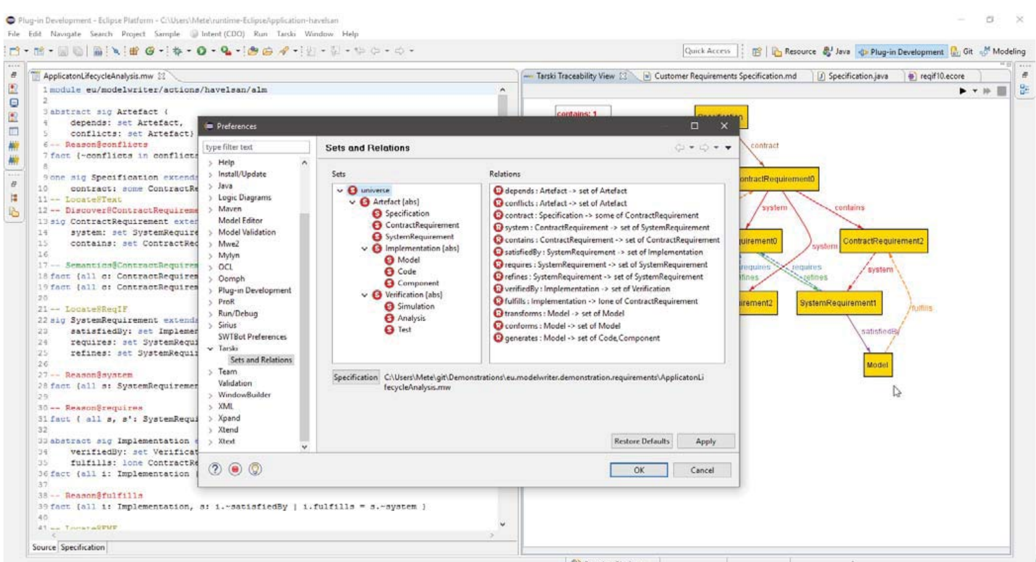
Technical Contributions @Tarski



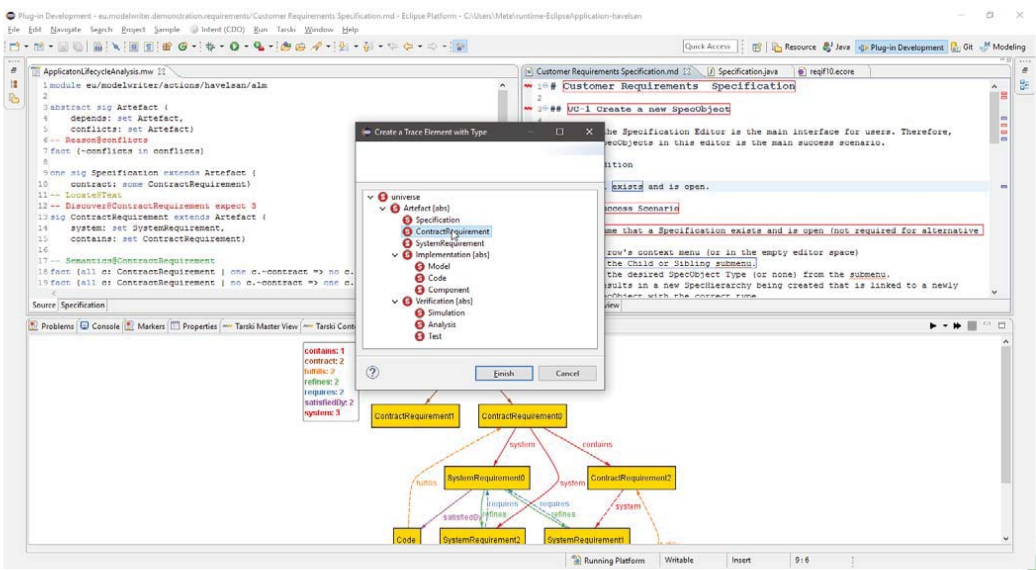
Traceability Analysis



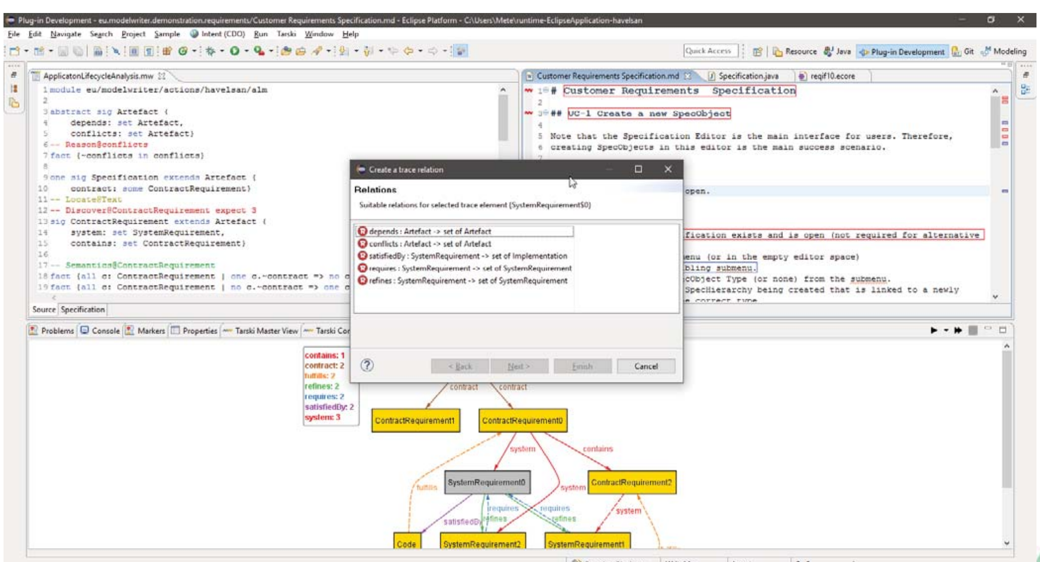
Types/Component Ontology derived from the specification



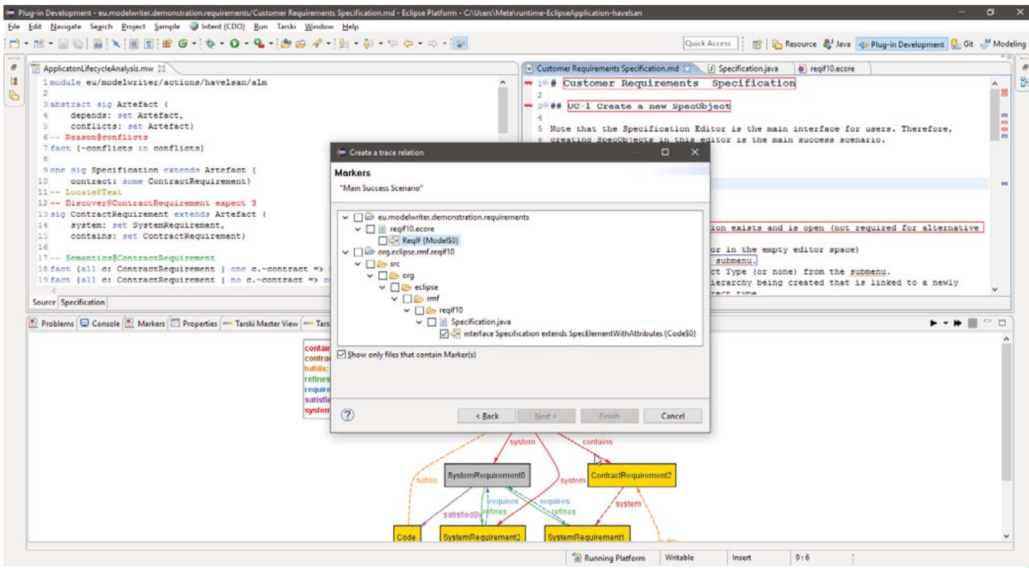
Assigning Unary Relations to a Traceable Elements



Assigning Binary Relations to a Trace Link



Selecting a range for a binary relation from an existing traceable elements



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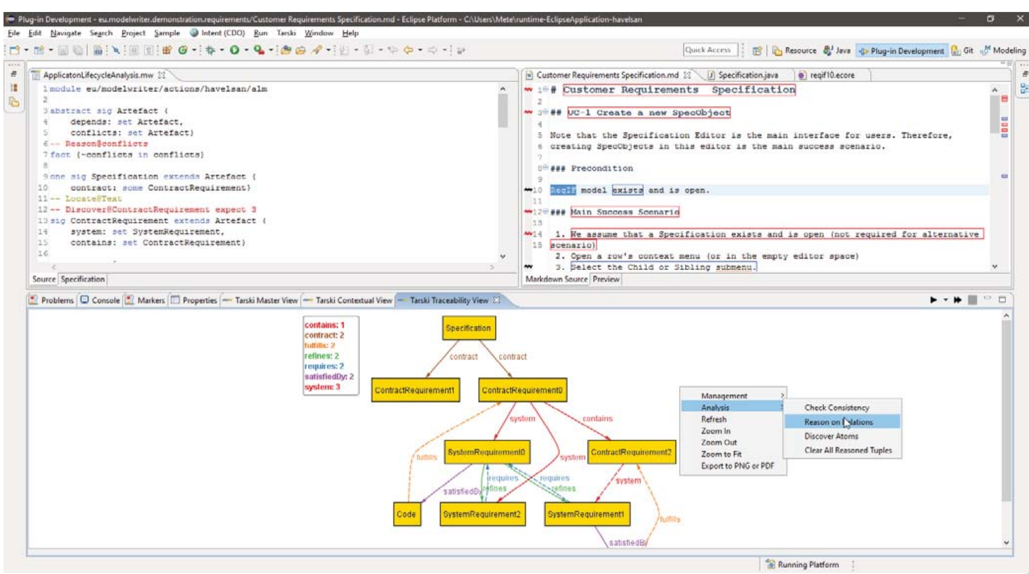
Automated Analysis of Traceability



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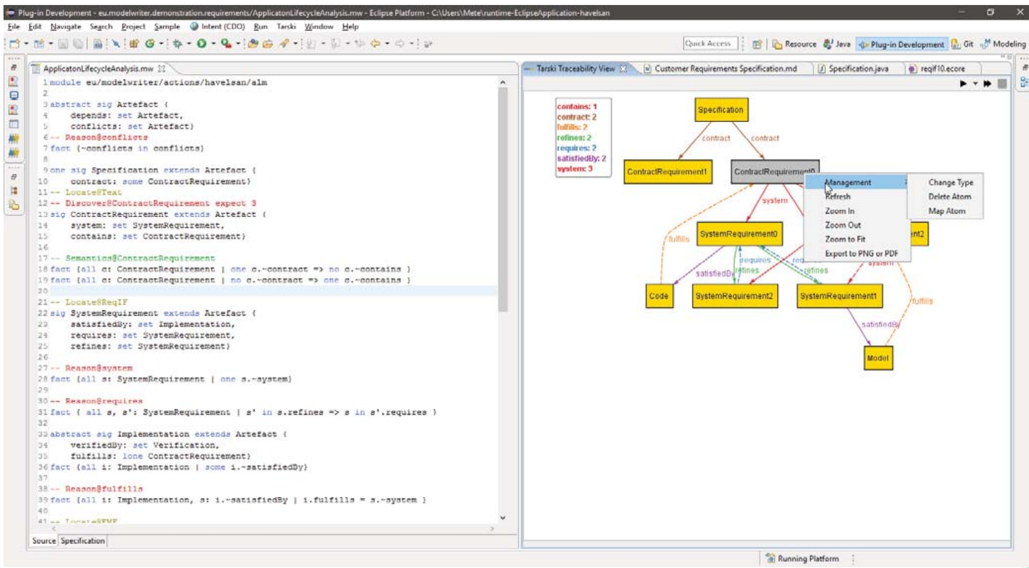
Dynamical Configuration & Model Management



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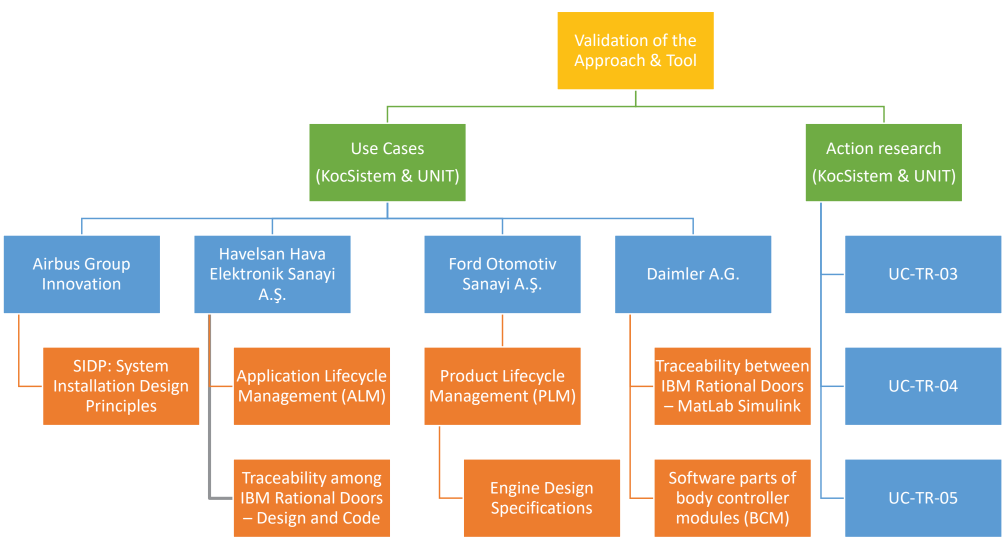
Validation of the Approach and Tool



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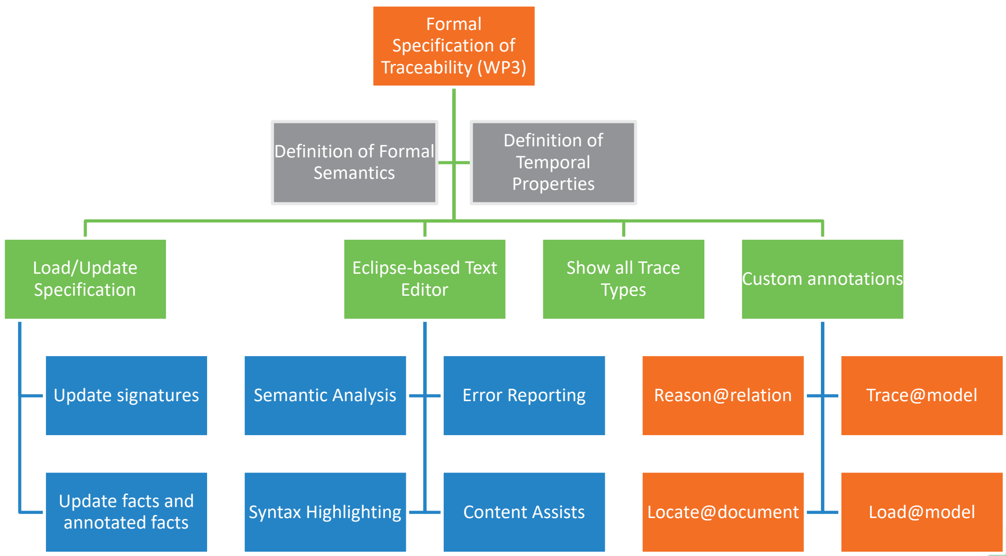
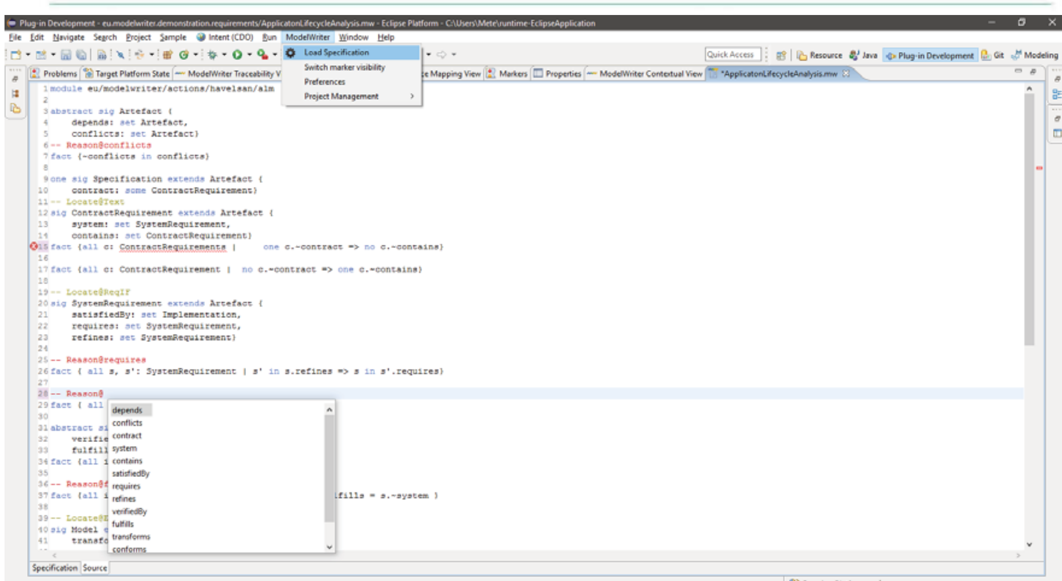
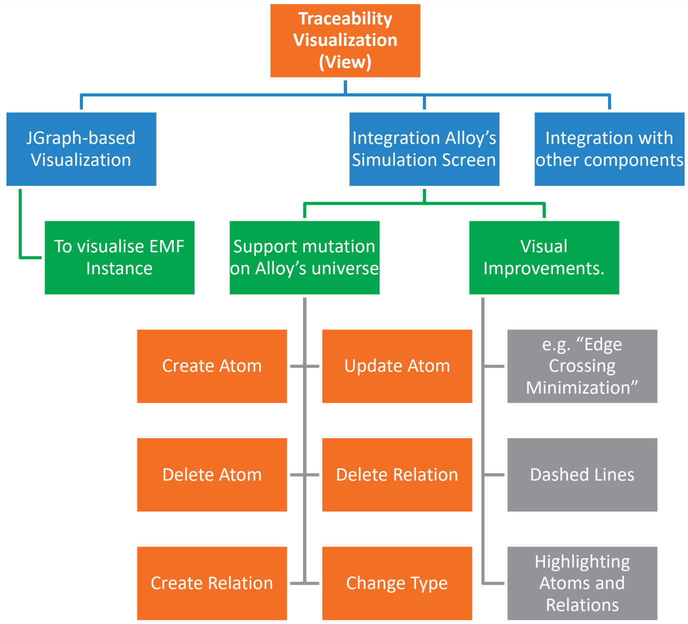
Formal Specification of Traceability



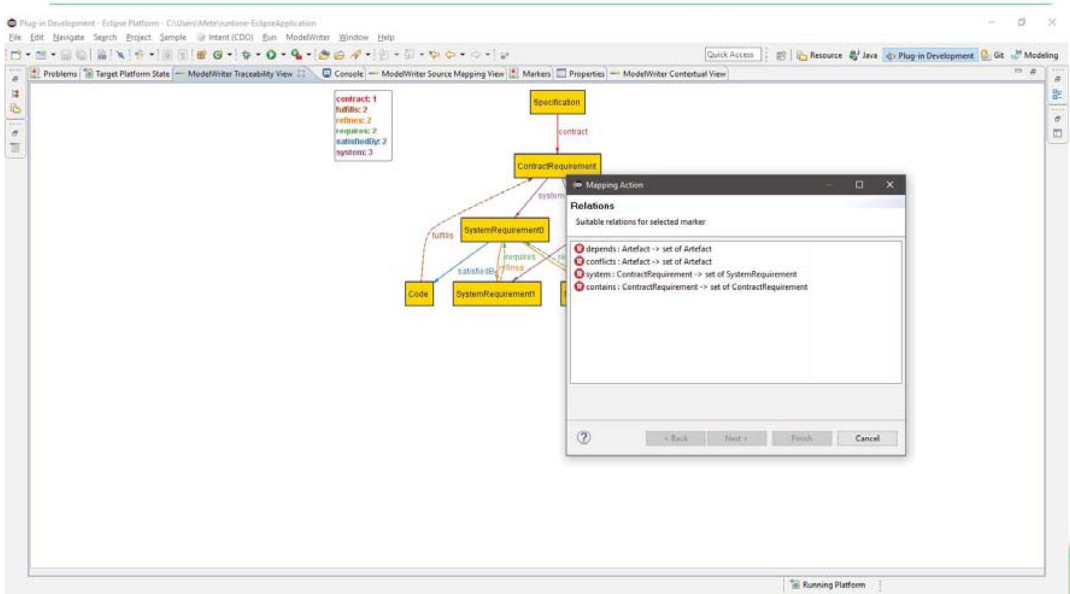
Textual Editor in Action



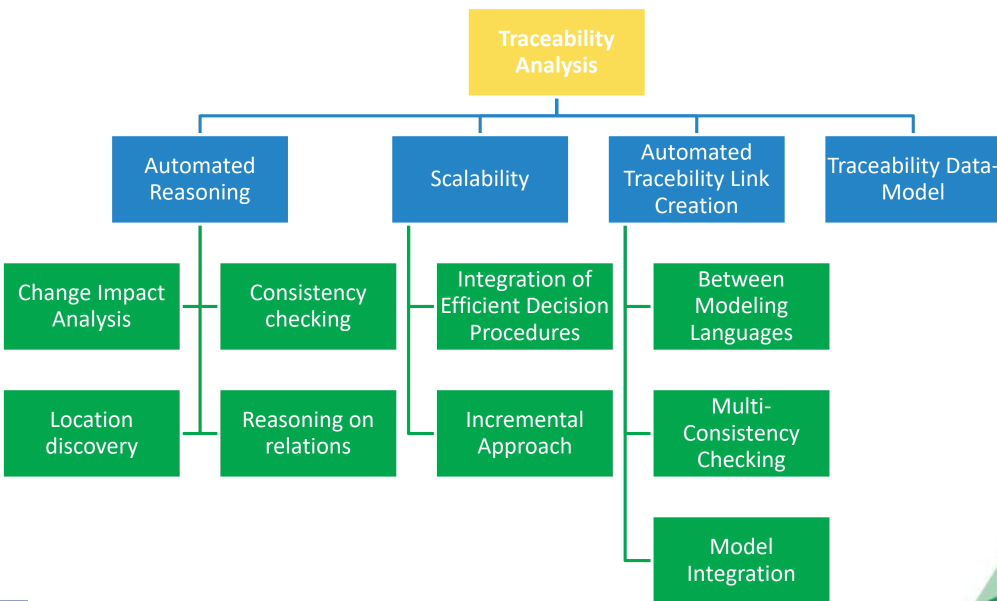
Traceability Visualization/View



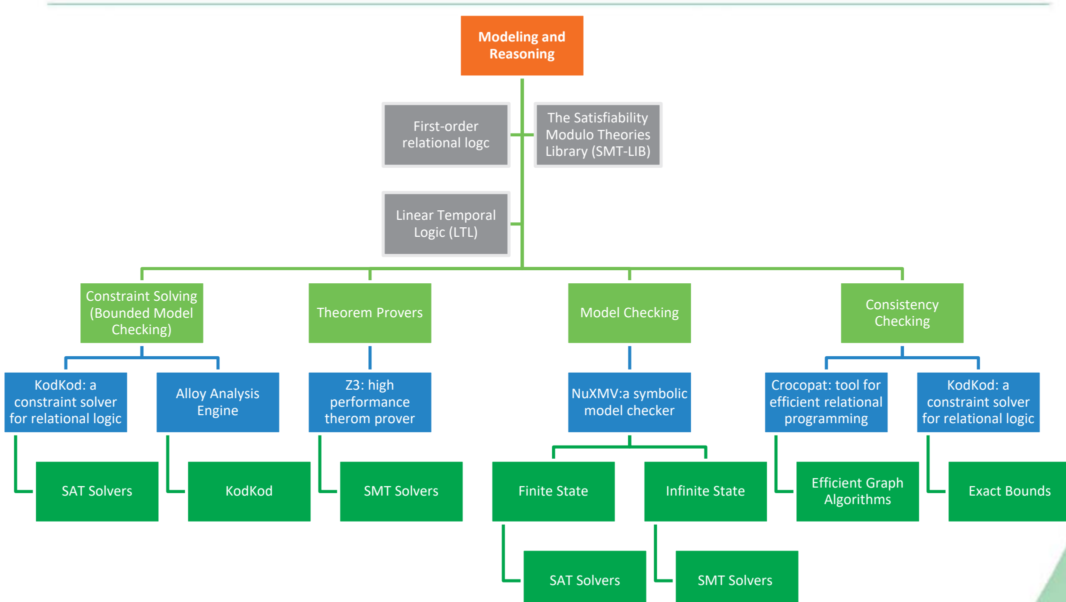
Demonstration Visualization in Action



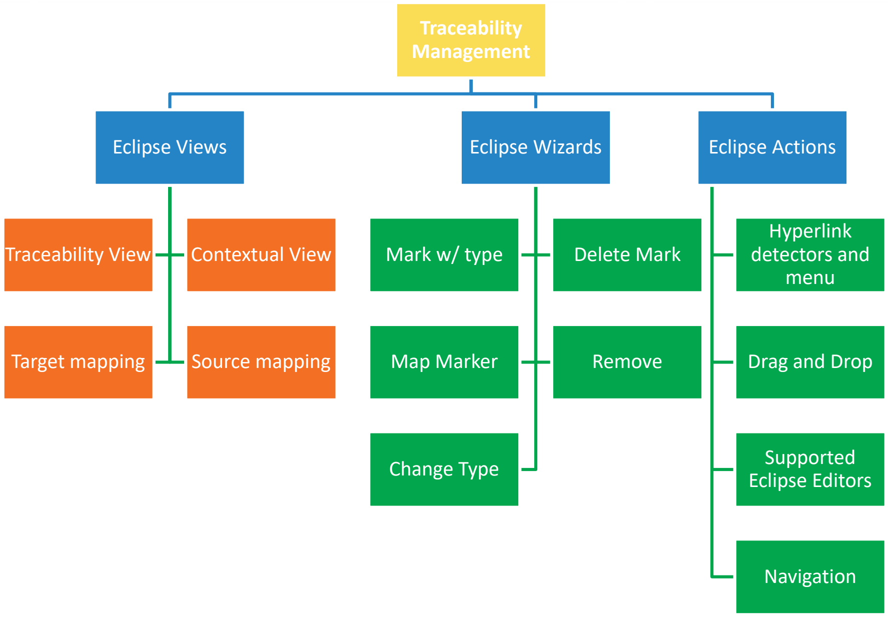
Traceability Analysis



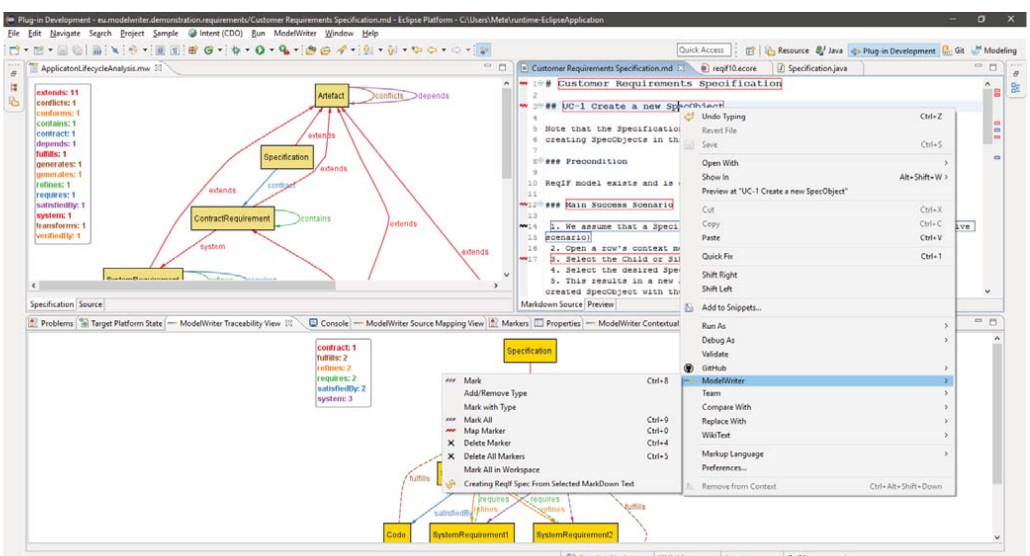
Modeling and Reasoning Approaches



Traceability Management (WP6)



Demonstration
Traceability Management in Action



Discussion

- First-order theory of relations to be a solution for traceability in MPM4CPS?
  - Preliminary results shows that the approach works on the synchronization of design rules with design/installation of physical components
- Currently, DPLL(T) solver does not exists for the theory
- What about other theories and combination of theories?
- Should we consider also the temporal behavior of the traceability?

IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems

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A hybrid master (discrete-event and discrete-time) for Functional Mockup Interface

Vincent Albert
LAAS-CNRS / University of Toulouse

MPM4CPS workshop – Malaga, Spain, 2016
COST Action IC1404

Overview

- Introduction
- Solution
- Experiments
- Conclusion and perspectives

2

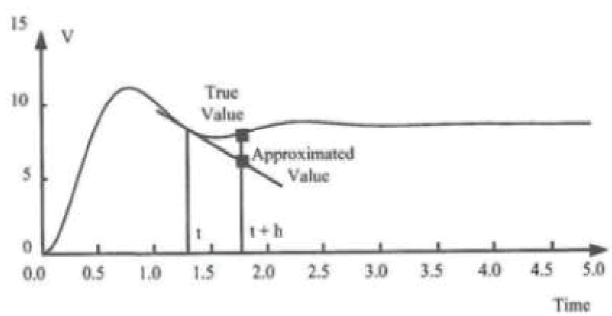
Introduction

3

Discrete-time simulation

Given a system under the form $\frac{dx\,(t)}{dt} = f\big(x(t), u(t)\big)$

$$x_i(t+h) = x_i(t) + \frac{dx_i(t)}{dt}.h$$



4

Discrete-event simulation

Given a system under the form $\dot{q}(t) = f\big(q(t), u(t)\big)$

$$q(t + \Delta t) = q(t) + \dot{q}(t).\Delta t$$

$$\Delta Q = |q(t + \Delta t) - q(t)|$$

5

Discrete-event simulation

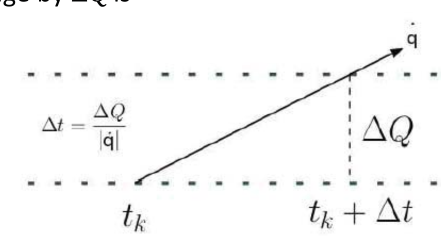
Given a system under the form $\dot{q}(t) = f\big(q(t), u(t)\big)$

$$q(t + \Delta t) = q(t) + \dot{q}(t).\Delta t$$

$$\Delta Q = |q(t + \Delta t) - q(t)|$$

1. The required time for the solution of $q(t)$ to change by ΔQ is

$$\Delta t = \begin{cases} \frac{\Delta Q}{|\dot{q}|} \ if \ \dot{q} \neq 0 \\ \infty \ otherwise \end{cases}$$



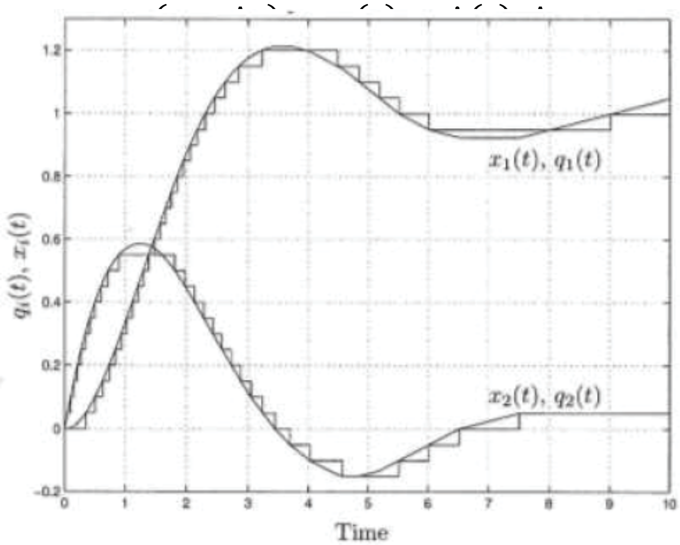
At this time, the next state will be

$$q(t_k + \Delta t) = q(t_k) + sign\big(\dot{q}(t_k)\big) * \Delta Q$$

6

Discrete-event simulation

Given a system under the form $\dot{q}(t) = f\big(q(t), u(t)\big)$



1. The requir

$\Delta t = \begin{cases} \frac{\Delta Q}{|\dot{q}|} \; if \; \dot{q} \\ \infty \; othe \end{cases}$

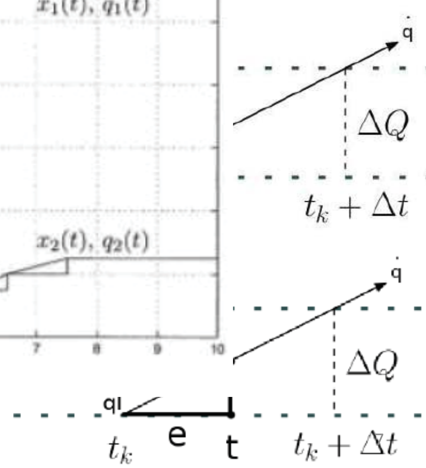
At this time, th

$q($

2. If $\dot{q}$ change

$q = q + \dot{q} * e$

$\Delta t = \begin{cases} \frac{\Delta Q - |q}{|\dot{q}|} \; if \; \dot{q} \neq 0 \\ \infty \; otherwise \end{cases}$



Discrete-Event System Specification

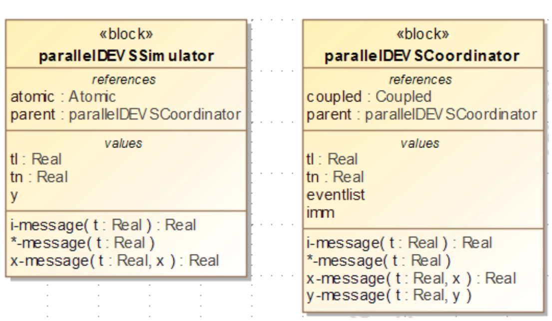
Model DEVS

Atomic component

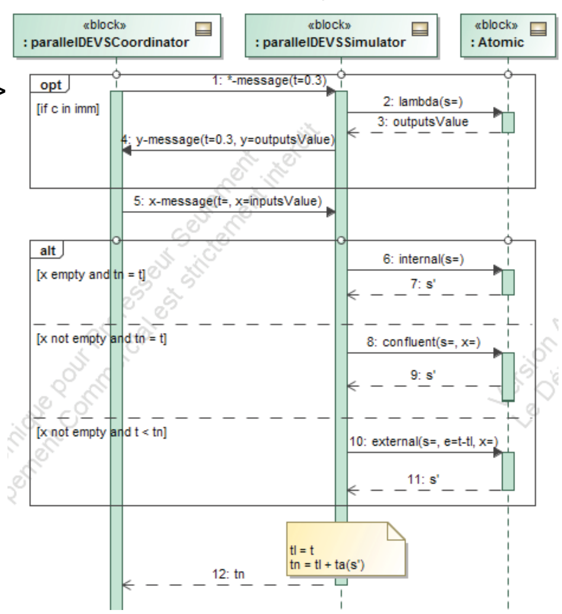
$< X, Y, S, \delta int, \delta ext, \delta con, \lambda, ta >$

$ta : S \rightarrow \mathbb{R}^{+}_{0,\infty}$

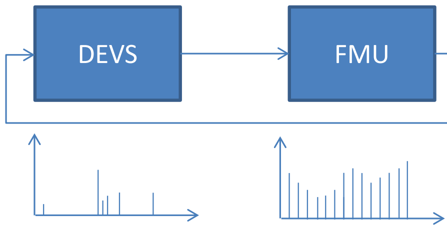
Simulator DEVS



Parallel DEVS protocol

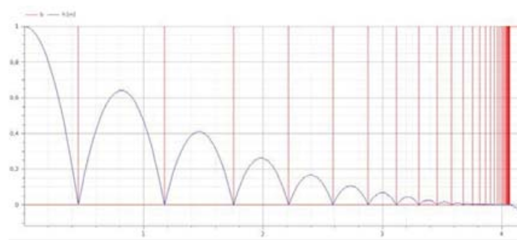


Issues



1. Continuous /discrete interface
2. Handle FMU input external event
3. Get time of FMU next event
4. Handle FMU internal event

```
model BouncingBall "The 'classic' bouncing ball model
  type Height=Real(unit="m");
  type Velocity=Real(unit="m/s");
  parameter Real e=0.8 "Coefficient of restitution";
  parameter Height h0=1.0 "Initial height";
  Height h;
  Velocity v;
initial equation
  h = h0;
equation
  v = der(h);
  der(v) = -9.81;
  when h<0 then
    reinit(v, -e*pre(v));
  end when;
end BouncingBall;
```



h<0 is false at the integration step before t_1

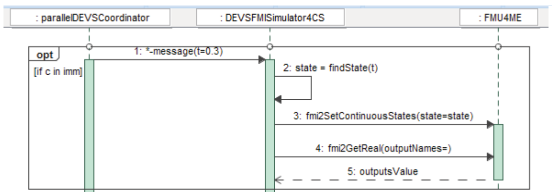
h<0 is true at the integration step after t_1

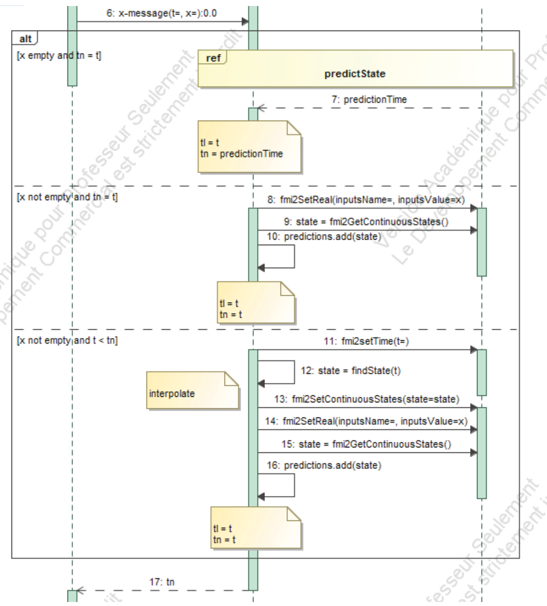
9

Hybrid Master for DEVS-FMI

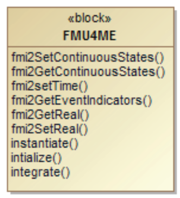
10

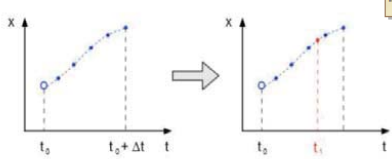
DEVS-FMI for ME






```
double predictState(double t)
{
  currentTime = t;
  horizon = t + lookAheadHorizon;
  while (currentTime < horizon)
    currentTime = integrate(currentTime+lookAheadStepSize);
    newState = fmi2getContinuousState();
    outputs = fmi2getReal();
    predictions.add(newState);
    eventInds = fmi2GetEventIndicators()
    for(eventInds.size)
      if(eventInds[i] != savedeventInds[i])
        handleEvent(); //bisectional search
        return currentTime;
    return currentTime;
}
```





11

Experiments

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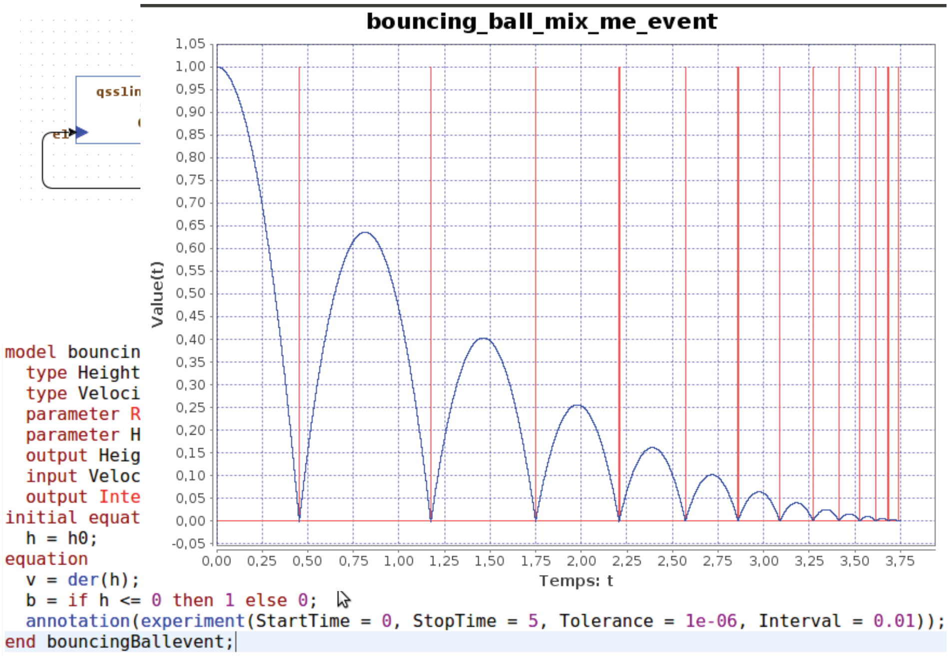
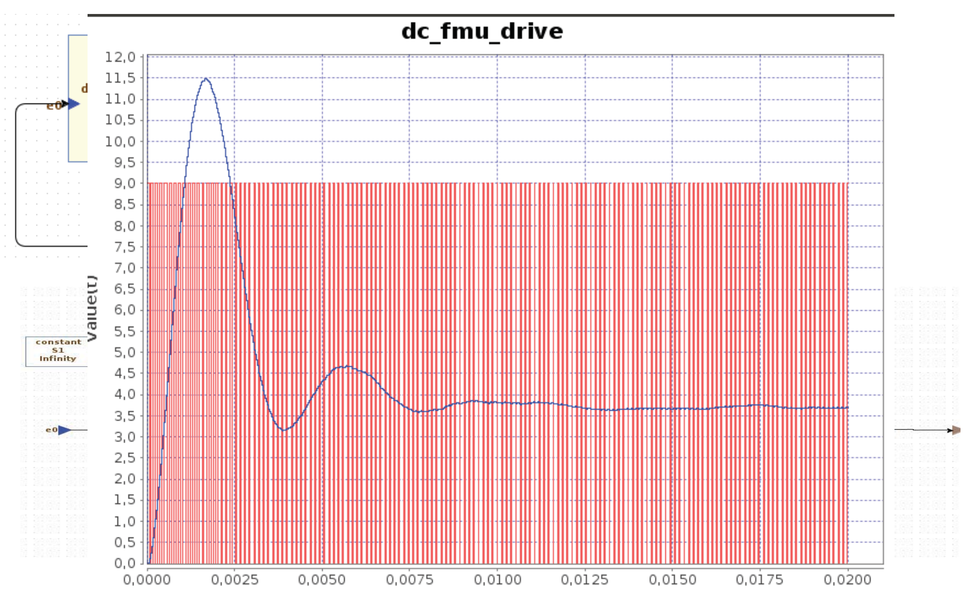
BouncingBall



13

DC-Motor and PWM Controller



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Conclusion and Perspectives

15

Conclusion and Perspectives

- Conclusion
  - Modular and hierarchical hybrid master (discrete-time and discrete-event simulation algorithms) for cosimulation and model exchange
  - Passed with JModelica, failed with FMUSDK (?)
  - Techno : FMIPP (SWIG, ODEINT)
- Perspectives
  - Extend the standard for discrete-event paradigm
  - Develop interface for VHDL simulator
  - Develop interface for FPGA

16

Adding Uncertainty and Units to Quantity Types in Software Models

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Workshop of IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems
November 24-25, 2016, Malaga, Spain

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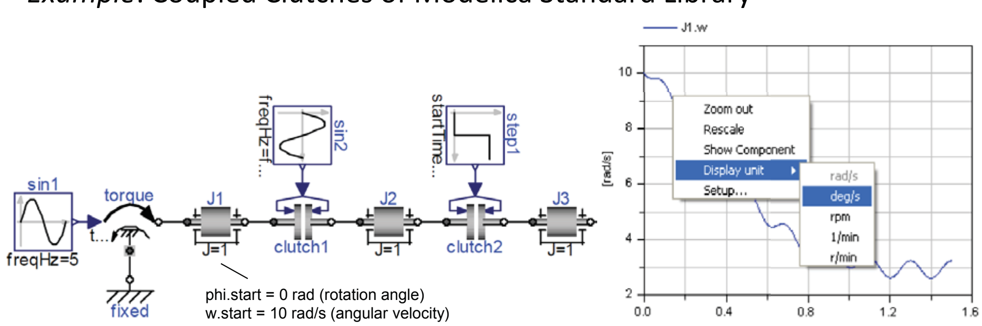
Motivation

Uncertainty and Units in Engineering Disciplines

- Engineers naturally think about *uncertainty* associated with *measured values* and *units of values*
- Uncertainty and units are explicitly defined in models and considered in model-based simulations

- *Example*: Coupled Clutches of Modelica Standard Library



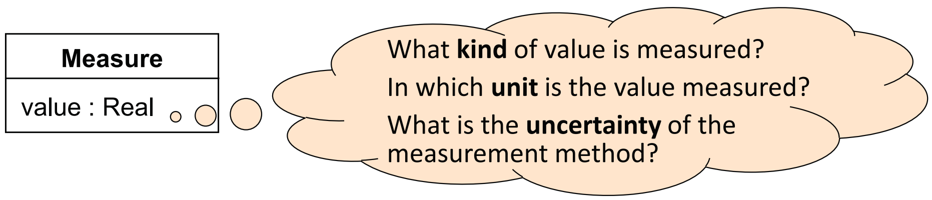
(Coupled Clutches Example of Modelica Standard Library)

Motivation

Uncertainty and Units in Software Engineering

- Very limited support for representing uncertainty and units in software models
- No support for considering such properties in model-based simulations

- *Example*: How to represent a measured value in UML?



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Contributions

1. **Type system** for representing measurement uncertainty and units
   - Kernel representation for quantities
2. **Algebra of operations** for performing computations with uncertain data and units
   - Computational kernel for computing quantities
3. **Implementations** for Java, OCL, UML

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International System of Units (SI)

- Base dimensions: Length, Mass, Time, Electric Current, Thermodynamic Temperature, Amount of Substance, Luminous Intensity
- Base units: Meter (m), Kilogram (kg), Second (s), Ampere (A), Kelvin (K), Mole (mol), Candela (cd)
- Derived dimensions: 90 dimensions derived from the base dimensions e.g., Area, Volume, Velocity
- Derived units: 90 units derived from the base units e.g., Square Meter (m^2), Cubic Meter (m^3), Meter per Second (m/s)

Other Systems of Units

- Centimeter-Gram-Second System (CGS)
- Imperial System
- United States Customary System (USCS, USC)

B. N. Taylor and A. Thompson. The International System of Units (SI). NIST, 2008. http://www.nist.gov/pml/pubs/sp811/. 5

- Any unit can be derived from the base units: $B_1^{e_1} * B_2^{e_2} \ldots B_n^{e_n}$ where B_i represents a base unit and e_i its exponent
- Hence, any unit can be defined by the exponents e_i of the base units: $\langle e_1, e_1, \ldots, e_n \rangle$
- *Examples*

$$Meter\ (m) = m^1 * kg^0 * s^0 * A^0 * K^0 * cd^0 * mol^0 * rad^0 = \langle 1,0,0,0,0,0,0,0 \rangle$$

$$Square\ Meter\ (m^2) = m^2 * kg^0 * s^0 * A^0 * K^0 * cd^0 * mol^0 * rad^0 = \langle 2,0,0,0,0,0,0,0 \rangle$$

$$Meter\ per\ Second\ (m/s) = m^1 * kg^0 * s^{-1} * A^0 * K^0 * cd^0 * mol^0 * rad^0 = \langle 1,0,-1,0,0,0,0,0 \rangle$$

R. Hodgson, P. J. Keller, J. Hodges, and J. Spivak. QUDT – Quantities, Units, Dimensions and Data Types Ontologies. TopQuadrant, Inc. and NASA AMES Research Center, 2014. http://qudt.org/. 6

Units and Dimensions — Conversion Between Units

- Conversion of quantity values from base units B_i to derived units D_i
  - Multiply the numerical value of the quantity value with conversion factor cf
  - Add an offset o to the resulting numerical value
- Definition: $x\,D_i = (x * cf_i + o_i)\,B_i$
- *Examples*:

$$x\,km = (x * 1000 + 0)\,m$$

$$x\,°C = (x * 1 + 273.15)\,\mathrm{K}$$

$$x\,km/h = (x * \frac{1000}{3600} + 0)\,\mathrm{m/s}$$

- Conversion factors and offsets can be defined relative to the base units: $cf_i: \langle cf_1, cf_1, \dots, cf_n \rangle, o_i: \langle o_1, o_2, \dots, o_n \rangle$
- *Examples*:

$$Kilometer\ (km):\ cf = \langle 1000, 1, 1, 1, 1, 1, 1, 1 \rangle,\quad of = \langle 0, 0, 0, 0, 0, 0, 0, 0 \rangle$$

$$Celcius\ (°C):\ cf = \langle 1, 1, 1, 1, 1, 1, 1, 1 \rangle,\quad of = \langle 0, 0, 0, 0, 273.15, 0, 0, 0 \rangle$$

$$Kilometer\ per\ Hour\ (km/h):\ cf = \langle 1000, 1, 3600, 1, 1, 1, 1, 1 \rangle,\ of = \langle 0, 0, 0, 0, 0, 0, 0, 0 \rangle$$

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Units and Dimensions — Model-Based Representation

- Domain Model

Unit

name : String
symbol : String
dimensions : Real [8]
conversionFactor : Real [8]
offset : Real [8]

- *Example Instances*

m : Unit

name = "Meter"
symbol = "m"
dimensions = <1,0,0,0,0,0,0,0>
conversionFactor = <1,1,1,1,1,1,1,1>
offset = <0,0,0,0,0,0,0,0>

km/h : Unit

name = "Kilometer per Hour"
symbol = "km/h"
dimensions = <1,0,-1,0,0,0,0,0>
conversionFactor = <1000,1,3600,1,1,1,1,1>
offset = <0,0,0,0,0,0,0,0>

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Measurement Uncertainty — Representation of Uncertainty

<u>Definition:</u> Standard Uncertainty [GUM]

- Uncertainty of the result of a measurement x expressed as a standard deviation u
- Representation: $x \pm u$ or (x, u)
- *Examples:*

  Normal distribution: (x, σ) with mean x, standard deviation σ

  Interval $[a, b]$: Uniform or rectangular distribution is assumed

$$(x, u) \text{ with } x = \frac{a+b}{2},\ u = \frac{(b-a)}{2\sqrt{3}}$$

[GUM] JCGM 100:2008. Evaluation of measurement data – Guide to the expression of uncertainty in measurement. Joint Committee for Guides in Metrology, 2008.

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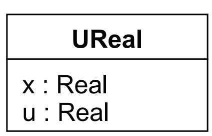
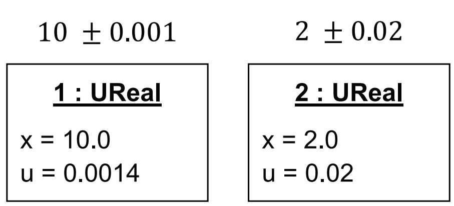
Measurement Uncertainty — Model-Based Representation

- Domain Model



- *Example Instances*



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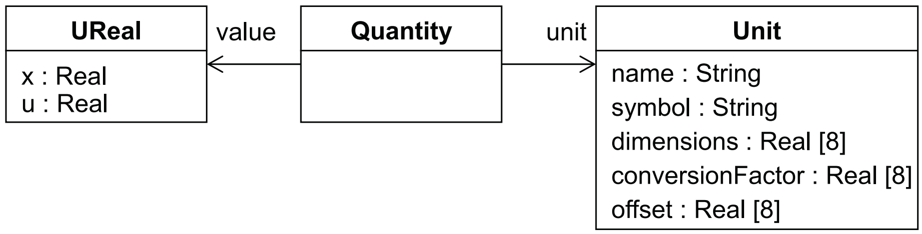
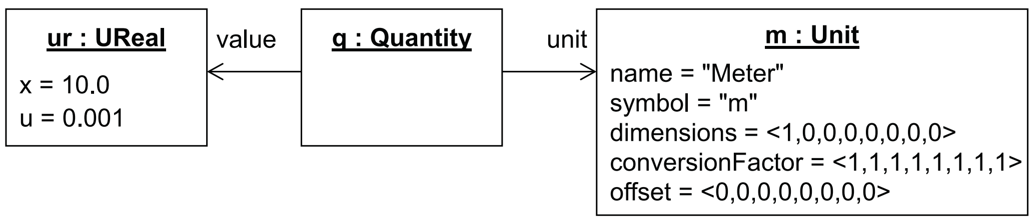
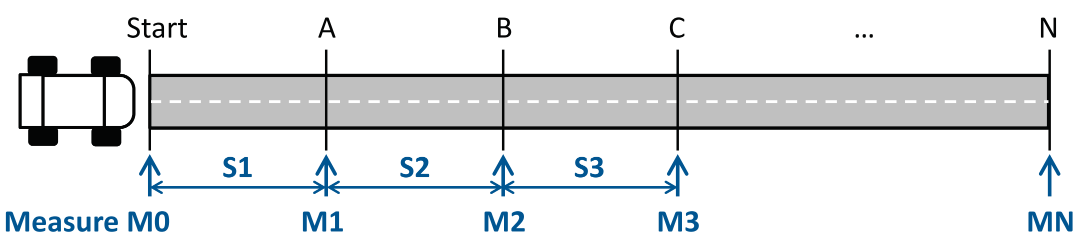
- Domain Model

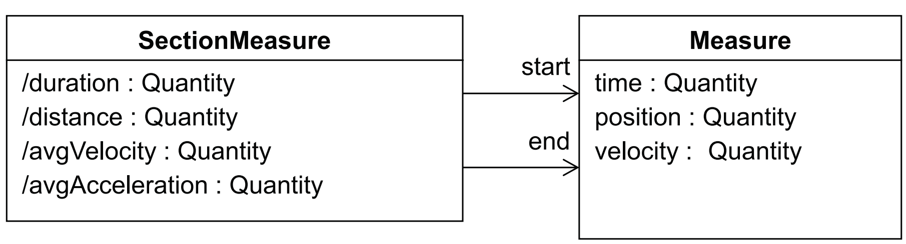


- *Example Instance:* $Length\ 10 \pm 0.001\ m$



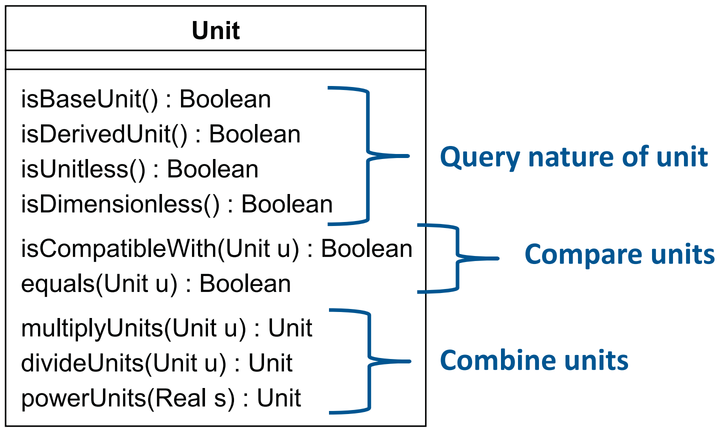
Example






```
duration = end.time – start.time
distance = end.position – start.position
avgVelocity = distance / duration
avgAcceleration = (end.velocity – start.velocity) / duration
```

Unit Operations



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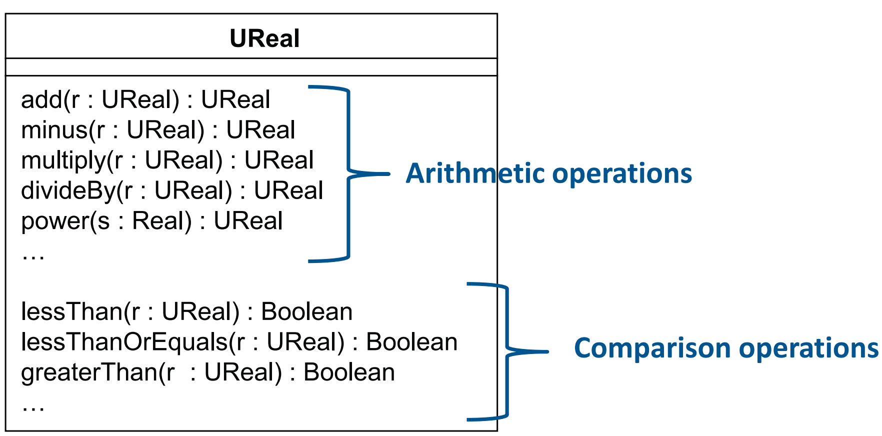
Measurement Uncertainty Operations



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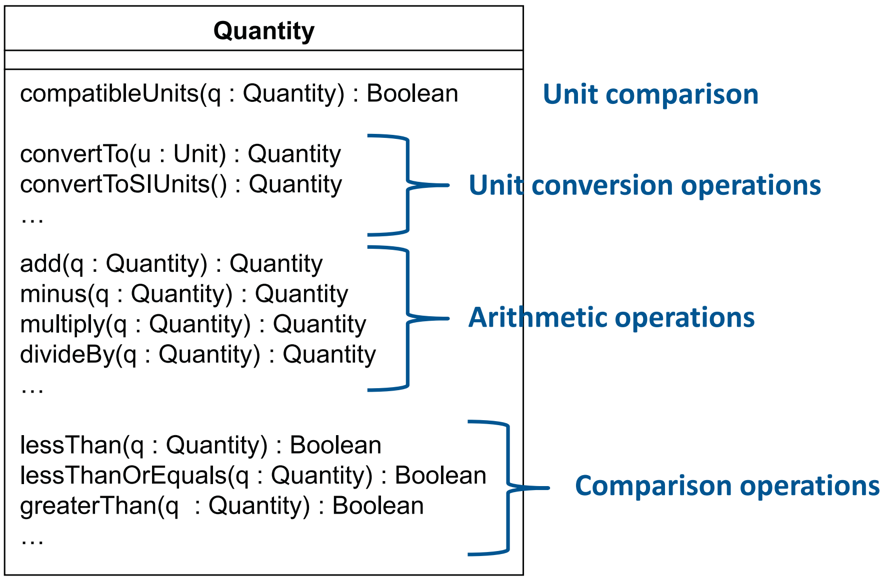
Quantity Operations



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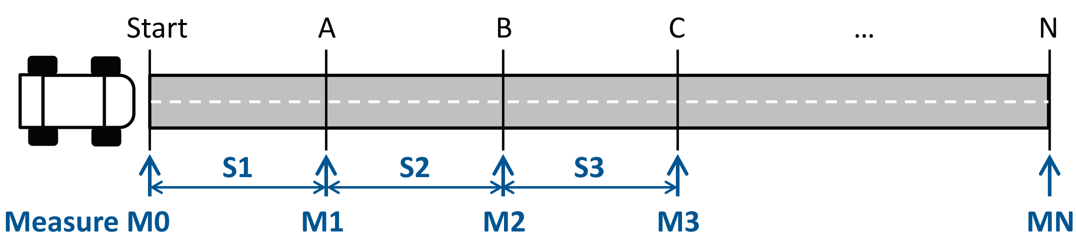
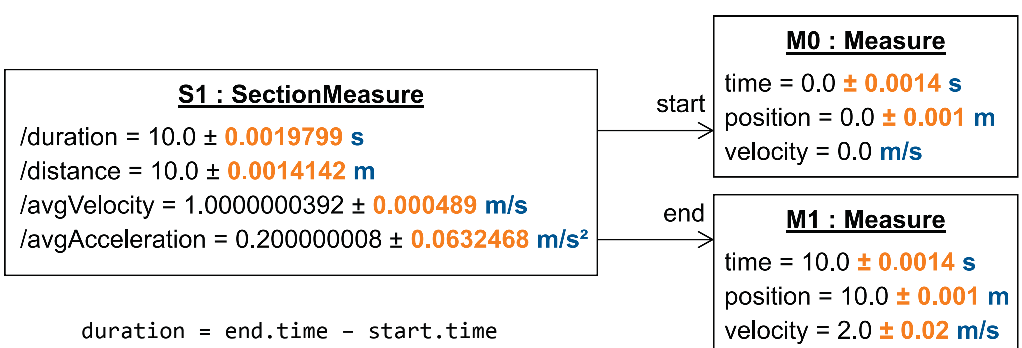
Example






```
duration = end.time – start.time
distance = end.position – start.position
avgVelocity = distance / duration
avgAcceleration = (end.velocity – start.velocity) / duration
```

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Implementation

Available Implementations

- Java: Reference implementation

Java Example

```
Length initialPosition = new Length(0, 0.001, Units.Meter);
Length finalPosition = new Length(10, 0.001, Units.Meter);
Length distance = finalPosition.minus(initialPosition);
```

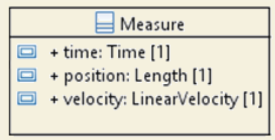
- OCL (USE Tool):
  - Specification of operations with preconditions and postconditions
  - Support for imperative use of operations (SOIL)

USE OCL Example

```
!new UReal('ip')
!ip.x : = 0.0
!ip.u := 0.001
!new Quantity('initialPosition')
!initialPosition.value := ip
...
!distance := finalPosition.minus(initialPosition)
```

- UML (Papyrus, MagicDraw):
  - Support for specifying quantities and computations with quantities
  - Proof-of-concept prototype for executing computations with quantities with fUML

Papyrus UML Example



- Download: https://github.com/moliz/moliz.quantitytypes

USE Tool: https://sourceforge.net/projects/useocl/ MagicDraw: http://www.nomagic.com/products/magicdraw.html
Eclipse Papyrus UML: https://eclipse.org/papyrus/

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Ongoing and Future Work

- **Implementation**
  - Evolve fUML proof-of-concept implementation to full implementation
  - Alf implementation (textual action language for fUML)
  - Full integration with Papyrus and MagicDraw
  - Eclipse OCL implementation
- **Refinement of the conceptual model of quantity types**
  - Different kinds of uncertainty (e.g., interval, different probability distributions)
  - Different kinds of units (e.g., length units, time units, etc.)
- **Representation of quantities**
  - Useable representation of quantities
  - Integration with existing standards, e.g., MARTE and SysML

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Thank You!

Questions?

Contact

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References

A. Vallecillo, C. Morcillo, and P. Orue. Expressing Measurement Uncertainty in Software Models. In Proc. of 10th Int. Conf. on the Quality of Information and Communications Technology (QUATIC), 1–10, 2016.

T. Mayerhofer, M. Wimmer, A. Vallecillo. Adding Uncertainty and Units to Quantity Types in Software Models. In Proc. of 2016 ACM SIGPLAN Int. Conf. on Software Language Engineering (SLE), ACM, 118–131, 2016.

Business Informatics Group

Atenea Modeling Software Systems

UNIVERSIDAD DE MÁLAGA

UiO University of Oslo
Faculty of mathematics and natural sciences

simula

INTEGRATING UNCERTAINTY MODELLING WITH USE CASE MODELLING TO DISCOVER UNKNOWNS

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http://www.u-test.eu/
Chief Research Scientist, **Simula Research Laboratory**, Oslo, Norway

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

MPM4CPS IC 1404

Workshop of ICT COST Action1404, Malaga, 2016

U-Test is a EU-funded H2020 project (2015 Jan. – 2017 Dec.)

TESTING CYBER-PHYSICAL SYSTEMS UNDER UNCERTAINTY

Website: http://www.u-test.eu
Overall Funding: 3.71 Million Euros
Duration: 2015 to 2018
Partners: 9

HORIZON 2020

We are going beyond the scope of this project and establishing a long-term, industry-oriented research foundation towards this direction.

2

Two industrial CPS

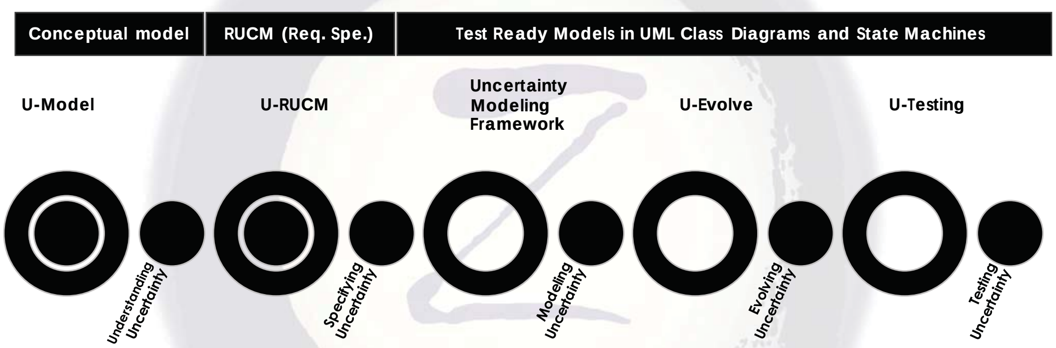
Automated Warehouse (AW)
ULMA Handling Systems, Spain

Geo Sports (GS)
Future Position X (FPX), Sweden

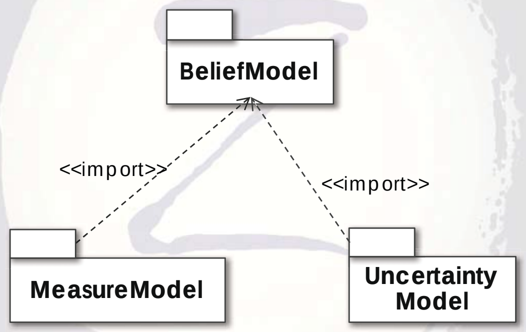
http://www.u-test.eu/use-cases/

3

U-RUCM is an extension to RUCM for **specifying uncertainties** as part of system requirements.

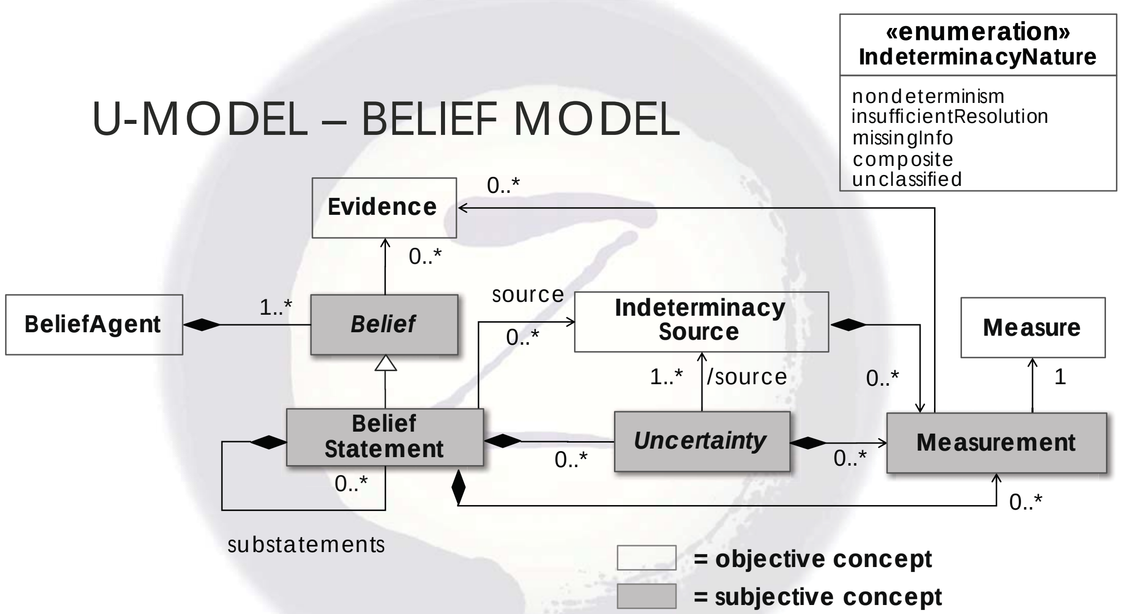


The U-Model takes a ***subjective*** approach to represent uncertainty.



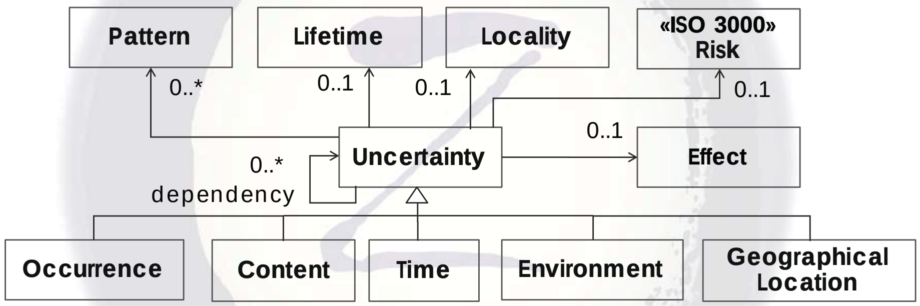
Man Zhang, Bran Selic, Shaukat Ali, Tao Yue, Oscar Okariz and Roland Norgren, **Understanding Uncertainty in Cyber-Physical Systems: A Conceptual Model**, 12th European Conference on Modelling Foundations and Applications (ECMFA), 2016. https://www.simula.no/file/u-modeltrfinalpdf/download

U-MODEL – BELIEF MODEL



6

The ***Uncertainty Model*** Expands On ***Uncertainty*** From Several Different Viewpoints And Introduces Related Abstractions.



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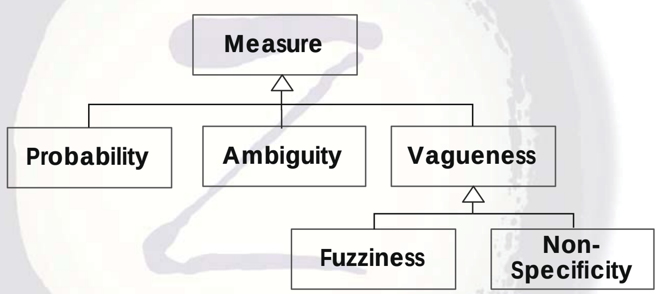
The Purpose Of The **Measure Model** Is To Give A High-level Introduction Of Commonly Known Uncertainty Measures.



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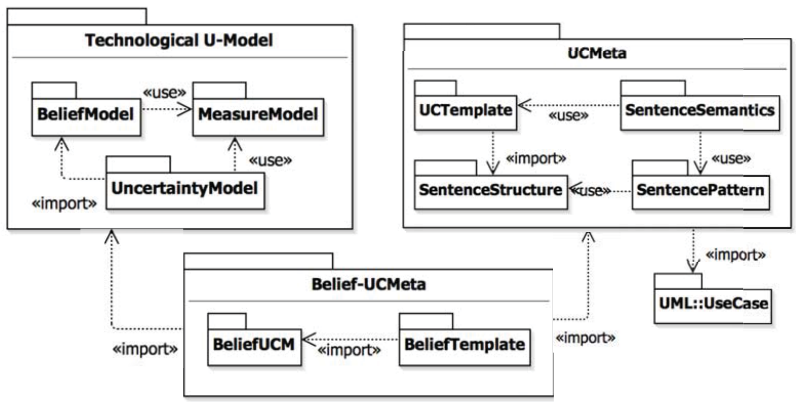
U-RUCM integrates U-Model and RUCM.



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Belief Template Is Newly Introduced To Specify **Belief Use Case Specification**, Which Inherits The RUCM Template.

Key Heading Fields

Different Flow of Events

Use Case Name	The name of the use case. It usually starts with a verb.	
Brief Description	Summarizes the use case in a short paragraph.	
Primary Actor	The actor who initiates the use case.	
Secondary Actor(s)	Other actors the system relies on to accomplish the services of the use case.	
Dependency	Include and extend relationships to other use cases.	
Generalization	Generalization relationships to other use cases.	
Belief Agent(s)	One or more agents who hold belief about this BUCS.	
Time Point and Duration	The time point when the BUCS is specified and the duration in which the belief agent(s)'s belief on the BUCS holds.	
Belief Degree	The degree to which the belief agent(s) believe the BUCS.	
Indeterminacy Source(s)	The set of indeterminacy sources related to this BUCS.	
Evidence	Evidence to support this BUCS, and its contained belief and uncertainty elements.	
Belief Precondition	Belief agent(s)' belief on the precondition, which describes what should be true before the use case is executed.	
Belief Basic Flow (*Belief degree*)	Specifies the main successful path, also called "happy path".	
	Steps (numbered)	A set of ordered belief sentences.
	Belief Postcondition	Belief agent(s)' belief on what should be true after the basic flow executes.
Belief Specific Alternative Flow (*Belief degree*)	Applies to one specific step of the reference flow.	
	URFS	The reference flow step where the belief agent(s) believe there are uncertainties.
	Alternative Step	An alternative to the reference flow step.
	Steps (numbered)	A set of ordered belief sentences.
	Belief Postcondition	Belief agent(s)' belief on what should be true after the specific alternative flow executes.
Belief Bounded Alternative Flow (*Belief degree*)	Applies to more than one step of the reference flow, but not all of them.	
	URFS	A list of reference flow steps where the belief agent(s) believe there are uncertainties.
	Alternative Steps	A set of alternatives to the reference flow steps.
	Steps (numbered)	A set of ordered belief sentences.
	Belief Postcondition	Belief agent(s)' belief on what should be true after the bounded alternative flow executes.
Belief Global Alternative Flow (*Belief degree*)	Applies to all the steps of the reference flow.	
	Belief Branching Condition	Belief agent(s)' belief on the condition, which describes what should be true when branching from any of the steps of the reference flow.
	Steps (numbered)	The set of ordered belief sentences
	Belief Postcondition	Belief agent(s)' belief on what should be true after the global flow executes.

Specify uncertainty with U-RUCM in industry settings

- U-RUCM was able to **significantly improve on characterization,** and **understanding of uncertainty** requirements.
- Key experience
  - ✓ Learn about uncertainty by applying U-RUCM
  - ✓ Systematically **discover unknown known indeterminacy sources and uncertainties** and **transforming them into known unknown uncertainties and known known indeterminacy sources**.

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More Information about U-RUCM:

- Video for demonstrating U-RUCM
  - ✓ http://zen-tools.com/rucm/U_RUCM.html
- Technical Report
  - ✓ https://www.simula.no/publications/specifying-uncertainty-use-case-models-industrial-settings

Specifying Uncertainty in Use Case Models in Industrial Settings

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[2]University of Oslo
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Oscar Okariz[3], Roland Norgren[4], Karmele Intxausti[5], Santiago Charramendieta[5]
[3]ULMA Handling Systems, [4]Future Position X, [5]Ikerlan
ookariz@manutencion.ulma.es, roland.norgren@fpx.se, {KIntxausti, scharramendieta }@ikerlan.es

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Foster long-term and community-wide benefits through standardization

- Uncertainty Modeling
  - ✓ Initiated the standardization process in June 2016
  - ✓ **Uncertainty RFI** is officially issued in Sep. 2016
  - ✓ Call for responses until Feb. 2017.
  - ✓ http://www.omgwiki.org/uncertainty/doku.php

OBJECT MANAGEMENT GROUP®

13

Model-Driven Testing of Cyber-Physical Systems with the Explicit Consideration of Uncertainty (U-Testing)

Shaukat Ali, Man Zhang, Tao Yue
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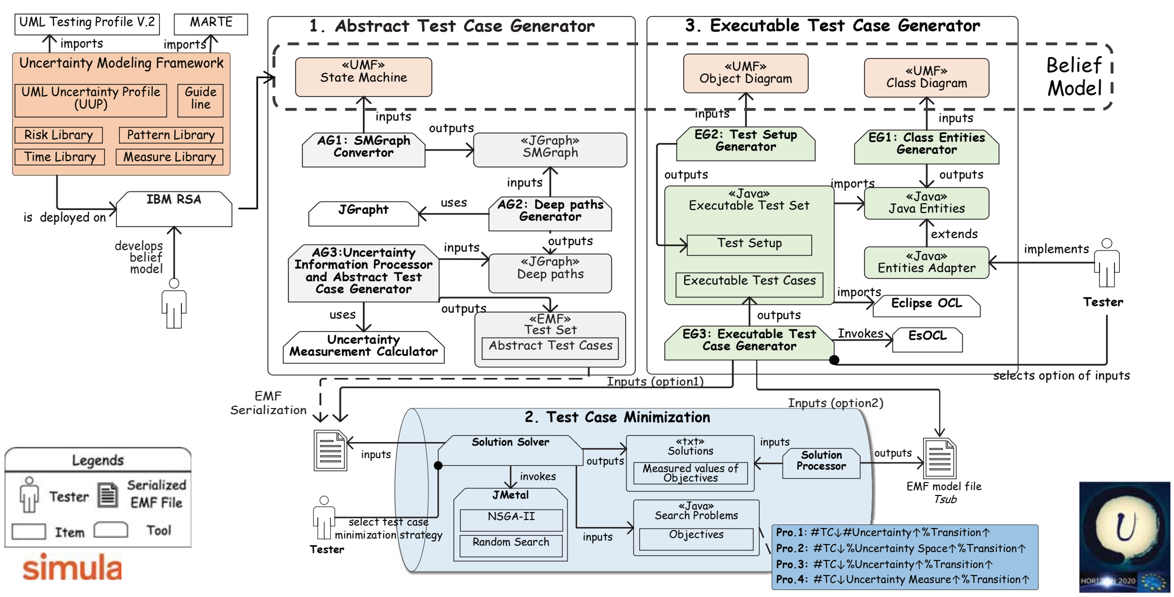
IC1404 Cost Action Meeting
MPM4CPS Malaga Workshop
Malaga, November 24, 2016

MPM4CPS

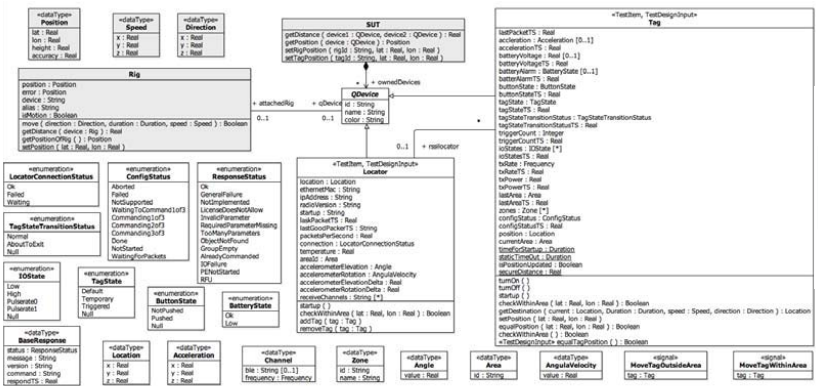
simula cost

UiO University of Oslo
Faculty of mathematics and natural sciences

The overall approach of U-Testing has several steps.



Test Interfaces of the Geo Sports system and test infrastructure are captured as a set of class diagrams.



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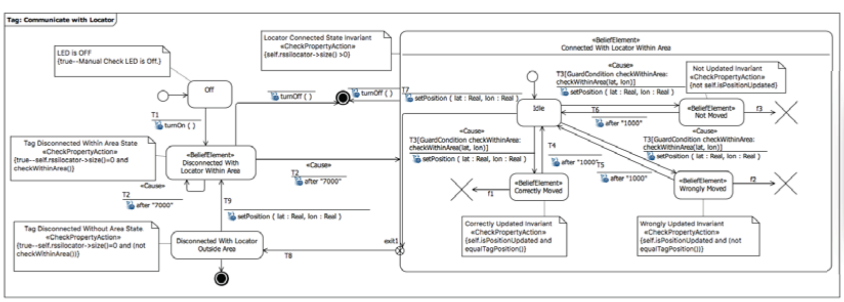
3

Expected behaviour of Geo Sports is modelled as a Belief State Machine.



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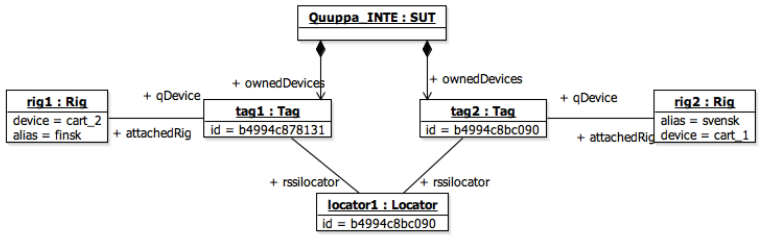
4

Test configuration is modelled as an object diagram.



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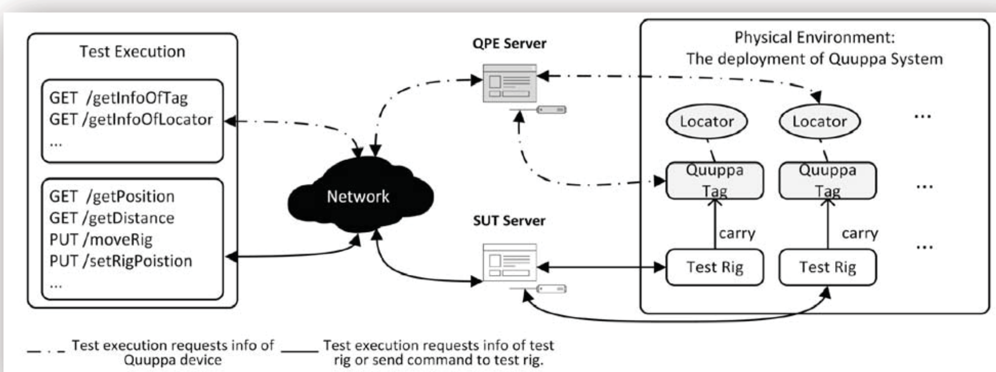
5

Automation of test execution is supported by test APIs implemented as REST APIs.



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6

Integrating MBT, uncertainty theory, and multi-objective search (**NSGA-II**).

Test Case Generation
- All Simple Path
- All Paths with Fixed Max. Length

Test Case Minimization

Uncertainty Related Objectives
(Uncertainty theory)
- Max. the number of uncertainties
- Max. the number of unique uncertainties
- Max. the subjective confidence (uncertainty measure)
- Max. the uncertainty space
- Min. the number of test cases
- Max. the transition coverage

Test Case Execution
- Mutation Testing
- Real Case Study Execution with introduced indeterminacy Source

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All strategies are evaluated in terms of **cost, effectiveness, and efficiency**.

Test Case Generation → **Test Case Minimization** → **Test Case Execution**

Safe Home

	#TC		#Min. TC	%Min.	Mutation Score	Efficiency $\frac{\text{mutation score}}{\text{PTM}}$	Efficiency $\frac{\text{\# of mutants killed}}{\text{time for executing test cases}}$
APL	2		-		8.9%		
APML	1253	#Uncertainty	490	60%	100%	2.5	0.06
		Uncertainty Space	136	80%	98%	8.8	0.22
		Uncertainty Measure	490	60%	100%	2.5	0.06
		Unique Uncertainties	109	91%	100%	11.2	0.27

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We apply the best strategy to test the real case study in terms of discovering uncertainties.

Test Case Generation → **Test Case Minimization** → **Test Case Execution**

GeoSports

	#TC		#Min. TC	%Min.	Observed Uncertainty	New Uncertainty
APML	**2085**	Unique Uncertainties	**336**	83.9%	**98**	**18**

- Test infrastructures have been built, which enable the **introduction of known indeterminacy sources**.
  - Signal Shielding box and Far From Locator
  - **Unknown indeterminacy sources**

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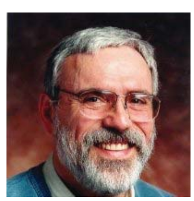
9

Acknowledgement



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10

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Separation of Concerns in Continuous Time Hierarchical Co-simulation

Cláudio Gomes, Joachim Denil, Bart Meyers, Hans Vangheluwe

IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems

November 24–25, 2016, Malaga, Spain

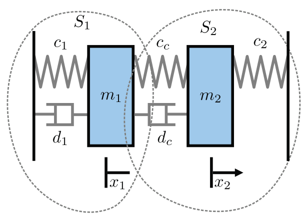
Motivation

- Simulation has helped us so far...
- ...but not to its full potential.
- Complex systems *have* to be partitioned into sub-systems, developed by specialized teams.
  - Their own M&S tools;
  - Some are external companies;
- Leading to locally (but not globally) optimal solutions:
  - Models of each partial solution cannot be integrated;
  - IP cannot be cheaply disclosed;

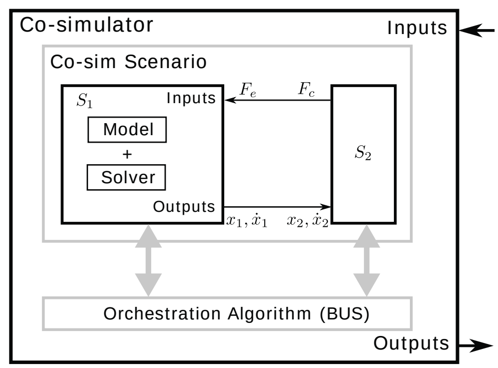
Co-simulation

- Theory and techniques to enable global simulation of a coupled system, via the composition of sub-system simulators.
- Sub-system simulators are virtual mock-ups:
  - Executable binaries;
  - Common API for communication...
  - ...but many different capabilities!

I / O Coupling:

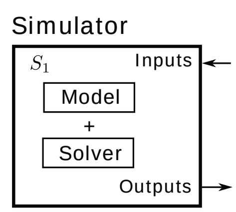


I / O Coupling Co-simulator:

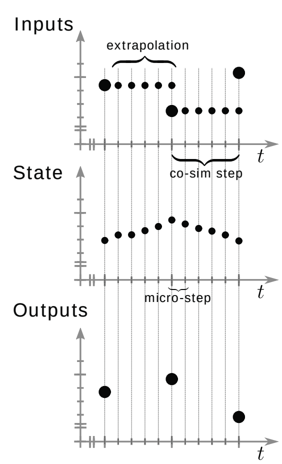


Simulator

- Time-stepped communication;
- Continuous-time dynamics;
- Approximated inputs;
- Physical laws;
- Instantaneous reactions;



$$S_i = \langle X_i, U_i, Y_i, \delta_i, \lambda_i, x_i(0), \phi_{U_i} \rangle$$
$$\delta_i : \mathbb{R} \times X_i \times U_i \to X_i$$
$$\lambda_i : \mathbb{R} \times X_i \times U_i \to Y_i \text{ or } \mathbb{R} \times X_i \to Y_i$$
$$x_i(0) \in X_i$$
$$\phi_{U_i} : \mathbb{R} \times U_i \times \ldots \times U_i \to U_i$$

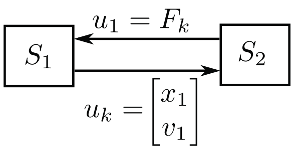


Co-simulation Scenario

$$CS = \langle U_{CS}, Y_{CS}, \{S_i\}, L, \phi_{U_{CS}} \rangle$$
$$L : Y_1 \times \ldots \times Y_n \times Y_{CS} \times U_1 \times \ldots \times U_n \times U_{CS} \to \mathbb{R}^m$$

ALGORITHM 1: Orchestration.

Data: An autonomous scenario $CS = \langle \emptyset, Y_{CS}, \{S_i\}, L, \emptyset \rangle$ and a communication step size H.
Result: A co-simulation trace.
$t := 0$;
while *true* **do**
  Solve: $\begin{cases} y_i(t) = \lambda_i(t, x_i(t), u_i(t)), \text{ for } i = 1, \ldots, n \\ L(y_1(t), \ldots, y_n(t), y_{CS}(t), u_1(t), \ldots, u_n(t)) = \bar{0} \end{cases}$;
  $x_i(t+H) := \delta_i(t, x_i(t), u_i(t)), \text{ for } i = 1, \ldots, n$;
  $t := t + H$;
end



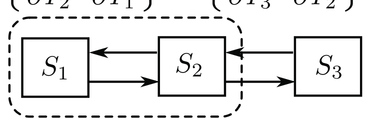
$$CS = \langle \emptyset, \emptyset, \{S_1, S_2\}, L, \emptyset \rangle$$

$$L = \begin{bmatrix} u_k - \begin{bmatrix} x_1 \\ v_1 \end{bmatrix} \\ u_1 - F_k \end{bmatrix}$$

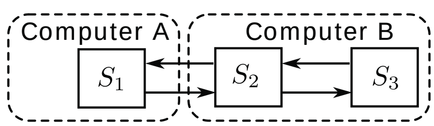
Concerns

$$\left\{ \frac{\partial F_1}{\partial Y_2}, \frac{\partial F_2}{\partial Y_1} \right\} \gg \left\{ \frac{\partial F_2}{\partial Y_3}, \frac{\partial F_3}{\partial Y_2} \right\}$$

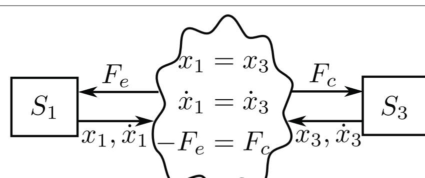
Strongly Coupled Clusters:
Requires: Jacobian



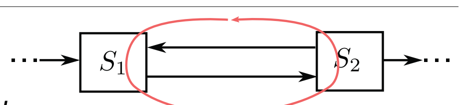
Limited Communication:
Requires: Availability



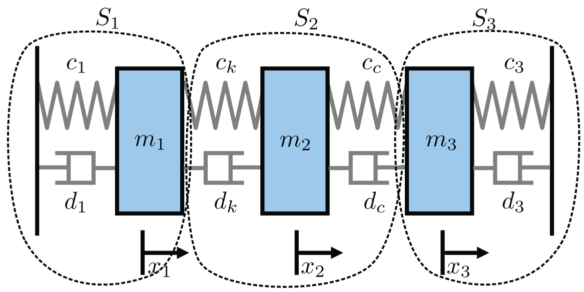
Causality Conflict:

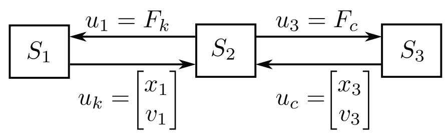


Algebraic Loops:
Requires: I/O Dependency



Example: Strongly Coupled Clusters Scenario

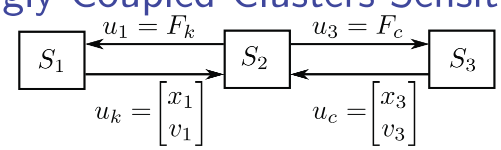




$$\dot{\begin{bmatrix} x_1 \\ v_1 \end{bmatrix}} = F_1\left(\begin{bmatrix} x_1 \\ v_1 \end{bmatrix}, u_1\right) \qquad \dot{\begin{bmatrix} x_2 \\ v_2 \end{bmatrix}} = F_2\left(\begin{bmatrix} x_2 \\ v_2 \end{bmatrix}, \begin{bmatrix} u_k \\ u_c \end{bmatrix}\right) \qquad \dot{\begin{bmatrix} x_3 \\ v_3 \end{bmatrix}} = F_3\left(\begin{bmatrix} x_3 \\ v_3 \end{bmatrix}, u_3\right)$$

$$\lambda_1 = \begin{bmatrix} x_1 \\ v_1 \end{bmatrix} \qquad \lambda_2 = \begin{bmatrix} F_k \\ F_c \end{bmatrix} \qquad \lambda_3 = \begin{bmatrix} x_3 \\ v_3 \end{bmatrix}$$

Example: Strongly Coupled Clusters Sensitivity



$$\dot{\begin{bmatrix} x_1 \\ v_1 \end{bmatrix}} = F_1\left(\begin{bmatrix} x_1 \\ v_1 \end{bmatrix}, u_1\right) \qquad \dot{\begin{bmatrix} x_2 \\ v_2 \end{bmatrix}} = F_2\left(\begin{bmatrix} x_2 \\ v_2 \end{bmatrix}, \begin{bmatrix} u_k \\ u_c \end{bmatrix}\right) \qquad \dot{\begin{bmatrix} x_3 \\ v_3 \end{bmatrix}} = F_3\left(\begin{bmatrix} x_3 \\ v_3 \end{bmatrix}, u_3\right)$$

$\frac{\partial F_1}{\partial u_1}$ is small

$\frac{\partial F_2}{\partial u_k}$ is small

$\frac{\partial F_2}{\partial u_c}$ is Large

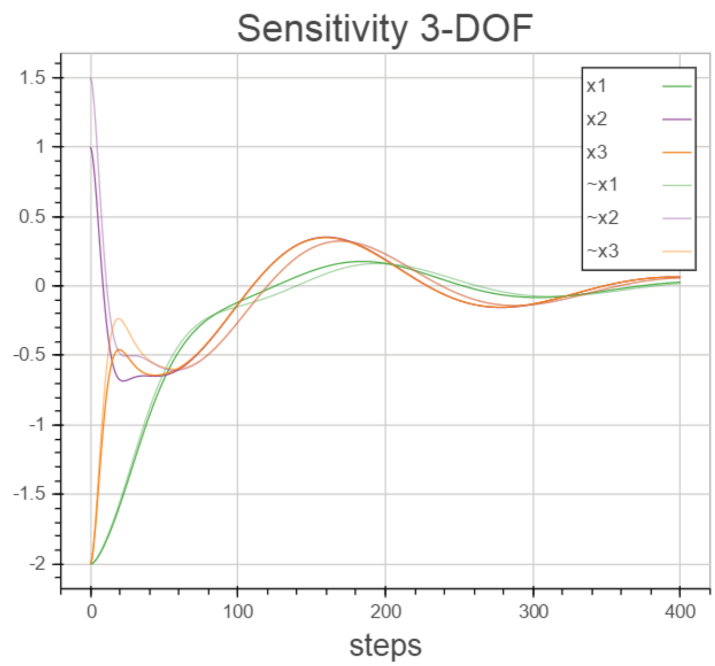
$\frac{\partial F_3}{\partial u_3}$ is Large

$m_1 = 1$
$c_1 = 0.1$
$d_1 = 0.5$

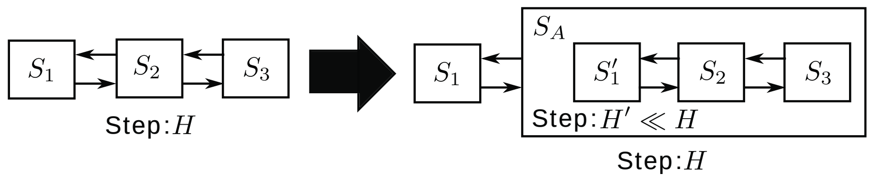
$m_2 = 1$
$c_k = 0.1 \quad d_k = 0.1$
$c_c = 2 \quad d_c = 1.3$

$m_3 = 1$
$c_3 = 0.1$
$d_3 = 0.1$

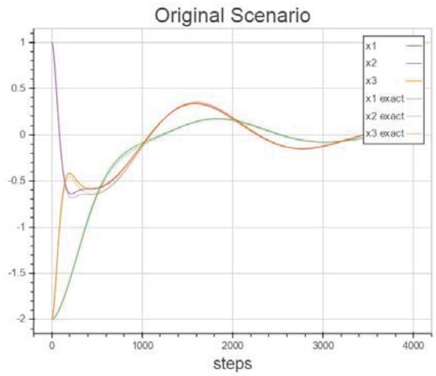
Example: Strongly Coupled Clusters Sensitivity

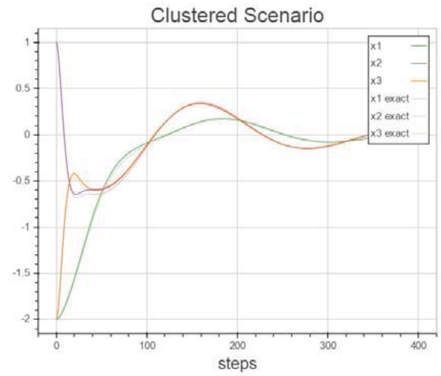


Strongly Coupled Clusters Optimization



Strongly Coupled Clusters Results





$$H = 0.01$$
$$\max \|x_1 - \tilde{x}_1\| = 0.0294$$
$$\max \|x_2 - \tilde{x}_2\| = 0.0583$$
$$\max \|x_3 - \tilde{x}_3\| = 0.0582$$

$$H = 0.1$$
$$H' = 0.005$$
$$\max \|x_1 - \tilde{x}_1\| = 0.0340$$
$$\max \|x_2 - \tilde{x}_2\| = 0.0217$$
$$\max \|x_3 - \tilde{x}_3\| = 0.0214$$

Conclusion

- Our approach, underpinned by MDD:
  - Introduce artificial simulators to solve local concerns;
  - Optimize conflicting concerns at global level;
- Correctness verified via:
  - Analytical solutions with toy examples;
  - Simulation of the coupled model;
  - High accuracy co-simulation;
- Benefits:
  - Leverage existing standards for co-simulation;
  - Systematically address concerns while reusing existing orchestration algorithms;
- Downsides (Future work):
  - Keep scenarios readable;
  - Huge search space for conflicting concerns;
  - Lack of formal proof of convergence;

Thank you!

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"IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems"

Modeling of Cooperation Behavior in flexible Vehicle Platoon based on Hybrid Automaton and Predicitive Analysis

Lejla Banjanovic-Mehmedovic
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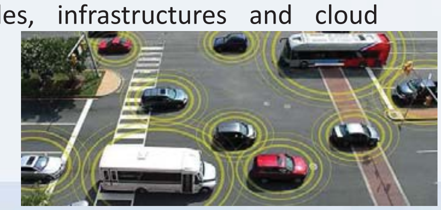
Bosnia and Herzegovina

Contest

- Cooperative intelligent transport system (C-ITS)
- Hybrid automaton modeling of flexible Vehicle Platoon
- Traffic Data Analytic: Prediction of cooperative behavior profile using neural network and fuzzy – neuro (ANFIS)

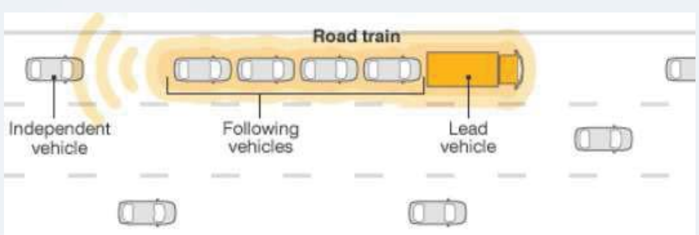
Introduction

- Intelligent Transport systems (ITS) is in the framework of cyber-physical systems;
  - the interaction between physical systems (vehicles)
  - distributed information gathering and dissemination infrastructure.
- Cooperative intelligent transport system (C-ITS).
  - use of computing resources for processing, analysis, predicting, understanding of data,
  - communication resources for vehicles, infrastructures and cloud services interaction and management,
  - control for systems



Flexible Vehicle Platoon

- **Vehicle Platoon**- the desired behaviour of a vehicle is generally defined by a desired distance to the previous vehicle in the platoon, they could also gather information about the behaviour and aspects of the platoon as a whole.
- **Flexible Platoon**- smart vehicles with artificial intelligence could enter, merge or leave the platoon whenever the driver wants.

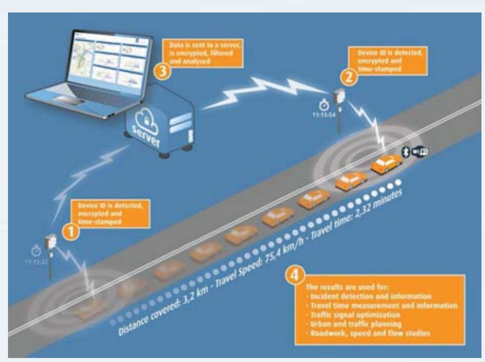


Main concept of Research

- Minor attention - to coordinated maneuvering, testing with real vehicles which can drive autonomously requires a large-scale infrastructure with important security measures.
- Modeling of Flexible Platoon
  - propose hybrid automaton modeling in Matlab/Simulink/Stateflow to emulate flexible platooning conditions
  - generation of specific maneuver profile

Goal of the research

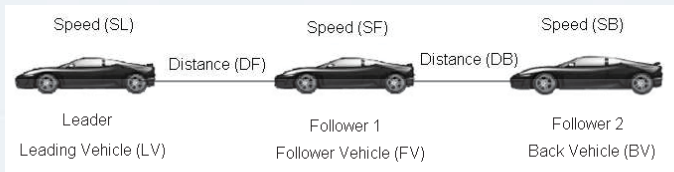
- Improvement of traffic mobility in ITS through accurate prediction
- An approach towards neuro-fuzzy and neural network prediction of flexible Platooning cooperation profile
- Reducing the uncertainty of future traffic states



Data Analytic Platform
Traffic Data Prediction

Flexible Platoon modelling

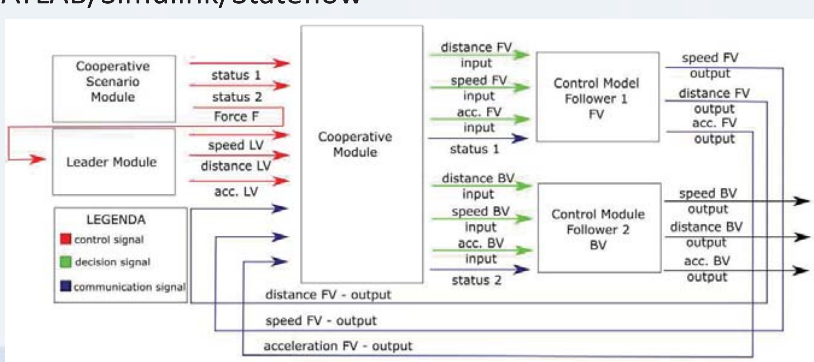
- 3 vehicles: 1 leader + 2 followers; start speed of leader: 80km/h; accelarating and decelarating of vehicles



- Three operations for followers in flexible Platoon:
  - joining
  - merging
  - leaving

Flexible Platoon modeling

- **Hybrid automaton** = complex dynamics of each vehicle + discrete cooperation approach (finite state machine, FSM)
- MATLAB/Simulink/Stateflow



Vehicle modeling

Z. Gacovski, S. Deskovski, "Different Control Algorithms for a Platoon of Autonomous Vehicles", International Journal of Robotics and Automation (IJRA), **3(3)**, 151 (2014)

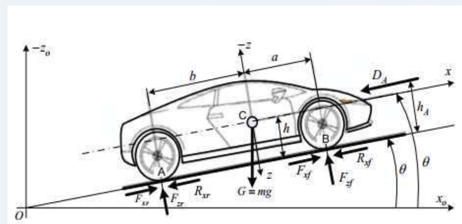
- Application of Newton's second law on vehicle moving

$$m\dot{u} = F_x - mg\sin\theta - f_r mg\cos\theta - \frac{1}{2}C_{air}(u + u_w)^2$$

$$\theta = 0 \quad u_w = 0$$

$$\dot{u} = a = \frac{1}{m}\left(F_x - f_r mg - \frac{1}{2}C_{air}u^2\right)$$

$$F_x = \Delta F_x + F_{x0}$$



Vehicle modeling

- Linear state space model of the *i*-th vehicle in the platoon:

$$\dot{x}_i = v_i$$

$$\dot{v}_i = a_i$$

$$\dot{a}_i = \frac{1}{m}\begin{bmatrix} K_{Pi}(x_{i-1} - x_i - hd_i) + K_{Vi}(v_{i-1} - v_i) + \\ K_{Di}(a_{i-1} - a_i) - C_{air}u^0 a_i \end{bmatrix}$$

- where hd_i is constant distance between *i-1*-th and *i*-th vehicle

Control module of Folowers

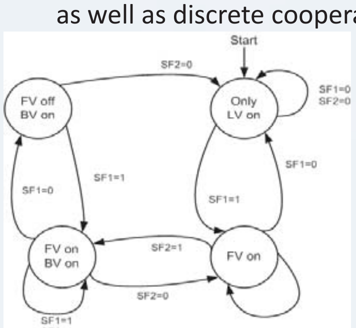
❖PID controller

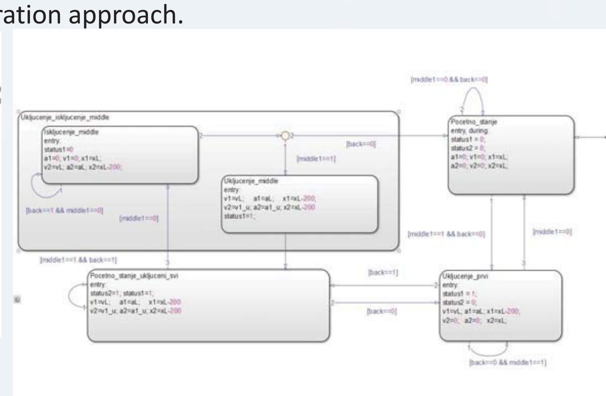
$$a_i = \frac{1}{m}\left[K_{Pi}(x_{i-1} - x_i - hd_i) + \frac{K_{Ii}}{s}(x_{i-1} - x_i - hd_i) + K_{Di}(v_{i-1} - v_i) + F_{x0} - f_r mg - \frac{1}{2}C_{air}u_i^2\right]$$

❖Z. Gacovski, S. Deskovski, "Different Control Algorithms for a Platoon of Autonomous Vehicles", International Journal of Robotics and Automation (IJRA), **3(3)**, 151 (2014)

Modelling of cooperation between vehicles

❖ Hybrid automaton takes into account complex dynamics of each vehicle as well as discrete cooperation approach.





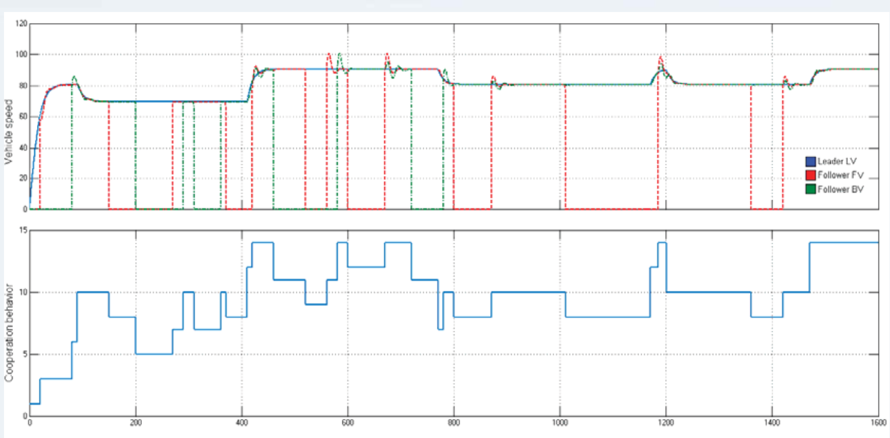
Output behaviour of flexible Platoon

- Output behaviour:

$$o(t) = c_1 \sum_{i=1}^{N} n_i(t) + c_2 \sum_{k=1}^{M} b_k(t)$$

Function of behavior pattern in time	Scenario description	Output behavior
1	Only LV	1
1+2	LV and FV	3
1+3	LV and BV	4
1+4	LV deceleration	5
1+2+3	All vehicles	6
1+2+4	LV and FV deceleration	7
1+3+4	LV and BV deceleration	8
1+2+8	LV and FV acceleration	11
1+3+8	LV and BV acceleration	12
1+2+3+4	All vehicles; deceleration	10
1+2+3+8	All vehicles; acceleration	14

Vehicles speed profiles and generated function of cooperation behavior



Traffic information predictions

- Traffic information predictions
  - speed,
  - flow and
  - travel time
- Three categories of existing traffic flow prediction approaches are recognized:
  - time-series approaches (ARMA and ARIMA model),
  - probabilistic approaches (Bayesian network, Markov chain and Markov random fields) and
  - nonparametric approaches (artificial neural networks, support vector regression (SVR), the adaptive neuro-fuzzy system (ANFIS))

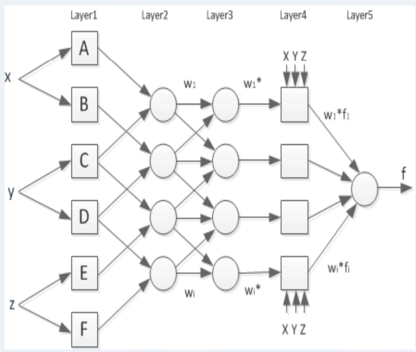
Adaptive Neurro-Fuzzy (ANFIS) prediction method

- The artificial neural network (ANN) - as an analytical method for various prediction purposes. Benefit: independency on the knowledge of internal system parameters, compressed compact solution in terms of multi-variable problems and rapid computation.
- The ANFIS is a particular class of the ANN family with attractive estimation and learning potentials.
- The ANFIS combines the power of the FIS with a neural network back-propagation learning algorithm.
- Adaptive neuro-fuzzy (ANFIS) computing technique- to estimate the cooperative interactions profile in relation to the speeds of the leader and first and second follower vehicles.

Neurro-Fuzzy Model (ANFIS)

- The ANFIS structure consists of 5 layers

$$\text{if } x \text{ is } A \text{ and } y \text{ is } C \text{ and } z \text{ is } E \text{ then } f_1 = p_1 x + q_1 y + r_1 z + t$$



ANFIS structure.

$O = \mu(i)$ *premise parameters*

$w_i = \mu(i)_i \mu(i)_{i+1}$, membership layer

$w_i^* = \frac{w_i}{\sum_i w_i}$ rule layer

$O_i^4 = w_i^* \cdot f = w_i^* (p_i x + q_i y + r_i z + t)$

consequent parameters.

$O_i^5 = \sum_i w_i^* \cdot f = \frac{\sum_i w_i f}{\sum_i w_i}$ output layer

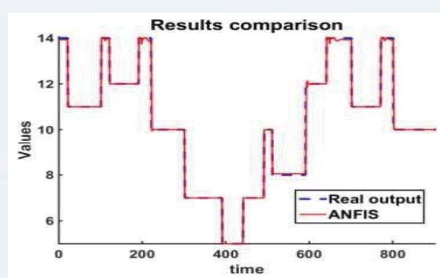
Prediction results of cooperation behavior profile using ANFIS

- RMSE (root mean square error), coefficient of determination (R^2)
- The best result of prediction R^2 =0.99, RMSE=0.155 and MSE=0.02 for 7 Gauss membership functions for each input variables in 10 epochs.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{N}(y_i - f_i)^2}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\hat{Y}_i - Y_i)^2$$

$$R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (f_i - \bar{y})^2}$$



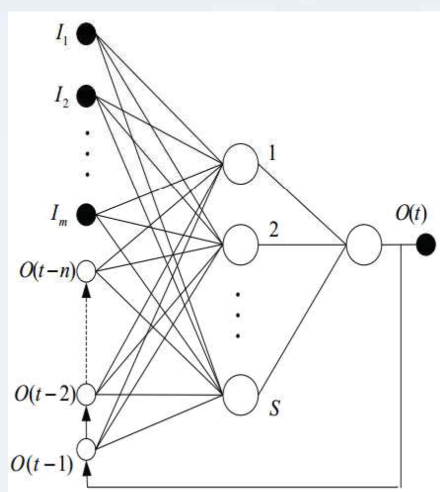
L. Banjanovic-Mehmedovic, N. Delic, I. Butigan, S. Kasapovic and I. Bosankic: Neuro-fuzzy prediction of cooperation interaction profile of flexible road train based on hybrid automaton modeling, 5th International Conference on Transportation and Traffic Engineering (ICTTE 2016), pp. 313-318, Lucern, Switzerland, 2016.

Neural network as prediction method

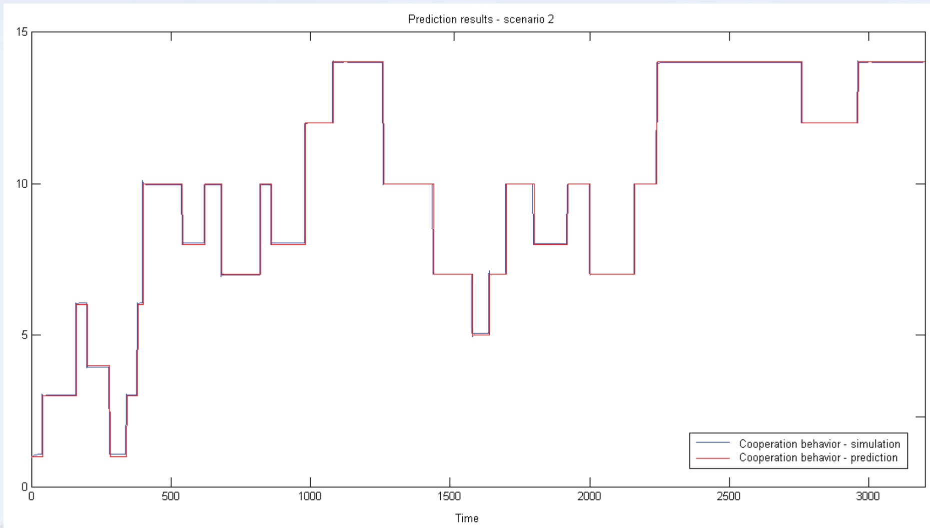
- The artificial neural network (ANN) - as an analytical method for various prediction purposes.
- Benefit: independency on the knowledge of internal system parameters, compressed compact solution in terms of multi-variable problems and rapid computation.
- NARX neural network- to estimate the cooperative interactions profile in relation to the speeds of the leader and first and second follower vehicles.

Structure of NARX

- NARX neural network - feedback dynamic neural network, the outputs in time series depends of current inputs and previous outputs.
- **The input parameters** of the NARX network - the time series of the leader, first and second follower's speeds
- **The output parameter** of the NARX network - the road cooperation behaviour profile from the Platoon hybrid automaton



Prediction results of cooperation behavior profile using NARX



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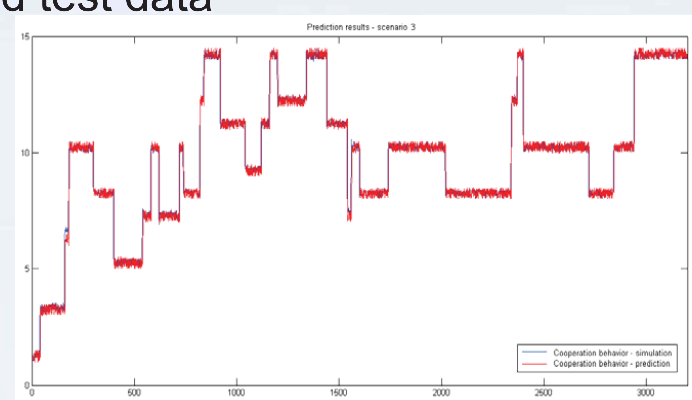
Prediction results of cooperation behavior profile using NARX for case noised test data



- Behaviour scenario, with 3201 samples.

L. Banjanovic-Mehmedovic, I. Butigan, M. Kantardzic, S. Kasapovic, "Prediction of Cooperative Platooning Maneuvers using NARX Neural Network", IEEE Smart systems and Technology (SST 2016) pp. 287-292, Croatia, Octobar, 2016.

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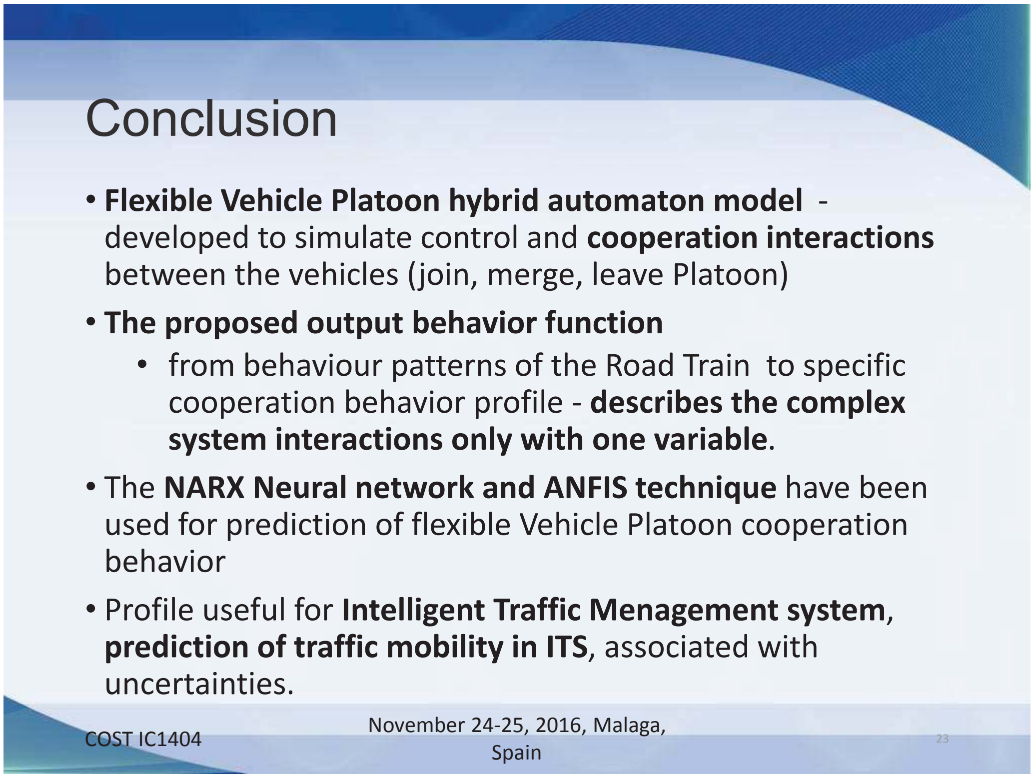
Conclusion
• Flexible Vehicle Platoon hybrid automaton model - developed to simulate control and cooperation interactions between the vehicles (join, merge, leave Platoon)
• The proposed output behavior function
• from behaviour patterns of the Road Train to specific cooperation behavior profile - describes the complex system interactions only with one variable.
• The NARX Neural network and ANFIS technique have been used for prediction of flexible Vehicle Platoon cooperation behavior
• Profile useful for Intelligent Traffic Menagement system, prediction of traffic mobility in ITS, associated with uncertainties.
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MPM4CPS

C1404 – Multi-Paradigm Modelling for Cyber-Physical Systems

Introduction to Physical-Systems Modelling with Bond Graphs

Jan F. Broenink
University of Twente, NL

24 November, Malaga, Spain

Modelling — basics

- System
  - Parts forming a whole; parts have functional relationship
  - Has boundary: what belongs to the system and what not
- Model (of a system)
  - Description of a system: parts & relations
  - Simplified, but complex enough
    - to study phenomena relevant for our problem context
  - Competent Model
    - as simple as possible, but sufficient for the goal of the model
  - Modelling goals
    - understand dynamic behaviour
    - compute a reaction in a control system
    - predict in a design context

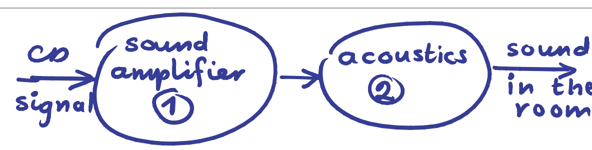
Figures taken from:
J van Amerongen “Dynamical Systems” text book, see reference on slide 31
Sometimes referred to as Fig n.n JvA

Modelling - choices what effects to describe

- Network of basic elements
  - complex: structure in submodels, sub-submodels etc
- What to model
  - depends on purpose / goal
- Our case
  - understand physics / dynamic behaviour
    - on a rather global level
    - a network of elements
  - control law design
    - function blocks (transfer functions) is enough

Interaction in Models

- Unilateral
  - signals approach
- Bilateral
  - physical-systems approach
  - mutual influence
  - exchange of energy



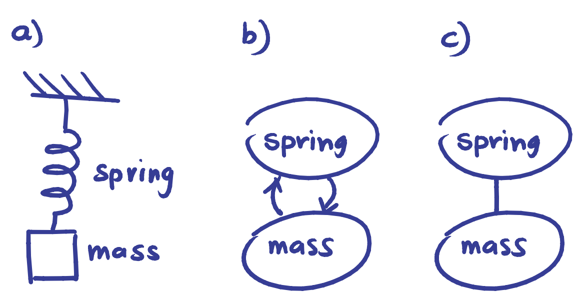


Fig 1.4 and 1.5 JvA

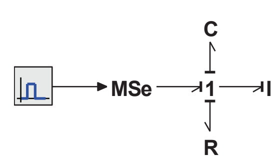
Modeling: essential dynamics

- Dynamics
  - Behaviour depends on the past!
  - Change of variables is essential here
- Time
  - continuous value of time
  - observe at fixed intervals: discrete time
- Examples

Modelling: physics domains, bond graphs

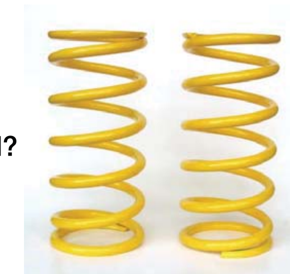
- Domains
  - Electro-Magnetic, Mechanical: translation, rotation
  - Hydraulic, Thermal
- Physical effects
  - in all domains the same
  - resulting in the same equations!
- 9 basic elements
  - C, I, R, Se, Sf
  - TF: transformer; GY: gyrator
  - Network:
    - common effort => 0 junction
    - common flow => 1 junction

	spring	friction	mass
mechanical	$F = \frac{1}{c}\int v\,dt$	$F - f v = 0$	$v = \frac{1}{m}\int F\,dt$
	capacitor	resistance	inductance
electrical	$u = \frac{1}{C}\int i\,dt$	$u - Ri = 0$	$i = \frac{1}{L}\int u\,dt$
	tank	restriction	
hydraulic	$p = \frac{1}{c}\int \varphi\,dt$	$p - r\varphi = 0$	$\varphi = \frac{1}{I}\int p\,dt$



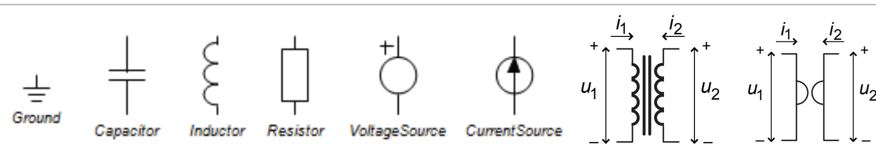
Ideal behaviour — real components

- Ideal: only the essential effect (only *one*)
  - Elementary behaviour
- Components
  - physical thing… Spring = spring, and mass, and friction, and?
  - parasitic effects



- Lumped-parameter Models
  - assume all elementary properties concentrated in elements
    - mass => point mass
    - spring => only the spring behaviour, nothing more

Electrical Domain



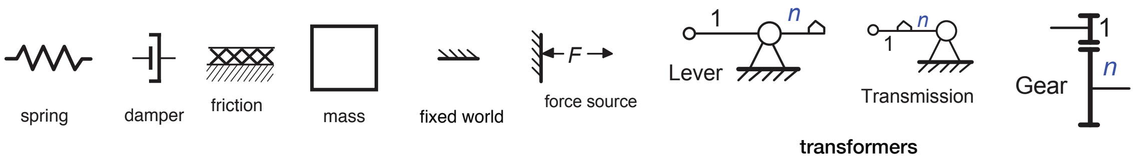
transformer

- Physics Concepts
  - Ideal Physical Models
- Transformer
  - like ideal electrical transformer
    - $u_1 = n\, u_2$
    - $i_2 = n\, i_1$
    - $n = n_1 / n_2$
- Gyrator
  - artificial element when within domain
    - $u_1 = r\, i_2$
    - $u_2 = r\, i_1$

Capacitor	Resistor	inductance
$u = \frac{1}{C}\int i\,dt$	$u = Ri$	$i = \frac{1}{L}\int u\,dt$
$q = \int i\,dt$		$\lambda = \int u\,dt$

TF, GY: only transduce! $P_1 = P_2$

Mechanical Domain



- Physics Concepts
  - Ideal Physical Models
- Transformer
  - like ideal lever / gears / chain wheels
    - $F_1 = n F_2$
    - $v_2 = n v_1$
    - $n = n_1 / n_2$
- Gyrator
  - transduction in electromotor
    - $u_1 = r \omega_2$
    - $T_2 = r i_1$

see later!

spring	friction	mass
$F = \frac{1}{c}\int v\,dt$	$F = f v$	$v = \frac{1}{m}\int F\,dt$
$x = \int v\,dt$		$p = m v$
$F = \frac{1}{c}x = kx$		$v = \frac{1}{m}p$

TF, GY: only transduce! $P_1 = P_2$

Bond Graphs — Essence

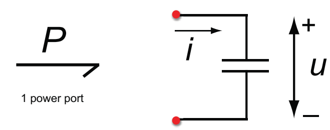
- Essential Idea
  - Graph to describe dynamic behaviour
  - Exchange of energy (flow of power between nodes)
    - Domain-independent
- Graphs: Bond Graphs / Ideal Physical Models
  - Directed graph: submodels & ideal connections
  - 5 basic physical effects
    - storage (C, I), dissipation (R), transformation (TF, GY), networks (0, 1), sources (Se, Sf)
  - Model elements
    - describe only one single physical effect
    - compound structures: network of elements
- Encapsulation of contents
  - Interface: ports with 2 variables
    - (u, i): voltage & current; (F, v): force & velocity
  - Equations as equalities (math. Equations)
    - Not as algorithm: u = i * R -> u := i * R of i := u / R

Domain-independent descriptions

- Use analogies of physical phenomena
  - concepts are the same in different domains
    - Capacitor ~ Spring
    - Coil ~ Mass
    - Resistor ~ Friction
    - E-Transformer ~ Lever, gear wheels
    - Kirchhoff, d'Alembert: 0 and 1 junction

Domain	Effort, e	Flow, f	C, q	I, p
Translation	F [N]	v [m/s]	x [m]	p [Ns]
Rotation	T [Nm]	ω [rad/s]	ϕ [rad]	b [Nms]
Electrical	U [V]	i [A]	q [C]	λ [Vs]
Hydraulic	P [N/m^2]	ϕ_v [m^3/s]	V [m^3]	Γ [Ns/m

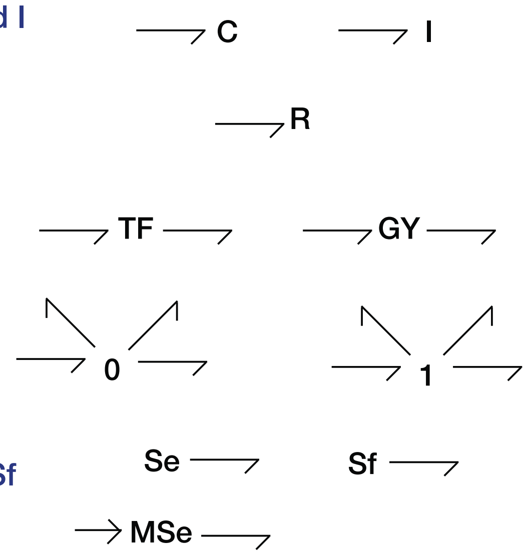
  - Mapping of variables to each other, and general version
    - u, F, e and i, v, f
    - methodological choice!
  - Based on energy exchange… using power ports
    - P = ui   P = Fv   P = Tω   P = pϕ
    - u, i   F, v   T, ω   p,ϕ   power conjugated variables
  - See connections of elements as ports
    - power goes in / out => energy flow
    - positive in direction of half-arrow head



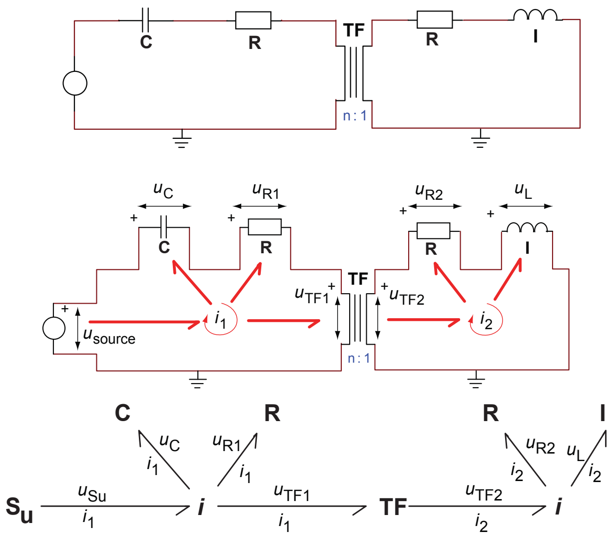
2 terminals -> 1 port

Bond Graphs — Elements

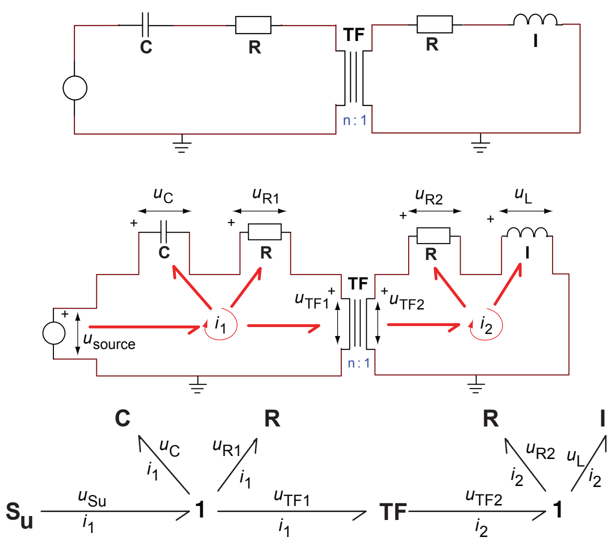
- Capacitor, Coil, and Spring, Mass: C and I
  - store energy (and retrieve energy),
  - differential equation
- Resistor, Damper, Friction: R
  - dissipates energy to thermal domain
  - gets lost for the E, M domains
- Transformers, Levers, Motors: TF, GY
  - transform energy,
  - transduce, often to other domain
  - have 2 ports!
- Junctions, 0 and 1
  - network, Kirchhoff, d'Alembert
  - common u, F -> 0 or common i, v -> 1
- Source: voltage, current, force etc: Se, Sf
  - energy in / out rest of system
  - boundary condition



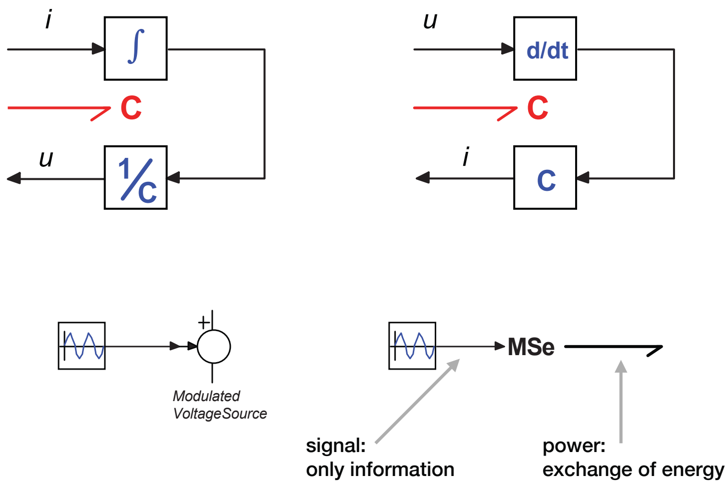
Produce bond graph out of physical-systems model — I



Produce bond graph out of physical-systems model — I

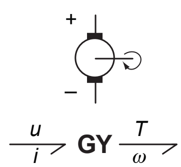


Signals versus Power Ports



Transducers: DC motor

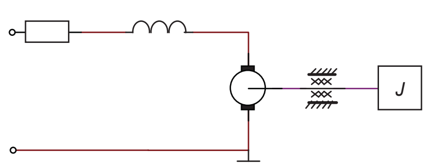
- Transduction only



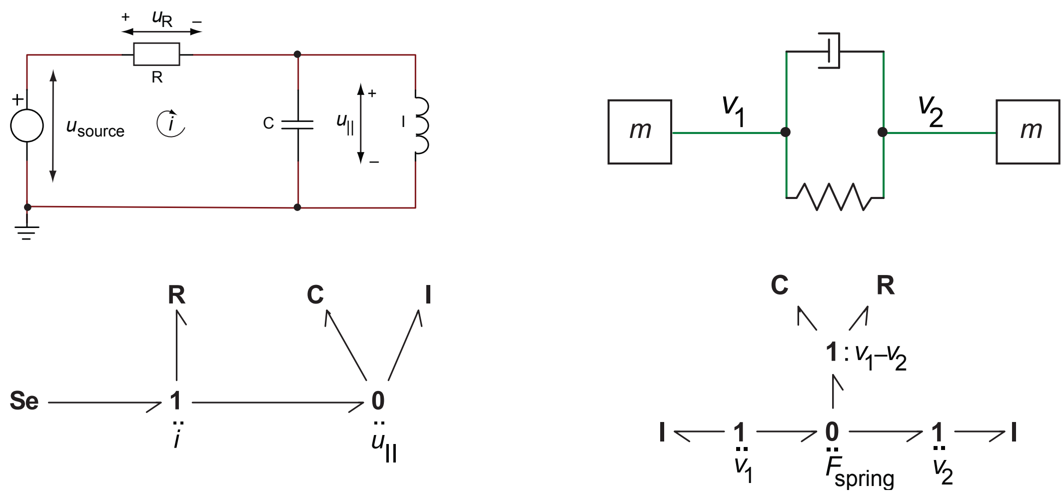
$$T = K_m i$$

$$u = K_m \omega$$

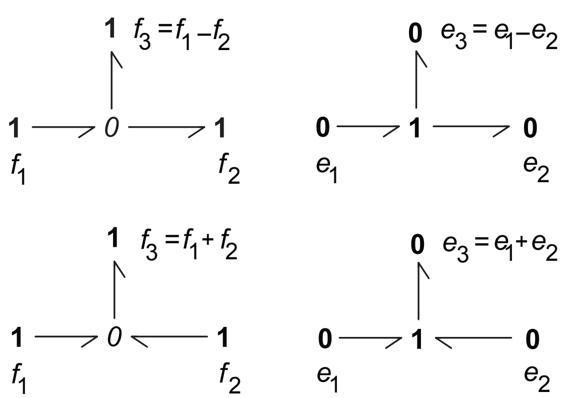
- Practical component
  - network model of it
  - motor E -> M
  - generator M-> E



Junctions: the equations



junctions: the equations — II

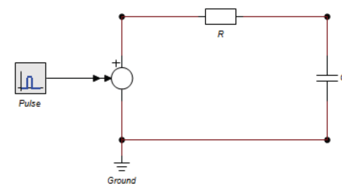


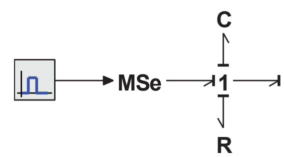
0: common effort
flows ± sum

1: common flow
efforts ± sum

Techniques — Modelling overview

- First step in Modelling - sketch, relational diagram
  - quite informal, first step in modelling choices
- Construct IPM or Bond Graph
  - Modelling choices are made
  - Network of ideal elements
- Construct Bond Graph from IPM
  - 8-step procedure (see handout)
- Convert Bond graph to Causal bond graph
  - add computational direction (automatically — 20-sim)
  - energy exchange => signals
  - gives insight in dynamic behaviour
    - on graph level already, no need to derive equations first
  - Derive Equations (automatically — 20-sim)
- Simulate
  - experiment, analyse



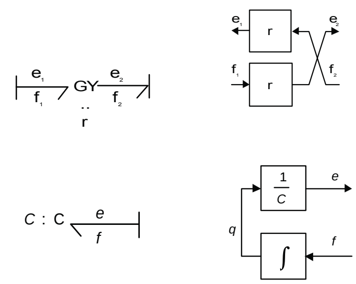


Produce a bond graph from an IPM

- Identify domains and elements
  - Determine domains and basic elements
  - Indicate reference effort (velocity)
- Generate connection structure
  - Identify all other efforts (velocities)
  - Draw efforts (velocities). not reference
  - Identify all effort differences (velocity differences)
  - Construct and draw effort (velocity) differences
- Connect elements & finish
  - Connect ports of elements
  - Simplify the graph

Causal analysis — causal constraints

- Determine the signal direction of variables at bonds
- Causal constraints imposed by equations
  - fixed causality
    - output is fixed: Sources, non invertible equations
  - constrained causality
    - relations between different element ports: TF, GY, 0, 1
  - preferred causality
    - integrating causality for storage elements: C, I
    - initial condition, numerically easier
  - indifferent causality, no constraint
    - equations do not impose a computational order: R

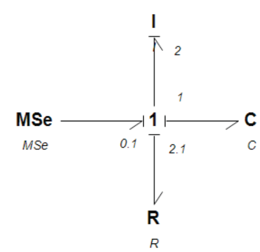


Causal analysis - procedure

- Procedure
  - work from strongest constraint downward
  - & propagate via junctions / TF, GY
    - 1. Fixed causality
    - 2. Preferred causality
    - 3. Indifferent causality

Let 20-sim do this!!!!

- Insight
  - Complete after 2, 3: OK
  - Complete after 1: OK, no dynamics
  - Conflicts
    - @ 1: wrong model
    - @ 2: dependent storage elements (something forgotten?)
    - @ 3: algebraic loop (something forgotten?)
  - Solve conflicts
    - change model / manipulate graph
    - just simulate — need iteration in solver …



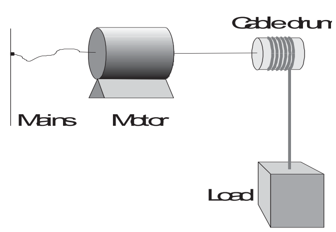
Numbering of Causal Strokes reveals the order of assigning

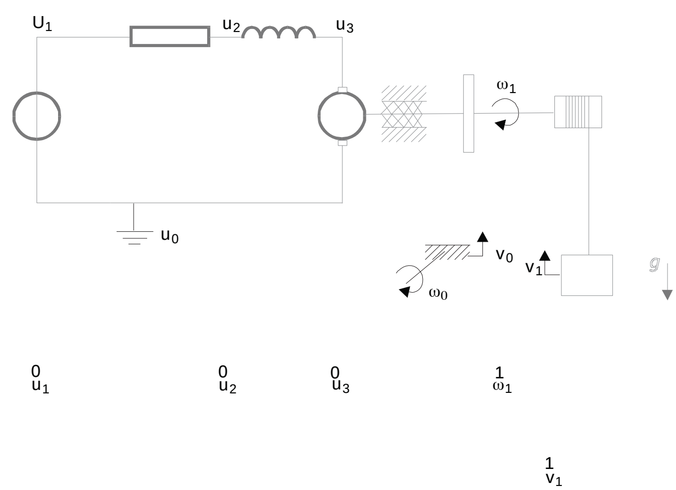
Generate Equations

- Causal bond graph
  - no causal conflicts -> ODE
  - causal conflicts -> DAE
  - automated in most bond-graph software
- Procedure
  - Mixed set of differential and algebraic equations
    - constitutive relations in causal form
    - 2n equations for n bonds
  - Eliminate algebraic equations
    - identities (Se, Sf, 0, 1),
    - multiplications (R, TF, GY)
    - Σ–equations junctions into ODE
  - Mark state variables (+ semi state vars)

Let 20-sim do this!!!!

Bond-graph construction: example





1: domains and elements

2: reference e , v

3: other e , v

4: draw e , v

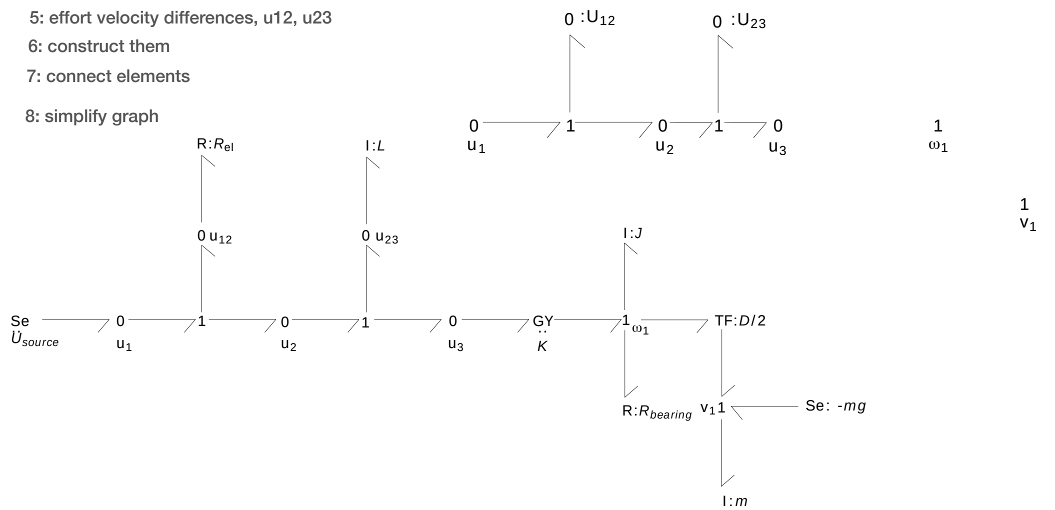
Bond-graph construction: example II

5: effort velocity differences, u12, u23

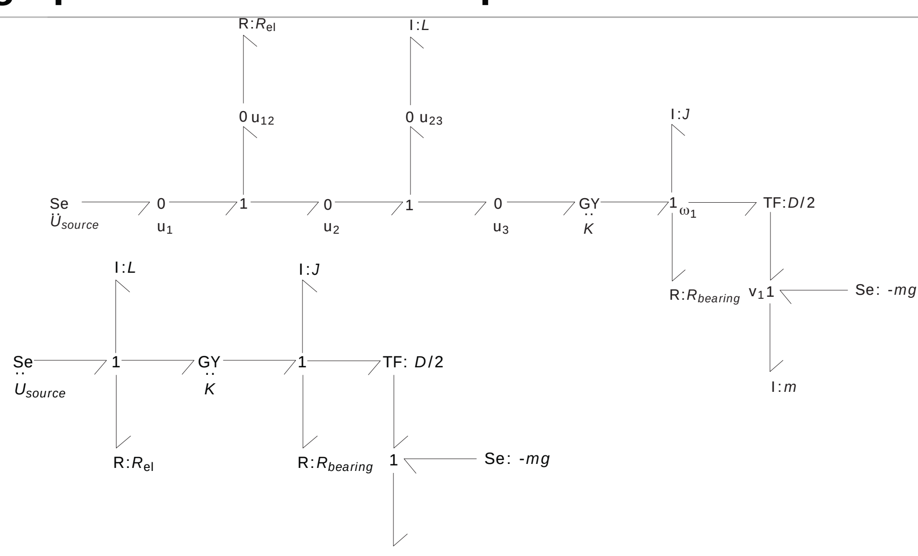
6: construct them

7: connect elements

8: simplify graph

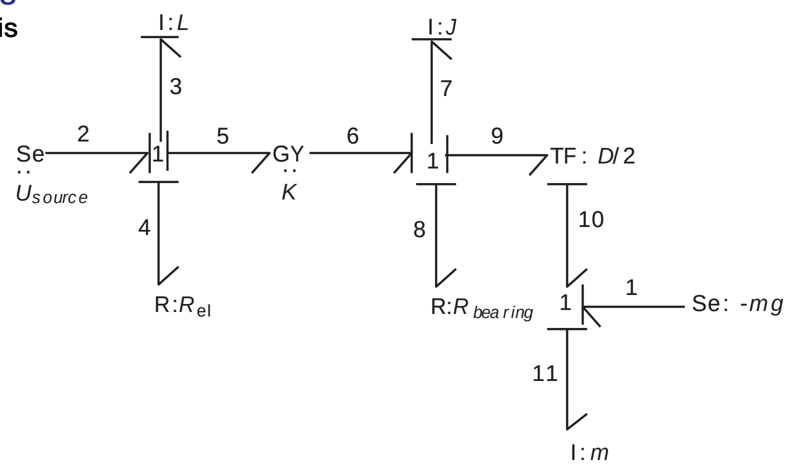


Bond-graph construction: example III



Bond-graph construction: example III

- Causality assignment
  - causal analysis



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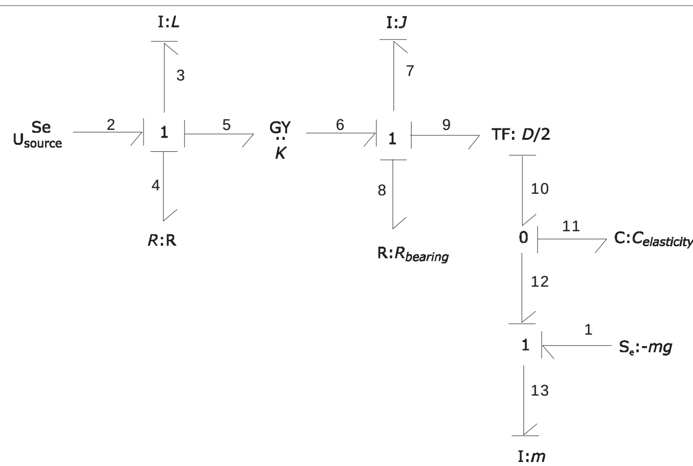
Bond-graph construction: example IV

- Generation of Equations

$$e_2 = u_{source}$$
$$\frac{df_3}{dt} = \frac{1}{L} e_3$$
$$e_4 = R_{el} f_4$$
$$f_2 = f_3$$
$$f_4 = f_3$$
$$f_5 = f_3$$
$$e_3 = e_2 - e_4 - e_5$$
$$e_5 = K f_6$$
$$e6 = K f_5$$
$$\frac{df_7}{dt} = \frac{1}{J} e_7$$
$$e_8 = R_{bearing} f_8$$
$$f_6 = f_7$$
$$f_8 = f_7$$
$$f_9 = f_7$$

$$e_7 = e_6 - e_8 - e_9$$
$$e_9 = -\frac{D}{2} e_{10}$$
$$f_{10} = -\frac{D}{2} f_9$$
$$e_{10} = e_{11}$$
$$e_{12} = e_{11}$$
$$f_{11} = f_{10} - f_{12}$$
$$\frac{de_{11}}{dt} = \frac{1}{C_{elasticity}} f_{11}$$
$$f_{12} = f_{13}$$
$$f_1 = f_{13}$$
$$e_{13} = e_1 + e_{12}$$
$$e_1 = -mg$$
$$\frac{df_{13}}{dt} = \frac{1}{m} e_{13}$$



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Bond-graph construction: example V

- Set ODEs

$$\frac{df_3}{dt} = \frac{1}{L}u_{source} - \frac{R_{el}}{L}f_3 - \frac{K}{L}f_7$$

$$\frac{df_7}{dt} = \frac{K}{J}f_3 - \frac{R_{bearing}}{J}f_7 - \frac{D}{2}e_{11}$$

$$\frac{de_{11}}{dt} = -\frac{D}{2C_{elasticity}}f_7 - \frac{1}{C_{elasticity}}f_{13}$$

$$\frac{df_{13}}{dt} = \frac{1}{m}e_{11} - g$$

$$\frac{d}{dt}\begin{pmatrix} f_3 \\ f_7 \\ e_{11} \\ f_{13} \end{pmatrix} = \begin{pmatrix} -\frac{\mathrm{Re}\,l}{L} & -\frac{K}{L} & 0 & 0 \\ \frac{K}{J} & -\frac{R_{bearing}}{J} & -\frac{D}{2} & 0 \\ -\frac{D}{2C_{elasticity}} & -\frac{1}{C_{elasticity}} & 0 & 0 \\ 0 & 0 & \frac{1}{m} & 0 \end{pmatrix} \begin{pmatrix} f_3 \\ f_7 \\ e_{11} \\ f_{13} \end{pmatrix} + \begin{pmatrix} \frac{1}{L} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & -\frac{1}{m} \end{pmatrix} \begin{pmatrix} u_{source} \\ mg \end{pmatrix}$$

Simulation

- Nicely automated by modern tools like 20-sim
- Model is ODE or DAE (conflicts)
- Aspects of models relevant for simulation
  - Presence of implicit equations
    - conflict at step 2 or at step 3
    - implicit integration methods only
  - Presence of discontinuities
    - special integration method
  - Numerical stiffness
    - S(t) = max(|Re(λ(t)|) / min(|Re(λ(t)|)
  - Oscillatory components (no damping)
    - stiff integration methods behave bad

Review

- Bond graphs
  - domain independent
  - only macroscopic: no quantum effects
  - directed graph: parts interconnected by bonds
  - bond: energy relation <-> bilateral signal flow
- Methods
  - systematic method IPM --> Bond graph
  - causal analysis
  - equations, block diagrams
- Object-oriented modeling
  - declarative, non-causal, hierarchical, definition & use
- Not presented
  - multiple connections
  - multiport elements (transducers)
  - other causality algorithms

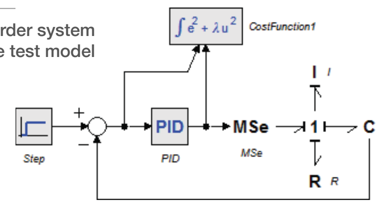
Further Reading

- Fundamentals
  - Paynter, 61: Analysis and design of engineering systems, Class Notes - origin!
  - Breedveld, 84: Physical systems theory in terms of bond graphs, PhD thesis,
  - Breedveld, 85: Multibond–graph elements in physical systems theory, J. Franklin Inst
- Textbooks
  - Karnopp, Margolis, Rosenberg, 90: System dynamics, a unified approach, Wiley
  - Thoma, 90: Simulation by bond graphs - Introduction to a graphical method, Springer
  - Cellier, 91: Continuous System Modeling, Springer
  - Job van Amerongen, 2011, Dynamical Systems for Creative technology (pdf also)
    - most figures in this slide set are from this text book
- Conferences
  - ICBGM, 93, 95, 97, 99, etc even in 2016: in Winter Multiconference USA
- Journals
  - Journal of the Franklin Institute, special issues on bond graphs (1991)
  - Journal of Dynamic Systems, Measurement and Control.
- Software
  - Enport (Rosenberg), CAMP (Granda), MS1 (Lorenz), 20-sim (Broenink), Amesim

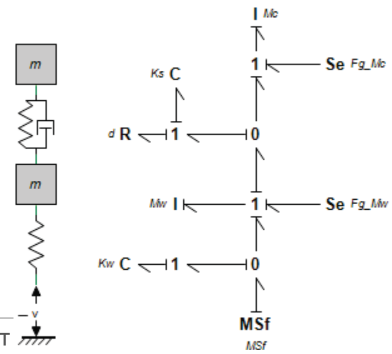
Examples to look at / or try out yourself

- Examples Directory
  - bond graphs
    - speaker - 2D transduction with storage
    - trolley - 2D mechanics
    - Newton Craddle - contact
  - 3D mechanics
    - knuckleBoomCraneKeyboard
    - Complex robot OSCAR
  - Control
    - Advanced Control / FSM
      - Finite State Machines stuffed in 20-sim
    - Standard Control
      - Active suspension

controlled 2nd order system
favorite test model



Quarter Car Model
vertical movement at 1 wheel



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Architecting the next generation of vehicles

Patrizio Pelliccione

Associate Professor (Docent), Chalmers|GU

www.patriziopelliccione.com

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

COST Action “IC1404 – Multi-Paradigm Modelling for Cyber-Physical Systems”

November 24-25, 2016, Malaga, Spain

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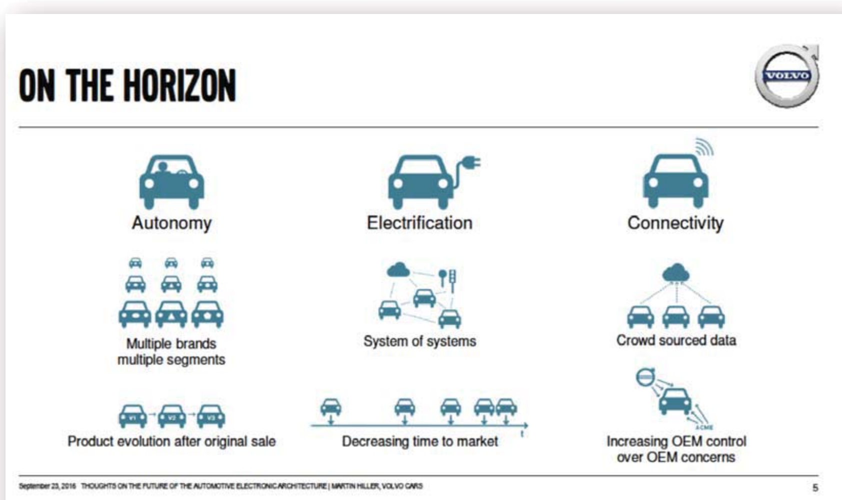
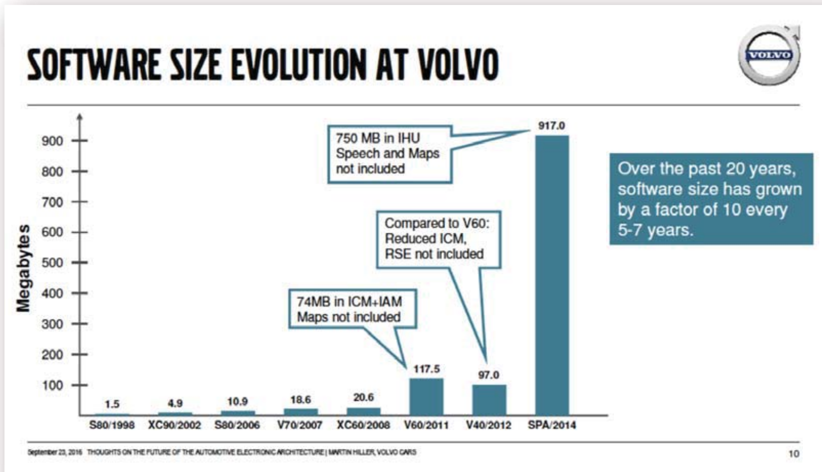
A car is a complex system



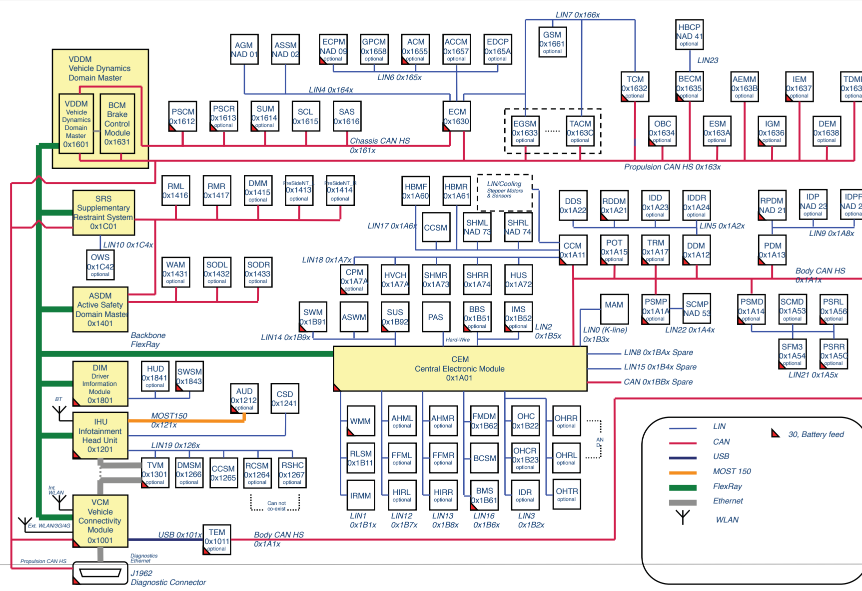
Thanks to Martin Hiller, Fuse meeting - September 23, 2016

A car is a complex system



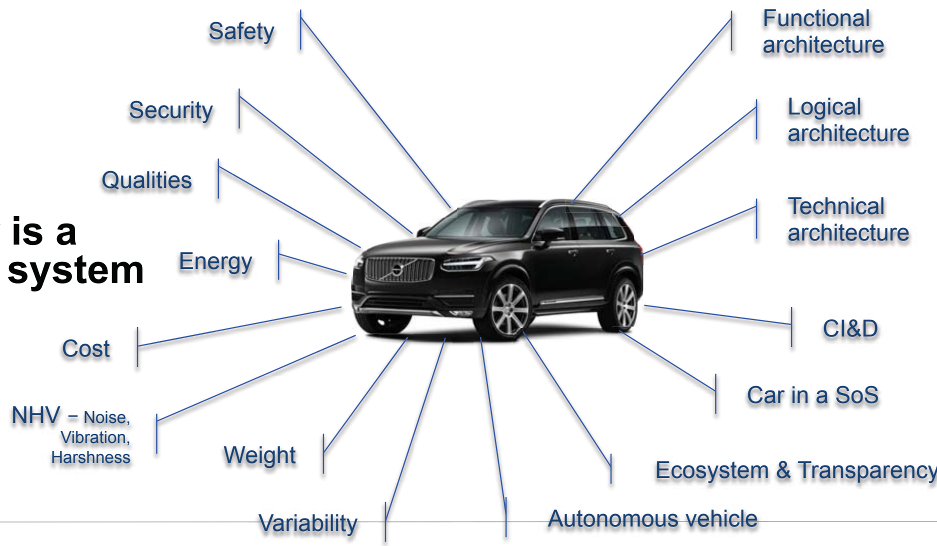
Thanks to Martin Hiller, Fuse meeting - September 23, 2016

How many Electronic Control Units (ECUs) in a car?



Kent Niesel http://slideqr.com/doc/173817/swc-reqs-test.v001

A car is a complex system



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Which formalism to use to describe the architecture of a complex system?

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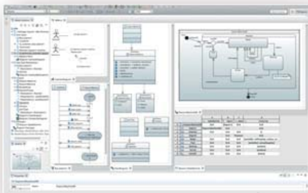
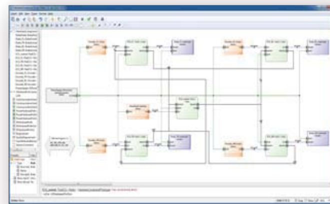
Which formalism to use to describe the architecture of a complex system?



UML / UML profile?



Architecture Description Language (ADL)?

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Survey on ALs – research questions

RQ1: What are the architectural description needs of practitioners?

RQ2: What features typically supported by existing architectural languages are useful (or not useful) for the software industry?


What Industry Needs from Architectural Languages: A Survey

Ivano Malavolta, Patricia Lago, Senior Member, IEEE, Henry Muccini, Patrizio Pelliccione, and Antony Tang, Member, IEEE

- Interviewed 48 practitioners from 40 different IT companies in 15 countries (questionnaire of 51 questions)

I. Malavolta, P. Lago, H. Muccini, P. Pelliccione, A. Tang (2013) **What Industry Needs from Architectural Languages : A Survey**, IEEE Transactions on Software Engineering (TSE) 39: 6. 869-891

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Survey on ALs – some findings

1. Architectural languages used in practice mostly **originate** from industrial development instead of from academic research
   - *Implication*: Need of understanding industrial requirement

2. ALs should combine features supporting both communication and disciplined development. We call this the **introvert** versus **extrovert** nature of architect role.

3. Organizations **prefer semi-formal** and generic ALs to formal and domain-specific ones
   - *Implication*: ALs should be **simple** and **intuitive** to communicate the right message to stakeholders, while enabling **formality** so to drive analysis and automatic tasks

4. Unclear the Return on Investment (**ROI**)

List of Architectural Languages: http://www.di.univaq.it/malavolta/al/

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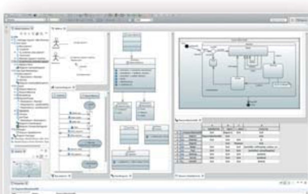
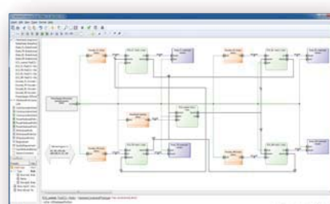
Which formalism to use to describe the architecture of a complex system?



UML / UML profile?



Architecture Description Language (ADL)?

papyrus

EAST-ADL

AADL

A set of them, many tools?

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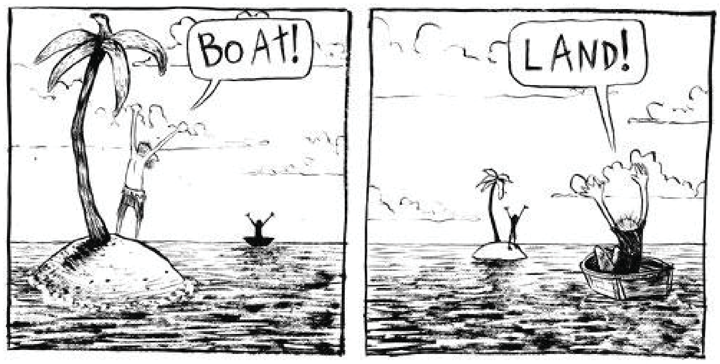
Multiple views!



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Multiple views !?!

- Who are the intended consumers of a view?
- What’s the purpose of a view?
- What’s the rationale of a view?
- Why are we using this specific modeling environment?
- How the different views relate each other?

Architecture Framework !

> "An architecture framework is a coordinated set of viewpoints, conventions, principles and practices for architecture description within a specific domain of application or community of stakeholders"

42010-2011 - ISO/IEC/IEEE Systems and software engineering -- Architecture description
https://standards.ieee.org/findstds/standard/42010-2011.html

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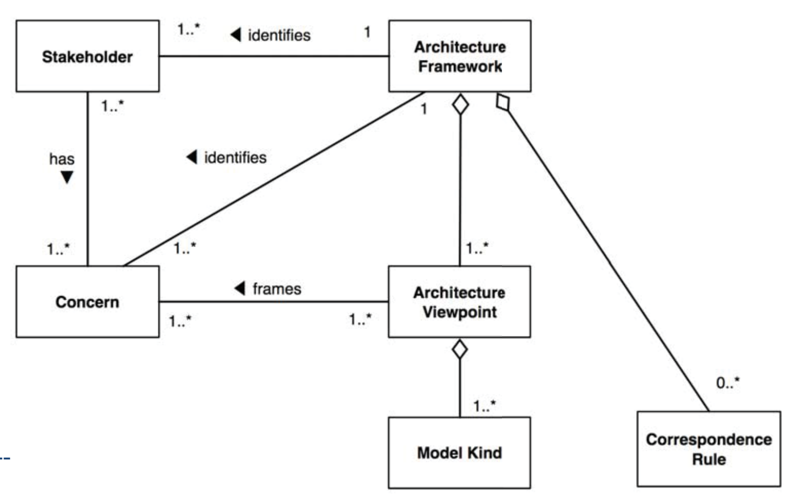
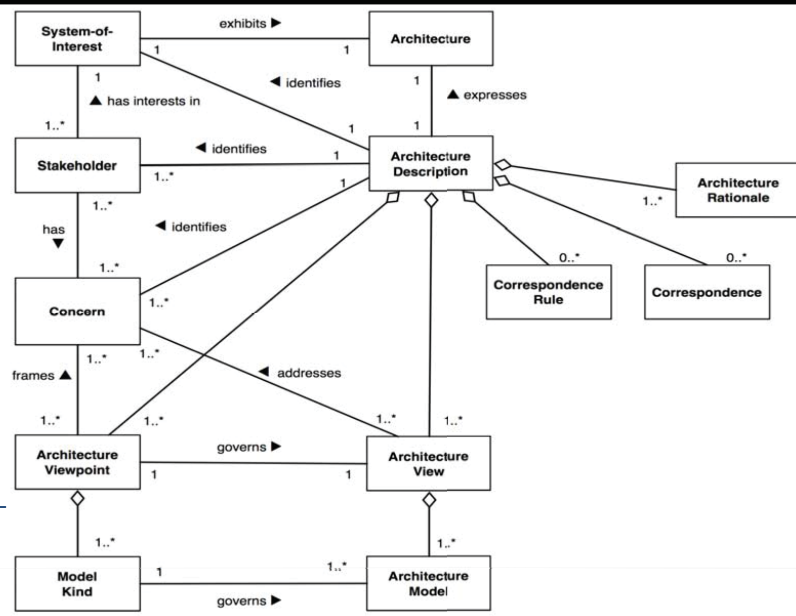
Architecture Framework



42010-2011 - ISO/IEC/IEEE Systems and software engineering -- Architecture description

Architecture Description



42010-2011 - ISO/IEC/IEEE
Systems and software engineering --
Architecture description

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Architecture Framework

- **A set of general elements of an architecture described by use of a concise and consistent terminology**
  - Guidance and rules for modelling, documenting, developing, understanding, analysing, using, and comparing architectures based on a common denominator (/ISO42010/) across a (virtual) development organization (i.e. value net).
- **The intention of an architecture framework for the automotive industry is to**
  - ensure that descriptions of vehicle architectures can be **compared and related** across different vehicle programs, development units and organizations
  - **establish the foundation** for overall value creation efficiency, risk reduction and, ultimately, increased innovation

M. Broy, M. Gleirscher, S. Merenda, D. Wild, **Automotive Architecture Framework: Towards a Holistic and Standardised System Architecture Description - an overview on description concepts, models and methods**, Tech. Rep. of the Techn. Universität München - June 2009.

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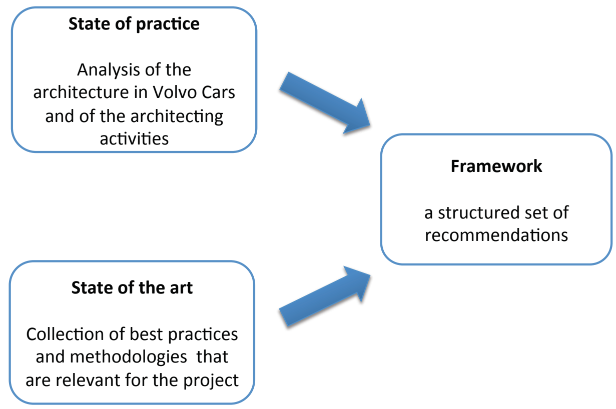
Volvo Cars Architecture framework

Macro organization of work



P. Pelliccione, E. Knauss, R. Heldal, M. Agren, P. Mallozzi, A. Alminger, D. Borgentun, **Automotive Architecture Framework: the experience of Volvo Cars**, submitted to Journal of System Architecture (JSA).
P. Pelliccione, E. Knauss, R. Heldal, M. Ågren, P. Mallozzi, A. Alminger, D. Borgentun, **A proposal for an Automotive Architecture Framework for Volvo Cars**, Second International Workshop on Automotive Software Architectures WICSA/CompArch 2016 April 5 2016, Venice, Italy (2016)

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Identified problem within Volvo Cars

State of Practice

- **The actual architecture of the car is not exactly the one conceived by the architects**
  - The architecture is also emerging during development (bottom-up)
  - Some architectural decisions are made unconsciously
    - Which decisions have an impact on the architecture? – not easy
  - Some "actual" architects do not have the title of architect

As-Intended GAP **As-Realized**

Architecture degradation
- Architecture erosion
- Architecture drift

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Limitations of the actual architecture description

State of Practice

- Importance varies over time
- Easily becomes out of date
- Too many details
- Variability management
- Should better document the design decisions
- Should better document / make explicit the assumptions made
- Should be a living document connected with the other development phases
- Should handle different views and viewpoints of different stakeholders' concerns
- Present and Future mixed in the same document

U. Eliasson, R. Heldal, P. Pelliccione, J.Lantz (2015) **Architecting in the Automotive Domain: Descriptive vs Prescriptive Architecture** In: In Proceedings of 12th Working IEEE / IFIP Conference on Software Architecture (WICSA 2015), IEEE, Montreal, Canada.
R. Heldal, P. Pelliccione, U. Eliasson, J. Lantz, J. Derehag, J. Whittle, **Descriptive vs Prescriptive Models in Industry**, Models 2016, St-Malo, France, 2016

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Volvo Cars Architecture framework

- Focus on:
  - System of Systems (SoS) viewpoint
  - Continuous Integration & Deployment (CI&D) viewpoint
  - Ecosystem viewpoint

P. Pelliccione, E. Knauss, R. Heldal, M. Agren, P. Mallozzi, A. Alminger, D. Borgentun, **Automotive Architecture Framework: the experience of Volvo Cars**, submitted to Journal of System Architecture (JSA).
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Architecture Framework: stakeholders

Table 1: Overview of Stakeholders

Stakeholder	Group	Comment	Synonyms
• Passengers	end-user		
• Drivers	end-user		
• Customers	customer	Purchaser of a car or related service	
• Product planner	customer	Acquirer of electrical system	
• Purchaser	customer	Purchasers of electrical system	
• Line managers	management	Has scheduling responsibility, long term quality responsibility, includes group, department	
• Project managers	management	Owns budget for development	
• System architects	developers of electrical system		
• Functional developers	developers of electrical system	Owns functional and non-functional aspects	function owner; function realizer; function developer, function realizer, system developer
• Component developers	developers of electrical system		
• SW supplier (internal/external)	developers of electrical system	Can be internal or external from the perspective of the OEM.	
• HW supplier (internal/external)	developers of electrical system	Can be internal or external from the perspective of the OEM.	
• Testers	developers of electrical system		
• Attribute Owners	developers of electrical system	Owns non-functional attributes like performance	
• Tool Engineers	developers of electrical system	Specifically testing tools, including design tools (e.g. for requirements)	
• Calibrators	developers of electrical system		
• Diagnostic method engineers	maintainers of electrical system		
• Workshop Personnel	maintainers of electrical system		
• Fault Tracing Specialists	maintainers of electrical system		
• Technical Specialist	specialists	Support developers and maintainers on specific topics	

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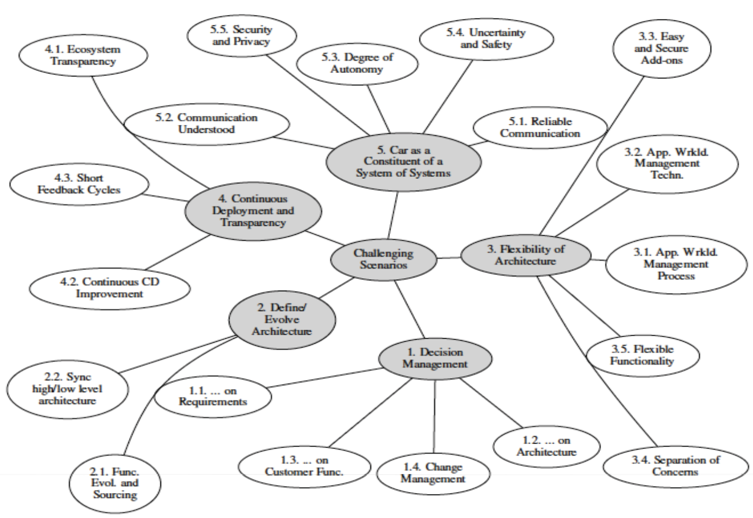
Architecture Framework: scenarios



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Car in a SoS: concerns

- Once the car is part of a SoS, how to guarantee **functional safety** requirements?
- Once functional **safety requirements involve devices that are outside of the vehicle** (other constituent systems of the SoS), how to ensure that these requirements will be guaranteed?
- How the methods and processes for **end-to-end function development** and continuous delivery of software need to evolve to be suitable in a systems of systems setting?
- Which functions in the car are allowed to **use data coming from other constituents**?

Safety

Distributed end-to-end functionality

P. Pelliccione, E. Johansson, T. Larsson, M. Aramrattana, M. Ågren, G. Jonsson and R. Heldal, **Cars as constituents of a System of Systems**, ECSA Colloquium on Software-intensive Systems-of-Systems (SiSoS), ACM 2017.
P. Pelliccione, E. Knauss, R. Heldal, M. Agren, P. Mallozzi, A. Alminger, D. Borgentun, **Automotive Architecture Framework: the experience of Volvo Cars**, submitted to Journal of System Architecture (JSA).

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Car in a SoS: concerns

- How to enable a **reliable and efficient communication** between the vehicle and heterogeneous entities, like other vehicles, road signals, pedestrians, etc.?
- How to be sure that the vehicle and other constituent systems of the SoS will be **able to exchange information and to use** the information that has been exchanged?
- How to **keep the data** shared within the SoS (and possible replication of data) sufficiently **updated or synchronized**?
- How to manage the **age of available information**?

Connectivity and Heterogeneity of communication channels

Interoperability among constituent systems (cars, road signals, road infrastructure, …)

P. Pelliccione, E. Johansson, T. Larsson, M. Aramrattana, M. Ågren, G. Jonsson and R. Heldal, **Cars as constituents of a System of Systems**, ECSA Colloquium on Software-intensive Systems-of-Systems (SiSoS), ACM 2017.
P. Pelliccione, E. Knauss, R. Heldal, M. Agren, P. Mallozzi, A. Alminger, D. Borgentun, **Automotive Architecture Framework: the experience of Volvo Cars**, submitted to Journal of System Architecture (JSA).

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Car in a SoS: concerns

- How to guarantee that the security of the vehicle is preserved once the vehicle becomes connected?
- How to identify the right tradeoff between shared data and users' privacy?
- Which functions in the car are allowed to make use of data coming from other constituents?

Cyber security and privacy

P. Pelliccione, E. Johansson, T. Larsson, M. Aramrattana, M. Ågren, G. Jonsson and R. Heldal, **Cars as constituents of a System of Systems**, ECSA Colloquium on Software-intensive Systems-of-Systems (SiSoS), ACM 2017.
P. Pelliccione, E. Knauss, R. Heldal, M. Agren, P. Mallozzi, A. Alminger, D. Borgentun, **Automotive Architecture Framework: the experience of Volvo Cars**, submitted to Journal of System Architecture (JSA).

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CI&D viewpoint: concerns

- How can we avoid building the **wrong architecture**?
- How can we reduce the number of architectural **assumptions**?
- How can a system respond **quicker** to changes in the market?
- How can we deal with **changing interfaces**?
- How can we deal with **dependencies**?

C. Yang, P. Liang, P. Avgeriou, U. Eliasson, R. Heldal, P. Pelliccione, T. Bi, **Documentation of software architectural assumptions: An industrial case study**, Submitted to Journal of systems and Software (JSS)
E. Knauss, P. Pelliccione, R. Heldal, M. Ågren, S. Hellman, D. Maniette: **Continuous Integration Beyond the Team: A Tooling Perspective on Challenges in the Automotive Industry**. ESEM 2016: 43:1-43:6
A. Shahrokni, P. Gergely, J. Söderberg, P. Pelliccione (2016) **Organic Evolution of Development Organizations - An Experience Report** In: SAE 2016 World Congress and Exhibition - Model-Based Controls and Software Development.

Ecosystem and transparency: concerns

- Which types of **value-chains** are implied by a given system architecture and what is their purpose?
- How to map **supplier development capabilities** to demands created by a specific system architecture?
- How can we **establish** the required level of **transparency** in a value-chain?
- How can we **manage transparency** (e.g. of architectural decisions) in the face of changing suppliers?

R. van der Valk, P. Pelliccione , P. Lago , R. Heldal , E. Knauss, and J. Juul, **Continuous Delivery in the Automotive Ecosystem: Transparency Trade-offs in Software Value-Chains**, Submitted to International Conf. Software Engineering (ICSE) SEIP 2017.

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Ongoing work

- Detailing the viewpoints
  - Identifying Model kinds
- Modeling and managing relationships among viewpoints
- Integrating Architecture framework with ATAM (Architecture Tradeoff Analysis Method)

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Takeaways

- Defining an architecture for a complex and real system is **much more than just modeling**
- Effective solution in practice need to combine **technical** aspects with **organization**, **process**, and **business** aspects
- **Architecture frameworks** are a promising way to manage the complexity of the architecture of a complex and big system

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Technical papers:

- **Abstracts (mandatory) due:** 5 January 2017
- **Full papers due:** 10 January 2017
- **Notification of acceptance:** 13 February 2017
- **Camera-ready due:** 28 February 2017
- **Online Proceedings:** 31 March 2017

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Mike Nicolai, Siemens PLM Software
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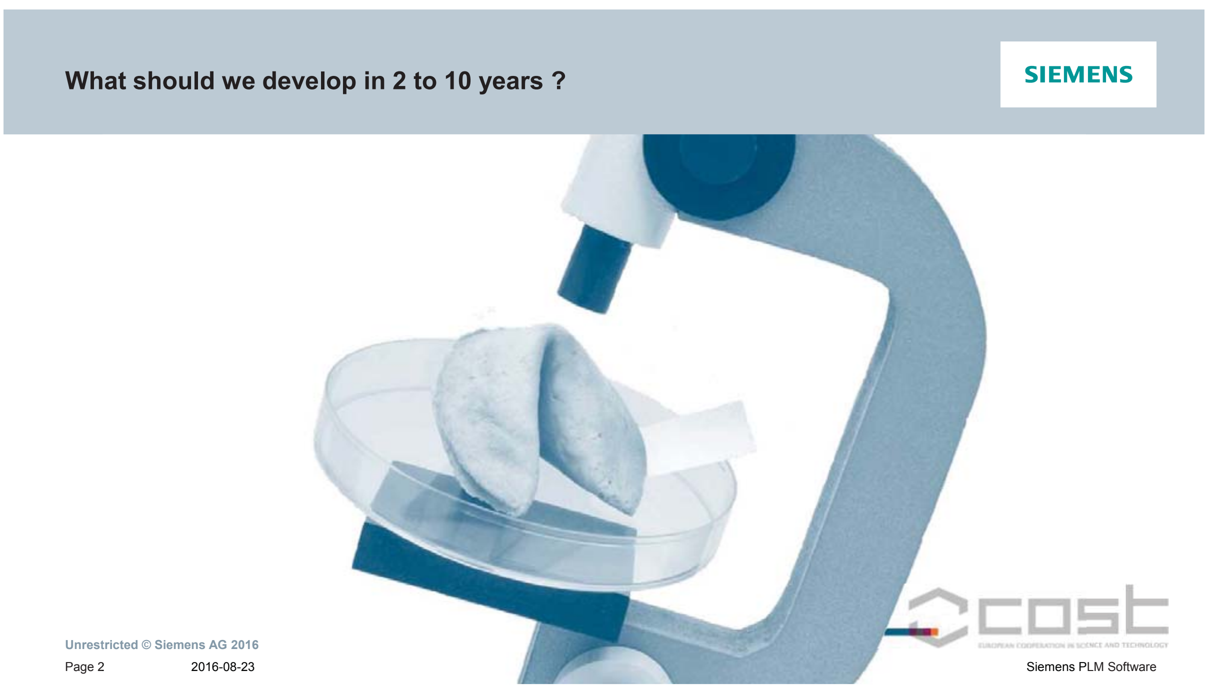
What should we develop in 2 to 10 years ?
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2016-08-23
cost
Siemens PLM Software

Topological Design Space Exploration
The overall workflow

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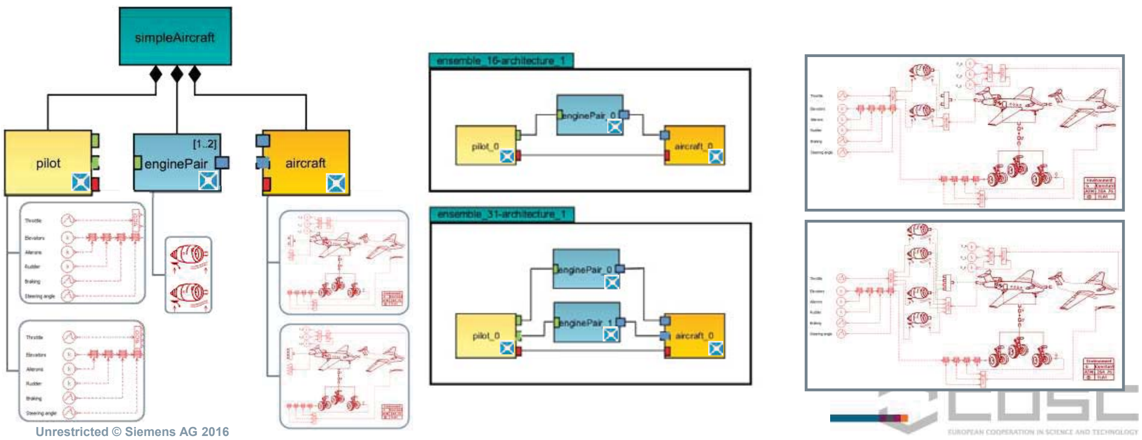
System declaration → **System instantiation** → **System realization**



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Motivation More- and All-Electric Aircrafts	5
Detailed A320-like Use Case:	10
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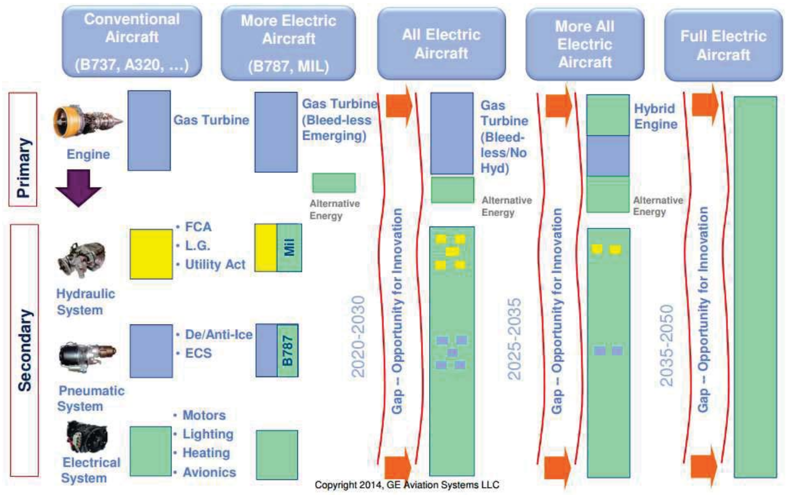
Homework	39

Towards Full Electric Aircraft

SIEMENS



More-electric aircraft = more advanced electrical power system

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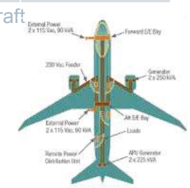
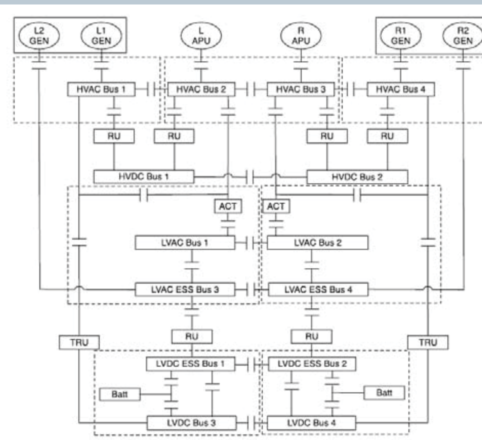
Priority Level	28 V DC	270 V DC	230 V AC
Essential	Avionics	Flight controls	
	Lights	Engine starter	
	Miscellaneous	eECS	
		Landing gear	
		Wheel brakes	
		Miscellaneous	
Non-essential	IFE (Audio)	Ice protection	Galleys
	Miscellaneous	Miscellaneous	IFE
			Miscellaneous

Example of electrical power consumers in aircraft

(e.g., Bornholdt et al. 2015)





Electrical system for more electric vehicle (Honeywell US 7439634 B2 patent, 2008)

Innovative Designs in aircraft electric power systems (EPS)
or
Design for Disaster

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"The Miracle on the Hudson"

Airbus 320, US Airways Flight 1549, 15. January 2009

"Gimli Glider"

Boeing 767, Air Canada Flight 143, 23. July 1983

Lets design something know !

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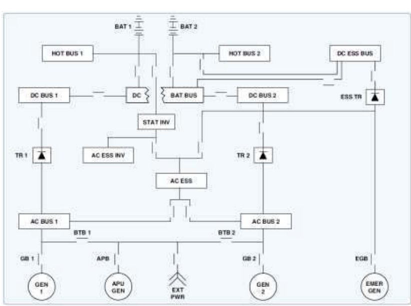

Electrical Power System – state-of-the-art

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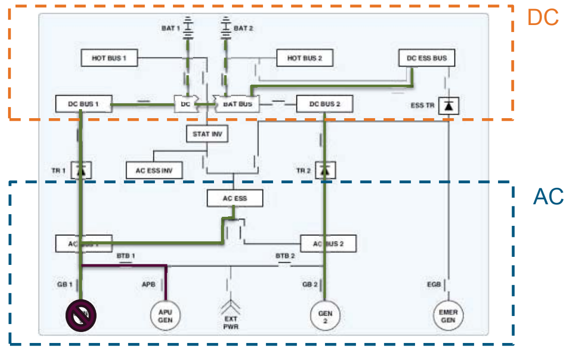
Network of electrical components used to supply, transfer, and consume electric power

Display of an Airbus A320 EPS[1]



Schematic of electrical system for twin-engine aircraft[2]

[1] E. Auxier - Airbus
[2] Federal Aviation Administration

The complete design process

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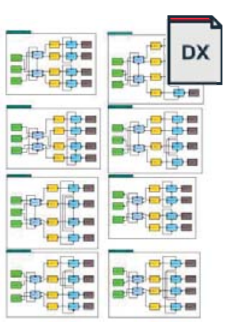
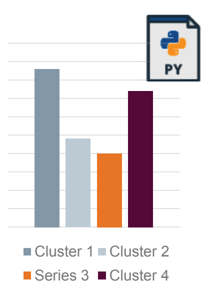
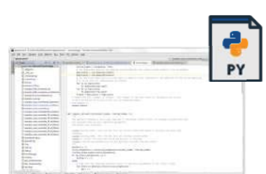
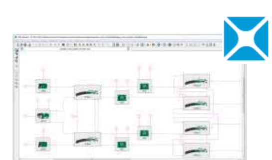
Design exploration	Architecture ranking	Controller generation	Simulation
Auto-generation of different possible architectures with DX	Rank and select architectures	Automatically generate a controller for the Electrical Power System	Integrate the controller with modelling software









A case-study

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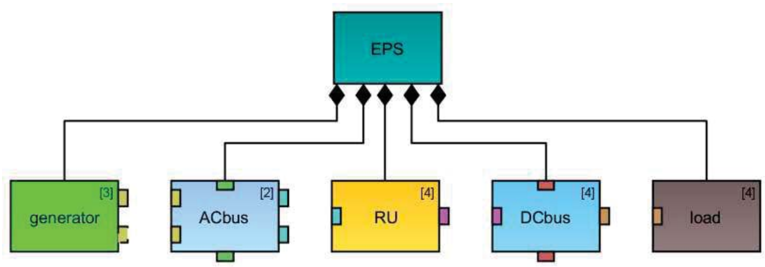

3-generator AC/DC system with 4 critical DC loads

Adapted from Nuzzo et al.: Contract-Based Methodology for Aircraft Electric Power System Design

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A case-study

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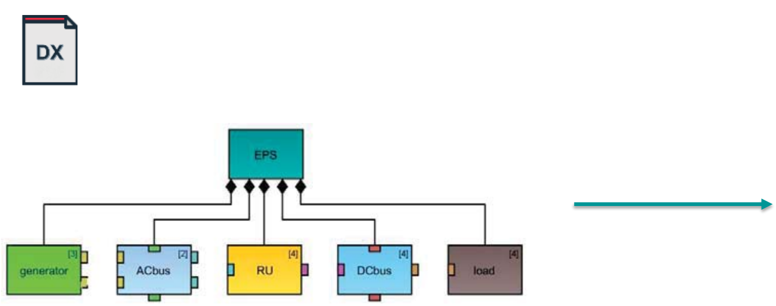
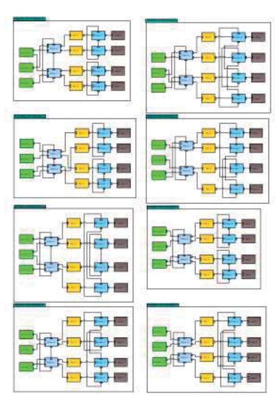
Design exploration → Architecture ranking → Controller generation → Simulation





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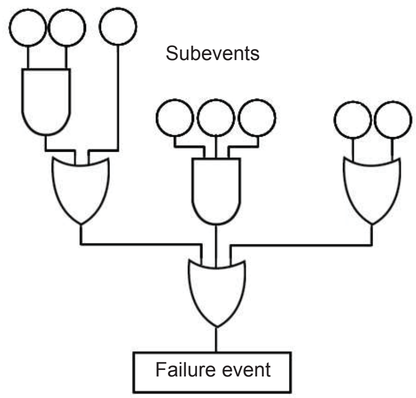
Fault Tree Analysis

SIEMENS

Design exploration | **Architecture selection** | Controller generation | Simulation

- Tool to determine the failure probability of critical components
- A top-down analysis using Boolean logic



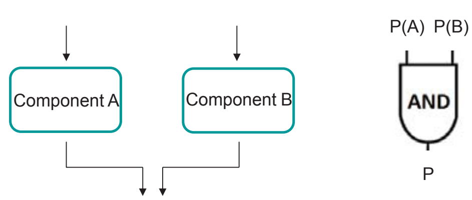
Fault Tree Analysis: example

SIEMENS

Design exploration | **Architecture selection** | Controller generation | Simulation

Parallel components:

$$P = [P(A) \text{ AND } P(B)] = P(A).P(B)$$



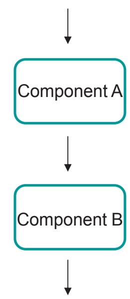
Fault Tree Analysis: example

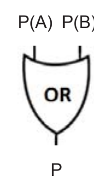
SIEMENS

Design exploration | **Architecture selection** | Controller generation | Simulation

Serial components:

$$P = [P(A)\ OR\ P(B)] = P(A) + P(B) - P(A).P(B)$$





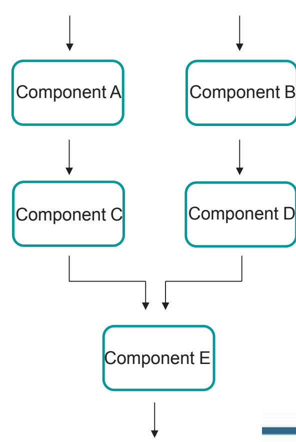
Fault Tree Analysis: example

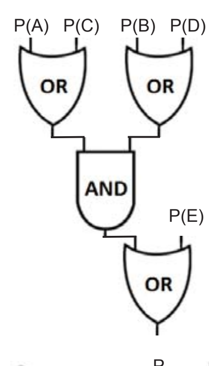
SIEMENS

Design exploration | **Architecture selection** | Controller generation | Simulation

Combination of components:

$$P = P(E) + (P(A) + P(C) - P(A).P(C)).$$
$$(P(B) + P(D) - P(B).P(D)) -$$
$$[P(E).\ (P(A) + P(C) - P(A).P(C)).$$
$$(P(B) + P(D) - P(B).P(D))\ ]$$



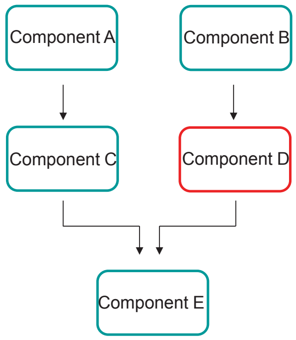


Fault Tree Analysis: extension to more complex architectures

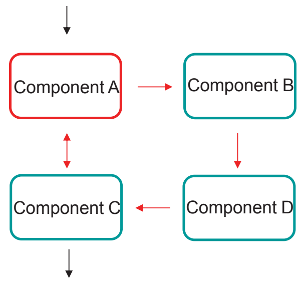
SIEMENS

Design exploration | **Architecture selection** | Controller generation | Simulation

2 difficulties:



Component is not aware of complete architecture



Existence of cycles

Fault Tree Analysis: extension to more complex architectures

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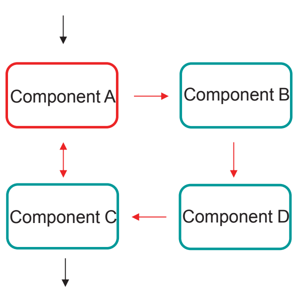
Design exploration | **Architecture selection** | Controller generation | Simulation

Solution: a recursive algorithm that walks carefully through the architecture (Nuzzo et al. 2014)



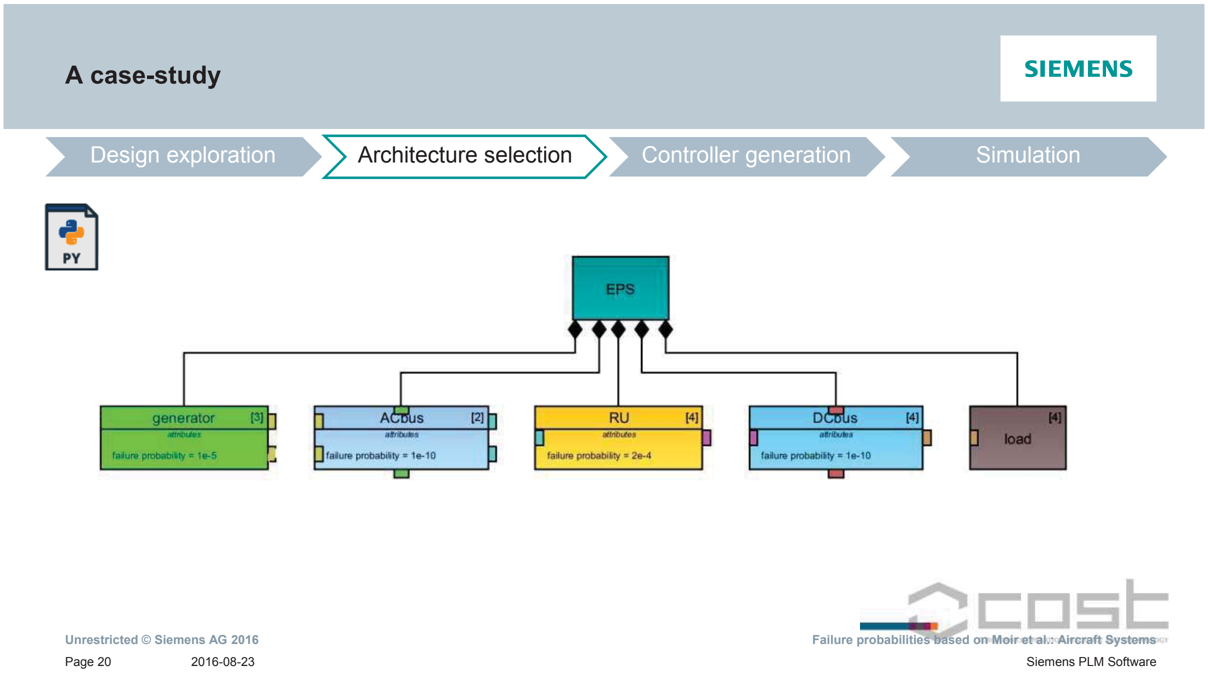
Algorithm 2 COMPRELIABILITY

Input: A directed graph $\mathcal{G}'$, an array of component failure probabilities P, an array of currently visited nodes C (at which failure probabilities must be computed), an array of previously visited nodes W
Output: $probFail$, array of probabilities of all failure events induced by the neighbors of the nodes in C

```
probFail ← [ ]
L ← UNVNEIGH(C, W)      ▷ unvisited neighbors of nodes in C
W ← [W, L]              ▷ update visited nodes

if ISEMPTY(L) then
    probFail ← 1        ▷ return the neutral element
else
    for all event in GENEVENT(L) do     ▷ all failure events
        fail ← 1
        for all k in L do
            if ISFAILING(k, event) then
                fail ← fail * P(k)      ▷ component fails
            else
                if ISGENERATOR(k) then
                    fail ← 0            ▷ healthy generator
                else
                    fail ← fail * (1 − P(k))
                end if
                C ← [C, k]
            end if
        end for
        if EXISTSHEALTHY(event) then    ▷ not all fail
            fail ← fail * SUM(COMPRELIABILITY(P, C, W))
        end if
        probFail ← [probFail, fail]
        C ← [ ]
    end for
end if
```

Algorithm 2 CompReliability from Nuzzo et al.: Contract-Based Methodology for Aircraft Electric Power System Design


A case-study
SIEMENS
Design exploration
Architecture selection
Controller generation
Simulation
PY
EPS
generator [3]
attributes
failure probability = 1e-5
ACbus [2]
attributes
failure probability = 1e-10
RU [4]
attributes
failure probability = 2e-4
DCbus [4]
attributes
failure probability = 1e-10
[4]
load
Failure probabilities based on Moir et al.: Aircraft Systems
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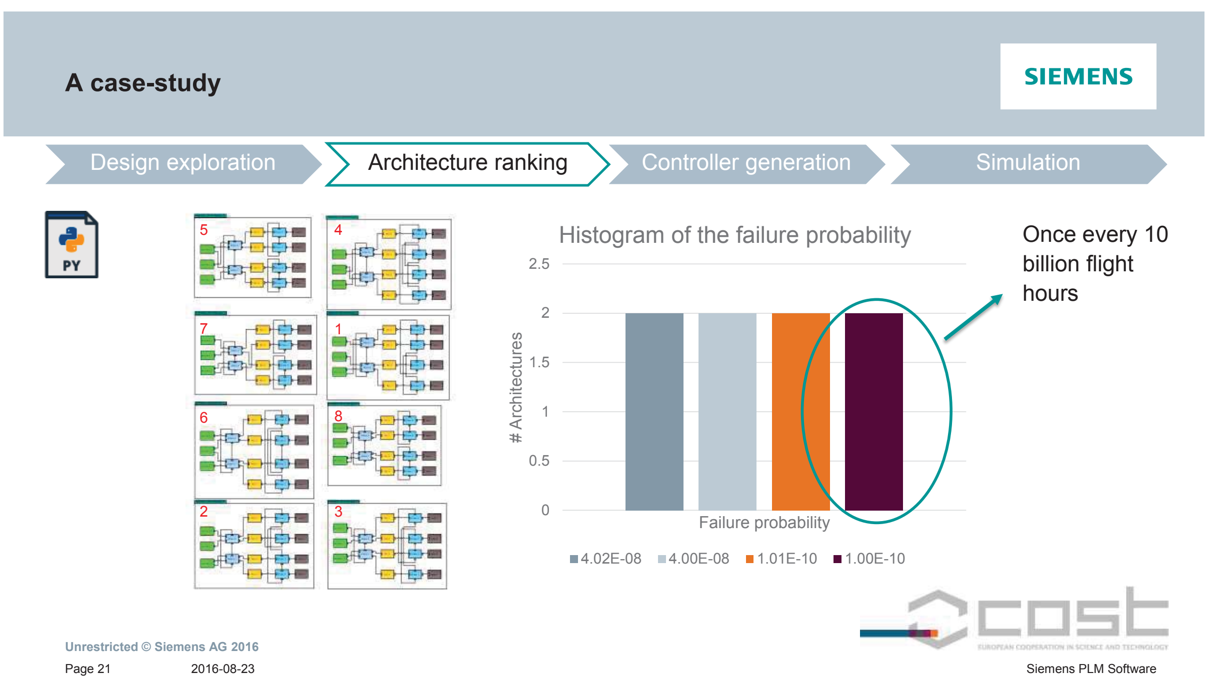
A case-study
SIEMENS
Design exploration
Architecture ranking
Controller generation
Simulation
PY
Histogram of the failure probability
Architectures
Failure probability
4.02E-08
4.00E-08
1.01E-10
1.00E-10
Once every 10 billion flight hours
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
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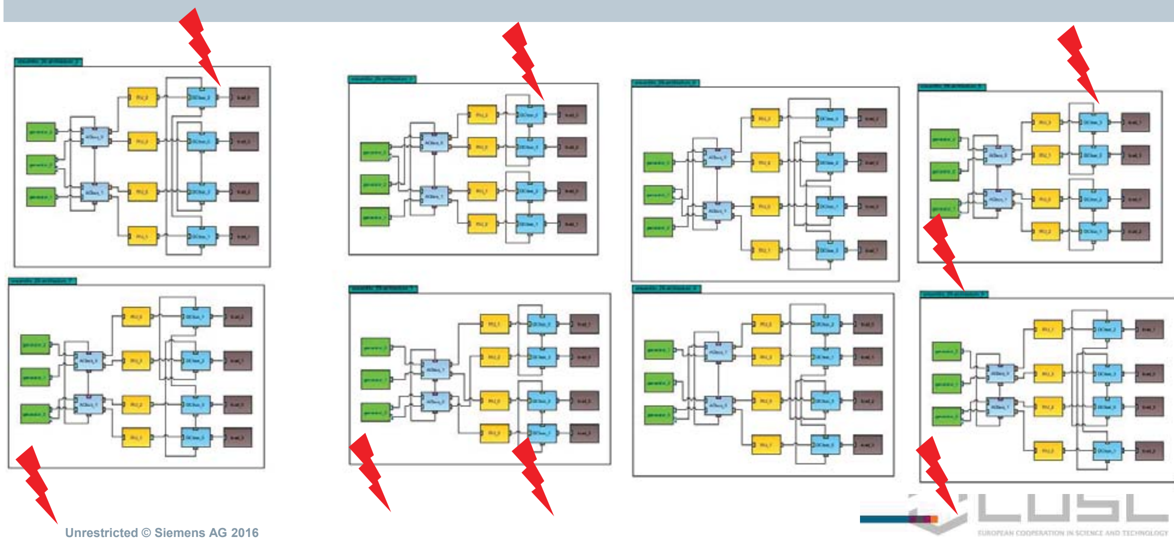

A case-study

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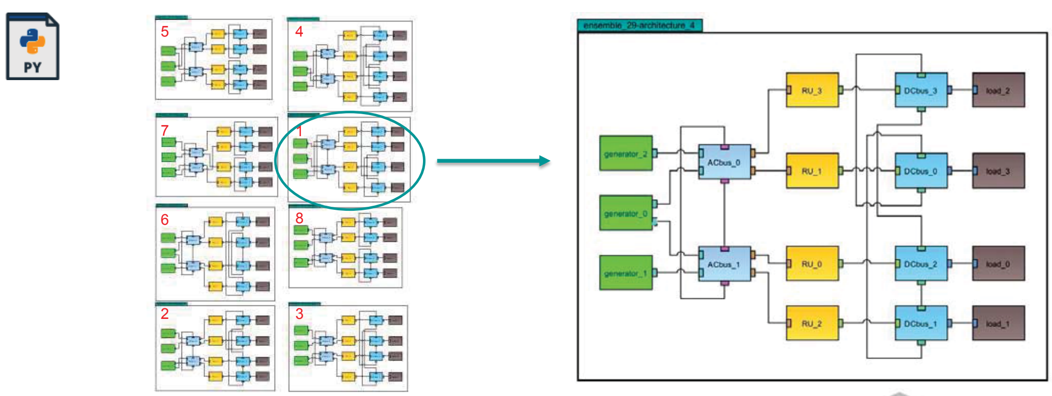
Design exploration | Architecture ranking | Controller generation | Simulation



The controller generation

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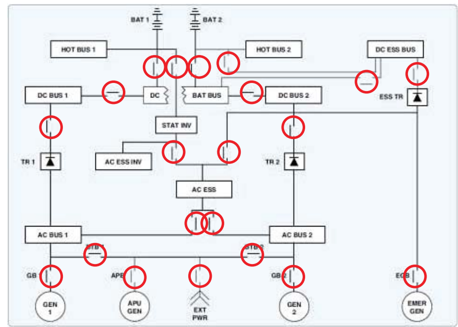
Design exploration | Architecture selection | **Controller generation** | Simulation

- Create a controller for one specific architecture
- A controller governs the switches between components



The controller description with LTL

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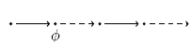
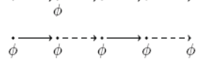
Design exploration | Architecture selection | **Controller generation** | Simulation

- Linear Temporal Logic (LTL) extends Boolean logic
- It is a modal temporal logic with modalities referring to time
- Logical operators + additional temporal operators

ne**X**t ◯ ϕ



Globally □ ϕ



The controller description with LTL

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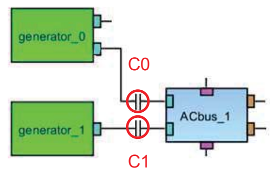
Design exploration | Architecture selection | **Controller generation** | Simulation

- The controller generation software requires a description in LTL strings
- For example the following EPS requirements:
  - Isolation of a failed generator
  - Powering of a component
  - Parallel sources

```
  ! gen_0Health -> ◯ ! C0Status
□ [Acbus_1Power <-> (gen_0Health && C0Status) ||
                            (gen_1Health && C1Status)]
□ ! ( C0Status && C1Status)
```



A case-study

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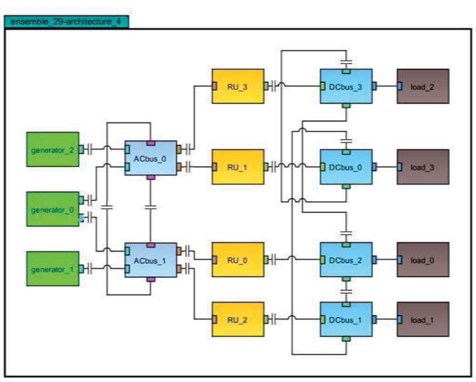
Design exploration | Architecture selection | **Controller generation** | Simulation



The resulting controller:
- 35000+ lines of validated code
- 103 states
- Automatically generated

A case-study

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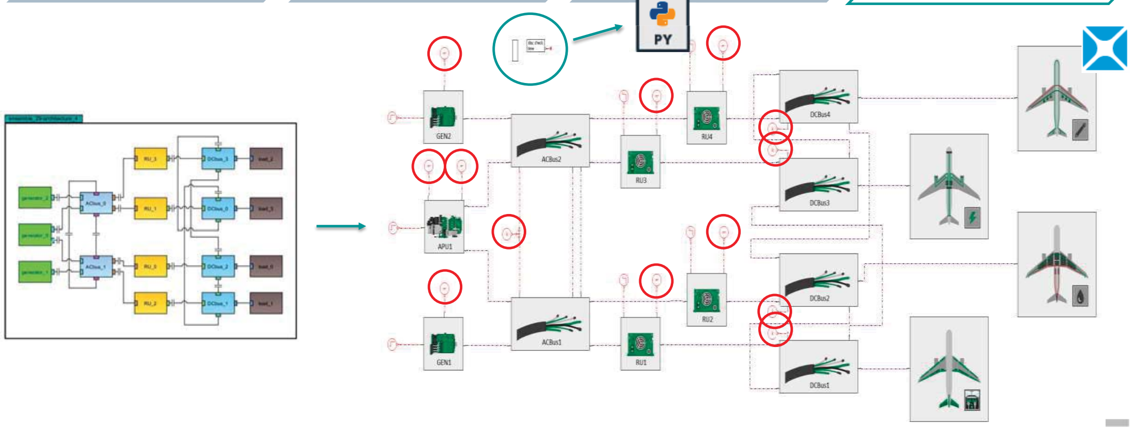
Design exploration → Architecture selection → Controller generation → **Simulation**



A case-study

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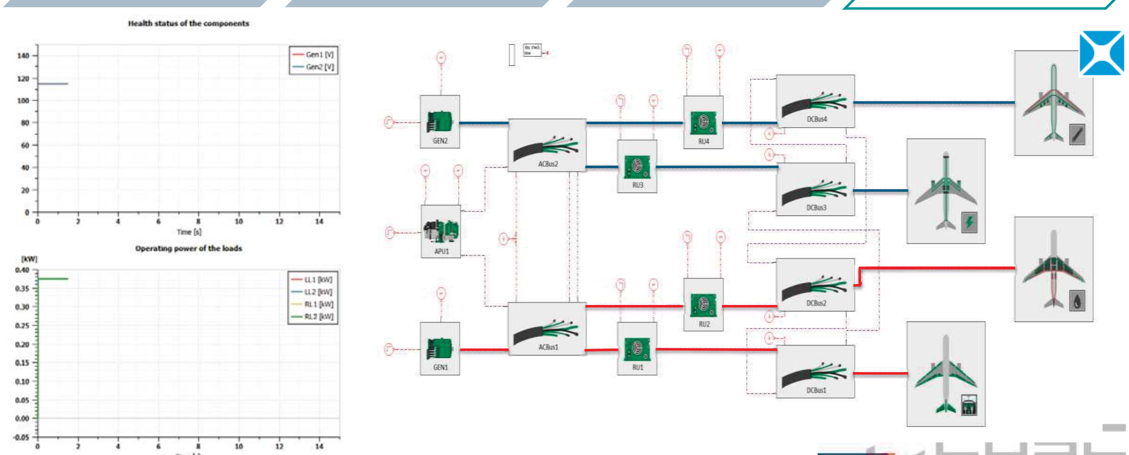
Design exploration → Architecture selection → Controller generation → **Simulation**



A case-study

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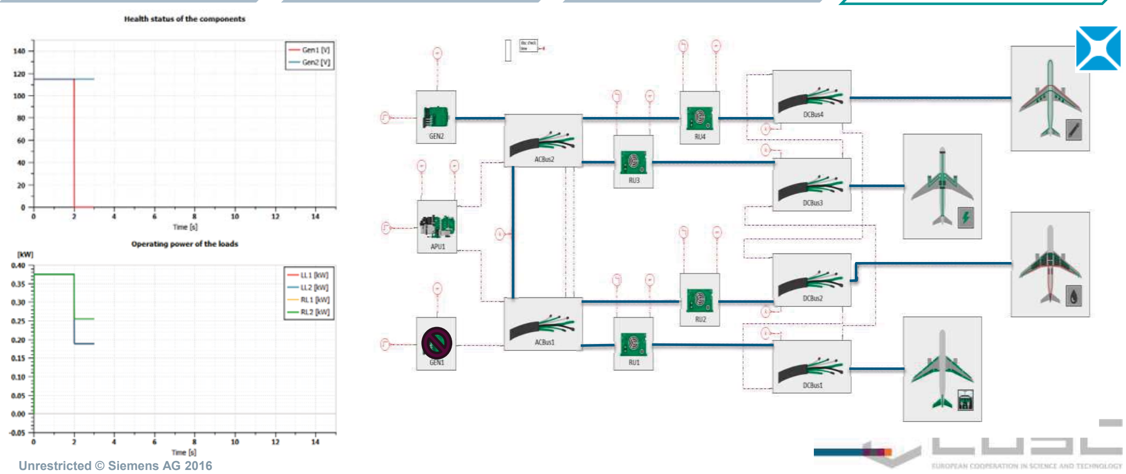
Design exploration | Architecture selection | Controller generation | **Simulation**



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A case-study

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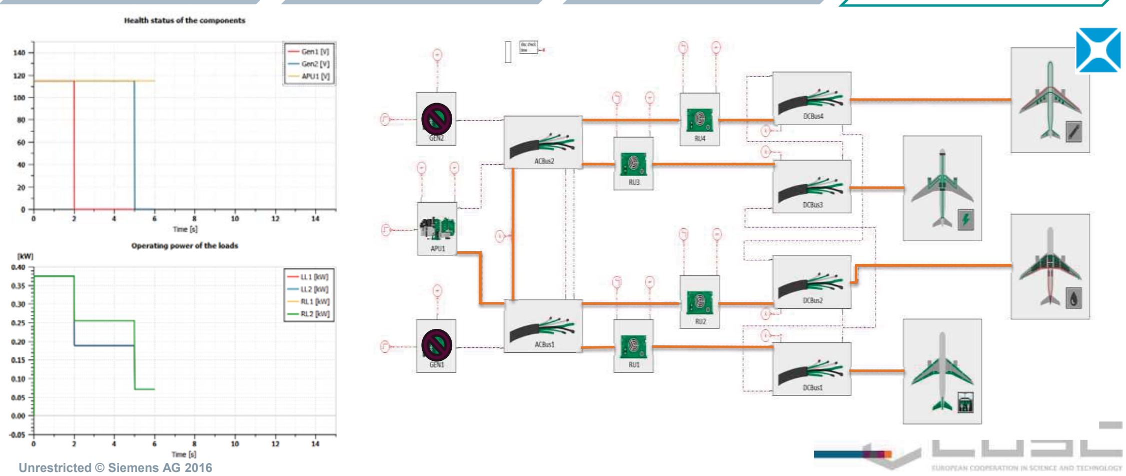
Design exploration | Architecture selection | Controller generation | **Simulation**



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A case-study

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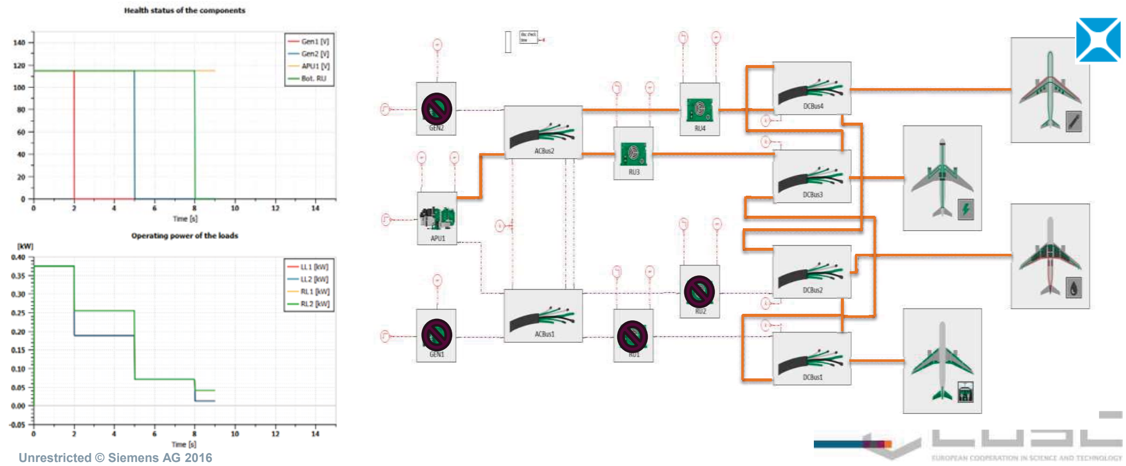
Design exploration | Architecture selection | Controller generation | **Simulation**



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A case-study

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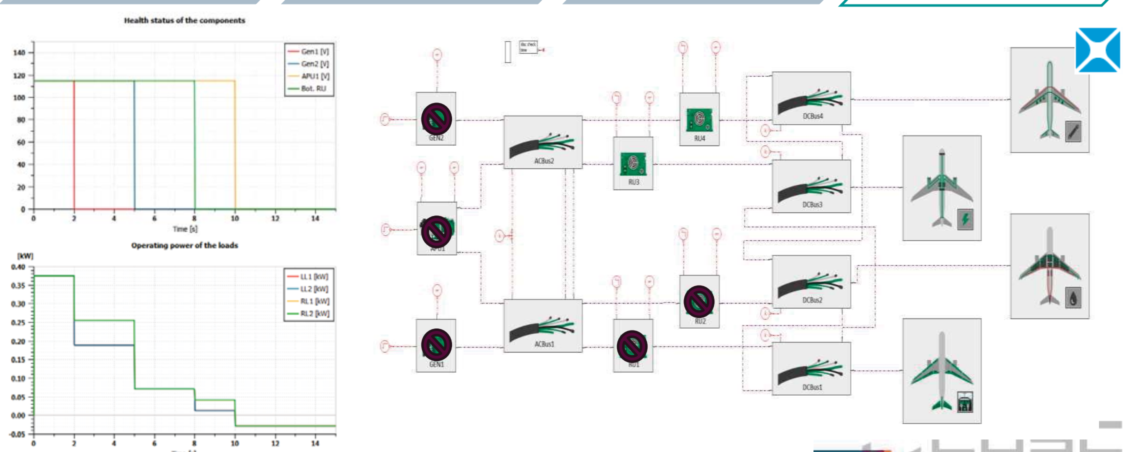
Design exploration | Architecture selection | Controller generation | **Simulation**



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Conclusion

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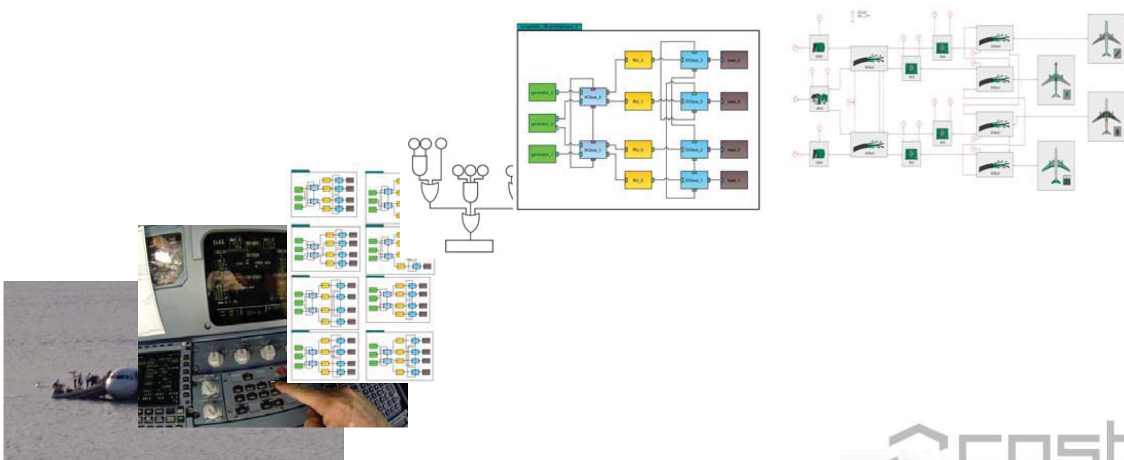

“The Miracle on the Hudson”

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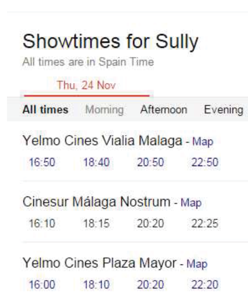
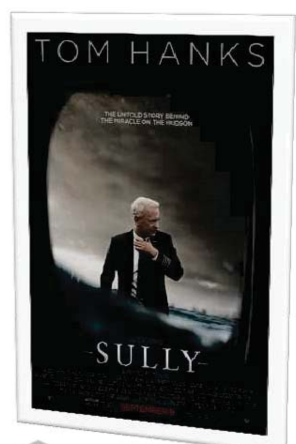
“The Miracle on the Hudson”

Airbus 320, US Airways Flight 1549, 15. January 2009





MPM4CPS

SIMULATION AND DESING-TIME ANALYSIS OF THE SMART GRID IN THE CZECH REPUBLIC

C1404 – Multi-Paradigm Modelling for Cyber-Physical Systems

Barbora Buhnova
buhnova@fi.muni.cz

COST Action Workshop
24.-25. 11. 2016, Malaga

LAB OF SOFTWARE ARCHITECTURES AND INFORMATION SYSTEMS

FACULTY OF INFORMATICS
MASARYK UNIVERSITY, BRNO

lasaris

Introduction and Industrial Context

- **My background**
  - **Software architecture design**
  - Formal methods
  - Functional correctness
  - Performance and reliability engineering
- **Affiliation**
  - Lab of Software Architecture and Information Systems (LaSArIS) – since **2009**
  - **4** academics, **10** PhD students
- **Industrial cooperation**
  - Association of Industrial Partners – **32** companies, since **2007**
    - including Honeywell, IBM, Siemens, Rad Hat, AT&T, Konica-Minolta, Y Soft, Kentico, …
  - CERIT Science Park – **20** companies in our building, since **2014**
  - Czech academic expert group – projects with ČEZ, E.ON, PRE, ČSRES

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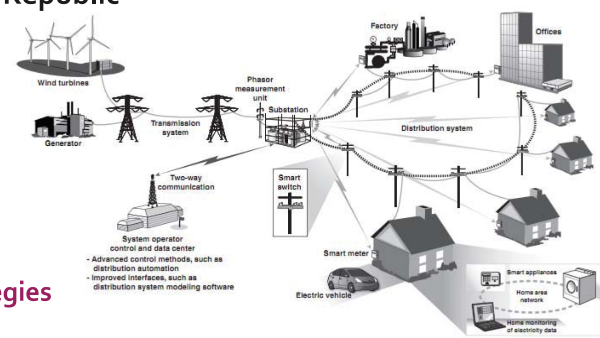
Smart Grid Analysis and Design

- **Smart Grid design in the Czech Republic**
  - **What-if analyses, studies**
  - Recommendations for the **Czech national action plan**
  - Assessment of the **limits of existing infrastructure**
  - Deployment and testing of **load control strategies**
  - Design of **communication strategies**



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- **Primary concerns**
  - Security, **safety**, availability, **privacy**, reliability, **cost efficiency**
  - Design and operation of critical infrastructures in general
    - **Cybercrime detection** – cybernetic proving ground (KYPO project)
    - **Big data analytics** – anomaly detection, forensic analysis (CERIT-SC project)

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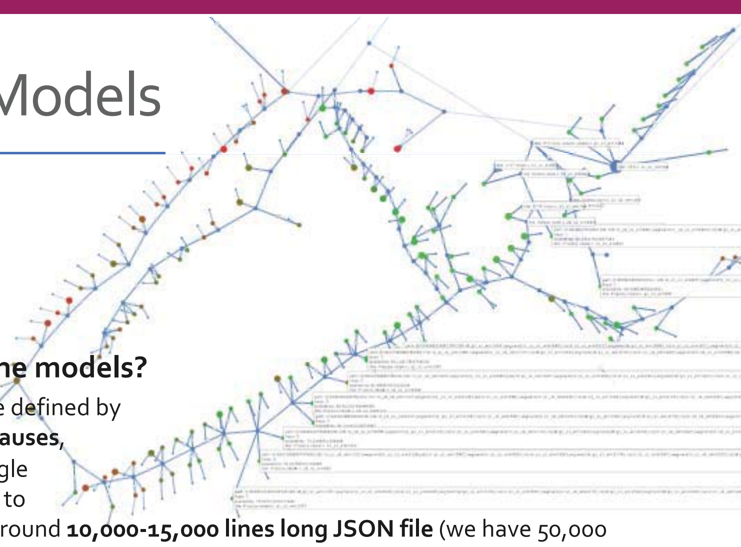
Smart Grid Models



- **Smart Grid models**
  - **Prolog** based models
  - **Grid Mind** simulation environment
- **How extensive are the models?**
  - **Size** – meta-models are defined by **thousands of prolog clauses,** model instance of a single substation area (equals to 50-100 households) is around **10,000-15,000 lines long JSON file** (we have 50,000 substations in the Czech Republic)
  - **Time** – the whole Smart Grid in a matter of **hours or days**
  - **Level of detail** - fed extensively with **technical details** (Testlab project)
  - **Scope** - now reaching till the Home Energy Management Systems (HEMS project)

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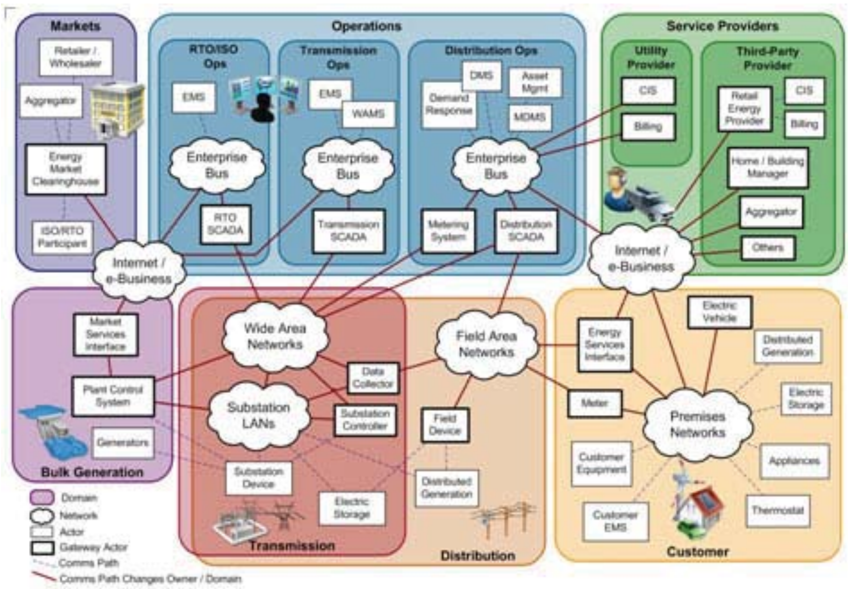
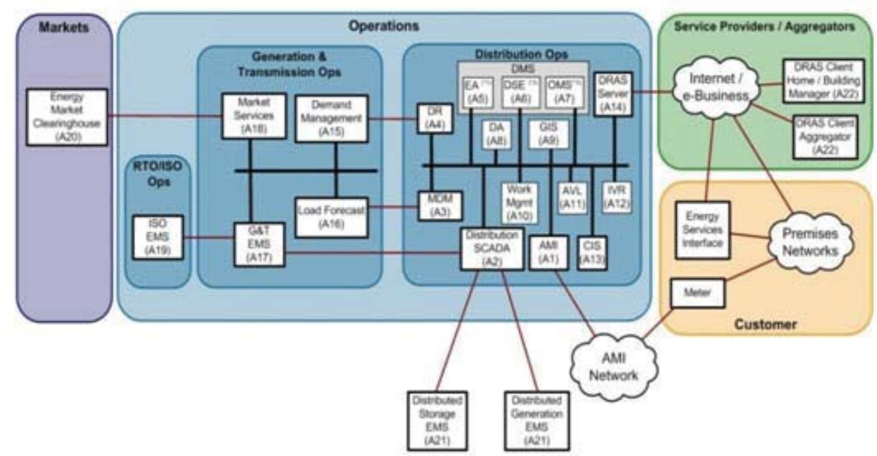
NIST Smart Grid Conceptual Model



NIST Exemplary Architecture for SG Applications

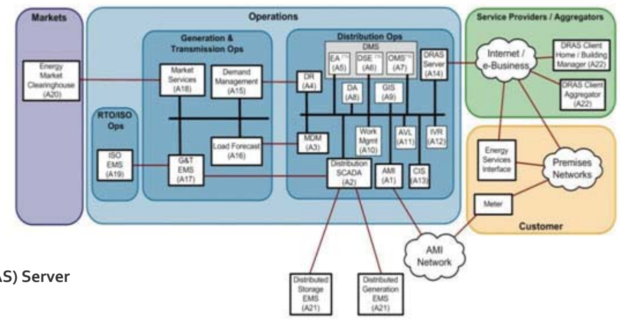


Notes

1: Engineering Analysis (planning, applications, including: topology model, facilities model, distribution power flow, optimization of feeder boundaries, and switch and capacitor placement)
2: Distribution State Estimation (real time application including: distribution operational analysis, Volt/VAr/Watt control, and multilevel feeder reconfiguration). The is not completely covered in MultiSpeak at present.
3: Outage Management System (including: fault isolation & restoration, planned outage reguest and switch orders)

NIST Exemplary Architecture for SG Applications

(A1) Advanced Metering Infrastructure (AMI)
(A2) Distribution domain Supervisory Control and Data Acquisition (SCADA)
(A3) Meter Data Management (MDM) systems
(A4) Demand Response (DR) systems
(A5) Engineering Analysis (EA)
(A6) Distribution State Estimation (DSE) systems
(A7) Outage Management System (OMS)
(A8) Distribution Automation systems
(A9) Geographic Information System (GIS)
(A10) Work Management (WM)
(A11) Automatic Vehicle Location (AVL)
(A12) Interactive Voice Response (IVR)
(A13) Customer Information System (CIS)
(A14) Demand Response Automation System (DRAS) Server
(A15) Demand Management (DM)
(A16) Load Forecast (LF)
(A17) Generation and Transmission (G&T) Energy Management System (EMS)
(A18) Market Services (MS)
(A19) Regional Transmission Operator (RTO) /Independent System Operator (ISO) Energy Management System (EMS)
(A20) Energy Market Clearinghouse
(A21) Distributed Energy Resources (DER) Energy Management System (EMS)
(A22) Demand Response Automation (DRAS) Client



Thank you for your attention!

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A Multi-Domain Approach to Design of CPS in Special Education: Issues of Evaluation and Adaptation

Maya Dimitrova, Anna Lekova, Snezhanka Kostova, Chavdar Roumenin, Milena Cherneva, Aleksandar Krastev and Ivan Chavdarov

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Abstract The paper presents a multi-domain approach to design of Cyber-Physical-Systems, especially in special education. The domains of game design for education and the control systems design are merged into the domain of novel educational technology design. The approach is tested within the recent EEA Grant project of Bulgaria and Norway "METEMSS: Methodologies and technologies for enhancing the motor and social skills of children with developmental problems". A formalized model is proposed to account for the nature and direction of the incremental game transformation based on the preferences of the individual child. The results provided statistically significant difference in the desired direction of game change. Examples with humanoid and non-humanoid educational robots are discussed with relevance to the topic of COST Action IC1404 WG3 Application Domains.

Keywords: Cyber-Physical Systems, multi-domain modeling, game design and evaluation, special education

1 Introduction

The concept of Cyber-Physical Systems (CPS) is being introduced to account for technical devices with certain adaptive, sensing and reasoning abilities with a varying degree of autonomous behavior within networked environments (briefly named Internet-of-Things) – with or without the human in the information and control loop [1, 2, 3]. Seven types of CPS are most often discussed in the working documents of the EU [4, 5] (first 7 rows of Table 1). To them 3 additional, but none less important, can be proposed as emerging and rapidly acquiring influence in present day society - under No 8-10 of Table 1.

Environmental robotics includes swarm robots, robots intended to replace bees in the field, growing robots like trees, robotic fish intended to collect the underwater pollution especially in bay areas of big cities and underwater cleaning of ship corpuses. Two such robotic systems are currently being developed under the FET Proactive funding scheme of the EC – 2015-2018: FLORA ROBOTICA and subCULTron [6].

The domain of CPS for creativity, art, social communication/media and companionship deal with the entertainment industry where robotic performance is comparable to the human one – in composing music, painting, performing music or dancing and in simulating human-to-human communication in the social media [e.g. 7, 8].

Table 1. Classification of Cyber-Physical Systems

No	Cyber-Physical Systems
1.	Disabled People
2.	Healthcare
3.	Agriculture & Food Supply
4.	Manufacturing
5.	Energy & Critical Infrastructures
6.	Transport & Logistics
7.	Community Security & Safety
8.	*Environmental Robotics*
9.	*Creativity, Art, Social Communication/media and Companionship*
10.	***Education & Pedagogical Rehabilitation***

The education & pedagogical rehabilitation frameworks have emerged recently but have been employed widely for implementing information and robotic technology in clinics and special education [e.g. 9, 10, 11]. A promising case is the Wizard of Oz experimental framework for the analysis of the human response to the performance of the robot [12].

We witness the emergence of a new ontology, so-called 'rob-ontology' with a special application domain being education. Currently robots are being used as part of the subject "informatics" (i.e. computer science) or in extra-curriculum lessons. Our view is that the moment of introducing robots at school is late – at the age of 12 or older - whereas almost all above mentioned robotic systems and platforms are designed for little children. If we populate the child's environment with robots from the age of 3, this will help feel comfortable with technology from a very early age, very much in the same way as smartphones and laptops have already done. This will also open workplace for technicians, engineers, software developers and multidisciplinary teams, including psychologists and special education teachers, at kindergarden and school and will give examples of highly skilled jobs to the children. The educators will learn technical and programming skills to operate the robotic platforms.

The robots will assist the teachers in the process by exhibiting cognitive and social skills in an amusing learning environment. The process of implementing robotic technology at school is to be gradual – from simple to more complex behaviors of the robot. The schools that decide not to implement robotics will be at disadvantage with the others, so **legal regulation** will be necessary to **promote** the new trend with using robot assistants to the teacher. Parents can be informed and attracted to the idea by pointing out the possibilities that robots can demonstrate regarding shaping their children's interests.

In general, all these 10 groups of CPS encompass the large, domain specific developments of robotic systems that are implemented in practice to this moment or are currently being designed. But in terms of the internal ontological specificity of the CPS, or the robots under consideration, the following taxonomy/categorization of robots is proposed along the dimension of the level of involvement of the human in defining, controlling or predicting the behavior of the robot from the lowest human involvement to the highest: **Autonomous CPS, Semi-autonomous CPS** and **Assistive CPS**. The latter are technological platforms (networked software and hardware, e.g. Aldebaran's NAO [13]) for design of scenarios of robot behavior. The main applications of the assistive CPS are: education, pedagogical rehabilitation, mental health, playing games, socializing (as well as in other domains).

One possible application of assistive CPS is presented further in the present paper. The domains of game design for education and the control system design are merged into the domain of novel educational technology design (Fig. 1).

Fig. 1. Multi-domain approach towards the process of game design in special education

The approach is implemented within the recent EEA Grant project of Bulgaria and Norway "METEMSS: Methodologies and technologies for enhancing the motor and social skills of children with developmental problems" (2015-2016) [14].

2 A Formal Model of the Design Process of Assistive CPS in Special Education

The proposed evolving design of games for children with special needs describes the transition from one experiment in real-life conditions to another, not just from pilot to real-life testing, which is the main specificity of the current approach. The pilot testing in the laboratory is denoted as Experiment 0 in Fig. 2.

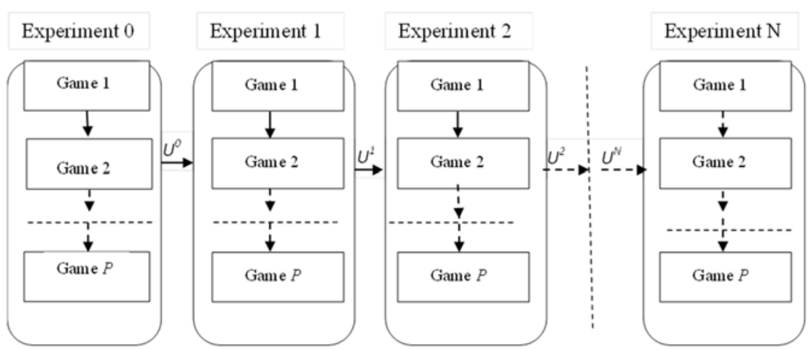

Fig. 2. A systems approach to the representation of the process of game testing in the evolving design framework

Consider the process of training motor and social skills of children using evolving game design. Children play games consecutively, either individually, or in groups (figure 2). The assessment of the game is made based on the set of averaged scores given by the teachers at the end of each game and at the end of each experiment along several game dimensions. After each experiment and in case of unsatisfactory result, improvements are being made in the games. These improvements in the games after each experiment are considered the manipulated process variables in terms of the control vector $\boldsymbol{U^k}$.

$$\boldsymbol{U^k} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \in \boldsymbol{\mathcal{R}^2},\ k = 1,2,\dots,\ N \quad (1)$$

is a 2-dimensional vector representing 2 types of possible improvements of the games after the k-th experiment, $k = 1,2,\dots, N$:
- adding a new function/functionality to the game - u_1;
- adding new elements to the construction of the game - u_2.
The process terminates when the game has no further capacity for improvement.

Let's denote the state after the *i*-th game from k-th experiment by $\boldsymbol{x(Game_i^k)}$. After completion of the k-th experiment, if the result is not satisfactory from a designer point of view, we make improvements in the games. The improvements can be of both types **-** u_1, u_2 **-** from the described above, or only one, in the opinion of the experts. These improvements are assumed the control actions on the process of enhancing the trained skills of children, playing the games, within the proposed model. Therefore, the initial value of the *k*+1-st experiment is determined by a non-homogeneous linear system described by

$$\boldsymbol{x}(\boldsymbol{Game_1^{k+1}}) = \boldsymbol{x}(\boldsymbol{Game_P^k}) + \boldsymbol{BU^k},\ k = 1,2,\dots,N, \qquad (2)$$

where $\boldsymbol{U^k}$ is the control variable from the k-th to k+1-st experiment.

Matrix $\boldsymbol{B} \in \boldsymbol{\mathcal{R}^{m\times 2}}$ consists of coefficients, reflecting the individual *m* number of skills of the participating children, as described by their teachers in the children's profiles. The detailed description of the model is presented in [15].

3 Types of Games Included in the Evolving Game Design Framework

The developed games within the METEMSS framework are intended for use in motor, cognitive and social skills training. Games of type I use Kinect sensor for 3D interaction within a virtual environment via gestures (Fig. 3).

Fig. 3. A child, playing game called "Flipper", hitting virtual balls to reach a target on the screen

Type II are games with humanoid robot NAO. The interaction with a humanoid robot is always very emotional (Fig. 4, right).

Fig. 4. A child playing basketball with NAO humanoid robot.

Type III are games with nonhumanoid robots – "Minion" doll with robotic arm (figure 5) and a walking robot called BigFoot (figure 6). The CPS implementing non-humanoid robots were designed at ISER-BAS especially for the project METEMSS with the assistance of the Departments of Medico-social sciences and Logopedics of the South West University, Bulgaria.

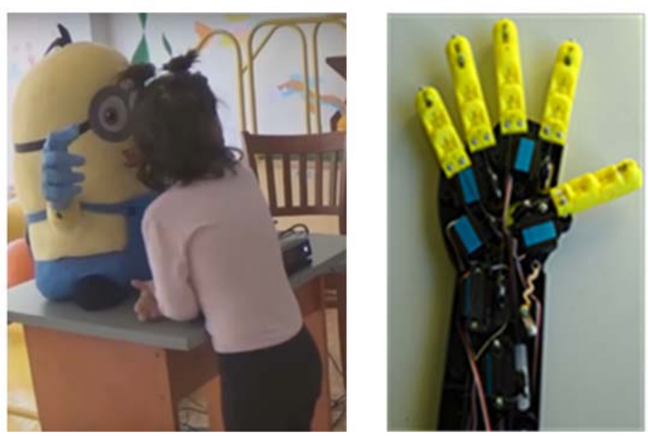

Fig. 5. A Minion doll with anthropomorphic robotic hand

A Minion doll was equipped with an anthropomorphic robotic hand designed with 3D printing technology and controlled by a Kinect sensor (Fig. 5, right). The doll imitates the gestures of the child. As a reward, a song is played when the child is attentive to the game. The observed effect was of assisting the development of the social skills via the robotic technology – both humanoid and non-humanoid by creating an entertaining and amusing environment in the special school [16].

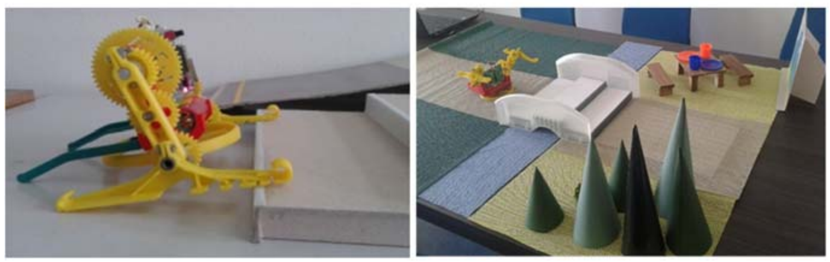

Fig.6 . Remotely controlled non-humanoid robot BigFoot in an imaginary environment

The walking robot BigFoot was placed in a social context – in a scene with buildings, trees, animals - and the task of the children was to remotely control its movements left-right, up-down, to reach a certain goal. It trains learning of colors, shapes and directions (figure 7).

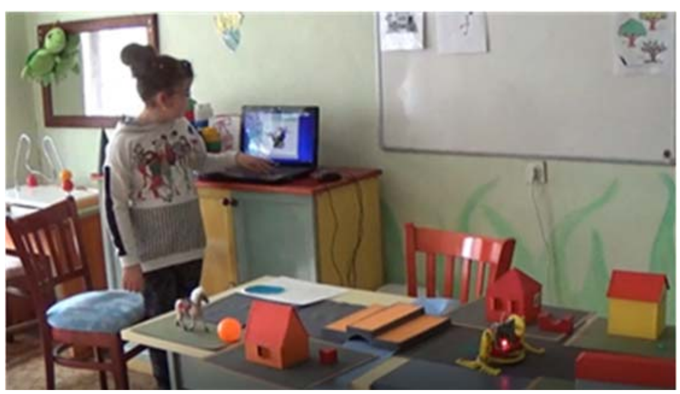

Fig. 7. A child remotely controlling the movement of the walking robot BigFoot

We have called the approach *Evolving design* of games for children with special learning needs. It consists of the following steps:

- Conducting Experiment 0 in the laboratory (piloting);
- Conducting Experiment 1 in real life settings;

- Analysis and recommendations for evolution of the game design;
- Game modifications;
- Conducting Experiment 2 in real life settings;
- Evaluation of the change in *quantitative* terms.

Examples of the proposed game modifications between 2 successive experiments as elements of vector $\mathbf{U}^k$ are the following. Changing the interface of a game is an example of u_1. The laptop from Fig. 6 was replaced with a joystick, so that the robot and its control are within the eye view of the child. Example of u_2 is adding a constructive element in the game (adding a holding platform to the Walking robot) as presented in Fig. 8, following the child's request.

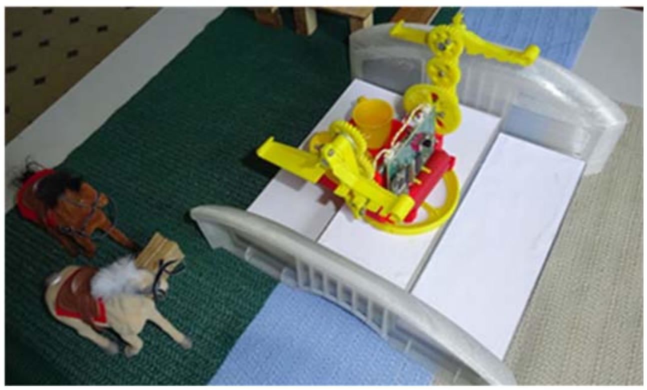

Fig. 8. Adding a holding platform to the Walking robot from Experiment 1 to Experiment 2

Adding a holding platform to the Walking robot on child's request makes the game design participative.

4 Issues of Evaluation and Adaptation: Main Hypotheses

The main hypotheses for the quantitative comparison of the games were the following:

H1. Games with bigger change in their design from experiment 1 to experiment 2 will be given scores by the teachers in the expected direction for positive change.

H2. Games with overall positive scores for improved design will score positively for both *motivation* and *interest* of the children.

In total 73 filled in questionnaires were collected from the teachers in both experiments. These consisted in 9 Likert scales along dimensions like "role for cognitive/social/motor development", "interest of the child", "motivating role of the game", etc. [15]. Four of the games produced subsequent testing according of the model and were used to validate the hypotheses - „Flipper", „Forms and Shapes", „Walking Robot BigFoot" and „Minion Doll with Robotic Hand". These 4 games were used to test hypotheses 1 and 2.

The results regarding H1 were the following: The 2-factor ANOVA did not reveal main effect of the factor "Game", nor of the factor "Experiment", however revealed significant interaction between the factors, $F(3, 56) = 3.70$, $p = 0.017$, which was expected, meaning that scores of games behaved differently in different conditions. The overall scores of the teachers of the games Walking Robot and Minion Doll were higher after experiment 2 in comparison with experiment 1, unlike the other 2 games, therefore supporting H1.

The results regarding H2 were the following: Two-way ANOVA did not reveal main effect of game on the scores and no interaction, but revealed main effect of Experiment for the games Walking Robot BigFoot and Minion Doll with Robotic Hand, in teacher's assessment of children's interest and motivation, $F(1, 28) = 4.77$, $p = 0.038$. Both evaluations of children's *motivation* and *interest* in the modified games after experiment 2 were significantly higher for these 2 games than after experiment 1, therefore supporting hypothesis 2.

5 Conclusion

The proposed system model for evaluation of the process of design of games is an effective instrument of the evolving design of games for children with special needs. The evolving design describing the transition from one experiment in real-life conditions to another, not just from pilot to real-life testing, is the main specificity of the current approach. It can be applied to predict the direction of game evolution in quantitative terms. The attitudes of the children towards the modified games are well reflected in the teachers' scores along several dimensions. The multi-domain approach is applicable in other educational scenarios and fulfills the role of bringing technology closer to children and assisting the teachers in their profession.

Acknowledgments This work was supported in part by the Financial Mechanism of EEA under Grant D03-90/15.05.2015 for project "METEMSS: Methodologies and technologies for enhancing the motor and social skills of children with developmental problems" of Bulgaria and Norway (2015-2016).

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COST Action IC1404 MPM4CPS

RTU ENERĢĒTIKAS UN ELEKTROTEHNIKAS FAKULTĀTE

How to exploit an experience gained in PCS related projects for master students training program in ERASMUS+ project?

Riga Technical University

A. Zabašta, N.Kuņicina, O.Nikiforova, A.Romanovs

Malaga, Spain October 24–25th 2016

Agenda

- Automation challenges and Arrowhead project approach
- A model of utilities systems control and practical implementation of System of systems
- Students training program in ERASMUS+: experience and ideas

Arrowhead approaches

Arrowhead: Process and energy system automation

- 4 years project
- 68M€
- 79 partners
- Coordinated by ARTEMIS Centres of Innovation Excellence (CoIEs)

- Riga Technical University together with Smart Meter ltd (SME)

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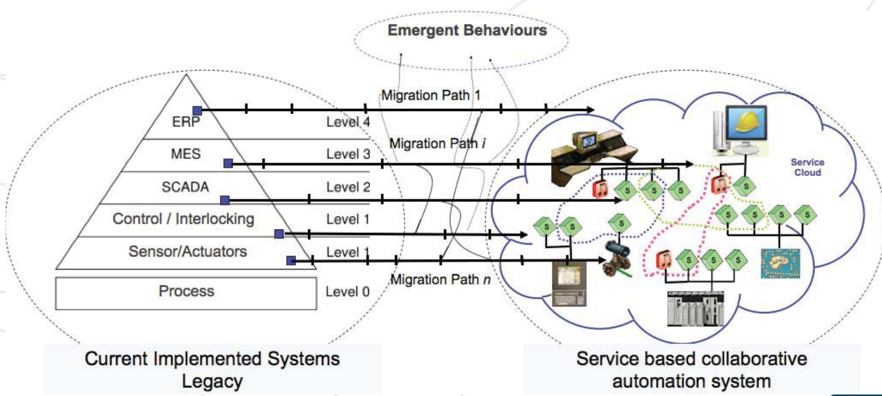
ARROWHEAD

ISA-95 systems in to the cloud?



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What's in the works Arrowhead

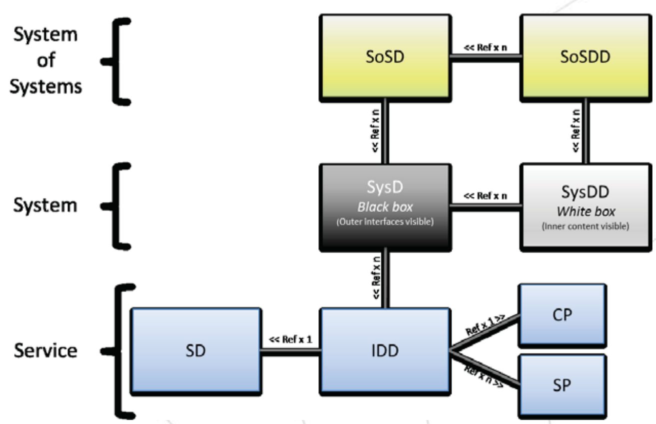
5

- Automation cloud integration technology - SOA based
  - Interoperability at service level across suppliers and technologies
  - Technology translation
  - Integration to legacy technology
  - Development support, documentation, training
  - Development tools
  - Test tools
  - Open source working examples
  - Commercial actors offering products

ARROWHEAD

Engineering tools for cloud automation systems development support, documentation

6



SoSD: System-of-Systems Description
SoSDD: System of Systems Design Description
SysD: System Description
SysDD: System Design Description
SD: Service Description
IDD: Interface Design Description
CP: Communication Profile
SP: Semantic Profile

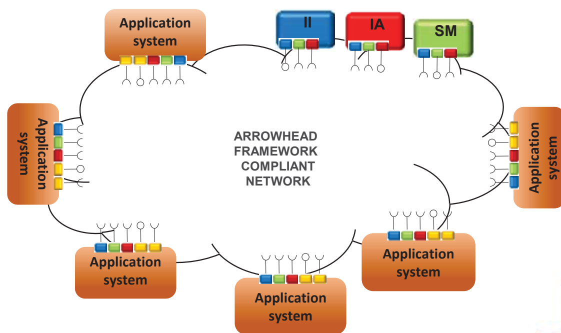
ARROWHEAD

Arrowhead Framework - support for: System of systems in a local cloud

7

- System of systems SoS, approach
- Information provided as a configurable services
- Orchestration of services possible and feasible with complex event processing

- Mandatory core systems:
  - Information infrastructure
  - System management
  - Information assurance



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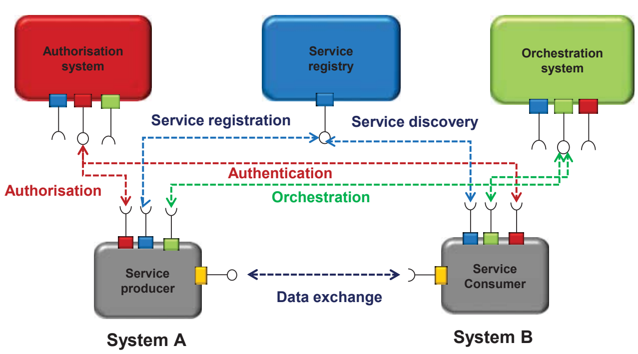
SOA implementation according to Arrowhead approach



The purpose is to enable the different application systems in an easy and flexible way being able to collaborate successfully due to support provided by the common core services.

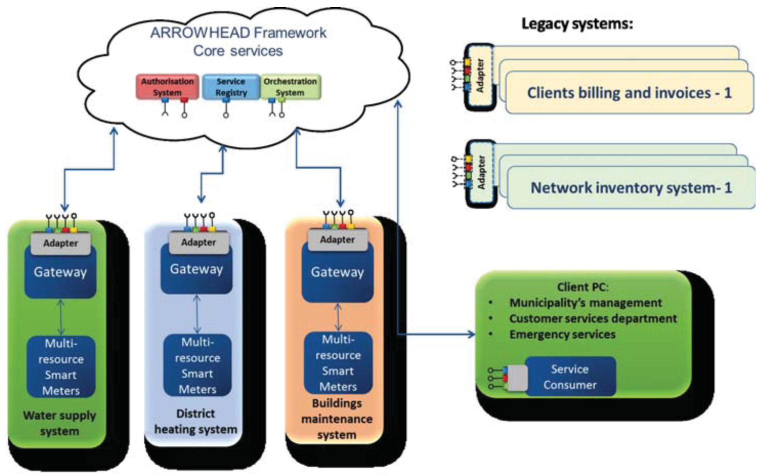
The problem issues of utilities networks maintenance

- Each utility maintains its own network of meters and sensors, own system for data collection and storage, separate customer service, inventory, bookkeeping, billing and etc.
- The majority of the systems are obsolete and incompatible.
- Development of sensor network for monitoring and control and its maintenance is a challenging process due to plenty of human work.

The tasks

- To provide an evidence of a practical implementation of public utility's network automated monitoring system, which complies with Arrowhead framework approach:
  - Development of SOA based application services as web services applying most suitable IEC standards.
  - A modular technical solution for sensors, and gateway nodes.
  - Develop a concept of common core services for the cloud of public utilities systems.

Arrowhead view of utilities automation cloud



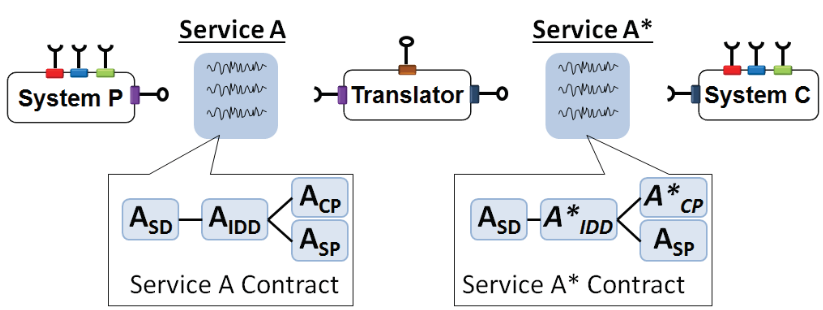
Interoperability

12

The project team investigated protocols to make machine assisted translation like:

- CoAP <-> XMPP <-> MQTT <-> OPC-UA <-> REST and so on
- Service integrity over protocols, data structures, semantics etc.

- Current status: REST - CoAP - MQTT - JASON



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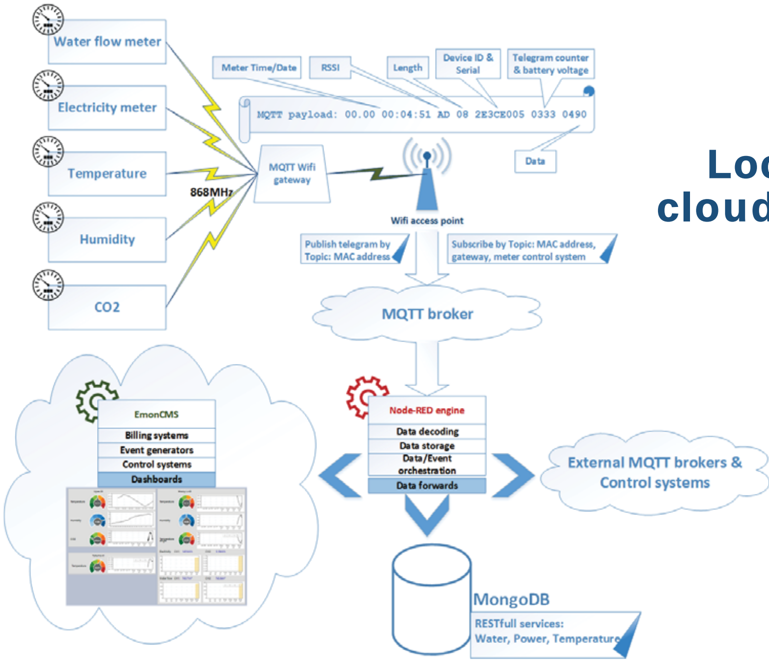
Hasan Derhamy, Pal Varga, Jens Eliasson, Jerker Delsing and Pablo Punal Pereira
Translation Error Handling for Multi-Protocol SOA Systems, ETFA 2015, Luxembourg

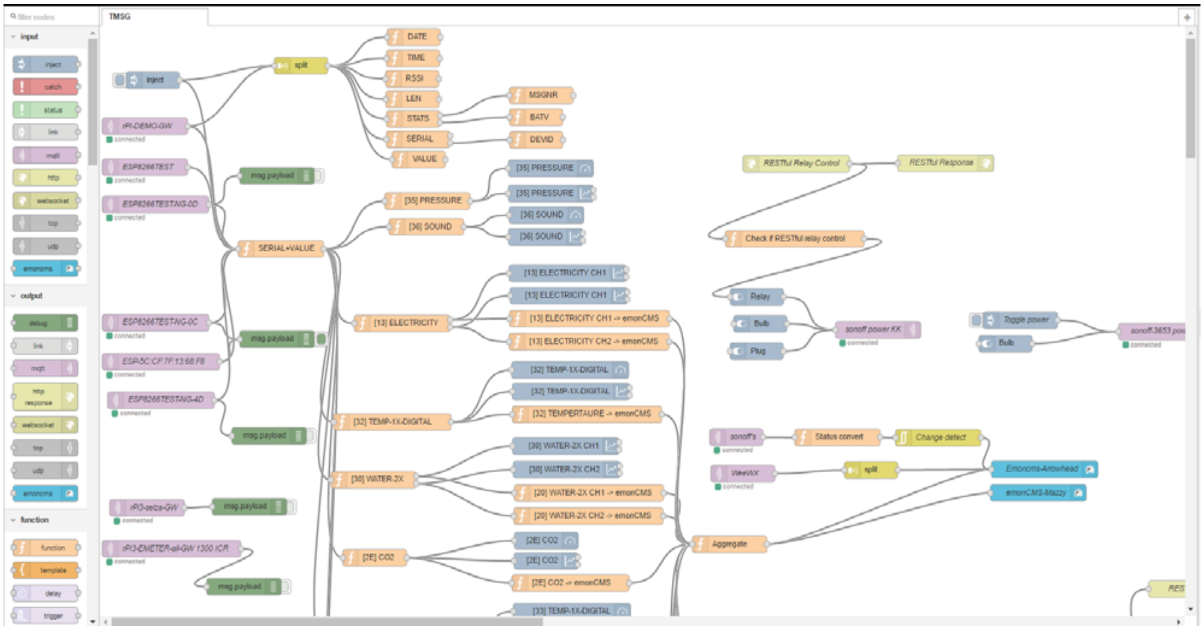
ARROWHEAD



Local automation cloud implementation

System architecture

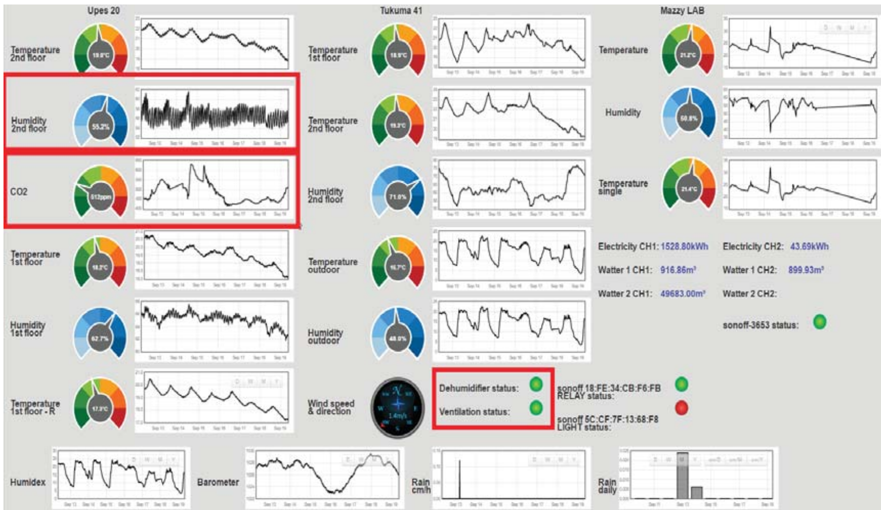
- SoS enables core services: service registry, orchestration and authorization
- Node-Red main functionality is
  - to decode and to route MQTT smart metering data to further service orchestration
  - or use in external services as customer billing or monitoring systems.
- Node-Red is an open source visual editor for wiring the internet of things
- EmonCMS is an open-source web application for processing, logging and visualising energy, temperature and other environmental data and is part of the Open Energy Monitor project.
- Multiple operations are implemented to decode the payload and forward it to a data storage and visualization service using the IoT approach



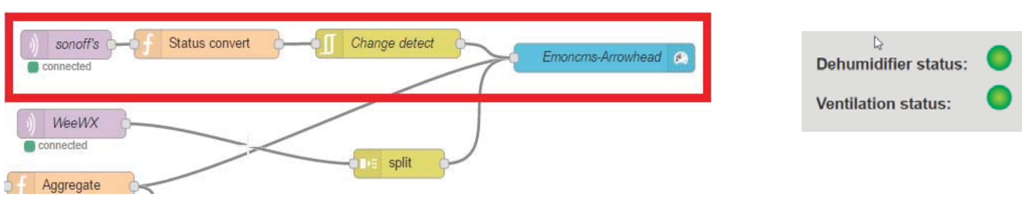
Services for third party control application

- Dashboard has been created to visualize different sensor feeds.
- A third party control application has been selected do demonstrates IoT system intercommunication using other independent service providers.
- For the purpose of demonstration a power relay Sonoff from ITEAD was used
- For the demo application two systems are controlled a ventilator with regeneration system and a dehumidifier
- Sonoff Wi-Fi enabled relay is able to communicate using MQTT or CoAP protocols with are of interest in the scope of the demo application.
- EmonCMS is used as the Orchestration service by:
  - processing incoming data feeds and triggering response events
  - or providing response streams for controlling external applications
  - or providing new data as status
  - or combining measurement results.

An example of service humidity control



An example of service humidity control



1. The application logic receives periodic MQTT messages that after decoding are injected into EmonCMS inputs
2. Upon state change Sonoff devices publish a status topic and message. This data is processed by the broker system and equipment status data is fed back into EmonCMS for bidirectional monitoring.
3. The status of the relays and the controlled equipment is visualized in EmonCMS dashboard (the green indicator id On, red is Off).
4. Sonoff relay handles the status published topic devices.
5. Status convert node – extracts the MAC address and builds a new MQTT message.
6. Change detect node – blocks repeat MQTT messages an allow the flow only if the last message topic and payload differ from the previous.

Conclusions and next steps

- **Conclusion**
  - We analysed protocols used for industrial automation that can be applied for utilities network control.
  - We applied an Arrowhead approach for creating a model view of utilities networks control System of Systems
  - We piloted a concept of sharing of application services among public utilities.
  - We applied MQTT broker as protocol adaptor when MQTT messages are being pre-processed using Node-RED a tool for compatibility .
- **Constrains**
  - The challenge still is services provision to municipality's legacy systems
- **Further plans**
  - The research team will look for the most efficient way of different protocols translation across the systems taking into account that a majority of utility systems apply metering devices with appropriate protocols and interfaces.

Erasmus+

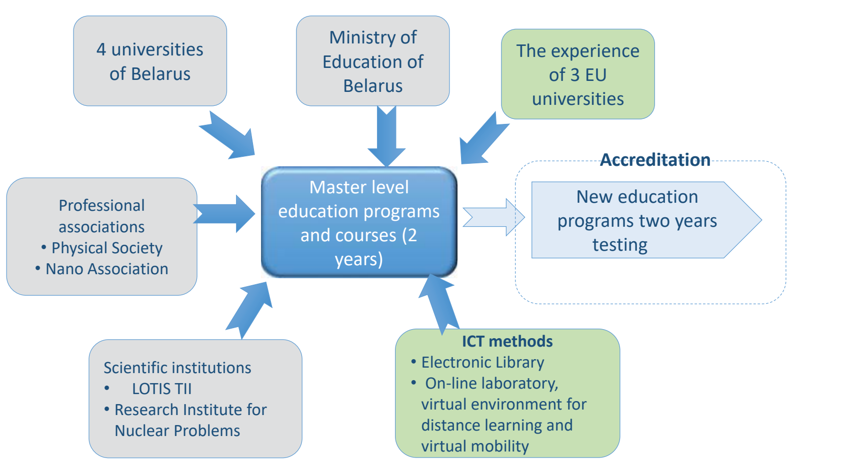
Analysis of the survey of master graduates employers

(within the framework of the project "Physics" Erasmus + EU)

Short description ERASMUS+ Physics

- Project implementation: 15th October 2015 – 14th October 2018
- Participants 10 partners from 4 countries
- RTU is a Leading partner
- The project total budget: EU Grant 660 576 euro, co-financing 67 270 euro.
- **The target is** to upgrade master-level education in the field of applied physics in four universities of Belarus according to Bologna practices, to enhance the quality and relevance of education in respect to the labour market needs

Project idea



What is the survey about?

Inspiration:

5 + 1 → 4 + 2

Expected results:

- Pooling ideas how to form the 2-year industry-oriented master-level education
- Figuring out what potential employers think about qualification requirements for graduates of practice-oriented masterships
- Identifying training requirements to graduates of masterships for the "4 + 2" system
- Defining of the need and requirements for the organization of master students internships

Who was interviewed?

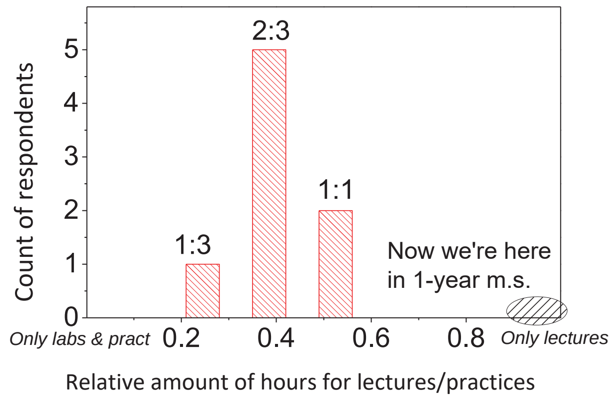
List of participants:

- Belarusian universities
- BSU departments of Semiconductor physics, Laser physics, Energy physics
- Research Institute for Nuclear Problems of BSU
- Belarusian Physical Society
- Republic Association of Nano Industry

The curriculum discussion

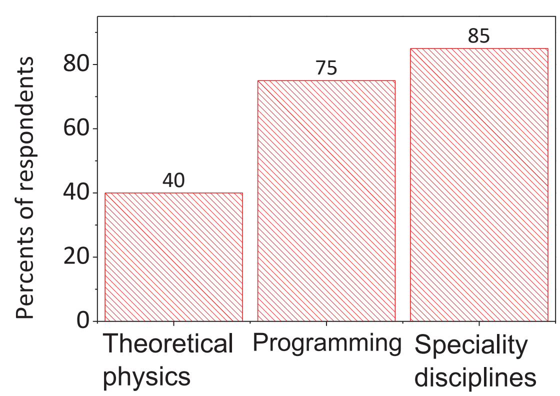
Ratio between time for lectures/labs and practices:

What should be the ratio of theoretical/practical training of master-students in the university, research institute or company?



The curriculum discussion

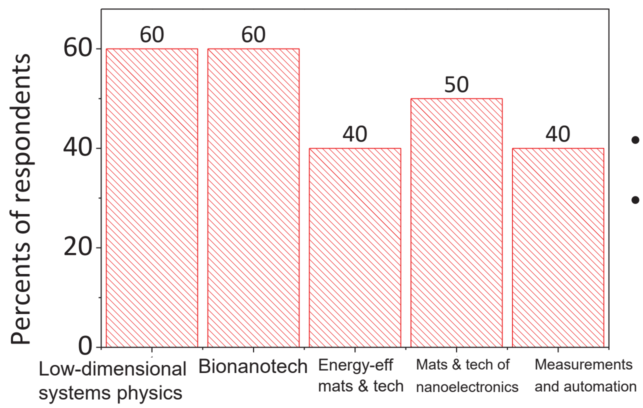
Most mentioned common preferred topics of subjects



Majority of respondents noted the importance of the mastering the principles of modern high-tech equipment work and exploitation

The curriculum discussion

Most mentioned specific subjects



Where is 70% for programming?

- Automation and microprocessors?
- Computer-related math and tools for scientific computation?

Training and work in company

How much time does it take to make student able to work "self-sufficiently" in company?

- For 16-18 weeks (the period of internship at the first stage of higher education) at the place of future work except of RANI answer: "Up to 1 year".

What do you think can be improved in the educational process to reduce this time?

- It is recommended to enhance the fundamental training of master-students in physical and mathematical disciplines and improve their general skills, reducing the time dedicated to humanitarian disciplines.

To which percent of master-level graduates company can offer to stay on a permanent job after practice?

- Respondents indicated that about 50-80 % of master-level undergraduates can stay after practice on a permanent job.

Conclusions

It is reasonable:

- Think how to keep balance of internship in "4+2" and "5+1" and prepare the labor market
  - ❑ At least need to be sure that employers are informed about additional intership weeks needed to make worker self-sufficient

- Consider the recommendations for MS curricula:
  - ❑ Increase the amount of special disciplines and various types of programming
  - ❑ Introduce courses dedicated to nano and biotechnology
  - ❑ Proportion of theoretical and practical training for master-level students is recommended from 1/3 to 2/3.

Inspiration for the next steps

From the COST action defined tacks:

- To identify the adequate profile(s) of CPS experts
- Set the base for an European Master/PhD Program in MPM4CPS involving several European leading Universities
- Promote literature on the topic, while defining course material

Beyond the COST action to initiate the next steps, e.g. ERASMUS+ project:

- Benefits to EU universities:
  - Practical steps to develop and to test courses and training programs
  - Opportunity to finance the creation of training materials
  - Dissemination and exploitation beyond the COST action
  - Opportunity to select motivated students from EU Partner countries

Thank you for your attention!

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