SAVI Behavior Model Integration Virtual Integration Process

David Redman, AVSI
Texas A&M University

GLOBAL PRODUCT DATA INTEROPERABILITY SUMMIT 2015

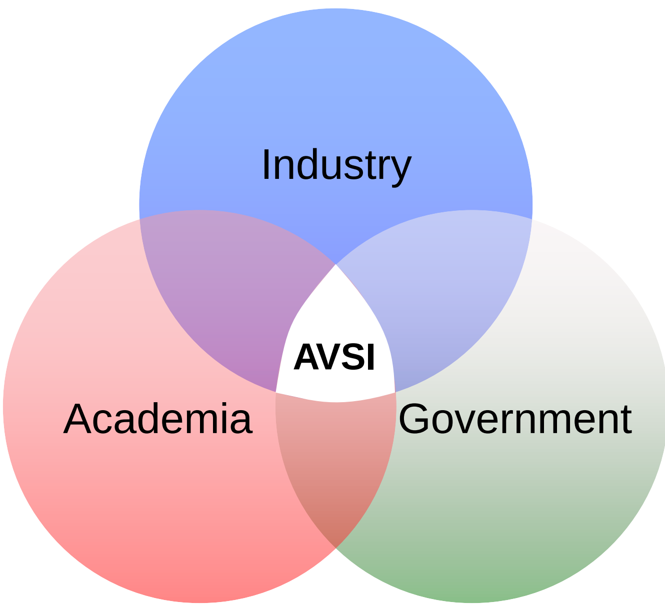
Outline

- **AVSI**
- **SAVI Motivation**
- **SAVI Program History**
- **SAVI Behavior Modeling**
- **Summary**

AVSI Facilitates Cooperative Research

MISSION

AVSI addresses issues that impact the aerospace community through international cooperative research and collaboration conducted by industry, government and academia.



- *Contribute to **standards** and **policies***
- *Establish the **environment** that **enables collaboration** and sharing of costs*
- *Create an **aerospace industry voice***

AVSI Membership Represents the Industry

Full Members

- Airbus
- Boeing
- DoD
- Airbus Group
- Embraer
- GE Aviation
- Honeywell
- Rockwell Collins
- Rolls Royce
- Saab
- United Technologies

Liaison Members

- FAA
- NASA
- Aerospace Valley
- SEI

Associate Members

- ATI Wah-Chang
- BAE Systems
- Rafael D. S.
- SAES-Getters
- Foresite
- Raytheon
- HARCO Labs

Current membership includes a cross-section of aerospace industry stakeholders, including aircraft producers, system suppliers, regulatory bodies, government and trade organizations, and academia.

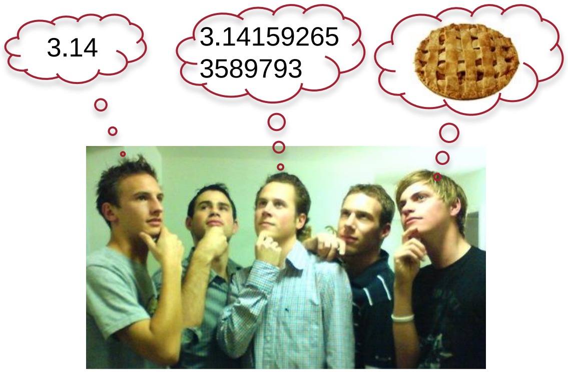
Everyone Knows the Problems…

Increasing System Complexity

Complex Development Environments

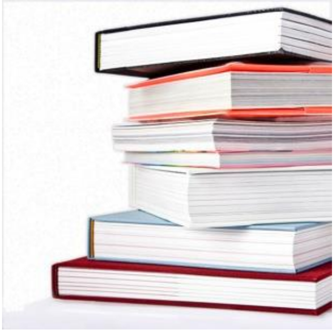
src: http://en.wikipedia.org/wiki/File:Gravis_UltraSound_PNP.jpg

“pi”



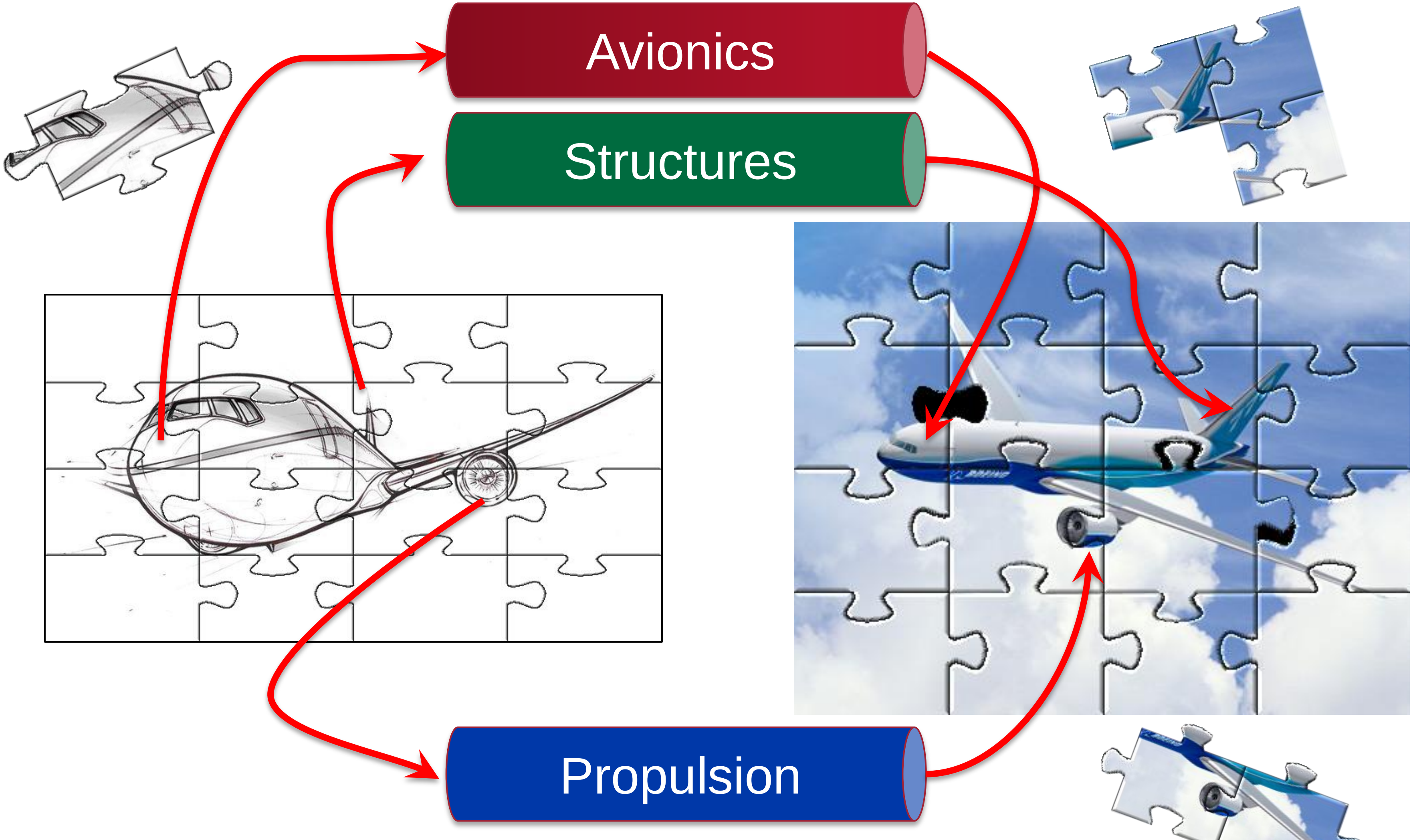
Mismatched Assumptions

Siloed Organizations



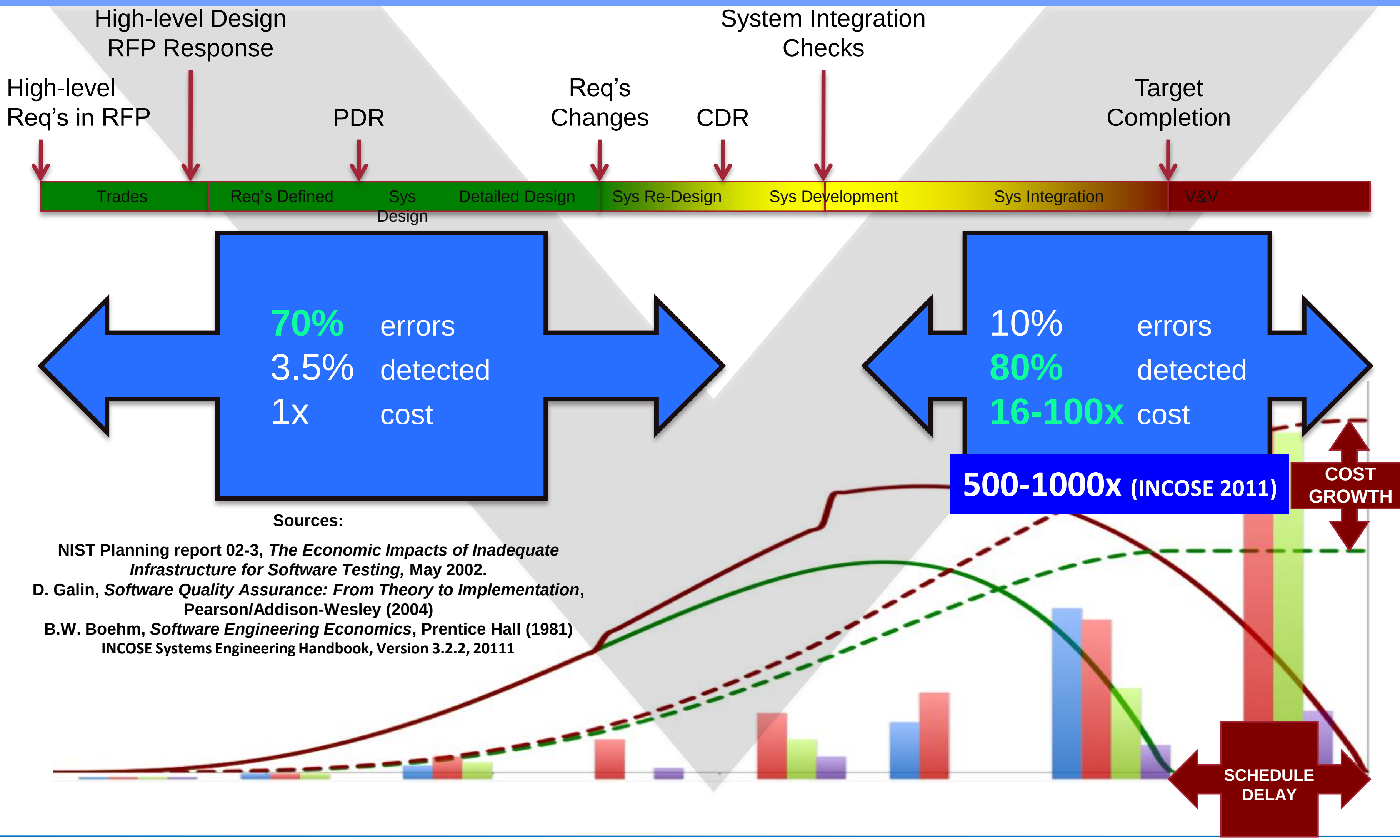
Written Requirements

We Start Integrated, But Don't Stay Integrated



The Impact is Documented

Global Product Data Interoperability Summit | **2015**



Sources:

NIST Planning report 02-3, ***The Economic Impacts of Inadequate Infrastructure for Software Testing***, **May 2002.**
D. Galin, ***Software Quality Assurance: From Theory to Implementation***, **Pearson/Addison-Wesley (2004)**
B.W. Boehm, ***Software Engineering Economics***, **Prentice Hall (1981)**
INCOSE Systems Engineering Handbook, Version 3.2.2, 20111

GLOBAL PRODUCT DATA INTEROPERABILITY SUMMIT 2015

The Problem Affects Everyone

- **Integration complexity will continue to increase**
- **Current solutions are insufficient**
- **Individual companies cannot solve it alone**
- **Industry cannot afford to solve it multiple times**
- **We can't afford not to solve it**

A coordinated, industry-wide effort is needed to solve this issue.

The AVSI Systems Architecture Virtual Integration Project

Full Members
- Airbus
- Boeing
- DoD
- Embraer
- GE Aviation
- Honeywell
- Rockwell Collins
- United Technologies

Liaison Members
- FAA
- NASA
- SEI

Tool Vendor Partners
- Adventium Labs
- Esterel Technologies
- Eurostep Limited

SAVI Goals and Approach

- **Reduce costs/development time through early and continuous model-based virtual integration**
  - **Distributed inter-domain/inter-model consistency checks throughout development - (start integrated, stay integrated)**
  - **Protect intellectual property (IP)**
  - **Capture incremental evidence for safety analysis and for certification Approach**
- **Capture Requirements and Use Cases that define the following:**
  - **SAVI Data Exchange Layer**
  - **SAVI Model Repository**
  - **SAVI Virtual Integration Process**
  - **SAVI distributed inter-domain/inter-model dependencies and consistency checks**

One Model To Rule Them All

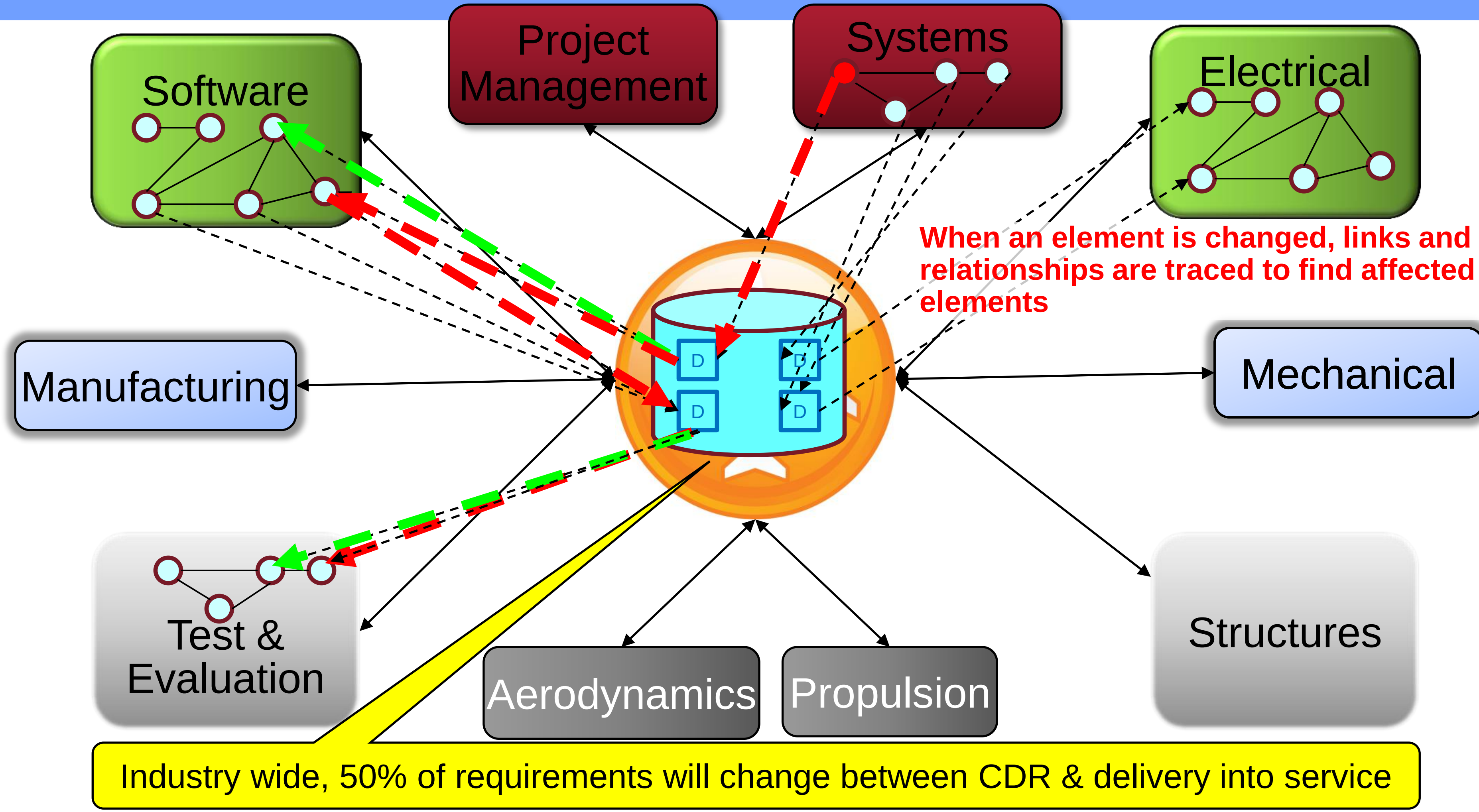
A Fellowship is More Practical

M/ECAD **Simulink** **Modelica** **AADL** **Excel**

Structure **Behavior** **Requirements** **Parametrics**

SysML

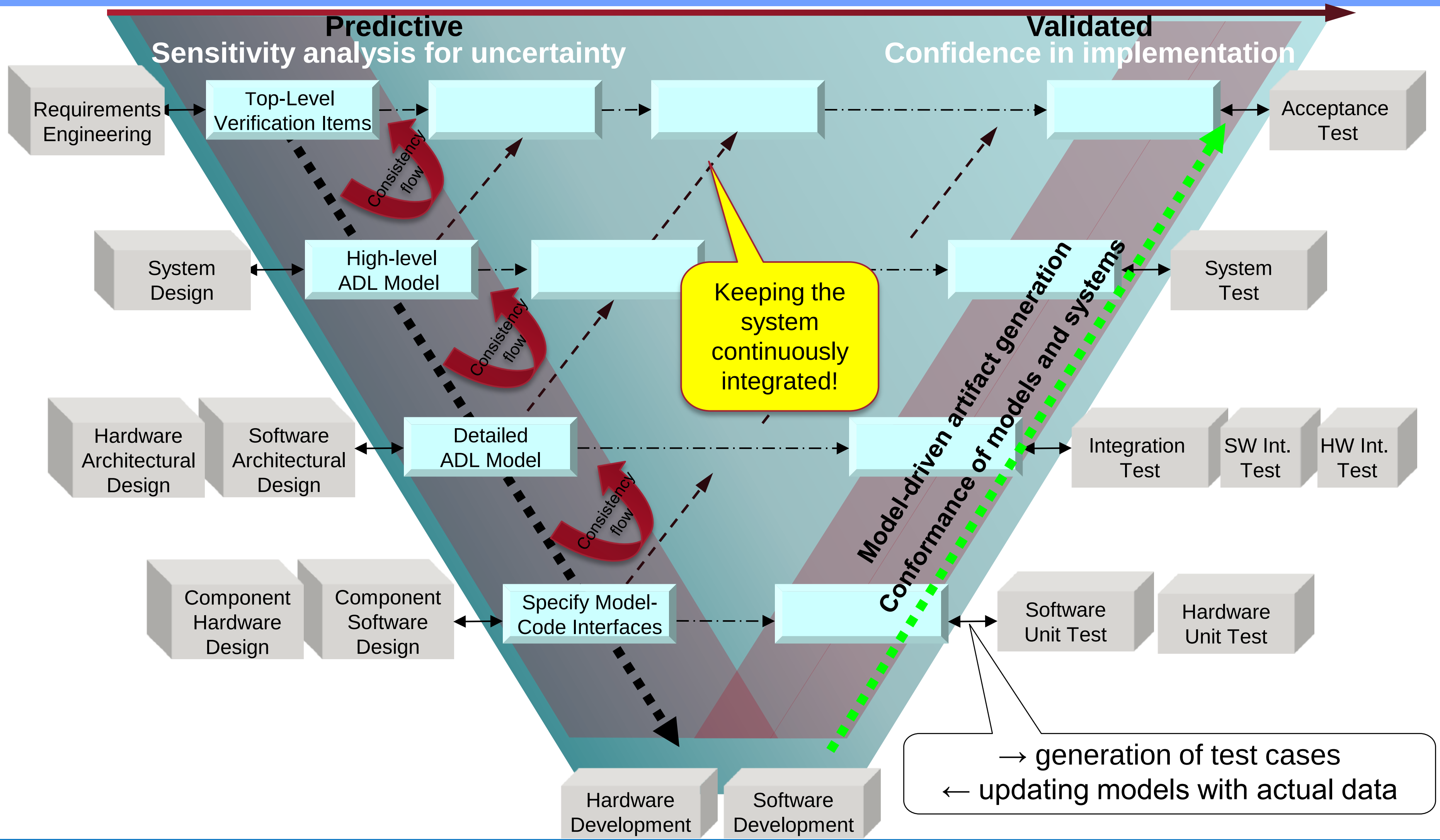
Dependencies Are Key



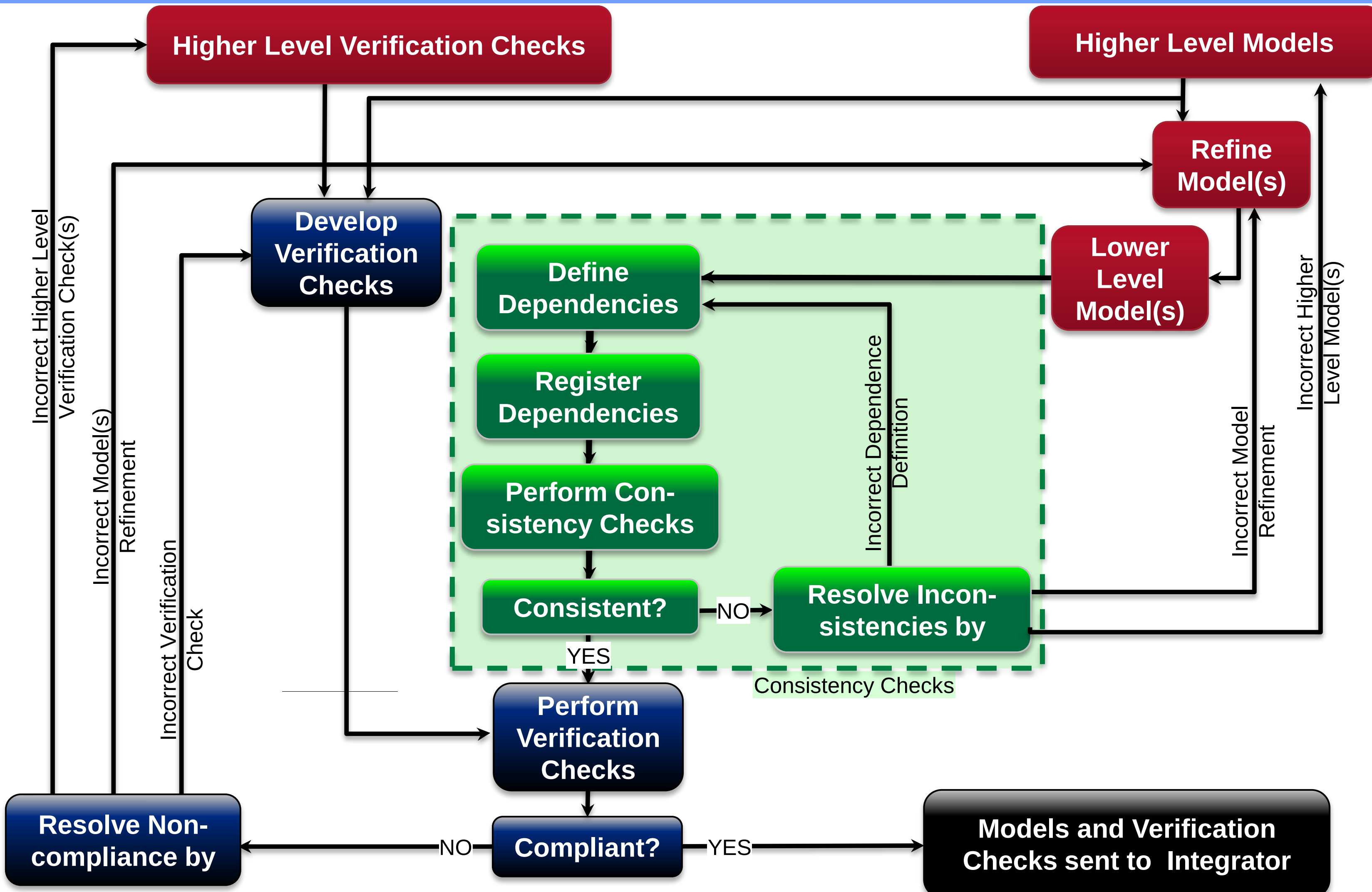
- **The SAVI Repository stores the links**

SAVI Virtual Integration "Vee"

Global Product Data Interoperability Summit | **2015**

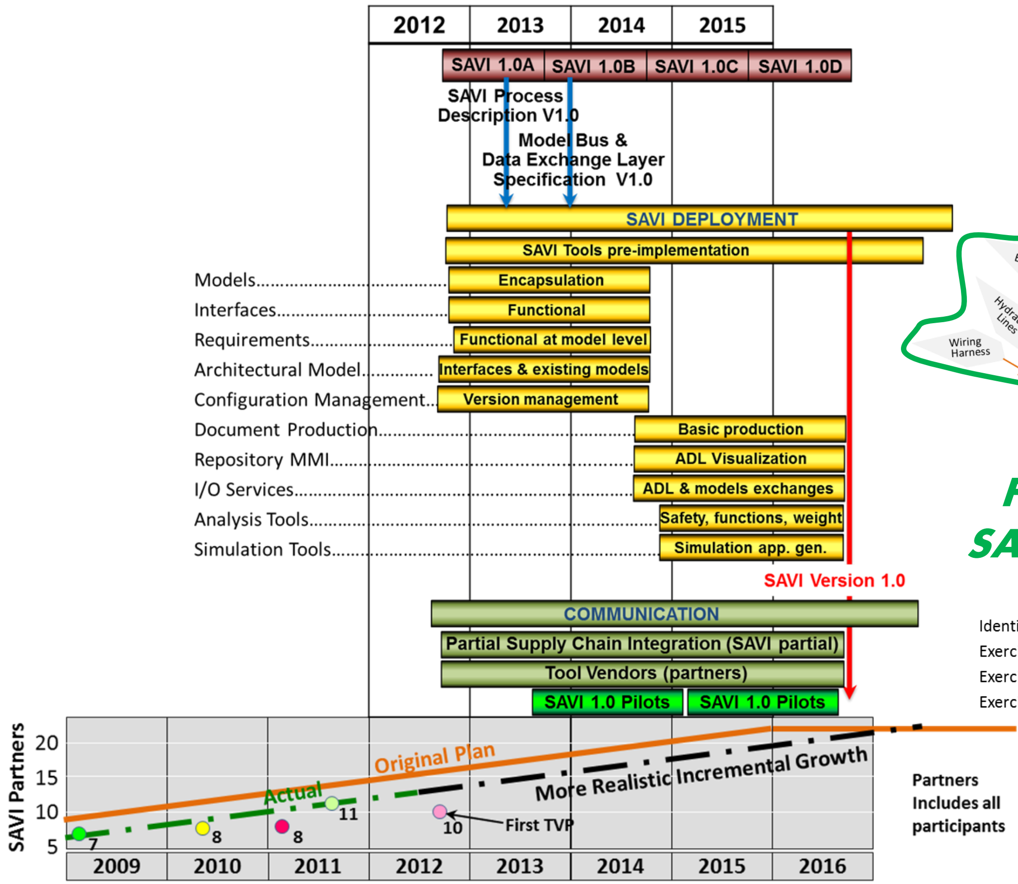


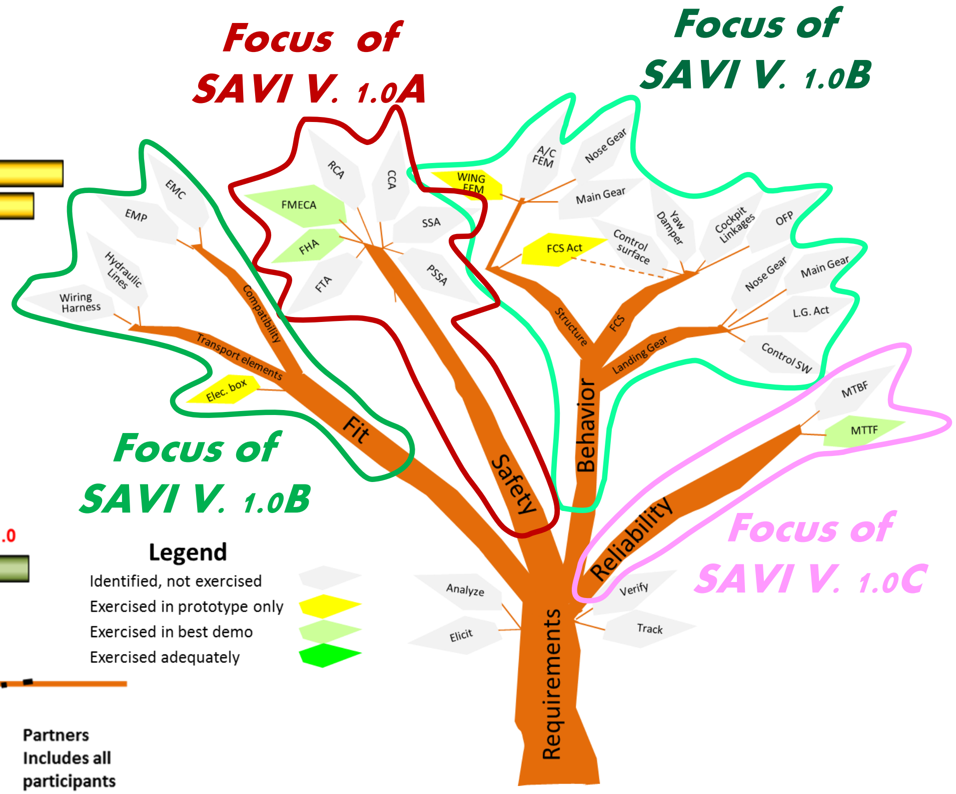
SAVI VIP


Higher Level Verification Checks
Higher Level Models
Refine Model(s)
Develop Verification Checks
Lower Level Model(s)
Define Dependencies
Register Dependencies
Perform Con-sistency Checks
Consistent?
NO
Resolve Incon-sistencies by
YES
Consistency Checks
Incorrect Dependence Definition
Incorrect Model Refinement
Incorrect Higher Level Model(s)
Incorrect Higher Level Verification Check(s)
Incorrect Model(s) Refinement
Incorrect Verification Check
Perform Verification Checks
Compliant?
NO
YES
Resolve Non-compliance by
Models and Verification Checks sent to Integrator

SAVI Roadmap for Next Stage

Global Product Data Interoperability Summit | **2015**





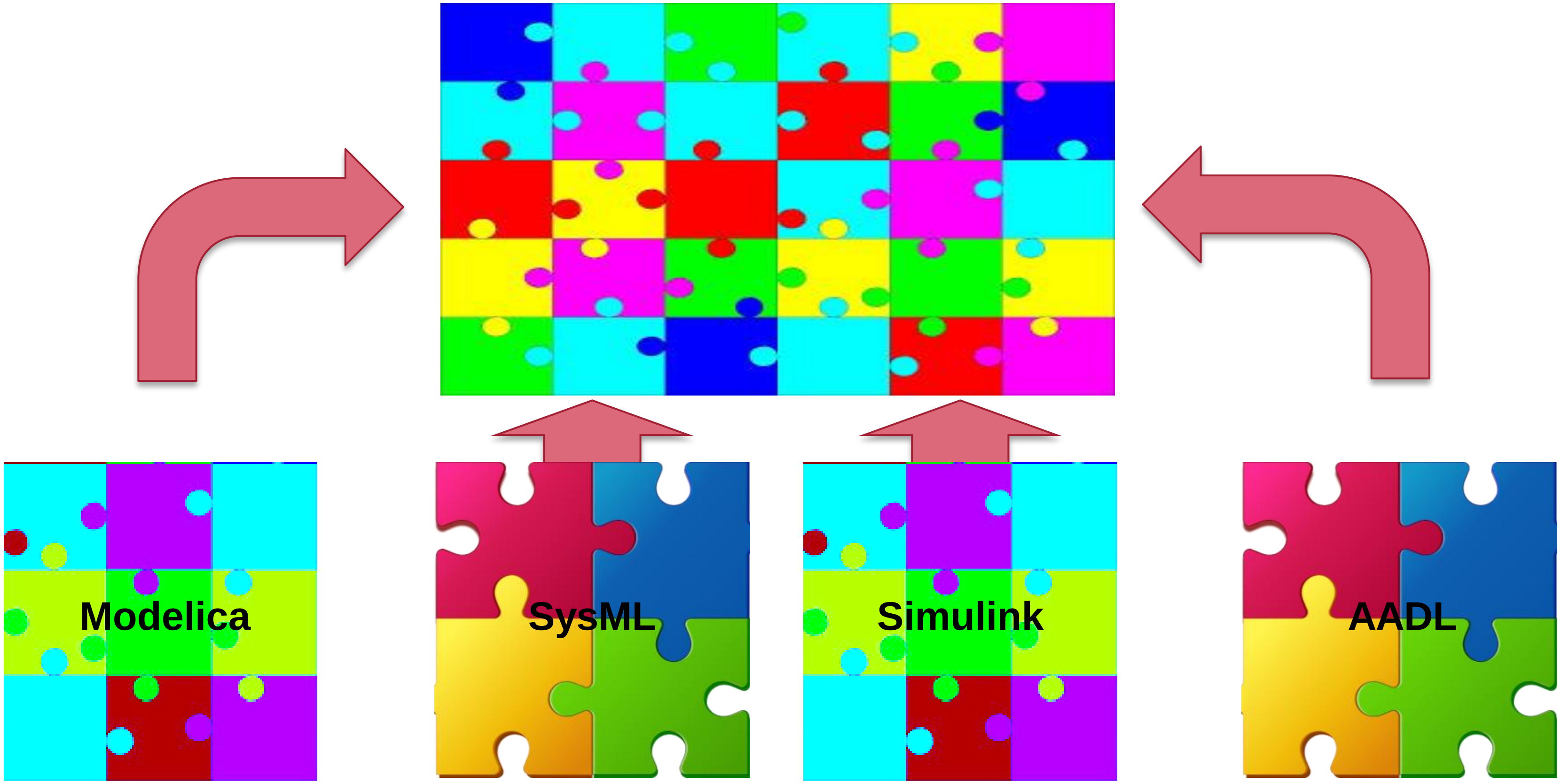
SAVI Behavioral Modeling – Acknowledgements

Global Product Data Interoperability Summit | **2015**

- **This work is being performed by SAVI members of the Behavior Working Group**
  - **K. Woodham – NASA**
  - **N. Shaw – Eurostep (SAVI Tool Vendor Partner)**
  - **D. Kuehlewind, E. Scholte – Sikorsky/UTAS**
  - **B. Hall – Honeywell**
  - **J. Chilenski – Boeing**
  - **R. Manners, S. Mandalapu – FAA**
  - **B. Horta, R. Filho – Embraer**

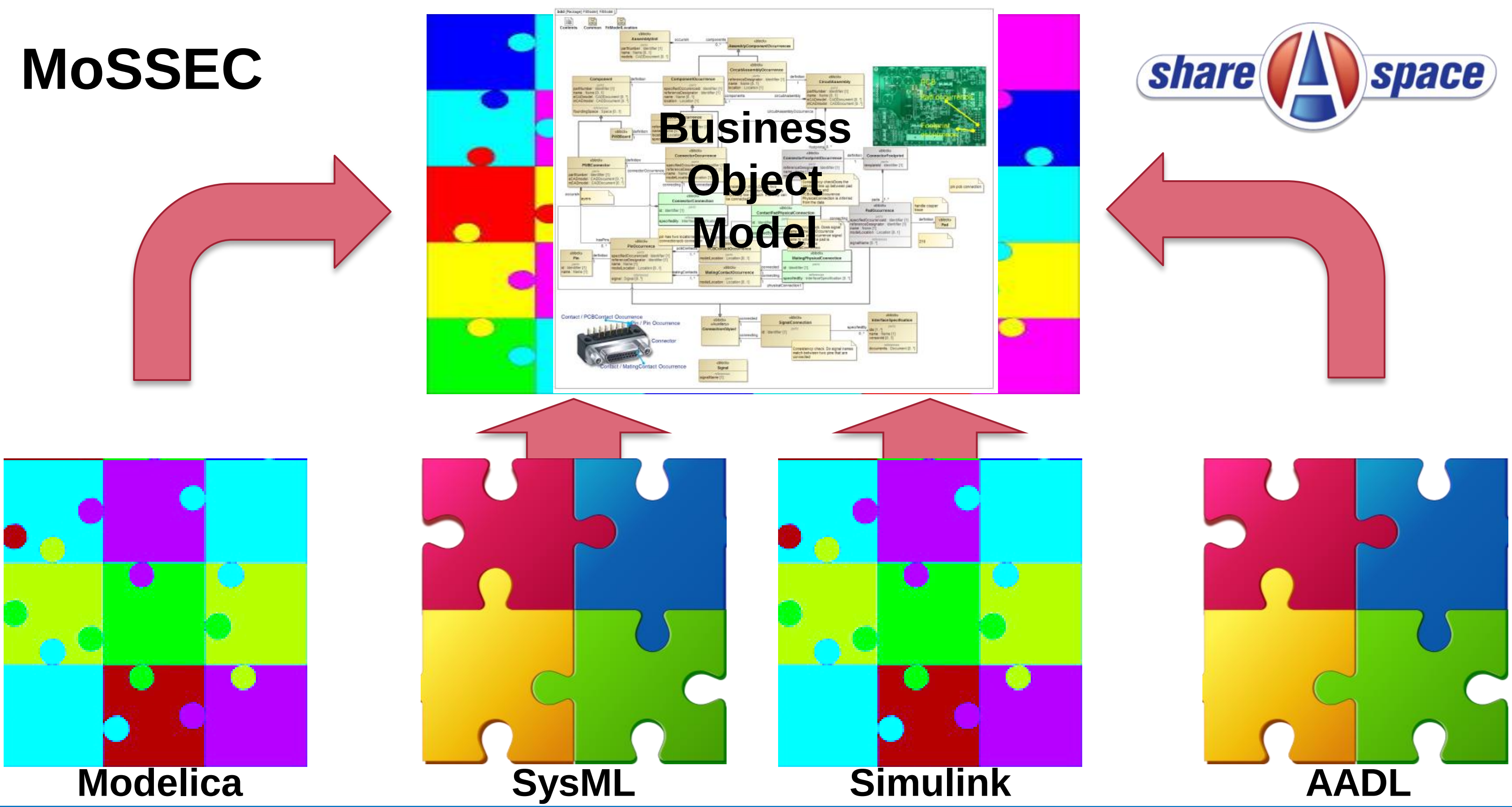
Back to the Puzzle Analogy

- **Consider trying to complete a jigsaw puzzle using bits from 4 different puzzles in different formats taking specifics from each source to make one picture**



The good news is

- We can use standards – some commonality
- We can design the target jigsaw to do the job



The Behavioral Model Integration Problem - Background

- **When an OEM commissions the design of a system which will be part of a new product, there are potentially many companies involved**
  - **The OEM creates a specification for the system**
    - **This is the first model, typically at a high-level**
- **These companies are all expert in their respective areas with established methods and tools**
  - **Increasingly these include the use of model-based approaches**
  - **Now there are many models using different approaches and at different levels of abstraction/detail**
  - **Some (sub-system and component) models will have been created in isolation, independent of the intended use**

The Behavioral Model Integration Problem

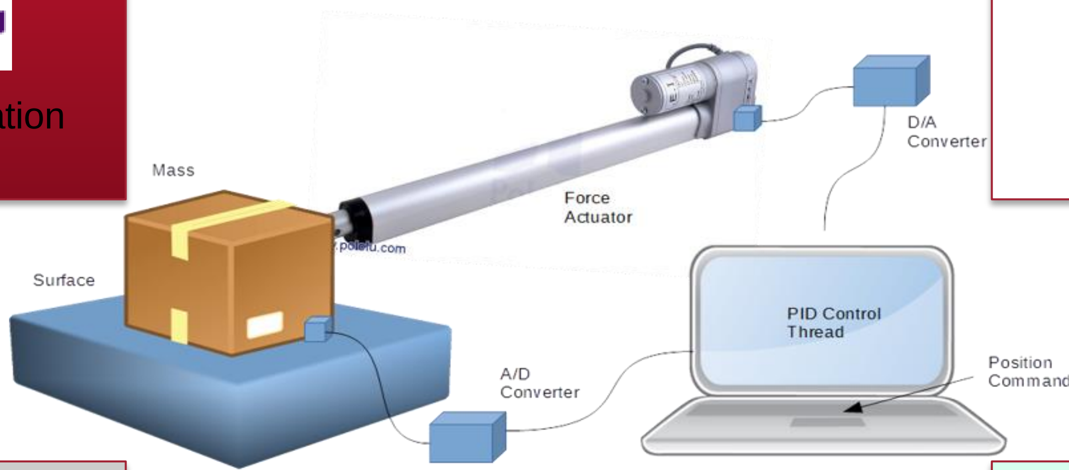
- **Need to determine if a set of models that relate to a system are consistent, when:**
  - **The models are possibly at different levels of abstraction/detail**
    - **Specifications versus simulations**
  - **The models are using different languages and paradigms**
- **Given a set of models:**
  - **How do we know which elements from the models should be consistent?**
  - **Once we know this we can check the consistency!**
- **What do we mean by consistent?**
  - **Data value consistency**
  - **Model property consistency**
  - **Model behavior consistency (time-history)**
  - **Model behavior consistency (property assertion)**

An example to start with

- **SAVI have created four models of the same simple system using different languages**

A system specification using SysML

A system model using AADL



The Sliding Mass Example System

A system model using Simulink®

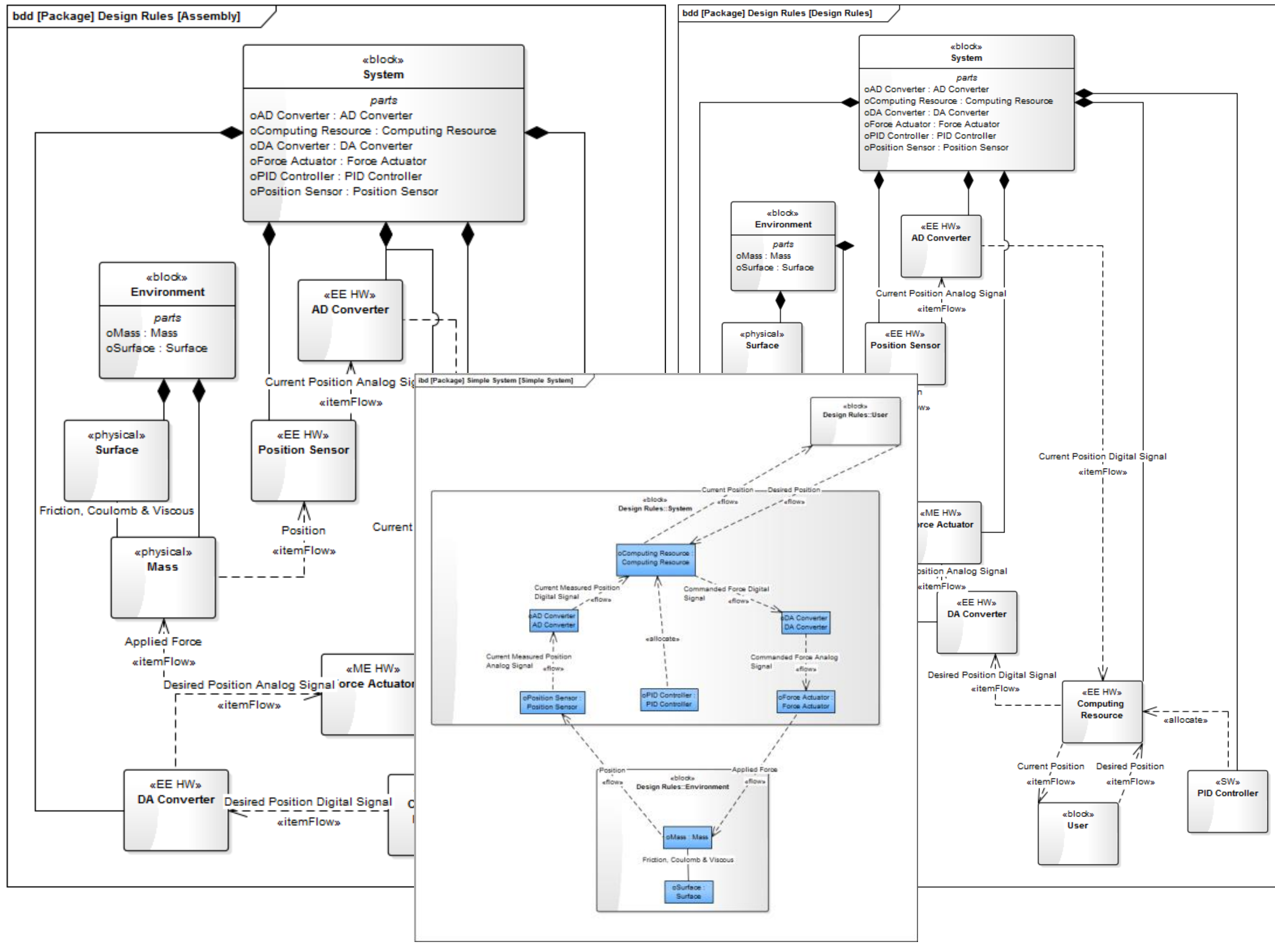
A system specification using Modelica

The SysML model

- **The SysML model was created in Enterprise Architect™**

A system specification using SysML

SysML is a Graphical Language
Stored as XML using the OMG's XMI (XML Metadata Interchange)



The AADL Model

- **Architecture Analysis & Design Language (AADL) is the SAE Standard AS-5506 for modelling safety critical systems**

A system model using AADL

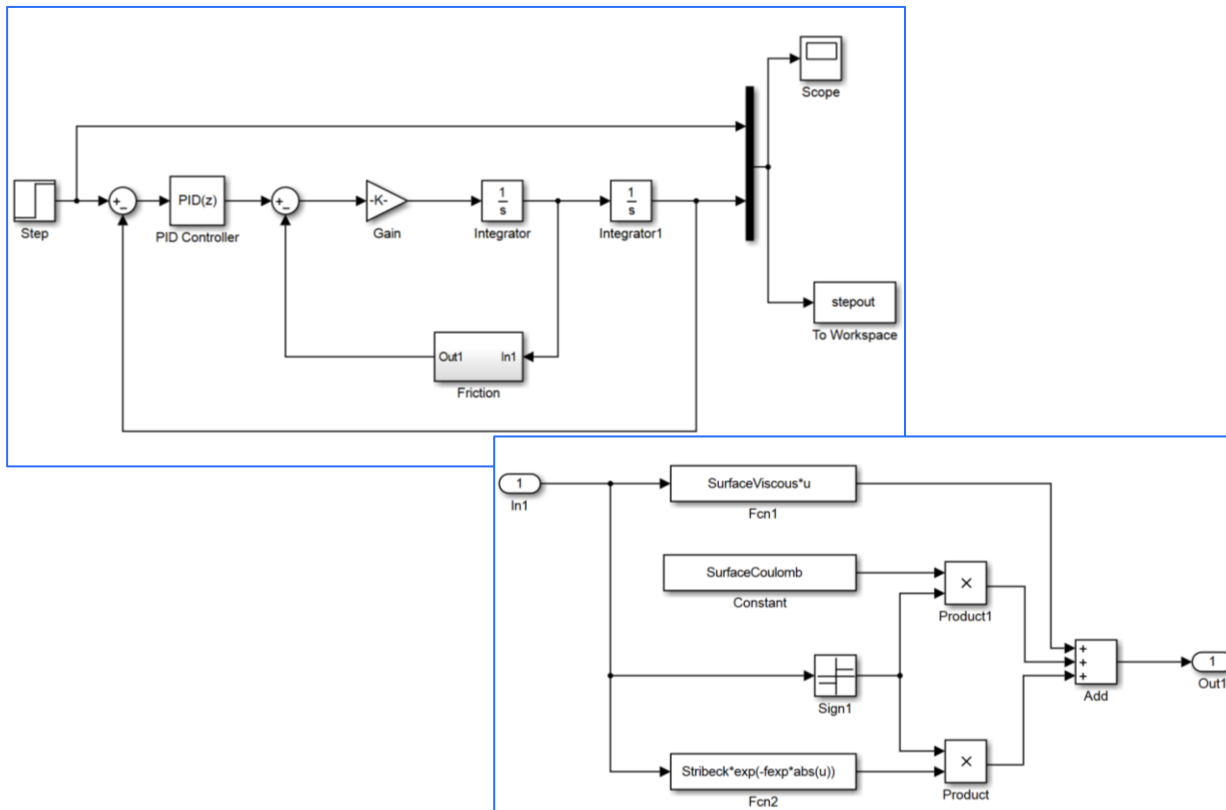
```
package SimpleModel
…
system FullSystem
end FullSystem;

system implementation FullSystem.impl
subcomponents
		ControlSys : system Platform.impl;
		PhysicalSys : system Plant.impl;
		UI : device ControlInput;
connections
		c1 :		feature group ControlSys.ActuationIF <->
PhysicalSys.ActuationIF;
		c2 :		feature group ControlSys.SenseIF <-> PhysicalSys.SenseIF;
		c3 :		feature group ControlSys.UserInterface <-> UI.Interface;
end FullSystem.impl;

end SimpleModel;
```

AADL is stored using ASCII text
There is also an XML form

The Simulink Model

- **Simulink is a graphical programming environment for modeling, simulating and analysing multi-domain dynamic systems.**

Simulink models are stored as Ascii text
There is also an XML form



SIMULINK
A system model using Simulink®

The Modelica Model

- **Modelica® is an object-oriented, equation based language to conveniently model complex physical systems**

```
model slidingblockpid1
  Modelica.Blocks.Sources.Step step1(startTime = 1, height = 1.0) ;
  Modelica.Blocks.Math.Add add1(k2 = -1) ;
  Modelica.Mechanics.Translational.Sources.Force force1 ;
  Modelica.Mechanics.Translational.Components.MassWithStopAndFriction boxwithfriction(
  L = 0, s(fixed = true), v(fixed = true), smax = 25, smin = -25, m = 10, F_prop = 0.05,
  F_Coulomb = 0.01, F_Stribeck = 1, fexp = 10) ;
  Modelica.Mechanics.Translational.Sensors.PositionSensor positionsensor1 ;
  Modelica.Blocks.Continuous.PID PID(k = 3.3437, Ti = 64.7929, Td = 6.998, Nd = 20.04, initType =
  Modelica.Blocks.Types.InitPID.DoNotUse_InitialIntegratorState);
equation
  connect(PID.y, force1.f) ;
  connect(add1.y, PID.u) ;
  connect(positionsensor1.s, add1.u2) ;
  connect(step1.y, add1.u1) ;
  connect(force1.flange, boxwithfriction.flange_a);
  connect(boxwithfriction.flange_b, positionsensor1.flange);
  annotation(experiment(StartTime = 0, StopTime = 6, Tolerance = 1e-006, Interval = 0.006));
end slidingblockpid1;
```

Modelica models are stored as ASCII text Depend on libraries of other Modelica models

MODELICA

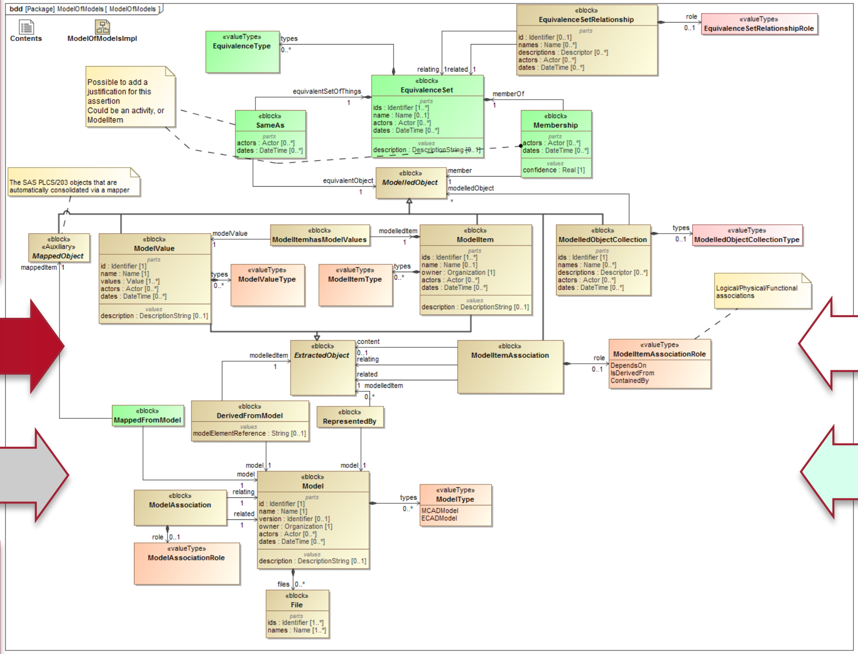
A system specification using Modelica

The Approach

- **In order to compare bring all the models into a common framework - a model of models**

A system specification using SysML

A system model using AADL



Model of Models specified in SysML

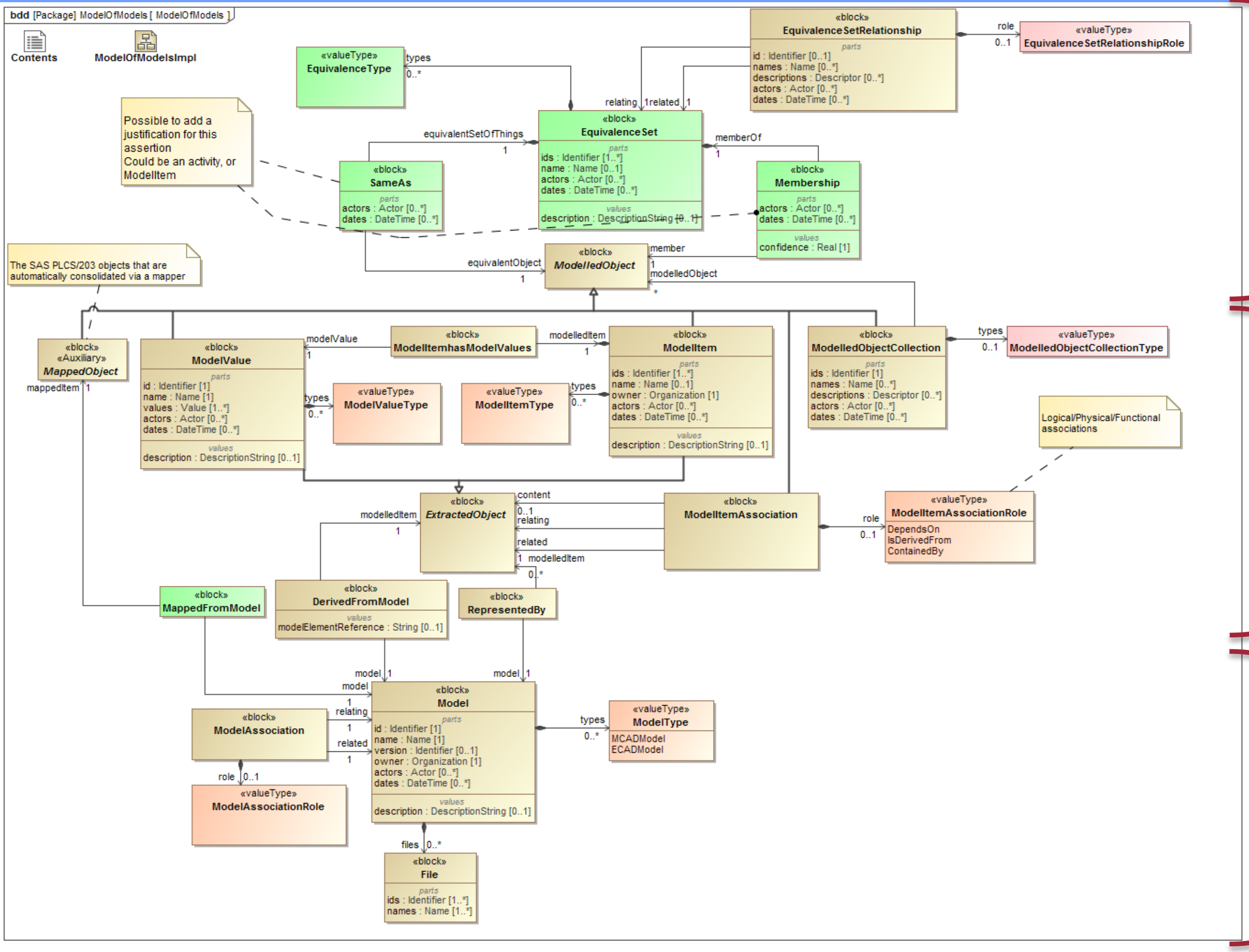
Mappers developed to extract from each into the Model of Models

A system model using Simulink®

A system specification using Modelica

The Model of Models

Global Product Data Interoperability Summit | **2015**



Information about equivalence between things found in the models

Information about things found in the models

Information about each model

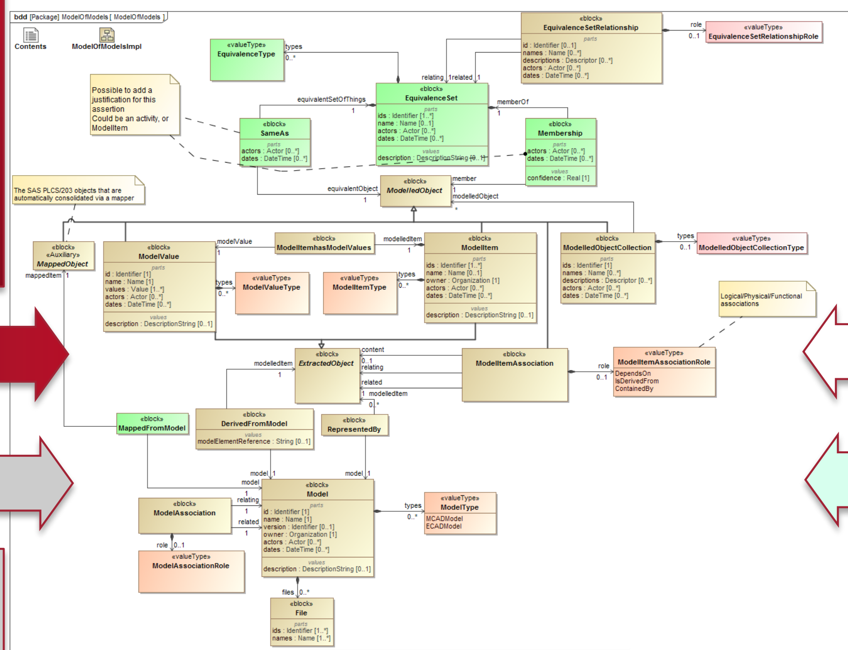
Implementation

Global Product Data Interoperability Summit | **2015**

- **The model of models is mapped into Eurostep's Share-A-space® collaboration hub**

A system specification using SysML

A system model using AADL



A system model using Simulink®

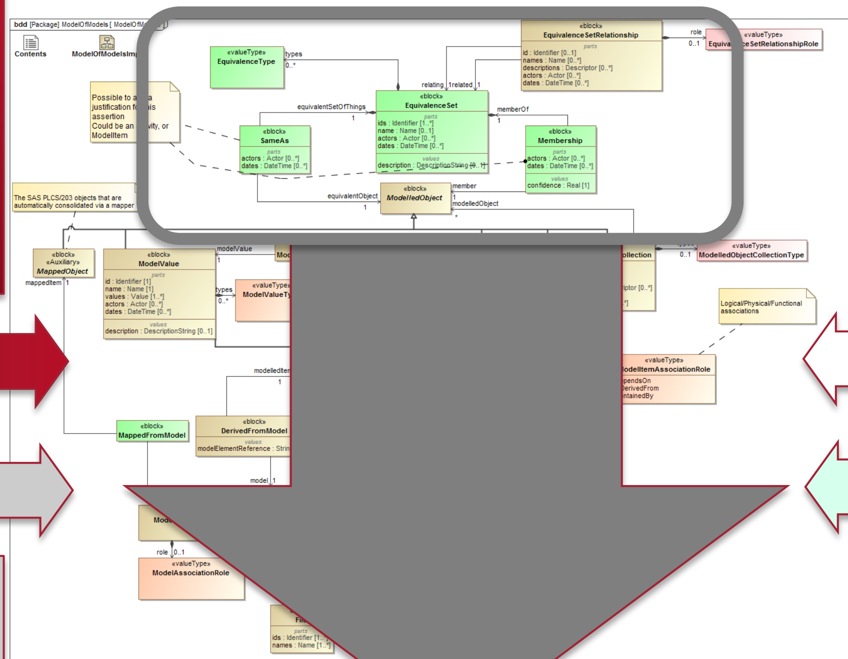
A system specification using Modelica

Implementation - Comparison

- **The potential equivalences are identified and the results added into Share-A-space**

A system specification using SysML

A system model using AADL



A system model using Simulink®

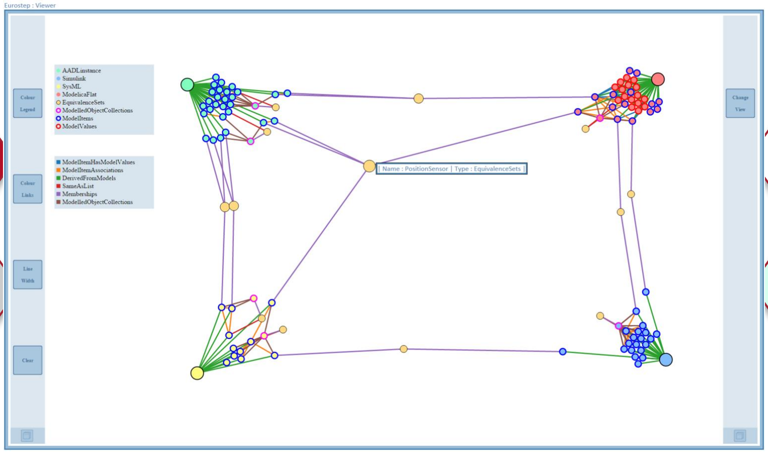
A system specification using Modelica

Implementation - Visualisation

- **The resulting data set (models, model content and equivalences is then visualised**

A system specification using SysML

A system model using AADL

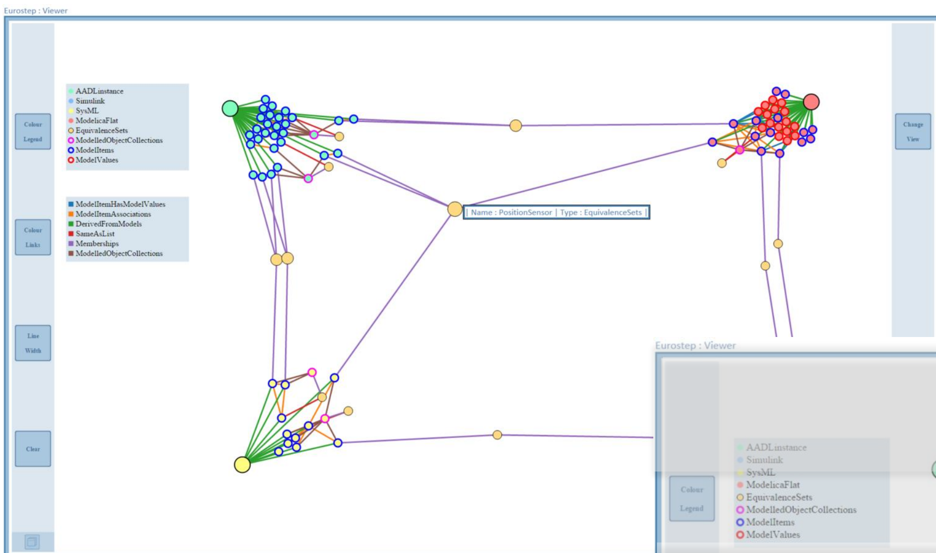


A system model using Simulink®

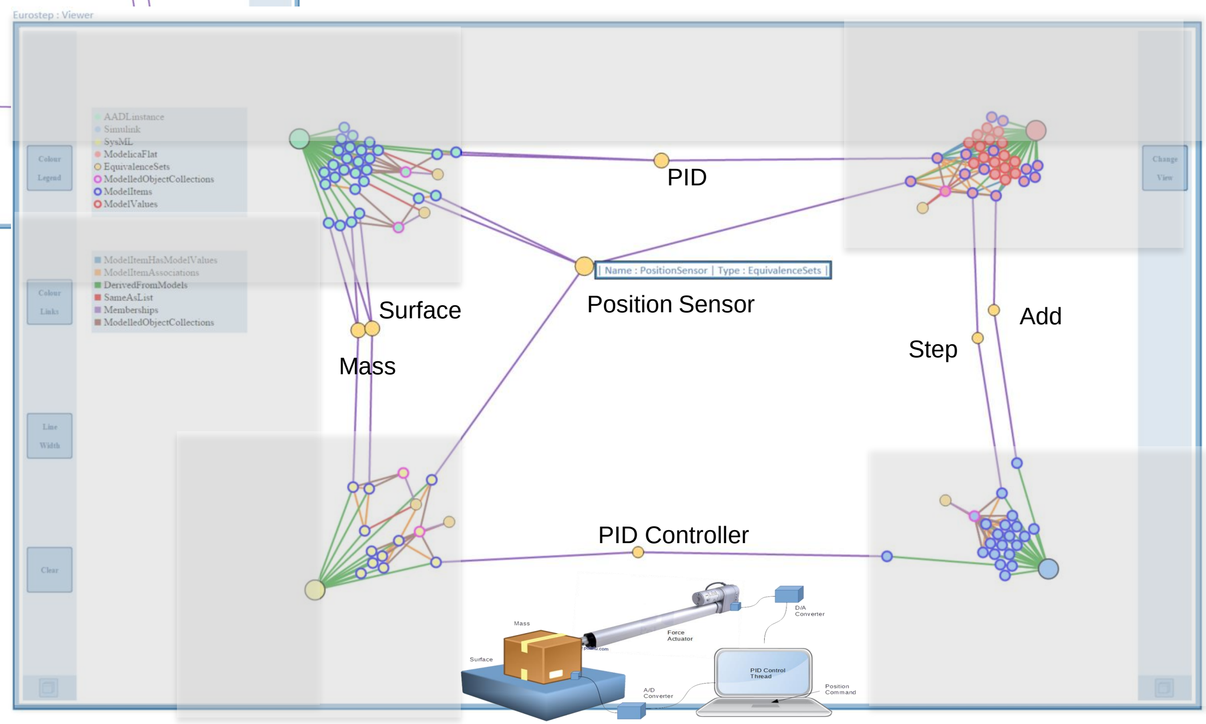
A system specification using Modelica

Visualization aid Identifying Equivalences

Global Product Data Interoperability Summit | **2015**



Equivalence sets were created on the basis of fuzzy name comparison



Conclusions

- **Using a common model-of-models approach is feasible**
  - **The different syntaxes of the four model types are not a barrier**
    - **Although some are harder than others to process**
  - **The approach did not need the tools that edit/execute the respective models**
- **A graphical approach is appropriate to present the results**
- **Initial approach to equivalence has identified equivalences across all four models**
  - **But nothing common to all four**

Summary

- **The AVSI SAVI project is demonstrating the use of the Virtual Integration Process, Model Repository, and Data Exchange Layer to analyze intermodel consistency**
- **The standards-based methodologies show promise based on proof of concept and simple system representations**
- **Additional work is being pursued to extend these concepts and add to the SAVI capability.**