SAVI Behavior Model Integration Virtual Integration Process

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Outline

• AVSI
• SAVI Motivation
• SAVI Program History
• SAVI Behavior Modeling
• Summary
AVSI Facilitates Cooperative Research

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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

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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

Mismatched Assumptions

Complex Development Environments

Siloed Organizations

Written Requirements

"pi"

3.14
3.14159265
3589793
We Start Integrated, But Don’t Stay Integrated
The Impact is Documented

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- High-level Design RFP Response
- System Integration Checks
- Target Completion
- High-level Req's in RFP
- PDR
- Req's Changes
- CDR
- Trades
- Req's Defined
- Sys Detailed Design
- Sys Re-Design
- Sys Development
- Sys Integration
- V&V

70% errors
3.5% detected
1x cost

10% errors
80% detected
16-100x cost

500-1000x (INCOSE 2011)

Sources:
INCOSE Systems Engineering Handbook, Version 3.2.2, 20111

COST GROWTH
SCHEDULE DELAY
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

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**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

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M/ECAD       Simulink       Modelica       AADL       Excel

Structure   Behavior   Requirements   Parametrics

SysML
Dependencies Are Key

- The SAVI Repository stores the links

Industry wide, 50% of requirements will change between CDR & delivery into service

When an element is changed, links and relationships are traced to find affected elements
SAVI Virtual Integration “Vee”

Predictive
Sensitivity analysis for uncertainty

Validation
Confidence in implementation

Requirements Engineering

System Design

Software Architectural Design

Hardware Architectural Design

Component Hardware Design

Component Software Design

Top-Level Verification Items

Consistency flow

High-level ADL Model

Detail ADL Model

Specify Model-Code Interfaces

Hardware Development

Software Development

Consistency flow

Consistency flow

Model-driven artifact generation

Conformance of models and systems

Integration Test

Software Unit Test

Hardware Unit Test

Acceptance Test

System Test

SW Int. Test

HW Int. Test

Keeping the system continuously integrated!

→ generation of test cases

← updating models with actual data
一致否？

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高阶验证检查

- 开发验证检查
- 定义依赖关系
- 注册依赖关系
- 执行一致性检查
- 一致否？

高阶模型

- 完善模型

低阶模型

- 错误高阶模型
- 错误模型

低阶模型

- 错误低阶验证检查
- 错误模型
- 错误验证检查

非一致性解决

- 非一致模型
- 非一致验证检查

一致模型

- 非一致模型
- 非一致验证检查

模型和验证检查发送到集成商

一致？”

非一致？

非一致模型和验证检查发送到集成商
SAVI Roadmap for Next Stage

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Focus of SAVI V. 1.0A

Focus of SAVI V. 1.0B

Focus of SAVI V. 1.0C

Legend
Identified, not exercised
Exercised in prototype only
Exercised in best demo
Exercised adequately

SAVI Version 1.0
Partial Supply Chain Integration (SAVI partial)
Tool Vendors (partners)
SAVI 1.0 Pilots
SAVI 1.0 Pilots

Focus of SAVI V. 1.0B

Focus of SAVI V. 1.0C

Requirements
Reliability
Safety
Behavior
Confidence
Compliance
Conformance
Compatibility
Security
Reliability
Safety
Behavior
Confidence
Compliance
Conformance
Compatibility
Security

Partners Includes all participants

Original Plan
More Realistic
Incremental Growth

5 10 15 20
SAVI Partners

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SAVI Behavioral Modeling – Acknowledgements

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
• 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

MoSSEC

Modelica  SysML  Simulink  AADL
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

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• 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

A system model using Simulink®

A system specification using Modelica

The Sliding Mass Example System
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

```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
The Modelica Model

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- **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.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.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

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
- A system model using Simulink®

Model of Models specified in SysML

Mappers developed to extract from each into the Model of Models

- A system specification using Modelica
The Model of Models

Information about equivalence between things found in the models

Information about things found in the models

Information about each model
Implementation

The model of models is mapped into Eurostep’s Share-A-space® collaboration hub.
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 specification using Modelica
- A system model using Simulink®
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

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.