SLIM for Model-Based Systems Engineering

Jan 26, 2013 | INCOSE IW 2013 - MBSE Workshop

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About InterCAX

• Small business based in Atlanta, spin-off from Georgia Tech
• Background in standards-based modeling and simulation technology – SysML, MBSE, CAD, CAE, PLM
• First-in-market and leading provider of full-featured SysML parametric analysis software – ParaMagic® (for MagicDraw), Melody™ (Rhapsody), ParaSolver™ (Artisan Studio), and Solvea™ (Enterprise Architect)
• Active contributor to the development of
  – OMG SysML International Standard
  – ISO 10303-210 (AP210) Standard and related standards
  – OMG Certified Systems Modeling Professional Certification (OCSMP) program
  – Model-based Systems Engineering technology and practice
About InterCAX (cont.)

• Customers in aerospace, defense, energy, electronics, automotive, biomedical, supply chain, telecom, and other sectors

• Business Focus
  – Software products
  – Services
    • SysML / MBSE training (2000+ participants since 2008)
    • Custom SysML/MBSE applications
    • Hands-on SysML/MBSE consultancy
Contents

• Motivation

• What is SLIM?
  – Conceptual Architecture
  – Use Cases

• SLIM – Bridging MBSE and PLM

• SLIM
  – NASA SBIR Phase 1 Project
  – SLIM Apps

• SLIM – Current capabilities and tools

• SLIM – Applications
A week in the life of a system engineer
Challenge

• **Identification**
  – System, sub-system, interfaces (SysML, CAD, Databases,...)
  – Parametric relations between system variables
  – Behavior models (Procedural, Discrete-event, Cont. dynamics,...)
  – Traceability to requirements (CRADLE, DOORS, PLM systems,...)

• **Integration**
  – Vertical (sys decomposition) and Horizontal (domains/aspects)
  – Different types (fidelity, abstraction, formalism) of models from different tools collectively define the overall system

• **Continuity**
  – Transition from conceptual to detailed design phase
  – Versions and configuration of models and generated documents
  – Systems engineering design and verification workflows
  – Tracing design decisions to analysis results
Challenge

Point-to-Point Ad-Hoc Information Flows

Use of models in systems engineering IS NOT model-based systems engineering (MBSE)
System Lifecycle Management (SLIM)
Enabling Model-Based Systems Engineering

Primavera, MS Project, Windchill ProjectLink and PPMLink, Teamcenter Portfolio, Program and Project Management...

Project Management

CAD
MCAD (Creo, NX, CATIA, ...) & ECAD (Mentor Expedition, OrCAD, ...)

Requirements
DOORS, Integrity, Cradle, RequisitePro, ...

Simulation/CAE
Mathcad, Mechanica, MATLAB, Simulink, ABAQUS, ANSYS, Mathematica, ...

Libraries / Databases
CAD models, cost models, analysis modules, parts and material databases, supplier database, ...

Optimization
Mathcad, ModelCenter, Isight, OpenMDAO, ...

Manufacturing, Supply Chain
Creo View, Windchill MPMLink, Tecnomatix, SAP, ...

SysML

PLM & SCM Systems (Windchill, Teamcenter, Git, ...)

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SLIM - Conceptual Architecture

SLIM is deployed in the SysML environment. It provides tools to federate (visualize, connect, execute) domain-specific models from the SysML environment.

System engineers work directly in their SysML environment - MagicDraw, Rhapsody, Artisan Studio, Enterprise Architect). SysML model is a conceptual map of the system.

SLIM uses enterprise PLM and SCM systems for configuration control.

SLIM allows users to wrap external model libraries (CAD, CAE, MATLAB,..) as plug-and-play SysML objects.
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Product Lifecycle Management

- Idea -> Design -> Manufacturing -> Service -> Disposal

...and much more

- Product structure (BOM)
- Related artifacts (CAD, doc, xls, ...)
- Versioning
- Configuration Control
Product Lifecycle Management

- Idea -> Design -> Manufacturing -> Service -> Disposal

Related artifacts (CAD, doc, xls, ...)

Product structure (BOM)

Versioning

Configuration Control
What has PLM go to do with MBSE?

- Who is responsible for different sub-systems and their functions?
- What specific sub-systems were allocated to CAD engineers?
- What specific version of the system model was used during this allocation?
- What specific versions of the CAD models were connected to the system model?
- What specific parameters of the sub-system X were connected to the CAD model parameters and how?
- What specific system measures-of-effectiveness was analyzed by the system engineer? What analysis models were used?
- What specific versions of the SysML parameteric model, and related domain-specific analysis models were used?
- What were the results of this analysis?
- What design decisions were taken following this analysis and by whom?
Technical Objectives

• Establish fine-grained, information-rich connections between the SysML-based system model and variety of other artifacts, such as CAD, CAE, Excel, MATLAB, Mathematica models, and Word documents to name a few, using integration patterns that facilitate different system engineering workflows.

• Demonstrate execution of patterns that are fundamental to realizing system engineering design and verification workflows, such as synchronizing values between SysML models and connected artifacts in PLM systems, and wrapping executable models (MATLAB/Simulink, Mathematica,...) managed in PLM systems as SysML constructs and executing them in the context of SysML model execution.

• Manage different versions and configurations of (a) the SysML-based system model, (b) the connected artifacts (e.g. CAD/CAE models and Word/Excel docs), and (c) the fine-grained relationships between the system model and artifacts, in an enterprise-class PLM environment such as Windchill or Teamcenter.
NASA SBIR Project – Phase 1

SLIM for Agile Mission Lifecycle Management

PLM Environment / Enterprise Config. Mgt. System
Windchill, Teamcenter

SLIM
Connection and Configuration Management
Services and Visualization

SysML Tool
(MagicDraw, Rhapsody, EA, Artisan Studio)

A system engineer will architect the system model in his/her favorite SysML tool, which will be the front-end.
Total System Model
Created and managed using SLIM

2012-07-12, 1000h US ET
Connections based on Reference, Data Map, Function Wrap, Model Transform, and Composite patterns
Total System Model History

Timeline

T1

T2
(Baseline B1)

T3

T4
(Baseline B2)
SLIM’s Connection Patterns

• Reference Connection
• Data Map Connection
• Function Wrap Connection
• Model Transform Connection
• Composite Connection
SLIM’s Connection Patterns

- **Transfer Data between Independent Models (Data Map)**
  - SysML-Excel, SysML-Databases

- **Wrap external functions/code (Function Wrap)**
  - External function calls (SysML–MATLAB/Simulink/Java)

- **Transform Model from Tool A to Tool B (Model Transform)**
  - SysML parametric solvers export equations to Mathematica, MATLAB, and OpenModelica
  - Seed FEA models from CAD models
  - Reverse engineering: Generate design models (SysML-based system models) from analytical models (Simulink models)

- **Mirror Model from Tool B in Tool A (Model Transform)**
  - SysML - CAD, STK (bi-directional data flow)

- **More Complex Patterns (Composite)**
  - Intermediate models and repositories
SLIM capabilities
(developed in SBIR Phase 1)

• SLIM Plugin for MagicDraw
• Repository Manager
• Connection Creator
• Connection Viewer
• History Viewer
• Requirement Impact Check
SLIM Plugin for MagicDraw

SLIM menu toolbar

SLIM browser context menus
Repository Manager
Connection Creator

Active filtering of all columns based on connection library

Switch repositories

Structure View

Folder View

Versions

Baseline View

SysML model (MagicDraw)

Connection function/type

Artifact Repository (Windchill shown)
Connection Creator (Teamcenter Repo)
Connection Creator - specs
SysML Instance-Excel Data Map

Specifications for Instance-Excel Data Map Connection

Workbook/Worksheet
- Default Workbook: LE_Trade.xlsx
- Default Worksheet: Sheet1

Cell Selection
- Cell Range
- Access Mode: Read
- Excel Preview: {}
Connection Viewer
History Viewer
Check for newer versions and baselines of connection models
Generating PLM part structure from SysML block structure and vice versa

SysML model block structure

Part structure (BOM) in PLM systems (e.g. Windchill)
Connection Creator – specs
SysML Block/Instance-Creo Data Map

Step 1: Select Creo assembly parameters of interest
Step 2: A surrogate SysML block element is generated with the Creo parameters. This block represents the Creo model for the system engineer.

Step 3: The surrogate SysML block element (and corresponding instance) is connected to the Creo model. System engineer can sync parameter values.

Values read from Creo
Check Requirement Impact (Total System Model)

All requirements directly / indirectly related to R3 are highlighted in the model tree and on the diagram.

Connections allow us to trace the impact of requirement changes to the specific CAD parts in the PLM system.
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Advanced Requirements Management with SLIM (Ford)

• **SysML Requirements** – connect requirements to system architecture, analyses, and test cases in details (qualitative and quantitative)

• **Teamcenter Requirements** – manage and version control a large set of requirements across the entire mission

• With SLIM, system engineers can
  – view TC requirements in SysML,
  – connect SysML and TC requirements,
  – push new SysML requirements to TC
Drag-and-Drop Requirements from a Requirements Management Tool to SysML (Teamcenter and MagicDraw example)
Response-Based Requirements (Ford)

• **Response-based Requirements** - Defining requirements using desired system response

• Connecting requirement definitions to rich media – images, video, live network feeds, cloud content.
Domain-specific Apps based on SLIM Manufacturing Capability Modeling Environment (DARPA AVM / iFAB Program)

M-Library Web Dashboard
Search and query M-Library

M-Library Java API
Programmatically access M-SysML knowledge graph and M-Library

M-Library Databases

830+ concepts

M-SysML Knowledge Graph
Knowledge-based representation of manufacturing concepts and related models

M-Library Excel Import/Export
Export instances as Excel spreadsheets, and import spreadsheets to update M-Library
Domain-specific Apps based on SLIM

**Maestro** – MBSE of complex electronics systems

(Sandia National Laboratories)


Document-based system definition
Maestro
Model-Based System Definition
System Decomposition

SysML IBDs
Generating Simulation Models
SysML, XML, and Java

System Design Representation (SysML)

SysML-based Analytical Model + design-analysis relationships

XML-based analytical model structure

Java-based simulation model
Maestro – A visual modeling environment for designers and analysts (SysML DSL Plugin for MagicDraw)
Questions?

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SLIM deployed as SysML plugins

ParaMagic® 17.0.1
(MagicDraw 17.0.1)

ParaSolver™ 2
(Artisan Studio 7.4)

Melody™ 3
(Rhapsody 7.6)

Solvea™ 1
(Enterprise Architect 9.3)

www.intercax.com/products
Standard Products

www.intercax.com/products

- **ParaMagic®** for **MagicDraw** (since Jul 2008)
  - www.magicdraw.com/paramagic
  - www.intercax.com/paramagic

- **Melody™** for **Rhapsody** (since Jan 2010)
  - www.intercax.com/melody

- **Solvea™** for **Enterprise Architect** (since Mar 2011)
  - www.intercax.com/solvea

- **ParaSolver™** for **Artisan Studio** (since Jan 2011)
  - www.atego.com/products/artisan-studio-parasolver/
  - www.intercax.com/parasolver
SysML Parametric Analysis and Integration Technology

• Represent fine-grained relationships between models (similar to parametric modeling in CAD)

• Execute math relationships inside SysML Models (next-generation spreadsheets for SE)

• Connect external models to SysML – MS Excel, MATLAB/Simulink, Databases, CAD/CAE,…

• Simulations, Analysis, Trade Studies, Optimization, Requirements Checking, Risk Assessment, … & more
SLIM’s Capabilities (as of Aug 2012)

• **SysML-based Parametric Solvers** (since 2008)
  – Acausal solving of parametric models (not diagrams)
  – Complex math relations & patterns for parametric relations (e.g. topology-independent relations, define for structure – execute for block instances)
  – Support for complex SysML parametric patterns such as recursion and redefinition
  – Automated requirements verification, *response-based requirements*
  – Ability to wrap external models (e.g. MATLAB, Mathematica, Excel)
  – Concept trade studies

• **SysML Integrators**
  – Excel interface (data r/w + SysML model generation & update)
  – Database interface*
  – MATLAB/Simulink interface
  – Mathematica interface
  – OpenModelica interface
  – CAD interface (NX, AP203/210)*
  – CAE interface (ABAQUS, ANSYS)*
  – STK interface*
  – *PLM interface (Windchill, Teamcenter)*
  – ...plus tailored interfaces

* alpha/beta-level maturity
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# Space Systems

**Cost and coverage trades and req. verification**

### Trade Study with 2 FireSats

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<th>Satellite 2</th>
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<th>Total Coverage</th>
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<td>Ang. Aperture deg</td>
<td>M$/yr</td>
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<td>(1 pass, 0 fail)</td>
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Military and Intelligence

Probability of mission success, mean response time

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</table>
Disaster Response

Search & rescue area coverage and response time

Helicopter: Aircraft
- scanWidth: Miles
- speed: Miles Per Hour

Sea: Marine Environment
- totalArea: Square Miles
- conditions: Sea State

Lifeboat: Boat
- speed: Miles Per Hour

Search Time: Hours
- width: Miles
- mst: Mean Search Time
  - constraints: \( t = \frac{\text{area}}{2 \text{speed}} \)
- speed: Miles Per Hour
- area: Square Miles

Rescue Time: Hours
- t: Hours
- speed: Miles Per Hour

Response Time Analysis
- lifeboatPositionX: Miles
- lifeboatPositionY: Miles
- rescueTime: Hours
- searchTime: Hours
- totalResponseTime: Hours
- yardHallDistance: Miles

Command Center
- values: signalResponseTime: Hours

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Smart Grid (supply/demand, ops cost)

Supply-Demand Balance

Daily Expense:  SmartGrid $60,228  DumbGrid $66,477

For more info, visit http://smartgrid.ieee.org/nist-smartgrid-framework
Manufacturing and Supply Chain

Computing value at risk, supply-demand balance
Banking and Financial Systems
Computing risk and checking compliance

Internal Bank Policies
- Locations

External Trading Partner Data
- Assets, Debts, Exposure

Internal Bank Holdings

External Market Data
- Stocks, Bonds, Options

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Questions?

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