PURDUE PLM CENTER FACULTY FELLOW PROJECT UPDATE

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**Synopsis**

**What**: Demonstrate the effectiveness of next generation design tools and integrate them with the early-phase PLM processes.

**Why**: Next-Gen design tools and model-based methods are expected to reduce cost and development time by effective complexity management, efficient design space exploration and designing products that are correct by construction against requirements.
Next Generation Design Process: Last Year’s Focus

Requirements

Component Libraries

Mathematic Representation
Formalized Design Language

Construction Rules, Semantic Definitions, Constraints

Verification and Validation
Stochastic Formal Verification

Design Space Exploration

Performance vs Complexity

Metrics

Performance = f(W, P, α ...)

Complexity = \sum_{s=1}^{c} \left( \sum_{i=1}^{n} W_i \right) + \sum_{k=1}^{m} W_k

Model Based Design

Manufacturing

PRODUCT LIFECYCLE MANAGEMENT CENTER OF EXCELLENCE

PURDUE COLLEGE OF TECHNOLOGY
SCOPE: Towards a Metrics Guidebook

Metrics Guidebook

Different Levels of Abstraction
- Low Level
- High Level

Design Manufacturing

Information theoretic metrics
Network theoretic metrics

Type of Data depends on what metric is chosen
- Cost-Complexity relationship
- Which subsystems are complex
- Integration with Design Space Exploration Tools

Data

Design

Cost
Case Study

Network Theoretic Metric Example

Structural Graph for Orsted

Type of interaction
Blue= information , Green= Force
Red=Energy Orange=Matter
Case Study with Network theoretic metric

Cost vs. Complexity for three spacecraft

Cost vs Complexity

Design Cost-Launch Cost (FY08$K*1000)

Coupling Complexity (Ccc)

Orsted  HETE  Clementine

Complexity of Subsystems

- System Complexity
- Integration
- Power
- Controls (ADCS)
- Communication (Comm.)
- Data Handling (CDH)
Key Insights

- Identified Cost-Complexity correlation for spacecraft case study.

- Formulated how this correlation can be used to analyze the impact of design changes on integration cost.

- Developed an algorithm for module identification which minimizes integration complexity.

- Demonstrated how complexity can be used with other non-traditional measures (such as flexibility and robustness) to guide decision making in a design space exploration environment.

- Companies identified product-variants as key focus area (vice brand new product)
This Year’s Focus: Connecting Models to Tools

Verification and Validation

Stochastic Formal Verification

Design Space Exploration

Performance vs Complexity

Metrics

\[ Performance = f(W, P, \alpha \ldots) \]

\[ Complexity = \sum_{i=1}^{c} \left( \sum_{i=1}^{n} W_i \right) + \sum_{k=1}^{m} W_k \]

Model Based Design

Requirements

Manufacturing

Component Libraries

Formalized Design Language

Construction Rules

Semantic Definitions

Constraints

Mathematic Representation

Purdue College of Technology

Product Lifecycle Management Center of Excellence
Enabling the ‘Digital Thread’

Exploring Model-Based Representations

• Design Space Exploration
  – Test complexity metrics and assessment using SysML representations

• Design Simulation
  – Connecting SysML to in-house ABM tool (Discrete Agent Framework, DAF)

Magic Draw
- SysML representations
- ParaMagic plugin

MATLAB
- DAF
- Simulink
Systems Modeling Language (SysML)

• Four set of viewpoints to define the system
  – Structural – definition of elements
  – Behavioral – interaction, architecture
  – Requirements – requirement management (checklist)
  – Parametric – constraints via logical, mathematical expressions

• Network sets
  – Logical
    • Exchange of information between systems
    • *What* information is transferred between systems
  – Physical
    • Connectivity of systems
    • Over *which* physical paths the information is transferred
Logical Network
Physical Network
4. Parametrics

Thank You
1. Structure

2. Behavior

3. Requirements

4. Parametrics

SysML Basics
Complexity enabled design-space exploration

Preliminary Exploration

Domain Knowledge

- Common features of good and bad designs
- Complexity threshold

EXPERT SYSTEM

Component Library

Design promotion scheme

Requirements

Design Generator

Good Designs

Design Space Exploration

Results for Fractionated Satellite Design

Complexity Enabled Design Space Exploration Framework
Case Study with Information Theoretic Metric

\[ C(Q) = e^{(h(Q))} \]

Q: Joint distribution of quantities of interest
C(Q): Complexity of the system
H(Q): Differential entropy of Q

This metric measures the potential of the system to show unexpected behavior in the quantities of interest.

Case Study

Case 1: Assume V1 and V2 to jointly normal distributed.

\[ h(X) = -\int_{\Omega} f_X(x) \log f_X(x) \, dx \]

Complexity = 5.3

Case 2: We know V1 and V2 to be independent uniformly distributed between 0 and 5V

\[ V_0 = (V_1 + V_2)/2 \]

V0 will have a triangular distribution with complexity of 3.39

Adder Circuit

Less Information more complexity

More Information reduces complexity

For additional details see the attached documentation
Case Study with Information Theoretic Metric

Data Required
1. Quantities of interest (Performance, Cost etc.)
2. Functional relationship between Quantities of interest and input variables.
3. Uncertainty in variables.

Things that can be measured
2. Possibility of system to show unexpected behavior.
Purdue Complexity Metric (based on Network Theory) [5]
Complexity is defined as the effect of the network topology of the system

\[ C_{cc} = \sum_{s=1}^{c} j_s \left( \sum_{i=1}^{n_s} W_i \right) + \sum_{k=1}^{m} W_k \]

Where -
- \( W_i \) = weights of links of a cycle
- \( j \) = size of the cycle
- \( c \) = no. of cycles
- \( W_k \) = weights of links not belonging to cycle
- \( m \) = no. of links not participating in any cycles
- \( n_s \) = no. of links participating in cycle ‘s’

**Case Study**

Structural Graph for Orsted

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Phase 1- Component 1

Month 1: Initial calls with PLM Center partners to identify priorities and revisit goals.
Month 2-3: Identifying available data flows, to guide choosing the appropriate metrics.
Month 4-5: Developing the ‘Metrics Guidebook’ demonstrating it on the case study.
Month 6: Writing and Publishing; Mid-project WEBEX presentation.

Phase 2- Component 2

Month 1: Understand and summarize design exploration tools used in the industry
Month 2-3: Identifying how to integrate the tool with PLM tools.
Month 4-5: Demonstrating the process on the case study.
Month 6: Writing and Publishing
Where we ended

• Next Generation Design Process
  – Model based design
• Metrics Guidebook
• Information Theoretic Metric
  – Circuit case study
• Network Theoretic Metric
  – Spacecraft case study
  – Baja buggy case study