Model-Based Conceptual Design of Mechatronic Systems

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Outline

- Motivation
- Model-Based Libraries in SysML
- Conceptual Design Automation
- Summary and Future Outlook
Significance of Conceptual Design

- The least amount of quantitative information is known and the most important decisions are being made.
- The possibility of influencing costs (80%) is the highest!
- The greatest potential exists for innovation.

Support of Conceptual Design

Current Situation
- Importance contradictory to available support
- Superior maturity and familiarity of paper-based methods

Goals
- Enable the design of innovative and complex mechatronic systems
- Provide new computational models and methods
- Explore complex solution spaces and constraints
- Create a continuous model, method and tool chain
- Create process-independent support
Example: New Vehicle Architectures

Creating new alternative architectures:

- Lightweight architectures
- Urban mobility vehicle
- Hybrid cars
- Electric cars

Personal Urban Mobility and Accessibility
Project P.U.M.A. © GM Corp.
http://media.gm.com/ProjectPUMA/
Conceptual Design Automation

Process

- Describe design spaces
- Enable generation of alternative, known and new designs
- Search for feasible, “good” solutions and optimal designs
- Automate design processes

→ 2 approaches
(SysML & object-oriented graph-based language)
Model-Based Engineering and Design Libraries

- Integrated, **formal product model** for mechatronic systems using SysML
- Function, behavior and structure levels
- Generic, model-based design **libraries**
- Support **conceptual design:**
  - rapidly model mechatronic designs
  - model re-use
  - ensure model consistency
  - find alternative, feasible solutions
  - model transformations

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SysML Approach

Functional Decomposition (using function library)

Allocating from Functions to Structure

Building the Structure (by associating single components)
Functions

- **Function**: Operator that changes a technical input flow into an output flow
- **Interfaces**: Typed pins represent the point of interaction of object flows between functions

Flow type | Operator (Activity)
--- | ---
RootFlow | RootOperation
Material | Convert
Signal | Control
Energy | Magnitude
StatusSignal | Stop
ControlSignal | Regulate
Material: Regulate
ControlSignal | Material

NIST Functional Basis

Components

- **Components**: (mostly) physical entity or module
- **Model**: block with attributes that allow evaluation, e.g. performance, cost and weight
- **Interfaces**: ports / connectors require additional types to flow types and additional information, e.g. orientations, positions, degree-of-freedom, etc.
Example: eCar

Level of abstraction and scope of model set by initial Modelica model:

Overall function:
Functional Modeling

drag & drop
**Allocation Matrix:**

**column:** elementary functions as actions (operator & flow)

**row:** (mostly physical) components from library

| ElectricalSignal:Store (for recuperation) is allocated to the component “Car Battery” |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pMSM motor | Car Battery | acc | recuperation and | pMSMcontroller | car data-bus | current sensor | temperature sensor | voltage sensor | speed sensor | hydraulic brake | two wheel differ | car wheel | software | Driver | Ground |
| 4 | 2 | 4 | 4 | 2 | 9 | 1 | 1 | 1 | 2 | 4 | 2 | 6 | 6 | 1 | 1 |
| 4 | 2 | 4 | 4 | 2 | 9 | 1 | 1 | 1 | 2 | 4 | 2 | 6 | 6 | 1 | 1 |
| 4 | 2 | 4 | 4 | 2 | 9 | 1 | 1 | 1 | 2 | 4 | 2 | 6 | 6 | 1 | 1 |
| 2 | 1 | 1 | | | | | | | | | | | | | |
| 2 | 1 | 1 | | | | | | | | | | | | | |
Assembly of Components
Conceptual Design Automation

Process

- Describe design spaces
- Enable generation of alternative, known and new designs
- Automate design processes
- Exploration of solution spaces
Graph Grammars and FBS

Vocabulary (metamodel)

Rules

Provide linear displacement

Convert energy to mec.
  transl. energy

Import energy

Helms and Shea, „Computational Synthesis of Product Architectures Based on Object-Oriented Graph Grammars“, Journal of Mechanical Design 134(2), 2012
Graph Grammars and EDS

- Vocabulary (metamodel)
- Rules
- Function
- Behavior
- Structure

Provide linear displacement

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Hybrid Powertrains

Serial Hybrid

Parallel Hybrid

Power-split Hybrid
Parametric Synthesis

# Model-based Libraries in SysML vs. Object-oriented Graph-based Languages

<table>
<thead>
<tr>
<th>i.e. general language</th>
<th>i.e. domain-specific language</th>
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<tbody>
<tr>
<td>+ Defined syntax</td>
<td>+ User-defined syntax definition according to language requirements</td>
</tr>
<tr>
<td>- Learning the (more complex) syntax</td>
<td>+ Deeper understanding of domain through language definition</td>
</tr>
<tr>
<td>- Hard to map domain concepts to language concepts</td>
<td>+ Reduced language</td>
</tr>
<tr>
<td>+ Improved manual modeling in SysML by formalization and libraries</td>
<td>- Knowledge about language specification required (→ learning the meta-syntax)</td>
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<tr>
<td>- No automation available</td>
<td>+ Design automation possible</td>
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<tr>
<td>+ Standardized tools and growing community</td>
<td>- Can be difficult to integrate and grow in industry</td>
</tr>
<tr>
<td>+ Customization and extension is possible</td>
<td></td>
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Future Outlook

→ Combination of model-based libraries in SysML and the automated design synthesis

- Support model re-use and faster modeling
- Broaden scope of applications
- Integration of requirements
- Simulation of system behavior
- Automated synthesis of SysML models
Thank you for your attention!

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