

### An Overview of the SysML-Modelica Transformation Specification

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# SysML-Modelica Transformation Specification: Context & Objective



- > Two complementary languages for Systems Engineering:
  - Descriptive modeling in SysML
  - Formal equation-based modeling for analyses and trade studies in Modelica

#### ➤ Objective:

- Leverage the strengths of both SysML and Modelica by integrating them to create a more expressive and formal MBSE language.
- Define a formal Transformation Specification:
  - a SysML4Modelica profile
  - a Modelica abstract syntax metamodel
  - a mapping between Modelica and the profile

#### **Presentation Overview**



- What is SysML?
- What is Modelica?
- ➤ Motivating Example: Design & Analysis of Robot
- SysML-Modelica Transformation Specification
- Transformations in Systems Modeling
- Model reuse and composition
- > Summary

### What is SysML?



- ➤ The Systems Modeling Language (OMG SysML<sup>TM</sup>) is a *visual, general purpose modeling language*
- > Is a modeling language that provides
  - Semantics = meaning
  - Notation = representation of meaning
- > Is not a methodology or a tool
  - SysML is methodology and tool independent
- Developed by the Object Management Group to support Model-Based Systems Engineering

### What Can be Expressed in SysML?

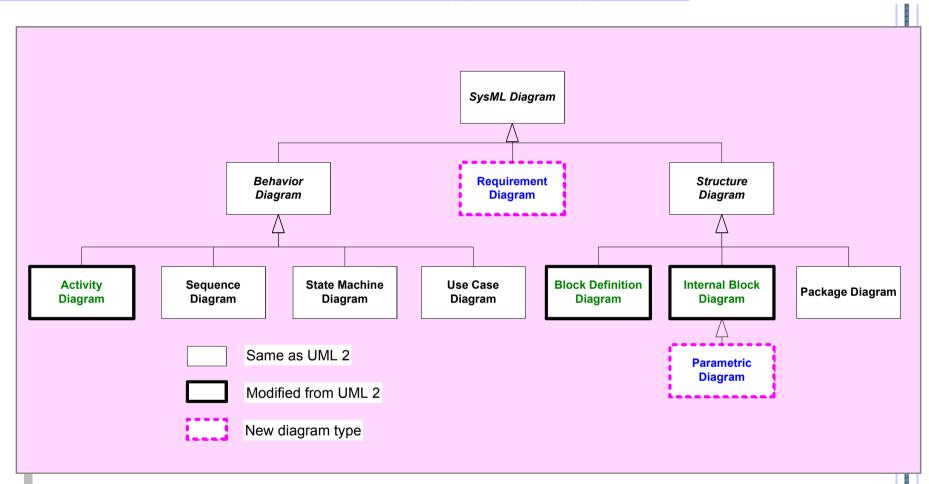


- SysML is a language to express the information and knowledge generated and processed during the application of a systems development methodology
  - Specification
  - Analysis
  - Design
  - Verification
  - Validation

- Hardware
- Software
- Data
- Personnel
- Procedures
- Facilities

### **SysML Diagram Taxonomy**





Think of SysML as an integrated collection of languages...

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### Some History...



Specification: http://www.omg.org/spec/SysML/

- v1.0: 2007-09

- v1.1: 2008-11

- v1.2: 2010-06

v2.x: RFI preparation workshop - 2008-12



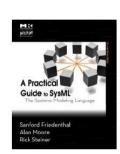
MagicDraw (No Magic), Artisan Studio (Atego),
 Enterprise Architect (Sparx Systems), Rhapsody (IBM),...

### Good learning infrastructure

Books, short courses, academic courses,
 INCOSE/OMG tutorial, public examples, etc.

### OMG Certified Systems Modeling Professional

– http://www.omg.org/ocsmp/



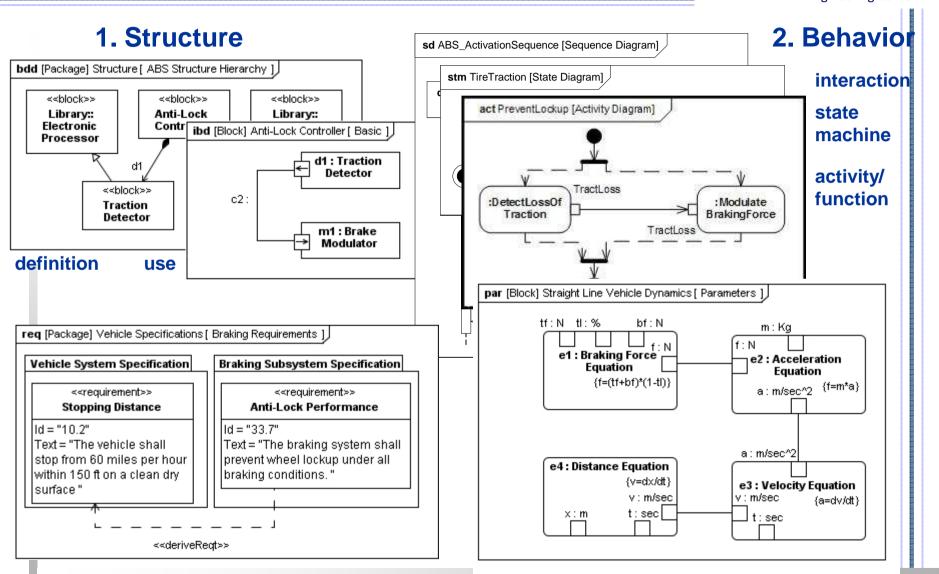






# What is SysML? (www.omgsysml.org)



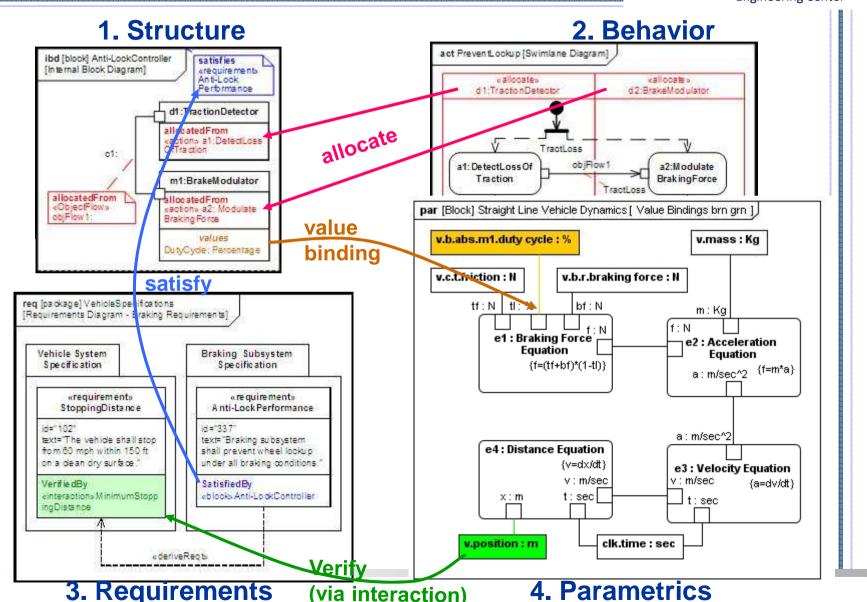


#### 3. Requirements

#### 4. Parametrics

# What is SysML? (www.omgsysml.org)





# What is Modelica? (www.modelica.org)

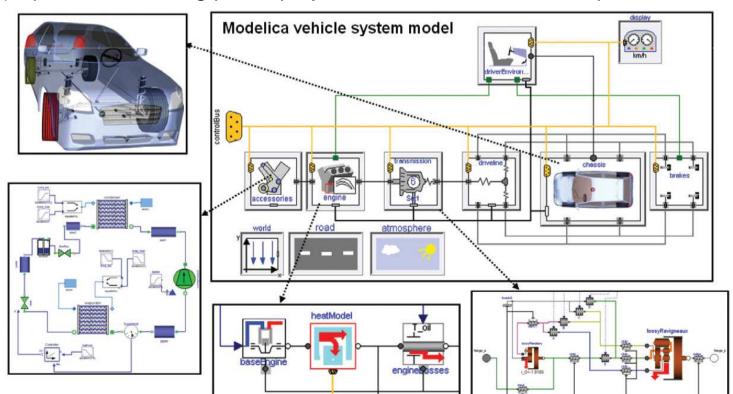


- State-of-the-art Modeling Language for System Dynamics
  - Differential Algebraic Equations (DAE)
  - Discrete Events
- > Formal, object-oriented language
- Standardized by the Modelica Association
  - Open language specification tool independent
- Multi-domain modeling
- Ports represent energy flow (undirected) or signal flow (directed)
- Acausal, equation-based, declarative (f-m\*a=0)

### **Modelica: Active and Mature Community**



- ➤ Modelica association 20+ free libs (www.modelica.org)
- ➤ 6 commercial solvers, 3 open-source solvers (Dymola, MapleSim, SimulationX, OpenModelica,...)
- ➤ EUROSYSLIB project 20+ libs under development (http://www.itea2.org/public/project\_leaflets/EUROSYSLIB\_profile\_oct-07.pdf)



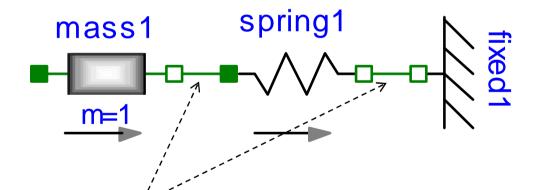
### Georgia Institute of Technology A Robot Example in Modelica Model-Based Systems Engineering Center mechanics axisControlBus initializeFlange axis3 tau1 [N.m] 2000 motor tordus tau4 [N.m] - tau5 [N.m -3000 + axisControlBus

#### **Modelica Semantics and Textual Syntax**



```
model Spring "Linear 1D translational spring"
  extends Translational.Interfaces.PartialCompliant;
  parameter SI.TranslationalSpringConstant c(final min=0, start = 1)
        "spring constant ";
  parameter SI.Distance s_rel0=0 "unstretched spring length";

equation
  f = c*(s_rel - s_rel0);
end Spring;
```



Graphical symbols defined as annotations in textual models

- > Connections represent Kirchhoff semantics
  - Across variables (voltage, pressure,...) are equal
  - Through variables (current, flow rate,...) add to zero

#### **Presentation Overview**

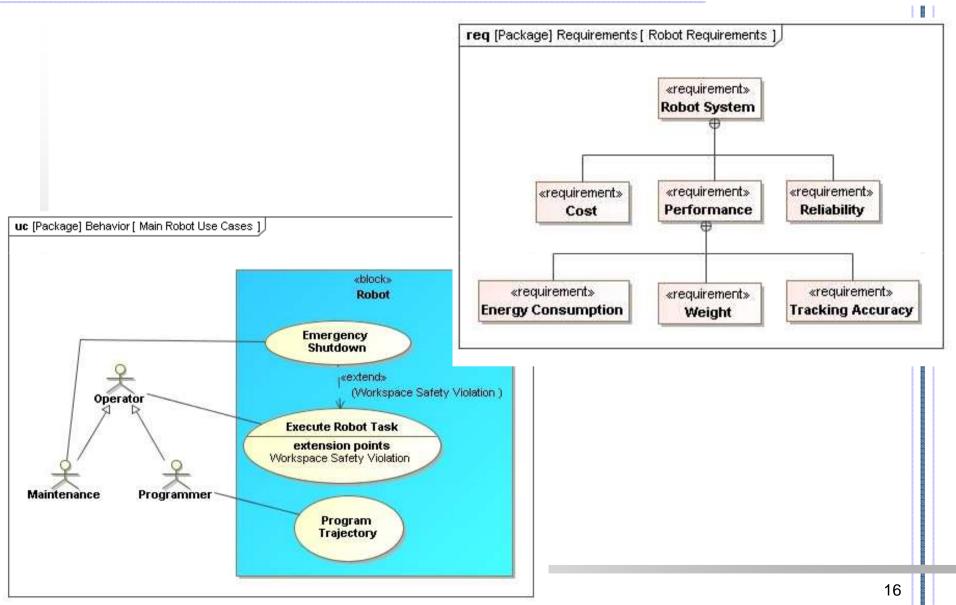


- ➤ What is SysML?
- What is Modelica?
- Motivating Example: Design & Analysis of Robot
  - SysML-Modelica Transformation Specification
  - > Transformations in Systems Modeling
  - > Timeline towards Specification Adoption
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### Georgia Institute of Technology A Robot Example in Modelica Model-Based Systems Engineering Center mechanics axisControlBus initializeFlange axis3 tau1 [N.m] 2000 motor tordus tau4 [N.m] - tau5 [N.m -3000 + axisControlBus

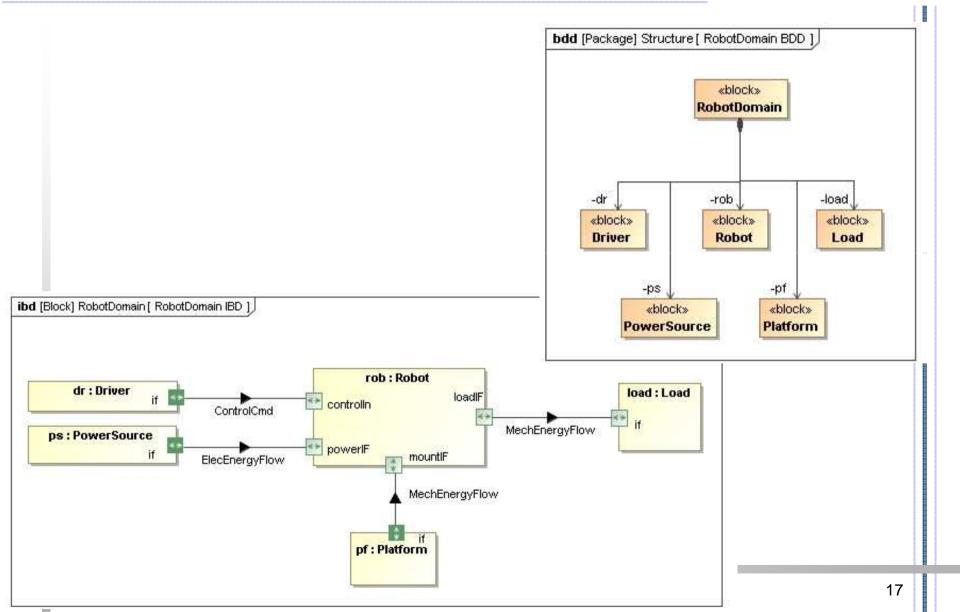
# SysML-Modelica Robot Example: UseCases & Requirements





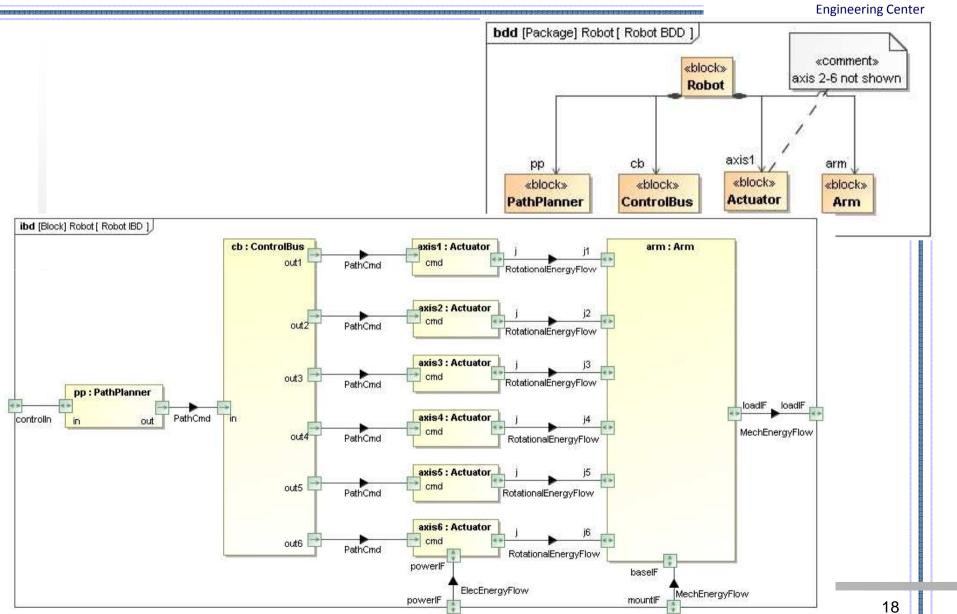
### SysML-Modelica Robot Example: Robot Domain BDD & IBD





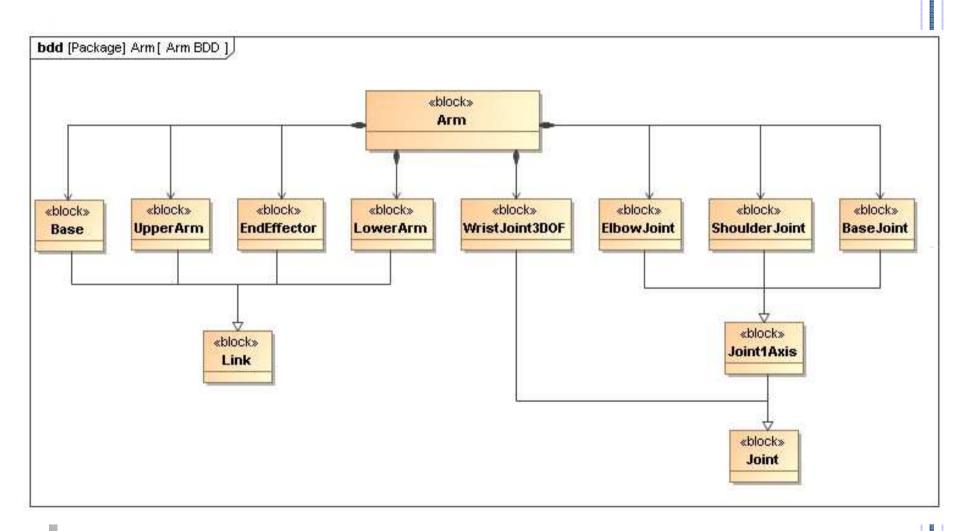
### SysML-Modelica Robot Example: Robot BDD & IBD





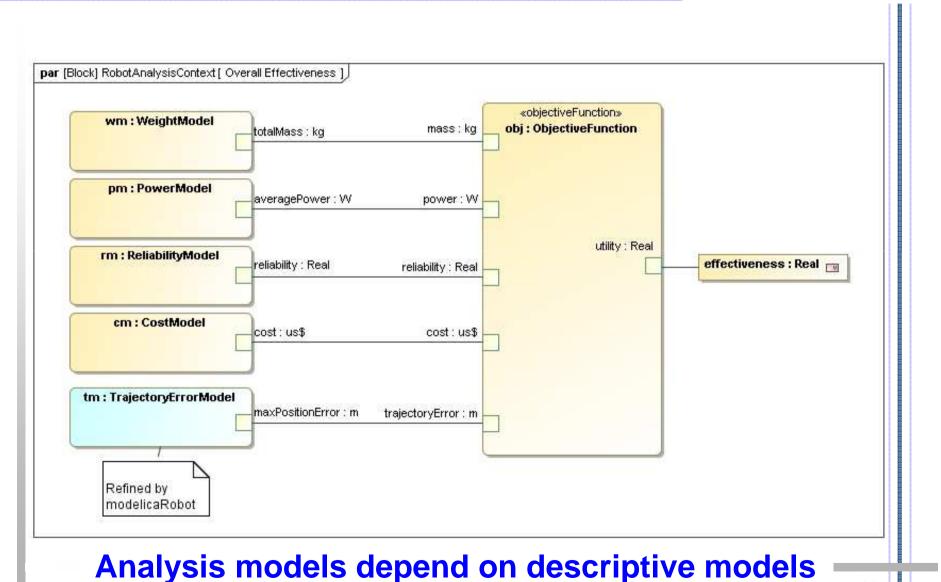
# SysML-Modelica Robot Example: Robot Arm BDD





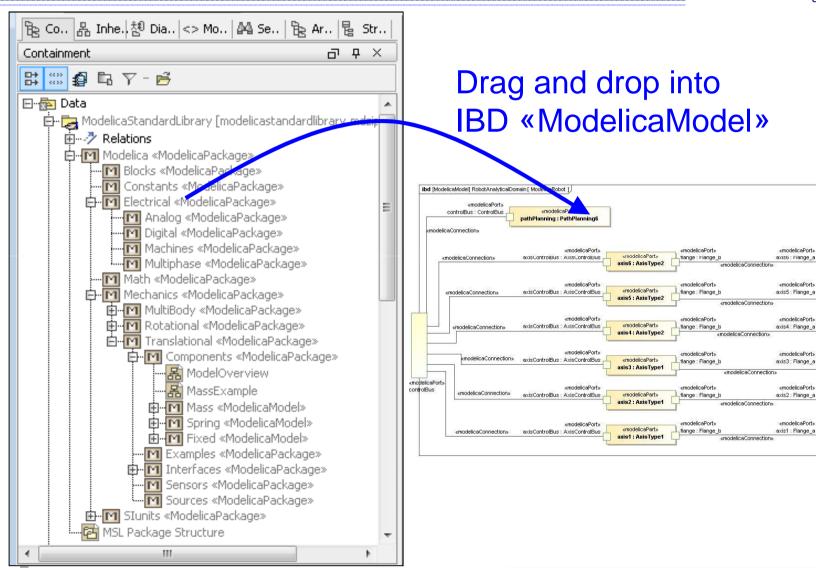
# SysML-Modelica Robot Example: Analysis and Trade Study





### SysML4Modelica Analytical Model: Compose Model from Standard Library

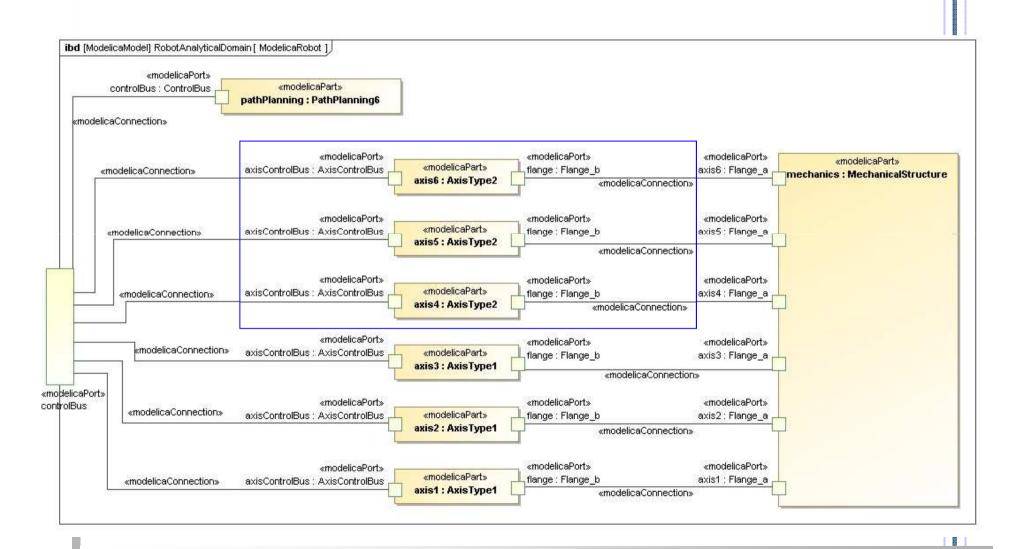




/modelicaParts

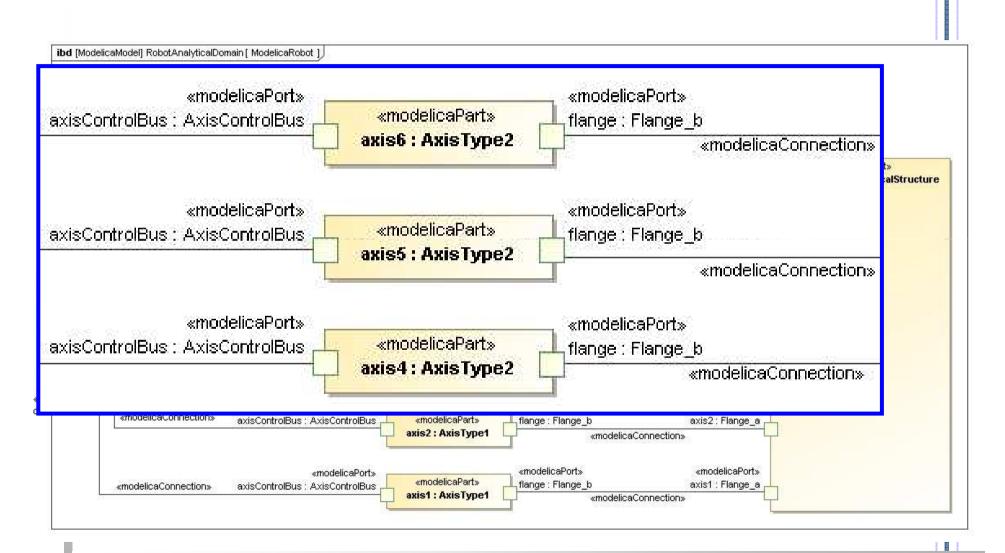
### SysML4Modelica Analytical Model: Detailed IBD





### SysML4Modelica Analytical Model: Detailed IBD





### SysML4Modelica Analytical Model: Relation to Modelica Native Model

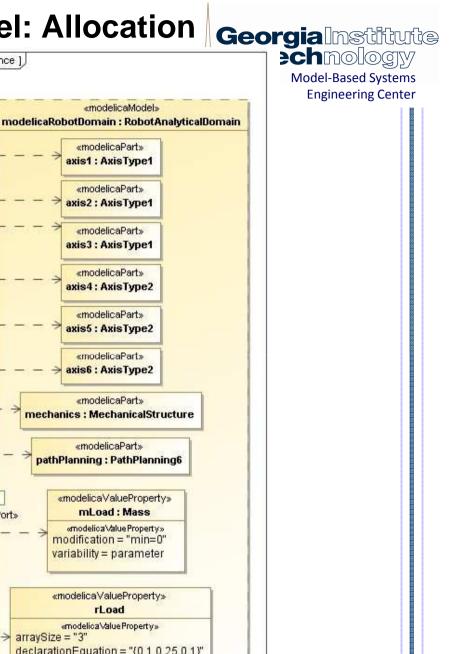


ibd [ModelicaModel] RobotAnalyticalDomain [ ModelicaRobot ] «modelicaPort» controlBus : ControlBus pathPlanning : PathPlanning6 «modelicaConnection» «modelicePort» «modelicePort» «modelicePort» emodelicaParts «modelicaConnection» axisControlBus : AxisControlBus flange : Flange\_b axis6 : Flange\_a ics : MechanicalStructure axis6 : AxisType2 «modelicaConnection «modelicaPort» «modelicaPort» «modelicaPort» axisControlBus : AxisControlBus «modelicaPart» axis5 : Flange\_a flange : Flange\_b «modelicaConnection» axis5 : AxisType2 «modelicaConnection» ~modelicaPort» «modelicaPort» «modelicaPort» «modelicaPart» axisControlBus : AxisControlBus flange : Flange\_b axis4: AxisType2 pathPlanning «modelicaPort» «modelicaPort» «modelicaPort» modelicaConnection» axisControlBus : AxisControlBus «modelicaPart» axis3 : Flange\_a flange : Flange b axis3: AxisType1 «modelicaPort» «modelicaPort» «modelicaPort» «modelicaPort» controlBus «modelicaConnection» axisControlBus : AxisControlBus «modelicaPart» flange : Flange\_b axis2: Flange\_a axis2: AxisType1 axis6 «modelicaPort» «modelicaPort» «modelicaPort» tro@ua6 flange : Flange\_b axis1 : Flange\_a mechanics axis1: AxisType1 axish axisControlBus5 axis4 controlBus axis3 axisControlBus3 axisControlBus2 axisControlBus1

# SysML4Modelica Analytical Model: Allocation Georgia Institute schnology

rd: RobotDomain

rob: Robot

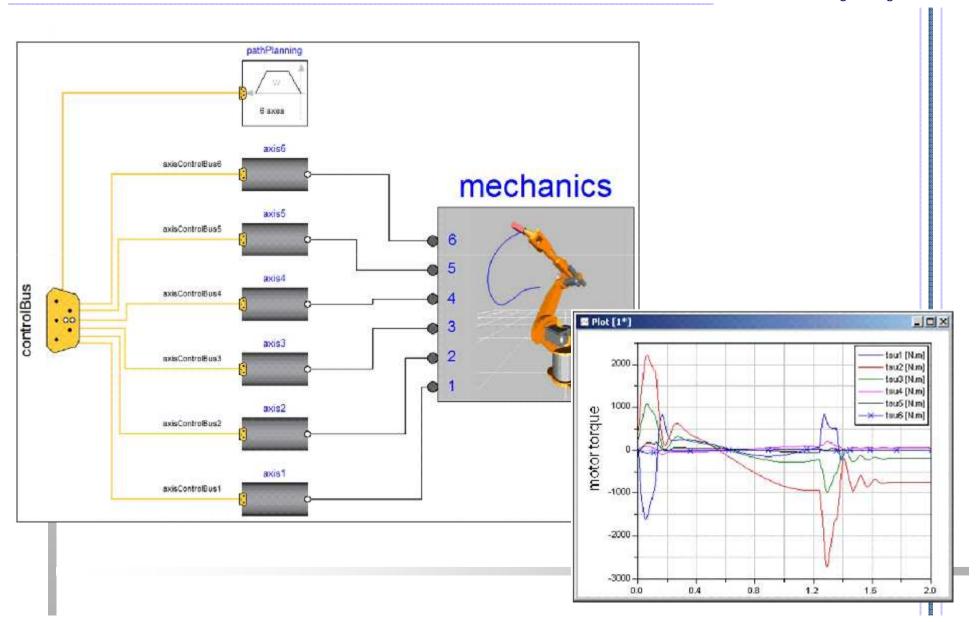


«modelicaModel»

### SysML-Modelica Robot Example: Modelica model with simulation results

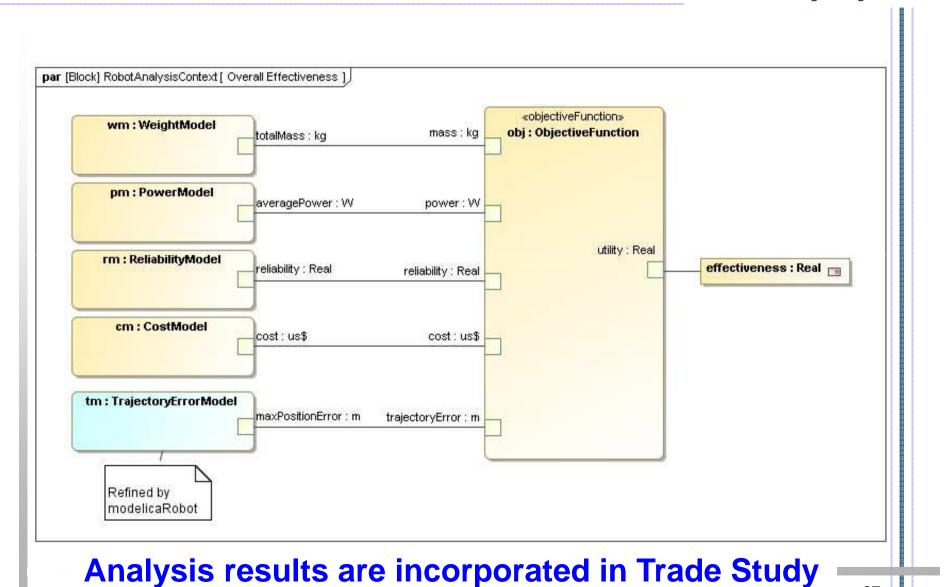


Nodel-Based Systems Engineering Center



# SysML-Modelica Robot Example: Analysis and Trade Study





#### **Presentation Overview**

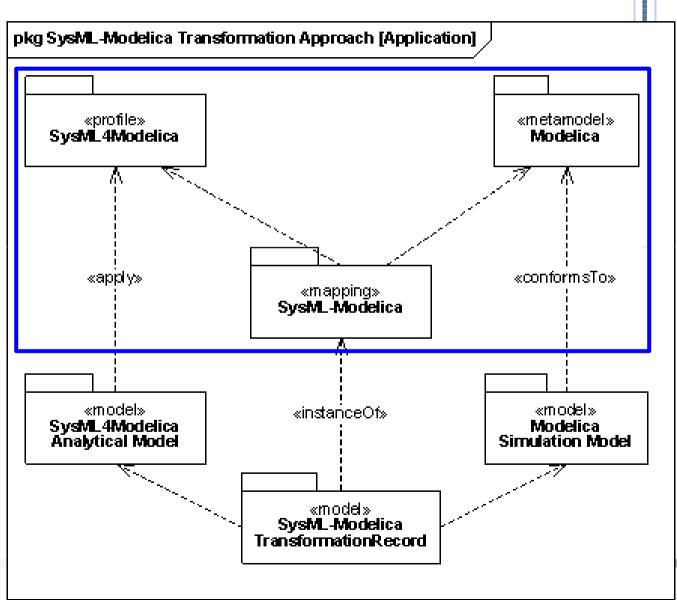


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# SysML-Modelica Transformation Specification

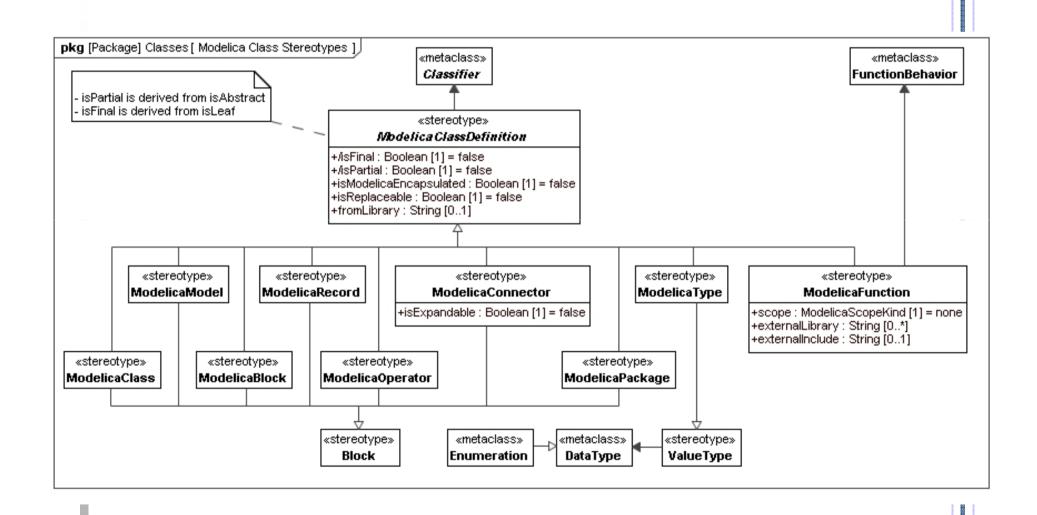


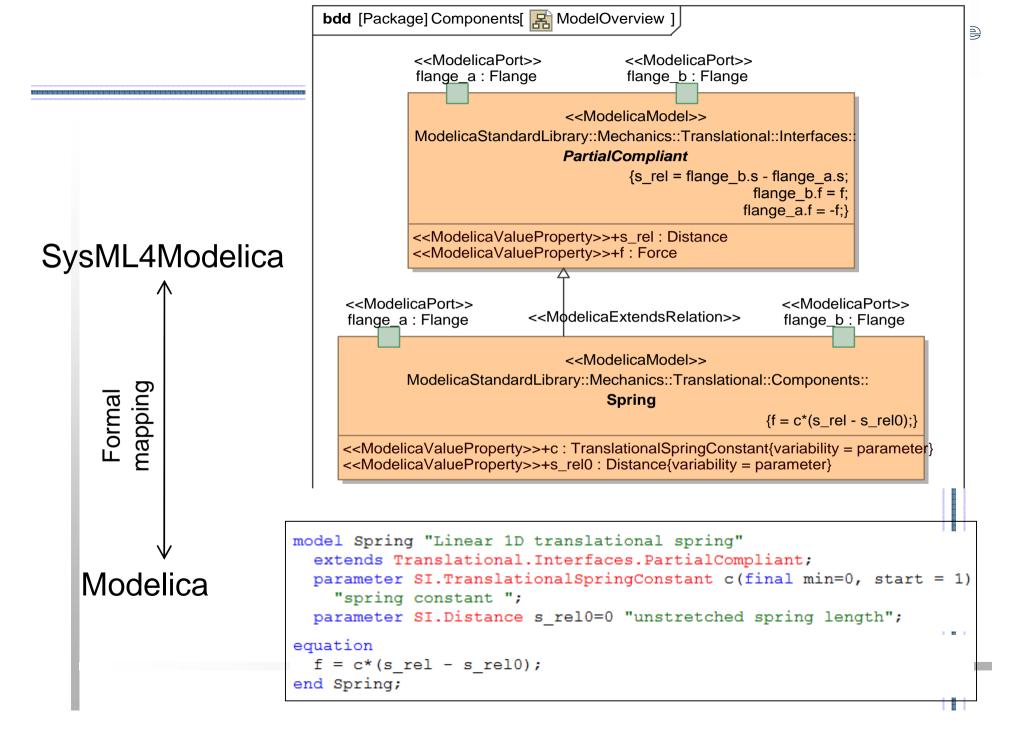
SysMLModelica
Transformation
follows the
principles
of ModelDriven
Architecture
(MDA)



### SysML4Modelica Profile

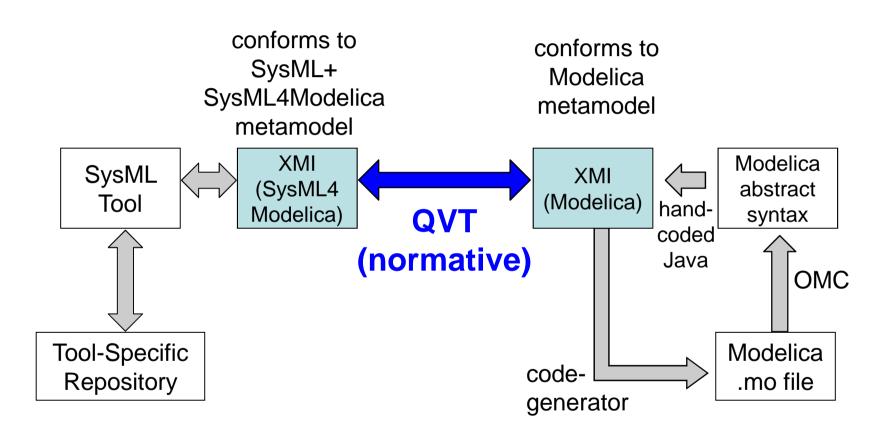






## Reference implementation: Based on OMG QVT



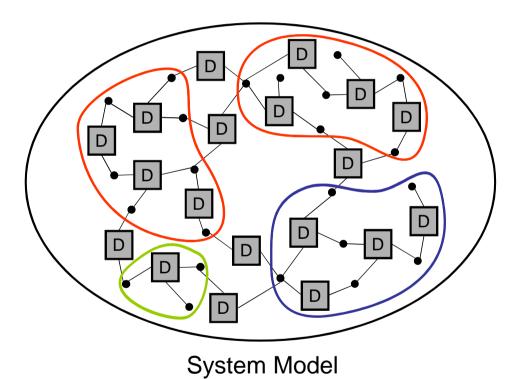


QVT = Query / View / Transformation

### **Transformations in Systems Modeling**

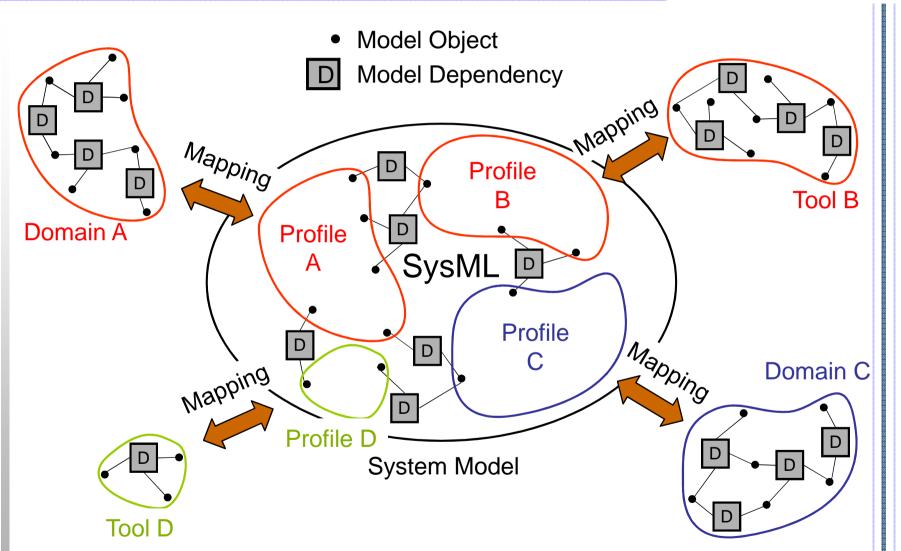


- Model Object
- **D** Model Dependency



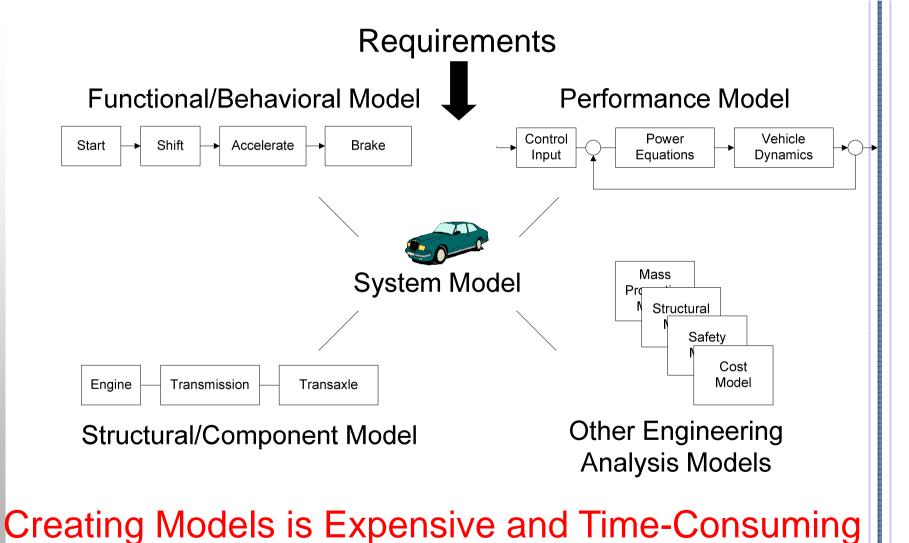
### **Transformations in Systems Modeling**





#### **Model Reuse in MBSE**





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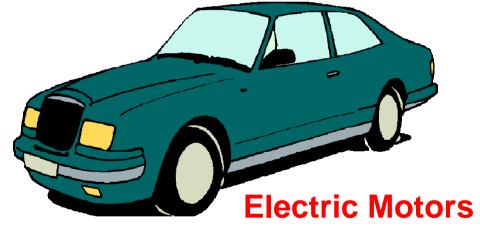
#### Reusable Models in MBSE



- Physical components are reused
- Portions of the systems model repeat
- Patterns for instantiating these portions









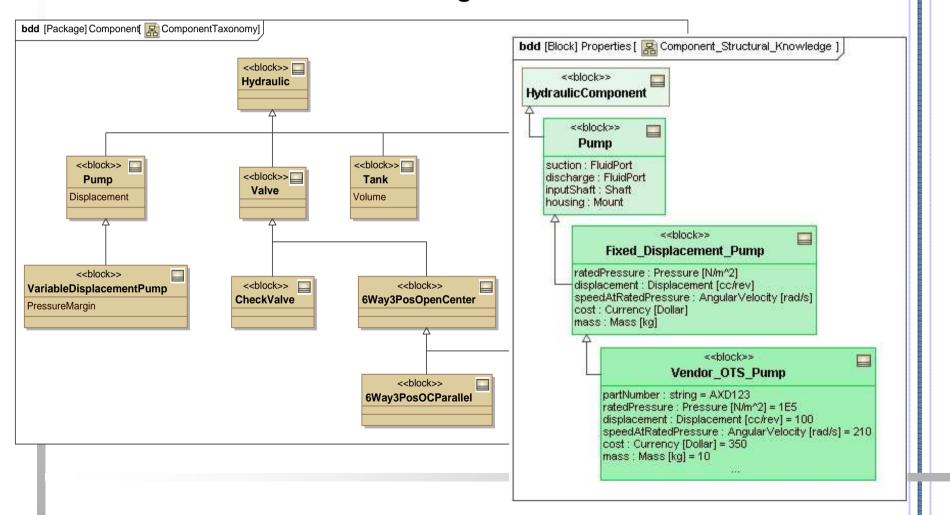
- ➤ Component models → Domain specific model libraries
- Application of pattern = model transformations

### **Model Library of Hydraulic Components**

- Georgia Institute
  of Technology

  Model-Based Systems

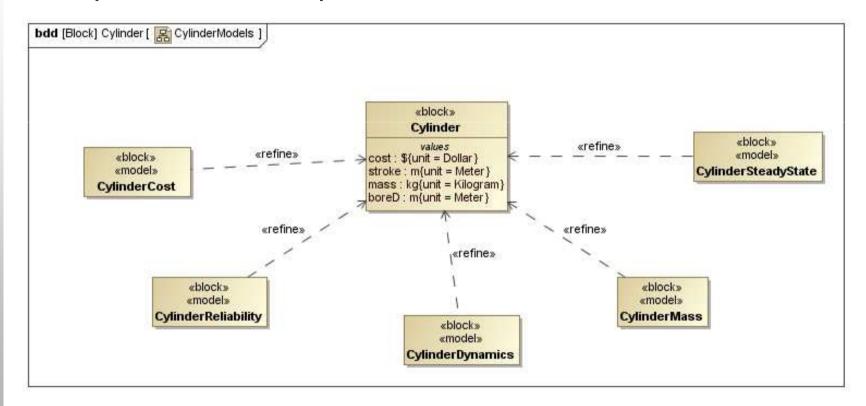
  Engineering Center
- Needs to be carefully designed and managed
- > Encodes domain knowledge



### Other Perspectives of Cylinder are Reusable



- When cylinder is used, other corresponding models are often used also
- → Capture the reuse pattern



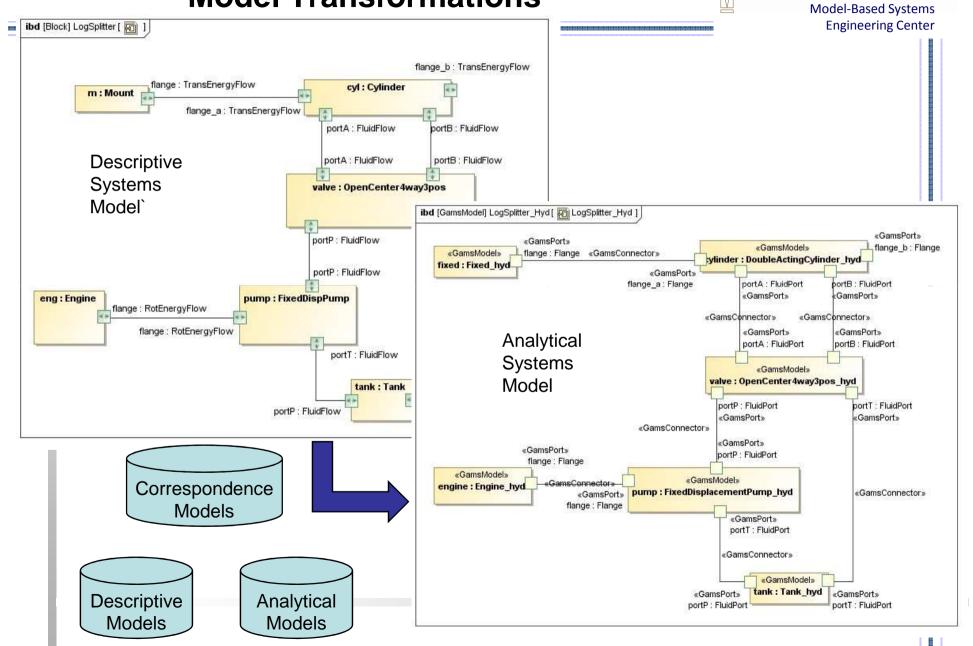
#### **Correspondence Patterns**



**Engineering Center** bdd [Package] ModelCorrespondence [ R ModelCorrespondence ] «block» ModelCorrespondenceContext -analytical -descriptive «GamsModel» portA: FluidFlow «allocate» portA: FluidConnector Cylinder Cylinder (boreDiameter =e= sum(cylinderId, cylinderSelect(cylinderId)\*boreDiameterCatalogData(cylinderId)) portB : FluidConnector portB : FluidFlow «allocate» cost =e= sum(cylinderId, cylinderSelect(cylinderId)\*costCatalogData(cylinderId)) sum(cylinderld, cylinderSelect(cylinderld))=e=1 cost: \${unit = Dollar} rodEnd : FluidConnector rod: TransEnergyFlow «allocate» f =e= (Pi\*0.25\*sqr(boreDiameter)\*portA.p) - (Pi\*0.25\*(sqr(boreDiameter)-sqr(rodDiameter))\*portB.q) stroke : m{unit = Meter} mass: kg{unit = Kilogram} mass =e= sum(cylinderId, cylinderSelect(cylinderId)\*massCatalogData(cylinderId)) base : TransEnergyFlow «allocate» baseEnd : FluidConnector boreD : m{unit = Meter} maxPressure =e= sum(cylinderld, cylinderSelect(cylinderld)\*maxPressureCatalogData(cylinderld)). portA.p = = maxPressure portA.g =e= v\*0.25\*Pi\*sgr(boreDiameter) portB.p = |= maxPressure portB.q\*sqr(boreDiameter) + portA.q\*(sqr(boreDiameter)-sqr(rodDiameter)) =e= 0, rodDiameter =e= 0.5\*boreDiameter strokeLength =e= sum(cylinderId, cylinderSelect(cylinderId)\*strokeLengthCatalogData(cylinderId)) time\*abs(portA.q) =e= I\*0.25\*Pi\*sqr(boreDiameter) time =q= 0.00001 «refine» abs(v)\*time =e= |} values «GamsVariable»boreDiameter : m «Gams Variable» stroke Length: m par [Block] ModelCorrespondenceContext [ R ModelCorrespondenceContext ] «Ga «Ga Analytical Model refines the «Ga «Ga Descriptive Model «Ga descriptive : Cylinder analytical: Cylinder «Ga «Ga • Structural ports are allocated to «Ga cost:\$ cost:\$ «Ga corresponding analytical ports «Ga «Ga strokeLength: m stroke: m • Descriptive properties bound to «Ga «Ga analytical properties mass: kg mass: kg boreD: m boreDiameter: m

### Model Composition using Model Transformations

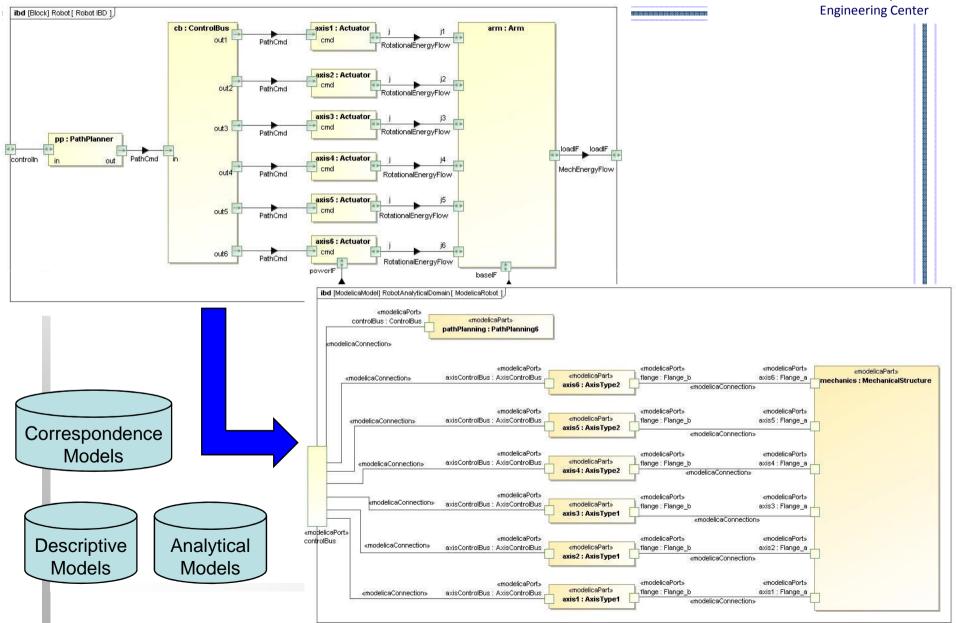




### **Descriptive to Analytical Transformation**



Model-Based Systems
Engineering Center



#### **Summary**



#### > Objective:

 Leverage the strengths of both SysML and Modelica by integrating them to create a more expressive and formal MBSE language.

Descriptive Modeling in SysML



Formal Equation-Based Modeling for Analyses and Trade Studies in Modelica

http://doc.omg.org/syseng/2010-6-8

### **Acknowledgements**



#### Working Group Members

- Yves Bernard (EADS)
- Roger Burkhart (Deere & Co)
- Wuzhu Chen (Univ. Braunschweig)
- Hans-Peter De Koning (ESA)
- Sandy Friedenthal (Lockheed Martin)
- Peter Fritzson (Linköping University)
- Nerijus Jankevicius (No Magic)
- Alek Kerzhner (Georgia Tech)
- Andreas Korff (Atego)
- Chris Paredis (Georgia Tech)
- Axel Reichwein (Georgia Tech)
- Nicolas Rouquette (JPL)
- Wladimir Schamai (EADS)

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  - Roxanne Moore
  - Marc Pare
- Axel Reichwein
  - Wladimir Schamai

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- National Science Foundation