

# SAVI Behavior Model Consistency Analysis

Mike Kerstetter, SAVI PM  
Kurt Woodham, NASA LaRC

## GLOBAL PRODUCT DATA INTEROPERABILITY **SUMMIT** 2016



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# Author background

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- **Mike Kerstetter**
  - AVSI SAVI Project Manager since 2015
  - The Boeing Company 1980 – 2014
    - Associate Technical Fellow
    - Manager of Adaptive Systems group
    - Program Manager of Intelligent and Adaptive Systems research portfolio
    - BS and MS in Aerospace Engineering from Texas A&M University
- **Kurt Woodham**
  - NASA Langley Research Center 2009-Present
    - Safety Critical Avionics Systems Group
  - NASA Software IV&V (1997-2009 - Contractor)
  - BS & MS in Aerospace Engineering from University of Colorado

# Talk outline

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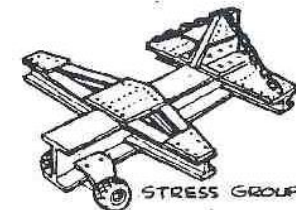
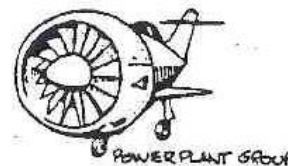
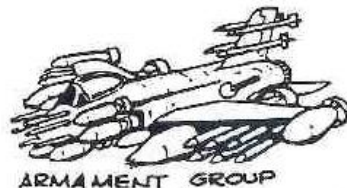
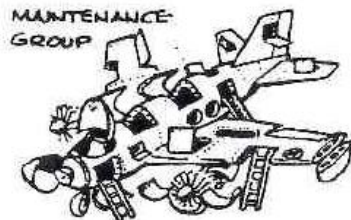
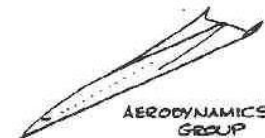
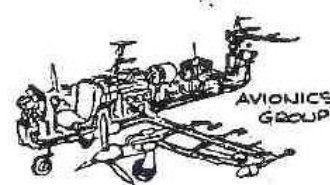
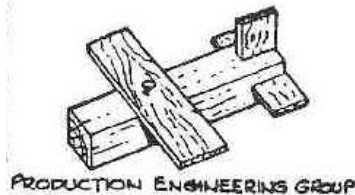
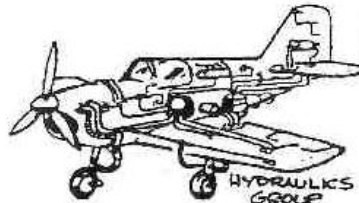
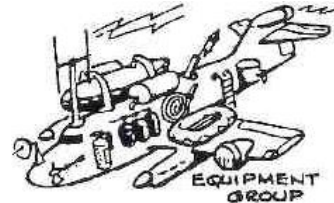
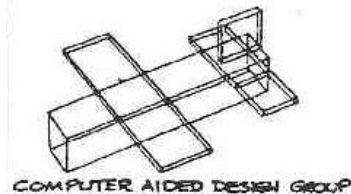
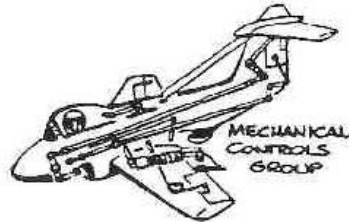
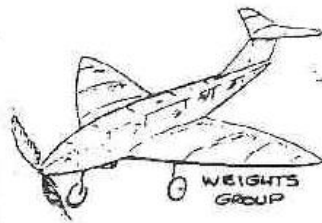
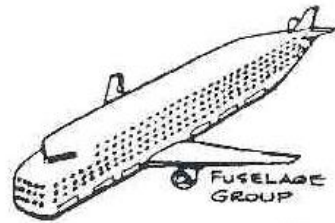
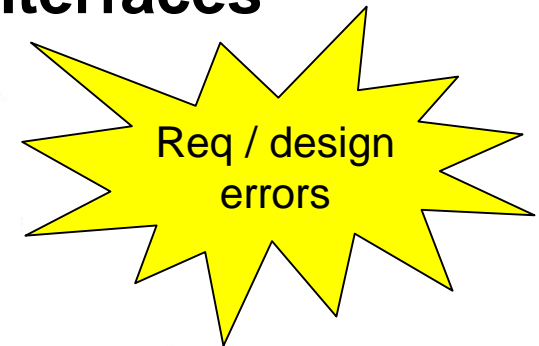
- **SAVI Overview**
- **What is a “Behavior Model”?**
- **What is “Consistency”?**
- **Examples**
- **Supporting framework**

- **SAVI Overview**
- What is a “Behavior Model”?
- What is “Consistency”?
- Examples
- Supporting framework

# Many systems integrated into one aircraft

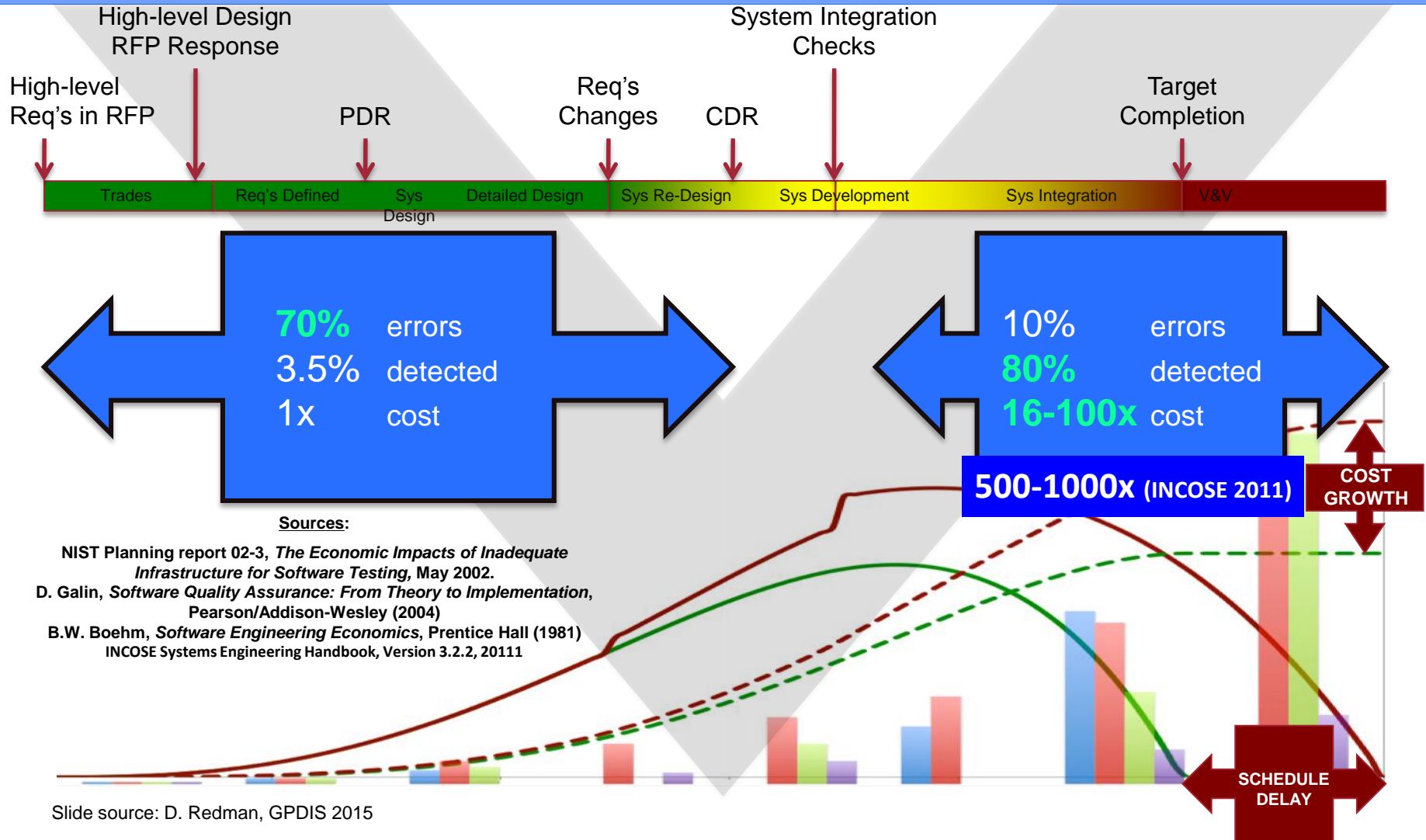
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- System complexity increasing
- Shared resources
- Complex interfaces



# The impact of requirement/design errors is documented

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# SAVI Approach

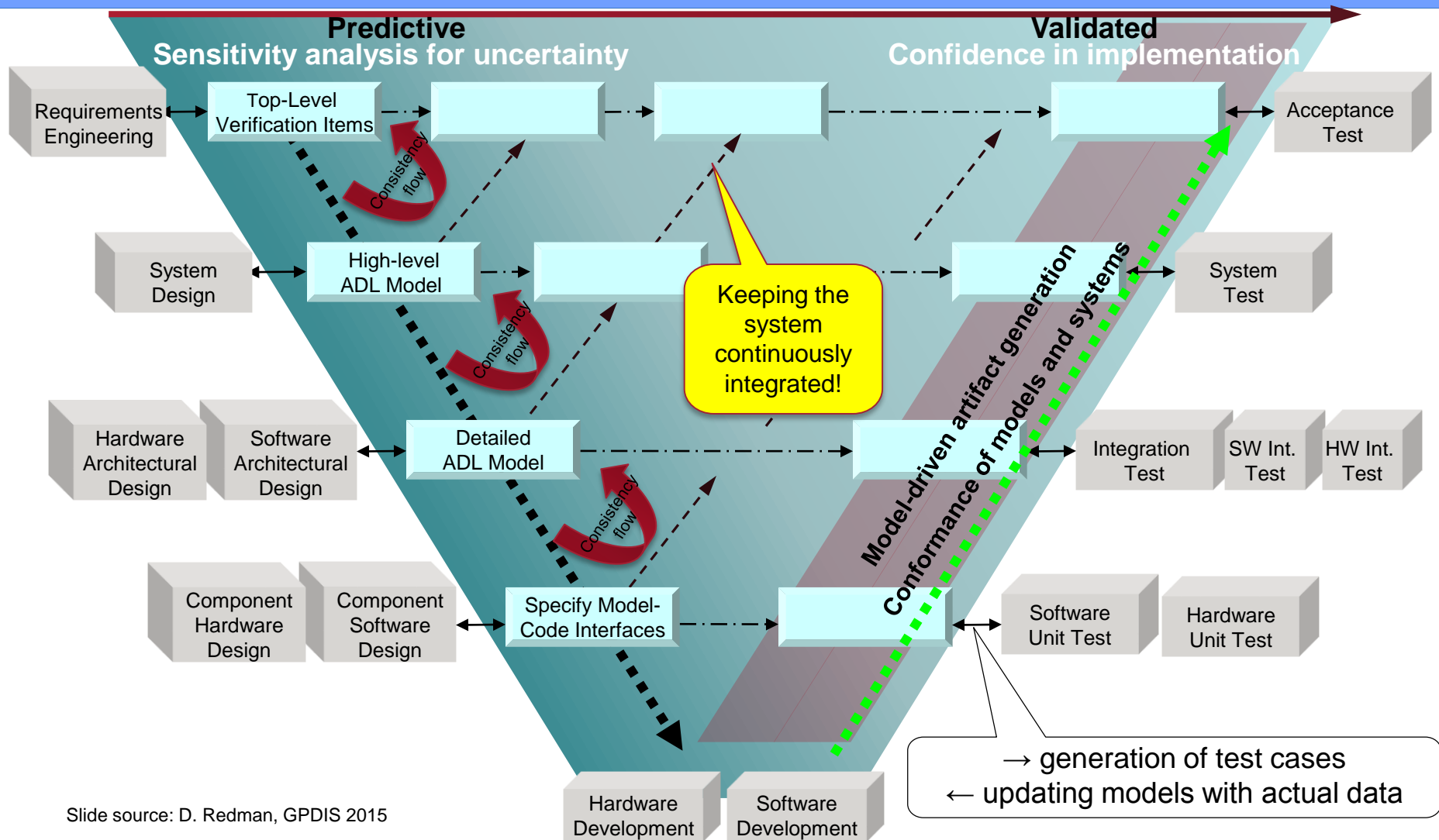
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- **“System Architecture Virtual Integration”**
- **Leverage MBSE best practices and tools**
  - SAVI developed with exemplar toolset – seek to define tool characteristics, but not specific tool selection
- **Reduce costs/development time through early and continuous model-based virtual integration**
  - Inter-domain and inter-model consistency checks
  - Protect Intellectual Property (IP)
  - Support definition/capture of incremental evidence for system safety analysis – supporting certification approach
  - Consistency checking of constituent models participating in integration is critical element of the SAVI concept



# SAVI Virtual Integration “V”ision

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Slide source: D. Redman, GPDIS 2015



# SAVI Participants

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## Full Members

- Airbus
- Boeing
- DoD
- Embraer
- GE Aviation
- Honeywell
- Rockwell Collins
- Lockheed Martin

## Liaison Members

- FAA
- NASA
- SEI



*Rockwell  
Collins*



**Honeywell**



Software Engineering Institute



**SAVI**  
System Architecture Virtual Integration



**AIRBUS**



## Tool Vendor Partners

- Adventium Labs
- Esterel Technologies
- Eurostep Limited



**BOEING**



**EMBRAER**

- SAVI Overview
- **What is a “Behavior Model”?**
- What is “Consistency”?
- Examples
- Supporting framework

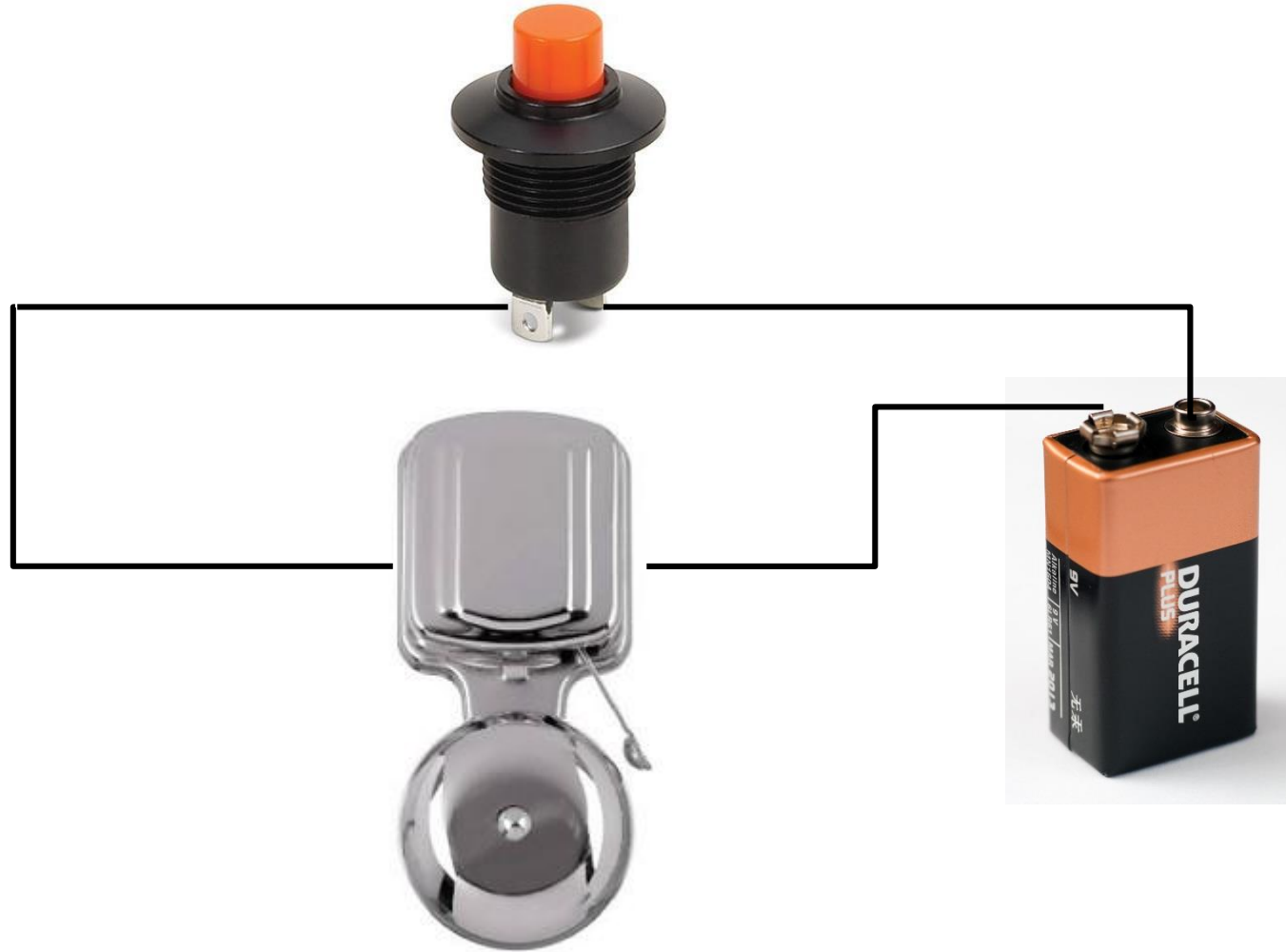
# SAVI defines two general model categories

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- **“Fit”**
  - Generally static properties
  - Integrated models queried for composite properties
    - Parts → Boards → Boxes → Subsystems → Integrated system
- **“Behavior”**
  - May contain “shared” properties with fit models
    - Mass properties, locations, hinge axis orientation
  - Intent is to represent dynamic or functional emergent properties
  - Emergent – meaning the property is not realized through an aggregation of model elements
  - Often analyzed via simulation, but other analysis methods available

# Emergent property – simple illustration

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- SAVI Overview
- What is a “Behavior Model”?
- **What is “Consistency”?**
- Examples
- Supporting framework

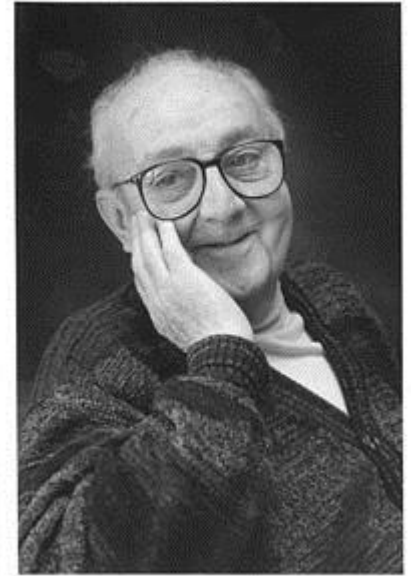
# Definition of consistency

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- **Short answer: Consistency is...**
  - ... really hard to nail down!
- **Long answer: Consistency is...**
  - ... a property of a set of models
  - ... dependent on the purpose of the analysis
  - ... a way to assure that there are no contradictions
  - ... essential to establish that integrated model set will provide meaningful, relevant results
- **Accounts for assumptions, approximations, ranges (altitudes, airspeed, temperature)**
- **Appropriate to the system context**

# This is not a new problem...

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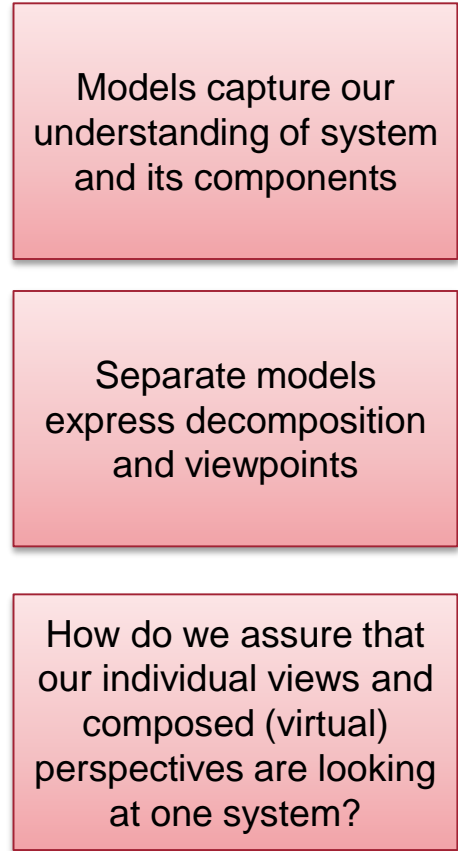


- **George E. P. Box (1919-2013)**
  - “Essentially, all models are wrong, but some are useful.”
  - “Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful.”
- **Challenge for SAVI “consistency checks”**
  - **How “right” does a model have to be to use it in a specific context (which may include other models)**

Box, G. E. P., and Draper, N. R., (1987), *Empirical Model Building and Response Surfaces*, John Wiley & Sons, New York, NY.



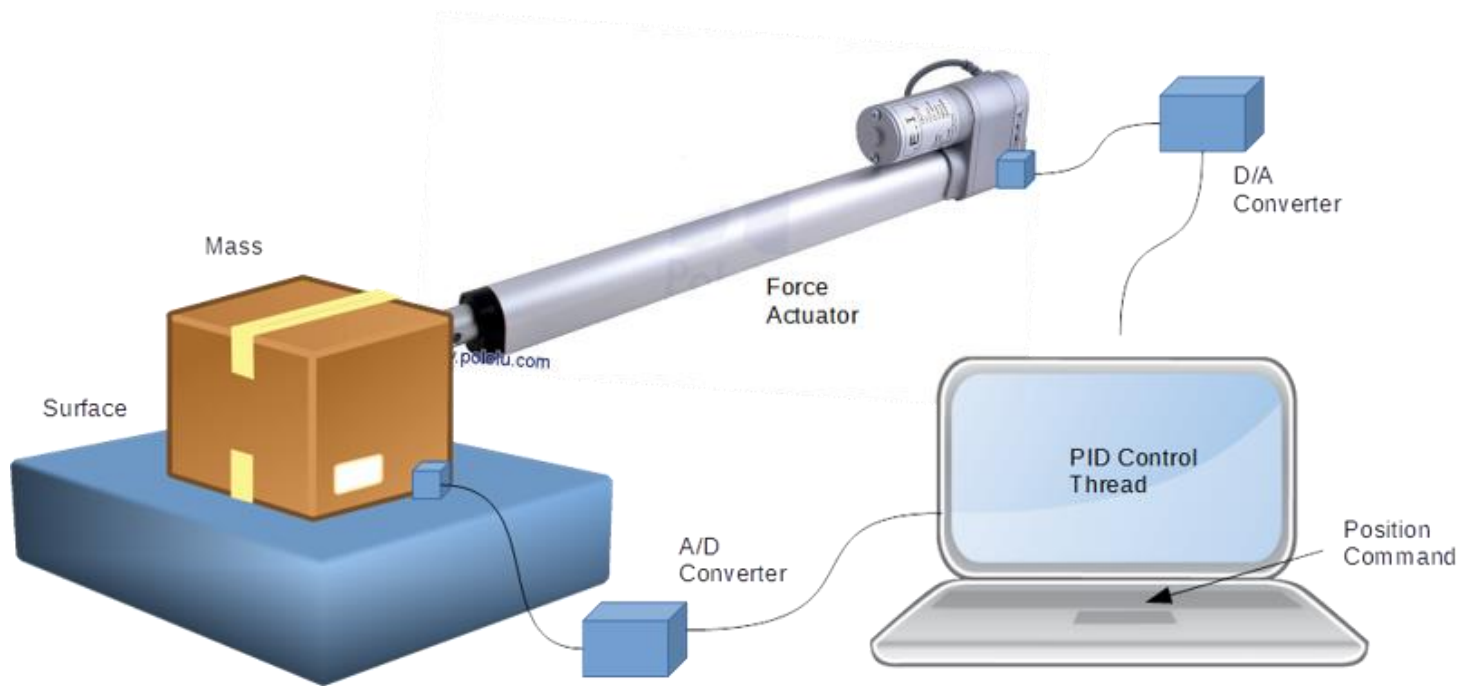
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Only by assuring ourselves that our models are consistent can we have confidence that subsequent analyses and their results can be trusted!

# Example system for illustration

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# Consistency property types illustrated

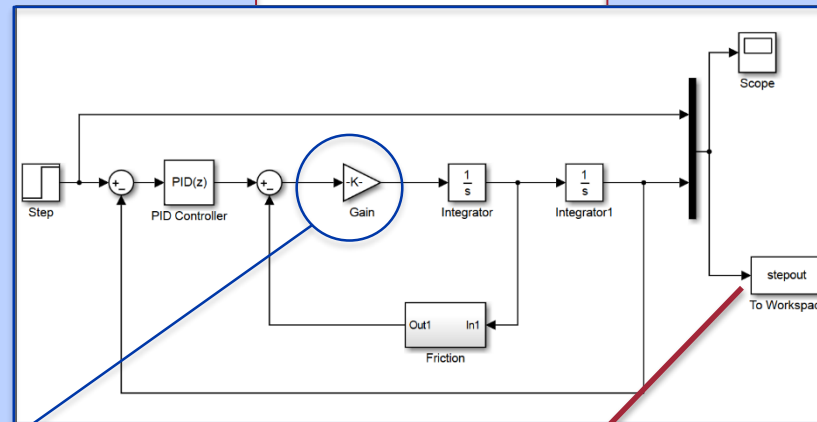
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**Data Value**  
(numerical values)

**Data Type**  
(variable types, units, range, tolerance)

**Data Semantics**  
(interpretation)

**Data Metadata**  
(restrictions, assumptions, source)

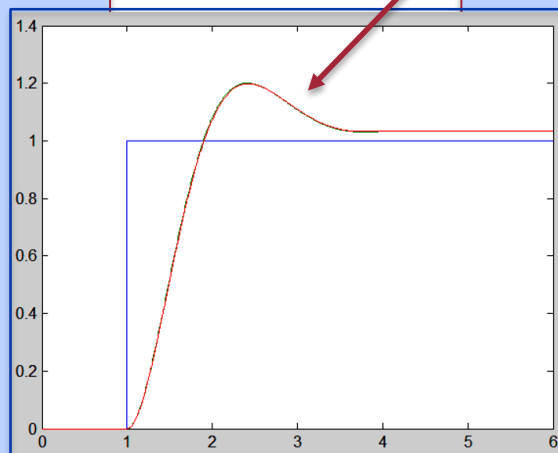


**Model Property**  
(patterns, component inventory, interfaces)

**Model Semantics**  
(interpretation)

**Model Metadata**  
(restrictions, assumptions, source)

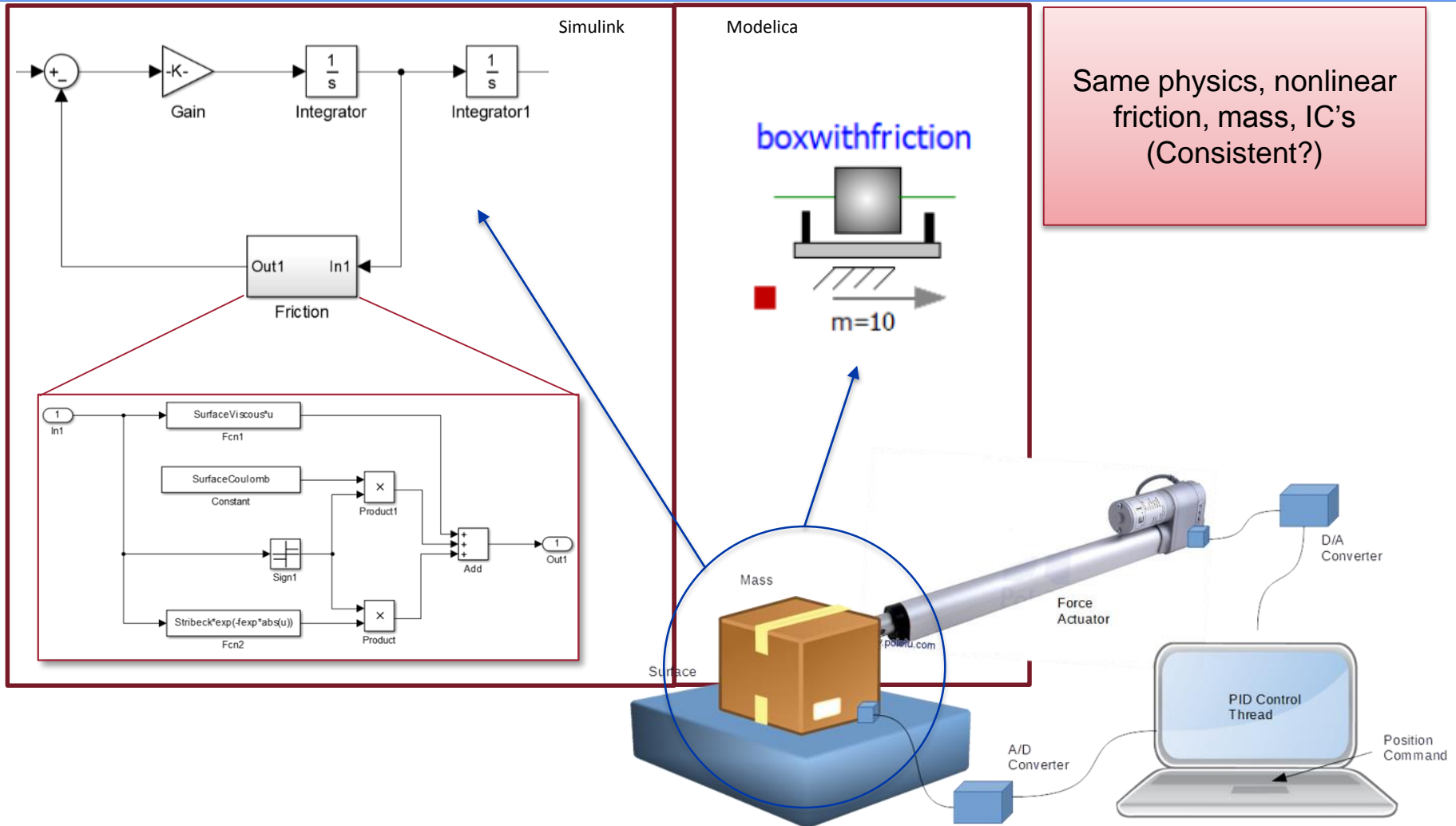
**Model Behavior**  
(time history response, invariant properties)



- SAVI Overview
- What is a “Behavior Model”?
- What is “Consistency”?
- **Examples**
- Supporting framework

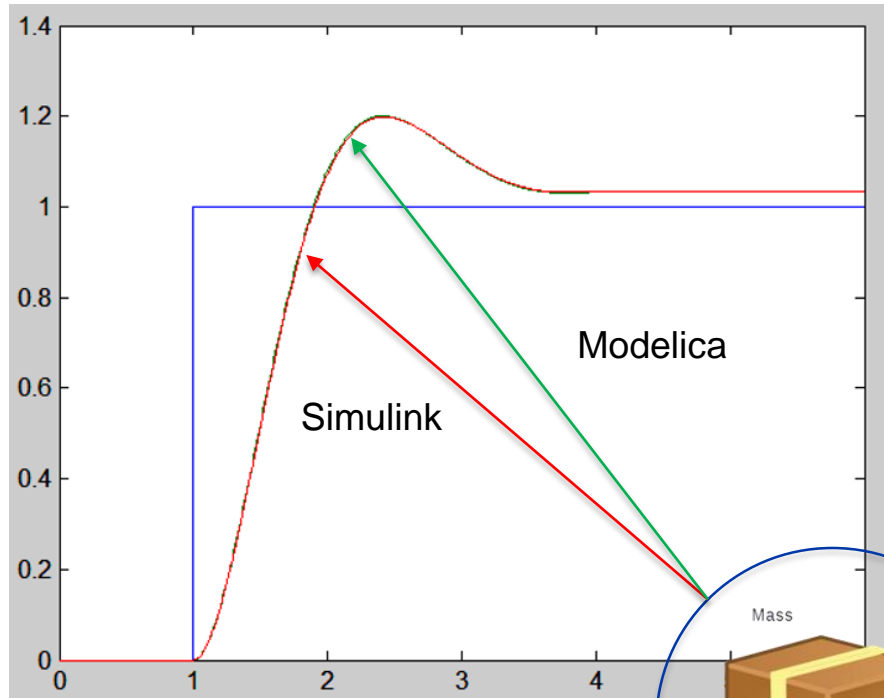
# Challenges of data and model component consistency

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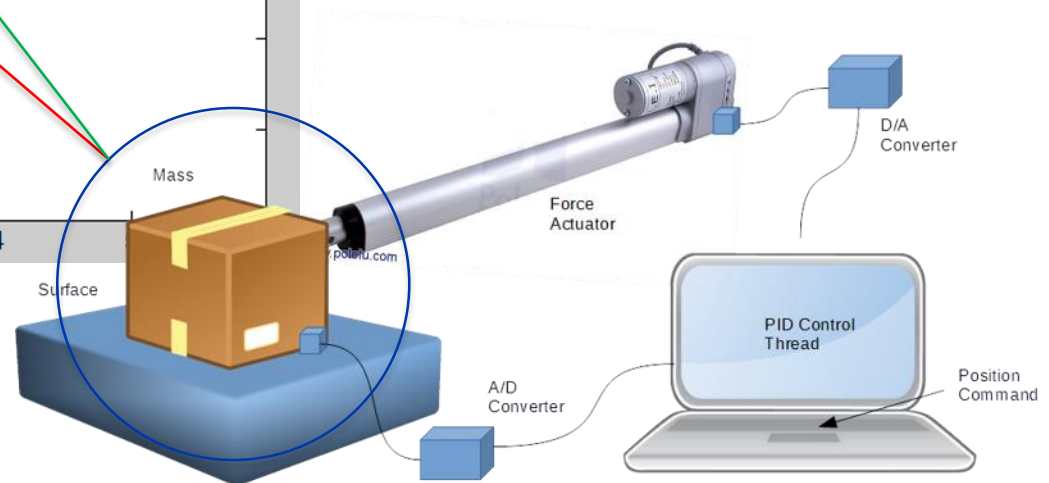


# Differing models of computation

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Different models of computation → subtle behavior difference around zero velocity (Inconsistent?)



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IMA  
Cabinets  
(2)

## Remote Data Concentrators (2)

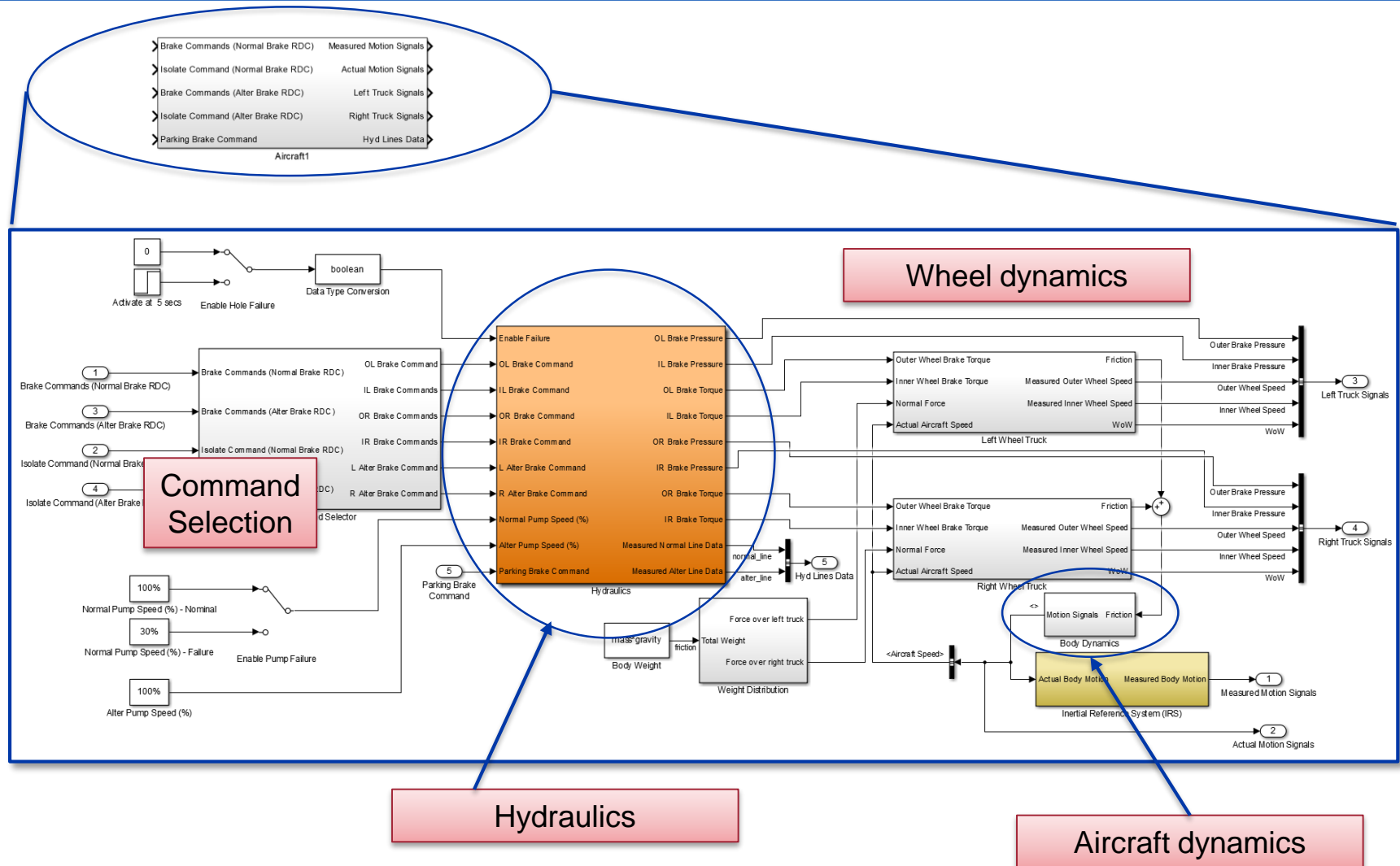
## Networks (2)

Hydraulics  
Brake actuation  
A/C dynamics



# Drill down to hydraulics model

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# Dramatically different abstraction – consistent?

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Complex

Simple

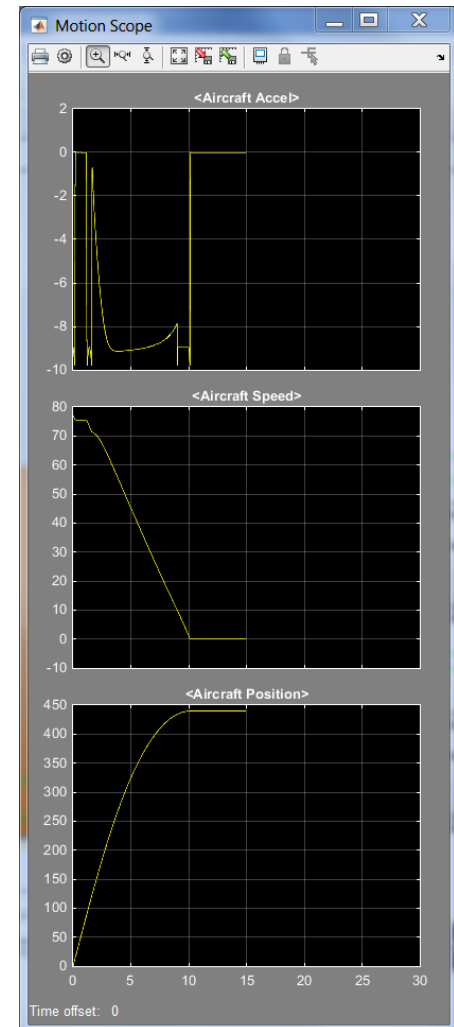
Enable Failure	OL Brake Pressure
OL Brake Command	IL Brake Pressure
IL Brake Command	OL Brake Torque
OR Brake Command	IL Brake Torque
IR Brake Command	OR Brake Pressure
L Alter Brake Command	IR Brake Pressure
R Alter Brake Command	OR Brake Torque
Normal Pump Speed (%)	IR Brake Torque
Alter Pump Speed (%)	Measured Normal Line Data
Parking Brake Command	Measured Alter Line Data

Hydraulics1

Enable Failure	OL Brake Pressure
OL Brake Command	IL Brake Pressure
IL Brake Command	OL Brake Torque
OR Brake Command	IL Brake Torque
IR Brake Command	OR Brake Pressure
L Alter Brake Command	IR Brake Pressure
R Alter Brake Command	OR Brake Torque
Normal Pump Speed (%)	IR Brake Torque
Alter Pump Speed (%)	Measured Normal Line Data
Parking Brake Command	Measured Alter Line Data

Hydraulics1

- Pump
  - Accumulators
  - Line pressure loss
  - Valve dynamics
  - Actuator
- Scale factor
- Actuator



- SAVI Overview
- What is a “Behavior Model”?
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- Examples
- **Supporting framework**

# 2016 model mapping and interface progress overview

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- Eurostep continuing to support SAVI Behavior work
  - Preliminary work described by D Redman: GPDIS 2015
    - Mapping of four model languages into common representation within SAVI Model-of-Models
    - Identify equivalences
    - Display in circle and network diagram interface
  - 2016
    - Rewrite of ShareAspace methodology
    - Instantiation of supporting tool features to identify and evaluate equivalences
    - Progress towards user display/feedback capability

# Tool to allow upload and extraction of Model-of-Models data

SAS Model Uploader

Converter Uploader

Controls

- SysML
  - SCADE
  - Enterprise Architect
- Others
  - Simulink
  - Modelica
  - AADL
- FIT
  - ECAD/AP210
  - MCAD/AP214
  - System Interconnect
  - PackageWright
  - AP214 Transformations

Remove Model

Reset

Status

Complete! JSON Models added to the Uploader tab

Model File Name	Default Version	Sub Type
<b>SYsML</b> 1 item(s)		
simple_system	1.0.0.0	EnterpriseAr
<b>Simulink</b> 1 item(s)		
blockdiagram	1.0.0.0	None
<b>Modelica</b> 1 item(s)		
slidingblockpid1-fullSecond	1.0.0.0	None
<b>AADLinstance</b> 1 item(s)		
SimpleModel	1.0.0.0	None

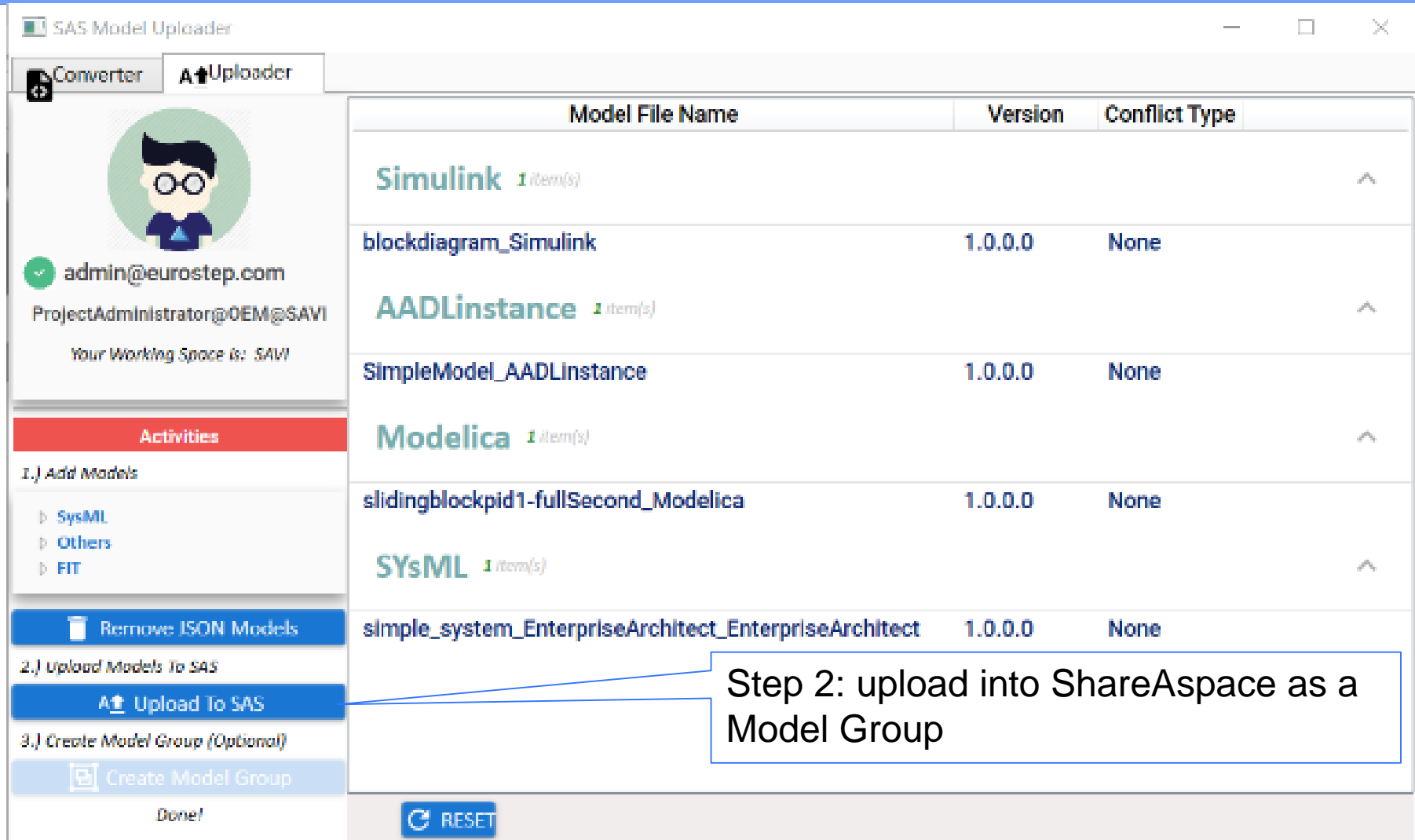
Step 1: execute data extraction from each model

Output JSON Path C:\Users\prajr\Downloads\Installers\Output

Generate JSON

# Tool to allow upload and extraction of Model-of-Models data

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The screenshot shows the SAS Model Uploader application window. It has a sidebar on the left with a user profile for 'admin@eurostep.com' and a list of activities. The main area displays a table of model groups and their contents. A callout box points to the 'Upload To SAS' button, indicating the next step in the process.

**SAS Model Uploader**

**Converter** **Uploader**

**admin@eurostep.com**  
ProjectAdministrator@OEM@SAVI  
Your Working Space is: SAVI

**Activities**

- 1.) Add Models
  - ▶ SysML
  - ▶ Others
  - ▶ FIT
- 2.) Upload Models To SAS
  - Upload To SAS**
- 3.) Create Model Group (Optional)
  - Create Model Group

Done!

**Model File Name** **Version** **Conflict Type**

<b>Simulink</b> 1 item(s)		
blockdiagram_Simulink	1.0.0.0	None
<b>AADLInstance</b> 1 item(s)		
SimpleModel_AADLInstance	1.0.0.0	None
<b>Modelica</b> 1 item(s)		
slidingblockpid1-fullSecond_Modelica	1.0.0.0	None
<b>SYsML</b> 1 item(s)		
simple_system_EnterpriseArchitect_EnterpriseArchitect	1.0.0.0	None

**Step 2: upload into ShareAspace as a Model Group**

**RESET**

# Resulting Model Group in ShareSpace

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ShareSpace / SAVI

ModelGroups

Modelling Struc...

CollectionAdmin

ProjectAdministrator@OEM@SAVI

✓ (0026) MGMOM, 1.0.0.0

(0022) blockdiagram\_Simulink, 1.0.0.0

(0023) SimpleModel\_AADLInstance, 1.0.0.0

(0024) slidingblockpid1-fullSecond\_Modelica, 1.0.0.0

(0025) simple\_system\_EnterpriseArchitect\_EnterpriseArchitect, 1.0.0.0

Edit

Open in

(0026) MGMOM, 1.0.0.0

✓	Instance Id	Id	Version Id	Name	Description
		0022	1.0.0.0	blockdiagram_Simulink	
		0023	1.0.0.0	SimpleModel_AADLInstance	
		0024	1.0.0.0	slidingblockpid1-fullSecond_Mode...	
		0025	1.0.0.0	simple_system_EnterpriseArchitect...	

(0026) MGMOM, 1.0.0.0

Collaboration Item

Id: 0026

Name: MGMOM

Description:

Version Id: 1.0.0.0

Type Class: MoM

Contract:

Parties

Controlling Organization:

Participating Organization:

Dates

Planned Start Date:

Planned End Date:

Actual Start Date:

Actual End Date:

Documents

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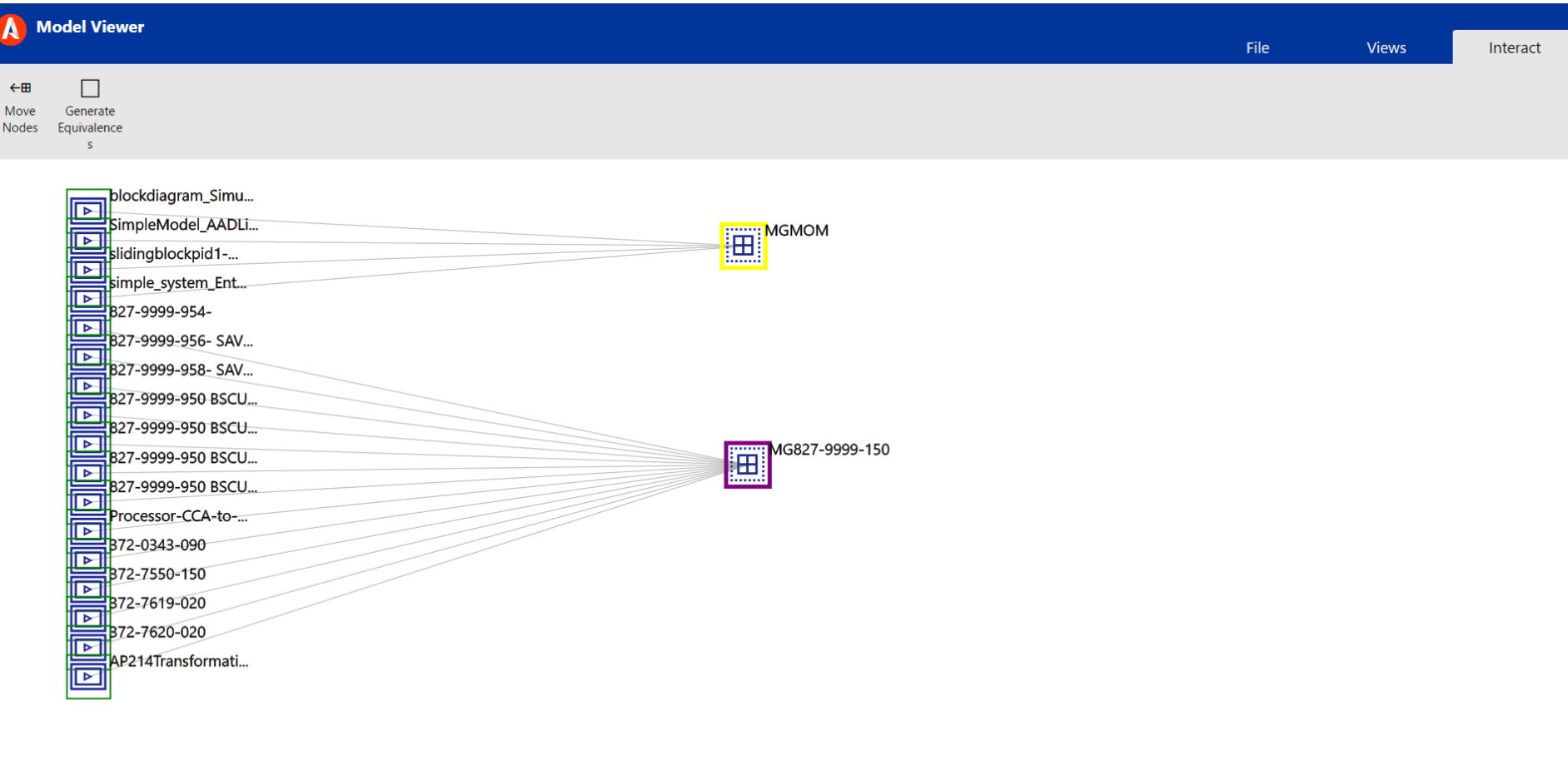
2016

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GPDIS\_2016.ppt | 29



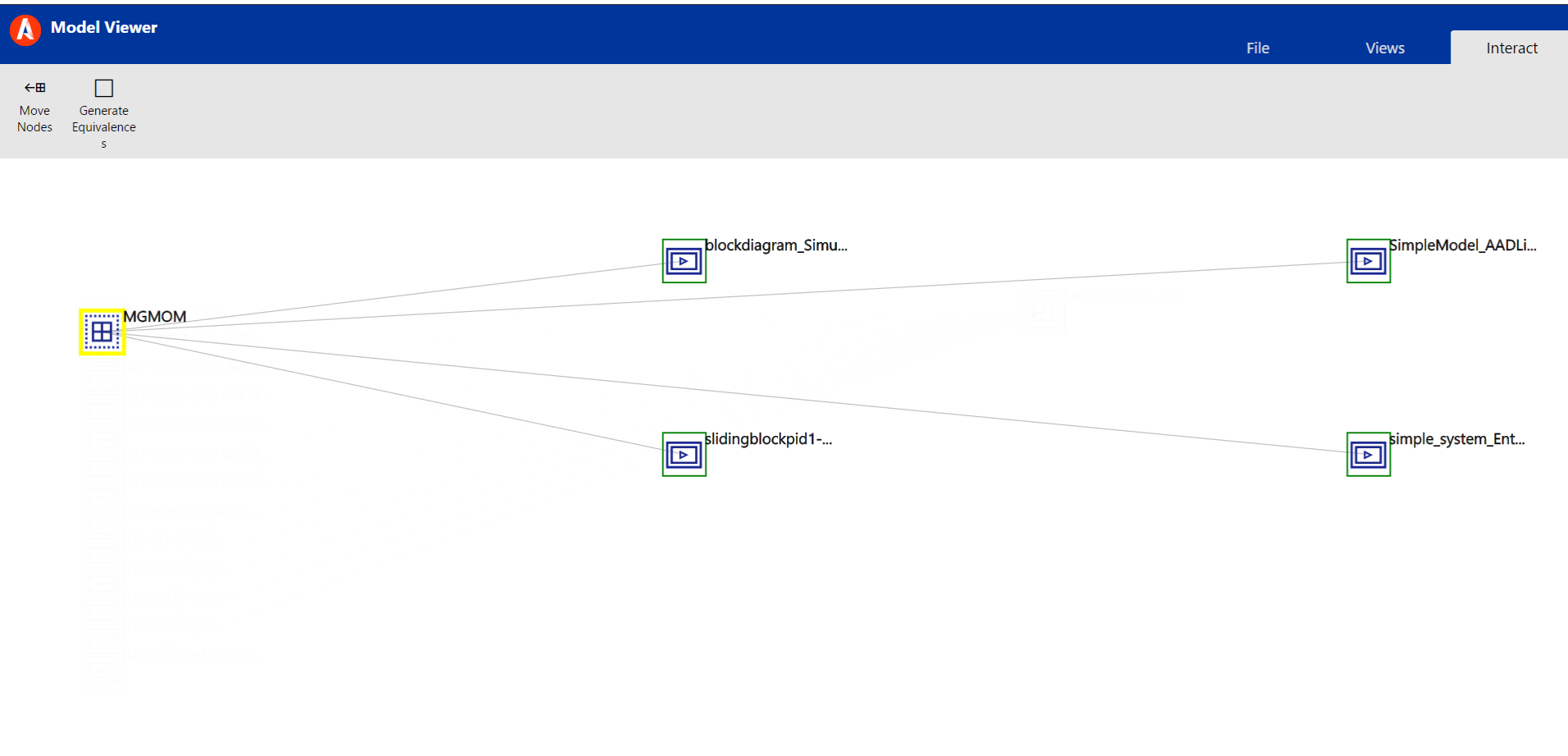
# Multiple Model Groups (Fit and Behavior test cases)

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# The Sliding Mass Model Group

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# Viewing the Model Group as Model-of-Models objects

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Model Viewer

File

Views

Interact

←

Move Nodes

□

Generate Equivalences

MGMOM

Add children to structure

Update structure

Clear

-----

Show children

View extracted data sets

Send to Share-A-Space

Open with MoM viewer

blockdiagram\_Simu...

SimpleModel\_AADLi...

slidingblockpid1-...

simple\_system\_Ent...

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GPDIS\_2016.ppt | 32

# Reporting of Rule set execution

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run

fact

fact

fact

rule

openfile

save

File

Views

Interact

Output

**Start Equivalence Set generation**

Processing files....

**Working with model : AADL\_Model1**

**Finished working with model : AADL\_Model1**

**Working with model : SysML\_Model1**

**Finished working with model : SysML\_Model1**

**Working with model : Modelica\_File\_Version1**

**Finished working with model : Modelica\_File\_Version1**

**Working with model : Simulink\_Model1**

**Finished working with model : Simulink\_Model1**

Asserting facts. .

Getting matches. . .

Getting matches

Matches found : 30

Model Item match : 226

Duplicate Model Item matches: 196

Model Value match : 0

Model Description match : 0

Saving Model Item match

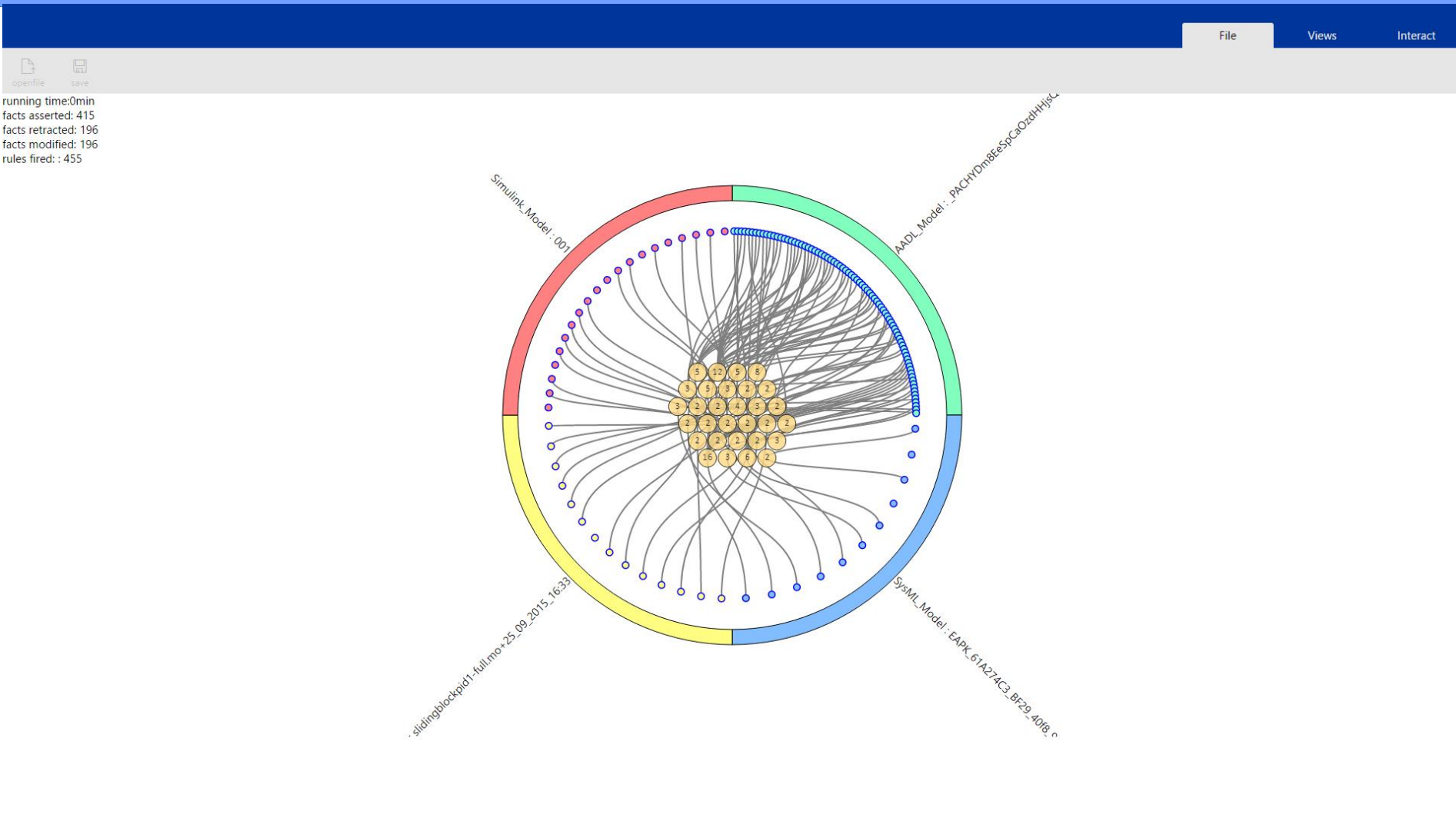
Equivalence sets generated : 30

**Ready**

Close

# Circle view showing model-internal and cross-model Equivalence Sets

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# Circle view showing only cross-model Equivalence Sets

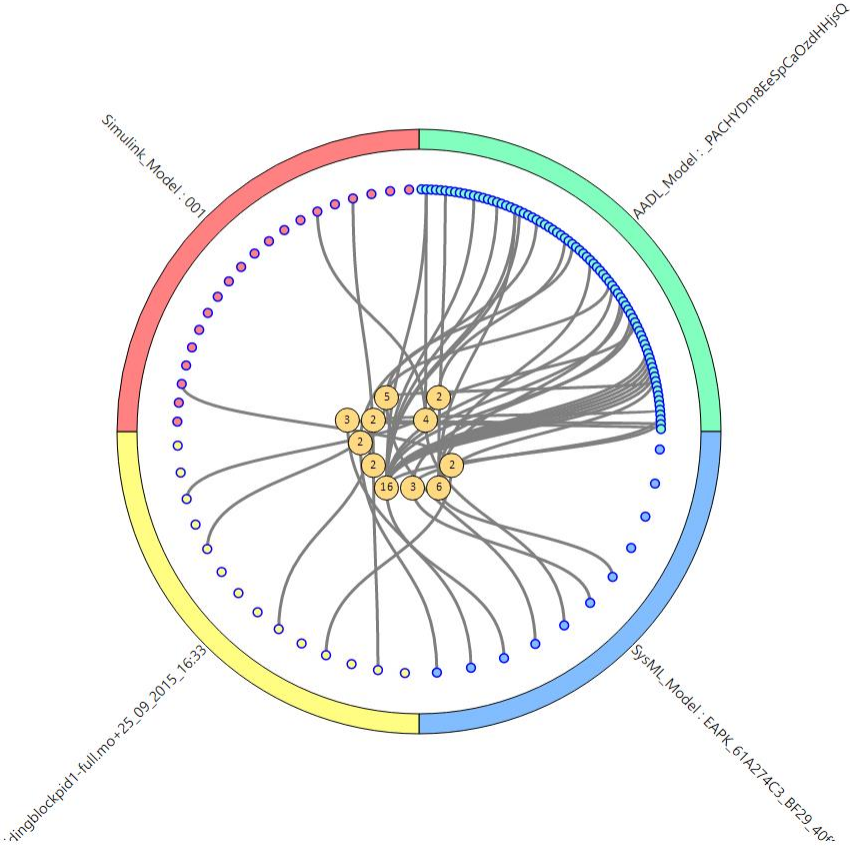
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File Views Interact

- Clear
- Reset View
- Related
- Equiv Sets in same model
- LineWidth
- Colour links
- Colour Legend

- AADLInstance
- SysML
- ModelicaFlat
- Simulink
- EquivalenceSets
- ModelItems

Memberships



# Select a particular Equivalence Set for analysis

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File

Views

Interact



running time:0min  
facts asserted: 415  
facts retracted: 196  
facts modified: 196  
rules fired: : 455





# Network view

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File Views Interact

Show signals

Clear

Reset View

Spread Out

Equiv Sets in same model

LineWidth

Colour links

Colour Legend

running time:0min

fac

fac

fac

rul

AADLInstance

SysML

ModelicaFlat

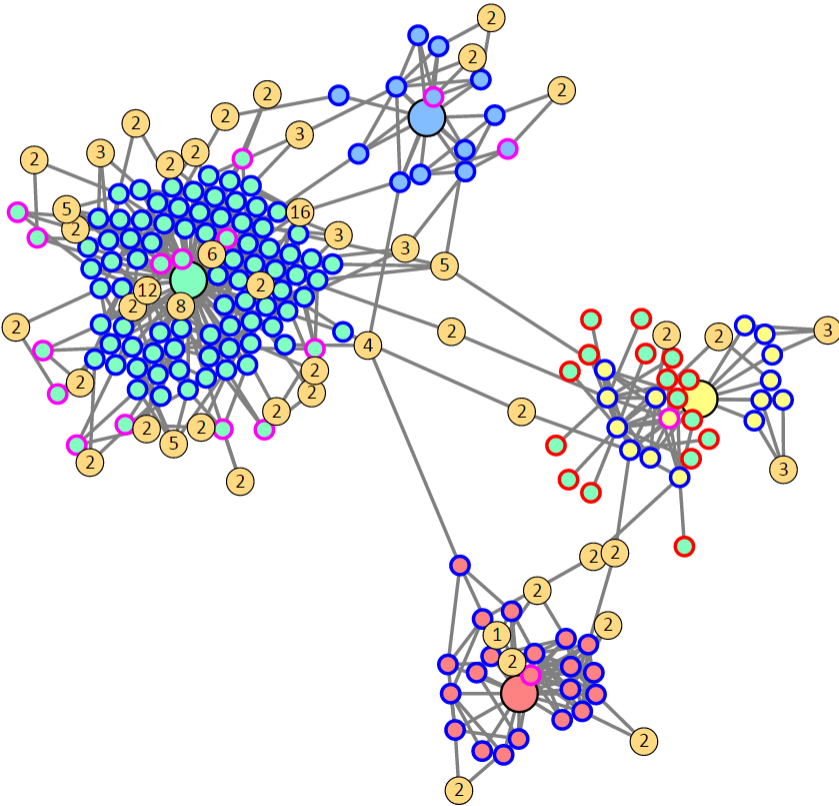
Simulink

EquivalenceSets

ModelledObjectCollections

ModelItems

ModelValues



# Spread models to clarify cross model equivalence sets

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File Views Interact

Show signals

Clear

Reset View

Spread Out

Equiv Sets in same model

LineWidth

Colour links

Colour Legend

running time:0min

fac

AADLInstance

fac

SysML

fac

ModelicaFlat

rule

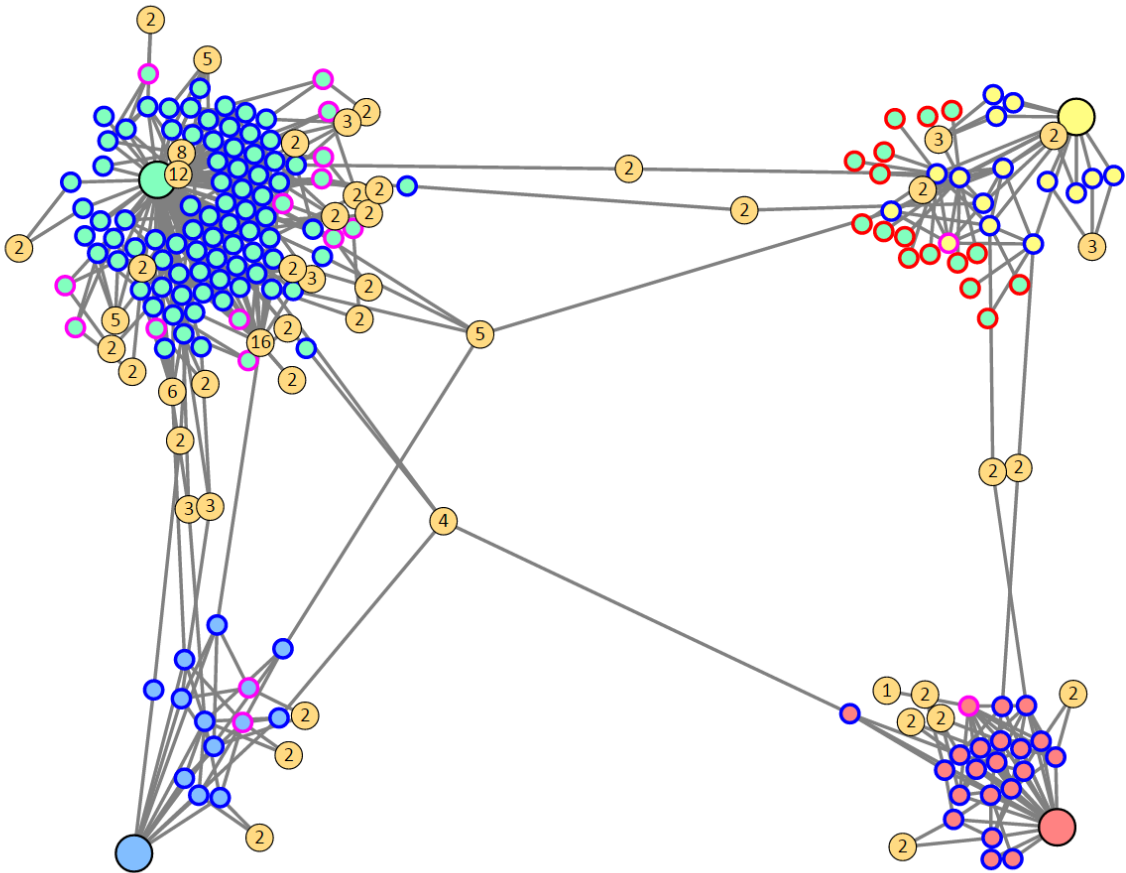
Simulink

EquivalenceSets

ModelledObjectCollections

ModelItems

ModelValues



# Highlight a single set by showing neighbours

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File

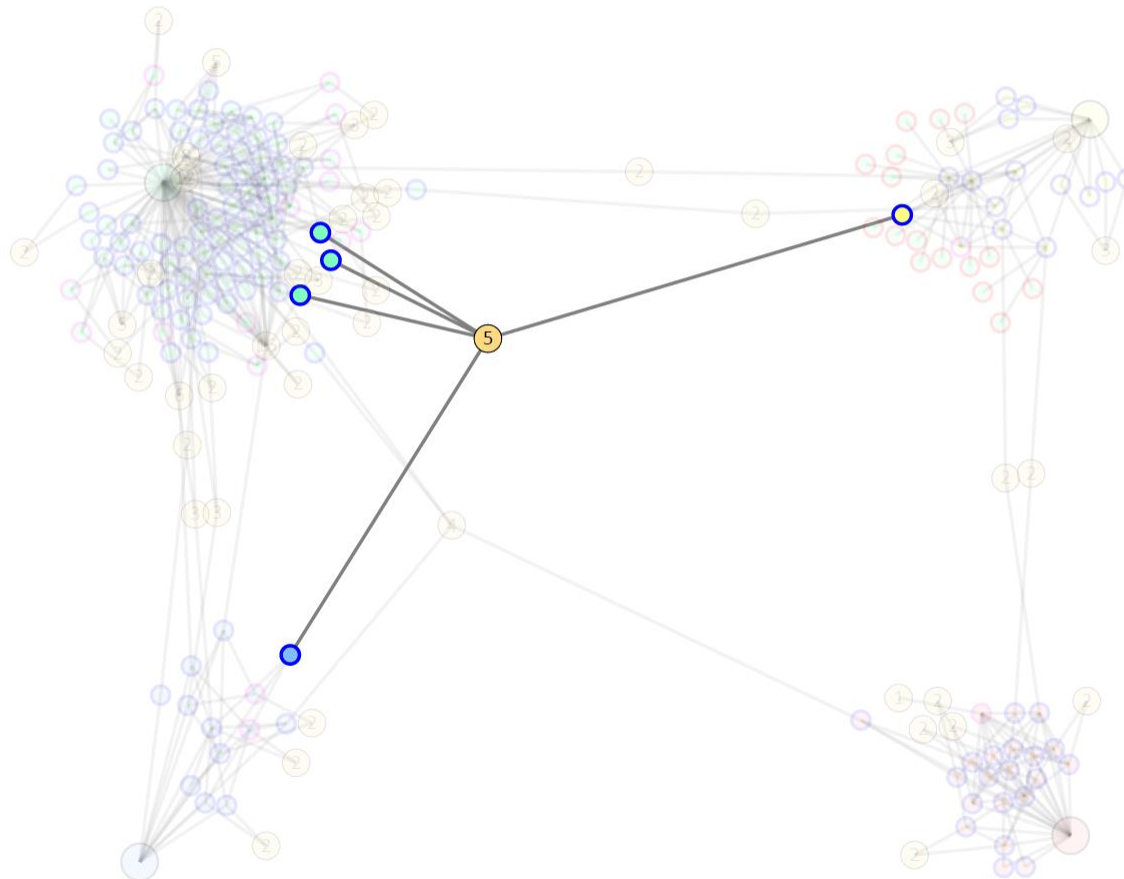
Views

Interact

Show signals  
Clear  
Reset View  
Spread Out  
Equiv Sets in same model  
LineWidth  
Colour links  
Colour Legend

running time:0min

fac  
fac  
fac  
rul  
AADLInstance  
SysML  
ModelicaFlat  
Simulink  
EquivalenceSets  
ModelledObjectCollections  
ModelItems  
ModelValues



# View content of proposed Equivalence Set

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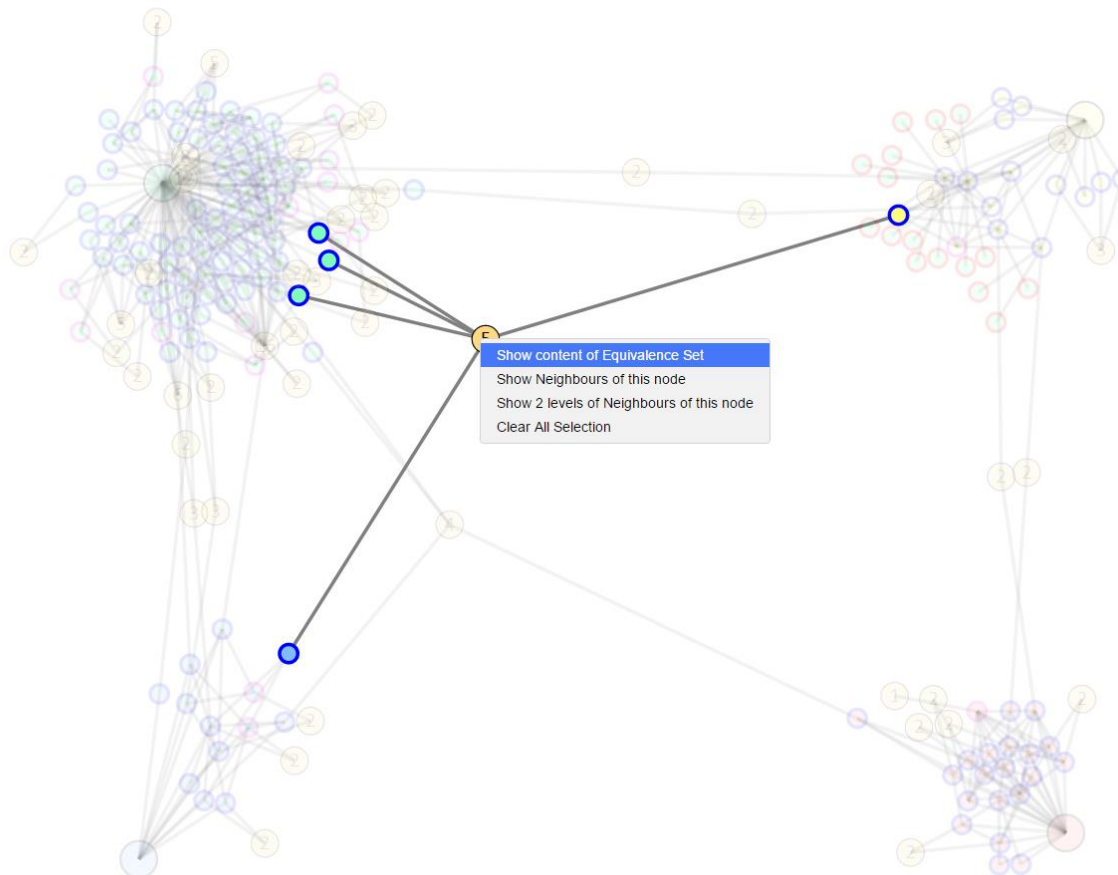
File

Views

Interact

Show signals  
Clear  
Reset View  
Spread Out  
Equiv Sets in same model  
LineWidth  
Colour links  
Colour Legend

running time:0min  
fac AADLInstance  
fac SysML  
fac ModelicaFlat  
rule Simulink  
EquivalenceSets  
ModelledObjectCollections  
ModelItems  
ModelValues





## View content of proposed Equivalence Set

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Equivalent Set : Position Sensor,positionsensor1,PositionSensor				
ID	NAME	DESCRIPTION	FROM MODEL	Remove
1.2.9.2+_PACHYDm8EeSp CaOzdHHjsQ+004_AADL_Model1	PositionFeedBack		FullSystem_impl_Instance	X
1.3.3+_PACHYDm8EeSpCa OzdHHjsQ+004_AADL_Model1	PositionSensor		FullSystem_impl_Instance	X
1.1.15+_PACHYDm8EeSp CaOzdHHjsQ+004_AADL_Model1	PositionSensor	[object Object]	FullSystem_impl_Instance	X
EAID_F36A161D_F580_40 97_B6B1_6B2EB7ED7685+ EAPK_61A274C3_BF29_40 f8_9DDB_6F54CF00CDAB +001_SysML_Model1	Position Sensor		EA_Model	X
slidingblockpid1- full.mo+Modelica.Mechanics. Translational.Sensors. PositionSensor+position sensor1_Modelica_File_Ver sion1	positionsensor1	[object Object]	slidingblockpid1-full.mo	X

# Equivalence Set editing



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 Equivalent Set : Position Sensor,positionsensor1,PositionSensor 

ID	NAME	DESCRIPTION	FROM MODEL	Remove
1.2.9.2+_PACHYDm8EeSpCaOzdHHjsQ+004_AADL_Model1	PositionFeedBack		FullSystem_impl_Instance	X
1.3.3+_PACHYDm8EeSpCaOzdHHjsQ+004_AADL_Model1	PositionSensor		FullSystem_impl_Instance	X
1.1.15+_PACHYDm8EeSpCaOzdHHjsQ+004_AADL_Model1	PositionSensor	[object Object]	FullSystem_impl_Instance	X
EAID_F36A161D_F580_4097_B6B1_6B2EB7ED7685+EAPK_61A274C3_BF29_40f8_9DDB_6F54CF00CDAB+001_SysML_Model1	Position Sensor		EA_Model	X
slidingblockpid1-full.mo+Modelica.Mechanics.Translational.Sensors.PositionSensor+positionsensor1_Modelica_File_Version1	positionsensor1	[object Object]	slidingblockpid1-full.mo	X

# Equivalence Set reduced to confirmed membership

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 Equivalent Set : Position Sensor,positionsensor1,PositionSensor 

ID	NAME	DESCRIPTION	FROM MODEL	Remove
1.3.3+_PACHYDm8EeSpCaOzdHHjsQ+004_AADL_Model1	PositionSensor		FullSystem_impl_Instance	X
1.1.15+_PACHYDm8EeSpCaOzdHHjsQ+004_AADL_Model1	PositionSensor	[object Object]	FullSystem_impl_Instance	X
EAID_F36A161D_F580_4097_B6B1_6B2EB7ED7685+EAPK_61A274C3_BF29_40f8_9DDB_6F54CF00CDAB+001_SysML_Model1	Position Sensor		EA_Model	X
slidingblockpid1-full.mo+Modelica.Mechanics.Translational.Sensors.PositionSensor+positionsensor1_Modelica_File_Version1	positionsensor1	[object Object]	slidingblockpid1-full.mo	X



# Set set name to preferred value: Position Sensor

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File Views Interact

Show signals

Clear

Reset View

Spread Out

Equiv Sets in same model

LineWidth

Colour links

Colour Legend

Cleared

run fac fac fac rule

AADLInstance

SysML

ModelicaFlat

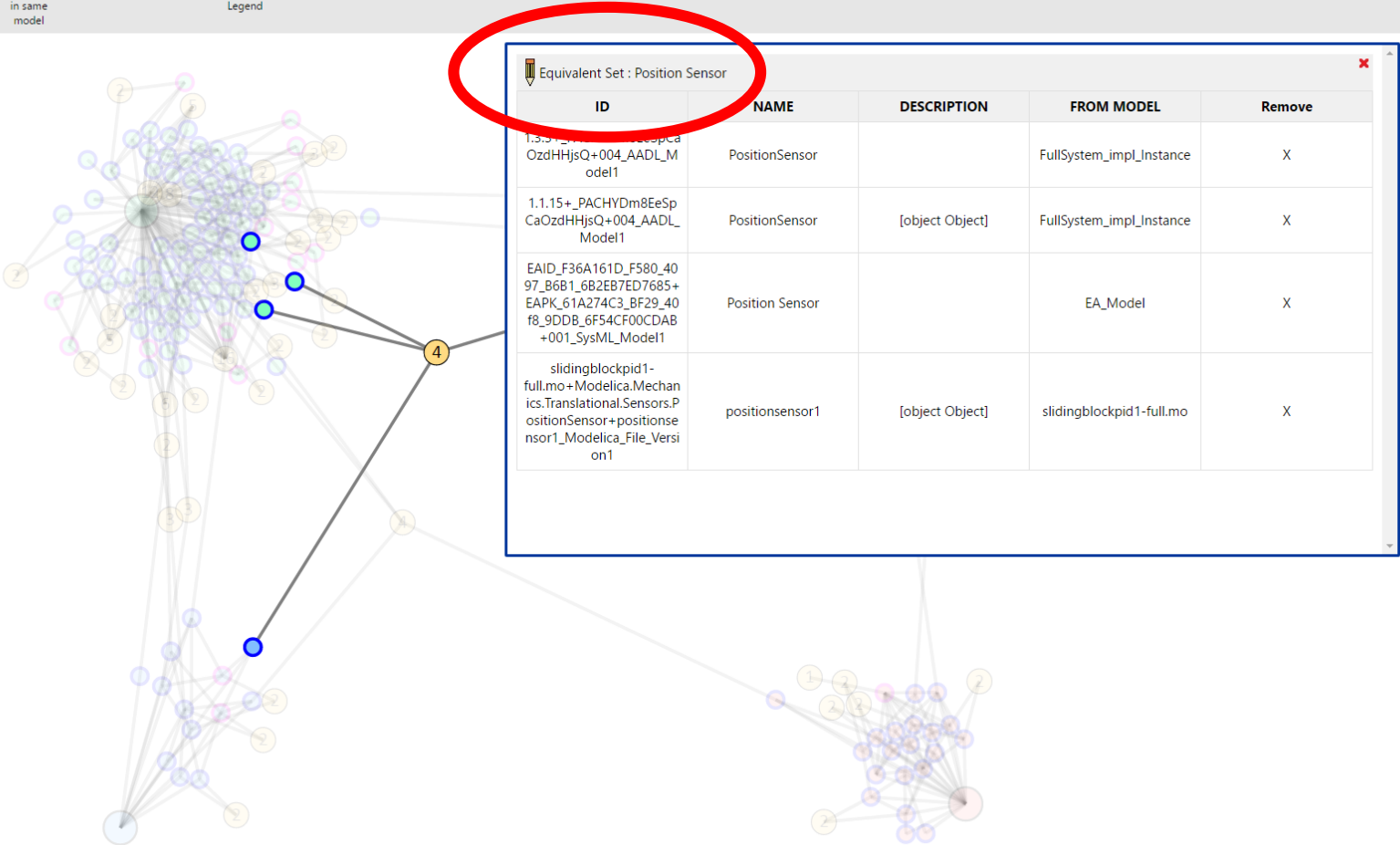
Simulink

EquivalenceSets

ModelledObjectCollections

ModelItems

ModelValues





# The edited Equivalence Set: Position Sensor

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File

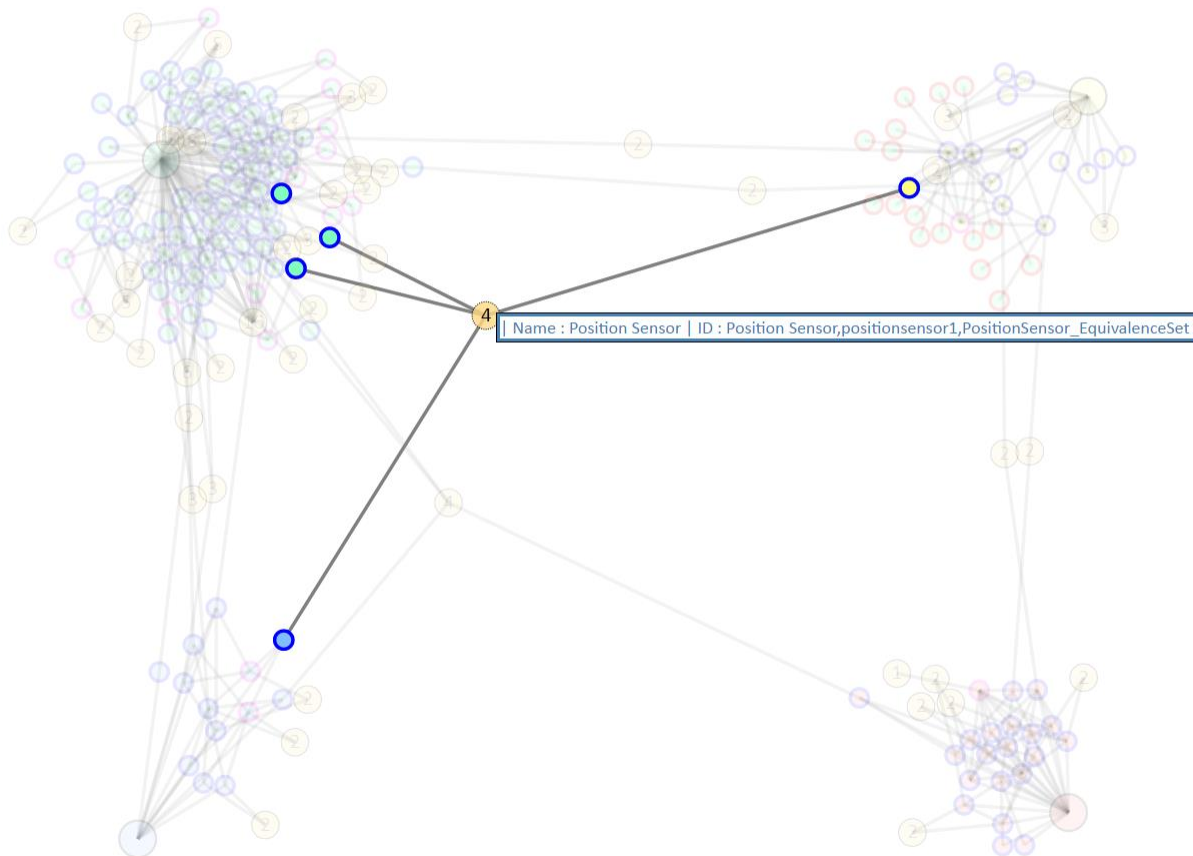
Views

Interact

Show signals  
Clear  
Reset View  
Spread Out  
Equiv Sets in same model  
LineWidth  
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run  
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AADInstance  
SysML  
ModelicaFlat  
Simulink  
EquivalenceSets  
ModelledObjectCollections  
ModelItems  
ModelValues



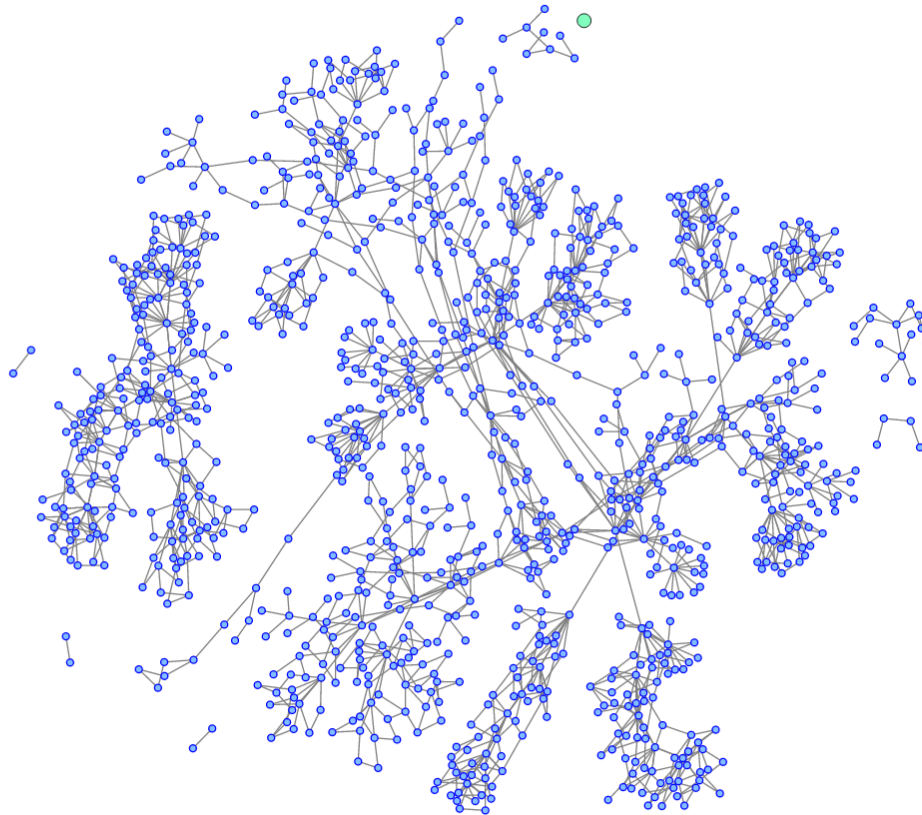
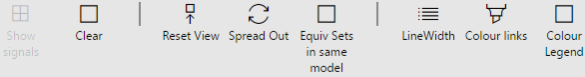
# SCADE Model of Wheel Brake System as network

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File

Views

Interact



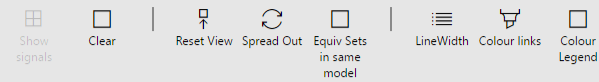
# SCADE Model of Wheel Brake System – separated out

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File

Views

Interact



Cleared

