75 Fifth Street NW, Suite 213
Atlanta, GA 30332, USA
Voice: +1-404-592-6897
Web: www.InterCAX.com
E-mail: info@intercax.com

ParaMagic™ v17.0.2 (beta)

Tutorials

Table of Contents

ParaMagic™ v17.0.2 (beta) **1**

1 Introduction and review **4**

1.1 Introduction *4*

1.2 Short Review of SysML *5*

1.3 Short Review of Solving Equations *7*

2 SysML Parametrics Tutorial - Addition **9**

2.1 Objective *9*
What the User Will Learn 9

2.2 Step-by-Step Tutorial *9*
Step I Create Project 9
Step II Create Infrastructure 10
Step III Create Structural Model 11
Step IV Create Constraints 13
Step V Create Parametrics Model 14
Step VI Validate Parametrics Model 16
Step VII Create an Instance 16
Step VIII Solve the Instance 20

3 SysML Parametrics Tutorial - Satellite **21**

3.1 Objective *21*
What the User Will Learn 21

3.2 Step-by-Step Tutorial *21*
Step I Create Project 21
Step II Create Infrastructure 22
Step III Create Structural Model 22
Step IV Create Constraints 23
Step V Create Parametrics Model 26
Step VI Validate Parametrics Model 28
Step VII Create an Instance 28
Step VIII Solve the Instance 30

4 SysML Parametrics Tutorial - LittleEye **34**

4.1 Objective *34*
What the User Will Learn 34

4.2 Step-by-Step Tutorial *35*
Step I Create Project 35
Step II Create Infrastructure 35
Step III Create Structural Model 35
Step IV Create Constraints 36
Step V Create Parametrics Model 36
Step VI Validate Parametrics Model 39
Step VII Create an Instance 39
Step VIII Solve the Instance 40

5 SysML Parametrics Tutorial - CommNetwork 44

5.1 Objective *44*
What the User Will Learn 44

5.2 Step-by-Step Tutorial *44*
Step I Create Project 44
Step II Create Infrastructure 44
Step III Create Structural Model 45
Step IV Create Constraints 48
Step V Create Parametrics Model(s) 48
Step VI Validate Parametrics Model 50
Step VII Create an Instance 50
Step VIII Solve the Instance 53

6 SysML Parametrics Tutorial - Orbital 54

6.1 Objective *54*
What the User Will Learn 54
System Requirements 55

6.2 Step-by Step Tutorial *55*
Step I Create Project 55
Step II Create Infrastructure 55
Step III Create Structural Model 55
Step IV Create Constraints 57
Step V Create Parametrics Model 59
Step VI Validate Parametrics Model 60
Step VII Create an Instance 60
Step VIII Solve the Instance 65

7 SysML Parametrics Tutorial - HomeHeating 68

7.1 Objective *68*
What the User Will Learn 68

7.2 Step-by Step Tutorial *69*
Step I Create Project 69
Step II Create Infrastructure 69
Step III Create Structural Model 69
Step IV Create Constraints 70
Step V Create Parametrics Model 72
Step VI Validate Parametrics Model 72
Step VII Create an Instance 72
Step VIII Solve the Instance 75

8 SysML Parametrics Tutorial – LittleEye Trade Study 77

8.1 Objective 77
What the User Will Learn 77

8.2 Step-by-Step Tutorial 77
Step VII Set-up a Trade Study 77
Step VIII Run the Trade Study 79

9 SysML Parametrics Tutorial - Electronics 80

9.1 Objective 80

9.2 Step-by-Step Tutorial 81
Step I Create Project 81
Step II Create Infrastructure 81
Step III Create Structural Model 81
Step IV Create Constraints 83
Step V Create Parametrics Model 84
Step VI Validate Parametrics Model 85
Step VII Create an Instance 85
Step VIII Solve the Instance 87
Step VII Create an Instance (Second Configuration) 88
Step VIII Solve the Instance (Second Configuration) 88

1 INTRODUCTION AND REVIEW

1.1 Introduction

The primary purposes of SysML up to this point have been Documentation, precise specification of system design, and Communication, sharing the design among multiple parties. Adding parametric execution to SysML enables additional purposes,

- Consistency, enforcing internal relationships to insure a coherent, self-consistent data set;
- Simulation, evaluating the performance, cost and other parameters of the system design;
- Verification, integrating checks of system properties against requirements.

Our general approach for tutorials on creating SysML model with parametrics follows

I. Create Project
II. Create Infrastructure
III. Create Structural Model
IV. Create Constraints
V. Create Parametric Model
VI. Validate Parametric Model
VII. Create an Instance
VIII. Solve the Instance

Steps I and III are equivalent to those already performed by SysML users and it is generally straightforward to add parametrics to existing models. Step II, Infrastructure, requires the user to import a standard module into each project to enable parametrics execution. Step IV, Constraints, has the user define the generic mathematical relationships to be used. Step V "wires up" the connections between numerical attributes in the structural model and the constraint equations, using one or more SysML Parametric diagrams. Step VI, Validation, checks that the parametrics model is properly constructed for the InterCAX plug-in. In Step VII, the user must create a specific example of the model, populating some of the attributes in the model with real numbers and identifying others as unknowns to be calculated in Step VIII. This outline is not offered as a general methodology for building parametric models, so much as a helpful outline for organizing the detailed instructions.

Before the user can reproduce these tutorials, the user must install and configure

- MagicDraw 17.0.1
- MagicDraw SysML 17.0.1 plug-in
- ParaMagic 17.0.1 or 17.0.1 Lite, the InterCAX SysML Parametrics plug-in for MagicDraw
- Mathematica 8 (Wolfram Research) and/or OpenModelica 1.7 (or 1.8)

Several features of the tutorial models are specific to the MagicDraw and ParaMagic 17.0.1 and may not work correctly with earlier versions. Contact NoMagic or InterCAX for further information.

The fifth and sixth tutorials use two additional tools:

- Microsoft Excel
- MATLAB (The MathWorks, Inc.) with the Simulink toolkit

In each case, refer to the installation instructions in the appropriate user guide. It is also necessary to modify ParaMagic so that it points to the copy of Mathematica. We assume that MagicDraw, ParaMagic,

OpenModelica MATLAB and Excel (if required) are all installed on the user's local machine. Mathematica may be local or accessed through a web services interface.

The first tutorial, Addition, starts with three objects in the simplest possible relationship, a + b = c, and describes the steps in minute detail for those unfamiliar not only with parametrics, but with the MagicDraw SysML plug-in (MagicDraw Version 17.0.1) as well. In the later tutorials, we will hide more of the procedural detail as we model more complex and realistic systems.

The second tutorial, Satellite, models the weight and power budgets of a satellite system, introducing concepts of hierarchy, requirements and multiple constraints. The third tutorial, LittleEye, models the operational capability of an unmanned aerial vehicle, introducing object-oriented programming in model design and non-arithmetic functions. The fourth tutorial, CommNetwork, introduces the use of simple elements to build up and simulate more complex networks.

The fifth and sixth tutorials provide an introduction to special features for interfacing to Excel and MATLAB. The Orbital tutorial shows how Excel may be used to load initial values into a model for space mission planning and to record parametric simulation results. The HomeHeating tutorial demonstrates how external functions and scripts programmed in MATLAB can be integrated into the parametric simulation. MATLAB scripts can, in turn, call Simulink models.

The seventh tutorial extends the LittleEye model from the third tutorial to demonstrate trade studies. The eighth tutorial, Electronics, introduces complex aggregates and generalization, powerful features of SysML that allow a simple parametric model to apply to a wide range of concrete system realizations.

Several of the tutorial models cannot be executed by ParaMagic 17.0.1 Lite because they include model elements that are not supported, including MATLAB, custom Mathematica and complex aggregate functions. Table 1.1 summarizes this information.

Tutorial	**ParaMagic™**	**ParaMagic™ Lite**
Addition	Yes	Yes
Satellite	Yes	Yes
LittleEye	Yes	Yes
CommNetwork	Yes	Yes
Orbital	Yes	Partial (No Mathematica graphing)
HomeHeating	Yes	No (MATLAB function and script)
LittleEye Trade Study	Yes	Yes
Electronics	Yes	No (complex aggregates)

Table 1.1 Tutorial Applicability for ParaMagic™ and ParaMagic™ Lite

As in many subjects, the best way to learn SysML Parametrics is by doing. The author recommends building the models described in the first four tutorials, comparing your results with the figures in the text and exploring variations. There are generally multiple ways to implement any model and, in a few cases, alternate procedures are described. The author would appreciate user feedback on errors and unclear descriptions in this document (info@intercax.com).

1.2 Short Review of SysML

SysML is a powerful and wide-reaching language for modeling systems. In this section, we will review a few aspects of SysML of special importance to parametrics, to help make sense of the detailed instructions in the tutorials for new users with limited SysML experience. This is not intended as a broad introduction or primer on SysML.

SysML supports three major classes of diagrams, which are ways at the looking at the system model:

- Structure diagrams, which describe what the system is composed of. Parametrics is part of structure and these diagrams are our principal focus in the tutorials.
- Behavior diagrams, which describe what the system does. We will not deal with any behavior diagrams in these tutorials.
- Requirements diagrams, which describe the design and performance objectives the system must meet. We introduce requirements diagrams in the tutorials Satellite and Electronics, to show how parametrics can help build requirements checking into a system model.

With respect to structure diagrams, there are three important types. These are illustrated in Figure 1.1.

- Block definition diagrams (BDD), which describe the organization of the structure, the hierarchy of system, subsystems, and all the elements that make up the system. In Figure 1.1, the Body, Engine, and Wheels are elements that belong to the object Automobile, the ownership relationships shown in black. Our tutorials usually begin by creating a BDD.
- Internal block diagrams (IBD), which describe qualitative flows between elements. In Figure 1.1, gasoline flows from a tank in the Body to the Engine, as shown in red. In the tutorial CommNetwork, we use an IBD to keep track of message traffic channels between stations, but IBDs do not affect parametrics directly.
- Parametric diagrams (PAR), which describe quantitative relationships between properties of the elements. In Figure 1.1, mileage, which is a property of Automobile, is a function of the drag of the Body, the efficiency of the Engine, and so forth in green. Creating and executing parametric diagrams is the primary focus of these tutorials.

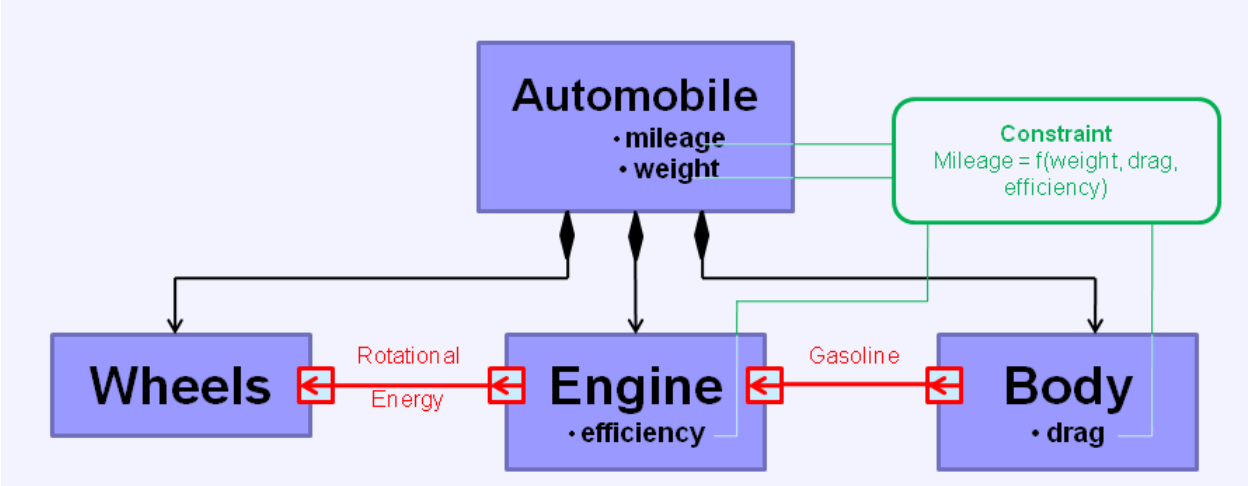


Figure 1.1 Structure diagram relationships

Finally, we need to clarify three types of objects within the system: blocks, part properties, and instances. Examples are illustrated in Figure 1.2.

- Blocks represent a generic object, like the Wheel in Figure 1.2a. A block may have value properties which describe it, like model number or radius, but these properties typically do not contain specific values.
- Part properties represent usages of a block; i.e. a block as part of some larger system. In Figure 1.2b, Front Wheel and Back Wheel are two separate roles that Wheel plays as part of Motorcycle.

- Instances represent a specific example of a generic object, like WhiteWallRadial in Figure 1.2c. The value properties have specific values, which may be fixed or calculated from other system values. ParaMagic executes parametric calculations for specific instances of system models.

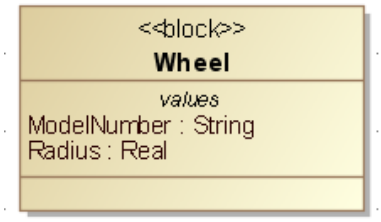


Figure 1.2a Block

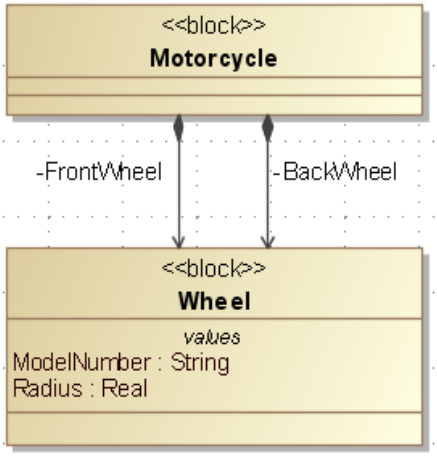


Figure 1.2b Part Properties

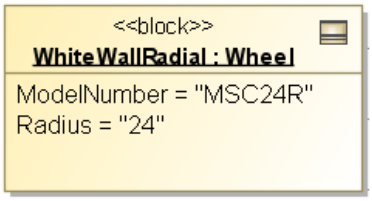


Figure 1.2c Instance of a Block

1.3 Short Review of Solving Equations

ParaMagic's primary function is to solve the often-complex network of parametric equations within the system model, so it is valuable to review a few concepts that will come up in the tutorials.

Causality is the organization of known and unknown variables in the equations. ParaMagic requires the assignment of a causality state to each variable, which can be done manually by the user or semi-automatically by the ParaMagic program. The allowable causality states are

- *Given* – a parameter with a known value provided by the user before the ParaMagic calculation.
- *Target* – a parameter with an initially unknown value that the user specifically wishes to calculate. Each ParaMagic calculation requires at least one target variable.
- *Undefined* – a parameter with an initially unknown value, that may be calculated in the process of solving for the target.
- *Ancillary* – an undefined parameter after its value has been calculated by ParaMagic. It can't be assigned before solution.

In the text, causalities are denoted in italics.

As an example, consider the two equation network

a + b = c **c + d = e**

Our objective is to calculate **e**, which is assigned *target* causality. If we know beforehand that **a** = 3, **b** = 2, and **d** = 5, these parameters would be assigned *given* causality. The remaining parameter, **c**, could be assigned *undefined* causality. When **c** is solved for in calculating **e**, its causality changes to *ancillary*. It is also possible to assign both **c** and **e** to *target* causality, but multiplying targets unnecessarily may slow down solving for larger equation sets.

Assigning causality requires consideration of overconstraint/underconstraint. Underconstraint occurs when insufficient variables are assigned values (and *given* causality) to calculate the targets. For example, in the equations above, if we set **a** = 3 and **d** = 5, there are an infinite number of solutions for **e**

and the equation set is underconstrained. Alternately, if we assigned **a** = 3, **b** = 2, **d** = 5, and **e** = 6, the system is overconstrained and there are zero possible solutions for **c**. In general, Mathematica and OpenModelica, the solver engines for ParaMagic, will alert the user when overconstraint/underconstraint occurs, but some analysis by the user might be required to determine the correct number of knowns for complex equation sets. In general, Mathematica is more robust in dealing with overconstraint/ underconstraint issues than OpenModelica.

A third issue to consider in assigning causality is reversibility. Some equations, like **c = a + b**, are reversible or acausal. We can solve for **c** knowing **a** and **b**, or we can solve for **a**, knowing **b** and **c**. Other equations are not. **a = sin(b)** can be solved uniquely for **a** knowing **b,** but may have multiple possible solutions for **b** knowing **a** (e.g. for a = 0, b can be equal to 0, π, 2π, …). Similarly, **a = minimum(b,c,d)** is not always reversible. ParaMagic treats these types of equations as "one-way" and causality assignments must take this into account.

2 SysML Parametrics Tutorial - Addition

2.1 Objective

Create a SysML project with three elements. Each element has one attribute. The attribute of the third element is the sum of the first two attributes. Create an instance of this model and solve for the third attribute parametrically.

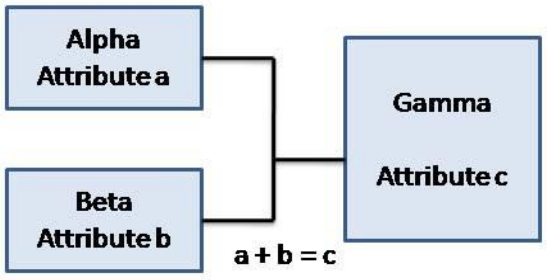


Figure 2.1 Outline of Objective

What the User Will Learn

- Creating the basic elements of SysML models in MagicDraw: blocks, properties, constraints, etc.
- Building a SysML parametrics model and diagram
- Creating a instance of the model with input and output parameters
- Opening and using the ParaMagic browser window
- Exporting a parametrics model to Mathematica

2.2 Step-by-Step Tutorial

Step I Create Project

1. Open MagicDraw.
2. On MagicDraw menu bar, select Options→Perspectives→Perspectives and set to System Engineer.
3. Create new project
    a. On MagicDraw menu bar, select File→New Project,
    b. In New Project window (Figure 2.2), choose SysML Project,
    c. Set Name = **Addition.** User-assigned names and constraints for specific SysML elements are given in Bold.
    d. Set or browse for location to save project.
4. Create a package within the project
    a. RC (Right-click) on Data folder in Containment tree (Figure 2.3)
    b. Select New Element→Package
    c. Enter Name = **Addition**

Note for Mac Users: Right-Click is substituted by the Mac keystroke: Control-Click. While ParaMagic is compatible for both Windows and Macintosh operating systems, certain keystrokes and paths are bound to vary. The author will make note of any significant differences in ParaMagic for Mac users hereafter.

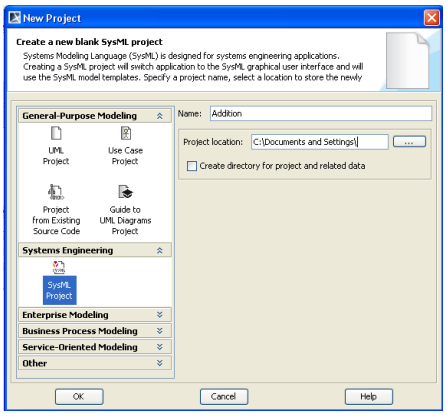


Figure 2.2 New Project window

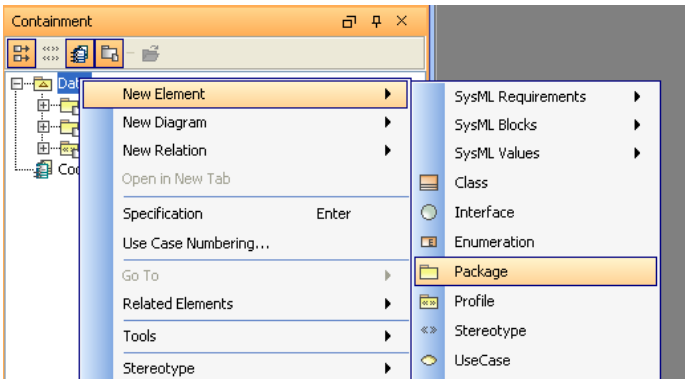


Figure 2.3 Creating Package in Data folder

Step II Create Infrastructure

5. Install ParaMagic Profile module
    a. On MagicDraw menu bar, select File→Use Module… and select as below (Figure 2.4). This loads a module containing all the ParaMagic features as part of the project.
        i. Click Next and Finish (Figure 2.5).

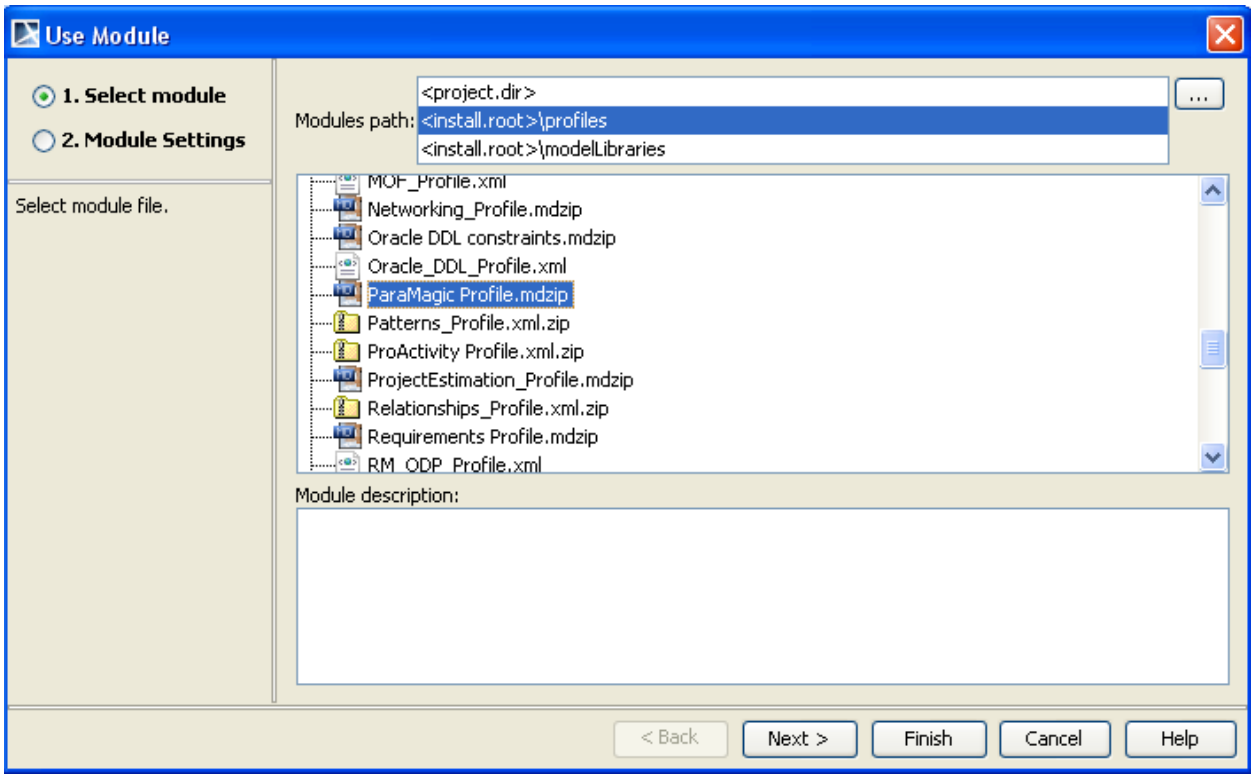


Figure 2.4 Use Module window

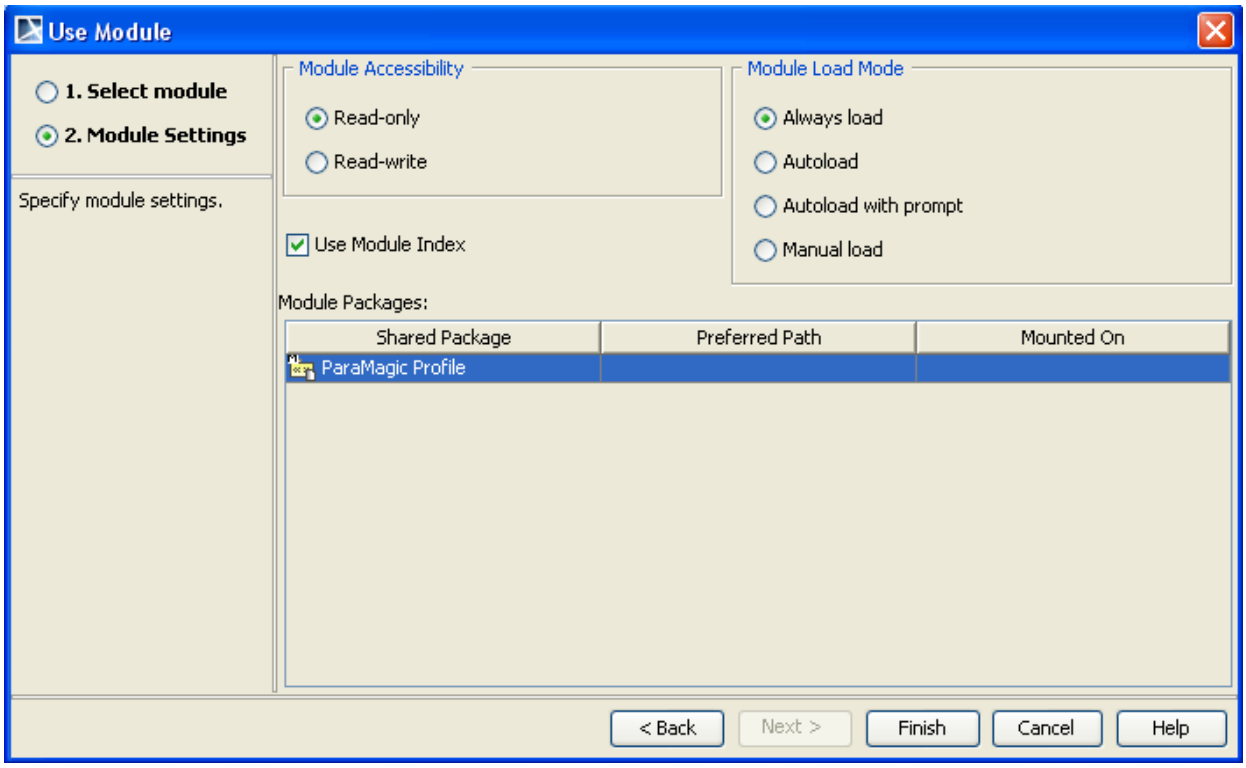


Figure 2.5 Module settings for ParaMagic Profile

Step III Create Structural Model

6. Create elements in model
    a. RC (Right-click) **Addition** package in Containment window
        i. Select New Element→SysML Blocks→Block
            1. Enter Name = **Alpha** in blank text box
    b. RC **Addition**
        i. Select New Element→SysML Blocks→Block
            1. Name = **Beta**
    c. RC **Addition**
        i. Select New Element→SysML Blocks→Block
            1. Name = **Gamma**
    d. RC **Alpha**
        i. Select New Element→SysML Properties→Value Property
            1. Name = **A**
            2. To set the Type of the property, DC (double click) on **A** and enter Real in the Value Property window (Fig. 1.6) or select Real from dropdown list
    e. RC **Beta**
        i. Select New Element→SysML Properties→Value Property
            1. Name = **B**
            2. Type = Real
    f. RC **Gamma**
        i. Select New Element→SysML Properties→Value Property
            1. Name = **C**
            2. Type = Real

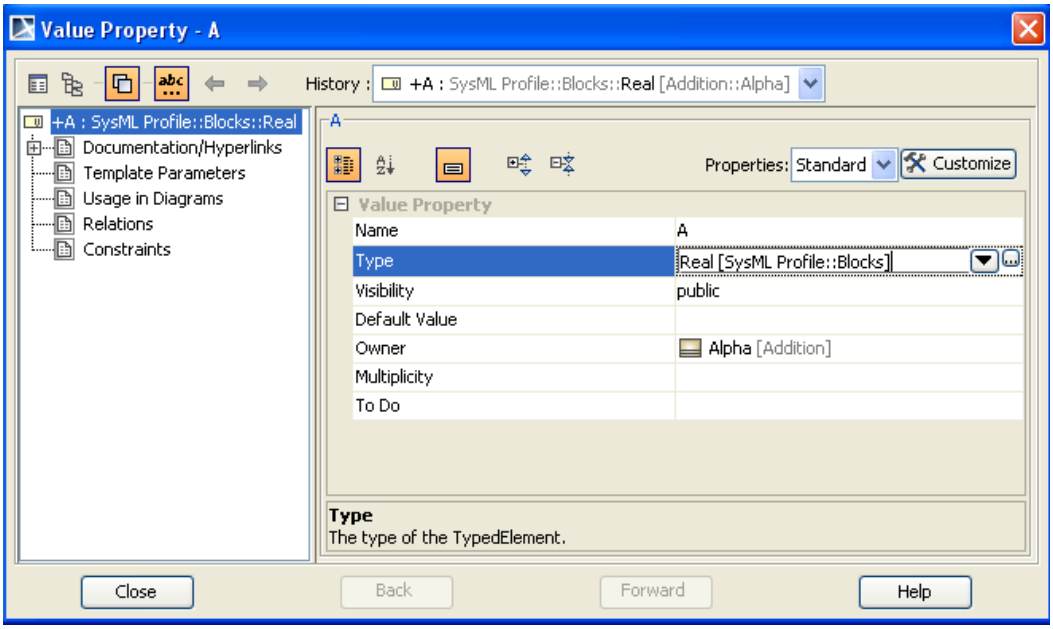


Figure 2.6 Value Property window, enter Type

7. Create a block definition diagram, a graphical view of the entire system
    a. RC **Addition**
    b. Select New Diagram→SysML Diagrams→SysML Block Definition Diagram
        i. Name = **AdditionBDD**
    c. Drag **Alpha**, **Beta**, and **Gamma** from Containment window into **AdditionBDD** (Figure 2.7)
        i. To rearrange position, drag using top half of block.
        ii. To resize block, click on top half of block and use cursors at corners
        iii. If attributes (e.g. B) are not listed inside the blocks, display the attributes by,
            1. RC on block,
            2. choose Presentation Options,
            3. uncheck Suppress Attributes.

    Alternatives: To show or hide the interior features of a block, right-click on the block and use the Symbol Properties, Edit Compartment and Presentation Options commands. Alternately, click on the block and look for small plus and minus icons on the left edge to display or suppress interior features.

8. Create relationships between elements of the model. **Alpha** and **Beta** can be used as parts of **Gamma**.
    a. Click on **Gamma** in the Block Definition Diagram
    b. Select Directed Composition arrow from floating toolbar (arrow with solid diamond at base).
    c. Drag end of arrow to **Alpha**
    d. Repeat steps a-c for **Beta** (Figure 2.8)

e. This procedure causes blocks **Alpha** and **Beta** to be used as Part Properties inside **Gamma**. Under the **Gamma** block in the Containment window, assign these Part Properties the names **alp** and **bet**, respectively.

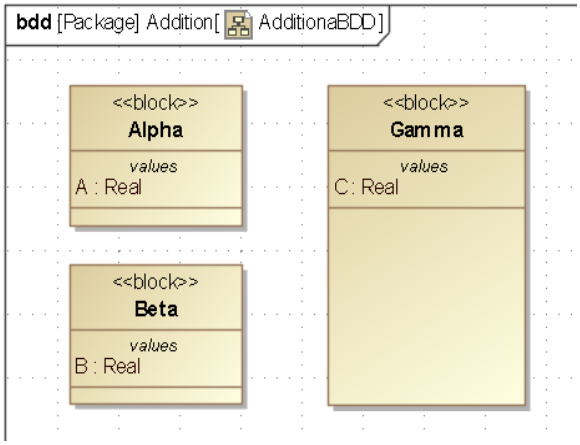


Figure 2.7 Block Definition Diagram

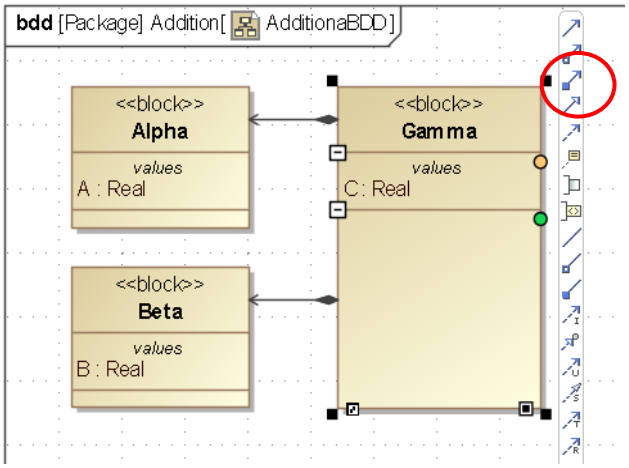


Figure 2.8 Block Definition Diagram with Floating Toolbar and Directed Composition Arrows

Step IV Create Constraints

9. Create a constraint block, which contains a mathematical relationship that the model will use.
    a. RC **Addition** package in the Containment tree.
        i. Select New Element→SysML Blocks→Constraint Block
            1. Name = **AdditionEqn**
    b. RC the **AdditionEqn** constraint block
        i. Select New Element→Constraint Parameter
            1. Name = **a**
            2. Type (of **a**) = Real
    c. RC **AdditionEqn**
        i. Select New Element→Constraint Parameter
            1. Name = **b**
            2. Type = Real
    d. RC **AdditionEqn**
        i. Select New Element→Constraint Parameter
            1. Name = **c**
            2. Type = Real
    e. DC (double-click) **AdditionEqn**
        i. In the window labeled Constraint Block – AdditionEqn (Figure 2.9),
            1. select Constraints, click Create
            2. under Name, enter **sum**
            3. under Specification, enter **c = a + b** (putting a space between each parameter and operation is optional, but enhances readability).
            4. click Close.

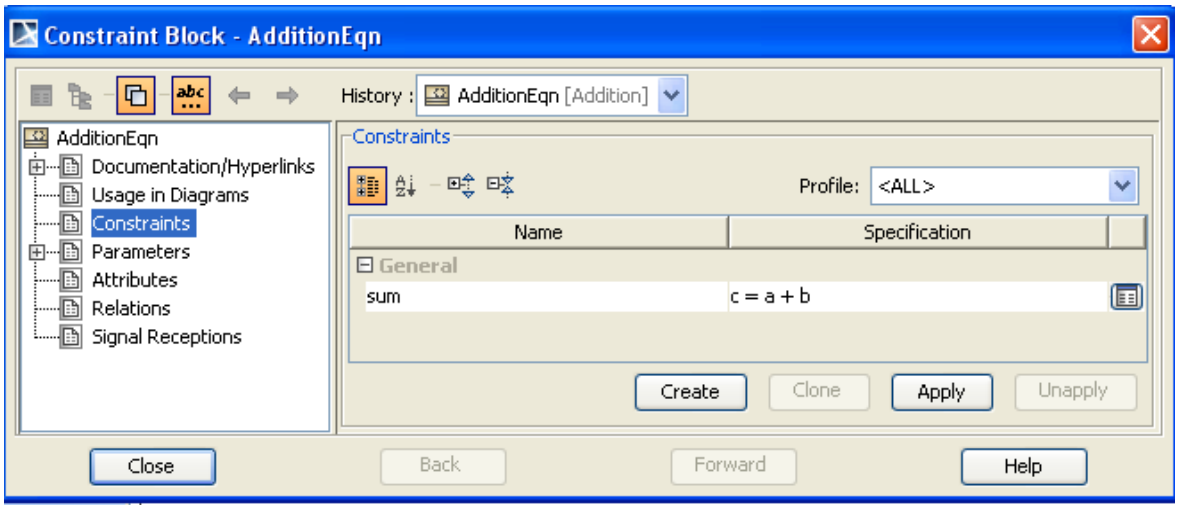


Figure 2.9 Constraint Block window showing Constraint

Step V Create Parametrics Model

10. Create a SysML Parametric diagram to define and display the relationships inside **Gamma**

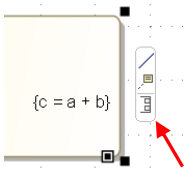


Figure 2.10

    a. RC the **Gamma** block in the Containment tree.
    b. Select New Diagram⟶ SysML Parametric Diagram
        i. The Select Parts window will appear. Select Enter, and all the value properties and part properties of **Gamma** will appear automatically on the diagram.
        ii. The default diagram name is **Gamma**.
    c. Drag the Constraint Block **AdditionEqn** into the **Gamma** parametric diagram.
        i. **AdditionEqn** will appear inside **Gamma** (in the Containment tree and in the parametric diagram) as a Constraint Property of the type **AdditionEqn**. Assign it a unique name, **add**.
        ii. Use the Display Parameters icon (Figure 2.10) and Select Parameters window (Figure 2.11) to show parameters **a**, **b** and **c**.
        iii. Arrange them at top of block as shown in Figure 2.13.
    d. Display the internal structure of **alp:Alpha** by
        i. RC on **alp:Alpha**
        ii. Select Edit Compartment⟶Structure from list
        iii. Select **A** from the Edit Compartment window (Figure 2.12)
        iv. Move it to the right side of window using central arrow or double arrow buttons
        v. Click OK
        vi. Repeat step i.-vi. for **B** in **bet:Beta**

Note: In general, Edit Compartment and Presentation Options provide control in displaying or hiding properties inside blocks, but displaying ports or parameters inside constraint blocks and constraint properties uses the floating toolbar icons like in Figure 2.10.

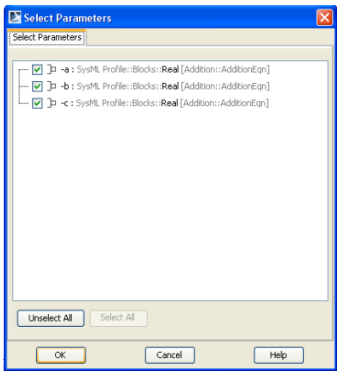


Figure 2.11 Select Parameters window

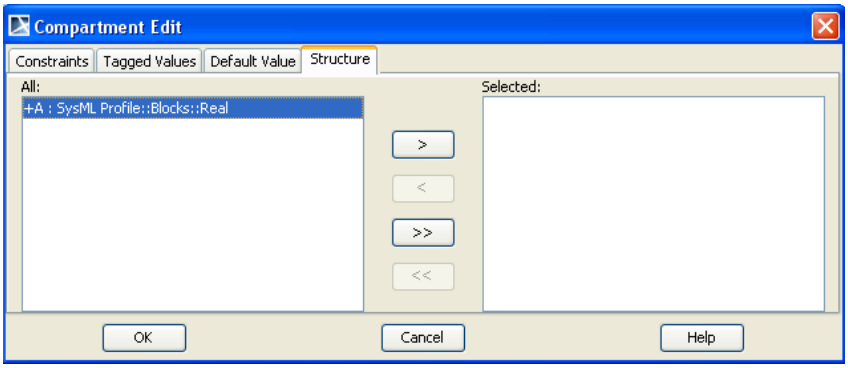


Figure 2.12 Edit Compartment window

e. The parametric diagram at this stage should appear something like Figure 2.13.

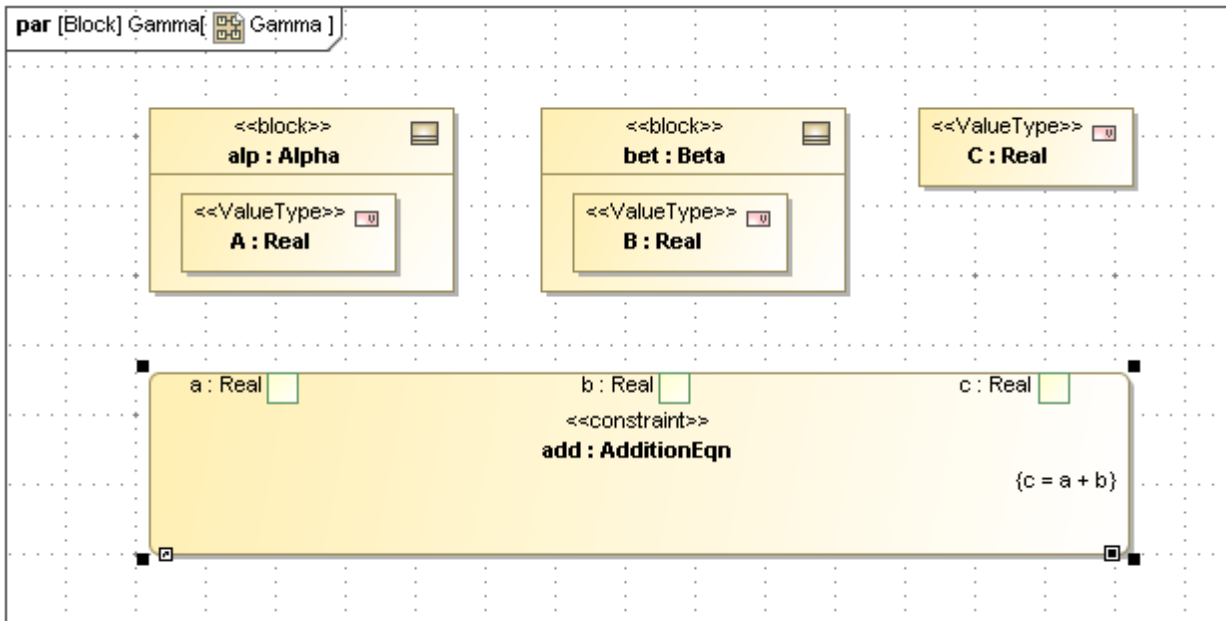


Figure 2.13 Parametric Diagram before Connectors added

f. Create the connections between the model attributes (**A**, **B**, and **C**) and the constraint parameters (**a**, **b**, and **c**).

i. Click on parameter **a** in the **add:AdditionEqn** constraint property in the **Gamma** diagram..

ii. From the floating toolbar that appears, choose the Connector icon (simple straight line, see highlight in Figure 2.14) and drag the end to **A** in the part property **alp:Alpha**. If the connection is yellow, then the parameter may be incorrectly linked to the outer rectagle, **alp:Alpha**, instead of the value property, **A**:Real.

iii. Repeat steps i. and ii. for **b** to **B** and **c** to **C** connectors.

iv. At this stage, the parametric diagram should look like Figure 2.14 and the Containment tree should look like Figure 2.15.

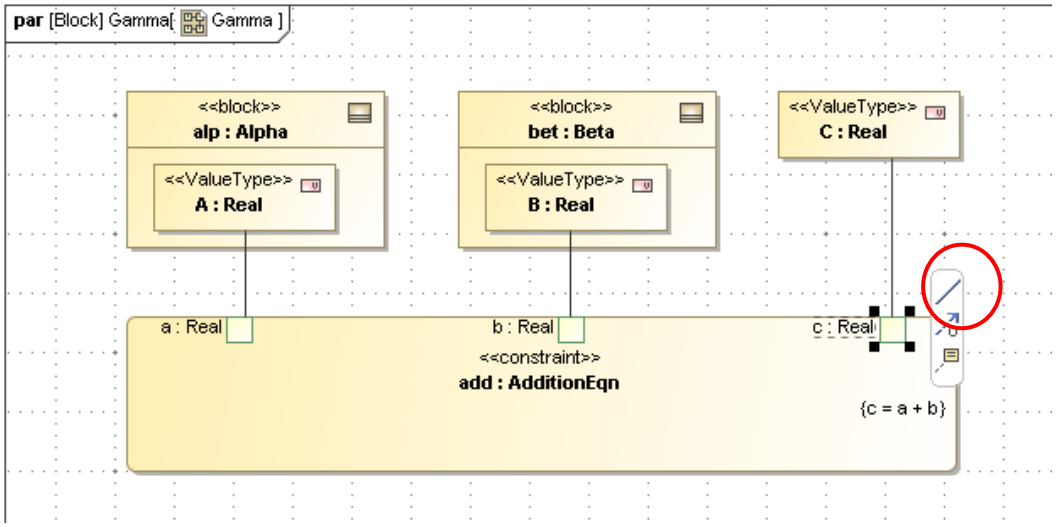


Figure 2.14 SysML Parametrics Diagram with connectors, connector icon highlighted

Step VI Validate Parametrics Model

11. To validate the model schema,
    a. Right-click on block **Gamma** in the Containment tree
        i. select ParaMagic→Validate
    b. If the message reads "SysML block structure is valid. Warning: schema structure validation does not check for equation over-constraints, etc. –See Users Guide Limitations", go on to Step VII. Otherwise, correct model errors, which will be specified in the message window at the bottom of the screen, and repeat validation.
    c. A Message window will appear with a listing of parametric model statistics.

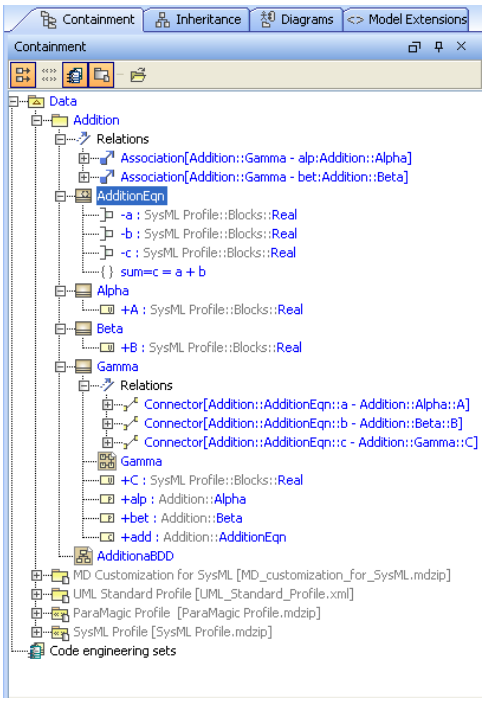


Figure 2.15 Containment Tree

Note: Validation is applied to **Gamma**, the "root block" of our parametric model. The root block is the highest level in the model structure; validation is applied to the root block and all its part properties.

Step VII Create an Instance

12. Create an instance. An instance is an example of the model with specific values assigned to the given parameters and which can be solved for the unknown(s).
    a. RC the **Addition** package in the Containment tree
        i. Create New Element → Package
            1. Name = **AdditionInstance01**

b. RC **AdditionInstance01**

i. Create New Diagram →SysML Diagrams →SysML Block Definition Diagram

1. Name = **Instance01**

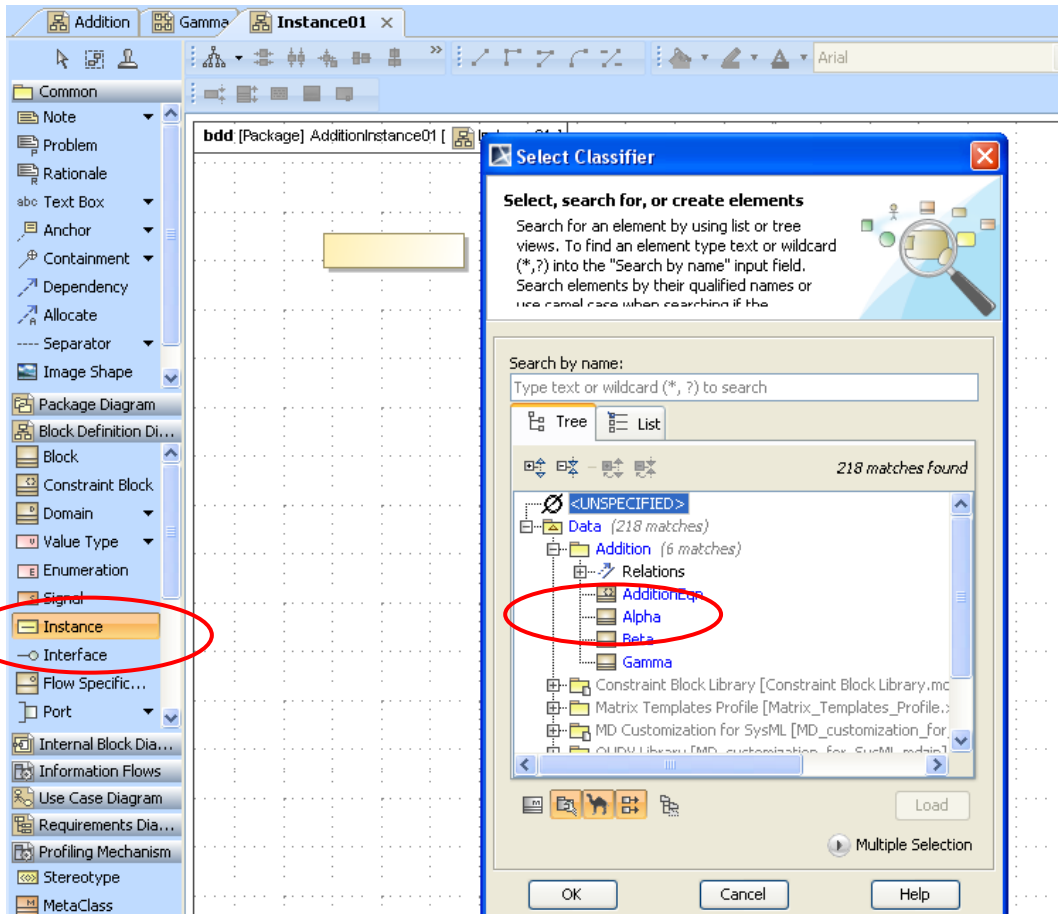


Figure 2.16 Creating an instance of Alpha inside AdditionInstance01

c. Click on Instance from the central toolbar (highlighted in Figure 2.16) and click inside the diagram to draw an Instance block.

i. Select **Alpha** on the Tree tab, Select Classifier window, and press OK.

ii. DC the **:Alpha** block on **Instance01** and name it **alpha01**.

Alternative: In the next tutorial, we introduce the "Create Instances" utility to expedite the process of creating an instance from each block in the schema.

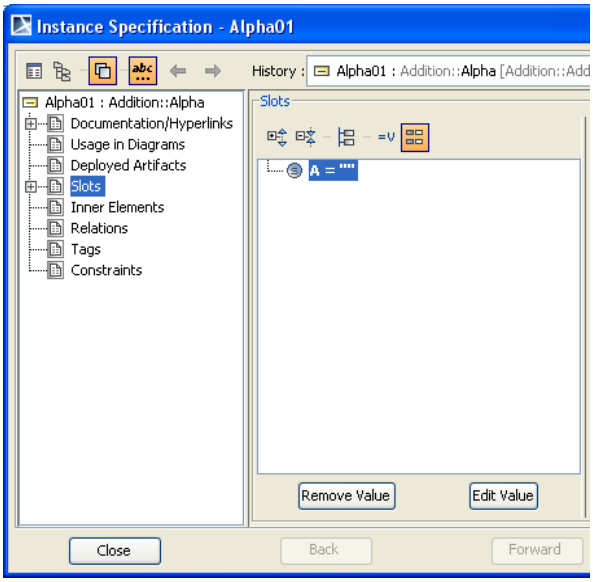


Figure 2.17 Instance Specification

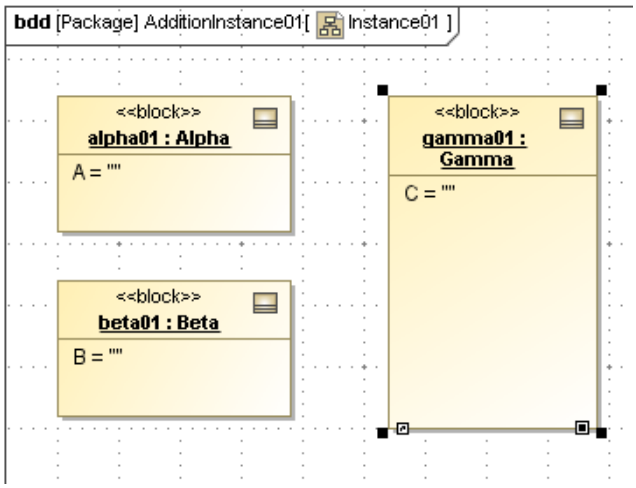


Figure 2.18 Instance diagram, preliminary

d. Repeat process in step c to create instances **beta01:Beta** and **gamma01:Gamma**. Instance diagram should appear similar to Figure 2.18.

e. Click **gamma01** and select link (top solid line with small L) on floating toolbar.

f. Draw the link from **gamma01** to **alpha01**

   i. On the Select Association window, check the box by the association and click OK. See Figure 2.19.

   ii. On the Create Slots window, check **alp:Alpha** and click OK (Figure 2.20).

g. Repeat steps e and f for a link from **gamma01** to **beta01**. See diagram in Figure 2.21.

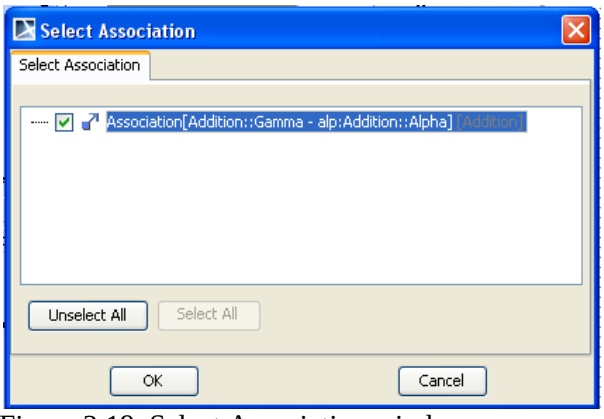


Figure 2.19 Select Association window

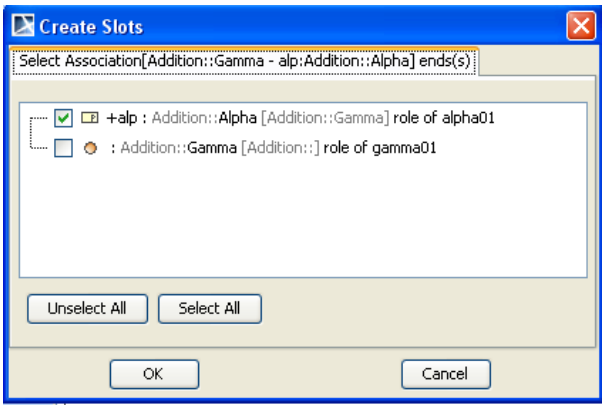


Figure 2.20 Create Slots window

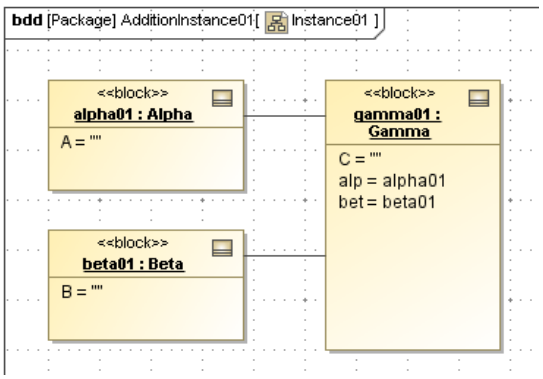


Figure 2.21 Instance diagram, preliminary

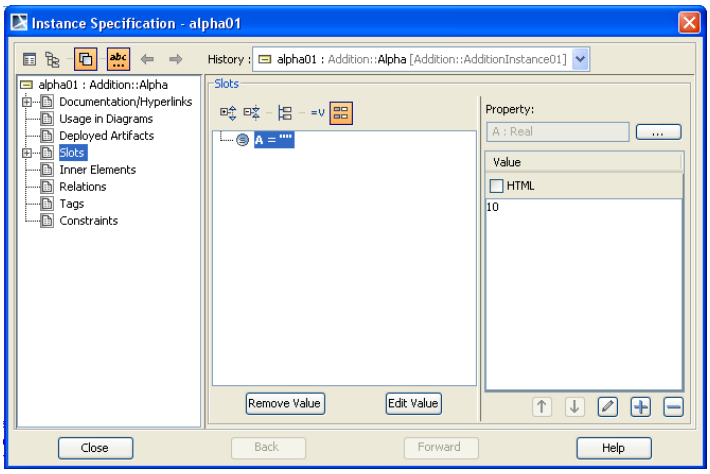


Figure 2.22 Setting value for A in Instance01

13. Add values to the instance and define inputs and outputs. Review Section 1.3 on causality.
    a. Add a value to **A** for to be used in solving the instance.
        i. Double-click on **alpha01**,
        ii. click on Slots,
        iii. click on A =”” in central Instance Specification window (Figure 2.22),
        iv. enter “10” as value on right side of window.
        v. Expand Slots (click on **+** box next to Slots),
        vi. expand A=””,
        vii. select Tags (see Figure 2.23).
        viii. DC on <<causality>> type.
        ix. Select *given* from dropdown list and Close.
    b. Repeat step a for **beta01**, specifying “20” as value and *given* as causality.
    c. Repeat step a for **gamma01**, but do not specify a value, and for <<causality>>, select *target*. Final instance diagram should appear similar to Figure 2.24.

Alternative: In the next tutorial, we assign causality directly in the ParaMagic browser.

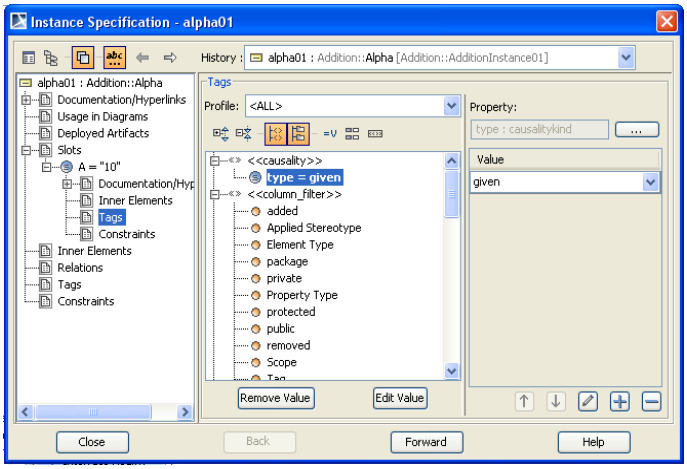


Figure 2.23 Instance diagram, preliminary

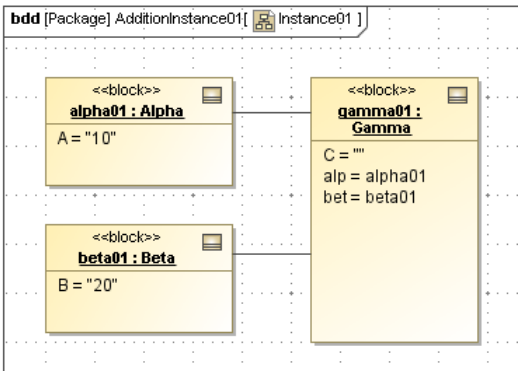


Figure 2.24 Instance diagram, final

Step VIII Solve the Instance

14. Run the parametric solver
    a. RC **gamma01** (instance of the root block) in the Containment tree.
    b. Select ParaMagic→Browse. Expand the **alp** and **bet** part properties in the browser (click the + sign beside them) and it should appear as in Figure 2.25.

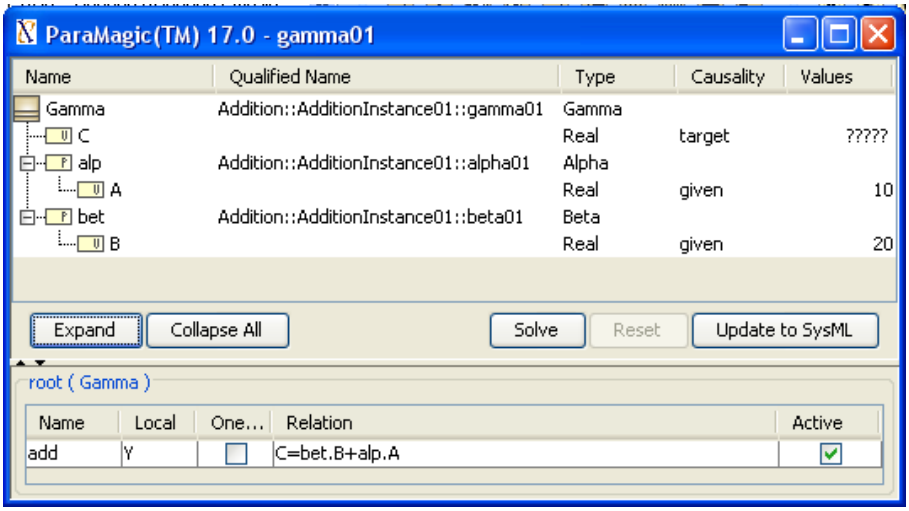


Figure 2.25 ParaMagic Browser window

    c. Press "Solve"
        i. The ????? symbols in the target variables should change to their calculated values, in this case C = 30 (Figure 2.26).
    d. Press "Update to SysML". C=30 should appear in the Containment tree and Instance diagram.

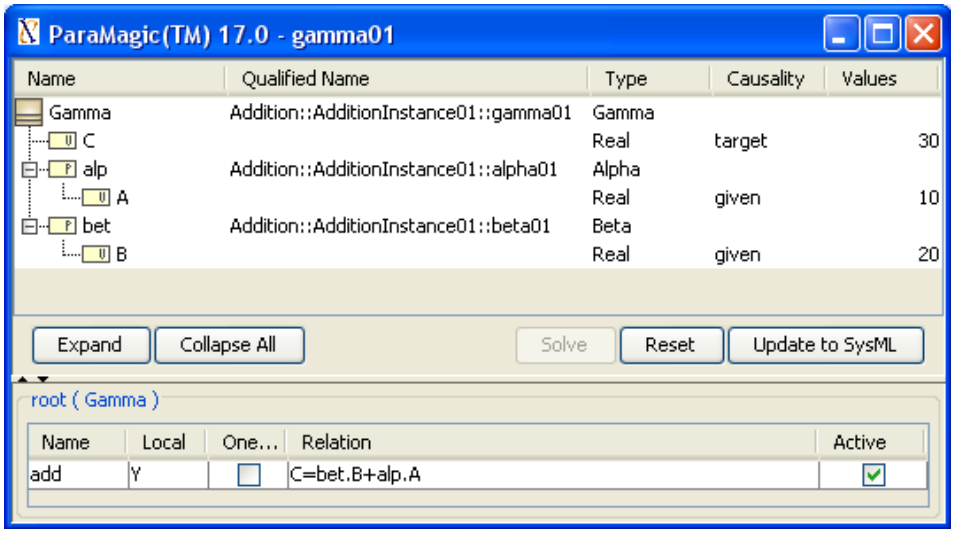


Figure 2.26 Browser window with solution

3 SysML Parametrics Tutorial - Satellite

3.1 Objective

Create a SysML project comprising a satellite system composed of four subsystems: Propulsion, Instrumentation, Control and PowerSystem. Each subsystem has a weight and there is a total weight budget for the satellite of 10,000 kilograms. The Propulsion, Instrumentation, and Control subsystems each draw electrical power from the PowerSystem, which can supply a maximum of 10 megawatts. Given the weights of all four subsystems and the power requirements of three, calculate the total weight and power demand for the system and compare against requirements.

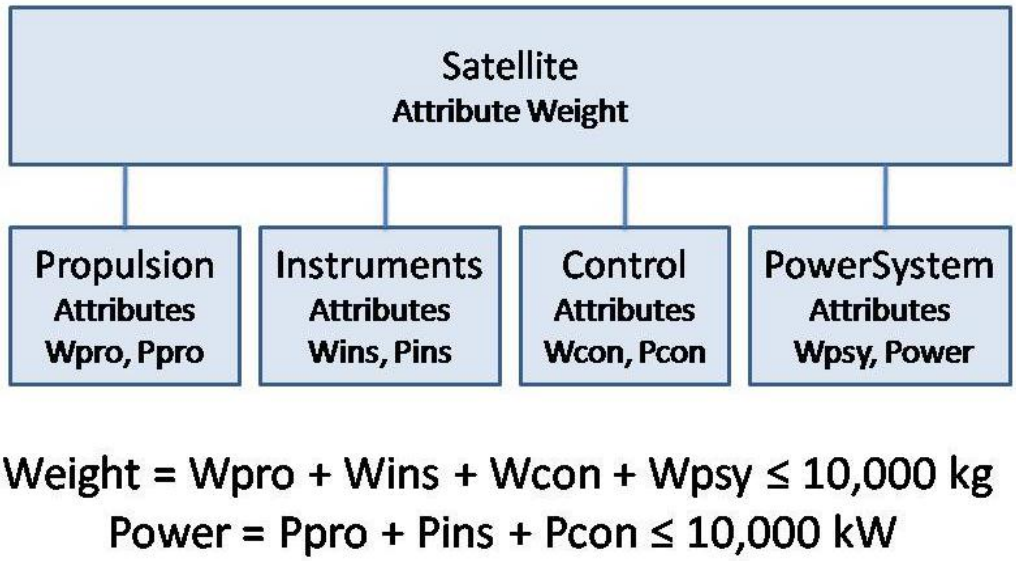


Figure 3.1 Outline of Objective

What the User Will Learn

- Apply SysML parametrics to a realistic system with subsystems
- Working with multiple constraints
- Working with requirements
- Working with ValueTypes
- Changing causality – reversing the direction of calculation

3.2 Step-by-Step Tutorial

Step I Create Project

1. Create new SysML project
   a. Name = **Satellite**
2. Create a package within the project
   a. RC (Right-click) on Data folder in Containment tree (left column)
   b. Choose New Element→Package
   c. Enter Name = **Satellite**

Step II Create Infrastructure

3. Install ParaMagic Profile module, same as in the first tutorial.

Step III Create Structural Model

4. Create elements in model
    a. RC on **Satellite**
        i. Create New Element→Package
            1. Name = **ValueTypes**
        ii. RC on ValueTypes, create New Element→SysML Values→ ValueType
            1. Name = **Kilowatt**
            2. Base Classifier = Real
                a. DC on **Kilowatt** in Containment tree
                b. In Value Type – Kilowatt window click to the right of Base Classifier row in table
                c. Click on button with three dots
                d. In Select Elements window, enter Real in Search by name text box
                e. Select Real (SysML Profile::Blocks)
                f. Click OK and Close.
        iii. RC on **ValueTypes**, create New Element→SysML Values→ ValueType
            1. Name = **Kilogram**
            2. Base Classifier = Real
    b. RC **Satellite**
        i. Create New Element→SysML Blocks→Block
            1. Name = **SatelliteSystem**
        ii. In **SatelliteSystem**, create three new value properties
            1. Name = **Weight**, Type = Kilogram
            2. Name = **Weight_MOS**, Type = Real
            3. Name = **Power_MOS**,
            4. Type = Real

Discussion – ValueTypes, Units, and Dimensions

We frequently want to apply units to a value property, for example, electrical power in our model will be expressed in kilowatts. We do this by assigning a ValueType to the value property. We can use the Type property to make this assignment. We create two new ValueTypes in step 4.a above, Kilograms and Kilowatts. ParaMagic expects valuetypes used for parameters to be subtypes of the Real valuetype, so we use the Base Classifier entry to make this assignment (alternatively, the quantityKind field can be populated, see ParaMagic User Guide).

Assigning valuetypes to properties makes the model more exact and helps identify mismatches when block properties and constraint parameters are linked in parametric diagrams. Note that units are not assigned to value properties directly, so the Kilogram unit in the MD SysML profile is not used in step 4.b.ii.1 above. The full description of the relationship between ValueTypes, Units and Dimensions is described in the MagicDraw User Guide.

c. RC on **Satellite**
   i. Create New Element→SysML Blocks→Block
      1. Name = **Propulsion**
   ii. In Propulsion, create two new block properties
      1. Name = **Wpro**, Type = Kilogram
      2. Name = **Ppro**, Type = Kilowatt

d. Repeat step b. for **Instrumentation**, **Control**, and **PowerSystem** subsystems with attribute names as shown in Figure 3.2

e. RC on **Satellite**
   i. Create New Diagram→SysML Diagrams→SysML Block Definition Diagram
   ii. Name the diagram **SatelliteBDD**.
   iii. Drag **SatelliteSystem**, **Propulsion**, **Instrumentation**, **Control** and **PowerSystem** from the Containment tree into the diagram and arrange

f. Click on **SatelliteSystem** in the diagram, choose a Directed Composition arrow from the floating toolbar, and drag the arrow to **Propulsion**.

g. Name part property **Pro1**.

h. Repeat steps f. and g. for **Instrumentation**, **Control**, and **PowerSystem** subsystems as shown in Figure 3.2.

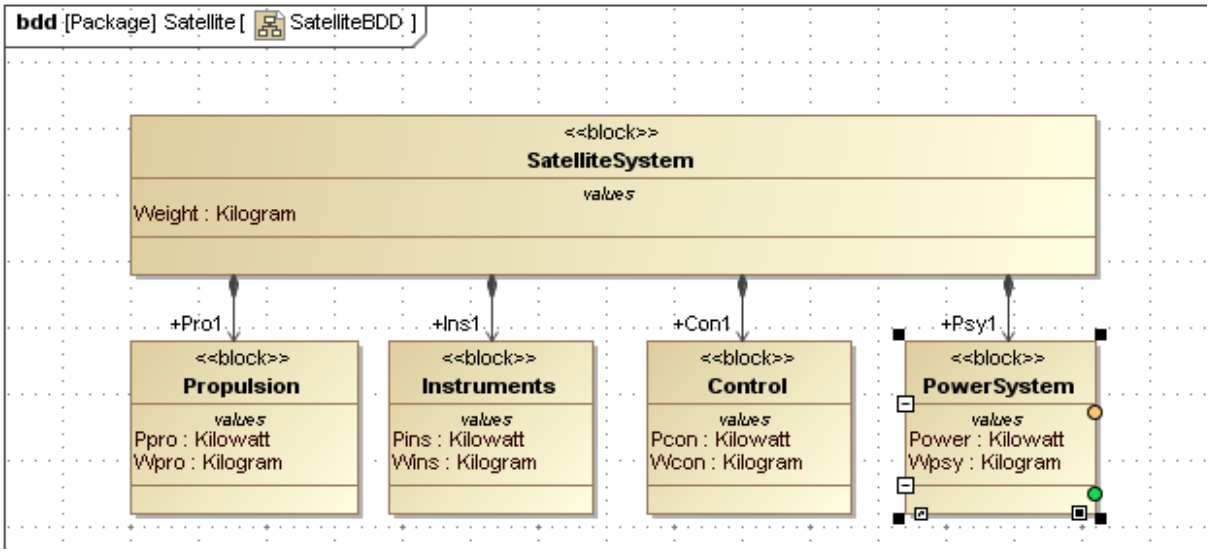


Figure 3.2 SysML Block Definition Diagram

Step IV Create Constraints

5. Inside Containment tree window, create two constraint blocks, which contains a mathematical relationship that the model will use for weight and power calculation
   a. RC Satellite, select New Element→SysML Blocks→Constraint Block, Name = **WeightBalance**
   b. RC **WeightBalance**, create New Element→Constraint Parameter
      i. Name = **w**, Type = Kilogram

c. Copy w, paste four times inside **WeightBalance** and rename to create parameters **w1**, **w2**, **w3** and **w4**.

d. DC (double-click) **WeightBalance**

   i. In the window labeled Constraint Block

      1. select Constraints
      2. click Create
      3. under Name, enter **weightbalance**
      4. under Specification, enter **w = w1 + w2 + w3 + w4**
      5. click Close

e. Create a second constraint block, name = **PowerBalance**, with four constraint parameters (**p**, **p1**, **p2**, **p3**), Type = Kilowatt, and one constraint, name = **powerdemand**, specification = **p = p1 + p2 + p3**, using the same process as steps as a.-d.

f. Drag both new constraint blocks into the **SatelliteBDD** block definition diagram, which will appear similar to Figure 3.3.

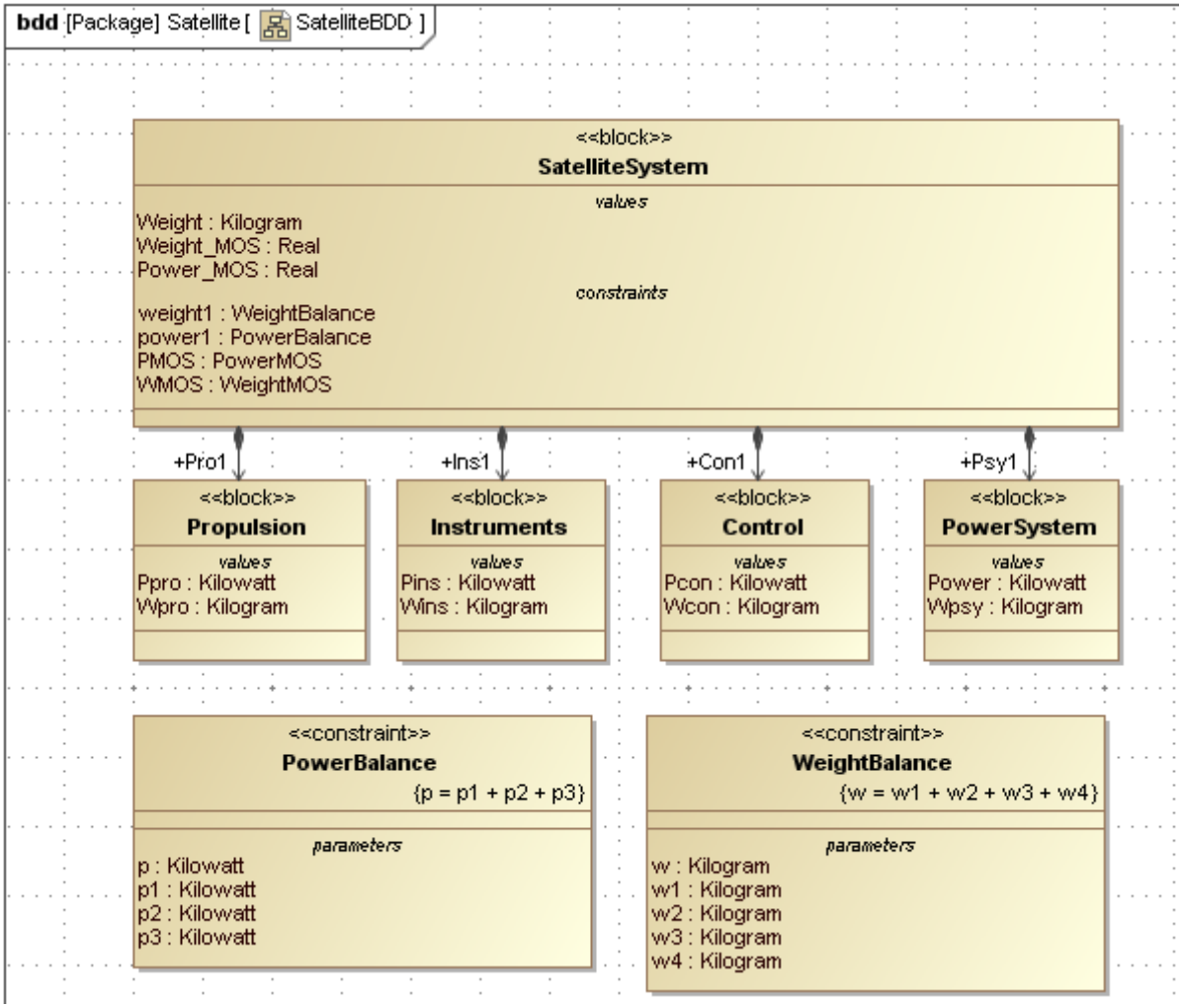


Figure 3.3 SysML Block Definition Diagram with Constraints

6. Create a Requirements diagram to show the specifications for the Satellite system. The purpose of a Requirements diagram is to make clear the requirements the system must meet and how these requirements tie to specific values of the model. For our purpose, we can pair each Requirement with a Constraint Block that mirrors it, making it easy to automatically verify the constraint when ParaMagic is executed.
    a. RC on **Satellite**, create New Element→Package, Name = **SatelliteReqts**
    b. RC on **SatelliteReqts**, create New Diagram→SysML Diagrams→SysML Requirements Diagram, Name = **SatelliteReqts**
    c. Drag two requirements blocks from the center toolbar into the diagram
        i. Name = **WeightReqt**, id = 1.0.1, text = Total system weight must be less than 10,000 kilograms
        ii. Name = **PowerReqt**, id = 2.0.1, text = Total system power use must be less than 10,000 kilowatts
    d. RC on **SatelliteReqts**, create New Element→SysML Blocks→Constraint Block
        i. Name = **WeightMOS** (Margin of Safety)
    e. RC on **WeightMOS** (in containment tree),
        i. Create a New Element→Constraint Parameter, Name = **mos**, Type = Real
        ii. Create a New Element→Constraint Parameter, Name = **actual**, Type = Kilogram
        iii. Create a constraint, Name = **wtmos**, Specification = **mos = (10000 - actual)/10000**. This constraint calculates the margin of safety as the difference between the target value, 10,000 kg, and the actual weight as calculated, divided by the target value. It will be positive if system weight is below the target value, negative if it exceeds the target.
    f. Repeat step e. for **PowerMOS** (see Figure 3.4 for specifics)
    g. Drag **PowerMOS** and **WeightMOS** into the Requirements diagram
    h. Use the Verify arrow (central toolbar) to show the relationship between each Constraint Block and the Requirement it verifies.

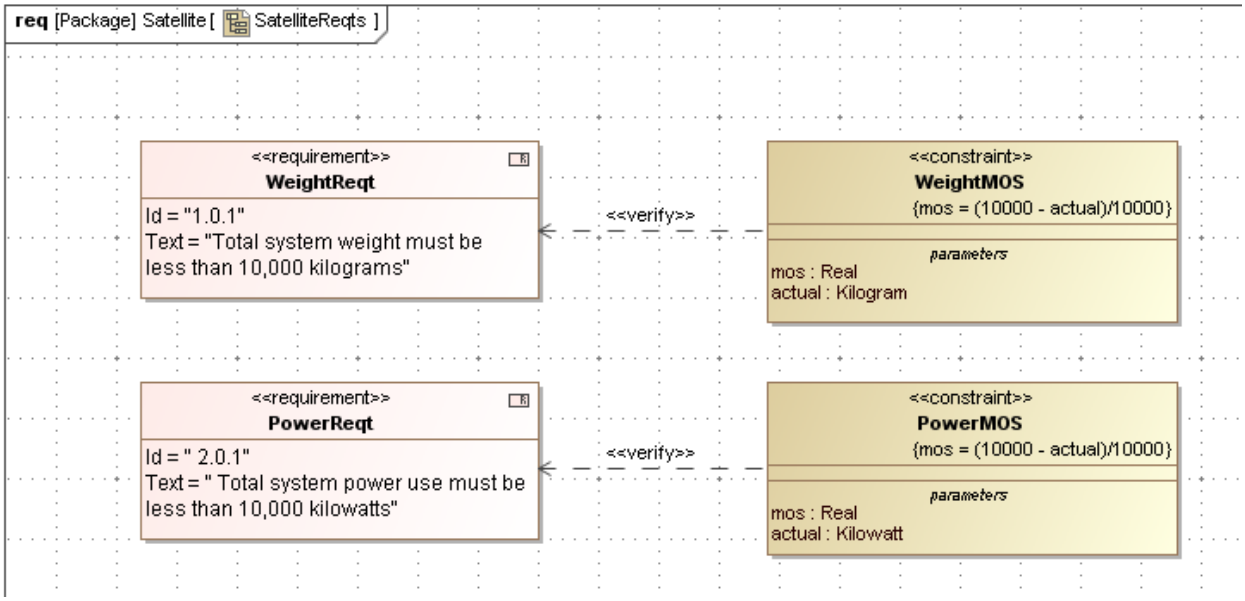


Figure 3.4 SysML Requirements Diagram

Step V Create Parametrics Model

7. Create a SysML Parametric diagram to define and display the relationships inside **SatelliteSystem**
    a. RC **SatelliteSystem**
    b. Create New Diagram→SysML Parametric Diagram, Name = **SatelliteSystem**
    c. Use the Select Parts window to select the **Weight** Value Property and four Part Properties inside **SatelliteSystem**. Uncheck Value Properties: **Weight_MOS** and **Power_MOS** as they will be used in the second Parametric Diagram.
        i. Use the Edit Compartment and Presentation Options commands to display the internal structure as shown in Figure 3.5
    d. Drag a constraint property icon from the central toolbar into the parametric diagram
        i. In Select/Create Part for Type window, choose **WeightBalance**
        ii. Name the constraint property **weight1**.
        iii. Click on **weight1** and select the Display Parameters icon from the floating toolbar (see Figure 2.10). Click OK on Select Parameters window.
        iv. Rearrange port icons inside **weight1** as shown in Figure 3.5.
    e. Repeat step d for a Constraint Property of the type of **PowerBalance**.
    f. Add connectors (central toolbar or floating toolbar) from the Value or Part Property attributes to the Constraint Property parameters as shown in Figure 3.5.

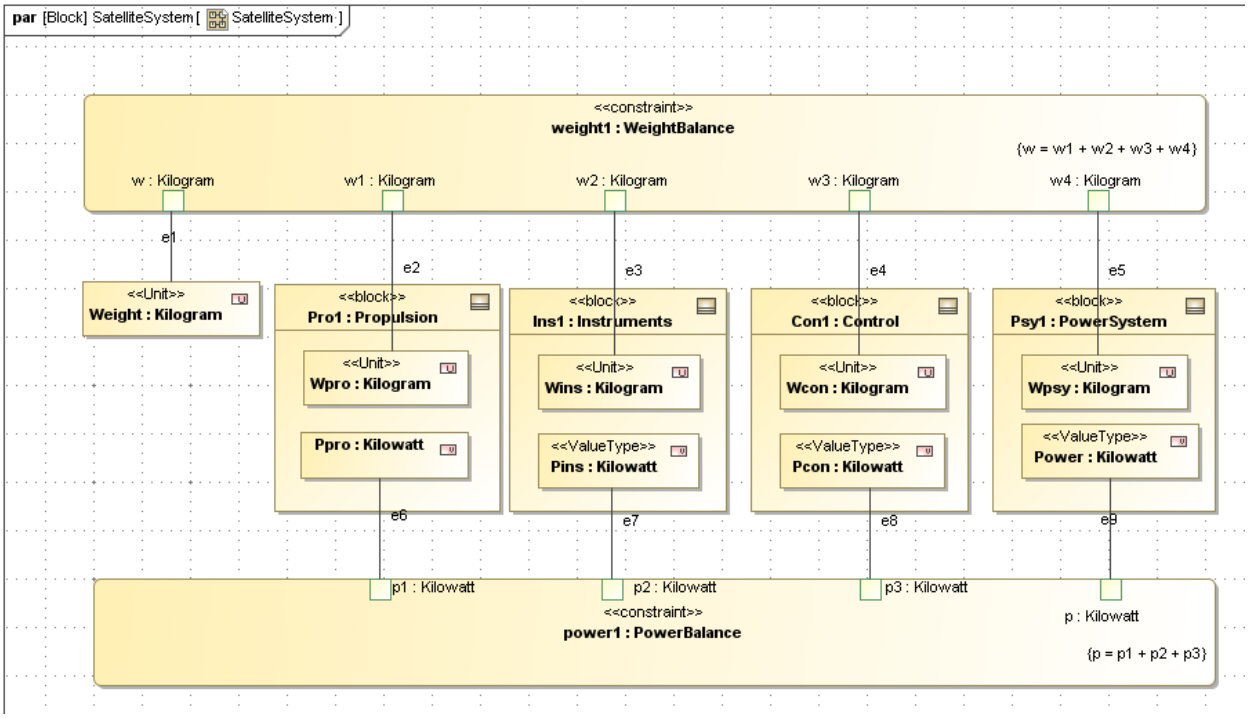


Figure 3.5 SysML Parametrics Diagram

8. Create a second SysML Parametric diagram to define and display the calculation of the requirements verification relationships inside **SatelliteSpecfication**
    a. RC **SatelliteSystem**
    b. Create New Diagram→ SysML Parametric Diagram, Name = **SatelliteVerify**
    c. Use the Select Parts Window to allow only the Part Property, **Psy1**, and the Value Properties: **Weight**, **Weight_MOS**, and **Power_MOS**, to appear in the parametric diagram.
    d. Use Edit Compartment to show the Value property, **Power**, inside **Psy1**.
    e. Drag the **WeightMOS** constraint block inside the diagram and give it the name **WMOS** as a constraint property of **SatelliteSystem**. Display the constraint parameters and arrange as shown in Figure 3.6.
    f. Repeat for the **PowerMOS** constraint block.
    g. Add connectors from the Value or Part Property attributes to the Constraint Property parameters as shown in Figure 3.6.

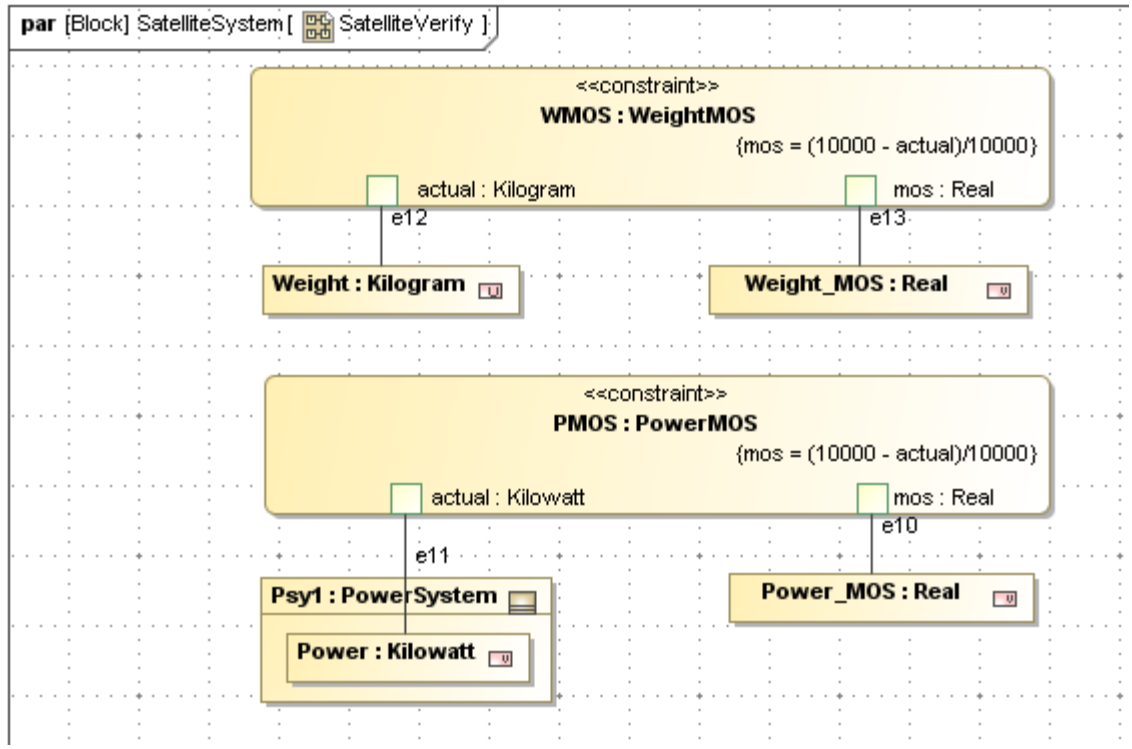


Figure 3.6 SysML Parametrics Diagram

Step VI Validate Parametrics Model

9. To validate the model schema, RC on **SatelliteSystem**, the root block, in the Containment tree and select ParaMagic→Validate.

Step VII Create an Instance

10. Create an instance by creating a new block definition diagram containing the model, the elements whose attributes are givens or unknowns in the calculation. In the first tutorial, we created the diagrams and instances individually. In this example, we use the Instantiation Wizard, which can create complex instances more efficiently, particularly where there are many elements.
    a. RC on **SatelliteSystem** (the root block) and select Create Instance…
        i. The Automatic Instantiation Wizard is launched as in Figure 3.7a.

Note: The shortcuts taught in this tutorial, including Create Instances… (step 10) and entering the values and causalities directly into the ParaMagic browser (step 11) can be quicker than the manual entry methods shown in the first tutorial. ParaMagic has the ability to create instances and set values directly from Excel spreadsheets (see the Orbital tutorial for an example), which can be even quicker for more complex models.

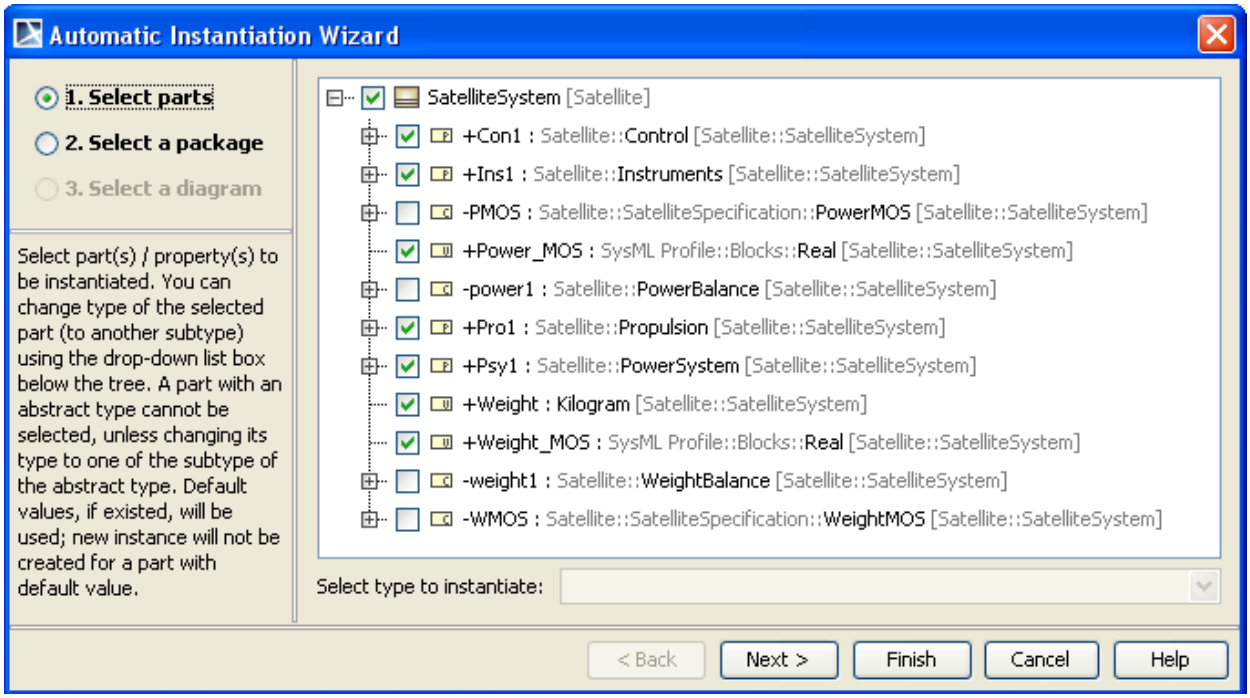


Figure 3.7a Automatic Instance Generation, Part 1

ii. Click Next.

iii. Click Create and create the **Instance_01** package in the **Satellite** package (see Figure 3.7b)

iv. Click Next.

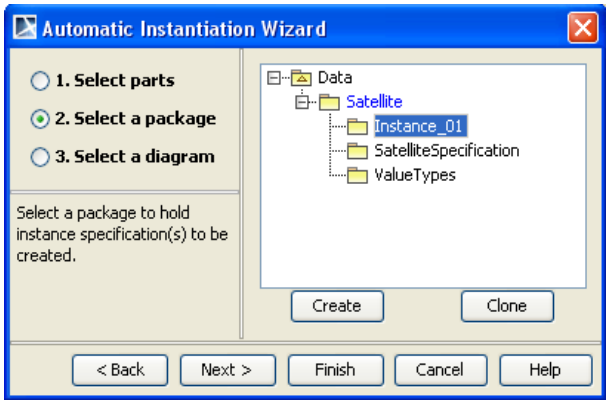


Figure 3.7b Automatic Instance Generation, Part 2

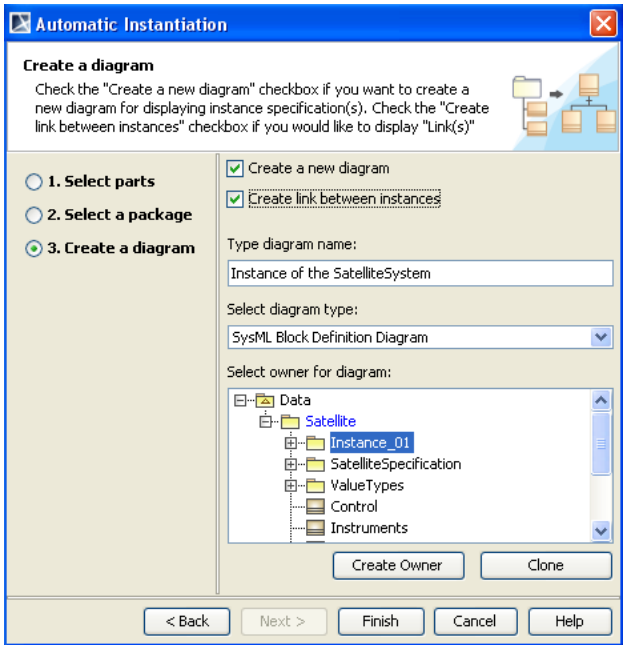


Figure 3.7c Automatic Instance Generation, Part 3

v. Click the "Create a new diagram" checkbox (see Figure 3.7c).
vi. Diagram name = **Instance_01**, Type = SysML Block Definition Diagram.
vii. Click Finish.

b. The diagram **Instance_01** looks similar to Figure 3.8

Step VIII Solve the Instance

11. Assign causality and value to all variables. In this example, we will enter these using ParaMagic and the browser, rather than directly into the instances as taught in the first tutorial.
    a. RC on **satelliteSystem:Satellite System** (the root instance).
        i. Select ParaMagic→Browse.
        ii. A message as shown in Figure 3.9 will appear. This indicates that no causalities have been assigned.
        iii. Click Reassign. This assigns *undefined* casuality to variables without values and *given* causality to variables with starting values. At this stage, no variables have been assigned a value. The ParaMagic browser appears as in Figure 3.10

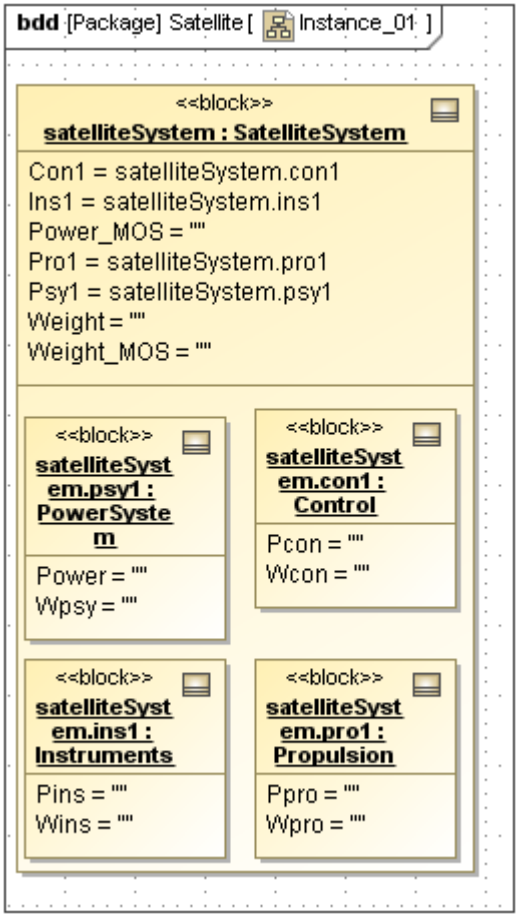


Figure 3.8 Satellite Instance_01 Diagram, after wizard

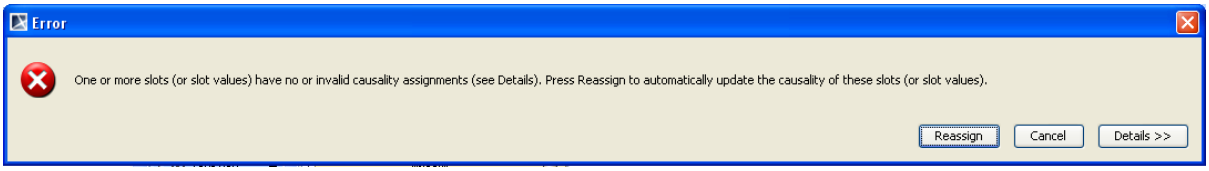


Figure 3.9 ParaMagic Browser for Instance_01, before solution

b. Assign a *given* value of 5000 (Kilowatts) to **Ppro**.
    i. Click on the causality assigned to **Ppro** , initially *undefined*.
    ii. On the pulldown menu that appears, change **Ppro**'s causality to *given*.
    iii. "InputValue!" appears in the Values column. Change it to 5000.
c. Repeat step c. for all the variables as shown in Figure 3.11. Note that **Power_MOS** and **Weight_MOS** are reassigned to *target* causality.

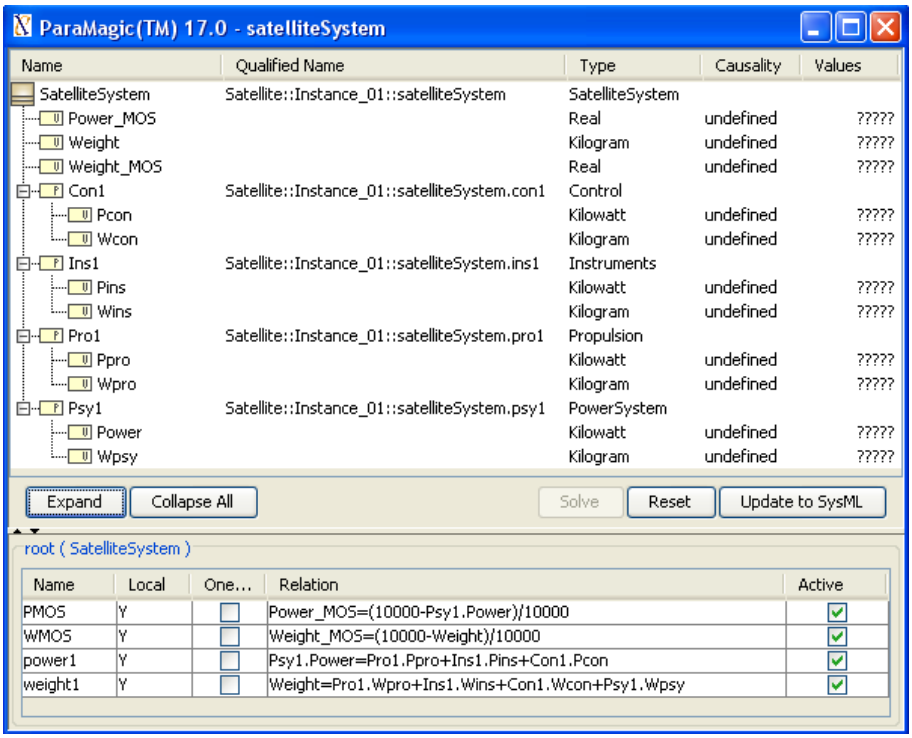


Figure 3.10 ParaMagic Browser for Instance_01, before solution

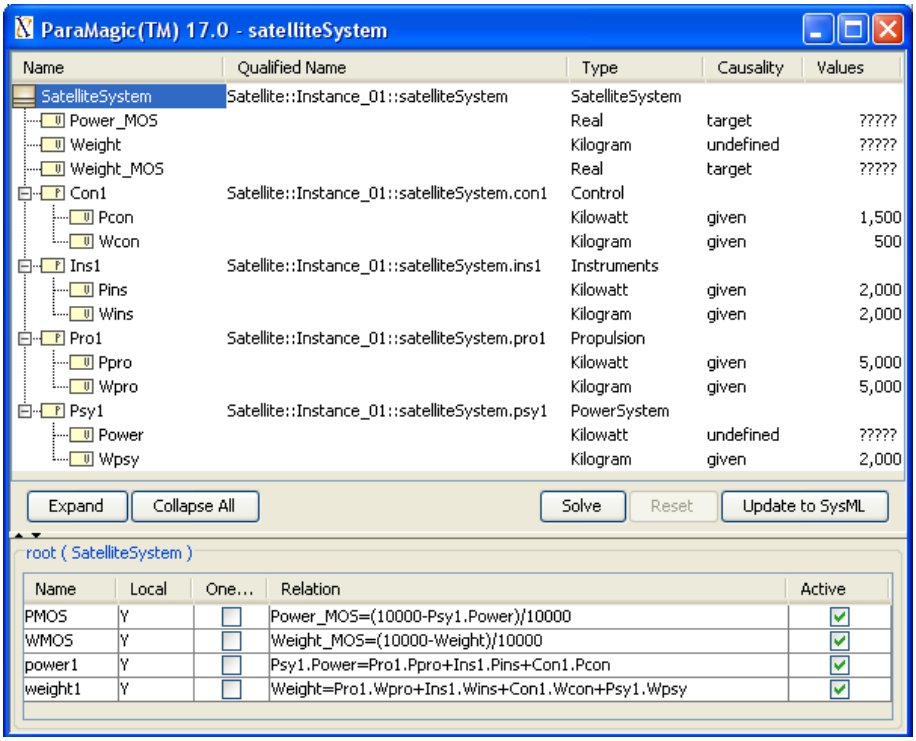


Figure 3.11 ParaMagic Browser for Instance_01, before solution

12. Solve the parametric model.
    a. Press “Solve”. The ????? symbols in the *target* variables should change to their calculated values.
        i. The results in Figure 3.12 show positive values of **Weight_MOS** and **Power_MOS**. In other words, both requirements have been successfully met with positives margins of safety.
        ii. After solution, parameters that began with *undefined* causality now have calculated values and *ancillary* causality. Slots for which no values were calculated remain as *undefined*. This may be caused by an error in building the parametric model, by a failure of Mathematica to solve the parametric equations, or by these slots not being in the path required to calculate the *target* values.
    b. Press “Update to SysML”. Then you should see the new calculated values in the Instance diagram.

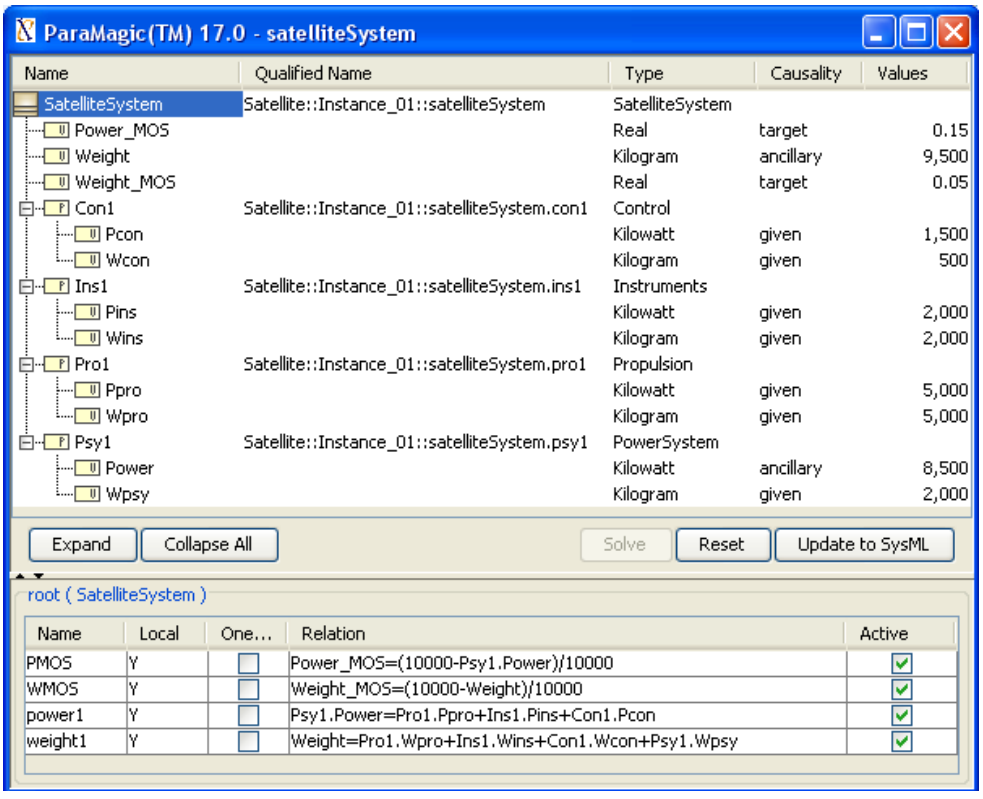
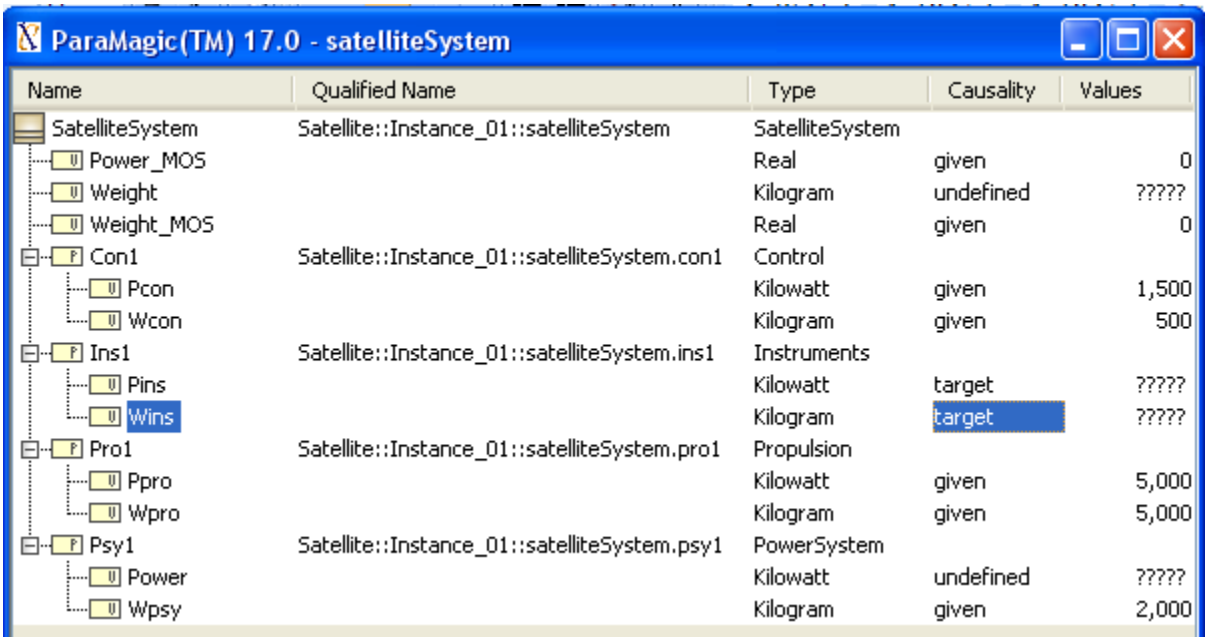


Figure 3.12 ParaMagic Browser for Instance_01, after solution

13. It is possible to manipulate the values inside the browser window to repeat the calculation with a new set of given values, or even change the choice of *given* and *target* values. Selecting the Causality type for a parameter in the Browser opens a pull-down list with three choices: *given*, *undefined*, and *target*.
    a. To change a given value, click on that value in the browser window and edit. This will reset the solution.

b. To change a *target* or *undefined* value to a *given*, or a *given* value to *target* or *undefined*, change the causality for that parameter. In Figure 3.12, the problem has been inverted.
"Given the weight budget (10,000 kg) and power budget (10,000 kW) and the properties of the other subsystems, how much weight and power can be allocated to the Instruments subsystem?". In this example, we set the margins of safety equal to zero and calculate **Wins** and **Pins** as targets.



Name	Qualified Name	Type	Causality	Values
SatelliteSystem	Satellite::Instance_01::satelliteSystem	SatelliteSystem		
Power_MOS		Real	given	0
Weight		Kilogram	undefined	?????
Weight_MOS		Real	given	0
Con1	Satellite::Instance_01::satelliteSystem.con1	Control		
Pcon		Kilowatt	given	1,500
Wcon		Kilogram	given	500
Ins1	Satellite::Instance_01::satelliteSystem.ins1	Instruments		
Pins		Kilowatt	target	?????
Wins		Kilogram	target	?????
Pro1	Satellite::Instance_01::satelliteSystem.pro1	Propulsion		
Ppro		Kilowatt	given	5,000
Wpro		Kilogram	given	5,000
Psy1	Satellite::Instance_01::satelliteSystem.psy1	PowerSystem		
Power		Kilowatt	undefined	?????
Wpsy		Kilogram	given	2,000

Figure 3.13 ParaMagic Browser for Instance_01, before solution, with changes in causality

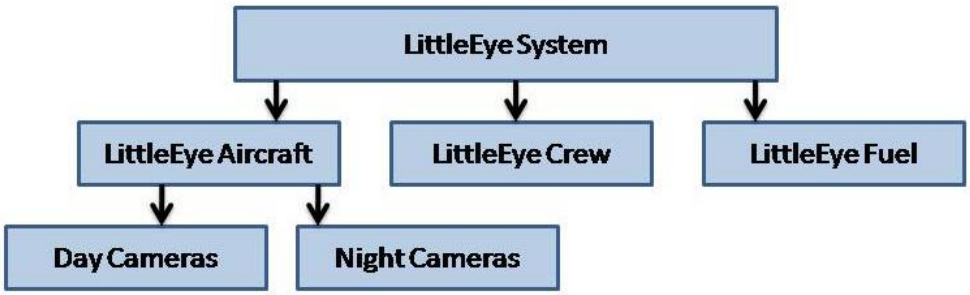
Discussion – Causality

Mathematica is an "acausal" solver, that is, it can solve many equations in any direction. The user can take advantage of this to use the same model to answer different kinds of questions. However, not all solvers are acausal (e.g. Microsoft Excel formulas work in one direction only) and not all functions work in multiple directions (e.g. A = MINIMUM(B,C,D) cannot always be solved uniquely for D given A, B and C). Keeping track of causality can require some effort on the part of the modeler.

4 SysML Parametrics Tutorial - LittleEye

4.1 Objective

The third tutorial concerns using SysML to determine operational performance using a sequence of equations. The system is the LittleEye unmanned aerial vehicle (UAV) which is used to provide reconnaissance. The objective is to calculate how many miles of road can be scanned per 24 hours, which will be determined by the number and duty cycle of aircraft, the number and duty cycle of crews, and the availability of fuel.



NumberMilesScannedPer24Hours = NumberAvailablePlanes x MilesScannedPerHour x 24

NumberAvailableSystems = MINIMUM(NumberAvailablePlanes, NumberAvailableCrews, NumberAvailableFuelLoads)

NumberAvailablePlanes = 0.5*(NumberAvailablePlanesByDay + NumberAvailablePlanesByNight)*DutyCyclePlane

DutyCyclePlane = (1-DutyCycleTurnaround) x (1-DutyCycleCameraRefit) x (1-DutyCycleMaintenance)

NumberAvailablePlanesByDay = MINIMUM(NumberPlanes, NumberDayCameras)

NumberAvailablePlanesByNight = MINIMUM(NumberPlanes, NumberNightCameras)

NumberAvailableCrews = NumberCrews x CrewTimeOn

NumberAvailableFuelLoads = FuelSupplyPerDay/DailyFuelLoadPerPlane

Information Provided
MilesScannedPerHour = 40 mph
CrewTimeOn = .42 (120 hours on over 12 day period)
DutyCycleTurnaround = .23 (30 hours turnaround per 100 flight minutes)
DutyCycleCameraRefit = .02 (15 minutes refit per 12 hour period)
DutyCycleMaintenance = .09 (3 hours maintenance per 30 flight hours)
DailyFuelLoadPerPlane = 50 gallons

Figure 4.1 Outline of Objective

The complexity of the model, with six elements, eight constraints and more than twenty parameters, makes it a good place to introduce "object-oriented" modeling techniques, which allow a complex model to be built from simple, independent and potentially reusable subsystems, tied together only at the highest levels

What the User Will Learn

- Applying an "object-oriented" approach to SysML parametrics
- Embedding constraints and parametric diagrams within multiple blocks in the model
- Using standard functions, e.g. Minimum
- Using simulation to explore a model with "what-if scenarios"

.

4.2 Step-by-Step Tutorial

Step I Create Project

1. Create new SysML project, Name = **LittleEye**
2. Create new Package, Name = **LittleEye**

Step II Create Infrastructure

3. Install ParaMagic Profile module, same as in the Addition tutorial.

Step III Create Structural Model

4. Create a Block Definition Diagram containing the four structural elements with attributes as shown in Figure 4.2

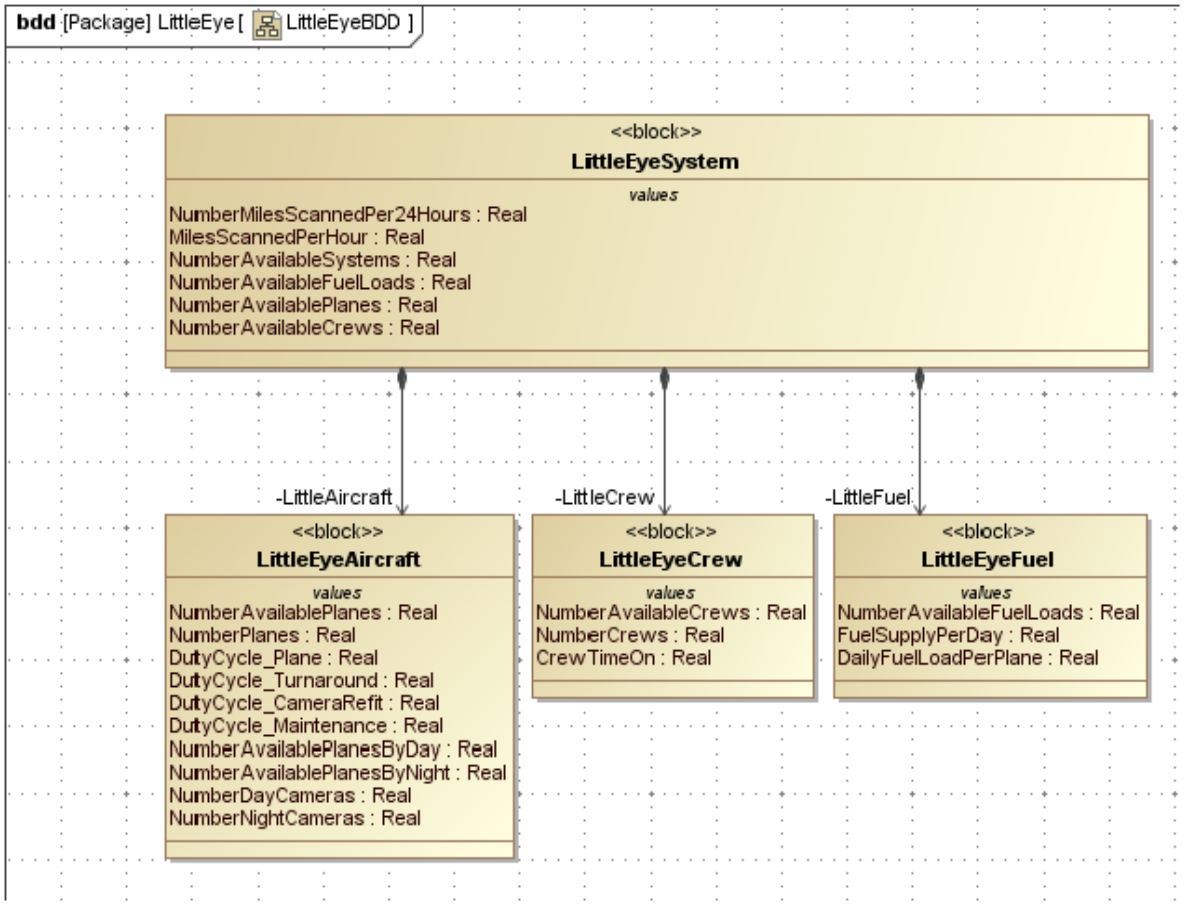


Figure 4.2 Structural Elements in Block Definition Diagram LittleEyeBDD

a. Create the Directed Composition arrows as demonstrated, to show that aircraft, crew and fuel are parts of the system.
b. Name the Part Properties created inside **LittleEyeSystem** by the Directed Composition arrows (**LittleAircraft** , **LittleCrew**, and **LittleFuel** in this example).

Step IV Create Constraints

5. Inside the **LittleEye** package, create eight constraint blocks, which contain the eight mathematical relationships appearing in Figure 4.1, using the procedure described in the earlier tutorials. Figure 4.3 shows the eight constraint blocks displayed on the right side of the **LittleEye** Block Definition Diagram. The parameter list has been hidden for the constraint blocks by selecting Presentation Options→Suppress Parameters, Operations, Attributes on each block.

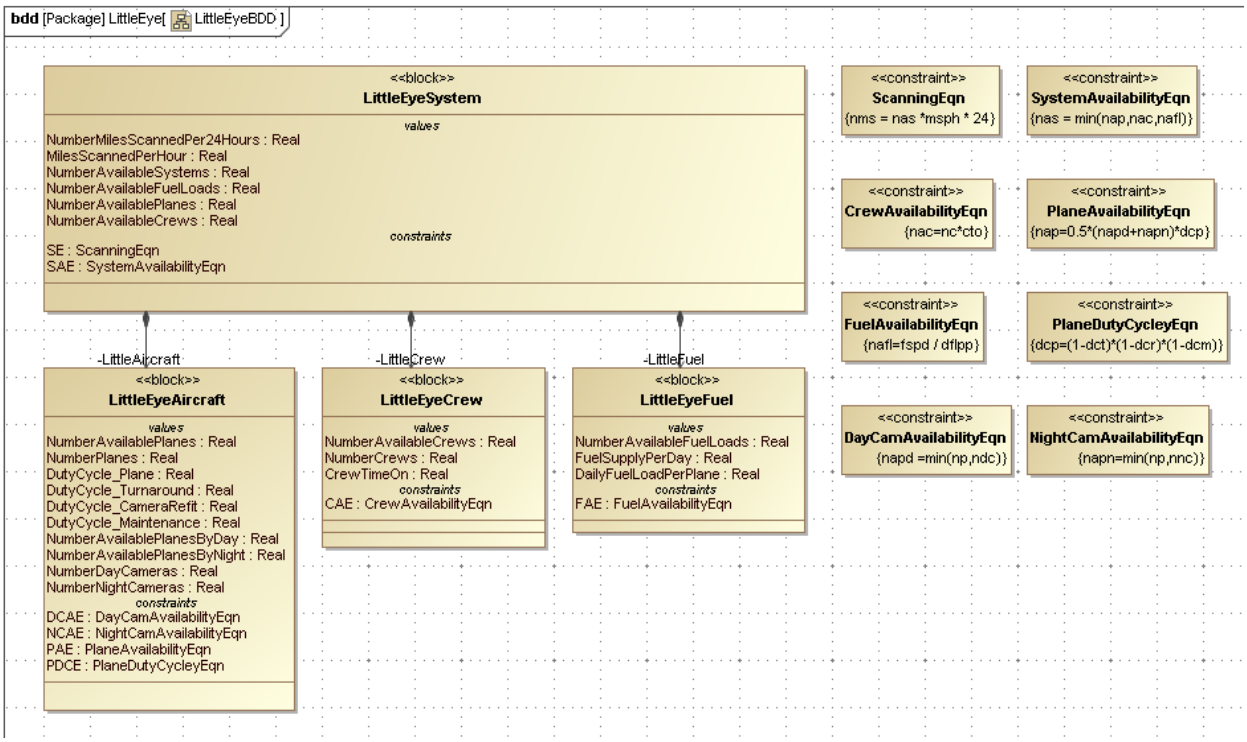


Figure 4.3 Block Definition Diagram with Constraints and Model added

Step V Create Parametrics Model

6. Using an "object-oriented" programming approach, the four elements of Figure 4.2 will be converted into independent submodels containing internal constraints and relationships. Each sub-model could be modified without damaging the larger system model. It could also be copied and reused in a different project.
    a. The submodel **LittleEyeSystem** will contain the six values listed in Figure 4.3 plus two constraints that connect them, the **Scanning Equation** and the **System Availability Equation** at the top right of Figure 4.2. See Figure 4.4.
        i. In the Containment window, drag **ScanningEqn** and **SystemAvailabilityEqn** inside the **LittleEyeSystem** block.
        ii. In **LittleEyeSystem**, create a New Diagram→SysML Parametrics Diagram, name = **LittleEyeSystem**
        iii. Use the Select Parts window to choose the six Value Properties inside **LittleEyeSystem** to appear on parametrics diagram.

iv. Create a new Constraint Property by dragging the Constraint Block **ScanningEqn** into the parametrics diagram, Name = **SE**. Use the Display Parameters icon to show **nms**, **msph**, and **nas** inside **SE**.

v. Repeat step iv. for a second constraint property, name = **SAE**, Type = SystemAvailabilityEqn.

vi. Using connectors, wire the value properties and constraint parameters as shown in Figure 4.4.

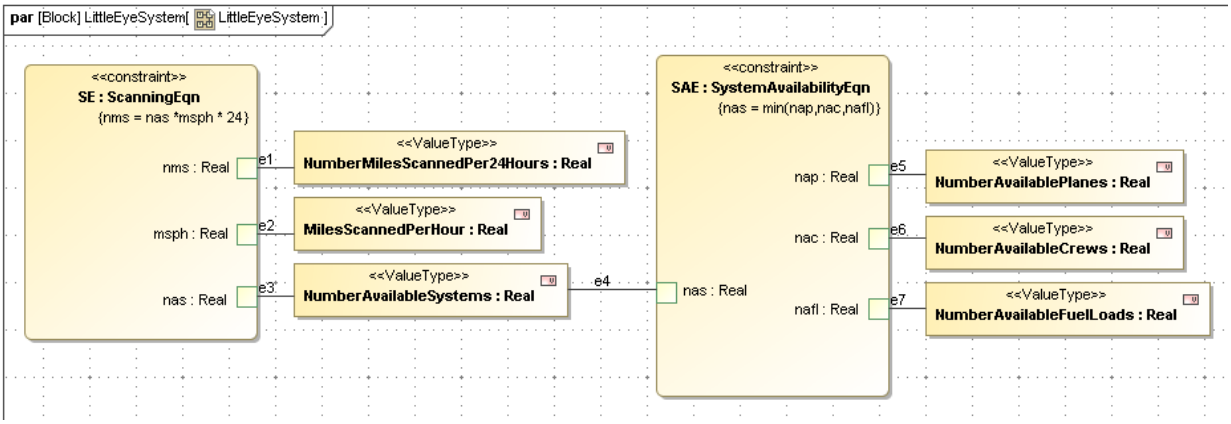


Figure 4.4 LittleEyeModel Parametrics Diagram

b. Create submodels for the Aircraft, Crew, and Fuel blocks using the same procedures, ending with the parametrics diagrams shown in Figures 4.5, 4.6 and 4.7

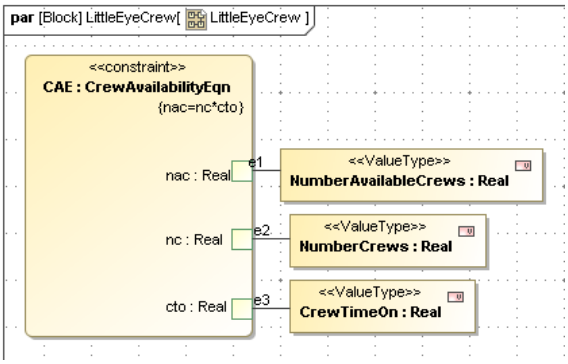


Figure 4.5 LittleEyeCrew Parametrics Diagram

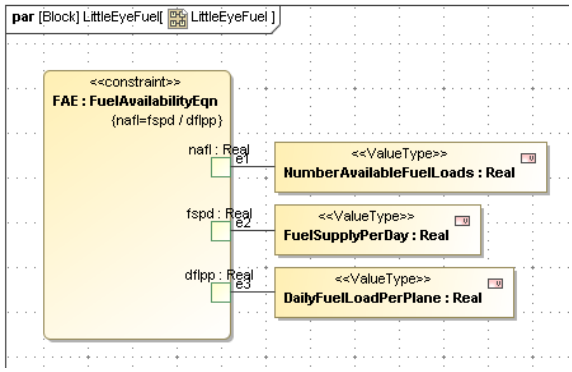


Figure 4.6 LittleEyeFuel Parametrics Diagram

Discussion: Adding Constraint Properties to Parametric Diagrams

In the first three tutorials, we have used slightly different methods to incorporate constraints into parametric diagrams. In the first, we dragged the Constraint Block from the Containment tree into the parametric diagram, creating a Constraint Property of the same type. In the second, we dragged a constraint property icon from the toolbar into the parametric diagram and used the Select Classifier window to identify it with an existing Constraint Block. In this example, we placed the Constraint Blocks inside the submodel blocks, before dragging them into the parametric diagrams to create individual Constraint Properties of the same type. In each case, we have had to

assign the Constraint Property created a unique name.

All three methods work. The third implies an exclusive ownership of the constraint by a particular submodel, which may be misleading if the constraint block is to be re-used by other parts of model. Assigning ownership may be useful in a collaborative environment, but it is also OK to keep Constraint Blocks anywhere in the project, e.g. in a Constraints library, and drag them into specific parametric diagrams as needed.

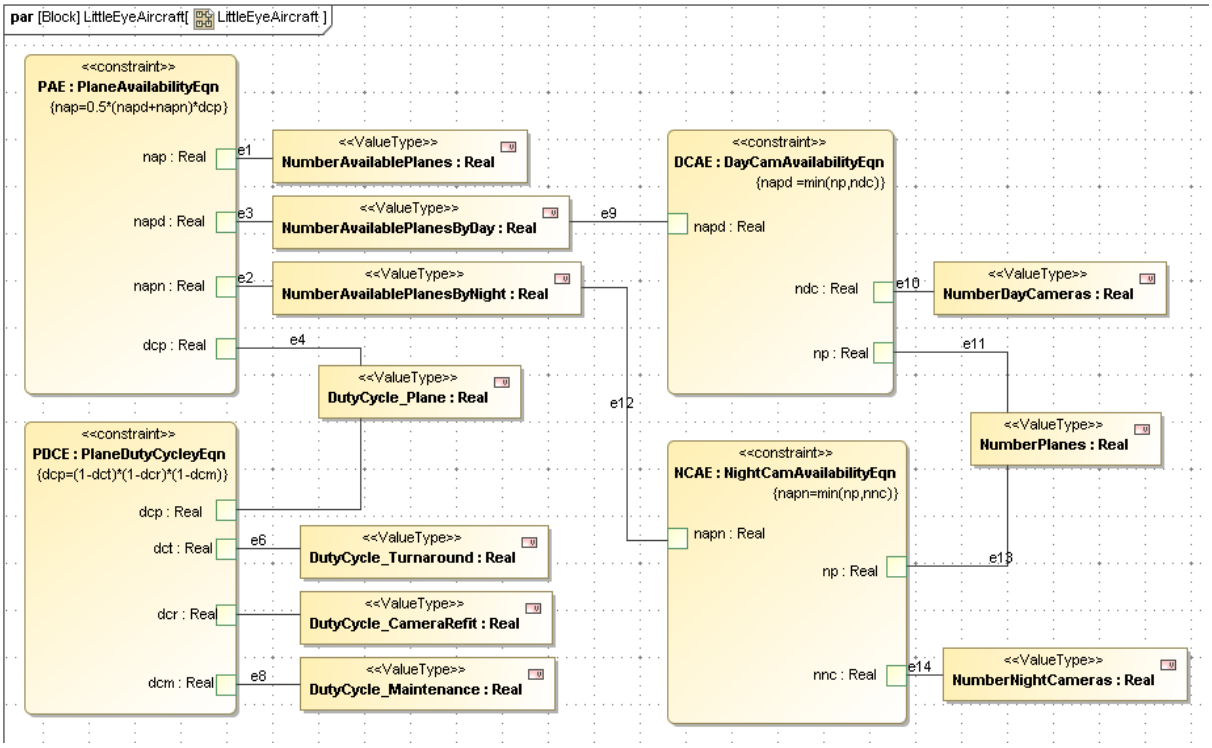


Figure 4.7 LittleEyeAircraft Parametrics Diagram

7. It is also necessary to create an overall parametric diagram to connect the different submodels. This is an objective of "object-oriented" programming, to create independent modules and link them in the simplest possible way. Within the top-level block, **LittleEye System**, several properties have been created with the same names as properties in the lower-level models, e.g. **NumberAvailablePlanes**. In the following steps, we use connectors to link models together through these duplicate parameters. (Alternate: the duplicate parameters could also be linked using explicit equality constraint relationships, created as an Equality constraint block in Step 8 and used three times within this parametric diagram. However, this involves a lot of extra work. ParaMagic interprets direct connections between value properties as equality relationships).
    a. Create a second SysML Parametrics diagram inside **LittleEyeSystem** called **LittleEyeSystem_2**.
    b. Use the Select Parts window to select the Part Properties **LittleAircraft**, **LittleCrew** and **LittleFuel**, to appear in the parametrics diagram.

c. Drag the three value properties of **LittleEyeSystem**: **NumberAvailablePlanes**, **NumberAvailableCrews** and **NumberAvailableFuelLoads** into the parametric diagram.
d. Using Edit Compartment and Presentation Options, display the internal structure of the three submodels as shown in Figure 4.8. Note that only the parameters necessary for wiring between the high-level model and the submodels are shown; all other parameters can remain hidden.
e. Draw connectors between model properties as shown in Figure 4.8.

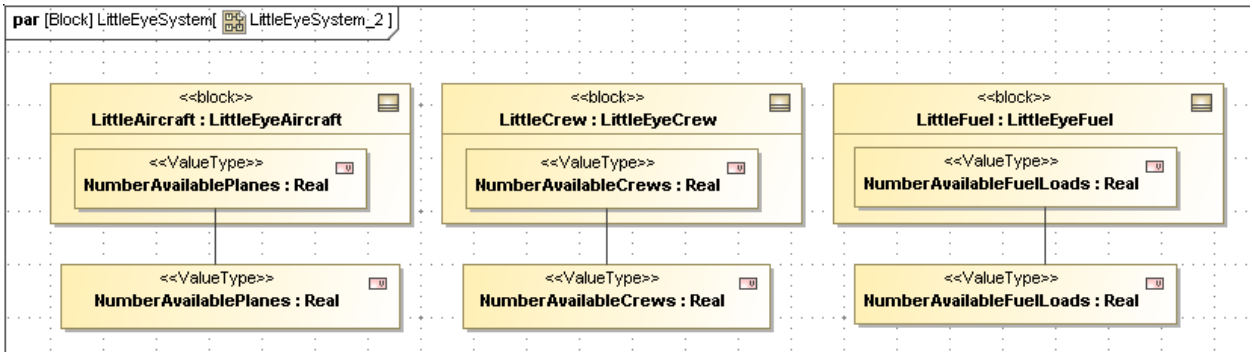


Figure 4.8 LittleEyeSystem_2 Parametric Diagram

Step VI Validate Parametrics Model

8. To validate the model schema,
    a. RC on **LittleEyeSystem**, the root block, and select ParaMagic→Validate.

Step VII Create an Instance

9. Create an instance of the model. The steps are similar to previous tutorials, however, some short-cuts are used. For example, the values of the given are assigned in step d below and most causality tags are set automatically using the "Assign default causalities" utility in step f. Figure 4.9 is an example of an instance. The values for several of the givens are taken from Figure 4.1. Others, such as the **NumberPlanes**, are user-set trial values, which will be varied during the solving operation.
    a. Create a package called **LittleEyeInstance01** inside the **LittleEye** package.
    b. Create a block definition diagram for the instance.
    c. Create instances of **System01**, **Aircraft01**, **Crew01** and **Fuel01**.
    d. To display parameters inside each instance, DC on the instance, select Slots, DC on each parameter to be displayed, assign a value if the parameter is a given, and close the window when all parameters in that instance are complete.
        i. When inputting decimal values less than one, it is necessary to use the notation 0.42 instead of .42 or the ParaMagic browser window will not open.
    e. Link the **Aircraft01**, **Fuel01** and **Crew01** blocks to **System01** block using the Link connector on the floating toolbar (click on the block to see toolbar).
    f. Assign causalities.

i. Right-click **LittleEyeInstance01**.
ii. Select ParaMagic→Util→Assign default causalities. All parameters that have been assigned a numerical value are now assigned as *givens*. All parameters that were assigned an empty value are now assigned as *undefined* (to be calculated by the solver). This same function is carried out automatically when the browser is opened if causalities are not already assigned.
iii. Assign **NumberMilesScannedPer24Hours** *target* causality in this example.
iv. RC System01 in the Containment tree and select ParaMagic→Util→Set default instance. This identifies the root instance within the **LittleEye Instance01** package and allows the parametric model to be browsed from either the root instance or the package.

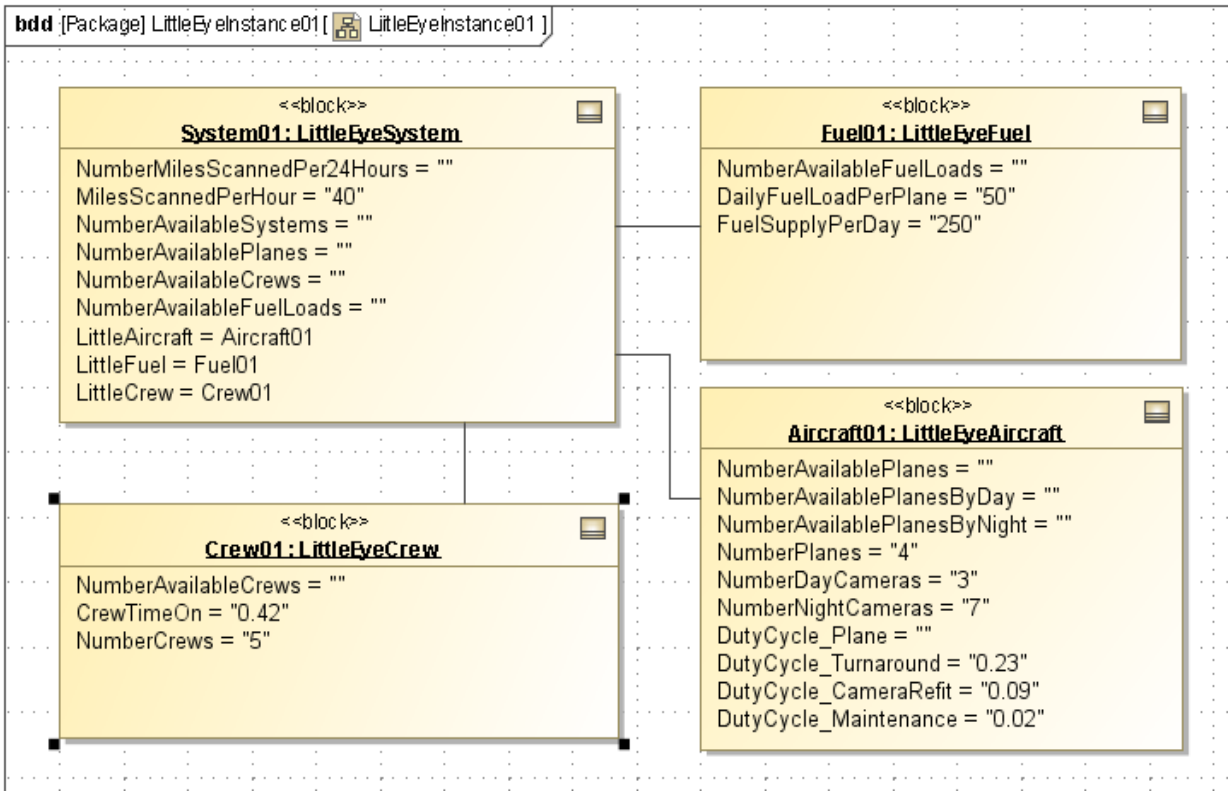


Figure 4.9 Creating an Instance of the LittleEye model

Step VIII Solve the Instance

The trial parameters appear in the browser window as shown in Figure 4.10. After solution, the results are shown in Figure 4.11. The target result, **NumberMilesScannedPer24Hours**, is 2, 016 miles. Note that the number of available systems is 2.1, on average, and is limited by the number of available crews. The number of available aircraft, 2.4, and fuel loads, 5, are not the limiting factors in keeping UAVs in the air.

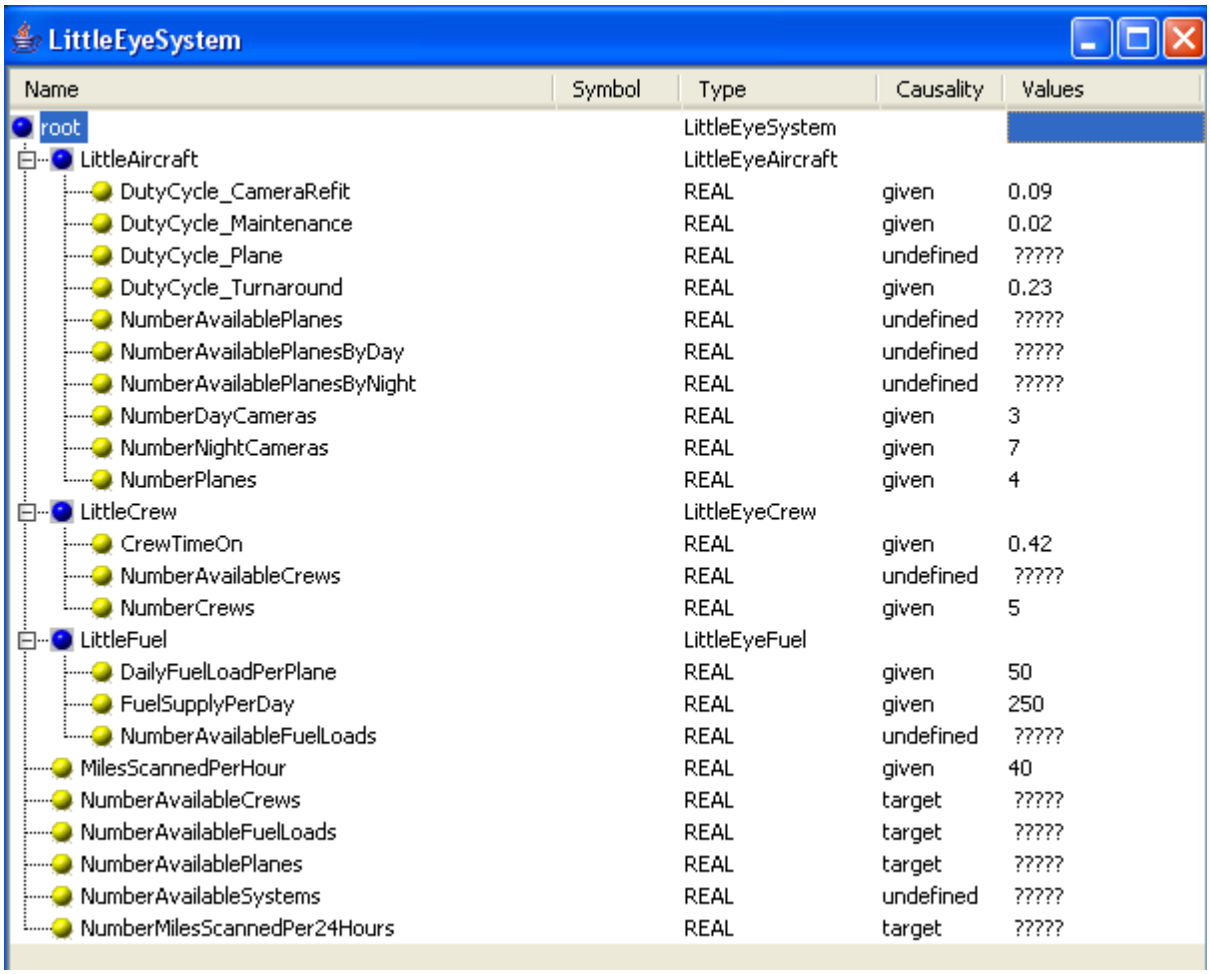


Figure 4.10 Browser for First Instance of the LittleEye model, before Solution

In Figure 4.11, several parameters are labeled “ancillary” after solution. This implies that they were calculated during the solution process, and were used in further calculations. For example, the number of available crews was calculated from the number of crews and the crew duty cycle, and is used in calculating the number of available systems.

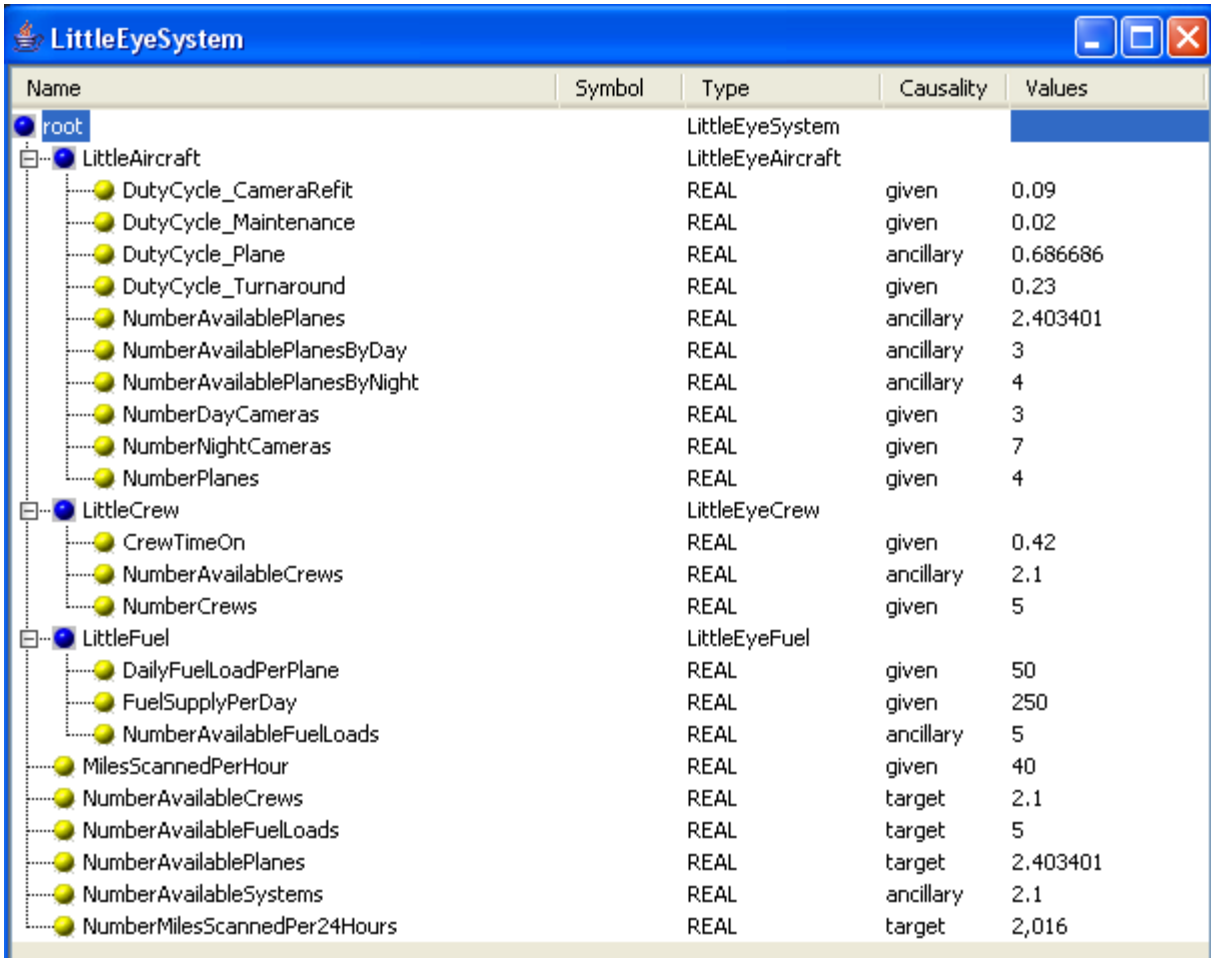
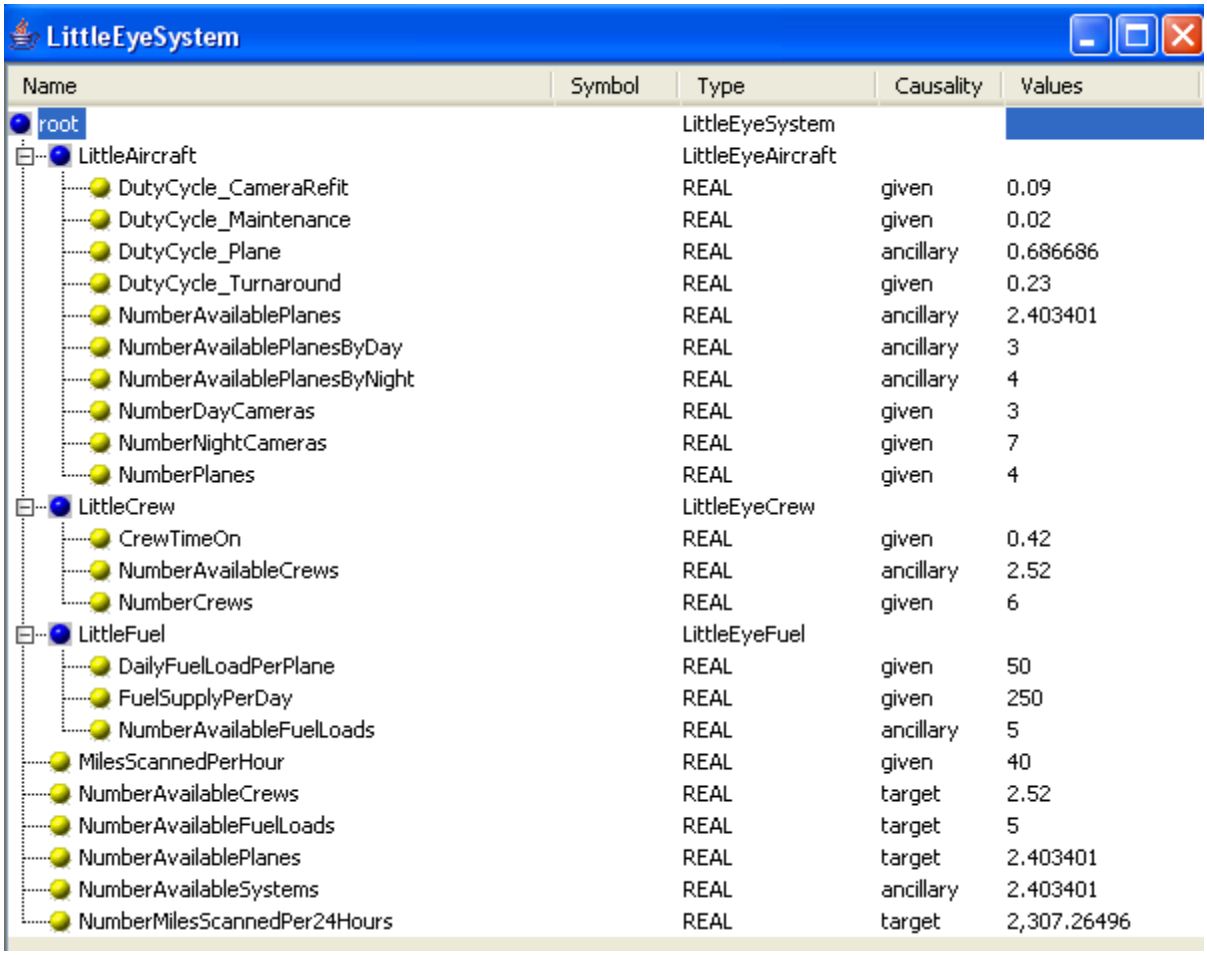


Figure 4.11 Browser for First Instance of the LittleEye model, after solution

In Figure 4.12, the number of crews assigned to the base is increased by one, from 5 to 6. After solution, the average number of available systems has increased to 2.4, now limited by the number of available planes, and the number of miles scanned per 24 hours has increased to 2307. Increasing the number of crews by 20% has increased the number of miles scanned by only 14% because a different resource became the limiting factor. Further experimentation would show how the numbers of planes, day cameras, and night cameras affects total miles scanned.

In some cases, the user will want to create and save multiple instances to record the effect of changing input variables. One way to do this is to make multiple copies of the original instance within the model and modify each one as desired, with a different set of input parameters, for example. The tutorial in Chapter 8 presents a different approach, using MS Excel to organize a trade study between parameter sets.



Name	Symbol	Type	Causality	Values
root		LittleEyeSystem		
LittleAircraft		LittleEyeAircraft		
DutyCycle_CameraRefit		REAL	given	0.09
DutyCycle_Maintenance		REAL	given	0.02
DutyCycle_Plane		REAL	ancillary	0.686686
DutyCycle_Turnaround		REAL	given	0.23
NumberAvailablePlanes		REAL	ancillary	2.403401
NumberAvailablePlanesByDay		REAL	ancillary	3
NumberAvailablePlanesByNight		REAL	ancillary	4
NumberDayCameras		REAL	given	3
NumberNightCameras		REAL	given	7
NumberPlanes		REAL	given	4
LittleCrew		LittleEyeCrew		
CrewTimeOn		REAL	given	0.42
NumberAvailableCrews		REAL	ancillary	2.52
NumberCrews		REAL	given	6
LittleFuel		LittleEyeFuel		
DailyFuelLoadPerPlane		REAL	given	50
FuelSupplyPerDay		REAL	given	250
NumberAvailableFuelLoads		REAL	ancillary	5
MilesScannedPerHour		REAL	given	40
NumberAvailableCrews		REAL	target	2.52
NumberAvailableFuelLoads		REAL	target	5
NumberAvailablePlanes		REAL	target	2.403401
NumberAvailableSystems		REAL	ancillary	2.403401
NumberMilesScannedPer24Hours		REAL	target	2,307.26496

Figure 4.12 Browser for Second Instance of the LittleEye model, NumberCrews increased by one, after solution

5 SysML Parametrics Tutorial - CommNetwork

5.1 Objective

The fourth tutorial uses SysML to simulate a simple communication network. The objective is to calculate the output of the network given the input and the loss in the individual channels between stations..

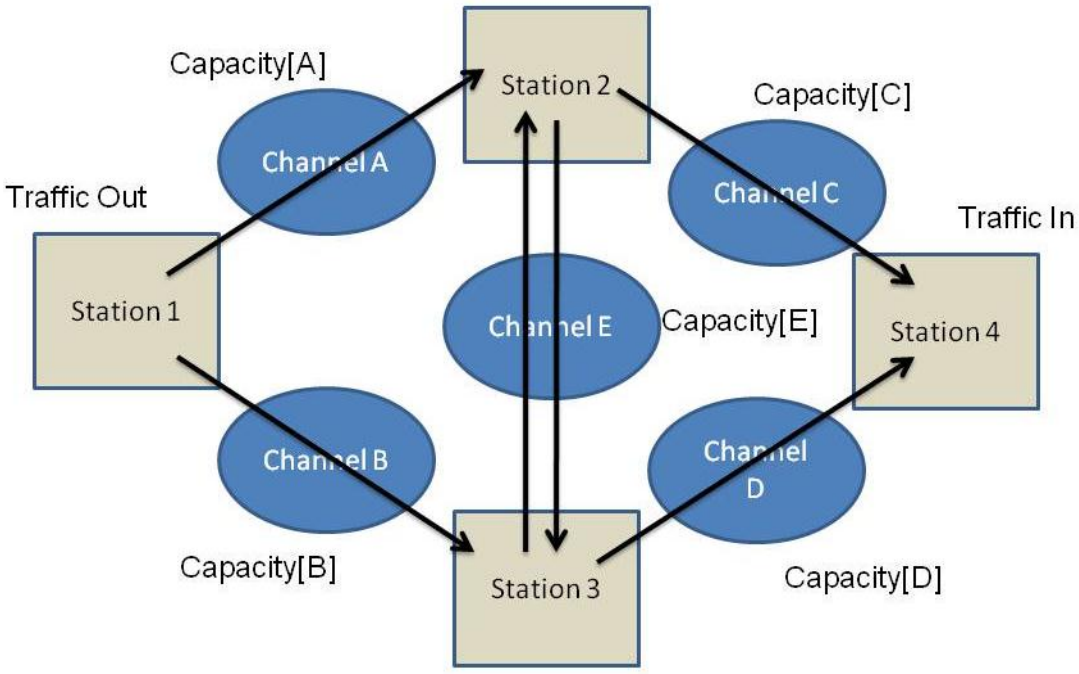


Figure 5.1 Outline of Network

The focus of this tutorial is working with limited number of standard elements to build up more complex structures. In this example, there are only two standard elements, stations (nodes) and channels. Each element contains constraint relations describing its behavior. An Internal Block Diagram is created to assist in completing the parametric diagrams correctly. Parametric constraints are also used at a higher level to define interactions between elements.

What the User Will Learn

- Building complex structures from multiple usages of simple structures
- Using internal block diagrams

5.2 Step-by-Step Tutorial

Step I Create Project

1. Create new SysML project and Package, Name = **CommNetwork**

Step II Create Infrastructure

2. Install ParaMagic Profile module, same as in first tutorial.

Step III Create Structural Model

3. Create three blocks: **Network**, **Node** and **Channel**.
    a. **Network** will be the top level (root) block, but contains no value properties.
    b. **Node** represents a station which can receive and transmit messages. It has two inputs, two outputs, and the ability to redistribute the message traffic depending on the capacity of the transmission channels. To build the node model, we will use flowports, value properties and parametric diagrams.
        i. Create a Flow Specification, Name = **Signal**, inside the **CommNetwork** package.
        ii. Each node has four flowports, two for receiving message traffic and two for transmitting (see Figure 5.2). To create a flowport
            1. RC on **Node**, create New Element→Port
            2. Double-click on the new port, Name = **Rec1**, AppliedStereotype = Flowport, Direction = in, Type = Signal.
            3. Repeat for other three flowports. Note that Direction is out for **Tr1** and **Tr2**.

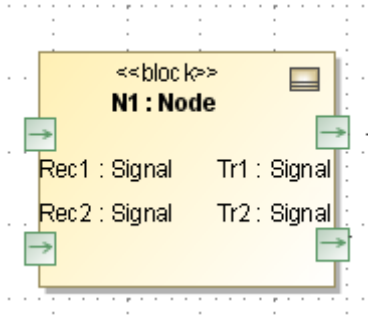


Figure 5.2 Node with Ports

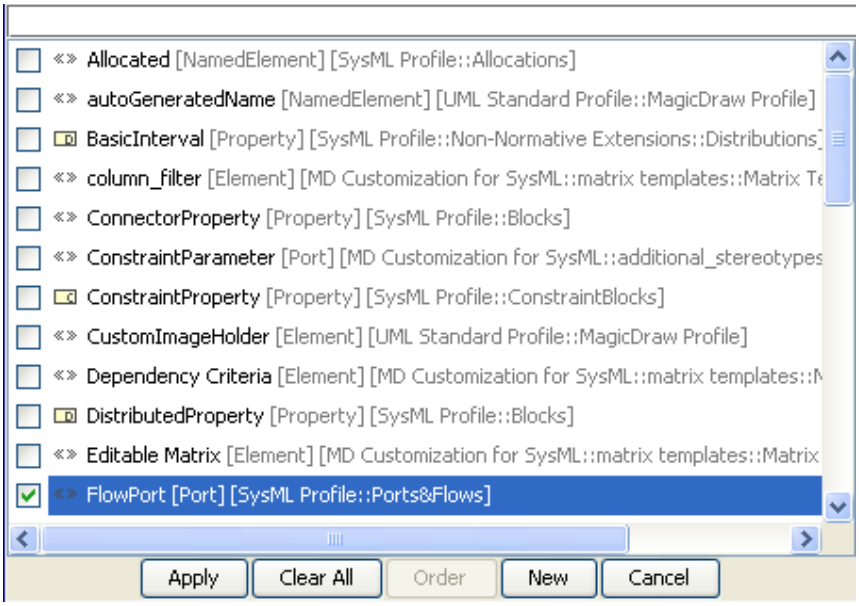


Figure 5.3 Select Applied Stereotype as Flowport

        iii. The Node block has nine Value Properties, all Real. Six represent levels of message traffic at input and output, units unspecified: **R1**, **R2**, **R**, **T1**, **T2**, and **T**. Two represent the capacities of the upstream channels: **C1** and **C2**. The final attribute, **D**, represents the redistribution factor in splitting outgoing message traffic between the **Tr1** and **Tr2** ports.
    c. **Channel** represents a two-way communication link between two stations. The throughput of each line, the output signal divided by the input, is a function of the channel capacity **C** and the total signal traffic level. It has two inputs and two outputs, but may use only one I/O pair in a particular instance. To build the channel model, we will use flowports, value properties and parametric diagrams.

i. Each channel has four flowports, two for input message traffic and two for output (see Channel blocks in Figure 5.6). To create a flowport
   1. RC on Channel, create New Element→Port
   2. Double-click on the new port, Name = **In1**, AppliedStereotype = Flowport, Direction = in, Type = Signal.
   3. Repeat for other three flowports. Note that Direction is out for **Out1** and **Out2**.

ii. The Channel block has six Value Properties, all Real. Five represent levels of message traffic at input and output, units unspecified: **IT1**, **IT2**, **IT**, **0T1**, and **0T2**. **C** represents the intrinsic capacity of the channel.

4. Create a Block Definition Diagram and an Internal Block Diagram
   a. RC on **CommNetwork** package, create New Diagram→SysML Diagrams→SysML Block Definition Diagram, Name = **Network_BDD**
      i. Drag **Network**, **Node** and **Channel** blocks into the diagram
      ii. Using the Direct Composition connector from the floating toolbar, connect as shown in Figure 5.4. Note that four connections are made from **Network** to a single **Node** block, and the resulting four Part Properties are named **N1**, **N2**, **N3** and **N4**. Similarly, five connections are made from **Network** to a single **Channel** block, named as **ChA** thru **ChE**.

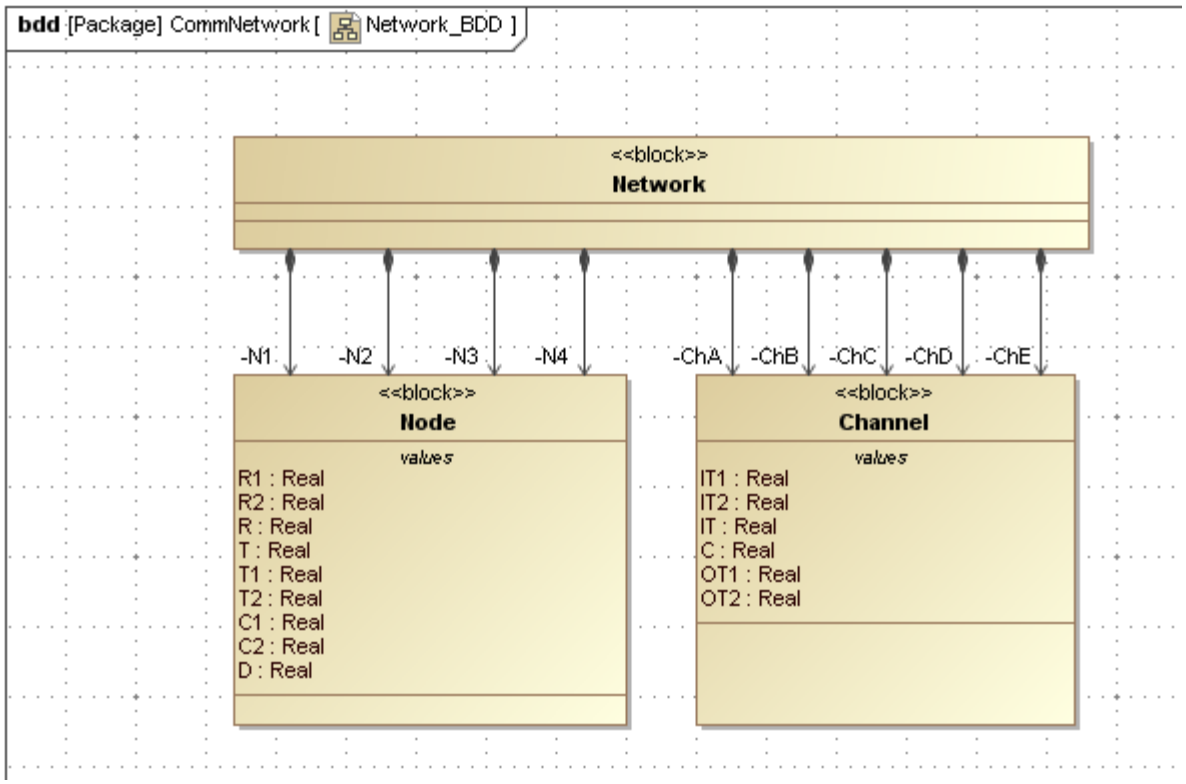


Figure 5.4 CommNetwork Block Definition Diagram

b. RC on **Network** block in Containment tree, create New Diagram→SysML Diagrams→SysML Internal Block Diagram, Name = **Network**.

i. Drag all nine part properties in **Network** (four node and five channels) into the diagram and arrange as shown in Figure 5.6.

ii. Click on each block and use the Display Ports icon on the floating toolbar (Figure 5.5a) to show the ports. Arrange the ports as shown in Figure 5.6.

iii. Click on a port and use the Connector icon on the floating toolbar (Figure 5.5b) to create a connector, which can be dragged to the matching port on another block. Arrange the connectors as shown in Figure 5.6.

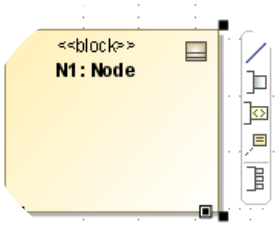


Figure 5.5a Display Ports icon

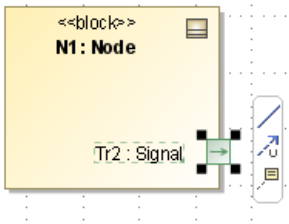


Figure 5.5b Connector icon

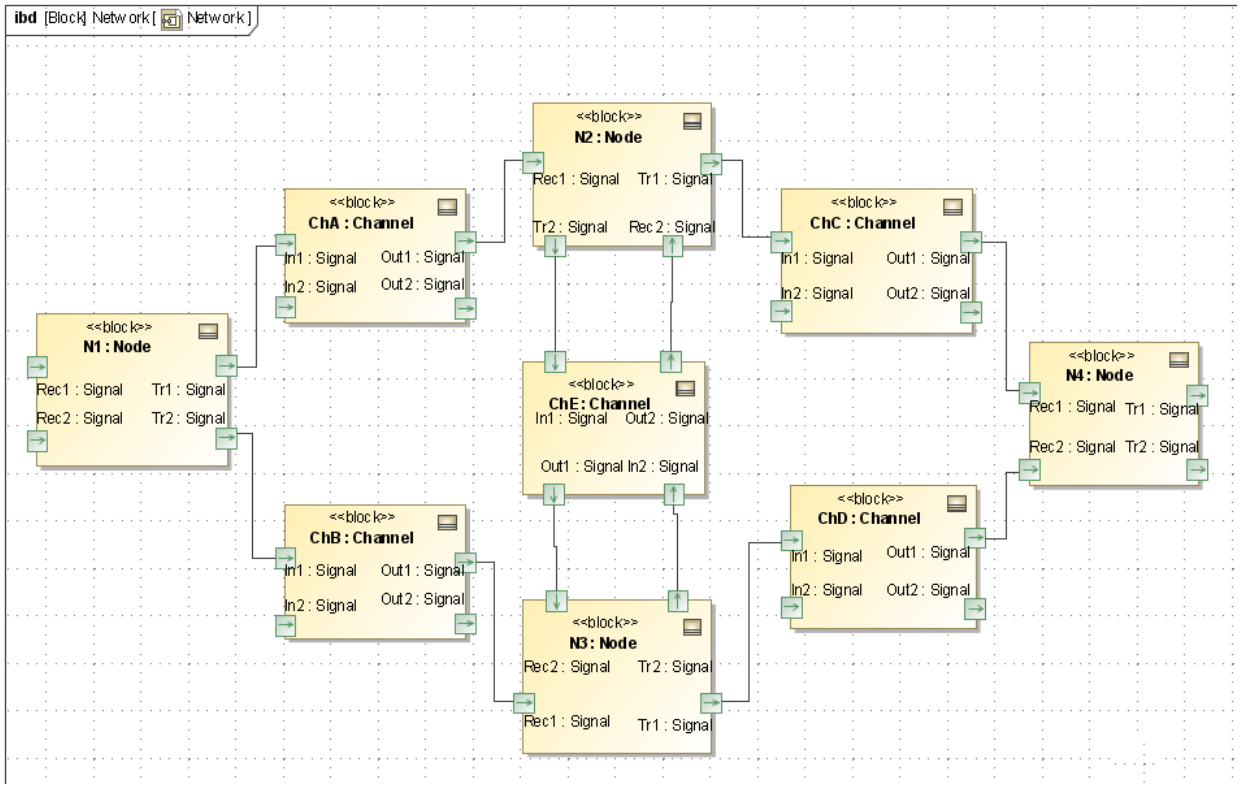


Figure 5.6 CommNetwork Internal Block Diagram

Step IV Create Constraints

5. Create the five constraint blocks required by the model: **ErrorRate**, **Fraction**, **Product**, **Product1** and **Sum**. Usage of these constraint blocks are shown in the parametric diagrams in Figure 5.7 and 5.8, which show the constraints and constraint parameters for each.

Step V Create Parametrics Model(s)

6. Create a parametric model for **CommNetwork**. There are standard relationships internal to **Node** and **Channel** elements and there are equalities tying the Nodes and Channels together into a network.
    a. Create a parametrics diagram within the **Node** block, Name = **Node**. This diagram, shown in Figure 5.7, contains four separate constraint properties, with the constraints shown, the nine internal value properties, and the nested connectors tying them together. In this example, the objective of the equations to redistribute the incoming signal to the two outgoing channels, based on their relative capacities. No claim is made about the realism of this model.

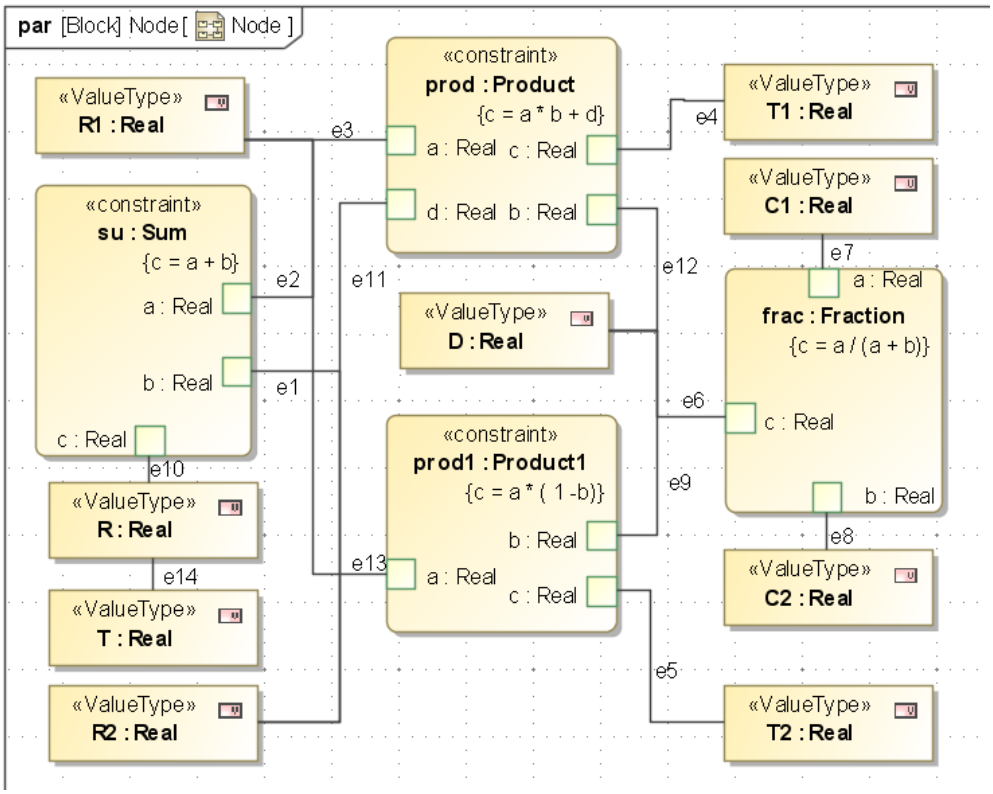


Figure 5.7 Node parametric diagram (flowports deleted from diagram)

    b. Create a parametrics diagram within the **Channel** block, Name = **Channel**. This diagram, shown in Figure 5.8, contains three constraint properties (including two usages of the ErrorRate constraint), with the constraints shown, the six internal value properties, and the nested connectors tying them together. In this example, the objective of the equations to reduce the signal throughput at the output of each line relative to the

input by an exponential factor based on Capacity **C** and total incoming traffic. No claim is made about the realism of this model.

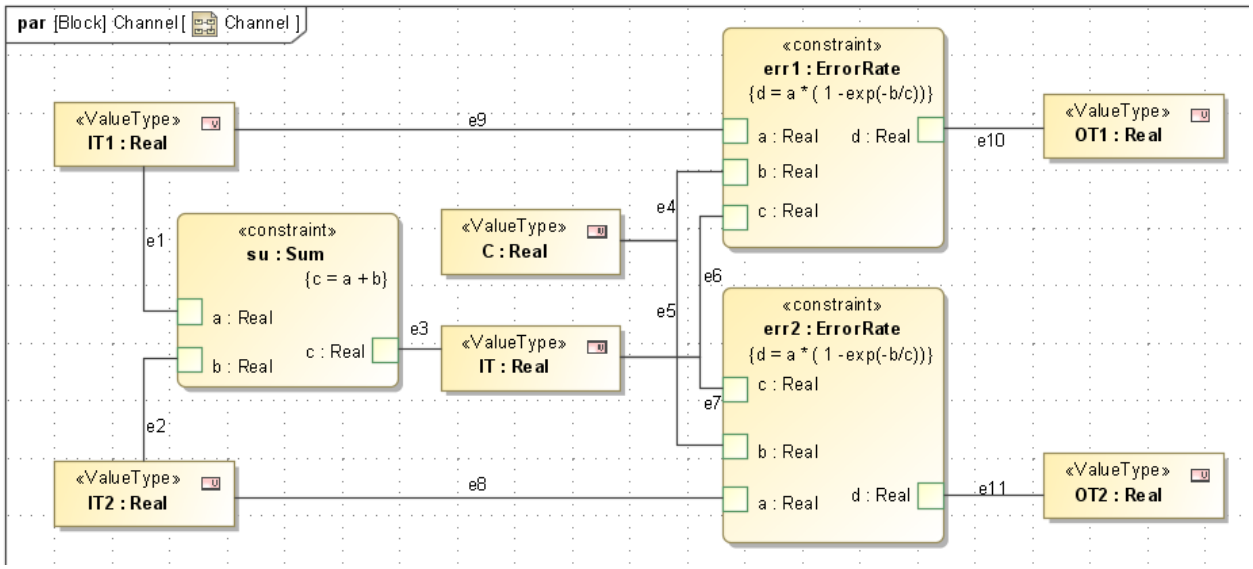


Figure 5.8 Channel parametric diagram (flowports deleted from diagram)

c. Create parametric diagrams connecting the channels and nodes through equalities as in Figure 5.9a-d. Use the internal block diagram in Figure 5.8 to keep track of which blocks and ports connect. In this example, we have chosen to divide the entire set of high level parametric relationships into four separate diagrams in order to keep each individual diagram simpler with fewer elements. This illustrates the combined use of internal block diagrams for a high-level qualitative perspective and narrower parametric diagrams to make the actual quantitative connections.

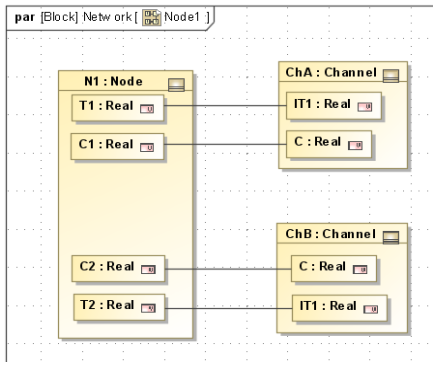


Figure 5.9a Node 1 parametric diagram (flowports deleted from diagram)

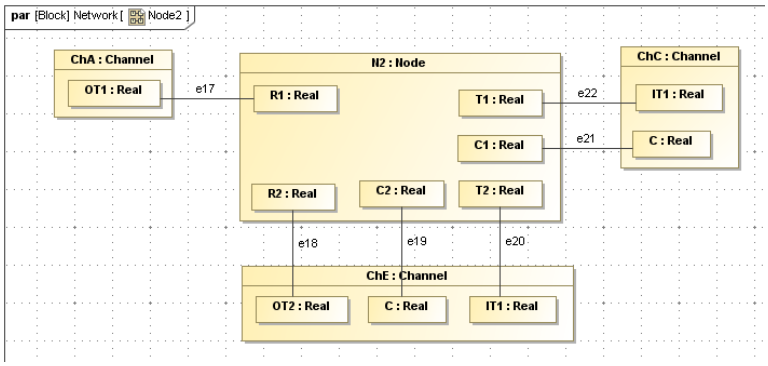


Figure 5.9b Node 2 parametric diagram (flowports deleted from diagram)

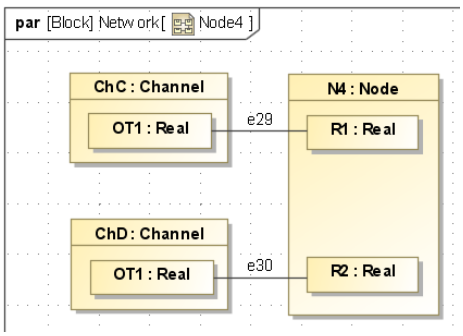


Figure 5.9c Node 4 parametric diagram (flowports deleted from diagram)

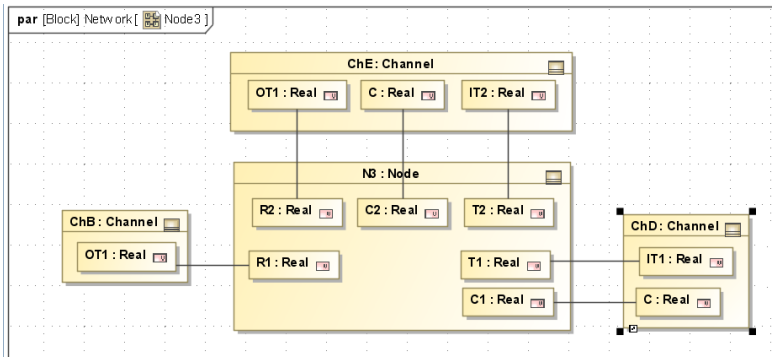


Figure 5.9d Node 3 parametric diagram (flowports deleted from diagram)

Step VI Validate Parametrics Model

7. To validate the model schema, RC on the **Network** block and select ParaMagic→Validate.

Step VII Create an Instance

8. We will create an instance of **CommNetwork** using a library of standard instances, rather than creating each instance individually.
    a. Create a library of standard instances of system element.
        i. RC on **CommNetwork** and select New Element→Package, Name = **InstanceLibrary**
        ii. RC on **InstanceLibrary** and select New Element→Instance Specification, Name = **StartNode**, Classifier = Node
        iii. Double-click on **StartNode** to open Instance Specification window (Figure 5.10a).

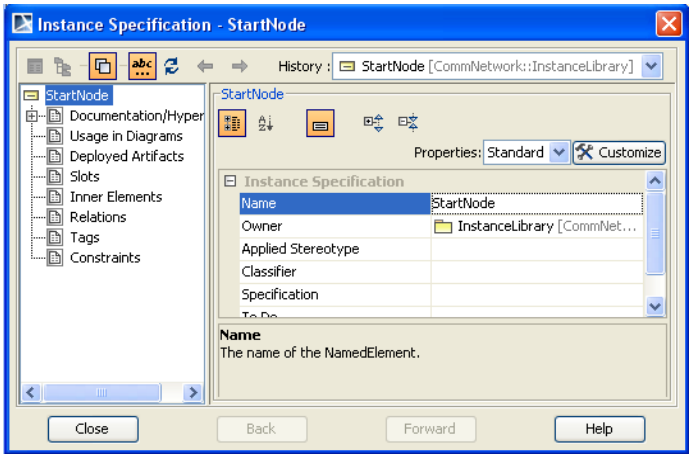


Figure 5.10a Instance Specification window

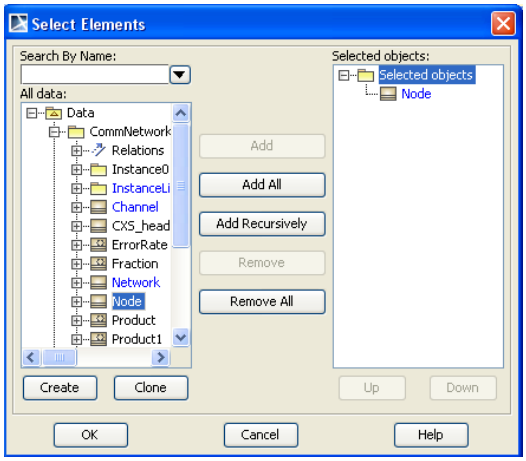


Figure 5.10b Select Elements window

iv. Select Classifier and click Edit icon to open window in Figure 5.10b
v. Double-click on Node to set **StartNode** as an instance of **Node** and click OK.
vi. Click Slots in Instance Specification window (Figure 5.10a) and double-click on each of the value properties to activate them. For the **StartNode** instance, we

assume a given input signal level by assigning **R1** as 10 (arbitrary units) and **R2** as 0. All the remaining slots are left empty. Click Close at the end.

vii. Repeat this process for four more standard instances:

1. **ThruNode** (stations which both receive from and transmit to other stations in the network). All slots are activated, but left empty.
2. **EndNode** (stations which only receive, i.e. final destination). Assign **C1** and **C2** values = 1 or any non-zero fixed value because there are no "downstream" channels to supply these values.
3. **SingleChannel** (channels in which only one I/O path is used). Classifier = Channel. Assign **C** = 5 (capacity in arbitrary units) and **IT2** = 0 because input to second I/O path is not used.
4. **DoubleChannel** (channels in which both I/O paths are used). Classifier = Channel. Assign **C** = 5 (capacity in arbitrary units).

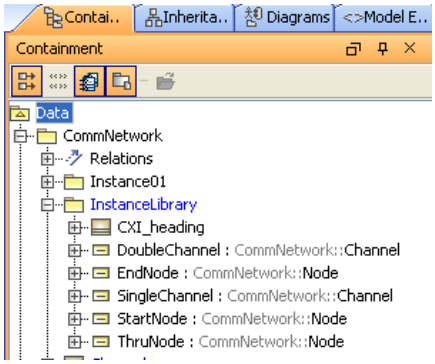


Figure 5.11 InstanceLibrary contents

viii. Assign causality to all standard instances by right-clicking on **InstanceLibrary** and selecting ParaMagic→Util→Assign default causalities.

ix. The final contents of **InstanceLibrary** should appear as in Figure 5.11. Any of these instances can be dragged into an instance diagram in another package and used without further modification.

b. Create a specific instance package for the network proposed

i. RC on **CommNetwork** and select New Element→Package, Name = **Instance01**

ii. RC on **Instance01** and select New Diagram→SysML Diagrams→SysML Block Definition Diagram, Name = **Instance01**.

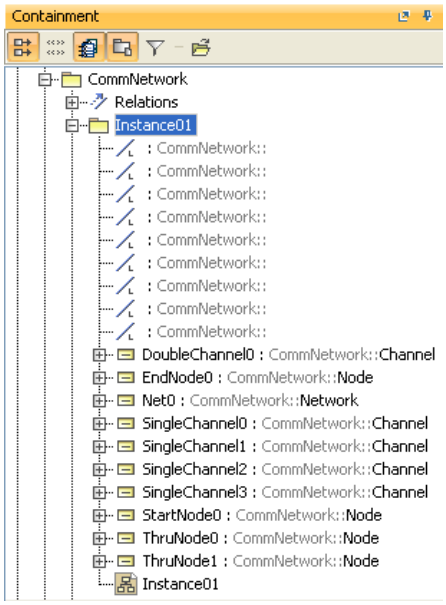


Figure 5.12 Instance01 contents

iii. We need four separate copies of **SingleChannel** in our network, to represent Channels A, B, C, and D. In this example, we will copy **SingleChannel** and paste four copies into **Instance01**, named **SingleChanne0**, **SingleChannel1**, **SingleChannel2** and **SingleChannel3**.

iv. We need two separate copies of **ThruNode** in our network, to represent Nodes 2 and 3. In this example, we will copy **ThruNode** and paste two copies into **Instance01**, named **ThruNode0** and **ThruNode1**.

v. We need copies of **DoubleChannel**, **StartNode** and **EndNode** in **Instance01**.

vi. Finally, create an instance of the **Network** block inside **Instance01**, Name = **Net0**. The final contents of **Instance01** should appear as in Figure 5.12

vii. Drag all the instances in **Instance01** into the **Instance01** diagram.

viii. Using the connector icon on the floating toolbar, create link from **Net0** to **StartNode0**. A Select Association window appears, as in Figure 5.13. Check the first line to assign the **StartNode0** instance to the **N1** part property.

ix. Draw connectors from **Net0** to the remaining instances. In each case, assign an appropriate instance to each part property, as shown in Figure 5.14.

x. Assign *target* causality to slot **R** in **EndNode0**.

xi. The final contents of **Instance01** diagram should appear as in Figure 5.14.

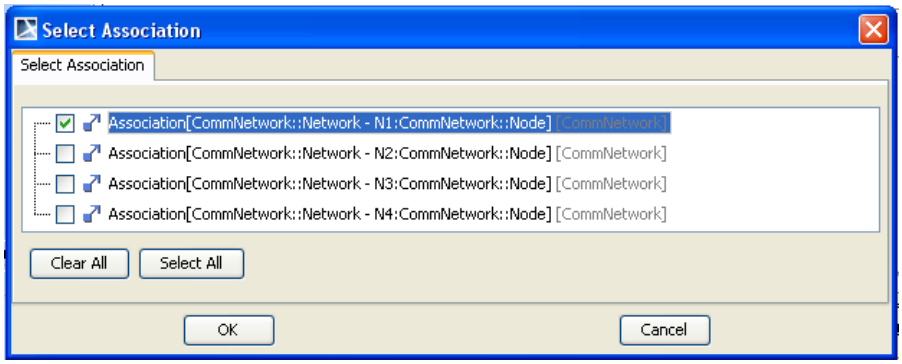


Figure 5.13 Select Association window assigning **StartNode0** instance to **N1**

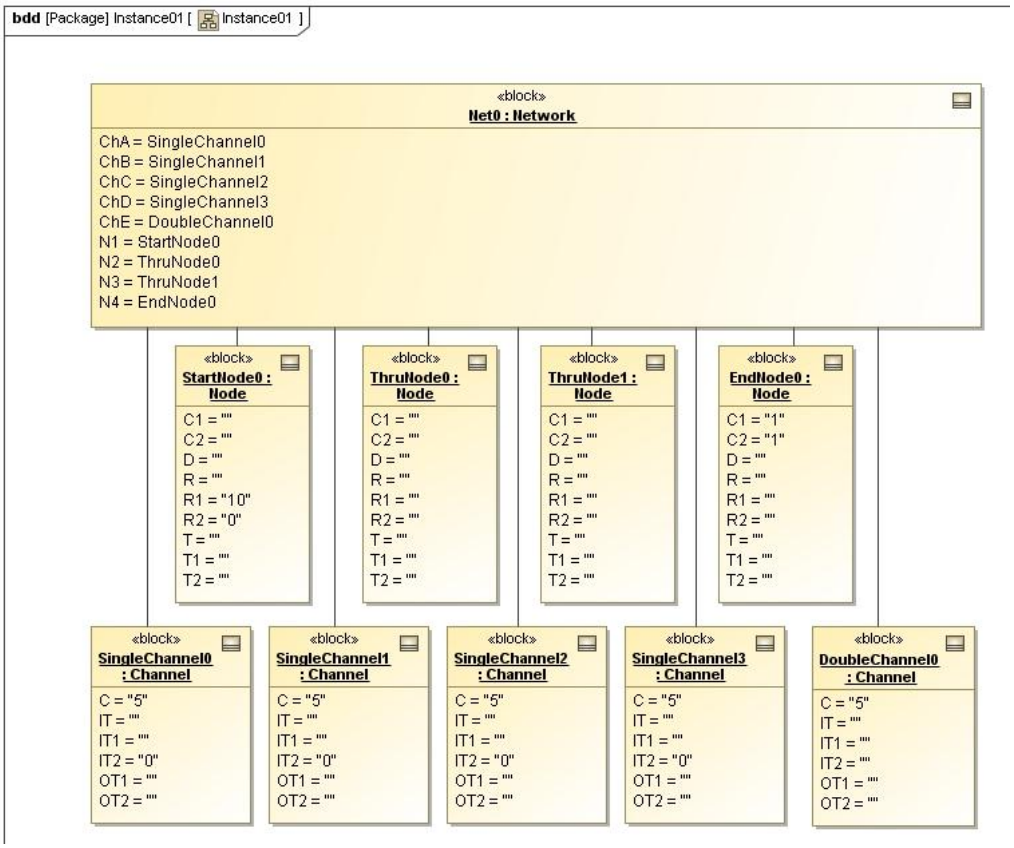


Figure 5.14 Instance01 diagram complete

Discussion – Instance Generation

We have used four different methods for creating instance in our first four tutorials,

- Creating individual instances from the central toolbar
- Creating individual instances using menu commands
- Using the Instance Generation Wizard
- Copying and pasting existing instances from a standard instance library

Similarly, there are at least two ways of linking instances,

- Draw a link from the higher block to the lower and use the Select Association window to assign the instance to an existing part property.
- Double-click on the higher block, click on Slots, double-click on a part property, and assign it to an existing instance. In this approach, no visible line connects the instances on the instance diagram, but the higher-level instance box displays the association, e.g. ChE = DoubleChannel0.

Which method to choose depends on the situation. Being familiar with multiple approaches is advantageous.

Step VIII Solve the Instance

9. In Figures 5.15 and 5.16, only a few of the output variables are expanded to display. All of the values are available, however.

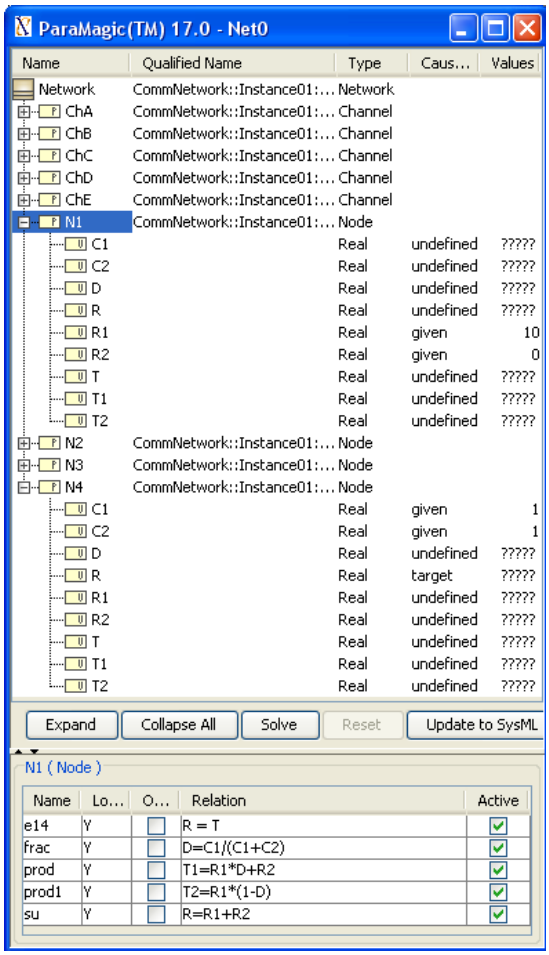


Figure 5.15 Browser for Instance01 before solution

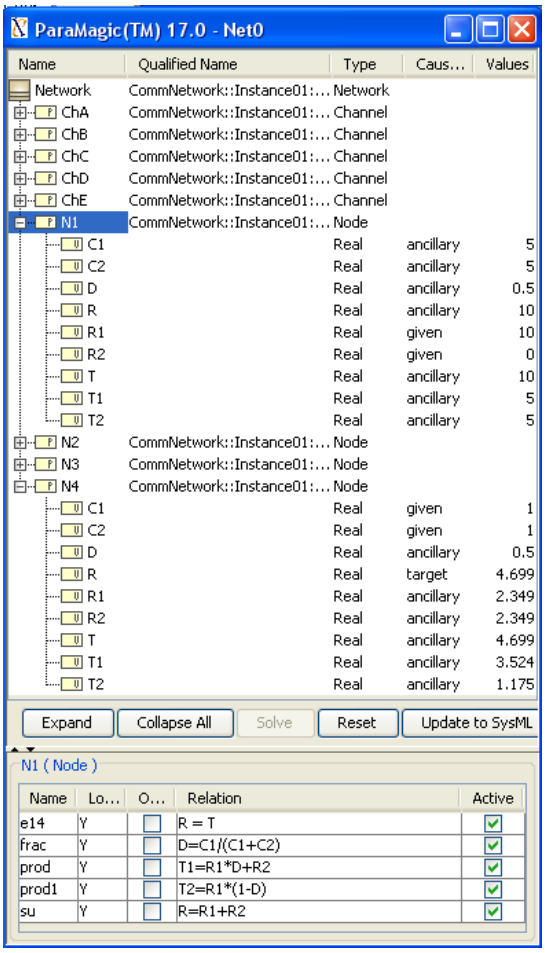


Figure 5.16 Browser for Instance01 after solution

6 SysML Parametrics Tutorial - Orbital

Note: ParaMagic Lite does not have the ability to call external Mathematica functions. The graphing function in the Orbital model will not be executable without upgrading to the full ParaMagic feature set. Standard ParaMagic users must set Mathematica as the core solver to access all program features.

6.1 Objective

Create a SysML project combining an orbital mechanics subsystem and a spacecraft subsystem. The orbital mechanics section is linked to a spreadsheet which calculated solar power levels and data transmission levels for ten sections in the spacecraft's orbit around Mars, based on the geometry between the spacecraft, Mars, Earth and the Sun. See Figure 6.1. Note that the writer claims no expertise in this field.

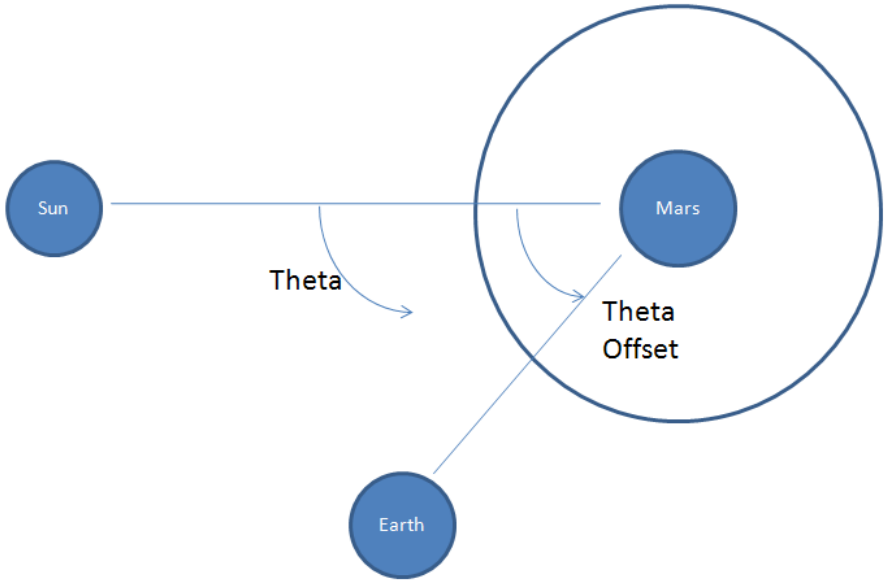


Figure 5.1 Outline of Objective

The spacecraft subsystem is tied to a second spreadsheet which contains the power and data transmission requirements for the spacecraft by subsystems, three instrument packages, a transmitter, and a power system. Information from both spreadsheets is combined at the Mission level using parametric constraints solved by Mathematica and final results are written to a third spreadsheet.

What the User Will Learn

- Read and write between Microsoft Excel spreadsheets and MagicDraw SysML instance blocks
- Working with aggregates (parameters that can contain a list of values)
- Plotting aggregates with standard Mathematica functions

Aggregates are parameters with multiple values, for example, A = [A_1, A_2, A_3, A_4], and are valuable in multiple ways. They can express vectors, time series, and other sets of numbers that will be handled collectively or repetitively. In this tutorial, the individual elements of the aggregates represent

values for ten separate sections of the orbital cycle. The specific number of elements does not need to be defined until the instance stage.

Mathematica has extensive graphics capability. Graphs can be created and saved during ParaMagic execution, using several ParaMagic-provided standard functions. User-created Mathematica functions, described in the ParaMagic Users Guide, provide even more flexibility.

Spreadsheets, such as Microsoft Excel, could be envisioned either as a means of loading data into a specific instance from an existing table or database, a means of reporting and organizing results from a parametric simulation, or a mathematical solver for parametric relationships that are part of the model. Currently, ParaMagic only supports the first two functions.

System Requirements

- Microsoft Excel 2003 or 2007. Note: Excel is not required to execute the ParaMagic-Excel interface. It is required to create, edit and view the spreadsheets used in the example.
- In order to use standard Mathematica functions that produce a graphics file, Mathematica must be loaded on the user's local machine or server (no web services) and the ICAX standard function library must be installed for autoloading.

6.2 Step-by Step Tutorial

Step I Create Project

1. Create new project
    c. Name = **Orbital**
2. Create a package within the project
    a. RC (Right-click) on Data folder in Containment tree (left column)
    b. Choose New Element→Package
    c. Enter Name = **Orbital**

Step II Create Infrastructure

3. Install ParaMagic Profile module, same as in the first tutorial.

Step III Create Structural Model

4. Create elements in model
    a. Inside the **Orbital** package, create blocks called **Mission**, **Orbital**, **Spacecraft**, **InPkg1**, **InPkg2**, **InPkg3**, **Transmitter**, and **PowerSystem**.
    b. Create a block definition diagram, Name = **Mission**, and drag the **Orbital** elements into the diagram. See Figure 6.2. Use Directed Composition connectors to link the blocks in the hierarchy shown.
    c. Inside **Mission**, create a value property called **AveragePowerWindow** and assign it a Type as Real. Repeat this procedure for three additional properties in Mission: **AverageXmitWindow**, **EffectivePowerBudget**, and **EffectiveXmitBudget**.
    d. Referring to Figure 6.2, create value properties as shown in the **Spacecraft**, **InPkg1**, **InPkg2**, **InPkg3**, **Transmitter**, and **PowerSystem** blocks, all type Real.

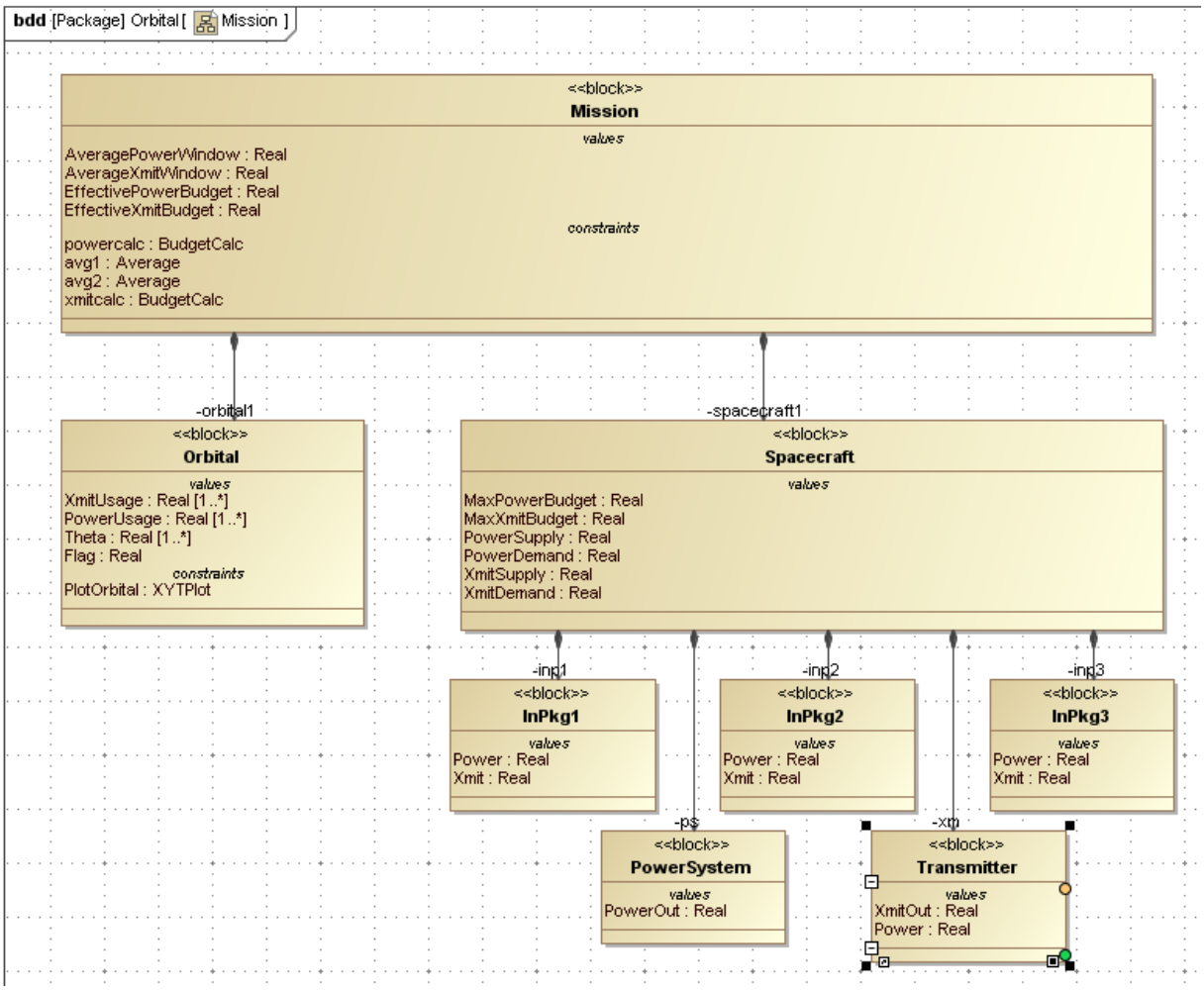


Figure 6.2 Block Definition Diagram for Orbital model

e. Inside the **Orbital** block, create the value properties as shown in Figure 6.2.
   i. Create **Theta**, Type = Real.
   ii. Double click on **Theta** (in Containment tree or on block definition diagram) and open the Value Property dialog box (see Fig. 6.3).
   iii. Choose 1…* from the dropdown list next to Multiplicity. This allows the variable **Theta** to contain any positive integer number of separate values.
   iv. Repeat this procedure for **PowerUsage** and **XmitUsage**.
   v. The **Flag** value property should not be created by users of ParaMagic 17.0.1 Lite, which does not support Mathematica graphing functions.

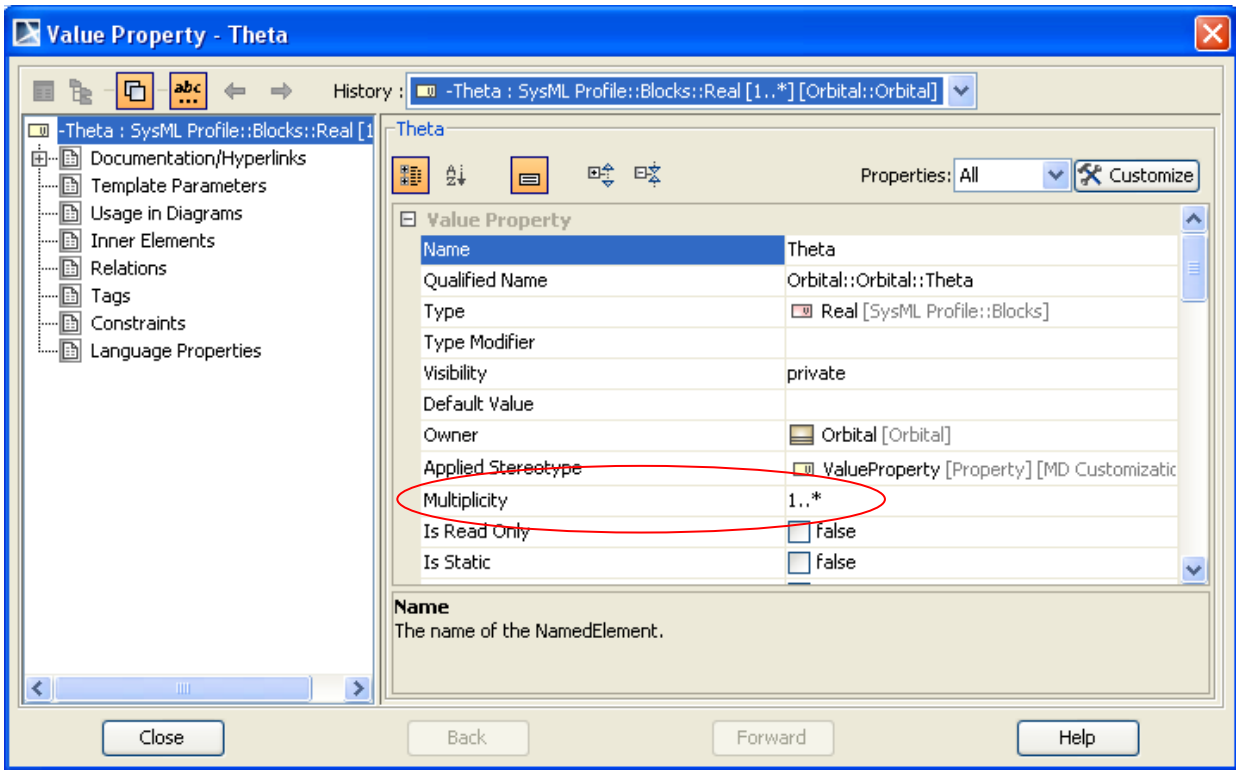


Figure 6.3 Setting the value property **Theta** multiplicity to 1…*

Step IV Create Constraints

5. Create two constraint blocks, **Average** and **BudgetCalc**, as shown in Figure 6.4. Note that **Average** uses **list**, a constraint parameter with multiplicity larger than one. To change the multiplicity of a constraint parameter, RC the constraint block in the BDD diagram. **Average** calculates the average of all the values contained in **list** and returns a single value result, **mean**. The ParaMagic User Guide provides a list of Mathematica functions that act on arguments with multiplicity > 1.

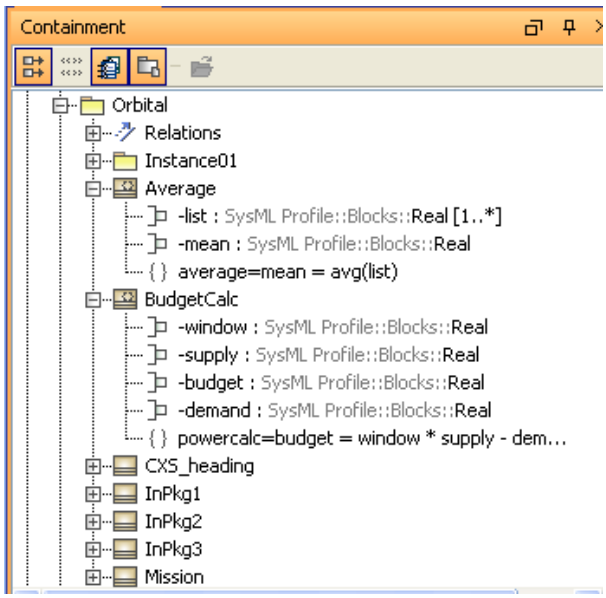


Fig. 6.4 Constraint Blocks

6. Create a constraint block for plotting the power and transmission availability versus **Theta**. Users of ParaMagic 17.0.1 Lite will not be able to execute this graphing function and should skip step 6 a-d.
    a. See User Guide for a list of standard Mathematica graphics and statistical functions that are provided with ParaMagic. These should be configured to automatically load when Mathematica is started.

b. Create a constraint block, **XYTPlot**, with four constraint parameters, **x**, **y**, **t** and **c**, where **x**, **y**, and **t** have multiplicity 1..*.

c. Add a constraint to **XYTPlot**.
c = cMathematica(ICAXPlotXYT,t,x,y,"Availability","Sector","Power")
ICAXPlotXYT is a standard function for graphing two lists of values against a third list (x, y, and t, respectively), with the three final string arguments (in quotes) determine graph title, x axis label, and y axis label.

d. Assign the destination for the **XYTPlot** graphics output file.
   i. Double-click on the constraint and open the Constraint window (see Figure 6.5)
   ii. Select Tags
   iii. Scroll down to <<External Models>> section
   iv. Double-click on working_dir (or select and click Create Value)
   v. Enter a destination directory for any plots generated, e.g. C:\\MD-temp. Note that this directory must already exist when the ParaMagic model is executed (it will not be created automatically) and a double back-slash character is used in the pathname.

Note for Mac Users: The destination directory needs to be phrased using the path notation common to Mac operating systems. For example /Users/JohnDoe/Documents/Orbital

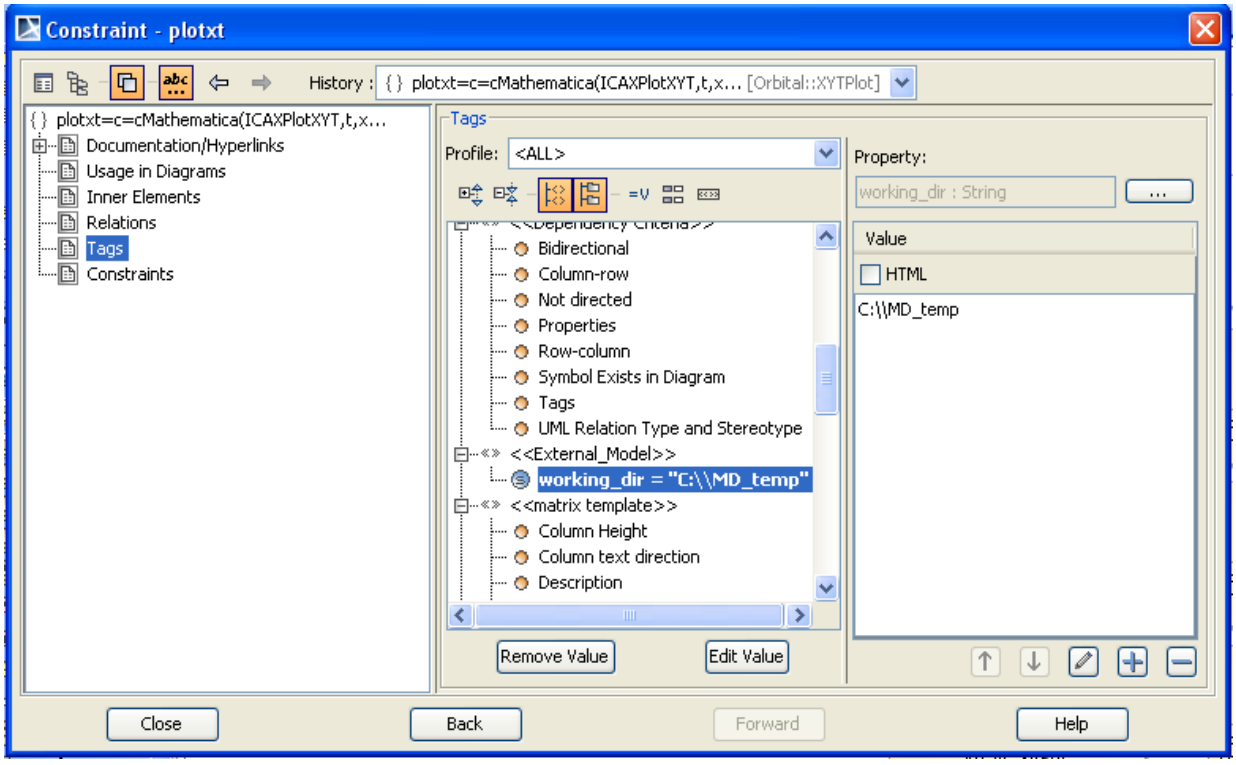


Figure 6.5 Constraint window for defining graph output destination

Step V Create Parametrics Model

7. Create the parametrics diagram shown in Figure 6.6 inside the block **Mission**. There are two usages of each of the constraint blocks defined in Step 5.

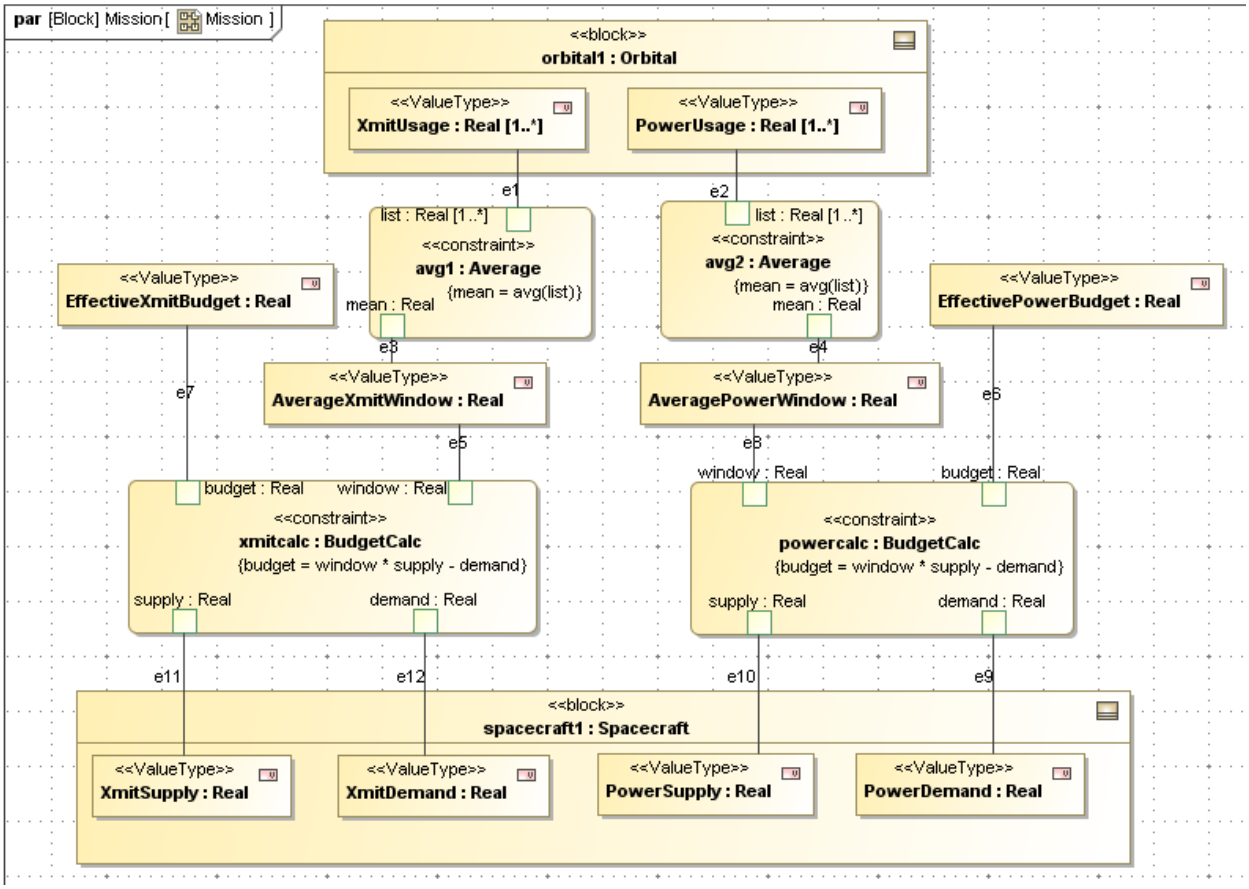


Figure 6.6 Parametric diagram for **Mission**

8. Create a second parametrics diagram inside **Orbital**, as shown in Figure 6.7. This diagram exists to plot the values of the **PowerUsage** and **XmitUsage** against **Theta** during ParaMagic execution. Users of ParaMagic 16.9 Lite will not be able to execute this graphing function and should skip step 8 a-b.
    a. Use Select Parts window to select **PowerUsage**, **XmitUsage**, **Theta** and **Flag** to appear in the diagram.
    b. Drag the constraint block **XYTPlot** into the diagram and connect as shown in 6.7. **ICAXPlotXYT** will return a value of 1 into the parameter **c** and then into the value property **Flag** when the Mathematica function is successfully executed.

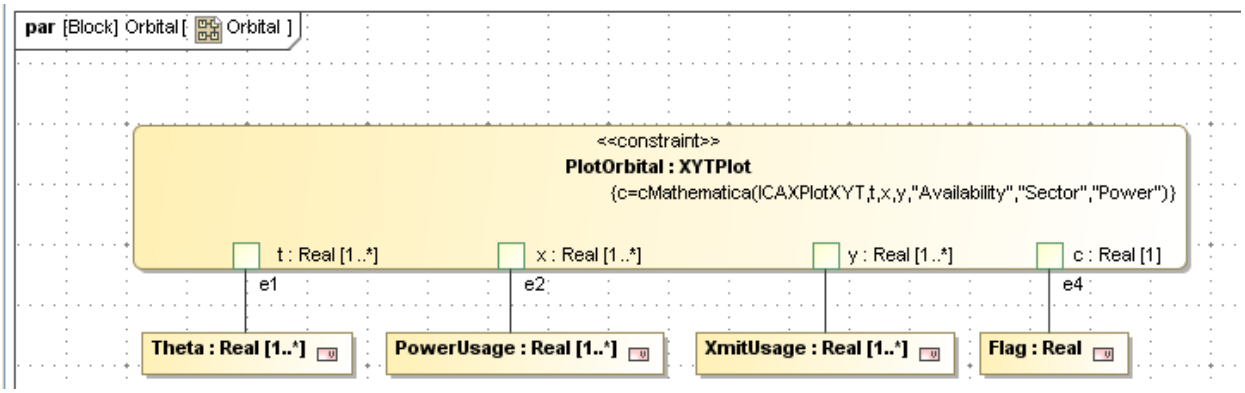


Figure 6.7 Parametric diagram for Orbital

Step VI Validate Parametrics Model

9. To validate the model schema, follow the instructions in Step VI of previous tutorials

Step VII Create an Instance

In this example, we will create an instance of the SysML model and three separate Microsoft Excel spreadsheets that will link to this instance and allow data to be written from Excel to MagicDraw SysML and from MagicDraw SysML to Excel. This supports the use of spreadsheets to load data into a model and to report results from parametric simulation of the model. In normal circumstances, some or all of these spreadsheets may exist prior to the SysML model, but in this tutorial, we will create them at this stage.

10. Create three workbooks in Microsoft Excel that instances of the model will link to.
    a. Open Excel and create and save the workbook **spacecraft** (**.xls** or **.xlsx)** shown in Figure 6.8 (in worksheet Sheet1).

	A	B	C
1	Spacecraft Model		
2		Power (Watts)	Xmit (Mb/sec)
3	Instrumentation Pkg 1	100	20
4	Instrumentation Pkg 2	100	50
5	Instrumentation Pkg 3	150	100
6	Power Supply Output	500	
7	Transmitter Output	300	300
8			
9	Max Budget	-150	130
10	Supply	500	300
11	Demand	650	170
12			

Figure 6.8a Workbook spacecraft, showing values

	A	B	C
1	Spacecraft Model		
2		Power (Watts)	Xmit (Mb/sec)
3	Instrumentation Pkg 1	100	20
4	Instrumentation Pkg 2	100	50
5	Instrumentation Pkg 3	150	100
6	Power Supply Output	500	
7	Transmitter Output	300	300
8			
9	Max Budget	=B6-B3-B4-B5-B7	=C7-C3-C4-C5
10	Supply	=B6	=C7
11	Demand	=B3+B4+B5+B7	=C3+C4+C5
12			

Figure 6.8b Workbook spacecraft, showing formulas

    b. Build and save the spreadsheet **orbital** shown in Figure 6.9 (in worksheet Sheet1).

	A	B	C	D
1	Orbital Mechanics Profile	Author		Date
2				
3		ThetaOffset	0.5236	
4				
5	Time Period	Theta	Power	Data
6	0	0.00	1.00	0.97
7	1	0.63	0.90	1.00
8	2	1.26	0.65	0.93
9	3	1.88	0.35	0.78
10	4	2.51	0.10	0.55
11	5	3.14	0.00	0.26
12	6	3.77	0.10	0.05
13	7	4.40	0.35	0.36
14	8	5.03	0.66	0.63
15	9	5.65	0.90	0.84

Figure 6.9a Workbook **orbital**, showing values

	A	B	C	D
1	Orbital Mechanics Profile	Author		Date
2				
3		ThetaOffset	0.5236	
4				
5	Time Period	Theta	Power	Data
6	0	=ROUND(A6*PI()/5,2)	=ROUND(COS(B6/2)^2,2)	=ROUND(ABS(COS((B6-C3)/2)),2)
7	1	=ROUND(A7*PI()/5,2)	=ROUND(COS(B7/2)^2,2)	=ROUND(ABS(COS((B7-C3)/2)),2)
8	2	=ROUND(A8*PI()/5,2)	=ROUND(COS(B8/2)^2,2)	=ROUND(ABS(COS((B8-C3)/2)),2)
9	3	=ROUND(A9*PI()/5,2)	=ROUND(COS(B9/2)^2,2)	=ROUND(ABS(COS((B9-C3)/2)),2)
10	4	=ROUND(A10*PI()/5,2)	=ROUND(COS(B10/2)^2,2)	=ROUND(ABS(COS((B10-C3)/2)),2)
11	5	=ROUND(A11*PI()/5,2)	=ROUND(COS(B11/2)^2,2)	=ROUND(ABS(COS((B11-C3)/2)),2)
12	6	=ROUND(A12*PI()/5,2)	=ROUND(COS(B12/2)^2,2)	=ROUND(ABS(COS((B12-C3)/2)),2)
13	7	=ROUND(A13*PI()/5,2)	=ROUND(COS(B13/2)^2,2)	=ROUND(ABS(COS((B13-C3)/2)),2)
14	8	=ROUND(A14*PI()/5,2)	=ROUND(COS(B14/2)^2,2)	=ROUND(ABS(COS((B14-C3)/2)),2)
15	9	=ROUND(A15*PI()/5,2)	=ROUND(COS(B15/2)^2,2)	=ROUND(ABS(COS((B15-C3)/2)),2)

Figure 6.9b **Workbook** orbital, showing formulas

c. Build and save the spreadsheet **mission** shown in Figure 6.10 (in worksheet Sheet1). This will be used to report the results of the parametric simulation, so the non-title cells are currently empty.

	A	B
1	Mission Estimates	
2		
3		
4	Average Power Window	
5	Average Xmit Window	
6	Effective Power Budget	
7	Effective Xmit Budget	
8		

Fig. 6.10 Workbook **mission**, showing titles

11. Create an instance. Review Step VII in the previous tutorials for the detailed procedures.
    a. Create a package, **Instance01**, within the package **Orbital**.
    b. Create a block definition diagram, **Instance01**, within the package **Instance01**.
    c. Create the instances of the model elements as shown in Figure 6.11 by dragging Instance from the toolbar, selecting the block it will be an instance of from the Select Classifiers window, and assigning the instance block a unique name.
    d. Create linkages between **mis:Mission** and **orb1:Orbital**, and between **mis:Mission** and **spa01:Spacecraft**. Note that no linkages have been created between **spa01:Spacecraft** and its subsystems. These are not required because there are no parametric calculations linking these blocks in SysML parametric diagrams. They are linked inside the spreadsheet **spacecraft.xlsx**.

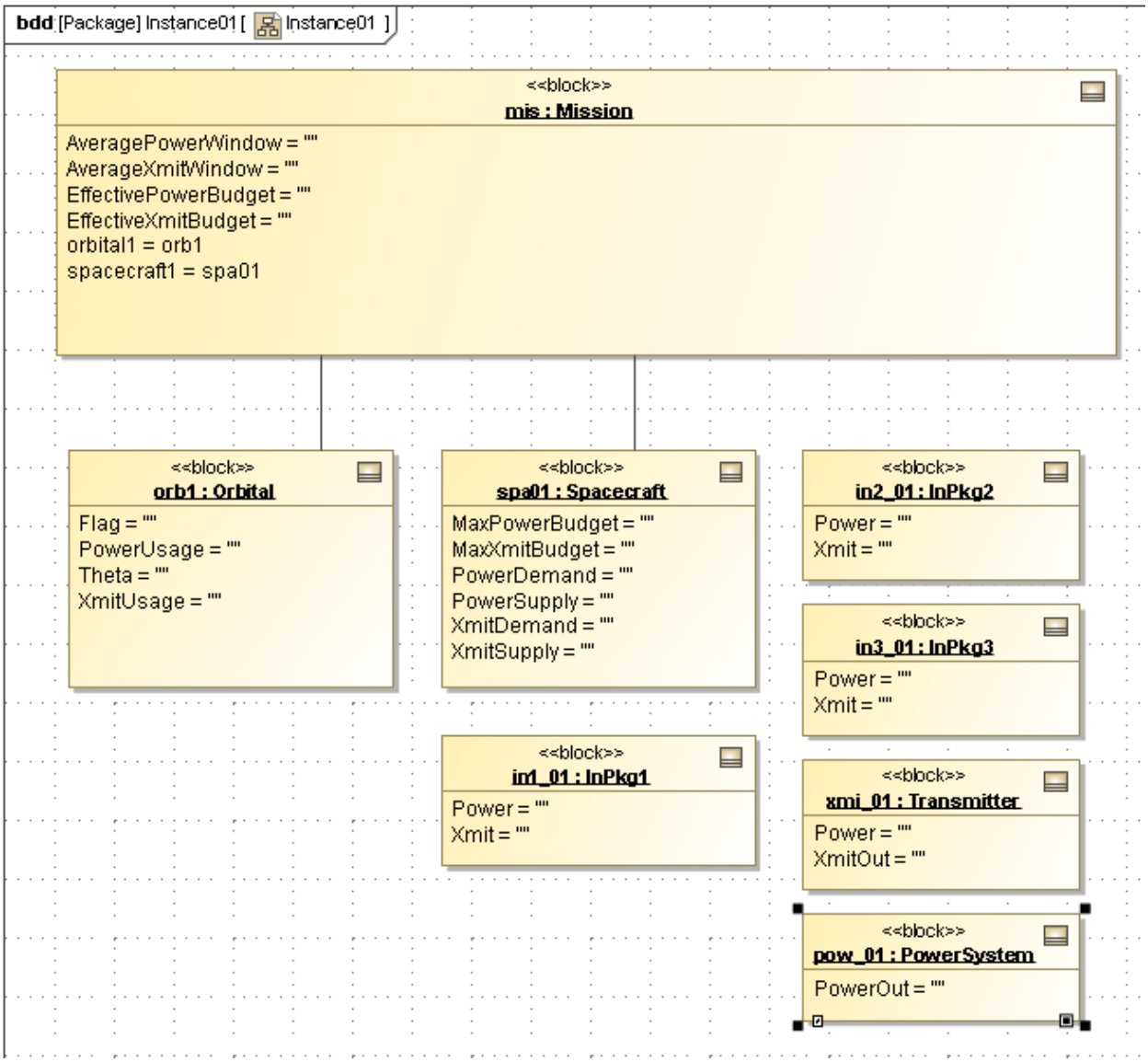


Figure 6.11 Instance01 Diagram

Discussion – Aggregates

There are two methods for creating Slots with multiple values (aggregates) in instances. The first method, which we use here, is to read multiple values into it (e.g., from a range of cells in a spreadsheet). Multiple slot values are automatically created. The second method is to create room for multiple values before we load the slots. For example, if we were to double-click **Theta** in the Instance Specification window as usual (see Figure 6.12), we could add additional empty slots by clicking the Plus button on the bottom right side of the Instance Specification window nine times to create a total of ten empty values. We could enter ten numbers in a similar way, using the Plus button after each value was entered.

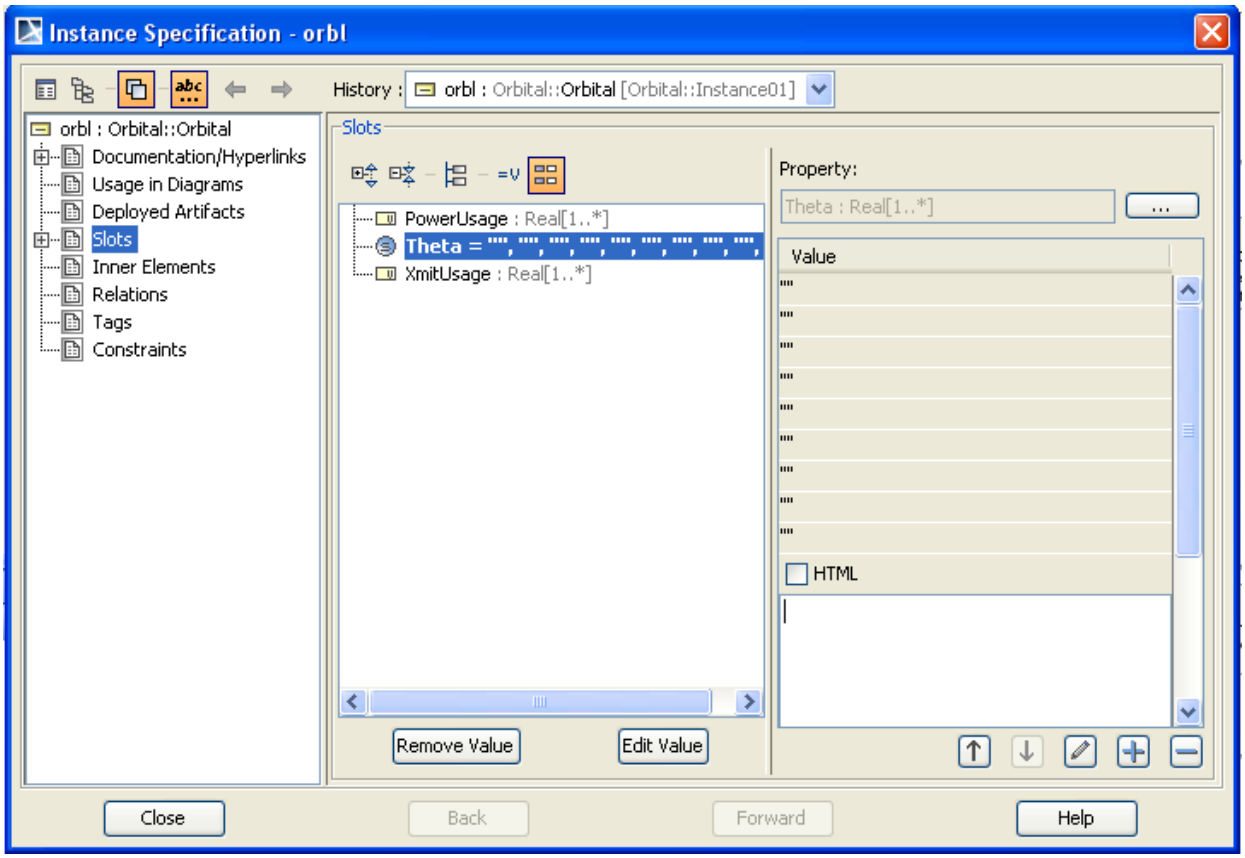


Figure 6.12 Assigning ten empty values to the Theta parameter in orb1

12. Create the connection between the spacecraft instance blocks and spreadsheet **spacecraft.xlsx**.
    a. In the Containment window, right-click on the instance block **In1_01** and select ParaMagic→Excel→Setup.
    b. The ParaMagic-Excel Setup window will appear as in Figure 6.13a. The spreadsheet to be linked can be identified in two ways
        i. Browse to the desired file. This will enter the full path name in the Workbook file text box, or
        ii. Type in the filename, e.g. **spacecraft.xlsx** and click Refresh. If no path is typed, it will assume spreadsheet is in the same folder as the model (.mdzip file). This may be more flexible if the model and spreadsheet are moved around between different systems.
    c. After the Workbook name is entered and the Refresh button is clicked, the available worksheets within that file will appear as a drop-down list by the Worksheet name label. Select the desired worksheet, Sheet1. See Figure 6.13b.

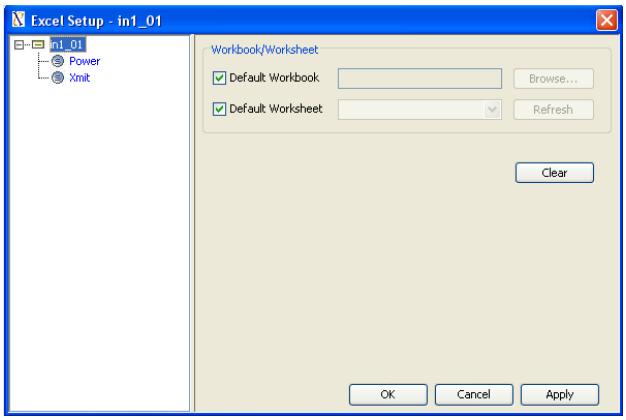


Figure 6.13a ParaMagic- Excel Set-up for instance

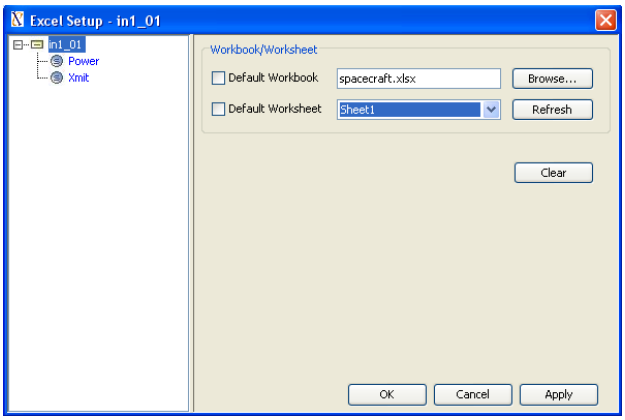


Figure 6.13b ParaMagic- Excel Set-up for instance after completion

d. In the Excel Setup browser, select the Power slot. See Figure 6.14.

i. Under Cell Range, enter the cell coordinates on the spreadsheet for the parameter desired, B3.

ii. Under Access Mode, select Read (the value in the spreadsheet cell will be copied to the instance, though only after we transfer the data in step 14).

iii. Repeat for **Xmit**. The corresponding Cell range is C3.

iv. Click OK

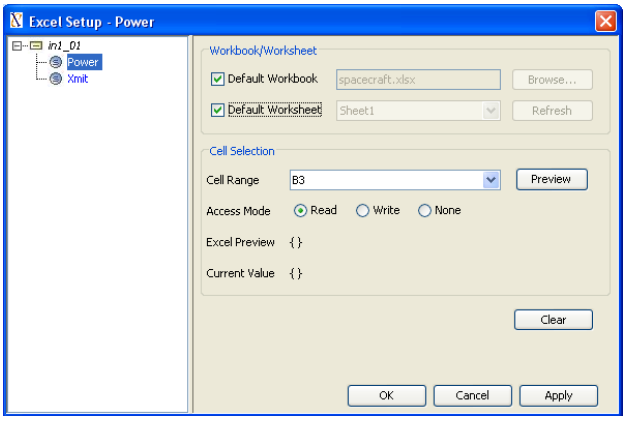


Figure 6.14 ParaMagic- Excel Set-up for slot

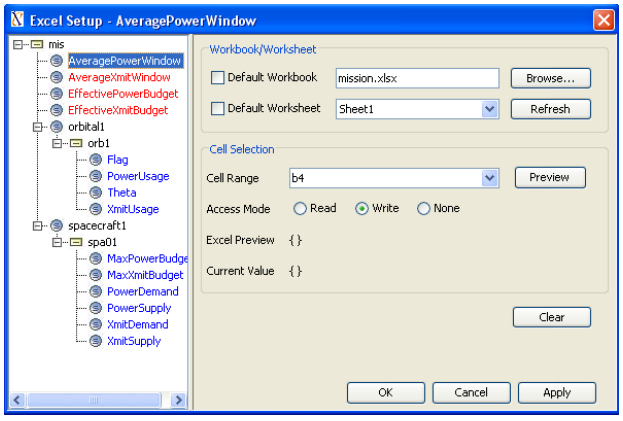


Figure 6.15 ParaMagic- Excel Set-up for slot

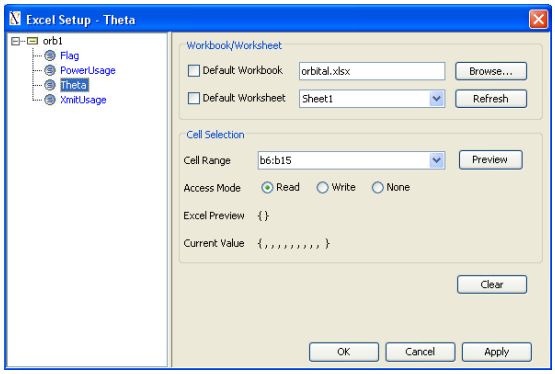


Figure 6.16 ParaMagic- Excel Set-up for aggregate slot

e. Repeat steps d, e, and f for the remainder of the instance blocks in the diagram.

i. For slots where we will write the result from the SysML model to the mission.xlsx spreadsheet, set the Access Mode to Write, as in Figure 6.15.

ii. For slots where we will read in multiple values from a spreadsheet, Cell range will contain a row or column of cells, as in Figure 6.16.

Step VIII Solve the Instance

13. Run the Excel→SysML data transfer
    a. Right-click the **Instance01** package.
    b. Select ParaMagic→Excel→Read from Excel
    c. During execution, all target values are read from all spreadsheets and written to the SysML instance diagram. See Figure 6.17.

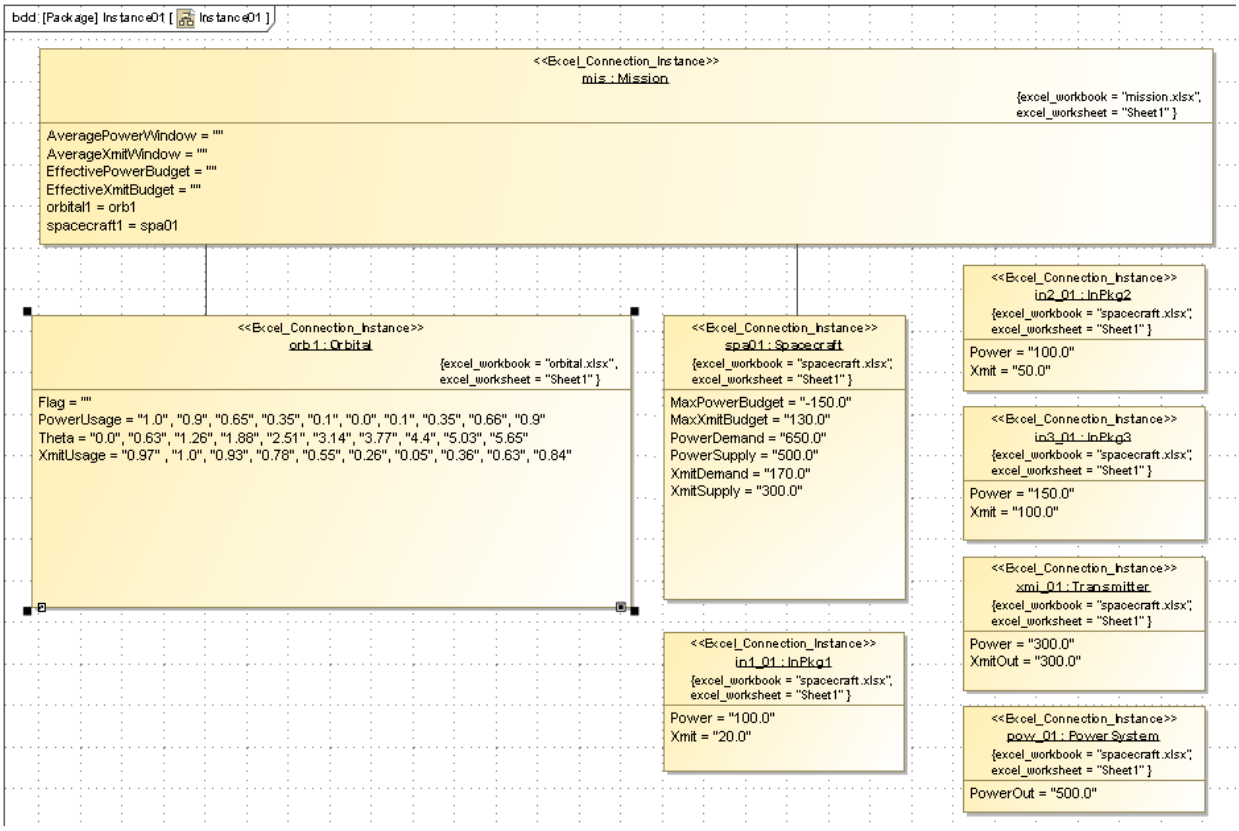


Figure 6.17 Values displayed in Instance01 diagram after Read from Excel

14. Define the ParaMagic causality for ParaMagic/Mathematica calculations.
    a. Right-click on **Instance01** and select ParaMagic→Util→Assign default causalities.
    b. Assign *target* causality to **EffectivePowerBudget**, **EffectiveXmitBudget** and **Flag** using the procedure described in previous tutorials. Users of ParaMagic 17.0.1 Lite will not have a **Flag** slot

15. Run the ParaMagic/Mathematica parametric simulation.
    a. Right-click the **Instance01** package.
    b. Select ParaMagic→Browse
    c. Click Solve. Browser before and after solution is shown in Figure 6.18. Note that **Flag** has a value of 1 after solution, indicating completion of the graph. Users of ParaMagic 17.0.1 Lite will not have a **Flag** slot.

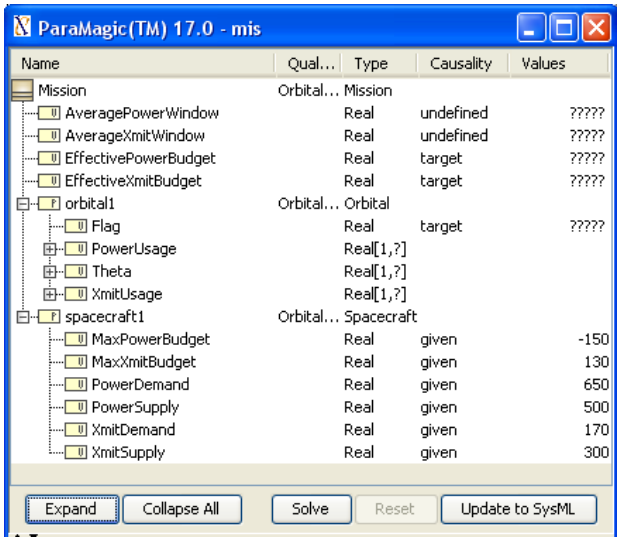


Figure 6.18a Browser before execution.

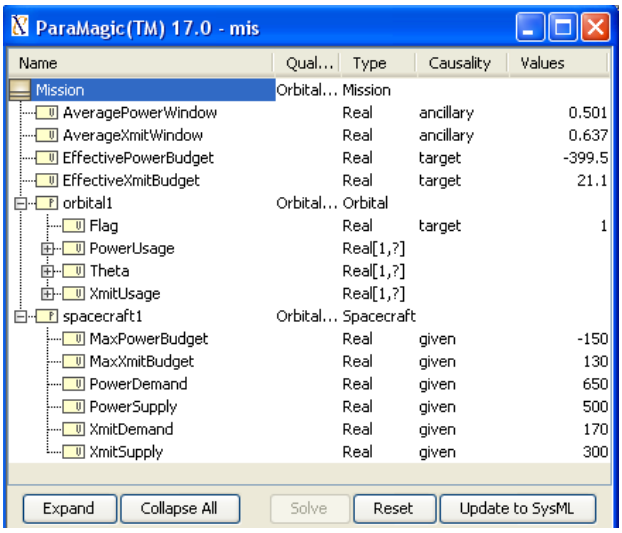


Figure 6.18b Browser after execution.

d. Click Update to SysML. **mis:Mission** slot values appear as in Figure 6.19.

16. Run the SysML→Excel data transfer
    a. Right-click the **Instance01** package.
    b. Select ParaMagic→Excel→Write to Excel
    c. During execution, all given values are read from the SysML instance diagram and written to the spreadsheet **mission.xlsx**. See Figure 6.20.

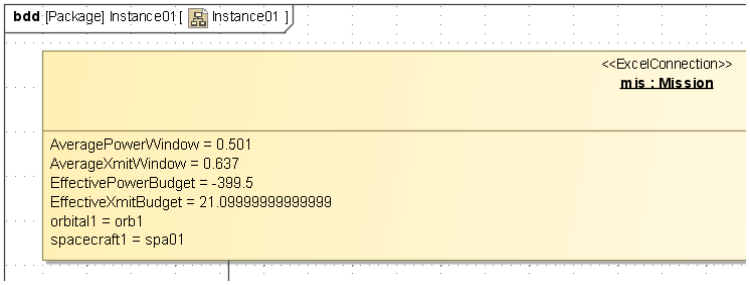


Figure 6.19 Browser before execution.

	A	B
1	Mission Estimates	
2		
3		
4	Average Power Window	0.501
5	Average Xmit Window	0.637
6	Effective Power Budget	-399.5
7	Effective Xmit Budget	21.1
8		

Figure 6.20 mission.xlsx after Write.

17. View the graph of **PowerUsage** and **XmitUsage** vs **Theta** created by ParaMagic. Users of ParaMagic 17.0.1 Lite will not have included this graphing function and should skip step 17.
    a. The ICAXPlotXYT function always returns a graphical file named **XYTlineplot.jpg** and saves it in the directory designated in step 6.d.
    b. Create a hyperlink from the model to the graph so that it can be called up quickly after the simulation is complete.
        i. Right-click on the package **Orbital** and select New Element→ Hyperlink
        ii. A dialog box will appear, as shown in Figure 6.21. User the browser (button with three dots) to point to the graphics file. Alternately, type in the name or select it from the list.

c. Double-click on the hyperlink in the Containment Tree to see graph, as in Figure 6.22.

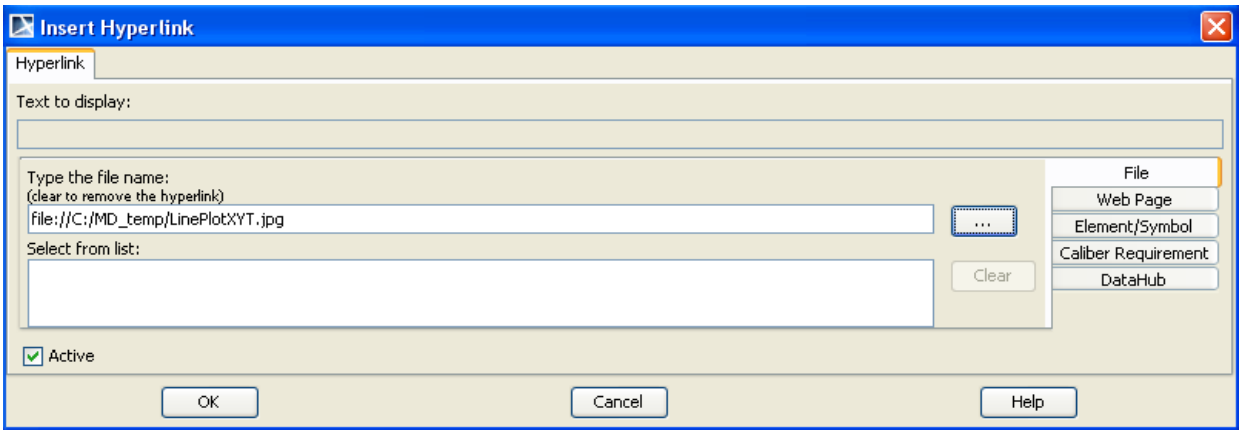


Figure 6.21 Hyperlink

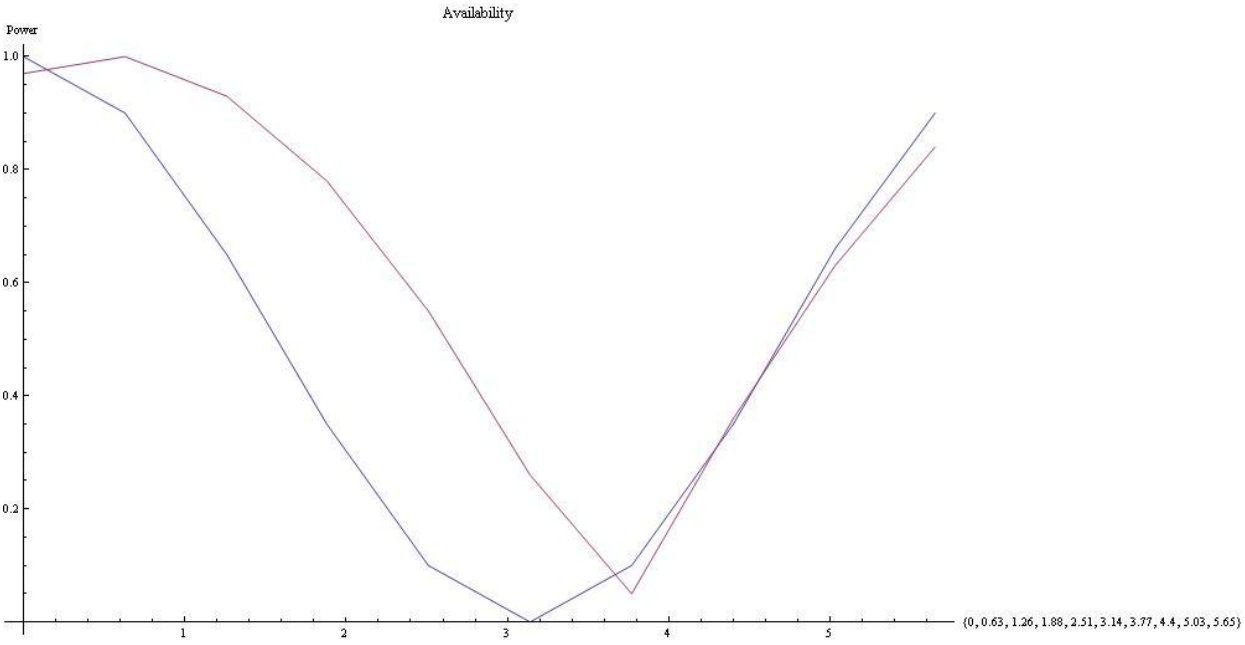


Figure 6.22 Graph created during ParaMagic execution

7 SysML Parametrics Tutorial - HomeHeating

Note: ParaMagic Lite does not have the ability to call MATLAB functions and scripts. The HomeHeating model will not be executable without upgrading to the full ParaMagic feature set. Standard ParaMagic users must set Mathematica as the core solver to access all program features.

7.1 Objective

Create a SysML project incorporating a Simulink simulation model of a home heating system and a MATLAB function that predicts outside temperature. The Simulink model, a minor modification of a standard demonstration model from MathWorks, is shown in Figure 7.1. Input 1 is the outside temperature, which varies periodically through the day and through the year. Outputs 1, 2 and 3 are the cumulative cost, indoor temperature, and outdoor temperature as a function of time. The objective is to estimate the cost per day of heating the home.

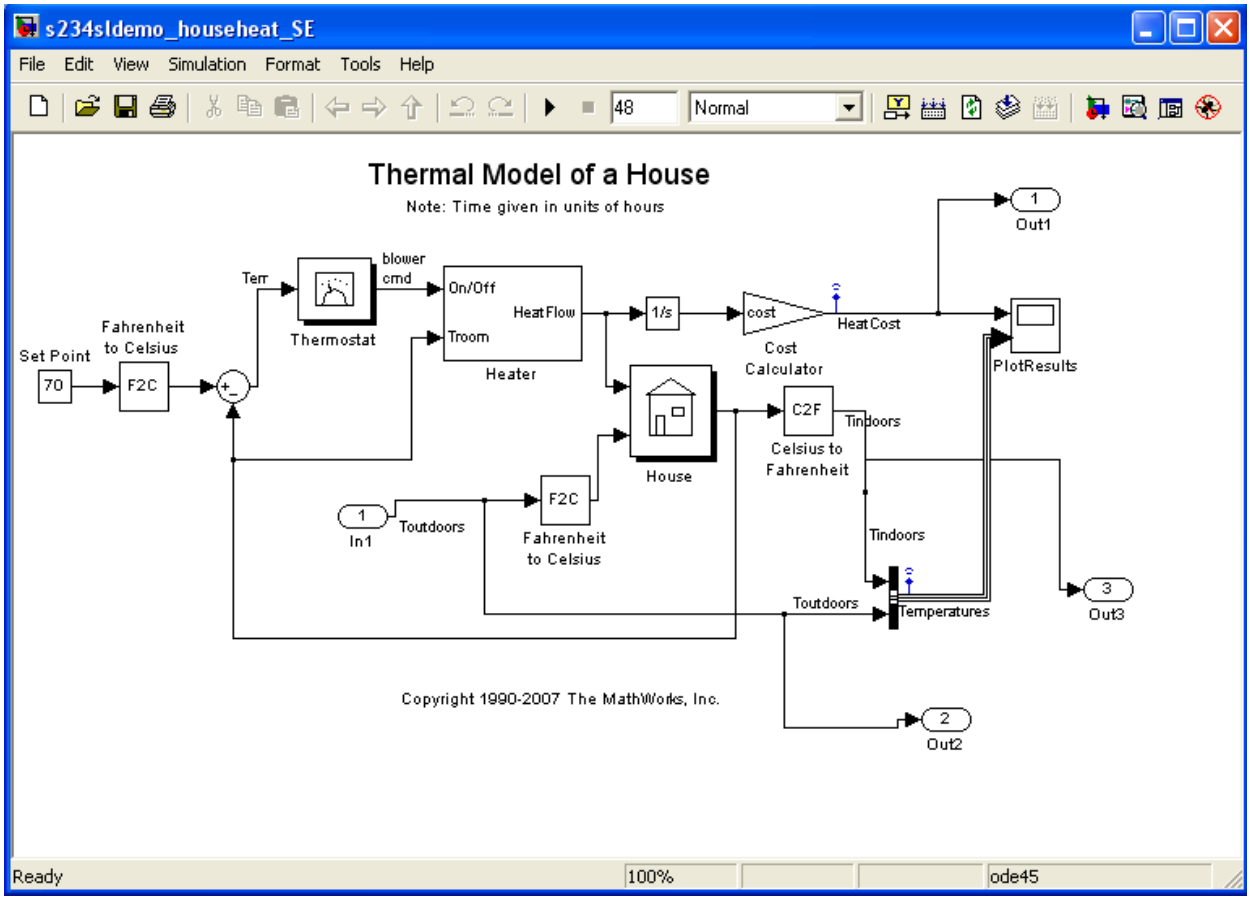


Figure 7.1 Outline of Objective

What the User Will Learn

- Connect to MATLAB functions and scripts through SysML constraint blocks
- Connect to Simulink models through SysML constraint blocks

A large body of simulation models have been developed and validated using MATLAB and Simulink (The MathWorks, Inc.). Being able to incorporate these existing models into larger SysML models can greatly accelerate system development. ParaMagic allows Simulink/MATLAB models to be treated as "black box" constraint blocks within MagicDraw parametric models. ParaMagic does not convert SysML models into Simulink models or the reverse.

We assume in this tutorial that the reader is familiar with MATLAB and Simulink and focus completely on the steps necessary to interface existing MATLAB/Simulink elements to SysML parametric diagrams. For further help, see the ParaMagic Users Guide and the user documentation for MagicDraw and MATLAB.

7.2 Step-by Step Tutorial

Step I Create Project

1. Create new project
    a. Name = **HomeHeating**
2. Create a package within the project
    a. RC (Right-click) on Data folder in Containment tree (left column)
    b. Choose New Element→Package
    c. Enter Name = **HomeHeating**

Step II Create Infrastructure

3. Install ParaMagic Profile module.

Step III Create Structural Model

4. Create elements in model
    a. Inside the **HomeHeating** package, create blocks **HomeHeatingSystem**, **Home** and **Outdoors**.
    b. Create a block definition diagram, Name = **HomeHeating**, and drag the blocks into the diagram. See Figure 7.2. Note that we use a Directed Composition connector to link **HomeHeatingSystem** to **Home** but reference the **Outdoors** block with a Directed Aggregation arrow.
    c. Create the Value Properties shown in Figure 7.2. All are Real with a multiplicity of 1.

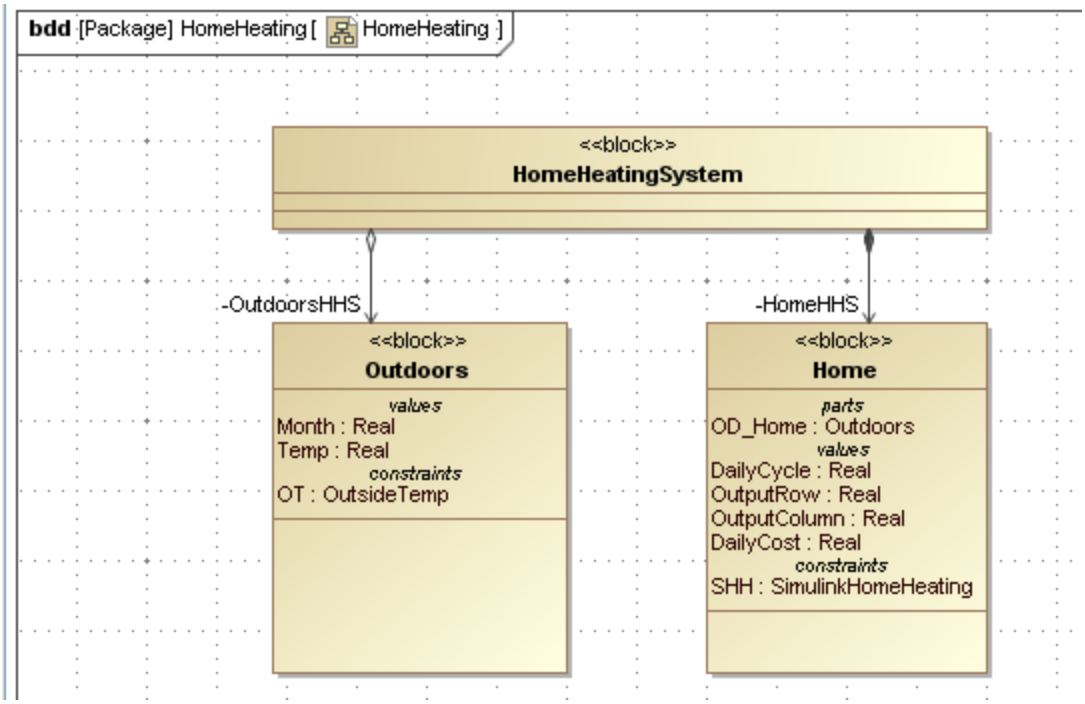


Figure 7.2 Block Definition Diagram for HomeHeating model

Step IV Create Constraints

5. Create a constraint block using the MATLAB function annualcycle,

```
function t = annualcycle(m)
%   returns t, average temperature, based on m, month from 1 to 12
t = 70 + 20 * sin(2 * pi() / 12 * (m - 4));
```

annualcycle takes a month in the form of a number from 1 to 12 and returns t, the average daily temperature (degrees F) for that month. We assume, for this tutorial, that the function already exists. To use it with ParaMagic,

a. Add the following final two lines to the function, using the MATLAB editor or some other text editor.

```
save('output.txt','t','-ASCII');
exit
```

These lines cause the value of t to be saved in an ascii file, output.txt, and retrieved by ParaMagic after MATLAB has exited.

b. Save the complete function as annualcycle.m in the directory set up for MATLAB files in ParaMagic.ini.

c. Create a constraint block, **OutsideTemp**, in the **HomeHeating** package, with two constraint parameters, **m** and **t**, and the constraint, **t = xfwExternal(matlab, function, annualcycle, m)**. The arguments of the function xfwExternal are

i. external solver being called, here MATLAB

ii. type of element called, function or script, here function

iii. the name of the function or script, here annualcycle
iv. the input argument(s), here **m**. There may be more than one input argument.

6. Create a constraint block using the MATLAB script demoscriptasciisimulink, which launches the Simulink model s234sldemo_househeat_SE.mdl. We assume that the Simulink model and MATLAB script has been previously developed and tested.
   a. Add the following initial and final lines to the script file

```
inSel= load('input.txt');

o1=inSel(1);
o2=inSel(2);
TempOutsite=inSel(3);
Amplitute=inSel(4);

(Body of existing script)

a=yout(o1,o2);
save('output.txt','a','-ASCII');
exit
```

The initial lines open a text file, input.txt, created by ParaMagic, and extract the four input parameters for use in the Simulink model. The final lines extract a single value for the 720 x 3 element matrix **yout** created by the Simulink model and save it to another text file to be read by ParaMagic.

   b. Save the modified script as demoscriptasciisimulink.m in the directory set up for MATLAB files in ParaMagic.ini.
   c. Create a constraint block, **SimulinkHomeHeating**, in the **HomeHeating** package, with five constraint parameters and the constraint, **cost=xfwExternal(matlab,scriptascii, demoscriptasciisimulink,row,col,outtemp,daycyc)**. The arguments of the function xfwExternal are
      i. the external solver being called, here MATLAB
      ii. type of element called, function or script, here scriptascii
      iii. the name of the function or script, here demoscriptasciisimulink
      iv. the first input argument, here **row**, the row of the matrix element to be returned (the 360th element is at time 24 hours in this Simulink model)
      v. the second input argument, here **col**, the column of the matrix element to be returned (the 3rd element is the cumulative cost in this Simulink model).
      vi. the third input argument, here **outtemp**, the outside temperature.
      vii. the fourth input argument, here **daycyc**, the amplitude of the daily temperature variation.
      viii. The value returned is **cost**, the cumulative cost after one day of heating, which corresponds to element (360, 3) of the output matrix calculated by the Simulink model.

Step V Create Parametrics Model

7. Create the parametrics diagram shown in Figure 7.3 inside the block **Outdoors**. The constraint block **OY:OutsideTemp** contains the MATLAB function *annualcycle*.

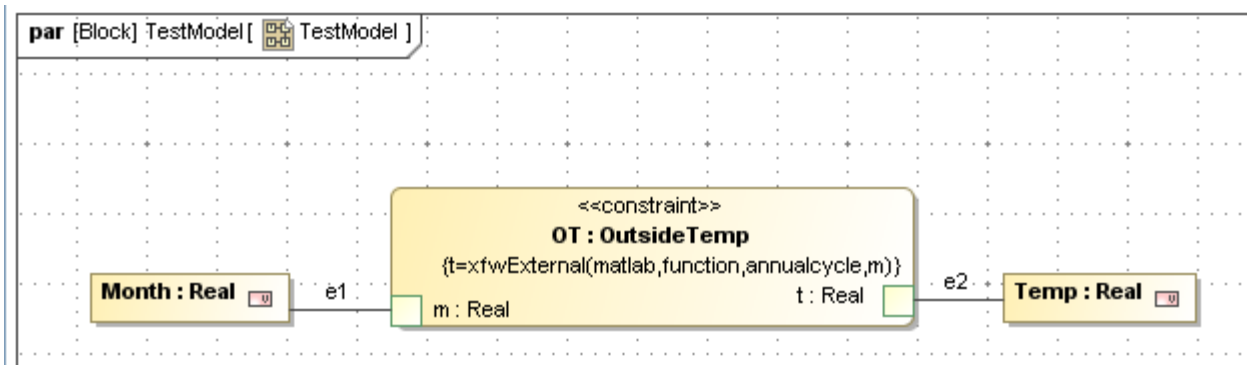


Figure 7.3 Parametric diagram for Outdoors

8. Create the parametric diagram shown in Figure 7.4 inside the block **Home**. The constraint block contains the MATLAB script *demoscriptasciisimulink*, which launches the Simulink model *s234sldemo_househeat_SE.mdl*. Note that the value **Temp** calculated by the MATLAB function *annualcycle* is one of the inputs to the Simulink model.

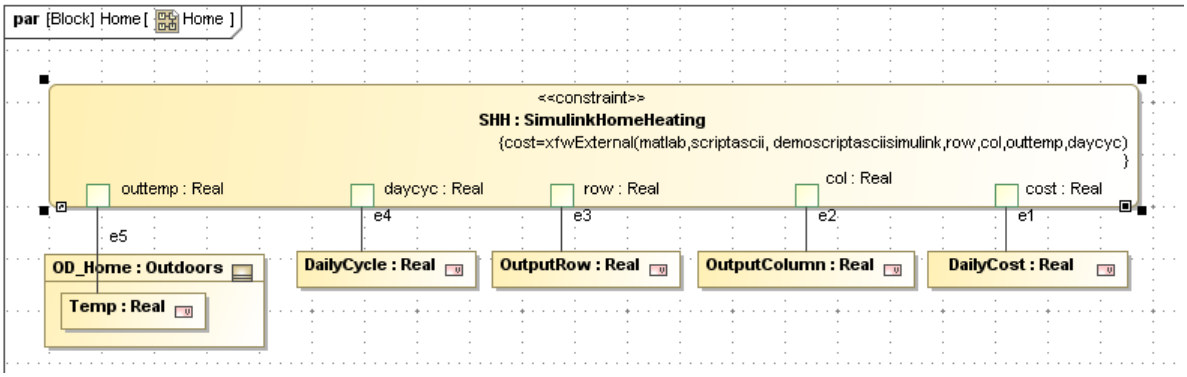


Figure 7.4 Parametric diagram for Home

Step VI Validate Parametrics Model

9. To validate the model schema, follow the instructions in Step VI of previous tutorials

Step VII Create an Instance

10. Create an instance as shown in Figure 7.5

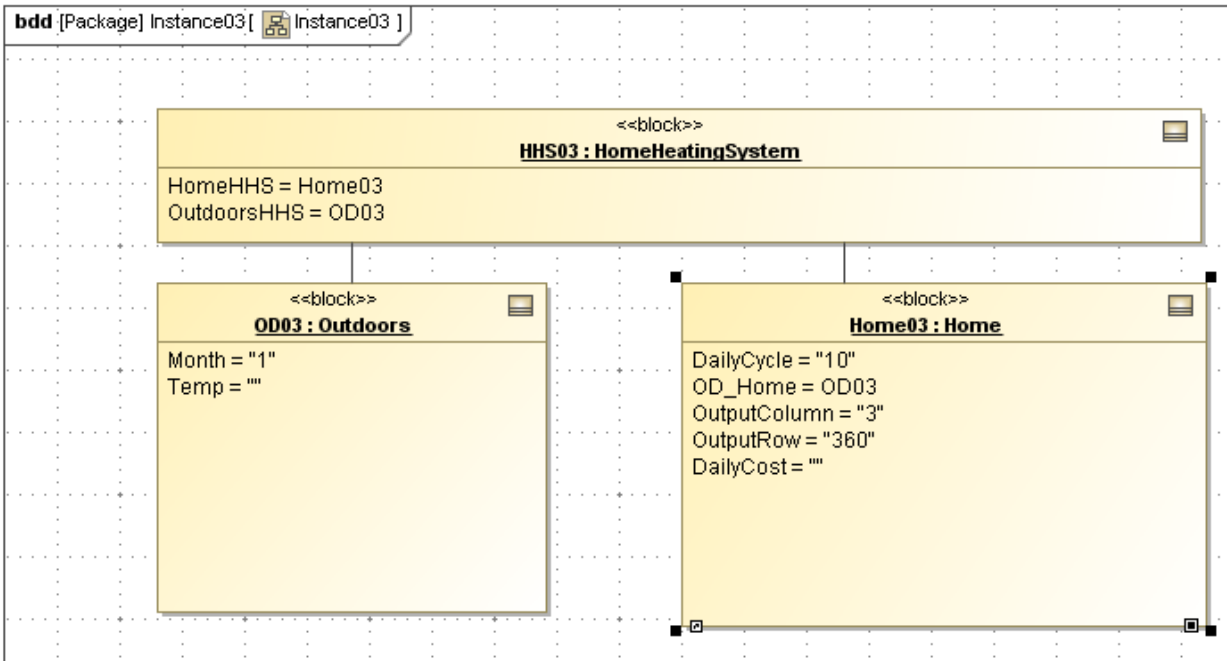


Figure 7.5 Instance of HomeHeatingSystem

a. Point the Part Property **OD_Home** inside **Home03** to the instance **OD03:Outdoors**. Note that this assignment is not made automatically in creating the linkages, as in previous examples.

   i. Open the Instance Specification for **Home03** (Figure 7.6)

   ii. Select Slots

   iii. Click on **OD_Home:Outdoors**

   iv. Click Create Value button

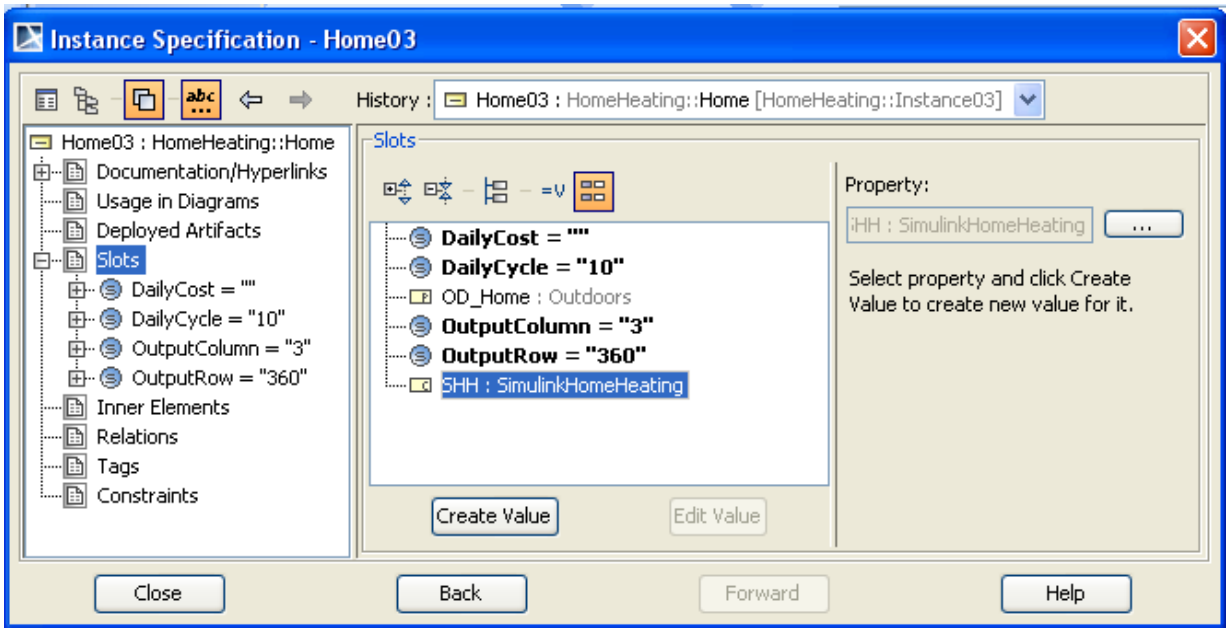


Figure 7.6 Instance Specification for Home03

v. Select **OD03:HomeHeating:Outdoors** in the Select Elements window (see Figure 7.7)

vi. Click Add, OK, and Close

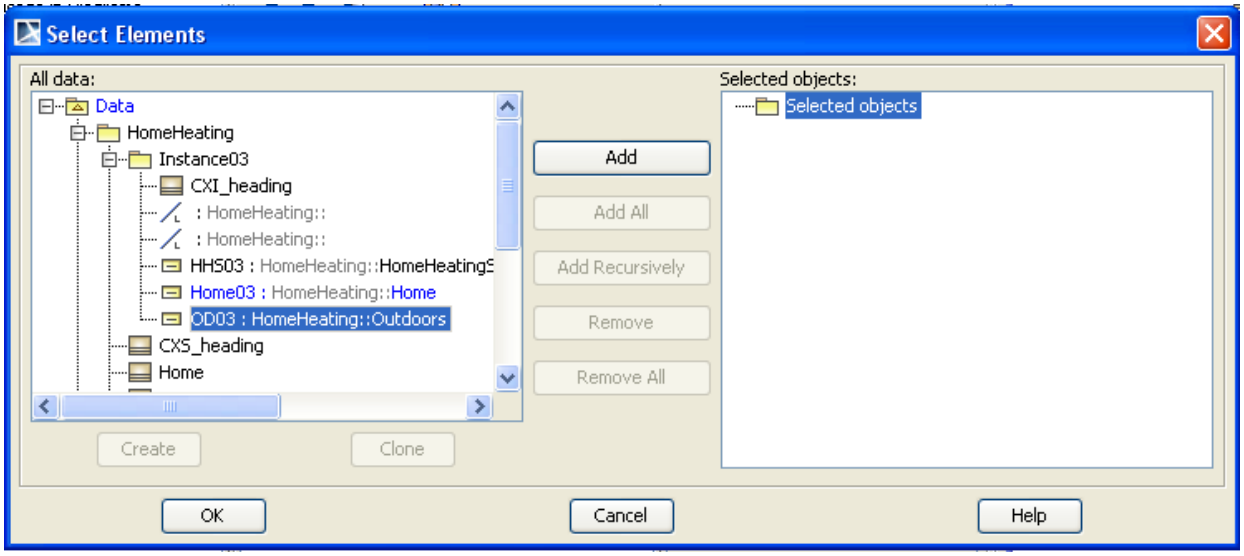


Figure 7.7 Select Elements to link **OD03** to **OD_Home**

b. Create the links and populate the slots as shown in previous tutorials. The givens are

i. **Month** = 1 (January)

ii. **DailyCycle** = 10 (temperature varies +/- 10 daily)

iii. **Row** = 360 (one day as Simulink model timescale is set)

iv. **Col** = 3 (cumulative cost as Simulink model output array is configured)

c. Assign causalities to slots using the Add default causalities utility. Change causality of **DailyCost** to *target*.

Step VIII Solve the Instance

11. Open the Browser (Figure 7.8) and click Solve.

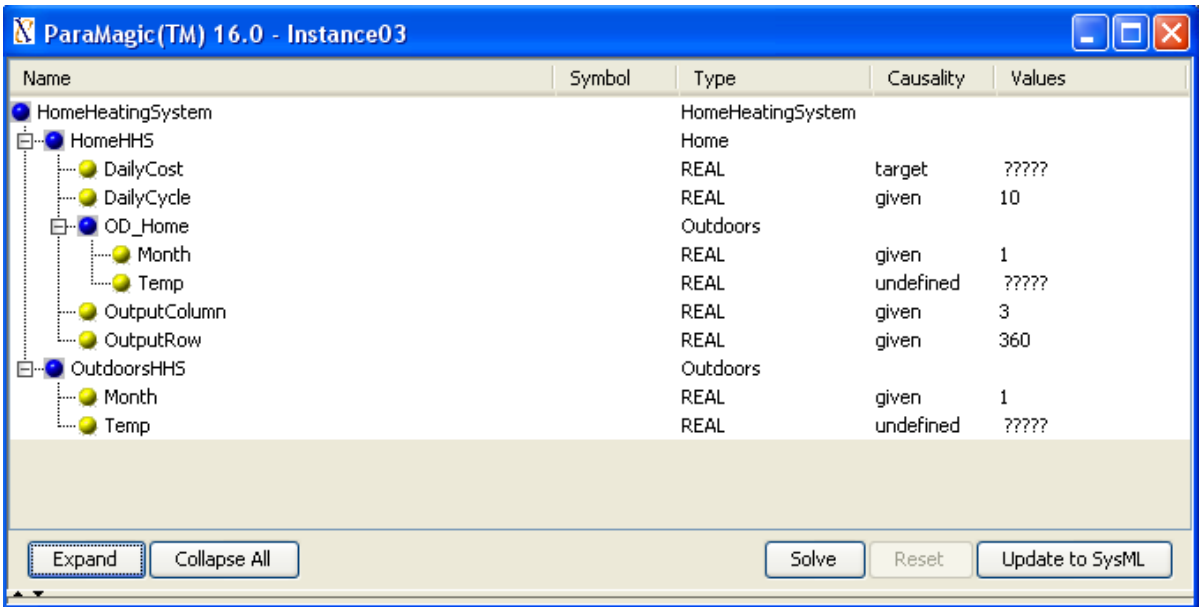


Figure 7.8 Browser before solution

a. During ParaMagic execution, MATLAB will launch and several figures will appear briefly on your screen, including the Simulink model diagram from Figure 7.1 and the PlotResults graph shown in Figure 7.9. The PlotResults window shows the cumulative cost in the upper window over a two day period. The lower window shows the outdoor temperature (violet) and the indoor temperature (yellow) on the same time scale. The target indoor temperature is a constant, 70 F, set inside the Simulink model (although the model could be modified to treat this as an input from SysML, as well), but the actual indoor temperature varies as the thermostat cycles on and off.

   The appearance of these figures is set in the Simulink model, not in the SysML model or in the MATLAB script. These windows will disappear when the simulation is complete and MATLAB exits.

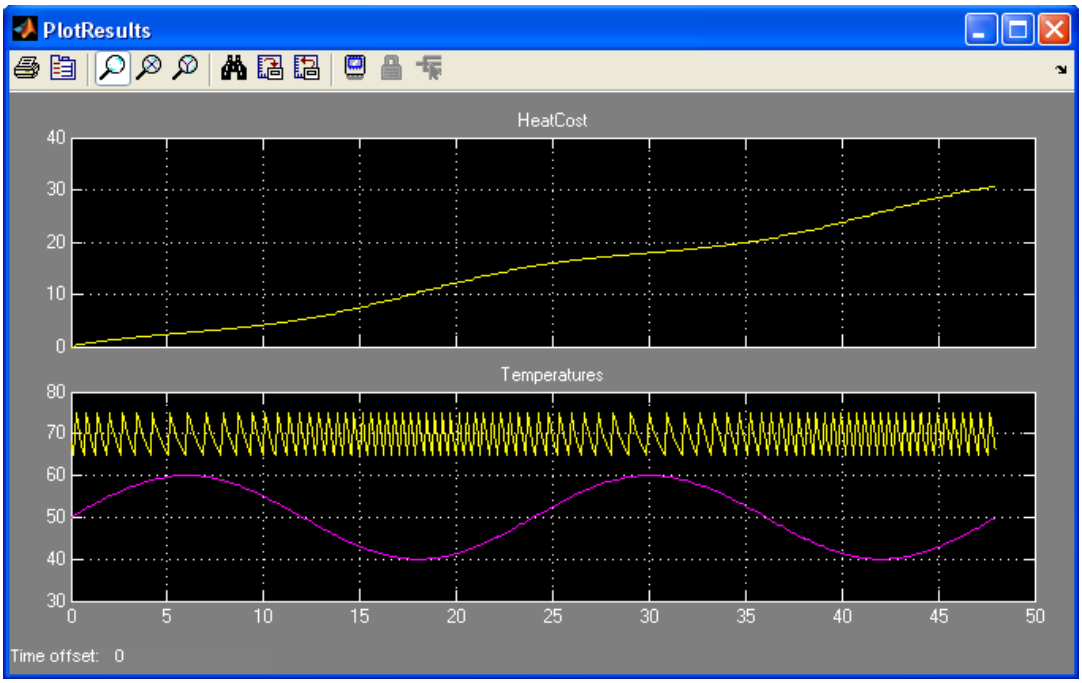


Figure 7.9 Plot Results window during Simulink execution

e. The final browser results are shown in Figure 7.10.

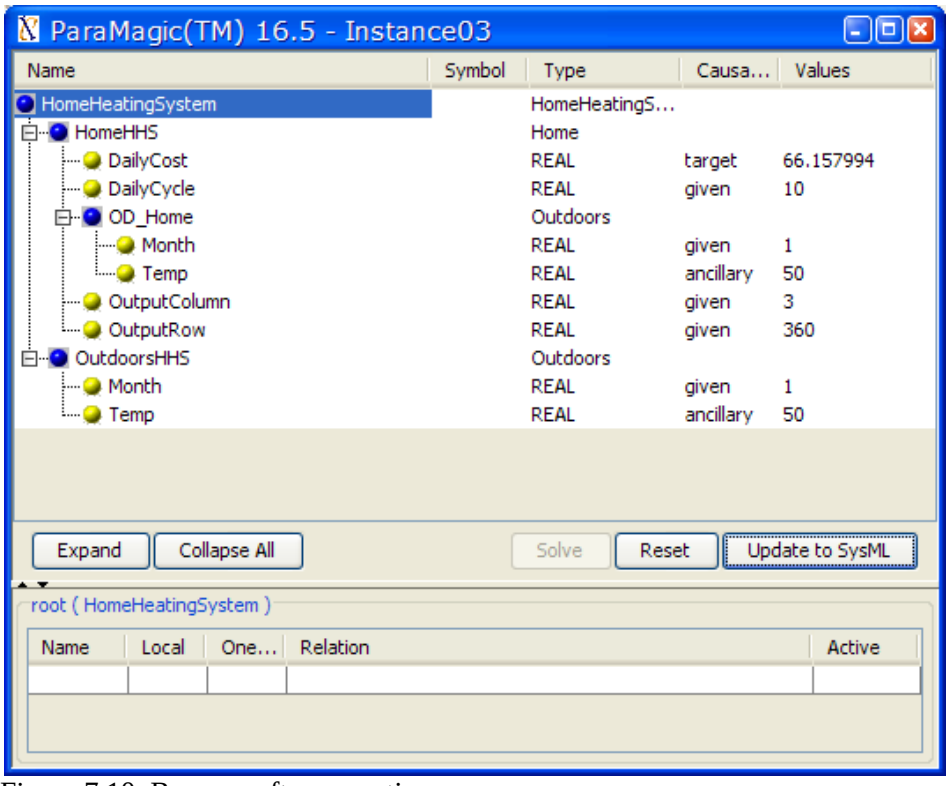


Figure 7.10 Browser after execution.

8 SysML Parametrics Tutorial – LittleEye Trade Study

8.1 Objective

This tutorial is a continuation of the LittleEye exercise in Section 4. Once a parametric model is built and validated, users frequently want to explore variations in the initial parameter set. This can be called a trade study, sensitivity analysis, or design of experiments and is helpful in identifying key inputs, assessing risk and optimizing results.

ParaMagic uses the Excel Connection feature to set up the different initial parameter sets or "scenarios" as rows in a spreadsheet. Parameter sets are automatically read, the model is repeatedly executed and output values written back to the spreadsheet. Using the LittleEye model, we will run a multi-variable trade study, to determine the sensitivity of the result to the number of planes, crews and fuel loads available.

What the User Will Learn

- Running a ParaMagic trade study

8.2 Step-by-Step Tutorial

Step VII Set-up a Trade Study

Start with the LittleEye model created in Section 4. The trade study uses the same ExcelConnection interface that was described in the earlier Orbital tutorial. The only difference is that, instead of reading in a single set of values from the spreadsheet, processing them using the parametric solver, and writing the results back to the spreadsheet, the Trades Studies feature runs multiple value sets in an automated batch mode process.

1. Create an MS Excel spreadsheet for the trade study, as in Table 8.1. The trade study will vary two parameters, Number of Planes and Number of Crews, and calculate a single output value, Miles Scanned Per 24 Hours. Each row is a single trial or scenario. The trade study will start with the first trial designated in the Excel interface and work down one row at a time. In this trade, we have 20 trials, a combinatorial explosion of 3,4,5,6 and 7 planes and 4, 5, 6 and 7 crews. We save the spreadsheet as **LE_Trade.xlsx.**

Number of Planes	Number of Crews	Miles Scanned Per 24 Hours
3	4	
4	4	
5	4	
6	4	
7	4	
3	5	
4	5	
5	5	
6	5	
7	5	
3	6	
4	6	
5	6	
6	6	
7	6	
3	7	
4	7	
5	7	
6	7	
7	7	

Table 8.1 LE_Trade.xlsx

2. Set up the Excel linkages for Read and Write as in the Orbital tutorial.
   a. RC **LittleEyeInstance01** and select ParaMagic→ Excel→ Setup

b. Select **NumberPlanes**
   i. Enter **LE_Trade.xlsx** under Workbook
   ii. Click Refresh
   iii. Select Sheet1 under Worksheet.
   iv. Under Cell Range, enter A2, the cell containing the first trial value for this parameter. Do not enter a cell range; the number of trials will be specified later.
   v. Under Access Mode, select Read (see Figure 8.1)

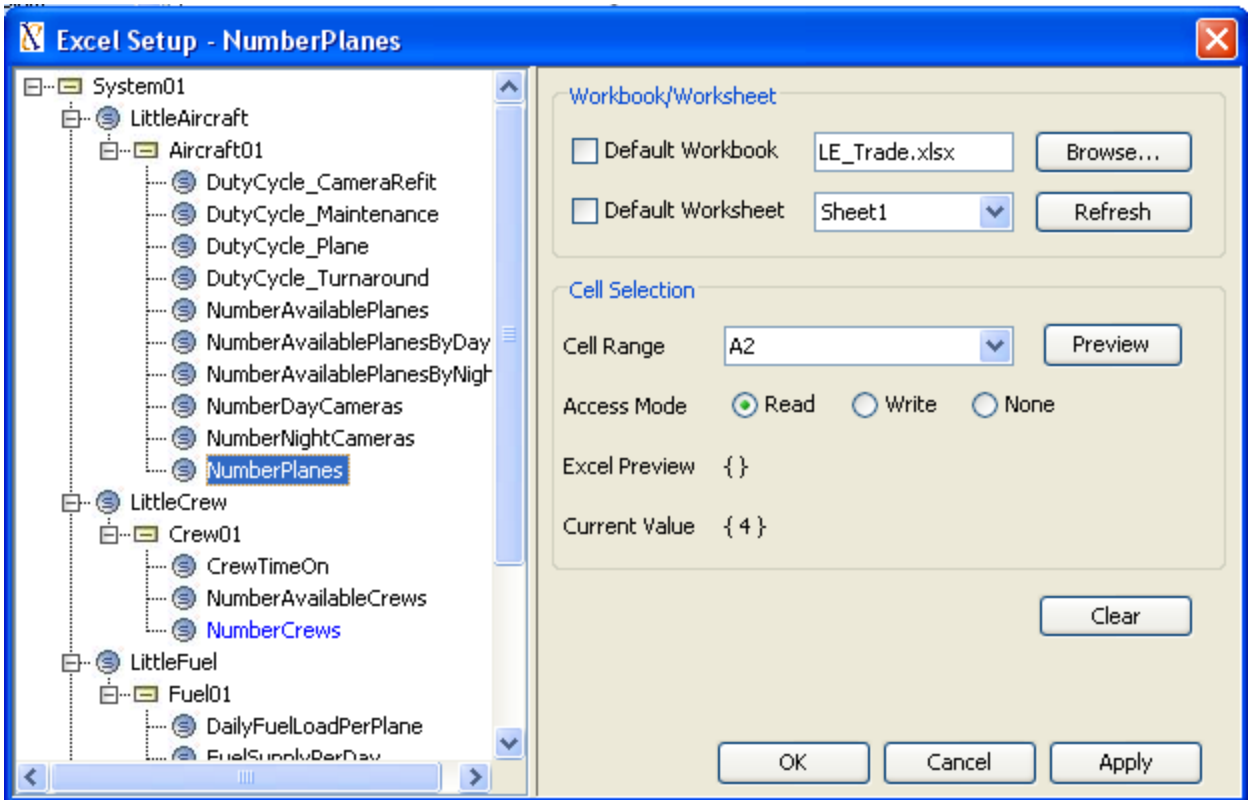


Figure 8.1 Excel Setup window for trade study

c. Repeat for **NumberCrews**, with Cell Range = B2, Access Mode = Read
d. Repeat for **MilesScannedPer24Hours**, Cell Range = C2, Access Mode = Write.
e. Click OK to close Excel Setup window.

3. Set number of trade study scenarios to run.
   a. Right-click on **LittleEyeInstance01** and select ParaMagic→ Trade Study→ Setup.
   b. As shown in Figure 8.2, enter the number of scenarios (20 in this example) and click OK.

Step VIII Run the Trade Study

4. Run the trade study.
   a. Make sure that the trade study spreadsheet LE_Trade.xlsx is closed. Results cannot be written to an open file.
   b. Right-click on **LittleEyeInstance01** and select ParaMagic→ Trade Study→ Run.
   c. Figure 8.3 shows the message when the trade study is complete. Click OK.
   d. Open **LE_Trade.xlsx**. It should appear similar to Table 8.2. Using the standard graphing functionality of Excel, a plot similar to Figure 8.4 can easily be created.

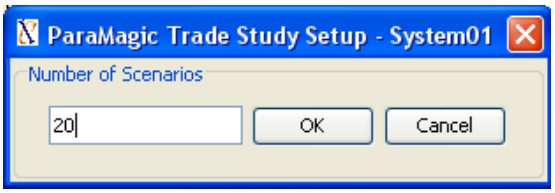


Figure 8.2 Trade Study Setup window

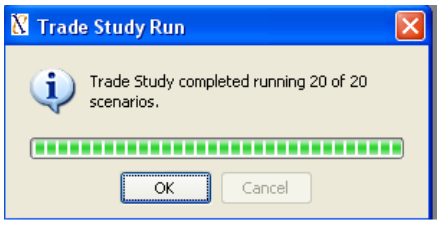


Figure 8.3 Trade Study Completion

Number of Planes	Number of Crews	Miles Scanned Per 24 Hours
3	4	1612.8
4	4	1612.8
5	4	1612.8
6	4	1612.8
7	4	1612.8
3	5	2016.0
4	5	2016.0
5	5	2016.0
6	5	2016.0
7	5	2016.0
3	6	2337.2
4	6	2419.2
5	6	2419.2
6	6	2419.2
7	6	2419.2
3	7	2337.2
4	7	2822.4
5	7	2822.4
6	7	2822.4
7	7	2822.4

Table 8.2 LE_Trade.xlsx after trade study

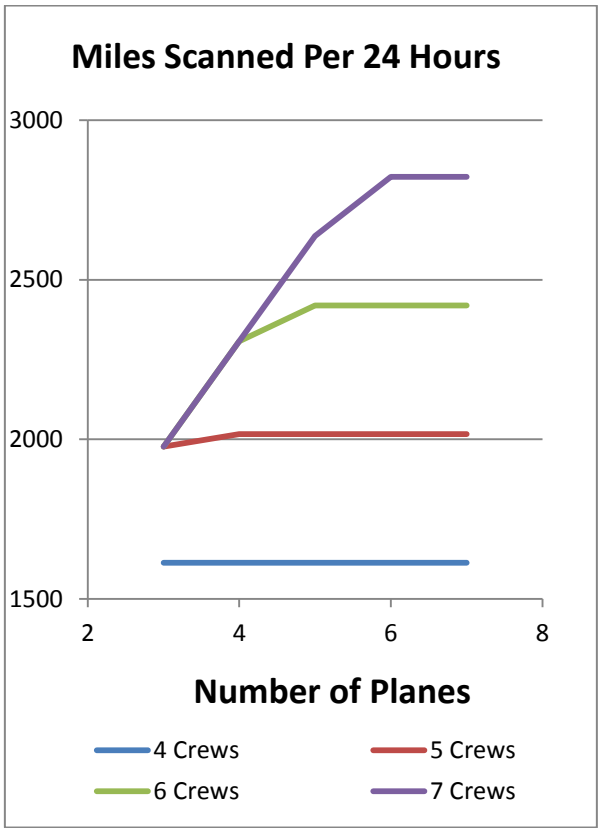


Figure 8.4 Excel plot of trade study results

9 SysML Parametrics Tutorial - Electronics

Note: ParaMagic Lite does not have the ability to calculate with complex aggregates. The Electronics model will not be executable without upgrading to the full ParaMagic feature set. Standard ParaMagic users must set Mathematica as the core solver to access all program features.

9.1 Objective

Create a SysML project describing a computer center that will be built in a variety of standard configurations. Each configuration of the center will consist of one or more independent computer cells, each composed of one or more server arrays, disk arrays, and other components. Each configuration can also be viewed as consisting of one or more electronics racks, each of which contains one or more electronic boxes, which might be a server array, a disk array, or some other component belonging to one of the cells.

Each of the standard configurations has a specific set of requirements that it must meet in terms of the number of cells and total computing capacity, e.g. server calculating speed, disk storage. In addition, each rack has a set of requirements that cannot be exceeded, including physical space, electrical power, cooling capacity, etc. Our objective is to create a SysML model that requires the minimum modeling effort, yet describes the full range of standard configurations and can test parametrically whether each configuration meets its requirements. Creating and modifying configurations should be simple and intuitive, so alternative designs can be evaluated. For simplicity, this tutorial only considers a few types of components and requirements.

Ordinarily, this type of problem is handled with a spreadsheet, which can grow quite complex. Handling these same calculations inside the SysML model parametrically has several advantages,

- There is a single model, not a model and separate spreadsheet which must be synchronized,
- There is a clear distinction between the abstract model (the schema) and the concrete configurations (instances) in SysML,
- The calculations are not hidden inside spreadsheet cells, but readily seen, modified and documented in the SysML model itself.

What the User Will Learn

- Using complex aggregates
- Using generalization/specialization
- Working with requirements

Complex aggregates involve parameters shared by part properties with a multiplicity greater than one. For example, if an assembly contains four equivalent parts, the weights of the four parts comprise a complex aggregate of four values. This contrasts with the earlier concept of a primitive aggregate, a single parameter containing multiple values. ParaMagic allows the user to sum, average, find a maximum, or find a minimum of a complex aggregate, similar to the fashion in which primitive aggregates are used in the Orbital example. The great value of complex aggregates is that parametric relationships can be defined at the schema level without specifying the number of parts that will be used in a specific instance.

Another useful feature of SysML is inheritance, or the ability to create generalized and specialized forms of a system object. This helps when we want to group diverse objects in one set of parametric calculations, but use each object's unique properties in other calculations.

9.2 Step-by-Step Tutorial

Step I Create Project

1. Create new SysML project and corresponding package named **Electronics**.

Step II Create Infrastructure

2. Install ParaMagic Profile module.

Step III Create Structural Model

3. Create a structural model corresponding to Figure 9.1.

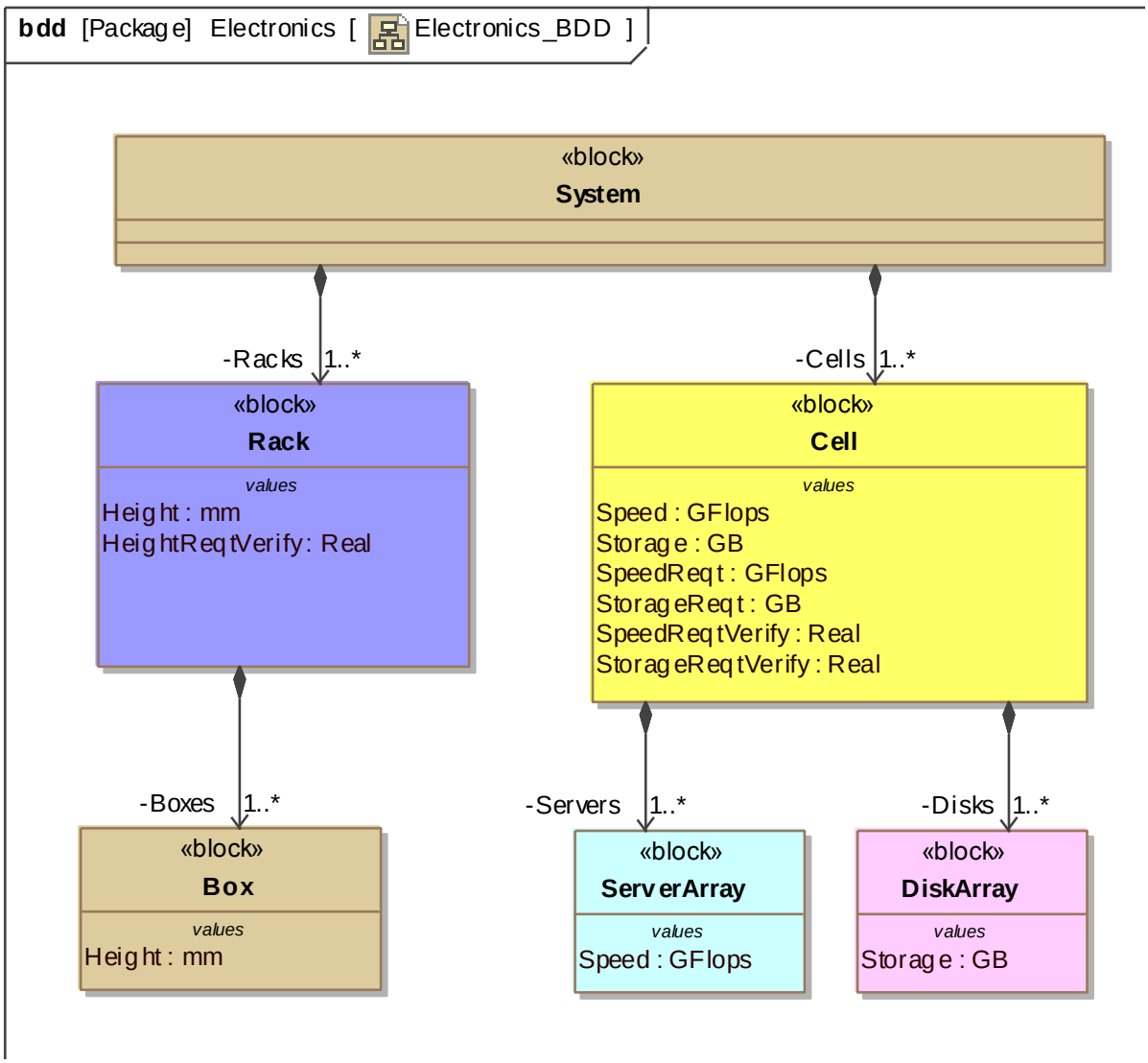


Figure 9.1 SysML Block Definition Diagram. Block color was set by right-clicking on block, selecting Symbol Properties, and setting Fill Color to the desired shade.

a. Create ValueTypes for **mm** (millimeters), **GFlops** (calculating speed) and **GB** (gigabytes, storage capacity). See the Satellite tutorial, Step 4a to review.

b. Create the blocks, value properties, and direct composition relationships as shown in Figure 9.1. Note the ValueTypes assigned to the value properties.

c. Set the Multiplicities of the part properties **Racks**, **Cells**, **Boxes**, **Servers** and **Disks** as 1 to 1…*. This indicates that there can be, for example, one, two or more racks in a system. To set the part property multiplicity for **Racks**,

   i. Double-click on the composition arrow between **System** and **Rack**,

   ii. In the Association Window, select Association Ends (see Figure 9.2)

   iii. Under Association End A, set Multiplicity to 1…*.

   iv. Repeat the process for the remaining part properties.

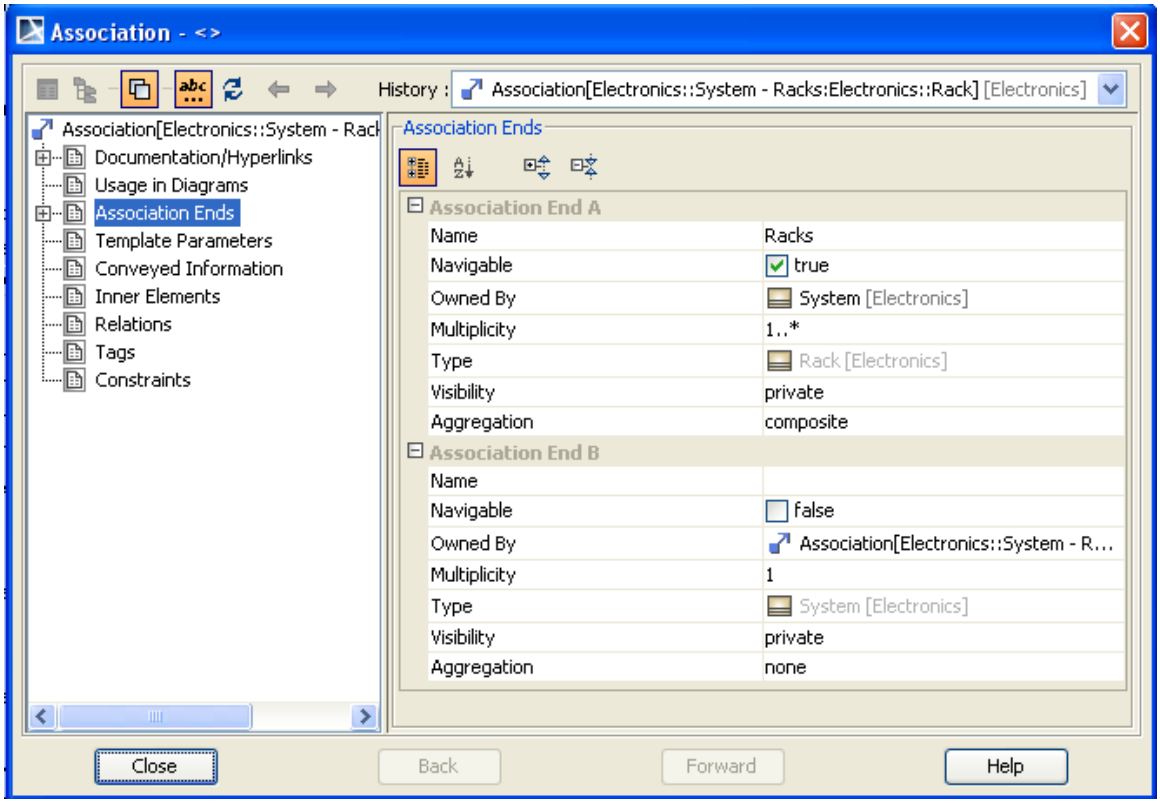


Figure 9.2 Association properties box, Association Ends table. Multiplicity under Association End A is set to 1…*

d. Create a generalization relationship between **Box** and its two sub-types, **ServerArray** and **DiskArray**.

   i. Drag the **Box**, **ServerArray** and **DiskArray** blocks from the Containment tree to an open area of the Electronics_BDD block definition diagram

   ii. Click on **ServerArray** and select the Generalization arrow (open triangular head pointing up and to the right) from the floating toolbar.

   iii. Click on **Box**. A generalization is created pointing from **ServerArray** to **Box**

   iv. Repeat for **DiskArray**. See Figure 9.3 (the two generalization arrows have been merged).

Generalization

In a generalization relationship, the sub-type, such as ServerArray, inherits the value property Height of its general type, Box, as well as having its own value property Speed. An instance of ServerArray is also an instance of Box. We will use this feature when we create instances of the system. Each component will serve as both an instance of Box as part of a specific Rack and an instance of ServerArray or DiskArray as part of a specific Cell. Other component types, e.g. Router, could have been created as additional sub-types of Box.

Generalization relationships allow other useful manipulations. For example, a constraint in a subtype overrides a constraint of the same name in the general type, so the parametric calculations can be different at the instance level without changing the schema.

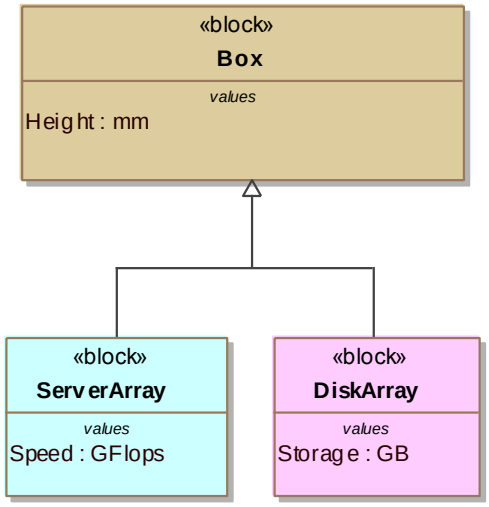


Figure 9.3 Generalization

Step IV Create Constraints

4. Create a set of Requirements and a corresponding set of Constraint Blocks which mirror the Requirements. See the Requirements diagram in Figure 9.4 for the contents. To review creating Requirements and Requirements Diagrams, see the Satellite tutorial, Section 6. Note that the constraint parameters have specific ValueTypes.

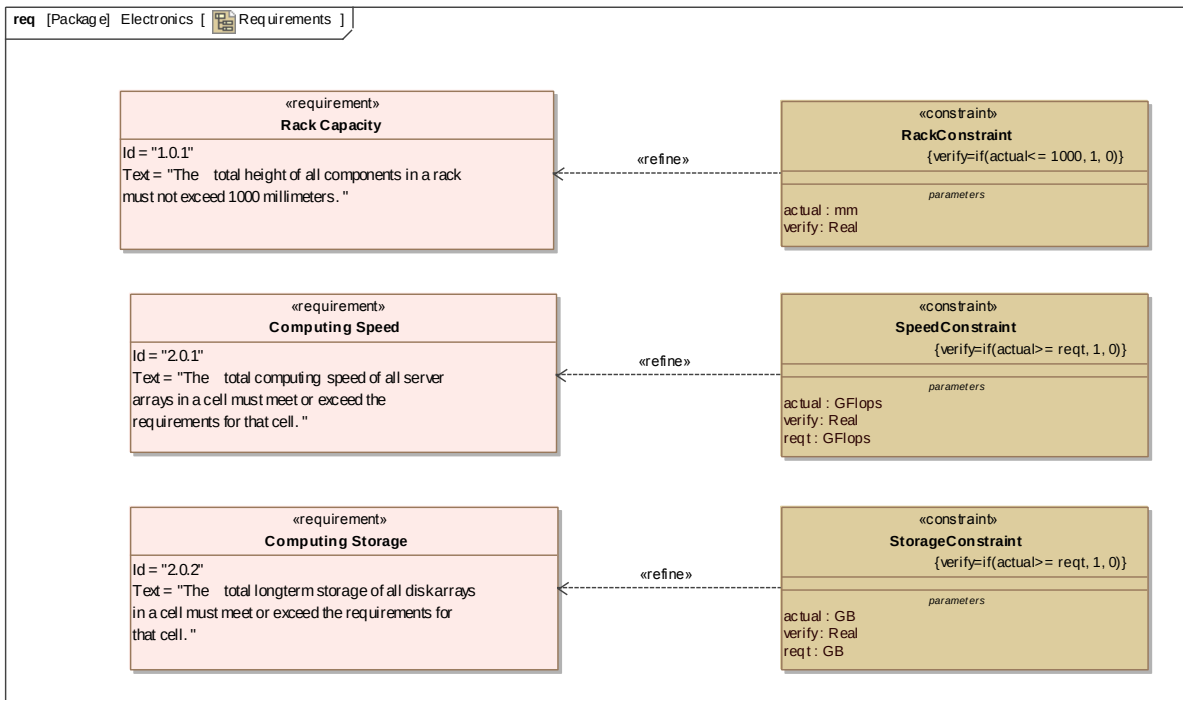


Figure 9.4 Requirements diagram

5. Inside the Containment tree, create three constraint blocks to sum over **Height**, in the case of **Rack**, and **Speed** and **Storage**, in the case of **Cell**. The contents of the constraint blocks **HeightSum**, **SpeedSum**, and **StoreSum**, are shown in the two parametric diagrams shown in Figure 9.5 and 9.6.

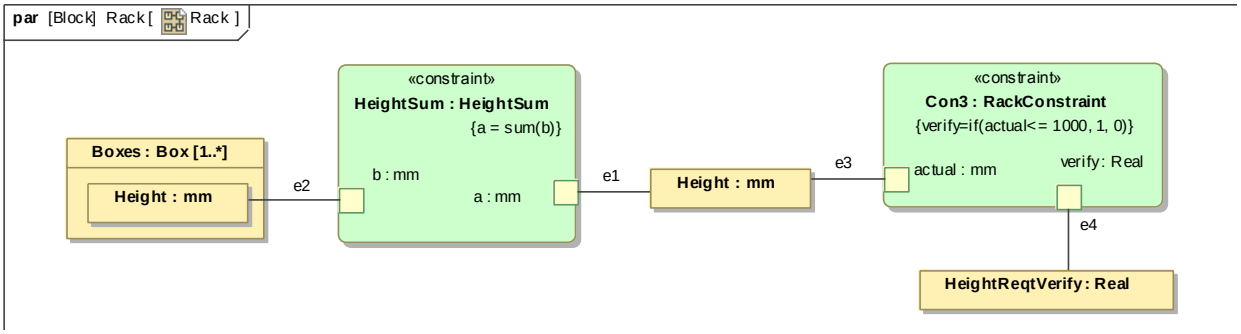


Figure 9.5 Parametric diagram for Rack

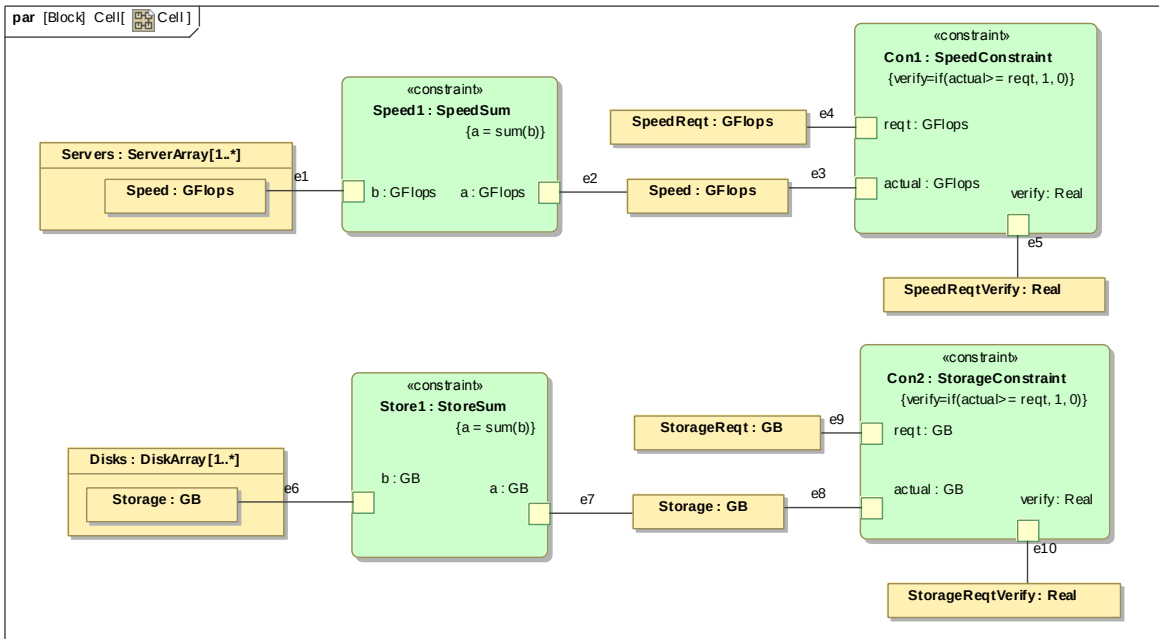


Figure 9.6 Parametric diagram for Cell

Step V Create Parametrics Model

6. Create a SysML Parametric diagram to define and display the relationships inside **Rack** (Figure 9.5). Note that the part property **Boxes:Box[1..*]** represents all boxes belonging to that rack and the constraint property **HeightSum** adds the heights of each of those boxes to calculate a total height for all boxes in the rack, even though the number of boxes has not been specified at this stage. The second constraint property in the diagram, **Con3**, compares the actual total height (in mm) to 1000 and returns a Boolean value, 1 if less than or equal to 1000 (requirement passed) and 0 if greater than 1000 (requirement failed).

7. Create a second SysML Parametric diagram to define and display the calculation of the requirements verification relationships inside Cell (Figure 9.6). This appears like a doubling of the Height requirement checking, with one branch for calculating speed of the Servers and another for the storage capacity of the Disks. Note that the Speed and Storage Requirements are left as variables, where the Height Requirement was "hard-coded" as 1000 in the constraint. In this project, each configuration (instance) of the system will have different speed and storage needs, while racks are of a standard size.

Step VI Validate Parametrics Model

8. To validate the model schema, RC on **System** in the Containment tree and select ParaMagic→Validate

Discussion - Schema and Instance

At this stage, we have created a rather simple schema which may be applied to multiple instances of arbitrary complexity. The algorithms we use to calculate system performance and resource needs are created once in an easily understood graphical format (parametric diagram), and re-used wherever the block holding that parametric diagram occurs. Compare this with a typical spreadsheet, where the distinction between schema and instance is not made. Each formula is buried in multiple cells, all of which must be updated when the model is changed. While spreadsheets excel at the organization and presentation of tabular data, they have their limits as system modeling tools.

Step VII Create an Instance

9. Create an instance library containing an instance block for each of the standard components to be used in building real system configurations. These instances can be used in each of the configurations we build.
    a. RC **Electronics** and create a new Package = **InstanceLibrary**
    b. RC **InstanceLibrary** and create a new Instance Specification with Name = **A501_Server** and Classifier = **ServerArray**
    c. Assign values of 200 (mm) and 15 (GFlops) to the Height and Speed slots in **A501_Server**.
    d. RC InstanceLibrary and create a new Instance Specification with Name = **J30_Disk** and Classifier = **DiskArray**
    e. Activate the Height and Speed slots in **J30_Disk** and assign values of 300 (mm) and 5 (GB).
    f. RC **InstanceLibrary** and select ParaMagic→Util→ Assign Default Causality.

10. Create an instance of a system configuration comprised of one computer cell spread over two racks. See Figure 9.7.
    a. RC **Electronics** and create a new Package = **Instance01**
    b. In **Instance01**, create one instance of System (**System01**), two instances of Rack (**Rack1** and **Rack2**), and one instance of Cell (**Cell1**).
    c. In **Instance01**, create a block definition diagram **Instance01**.
    d. Drag **System01**, **Cell1**, **Rack1** and **Rack2** into the diagram.

e. Drag **A501_Server** into the diagram 3 times. This creates 3 symbols of the same instance block, not 3 blocks.
f. Drag **J30_Disk** into the diagram 3 times.
g. Create the links as shown in Figure 9.7. Note that each component instance is linked to one rack (where it is physically located) and one cell (where it is electronically part of a specific computer system).

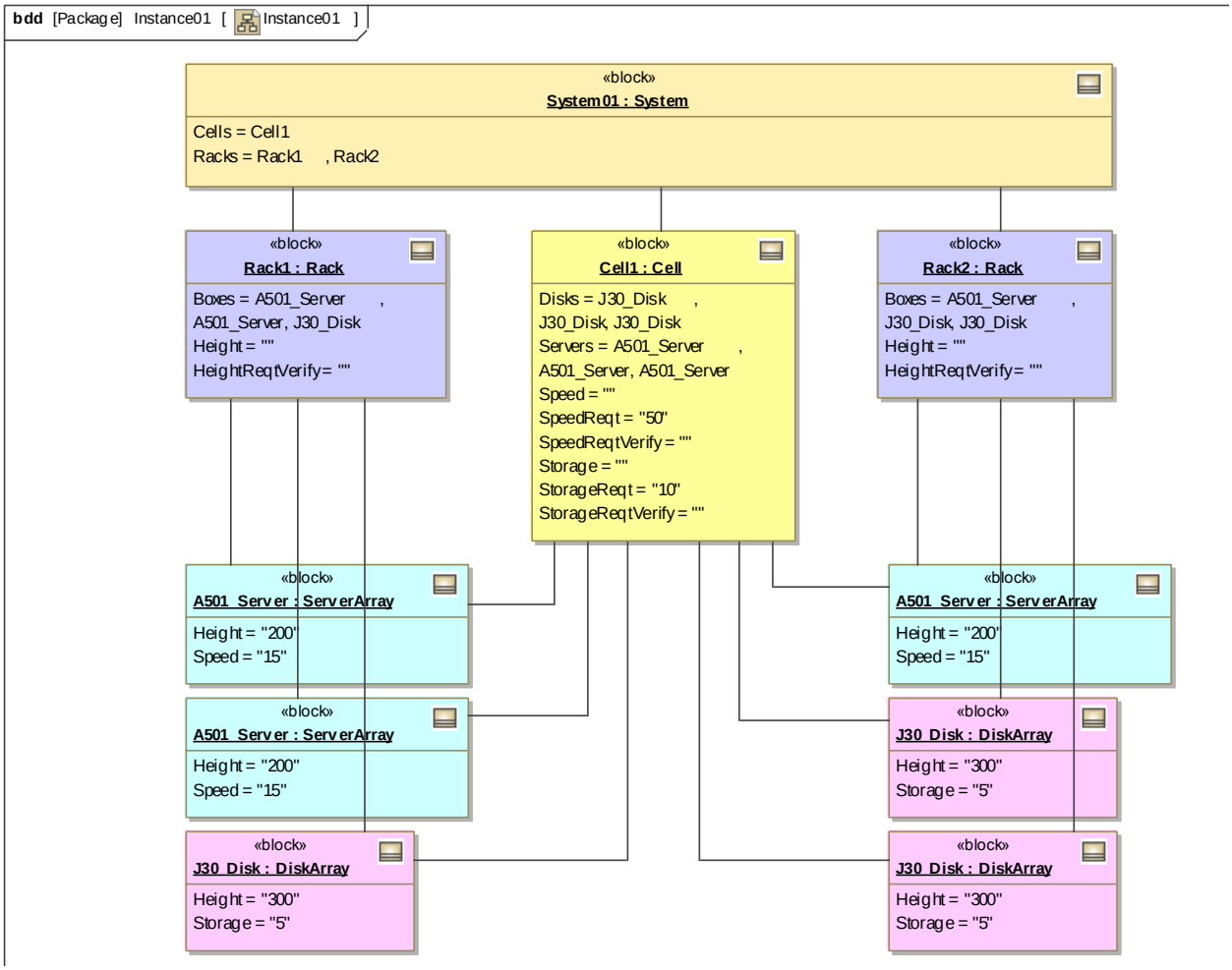


Figure 9.7 Instance01 diagram containing one Cell spread over two Racks

h. Activate the slots in the rack and cell instances. In Cell1, SpeedReqt = 50 and StorageReqt = 10. Other values are initially unknowns.
i. Apply Assign Default Causality to **Instance01**. Change causality of the **…Verify** slots to *target*.

Discussion – Instance Libraries

There are alternate ways to build instances from instance libraries, which may provide the same answers but each with different strengths and weaknesses.

- In the approach shown above, a single instance block of each type appears multiple times in the diagram, but each diagram symbol refers back to the same instance. A change in a slot value for the instance block will appear in all of the diagram symbols for that component.
- Alternately, we could cut-and-paste multiple copies of the component in **InstanceLibrary** into **Instance01,** then drag those copies into the instance diagram. In this case, each instance of the component is independent and each slot value can be varied independently. This is a much better approach when the instance block contains an unknown calculated during parametric execution, because each instance can hold a different calculated value for this slot.
- Alternately, we could drag a single instance block into the diagram and create multiple links to it. For example, the **A501_Server** instance block would be the destination of two links from **Rack1**, three from **Cell1** and one from **Rack2**. While the resulting diagram might be somewhat smaller, it mignt also be more difficult to understand.

Step VIII Solve the Instance

11. Run the parametric solver
    a. RC the **Instance_01** package.
    b. Select ParaMagic→Browse.

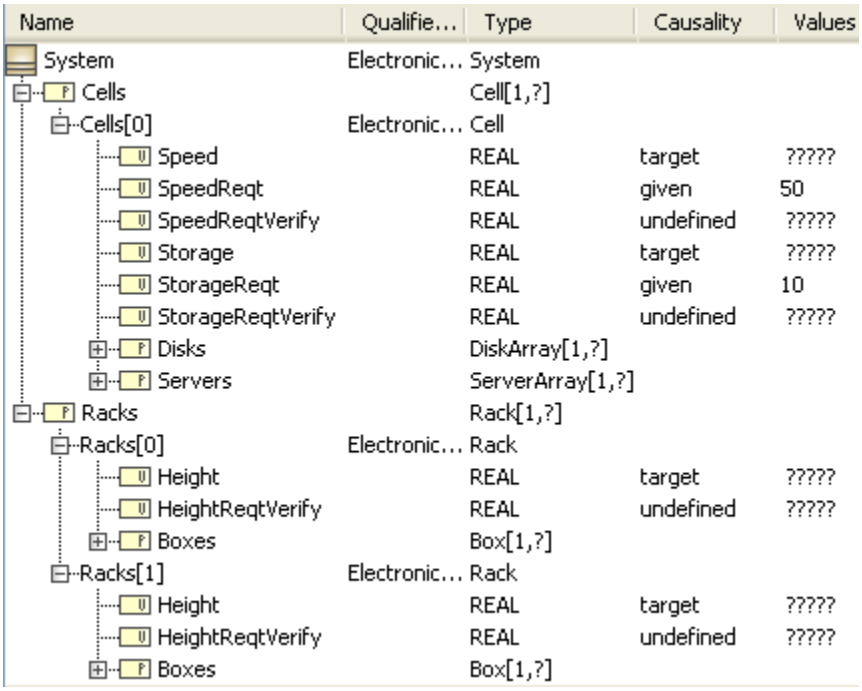


Figure 9.8 ParaMagic Browser for Instance_01, before solution, partially expanded

    c. Press "Solve". The results in Figure 9.9 show 1 (Pass) for **HeightReqtVerify** for both racks and for **StorageReqtVerify** for **Cell1**. **SpeedReqtVerify** for **Cell1** is 0 (Fail) because the cumulative calculating speed of all servers in the cell is 45 GFlops, less than the requirement of 50.

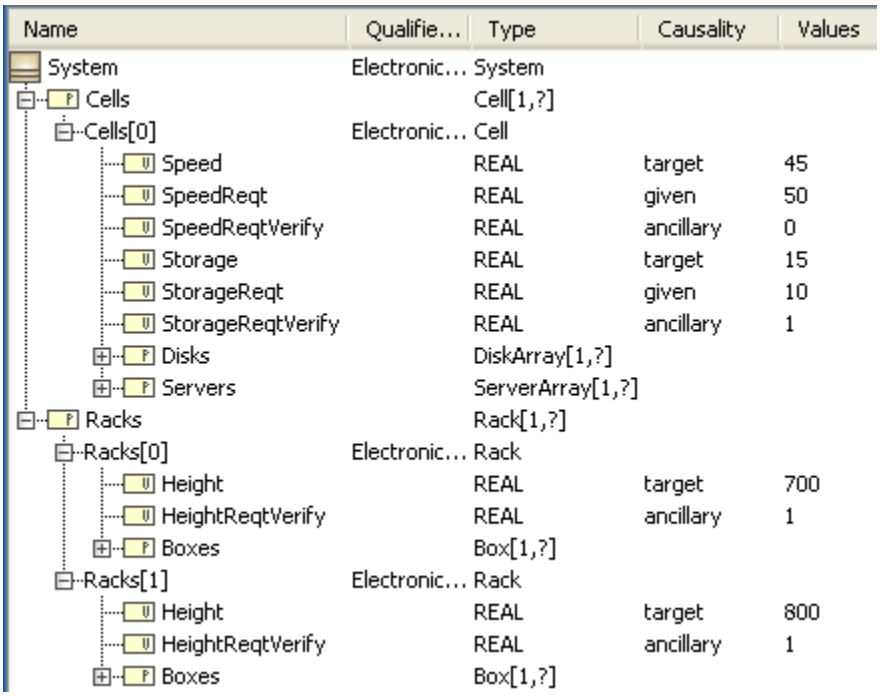


Figure 9.9 ParaMagic Browser for Instance_01, after solution

Step VII Create an Instance (Second Configuration)

12. Create a new instance of a system configuration comprised of two computer cells spread over three racks. See Figure 9.10. Repeat process in Step 10.

Step VIII Solve the Instance (Second Configuration)

13. Run the parametric solver. See Figure 9.11 for results. Note that no changes had to be made to the parametric diagram or any other part of the schema to run the new parametric model calculations.

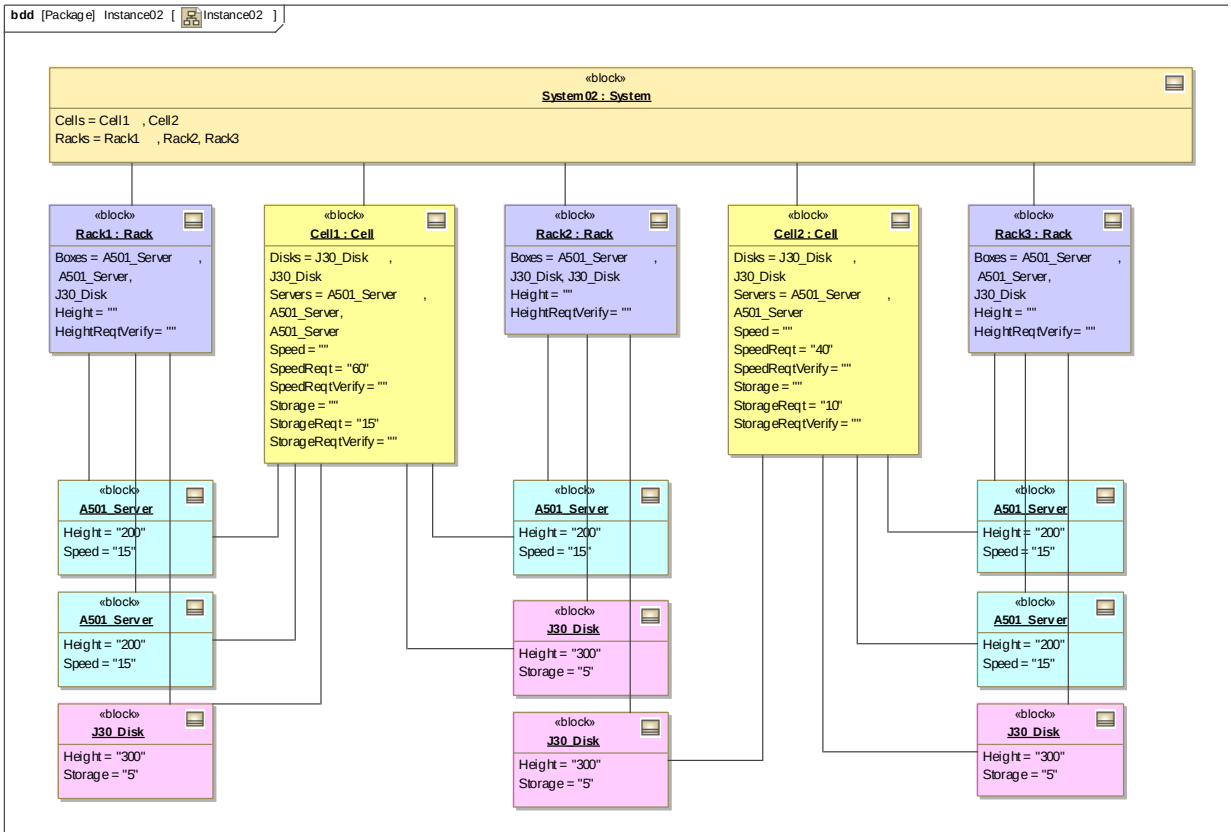


Figure 9.10 Instance02 diagram containing two Cells spread over three Racks

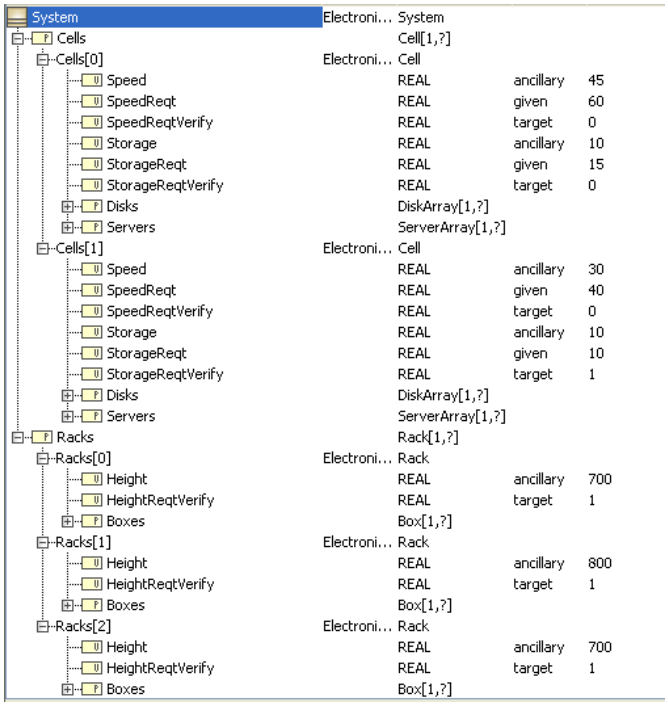


Figure 9.11 Browser for Instance02 after solution