Towards Improved Class Parameterization and Class Generation in Modelica

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Motivation

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This presentation presents a proposal for a change in the Modelica language.

- The corresponding paper represents one of the first versions of this proposal.
- Here, the focus was to elaborate new ideas and not let ourselves hamper by political or technical restrictions (e.g. backward-compatibility).

Motivation

Later on, we (Martin Otter and me) have changed our proposal w.r.t Modelica 3 in preparation of the Modelica-Design meeting (held in Atlanta this September).

- We improved backward compatibility.
- We reduced the amounts of changes in the syntax.
- We updated many examples, etc.
- After all, the proposal changed quite a lot.

- But I still decided to present the original version of the proposal here, because I think that it points out the original ideas way better than the newer versions that includes many concessions and compromises.

Motivation

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This turned out to be a good idea…

- …since one of the first things that was decided at the Modelica design meeting was to start a new development branch for Modelica 4.
- Modelica 4 should be a complete new language, essentially designed from scratch.
- So all the concessions we made, turned out to be irrelevant.
- Also the design-decisions w.r.t syntax are less relevant. Of importance are the main ideas behind the concept.

The Origin of Evil

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Many users of Modelica are annoyed by the tedious handling of class parameterization in Modelica.

- The main problem originates from the fact that a single tool is used for two entirely distinct concepts.
- These are **class parameterization** and **class generation**.
- Let us look at the current applications of these two concepts within Modelica.

Class Parameterization

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Class parameterization means that a class itself or a component is a parameter (of the model)

Example 1 for C$_{lass}$P$_{arameterization}$

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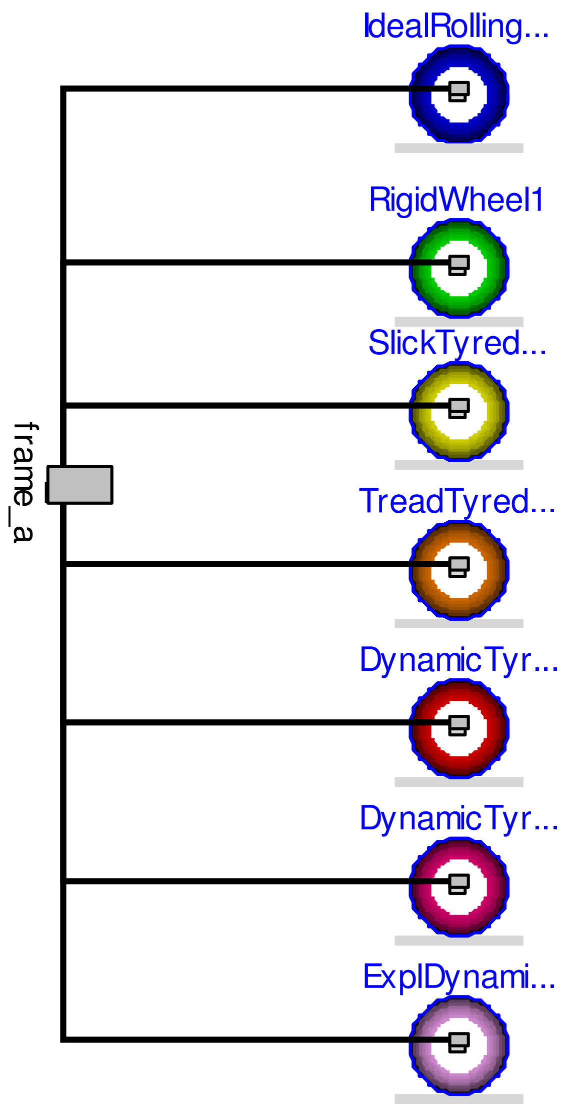

- This picture presents a container model that enables switching between different wheel models.

- The model parameterization is done indirectly by transforming a regular parameter into the conditional declaration of sub-models.

Example 1 for C_{lass} P_{arameterization}

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```
model MultiLevelWheel
  //enumeration
  parameter ModLevels level
  Interfaces.Frame_a frame_a;
  …
  IdealWheel wheel1(...)
    if level == ModLevels.IdealWheel;
  RigidWheel wheel2(...)
    if level == ModLevels.RigidWheel;
  SlickTyredWheel wheel3(...)
    if level == ModLevels.SlickWheel;
  …

equation
  connect(wheel1.frame_a, frame_a);
  connect(wheel2.frame_a, frame_a);
  connect(wheel3.frame_a, frame_a);
  …


end MultiLevelWheel;
```

- The container model is one of the most primitive methods to achieve class-parameterization.
- Essentially, it represents a set of conditionally declared components.
- Given a parameter value (mostly an enumeration value), one of the conditions evaluates to true, whereas all other components are disabled.

Example 2 for $C_{lass}P_{arameterization}$

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```
model Circuit1
replaceable Resistor R1(R=100);
…
end Circuit1;




model Test
Circuit1 C(
  redeclare ThermoRes R1(R=100)
 );
    …
end Test;
```

- Given the construct of replaceable / redeclare, this design pattern has actually become redundant.
- The standard method of model parameterization is performed by means of a replaceable model.
- An electric circuit may contain a replaceable resistor component.
- A potential user of this circuit model may now exchange the resistor.

Example 3 for C_{lass} P_{arameterization}

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```
model TemperatureSensor
  replaceable package Medium =
    Interfaces.PartialMedium;

  Interfaces.FluidPort_in port
  (
    redeclare package Medium =
      Medium
  )

  Medium.BaseProperties medium;

  RealOutput T(unit="K");

equation
  …
  port.p = medium.p;
  port.h = medium.h;
  port.Xi = medium.Xi;
  T = medium.T;

end Temperature;
```

- Having parameters for class definitions enables more advanced modeling techniques.
- The models of the Modelica Fluid library serve as a good example.
- Here each fluid model contains a parameter for a package definition.
- Given this package, the model declares now those package members that it requires.

Class Generation

Class Generation is a collective term for all those methods that are used to generate a new class. Most commonly, the new class is created out of one or more existing ones.

Example 1 for C_{lass}G_{eneration}


```
package PartialPureSubstance
 replaceable model BaseProperties
   …

end PartialPureSubstance;

package SingleGasNasa
  extends PartialPureSubstance(…)

  redeclare model
    extends BaseProperties(…)

  equation
    …
    MM = data.MM;
    R = data.R;
    h =h_T(data, T, h_offset);
    u = h - R*T;
    d = p/(R*T);
    state.T = T;
    state.p = p;
  end BaseProperties;
  …
end SingleGasNasa;
```

- Another example for class generation can be found in the Modelica MediaLib.
- Here, an individual package is created for each medium.
- the package contains a model BaseProperties that describes the medium-specific equations
- A new medium may now inherit from an existing medium package and redefine its BaseProperties model.
- In this way a class is generated for each medium

Example 2 for C_{lass}G_{eneration}


```
package Mech3D

  connector Frame
    Potentials P;
    flow SI.Force f[3];
    flow SI.Torque t[3];
  end Frame;


  model FixedTranslation
    replaceable Frame_a frame_a;
    replaceable Frame_b frame_b;
    …
  end FixedTranslation;


end Mech3D;
```

- The MultiBondLib features various mechanical libraries.
- In addition to the continuous 3D-mechanical , there is the library that includes the modeling of force-impulses.
- This library was derived from its continuous-system version.
- To this end, the connector of the classic mechanical package was made replaceable.

Example 2 for C$_{lass}$G$_{eneration}$


```
connector IFrame
  extends Mech3D.Interfaces.Frame;
  Boolean contact;
  SI.Velocity Vm[3];
  SI.AngularVelocity Wm[3];
  flow SI.Impulse F[3];
  flow SI.AngularImpulse T[3];
end IFrame;


model FixedTranslation
  extends Mech3D. FixedTranslation(
    redeclare IFrame_a frame_a,
    redeclare IFrame_b frame_b
   );
  …
equation
  frame_a.contact = frame_b.contact;
  frame_a.F + frame_b.F = zeros(3);
  frame_a.T + frame_b.T +
    cross(r,R*frame_b.F) = zeros(3);
  …
end FixedTranslation;
```

- The connector of the impulse library was then extended from its continuous version.
- Finally, each component of the impulse-library was inherited from its continuous counterparts.
- Their had their connectors replaced and the required impulse equations added.
- The drawback is that all connectors of the continuous version appear in the parameter window.

The two concepts

Class Parameterization

vs.

Class Generation

Foresight vs. Hindsight

- Class parameterization is requested by the model designer to be performed by a user of its library.

  ➔ Thus, it is performed **in foresight** since the corresponding parameterization needs to be declared.

- Rules for class parameterization must be rather strict to prohibit abuses by the user to a meaningful extent.

Foresight vs. Hindsight

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- It is performed by the model designer and requested to from an existing library.

  ➔ In contrast, class generation is done **in hindsight.**

- Since it is done in hindsight and mostly performed by experts, rules for class generation should not be prohibitive.

- A use of replaceable is not meaningful and represents an unwanted parameterization.

Type System

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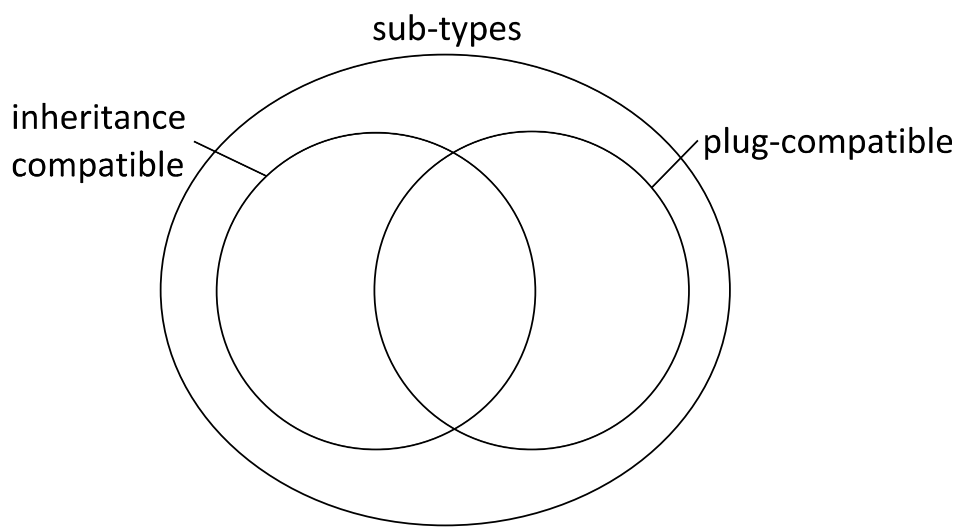
- A proper class parameterization requires that the new type **A** is compatible to the original type **B**.

- Obviously **A** must be a subtype of **B**.

- An even more strict requirement is that it needs to be plug-compatible since it is not possible to introduce new connections into a parameter-ized model.



Type System

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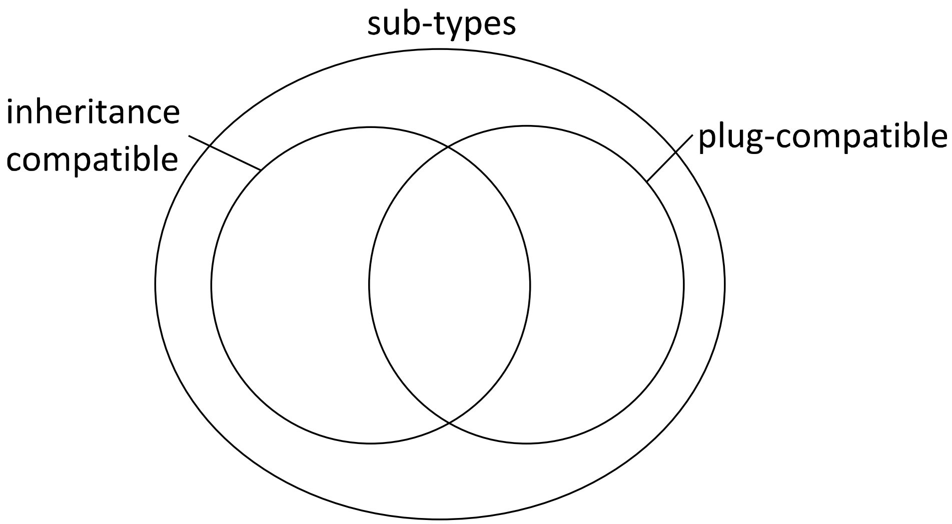
- Plug-compatibility is of no relevance for class generation. When a new class is generated, new connections can also be introduced in an effortless way.

- Instead, it is important that the new type is inheritance-compatible since potential extensions of a redefined model ought to remain valid.

- Inheritance compatibility means that type A could replace type B as an ancestor for an arbitrary type C. To this end, the sub-type requirements are extended to protected elements.



Current Deficiencies

The current confusion of class parameterization and class generation involves a number of disadvantages:

- Non-uniform parameterization
- Inappropriate sub-elements
- Prohibitive class generation
- Unwanted parameterization
- Unnecessary restrictions
- Overelaborated syntax

Design Decisions

For the partial redesign of Modelica, we establish the following guidelines:

- Separate class parameterization and class generation
- Give classes first class status on the parameter level
- Enable non-prohibitive class generation
- Unify and simplify the language

Class Parameterization

New class parameterization

Example 3 for C_{lass}P_{arameterization}

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```
model TemperatureSensor
  replaceable package Medium =
    Interfaces.PartialMedium;

  Interfaces.FluidPort_in port
  (
    redeclare package Medium =
      Medium
  )

  Medium.BaseProperties medium;

  RealOutput T(unit="K");

equation
  …
  port.p = medium.p;
  port.h = medium.h;
  port.Xi = medium.Xi;
  T = medium.T;

end Temperature;
```

```
model TemperatureSensor
  parameter package
   Interfaces.PartialMedium Medium;

  Interfaces.FluidPort_in port
  (Medium = Medium)

  Medium.BaseProperties medium;

  RealOutput T(unit="K");

equation
  …
  port.p = medium.p;
  port.h = medium.h;
  port.Xi = medium.Xi;
  T = medium.T;

end Temperature;
```

Example 3 for C$_{\text{lass}}$P$_{\text{arameterization}}$

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- Class parameters are treated as that what they are:

  As parameters!

- In this way it is also possible to propagate the parameter

- Also the package is not a part of the model anymore. It is just a parameter.

```
model TemperatureSensor
  parameter package
   Interfaces.PartialMedium Medium;

  Interfaces.FluidPort_in port
  (Medium = Medium)




  Medium.BaseProperties medium;

  RealOutput T(unit="K");

equation
  …
  port.p = medium.p;
  port.h = medium.h;
  port.Xi = medium.Xi;
  T = medium.T;

end Temperature;
```

Example 2 for C$_{lass}$P$_{arameterization}$

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```
model Circuit1
replaceable Resistor R1(R=100);
…
end Circuit1;


model Test
Circuit1 C(
  redeclare ThermoRes R1(R=100)
 );
   …
end Test;
```

```
model Circuit1
  parameter component
    Resistor R1(R=100);
…
end Circuit1;


model Test
  Circuit1 C(R1 = ThermoRes(R=100));
   …
end Test;
```

Example 2 for C_{lass}P_{arameterization}

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- The same can be done for components.
- Classes can be part of a normal expression (first-class status).
- Curly braces are introduced in order to distinguish a class-expression from a function call.

```
model Circuit1
  parameter component
    Resistor R1(R=100);
…
end Circuit1;

model Test
  Circuit1 C(R1 = ThermoRes{R=100});
   …
end Test;
```

Example 1 for C_{lass}P_{arameterization}

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```
model MultiLevelWheel
  //enumeration
   parameter ModLevels level
   Interfaces.Frame_a frame_a;
   …
   IdealWheel wheel1(...)
     if level == ModLevels.IdealWheel;
   RigidWheel wheel2(...)
     if level == ModLevels.RigidWheel;
   SlickTyredWheel wheel3(...)
     if level == ModLevels.SlickWheel;
   …

equation
   connect(wheel1.frame_a, frame_a);
   connect(wheel2.frame_a, frame_a);
   connect(wheel3.frame_a, frame_a);
   …

end MultiLevelWheel;
```

```
model MultiLevelWheel
//enumeration
   parameter TModLevels level
   Interfaces.Frame_a frame_a;
   …
protected
   final parameter model BaseWheel
   wheelModels[7]= {
     IdealWheel {…},
     RigidWheel{…},
     SlickTyredWheel{…},
     …
   };

   final parameter component BaseWheel
    wheel = wheelModels[level];

equation
   connect(wheel.frame_a, frame_a);

end MultiLevelWheel;
```

Example 1 for C_{lass}P_{arameterization}

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- Class-Expressions are very powerful.
- Now we can transform an enumeration parameter into a class parameter by means of a simple array.

```
model MultiLevelWheel
public
  //enumeration
   parameter TModLevels level
   Interfaces.Frame_a frame_a;
   …
protected
   final parameter model BaseWheel
   wheelModels[7]= {
     IdealWheel {…},
     RigidWheel{…},
     SlickTyredWheel{…},
     …
   };
   final parameter component BaseWheel
    wheel = wheelModels[level];

equation
   connect(wheel.frame_a, frame_a);
end MultiLevelWheel;
```

Class Parameterization

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New class generation

Example 1 for C_{lass}G_{eneration}

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```
package PartialPureSubstance
 replaceable model BaseProperties
   …

end PartialPureSubstance;

package SingleGasNasa
  extends PartialPureSubstance(…)

  redeclare model
    extends BaseProperties(…)

  equation
    …
    MM = data.MM;
    R = data.R;
    h =h_T(data, T, h_offset);
    u = h - R*T;
    d = p/(R*T);
    state.T = T;
    state.p = p;
  end BaseProperties;
  …
end SingleGasNasa;
```

```
package PartialPureSubstance
  model BaseProperties
   …

end PartialPureSubstance;

package SingleGasNasa
  extends PartialPureSubstance(…)

  redefined model BaseProperties(…)
  equation
    …
    MM = data.MM;
    R = data.R;
    h =h_T(data, T, h_offset);
    u = h - R*T;
    d = p/(R*T);
    state.T = T;
    state.p = p;


  end BaseProperties;
  …
end SingleGasNasa;
```

Example 1 for C_{lass}G_{eneration}

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- Since any model can be redefined, it is no longer necessary to mark a model definition as replaceable

- The newly redefined model, must no be inheritance-compatible to the former one.

```
package PartialPureSubstance
  model BaseProperties
   …

end PartialPureSubstance;

package SingleGasNasa
  extends PartialPureSubstance(…)

  redefined model BaseProperties
  equation
    …
    MM = data.MM;
    R = data.R;
    h =h_T(data, T, h_offset);
    u = h - R*T;
    d = p/(R*T);
    state.T = T;
    state.p = p;


  end BaseProperties;
  …
end SingleGasNasa;
```

Example 2 for ClassGeneration

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```
package Mech3D

  connector Frame
    Potentials P;
    flow SI.Force f[3];
    flow SI.Torque t[3];
  end Frame;

  model FixedTranslation
    replaceable Frame_a frame_a;
    replaceable Frame_b frame_b;
    …
  end FixedTranslation;

end Mech3D;
```

```
package Mech3D

  connector Frame
    Potentials P;
    flow SI.Force f[3];
    flow SI.Torque t[3];
  end Frame;

  model FixedTranslation
    Frame_a frame_a;
    Frame_b frame_b;
    …
  end FixedTranslation;

end Mech3D;
```

Example 2 for C$_{lass}$G$_{eneration}$

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- The unwanted parameterization can now be removed from the FixedTranslation model

- The keyword replaceable has become redundant.

```
package Mech3D


  connector Frame
    Potentials P;
    flow SI.Force f[3];
    flow SI.Torque t[3];
  end Frame;


  model FixedTranslation
    Frame_a frame_a;
    Frame_b frame_b;
    …
  end FixedTranslation;


end Mech3D;
```

Example 2 for ClassGeneration


```
connector IFrame
  extends Mech3D.Interfaces.Frame;
  Boolean contact;
  SI.Velocity Vm[3];
  SI.AngularVelocity Wm[3];
  flow SI.Impulse F[3];
  flow SI.AngularImpulse T[3];
end IFrame;


model FixedTranslation
  extends Mech3D. FixedTranslation(
    redeclare IFrame_a frame_a,
    redeclare IFrame_b frame_b
   );
  …
equation
  frame_a.contact = frame_b.contact;
  frame_a.F + frame_b.F = zeros(3);
  frame_a.T + frame_b.T +
    cross(r,R*frame_b.F) = zeros(3);
  …
end FixedTranslation;
```

```
connector IFrame
  extends Mech3D.Interfaces.Frame;
  Boolean contact;
  SI.Velocity Vm[3];
  SI.AngularVelocity Wm[3];
  flow SI.Impulse F[3];
  flow SI.AngularImpulse T[3];
end IFrame;


model FixedTranslation
  extends Mech3D. FixedTranslation;
  redeclare IFrame_a frame_a,
  redeclare IFrame_b frame_b
  …

equation
  frame_a.contact = frame_b.contact;
  frame_a.F + frame_b.F = zeros(3);
  frame_a.T + frame_b.T +
    cross(r,R*frame_b.F) = zeros(3);
  …
end FixedTranslation;
```

Example 2 for C_{lass}G_{eneration}

- The redeclaration can be performed on any element.
- But it is removed from the modifier and is now part of the new model.
- In this way, the existing models are protected from being corrupted.

```
connector IFrame
  extends Mech3D.Interfaces.Frame;
  Boolean contact;
  SI.Velocity Vm[3];
  SI.AngularVelocity Wm[3];
  flow SI.Impulse F[3];
  flow SI.AngularImpulse T[3];
end IFrame;


model FixedTranslation
  extends Mech3D. FixedTranslation;
  redeclare IFrame_a frame_a,
  redeclare IFrame_b frame_b
  …

equation
  frame_a.contact = frame_b.contact;
  frame_a.F + frame_b.F = zeros(3);
  frame_a.T + frame_b.T +
    cross(r,R*frame_b.F) = zeros(3);
  …
end FixedTranslation;
```

Conclusions

Lessons learned for Modelica 4

- Class parameterization and class generation should be treated separately.
- They have a very different underlying motivation.
- Class parameterization is requested in foresight and performed by an average user.
- Class generation is applied in hindsight and performed by a potential expert.

Lessons learned for Modelica 4

- Unlike in programming languages, it is difficult in Modelica to impose a strict hierarchy on the type system. The terms sub- and super-type are only of limited value.

- Unlike in programming languages, it is hardly sufficient in Modelica to focus on the assignment operation.

- The criteria for compatibility vary from application to application
  - It is a difference if ones compares components (fully parameterized) or classes (not parameterized).
  - It is a difference if one replaces a component/class by a given parameter or by a redeclaration in a new model.
  - There are more potential differences…

Lessons learned for Modelica 4

- It is meaningful, to have a common syntax for all parameters. Let that be parameters for values, for components, or classes.

- This simplifies the language while making it more powerful.

- It might, however, be meaningful to separate structural parameters from normal parameters. Nevertheless, they should still have the same syntax.

Lessons learned for Modelica 4

- Classes and Components shall represent simple expressions.
- The power of a well-designed language results from the possible combinations of its basic components.
- To this end, each component must form a meaningful entity by itself. Hence, the language must be designed from bottom-up.
- This is not so easy, because practitioners evaluate the language according to relevant examples. And this enforces a top-down view.

The End