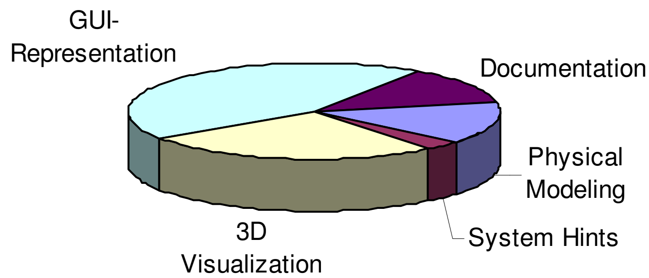
Multi-Aspect Modeling in Equation-Based Languages

EOOLT 2008, Cyprus



Author: Dirk Zimmer

ETH Zürich, Institute of Computational Science, Department of Computer Science

Overview

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- Motivation
- Classification of aspects
- Multiple aspects in Modelica
- Current downfalls
- Improved handling in SOL
- Demonstration
- Conclusions

Motivation

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- Contemporary equation-based modeling languages are embedded in modeling and simulation environments that feature various types of data-representation:
  - Icons for the graphical user interface (GUI)
  - 3D-Visualization
  - Sound-Module
  - Auto-Documentation
  - etc…
- Thus, the corresponding models contain more information than what is needed for the actual physical model.
- Nowadays, a modeler has to cope with many multiple aspects.

Motivation: Example

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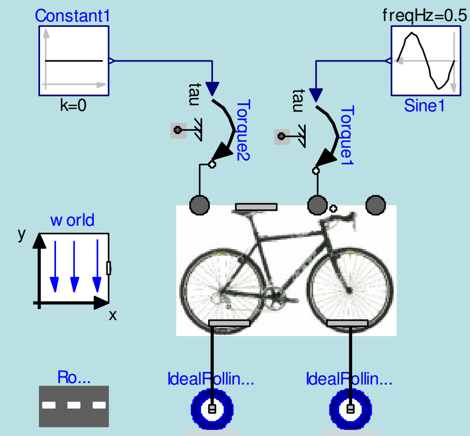
Physical modeling

```
equation
  connect(Torque1.flange_b, DiamondFrame1.flange_steering);
  connect(Torque2.flange_b, DiamondFrame1.flange_rw);
  connect(Constant1.y, Torque2.tau);
  connect(Sine1.y, Torque1.tau);
  connect(IdealRollingWheel2.frame_a, DiamondFrame1.frame_rw);
  connect(IdealRollingWheel1.frame_a, DiamondFrame1.frame_fw);
end IdealBike;
```

Visualization



Diagram

Documentation

Information
This example presents the model of a bicycle.

The joints of the bicycle are frictionless and the wheels are ideally rolling. The bicycle is uncontrolled, but due to its initial velocity it is self-stabilizing. Within a certain a range of driving velocity a bicycle is stable.

A bicycle has 7 degrees of freedom on positional level and 3 degrees of freedom on velocity level.

```
[...]
phi(stateSelect =
  if chooseStates
then
  StateSelect.always
else
  StateSelect.default
),
[...]
```

System hints

Classification of aspects

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- **Following classification of aspects seems appropriate for Modelica**
  - **Physical modeling:** The modeling of the physical processes based on differential-algebraic equations (DAEs).
  - **System hints:** The supply of hints or information for the simulation-system.
  - **3D Visualization:** Description of corresponding 3D-entities that enable a visualization of the models.
  - **GUI-Representation:** Description of an iconographic representation for the GUI of the modeling environment.
  - **Documentation:** Additional documentation that addresses to potential users or developers.

Code - Analysis

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- We analyzed the distribution of these aspects for three exemplary models.
- The examples originate from the Modelica-Standard-Library
- All formatting has been removed.
- The remaining characters have been manually categorized and then counted.
- Let us see the results…

Code - Analysis

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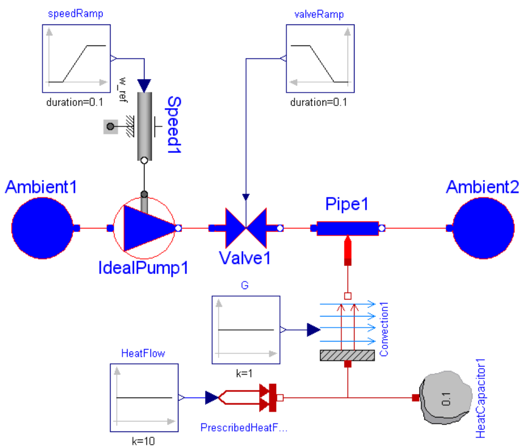
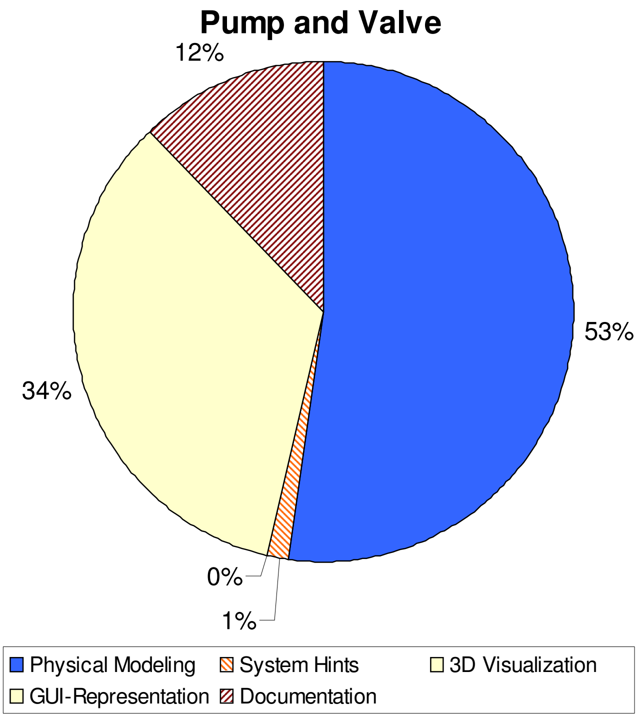
- A complete example: **Modelica.Thermal. FluidHeatFlow.Examples. PunpAndValve**





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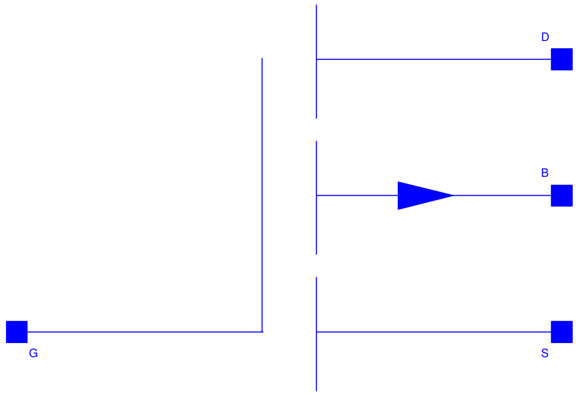
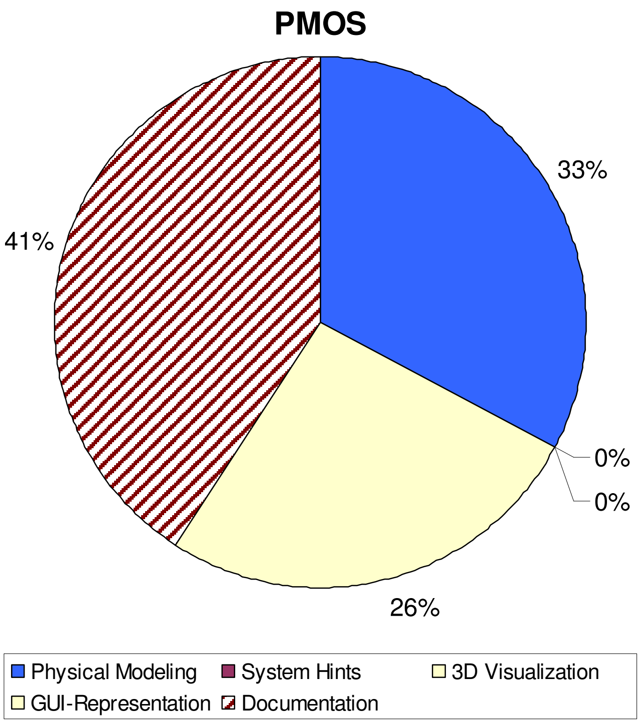
- A component model: **Modelica.Electrical. Analog.Semiconductors. PMOS**





Code - Analysis

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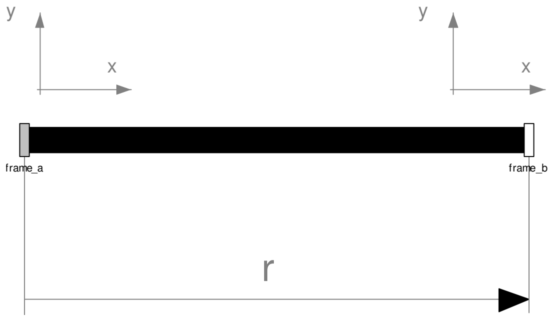
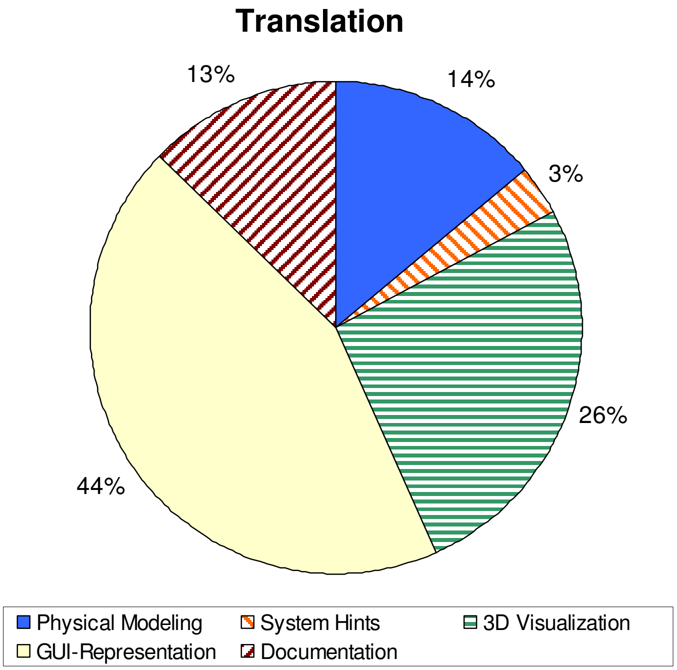
- A basic component:
Modelica.Mechanics.
MultiBody.Parts.
FixedTranslation





Code - Analysis: Conclusions

- The primary aspect cannot be stated to be predominant.
- The discussion about Modelica and other EOO-languages is often constrained to its primary aspect.
- The disregard of other modeling aspects cannot be justified.
- The ability to cope with multiple aspects has become a definite prerequisite for many modern modeling languages.

Multiple Aspects in Modelica

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- Certain modeling aspects are supported by keywords. For instance: **`stateSelect, fixed`**
- Modelica introduced the concept of annotations. These items are placed alongside the definition of models and the declaration of members.
- Example:

```
Capacitor C1(C=c1) "Main Capacitor"
   annotation (extent=[50,-30; 70,-10],
   rotation=270);
```

- Since annotations tend to inflate the modeling code, they are mostly hidden by the editors

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Situation in Modelica

- Overview on the current mixture of data-representation:
  - The **physics** of a model is naturally described by DAEs
  - **Hints** or information for the simulation-system are mostly also part of the main Modelica language but some of them have to be included in special annotations.
  - **Information that is used by the GUI** is included in annotations. But also information from textual descriptions is used.
  - The description of **3D-visualization** is done by dummy-models.
  - **Documentation** is extracted from the textual descriptions, but further documentation shall be provided by integrating HTML-code into a special annotation. Other annotations store information about the author and the library version.

Current Downfalls

- There is an evident lack of concept.
- Only pre-thought functionalities are applicable.
- The functionalities are mostly not customizable.
- The code-visibility is selected based on syntax not on semantics.
- The hiding of annotations hinders the editing.

Multiple aspects in Sol.

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SOL

- Sol is a language conceived for research purposes.
- It aims to enable the future handling of variable-structure systems.
- It owns a relatively simple grammar that is similar to Modelica.
- Fundamentals have been reviewed in the language-design of Sol. New methods have been included in the language.
- These methods aid also the modeling of multiple aspects.
- The Sol project is supported by the Swiss National Science Foundation.

Multiple aspects in Sol.

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- Starting from an example, I will present language constructs that meet the following requirements:

1. We shall have an open and transparent interface for each aspect.
   → **Environment-packages**
2. A convienient notation shall be provided.
   → **Anonymous declarations**
3. The modeler shall be enabled to form semantic entities.
   → **Sections**
4. The solution should well integrate into complex object-oriented model-structures.
   → **Referencing mechanisms**

Sol: The example

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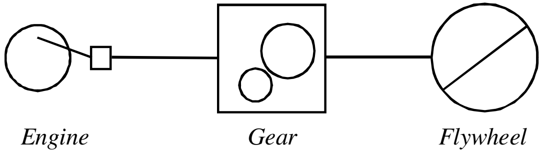
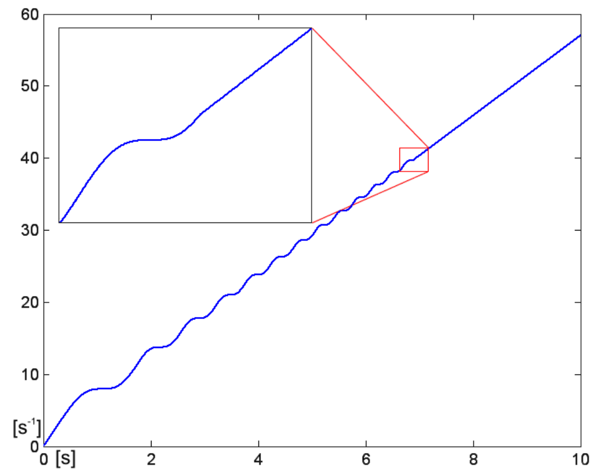
- The model consists of an engine that drives a flywheel. In the middle there is a simple gear box.



- The simulation yields to the plot on the right. It displays the angular velocity.



- The model contains a structural change: Reaching a threshold speed, causes the switch to a simpler engine model.

Sol: The example

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```
model Machine

implementation:
  static Mechanics.FlyWheel F{inertia<<1};
  static Mechanics.Gear G{ratio<<1.8};
  dynamic Mechanics.Engine2 E {meanT<<10};

  connection c1(a << G.f2, b << F.f);
  connection c2(a << E.f, b << G.f1);

  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10};
  end;

end Machine;
```

Sol: The example

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```
model Machine

implementation:
  static Mechanics.FlyWheel F{inertia<<1};
  static Mechanics.Gear G{ratio<<1.8};
  dynamic Mechanics.Engine2 E {meanT<<10};

  connection c1(a << G.f2, b << F.f);
  connection c2(a << E.f, b << G.f1);

  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10};
  end;

end Machine;
```

Declaration of Components

Sol: The example

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```
model Machine

implementation:
  static Mechanics.FlyWheel F{inertia<<1};
  static Mechanics.Gear G{ratio<<1.8};
  dynamic Mechanics.Engine2 E {meanT<<10};

  connection c1(a << G.f2, b << F.f);
  connection c2(a << E.f, b << G.f1);

  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10};
  end;

end Machine;
```

Connections

Sol: The example

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```
model Machine

implementation:
  static Mechanics.FlyWheel F{inertia<<1};
  static Mechanics.Gear G{ratio<<1.8};
  dynamic Mechanics.Engine2 E {meanT<<10};

  connection c1(a << G.f2, b << F.f);
  connection c2(a << E.f, b << G.f1);

  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10};
  end;

end Machine;
```

Event that triggers a structural change

Sol: Environment-Packages

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- Many modeling aspects refer to an **external environment** that is supposed to process the exposed information.
- The **example** presents a package of models that can be used to store information for the documentation of arbitrary models.
- The keyword **environment** does specify that the corresponding models address the environment and are therefore not self-contained.
- Environment-packages merely offer an **interface**.
- The concrete semantics is finally determined by the environment itself.
- Different environments may have **different interpretations**.

Sol: Environment-Packages

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```
environment package Documentation

        model Author
        interface:
                parameter string name;
        end Author;

        model Version
        interface:
                parameter string v;
        end Version;

        model ExternalDoc
        interface:
                parameter string fname;

        end ExternalDoc;

end Documentation
```

Sol: Environment-Packages

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```
environment package Documentation

        model Author
        interface:
                parameter string name;
        end Author;

        model Version
        interface:
                parameter string v;
        end Version;

        model ExternalDoc
        interface:
                parameter string fname;

        end ExternalDoc;

end Documentation
```

Defintion of an environment package

Sol: Environment-Packages

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```
environment package Documentation
        model Author
        interface:
                parameter string name;
        end Author;
        model Version
        interface:
                parameter string v;
        end Version;
        model ExternalDoc
        interface:
                parameter string fname;

        end ExternalDoc;
end Documentation
```

„Dummy model“ that enables the specification of the author

Sol: Anonymous Declarations

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- To take use of an environment package we have to **declare instances** of its models
- In Sol, any model can be **declared anonymously** anywhere in the implementation.
- This way, we can **conveniently** create the documentation for our model.

Sol: Anonymous Declarations

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```
model Machine
implementation:

  [...]

  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10 };
  end;

  Documentation.Author{name<<"DirkZimmer"};
  Documentation.Version{v << "1.0");
  Documentation.ExternalDoc{fname<<"MachineDoc.html"};

end Machine;
```

Sol: Sections

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- Sections can be defined using an arbitrary package name.
- Sections are a pure **grouping mechanism** and nothing more.
- Sections incorporate **three advantages**:

1. Code can be structured into **semantic entities**.
2. Sections add **convenience**, since the sub-models of the corresponding package can now be directly accessed.
3. Sections enable an intuitive **control of visibility**.

Sol: Sections

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```
model Machine
implementation:
  […]
  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10 };
  end;

  section Documentation:
    Author{name << "Dirk Zimmer"};
    Version{v << "1.0"};
    ExternalDoc{fname<<"MachineDoc.html"};
  end;

  section Simulator:
    IntegrationTime{t << 10.0};
    IntegrationMethod{method<<"euler",
    step << "fixed", value << 0.01};
  end;

end Machine;
```

Sol: Sections

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```
model Machine
implementation:
  […]
  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10 };
  end;

  section Documentation:
    Author{name << "Dirk Zimmer"};
    Version{v << "1.0"};
    ExternalDoc{fname<<"MachineDoc.html"};
  end;

  section Simulator:
    IntegrationTime{t << 10.0};
    IntegrationMethod{method<<"euler",
    step << "fixed", value << 0.01};
  end;

end Machine;
```

The documentation is now grouped within a section.

Sol: Sections

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```
model Machine
implementation:
  […]
  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10 };
  end;

  section Documentation:
    Author{name << "Dirk Zimmer"};
    Version{v << "1.0"};
    ExternalDoc{fname<<"MachineDoc.html"};
  end;

  section Simulator:
    IntegrationTime{t << 10.0};
    IntegrationMethod{method<<"euler",
    step << "fixed", value << 0.01};
  end;

end Machine;
```

The writing gets more convenient.

Sol: Sections

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```
model Machine
implementation:
  […]
  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10 };
  end;

  section Documentation:
    Author{name << "Dirk Zimmer"};
    Version{v << "1.0"};
    ExternalDoc{fname<<"MachineDoc.html"};
  end;

  section Simulator:
    IntegrationTime{t << 10.0};
    IntegrationMethod{method<<"euler",
    step << "fixed", value << 0.01};
  end;

end Machine;
```

Another section for system hints …

Sol: Sections

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```
model Machine
implementation:
  […]
  when F.w > 40 then
    E <- Mechanics.Engine1{meanT << 10 };
  end;

  section Documentation:
    Author{name << "Dirk Zimmer"};
    Version{v << "1.0"};
    ExternalDoc{fname<<"MachineDoc.html"};
  end;

+ section Simulator:

end Machine;
```

…that may be hidden by the editor

Sol: Referencing

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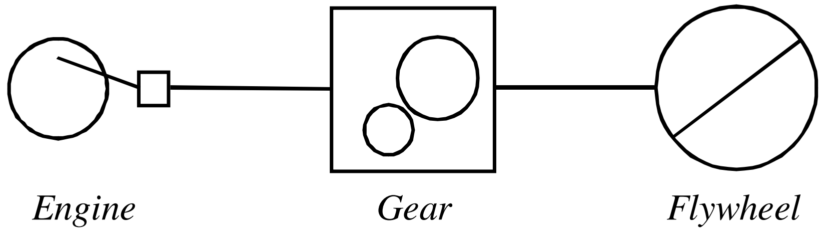

- This solution is feasible for simple applications.
- However, providing a GUI is more complex.
- The icons of a model-diagram relate to specific instances.
- Thus, we need to be able to refer on other model instances.

Sol: Referencing

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- To refer on other model-instances Sol offers two solutions:

  1. **Member models:** These are models defined in the interface of a model and that are bounded to the corresponding instance of its top-model. Thus, they may address the top-model's members.
  2. **First-class status** for any model instance: This means that instances of models can be treated as basic variables. Hence, they might be passed as parameters or they are dynamically transmitted.

- The demonstration example uses both techniques.

Sol: Demonstration

Demo

Summary

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- Let us review the four language constructs:

1. **Environment-packages** that enable the aspect-specific declaration of interfaces.
2. **Anonymous declarations** of model instances.
3. **Sections** can be used to form semantic entities and control visibility.
4. **Referencing mechanisms** between model-instances. (In Sol, these mechanisms are provided by giving model-instances a first class status and enabling so-called member-models.)

Conclusions

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- Environment packages provide a transparent interface.
- The interface is customizable
- Anonymous declarations enable a convenient usage
- User-defined sections help to organize the model.
- The text-filtering criteria are based on semantic entities.
- The embedment into an existing object-oriented framework enables a uniform approach for a wider range of modeling aspects.

Conclusions

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Main conclusion:

- The ability of the language to help and to **extend itself** by its own means has been improved.
- Further development is now possible **within the language** and does not require a constant update and growth of the language definition.
- Important are not the precise grammar construct. Important is to **meet the four requirements** they have been built for. This way the proposed solution can be adopted for other languages.

Questions?