Software Design, Modelling and Analysis in UML

Lecture 19: Inheritance II, Meta-Modelling

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Contents & Goals

Last Lecture:

- Live Sequence Charts Semantics

This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - What's the Liskov Substitution Principle?
  - What is late/early binding?
  - What is the subset, what the uplink semantics of inheritance?
  - What's the effect of inheritance on LSCs, State Machines, System States?
  - What's the idea of Meta-Modelling?
- **Content:**
  - Inheritance in UML: concrete syntax
  - Liskov Substitution Principle — desired semantics
  - Two approaches to obtain desired semantics

Inheritance: Desired Semantics

Desired Semantics of Specialisation: Subtyping

There is a classical description of what one **expects** from **sub-types**, which in the OO domain is closely related to inheritance:

The principle of type substitutability [Liskov, 1988, Liskov and Wing, 1994]. (**Liskov Substitution Principle** (LSP).)

"If for each object o_1 of type S there is an object o_2 of type T such that for all programs P defined in terms of T, **the behavior of P is unchanged** when o_1 is substituted for o_2 then S is a **subtype** of T."

S sub-type of T $:\iff \forall o_1 \in S\ \exists o_2 \in T\ \forall P_T \bullet [\![P_T]\!](o_1) = [\![P_T]\!](o_2)$

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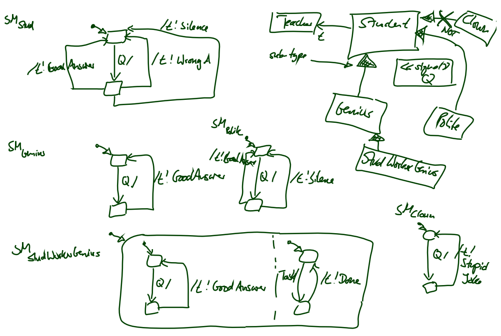
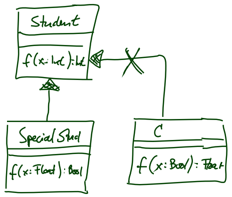
In other words: [Fischer and Wehrheim, 2000]

"An instance of the **sub-type** shall be **usable** whenever an instance of the supertype was expected, **without a client being able to tell the difference**."





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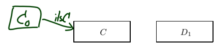
without a client being able to tell the difference."

So, what's "**usable**"? Who's a "**client**"? And what's a "**difference**"?

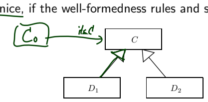
What Does [Fischer and Wehrheim, 2000] Mean for UML?

"An instance of the **sub-type** shall be **usable** whenever an instance of the supertype was expected, without **a client** being able to tell the **difference**."

- Wanted: sub-typing for UML.
- With



we don't even have usability.
- It would be nice, if the well-formedness rules and semantics of

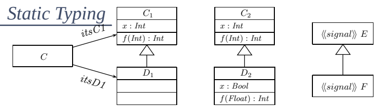


would ensure D_1 **is a sub-type** of C:
  - that D_1 objects can be used interchangeably by everyone who is using C's,
  - is not able to tell the difference (i.e. see unexpected behaviour).

"...shall be usable..." for UML

Easy: Static Typing

Given:



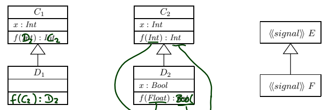
Wanted:

- $x > 0$ also **well-typed** for D_1
- assignment $itsC1 := itsD1$ being **well-typed**
- $itsD1.x = 0$, $itsD1.f(0)$, $itsD1 \,!\, F$
  being well-typed (and doing the right thing).

Approach:

- Simply define it as being well-typed,
  adjust system state definition to do the right thing.

Static Typing Cont'd



Notions (from category theory):

- **invariance**,
- **covariance**,
- **contravariance**.

We could call, e.g. a method, **sub-type preserving**, if and only if it

- accepts **more general** types as input (**contravariant**),
- provides a **more specialised** type as output (**covariant**).

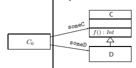
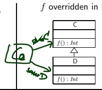
This is a notion used by many programming languages — and easily type-checked.

Excursus: Late Binding of Behavioural Features

Late Binding

What transformer applies in what situation? (Early (compile time) binding.)

type of link determines which implementation is used (not caring for what the object really "is")

	f not overridden in D	f overridden in D	value of someC/someD
			
someC -> f()	C::f()	C::f()	u_1 : C
someD -> f()	C::f()	D::f()	u_2 : D
someC -> f()	C::f()	C::f()	u_2 : D

What one could want is something different: (Late binding.)

type of object determines which impl. is used

someC -> f()	C::f()	C::f()	u_1 : C
someD -> f()	C::f()	D::f()	u_2 : D
someC -> f()	C::f()	D::f()	u_2 : D

Late Binding in the Standard and Programming Lang.

- In **the standard**, Section 11.3.10, "CallOperationAction":
  "**Semantic Variation Points**
  The mechanism for determining the method to be invoked as a result of a call operation is unspecified." [OMG, 2007b, 247]
- In C++,
  - methods are by default "(early) compile time binding",
  - can be declared to be "late binding" by keyword "`virtual`",
  - the declaration applies to all inheriting classes.
- In **Java**,
  - methods are "late binding";
  - there are patterns to imitate the effect of "early binding"

Exercise: What could have driven the designers of C++ to take that approach?

Note: late binding typically applies only to **methods**, **not** to **attributes**.
(But: getter/setter methods have been invented recently.)

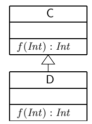
Back to the Main Track: "...tell the difference..." for UML

With Only Early Binding...

- ...we're **done** (if we realise it correctly in the framework).
- Then
  - if we're calling method f of an object u,
  - which is an instance of D with $C \preceq D$
  - via a C-link, C::f() will be called
  - then we (by definition) only see and change the C-part.
  - We cannot tell whether u is a C or an D instance.

So we immediately also have behavioural/dynamic subtyping.

Difficult: Dynamic Subtyping



- $C::f$ and $D::f$ are **type compatible**,
  but D is **not necessarily** a **sub-type** of C.
- **Examples:** (C++)

```
int C::f(int) {
   return 0;
};
```

vs.

```
int D::f(int) {
   return 1;
};
```

Sub-Typing Principles Cont'd

- In the standard, Section 7.3.36, "**Operation**":

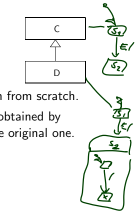
  "**Semantic Variation Points**

  [...] When operations are redefined in a specialization, rules regarding **invariance**, **covariance**, or **contravariance** of types and preconditions determine whether the specialized classifier is substitutable for its more general parent. Such rules constitute semantic variation points with respect to redefinition of operations." [OMG, 2007a, 106]
- So, better: call a method **sub-type preserving**, if and only if it
  - (i) accepts **more input values** (**contravariant**),
  - (ii) on the **old values**, has **fewer behaviour** (**covariant**).

  Note: ~~This~~ (ii) is no longer a matter of simple type-checking!
- And not necessarily the end of the story:
  - One could, e.g. want to consider execution time.
  - Or, like [Fischer and Wehrheim, 2000], relax to "fewer observable behaviour", thus admitting the sub-type to do more work on inputs.

  Note: "testing" differences depends on the **granularity** of the semantics.
- **Related**: "has a weaker pre-condition," (**contravariant**), "has a stronger post-condition." (**covariant**).

Ensuring Sub-Typing for State Machines



- In the CASE tool we consider, multiple classes in an inheritance hierarchy can have state machines.
- But the state machine of a sub-class **cannot** be drawn from scratch.
- Instead, the state machine of a sub-class can only be obtained by applying actions from a **restricted** set to a copy of the original one. Roughly (cf. User Guide, p. 760, for details),
  - add things into (hierarchical) states,
  - add more states,
  - attach a transition to a different target (limited).
- They **ensure**, that the sub-class is a **behavioural sub-type** of the super class. (But method implementations can still destroy that property.)
- Technically, the idea is that (by late binding) only the state machine of the most specialised classes are running.

  By knowledge of the framework, the (code for) state machines of super-classes is still accessible — but using it is hardly a good idea...

Towards System States

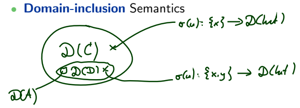
Wanted: a formal representation of "if $C \preceq D$ then D '**is a**' C", that is,

(i) D has the same attributes and behavioural features as C, and

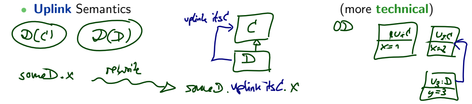
(ii) D objects (identities) can replace C objects.

We'll discuss **two approaches** to semantics:

- **Domain-inclusion** Semantics (more **theoretical**)



- **Uplink** Semantics (more **technical**)



Meta-Modelling: Idea and Example

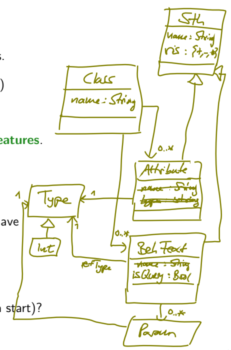
Meta-Modelling: Why and What

- **Meta-Modelling** is one major prerequisite for understanding
  - the standard documents [OMG, 2007a, OMG, 2007b], and
  - the MDA ideas of the OMG.
- The idea is **simple**:
  - if a **modelling language** is about modelling **things**,
  - and if UML models are and comprise **things**,
  - then why not **model** those in a modelling language?
- In other words:

  Why not have a model $\mathcal{M}_U$ such that
  - the set of legal instances of $\mathcal{M}_U$

  is
  - the set of well-formed (!) UML models.

Meta-Modelling: Example

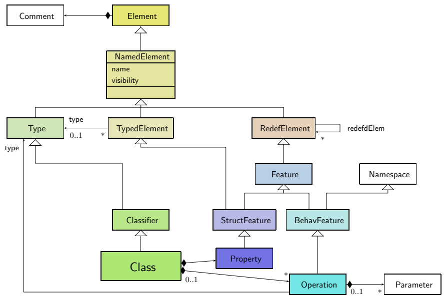


- For example, let's consider a class.
- A **class** has (on a superficial level)
  - a **name**,
  - any number of **attributes**,
  - any number of **behavioural features**.

  Each of the latter two has
  - a **name** and
  - a **visibility**.

  Behavioural features in addition have
  - a boolean attribute **isQuery**,
  - any number of parameters,
  - a return type.
- Can we model this (in UML, for a start)?

UML Meta-Model: Extract



Classes [OMG, 2007b, 32]

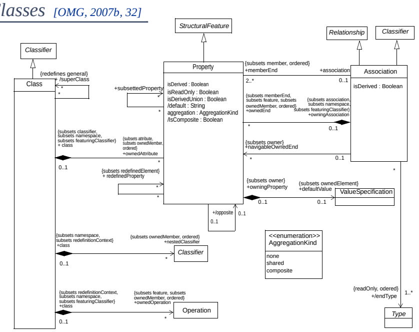


Figure 7.12 - Classes diagram of the Kernel package

Operations [OMG, 2007b, 31]

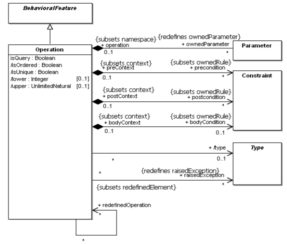


Figure 7.11 - Operations diagram of the Kernel package

Operations [OMG, 2007b, 30]

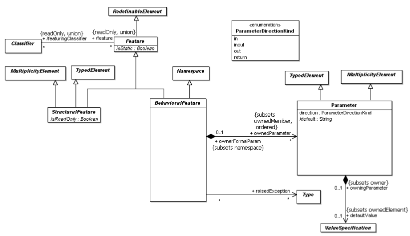


Figure 7.10 - Features diagram of the Kernel package

Classifiers [OMG, 2007b, 29]

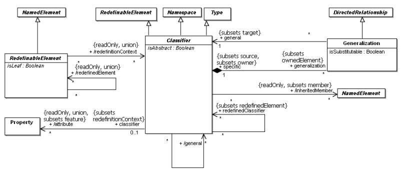


Figure 7.9 - Classifiers diagram of the Kernel package

Namespaces [OMG, 2007b, 26]

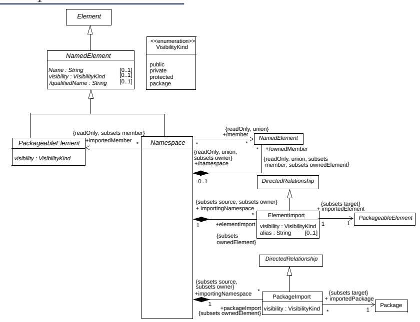


Figure 7.4 - Namespaces diagram of the Kernel package

Root Diagram [OMG, 2007b, 25]

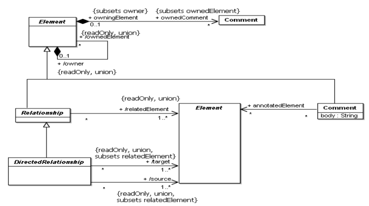


Figure 7.3 - Root diagram of the Kernel package

Interesting: Declaration/Definition [OMG, 2007b, 424]

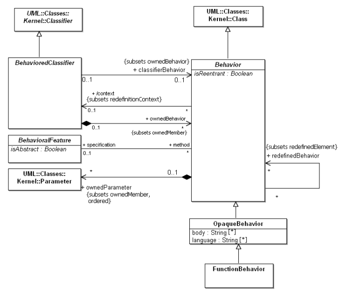
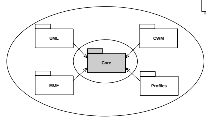


Figure 13.6 - Common Behavior

UML Architecture [?, 8]

- Meta-modelling has already been used for UML 1.x.
- For UML 2.0, the request for proposals (RFP) asked for a separation of concerns: **Infrastructure** and **Superstructure**.
- **One reason**: sharing with MOF (see later) and, e.g., CWM.



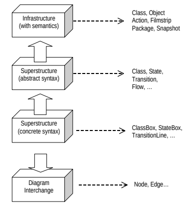


Figure 0-1 *Overview of architecture*

UML Superstructure Packages [OMG, 2007a, 15]

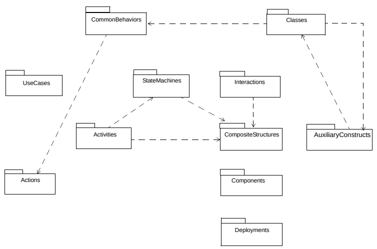
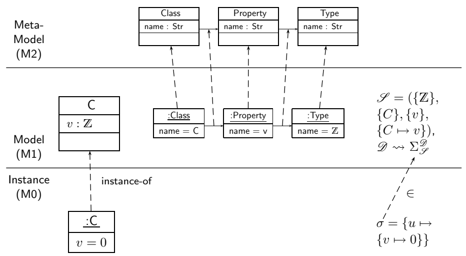


Figure 7.5 - The top-level package structure of the UML 2.1.1 Superstructure

Meta-Modelling: Principle

Modelling vs. Meta-Modelling



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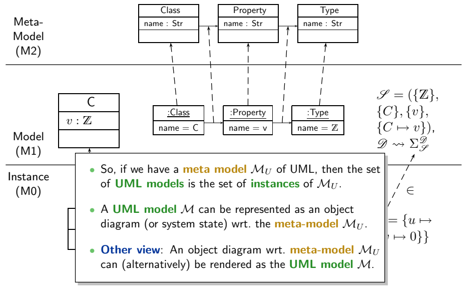

- So, if we have a **meta model** $\mathcal{M}_U$ of UML, then the set of **UML models** is the set of **instances** of $\mathcal{M}_U$.
- A **UML model** $\mathcal{M}$ can be represented as an object diagram (or system state) wrt. the **meta-model** $\mathcal{M}_U$.
- **Other view**: An object diagram wrt. **meta-model** $\mathcal{M}_U$ can (alternatively) be rendered as the **UML model** $\mathcal{M}$.

Well-Formedness as Constraints in the Meta-Model

- The set of **well-formed UML models** can be defined as the set of object diagrams satisfying all constraints of the **meta-model**.

  For example,

  > "[2] Generalization hierarchies must be directed and acyclical. A classifier cannot be both a transitively general and transitively specific classifier of the same classifier.
  >
  > not self . allParents() -> includes(self)" [OMG, 2007b, 53]

- The other way round:

  Given a **UML model** $\mathcal{M}$, unfold it into an object diagram O_1 wrt. $\mathcal{M}_U$.
  If O_1 is a **valid** object diagram of $\mathcal{M}_U$ (i.e. satisfies all invariants from $Inv(\mathcal{M}_U)$), then $\mathcal{M}$ is a well-formed UML model.

  That is, if we have an object diagram **validity checker** for of the meta-modelling language, then we have a **well-formedness checker** for UML models.

Reading the Standard

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UML Superstructure Specification, v2.1.2 iii

Reading the Standard Cont'd

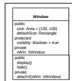


Figure 7.29 - Class notation: attributes and operations grouped according to visibility

7.3.8 Classifier (from Kernel, Dependencies, PowerTypes)

A classifier is a classification of instances, it describes a set of instances that have features in common.

Generalizations

- "Namespace (from Kernel)" on page 99
- "RedefinableElement (from Kernel)" on page 130
- "Type (from Kernel)" on page 135

Description

A classifier is a namespace whose members can include features. Classifier is an abstract metaclass.

A classifier is a type and can own generalizations, thereby making it possible to define generalization relationships to other classifiers. A classifier can specify a generalization hierarchy by referencing its general classifiers.

A classifier is a redefinable element, meaning that it is possible to redefine nested classifiers.

Attributes

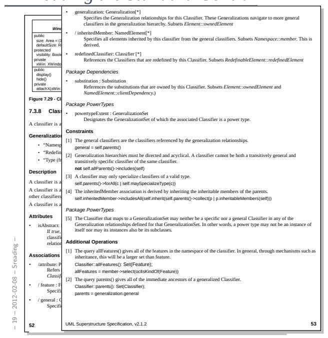
- isAbstract: Boolean
  If *true*, the Classifier does not provide a complete declaration and can typically not be instantiated. An abstract classifier is intended to be used by other classifiers (e.g., as the target of general metarelationships or generalization relationships). Default value is *false*.

Associations

- /attribute: Property [*]
  Refers to all of the Properties that are direct (i.e., not inherited or imported) attributes of the classifier. Subsets *Classifier::feature* and is a derived union.
- / feature : Feature [*]
  Specifies each feature defined in the classifier. Subsets *Namespace::member*. This is a derived union.
- / general : Classifier[*]
  Specifies the general Classifiers for this Classifier. This is derived.

52 UML Superstructure Specification, v2.1.2

Reading the Standard Cont'd



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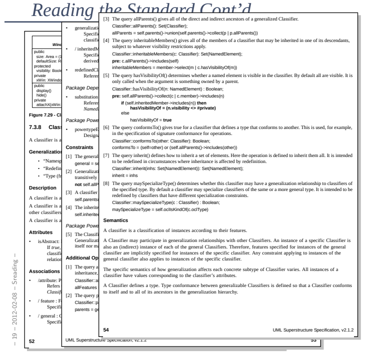

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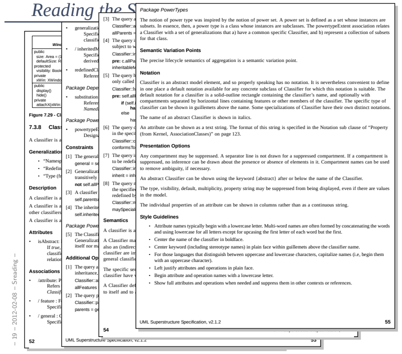

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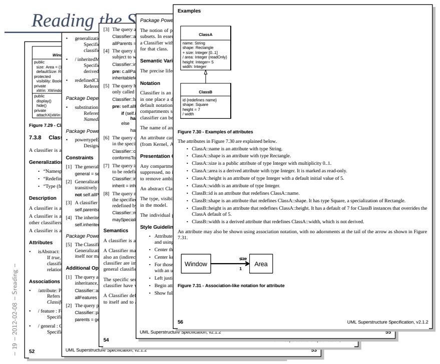

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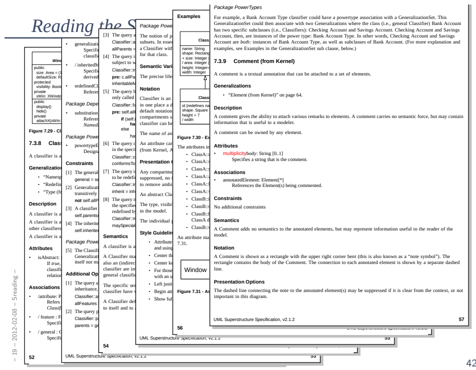

Meta Object Facility (MOF)

Open Questions...

- Now you've been "**tricked**" again. Twice.
  - We didn't tell what the **modelling language** for meta-modelling is.
  - We didn't tell what the **is-instance-of** relation of this language is.
- **Idea**: have a **minimal object-oriented core** comprising the notions of **class**, **association**, **inheritance**, **etc.** with "self-explaining" semantics.
- This is **Meta Object Facility** (MOF), which (more or less) coincides with UML Infrastructure [OMG, 2007a].
- So: things on meta level
  - M0 are object diagrams/system states
  - M1 are **words of the language UML**
  - M2 are **words of the language MOF**
  - M3 are **words of the language** ...

MOF Semantics

- One approach:
  - Treat it with **our signature-based theory**
  - This is (in effect) the right direction, but may require new (or extended) signatures for each level.
    (For instance, MOF doesn't have a notion of Signal, our signature has.)

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- Other approach:
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  - Object diagrams (that **are** graphs) then **are** the system states — not **only graphical representations** of system states.

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  - If this works out, good: We can easily experiment with different language designs, e.g. different flavours of UML that immediately have a semantics.

MOF Semantics

- One approach:
  - Treat it with **our signature-based theory**
  - This is (in effect) the right direction, but may require new (or extended) signatures for each level.
    (For instance, MOF doesn't have a notion of Signal, our signature has.)
- Other approach:
  - Define a **generic**, **graph based** "is-instance-of" relation.
  - Object diagrams (that **are** graphs) then **are** the system states — not **only graphical representations** of system states.
  - If this works out, good: We can easily experiment with different language designs, e.g. different flavours of UML that immediately have a semantics.
  - Most interesting: also do generic definition of behaviour within a closed modelling setting, but this is clearly still research, e.g. [?]

Meta-Modelling: (Anticipated) Benefits

Benefits: Overview

- We'll (superficially) look at three aspects:
  - Benefits for **Modelling Tools**.
  - Benefits for **Language Design**.
  - Benefits for **Code Generation and MDA**.

Benefits for Modelling Tools

- The meta-model $\mathcal{M}_U$ of UML **immediately** provides a **data-structure** representation for the abstract syntax ($\sim$ for our signatures).

  If we have code generation for UML models, e.g. into Java,
  then we can immediately represent UML models **in memory** for Java.

  (Because each MOF model is in particular a UML model.)

- There exist tools and libraries called **MOF-repositories**, which can generically represent instances of MOF instances (in particular UML models).

  And which can often generate specific code to manipulate instances of MOF instances in terms of the MOF instance.

Benefits for Modelling Tools Cont'd

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  → XML Metadata Interchange (XMI)

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  And different tools by different vendors often seem to lie at opposite ends on the scale of interpretation. Which is surely a coincidence.

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- **To re-iterate**: this is **generic for all** MOF-based modelling languages such as UML, CWM, etc.
  And also for **Domain Specific Languages** which don't even exit yet.

Benefits for Language Design

- Recall: we said that code-generators are possible "readers" of stereotypes.
- For example, (heavily simplifying) we could
  - introduce the stereotypes **Button**, **Toolbar**, ...
  - for convenience, instruct the modelling tool to use special pictures for stereotypes — in the meta-data (the abstract syntax), the stereotypes are clearly present.
  - instruct the code-generator to automatically add inheritance from Gtk::Button, Gtk::Toolbar, etc. **corresponding** to the stereotype.

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Et voilà: we can model Gtk-GUIs and generate code for them.

- Another view:
  - UML with these stereotypes **is a new modelling language**: Gtk-UML.
  - Which lives on the same meta-level as UML (M2).
  - It's a **Domain Specific** Modelling **Language** (DSL).

One mechanism to define DSLs (based on UML, and "within" UML): **Profiles**.

Benefits for Language Design Cont'd

- For each DSL defined by a Profile, we immediately have
  - in memory representations,
  - modelling tools,
  - file representations.
- **Note**: here, the **semantics** of the stereotypes (and thus the language of Gtk-UML) **lies in the code-generator**.

  That's the first "reader" that understands these special stereotypes.
  (And that's what's meant in the standard when they're talking about giving stereotypes semantics).
- One can also impose additional well-formedness rules, for instance that certain components shall all implement a certain interface (and thus have certain methods available). (Cf. [Stahl and Völter, 2005].)

Benefits for Language Design Cont'd

- One step further:
  - Nobody hinders us to obtain a model of UML (written in MOF),
  - throw out parts unnecessary for our purposes,
  - add (= integrate into the existing hierarchy) more adequat new constructs, for instance, **contracts** or something more close to hardware as **interrupt** or **sensor** or **driver**,
  - and maybe also stereotypes.

  → a new language standing next to UML, CWM, etc.
- Drawback: the resulting language is not necessarily UML any more, so we **can't use** proven UML modelling tools.
- But we can use all tools for MOF (or MOF-like things).

  For instance, Eclipse EMF/GMF/GEF.

Benefits for Model (to Model) Transformation

- There are manifold applications for model-to-model transformations:
  - For instance, tool support for **re-factorings**, like moving common attributes upwards the inheritance hierarchy.

    This can now be defined as **graph-rewriting** rules on the level of MOF.
    The graph to be rewritten is the UML model

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    The transformation would add this class Gtk::Button and the inheritance relation and remove the stereotype.
  - Similarly, one could have a **GUI-UML** model transformed into a **Gtk-UML** model, or a Qt-UML model.

    The former a PIM (Platform Independent Model), the latter a PSM (Platform Specific Model) — cf. MDA.

Special Case: Code Generation

- Recall that we said that, e.g. Java code, can also be seen as a model.

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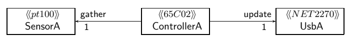
- **Note:** Code generation needn't be as expensive as buying a modelling tool with full fledged code generation.
  - If we have the UML model (or the DSL model) given as an XML file, code generation can be **as simple as** an XSLT script.

    "Can be" in the sense of

    > *"There may be situation where a graphical and abstract representation of something is desired which has a clear and direct mapping to some textual representation."*

  In general, code generation can (in colloquial terms) become **arbitrarily difficult**.

Example: Model and XMI




```
<?xml version = '1.0' encoding = 'UTF-8' ?>
<XMI xmi.version = '1.2' xmlns:UML = 'org.omg.xmi.namespace.UML' timestamp = 'Mon Feb 02 18:23:12 CET 2009'>
  <XMI.content>
    <UML:Model xmi.id = '...'>
      <UML:Namespace.ownedElement>
        <UML:Class xmi.id = '...' name = 'SensorA'>
          <UML:ModelElement.stereotype>
            <UML:Stereotype name = 'pt100'/>
          </UML:ModelElement.stereotype>
        </UML:Class>
        <UML:Class xmi.id = '...' name = 'ControllerA'>
          <UML:ModelElement.stereotype>
            <UML:Stereotype name = '65C02'/>
          </UML:ModelElement.stereotype>
        </UML:Class>
        <UML:Class xmi.id = '...' name = 'UsbA'>
          <UML:ModelElement.stereotype>
            <UML:Stereotype name = 'NET2270'/>
          </UML:ModelElement.stereotype>
        </UML:Class>
        <UML:Association xmi.id = '...' name = 'in' >...</UML:Association>
        <UML:Association xmi.id = '...' name = 'out' >...</UML:Association>
      </UML:Namespace.ownedElement>
    </UML:Model>
  </XMI.content>
</XMI>
```


References

References

[Fischer and Wehrheim, 2000] Fischer, C. and Wehrheim, H. (2000). Behavioural subtyping relations for object-oriented formalisms. In Rus, T., editor, AMAST, number 1816 in Lecture Notes in Computer Science. Springer-Verlag.

[Liskov, 1988] Liskov, B. (1988). Data abstraction and hierarchy. SIGPLAN Not., 23(5):17–34.

[Liskov and Wing, 1994] Liskov, B. H. and Wing, J. M. (1994). A behavioral notion of subtyping. ACM Transactions on Programming Languages and Systems (TOPLAS), 16(6):1811–1841.

[OMG, 2007a] OMG (2007a). Unified modeling language: Infrastructure, version 2.1.2. Technical Report formal/07-11-04.

[OMG, 2007b] OMG (2007b). Unified modeling language: Superstructure, version 2.1.2. Technical Report formal/07-11-02.

[Stahl and Völter, 2005] Stahl, T. and Völter, M. (2005). Modellgetriebene Softwareentwicklung. dpunkt.verlag, Heidelberg.