Software Design, Modelling and Analysis in UML

Lecture 22: Meta-Modelling, Inheritance III

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Contents & Goals

Last Lecture:

- Inheritance in UML: desired 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:**
  - Meta-Modelling
  - Two approaches to obtain desired semantics

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 $\mathcal{M}_U$

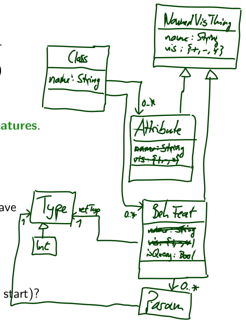
  is
  - the set of well-formed (!) UML models.

Meta-Modelling: Example

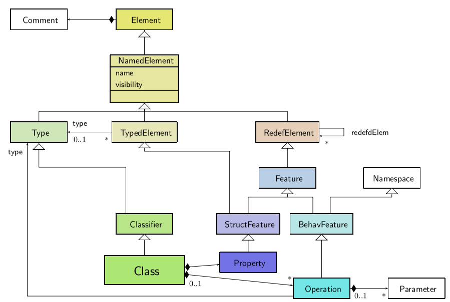
- For example, let's consider a class.
- A **class** has (on a superficial level)
  - a **name**,
  - any number of **attributes**,
  - any number of **behavioural features**.

  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]

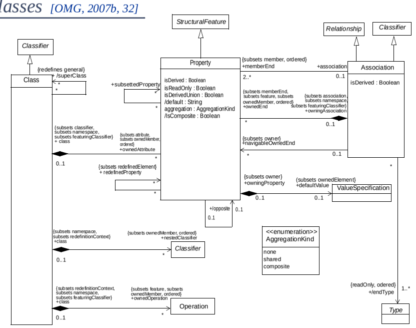


Figure 7.12 - Classes diagram of the Kernel package

Operations [OMG, 2007b, 31]

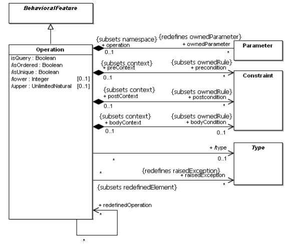


Figure 7.11 - Operations diagram of the Kernel package

Operations [OMG, 2007b, 30]

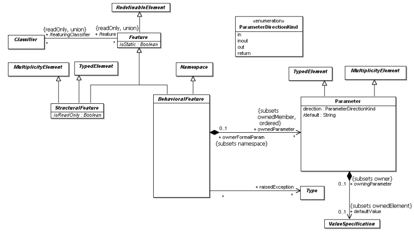


Figure 7.10 - Features diagram of the Kernel package

Classifiers [OMG, 2007b, 29]

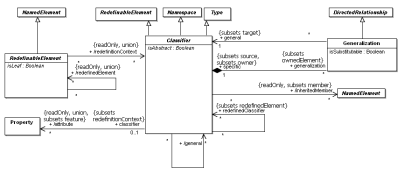


Figure 7.9 - Classifiers diagram of the Kernel package

Namespaces [OMG, 2007b, 26]

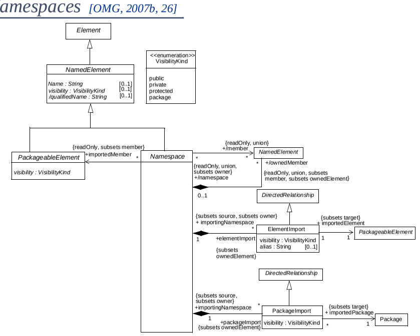


Figure 7.4 - Namespaces diagram of the Kernel package

Root Diagram [OMG, 2007b, 25]

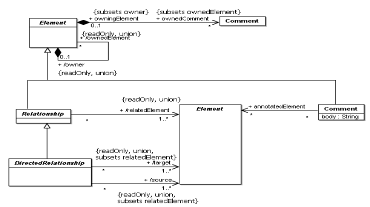


Figure 7.3 - Root diagram of the Kernel package

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

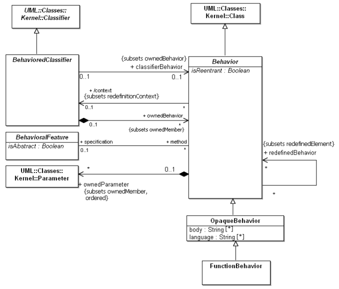


Figure 13.6 - Common Behavior

UML Architecture [OMG, 2003, 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.

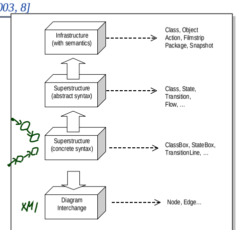
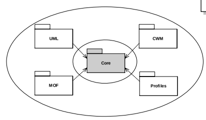


Figure 0-1 *Overview of architecture*



UML Superstructure Packages [OMG, 2007a, 15]

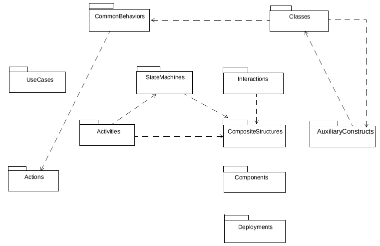
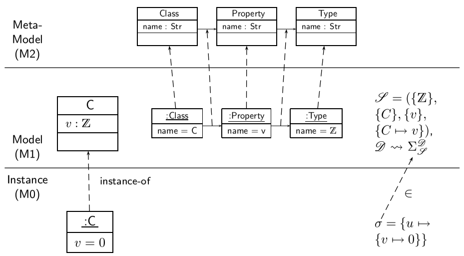


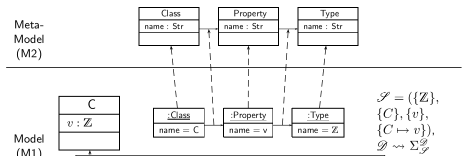
Figure 7.5 - The top-level package structure of the UML 2.1.1 Superstructure

Meta-Modelling: Principle

Modelling vs. Meta-Modelling



Modelling vs. Meta-Modelling



- 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 i

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Reading the Standard

UML Superstructure Specification, v2.1.2 iii

Reading the Standard Cont'd

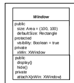

Figure 7.29 - Class notation: attributes and operations grouped according to visibility

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.

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Reading the Standard Cont'd

- generalization: Generalization[*]
  Specifies the Generalization relationships for this Classifier. These Generalizations navigate to more general classifiers in the generalization hierarchy. Subsets *Element::ownedElement*
- / inheritedMember: NamedElement[*]
  Specifies all elements inherited by this classifier from the general classifiers. Subsets *Namespace::member*. This is derived.
- redefinedClassifier: Classifier [*]
  References the Classifiers that are redefined by this Classifier. Subsets *RedefinableElement::redefinedElement*

Package Dependencies

- substitution : Substitution
  References the substitutions that are owned by this Classifier. Subsets *Element::ownedElement* and *NamedElement::clientDependency*.)

Package PowerTypes

- powertypeExtent : GeneralizationSet
  Designates the GeneralizationSet of which the associated Classifier is a power type.

Constraints

[1] The general classifiers are the classifiers referenced by the generalization relationships.
general = self.parents()

[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)

[3] A classifier may only specialize classifiers of a valid type.
self.parents()->forAll(c | self.maySpecializeType(c))

[4] The inheritedMember association is derived by inheriting the inheritable members of the parents.
self.inheritedMember->includesAll(self.inherit(self.parents()->collect(p | p.inheritableMembers(self)))

Package PowerTypes

[5] The Classifier that maps to a GeneralizationSet may neither be a specific nor a general Classifier in any of the Generalization relationships defined for that GeneralizationSet. In other words, a power type may not be an instance of itself nor may its instances also be its subclasses.

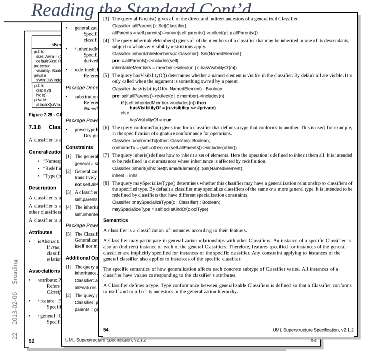
Additional Operations

[1] The query allFeatures() gives all of the features in the namespace of the classifier. In general, through mechanisms such as inheritance, this will be a larger set than feature.
Classifier::allFeatures(): Set(Feature);
allFeatures = member->select(oclIsKindOf(Feature))

[2] The query parents() gives all of the immediate ancestors of a generalized Classifier.
Classifier::parents(): Set(Classifier);
parents = generalization.general

UML Superstructure Specification, v2.1.2 53

Reading the Standard Cont'd



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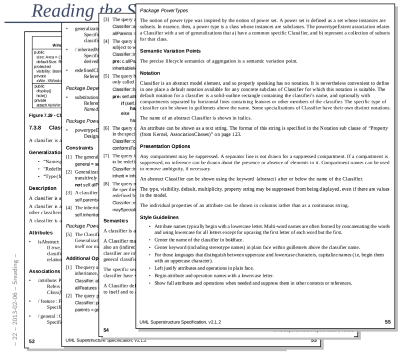

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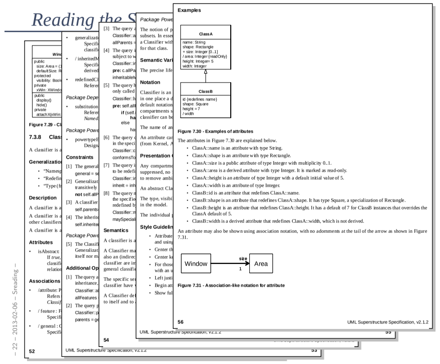

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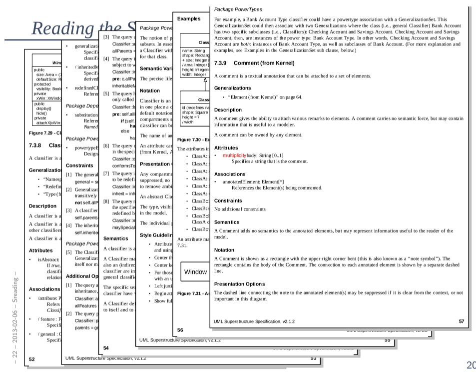


Meta Object Facility (MOF)

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 (objects/instances of classes in a UML model)
  - M1 are **words of the language UML** (objects/instances of classes in the UML-meta-model)
  - M2 are **words of the language MOF** (instances of MOF meta-model)
  - M3 are **words of the language** MOF
  - ⋮
- ⋮

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. [Buschermöhle and Oelerink, 2008]

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

- And not only **in memory**, if we can represent MOF instances in files, we obtain a canonical representation of UML models **in files**, e.g. in XML.
  → XML Metadata Interchange (XMI)
- **Note**: A priori, there is no graphical information in XMI (it is only abstract syntax like our signatures) → OMG Diagram Interchange.
- **Note**: There are slight ambiguities in the XMI standard.
  And different tools by different vendors often seem to lie at opposite ends on the scale of interpretation. Which is surely a coincidence.
  In some cases, it's possible to fix things with, e.g., XSLT scripts, but full vendor independence is today not given.
  Plus XMI compatibility doesn't necessarily refer to Diagram Interchange.
- **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: Overview

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

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.

  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: Overview

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

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
  - Similarly, one could transform a **Gtk-UML** model into a **UML model**, where the inheritance from classes like Gtk::Button is made explicit:

    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.

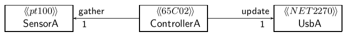
  So code-generation is a **special case** of model-to-model transformation; only the destination looks quite different.
- **Note**: Code generation needn't be as expensive as buying a modelling tool with full fledged code generation.
  - If we have the UML model (or the DSL model) given as an XML file, 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
<?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'/>
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        <UML:Association xmi.id = '...' name = 'out' >...</UML:Association>
      </UML:Namespace.ownedElement>
    </UML:Model>
  </XMI.content>
</XMI>
```

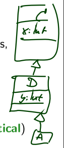

Recall

Towards System States

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

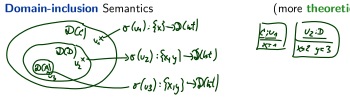
(i) D has the same attributes and behavioural features as C, and

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

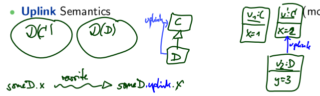


We'll discuss **two approaches** to semantics:

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



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



Domain Inclusion Semantics

Domain Inclusion Structure

Let $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr, \mathscr{E}, F, mth, \lhd)$ be a signature.

Now a **structure** $\mathscr{D}$

- **[as before]** maps types, classes, associations to domains,
- **[for completeness]** methods to transformers,
- **[as before]** indentities of instances of classes not (transitively) related by generalisation are disjoint,
- **[changed]** the indentities of a super-class comprise all identities of sub-classes, i.e.

$$\forall C \in \mathscr{C} : \mathscr{D}(C) \supsetneq \bigcup_{C \lhd D} \mathscr{D}(D).$$

Note: the old setting coincides with the special case $\lhd = \emptyset$.

Domain Inclusion System States

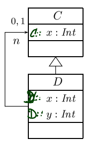
Now: a **system state** of $\mathscr{S}$ wrt. $\mathscr{D}$ is a **type-consistent** mapping

$$\sigma : \mathscr{D}(\mathscr{C}) \nrightarrow (V \nrightarrow (\mathscr{D}(\mathscr{T}) \cup \mathscr{D}(\mathscr{C}_{0,1}) \cup \mathscr{D}(\mathscr{C}_*)))$$

that is, for all $u \in \mathrm{dom}(\sigma) \cap \mathscr{D}(C)$,

- **[as before]** $\sigma(u)(v) \in \mathscr{D}(\tau)$ if $v : \tau$, $\tau \in \mathscr{T}$ or $\tau \in \{C_*, C_{0,1}\}$.
- **[changed]** $\mathrm{dom}(\sigma(u)) = \bigcup_{C_0 \preceq C} atr(C_0)$,

Example:



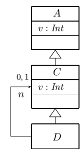
$u \in \mathscr{D}(D)$

$dom(\sigma(u)) = atr(D) \cup atr(C)$

$= \{D::x, D::y, C::x\}$

Note: the old setting still coincides with the special case $\lhd = \emptyset$.

Preliminaries: Expression Normalisation



Recall:

- we want to allow, e.g., "context D inv $v < 0$".
- we assume **fully qualified names**, e.g. $C::v$.

Intuitively, v shall denote the "**most special more general**" $C::v$ according to $\lhd$.

To keep this out of typing rules, we assume that the following **normalisation** has been applied to all OCL expressions and all actions.

- Given expression v (or f) in **context** of class D, as determined by, e.g.
  - by the (type of the) navigation expression prefix, or
  - by the class, the state-machine where the action occcurs belongs to,
  - similar for method bodies,
- **normalise** v to (= replace by) $C::v$,
- where C is the **greatest** class wrt. "$\preceq$" such that
  - $C \preceq D$ and $C::v \in atr(C)$.

If no (unique) such class exists, the model is considered **not well-formed**; the expression is ambiguous. Then: explicitly provide the **qualified name**.

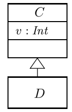
OCL Syntax and Typing

- Recall (part of the) OCL syntax and typing: $v, r \in V;\ C, D \in \mathscr{C}$

$$\begin{aligned} expr ::= \;& v(expr_1) && : \tau_C \to \tau(v), && \text{if } v : \tau \in \mathscr{T} \\ |\;& r(expr_1) && : \tau_C \to \tau_D, && \text{if } r : D_{0,1} \\ |\;& r(expr_1) && : \tau_C \to Set(\tau_D), && \text{if } r : D_* \end{aligned}$$

The definition of the semantics remains (textually) **the same**.

More Interesting: Well-Typed-ness



- We want

  context D inv : $v < 0$

  to be well-typed.

  Currently it isn't because

  $$v(expr_1) : \tau_C \to \tau(v)$$

  but $A \vdash self : \tau_D$.

  (Because τ_D and τ_C are still **different types**, although $\mathrm{dom}(\tau_D) \subset \mathrm{dom}(\tau_C)$.)

- So, add a (first) new typing rule

$$\frac{A \vdash expr : \tau_D}{A \vdash expr : \tau_C}, \text{ if } C \preceq D. \qquad \text{(Inh)}$$

Which is correct in the sense that, if '$expr$' is of type τ_D, then we can use it everywhere, where a τ_C is allowed.

The system state is prepared for that.

Well-Typed-ness with Visibility Cont'd

$$\frac{A, D \vdash expr : \tau_C}{A, D \vdash C{::}v(expr) : \tau}, \quad \xi = + \qquad \text{(Pub)}$$

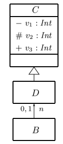
$$\frac{A, D \vdash expr : \tau_C}{A, D \vdash C{::}v(expr) : \tau}, \quad \xi = \#,\ C \preceq D \qquad \text{(Prot)}$$

$$\frac{A, D \vdash expr : \tau_C}{A, D \vdash C{::}v(expr) : \tau}, \quad \xi = -,\ C = D \qquad \text{(Priv)}$$

$\langle C{::}v : \tau, \xi, v_0, P\rangle \in atr(C)$.

Example:

context/ inv	$(n.)v_1 < 0$	$(n.)v_2 < 0$	$(n.)v_3 < 0$
C			
D			
B			



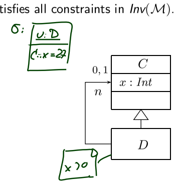
Satisfying OCL Constraints (Domain Inclusion)

- Let $\mathcal{M} = (\mathscr{CD}, \mathscr{OD}, \mathscr{SM}, \mathscr{I})$ be a UML model, and $\mathscr{D}$ a structure.
- We (**continue to**) say $\mathcal{M} \models expr$ for $\underbrace{\text{context } C \text{ inv} : expr_0}_{=expr} \in \mathit{Inv}(\mathcal{M})$ iff

$$\forall \pi = (\sigma_i, \varepsilon_i)_{i \in \mathbb{N}} \in [\![\mathcal{M}]\!] \quad \forall i \in \mathbb{N} \quad \forall u \in \mathrm{dom}(\sigma_i) \cap \mathscr{D}(C) :$$
$$I[\![expr_0]\!](\sigma_i, \{self \mapsto u\}) = 1.$$

- $\mathcal{M}$ is (still) consistent if and only if it satisfies all constraints in $\mathit{Inv}(\mathcal{M})$.

- **Example:**



Transformers (Domain Inclusion)

- Transformers also remain **the same**, e.g. [VL 12, p. 18]

$$update(expr_1, v, expr_2) : (\sigma, \varepsilon) \mapsto (\sigma', \varepsilon)$$

with

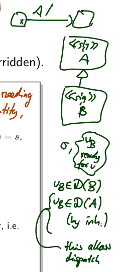
$$\sigma' = \sigma[u \mapsto \sigma(u)[v \mapsto I[\![expr_2]\!](\sigma)]]$$

where $u = I[\![expr_1]\!](\sigma)$.

Semantics of Method Calls

- **Non late-binding**: clear, by normalisation.
- **Late-binding**:
  Construct a **method call** transformer, which is applied to all method calls.

Inheritance and State Machines: Triggers



- **Wanted**: triggers shall also be sensitive for inherited events, sub-class shall execute super-class' state-machine (unless overridden).

$$(\sigma, \varepsilon) \xrightarrow[u]{(cons, Snd)} (\sigma', \varepsilon') \text{ if}$$

- $\exists\, u \in \mathrm{dom}(\sigma) \cap \mathscr{D}(C)\ \exists\, u_E \in \mathscr{D}(\mathscr{E}) : u_E \in ready(\varepsilon, u)$
- u is stable and in state machine state s, i.e. $\sigma(u)(stable) = 1$ and $\sigma(u)(st) = s$,
- a transition is enabled, i.e.

$$\exists\, (s, F, expr, act, s') \in \to (\mathcal{SM}_C) : F = E \wedge I[\![expr]\!](\tilde{\sigma}) = 1$$

where $\tilde{\sigma} = \sigma[u.params_E \mapsto u_e]$.

and

- (σ', ε') results from applying t_{act} to (σ, ε) and removing u_E from the ether, i.e.

$$(\sigma'', \varepsilon') = t_{act}(\tilde{\sigma}, \varepsilon \ominus u_E),$$

$$\sigma' = (\sigma''[u.st \mapsto s', u.stable \mapsto b, u.params_E \mapsto \emptyset])|_{\mathscr{D}(\mathscr{C}) \setminus \{u_E\}}$$

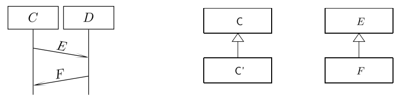
where b **depends**:

- If u becomes stable in s', then $b = 1$. It **does** become stable if and only if there is no transition **without trigger** enabled for u in (σ', ε').
- Otherwise $b = 0$.

- Consumption of u_E and the side effects of the action are observed, i.e.

$$cons = \{(u, (E, \sigma(u_E)))\}, Snd = Obs_{t_{act}}(\tilde{\sigma}, \varepsilon \ominus u_E).$$

Domain Inclusion and Interactions



- Similar to satisfaction of OCL expressions above:
  - An instance line stands for all instances of C (exact or inheriting).
  - Satisfaction of event observation has to take inheritance into account, too, so we have to **fix**, e.g.

$$\sigma, cons, Snd \models_\beta E^!_{x,y}$$

if and only if

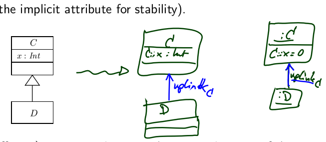
$$\beta(x) \text{ sends an } F\text{-event to } \beta y \text{ where } E \preceq F.$$

- **Note**: C-instance line also binds to C'-objects.

Uplink Semantics

Uplink Semantics

- **Idea**:
  - Continue with the existing definition of **structure**, i.e. disjoint domains for identities.
  - Have an **implicit association** from the child to each parent part (similar to the implicit attribute for stability).



- Apply (a different) pre-processing to make appropriate use of that association, e.g. rewrite (C++)

$$\mathtt{x} = 0;$$

in D to

$$\mathtt{uplink}_C \; \texttt{->} \; \mathtt{x} = 0;$$

Pre-Processing for the Uplink Semantics

- For each pair $C \lhd D$, extend D by a (fresh) association

$$uplink_C : C \text{ with } \mu = [1, 1],\ \xi = +$$

(**Exercise**: public necessary?)

- Given expression v (or f) in the **context** of class D,
  - let C be the **smallest** class wrt. "$\preceq$" such that
    - $C \preceq D$, and
    - $C{::}v \in atr(D)$
  - then there exists (by definition) $C \lhd C_1 \lhd \ldots \lhd C_n \lhd D$,
  - **normalise** v to (= replace by)

$$uplink_{C_n} \texttt{->} \cdots \texttt{->} uplink_{C_1}.C{::}v$$

- Again: if no (unique) smallest class exists, the model is considered **not well-formed**; the expression is ambiguous.

Uplink Structure, System State, Typing

- Definition of structure remains **unchanged**.
- Definition of system state remains **unchanged**.
- Typing and transformers remain **unchanged** — the preprocessing has put everything in shape.

Satisfying OCL Constraints (Uplink)

- Let $\mathcal{M} = (\mathscr{CD}, \mathscr{OD}, \mathscr{SM}, \mathscr{I})$ be a UML model, and $\mathscr{D}$ a structure.
- We (**continue to**) say

$$\mathcal{M} \models expr$$

for

$$\underbrace{\text{context } C \text{ inv} : expr_0}_{=expr} \in Inv(\mathcal{M})$$

if and only if

$$\forall \pi = (\sigma_i)_{i \in \mathbb{N}} \in [\![\mathcal{M}]\!]$$
$$\forall i \in \mathbb{N}$$
$$\forall u \in \operatorname{dom}(\sigma_i) \cap \mathscr{D}(C) :$$
$$I[\![expr_0]\!](\sigma_i, \{self \mapsto u\}) = 1.$$

- $\mathcal{M}$ is (still) consistent if and only if it satisfies all constraints in $Inv(\mathcal{M})$.

Transformers (Uplink)

- What **has to change** is the **create** transformer:

$$create(C, expr, v)$$

- Assume, C's inheritance relations are as follows.

$$C_{1,1} \lhd \ldots \lhd C_{1,n_1} \lhd C,$$
$$\ldots$$
$$C_{m,1} \lhd \ldots \lhd C_{m,n_m} \lhd C.$$

- Then, we have to
  - create one fresh object for each part, e.g.

$$u_{1,1}, \ldots, u_{1,n_1}, \ldots, u_{m,1}, \ldots, u_{m,n_m},$$

  - set up the uplinks recursively, e.g.

$$\sigma(u_{1,2})(uplink_{C_{1,1}}) = u_{1,1}.$$

  - And, if we had constructors, be careful with their order.

Late Binding (Uplink)

- Employ something similar to the "`mostspec`" trick (in a minute!). But the result is typically far from concise.

  (Related to OCL's `isKindOf()` function, and RTTI in C++.)

Domain Inclusion vs. Uplink Semantics

Cast-Transformers

- `C c;`
- `D d;`
- **Identity upcast** (C++):
  - `C* cp = &d;` *// assign address of 'd' to pointer 'cp'*
- **Identity downcast** (C++):
  - `D* dp = (D*)cp;` *// assign address of 'd' to pointer 'dp'*
- **Value upcast** (C++):
  - `*cp = *dp;` *// copy attribute values of 'd' into 'c', or,*
    // more precise, the values of the C-part of 'd'

Casts in Domain Inclusion and Uplink Semantics

	Domain Inclusion	**Uplink**
`C* cp = &d;`	**easy**: immediately compatible (in underlying system state) because `&d` yields an identity from $\mathscr{D}(D) \subset \mathscr{D}(C)$.	**easy**: By pre-processing, `C* cp = d.uplink`$_C$;
`D* dp = (D*)cp;`	**easy**: the value of `cp` is in $\mathscr{D}(D) \cap \mathscr{D}(C)$ because the pointed-to object is a D. Otherwise, error condition.	**difficult**: we need the identity of the D whose C-slice is denoted by cp. (See next slide.)
`c = d;`	**bit difficult**: set (for all $C \preceq D$) $(C)(\cdot,\cdot) : \tau_D \times \Sigma \to \Sigma\vert_{atr(C)}$ $(u, \sigma) \mapsto \sigma(u)\vert_{atr(C)}$ Note: $\sigma' = \sigma[u_C \mapsto \sigma(u_D)]$ is not type-compatible!	**easy**: By pre-processing, `c = *(d.uplink`$_C$`);`

Identity Downcast with Uplink Semantics

- **Recall** (C++): `D d;` `C* cp = &d;` `D* dp = (D*)cp;`
- **Problem**: we need the identity of the D whose C-slice is denoted by cp.
- **One technical solution**:
  - Give up disjointness of domains for **one additional type** comprising all identities, i.e. have

$$\texttt{all} \in \mathscr{T}, \qquad \mathscr{D}(\texttt{all}) = \bigcup_{C \in \mathscr{C}} \mathscr{D}(C)$$

  - In each $\preceq$**-minimal class** have associations "`mostspec`" pointing to **most specialised** slices, plus information of which type that slice is.
  - Then **downcast** means, depending on the `mostspec` type (only finitely many possibilities), **going down and then up** as necessary, e.g.

```
switch(mostspec_type){
  case C :
    dp = cp -> mostspec -> uplink_Dn -> ... -> uplink_D1 -> uplink_D;
...
}
```


Domain Inclusion vs. Uplink Semantics: Differences

- **Note**: The uplink semantics views inheritance as an abbreviation:
  - We only need to touch transformers (create) — and if we had constructors, we didn't even needed that (we could encode the recursive construction of the upper slices by a transformation of the existing constructors.)
- **So**:
  - Inheritance **doesn't add** expressive power.
  - And it also **doesn't improve** conciseness **soo dramatically**.

As long as we're "**early binding**", that is...

Domain Inclusion vs. Uplink Semantics: Motives

- **Exercise**:

  What's the point of

  - having the **tedious** adjustments of the **theory**
    if it can be approached **technically**?
  - having the **tedious** technical **pre-processing**
    if it can be approached **cleanly** in the **theory**?

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