Analyzing UML/OCL Models with HOL-OCL

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Toulouse, 28th September 2008

Outline

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1. Introduction
2. Background
3. Formalization of UML and OCL
4. Mechanized Support for Model Analysis Methods
5. The HOL-OCL Architecture
6. Applications
7. Conclusion and Future Work

The Situation Today

A Software Engineering Problem

- Software systems
    - are becoming more and more complex and
    - are used in safety and security critical applications.
- Formal methods are one way to increase their reliability.
- But, formal methods are hardly used by mainstream industry:
    - difficult to understand notation
    - lack of tool support
    - high costs
- Semi-formal methods, especially UML,
    - are widely used in industry, but
    - they lack support for formal methodologies.

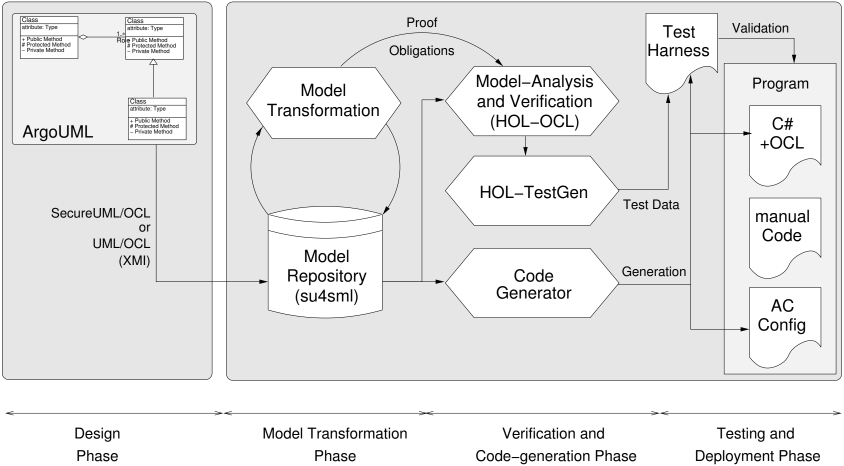
Is OCL an Answer?

- UML/OCL attracts the practitioners:
  - is defined by the object-oriented community,
  - has a “programming language face,”
  - increasing tool support.
- UML/OCL is attractive to researchers:
  - defines a “core language” for object-oriented modeling,
  - provides good target for object-oriented semantics research,
  - offers the chance for bringing formal methods closer to industry.

Turning OCL into a full-fledged formal methods is deserving and interesting.

The HOL-OCL Vision:

Tool Supported Formal Methods for (Model-driven) Software Development



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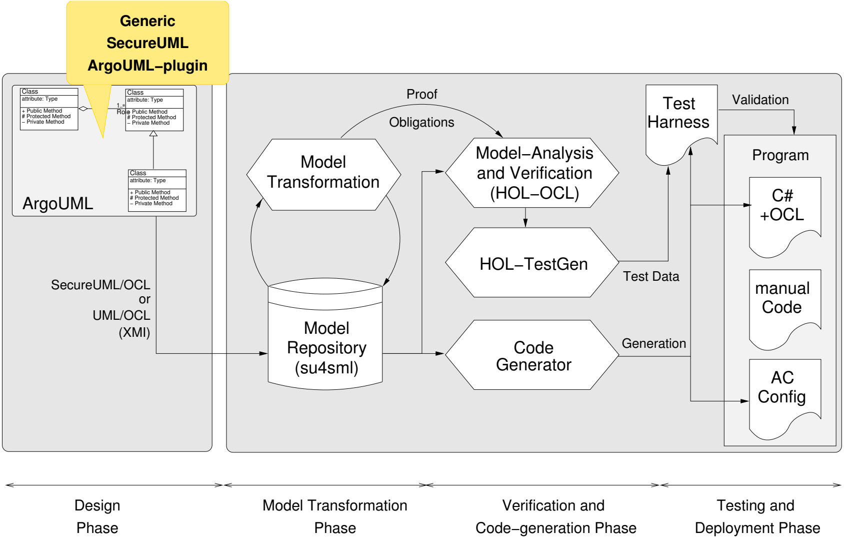

Generic SecureUML ArgoUML–plugin

ArgoUML

SecureUML/OCL or UML/OCL (XMI)

Model Transformation

Model Repository (su4sml)

Proof Obligations

Model–Analysis and Verification (HOL–OCL)

HOL–TestGen

Test Data

Code Generator

Generation

Test Harness

Validation

Program

C# +OCL

manual Code

AC Config

Design Phase

Model Transformation Phase

Verification and Code–generation Phase

Testing and Deployment Phase

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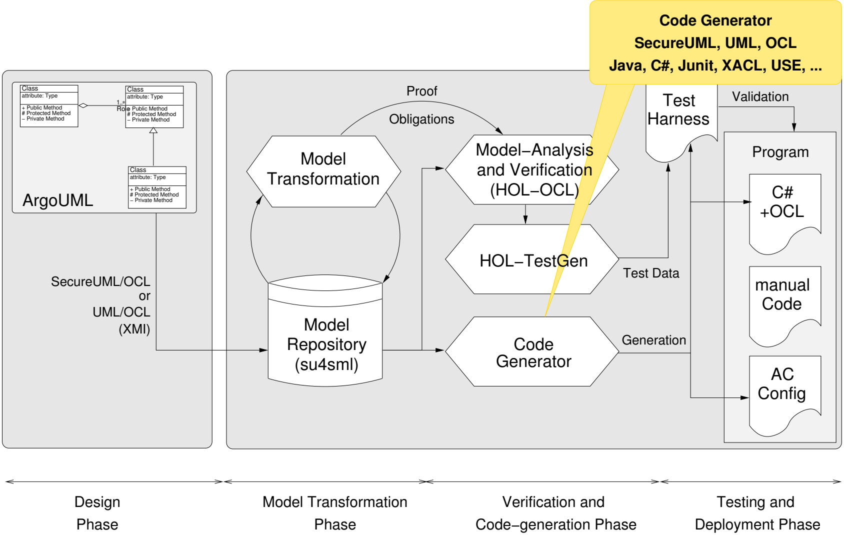

Code Generator
SecureUML, UML, OCL
Java, C#, Junit, XACL, USE, ...

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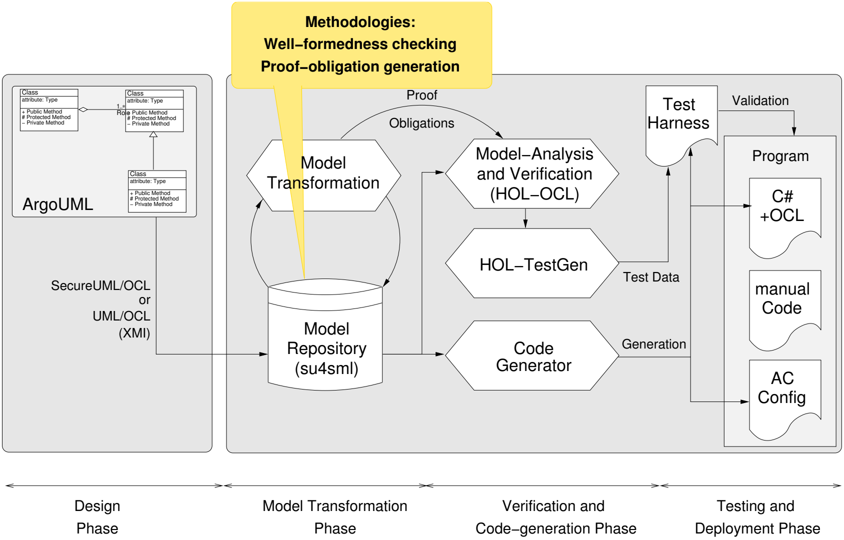

Methodologies:
Well–formedness checking
Proof–obligation generation

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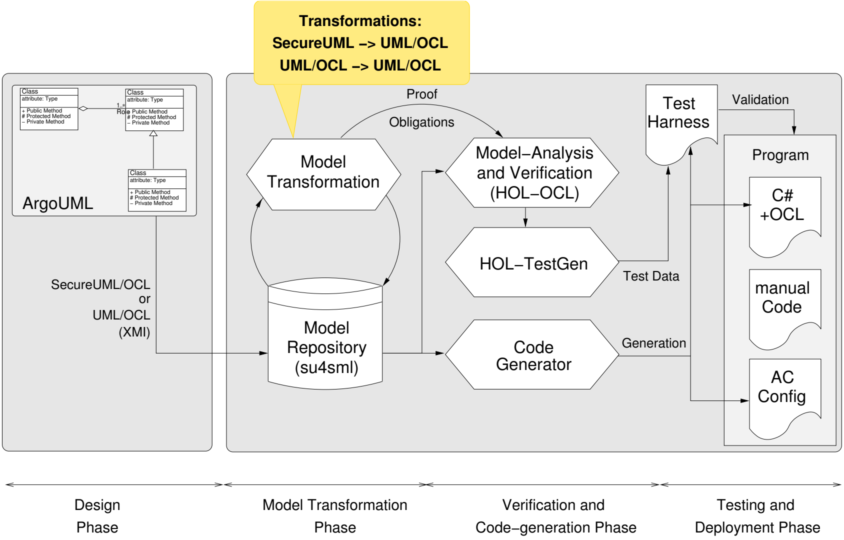

Transformations:
SecureUML –> UML/OCL
UML/OCL –> UML/OCL

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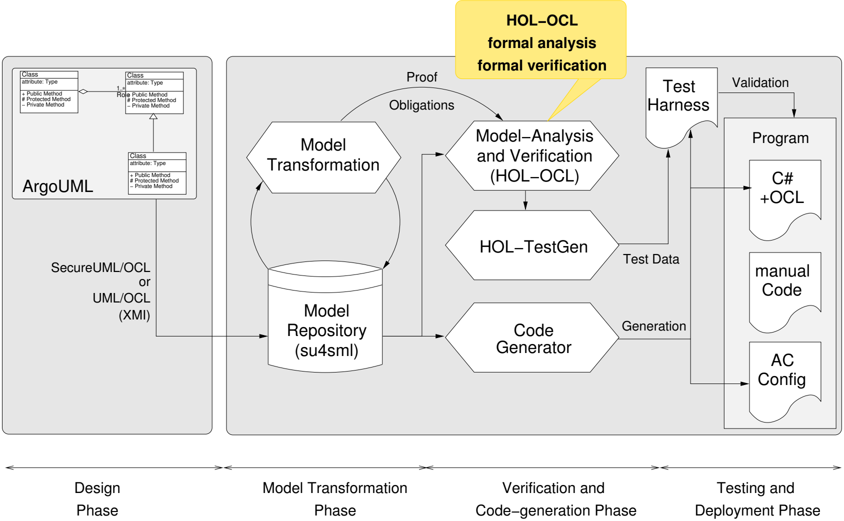

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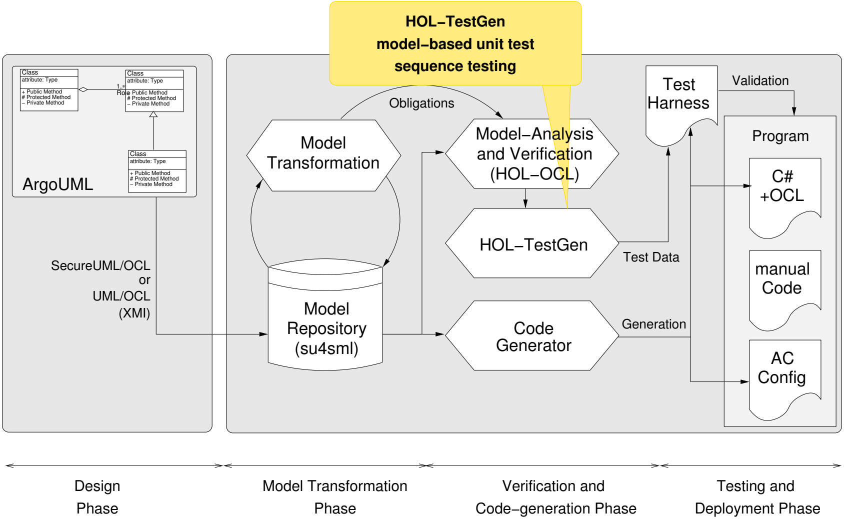

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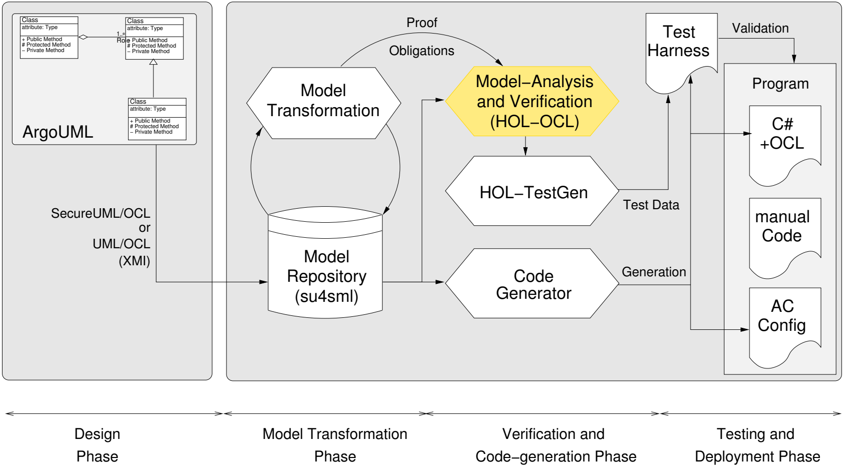

ArgoUML

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or
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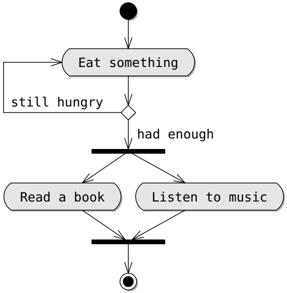
The Unified Modeling Language (UML)

- Visual modeling language
- Object-oriented development
- Industrial tool support
- OMG standard
- Many diagram types, e. g.,
    - activity diagrams
    - class diagrams
    - . . .



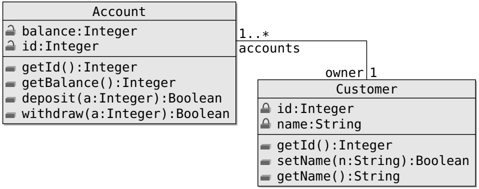
Eat something

still hungry

had enough

Read a book

Listen to music



Account

balance:Integer

id:Integer

getId():Integer

getBalance():Integer

deposit(a:Integer):Boolean

withdraw(a:Integer):Boolean

1..*

accounts

owner 1

Customer

id:Integer

name:String

getId():Integer

setName(n:String):Boolean

getName():String

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    - **class diagrams**
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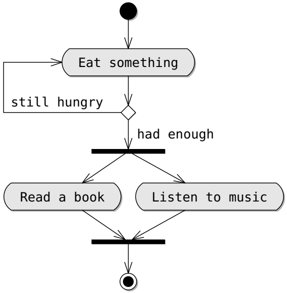
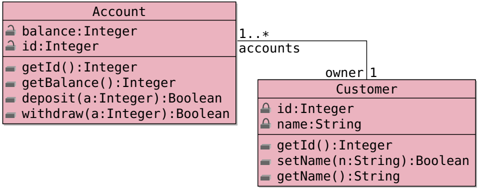
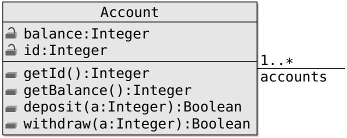




The Object Constraint Language (OCL)

- Textual extension of the UML
- Allows for annotating UML diagrams
- In the context of class–diagrams:
    - invariants
    - preconditions
    - postconditions
- Can be used for other diagrams



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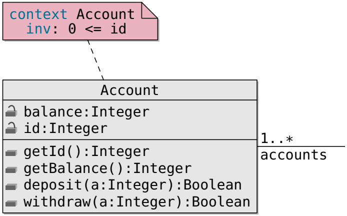

```
context Account
  inv: 0 <= id
```

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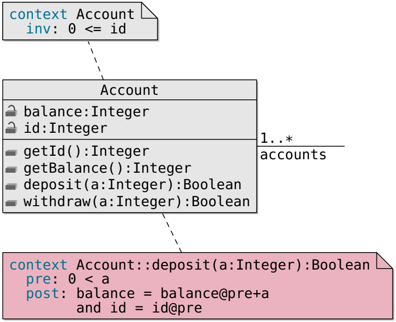

```
context Account
  inv: 0 <= id
```

```
context Account::deposit(a:Integer):Boolean
  pre: 0 < a
  post: balance = balance@pre+a
        and id = id@pre
```

OCL by Example

- Class invariants:

```
context Account inv: 0 <= id
```

- Operation specifications:

```
context Account::deposit(a:Integer):Boolean
pre: 0 < a
post: balance = balance@pre + a
```

- A “uniqueness” constraint for the class `Account`:

```
context Account inv:
    Account::allInstances()
      ->forAll(a1,a2 | a1.id = a2.id implies a1 = a2)
```

OCL context OCL keywords UML path expressions

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Developing Formals Tools for UML/OCL?

Turning UML/OCL into a formal method

1. A formal semantics of **UML class models**
    - typed path expressions
    - inheritance
    - dynamic binding
    - . . .
2. A formal semantics of **OCL** and proof support for OCL
    - reasoning over UML path expressions
    - large libraries
    - three-valued logic
    - . . .

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   - **Formalization of OCL**
   - Formalization of UML
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How to Formalize OCL ?

The semantic foundation of the OCL standard:

Chapter 11 “The OCL Standard Library” (normative):
describes the requirements (pre-/post-style)

Appendix A “Semantics” (informative):
presents a formal semantics (paper and pencil)

The OCL Semantics: An Example

- The Interpretation of “`X->union(Y)`” for sets (“$X \cup Y$”):

$$I(\cup)(X,Y) \equiv \begin{cases} X \cup Y & \text{if } X \neq \perp \text{ and } Y \neq \perp, \\ \perp & \text{otherwise} \end{cases}$$

- This is a
  - **lifted** (sets can be undefined, denoted by $\perp$) and
  - **strict** (the union of undefined with anything is undefined)

  version of the union of “mathematical sets.”

A Machine-checked Semantics

- Our formalization of "`X->union(Y)`" for sets ("$X \cup Y$"):

$$\_\texttt{->union}\_ \equiv \Big(\text{strictify}\big(\lambda X.\ \text{strictify}(\lambda Y.\ \lfloor \ulcorner X \urcorner \cup \ulcorner Y \urcorner \rfloor)\big)\Big)\ .$$

- We model concepts like **strict** and **lifted** explicit, i. e., we introduce:
  - a datatype for lifting:

$$\alpha_\perp := \lfloor \alpha \rfloor \mid \perp$$

  - a combinator for strictification:

$$\text{strictify}\ f\ x \equiv \text{if}\ x = \perp\ \text{then}\ \perp\ \text{else}\ f\ x$$

Is This Semantics Compliant?

- We prove formally (within our embedding):

$$\mathrm{Sem}[\![\texttt{not}\ \ X]\!]\gamma = \begin{cases} \llcorner\neg\ulcorner\mathrm{Sem}[\![X]\!]\gamma\urcorner\lrcorner & \text{if } \mathrm{Sem}[\![X]\!]\gamma \neq \bot\,, \\ \bot & \text{otherwise}\,. \end{cases}$$

```
lemma "(Sem⟦not x⟧γ) = (if Sem⟦x⟧γ ≠ ⊥ then ⌞¬⌜Sem⟦x⟧γ⌝⌟ else ⊥)"
  apply(simp add: OclNot_def DEF_def lift0_def lift1_def lift2_def
                  semfun_def )
done
```

Proving Requirements

isEmpty() : Boolean (11.7.1-g)

Is self the empty collection?

```
post: result = ( self->size() = 0 )
```

Bag

lemma (*self* `->isEmpty()`) = ((self, β :: bot)Bag)`->size()` $\doteq$ 0
apply(rule Bag_sem_cases_ext, simp_all)
apply(simp_all add: OCL_Bag.OclSize_def OclMtBag_def
OclStrictEq_def
Zero_ocl_int_def ss_lifting')
done

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A Semantics of Typed Path Expressions

Question: What is the semantics of `self.s`?

Access the value of the attribute s of the object `self`.

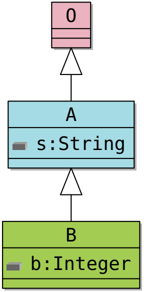
- Formalizing **type safe** path expressions requires
  - a HOL representation of class types
  - HOL functions for accessing attributes
  - support for inheritance and subtyping
- After **adding new classes** to a model
  - there is no need for re-proving
  - definitions can be re-used
- Goal: a type-safe object store, supporting modular proofs

Representing Class Types

- The “extensible records” approach
  - We assume a common superclass (0).
  - The uniqueness is guaranteed by a *tag type*, e. g.:

$$O_{\text{tag}} := \text{classO}$$

  - Construct class type as tuple along inheritance hierarchy



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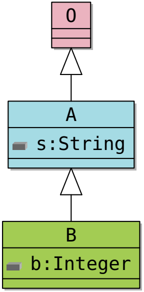

$B :=$

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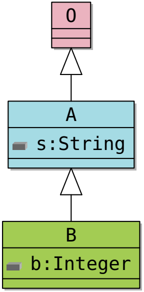
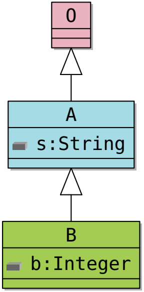


$$B := (O_{\mathrm{tag}} \times \mathrm{oid})$$

Representing Class Types



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$$\mathrm{B} := (\mathrm{O}_{\mathrm{tag}} \times \mathrm{oid}) \times \Big((\mathrm{A}_{\mathrm{tag}} \times \mathtt{String}) \qquad\qquad\qquad\qquad \Big)$$

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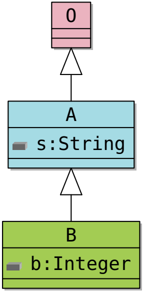

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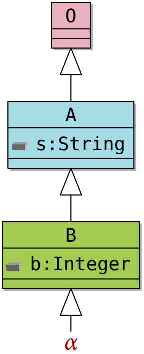

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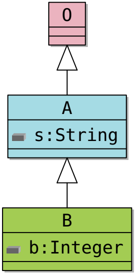
$$\alpha\ \mathrm{B} := (\mathrm{O}_{\mathrm{tag}} \times \mathrm{oid}) \times \Big((\mathrm{A}_{\mathrm{tag}} \times \mathtt{String}) \times \big((\mathrm{B}_{\mathrm{tag}} \times \mathtt{Integer}) \times \alpha_{\perp}\big)_{\perp}\Big)_{\perp}$$

where $\_{}_{\perp}$ denotes types supporting undefined values.

Representing Class Types: Summary

- Advantages:
  - it allows for extending class types (inheritance),
  - subclasses are type instances of superclasses

  ⇒ **it allows for modular proofs**, i. e., a statement $\phi(x :: (\alpha\ \mathrm{B}))$ proven for class B is still valid after extending class B.
- However, it has a major disadvantage:
  - modular proofs are only supported for **one** extension per class

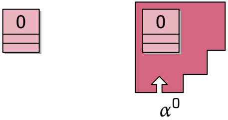


A Universe Type

A **universe** type represents all classes

- supports modular proofs with arbitrary extensions
- provides a formalization of a extensible typed object store

An Extensible Object Store



$$\mathsf{U}^0_{(\alpha^0)} = O \times \alpha^0_\perp$$

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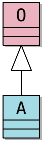

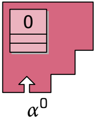

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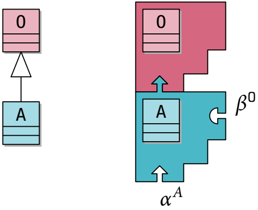

$$\mathsf{U}^0_{(\alpha^0)} = O \times \alpha^0_\perp$$

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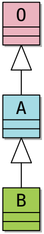

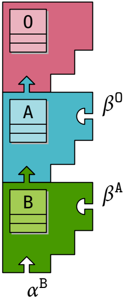

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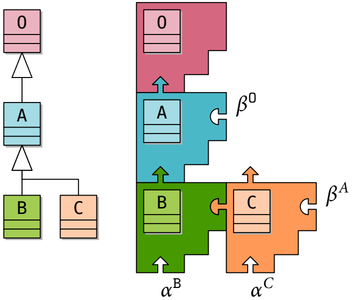

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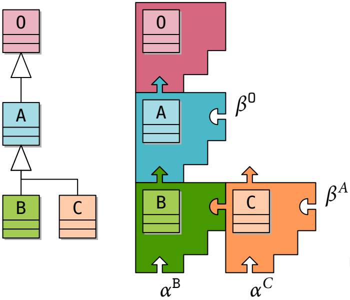

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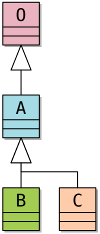
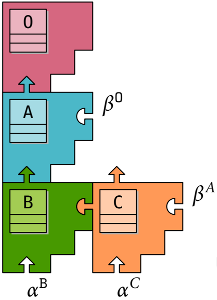
$$\mathsf{U}^3_{(\alpha^B,\alpha^C,\beta^0,\beta^A)} = O \times (A \times (B \times \alpha^B_\perp + (C \times \alpha^C_\perp + \beta^A))_\perp + \beta^0)_\perp$$

An Extensible Object Store





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$$\mathsf{U}^2_{(\alpha^B,\beta^0,\beta^A)} = O \times (A \times (B \times \alpha^B_\perp + \beta^A)_\perp + \beta^0)_\perp$$

$$\mathsf{U}^3_{(\alpha^B,\alpha^C,\beta^0,\beta^A)} = O \times (A \times (B \times \alpha^B_\perp + (C \times \alpha^C_\perp + \beta^A))_\perp + \beta^0)_\perp$$

$$\mathcal{U}^3_{(\alpha^B,\alpha^C,\beta^0,\beta^A)} \prec \mathcal{U}^2_{(\alpha^B,\beta^0,\beta^A)} \prec \mathcal{U}^1_{(\alpha^A,\beta^0)} \prec \mathcal{U}^0_{(\alpha^0)}$$

Operations Accessing the Object Store

- injections

  $\mathsf{mk}_{\mathsf{O}}\, o = \mathsf{Inl}\, o$ with type $\alpha^{O}\ \mathsf{0} \to \mathscr{U}^{\mathsf{0}}_{\alpha^{O}}$

- projections

  $\mathsf{get}_{\mathsf{O}}\, u = u$ with type $\mathscr{U}^{\mathsf{0}}_{\alpha^{O}} \to \alpha^{O}\ \mathsf{0}$

- type casts

  $\mathsf{A}_{[\mathsf{O}]} = \mathsf{get}_{\mathsf{O}} \circ \mathsf{mk}_{\mathsf{A}}$ with type $\alpha^{A}\ \mathrm{A} \to (A \times \alpha^{A}_{\perp} + \beta^{O})\ \mathsf{0}$

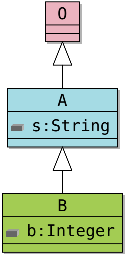
  $\mathsf{O}_{[\mathsf{A}]} = \mathsf{get}_{\mathsf{A}} \circ \mathsf{mk}_{\mathsf{O}}$ with type $(A \times \alpha^{A}_{\perp} + \beta^{O})\ \mathsf{0} \to \alpha^{A}\ \mathrm{A}$

- . . .

All definitions are generated automatically

Does This Really Model Object-orientation?

For each UML model, we have to show several properties:



- subclasses are of the superclasses kind:

$$\frac{\mathrm{isType}_{\mathrm{B}}\ \mathit{self}}{\mathrm{isKind}_{\mathrm{A}}\ \mathit{self}}$$

- "re-casting":

$$\frac{\mathrm{isType}_{\mathrm{B}}\ \mathit{self}}{\mathit{self}_{[\mathrm{A}][\mathrm{B}]} \neq \bot \wedge \mathrm{isType}_{\mathrm{B}}\ (\mathit{self}_{[\mathrm{A}][\mathrm{B}][\mathrm{A}]})}$$

- monotonicity of invariants, . . .

All rules are derived automatically

First Results of Formalizing the OCL Standard

- We found several glitches:
  - inconsistencies between the formal semantics and the requirements
  - missing pre- and postconditions
  - wrong (e.g., to weak) pre- and postconditions
  - . . .
- and examined possible extensions (open problems):
  - operations calls and invocations
  - smashing of datatypes
  - equalities
  - recursion
  - semantics for invariants (type sets)
  - . . .

Outline

1. Introduction
2. Background
3. Formalization of UML and OCL
4. **Mechanized Support for Model Analysis Methods**
5. The HOL-OCL Architecture
6. Applications
7. Conclusion and Future Work

Motivation

Observation:

- UML/OCL is a *generic* modeling language:
  - usually, only a sub-set of UML is used and
  - per se there is no standard UML-based development process.
- Successful use of UML usually comprises
  - a well-defined development process and
  - tools that integrate into the development process.

Conclusion:

- Formal methods for UML-based development should
  - support the local UML development methodologies and
  - integrate smoothly into the local toolchain.

A toolchain for formal methods should provide
tool-support for **methodologies**.

Well-formedness of Models

Well-formedness Checking

- Enforce **syntactical** restriction on (valid) UML/OCL models.
- Ensure a minimal quality of models.
- Can be easily supported by fully-automatic tools.

Example

- There should be at maximum five inheritance levels.
- The Specification of public operations may only refer to public class members.
- . . .

Proof Obligations for Models

Proof Obligation Generation

- Enforce **semantical** restriction on (valid) UML/OCL models.
- Build the basis for formal development methodologies.
- Require formal tools (theorem prover, model checker, etc).

Example

- Liskov’s substitution principle.
- Model consistency
- Refinement.
- . . .

Proof Obligations: Liskov's Substitution Principle

Liskov substitution principle

Let $q(x)$ be a property provable about objects x of type T. Then $q(y)$ should be true for objects y of type S where S is a subtype of T.

For constraint languages, like OCL, this boils down to:

- *pre-conditions* of overridden methods must be *weaker*.
- *post-conditions* of overridden methods must be *stronger*.

Which can formally expressed as implication:

- Weakening the pre-condition:

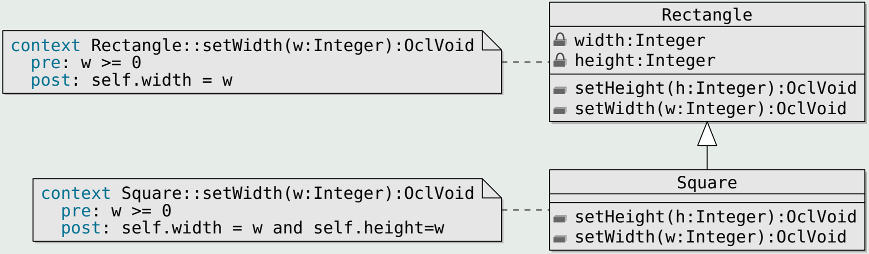
$$op_{\text{pre}} \longrightarrow op_{\text{pre}}^{\text{sub}}$$

- Weakening the pre-condition:

$$op_{\text{post}}^{\text{sub}} \longrightarrow op_{\text{post}}$$

Proof Obligations: Liskov’s Substitution Principle

Example



```
context Rectangle::setWidth(w:Integer):OclVoid
  pre: w >= 0
  post: self.width = w
```

```
context Square::setWidth(w:Integer):OclVoid
  pre: w >= 0
  post: self.width = w and self.height=w
```

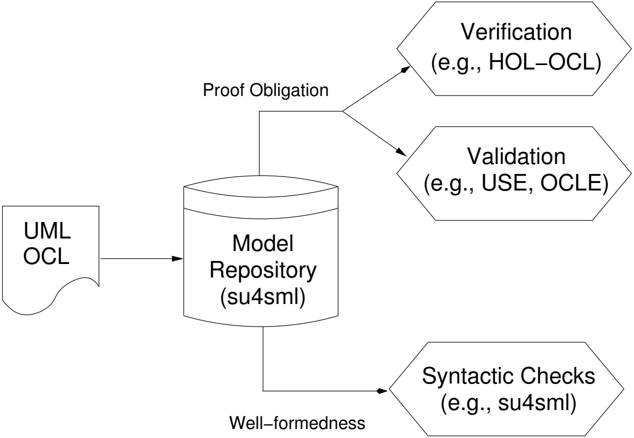
- Weakening the pre-condition:

$$(\texttt{w >= 0}) \longrightarrow (\texttt{w >= 0})$$

- Strengthening the post-condition:

$$(\texttt{self.width = w and self.height = w}) \longrightarrow (\texttt{self.width = w})$$

Well-formedness and Proof Obligations



Methodology

A tool-supported methodology should

- integrate into existing toolchains and processes,
- provide a unified approach, integrating ,
  - syntactic requirements (well-formedness checks),
  - generation of proof obligations,
  - means for **verification** (proving) or **validation**, and of course
- all phases should be supported by tools.

Example

A package-based object-oriented refinement methodology.

Refinement – Motivation

Support top-down development from an abstract model to a more concrete one.

- We start with an abstract transition system

$$sys_{\text{abs}} = (\sigma_{\text{abs}}, init_{\text{abs}}, op_{\text{abs}})$$

- We refine each abstract operation op_{abs} to a more concrete one: op_{conc}.
- Resulting in a more concrete transition system

$$sys_{\text{conc}} = (\sigma_{\text{conc}}, init_{\text{conc}}, op_{\text{conc}})$$

- Such refinements can be chained:

$$sys_1 \leadsto sys_2 \leadsto \cdots \leadsto sys_n$$

E.g., from an abstract model to one that supports code generation.

Refinement: Well-formedness

If package *B* refines a package *A*, then
one should be able to substitute every usage of package *A* with package *B*.

1. The concrete package must provide at a corresponding public class for each public class of the abstract model.
2. For public attributes we require that their type and for public operations we require that the return type and their argument types are either basic datatypes or public classes.
3. For each public class of the abstract package, we require that the corresponding concrete class provides at least
    1. public attributes with the same name and
    2. public operations with the same name.
4. The types of corresponding abstract and concrete attributes and operations are compatible.

Refinement: Proof Obligtations – Consistency

A transition system is consistent if:

- The set of initial states is non-empty, i. e.,

$$\exists \sigma.\ \sigma \in \mathit{init}$$

- The state invariant is satisfiable, i. e., the conjunction of all invariants is invariant-consistent:

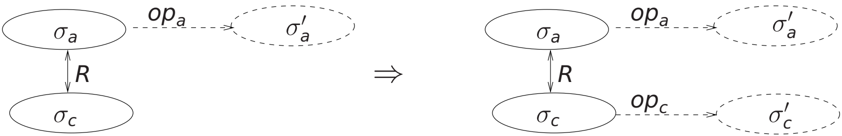
$$\exists \sigma.\ \sigma \models \mathit{inv}_1 \land \exists \sigma.\ \sigma \models \mathit{inv}_2 \land \cdots \land \exists \sigma.\ \sigma \models \mathit{inv}_n$$

- All operations op are implementable, i. e., for each satisfying pre-state there exists a satisfying post-state:

$$\forall\ \sigma_{\text{pre}} \in \Sigma, \mathit{self}, i_1, \ldots, i_n.\ \sigma_{\text{pre}} \models \text{pre}_{op} \longrightarrow \exists\ \sigma_{\text{post}} \in \Sigma, \mathit{result}.\ (\sigma_{\text{pre}}, \sigma_{\text{post}}) \models \text{post}_{op}$$

Refinement: Proof Obligtations – Implements

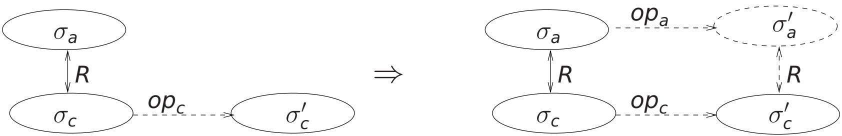
- Given an abstraction relation $R : \mathbb{P}(\sigma_{\text{abs}} \times \sigma_{\text{conc}})$ relating a concrete state S and an abstract states T.
- A forward refinement $S \sqsubseteq_{FS}^{R} T \equiv po_1(S,R,T) \wedge po_2(S,R,T)$ requires two proof obligations po_1 and po_2.
- **Preserve Implementability (po_1):**



$$po_1(S,R,T) \equiv \forall \sigma_a \in \text{pre}(S), \sigma_c \in V.\ (\sigma_a, \sigma_c) \in R \rightarrow \sigma_c \in \text{pre}(T)$$

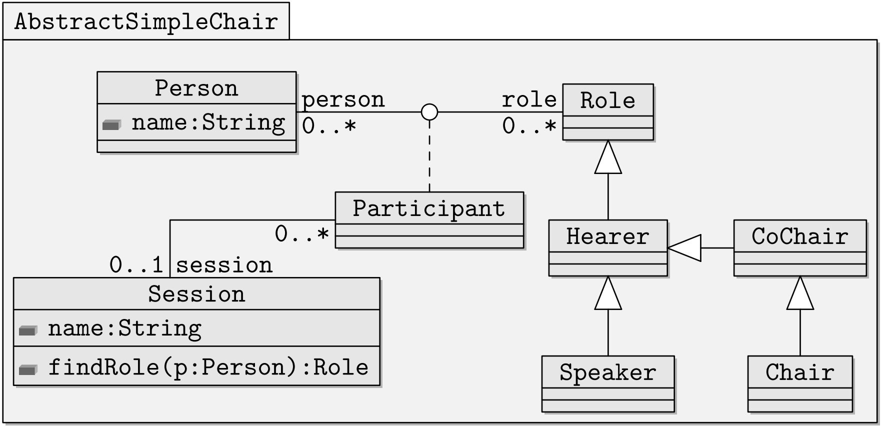
Refinement: Proof Obligtations – Refines

- Given an abstraction relation $R : \mathbb{P}(\sigma_{\text{abs}} \times \sigma_{\text{conc}})$ relating a concrete state S and an abstract states T.
- A forward refinement $S \sqsubseteq^{R}_{FS} T \equiv po_1(S,R,T) \wedge po_2(S,R,T)$ requires two proof obligations po_1 and po_2.
- **Refinement (po_2):**

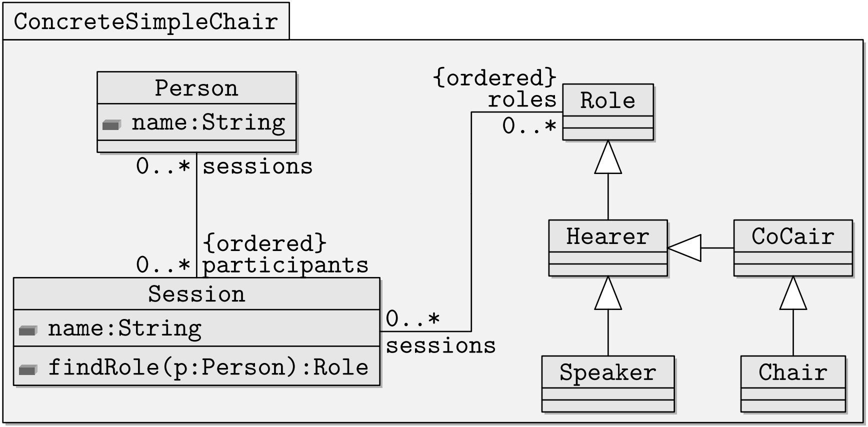


$$
\begin{aligned}
po_2(S,R,T) \equiv \forall \sigma_a \in \text{pre}(S), \sigma_c \in V.\ \sigma_{c'}.\ (\sigma_a, \sigma_c) \in R \\
\wedge\ (\sigma_c, \sigma'_c) \models_M T \longrightarrow \exists \sigma'_a \in V.\ (\sigma_a, \sigma'_a) \models_M S \wedge (\sigma_{a'}, \sigma_{c'}) \in R
\end{aligned}
$$

Refinement Example: Abstract Model



Refinement Example: Concrete Model



Outline

1. Introduction
2. Background
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4. Mechanized Support for Model Analysis Methods
5. The HOL-OCL Architecture
6. Applications
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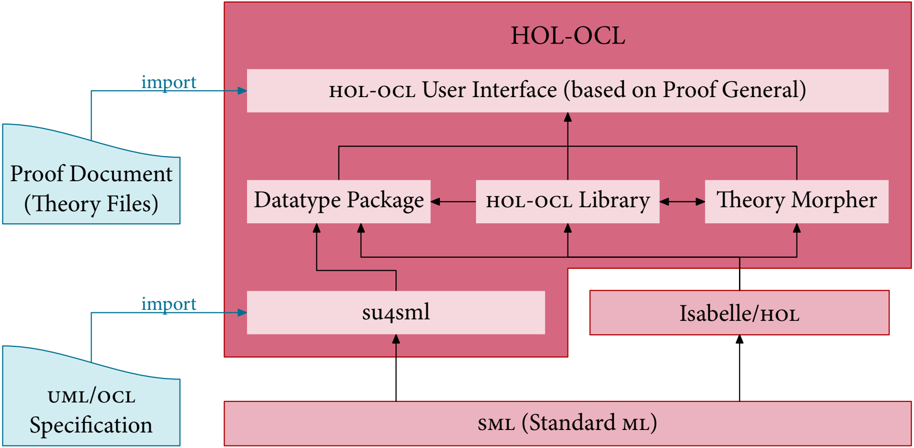
The HOL-OCL Architecture



su4sml – Overview

su4sml is a UML/OCL (and SecureUML) model repository providing

- a database for syntactic elements of UML core, namely class models and state machines as well as OCL expressions.
- support for SecureUML.
- import of UML/OCL models in different formats:
  - XMI and ArgoUML (class models and state machines)
  - OCL (plain text files)
  - USE (plain text files describing class models with OCL annotations)
- a template-based code generator (export) mechanism.
- an integrated framework for model transformations.
- a framework for checking well-formedness conditions.
- a framework for generating proof obligations.
- an interface to HOL-OCL (encoder, po manager).

su4sml – Code Generators

su4sml provides a template-based code generator for

- Java, supporting
    - class models and state machines
    - OCL runtime enforcement
    - SecureUML
- C#, supporting
    - class models and state machines
    - SecureUML
- USE
- . . .

su4sml – Model Transformations

su4sml provides a framework for model transformation that

- supports the generation of proof obligations
- can be programmed in SML.

Currently, the following transformations are provided:

- a family of semantic preserving transformations for converting associations (e. g., *n*-ary into binary ones)
- a transformation from SecureUML/ComponentUML to UML/OCL.

su4sml – Well-formedness Checks

su4sml provides an framework for extended well-formedness checking:

- Checks if a given model satisfies certain syntactic constraints,
- Allows for defining dependencies between different checks
- Examples for well-formedness checks are:
  - restricting the inheritance depth
  - restringing the use of private class members
  - checking class visibilities with respect to member visibilities
  - . . .
- Can be easily extended (at runtime).
- Is integrated with the generation of proof obligations.

su4sml – Proof Obligation Generator

su4sml provides an framework for proof obligation generation:

- Generates proof obligation in OCL plus minimal meta-language.
- Only minimal meta-language necessary:
  - Validity: $\models \_$, $\_ \models \_$
  - Meta level quantifiers: $\exists \_ .\ \_$, $\exists \_ .\ \_$
  - Meta level logical connectives: $\_ \vee \_$, $\_ \wedge \_$, $\neg \_$
- Examples for proof obligations are:
  - (semantical) model consistency
  - Liskov's substitution principle
  - refinement conditions
  - ...
- Can be easily extended (at runtime).
- Builds, together with well-formedness checking, the basis for tool-supported methodologies.

The Encoder

The model encoder is the main interface between su4sml and the Isabelle based part of HOL-OCL. The encoder

- declarers HOL types for the classifiers of the model,
- encodes
  - type-casts,
  - attribute accessors, and
  - dynamic type and kind tests implicitly declared in the imported data model,
- encodes the OCL specification, i. e.,
  - class invariants
  - operation specifications

  and combines it with the core data model, and
- proves (automatically) methodology and analysis independent properties of the model.

The Library

The HOL-OCL library

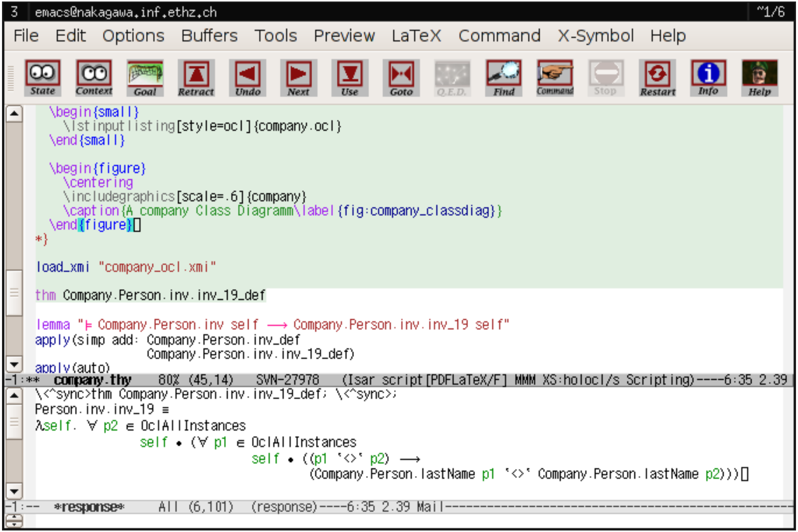
- formalizes the built-in operations of UML/OCL,
- comprises over 10 000 definitions and theorems,
- build the basis for new, OCL specific, proof procedures,
- provides proof support for (formal) development methodologies.

Tactics (Proof Procedures)

- OCL, as logic, is quite different from HOL (e. g., three-valuedness)
- Major Isabelle proof procedures, like `simp` and `auto`, cannot handle OCL efficiently.
- HOL-OCL provides several UML/OCL specific proof procedures:
  - embedding specific tactics (e. g., unfolding a certain level)
  - a OCL specific context-rewriter
  - a OCL specific tableaux-prover
  - . . .

  These language specific variants increase the degree of proof for OCL.

The HOL-OCL User Interface



```
  \begin{small}
    \lstinputlisting[style=ocl]{company.ocl}
  \end{small}

  \begin{figure}
    \centering
    \includegraphics[scale=.6]{company}
    \caption{A company Class Diagramm\label{fig:company_classdiag}}
  \end{figure}
*}

load_xmi "company_ocl.xmi"

thm Company.Person.inv.inv_19_def

lemma "⊨ Company.Person.inv self ⟶ Company.Person.inv.inv_19 self"
apply(simp add: Company.Person.inv_def
                Company.Person.inv.inv_19_def)
apply(auto)
-1:**  company.thy     80% (45,14)    SVN-27978    (Isar script[PDFLaTeX/F] MMM XS:holocl/s Scripting)----6:35 2.39
```

```
\<^sync>thm Company.Person.inv.inv_19_def; \<^sync>;
Person.inv.inv_19 ≡
λself. ∀ p2 ∈ OclAllInstances
               self • (∀ p1 ∈ OclAllInstances
                              self • ((p1 `<>` p2) ⟶
                                      (Company.Person.lastName p1 `<>` Company.Person.lastName p2)))
-1:--  *response*    All (6,101)   (response)----6:35 2.39 Mail------------------------------------------------
```

The HOL-OCL High-level Language

The HOL-OCL proof language is an extension of Isabelle’s Isar language:

- importing UML/OCL:

```
import_model "SimpleChair.zargo" "AbstractSimpleChair.ocl"
             include_only "AbstractSimpleChair"
```

- check well-formedness and generate proof obligations for refinement:

```
analyze_consistency [data_refinement] "AbstractSimpleChair"
```

- starting a proof for a generated proof obligation:

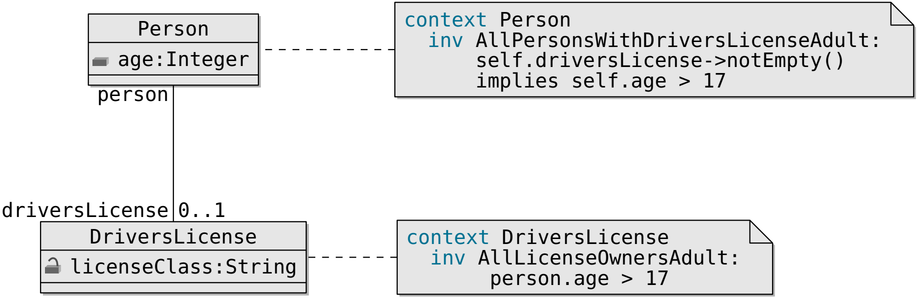
```
po "AbstractSimpleChair.findRole_enabled"
```

- generating code:

```
generate_code "java"
```

Outline

Simple Consistency Analysis I



```
context Person
  inv AllPersonsWithDriversLicenseAdult:
      self.driversLicense->notEmpty()
      implies self.age > 17
```

```
context DriversLicense
  inv AllLicenseOwnersAdult:
      person.age > 17
```

Figure: A simple model of vehicles and licenses

Simple Consistency Analysis II

```
lemma
assumes "τ ⊨ (Vehicles.Person.driversLicense(
                Vehicles.DriversLicense.person self)).IsDefined()"
                and "τ ⊨ (Vehicles.Person.age
                       (Vehicles.DriversLicense.person self)).IsDefined() "
  shows "τ ⊨ Person.inv.AllPersonsWithDriversLicenseAdult (
                  Vehicles.DriversLicense.person self)
           ⟶ τ ⊨ DriversLicense.inv.AllLicenseOwnersAdult self"
  apply(auto elim!: OclImpliesE)
  apply(cut_tac prems)
  apply(auto simp: inv.AllPersonsWithDriversLicenseAdult_def
                   inv.AllLicenseOwnersAdult_def
            elim!: OclImpliesE SingletonSetDefined)
done
```

Liskov's Substitution Principle I

```
context A::m(p:Integer):Integer
  pre: p > 0
  post: result > 0

context A::m(p:Integer):Integer
  pre: p >= 0
  post: result = p∗p + 5

-- The following constraints overrides the specification for
-- m(p:Integer):Integer that was originally defined in
-- class A, i.e., C is a subclass of A.
-- (Stricly, this is not valid with respect to the
--  UML/OCL standards...)
context C::m(p:Integer):Integer
  pre:  p >= 0
  post: result > 1 and result = p∗p+5
```

Liskov's Substitution Principle II

```
import_model "overriding.zargo" "overriding.ocl"

generate_po_liskov "pre"
generate_po_liskov "post"

po "overriding.OCL_liskov−po_lsk_pre−1"
  apply(simp add: A.m_Integer_Integer.pre1_def
                  A.m_Integer_Integer.pre1.pre_0_def
                  C.m_Integer_Integer.pre1_def
                  C.m_Integer_Integer.pre1.pre_0_def
                  A.m_Integer_Integer.pre1.pre_1_def)
  apply(ocl_auto)
discharged
```

Outline

Conclusion

- HOL-OCL provides:
  - a formal, machine-checked semantics for OO specifications,
  - an interactive proof environment for OO specifications,
  - publicly available: `http://www.brucker.ch/projects/hol-ocl/`,
  - next (major) release planned in October/November 2008.
- HOL-OCL is integrated into a toolchain providing:
  - extended well-formedness checking,
  - proof-obligation generation,
  - methodology support for UML/OCL,
  - a transformation framework (including PO generation),
  - code generators,
  - support for SecureUML.

Ongoing and Future Work

- Ongoing work includes improving the infrastructures for
    - well-formedness-checking,
    - proof-obligation generation (Liskov, Refinement,),
    - consistency checking,
    - Hoare-style program verification,
    - better proof automation in general.
- Future works could include the development for
    - integrating OCL validation tools, e.g., USE,
    - test-case generation (i.e., integrating HOL-TestGen),
    - supporting SecureUML.
    - . . . .

Thank you
for your attention!

Any questions or remarks?

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The HOL-OCL Website.
`http://www.brucker.ch/projects/hol-ocl/`.

Part II

Appendix

Outline

8 SecureUML – Model-driven Security

Outline

8 SecureUML – Model-driven Security
- SecureUML
- A Formal Model Transformation
- Consistency Analysis

Model-driven Security

Goals:

- A method to model secure designs and automatically transform these into secure systems.
- Supports well-established standards/technology for modelling components and security.
- Models are expressive, comprehensible, and maintainable.
- Reduces complexity of application development and improves the quality of the resulting applications.
- The entire process is semantically well-founded.
- Allows integrated formal reasoning over security design models.

SecureUML

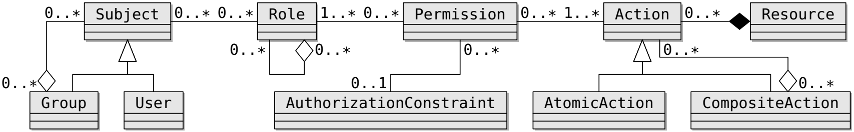


Figure: The SecureUML Metamodel

SecureUML

- provides abstract Syntax given by MOF compliant metamodel
- is a UML-based notation supporting role-based access control
- is pluggable into arbitrary design modeling languages
- is supported by an ArgoUML plugin

Modeling Access Control with SecureUML

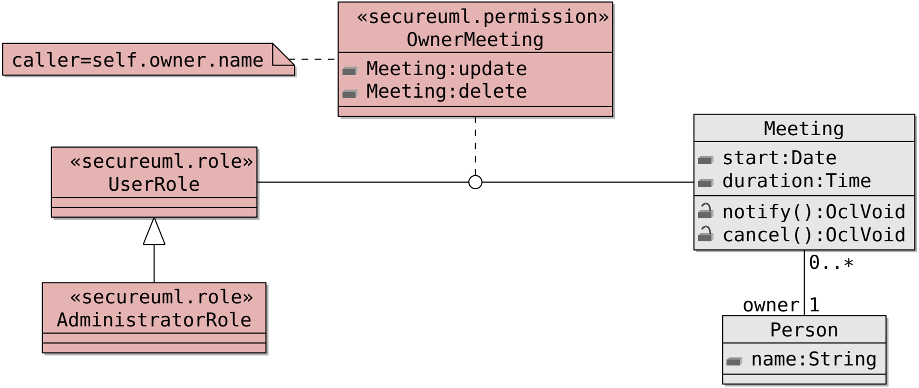
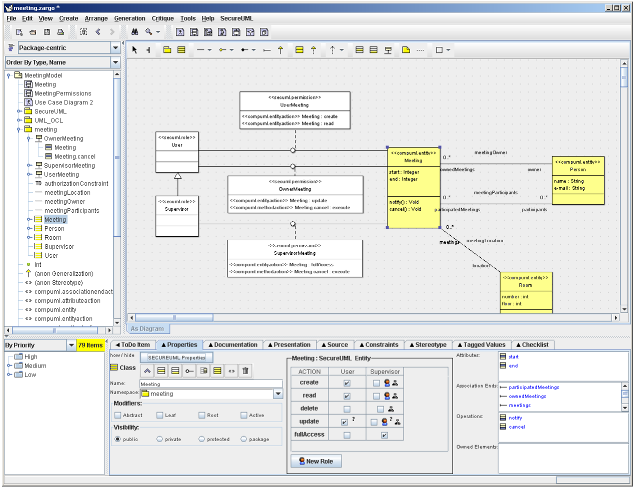


Figure: Access Control Policy for Class Meeting Using SecureUML

Supporting SecureUML in ArgoUML



Name: Meeting
Namespace: meeting

Modifiers:
☐ Abstract ☐ Leaf ☐ Root ☐ Active

Visibility:
● public ○ private ○ protected ○ package

Meeting : SecureUML Entity

ACTION	User	Supervisor
create	☑	☐
read	☑	☐
delete	☐	☐
update	☑ ?	☐ ?
fullAccess	☐	☑

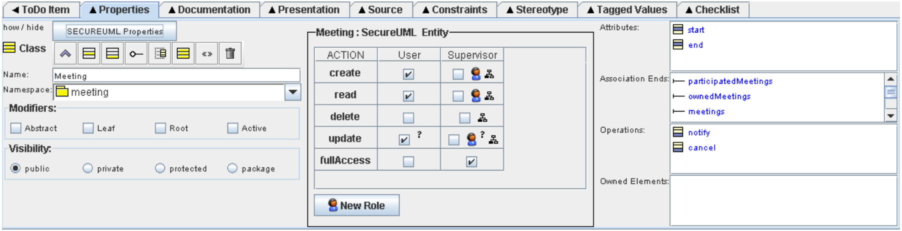
Attributes: start, end

Association Ends: participatedMeetings, ownedMeetings, meetings

Operations: notify, cancel

Owned Elements:

Supporting SecureUML in ArgoUML



Name: Meeting

Namespace: meeting

Modifiers: ☐ Abstract ☐ Leaf ☐ Root ☐ Active

Visibility: ● public ○ private ○ protected ○ package

Meeting : SecureUML Entity

ACTION	User	Supervisor
create	☑	☐
read	☑	☐
delete	☐	☐
update	☑ ?	☐ ?
fullAccess	☐	☑

Attributes:
- start
- end

Association Ends:
- participatedMeetings
- ownedMeetings
- meetings

Operations:
- notify
- cancel

Owned Elements:

From SecureUML to UML/OCL

Substitute the SecureUML model by an *explicit* enforcement model using UML/OCL.

The transformation basically

1. initializes a concrete authorization environment,
2. transforms the design model, and
3. transforms the security model.

The Authorization Environment

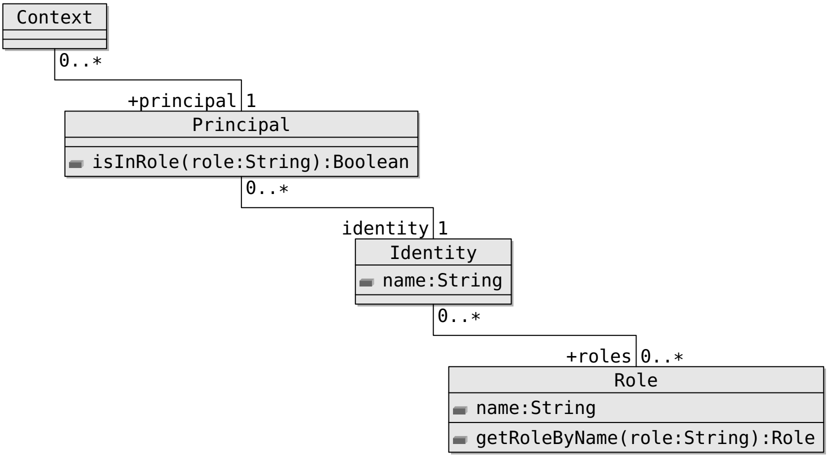


Figure: Basic Authorization Environment

Design Model Transformation

Generate *secured* operations for each class, attribute and operation in the design model.

- For each class C we add constructors and destructors,
- for each attribute of class C we add getter and setter operations, and
- for each operation op of class C we add a secured wrapper:

`context C::op_sec(...):...`
`pre:` pre_{op}
`post:` $\overline{\mathit{post}_{op}} = \mathit{post}_{op}$`[f()` $\mapsto$ `f_sec(), att` $\mapsto$ `getAtt()]`

Design Model Transformation: Classes

- for each class C

```
context C::new():C
  post: result.oclIsNew() and result->modifiedOnly()
context C::delete():OclVoid
  post: self.oclIsUndefined() and self@pre->modifiedOnly()
```

Design Model Transformation: Attributes

- for each Attribute `att` of class `C`

```
context C::getAtt():T
  post: result=self.att
context C::setAtt(arg:T):OclVoid
  post: self.att=arg and self.att->modifiedOnly()
```

Design Model Transformation: Operations

- for each Operation op of class C

`context C::op_sec(...):...`
  `pre:` pre_{op}
  `post:` $\overline{\mathrm{post}_{op}} = \mathrm{post}_{op}[\texttt{f()} \mapsto \texttt{f\_sec()},\ \texttt{att} \mapsto \texttt{getAtt()}]$

Security Model Transformation

- The role hierarchy is transformed into invariants for the `Role` and `Identity` classes.
- Security constraints are transformed as follows:

$$
\begin{array}{lcl}
\text{inv}_C & \longmapsto & \text{inv}_C \\
\text{pre}_{op} & \longmapsto & \text{pre}_{op} \\
\text{post}_{op} & \longmapsto & \texttt{if }\ \text{auth}_{op} \\
 & & \texttt{then }\ \overline{\text{post}}_{op} \\
 & & \texttt{else result.oclIsUndefined()} \\
 & & \qquad\quad \texttt{and Set\{\}->modifiedOnly()} \\
 & & \texttt{endif}
\end{array}
$$

where auth_{op} represents the authorization requirements.

Security Model Transformation: Role Hierarchy

- The total set of roles in the system is specified by enumerating them:

```
context Role
inv: Role.allInstances().name=Bag{<List of Role Names>}
```

The inheritance relation between roles is then specified by an OCL invariant constraint on the `Identity` class:

```
context Identity
inv: self.roles.name->includes('<Role1>')
     implies self.roles.name->includes('<Role2>')
```

Relative Consistency

- An invariant (class) is **invariant-consistent**, if a satisfying state exists:

$$\exists \sigma.\ \sigma \models \mathit{inv}$$

- A class model is **global consistent**,
  if the conjunction of all invariants is invariant-consistent:

$$\exists \sigma.\ \sigma \models \mathit{inv}_1 \ \ \text{and}\ \ \mathit{inv}_2 \ \ \text{and}\ \ \cdots \ \ \text{and}\ \ \mathit{inv}_n$$

- An operation is **implementable**, if
  for each satisfying pre-state there exists a satisfying post-state:

$$\forall\, \sigma_{\text{pre}} \in \Sigma, \mathit{self}, i_1, \ldots, i_n.\ \sigma_{\text{pre}} \models \text{pre}_{op} \longrightarrow \\ \exists\, \sigma_{\text{post}} \in \Sigma, \mathit{result}.\ (\sigma_{\text{pre}}, \sigma_{\text{post}}) \models \text{post}_{op}$$

Proof Obligations

- We require:
  - if a security violation occurs, the system state is preserved
  - if access is granted, the model transformation preserves the functional behavior

  Which results for each operation in a *security proof obligation*:

$$\mathrm{spo}_{op} := \mathrm{auth}_{op}\ \ \texttt{implies}\ \ \mathrm{post}_{op} \triangleq \overline{\mathrm{post}}_{op}$$

- A class system is called **security consistent** if all spo_{op} hold.

Modularity Results

Our method allows for
a modular specifications and reasoning for secure systems.

Theorem (Implementability)

An operation op_sec of the secured system model is implementable provided that the corresponding operation of the design model is implementable and spo_{op} *holds.*

Theorem (Consistency)

A secured system model is consistent provided that the design model is consistent, the class system is security consistent, and the security model is consistent.