A Shallow Embedding of OCL into Isabelle/HOL and its Application to Formal Testing

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Motivation

The Situation Today:

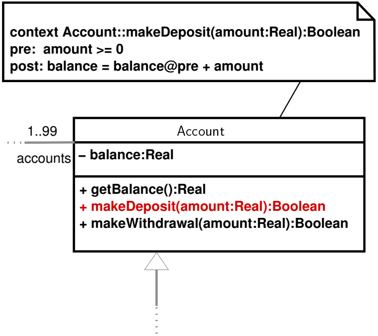
- Software systems are
  - getting more and more complex.
  - used in safety and security critical applications.
- We think that
  - complex software systems require a precise specification.
  - semi-formal methods are not strong enough.

There are many reasons for using formal methods:

- safety critical applications, e.g. flight or railway control.
- security critical applications, e.g. access control.
- legal reasons, e.g. certifications.
- financial reasons (e.g. warranty), e.g. embedded devices.

UML Class Diagrams and OCL

- designed for annotating UML diagrams (and give foundation for injectivities, ...)
- based on logic and set theory
- in the context of class-diagrams:
  - preconditions
  - postconditions
  - invariants
- can also be used for other diagram types



Machine Checkable Semantics

- A machine checked semantics
  - as a *conservative* embedding guarantees the consistency.
  - builds the basis for analyzing language features.
  - allows for incremental changes of semantics.
  - builds the basis for further extensions and tool support.
- The definition of the logical *and* (Kleene-logic):

$$\begin{aligned} S \textbf{ and } T \equiv \lambda c.\ & \textbf{if } \mathrm{DEF}\,(S\ c)\ \textbf{then} \\ & \quad \textbf{if } \mathrm{DEF}\,(T\ c)\ \textbf{then } \lfloor \lceil S\ c \rceil \wedge \lceil T\ c \rceil \rfloor \\ & \quad \textbf{else } \textbf{if } S\ c = (\lfloor \mathrm{False} \rfloor)\ \textbf{then } \lfloor \mathrm{False} \rfloor\ \textbf{else } \bot \\ & \textbf{else } \textbf{if } T\ c = (\lfloor \mathrm{False} \rfloor)\ \textbf{then } \lfloor \mathrm{False} \rfloor\ \textbf{else } \bot \end{aligned}$$

  The truth-table can be derived from this definition.
- The *union* of sets is defined as the *strict* and *lifted* version of $\cup$:

$$\mathrm{union} \equiv \mathrm{lift}_2\,(\,\mathit{strict}\,(\lambda X.\mathit{strict}\,(\lambda Y.\mathrm{Abs}_{\mathrm{SSet}}(\lfloor \lceil \mathrm{Rep}_{\mathrm{SSet}} X \rceil \cup \lceil \mathrm{Rep}_{\mathrm{SSet}} Y \rceil \rfloor))))$$

HOL-OCL: An Interactive OCL Proof Environment

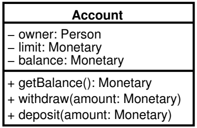
- Foundation:
  - *Isabelle* is a generic theorem prover.
  - *HOL* is a classical logic with higher-order functions.
  - *Isabelle*'s logics are designed to be extensible.
- HOL-OCL is
  - build on top of Isabelle/HOL.
  - a shallow embedding of OCL into HOL.
  - a conservative extension of Isabelle/HOL.
- HOL-OCL is an interactive theorem prover for OCL that
  - provides a consistent (machine checked) OCL semantics.
  - allows one to examine OCL features.
  - has built-in over 2000 theorems (proven language properties).
  - builds the basis for OCL tool development.

Excursion: Formal Challenges

Only few formal methods are specialized for analyzing object oriented specifications.

- Problems and open questions:
  - object equality and aliasing
  - embedding of object structures into logics
  - referencing and dereferencing, including "null" references
  - dynamic binding
  - polymorphism
  - ...
- Turning UML/OCL into a formal method:
  - semantics for OCL only given in a semi-formal way
  - OCL expressions are only meaningful together with the underlying UML model
  - no proof calculi for OCL
  - no refinement notions for OCL
  - ...

Specification Based Test Case Generation




```
context: Account.withdraw(amount : Integer)
pre:     0 < amount and ((caller=owner
                     and amount < 1000)
         or caller.isInRoke(clerk))
post: balance=balance@pre - amount
```

A *owner* can only withdraw up to a specific limit, a *clerk* (assuming, in behalf of the account owner) can withdraw an unlimited amount. Only positive amounts can be withdrawn.

Observation: In a an OCL proof environment like HOL-OCL one can prove security properties on specification-level.

Problem: How can one be sure, that a given *implementation* fulfills the given security constraints.

Solution: Generate test case based on the specification and use them for testing the implementation (in its real-world environment).

Application: Automatic Test Case Generation

- A withdrawal is allowed only in the following two cases:
  1. $[\![0 < \texttt{amount}; \texttt{amount} < 1000; \texttt{caller} = \texttt{owner}]\!]$
  2. $[\![0 < \texttt{amount}; \texttt{caller.isInRole}(\texttt{clerk})]\!]$
- and should be denied in the following cases:
  1. $[\![\neg 0 < \texttt{amount}]\!]$
  2. $[\![\neg \texttt{caller.isInRole}(\texttt{clerk}); \texttt{caller} \neq \texttt{owner}]\!]$
  3. $[\![\neg \texttt{caller.isInRole}(\texttt{clerk}); \neg \texttt{amount} < 1000]\!]$

Selecting at least one set of concrete test data out of each partition assures path coverage on the specification. In addition, additionally boundary cases (min/max values, etc) are also tested.

Conclusion

- UML class diagrams *with* OCL
  - are a formal specification notion.
  - allowing one to introduce formal specification stepwise.
- HOL-OCL
  - provides a consistent semantics for OCL.
  - allows the definition of a proof calculi over OCL.
  - allows a refinement notion for OCL specifications.
  - allows verification and validation of OCL specifications.

Further Readings

- http://www.brucker.ch/research/holocl.en.html.

- Achim D. Brucker and Burkhart Wolff. HOL-OCL: Experiences, consequences and design choices. In Jean-Marc Jézéquel, Heinrich Hussmann, and Stephen Cook, editors, *UML 2002: Model Engineering, Concepts and Tools*, number 2460 in Lecture Notes in Computer Science, pages 196–211. Springer-Verlag, Dresden, 2002. http://www.brucker.ch/bibliography/abstract/brucker.ea-hol-ocl-2002.

- Achim D. Brucker and Burkhart Wolff. A proposal for a formal OCL semantics in Isabelle/HOL. In César Muñoz, Sophiène Tahar, and Víctor Carreño, editors, *Theorem Proving in Higher Order Logics*, number 2410 in Lecture Notes in Computer Science, pages 99–114. Springer-Verlag, Hampton, VA, USA, 2002. http://www.brucker.ch/bibliography/abstract/brucker.ea-proposal-2002.