Software Design, Modelling and Analysis in UML

Lecture 03: Object Constraint Language

2016-10-27

Prof. Dr. Andreas Podelski, **Dr. Bernd Westphal**

Albert-Ludwigs-Universität Freiburg, Germany

Content

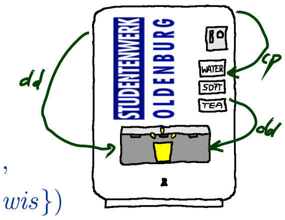
- The **Object Constraint Language** (OCL):
  Syntax
  - Running Example
  - Overview
  - Expressions
    - Notational Conventions
      ("." (OCL-Dot) and "->" (OCL-Arrow))
  - Constants & Arithmetics
  - Iterate
  - Context
    - More Notational Conventions
  - The Running Example Revisited
- **"Not Interesting"**

(Core) OCL Syntax OMG (2006)

Overview

$$
\begin{array}{lll}
\mathit{expr} ::= & w & : \tau(w) \\
& \mid \mathit{expr}_1 =_\tau \mathit{expr}_2 & : \tau \times \tau \to \mathit{Bool} \\
& \mid \mathsf{oclIsUndefined}_\tau(\mathit{expr}_1) & : \tau \to \mathit{Bool} \\
& \mid \{\mathit{expr}_1, \dots, \mathit{expr}_n\} & : \tau \times \dots \times \tau \to \mathit{Set}(\tau) \\
& \mid \mathsf{size}(\mathit{expr}_1) & : \mathit{Set}(\tau) \to \mathit{Int} \\
& \mid \mathsf{allInstances}_C & : \mathit{Set}(\tau_C) \\
& \mid v(\mathit{expr}_1) & : \tau_C \to \tau(v) \\
& \mid r_1(\mathit{expr}_1) & : \tau_C \to \tau_D \\
& \mid r_2(\mathit{expr}_1) & : \tau_C \to \mathit{Set}(\tau_D) \\
& \mid \mathsf{true}, \mathsf{false} & : \mathit{Bool} \\
& \mid \mathsf{not}\ \mathit{expr}_1 & : \mathit{Bool} \to \mathit{Bool} \\
& \mid \mathit{expr}_1 \ \{\mathsf{and}, \mathsf{or}, \mathsf{implies}\}\ \mathit{expr}_2 & : \mathit{Bool} \times \mathit{Bool} \to \mathit{Bool} \\
& \mid \dots & \\
& \mid \mathsf{OclUndefined}_\tau & : \tau \\
& \mid \mathit{expr}_1\text{->}\mathsf{iterate}(w_1 : T_1 ; w_2 : T_2 = \mathit{expr}_2 \mid \mathit{expr}_3) & : \mathit{Set}(\tau_0) \to \tau_{T_2} \\
\mathit{context} ::= & \mathsf{context}\ w_1 : T_1, \ \dots, w_n : T_n\ \mathsf{inv} : \mathit{expr} & : \mathit{Bool}
\end{array}
$$

Recall: Vending Machine Structure



$$\mathscr{S} = (\{Bool, \overset{Nat}{\cancel{Int}}\}, \{VM, CP, DD\},$$
$$\{cp : CP_*, dd : DD_{0,1}, wen : Bool, wis : Nat\},$$
$$\{VM \mapsto \{cp, dd\}, CP \mapsto \{wen, dd\}, DD \mapsto \{wis\})$$

Claim: this is a proper OCL constraint over $\mathscr{S}$:

context CP inv : wen implies $dd\,.\,wis > 0$

String $\quad \tau \to Int \quad \tau \times \tau \to Bool$

$T ::= ✿ \mid \square(T) \mid ♡(T_1, T_2)$

✿, ✓

$\square(✿) : \overset{Int}{\cancel{Bool}}$ ✓

$♡(✿, ✿) : Bool$ ✓

⋮

$♡(\underset{String}{✿}, \overset{Int}{\square(✿)})$ ✗ (not well-typed)

Plan

	$expr ::=$	w	$: \tau(w)$
1/4		$\mid expr_1 =_\tau expr_2$	$: \tau \times \tau \to Bool$
		$\mid$ oclIsUndefined$_\tau(expr_1)$	$: \tau \to Bool$
		$\mid \{expr_1, \dots, expr_n\}$	$: \tau \times \dots \times \tau \to Set(\tau)$
		$\mid$ size$(expr_1)$	$: Set(\tau) \to Int$
		$\mid$ allInstances$_C$	$: Set(\tau_C)$
		$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
		$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
		$\mid r_2(expr_1)$	$: \tau_C \to Set(\tau_D)$
2/4		$\mid$ true, false	$: Bool$
		$\mid$ not $expr_1$	$: Bool \to Bool$
		$\mid expr_1$ {and, or, implies} $expr_2$	$: Bool \times Bool \to Bool$
		$\mid \dots$	
		$\mid$ OclUndefined$_\tau$	$: \tau$
3/4		$\mid expr_1$->iterate$(w_1 : T_1 ; w_2 : T_2 = expr_2 \mid expr_3)$	$: Set(\tau_0) \to \tau_{T_2}$
4/4	$context ::=$	context $w_1 : T_1, \dots, w_n : T_n$ inv : $expr$	$: Bool$

OCL Syntax 1/4: Expressions

$$
\begin{array}{lll}
expr ::= & & \\
\quad w & : \tau(w) & \\
\quad \mid expr_1 =_\tau expr_2 & : \tau \times \tau \to \underset{T_B}{Bool} & \\
\quad \mid \mathsf{oclIsUndefined}_\tau(expr_1) & : \tau \to Bool & \\
\quad \mid \{expr_1, \dots, expr_n\} & : \tau \times \dots \times \tau \to Set(\tau) & \\
\quad \mid \mathsf{isEmpty}(expr_1) & : Set(\tau) \to Bool & \\
\quad \mid \mathsf{size}(expr_1) & : Set(\tau) \to Int & \\
\quad \mid \mathsf{allInstances}_C & : Set(\tau_C) & \\
\quad \mid v(expr_1) & : \tau_C \to \tau & \text{where } v : \tau \in atr(C),\ \tau \in \mathscr{T}, \\
\quad \mid r_1(expr_1) & : \tau_C \to \tau_D & \text{where } r_1 : D_{0,1} \in atr(C), C, D \in \mathscr{C}, \\
\quad \mid r_2(expr_1) & : \tau_C \to Set(\tau_D) & \text{where } r_2 : D_* \in atr(C), C, D \in \mathscr{C}.
\end{array}
$$

Where, given $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr)$,

- $w \in W \supseteq \{self_C : \tau_C \mid C \in \mathscr{C}\}$ is a set of typed logical variables, w has type $\tau(w)$
- τ is any type from $\mathscr{T} \cup T_B \cup T_{\mathscr{C}} \cup \{Set(\tau_0) \mid \tau_0 \in \mathscr{T} \cup T_B \cup T_{\mathscr{C}}\}$
  - T_B is a set of (OCL) basic types, in the following we use $T_B = \{Bool, Int, String\}$
  - $T_{\mathscr{C}} = \{\tau_C \mid C \in \mathscr{C}\}$ is the set of object types,
  - $Set(\tau_0)$ denotes the set-of-τ_0 type for $\tau_0 \in T_B \cup T_{\mathscr{C}}$ (sufficient because of "flattening" (cf. standard)).

Expression Examples

$$
\begin{array}{ll|ll}
expr ::= & & \mid \mathsf{size}(expr_1) & : Set(\tau) \to Int \\
\quad w & : \tau(w) & \mid \mathsf{allInstances}_C & : Set(\tau_C) \\
\quad \mid expr_1 =_\tau expr_2 & : \tau \times \tau \to Bool & \mid v(expr_1) & : \tau_C \to \tau(v) \\
\quad \mid \mathsf{oclIsUndefined}_\tau(expr_1) & : \tau \to Bool & \mid r_1(expr_1) & : \tau_C \to \tau_D \\
\quad \mid \{expr_1, \dots, expr_n\} & : \tau \times \dots \times \tau \to Set(\tau) & \mid r_2(expr_1) & : \tau_C \to Set(\tau_D) \\
\quad \mid \mathsf{isEmpty}(expr_1) & : Set(\tau) \to Bool & &
\end{array}
$$

$$\mathscr{S}_0 = (\{Int_0\}, \{\bar{C}, \bar{D}\}, \{x : Int_0, p : \bar{C}_{0,1}, n : \bar{C}_*\}, \{\bar{C} \mapsto \{p, n\}, \bar{D} \mapsto \{x\}\})$$

- $self_{\bar{D}} : \tau_{\bar{D}}$ ✓
- $x(self_{\bar{D}}) : Int_0$ ✓
- $p(self_{\bar{D}})$ ✗ $p \in atr(\bar{D})$
- $p(self_{\bar{C}}) : \tau_{\bar{C}} \to \tau_{\bar{C}}$ ✓
- $n(self_{\bar{C}}) : \tau_{\bar{C}} \to Set(\tau_{\bar{C}})$ ✓
- $n(\underbrace{p(self_{\bar{C}})}_{:\tau_{\bar{C}}}) : \tau_{\bar{C}} \to Set(\tau_{\bar{C}})$ ✓ $[self_{\bar{C}}.p.n]$
- $p(\underbrace{n(self_{\bar{C}})}_{\tau_{\bar{C}} \to Set(\tau_{\bar{C}})})$ $\lightning$ $[self_{\bar{C}}.n.\overset{\lightning}{p}]$
- $size(n(self_{\bar{C}})) : Set(\tau_{\bar{C}}) \to Int$

Expression Examples

$$
\begin{array}{lll|ll}
\mathit{expr} ::= & & & & \\
\quad w & : \tau(w) & & \mid \mathsf{size}(\mathit{expr}_1) & : \mathit{Set}(\tau) \to \mathit{Int} \\
\quad \mid \mathit{expr}_1 =_\tau \mathit{expr}_2 & : \tau \times \tau \to \mathit{Bool} & & \mid \mathsf{allInstances}_C & : \mathit{Set}(\tau_C) \\
\quad \mid \mathsf{oclIsUndefined}_\tau(\mathit{expr}_1) & : \tau \to \mathit{Bool} & & \mid v(\mathit{expr}_1) & : \tau_C \to \tau(v) \\
\quad \mid \{\mathit{expr}_1, \dots, \mathit{expr}_n\} & : \tau \times \dots \times \tau \to \mathit{Set}(\tau) & & \mid r_1(\mathit{expr}_1) & : \tau_C \to \tau_D \\
\quad \mid \mathsf{isEmpty}(\mathit{expr}_1) & : \mathit{Set}(\tau) \to \mathit{Bool} & & \mid r_2(\mathit{expr}_1) & : \tau_C \to \mathit{Set}(\tau_D)
\end{array}
$$

$$\mathscr{S}_0 = (\{\mathit{Int}\}, \{C, D\}, \{x : \mathit{Int}, p : C_{0,1}, n : C_*\}, \{C \mapsto \{p, n\}, D \mapsto \{x\}\})$$

context CP inv : wen implies $dd\,.\,wis > 0$

Notational Conventions for Expressions

- **Each expression**

$$\omega(\mathit{expr}_1, \mathit{expr}_2, \dots, \mathit{expr}_n) : \tau_1 \times \dots \times \tau_n \to \tau$$

may **alternatively** be written ("**abbreviated as**")

- $\mathit{expr}_1\ .\ \omega(\mathit{expr}_2, \dots, \mathit{expr}_n)$ if τ_1 is an **object type**, i.e. if $\tau_1 \in T_{\mathscr{C}}$.
- expr_1 -> $\omega(\mathit{expr}_2, \dots, \mathit{expr}_n)$ if τ_1 is a **collection type** (here: only sets), i.e. if $\tau_1 = \mathit{Set}(\tau_0)$ for some $\tau_0 \in T_B \cup T_{\mathscr{C}}$.

- **Examples:** $(\{\mathit{Int}\}, \{C, D\}, \{x : \mathit{Int}, p : C_{0,1}, n : C_*\}, \{C \mapsto \{p, n\}, D \mapsto \{x\}\})$
  - $\overbrace{\mathit{self}_C}^{\mathit{expr}_1}\ .\ \overbrace{p}^{\omega} \rightsquigarrow p(\mathit{self}_C)$
  - $\mathit{self}_C\ .\ p\ .\ n \rightsquigarrow n(p(\mathit{self}_C))$
  - $\underbrace{\mathit{self}_C\ .\ p\ .\ n}_{\mathit{expr}_1}$ -> $\underbrace{\mathsf{isEmpty}}_{\omega} \rightsquigarrow \mathsf{isEmpty}(n(p(\mathit{self}_C)))$
  - context CP inv : wen implies $dd\,.\,\underbrace{wis}_{wis(dd)} > 0$ $\quad (\mathit{atr}(CP) = \{wen : \mathit{Bool}, dd : DD_{0,1}\})$

OCL Syntax 2/4: Constants & Arithmetics

For example:

$$
\begin{array}{rll}
expr ::= & \ldots & \\
& \mid \mathsf{true} \mid \mathsf{false} & : Bool \\
& \mid expr_1 \; \{\mathsf{and}, \mathsf{or}, \mathsf{implies}\} \; expr_2 & : Bool \times Bool \to Bool \\
& \mid \mathsf{not} \; expr_1 & : Bool \to Bool \\
& \mid 0 \mid -1 \mid 1 \mid -2 \mid 2 \mid \ldots & : Int \\
& \mid expr_1 \; \{+, -, \ldots\} \; expr_2 & : Int \times Int \to Int \\
& \mid expr_1 \; \{<, \leq, \ldots\} \; expr_2 & : Int \times Int \to Bool \\
& \mid \mathsf{OclUndefined}_\tau & : \tau
\end{array}
$$

Generalised notation: (prefix normal form)

$$expr ::= \omega(expr_1, \ldots, expr_n) \qquad : \tau_1 \times \cdots \times \tau_n \to \tau$$

with $\omega \in \{+, -, \ldots\}$

$$1 + 2 \rightsquigarrow \underbrace{+}_{\omega}(\underbrace{1}_{expr_1}, \underbrace{2}_{expr_2})$$

Constants & Arithmetics Examples

$$
\begin{array}{rll}
expr ::= & \ldots & \\
& \mid \mathsf{true}, \mathsf{false} & : Bool \\
& \mid expr_1 \; \{\mathsf{and}, \mathsf{or}, \mathsf{implies}\} \; expr_2 & : Bool \times Bool \to Bool \\
& \mid \mathsf{not} \; expr_1 & : Bool \to Bool \\
& \mid 0, -1, 1, -2, 2, \ldots & : Int \\
& \mid expr_1 \; \{+, -, \ldots\} \; expr_2 & : Int \times Int \to Int \\
& \mid expr_1 \; \{<, \leq, \ldots\} \; expr_2 & : Int \times Int \to Bool \\
& \mid \mathsf{OclUndefined}_\tau & : \tau
\end{array}
$$

$$\mathscr{S}_0 = (\{Int\}, \{C, D\}, \{x : Int, p : C_{0,1}, n : C_*\}, \{C \mapsto \{p, n\}, D \mapsto \{x\}\})$$

implies(wen, >(wis(dd), 0))

$$>(\underbrace{wis(dd)}_{expr_1}, \underbrace{0}_{expr_2})$$

wis(dd)

context CP inv : wen implies $dd \,.\, wis > 0$

OCL Syntax 3/4: Iterate

$$expr ::= \cdots \mid expr_1\text{->iterate}(w_1 : T_1 \,;\, w_2 : T_2 = expr_2 \mid expr_3)$$

or, with a little renaming,

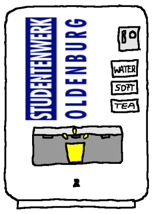
$$expr ::= \cdots \mid expr_1\text{->iterate}(iter : T_1 ; result : T_2 = expr_2 \mid expr_3)$$

where

- $expr_1$ is of a **collection type** (here: a set $Set(\tau_0)$ for some τ_0),
- $iter \in W$ is called **iterator**, of the type denoted by T_1
  (if T_1 is omitted, τ_0 is assumed as type of $iter$)
- $result \in W$ ≠ iter is called **result variable**, gets type τ_2 denoted by T_2,
- $expr_2$ in an expression of type τ_2 giving the **initial value** for $result$,
  ($\text{OclUndefined}_{\tau_2}$, if omitted)
- $expr_3$ is an expression of type τ_2,
  in particular $iter$ and $result$ may appear in $expr_3$.

Iterate Example

$$\begin{aligned}\mathscr{S} = (\{&Bool, \overset{Nat}{\cancel{Int}}\}, \{VM, CP, DD\},\\ &\{cp : CP_*, dd : DD_{0,1}, wen : Bool, wis : Nat\},\\ &\{VM \mapsto \{cp, dd\}, CP \mapsto \{wen, dd\}, DD \mapsto \{wis\})\end{aligned}$$



$$expr ::= expr_1\text{->iterate}(w_1 : T_1 ; w_2 : T_2 = expr_2 \mid expr_3)$$

- $\underbrace{cp(self_{vm})}_{:Set(\tau_{cp})}\text{->iterate}(\underbrace{iter}_{:\tau_{cp}} ; res : Int = 0 \mid res + \underbrace{iter.dd.wis}_{:Nat \in \mathcal{T}_\mathscr{S}})$
- $cp(self_{vm})\text{->iterate}(iter ; res : Bool = true \mid res \text{ and } iter.wen)$

Abbreviations on Top of Iterate

$$expr ::= expr_1\text{->iterate}(w_1 : T_1; w_2 : T_2 = expr_2 \mid expr_3)$$

- $expr_1\text{->forAll}(w_1 : T_1 \mid expr_3)$ ("$\forall w_1 \in expr_1 \bullet expr_3$")

  is an abbreviation for

  $$expr_1\text{->iterate}(w_1 : T_1; w_2 : Bool = \text{true} \mid w_2 \text{ and } expr_3).$$

- $expr_1\text{->Exists}(w : T_1 \mid expr_3)$

  is an abbreviation for

  $expr_1 \text{->} \text{iterate}(w : T_1 ; w_2 : Bool = \text{false} \mid w_2 \text{ or } expr_3)$

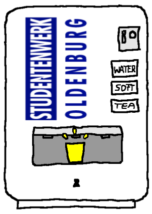
To ensure confusion, we may again omit all kinds of things, cf. OMG (2006).

Recall: Overview

$expr ::=$	w	$: \tau(w)$
	$\mid expr_1 =_\tau expr_2$	$: \tau \times \tau \to Bool$
	$\mid \text{oclIsUndefined}_\tau(expr_1)$	$: \tau \to Bool$
	$\mid \{expr_1, \dots, expr_n\}$	$: \tau \times \dots \times \tau \to Set(\tau)$
	$\mid \text{size}(expr_1)$	$: Set(\tau) \to Int$
	$\mid \text{allInstances}_C$	$: Set(\tau_C)$
	$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
	$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
	$\mid r_2(expr_1)$	$: \tau_C \to Set(\tau_D)$
	$\mid \text{true}, \text{false}$	$: Bool$
	$\mid \text{not } expr_1$	$: Bool \to Bool$
	$\mid expr_1 \{\text{and}, \text{or}, \text{implies}\} expr_2$	$: Bool \times Bool \to Bool$
	$\mid \dots$	
	$\mid \text{OclUndefined}_\tau$	$: \tau$
	$\mid expr_1\text{->iterate}(w_1 : T_1 ; w_2 : T_2 = expr_2 \mid expr_3)$	$: Set(\tau_0) \to \tau_{T_2}$
$context ::=$	$\text{context } w_1 : T_1, \dots, w_n : T_n \text{ inv} : expr$	$: Bool$

More Iterate Examples

$$\mathscr{S} = (\{Bool, \overset{Nat}{\cancel{Int}}\}, \{VM, CP, DD\},$$
$$\{cp : CP_*, dd : DD_{0,1}, wen : Bool, wis : Nat\},$$
$$\{VM \mapsto \{cp, dd\}, CP \mapsto \{wen, dd\}, DD \mapsto \{wis\})$$



$$expr ::= expr_1\text{->iterate}(w_1 : T_1; w_2 : T_2 = expr_2 \mid expr_3)$$

allInstances$_{CP}$ -> iterate (self$_{CP}$: CP ; res : Bool = true |
res and (self$_{CP}$. wen implies self$_{CP}$. dd . wis > 0))

or:

allInstances$_{CP}$ -> forAll (self$_{CP}$ | self$_{CP}$. wen implies self$_{CP}$. dd . wis > 0)

context CP inv : wen implies dd . wis > 0

OCL Syntax 4/4: Context

Syntax: (Assuming signature $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr)$.)

$$context ::= \text{context } w_1 : T_1, \; \ldots, w_n : T_n \text{ inv} : expr$$

where $T_i \in \mathscr{C}$ and $w_i : \tau_{T_i} \in W$ for all $1 \leq i \leq n, n \geq 0$.

Semantics:

$$\text{context } w_1 : C_1, \ldots, w_n : C_n \text{ inv} : expr$$

is (just) an **abbreviation** for

$$\text{allInstances}_{C_1} \text{ -> forAll}(w_1 : \tau_{C_1} \mid$$
$$\ldots$$
$$\text{allInstances}_{C_n} \text{ -> forAll}(w_n : \tau_{C_n} \mid$$
$$expr$$
$$)$$
$$\ldots$$
$$)$$

Context: More Notational Conventions

- For

  context $\mathit{self} : T$ inv : expr

  we may **alternatively** write ("**abbreviate as**")

  context T inv : expr

- **Within** the latter abbreviation, we may omit the "self" in expression expr, i.e. for

  context T inv : $\mathit{self}.v$

  (which is an abbreviation for context T inv : $v(\mathit{self})$)

  we may alternatively write ("**abbreviate as**")

  context T inv : v

The Running Example

context CP inv : wen implies $\mathit{dd} . \mathit{wis} > 0$

context self : CP inv : wen implies dd.wis > 0

context self : CP inv : self.wen implies self.dd.wis > 0

allInstances$_{CP}$ -> forAll(self | self.wen implies self.dd.wis > 0)

– " – iterate(....)

Recall: Overview

$$
\begin{array}{lll}
expr ::= & w & : \tau(w) \\
& \mid expr_1 =_\tau expr_2 & : \tau \times \tau \to Bool \\
& \mid \mathsf{oclIsUndefined}_\tau(expr_1) & : \tau \to Bool \\
& \mid \{expr_1, \dots, expr_n\} & : \tau \times \dots \times \tau \to Set(\tau) \\
& \mid \mathsf{size}(expr_1) & : Set(\tau) \to Int \\
& \mid \mathsf{allInstances}_C & : Set(\tau_C) \\
& \mid v(expr_1) & : \tau_C \to \tau(v) \\
& \mid r_1(expr_1) & : \tau_C \to \tau_D \\
& \mid r_2(expr_1) & : \tau_C \to Set(\tau_D) \\
& \mid \mathsf{true}, \mathsf{false} & : Bool \\
& \mid \mathsf{not}\ expr_1 & : Bool \to Bool \\
& \mid expr_1\ \{\mathsf{and}, \mathsf{or}, \mathsf{implies}\}\ expr_2 & : Bool \times Bool \to Bool \\
& \mid \dots & \\
& \mid \mathsf{OclUndefined}_\tau & : \tau \\
& \mid expr_1\mathsf{\text{->}iterate}(w_1 : T_1 ; w_2 : T_2 = expr_2 \mid expr_3) & : Set(\tau_0) \to \tau_{T_2} \\
context ::= & \mathsf{context}\ w_1 : T_1, \ \dots, w_n : T_n\ \mathsf{inv} : expr & : Bool
\end{array}
$$

"Not Interesting"

Among others:

- Enumeration types
- Type hierarchy
- Complete list of arithmetical operators
- The two other collection types Bag and Sequence
- Casting
- Runtime type information
- Pre/post conditions
  (maybe later, when we officially know what an operation is)
- ... context f pre: $expr_1$,
  post: $expr_2$

References

References

OMG (2006). Object Constraint Language, version 2.0. Technical Report formal/06-05-01.

OMG (2011a). Unified modeling language: Infrastructure, version 2.4.1. Technical Report formal/2011-08-05.

OMG (2011b). Unified modeling language: Superstructure, version 2.4.1. Technical Report formal/2011-08-06.

Warmer, J. and Kleppe, A. (1999). *The Object Constraint Language*. Addison-Wesley.