Software Design, Modelling and Analysis in UML

Lecture 03: Object Constraint Language

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

Albert-Ludwigs-Universität Freiburg, Germany

Contents & Goals

Last Lecture:

- Basic Object System Signature $\mathscr{S}$ and Structure $\mathscr{D}$, System State $\sigma \in \Sigma_{\mathscr{S}}^{\mathscr{D}}$

(Seems like they're related to class/object diagrams, officially we don't know yet...)

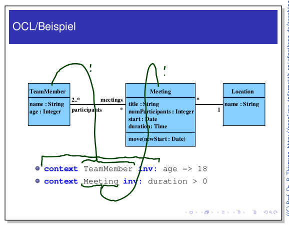
This Lecture:

- **Educational Objectives:** Capabilities for these tasks/questions:
  - Please explain this OCL constraint.
  - Please formalise this constraint in OCL.
  - Does this OCL constraint hold in this system state?
  - Can you think of a system state satisfying this constraint?
  - Please un-abbreviate all abbreviations in this OCL expression.
  - In what sense is OCL a three-valued logic? For what purpose?
  - How are $\mathscr{D}(C)$ and τ_C related?
- **Content:**
  - OCL Syntax, OCL Semantics over system states

What is OCL? And What is It Good For?

What is OCL? How Does it Look Like?

- **OCL**: Object Constraint Logic.



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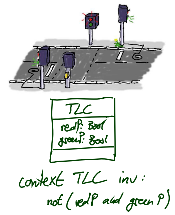
What's It Good For?

- **Most prominent:**
  write down **requirements** supposed to be satisfied by all system states.

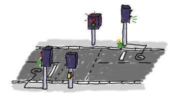
  Often targeting all alive objects of a certain class.

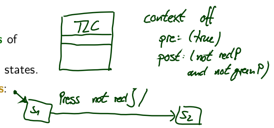


What's It Good For?

- **Most prominent:**
  write down **requirements** supposed to be satisfied by all system states.

  Often targeting all alive objects of a certain class.
- **Not unknown:**
  write down **pre/post-conditions** of methods (*Behavioural Features*).
  Then evaluated over **two** system states.
- **Common with State Machines:**
  guards in transitions.
- **Lesser known:**
  provide **operation bodies**.
- **Metamodeling**: the UML standard is a MOF-Model of UML.
  OCL expressions define well-formedness of UML models (cf. Lecture ∼ 21).

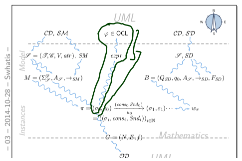


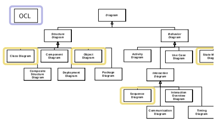


Plan.

- **Today**:
  - The set $OCLExpressions(\mathscr{S})$ of OCL expressions over $\mathscr{S}$.
- **Next time**:
  - Given an OCL expression $expr$, a system state $\sigma \in \Sigma_{\mathscr{S}}^{\mathscr{D}}$, and a valuation of logical variables β, define the **interpretation function**

$$I[\![expr]\!](\sigma, \beta) \in \{true, false, \bot\}.$$





(Core) OCL Syntax [OMG, 2006]

OCL Syntax 1/4: Expressions

$expr ::=$

w	$: \tau(w)$
$\mid expr_1 =_\tau expr_2$	$: \tau \times \tau \to Bool$
$\mid$ oclIsUndefined$_\tau(expr_1)$	$: \tau \to Bool$
$\mid \{expr_1, \dots, expr_n\}$	$: \tau \times \dots \times \tau \to Set(\tau)$
$\mid$ isEmpty$(expr_1)$	$: Set(\tau) \to Bool$
$\mid$ size$(expr_1)$	$: Set(\tau) \to Int$
$\mid$ allInstances$_C$	$: Set(\tau_C)$
$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
$\mid r_2(expr_1)$	$: \tau_C \to Set(\tau_D)$

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

- $W \supseteq \{self_C \mid C \in \mathscr{C}\}$ is a set of typed logical variables, w has type $\tau(w)$, $\tau(self_C) = \tau_C$
- τ is any type from $\mathscr{T} \cup T_B \cup T_\mathscr{C} \cup \{Set(\tau_0) \mid \tau_0 \in T_B \cup T_\mathscr{C}\}$
  - T_B is a set of 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))
- $v : \tau(v) \in atr(C)$, $\tau(v) \in \mathscr{T}$,
- $r_1 : D_{0,1} \in atr(C)$,
- $r_2 : D_* \in atr(C)$,
- $C, D \in \mathscr{C}$.

Expression Examples

$expr ::=$

w	$: \tau(w)$	$\mid$ size$(expr_1)$	$: Set(\tau) \to Int$
$\mid expr_1 =_\tau expr_2$	$: \tau \times \tau \to Bool$	$\mid$ allInstances$_C$	$: Set(\tau_C)$
$\mid$ oclIsUndefined$_\tau(expr_1)$	$: \tau \to Bool$	$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
$\mid \{expr_1, \dots, expr_n\}$	$: \tau \times \dots \times \tau \to Set(\tau)$	$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
$\mid$ isEmpty$(expr_1)$	$: Set(\tau) \to Bool$	$\mid r_2(expr_1)$	$: \tau_C \to Set(\tau_D)$

Notational Conventions for Expressions

- Each expression

$$\omega(expr_1, expr_2, \dots, expr_n) : \tau_1 \times \dots \times \tau_n \to \tau$$

may alternatively be written ("abbreviated as")

- $expr_1$. $\omega(expr_2, \dots, expr_n)$ if τ_1 is an **object type**, i.e. if $\tau_1 \in T_\mathscr{C}$.
- $expr_1$ -> $\omega(expr_2, \dots, expr_n)$ if τ_1 is a **collection type** (here: only sets), i.e. if $\tau_1 = Set(\tau_0)$ for some $\tau_0 \in T_B \cup T_\mathscr{C}$.

- **Examples:** $(self : \tau_C \in W; \quad v, w : Int \in V; \quad r_1 : D_{0,1}, r_2 : D_* \in V)$
  - $self . v$
  - $self . r_1 . w$
  - $self . r_2$ -> isEmpty

OCL Syntax 2/4: Constants & Arithmetics

For example:

$expr ::= \dots$	
$\mid$ true $\mid$ false	$: Bool$
$\mid expr_1$ {and, or, implies} $expr_2$	$: Bool \times Bool \to Bool$
$\mid$ not $expr_1$	$: Bool \to Bool$
$\mid 0 \mid -1 \mid 1 \mid -2 \mid 2 \mid \dots$	$: Int$
$\mid$ OclUndefined$_\tau$	$: \tau$
$\mid expr_1 \{+, -, \dots\} expr_2$	$: Int \times Int \to Int$
$\mid expr_1 \{<, \leq, \dots\} expr_2$	$: Int \times Int \to Bool$

Generalised notation:

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

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

OCL Syntax 3/4: Iterate

$$expr ::= \cdots \mid expr_1\text{->iterate}(w_1 : \tau_1 ; w_2 : \tau_2 = expr_2 \mid expr_3)$$

or, with a little renaming,

$$expr ::= \cdots \mid expr_1\text{->iterate}(iter : \tau_1; result : \tau_2 = expr_2 \mid expr_3)$$

where

- $expr_1$ is of a **collection type** (here: a set $Set(\tau_0)$ for some τ_0),
- $iter \in W$ is called **iterator**, gets type τ_1 (if τ_1 is omitted, τ_0 is assumed as type of $iter$)
- $result \in W$ is called **result variable**, gets type τ_2,
- $expr_2$ in an expression of type τ_2 giving the **initial value** for $result$, ('OclUndefined' if omitted)
- $expr_3$ is an expression of type τ_2 in which in particular $iter$ and $result$ may appear.

Iterate: Intuitive Semantics (Formally: later)

$$expr ::= expr_1\text{->iterate}(iter : \tau_1; result : \tau_2 = expr_2 \mid expr_3)$$

pseudocode

$Set(\tau_0)$ $hlp = \langle expr_1 \rangle$;
τ_1 $iter$;
τ_2 $result = \langle expr_2 \rangle$;
while ($!hlp.empty()$) *do*
  $iter = hlp.pop()$; ← pick one element and remove
  $result = \langle expr_3 \rangle$;
od

allInstances$_{TA}$ ->iterate(iter : τ_{TA} ; result : Bool = true | result and iter.age ≥ 18)

Iterate: Intuitive Semantics (Formally: later)

$$expr ::= expr_1\text{->iterate}(iter : \tau_1; result : \tau_2 = expr_2 \mid expr_3)$$

$Set(\tau_0)$ $hlp = \langle expr_1 \rangle$;
τ_1 $iter$;
τ_2 $result = \langle expr_2 \rangle$;
while ($!hlp.empty()$) *do*
  $iter = hlp.pop()$;
  $result = \langle expr_3 \rangle$;
od

Note: In our (simplified) setting, we always have $expr_1 : Set(\tau_1)$ and $\tau_0 = \tau_1$. In the type hierarchy of full OCL with inheritance and `oclAny`, they may be different and still type consistent.

Abbreviations on Top of Iterate

$$expr ::= expr_1\text{->iterate}(w_1 : \tau_1; w_2 : \tau_2 = expr_2 \mid expr_3)$$

- $expr_1\text{->forAll}(w : \tau_1 \mid expr_3)$ is an abbreviation for

  $$expr_1\text{->iterate}(w : \tau_1; w_1 : Bool = true \mid w_1 \, and \, expr_3).$$

  e.g. allInstances$_{TA}$ ->forAll(i | i.age ≥ 18)

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

- Similar: $expr_1\text{->Exists}(w : \tau_1 \mid expr_3)$

OCL Syntax 4/4: Context

$$context ::= \text{context } w_1 : \tau_1, \dots, w_n : \tau_n \text{ inv : } expr$$

where $w \in W$ and $\tau_i \in T_{\mathscr{C}}$, $1 \le i \le n$, $n \ge 0$.

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

is an **abbreviation** for

allInstances$_{C_1}$ -> forAll($w_1 : C_1$ |
  . . .
    allInstances$_{C_n}$ -> forAll($w_n : C_n$ |
      $expr$
)
  . . .
)

context TA, M inv: self$_M$ -> partic -> contains (self$_{TA}$) implies self$_{TA}$.meeting = self$_M$

context TA inv: age ≥ 18 ⇔ allInstances$_{TA}$ ->forAll(self$_{TA}$ | self$_{TA}$.age ≥ 18)

Context: More Notational Conventions

- For

  $$\text{context } self : \tau_C \text{ inv : } expr$$

  we may alternatively write ("abbreviate as")

  $$\text{context } \tau_C \text{ inv : } expr$$

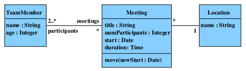
- **Within** the latter abbreviation, we may omit the "$self$" in $expr$, i.e. for

  $$self.v \quad \text{and} \quad self.r$$

  we may alternatively write ("abbreviate as")

  $$v \quad \text{and} \quad r$$

Examples (from lecture



- **context** TeamMember **inv:** age => 18
- **context** Meeting **inv:** duration > 0

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unabbreviate

context $self_{TM}$: TeamMember inv: $self_{TM}$. age >= 18

allInstances$_{TM}$ -> forAll ($self_{TM}$: TM | $self_{TM}$. age ≥ 18)

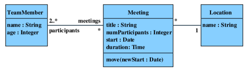
allInstances$_{TM}$ -> iterate($self_{TM}$: TM; res : Bool = true | res and $self_{TM}$. age ≥ 18)

normalize

allInstances$_{TM}$ -> iterate($self_{TM}$: TM; res : Bool = true | and (res, ≥ (age ($self_{TM}$), 18))

Examples (from lecture "Softwaretechnik 2008")

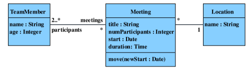
OCL/Mehr Navigation/Beispiele



- **context** Meeting
  - **inv:** self.participants->size() = numParticipants
- **context** Location
  - **inv:** name="Lobby" **implies** meeting->isEmpty()

(C) Prof. Dr. P. Thiemann, http://proglang.informatik.uni-freiburg.de/teaching/swt/2008/

Example (from lecture "Softwaretechnik 2008")



- context *Meeting* inv :

  $participants$ -> iterate($i : TeamMember; n : Int = 0 \mid n + i\,.\,age$)

  $/ participants$ -> size() > 25

"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)
- ...

OCL Semantics: The Task

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

- Given an OCL expression $expr$, a system state $\sigma \in \Sigma_\mathscr{S}^\mathscr{D}$, and a valuation of logical variables β, define

$$I[\![\cdot]\!](\cdot, \cdot) : OCLExpressions(\mathscr{S}) \times \Sigma_\mathscr{S}^\mathscr{D} \times (W \to I(\mathscr{T} \cup T_B \cup T_\mathscr{C})) \to I(Bool)$$

i.e.

$$I[\![expr]\!](\sigma, \beta) \in \{\mathit{true}, \mathit{false}, \bot_{Bool}\}.$$

σ = { 1_{TM} ↦ { age = 27, meeting = 5_M } }   ⊨? self.age ≥ 18 ,   β : self ↦ 1_{TM}

References

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

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

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

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