Software Design, Modelling and Analysis in UML

Lecture 03: Object Constraint Language (OCL)

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Contents & Goals

Last Lecture:

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

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

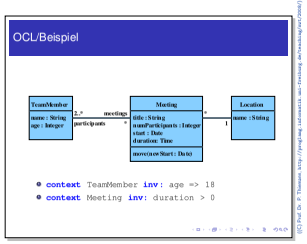
This Lecture:

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

  Often targeting all alive objects of a certain class.

context TLC inv : not (red and green)

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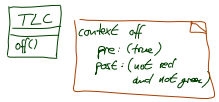
  Then evaluated over **two** system states.



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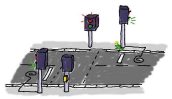

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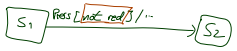

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- **Common with State Machines**:
  guards in transitions.
- **Lesser known**:
  provide **operation bodies**.
- **Metamodeling**: the UML standard is a MOF-Model of UML.
  OCL expressions define well-formedness of UML models (cf. Lecture $\sim$ 21).

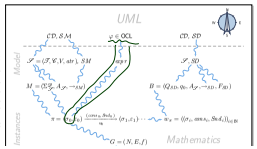
Plan.

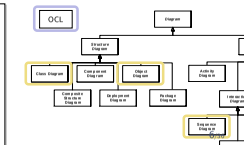
$\mathcal{I} : OCLExpr(\mathcal{S}) \times \Sigma^{\mathcal{D}}_{\mathcal{Y}} \times \mathcal{B} \to \{true, false, \bot\}$

$\mathcal{I}(expr, \sigma, \beta)$ — β: valuations of $\mathcal{V}$

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

    $$I[\![expr]\!](\sigma, \beta) \in \{true, false, \bot\}.$$
- **Later**: use I to define $\models \subseteq \Sigma^{\mathscr{D}}_{\mathscr{Y}} \times OCLExpressions(\mathscr{S})$.





(Core) OCL Syntax [OMG, 2006]

OCL Syntax 1/4: Expressions

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

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))
- $v : \tau(v) \in atr(C), \tau(v) \in \mathscr{T}$,
- $r_1 : D_{0,1} \in atr(C)$,
- $r_2 : D_* \in atr(C)$,
- $C, D \in \mathscr{C}$.

$\mathcal{S} = \big(\{Integer\}, \{C, D\}, \{x : Integer, y : Integer\ \mathrm{not}, p : C_*, q : D_{0,1}\}, \{C \mapsto \{x, y, p, q\}, D \mapsto \{y, q\}\} \big)$

$W = \{self_C : \tau_C,\ self_D : \tau_D\} \cup \{a, b, c : Integer\} \cup \{u, w : \tau_D, M : Set(\tau_C)\}$

- $self_C$
- a
- n
- $\mathsf{oclIsUndefined}(a)$
- $\{u, w\} : Set(\tau_D)$
- $\mathsf{size}(N) : Int$
- $\mathsf{allInstances}_C$

$p(n) : Set(\tau_C)$ — $n : \tau_C$, $p : C_* \in atr(C)$

$q(n) : \tau_D$ — $n : \tau_C$, $q : D_{0,1} \in atr(C)$

$q(p(n)) : \tau_D$ — $q : D_{0,1} \in atr(D)$

$x(n)$: Integer — $n : \tau_C$, $x : Integer \in atr(C)$, $Integer \in \mathcal{T}$

$x(a)$? NO (type mismatch)

$x(n)$? YES / NO / ??? — NO, a is not an attribute of C

$x(p)$? NO, p is an attribute and not a (typical) navigation

OCL Syntax: Notational Conventions for Expressions

- Each expression

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

may alternatively be written ("abbreviated as")

- $expr_1 \bullet \omega(expr_2, \ldots, expr_n)$ if τ_1 is an **object type**, i.e. if $\tau_1 \in T_{\mathscr{C}}$.
- $expr_1$ **->** $\omega(expr_2, \ldots, expr_n)$ 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:** ($self : \tau_C \in W$; $v, w : Int \in V$; $r_1 : D_{0,1}, r_2 : D_* \in V$)
  - $self \bullet v$
  - $self \bullet r_1 \bullet w$
  - $self \bullet r_2$ **->** isEmpty

OCL Syntax 2/4: Constants, Arithmetical Operators

For example:

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

Generalised notation:

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

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

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)

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

pseudo code

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

pick and remove one element

e.g. result + size(iter-2)

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

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

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

is an **abbreviation** for

context $w_1 : C_1, \ldots, w_n : C_n$ inv : $expr$
allInstances$_{C_1}$ -> forAll($w_1 : C_1$ |
  ...
    allInstances$_{C_n}$ -> forAll($w_n : C_n$ |
      $expr$
)
  ...
)

Context: More Notational Conventions

- For

  context $self : \tau_C$ inv : $expr$

  we may alternatively write ("abbreviate as")

  context τ_C inv : $expr$

  e.g. context C, inv: expr

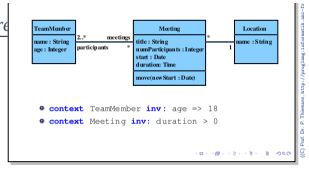
- **Within** the latter abbreviation, we may omit the "$self$" in $expr$, i.e. for

  $self.v$ and $self.r$

  we may alternatively write ("abbreviate as")

  $:: v$ and r

Examples (from lecture



context self : TM inv: age ⩾ 18

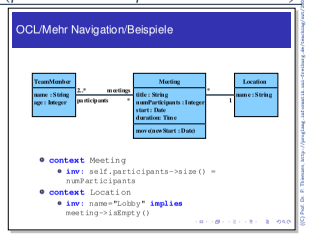
——"—— self.age ⩾ 18

——"—— age(self) ⩾ 18

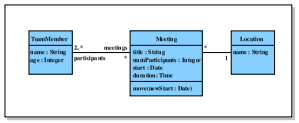
——"—— ⩾ (age(self), 18)

↳ allInstances$_{TM}$ -> forAll (self : TM | ⩾ (age (self), 18)

Examples (from lecture "Softwaretechnik 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)
- ...

References

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.