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...)

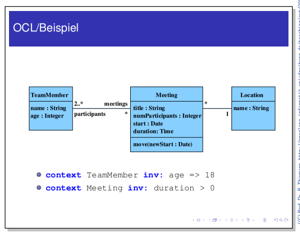
This Lecture:

- **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.

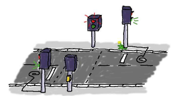


(C) Prof. Dr. P. Thiemann, http://proglang.informatik.uni-freiburg.de/teaching/swt/2008/

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.

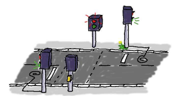


context TLC inv: not (red and green)

What's It Good For?

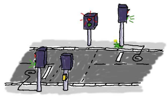
- **Most prominent:**
  write down **requirements** supposed to be satisfied by all system states.

  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.



context off
pre: (true)
post: (not green and not red)

What's It Good For?



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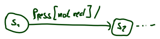
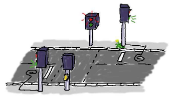
- **Common with State Machines**:
  guards in transitions.



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.

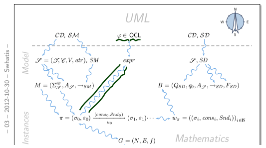
$I(expr, \sigma, \beta) \in \{true, false, \bot\}$

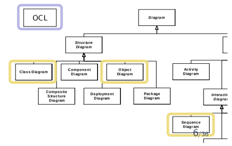
$I: OCLExpressions(\mathscr{S}) \times \Sigma_{\mathscr{S}}^{\mathscr{D}} \times \Omega \to \{true, false, \bot\}$

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

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

- **Later**: use I to define $\models \; \subseteq \Sigma_{\mathscr{S}}^{\mathscr{D}} \times OCLExpressions(\mathscr{S})$.





(Core) OCL Syntax [OMG, 2006]

OCL Syntax 1/4: Expressions

$expr ::=$	
w	$: \tau(w)$
$\mid expr_1 =_\tau expr_2$	$: \tau \times \tau \to Bool$
$\mid$ 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$_C$	$: Set(\tau_C)$
$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
$\mid r_2(expr_1)$	$: \tau_C \to Set(\tau_D)$

type of $expr_2$

type of $expr_1$

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 $\tau(w)$

  assumption: disjoint
- 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 $\tau_0 \in T_B \cup T_{\mathscr{C}} \cup \mathscr{T}$ (sufficient because of "flattening" (cf. standard))
- $v : \tau(v) \in atr(C)$, $\tau(v) \in \mathscr{T}$,
- $r_1 : D_{0,1} \in atr(C)$,
- $r_2 : D_* \in atr(C)$,
- $C, D \in \mathscr{C}$.

OCL Syntax: 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 $\tau_0 \in T_B \cup T_{\mathscr{C}}$.

OCL Syntax: 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") omit parentheses if n=1

- $expr_1$. $\omega(expr_2, \dots, expr_n)$ if τ_1 is an **object type**, i.e. if $\tau_1 \in T_{\mathscr{C}}$.
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expr1 ω logical variables attributes

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

assume: $v \in atr(C)$

- $self\ .\ v()$
  - ~~ω(self, v)~~
  - v(self)
  - self -> v not OCL
  - if we have methods, e.g. C / f(Int, Int) : Int, then we will also allow in OCL self.f(1,2) which normalises to f(self, 1, 2). NOT: 1.f(2)

$r_1 \in atr(C)$, $w \in atr(D)$

- $self\ .\ r_1\ .\ w$
  - $w(\underbrace{r_1(\underbrace{self}_{:\tau_C})}_{:\tau_D})$

$r_2 \in atr(C)$

- $self\ .\ r_2$ -> isEmpty
  - $isEmpty(\underbrace{r_2(\underbrace{self}_{:\tau_C})}_{:Set(\tau_D)})$

OCL Syntax 2/4: Constants, Arithmetical Operators

For example:

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

Generalised notation:

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

with $\omega \in \{+, -, \dots\}$ i.e. $+(expr_1, expr_2)$ instead of $expr_1 + expr_2$; $expr_1 + (expr_2 + expr_3)$

OCL Syntax 3/4: Iterate

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

or, with a little renaming,

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

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

$Set(\tau_0)\ hlp = \langle expr_1 \rangle;$
$\tau_1\ iter;$
$\tau_2\ result = \langle expr_2 \rangle;$
$while\ (!hlp.empty())\ do$ — pick and remove one element
  $iter = hlp.pop();$
  $result = \langle expr_3 \rangle;$ — e.g. result + iter
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

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

- $expr_1$->forAll($w : \tau_1 \mid expr_3$)

  is an abbreviation for

  $expr_1$->iterate($w : \tau_1;\ w_1 : Bool = true \mid w_1 \wedge expr_3$).

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

- Similar: $expr_1$->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 $\tau_i \in T_{\mathscr{C}}$, $1 \leq i \leq n$, $n \geq 0$.

denotes τ_{C_1}

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

requires that $w_1 : \tau_{C_1} \in W$

is an **abbreviation** for

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 : $expr$

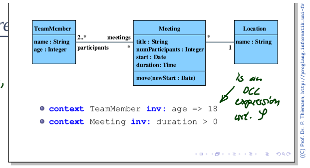
- **Within** the latter abbreviation, we may omit the "$self$" in $expr$, i.e. for

  $self.v$ and $self.r$

  we may alternatively write ("abbreviate as")

  v and r

Examples (from lecture "Softwaretechnik 2008")



is an OCL expression wrt. $\mathcal{S}$

$\mathcal{S} = (\{String, Integer, Date, Time\}, \{TeamMember, Meeting, Location\}, \{age : Integer, \ldots\}, \{TeamMember \mapsto \{age, name\}\})$

context TeamMember inv : age ≥ 18

⇝ context self : TeamMember inv: age ≥ 18

⇝ allInstances$_{TeamMember}$ -> forAll (self : TeamMember | age ≥ 18)

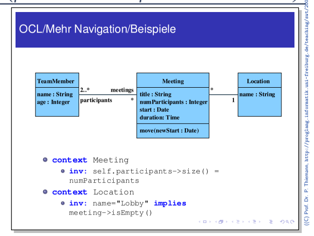
⇝ ——— . ——— -> iterate (self : TeamMember ; res : Bool = true | res and age ≥ 18)

⇝ ——— . ——— res and self.age ≥ 18)

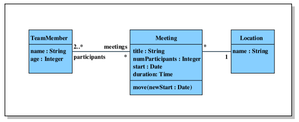
⇝ ——— . ——— age (self) ≥ 18)

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

Examples (from lecture "Softwaretechnik 2008")



Example (from lecture "Softwaretechnik 2008")



- context self: $Meeting$ inv :

  $((self.participants$ -> 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 [OMG, 2006]

The Task

OCL Syntax 1/4: Expressions

$expr ::=$

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$\mid \{expr_1, \dots, expr_n\}$	$: \tau \times \dots \times \tau \to Set(\tau)$
$\mid \mathsf{isEmpty}(expr_1)$	$: Set(\tau) \to Bool$
$\mid \mathsf{size}(expr_1)$	$: Set(\tau) \to Int$
$\mid \mathsf{allInstances}_C$	$: Set(\tau_C)$
$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
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Where, given $\mathscr{S} = (\mathscr{T}, \mathscr{C}, V, atr)$,

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- $C, D \in \mathscr{C}$.

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

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

such that

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

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.