Software Design, Modelling and Analysis in UML

Lecture 03: Object Constraint Language

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Contents & Goals

$(\{Int\}, \{C, D\}, \{x : Int\}, \{C \mapsto \{x\}, D \mapsto \emptyset\})$

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...)

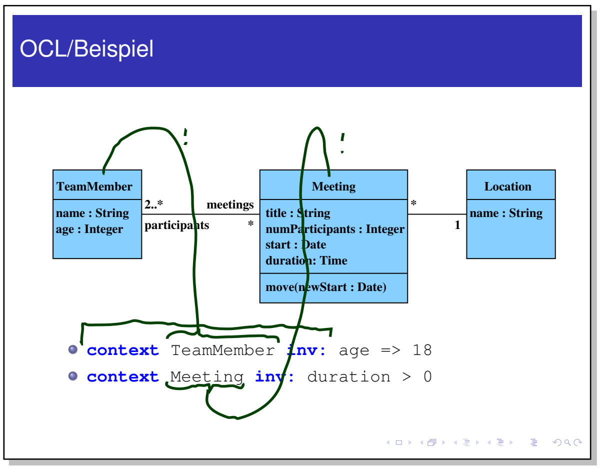
This Lecture:

- **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.

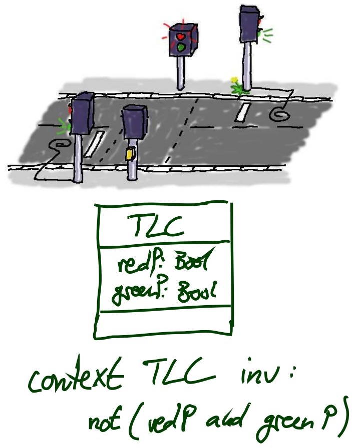


((C) Prof. Dr. P. Thiemann, http://proglang.informatik.uni-freiburg.de/teaching/swt/2008/)

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.



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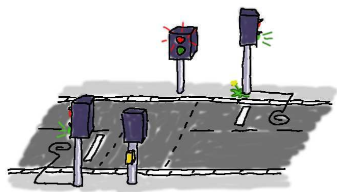
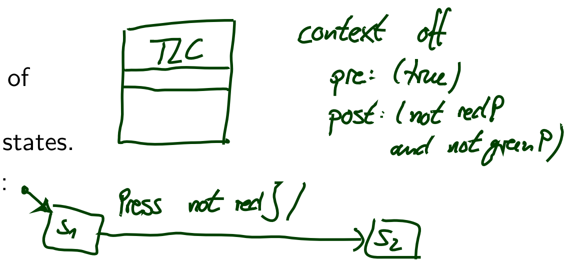


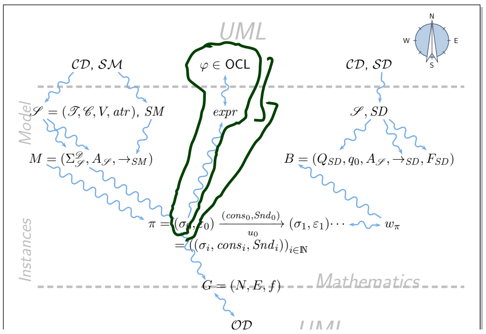
- **Not unknown**:
  write down **pre/post-conditions** of methods (*Behavioural Features*).
  Then evaluated over **two** system states.
- **Common with State Machines**:
  guards in transitions.
- **Lesser known**:
  provide **operation bodies**.
- **Metamodeling**: the UML standard is a MOF-Model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

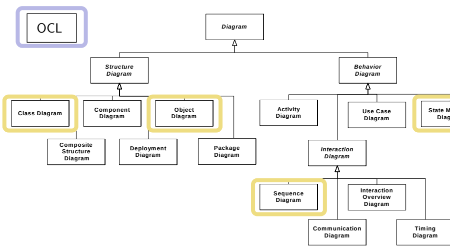


Plan.

- **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**

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





(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 $\mathscr{T} \cup T_B \cup T_{\mathscr{C}}$ $\cup \{Set(\tau_0) \mid \tau_0 \in T_B \cup T_{\mathscr{C}} \cup \mathscr{T}\}$ from $\mathscr{S}$
  - 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))
- $\underbrace{v : \tau(v)} \in atr(C)$, $\tau(v) \in \mathscr{T}$,
- $\underbrace{r_1 : D_{0,1}} \in atr(C)$,
- $\underbrace{r_2 : D_*} \in atr(C)$,
- $C, D \in \mathscr{C}$.

Expression Examples

$expr ::=$

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$_C$	$: Set(\tau_C)$
$\mid v(expr_1)$	$: \tau_C \to \tau(v)$
$\mid r_1(expr_1)$	$: \tau_C \to \tau_D$
$\mid r_2(expr_1)$	$: \tau_C \to Set(\tau_D)$

$\mathscr{S} = (\{Int\}, \{TeamMember, Meeting\}, \{age : Int, meeting : M_{0,1}, partic : TM_*\},$ (short: TM) (short M) $\{TM \mapsto \{age, meeting\}, M \mapsto \{partic\}\})$

- $self_{TM} : \tau_{TM}$
- $allInstances_M : Set(\tau_M)$
- $size(allInstances_M) : Int$ $\xrightarrow{} Set(\tau_M)$
- $age(self_{TM}) : \tau_{TM} \to Int$
- $age(self_M)$ NO, because $age \notin atr(M)$
- $meeting(self_{TM}) : \tau_{TM} \to \tau_M$
- $partic(self_M) : \tau_M \to Set(\tau_{TM}$

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

$\mathscr{C} = \{C, D\}$, $atr(C) = \{v, r_2, r_1\}$, $atr(D) = \{w\}$

- **Examples:** $(self : \tau_C \in W; \quad v, w : Int \in V; \quad r_1 : D_{0,1}, r_2 : D_* \in V)$
  - $\underbrace{self}_{expr_1 : \tau_C} \,.\, \underbrace{v}_{\omega} \quad \longleftrightarrow \quad \underbrace{v}_{\omega}(\underbrace{self}_{expr_1})$
  - $\underbrace{self \,.\, r_1}_{expr_1} \,.\, \underbrace{w}_{\omega} \quad \longleftrightarrow \quad w(\underbrace{self.r_1}_{expr_1}) \quad \longleftrightarrow \quad w(r_1(self))$
  - $\underbrace{self \,.\, r_2}_{expr_1 : Set(\tau_0)}$ -> isEmpty $\quad \longleftrightarrow \quad isEmpty(r_2(self))$

OCL Syntax 2/4: Constants & Arithmetics

For example:

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

Generalised notation:

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

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

e.g. $+(expr_1, expr_2)$ for $expr_1 + expr_2$

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

Iterate: Intuitive Semantics (Formally: later)

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

$$
\begin{array}{l}
Set(\tau_0)\ hlp = \langle expr_1 \rangle; \\
\tau_1\ iter; \\
\tau_2\ result = \langle expr_2 \rangle; \\
while\ (!hlp.empty())\ do \\
\quad iter = hlp.pop(); \\
\quad result = \langle expr_3 \rangle; \\
od
\end{array}
$$

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

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

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

  e.g.
  allInstances$_{T4}$
  ->forAll(i | i.age
  ≥ 18)

  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

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

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

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

is an **abbreviation** for

$$\begin{array}{l} \text{allInstances}_{C_1} \text{ -> forAll}(w_1 : C_1 \mid \\ \quad \dots \\ \quad\quad \text{allInstances}_{C_n} \text{ -> forAll}(w_n : C_n \mid \\ \quad\quad\quad expr \\ \quad\quad) \\ \quad \dots \\ ) \end{array}$$

context TM, M inv:
$self_M$ -> partic
-> contains ($self_{TM}$)
implies
$self_{TM}$. meeting
= $self_M$

context TM inv:
age $\geq$ 18

$\Updownarrow$

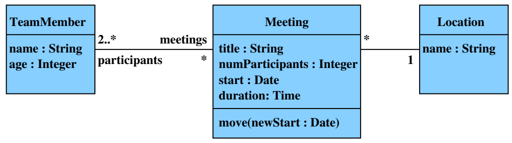
allInstances$_{TM}$
->forAll ($self_{TM}$ |
$self_{TM}$. age $\geq$ 18)

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 lectur



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

Unabbreviate

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

$\Updownarrow$

$allInstances_{TM} \to forAll(self_{TM} : TM \mid self_{TM} . age \geq 18)$

$\Updownarrow$

$allInstances_{TM} \to iterate(self_{TM} : TM ; res : Bool = true \mid res \text{ and } self_{TM} . age \geq 18)$

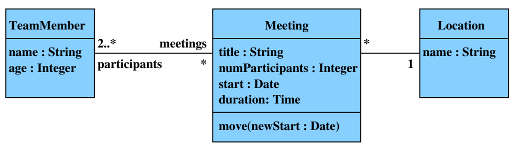
$\Updownarrow$ normalize

$allInstances_{TM} \to iterate(self_{TM} : TM ; res : Bool = true \mid$

$\qquad and(res, \geq(age(self_{TM}), 18)))$

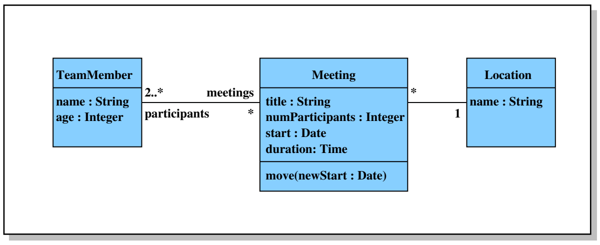
Examples (from lecture "Softwaretechnik 2008")

OCL/Mehr Navigation/Beispiele



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

Example (from lecture "Softwaretechnik 2008")



- context $Meeting$ inv :

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

$$/ participants \; \texttt{->} \; \mathsf{size}() > 25$$

"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

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

- 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.

$\sigma = \{1_{TM} \mapsto \{age = 27, meeting = 5_M\}\}$

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

$\models^?$ $self.age \geq 18$, $\beta : self \mapsto 1_{TM}$

– 03 – 2014-10-28 – main –

References

– 03 – 2014-10-28 – main –

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

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